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28-30 October 2014, Lisbon, Portugal

OPERATIONAL OCEANOGRAPHY FOR SUSTAINABLE BLUE GROWTH

EuroGOOS
European Global Ocean Observing System

Operational Oceanography for Sustainable Blue Growth

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INTRODUCTION

In memory of Kostas Nittis

Dr. Erik Buch, EuroGOOS AISBL Chair

In July 2014, Dr. Kostas Nittis, Secretary General of EuroGOOS passed away after a long illness. Kostas was a physical oceanographer from the Hellenic Centre for Marine Research who made a significant contribution to understanding the oceanography of the Eastern Mediterranean and to the development of operational oceanography in his native Greece and further afield in Europe. Kostas also understood the science-policy interface better than most and played a significant role in the activities of the European Marine Board as its chair. He contributed directly to many of the EU level declarations that guide the development of marine science in Europe today.

Much of the statement included as an introduction to the 2014 conference is based on Kostas' good work.

The EuroGOOS community extend our sincere condolences to Kostas' wife Eleni Kanari, daughter Despina Nitti and son Stelios Nittis. Kostas' positive influence and actions will be remembered by our community for years to come.

EuroGOOS Conference 2014 Statements

Earth's climate is facing severe changes – the carbon dioxide levels are higher than ever, the melt of the ice sheets at Greenland and Antarctica are accelerating, and we experience more and unprecedented extreme weather conditions leading to large loss of life and damage to property. These changes also affect the physical and biogeochemical conditions of the ocean with the risk of shifting the marine ecosystem across the tipping point of irreversible change in species composition.

The effects of climate change on the ocean will have an impact on all economic activities at sea that include shipping, fishery, energy, land-ocean interactions, coastal protection, sustainable environmental and ecosystem management, tourism and security. Therefore, there is a demand for timely delivery of high quality operational oceanographic services and products to support planning over short and long time scales, as they are fundamental for safe performance of marine and maritime activities. Moreover, there is a critical need to inform society, ocean governance and decision-making to support a future sustainable knowledge-based maritime economy.

User needs for regular, near real-time and quality-assured services require an operational approach across a wide range of societal benefit areas. This has triggered a new wave of marine knowledge innovation in order to fill the gaps and improve the quality and resolution of the services, e.g., seamless forecasting, an operational ecosystem approach and operational marine climate services.

This challenge requires close communication and cooperation between industry, marine science and operational oceanography service providers to address user requirements, scientific challenges and the development of products and services. Recent surveys reveal important gaps in knowledge and data about the state of the oceans and regional seas, coupled physical-biogeochemical processes, seabed resources, marine life and risks to habitats and ecosystems. This calls for coordinated investments in basic marine research, establishing sustained in-situ European Ocean Observing System (EOOS) including an open and free data exchange via the existing ROOS Data Portals and EMODnet initiative, developments of very high resolution qualified coupled physical-biogeochemical models, and a sustained European Operational Oceanographic Service (Copernicus Marine Service) including national uptake initiatives.

Over the past 20 years, EuroGOOS members have contributed to development of:

- Ocean forecasting via national and EU supported research,
- Improved use of new real-time observation technologies,
- Open and free real-time exchange of ocean observations and model forecast products,
- The Copernicus Marine Service and integration of European operational Oceanography,
- Numerous new operational oceanographic products and services.

EuroGOOS is therefore well-suited and prepared to play an active role in the future development of operational oceanography and marine services in Europe with particular focus to:

1. **Identify European priorities for operational Oceanography;** main focus will be to define research priorities and work with key European initiatives such as Copernicus, EMODnet and Marine Research Infrastructures. As part of this activity EuroGOOS will also work intensively to link with the research community, industry, users and EU policies.
2. **Promotion of operational oceanography;** especially through networking, publications, conferences, EuroGOOS webpage, social media and increased engagement with various organizations such as GOOS Regional Alliances, GEO, European Marine Board and JPI-Oceans.
3. **Foster Cooperation;** EuroGOOS will actively engage in close cooperation with key organizations on a global, European and regional scale to stimulate cross-fertilization between operational oceanography, marine research and technological innovation that will bring mutual benefits to all the communities.
4. **Coordinate co-production of knowledge:** to promote cost effective creation of operational observation and model based products and services through sharing of expertise and capabilities meeting the requirements of the users. EuroGOOS will aim to make best use of all its members capability to co-produce the knowledge and evidence for assessment of Good Environmental Status required by the Marine Strategy Framework Directive.
5. **Sustained Ocean Observations;** EuroGOOS will take a leading role to ensure coordination of the European contribution to sustained marine observational system through the promotion and rationalization of a European Ocean Observing System (EOOS). In this context, EuroGOOS will work closely with European Marine Board, EU Copernicus Marine Service, EMODNET, EU Marine Research Infrastructures, JPI Oceans, EEA, ESA, EUMETSAT as well as the climate community.

EuroGOOS AISBL is ready to support the European marine and maritime community by focussing on the above five initiatives. It will use established networks with the scientific and user communities, and service providers, as well as links to industry and the public sector (global, EU, regional and national partners and authorities) to support interdisciplinary and collaborative cooperation focused on challenges of development and provision of high quality operational oceanographic products and services in the future.

Presentations at the 7th EuroGOOS Conference have demonstrated an impressive high performance level within marine science and service provision by the EuroGOOS members, showing Europe to be extremely well positioned to take a global lead in the field of operational oceanography.

Dr. Erik Buch
EuroGOOS AISBL Chair

Biochemical Modelling and Users

Operational ocean modelling system for Irish waters: products and services for aquaculture and fisheries

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Abstract:

The Marine Institute (MI), Ireland, are running a suite of operational regional and coastal ocean models of the North East Atlantic and the Irish coastal waters. Recent developments have been tailored to address several key needs of the aquaculture industry in the region. The authors present an overview of these model products and services. A shellfish model that includes growth and physiological interactions with the ecosystem has been developed and fully embedded within the 3D numerical modelling framework. It consists also of a microbial module for predicting the level of mussel contamination by coliforms. These models can assist in the estimations of carrying capacity and for assessing the impacts of pollution on aquaculture grounds and aid in the classification of shellfish waters. The physical coastal model of south-west Ireland provides 3 day forecasts of shelf water movement in the region, which are assimilated into a new HAB warning system produced for the end-users. Further services include the use of models for the identification of potential sites for offshore aquaculture, studies on cross-contamination of farms, e.g. dispersal of planktonic larval salmon lice, and products that underpin the assessment and advisory services on the sustainable exploitation of the marine fisheries resources.

Keywords: numerical modelling, aquaculture, operational forecasting, HAB, shellfish

1. Introduction

According to the Food and Agriculture Organisation of the United Nations, aquaculture is the fastest growing food-producing sector in the world. As such, one of the key needs of this sector is the implementation of effective analysis and management methods to ensure the sustainability, economic viability, minimization of negative impacts on the environment and risks to human health. The above measures can nowadays be effectively supported by different computer tools, varying in complexity from highly aggregated, low data requirement tools to more detailed and complex numerical models of coastal oceans. The latter themselves can vary in complexity from general ocean circulation models to sophisticated coupled physical – biogeochemical – eco-physiological models, such as that presented in Dabrowski et al. (2013).

The Marine Institute (MI), Ireland, are running a suite of operational forecasting regional and coastal ocean models. Developments in recent years have been tailored to address several key needs of the aquaculture industry in the region. This paper presents an overview of these model-based products and services.

2. Description of the models

The 3D operational models implemented by the MI are based on the Regional Ocean Modelling System (ROMS) which is a free-surface, hydrostatic, primitive equation ocean model described in Shchepetkin and McWilliams (2005). ROMS uses orthogonal curvilinear coordinates on an Arakawa-C grid in the horizontal while utilizing a terrain-following (sigma) coordinate in the vertical. The prognostic variables of the hydrodynamic model are surface elevation, potential temperature, salinity and horizontal velocities.

The local model of the south-west coast or Ireland, hereafter called the Bantry Bay model, consists of 557 x 419 grid cells relating to a horizontal spacing of 200 – 250m and 20 vertical levels. The model is nested offline in a regional North East Atlantic (NE_Atlantic model) model run operationally at the Marine Institute and is a refinement of the latter by a factor of five. Time series of water levels, 2D and 3D momentum, temperature and salinity are provided every 10 minutes. The Bantry Bay model was initialized in February 2010 from the parent model output interpolated onto a child grid. Surface forcing is taken from the half-degree Global Forecasting System (GFS) that is available at three-hourly intervals and the model interpolates data onto its current time step. Heat fluxes are calculated from the bulk formulae and surface freshwater fluxes are obtained from the prescribed rainfall rates and the evaporation rates calculated by the model. Freshwater discharges from five rivers are included in the model.

Some of the products and services presented in this paper concern another coastal model run operationally at the MI and covering the mid-west coast of Ireland and called hereafter the Connemara model. The set-up is analogous to that of the Bantry Bay model.

The parent model domain (NE_Atlantic) covers a significant portion of the North-West European continental shelf at a variable horizontal resolution between 1.2 and 2.5 km and with 40 sigma levels. It is nested within the high resolution (1/12°) Mercator Ocean PSY2V4R2 operational model of the North Atlantic whereby daily values for potential, temperature, sea surface height and velocity are linearly interpolated from the parent model onto the NE_Atlantic model grid at the boundaries. Tide forcing is prescribed at the model boundaries by applying elevations and barotropic velocities for ten major tide constituents, which are taken from the TPXO7.2 global inverse barotropic tide model (Egbert and Erofeeva, 2002).

The above model domains are presented in Figure 1.

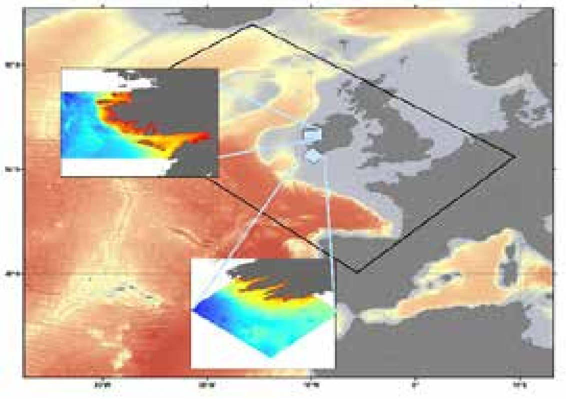

Figure 1 The MI operational general ocean circulation models domains: (a) NE_Atlantic, (b) Bantry Bay and (c) Connemara.

The authors also developed a wave model based on SWAN (Simulating Waves Nearshore) to estimate wave climate on the west coast of Ireland for offshore aquaculture siting. The model domain encompasses Irish coastal waters from 12 to 7.5 W and 50 to 56.5 N at horizontal resolution of 0.004 degrees. The model was forced with winds from GFS model and wave data at the boundaries from the Wave Watch 3 (WW3) model developed by FNMOC (U.S. Navy Fleet Numerical Meteorology and Oceanography Center).

3. Products and services

3.1 Shellfish growth and carrying capacity

The Bantry Bay model also contains the biogeochemical module, which is based on the nutrient-phytoplankton-zooplankton-detritus model (NPZD) developed by Fennel et al. (2006). All biogeochemical model state variables are provided every 3 hours at the open boundaries and are interpolated from the 'parent' North-East Atlantic biogeochemical model, which is a coarser resolution version (~5km) of the NE_Atlantic model described in section 2.

This biogeochemical module is further coupled to the shellfish eco-physiological model developed and implemented by Dabrowski et al. (2013). This shellfish model has been written for the species of *Mytilus edulis* and comprises of two modules, namely the shellfish growth and the shellfish-ecosystem interactions. The former is a Fortran 90 implementation the Dynamic Energy Budget (DEB) algorithm (Kooijman, 2010) and the latter is a new model developed by the authors and presented in detail in Dabrowski et al. (2013). The following processes are included: food uptake and assimilation of nitrogen and carbon in bivalve, egestion of faeces, NH_4 excretion, oxygen utilization and CO_2 production. The food comprises of phytoplankton and small detritus and the model dynamically adjusts food preferences through the inclusion of the food selection factor, and the egestion of faeces adds to the large detritus pool in the model.

The shell length, L, and dry weight, DW, are derived from the model, as these are important parameters from the farm operations and management perspectives and they have an impact on the price. Figure 2 presents the distribution of predicted L after c.1 year simulation carried out for years 2010-2011. These results were validated and compare well with data collated from the bay over the same time period. Red colour represents good growth areas (greater L), whereas blue colour poorer growth areas (lower L).

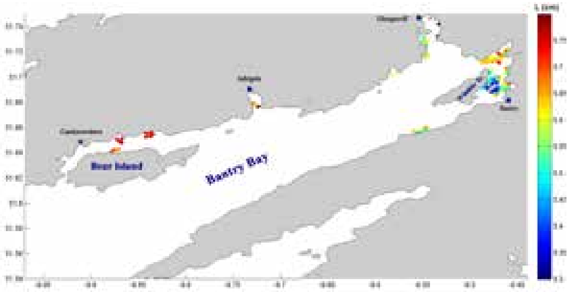

Figure 2 Predicted shell lengths at the end of June 2011 after c. 1 year simulation with initial shell lengths of c.3.3cm.

The presented model can thus answer two overarching questions: what is the spatial distribution of growth rates in the bay and what impacts on the ecosystem are exerted by the farms (e.g. depletion of phytoplankton, DIN enrichment). Furthermore, the model can assist in addressing the issues of production carrying capacity and ecological carrying capacity by running the experiments with changes to standing stocks and with relocation and addition of new farms.

3.2 Shellfish microbial contamination

The model described in section 1.1 has been further extended to include a microbial module developed and presented in Dabrowski et al. (2014). In the above paper the authors present a new method to simulate an uptake of *E. coli* from seawater and subsequent depuration by *M. edulis* that dynamically predicts *E. coli* concentration in the mussel tissue. Concentration of *E. coli* in water is determined by its die-off rate, dependent on light, temperature and salinity, the rate of uptake by mussels and the rate of input from the point sources in the bay. Depuration is undergoing in the mussel tissue following first-order decay and assuming a constant T_{90} of 3 hours, which yields a decay rate of 18.4 d^{-1}. Dabrowski et al. (2014) derived an equation for the filtration rate resulting from the energy ingestion rate predicted by the DEB model for *M. edulis*. This energy ingestion rate is converted to carbon ingestion rate and its uptake in food is subsequently calculated. Phytoplankton is one of the food sources in the presented model; therefore the filtration rate can be expressed in terms of the ratio of phytoplankton carbon ingestion rate to phytoplankton carbon concentration.

Shellfish water classes defined in the EC directive and based on coliform concentration in shellfish flesh can be derived from the model. Figure 3 presents the distribution of these water classes in Bantry Bay; these compare well with the classes established from the national monitoring programme.

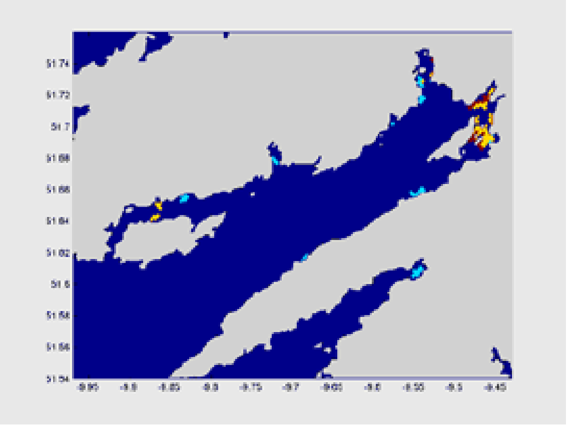

Figure 3 Shellfish waters classification in Bantry Bay predicted by the model.

Some overarching questions that can be addressed by the presented model include:

- How does new/existing outfall impact on shellfish waters?
- Is it a safe location for a new farm?
- What is the best time for harvesting (to include short term forecasts if implemented operationally)?

3.3 HAB warning

A number of customised products are generated from the Bantry Bay model and are intended to improve our knowledge on driving forces behind HAB events off southwest Ireland. The products include Bantry Bay cross-sections at the mouth of the bay and midway between the mouth and the head showing 3-day averaged volumetric flows, temperature, salinity and density (Figure 4).

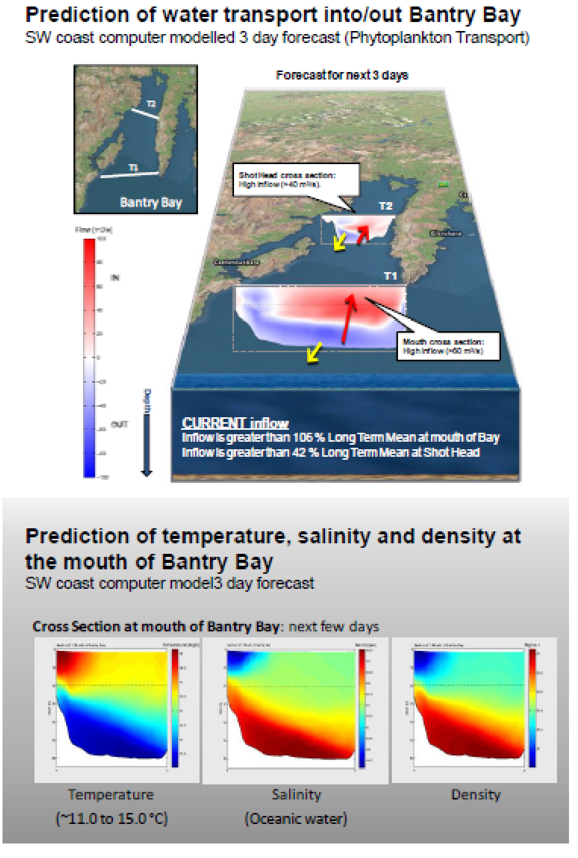

Figure 4 Excerpt from HAB bulletin published by the MI and showing model-derived volumetric flows in and out of Bantry Bay and cross sections through temperature, salinity and density.

Another operational product is based on the predicted tracks of the particles released at surface layer, at 20 m depth and at the bottom layer across the mouth of Bantry Bay and a transect perpendicular to the coast, through offshore waters, southeast of Bantry Bay at Mizen Head. The particles are released at the above transects over the first 12 hours and at 30 minute intervals upon the execution of each model 3-day forecast. The particles are passive, that is they do not have any behaviour attached to them and are advected freely by the model-predicted currents. The end product are maps (one per transect and release depth) presenting the total time spent by all particles at each model computational cell over the duration of the forecast, so called the particle-hours, and these maps are available 'on-line' (http://vis.marine.ie/particles). An example map is presented in Figure 5. Furthermore, a set of Matlab scripts have been developed allowing to execute the particle transport model in a hindcast mode upon notification of suspected toxic bloom locations.

These products aim to quantify the strength of shelf water inflow into Bantry Bay, highlight upwelling/downwelling events and depict the strength of the Irish Coastal Current.

The products are continuously assessed with observed HAB events in Bantry Bay. In 2013 the outbreaks of *Karenia spp*. and *Dinophysis spp*., associated with upwelling and downwelling events, respectively, were observed and both events were reflected in the presented model and products.

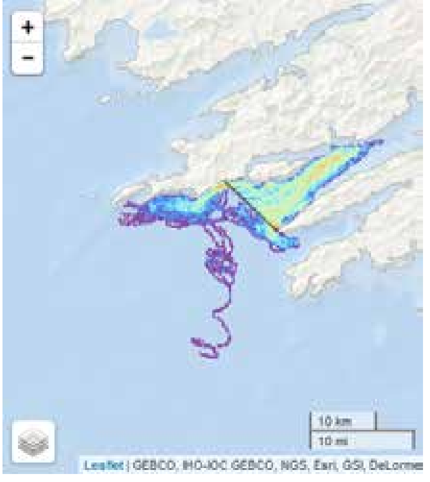

Figure 5 The particle-hours map from the 3-day forecast starting on 14 May 2014. Particles were released at the bottom layer along the transect shown. Colour scheme: purple – low values, orange – high values.

3.4 Offshore aquaculture

Offshore aquaculture development requires accurate knowledge of environmental conditions (e.g. weather and wave climate; characteristics of water currents, etc) at proposed sites. Knowing the environmental conditions, over a large area, facilitates intelligent targeted site selection for offshore aquaculture development. Site classification can be achieved by considering a number of factors such as exposure (e.g. wave, wind, currents), accessibility (which is related to exposure), and distance to shore/infrastructure.

A 13-month simulation was carried out using the wave model described in section 2 and statistics for significant wave height, *Hs*, were calculated for every model grid node. The authors created raster files of mean *Hs* and the 90% percentile value of *Hs* (*Hs_P90*). Also created was a raster file of maximum tidal velocity using output from the NE_Atlantic model. These files along with a raster file of water depths comprised the data sources for a Geographical Information System (GIS) using ESRI's ArcGIS.

The GIS allowed identification of potential offshore aquaculture sites using simple rules to isolate areas where certain exposure criteria were met. As an example, the following simple model to highlight potential sites was enforced: water depth >= 15 m; max tidal velocity < 1 m/s; mean *Hs* < 4 m; *Hs_P90* < 2 m. Figure 6 shows the results of this query for a portion of the west coast of Ireland.

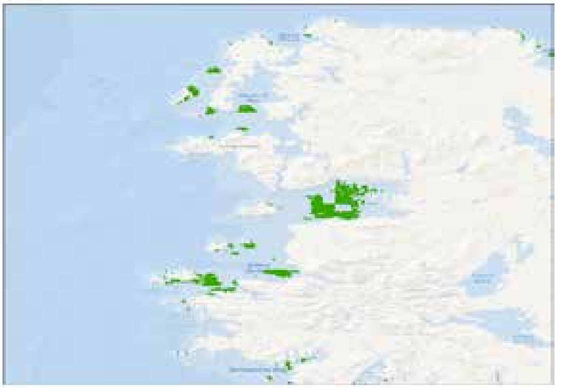

Figure 6 Potential offshore aquaculture sites (green) off the west coast of Ireland.

Further work is required to improve the GIS model, such as the addition of infrastructural data, but there is great potential for using this type of rule-based GIS to aid in the planning and development of offshore aquaculture sites.

3.5 Cross-contamination of farms

Since the dispersal of planktonic larval salmon lice is largely controlled by surface currents, it is possible to simulate their dispersal using hydrodynamic modeling. For this study, the Connemara model was run with Lagrangian particle tracking activated. This allows the introduction of model particles into the domain at a location of the user's choosing (e.g. a salmon farm) and the particles are advected around the domain by the model currents. The model particles behave as passive drifters with neutral buoyancy. The particles are assumed to have a "lifespan" of 14 days, after which they were considered "dead", i.e. excluded from the analysis.

The particles were released near the surface at the locations of the aquaculture farms in the region every 3 hours for 35 days and the location of each particle was recorded over the duration of 14 days. The particle-hours, defined in section 1.3, were then calculated for each model cell and projected on the map showing the relative infection risk for fish in each cell of the model domain. An example map for the infection risk from Daonish farm is presented in Figure 7.

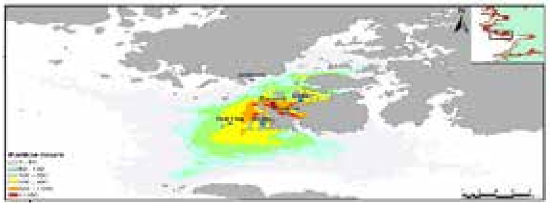

Figure 7 Sea lice infection risk map from Daonish farm located in the west of Ireland.

Another product that the authors developed from the simulations and the particle-hour calculations is the cross-contamination matrix. It was created by defining each salmon farm as a 500 m^2 polygon centred on each release site and calculating the particle-hour value for that salmon farm due to particles released from each of the remaining sites in the region. Table I is the matrix developed for the three releasing sites in the region.

Table I. Cross-contamination matrix for salmon aquaculture farming region in the west of Ireland.

Release sites	**Receiving sites**				
	Casheen	Cnoc	Daonish	Golam	Red Flag
Cnoc	129		202	111	525
Daonish	1359	192		73	439
Golam	155	37	206		237

More results from the presented study can be found in Jackson et al. (2012).

3.6 Products for fisheries

Output from the MI operational models also underpin the assessment and advisory services on the sustainable exploitation of the marine fisheries resources in the waters around Ireland and on the impacts of fisheries on the ecosystem. Monthly averages of the model-predicted bottom temperatures and bottom shear stress are produced operationally along with other model prognostic variables and are published on the MI data portal at http://data.marine.ie/. The authors also maintain an archive of 3-hourly model prognostic variables for Irish waters from the NE_Atlantic model, which is used to force an offline particle tracking model in the MI in the investigations into fish larvae transport. Readers are referred to O'Sullivan et al. (2014) for details on the study on the potential dispersal fields of *Nephrops* larvae from individual fishing grounds and assessment of stock connectivity using the output from the presented models.

Acknowledgements

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Copernicus Marine Service

Ocean Forecasting at the Met Office

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Abstract:

Operational oceanography has evolved from a range of user communities. From the public safety aspect wave and surge services are driven by both Safety Of Life At Sea and the need to provide flood warnings. Meteorological services need operational analyses of ice and sea surface temperature for weather prediction. Services which monitor and forecast the three dimensional marine environment have also been developed for a range of government and commercial users.

The recognition of the importance of ocean-wave-atmosphere interactions is increasingly an opportunity and challenge for our community. Integrating the surge, wave and three-dimensional ocean forecasting capabilities has the potential to improve the quality of our services. Furthermore, the recognition that the ocean has a role in weather on short timescales is driving further research on integration with numerical weather prediction systems, including research on coupled data assimilation.

The Ocean Forecasting group at the Met Office undertakes R&D to improve and diversify its products and services. An overview is presented of the systems currently in place at the Met Office, of the assessments and assessment techniques used to evaluate them, and the research activities that will give rise to the future systems providing marine monitoring and forecasting services.

Keywords: meteorology, wave, surge, ocean, forecasting, OSTIA, FOAM

1. Introduction

The Met Office operate and develop, in collaboration with science partners, a range of operational analysis and forecasting systems. The priority for the ocean forecasting R&D area is in developing systems for global ocean capability and for the North-West European continental shelf waters that surround the United Kingdom. There are also a number of other regional services for government and commercial customers, but these are not detailed here.

A brief overview of the systems used for operational short-range forecasting and analysis is given below. This is followed by a summary of some of the key areas of research which will lead to fundamental changes in the way we do operational ocean forecasting in the future.

2. Analysis and forecasting systems

2.1 Surface Waves

The Met Office wave models are based on NCEP's WAVEWATCH III™ (WWIII, Tolman, 2009). WWIII has recently adopted a community model status, enabling users to benefit from model developments implemented by numerous research groups worldwide. For example, in the present operational configurations run at the Met Office model options to use a flavour of WAM source terms physics (Saulter, 2015) and a 2nd order propagation scheme (Li, 2008) have been selected.

Deterministic operational forecasts are based on three configurations. A global wave model at approximately 35km resolution runs four times daily, alternating between forecasting two days and five days ahead. This provides boundary conditions for a European wave model at approximately 8 km resolution, running a similar cycle, and for a UK waters model at 4km resolution, which also runs four times daily but is limited to two day forecasts. The Met Office has also built and run higher resolution wave models for coastal applications on an ad-hoc basis using the SWAN model. For example, an application was run for Weymouth Bay as part of the Met Office's support for the London 2012 Olympics (Golding et al., 2014).

Most operational centres run similar setups, with a suite of nested configurations allowing resolution in areas of interest at achievable costs and with the aim of producing forecasts as soon as possible after generation of the atmospheric weather forecast, in order to make maximum use of the forcing skill.

Research at the Met Office is presently focused on three enhancements to this system. The first is use of grid refinement, in which the wave model comprises cells of different resolutions so that high resolutions can be applied near the coast whilst retaining more computationally efficient larger cells in deeper open waters. The advantage of adopting this method is to reduce the need to maintain multiple nested model configurations. The grid refinement method developed at the Met Office uses the spherical multiple-cell (SMC) grid (Li, 2011) and has been tested in a global wave model (Li, 2012; Li and Saulter, 2014).

An SMC grid model for the Atlantic has also been implemented as part of a wave Ensemble Prediction System (wave-EPS, Bunney, 2014; Bunney and Saulter, 2014). Forecasts from the system are being trialled based on increasing user requirements for probabilistic decision making data. As a forced-dissipative system, spread in wave forecast errors can be primarily simulated using spread derived in wind data from an atmospheric ensemble. In this case, the Atlantic wave model is driven using members from the Met Office Global atmospheric ensemble MOGREPS-G (Bowler et al., 2008).

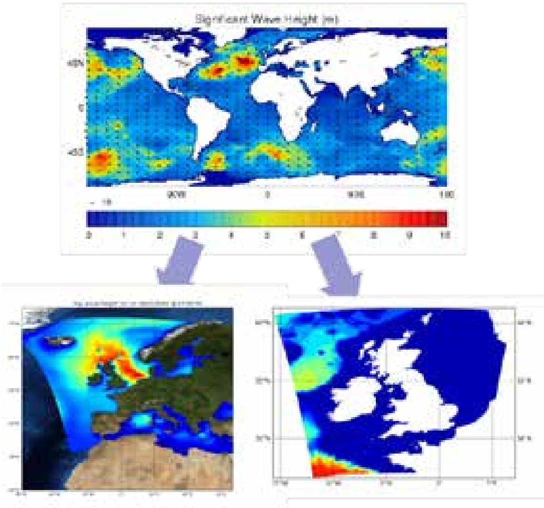


Figure 1 Operational wave model configurations.

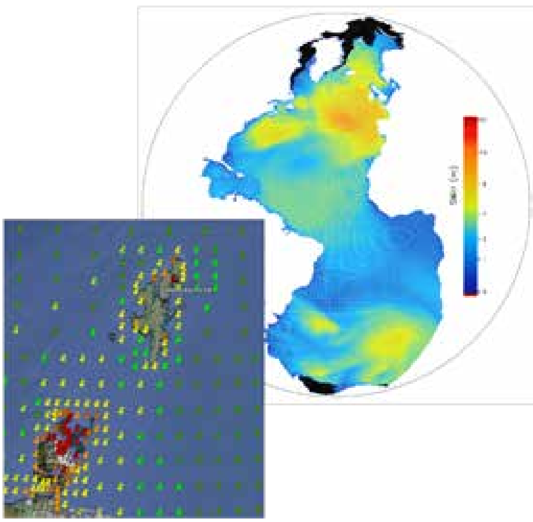


Figure 2: SMC grids.

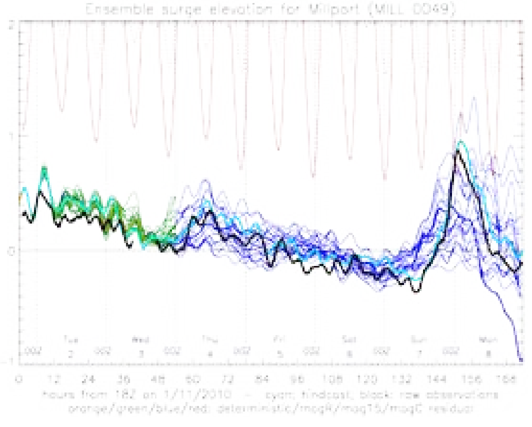
The third area of active research is based around the UK, where it is recognised that a high degree of variability in the oceanic conditions, particularly associated with the tides, will introduce variability in the wave field. At the same time, waves on the ocean surface will feed back to atmosphere and ocean (Cavaleri and Fox-Kemper, 2012), so work in this area is closely tied to longer term development of coupled atmosphere-wave-ocean systems.

2.2 Surge

Tide-surge models are run in real-time as part of the forecast suite of models. Results are used by the joint Environment Agency/Met Office Flood Forecasting Centre, together with data from the National Tide Gauge Network, for coastal flood warning in England and Wales.

The first operational surge forecasts were run in 1978 using coarse grid surge and atmospheric models. The present system comprises a 12 km shelf model (CS3X), with refinements to 1km and a 1-D river model to provide useful predictions in the complex regime of the Bristol Channel and Severn Estuary.

A deterministic surge model suite comprising CS3X, Bristol Channel and Severn Estuary models is run four times daily, forced by wind and surface pressure data from the Met Office's global weather forecast model (horizontal resolution approximately 17km). CS3X is also ensemble mode forced by MOGREPS-G. Similar to waves, uncertainty in the surge forecast is primarily influenced by uncertainty in the atmospheric forecast, such that good probabilistic performance can be achieved by a surge-EPS perturbed only by the atmosphere (Flowerdew et al., 2010).



A new generation surge model is being developed based on NEMO. The CS3X uses legacy code not suited for new HPC requirements and is not subject to ongoing operational development. The move to NEMO will allow the surge model to benefit from developments in the community model code, with the potential for further system improvements based on ensemble initialisation, data assimilation and coupled modelling discussed elsewhere in this paper.

Coastal flood events are determined by tide, surge, wave 'set-up' and crest height and the minimum sea defence height. Coupling tide, wave and surge models to give a combined sea level is a future development under consideration.

2.3 OSTIA

The Operational Sea surface Temperature and sea Ice Analysis (OSTIA; Donlon et al., 2012) system was developed at the Met Office, where it is run in near real time on a daily basis. OSTIA produces a global field of sea surface temperature (SST) (free of diurnal variability) every day on a 1/20 degree (~6 km) grid. The system uses SST input data from infrared and microwave satellite measurements together with in-situ data and a sea ice concentration product. Data assimilation methods are used to combine the different SST input data, taking into account estimates of the observational error, to produce a gridded analysis. OSTIA is widely used, particularly in numerical weather prediction centres (including the Met Office and ECMWF) where it is used as a lower boundary condition in weather forecast models. It is also used in operational ocean forecasting systems and by climate monitoring groups. The OSTIA system is continually being developed and improved; Figure 3 shows the impact on SST gradients of improvements to the error covariances and numerical convergence used in the system. A new diurnal component to OSTIA has recently been developed which produces hourly skin SST fields. OSTIA is a MyOcean product (available from www.myocean.eu).

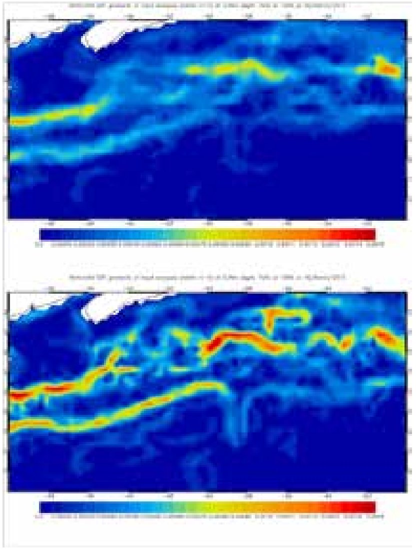


Figure 3 OSTIA SST gradients (10^{-2} K / m) in the Gulf Stream region on an example day. Top: Old system; Bottom: Improved system.

2.4 FOAM

The Forecast Ocean Assimilation Model (FOAM) is an ocean analysis and forecast system which runs operationally every day at the Met Office. The FOAM system includes deep ocean configurations (1/4° global and 1/12° regional; Blockley et al, 2014) and a higher resolution shelf configuration (European NorthWest Shelf at 7 km horizonal resolution; O'Dea et al., 2012). The configurations are one way nested, e.g. the global model provides boundary conditions for a North Atlantic regional model which in turn provides boundary inputs for the European shelf model. The FOAM system produces analyses and 6 or 7 day forecasts for the various configurations everyday.

FOAM uses the ocean model NEMO (Nucleus for European Modelling of the Ocean; Madec, 2008) and the Los Alamos sea ice model CICE (Hunke and Lipscomb, 2010) in configurations with sea ice. The European shelf configuration is also one way coupled to the European Regional Seas Ecosystem Model (ERSEM; Baretta et al., 1995). FOAM is forced with atmospheric data from the Met Office's global Numerical Weather Prediction system. The FOAM system assimilates observations using the NEMOVAR (Waters et al., 2014) data assimilation scheme. The deep ocean configurations assimilate the following observations: satellite and in-situ SST; temperature and salinity profiles, satellite sea surface height anomalies and satellite sea ice concentration. The shelf seas configurations currently only assimilate SST and are being developed to use other data types.

The Met Office leads the European North West Shelf Monitoring and Forecasting Centre within the MyOcean Project and provides analyses and forecasts from the FOAM shelf configuration (available from www.myocean.eu).

3. QUANTIFYING SKILL AND UNCERTAINTY

3.1 Verification Science

Verification is performed routinely at the Met Office on a range of ocean models and forecasts. It is primarily undertaken as a means to monitor model performance and to objectively assess the quality of our forecasts, so that users can have confidence in the data provided. An additional motivation for verification is to identify flaws or improvements that could be made to our models, and feed these issues back to the model developers for further investigation. By assessing the long term performance of our models it is possible to not only identify where improvements have been made (Figure 4), but also where changes may have been detrimental. This cycle of forecast, followed by assessment and then feedback occurs routinely, with Met Office scientists regularly reviewing the output from all of the ocean and wave models that are run each day.

As part of our ongoing commitment to improving our modelling capabilities we also take part in intercomparison activities with other forecasting centres, and have contributed to projects such as MyOcean, MyWave and GODAE OceanView. In agreement with our collaborators, we have identified common sets of observations against which to assess each centre's forecasting skill. Figure 5 (Ryan *et al*., 2015) shows an example from the GODAE OceanView intercomparison exercise, in this case verification of SST forecasts against drifter observations.

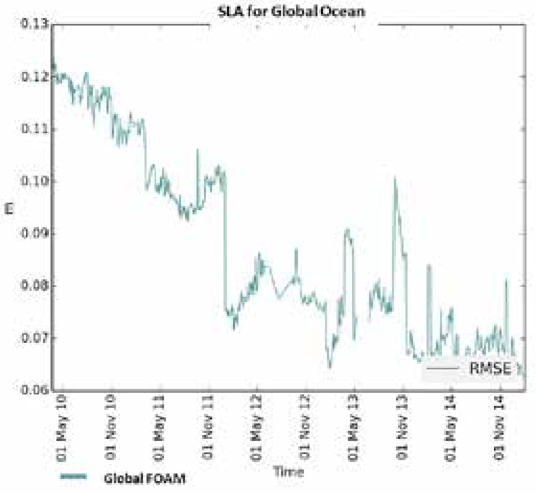


Figure 4 Improvements in forecasting skill for sea level anomaly in the global ocean FOAM model.

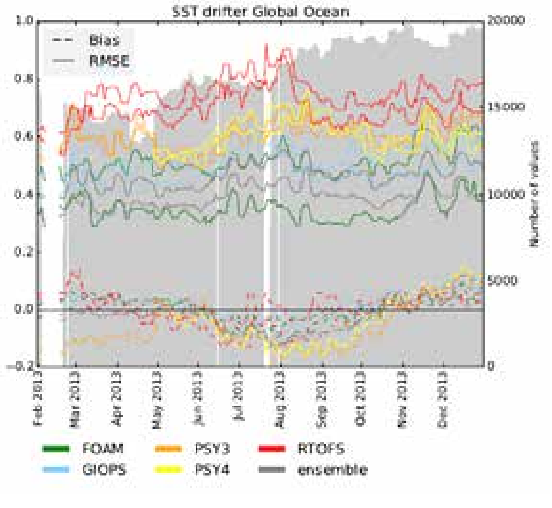


Figure 5 RMSE/bias time series of 12h and 84h forecasts filtered using a median weekly filter. The background grey represents the number of data values per day.

Similar assessments were performed within the MyOcean project, where attention was focused on conveying the accuracy and quality of MyOcean products to the user community. The Met Office led this pan-European activity on product quality, interacting with a number of institutions to define appropriate metrics, datasets and common guidelines for the provision of verification results. These were then collated and displayed for user access through a bespoke web-based interface.

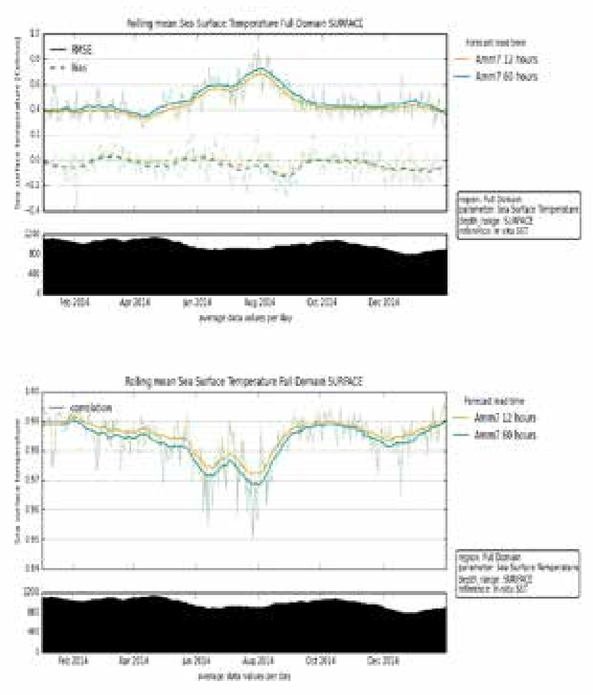


Figure 6 SST accuracy for the North West Shelf.

3.2 Ensembles

Ensembles are routinely produced for surge modelling, which uses a forced ensemble approach. The sole source of spread is from the spread in the atmospheric forcing. Recent developments are also being made to allow ensemble predictions in the wave modelling system. For surge and waves, which are forced-dissipative regimes, good spread can be seen in the ensemble from these methods.

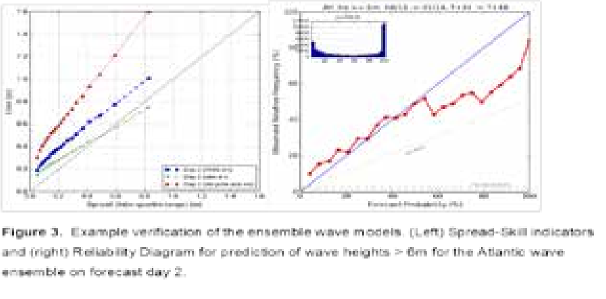


Figure 7: Example verification of the ensemble wave models. (Left) Spread-Skill indicators and (right) Reliability Diagram for prediction of wave heights > 6m for the Atlantic wave ensemble on forecast day 2.

This is not likely to be the case for other prediction systems, and research into the generation of ensemble ocean forecasts, beginning with the global FOAM configuration, is underway. Ensemble information is expected to be useful for various users of the data including the initialisation of coupled seasonal forecasts where ensembles are an essential component. The ensemble information will also be useful for improving the background error covariance representation in the data assimilation system, thereby improving the use of observations to initialise forecasts. A hybrid 3DVar-ensemble capability is being developed in collaboration with other groups in the NEMOVAR consortium in order to make use of ensemble background information. Initially, only small numbers of ensembles are likely to be available, and the data assimilation scheme is designed to reduce the impact of sampling issues on the data assimilation increments.

4. THE NEXT GENERATION OF FORECAST MODELS

4.1 The ocean component in coupled NWP

The Met Office has recently started to assess whether using a coupled atmosphere-ocean modelling system can provide benefit for both operational NWP and ocean forecasting. Comparisons with atmosphere-only control experiments have demonstrated benefit for atmospheric verification metrics (particularly in the tropics) from coupling an ocean configuration essentially identical to the global FOAM configuration to a low resolution version of the Met Office Unified Model operational NWP configuration. Impacts on the ocean forecasts are smaller, and in some cases larger SST biases in the coupled model have a detrimental impact on forecast quality, but more benefits are expected to be realised as increased atmosphere and ocean (1/12^{o}) resolution allow feedbacks between SST and the atmospheric boundary layer to be better captured.

Ocean forecasts from a Met Office coupled atmosphere-ocean system have been available through the MyOcean portal since early 2014 and it is expected that the coupled system will be upgraded to higher resolution in the medium term. Currently the system is initialised from separate atmosphere and ocean analyses but a demonstration 'weakly coupled data assimilation' system has now been set up to allow the coupled model to be initialised in a more consistent manner. A further enhancement expected is the inclusion of a WWIII wave component – early testing allowing the atmosphere model to see a wave-dependent surface roughness has shown some positive impacts.

4.2 Environmental Prediction

There is increasing interest at the Met Office and among a number of operational centres, in developing and evaluating more integrated prediction systems which represent the feedbacks between different components of the environment (atmosphere, land, ocean, sea-ice etc). Whilst this coupled approach is well established for climate prediction, its use for delivering more useful information on shorter timescales is relatively less well developed. The need to accelerate progress in Earth System prediction across all scales (climate and weather, global and local) was discussed by Shapiro et al. (2010). At the Met Office, development towards using global coupled atmosphere-land-ocean-sea ice prediction, including coupled data assimilation, for short-range forecasts has demonstrated modest improvements in coupled compared to uncoupled atmospheric and ocean forecast skill (Shelly et al., 2014).

For regional high resolution prediction, the foundations of a UK environmental prediction system that links together predictions of the atmosphere, coastal ocean, land surface processes and hydrology are being established by the Met Office, Centre for Ecology and Hydrology, National Oceanography Centre and Plymouth Marine Laboratory. The potential value for this UK Environmental Prediction system is significantly increased by existing linkages between weather, ocean and hydro-meteorological service providers in the UK, formalised through operational and service-led collaborations such as the Natural Hazards Partnership. The challenge now is to realise the potential of integrated regional coupled prediction in the UK context. This will require a unified approach across traditional disciplinary boundaries to better understand and represent the interactions between the relevant bio-geophysical systems, and to better observe, initialise and verify these processes. If successful, improved predictions could galvanise research and development effort over the next decade, and should increase the value and use of operational oceanographic science capability and investment to society.

Acknowledgements

This is the synthesis of the work a large number of science staff in the Met Office and collaborating organisations, most notably the National Oceanography Centre and Plymouth Marine Laboratory.

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My Ocean Baltic Sea Monitoring and Forecasting Centre

The BAL MFC group*

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Abstract:

This paper describes the EU-funded MyOcean project ocean monitoring and forecasting centre for the Baltic Sea. The centre has developed a state-of-the-art physical-biochemical ocean forecast system for the Baltic Sea. Since its launch in 2009 the system has been undergoing regular version upgrades with documented product quality improvements. The system is characterised by very high code standard and accurate model description of the physical and biochemical processes. It has flexible operational modelling facilities such as dynamic two-way nesting, flooding and drying. Besides providing regular ocean forecasts the system has also produced a number of multi-decadal reanalysis products for the Baltic Sea.

Keywords: MyOcean, Baltic Sea, forecast, reanalysis

1. Introduction

The MyOcean project (www.myocean.eu), funded by the European Commission, aims at delivering regular information to describe and forecast the physical state and low trophic level ecosystem of the European regional seas and global ocean. For the Baltic Sea this information has been provided by a group of Baltic oceanographic institutes, led by DMI, comprising of the Baltic Sea Monitoring and Forecasting Centre (BAL MFC), see Figure 1.

Fig.1. Partners of the Baltic Sea Monitoring and Forecasting Centre are Bundesamt für Seeschifffahrt und Hydrographie (BSH), Danish Meteorological Institute (DMI), Finnish Meteorological Institute (FMI), Marine Systems Institute – Tallinn Technical University (MSI) and Swedish Meteorological and Hydrological Institute (SMHI).

In this article we present the Baltic Sea model system and its evolution during the six year period with MyOcean financial support (MyOcean: 2009 – 2012, MyOcean 2: 2012 – 2014, MyOcean Follow On: 2014 – 2015). Focus will be on the model systems, quality of the provided model products and on the services provided to users.

During the MyOcean projects we have upgraded the BAL MFC system and the operational oceanographic products - freely available via the MyOcean portal - at least once per year with documented quality improvements each time. Model developers of the BAL MFC group have special focus on both maintaining very high technical standards of the model codes and on improving the model processes describing the physical and biochemical state of the ocean. For the Baltic Sea we deliver two operational MyOcean products providing forecast information of the physical state and the biochemical state of the ocean, respectively. The products are calculated with the online coupled model system HBM-ERGOM (see Berg and Weismann Poulsen, 2012; Neumann, 2000). In addition we provide a number of different reanalysis products.

2. The Baltic Sea MFC models

Here we detail the BAL MFC coupled physical and bio-chemical model system, HBM-ERGOM.

2.1 HBM

HBM (HIROMB-BOOS-Model[1]) is an operational three-dimensional, free-surface, baroclinic ocean circulation and sea ice model that solves the primitive (Navier-Stokes) equations for horizontal momentum and mass, and budget equations for salinity and heat on a spherical grid that co-moves with the Earth's rotation. The vertical transport assumes hydrostatic balance and incompressibility of sea water. Horizontal transport is modelled using the Boussinesq approximation, where density differences are neglected in all but gravity terms. Higher order contributions to the dynamics are parameterized following Smagorinsky (1963) in the horizontal direction and a k-ω turbulence closure scheme, which has been extended for buoyancy-affected geophysical flows in the vertical direction (Berg, 2012). The turbulence model includes a parameterisation of breaking surface and internal waves. Stability functions from Canuto *et al*. (2002) for the vertical eddy diffusivities of salinity, temperature and momentum have been applied. The model allows for fully two-way nesting of grids with different vertical and horizontal resolution, as well as time resolution. The numerical model implementation uses a staggered Arakawa C-grid and z-level coordinates, a flux-corrected horizontal advection scheme and free-slip conditions along the coastlines.

For MyOcean, HBM is set up with a horizontal grid spacing of 3 nautical miles (nm) in the North Sea, 1 nm in the Baltic Sea and Wadden Sea, and 0.5 nm (30'' latitude by 50'' longitude) in the inner Danish waters. In the vertical the model has up to 122 levels with a top layer thickness of 2 m. At open model boundaries between Scotland and Norway and in the English Channel, tides composed of the 8 major constituents and pre-calculated surges from a barotropic model of North Atlantic (Dick *et al*., 2001) are applied. Freshwater runoff from the 79 major rivers in the region is obtained from a mixture of real-time observations and climatology (North Sea rivers) and hydrological forecasts (Baltic Sea). At the surface the model is forced with atmospheric model data.

As state of the art ocean model, HBM is exceptional because of the high level of rigorous testing and standardisation, which makes code maintenance easier and more efficient (Berg and Weismann Poulsen, 2012). The model development project follows ANSI FORTRAN standards, as well as OpenMP and MPI standards, but is also guided by styling rules that ensure high portability of the code. Numerical validation procedures have been devised to inter-compare standardized test-runs of HBM with distributed, shared and hybrid OpenMP-MPI memory parallelization. Daily code validation results are requested to be reproducible across CPU configurations and must be within certain specified limits across compilers. Portability and model correctness in term of reproducible output are key pillars of HBM model development, and are never sacrificed against speed or against

1 HIROMB is an abbreviation for High Resolution Oceanographic Model for the Baltic. BOOS stands for the Baltic Operational Oceanographic System.

added functionality. Optimization with regard to performance, that is efficient use of the system at hand, requires a focus on right architecturing, starting with the choice of appropriate data structures and with attention to data locality and the application of threading and vectorization techniques (Single Instruction Multiple Data). Optimal data structures are key components for high performance computing allowing for high degree of parallelism on multi-core and many-core platforms (Weismann Poulsen *et al*., 2014).

2.2 ERGOM

The biochemical model ERGOM (Ecological Regional Ocean Model; Neumann, 2000) is online coupled with HBM. The current operational version ERGOM contains 12 state variables: ammonia, nitrate, phosphate, silicate, diatom, flagellate, cyanobacteria, micro-zooplankton, meso-zooplankton, detritus of nitrogen, detritus of silicate and oxygen.

The model parameters, calibrated originally with observations from the 1980'ies, were recalibrated for the particular MyOcean setup with observations from the period 2000-2012 (Wan *et al*., 2012). The impact of Suspended Particulate Matters on light attenuation is parameterized based on turbidity and bathymetry depth (Wan *et al*., 2013).

3. Products and dissemination

Two Baltic Sea, 2.5 day long forecast products of hourly data are produced twice daily by HBM-ERGOM. The horizontal resolution of the products are identical to the native model grid in the Baltic Sea area, whereas the provided 25 levels in the vertical are only a subset of the model's native grid which has up to 122 levels (see section 2.1). The two operational forecast products are produced on two independent platforms running synchronously to ensure a product delivery as close to 100% as possible to the MyOcean users. The products are produced by:

• The nominal production system, running at DMI

• The backup production system, running at BSH

In case of a failure in the production at the nominal system running at DMI, the BAL MFC dissemination unit at SMHI will shift over to use data from the Baltic MFC backup system running at BSH. These data are then delivered into the MyOcean catalogue. Users will be informed about such a shift in production via the News Flash on the MyOcean website but will not experience breach in service.

To ensure the two production systems to be aligned with respect to model results, the latest restart field is transferred from the nominal production system at DMI to the backup system at BSH after each model run. The only differences between the nominal and the backup production systems are different meteorological forcing fields (DMI uses data from the DMI-HIRLAM model and BSH uses data from Deutsche Wetterdienst) and different computing platforms. Model code and model set up are identical.

Several reanalysis products, differing in time span, assimilation methods etc. have been provided for the Baltic Sea (Fu *et al*., 2012). This effort has, for the last couple of years, been led by SMHI. Two new physical and biochemical reanalysis products covering the last 25 and 30 years, respectively, will be released in spring 2015 (Liu *et al*., 2014).

4. Product quality assessment

The MyOcean project has high focus on quantifying and documenting the quality of the delivered products to end users. MSI and BSH have led this quality assessment work in the BAL MFC group.

Releases of new or upgraded products are always accompanied with comprehensive quality assessment reports. These quality reports are available together with the products at the MyOcean data portal. When a product is released into operational production the quality of the delivered results are furthermore assessed in near real time with metrics for the latest 3 months. This statistic is accessible via the MyOcean validation portal (data.ncof.co.uk/calval/test/index.html).

In the BAL MFC group we have developed the general validation frame work for the Baltic Sea (Lagemaa *et al.,* 2013) which is applied to a fixed two year period, 2007-2008, where simulations with a new model release candidate is tested and compared to the existing operational model and to a large number of observations. A new candidate has to show improvements compared to the existing system before a code or system upgrade may take place. These quality metrics are publicly available via the MyOcean portal for each delivered product.

The BAL MFC group has managed to upgrade the operational products at least once per year during the MyOcean projects. New features have been included as well as improved sanity of the code. The core targets for the Baltic products have been to assess the quality for the parameters: sea level variations, temperature, salinity and sea ice. MSI and BSH have led this quality assessment work within the BAL MFC group.

Following the system upgrades over the last years from 2012 (version v2.1) to the most recent upgrade, becoming operational in April 2015, we are going to present some of the major upgrades of the BAL MFC. Continuously on-going works like purely numerical improvements of the model code or boundary and initial data revisions, which take a large part of the working times, are left out and focus is put on these developments that improved the model physics. More information is available on www.myocean.eu, on the documentation page of the "Baltic Sea Physics Analysis and Forecast" product.

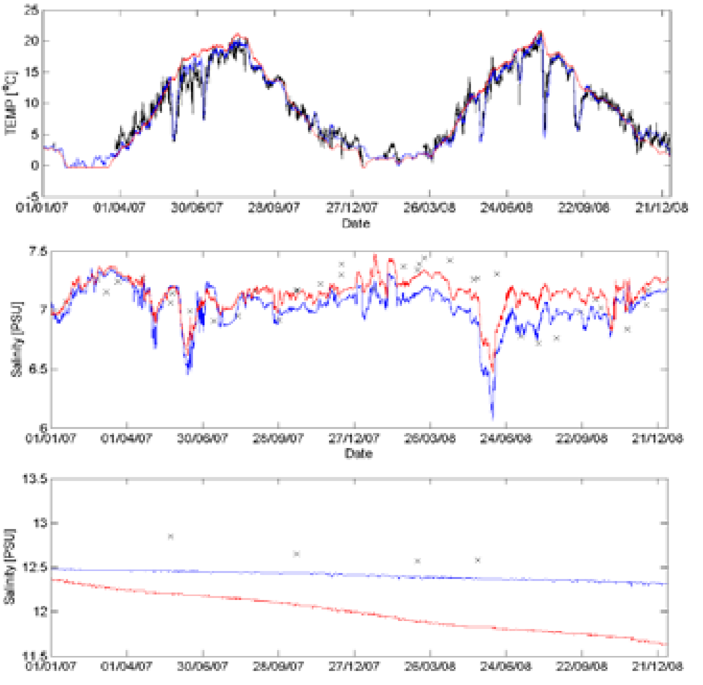

Figure 2 Observed (black line) and modelled sea surface temperature at a coastal location at Estonia (top) and sea surface salinity (middle) and bottom salinity (down) east of Gotland. Improvement in modelled sea surface temperature is clear between model version 3 (blue line), released April 2013, and the previous version 2.2 (red line), released November 2012. Changes between the two release versions include improved model resolution and coastal bathymetry.

The beginning of MyOcean2 marked version v2.1/2.2 of the BAL MFC, which was updated to version v3 in April 2013 by a revision of the model code and set-up. The horizontal and vertical resolution was increased from 3 nm to 1nm (i.e. from 3’ to 1’) and from 50 layers to 122 layers, now featuring a 2 meter surface layer and 1 meter layers below, down to the halocline. In the Øresund region, the 0.5’ grid was revised and spatially variable bottom friction parameter were implemented to better capture storm surge events like the November storm 2011, which led to strong sea level gradients across the Sund. The higher grid resolution and updated near coastal bathymetry improved the quality of the SST product at near coastal tide gauge stations significantly (Figure 2), especially along the coastline of Estonia. The increase in vertical resolution led to a better description of the mixing processes, especially at deeper layers, which improved the quality of the salinity product.

For the next version v4 (2014) the model thermodynamics was updated with revised surface boundary conditions (BC) at the ocean interface to the air: Neumann BC for vertical heat diffusion, instead of previously used bulk formulas; and ocean-ice-snow-interface to the air: implementation of a new snow model and a new albedo model.

Latter improved especially the melting of sea ice (see figure 3). The air-sea exchange coefficients of latent and sensible heat have been revised using a blend of Kara et al, 2005 and the COARE 3.0 algorithm (Fairall et.al. 2003), to transfer 2 meter air temperatures from the HIRLAM weather model to 10 meter values. And mixing in HBM was updated to account for rather fresh Baltic Sea water to become less dense when cooled down near the freezing point.

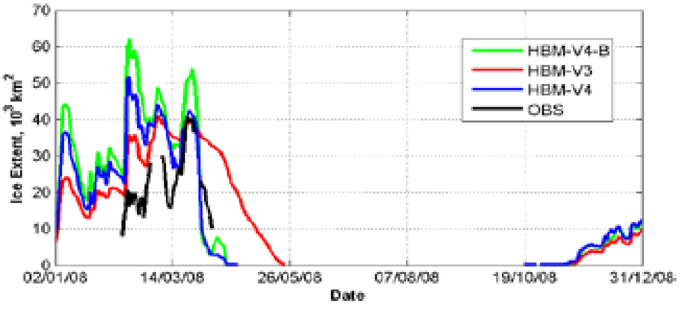

Figure 3 Observed (black line) and modelled (red, blue and green) sea ice extent (in km^2) in the Baltic Sea during the winter of 2008. Improvement in modelled sea ice extent is evident between model version 4 (blue line and green line), released April 2014, and the previous version 3 (red line), released April 2013. Version 4 shows modelled sea ice extend for both the nominal (red line) and the back-up (green) models. The nominal and backup use identical model codes but surface forcings are different (nominal is using DMI-HIRLAM and backup is using data from Deutsche Wetterdienst, see section 3).

The v4 model upgrade improved the sea surface temperature (SST) quality in the whole domain, by reducing the mean bias in comparison with satellite SST and measurements at tide gauge stations. The model quality was improved in upwelling regions, traditionally areas with a high RMSD (figure 4: Root Mean Square Difference, model minus observation).

The version v5 for 2015 introduced frequent updates of river temperatures which significantly reduced RMSD and bias of SST at river mouths, which were present in previous versions (v3 and v4 in figure 4) and were quite significant for the river Neva, at the eastern tip of the Gulf of Finland.

The stability of the HBM model is improved, by frequently updating the baroclinic pressure gradient terms through a liasing of baroclinic and barotropic pressure.

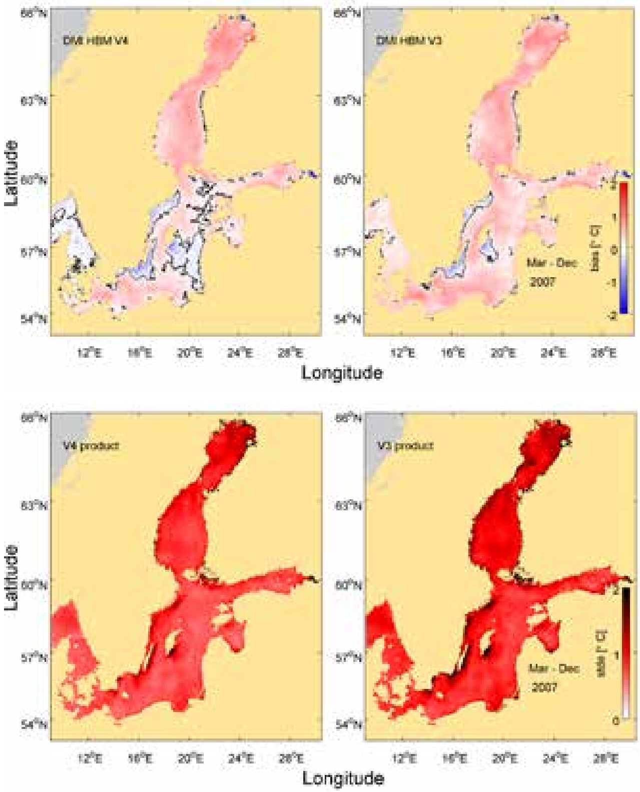

Figure 4 Sea Surface Temperature (SST) model statistics: bias (top) and Root mean Square Difference RMSD (down) in the Baltic Sea in the year 2007. The positive effect of a complete revision of the HBM thermodynamic routines in version4 (left), released in 2014 is clearly visible everywhere in the Baltic Sea, when compared with version 3, released in April 2013.Frequent update of SST at river mouths in version5 (not shown here) has largely removed the bias and RMSD for river Neva at the eastern tip of the Gulf of Finland.

Another major upgrade is the implementation of a tidal potential, which acts additionally to the composed signal of the 8 tidal constituents applied to the open model boundaries. This has improved the sea level bias at most of the stations and increased the variability, but it has also slightly increased the RMSD value of the de-biased sea level time series.

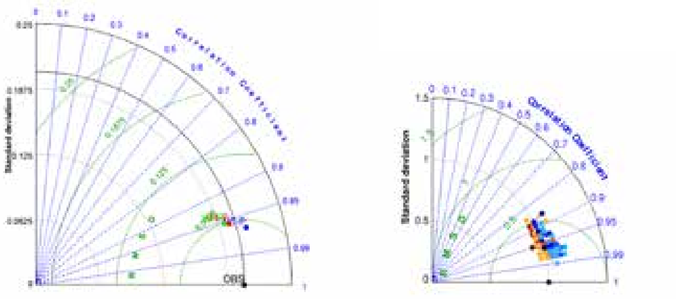

Figure 5 Water level statistics: Taylor diagram at tide gauge station Drogden (left: version3/4/5 green/red/blue) and re-normalised Taylor diagram: $RMSD_{renorm}$=RMSD/σ(obs) at all tide gauge stations: version3/4 are represented by red/blue colour scales and identical stations are connected by lines.

5. Conclusions and discussions

During the past 6 years, with support from the European Commission, BAL MFC has successfully developed a state-of-the-art physical-biochemical ocean model forecast system for the Baltic Sea. The system has been undergoing comprehensive version upgrades on an annual basis. The model numerics, parameterisation of physical and biochemical processes, resolution and forecast quality have been constantly improved in response to user needs. The system has flexible operational modelling facilities such as dynamic two-way nesting, flooding and drying. Very high code standard has been applied in the model development, such as ANSI FORTRAN standards, OpenMP and MPI standards, as well as daily code validation, to ensure reproducibility, high portability, stability and numerical accuracy of the code. The high performance computing of the model system is at the cutting-edge of ocean and atmosphere models. Data assimilation has been developed for producing the reanalysis for the Baltic Sea. Next stage of the model development has been planned and is on its way. The focus in the coming years will be the continuation of the development and operationalization of a new sea ice model with an improved description of fast ice, particularly important in the Baltic Sea, and data assimilation of sea surface temperature and profile data using ensemble methods and extensive validation of the ecological model. The value-added products will be developed for supporting ecosystem-based management and coastal applications such as the European Union's Marine Strategy Framework Directive (with indicator-based information products), Integrated Coastal Management and Common Fishery Policy. For the mid- and long-term, data assimilation will be extended to include biochemical parameters; ensemble forecast methods and coupled weather-ocean-ice-wave forecasting system will be developed and implemented.

Acknowledgements

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Validation of results from a real-time ocean prediction system

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Abstract:

A validation system is an essential component of any operational forecasting system. Here, the system developed and implemented for the MyOcean Arctic Centre is outlined. Its applications are discussed, and a selection of examples is given. Updated results are online at http://myocean.met.no/ARC-MFC/Validation/

Keywords: ocean forecasting, validation

1. Introduction

The TOPAZ model system for ocean prediction has since spring 2008 been providing daily updated forecasts (with weekly assimilation) for the Arctic region (Arctic Ocean, Nordic Seas, and marginal polar seas). This service is provided free for users, available from the MyOcean Arctic Monitoring and Forecasting Centre (MyO-ARCMFC).

TOPAZ (Sakov *et al*., 2012) consists of an Ensemble Kalman filter module for data assimilation (Evensen, 2003) and the HYCOM ocean circulation model (Chassignet *et al*., 2006) coupled with a sea ice model for prediction (Hunke & Dukowicz).

In order to assess the level of accuracy of the forecasts, an automated (operational) validation system has been implemented (Melsom *et al*., 2011). This system includes validation of sea ice quantities (concentration, edge position, ice drift, tabulated contingencies), SLA, SST, salinity and temperature profiles, near-surface drift and concentration of chlorophyll a. Where available, non-assimilated data sources are used in order to establish an independent measure of quality. Validation results for the region north of 50ºN are updated weekly.

2. Validation metrics

Generally, observations are *in situ* measurements, or on a real average based on remote sensing data from satellite-born instruments. When considering the former, there is a mismatch between sampling and model representation that will restrict the representativeness of such observations. In the latter case, this is not so much of a problem, since the finer-resolution product can be integrated onto the projection and resolution of the coarser product (see Melsom, 2010).

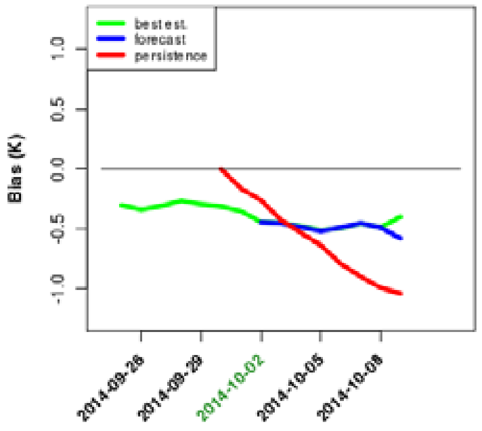

Figure 1 SST bias as a function of date from two model products, and persistence. Observations are from drifting buoys.

Validation metrics are available as one or more of the following types: [a] integral products, [b] distribution, and/or [c] point data. When relevant, we supplement the validation of TOPAZ results with a reference forecast such as persistence. We illustrate the different types by considering validation of model results for SST *vs*. observations from drifting buoys. Figure 1 shows the time series of differences between model and buoy SSTs. Differences are averaged over all positions where observations are available for each day, thus, an integral validation metric (type [a]) is produced.

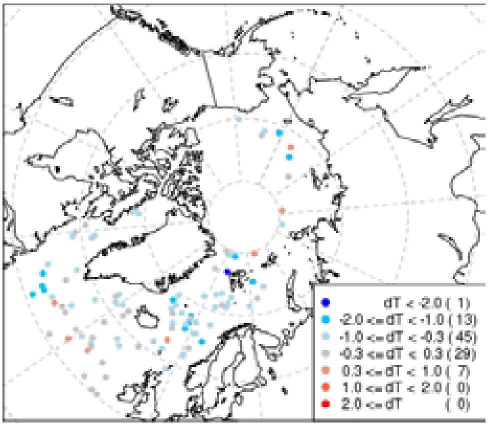

Figure 2 SST offsets from drifting buoy data north of 50°N. Specification of color coded differences are given in the inset.

In Figure 2, SST differences from a sample date is shown by color coded dots, thus displaying results of type [c]. Moreover, the count of differences inside the intervals are given in parenthesis in the in-set table in Figure 2, giving validation results of type [b].

Another type [b] metric that has been adopted, is the categorical confusion matrix (not shown). This is a metric which is richer in information content than the difference count in Figure 2, and it is implemented as part of the validation of sea ice concentration in MyO-ARCMFC (see Melsom, 2010 for details).

3. APPLICATIONS

3.1 Validation statistics

Statistics from production of validation metrics may be taken advantage of in many aspects of operational forecasting. Some of the applications are particularly valuable from the point of view of a user. One example is the expected bias and root-mean-square

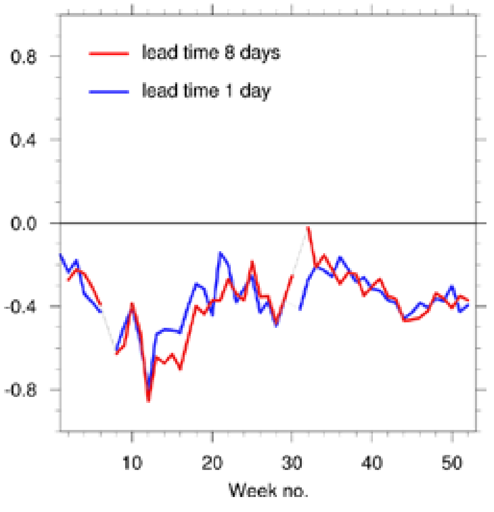

Figure 3 SST bias as a function of forecast lead time, during 2013.

offsets of each product, which are provided in the Product Quality documents from the various MyOcean MFCs. Another example, displayed in Figure 3, is the degree of degradation in forecast quality with increasing forecast lead times. We find only minor degradation during the 10 day forecast period which is presently implemented in the production cycle at MyO-ARCMFC. This is due to the much higher inertia of the ocean when compared to the short memory (low inertia) of the atmosphere.

3.2 Forecast system upgrade

Next, validation is essential when operational model systems are upgraded. Best practice is to run the existing version and the new version in parallel, and apply the same validation system to both, in order to determine whether or not the new version is an improvement. A minimum requirement when replacing an existing operational model system is that the performance of the new system does not give degraded results.

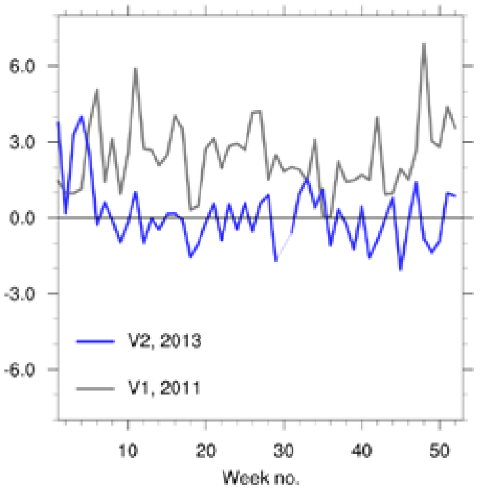

Figure 4 24h sea ice drift distance bias vs. SAR data, in km.

A problematic issue in the context of parallel production is the resources this requires, possibly combined with an imposed set of requirements (e.g. contractual obligations). In MyO-ARCMFC we have experience with both the rigorous implementation procedure outlined above, and upgrading when the necessary resources are not available. An example of the latter is displayed in Figure 4, which shows the change in the quality of sea ice drift forecasts from this system's V1 and V2. In this case, we note that changes in the assimilation from V1 to V2 which concerned sea ice drift data led to elimination of the excessive sea ice drift that occurred with V1.

3.3 System monitoring

Finally, validation is essential in the context of monitoring. Results may reveal both general problems (*e.g.* misrepresentation of water masses) as well as production system problems. The MyO-ARCMFC experienced a severe production system issue in the second half of 2011 when assimilation of altimetry data was not functioning. This was seen in the validation results that are shown here as Figure 5. The problem was fixed in late 2011, and the operational system quickly returned to the expected level of quality where it has remained since.

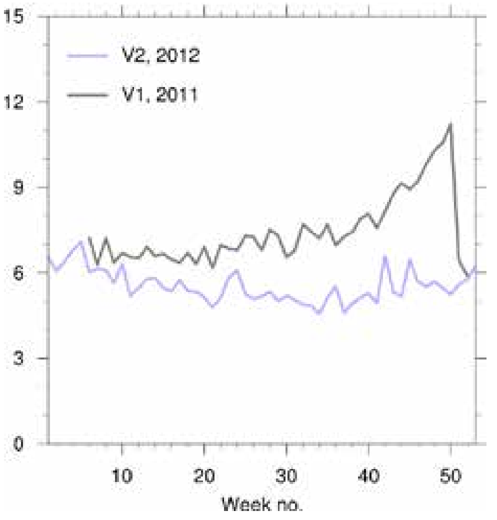

Figure 5 SLA RMS from altimeter data (JASON), in cm.

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The Met Office's operational analysis and forecasting system for the European North-West Shelf (FOAM AMM)

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Abstract: The Forecasting Ocean Assimilation Model 7km Atlantic Margin Model (FOAM AMM) is a coupled hydrodynamic-biogeochemical forecasting system for the tidally dominated European North-West continental Shelf (NWS). The system is run daily at the Met Office and provides the operational analysis and forecasting component of the MyOcean NWS Monitoring and Forecasting Centre (MFC). The FOAM AMM has recently undergone a major upgrade which has seen, amongst other developments, the introduction of a new data assimilation scheme. This paper provides an overview of the new system and the changes that have been made.

Keywords: FOAM, operational oceanography, NEMO, NEMOVAR, data assimilation, tidal, shelf seas

1. INTRODUCTION

The FOAM AMM system is a coupled physical-ecosystem ocean forecasting system nested, via a series of one-way nests, to the Met Office Global FOAM configuration (Blockley et al., 2014). The system is run daily at the Met Office and produces 24-hour analyses and 6-day forecasts of ocean currents and tracers at hourly resolution as well as daily forecasts of biogeochemical and optical quantities. Forecasts are made freely available through the MyOcean web-catalogue at www.myocean.eu. The system provides the near-real-time analysis and forecast product for the European North-West continental Shelf regional seas (NWS) as part of the MyOcean project.

The hydrodynamics are supplied by the Nucleus for European Modelling of the Ocean (NEMO) community modelling framework which has been adapted for use in the tidally dominated NWS region as described by O'Dea et al. (2012). The physical model is run with a nonlinear free surface along with 15 tidal constituents to better resolve tidal processes. Assimilation of satellite and in-situ sea surface temperature data is performed using the NEMOVAR 3D-Var First Guess at Appropriate Time (FGAT) system (Mogensen et al., 2012). Biogeochemical and optical forecasts are made by coupling NEMO to the European Regional Seas Ecosystem Model (ERSEM) as described in Edwards et al. (2012) and Sykes et al. (2012).

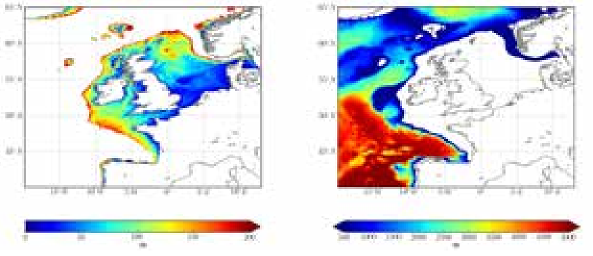

Figure 1 The FOAM AMM bathymetry partitioned according to depth. The left panel shows "On Shelf" regions where bathymetry is less than 200m deep whilst the right panel shows "Off Shelf" regions with bathymetry greater than 200m deep.

The FOAM AMM is run on a regular lat-lon grid with 1/15° latitudinal and 1/9° longitudinal resolution (approximately 7km square). The domain – shown in Figure 1 – runs from 40° N to 65° N and from 20° W to 13° E extending beyond the shelf to include some of the adjacent North-East Atlantic. However the focus of the system is on the shelf itself and the deep water is included primarily to ensure there is appropriate cross-shelf exchange.

2. Foam amm v8 upgrade

The operational FOAM AMM system has recently been upgraded from the original NEMO implementation of O'Dea et al. (2012) to a newly developed AMM system - termed FOAM AMM v8. The details of this major upgrade – which has been running operationally since 4th February 2015 - are described in the remainder of this section.

2.1 Ocean model changes

The NEMO base code used for the model has been updated to use NEMO vn3.4 (from vn3.2) and the vertical resolution has been increased from 33 to 51 levels. A new novel vertical coordinate stretching function (SF13: Siddorn and Furner, 2013) has been implemented as illustrated in Figure 2. As well as providing reduced horizontal pressure gradient errors in areas of particularly steep bathymetry, the SF13 scheme allows the AMM to use a constant surface level depth of 1m throughout the whole domain which is important for resolving diurnal variability (Bernie et al., 2005).

The freshwater inputs into the AMM have also been changed. The climatological river and Baltic Sea outflow forcing have been replaced with real-time E-Hype river inputs and MyOcean Baltic forecasts (produced by SHMI and DMI respectively). In order to apply the Baltic boundary conditions away from the Danish Straits the model domain has been modified in the Kattegat where it now terminates at 56.5° N (see Figure 1).

2.2 Data assimilation changes

The Analysis Correction data assimilation scheme featured in O'Dea et al. (2012) has been replaced with the NEMOVAR 3D-Var FGAT data assimilation scheme (Mogensen et al., 2012). Although NEMOVAR was developed primarily for assimilation in deep ocean models it has been modified at the Met Office for use on the tidally dominated NWS region. Assimilation of SST data with NEMOVAR is conducted using a 3D-Var system in an incremental framework which is similar in operation to the system described in Hyder et al. (2013) for the Arabian Gulf. However the NEMOVAR implementation within the AMM differs from that of Hyder et al. (2013) as it features an improved specification of observation error variances - to specify measurement and representativity errors separately - and the use of a flow dependent length-scale parameterisation based on potential vorticity gradients.

2.3 Biogeochemical model changes

The biogeochemical model changes have mainly focused around updating the existing NEMO-ERSEM setup of Edwards et al. (2012) to produce satisfactory results when coupled with the upgraded model physics and data assimilation schemes. As part of this the NEMO-ERSEM coupling has been updated for use with NEMO vn3.4 and the frequency of coupling has been halved so ERSEM is now called at every NEMO model time step.

As well as improvements to the coupling the lateral nutrient boundary forcing has also been modified to provide a more realistic representation of primary productivity and chlorophyll in the deep water (off shelf) areas.

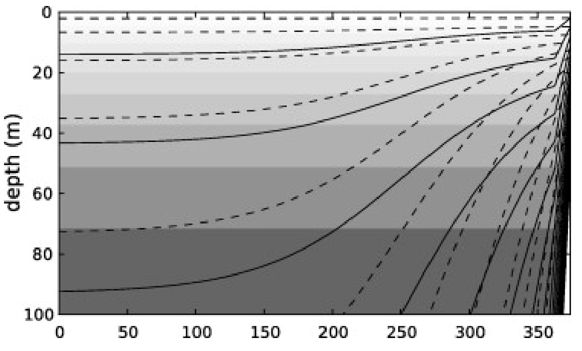

Figure 2 A comparison of the Song and Haidvogel (1994) s-coordinate (solid lines) and the new SF13 s-coordinate (dashed lines) in the surface 100 m for a idealised bathymetry that goes from 50m to 5500 m depth. The grey contours depict a standard z-level vertical coordinate system. (Image reproduced from Siddorn and Furner, 2013.)

Acknowledgements

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In-situ Observations

HF Radar Supporting Blue Growth in NW Europe: The Brahan Project

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Abstract

Blue growth must be obtained sustainably in European seas. Offshore oil and gas exploration continues to expand into deeper waters along the NW European shelf edge, and the competition for sea space on the European continental shelf is accelerating. At the same time national resources to monitor anthropogenic environmental impact are reducing. In order to expand our network of monitoring, in an environment of reducing resources, means we must regionally coordinate monitoring activities. Legislation such as the Marine Strategy Framework Directive (MSFD) requires single member states to coordinate environmental monitoring regionally. High Frequency (HF) radar, with its current expanding spatial range, provides an underpinning technology which can pull together regional monitoring efforts. The Brahan Project, using the Long Range SeaSonde HF radar system manufactured by CODAR Ocean Sensors measuring the speed and direction of ocean surface currents in near real time over a large region between Orkney and Shetland, has demonstrated the potential of HF radar technology in this key area of the NW European shelf seas. An operational network of HF radar deployments, between Faroe and Scotland, Scotland and Norway, and around the North Sea basin could provide the underpinning data supporting oil spill response, search and rescue response, renewable marine energy industries, prevailing conditions monitoring for the MSFD, as well as fundamental measurements that will aid the understanding of climatic change in the North Sea and Arctic Ocean. Here, the Brahan project is introduced, and a possible future expansion to include the key gateway areas of the Arctic and NW European seas is discussed.

Keywords: MSFD, Operational Oceanography, Prevailing Conditions, Environmental Monitoring

1. Introduction

High Frequency (HF) oceanographic radar is becoming a mature ocean monitoring technology that can contribute to a large range of marine end uses (e.g. Harlan *et al*., 2010). With HF radar, it is possible to remotely sense, from the shore or from offshore platforms, surface water movement (e.g. Paduan and Washburn, 2013), and properties of surface waves (e.g. Lipa and Nyden 2005). Secondary information about near-surface winds (e.g. Kirincich, 2013) may also be derived, as can information about vessel movement (e.g. Roarty *et al*., 2011).

This paper introduces the technology using a demonstration deployment in Scottish waters; the Brahan Project. It then goes on to discuss how the technology might be applied to support blue growth in northwest Europe.

1.1 A Current Gap in European Marine Monitoring

Before demonstrating the usefulness of HF radar, it is interesting to note the current deployment of operational radars in European waters. In a recent survey by the EuroGOOS HF Radar Team (Gorringe *et al*., 2014), of the 47 operational radar systems identified in Europe, none were located in northwest European waters, i.e. from Ireland, or the UK. In the North Sea only two operational radar installations were found (Figure 1).

Figure 1 From Gorringe et al. (2014). Location of operational HF radar installations(red dots) located by the EuroGOOS HF Radar team in 2014. The absence of HF radar installations in NW European waters is highlighted.

The questions this map raises are, what services are being provided by the operational HF radars in southern Europe that are not available to northwest Europe, and how might these gaps be filled?

2. The brahan project

In order to demonstrate the potential use of operational HF radar in the UK to a range of end users, QUALITAS Remos S.L., cooperating with CODAR Ocean Sensors Ltd., and Marine Scotland Science assembled a project team consisting of UK Government agencies (Marine Scotland, the UK Department of Energy and Climate Change, the UK Met Office, UK-IMON), oil companies (BP Exploration Operating Company Limited, Nexen Petroleum UK), and academia (International Centre for Island Technology, Heriot-Watt University).

The geographical location for the demonstration, the sea area separating Orkney from Shetland (Figure 2), was chosen for a number of reasons.

In terms of the scientific understanding of the oceanography of the northwest European continental shelf, the area is a key one. The Fair Isle Passage (the channel between Orkney and Shetland) is one of the principal entrances to the North Sea. It is stirred by strong semi-diurnal tides, resulting in intense tidal mixing and dispersion. Turrell *et al.* (1992) estimated that 12% of the inflow to the North Sea occurs through this Passage. A second important inflow occurs southwards along the east coast of Shetland, resulting in about 25% of the total North Sea inflow in the summer when it is forced by seasonal stratification (Turrell *et al.,* 1992). A number of tidal fronts and seasonal jets are also present in the area (Hill *et al*., 2008), and the Continental Slope Current flows towards the north east, along the edge of the continental shelf to the west of Shetland. Additionally the Fair Isle Passage is one of the principal routes by which wind generated storm surges enter the North Sea from the west Scottish shelf.

In terms of human activities, the area is heavily fished, there are oil and gas pipelines and offshore platforms both east and west of Shetland and Orkney, and the area is a vital shipping route out from and in to the North Sea from the west. In 1993, the grounding of the oil tanker MV Braer close to Sumburgh on the southern tip of Shetland showed the potential for shipping related pollution events in this harsh environment. Search and rescue (SAR) facilities operate both on Shetland and Orkney, and helicopter flights related to the oil industry fly from both island groups. There is current interest in the extraction of energy from the sea through both waves and tides in the area, and there is extensive aquaculture facilities along the west coast of Shetland.

Due to the extreme environmental conditions, and the intensive human use of the area, few *in situ* measurements have been possible of ocean currents and waves, as maintaining traditional oceanographic moorings in this area has been difficult in the past.

Hence there are a wide range of reasons to use this area for a demonstration of the potential of HF radar.

2.1 The Brahan Project Technical Set-Up

Two long range 5MHz CODAR SeaSonde radars were provided to the project by CODAR and Qualitas Remos. They were installed close to the North Ronaldsay lighthouse, Orkney, and the Sumburgh Lighthouse, Shetland (Figure 2).

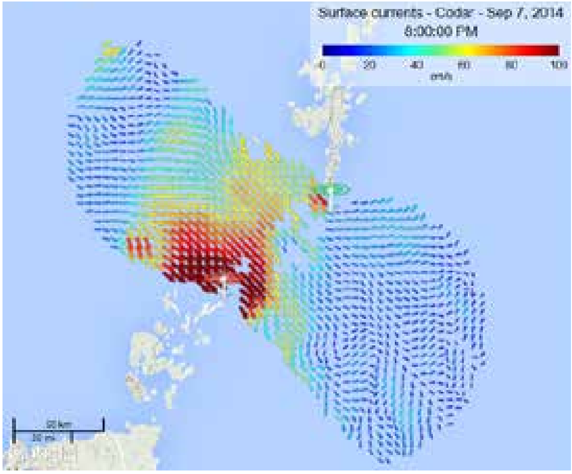

Figure 2 An extracted 1-hour average (2000UTC, 7/9/14) image of current vectors observed using the long-range CODAR SeaSonde HF radar systems installed at the North Ronaldsay lighthouse, Orkney (lower red mast symbol) and at the Sumburgh lighthouse, Shetland (upper green mast symbol). Vectors are scaled by velocity, and also coloured (scale shown as inset – from www.thebrahanproject.com)

The SeaSonde systems were installed once land owner permissions, local authority planning permissions, and national authority EMF spectrum licences were obtained. Both sites are of high scenic value, and used extensively by the public, and hence the unobtrusive nature of the SeaSonde antennae was an important feature. For long range systems such as Brahan, two antennae were needed at each site, a transmit (4m) and a receive (5m). Both were simple mast structures with guy wires, and owing to their low power did not interfere with the public use of the adjacent areas.

Both systems needed mains electrical power supplies, and connection to the internet. Power was available at both sites, but poor telecommunications at the Orkney site meant that a dedicated satellite phone link was installed there. Minimal civil works were needed at both sites, consisting of a concrete block under each antennae, and channelling for cables. Existing shelters were used for the system electronics, consisting of a small 19 inch rack installation.

Installation of the systems were "turn key" operations, and no difficult technical issues were encountered on their installation or operation. The systems could be accessed remotely using the internet connections to check operation. Data was logged locally, as well as being transmitted to a central server located in Edinburgh.

The HF radars measured the Doppler shift of radiated energy reflected from waves on the surface of the sea. The process of deriving currents is a complex one, and is handled by the accompanying electronics and software. The user can access the ocean energy spectra raw data, or simply use processed gridded vectors of ocean current (e.g. Figure 2). Data is normally averaged over a pre-set period, depending on the needs of the user and the frequency of operation of the radar system. For Brahan, the system provides hourly outputs and the averaging period was initially set to three hours, but all raw data has been archived and hence other averaging periods can be re-calculated. The range resolution depends on the allocated bandwidth and the post-processing applied to the raw data, but in Figure 2 we have selected 5 km.

In addition to the current data, the SeaSonde system also returns information on the surface waves in the illuminated sea area, such as significant wave height and period. However, it does this averaged over wider spatial areas than the highly-resolved current data.

2.2 The Brahan Data Set

In Brahan, the first data was recorded at 0000 UTC 1/9/2013, and the last recorded at 0700 UTC 8/9/2014. Hence there were 8936 hours of operation, over 373 days. In that time, 8516 valid gridded hourly- averaged files were created, hence there was a data recovery of around 95%.

The spatial range of the data did vary, principally with atmospheric conditions, and diurnally. However, Figure 2 shows the typical spatial extent of the data. With the configuration in Brahan, i.e. two radars either side of a channel, the pattern of illuminated sea is two lobes, one either side of the central line between the two radars. In Brahan, each lobe was approximately 150 km "long" perpendicularly to the central connecting line, and 100 km "wide", hence the radars illuminated 30,000km^2 of the adjacent seas.

During the Brahan deployment period, the North Sea experienced some extreme storms, including the "Xaver" storm on the 5/6 December 2013 when tragically at least seven people were killed in northwest Europe, and there was extensive coastal flooding owing to storm surges.

2.3 Brahan In-Situ Data Set

Between May 2013 and December 2013 a variety of *in situ* instruments were deployed in the Brahan radar area on oceanographic moorings. These included single point current meters, and profiling (ADCP) current meters. In addition a number of drifting buoys were released in the area.

2.4 Brahan Project - Summary

The year-long demonstration of HF radar in Scotland was hugely successful in one of its objectives, to demonstrate the technology. The two SeaSonde systems ran without any serious problems for one year. The installation was simple, and the operation virtually "plug-and-play".

The legacy of Brahan is a permanent archive of 12 months of high quality ocean radar data, from a key area of the northwest European shelf covering approximately 30,000 km^2, available alongside an extensive *in situ* measurement data set. The data captured some severe weather, including extreme storm surges, as well as covering a full seasonal cycle of stratification, and stratification breakdown in the northern North Sea.

The Brahan data set will now be used to support a range of studies and studentships.

Where the Brahan Project was less successful was in stimulating user commitment to the system. We go on to discuss potential applications of HF radar technology in northwest Europe.

3. A nw european hf radar network

figure 1 reveals the absence of operational radar in northwest European waters. Figure 3 repeats Figure 1, but includes a hypothetical realisation of an operational observing system utilising less than 20 HF radar systems.

Figure 3 A repeat of Figure 1, but with a hypothetical deployment of less than 20 HF radar systems (red dots) in northwest European waters. Red shaded areas indicate potential radar coverage. Black arrows show principal flows of oceanic water.

The maritime economy of the North Sea and Norway is estimated at €230 billion, employing 1 million people (EU Commission, 2012). The hypothetical network of Figure 3 would cost of the order of 0.003% the annual value of the region's maritime economy. But how could European blue growth benefit from an HF radar network?

3.1 The Modelling Community

This may seem an odd "end user" to start with. However, many of the services below today increasingly rely upon accurate numerical models of the sea. We use models to predict tides, storm surges, spill dispersion, wreckage drift, nutrient budgets, impact of climate change, coastal flooding, coastal erosion, and much more. A regional-scale network of HF radars is ideally suited to calibrate, validate, and improve through data assimilation the numerous operational models of our seas.

3.2 Offshore Industries

Oil, gas, and offshore wind industries require many of the services below, such as SAR and spill response. However, they also specifically need engineering data when designing structures, real-time estimates of currents and waves when conducting offshore engineering work, and predictions to plan work. Regional scale HF radar, coupled with models, can provide this.

Although the North Sea oil and gas industry is ageing, the new deepwater areas within our region, off the shelf edge north and west of the UK and Norway, all pose new environmental challenges. We have very few measurements from these areas compared to the North Sea, hence the regional network of HF radar would give vital information in these areas.

3.3 Spill Response

Spill response starts at small space and time scales, with pollution possibly spreading tens of kilometres in a few days. However, an extended event such as a sea bed blowout, can last for months, with pollution extending to North Sea basin scales (Figure 4). It has been seen repeatedly that present day numerical models can fail to accurately predict the track and spread of spills, particularly in the challenging waters off the European shelf edge. Numerical models, coupled with a regional scale HF radar network, would provide Europe with the best protection and response infrastructure for regionally-important events, as well as more local national events.

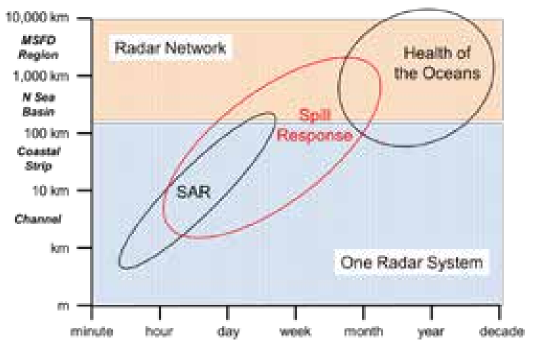

Figure 4 An analysis of the space and time scales involved in Search and Rescue (SAR), spill response and the provision of prevailing conditions information for Health of the Oceans (HOTO) assessments, such as required by the European Marine Strategy Framework Directive. Blue lower rectangle – information return from a single radar system such as employed in the Brahan Project, red upper rectangle – the increase in information provided by a regional network of radar.

3.4 Shipping

38% of all EU maritime cargo comes through the North Sea (EU Commission, 2012). A basin scale HF radar network could provide route planning and hence fuel saving facilities on a regional basis. In addition, the secondary information concerning vessel detection can help detect activities such as illegal fishing and drug trafficking (Roarty *et al.*, 2011)

3.5 Search and Rescue

Search and Rescue in northwest Europe is principally a national responsibility, and implemented on national scales (Figure 4). However, an improved European SAR model, using data assimilation from an HF radar network could benefit all maritime countries in the region. Within the United States for example, the Coastguard uses HF radar in their operational SAR programme, and has shown that this can reduce their target search area by 66% after 96 hours, compared to not using radar data (Harlan *et al.*, 2010).

3.6 Coastal Protection

Europe faces an increasing threat from coastal flooding owing to climate change. Storm surges coupled with sea level rise may well threaten our current coastal defences. Storm surge models used currently to manage coastal defence use technology and knowledge which has not changed for more than a decade. A regional scale HF radar network would bring coastal flooding modelling into a new era of real-time data assimilation.

3.7 Science

This may not be an obvious end-user, but the basic scientific understanding of circulation, dispersion, mixing and ocean-atmosphere interactions would benefit hugely from a regional scale HF radar network, particularly as in our region we still have some areas where human activities such as fishing prohibit traditional measurement techniques, and data during extreme events such as storms is lacking.

3.8 Health of the Ocean - MSFD

Finally, we consider the benefit of a northwest European regional HF radar network to Health of the Ocean assessments, such as the one enshrined in the EU Marine Strategy Framework Directive (MSFD).

The MSFD requires European Member States to assess the health of their seas using 11 descriptors (Biological diversity, Invasive and non-native Species, Commercial fish and shellfish, Food webs, Eutrophication, Seabed integrity, Hydrography, Contaminants, Contaminants in food, Litter, Introduced energy – i.e. noise). Member States must define what Good Environmental Status (GES) looks like for each of these descriptors for their seas, and also define quantitative indicators of health within each descriptor.

The Directive gives Member States two more directions; they must coordinate the assessments regionally, and they must take into account "prevailing conditions" (EU Commission, 2008).

In order to define basin scale targets for GES for nutrients and contaminants, transport of these materials through the open boundaries of the region are required. The flux of nutrients and plankton are needed in order to understand changes in food webs. Numerical models of the North Sea basin that will be used extensively for such studies, and for setting targets, need to accurately estimate transports through the open boundaries to the north (Orkney/Shetland, Shetland/Norway), east (Baltic) and south (Channel). A regional network of HF radar would enable these open boundary transports to be more accurately estimated, and validated.

3.9 A Regional Framework

Finally, while basin scale surveys in the North Sea such as the International Bottom Trawl Survey (IBTS) provide a unifying framework for much of the biodiversity, food web and litter aspects of the MSFD, no such regional scale framework exists which can pull together operational oceanographic observations in the region, or provide the underlying physical support for all of the above end-users. A northwest European regional HF radar network would provide that organisational framework upon which much could be built.

4. SUMMARY

The Brahan Project has demonstrated how multiple users can come together to implement an operational HF radar network in northwest Europe. The operating conditions we have here, including the wave climate, permits long ranges and reliability to be achieved. The ranges now possible, coupled with the geography of our region, means that a relatively small regional investment can provide multiple returns to European blue growth. What is now needed is an organisation to take the lead in coordinating such an initiative, and perhaps EuroGOOS, NOOS or EMODnet can help provide that leadership.

Acknowledgements

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Ocean Data Portal: from data access to integration platform

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Abstract

Development of a distributed information infrastructure is highly important for the marine science and maritime activities because of the trend towards integration of both local and geographically distributed applications that provide access to heterogeneous data and information resources of the marine environment. Data integration platform, developed within the framework of the IODE Ocean Data Portal (ODP) project is called to organize and manage distributed access and processing of information about the world oceans. ODP is developed as a component of the IODE system to provide modern data exchange and dissemination infrastructure to achieve the IODE objectives: to facilitate and promote the exchange of data and information including metadata, products and information in real-time, near real time and delayed mode; to ensure the long term archival, management and services of all marine data and information; to promote the use of international standards, and develop or help in the development of standards and methods for the global exchange of marine data and information, using the most appropriate information management and information technology; to assist Member States to acquire the necessary capacity to manage marine data and information and become partners in the IODE network.

Keywords: ocean, interoperability, portal, platform, IODE

1. INTRODUCTION

The birth of the Internet has resulted in great change in how science works and the expectations of the scientific community. Although science has always been global, the digital age has improved the visibility of research activities and has made collaboration easier. It is now much easier to access the data and analytical products used by peers in the development of their research publications for other activities. However, in addition to improving the visibility and accessibility of publications via the Web, the data and other analytical products supporting the publication are now expected to be accessible to the global community. Relying on static tables and images is no longer sufficient.

In some cases, the accessibility of data and analytical products is a condition placed upon the researcher by the publisher. Although there are increased demands placed upon the researcher, there is the benefit of increased visibility for the researcher and their accomplishments.

Researchers face many challenges when looking to work in this global digital community. Although data and other value added products exist which may advance one's own work, finding and leveraging these resources on the Web presents many challenges. Knowing where to look, how to search, how to access, and how to integrate data and products from many disparate sources can be difficult. Furthermore, contributing one's own data and analytical products for use by others, especially when resources are limited, can present many significant barriers.

The solution to these challenges is a mix of standards, technology, people, and education. Benefits are worth the investment, both to the data provider and the data user

2. IODE

The International Oceanographic Data and Information Exchange (IODE) was established by in 1961. It strives to enhance marine research, exploitation, and development through exchange of data and information between member states. IODE supports a variety of programs including standards development, technology, data access, capacity building (education). IODE adheres to the IOC data policy – free and open access to data and information.

Timely access to quality data is essential for the understanding of marine processes. The IOC IODE through its distributed network of national oceanographic data centres (NODCs) and new information technologies has developed the Ocean Data Portal (ODP) to facilitate seamless access to oceanographic (and beyond it) and other data/products and to promote the exchange and dissemination of marine data and services. IODE Ocean Data Portal is one of the IODE projects, formally established in 2007 and started its operation in 2009. Major underlying principles of the IODE Ocean Data Portal are Interoperability, Non-intervention and Free access to data and services.

3. OCEAN DATA PORTAL

In 2013, a resolution was passed that will result in all member states of the IODE to enable access to data through the ODP, so the ODP is now considered as an IODE platform for data share and exchange.

The role of the ODP is to simplify the process of making data openly available to the marine community through the delivery of supported technical solutions (software), support for data providers, and training. Following benefits can be considered from the data providers prospective while sharing data and information through the IODE ODP:

- scalable environment to support the capacity of the data provider's environment
- It promotes standards
- It is engaged with other IODE data systems

- supported technology for data discovery, evaluation, and access
- Improved visibility of data and geospatial web services
- Improved interoperability with other major marine data systems
- operational assistance and support from the technical point of view
- Benefits for data and information includes:
- one-stop shop for data and web services
- increased visibility for one's research data
- increased visibility of the researcher within the marine domain (IODE Ocean Experts)

The IODE Ocean Data Portal (ODP) project development had two stages: Version 1 (V1, 2008 - 2009) and version 2 (V2, 2009 - 2013). The ODP V1 (Figure 1) had the initial capabilities and was based on the technical specifications and software of End-to-End Data Management (E2EDM) technology developed by JCOMM/IODE ETDMP and Russian NODC (RIHMI-WDC). ODP (V2) has full capabilities with use of the international interoperability standards and tools. ODP V1 was aimed to provide data access functionality to NODCs and other stakeholders mainly. ODP V2 (Figure 2) has been called to provide not only way to access data, but also allow communities to set up their own distributed data systems using ODP tools, link them (and to be linked as well) with other projects, programmes and initiatives using internationally endorsed standards such as ISO, OGC, etc.

The ODP Partnership Centre was officially opened in 2013 on the base of NODC of Russia and provides the development and hands-on support for the ODP and its related resources (web site, wiki, etc.). The technology, support, and training provided by the team is intended to facilitate open, standards based access to marine data and by providing a supported solution, institutes save on the costs of building and maintaining proprietary solutions.

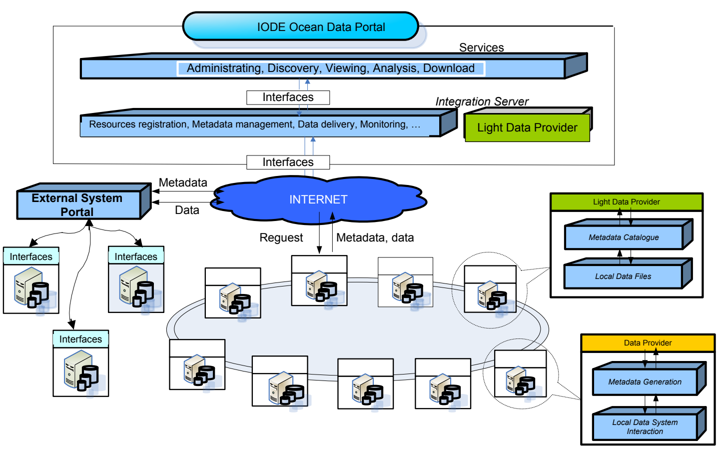

Figure 1 ODP V1 technical architecture

ODP technology provides a certain level of data interoperability providing an access to local data systems with a wide variety of structures, formats, systems of coding of data and metadata, systems of data storage. The ODP standards development is based on a paradigm that standards and technical solutions of the ODP interoperability infrastructure will be evaluated and accepted according to the IODE/JCOMM Standards Process.

The ODP adopts and supports major standards from ISO and the Open Geospatial Consortium (OGC) in order to maximize the interoperability between the ODP and other major data systems. By doing this, ODP can provide access to data from many major platforms within a single portal.

ODP do not require data centres to re-format their data, as it has tools to understand local data structures (database tables, formats of data files) and translate the required data into the common transport data format or provide web-services to interact with local data systems.

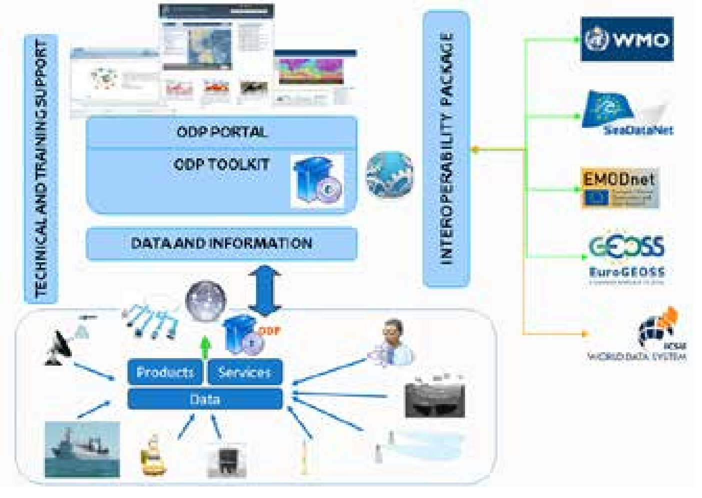

Figure 2 ODP V2 simplified architecture

The inhomogeneity of data sources, data storage types and formats and its integration in most cases will be separated on individual issues to deal with. ODP is delivering tools to connect and describe such data and information, provide capabilities to discover it, present and download. ODP toolkit is aimed to handle these functions and far more beyond them.

The ODP is comprised of 3 major classes:

1. ODP toolkit – plug-and-pay base back-office software stack supports the deployment of ODP nodes via virtual machine packages maintained by the ODP Partnership Centre. Also includes web portal component that may be extended and stylized to support node requirements.

2. Interoperability package – specifically developed to enable interoperability with other major data systems such as the WMO Information System (WIS) and SeaDataNet. By doing this, the ODP not only extends the scope of resources discoverable to the data user visiting the ODP (one-stop-shop), but also advertises the contributed resources to a much greater audience, thus promoting the researchers and institutes contributing to the ODP.
3. Technical and Training Support - in parallel with the physical infrastructure components, the Partnership Centre for the ODP provides development/technical support and training support through the IODE Ocean Teacher Academy.

ODP toolkit is used to set up the ODP node. ODP node can be either virtual or physical. Virtual nodes are used to provide "light" data provider services. Light data providers are meant for those having very limited infrastructure or supporting personnel, to enable access to data. In this environment, and existing ODP node provider (either the ODP global node in NODC of Russia, or a regional node provider) hosts all major infrastructure. The data provider must enable read access to data and associated metadata, but does not need to administer any ODP infrastructure. This offering is meant to enable the most participation in the ODP with minimal impact on the data provider. The ODP global portal is the system used to discover and connect to data hosted by the provider.

Physical ODP node implementations are hosted by the data provider and although they require more effort, they provide a greater level of functionality for the organization. A node provider can act as a central node for other institutes using the same technology and approaches as the ODP global node, while simultaneously contributing to the ODP global node. ODP node implementations can also host their own customized version of the ODP portal interface, thus supporting regional and national needs while simultaneously contributing to the global view through the ODP global node.

ODP has several level of nodes to support according main principles and activities of IODE - regional (ODINs), specialized (projects) and IODE wide - global node. Each of them has own portals as shopping windows for their data and services using ODP toolkit (Figure 3).

Figure 3 ODP global and regional portals

In addition to the fact that ODP has been tested and widely used for different national projects in Russia, where it was developed and still supported by the Partnership Centre for IODE ODP, one of the real examples of using ODP as integration platform is SNDM of Argentina which connects 9 institutions around the country, holding significant data and information holdings to be submitted into the national data system, and later to be harnessed with other disciplinary national systems (biology, magnetics, etc.). Importance for this use case consists in:

- Example of full implementation of regional node and virtual data providers.
- Contributed to the advancement of ODP packaging to simplify implementation and support.
- Demonstrates flexibility of ODP technology to support other themes.
- Contributed to the development of the ODP training offerings.

At present moment IODE ODP has established a global node (NODC of Russia), two regional nodes (China for IODE ODINWESTPAC and Kenya for IODE ODINAFRICA) and one specialized node (SNDM of Argentina) which provides access to more than 120 national, regional and global datasets and products. ODP interoperability package provides access to almost 7300 datasets from WIS system and more than 400 datasets from EU SeaDataNet project. It also delivers operational and delay-mode GTS data for the subscribed datasets from the region of interest and required parameters directly to the EMODNet Physics FTP server.

4. CONCLUSIONS

In terms of contents IODE ODP fully depends on the data contributions from IODE Member states and related projects, programmes and initiatives. Even though IODE has created a great scalable platform that should assist each interested party to connect and share data, to be visible from other systems and, potentially, to help the community of students, researchers, scientists, and general public users for better data access.

EMODnet Physics

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Abstract

The EMODnet - Physics is a Marine Observation and Data Information System that provides a single point of access to near real time and historical achieved data (www.emodnet-physics.eu/map) it is built on existing infrastructure by adding value and avoiding any unless complexity, it provides data access to any user, it is aimed at attracting new data holders, better and more data. The EMODnet - Physics is supporting the coordination of the EuroGOOS Regional components and the empowerment and improvement of their observing and data management infrastructure. The EMODnet Physics already implemented high level interoperability layers (WMS, Web catalogue, web services, etc) to facilitate connection and interoperability towards global observing system for itself, the ROOS and the Institutes within the ROOSs (www.emodnet-physics.eu/services). The on - going EMODnet- includes systems for physical data from the whole Europe provided mainly by fixed stations and ferry-box platforms, from about 1500 platforms.

Keywords: Operational Oceanography, Near Real Time, in-situ, National Oceanographic Data Centre, EMODnet

1. Introduction

The "Marine Knowledge 2020" [1] aims at bringing

together marine data from different source at European Level to support industry, public authorities and researchers in finding the data and make more effective use of them to develop new products and services and improving our understanding of how the seas behave. In this context National data do not tell us all we need to know about the seas as a global system connected by shifting winds, seasonal currents and migrating species, and the analysis at European level is essential. Member States already share their observations made in coastal, transitional and marine waters with other Parties such as Marine Conventions and with the EEA through the EIONET. The advent of the INSPIRE Directive (2007/2/EC) [2] and Marine Strategy Framework Directive (2008/56/EC) [3] made compulsory a comprehensive monitoring of the marine environment beyond the geographical limits by means of better discovery of data, free access to data and few restrictions on use and reuse of data. To accomplish sharing of marine data and information between Member States, the Marine Conventions, and the EEA, an efficient data and information system needs to be put in place. The Commission conceived WISE [4] as the water related component of environmental data reporting and access to marine data available on the European level under the proposed Shared Environmental Information System (SEIS) [5]. As a result, in its Blue Book for Maritime Policy the European Commission undertook to take steps towards a European Marine Observation and Data Network (EMODnet) [6] in order to standardize method for observing and assessing the grade of the Member States seas and improve access to high quality data. Since 2008-2009, European Commission, represented by the Directorate-General for Maritime Affairs and Fisheries (DG MARE), is running a central portal (www.emodnet.eu) and several service contracts for creating pilot thematic components of the ur-EMODnet:

- Biology,
- Bathymetry,
- Chemistry,
- Geology,
- Habitats
- ***Physics***.

As well as some checkpoints (i.e. Mediterranean and North Sea check points).

2. EMODnet Physics

The EMODnet Physics was designed to build up on existing infrastructure and networks, i.e. EuroGOOS association and its regional components (ROOSs), the Copernicus/GMES MyOcean project and the network of National Oceanographic Data Centres (NODC) organized into the SeaDataNet consortium (Fig 1).

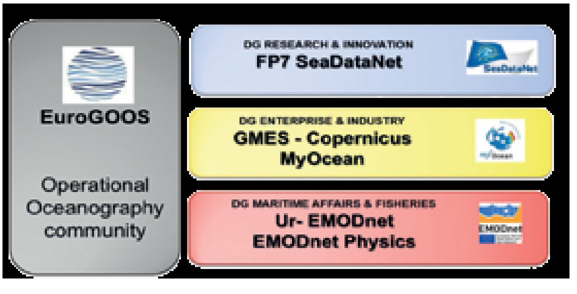

Figure 1 European Oceanographic Infrastructures

The EMODnet-Physics portal (www.emodnet-physics.eu) makes layers of physical data and their metadata available for use and contributes towards the definition of an operational European Marine Observation and Data Network (EMODnet). It is based on a strong collaboration between EuroGOOS associates and its regional operational systems (ROOSs), and it is bringing together two marine but very different communities: the "real time" ocean observing institute and centers and NODCs that are in charge for ocean data validation, quality check and update for marine environmental monitoring.

The "real time" community, i.e. the in-situ Thematic Assembly Centre (in-situ TAC), is a distributed service integrating data from different sources for operational oceanography needs, in particular in-situ TAC has been designed to fulfil the GMES Marine Core Service needs and the EuroGOOS regional systems (ROOS) needs.

The network of National Oceanographic Data Centres – NODCs - (http://www.seadatanet.org) is developing and operating an infrastructure for managing, indexing and providing access to ocean and marine environmental data sets and data products, once data resources are quality controlled and managed at distributed interconnected data centres. NODCs are also establishing and maintaining accurate metadata directories and data access services, as well as common standards for vocabularies, metadata formats, data formats, quality control methods and quality flags.

The EMODnet Physics represents these groups and their infrastructures and combines considerable expertise and experience of collecting, processing, and managing of ocean and marine physical data together with expertise in distributed data infrastructure development and operation for a pan-European marine data management and data access system.

3. Results

The EMODnet-Physics portal (www.emodnet-physics.eu) makes layers of physical data and their metadata available for use and contributes towards the definition of an operational European Marine Observation and Data Network (EMODnet), in particular, it provides a single point of access to near real time and historical achieved data (www.emodnet-physics.eu/map) regarding:

- wave height and period
- temperature of the water column
- wind speed and direction
- salinity of the water column
- horizontal velocity of water column
- water clarity (light attenuation)

The monitored areas are the Baltic, Black, the Mediterranean and North Seas, and jurisdictional waters, including the continental shelf, of European Member States and Norway for the North East Atlantic (i.e. Celtic Seas, Iberian Coast and Bay of Biscay, Macaronesia, Norwegian Sea) as well as Icelandic Sea and Barents Sea. The portal is composed mainly of three sections: the Map, the Selection List and the Station Info Panel.

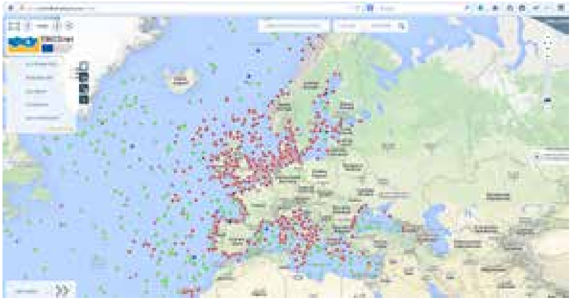

Figure 2 Map Page (http://www.emodnet-physics.eu/map/)

The “map page” is the core of the EMODnet Physics system: here the user can access all available data, customize the map visualization and set different display layers. Figure 2 shows the map and its features.

The dots on the map represent the platforms in the system, the color of the marker indicates the type of platform and the shape (circular or triangular) visually indicates if there are recent data associated with that particular station. Filters can be used to select the stations of interest depending on the type, measured physical parameters, the time period of the observations in the database of the system, country of origin, the water basin of reference.

By selecting one or more stations on the map, the user creates a “selection list” (Figure 3).

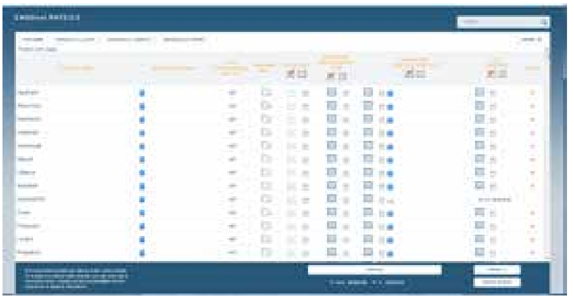

Figure 3 platforms list

Each platform is provided with metadata information such as name, WMO code, location, provider, data assembly center, acquired parameters, and let the user to download the available data.

Available data consists of observations of both the last 60 days (near real time) and the correspondent long term time series (monthly, historical validated data) and are available in different format: .xls, .csv and .nc (NetCDF - Network Common Data Form, the standard interoperability format used in the marine area).

A “platform page” (Figure 4) is available for each station with tailored plots and information.

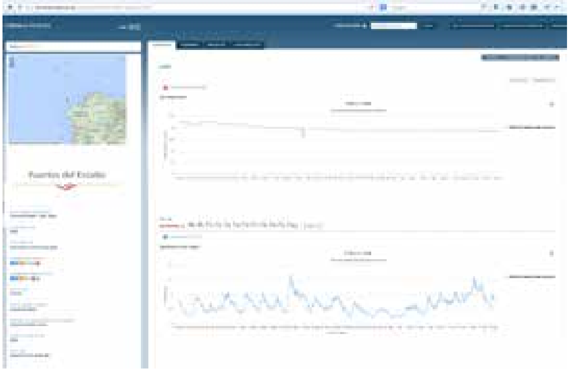

Figure 3 platforms page

The page is divided into 3 sections where the user can: view the charts representing the curve trend of different parameters through an interactive plot, check the availability of data over time, download selected data and request the validated historical data via their CDIs (common data index).

EMODnet Physics provides data discover, view and download features for more than 2000 platforms (fixed stations, ferry-box platforms, ARGOs, gliders, etc..), The table 1 shows the available parameters.

Moreover, the system provides full interoperability with third-party software through WMS service, Web Service and Web catalogue in order to exchange data and products according to the most recent interop standards. Further developments will ensure the compatibility to the OGS-SWE (Sensor Web Enablement) standard for the description of sensors and related observations using OpenGIS specifications (SensorML, O&M, SOS). The full list of services is available at:

http://www.emodnet-physics.eu/portal/documents-and-services.

	platforms	operational	validated dataset
drifting bouys (DB)	59	36	
ferrybox (FB)	10	6	
gliders (GL)	13	1	
fixed buoys or mooring time series (MO)	718	658	794
profiling floats vertical profiles (PF)	61	58	
Argo Floats (AR)	623	443	
TOTAL	1484	1202	794

Table. 1 platforms

The result is an excellent example of the application of innovative technologies for providing access to geo-referenced data for the creation of new advanced services.

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The European Marine Data and Observation Network (EMODnet)

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Abstract

Data from the marine environment are a valuable asset for marine industries, decision-making bodies and scientific research, but in Europe marine data are stored in a wide range of national, regional and international databases and repositories using different formats and standards which makes it difficult to find, assemble and use them efficiently. The European Marine Observation and Data Network (EMODnet) is a network of organisations set up in 2007 by the European Commission in the framework of EU's Integrated Maritime policy to address the fragmented marine data collection, storage and access in Europe. This paper introduces EMODnet in the context of EU's Marine Knowledge 2020 Strategy and highlights some of the core functionalities of key EMODnet Data Portals, as well as those being developed by the EMODnet central portal.

Keywords: EMODnet, Marine Data Management, Data Portal, Open Access

1. Introduction

Data from the marine environment are a valuable asset. Rapid access to reliable and accurate information is vital to obtain the knowledge necessary to address threats to the marine and coastal environment, in the development of policies and legislation to protect vulnerable areas of our coasts and oceans, in understanding trends and in forecasting future changes. Likewise, better quality and more easily accessible data is a prerequisite for innovation and further sustainable maritime economic development or 'Blue Growth'.

The costs of acquiring marine data through ocean observations in the EU is enormous, estimated at 400 million euro per year for data from remote sensing using satellites and more than 1 billion euro per year for collecting in situ data by public authorities (European Commission, 2010). In Europe, these costs are largely carried by the Member States. In addition, private bodies spent about 3 billion euro annually on sea and ocean data gathering and monitoring (European Commission, 2010).

While access to marine data is critical for marine industries, decision-making bodies and scientific research, up to now it has been difficult to find, access, assemble and apply the data collected through observations in Europe. This is because most of Europe's marine data resources are collected by various local, national and regional entities and stored in unconnected databases and repositories. When available, the data are often not compatible making aggregation and wider scale use impossible. Recent studies have revealed that making high quality marine data held by EU public bodies more widely available would improve offshore operators' efficiency and save about 1 billion euros per year in gathering and processing marine data for operational and planning purposes. It would also stimulate competition and innovation in established and emerging maritime sectors, estimated at 200-300 million euro per year (European Commission, 2014).

In addition it would improve efficiency of marine planning and legislation and reduce uncertainty in our knowledge and ability to forecast the behaviour of the sea.

To address the fragmented marine data collection, storage and access in Europe, the European Commission initiated the development of the European Marine Observation and Data Network (EMODnet) in the framework of EU's Integrated Maritime policy in 2007. The primary aim of EMODnet is to unlock existing but fragmented and hidden marine data and make them accessible for a wide range of users including private bodies, public authorities and researchers. At the onset of 2015, EMODnet consists of more than 100 organisations working together to observe the sea, to make the marine data collected freely available and interoperable, to create seamless data layers across sea-basins and to distribute the data and data products through the internet.

2. The emodnet development process

The term EMODnet was first coined in 2006 in the preparations of the EC Integrated Maritime Policy as a way to provide a sustainable focus for improving systematic observation (*in situ* and from space), interoperability and increasing access to data, based on robust, open and generic ICT solutions (European Commission, 2006). The aim has always been to increase productivity in all tasks involving marine data gathering and management, to promote innovation and to reduce uncertainty about the behaviour of the sea. EMODnet has since been promoted as a key tool to lessen the risks associated with private and public investments in the blue economy and facilitate more effective protection of the marine environment.

Since its adoption as a long-term marine data initiative, EMODnet has been developed through a stepwise approach in three major phases.

- Phase I (2009-2013) developed a prototype (so called ur-EMODnet) with coverage of a limited selection of sea-basins, parameters and data products at low resolution;
- Phase II (2013-2016) works towards an operational service with full coverage of all European sea-basins, a wider selection of parameters and medium resolution data products;
- Phase III (2015-2020) will work towards providing a seamless multi-resolution digital map of the entire seabed of European waters providing highest resolution possible in areas that have been surveyed, including topography, geology, habitats and ecosystems; accompanied by timely information on physical, chemical and biological state of the overlying water column as well as oceanographic forecasts.

Currently EMODnet is in the 2nd phase of development and provides access to marine data, metadata and data products spanning seven broad disciplinary themes: bathymetry, geology, physics, chemistry, biology, seafloor habitats and human activities. These data are being used to create medium-resolution maps of all Europe's seas and oceans spanning all seven disciplinary themes - these are expected to be complete in 2015. The next phase of EMODnet will involve the development of multi-resolution sea basin maps, commencing in 2015.

The development of EMODnet is a dynamic process so new data, products and functionality are added regularly while portals are continuously improved to make the service more fit for purpose and user friendly with the help of users and stakeholders.

Each theme is looked after by a partnership of organisations that have the necessary expertise to standardise the presentation of data and create data products. From the onset, EMODnet has been developed based on a set of core principles:

- Collect data once and use them many times;
- Develop data standards across disciplines as well as within them;
- Process and validate data at different scales: regional, basin and pan-European;
- Build on existing efforts where data communities have already organised themselves;
- Put the user first when developing priorities and taking decisions;
- Provide statements on data ownership, accuracy and precision;
- Sustainable funding at a European level to maximise benefit from the efforts of individual Member States;
- Free and unrestricted access to data and data products.

3. Overview of emodnet data portals

3.1 Introduction

For each of its core themes, EMODnet has created a gateway to a range of data archives managed by local, national, regional and international organisations. Through these gateways, users have access to standardised observations, data quality indicators and processed data products, such as basin-scale maps. These data products are free to access and use.

3.2 EMODnet Bathymetry

Bathymetry is the information that describes the topography of the seabed, as depth from the sea surface to the seafloor. It is an essential component in understanding the dynamics of the marine environment: the shape of the seabed is controlled by the underlying geology, and it exerts a strong influence on ocean circulation and currents, local fauna and seafloor habitats. Safe ocean navigation relies on accurate bathymetry data, which are also essential for planning marine installations and infrastructure such as wind turbines, coastal defences, oil platforms and pipelines. Bathymetry forms the foundation of any comprehensive marine dataset; without it, the picture is incomplete.

Currently, EMODnet provides bathymetric data and data products for all European sea basins. Users have access to Geographical Information System (GIS) layers covering water depth on a grid of up to 1/8 minute latitude and longitude or in vector form at 1:100 000 scale; depth profiles along survey tracks, and survey metadata.

Users can download digital terrain model (DTM) data products that can be used in combination with other data layers from within EMODnet. A continually-updated data discovery and access service allows users to identify and request access to the underlying bathymetric survey data, held by a range of organisations, which form the basis of the DTM products. As EMODnet evolves, current bathymetry maps will be regularly updated with new data and complemented by coastal maps where the resolution is as high as the underlying data allows.

3.3 EMODnet Geology

Geological data are collected in a number of ways: physical samples via coring, drilling, grab sampling or dredging; direct observations using towed cameras and remotely operated vehicles, and acoustic remote sensing techniques that give an indication of the seafloor substrate. Of these techniques, only drilling or coring can reveal more than just the surficial geology. To probe deeper into the sub-seafloor, seismic survey methods are required.

Primary geological survey information requires significant expert interpretation to generate maps, and geological data are often used in combination with bathymetry to build up a comprehensive picture of the seabed. These data are a vital component of seafloor habitat maps, and are essential tools in marine spatial planning, coastline protection, offshore installation design, environmental conservation, risk management and resource mapping.

Currently, EMODnet provides access to geological data and maps at a resolution of 1:250,000 wherever possible that provide information on seabed substrate, seafloor geology (including boundaries, faults, lithology and age), sediment accumulation rates, coastline erosion and migration, areas of mineral resources, and the location and probable frequency of significant geological events such as earthquakes and volcanic eruptions.

3.4 EMODnet Seabed Habitats

Habitat maps are constructed from a number of basic data layers containing physical data that describe the environment in any given location. A habitat type is then derived on the basis of those environmental characteristics. EMODnet uses the latest European Nature Information System (EUNIS) habitat classification, which is the standard system in operation across Europe.

EMODnet provides a predictive seabed habitat map covering all European seas at 1:250 000 scale resolution. It builds on the broad-scale seabed habitat map developed under the EUSeaMap project, with enhanced validation and inclusion of regional and local habitat maps produced by Member States. EMODnet data on seabed substrate, energy at the seabed, biological zone and salinity at the seabed are combined to produce EUNIS habitat maps, with confidence indices to demonstrate the level of certainty for any given location.

Future developments will include increased emphasis on ecologically crucial coastal areas, with a view to mapping shallow inshore waters and eventually creating a seamless land-to-sea habitat map. Biologically-defined habitats, such as *Posidonia* seagrass beds in the Mediterranean will be included alongside habitats defined purely on their physical characteristics.

3.5 EMODnet Chemistry

Early detection, tracking and prediction of the movement of pollutants at sea are vital for the effective mitigation of their impacts on marine habitats and human infrastructure. Seawater chemistry data is used in combination with physical oceanographic data and bathymetry to trace the source of pollution, track its likely future trajectory, concentration and persistence, and to formulate a course of action to prevent or reduce impacts on the marine environment and to human well-being. Water chemistry data acquisition is often at the centre of routine monitoring efforts of Member States in response to national and European legislation or regional obligations.

EMODnet provides access to individual measurements as well as a range of products such as interpolated maps of chemical variables per region over time and graphics of station time series. Data include measurements of diverse parameters including fertilisers, dissolved gases, chlorophyll, silicates, pH, organic matter, synthetic compounds, heavy metals, hydrocarbons, radionuclides, plastics.

3.6 EMODnet Biology

Measuring or observing marine life on a large scale is difficult. For the most part, data are collected over short time periods or in relation to specific species in target locations. Often, data are collected using different standards, technologies and conventions, making it challenging to combine information from different surveys or different databases.

EMODnet assembles these individual datasets and processes them into interoperable data products for assessing the environmental state of ecosystems and sea basins. These data products illustrate the temporal and geographic variability of occurrences and abundances of marine phytoplankton, zooplankton, macro-algae, angiosperms, fish, reptile, benthos, bird and sea mammal species - in particular, introduced or harmful species, species of conservation concern and those used as ecological indicators.

Products include gridded map layers showing the average abundance of at least three species per species group for different time windows (seasonal, annual or multi-annual) using geospatial modelling and spatially distributed data products. Calculation of specific aggregated and gridded products indicating the presence, absence, abundance and diversity of species and communities can give an indication of ecosystem health and temporal trends for specific sea basins, which can be used to improve ecosystem-based management.

3.7 EMODnet Physics

Europe's oceans and atmosphere are constantly measured and monitored through an extensive network of remote, fixed and mobile *in situ* observing stations. The volume of data collected is enormous, ranging from the most fundamental information such as sea level, atmospheric pressure, sea temperature and salinity, to more complex measurements of turbidity and fluorescence in the water column.

EMODnet provides a gateway to this vast resource of ocean physics data. Users can access both near-real time (within a few hours of measurement) and historical archive data that are managed by oceanographic institutes and made available via EuroGOOS and National Oceanographic Data Centres, combined with supplementary data from ongoing observing programmes such as EuroArgo. Future developments will include closer collaboration with the marine component of the EU's Copernicus earth observation programme.

Data layers currently available via EMODnet include salinity, temperature, currents, oxygen, fluorescence, pH, turbidity, sea level data, wave data (horizontal wind speed and direction), atmospheric pressure, dew point, dry air temperature and humidity.

3.8 EMODnet Human Activities

Pressure on Europe's marine space and resources is at an all-time high. Continual demand for resources such as oil and gas, marine minerals and fish must be managed alongside the need to use marine space for renewable energy installations, communications cables, waste disposal sites and shipping. Additionally, societal demand for marine tourism and leisure activities, and the need to conserve marine ecosystems and habitats is leading to increasing competition and conflict between different marine sectors. Having access to accurate information to assist with planning, regulating and managing marine activities in a sustainable and responsible manner is critical.

EMODnet provides access to data describing the geographical position, spatial extent, and attributes of a wide array of human activities in the marine environment. From pipeline routes and waste disposal sites, to ports and protected areas, EMODnet maps activities or installations that could affect other ocean users, have an impact on the marine environment or that are themselves vulnerable to disturbance. It also provides a historical view of activities so that trends can be analysed and future requirements better anticipated.

EMODnet provides information on various activities such as aggregate extraction, shipping (commercial/leisure), cultural heritage, dredging, fisheries zones, hydrocarbon extraction, major ports, mariculture, ocean energy facilities, pipelines and cables, protected areas, waste disposal (solids), wind farms, other forms of area management or designation.

3.9 EMODnet Central Portal

To improve the user experience and strengthen the coherence and functionality of EMODnet as a whole, a central EMODnet Entry Portal was established later 2013 to provide an entry point (www.emodnet.eu) delivering access to data, metadata and data products held by EMODnet thematic sites as well as developing data products and search results combining data from several thematic portals. Since October 2014, the central portal made available a first data service (the EMODnet Central Portal Query Tool) which allows user to simultaneously access data layers made available by the different EMODnet thematic portals, combining them in one single output. The tool will be gradually expanded with more parameters, search options and functions to allow manipulation of the outputs.

4. Emodnet sea-basin checkpoints

User requirements are a priority in EMODnet, so a series of sea-basin 'Checkpoints' are being put in place, starting with the Mediterranean and North Sea in 2013. These regional mechanisms have been established to assess the observation capacity in all regional sea-basins from the perspective of concrete application areas (e.g. spill response, offshore installation siting, etc.). EMODnet Checkpoints are expected to identify whether the present observation infrastructure is the most effective possible, and whether it meets the needs of users. Tenders for additional regional assessment hubs covering the Arctic, Atlantic, Baltic and Black Sea have been launched in 2014 and are expected to be initiated early in 2015.

5. Coordination and monitoring

Since September 2013, EMODnet activities are supported by a dedicated Secretariat responsable for public relations and communication, coordination of activities and monitoring of the performance of the EMODnet projects. Under supervision of DG MARE and the EMODnet Secretariat, a Steering Committee consisting of coordinators from EMODnet portals as well as observers from EEA and DG ENV oversees the development of the Central EMODnet portal and guides the development of complementary services. This has greatly improved internal collaboration and exchange of best practices leading to a more coherent development of all EMODnet projects working towards a common goal.

6. Conclusions

EMODnet is a long-term marine data initiative supporting a sustainable blue economy in Europe, constructed through a stepwise approach. Halfway through its development, the resources and services are already useful and data portals are progressing rapidly to (i) become fully operational; (ii) provide the best available data, free of restrictions on use; and (iii) become more user friendly & fit for purpose. Bringing observations, products, services and knowledge to users and the public requires appropriate tools and guidance. Ensuring fitness for purpose can only be done together with a growing number of data providers and users and EMODnet will increasingly rely on the involvement of stakeholders to guide further developments.

Today, more than 110 organisations are involved in the EMODnet programme and new contributors are always welcome. EMODnet will continue to strengthen its collaboration with other marine knowledge providers, including fisheries, the marine component of the EU's Copernicus programme and the private sector, to create a common platform for marine data in Europe.

Acknowledgements

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The RITMARE Italian coastal radar network: operational system and data interoperability framework

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Abstract

Understanding marine transport and the dispersion of tracers is crucial for an effective strategy for protecting marine biodiversity and mitigating anthropogenic hazards. Single standalone observational sites are not effective for a long-term and large-scale strategy unless they are integrated into a network. Here we present the Italian coastal radar network that has been designed and implemented within the flagship project RITMARE. The network nodes are both HF and X-band radars, covering wide areas with different spatial and temporal resolutions. The network has the potential to provide real-time information of the velocity of surface currents and wave parameters. The data sharing IT framework is under development, aimed to the design and standardization of data format definitions, Quality Assessment and Quality Control (QA/QC) strategies, data management and dissemination policies. Data access tools are compliant to Open Geospatial Consortium (OGC) standards and to INSPIRE and Climate and Forecast (CF) conventions. The use of netCDF format allows an easy implementation of all the open source services developed by UNIDATA.

Keywords: HF radar, X-band radar, interoperability, marine transport, current

1. Introduction

In the last decade High Frequency (HF) Radar has become a well established and widely used instrument for measuring surface currents and estimating wave parameters, providing effective coverage of wide coastal areas where observing and modelling marine transport and dispersion processes are difficult tasks. Coastal radars provide information on the environmental state of oceans (Harlan *et al.,* 2010), allowing the collection of current and wave parameters and enabling integrated monitoring of different physical processes. From a modelling perspective, HF radar data offer great benefits, as they cover significant portions of coastal ocean model domains and can be used for blending and assimilation or validation (Marmain *et al.,* 2014).

The interest in monitoring sea state using marine X-band radar images is also strongly growing in the last years, since such systems give the opportunity to scan the sea surface with high temporal and spatial resolution (Serafino *et al.*, 2010), providing surface current fields, bathymetry map and sea wave parameters.

Understanding marine transport and dispersion of tracers is crucial for planning an effective strategy for protecting marine biodiversity and mitigating anthropogenic hazards, especially in nearshore areas, as coastal seas are critical in terms of ship traffic, port activity, border security and mineral exploitation. Single standalone observational sites are not effective in a long-term and large-scale strategy unless they are integrated into a network. To overcome this challenge, the Italian flagship project RITMARE (www.ritmare.it) focuses its efforts on the integration of the existing local observing systems, toward a unified operational Italian framework and on the harmonization of data collection and data management procedures. A specific action is dedicated to the establishment of a national coastal radar network that includes both HF and X-band technologies. Furthermore, a dedicated action has been undertaken within RITMARE to foster interoperability among data providers. An IT framework is under development that aims at providing software tools for data collection and data sharing. It suggests harmonization on data format definitions, QA/QC strategies, data management and dissemination policies.

Here we present the Italian coastal radar network, reviewing recent developments in interoperability and describing ongoing applications. Section 2 describes the radar network, detailing the different HF and X-band nodes. The data sharing strategy and the defined interoperable data structures are presented in Section 3. Section 4 illustrates the applications of the radar based coastal monitoring and Section 5 summarizes the network state and presents critical issues and ongoing research.

2. The italian coastal radar network

2.1 The network

The Italian coastal radar network is presently composed of five sub-networks managed by the partner institutions, namely the Institute of Marine Science (ISMAR-CNR), the OGS-National Institute of Oceanography and Geophysics, the Institute for Electromagnetic Sensing of the Environment (IREA-CNR), AMRA and CoNISMA local research unit at DiST-Università degli Studi di Napoli “Parthenope”, and Institute for Coastal Marine

Environment (IAMC-CNR) UOS Messina. The network gathers both X-band radars (7-12.5 GHz) and High Frequency (HF) radars (3-30 MHz). In 2015 the national network is expanding as OGS will be deploying two more systems. Other institutions that are planning or operating HF radars nodes (LAMMA, ARPA Sicilia and Università di Palermo) will be invited to join the network.

Figure 1 The Italian coastal radar network.

Figure 1 shows the network structure: the sub-networks presently active in the network are depicted in yellow, nodes already operative outside the network are depicted in orange, sub-networks to be deployed are depicted in grey.

2.2 The HF radar nodes

HF radar is based on the relationship between the transmitted signal (in the High Frequency range [3-30] MHz, with corresponding wavelengths in the range [100-10] m) and the signal backscattered by the surface ocean waves of half the transmitted wavelength, referred to as Bragg scattering. The backscattered signal is Doppler-shifted depending on the speed of the scattering surface. From the frequency shift in the first-order backscatter, the surface current velocity is retrieved, while waves parameters are evaluated from both the first and the second-order backscatter spectra (Barrick, 1977). Over a given time period, the radar generates maps of the velocity radial components, with typical spatial resolution of [1-6] km and angular resolution of [1°-5°] (Barrick and Lipa, 1996). Since the Doppler shift only resolves the current components moving (toward or away) along radial directions with respect to the antenna, total surface velocity maps can be obtained geometrically combining radials from at least two sites, provided some geometrical constraints are satisfied. Over the years different types of HF radars have been developed and presently two of the mostly spread off-the-shelf instruments are: Coastal Ocean Dynamics Applications Radar (CODAR), (Barrick, 1977), and the WEllen RAdar (WERA) (Gurgel *et al.*, 1999).

The HF radar nodes of the Italian coastal network are both CODAR and WERA. The three operative sub-networks are deployed in the Gulf of Trieste (managed by OGS), in the Gulf of Naples (owned by AMRA scarl and managed by the local research unit of CoNISMa at the Parthenope University of Naples) and in the Gulf of Manfredonia (managed by CNR-ISMAR).

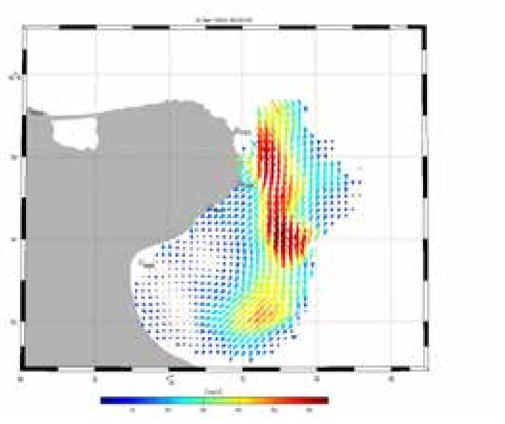

Figure 2 Total current velocity measured by the HF radar sub-network in the Gulf of Manfredonia.

The nodes operate at the frequencies of 16 MHz and 25 MHz accordingly to the ITU plan, with different spatial coverages (100 km and 35-50 km respectively). The spatial resolution ranges between [1-1.5] km and the angular resolution ranges is [1-5]°. The temporal resolution of data generation is 10 minutes to 1 hour. All the sub-networks produce current radial velocity and current total velocity. Two sub-networks also provide wave fields and wind fields. Figure 2 shows an example of current total velocity produced by the CNR-ISMAR sub-network.

2.3 The X-band radar nodes

Under specific conditions (Serafino *et al.*, 2010), the backscattering from the sea is revealed in marine radar images, up to some kilometres from the observation platform and it represents a useful signal to be processed to achieve a spatial–temporal image of the sea state. The backscattering by the sea arises due to the presence on the sea surface of the capillary waves caused by the action of the wind. The longer surface waves modulate the backscattering phenomenon, thus becoming visible in the radar images. This modulation arises due to two main effects: tilt modulation (TM), and shadowing (SH). TM is the modulation due to the variation of the angle under which the ocean wave is viewed by the radar, and SH accounts for the electromagnetic shadowing of the sea surface by higher waves (Lee *et al*., 1995). As a result, the radar image is not a direct representation of the sea state, and thus, a transformation procedure is needed. The data processing is an inversion problem for retrieving the elevation of sea surface evaluated from the time series of spatial radar imagery collected at different times (Serafino *et al*., 2010).

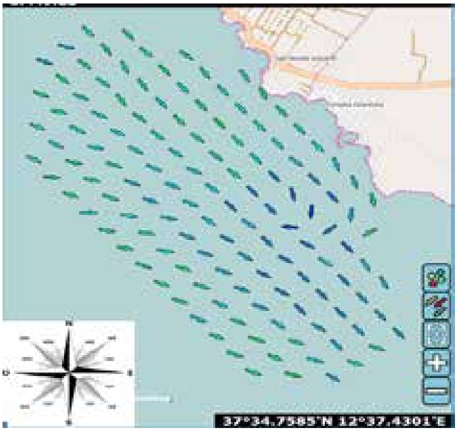

Figure 3 Bathymetry map relevant to the neighborhood of Capo Granitola, as measured by the CNR-IAMC X-band radar.

Starting from the 3D spectrum of the radar sequence, through a number of steps devoted to filter out the distortions introduced by the imaging process (e.g., the power decay, the tilt modulation), it is possible to obtain the directional sea-wave spectrum, and then the hydrodynamic parameters, as well as the surface currents and the bathymetry.

The X-band radar sub-networks of the Italian coastal network are deployed in the off-shore platform in Venice, in Capo Granitola and in Sciacca and are managed by CNR-IAMC and IREA-CNR. The X-band nodes operate both at the central frequency of 9.5 GHz, with spatial coverage of about 3 km, spatial resolution of 7 m and angular resolution of 0.9°. The temporal resolution of data generation is 1 hour. The generated products are current velocity maps, sea state parameters and bathymetry maps.

3. The data interoperability framework

In the framework of the RITMARE project and jointly with the HF Radar group within EuroGOOS, the design and the standardization of QA/QC strategies at Italian and European level is under development. At the moment the validation of surface current data collected by HF radars has been carried out within the Italian coastal radar network community mainly in terms of transport processes: trajectories of passive particles advected by radar-measured currents were successfully compared with real drifter tracks (Bellomo *et al*., in preparation) and with the time evolution of the distribution of the satellite-derived diffuse attenuation coefficient at the wavelength 490 nm, used as a proxy for water turbidity (Uttieri *et al*., 2011). The validation processes proved the general reliability of HF radar data and showed that errors are due to improper analysis settings or can be interpreted as intrinsic geophysical variability within the water column and the different sampling approaches (Cosoli et al, 2010). The reconstruction procedure to extract the sea state parameters from X radar data has been already tested in a number of application scenarios (Ludeno *et al*., 2014) (Serafino *et al*., 2010) and its estimation results have been successfully compared with the current's values measured by HF CODAR systems. (Serafino *et al*., 2012).

It is expected that in 2015, once the common strategies will have been defined, further enhancements in the standard signal-to-noise filtering on spectra, data cleaning and interpolation procedures will be developed and applied to the produced data.

3.1 The netCDF interoperable format

In order to produce data in interoperable formats, according to the standards of Open Geospatial Consortium (OGC) (Botts *et al.,* 2008) for the access and delivery of geospatial data, the netCDF file format has been chosen, whose architecture has been built according to the Radiowave Operators Working Group (US ROWG) standard (Harlan *et al.,* 2010) and compliant to the Climate and Forecast (CF) Metadata Conventions CF-1.6 (Gregory, 2003). Each node of the network generates its hourly data in netCDF format.

3.2 The Thematic Real-time Environmental Distributed Data Services (THREDDS)

Some of the partners automatically upload, aggregate and attach their hourly netCDF files to a Thematic Real-time Environmental Distributed Data Services (THREDDS) catalogue which provides metadata and data access (*ritmare.artov.isac.cnr.it/thredds/ritmare_xml/ritmare_cros_tot.html*). By the end of 2015 it is expected that all the partners will implement this workflow. The catalogue offers different remote-data-access protocols such as OpenDaP, Web Coverage Service (WCS), Web Map Service (WMS) (OGS standards), as well as pure HTTP or NetCDF-Subsetter. They allow for metadata interrogation and data download (even subsetting the dataset in terms of time and space) while embedded clients, such as GODIVA2, NetCDF-JavaToolsUI and Integrated Data Viewer, grant real-time data visualization directly via browser and allow for navigating within the plotted maps, saving images, exporting-importing on Google Earth, generating animations in selected time intervals. On RITMARE webpage a link is available to the THREDDS catalogue.

4. Applications

HF radar data are presently used in a number of applications, ranging from oil spill and search-and-rescue to fishery and coastal management. The surface dynamics in the Gulf of Naples (an area where zones of great environmental and touristic value coexist with one of the largest seaports in the Mediterranean Sea, industrial settlements and many other pollution sources) have been investigated with HF radar data in terms of transport of passive tracers and pollutants, of water renewal mechanisms, of coastal/offshore exchanges (Uttieri *et al*., 2011) (Cianelli *et al*., 2015). The Manfredonia Gulf is a known nursery area for small pelagic species (anchovies and sardines), and an important question for fishery management is understanding where are larvae coming from. HF radar and drifter data are presently used to address this question (Carlson *et al*., in preparation). Data are also used to provide information on biological connectivity between Marine Protected Areas and other relevant ecological regions in the Adriatic. HF radar measurements, together with satellite ocean colour data, are also used to understand sediment transport and impact of flood events in the Gargano area. HF radar velocity fields are also used in validating ocean circulation models (Cosoli et al., 2013), for the optimization of the forecast of the trajectories of oil spills (Berta *et al*., 2014) and for the forecast of sea-surface currents (Mihanovic et al, 2011). HF radars were in fact successfully used in the Northern Adriatic Sea in association with satellite imagery and AIS navigation data to identify a cargo ship responsible of an oil spill that impacted the coast of Croatia and Slovenia in 2008.

Several results relevant to the monitoring of sea state parameters, surface currents and bathymetry, provided by the wave radar systems showed the reliability of such information to assess the sea state monitoring capabilities of X-band marine radars. Therefore, these systems can represent a useful and low-cost tool to support a wide variety of applications. As a matter of fact, these devices are widely used to validate/calibrate numerical models aimed at the prediction of the propagation of the sea waves towards the near-shore areas. Their capability to detect in a quasi-real-time the incident, diffracted and reflected sea waves impinging on a coastal zone, can significantly improve the management, logistics and safety of harbour activities.

The combination of the measuring capabilities of HF radars and X-band radars allows for strengthening the coverage on target areas thanks to the possibility of downscaling the observing resolution (Serafino *et al*., 2012). This fact enables a highly effective coverage of wide coastal areas and the observation of phenomena occurring at different scales,. The integrated use of HF and X-band radars is a promising opportunity in plenty of marine applications, such as Search And Rescue, monitoring of ports and of ship tracks along the coast, support to navigation in densely operated areas and monitoring of Marine Protected Areas and marine connectivity among them.

5. Conclusions

The Italian coastal radar network is currently operative with 8 HF radars and 3 X-band radars, covering about 1.700 square kilometres. Potentially it will expand to 5 operative X-band radars and 13 HF radars in 2015, when the total coverage will reach more than 10.000 square kilometres and spread on wide portion of coast, thanks to the new nodes to be installed adjacent to the existing ones. The use of radar data in marine applications is known to grow, thanks to the extension of the network and to the potentialities offered by the integration of HF and X-band radar measurements. Furthermore, a promising networking activity is currently carried out in order to build a European coastal radar network that will include the Italian network. CNR-ISMAR represents the Italian partners as a member of the EuroGOOS HFR Task Team, responsible to set the foundation of the European network.

There are anyway critical points to be faced in these tasks: the spatial coverage is not yet at a national scale and it will not be at a national scale even after the expected project extension in 2015; HF radars have high purchase and maintenance costs; radar deployment requires a high number of permissions from several national and regional authorities. Due to the lack of a national funding plan for infrastructures acquisition and maintenance, the networking activity in progress, aimed at growing interest about coastal radars and at building synergies within Italian research institutions and management agencies, seems the only way to maintain and hopefully empower and extend the network. From a technical point of view, the activities currently in progress are aimed at the improvement of QA/QC procedures and at their harmonization at national and international level.

Acknowledgements

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MyOcean In-Situ Thematic Centre: A service for operational Oceanography

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Abstract

In 2008 EUROGOOS partners endorsed the recommendations proposed by the DATA Management/Exchange/Quality working group (http://eurogoos.eu/increasing-eurogoos-awareness/working-groups/data-management-exchange-quality-working-group-data-meq/) to set up a Pan-European system for EuroGOOS articulated with the Regional Operational Oceanographic Systems (ROOS) consolidating achievements realized through projects in particular MyOcean1&2 (implementation of the Copernicus Marine Service), SeaDataNET1&2 (consolidation the National Data Centres network in Europe) and EMODnet-Physics1&2 (contribution towards the definition of an operational European Marine Observation and Data Network). The in-situ Thematic Assembly Centre of MyOcean is a distributed service integrating data from different sources for operational oceanography needs. It collects and carries out quality control in a homogeneous manner on data from outside MyOcean data providers, especially EuroGOOS partners in Europe,

to fit the needs of internal and external users. It provides access to integrated datasets of core parameters (temperature, salinity, current, sea level, chlorophyll, oxygen and nutrient) to characterise ocean state and ocean variability, by this contributing to initialization, forcing, assimilation and validation of ocean numerical models and ocean reanalysis. It provides both near real time products aggregated from automatic observatories at sea (e.g. floats, buoys, gliders, ferrybox, drifters, SOOP) which are transmitting to the shore in real-time, and historical products over 1990-now developed jointly with SeaDataNet that provides high quality scientific data and EMODnet that foster collaboration with observing system operators in Europe. The product and services provided by the in situ thematic assembly centre will be presented as well as how it developed to provide products useful for operational oceanography needs both for forecasting and reanalysis activities, downstream services and for the research communities.

Keywords: in situ , data exchange , data management, operational oceanography

1. Introduction

Society is increasingly concerned about global change and its regional impacts. Sea level is rising at an accelerating rate of 3 mm/year, Arctic sea ice cover is shrinking and high latitude areas are warming rapidly. Extreme weather events cause loss of life and enormous burdens on the insurance industry. Globally, 8 of the 10 warmest years since 1860, when instrumental records began, were in the past decade. These effects are caused by a mixture of long-term climate change and natural variability. Their impacts are in some cases beneficial (lengthened growing seasons, opening of Arctic shipping routes) and in others adverse (increased coastal flooding, severe droughts, more extreme and frequent heat waves and weather events such as severe tropical cyclones). Understanding, and whenever possible, predicting changes in both the atmosphere and ocean are needed to guide international actions, to optimize governments' policies and to shape industrial strategies. To make those predictions we need improved models of climate and of the entire earth system (including socio-economic factors).

Ocean observation is currently a key component to the EU Strategy for Marine and Maritime Research and has become a higher priority on the worldwide environmental political agenda.

2. Marine infrastructure in europe

Oceans can be observed by satellite and in situ. While satellites provide a global coverage, in situ is necessary to observe in depth and with more parameters. Available in situ ocean observing platforms (e.g. ships, moorings, drifters, tide gauges, floats, remote sensing satellites, marine mammals, autonomous vehicles) have individual sampling limitations, weaknesses and strengths. In order to obtain a comprehensive observing system that allows multidisciplinary monitoring of the ocean at multiple scales, a combination of observing platforms is required.

Today, there are up to 800 distributed facilities in Europe, in various domains such as ocean and coastal sea observation, marine biology research, blue biotechnology innovation, research in aquaculture and ocean engineering. Marine Research Infrastructures may take the form of:

- Research vessels and their underwater vehicles (sea access and deep sea exploration/ sampling);
- *In situ* observing systems (seawater column & seabed observation and monitoring);
- Satellites (remote sensing for sea-surface monitoring);
- Marine data centres (for data validation, storage and dissemination, including access to high computing facilities & generic modelling);
- Marine land-based facilities for ocean engineering (deep wave basins, water circulation canals, hyperbaric tanks, material testing laboratories, marine sensors calibration laboratories);

The main characteristics of the Marine Research Infrastructures are that they are distributed and mainly funded by nations. They have developed as networks through ESFRI in I3 projects that have:

- increased cross institutes coordination
- enhanced interoperability of the infrastructures by defining common standards, best practices and infrastructure sharing
- allowed to conduct joint development to develop further the infrastructure
- enhanced access to the observation data

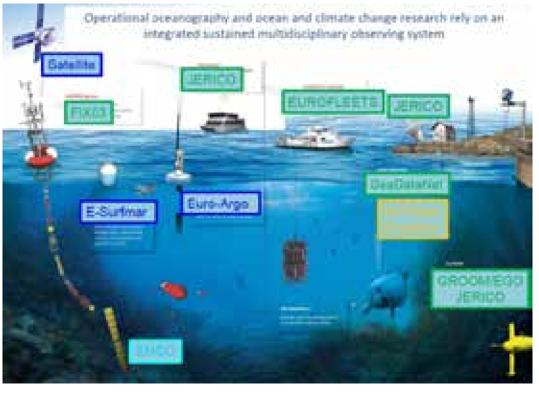


Figure 1 Observing the Ocean relies a wide variety of platforms coordinated other through sustained bodies (satellite and ERIC in dark blue) or in phase to be sustained (in light blue) or through I3 projects (in green) or through other EC funding mechanism (in yellow).

3. Towards an integrated european data system

In 2008 the DATAMEQ (DATA Management Exchange and Quality) working group, composed of data managers representative from the EuroGOOS ROOSes and EU projects addressing data management issues (EuroArgo, EuroSites, SeaDataNet, ICES, Ferrybox, INSPIRE, ECOOP, Satellite), issued a set of recommendations [Pouliquen et al., 2008] that was endorsed by the Members at the annual EuroGOOS meeting in 2008. It was agreed that the ROOSes should set up regional portals extending what had been benchmarked in ECOOP and consolidated/certified in MyOcean as basic infrastructure for EuroGOOS Data Exchange. It was also recommended that theses portals should use standard vocabularies developed within SeaDataNet and use the OceanSites NetCDF format for data distribution. It was agreed that the ROOSes should maintain regional catalogues of the operational observing systems that should be used to update a European catalogue more easily in a semi-automatic way. Finally it was agreed that a set of quality control procedures applicable in near real time automatically should be assembled by the DATAMEQ working group and used by the EuroGOOS members as a minimum level of quality control processing. A first version was issued in [Pouliquen et al., 2010]

Setting up such a system reduced the duplication of efforts among the agencies, improved the quality and reduced cost of the observation distribution, improved access to the observations and therefore increased the benefit of the observation "observed once---used multiple". It has strengthened key partnerships to increase data availability inside each region making it more sustainable over time and allowing the development of downstream services.

It necessitated agreement on common data policy enabling open and free access to data and agreement on common standards and protocols to share data between institutes. Such developments were managed jointly by EuroGOOS ROOSes, MyOcean INSTAC partners, SeaDataNet NODCs and EMODnet-physics partners.

4. MYOCEAN IN SITU TAC

MyOcean aims at providing a sustainable service for Ocean Monitoring and Forecasting, validated and commissioned by users. The MyOcean information includes observations, analysis, reanalysis and forecasts describing the physical state of the ocean, its variability and the ecosystem response through primary biogeochemical parameters. It also contributes to research on climate by providing long time-series of re-analysed parameters. It started in 2009 for 3 years and continued for 2.5 additional years through the MyOcean II project in April 2012 followed by MyOcean-FO until end of April 2015.

Within these projects, the in-situ Thematic Assembly Centre of MyOcean is a distributed service integrating data from different sources for operational oceanography needs. The MyOcean in-situ TAC is collecting and carrying out quality control in a homogeneous manner on data from outside MyOcean data providers (national and international networks), to fit the needs of internal and external users. It provides access to integrated datasets of core parameters to characterise ocean state and ocean variability, by this, contributing to initialization, forcing, assimilation and validation of ocean numerical models which are used for forecasting, analyses and re-analysis of ocean conditions. Since the primary objective of MyOcean and MyOcean2 was to forecast the ocean state, the initial focus was on observations from automatic observatories at sea (e.g. floats, buoys, gliders, ferrybox, drifters, SOOP) which are transmitted in real-time to the shore at *global* and r*egional* scales both for *physical* and *biogeochemical* parameters. The second objective is to set up a system for re-analysis purposes that requires products integrated over the past 30 years, for temperature and salinity parameters.

Since the elaboration of the first proposal, the MyOcean in-situ TAC has been designed to rely on the EuroGOOS ROOSes with regional coordination endorsed by partners from the ROOSes and on a global component based on Coriolis data centre (http://www.coriolis.eu.org) that acts as a GDAC (Global Data Centre) for some of the JCOMM networks.

The MyOcean in-situ TAC is focused on a limited number of parameters:

- *Temperature and salinity*: global and regional, produced in real time and delayed mode (all components)
- *Currents:* global and regional, produced in real time (global, North West Shelves, Mediterranean Sea, Baltic)
- *Sea level:* regional, produced in real time (South West Shelves, North West Shelves, Baltic)
- *Biogeochemical (chlorophyll, oxygen and nutrients):* global and regional, produced in real time (all components)

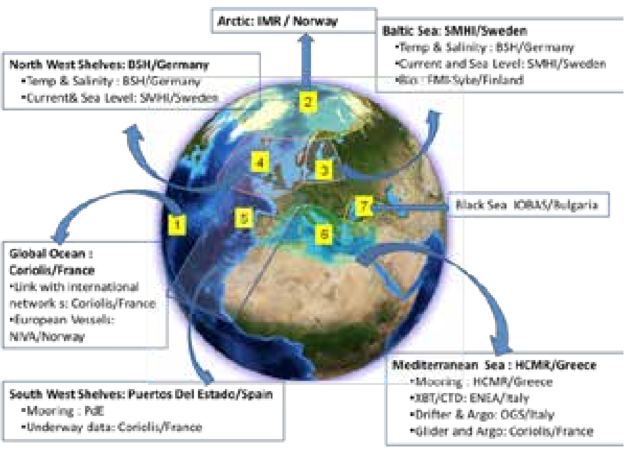


Figure 2 The in-situ TAC global and regional components: Institute responsibilities inside each component

The in-situ TAC architecture is decentralized. However, quality of the products delivered to users must be equivalent wherever the data are processed [Pouliquen et al., 2010]. The different functions implemented by the global and regional components of the in-situ TAC are :

- *Acquisition*: Gather data available on international networks or though collaboration with regional partners
- *Quality control*: apply automatic quality controls that have been agreed at the in- situ TAC level. These procedures are defined by parameter, elaborated in coherence with international agreement, in particular SeaDataNet, and documented in MyOcean catalogue
- *Product Assessment*: Assess the consistency of the data over a period of time and

an area to detect data not coherent with their neighbours but could not be detected by automatic quality control (QC). This function has a level of complexity on its implementation which is clearly different from the other three as it highly relies on scientist expertise

- *Product distribution*: make the data available within MyOcean and to the external users

As a consequence, for all European seas, a unique way of distributing the data has been set up:

- *Same format*: The OceanSites NetCDF format has been chosen because it is CF compliant, it relies on SeaDataNet vocabularies and it is able to handle profiles and time series data coming from floats, drifters, moorings, gliders and vessels.
- *Same ftp portal organization*: the data are organized in three main directories:
  - Latest: Providing access to a sliding window on the latest 30 days of observations for real-time applications.
  - Monthly: Accumulating the best copy of a dataset, organized by platform and by month.
  - History: Providing historical aggregated datasets (30 years) for reanalysis activities.

4.1 The Near-Real Time Service

Presently in near real –time about 2500 platforms for the global, between less than 10 for the Black Sea and 450 for the Iberian-Biscay-Irish seas are distributed every day on the In situ TAC portals. Depending on the seas, the platforms used are diverse, from mainly fixed stations and ferrybox for the Baltic, to research vessels and Argo for the Arctic, to wider kinds of platforms for North and South West Shelves and Mediterranean Sea. The number of platforms are sparse in the Black Sea but improving since the start of the Argo program in the area.

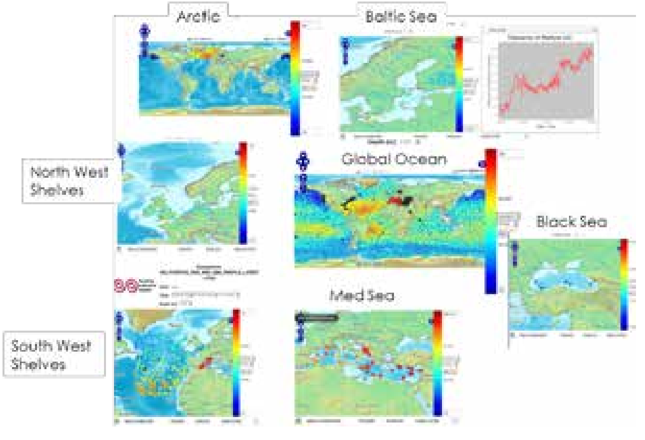


Figure 3 Latest 3 months of observations in each region displayed using the WMS service provided by Oceantron[1]

1 https://forge.ifremer.fr/plugins/mediawiki/wiki/oceanotron/index.php/Accueil

4.2 The Service for reanalysis

Based on the Coriolis Global product experience (http://www.coriolis.eu.org/Science2/Global-Ocean/CORA) and in partnership with the SeaDataNet European project (http://www.seadatanet.org/), reprocessed products for the European seas have been developed. These products integrate observations aggregated from Regional EuroGOOS consortium (Arctic-ROOS, BOOS, NOOS, IBI-ROOS, MONGOOS) and Black Sea GOOS, from SeaDataNet2 National Data Centres (NODCs), from World Ocean Data Base (US-NODC), JCOMM global networks (Argo, GOSUD, OceanSITES, GTSPP, DBCP) and from the Global telecommunication system (GTS) used by the Met Offices.

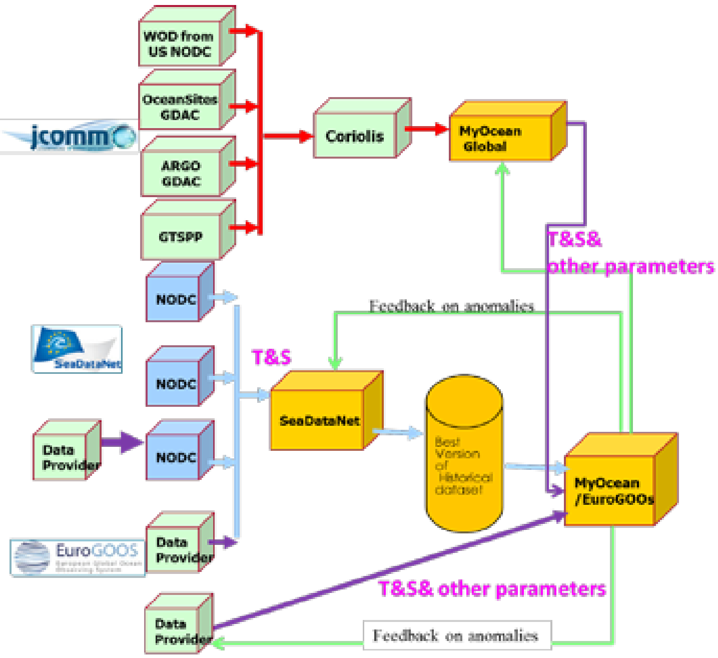


Figure 4 External and internal interfaces for Reprocessed in situ product elaboration

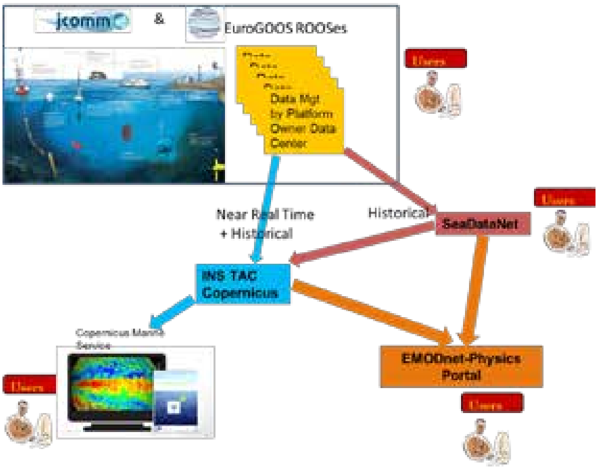
To elaborate these products it is important to retrieve, whenever possible, the observation qualified in delayed mode, eventually corrected from offset or drift either from ROOS national centres or SeaDataNet NODCs or JCOMM networks. In case a duplicate is detected between the new data provided and a copy that was already provided in real time, each regional in situ TAC has defined rules to handle them and a visual inspection is performed when it's not clear from the provided metadata which copy have been through scientific validation.

The scientific validation is performed on a frozen copy of the history directory. It consists of statistical tests to check the consistency of the observation with its neighbours, climatology test and the detected outliers are examined by a scientists to avoid flagging as bad data sampling a real phenomenon. Feedbacks to providers (ROOS partners or

SeaDataNet NODCs) on the anomalies detected are performed so that this validation helps to enhance not only the MyOcean products but also the provider datasets. These fully validated T&S regional products are available since MyOcean V4 in April 2014.

5. Link with emodnet_physiscs

The EMODnet Physics project is aimed at providing layers of physical data and metadata available for use by public authorities, scientists and industry, and contributes towards the definition of an operational European Marine Observation and Data Network (EMODnet). The portal is being developed by a European consortium and operates in cooperation between EuroGOOS, its Regional components (ROOSs), and exploiting SeaDataNet and Copernicus/MyOcean infrastructures and services bringing together many marine data users and providers.



The EMODnet Physics portal provides access to near real time and archived data series from in situ platforms in the European Sea and provides OGC services (WMS, WFS, and WCS) for data discovery, view and download. It relies on access services provided by MyOcean/EuroGOOS for real time and SeaDataNet for historical observation data.

EMODnet-Physics partners also work closely with MyOcean and SeaDataNet to improve interoperability between the two systems and integrate observation data from more providers though outreach and training workshops.

6. Extension outside myocean

This infrastructure developed jointly by MyOcean and EuroGOOS ROOSes has set up a useful service both for operational oceanography in Europe but also for the research community and the development of downstream services. It relies on *open and free data policy* and the EUROGOOS ROOSes should encourage such data policy.

MyOcean service has also been extended to coastal data within the JERICO project (www.jerico-fp7.eu/) as well as in Mediterranean Sea within Perseus (http://www.perseus-fp7.eu/). At global scale a better integration of the European glider data is developed in partnership with the GROOM project (http://www.groom-fp7.eu/).

7. Future developments

The infrastructure described in this article has been set up to fulfil the Operational Oceanography and EuroGOOS partner needs. The foundations of a reliable data exchange system have been built, for operational oceanography applications both for core and downstream applications as well as research activities. It has improved the in situ data services at European scale and will show its benefit to the community if it is sustained on the long term jointly by the regions and the European Commission. The main priorities for MyOcean and EuroGOOS partners are:

- Sustain the existing service in near Real Time and for reanalysis within the Copernicus Marine Service.
- Consolidate interoperability with EUROGOOS , SeaDataNet , EMODNet and JCOMM systems.
- Collaborate with other EU projects to enhance the service without duplication of efforts (JERICO-Next, PERSEUS, ATLANTOS,..)
- Extend some of the services developed for Temperature and Salinity to other EOVs (Earth Ocean Variable) such as current or chlorophyll.

Acknowledgements

This work is part of the MyOcean, MyOcean2 and MyOcean-FO projects. Additional observations are acquired outside MyOcean and especially by EuroGOOS ROOS institutes at European Scale . Historical products were built in partnership with SeaDataNet2 EU and EMODnet-Physics projects.

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FixO^3 - One year into multidisciplinary observations

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Abstract

The Fixed point Open Ocean Observatory network (FixO3, http://www.fixo3.eu/) seeks to integrate and harmonise 23 European open ocean fixed point observatories and to improve access to these infrastructures for the broader community. These provide multidisciplinary observations in all parts of the oceans from the air-sea interface to the deep seafloor. Started in September 2013 with an EU contribution of 7 Million Euros over 4 years, the project has 29 partners drawn from academia, research institutions and SME's coordinated by the National Oceanography Centre, UK. Open ocean observation is a high priority for European marine and maritime activities. FixO^3 provides important data and services to address the Marine Strategy Framework Directive and in support of the European Integrated Maritime Policy. FixO^3 provides a strong integrated framework of open ocean facilities in the Atlantic from the Arctic to the Antarctic and throughout the Mediterranean, enabling an integrated, regional and multidisciplinary approach to understand natural and anthropogenic change in the ocean. Here we present an introduction to the structure of the project, it's achievements in the first year and the activities of the 12 Work Packages.

Keywords: FixO^3, sustained, ocean, observations

1. Introduction

The Fixed-point Open Ocean Observatories Network (FixO^3) is a collaborative project between 29 partners in 11 European countries drawn from academia, research organizations and small and medium enterprises (SME's).

FixO^3 is a four year project which started in September 2013, as part of the EU's Seventh Framework Programme for Research (FP7), with an EU contribution of 7 million Euros. The project's main goal is to bring together all sustained multidisciplinary open ocean observatories operated by the EU into a single coordinated network. FixO^3 aims to:

- **Integrate and harmonise** current procedures and processes of 23 EU open ocean observatories spread across the Atlantic Ocean from the Arctic to the Antarctic and the Mediterranean Sea (Figure 1)
- **Improve access** to these key installations as well as **offer free and open access** of data services and products to the broader community

- **Innovate and enhance** current capability for multidisciplinary in situ ocean observations

1.1 FixO³ Project Structure

FixO³ consists of 12 work packages, a Steering Committee and a carefully selected international Advisory Board all working closely together in order to drive forward the mission of the project and achieve the goals of the programme. The FixO³

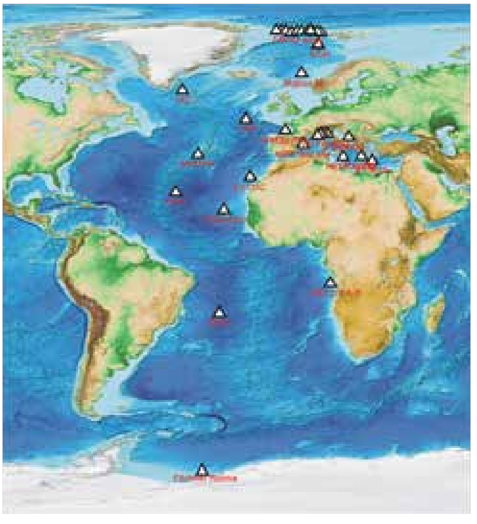

Figure 1 Location of European fixed point open ocean observatories included in the FixO³ Network

project is coordinated by NERC's National Oceanography Centre (NOC) in Southampton, UK, which comprises Work Package 1 (WP1) – Project Management. Furthermore, WP1 acts as a bridge between the European Commission, the Advisory Board and the FixO³ consortium.

The remaining 11 work packages are split into three types of activities with different and varied aims and responsibilities within the project (Figure 2):

1. **Coordination** – WP's 2 to 8 participate in activities to integrate and harmonise the current procedures and processes. Fostering links with the wider community across academia, industry, policy and the general public through outreach, conferences, media publications, knowledge exchange and training, through workshops.
2. **Support –** WP's 9 and 10 participate in activities to offer a) access to observatory infrastructures to those who do not have such access, such as scientists/students outside the consortium, developing EU nations and of course to industry candidates who want to test run their censors and b) free and open data products and services.
3. **Joint research activities** – WP's 11 and 12 participate in activities to innovate and enhance the current capability for multidisciplinary in situ ocean observation.

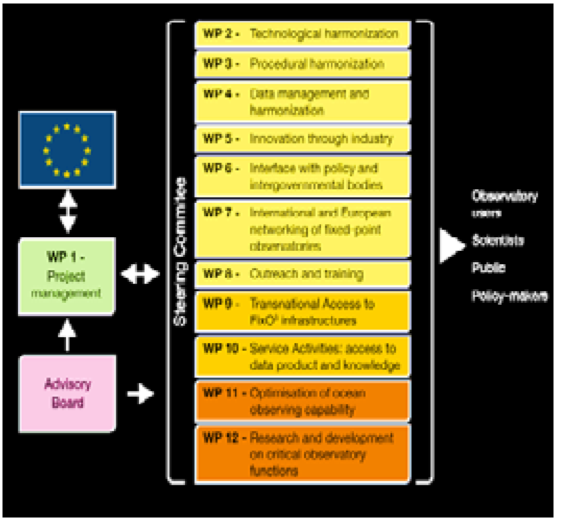

Figure 2 Flow diagram of FixO³ project structure and work package descriptions

2. First year of FIXO³

FixO³ has had quite a productive first year, with Project Coordinator, Prof. Richard Lampitt, and Project Managers Dr. Luisa Cristini and Sofia Alexiou, attending conferences, giving talks, networking with scientists and industry sector members all around the world promoting the FixO³ project and the opportunities it offers, such as Transnational Access to infrastructures (TNA). Furthermore, scientific talks and training workshops have been hosted by scientists, work package leaders and their teams within the consortium, actively contributing to the achievements of FixO³ throughout the year.

2.1 FixO³ first year achievements

The collaborated effort of the FixO³ consortium members has resulted in the completion of 20 deliverables and 13 milestones ahead of scheduled deadlines, hosted 7 Steering Committee and 4 Advisory Board meetings, and held the first Annual Consortium Meeting in Crete during October 2014. Some key achievements of FixO³'s first year include:

- Launch of the project website: www.fixo3.eu
- Review of current status at all sites within the FixO³ Network
- Presentation of a FixO³ label, common protocols, and standards and best practices
- Collaborative workshops and meetings between work packages, including data management workshop and best practices workshop
- FixO³ and TNA featured in several publications, such as the Marine Technology News, the International Ocean Systems and the Hydro International
- Active presence at various international conferences, including the AGU Ocean Sciences in Hawaii, Oceanology International in London, the EGU General Meeting

in Vienna, the Challenger Society Conference in Plymouth UK, EurOCEANS 2014 in Rome and EuroGOOS 2014 in Lisbon

- Data products launched on the website
- First Annual Newsletter
- First call for TNA proposals

2.2 Transnational Access

The Transnational Access is a mechanism which offers researches or industry members, who do not normally have access to open ocean fixed point observatories, to gain such access to run experiments and/or test-run their sensors, equipment or new innovations, while the costs of their travel and subsistence is funded by FixO^3. Within the FixO^3 Network only 15 of the 23 observatories are part of the Transnational Access activity.

Figure 3 FixO^3 Transnational Access flyer

The first call for Transnational Access proposals was open from June 15th to July 31st 2014, and received 15 applications, with 9 out of the 15 TNA observatories receiving proposals (some receiving several). After formal reviews and evaluations by the TNA team, consortium reviewers and infrastructure managers, all 15 applications were successful and funded for.

A second TNA call for proposals will be opened in the Spring of 2015, to promote further interactions with institutions, organisations and companies across Europe as well as non-EU members. More details can be found on the FixO^3 website (www.fixo3.eu).

3. OBSERVING OUR CHANGING OCEAN

The global ocean is our planet's largest feature. It influences the life of all of us in a wide variety of ways including supplying food, providing renewable energy and regulating the Earth's climate. Its effect reaches far beyond the continents' coasts where the majority of the world population lives. For centuries its huge extent has led us to believe that we can have no significant impact on its ecosystems.

Yet we know so little about the ocean. Human exploration of the ocean has been limited by several challenges and the study of its features addressed with a variety of means, from satellite remote sensing, to explorative cruises, to the use of remote-operated vehicles, to numerical modelling of ocean physics and biogeochemistry, to permanent fixed observing platforms. Each of these means presents advantages and limitations and contributes in its own way to putting together the pieces of the puzzle that compose the big picture of how the ocean works and changes.

The complexity and extent of the ocean system require studying it as a collaborative effort to overcome the scientific, technical, logistical and financial challenges that one single research institution or government would not be able to tackle alone. Ocean observations, as a mean to understand the ocean system and its changes, are undertaken through collaborative projects and international frameworks, such as the Global Ocean Observing System (GOOS, http://www.ioc-goos.org/), the global system for sustained observations of the ocean comprising the oceanographic component of the Global Earth Observing System of Systems (GEOSS).

FixO^3, the fixed-point open ocean observatories network, contributes to GOOS as the European contribution to OceanSITES (http://www.oceansites.org/) the worldwide system of long-term, open-ocean fixed point observatories monitoring the full depth of the ocean water column but in addition has an important seafloor component. FixO^3 builds on several previous successful projects with the aim of providing an integrated network of sustained ocean observations producing high-quality time-series data critical to reveal physical, biogeochemical and geological processes in the open ocean and to detect changes over decades.

Over its first year FixO^3 has made huge progresses in harmonising data management procedures to facilitate the use of data products and services by both scientists and public, in linking with the industry sector to innovate ocean observations and in improving the access to world-class installations to the wider community of researchers and developers. Although within the first year, FixO^3 has had many achievements, the road ahead is long and difficult, but it will be walked together with a team of excellent and engaged contributors.

High Frequency Surface Wave Radar in the French Mediterranean Sea: an element of the Mediterranean Ocean Observing System for the Environment

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Abstract

A Mediterranean Ocean Observing System for the Environment (MOOSE) has been set up as an interactive, distributed, and integrated observatory system of the North West Mediterranean Sea in order to detect and identify long-term environmental anomalies. In this framework, the Mediterranean Institute of Oceanography (MIO) operates two couple of High Frequency Surface Wave Radars (HFSWR). HFSWRs provide synoptic observations of sea surface currents with high temporal (0.25-1 h) and spatial (1-3 km) resolution and long range (30-100 km). They can therefore be used to study the variability of the current as well as eddy dynamics. One site, based on the WERA (Helzel Messtechnik) technology and installed near Toulon, is operational and monitored in real-time for more than 3 years. It is composed of two WERA systems featuring respectively a non-linear receiving array and a full bistatic configuration, both working in Direction Finding mode. The second site, intended to extend further East the coverage of the Observatory, was set up in 2014 near Nice with two SeaSonde (Codar) systems. We present here an overview of the HFSWR network, the surface current mapping facility offered by the system, and recent observational results and applications.

Keywords: High Frequency Surface Wave Radar, Coastal Observing System, Northern Current, North Western Mediterranean Sea

1. Introduction

The Mediterranean Ocean Observing System for the Environment (MOOSE) focuses on documenting the long-term evolution of the North West (NW) Mediterranean Sea in the context of climate change and anthropogenic pressure. Furthermore, it targets building efficient indicators of the health of the basin. Finally, MOOSE will provide a large flux of real-time data to facilitate validation of operational oceanographic models.

The MOOSE concept is based on a multisite system of continental shelf and deep-sea fixed stations as well as on an autonomous mobile platform network devoted to the observation of the space-time variability of processes interacting between the coastal/open ocean and the ocean/atmosphere. It supplies and maintains long-term time series, thus allowing climatic trends to be elucidated. These data sets are included in the MISTRALS project and use the MyOcean data distribution infrastructure through Coriolis.

The predominant and most energetic circulation feature of the NW Mediterranean Sea is the Northern Current, a border current flowing cyclonically above the slope roughly over the 1000-2000 m isobaths. Its activity is highly variable. It is narrower, deeper and more intense during wintertime [Albérola *et al.*, 1995] with an intense mesoscale activity generating meanders, filaments, and eddies. Recent oceanographic studies in the Gulf of Lions (NW Mediterranean) have indeed shown the existence of vortex structures and instabilities on a wide range of scales. Namely, they have been well described in the context of the ECCOLO campaign [Schaeffer *et al.*, 2011], where a certain number of *in situ* and remote sensors have been conjointly used, such as SST and water colour satellite imagery, satellite-tracked drifting buoys and HF radar.

Today, High Frequency Surface Wave Radar (HFSWR) is indeed routinely used for the remote sensing of the ocean surface. Current measurements are obtained from the Doppler shift of the first-order Bragg-resonant echoes [Crombie, 1955]. The Mediterranean Institute of Oceanography (MIO) has proven its expertise in radar measurement of surface currents [Broche *et al.*, 1987, Molcard *et al.*, 2009] and has been assigned the task to deploy the HFSWR network for the MOOSE program.

2. Description of the sites

The sites chosen for the HF radar network have been identified in order to cover the position of two instrumented lines (*Figure 1*) with long time series of ocean parameters: ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch), and DYFAMED (DYnamics of Atmospheric Fluxes in the MEDiterranean sea). The main difficulties for deploying HFSWR lie in hardware and maintenance costs, frequency licenses, and site finding, especially when the coast is irregularly shaped, steep, or close to touristic and crowded regions.

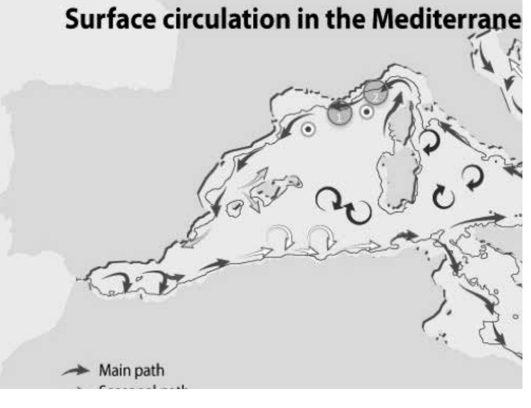

Figure 1 Surface circulation scheme in the Western Basin of the Mediterranean Sea [Millot & Taupier-Letage, 2005] (cartographer GRID-Arendal) with the two site locations of the HFSWR measurements around the areas of interest: 1- Antares (near Toulon), 2- Dyfamed (near Nice).

2.1 First area of interest: ANTARES (Toulon)

The first target area off the coast of Toulon, related to the ANTARES instrumented line, is a key zone conditioning the behaviour of the North Current just upstream of the Gulf of Lions. It displays significant cross-shelf exchanges correlated to the strong north-westerlies present in the region (Mistral, Tramontane). This fully operational site is composed of two Wellen Radar (WERA [Gurgel *et al*., 1998]) systems manufactured by Helzel Messtechnik GmbH providing real-time data. The first radar system has been installed at the Cap Sicié in 2010 and works in quasi-monostatic configuration with a non-linear, W-shaped, 8-antenna receiving array and a single emitting antenna. Such irregular configuration of the array was the only solution to cope with the insufficient space available.

This site has been complemented in May 2012 with a fully bistatic second system, a pioneering configuration for WERA at the time of the setup. The receiver, a regular linear 8-antenna array, is located at Cap Bénat while the transmitter, GPS-synchronized, is installed in the Porquerolles Island, 17 km away from the receiver, in order to circumvent the presence of several large islands. The bistatic configuration has required some dedicated and original hardware and software processing. It also allowed us to experimentally study the effects of bistatism on the HF Doppler spectra, namely evidencing good potential for the purpose of wave spectrum inversion [Grosdidier *et al*., 2013].

Our systems are continuously working in the frequency band of 16.1 to 16.2 MHz allocated by the ITU (International Telecommunication Union) to the oceanographic radar operators. They sweep over a 50 kHz bandwidth, *i.e*. half of the allocated bandwidth, resulting in a 3 km range resolution. A 2 degree azimuthal resolution is achieved through a Direction Finding method based on Music [Lipa *et al*., 2006, Molcard *et al*., 2009]. The integration time can vary from 20 minutes to 1 hour. The radial velocities maps are transmitted every 20 minutes. Cartesian velocities are then reconstructed on a regular 2 x 2 km grid (*Figure 2*) and displayed in near real-time on a dedicated website: http://hfradar.univ-tln.fr.

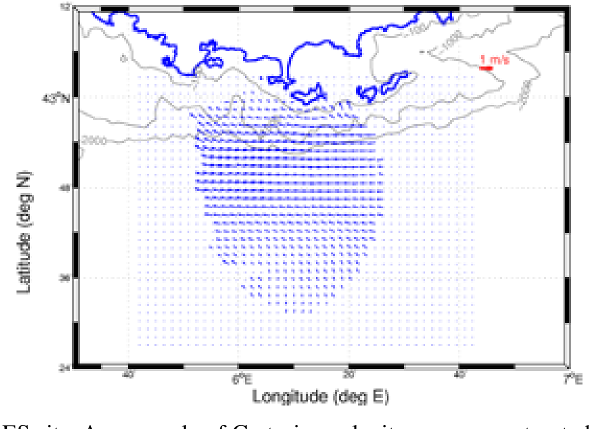

Figure 2 ANTARES site. An example of Cartesian velocity map reconstructed on a grid 2x2 km^2 from the two radial velocity maps measured at the Cap Sicié and Cap Bénat sites using a Direction Finding method based on MUSIC.

2.2 Second area of interest: DYFAMED (Nice)

The installation of the second HFSWR site related to the DYFAMED buoy (*Figure 3*) in the Ligurian Sea area, extended the observation zone to the full coastal area between Toulon and Nice, allowing a much larger coverage of the Northern Current. The selected equipment is a pair of more compact HFSWR systems, namely 2 SeaSondes from CODAR Ocean Sensors [Barrick, 1979]. The two locations are the lighthouse of Cap Ferrat in Saint-Jean Cap Ferrat (set up on October 2013) and the semaphore of Cap Dramont in Saint-Raphaël (set up on May 2014), resulting in a 50 km baseline. The latter was struck by lightning in June 2014 and is currently out of service.

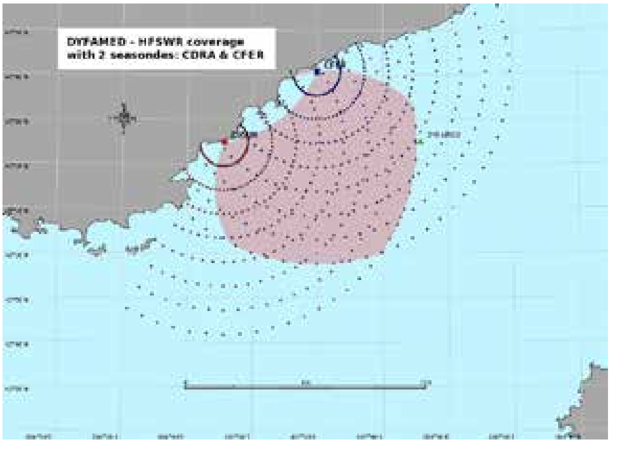

Figure 3 DYFAMED site. Simulation of the coverage of each HFSWR station (Cap Dramont in red points, and Cap Ferrat in blue points) and coverage of the Cartesian velocity map (pink area).

Our pair of SeaSondes works in the 13.5 MHz frequency band allocated by the ITU with a 50 kHz bandwidth. The parameters are similar to those of the WERA systems, except for the azimuthal resolution set at 5 deg.

The ever-increasing deployment of HFSWRs has led the international community to build a frequency sharing plan. Although our radars follow the ITU's recommendations and operate over the frequency bands specified for oceanographic purposes, strong Radio Frequency Interference (RFI) is often present, due to official and non-official radio services. The result is a radical reduction in coverage and the presence of outliers in the velocity maps.

3. Data flow and quality controls

The first product of the measurement made by a HFSWR is the radial velocity. Total vector is a combination of at least two HFSWR measurements. The quality assurance of the total vector map is depending on all the steps of the processing chain, so the quality control must be hierarchized following firstly, the control of the instrument and secondly, the control of the measurement on each component related to each site.

Level 0 – Availability of the instrument

Our first indicator is related to the first level of the data acquisition chain and determines if the data is available or not. A first diagnostic is done on the HFSWR system: controlling if emitter and receiver are properly functioning (and well synchronized if necessary using GPS timing service), and if the contamination by radio interference is not prejudicial to the measurement. These diagnostics alert the operator of troubleshooting on the hardware system.

The coverage of the radial velocity measurement is then analysed. If the coverage is not sufficient the radial file is rejected. The number of radial files per ten days is a good indicator (Figure 4) on the availability of the data.

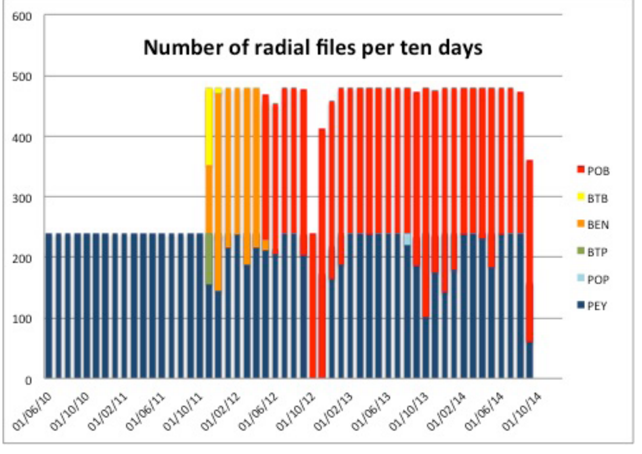

Figure 4 ANTARES: availability of the data given by the number of radial files per ten days on each couple of receiver/transmitter according to the different mono and bi-static configurations. The main ones are in blue PEY- collocated receiver and transmitter, and POB- Porquerolles transmitter/Cap Bénat receiver.

Level 1 – Control of the instrument

Best practices for the operation and maintenance of HFSWRs prescribe regular measurement of the directional antenna pattern of the receiver as a necessary component of the quality assurance and quality control [Cook *et al.*, 2008]. An idealised antenna pattern can be used for a first guess, but it doesn't take into account the environment of the site. We perform at least every year an Antenna Pattern Measurement (APM) on each HFSWR site. The comparison between different measurements ensured the stability of the antenna system and characterised the performance of the system.

Level 2 – Measurement performance

In the ANTARES area, different campaigns (TOSCA, SUBCORAD and BOMBYX) allow us to validate the HFSWR radial velocities measurements by comparison with *in situ* measurements as lagrangian drifters and ADCP (tracked and moored). The comparisons give good agreement in the limits of the intrinsic radar accuracy, in the order of 5 $cm.s^{-1}$ [Fraunié *et al*., 2014].

4. Applications

The applications of our HFSWR measurements have spanned the fields of ocean circulation to operational oceanography to methodological development.

In the first step of the ANTARES implementation (2010-2011), when only one radar site was operational (Cap Sicié), [Marmain *et al*., 2011] developed and successfully tested the Vortex Identification Method (VIM) to reveal the presence of eddy-like structures through radial current velocity maps. During the PHYOCE experiment (March, 31 – April, 3 2011) the variability of the current flow was deduced from the radial velocity field and was used to complement *in-situ* measurements to confirm the existence of a mesoscale meander. This was also visible in the numerical circulation model GLAZUR-64 developed at MIO [Guihou *et al*., 2013].

Full vector current maps are available since late 2011 at the ANTARES site. Two experiments were performed in the framework of the TOSCA (Tracking Oil Spills & Coastal Awareness network) project, a EU-funded MedProgram, gathering a comprehensive data set of surface drifter trajectories and *in-situ* measurements (including gliders) in the HFSWR area. These data have been combined into a web-based decision tool designed for authorities in charge of maritime crises such as Search-and-Rescue and oil spills. Surface drifter trajectories have also served to validate the HFSWR velocities, and to develop a new tool for blending both kinds of measurements [Berta *et al*., 2014]. Finally, hydrological data have complemented HFSWR current velocity maps in order to study the Northern Current variability under wind forcing [Bellomo *et al*., 2013].

The potential of this real-time observation lies also in the possibility of assimilating the surface current velocities in numerical ocean models. As an example, [Marmain *et al*., 2014] successfully used the HFSWR data to correct hydrographic boundary conditions as well as the wind forcing.

Finally, two projects are currently focusing on the physical understanding of the HFSWR current measurement. Namely, SUBCORAD is investigating the impact of sub-grid variability, whereas within STRING surface drifters designed to sense the vertical shear of the current as the HFSWR does, have been built and experimentally tested.

5. CONCLUSIONS

An HFSWR network has being deployed by the MIO along the Mediterranean coast of France, including both WERA and SeaSonde systems. For the former ones, some innovative technical solutions have solved limitations due to the geographical configuration of the sites, including the successful use of a non-linear array of antennas and the exploitation of a full bistatic configuration. Furthermore, a Direction Finding algorithm based on MUSIC has for the first time been used with a WERA system, and adapted to the bistatic case.

Antenna Pattern Measurements are routinely performed to take into account the specificity of the environment where the antennas are placed as well as their ageing. Validation experiments have been performed, demonstrating the accuracy of the HFSWR-derived surface current velocity maps as well as their importance for operational oceanography as well as circulation studies.

With a dataset of more than four years of radial velocity maps and two years of total ones for the first site (ANTARES), this work is the start of a long-term observational effort with HFSWR aimed at providing continuous surface current data in the context of the MOOSE program.

Acknowledgements

The National Institute for Earth Science and Astronomy (INSU) of CNRS supports MOOSE with the Alliance ALLENVI on behalf of the French research organizations on the environment. The HF radar deployment near Toulon was initially funded with national programs such as LEFE IDAO/ECCOP and by the EU MED Program TOSCA. We are grateful to P. Guterman and K. Bernadet from the DT-INSU (CNRS) who supervised the deployment of the Seasonde in Saint-Jean Cap Ferrat and helped to develop the data transfer by GSM. We thank the cartographer GRID-Arendal for his illustration scheme of the circulation in Mediterranean sea (http://www.grida.no/graphicslib/ detail/surface-circulation-in-the-mediterranean-sea_052b).

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Integrating capacities towards PLOCAN observational in-situ programme

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Abstract

The Oceanic Platform of the Canary Islands (PLOCAN) represents an open space and singular infrastructure for science and technology with an international scope. By 2015, PLOCAN will be operating a scientific offshore platform located on the eastern coast of Gran Canaria.

PLOCAN is setting up an integrated observatory which aims to become part of the emerging pan-European networks, offering an extension towards the southern boundaries of interest. It will obtain observations from the European Station for Time series in the Ocean, Canary Islands (PLOCAN/ESTOC), an oceanic station, sampling through two decades which has provided a historical set of data about physical and biogeochemical variables in the surface and mid-water ocean; a coastal observatory, a real time permanent observing system used as an instrumentation test site, and the extended observatory a mobile observational system carrying out missions at different geographical scales (e.g. gliders).

The management of observational data in an integrated manner will permit to focus on, upgrade and enhance the quality, quantity, projection and usefulness of such an integrated observatory. The data collected is expected to contribute to the understanding of factors affecting the ocean in key issues like climate change, acidification and circulation, among others.

Keywords: Observation, integration, test site, oceanic, coastal

1. INTRODUCTION

The Oceanic Platform of the Canary Islands (PLOCAN) is a public consortium to design and construct an offshore platform for research and innovation in the marine science and technologies, expected to be finished by 2015 (Figure 1).

Figure 1 Artistic drawing of the future ocean platform being constructed.

This fixed structure will be located in the Northeast of the Atlantic Ocean, and specifically at the eastern coast of Gran Canaria (Canary Islands, Spain) over 30m of depth and about 4 km from the coast.

PLOCAN is not only considered a platform, it is also an infrastructure for science and technologies. It aims to produce and make use of resources, generate specialised services, monitor and observe and finally provide training and outreach. Among the different areas of PLOCAN, the scientific and technological area takes care of the observational programme, which is done by three means.

This public infrastructure has inherited the mandate to operate the open ocean ESTOC (European Station for Time series in the Ocean Canary Islands) station at least until 2021. It has also been given the control of a coastal test site for testing instrumentation with a permanent observational programme, in order to guarantee the environmental conditions. Moreover, it counts on a base with different underwater vehicles and instruments, which makes a mobile extended observing system to complement the coastal and deep observatories. These three capacities make possible the integrated observationl in-situ programme of PLOCAN in the Canary Islands and surrounding environments.

2. INTEGRATED OBSERVATORY

PLOCAN intends to set up an integrated and complex observatory (Delory et al., 2011) aiming to become part of the emerging pan-European networks, offering an extension towards the southern boundaries of interest (Figure 2). It is formed by three components, i.e. deep, coastal and extended observatories, which complement each other to allow a regional observational programme.

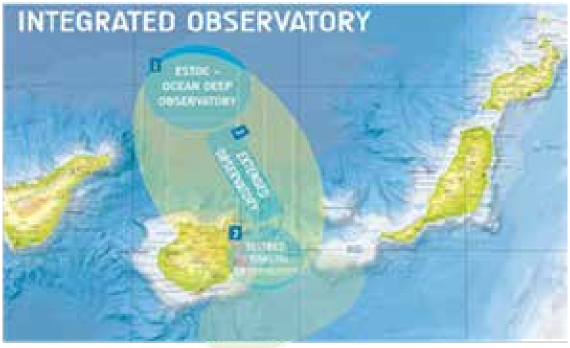

Figure 2 Geographic view of the integrated observatory showing only the extended portion of Gran Canaria Island.

2.1 Deep observatory

ESTOC is a deep open ocean station located at a nominal latitude of 29º 10'N and 15º 30'W of longitude; this observatory is located at a distance of about 60 nautical miles from the main islands of the archipelago and it has been in operation for more than 15 years (Neuer et al., 2006). Diverse measurements of physical and biogeochemical variables have been taken in-situ at the surface and in the water column along the years, either by means of moorings with diverse sensors, rosette with CTD (Conductivity, Temperature and Depth) casts or XBTs (Expandable Bathy-Thermograph).

Figure 3 shows the temperature and salinity variation during 7 years (1994-2011) of historical data collected by CTDs and microcats at ESTOC (on the left up and down). The CTD measurements show the variability of the intermediate waters (Mediterranean and Antarctic Intermediate waters), whereas the graphs to the right depicts data taken with microcats and the results are coherent with the CTD measurements. However, the increase in sampling provides higher resolution giving a more detailed mesoscale and submesoscale changes.

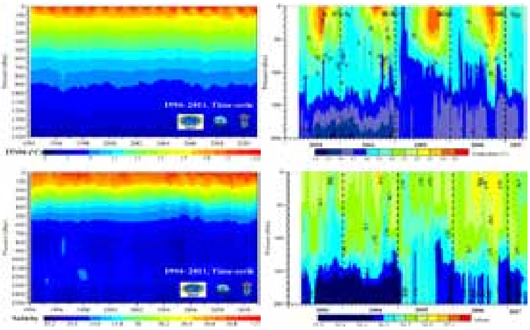

Figure 3 Left: Temperature (up) and salinity (down) from CTD to 1500m; right: the same parameters taken by micocats to 200m.

The ESTOC station is part of a group of deep ocean stations established by different countries in several oceans to study their variability. One of these stations is located at similar latitude but to the part of the Atlantic, which is known as BATS (Bermuda ATlantic Station) and managed by the NOOA (USA, National Oceanographic Operational Administration). As part of a comparative exercise for both sides of the Atlantic, diverse variables from both stations were plotted and compared for the same periods (Cianca et al., 2002, 2007). The information was gathered through rosette samples taken in-situ and analysed in the land laboratories.

Figure 4 portraits data from two biogeochemical variables, the chlorophyll “a” and nitrate down to 200m. The variability between the stations is similar and dependent on the inter-annual changes of both stations. The observations show that the deep chlorophyll maximum at ESTOC is deeper than at BATS, whereas the mixed layer is greater at BATS.

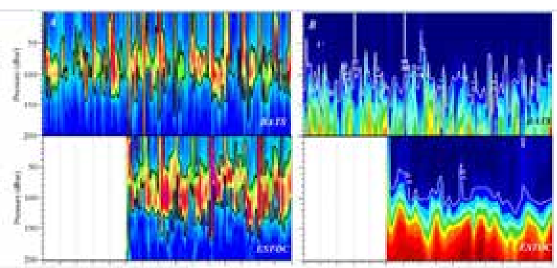

Figure 4 Left: Chlorophyll “a” from BATS (above) and ESTOC (below); right: nitrate from the same stations to 200m (extracted from Cianca et al.).

The last exchange of a mooring for data collection at ESTOC took place the 2nd of June 2014 (Figure 6), deploying an ODAS buoy to measure meteorological (Figure 5) and physical and biogeochemical surface data, including a mooring to collect mid-water variable in the water column. Data from the surface buoy is received on real time, whereas the records taken by the sensors framed in the mooring at 100m will be extracted in delayed mode. Real raw time data is shown via a portal for buoys in Macaronesia, the later being named after the biogeographical region where Canaries is located. Data is also quality controlled and verify against historical records obtained per year.

Figure 5 Graph extracted from portal shows the wind speed during a period of 7 months at ESTOC. Colours indicate daily minimum (green) and maximum (red).

PLOCAN/ESTOC site is also part of EMSO (European Multidisciplinary Seafloor & water column Observatory, http://www.emso-eu.org/). Furthermore, this observatory is part of the network of infrastructures involved in the FixO3 project (www.fixo3.eu), and participates in the calls for transnational activities.

2.2 Coastal observatory

PLOCAN has been granted a coastal area located to the east of the island of Gran Canaria (Figure 8) as a test site, which includes a total of 23 km^2. It is within this area where the physical PLOCAN infrastructure will be located. Construction of the platform itself as well as the different uses of the test site (e.g. testing ocean energy prototypes) makes necessary strict control of the changes in the environmental conditions to guarantee the ocean health in the area (Gonzalez et al., 2011).

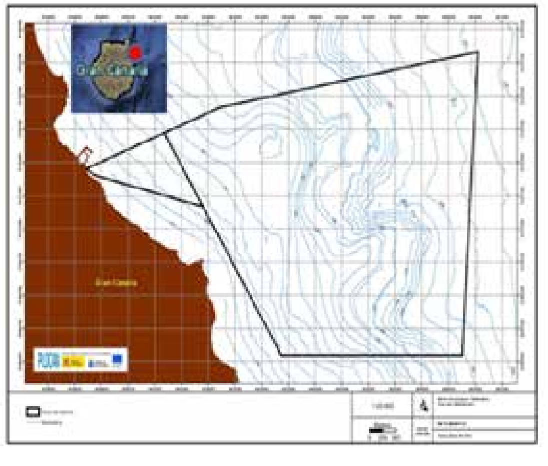

Figure 8 Test site enclosed in black line over batiymetry of the area located to the east of Gran Canaria Island.

With the aim to carry out the monitoring of this enclosed zone, a test site characterization programme is executed on a seasonal basis. Diverse ocean characteristics (e.g. metals, chlorophyll "a", oxygen, currents, etc.) as well as seafloor sediment quality (e.g. organic matter, PAHs, PCBs, etc.) are measured and analysed. Additionally, identification of biotic communities and ocean noise by means of hydrophones is also studied to detect possible impacts in the fauna and flora. This on-going process also includes a fixed buoy in the test area to have a continuous coastal observing system, which can also be used as an instrument test site.

2.3 Extended observatory

This is composed of all the observations provided by mobile observational systems, which carry out coastal, regional and global observation missions. Among them are included drifters, gliders or XBTs. An example is the programme carried out with the NOAA from USA to deploy NOAA drifters© at the ESTOC site since 1998 to study subsurface currents. More than 130 drifters have been deployed from the site, and the results have allowed

Figure 6 Picture taken after deployment the PLOCAN/ESTOC mooring (back) and the NOAA drifter© (front).

the characterisation of the station environment, providing seasonal and yearly variability. This NOAA programme still continues at present in a seasonal mode; the picture of Figure 6 shows the last one deployed just after finishing the mooring deployment at PLOCAN/ESTOC.

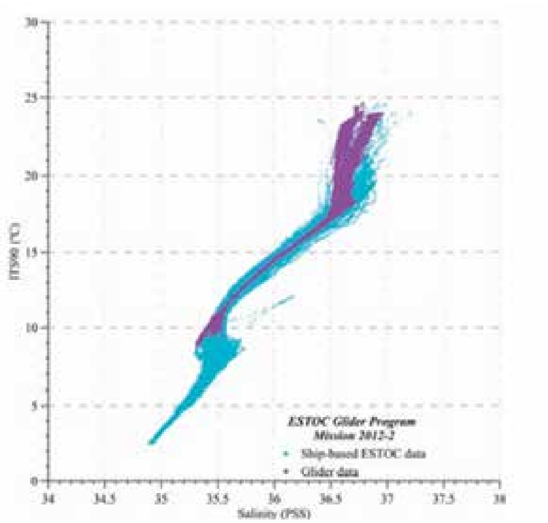

Figure 7 T/S diagram depicts glider mission from 2012 to 1000m (purple) superimposed over historical T/S data from ESTOC site (turquoise).

The gliders operate on a seasonal basis during 3-4 weeks missions, including the deep observatory and surrounding areas detailed sampling (Barrera et al., 2013). The trajectories of the missions and the raw data plots are provided in real time at http://gliders.plocan.eu.

Variables like salinity, temperature, currents, chlorophyll “a” or oxygen among others, are compared with historical data at ESTOC and quality controlled (Figure 7).

A line of XBTs down to 700m was done monthly between Las Palmas harbour and the PLOCAN/ESTOC station from 1996 to 2004. And this historical data has also permitted to make comparisons with the measurements taken nowadays by the gliders.

3. ON-GOING INTEGRATION ACTIVITIES

PLOCAN has been developing tools to carry out the quality control of the data coming from the different observation capacities, with the objective to obtain a data integration and to allow the comparison of the same parameters obtained by diverse means. An adaptation to the established distribution formats is currently being done, in order to fulfil the corresponding international standards for the European initiatives and projects.

The different platforms, i.e. base for underwater vehicles and instruments, test-side instrumentation and characterisation and the long-term oceanic time series station PLOCAN/ESTOC, permit to focus on, upgrade and enhance the quality, quantity, projection and usefulness of such an integrated approach to observe the ocean.

A new study on the different elements of buoys, moorings and sensors is currently taking place to optimize the PLOCAN/ESTOC buoy and mooring, being able to make use of smaller national ships and adapt it to transnational activities. The environmental buoy to include at the test site is also being completed, with the possibility to test new sensors. It is expected to purchase new gliders with updated instrumentation to optimize their missions.

The data collected expects to contribute to the understanding of the factors affecting the ocean in key issues like climate change, acidification, biochemistry, upwelling and Saharan dust affection, among others. An example of the need to have a continuous ocean observation is shown in Figure 9, where a buoy located at Tenerife recorded the drastic change of about 8 degrees Celsius in four hours of the air temperature, due to the Delta tropical storm the 28 of November 2005 (Barrera et al., 2014).

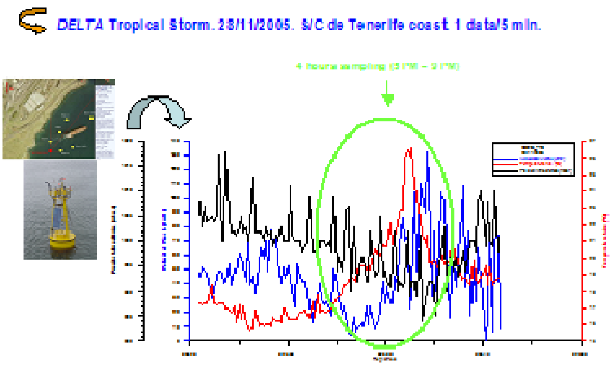

Figure 9 Great temperature change (green circle) due to Delta tropical storm recorded with an observational buoy (extracted from Barrera et al., 2014).

Acknowledgements

We want to acknowledge the invaluable work of a large number of scientists, technicians and ICT people who make possible the arrival, integration and quality control of the data from the three observing systems.

We are also indebted to all the crew members from the different ships used to collect this diverse information; they made possible all the different works carried out at sea, and without their valuable help we could not have obtained this amount of data.

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CORA4.1: A delayed-time validated temperature and salinity profiles and time series product.

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Abstract

The Coriolis dataset for Re-Analysis (CORA 4.1) is a comprehensive *in-situ* product provided by the French program Coriolis and supported by MyOcean2. The main purpose of this dataset is to provide validated temperature and salinity measurements from different platform types on the global scale and for the period 1950-2013 (Cabanes et al. 2012). XBT and CTD measurements covering the period 1950-1989 are extracted from the EN4 dataset and put to the CORA format. The measurements covering the period 1990-2013 are extracted from the Coriolis database. CORA4.1 stands out from CORA 4.0 since a better cooperation with the regional data centers and SeaDataNet have allowed to increase significantly the ocean sampling, especially in the shelf seas, in the European Seas and in the TAO/RAMA/PIRATA mooring zone. Smaller scientifically validated datasets are added to the CORA4.1 product in order to improve the space-time sampling and/or to update near real time validated measurements. The corrections applied on the XBT measurements of the CORA 4.1 product are estimated following the method by Hamon et al. 2012 and are consistent during all the covered period (1950-2013). The CORA 4.1 dataset is meant to be used for general oceanographic purposes, for ocean model validation and also for initialization or assimilation in ocean circulation models. The temporal extent allows to move towards the development and the study of long term trend indicators.

Keywords: Temperature and salinity measurements, delayed time data validation, data assimilation, operational oceanography

1. Introduction

The development of large ocean temperature and salinity datasets is a key issue in the evolution of modern operational oceanography and research purposes. Several datasets of this kind already exist, among which the EN4 dataset (Good et al, 2013) and the World Ocean Database (Boyer et al, 2009) are the most famous. CORA 4.1 is a global dataset providing temperature and salinity measurements from 1950 to 2013. Contrary to the other datasets, the CORA profiles are provided at their observed levels rather than interpolated at standard levels.

1.1 Updates from the version 3.4

Most of the CORA measurements come from the Coriolis database, which collects measurements from OceanSites GDAC, ARGO GDAC, GTSPP, ICES and Word Ocean Database from NODC. On the other hand, measurements from the SISMER, the SHOM (the French Service Hydrographique de la Marine), and the European data centers are collected by the SeaDataNet program. The measurements are aggregated with CORA within MyOcean 2.

The CORA 4.1 dataset is an updated version of the CORA products. Two successive updated versions of the CORA product have been deployed since the release of CORA 3.4 (Cabanes et al, 2012). The CORA 4.0 dataset covers the period 1990-2012, with the addition of measurements from high frequency moorings, surface drifters and thermo-salinographs. In addition to that, validation procedures have been updated (see section 2.1 for details). The CORA 4.1 release is an update of the CORA4.0 dataset with the addition of year 2013, the extraction of XBT and CTD measurements from the EN4 dataset (http://www.metofice.gov.uk/hadobs/en4/). The XBT measurements distributed in the CORA4.1 product are corrected with the method developed by Hamon et al, 2012.

Some specific datasets have been updated and validated by scientific teams. They have replaced their older version (see section 1.2 for details). All the other updated profiles extracted from the Coriolis database have been validated using the same method as the CORA 4.0 version. The quality checks (QC) of the profiles extracted from the scientifically validated datasets and EN4 database have been conserved. The QCs of the profiles already validated in version 4.0 have been carried forward in the CORA4.1 product.

1.2 Updated datasets

Among the scientifically validated datasets aggregated in the CORA 4.1 dataset, the sea mammals measurements dataset have a special interest. Sea mammals measurements are providing temperature and salinity observations measured by sensor glued on the head of sea mammals such as elephant seals (www.biology.st-andrews.ac.uk/seaos/, Roquet et al, 2013,2014). These animals migrate from small islands in the southern ocean to the coast of Antarctica, performing measurements in a region of sparse ARGO coverage (see fig 1 for a sampling of the sea mammal data coverage in 2012).

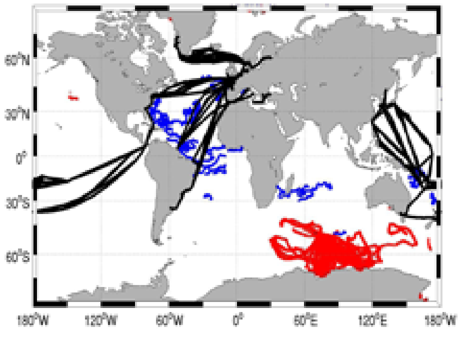

Figure 1 Position of sea mammals (red), surface drifters (blue) and TSG (black) measurements during 2012.

Another high quality product aggregated to CORA 4.1 is a surface drifter dataset provided by G.Reverdin from LOCEAN. This dataset gathers surface temperature and sometimes salinity measurements taken by sensor embedded in a surface buoy drogued at some depth. This dataset has been validated by the LOCEAN scientific teams (G. Reverdin, personal communication). It covers the period from 1996 to 2013.

Finally, a large dataset of temperature and salinity measurements by thermosalinographs (TSG) embedding in trans-oceanic cargos have been provided by the SO-SSS teams (Delcroix et al, 2005, www.legos.obs-mip.fr/observations/sss/). These measurements give observations along the ship tracks, providing regular cross-ocean transects along ferry lines and cargo tracks. The positions of sea mammals, surface drifters and TSG measurements during year 2012 are shown on Fig:1.

2. Data processing

2.1 Quality checks

The delayed time validation of the CORA products is based on a set of automatic and semi-automatic tests. Their list is given on table 1.

Name	Description	Automatic (A) or semi-automatic (S-A)
Measure on land	Check the presence of measurements on the land	A
Date check	Check that the date corresponds to the name of the file	A
Parameter range check	Check the consistency of temperature, salinity, pressure and depth	A
Ascending immersion test	Check that the pressure and the depth are increasing along the profile	A
Duplicated level check	Check that the immersion levels are not duplicated	A
Quality flag relevance	Control that a given QC is relevant with the associated measurement	A
Depth wrote in pressure field	Check that depth is not written in the pressure field	A
Duplicate profile	Detect duplicated profiles and delete those having the worse quality or the less meta-data	A
Climatological test	Check the distance from the climatology: $\lvert T_{CLIM} - T \rvert < 5 * \sigma_{CLIM}$ and $\lvert S_{CLIM} - S \rvert < 5 * \sigma_{CLIM}$	S-A
Spike check	Detect spot spikes on profiles	S-A
Assimilation feedback	Raise an alert on profiles that have a too strong innovation value when assimilated	S-A

Table 1 Name and description of the validation tests.

The automatic tests check measurements consistency and some obvious error (constant temperature/salinity among depth, measurement on land, etc...). The semi-automatic tests are designed to raise a warning on potentially erroneous profiles. Such measurements are then visually checked by an operator who validates or invalidates the quality check.

As an example, about 30% of the alerts raised by the climatological test are confirmed. We consider that most of the erroneous measurements are detected by this test (see Cabanes et al 2013 for details). The objective analysis feedback is another validation step based on the detection of profiles that produce a too strong residual in the objective analysis of the dataset. This test has been performed in the version 3.4 and 4.0 of the CORA products. Finally, the assimilation feedback is a post-release upgrade of the dataset based on the feedback from the data assimilation community on the previous version of CORA.

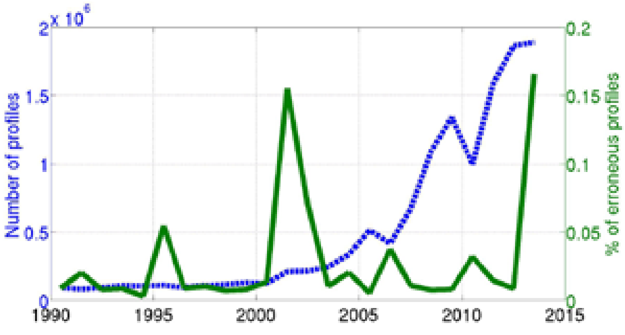

Figure 3 Number of profiles in CORA4.1 (blue) and percentage of detected erroneous profiles (green).

Figure 3 shows the variability of the number of profiles in the CORA4.1 product together with the percentage of detected erroneous profiles. The percentage of erroneous data is lower than 0.05% before 2013 and of about 0.15% in 2002 and 2013. Most of the QC corrections applied in CORA4.0 have been updated in the Coriolis database. This is due to the relatively low rating of correction before 2013. The 2002 spike is associated to a list of Bathythermograph measured profiles that have not already been updated in the Coriolis database at the time of the CORA4.1 extraction.

2.2 XBT bias corrections

Before 1990, a large part of the present dataset is composed of measurements from expendable bathythermographs (XBT). The XBT is a rocket-shaped instrument dropped into the water from a marching ship without slowing down. The temperature sensor is linked to the ship by a capillary wire and transfers the measured temperature while falling. It is then necessary to assess the falling rate of the XBT in order to assess the depth of the measurements. This falling rate non-linearly depends on temperature, salinity. There is an uncertainty of the correction method applied to the XBT profiles since the methadata of XBT profiles are often incomplete in the early period of XBT exploitation. As a consequence, Hamon et al, 2012 have developed a correction method based on the statistical fit of XBT measurements with accurate reference profiles.

In the CORA4.1 dataset, it is chosen to apply a correction, and to write the corrected temperature in an adjusted field apart from the original one, so one can still use the original TEMP quantity and apply his own correction. This XBT correction method is based on the work by Hamon et al. 2012. This method first applies a correction on the mean temperature offset in the upper layer, between XBT measurements and CTD measurements. Then, it applies a correction based on the computation of the quadratic regression of the mean depth error between XBTs and a local mean temperature measured by CTDs. The XBT measurements are separated into 2 categories: the shallow XBTs, with a maximal depth lower than 500 m, and the deep XBTs with a maximal depth lower than 500 m. These two groups are then divided into 2 sub-categories, the "Warm" XBT's, for which mean temperature between 0 and 200 m is higher than 8°C , and the "Cold" XBTs for which this temperature is lower than 12°C, the two categories overlapping for lowering the gap between the two corrections.

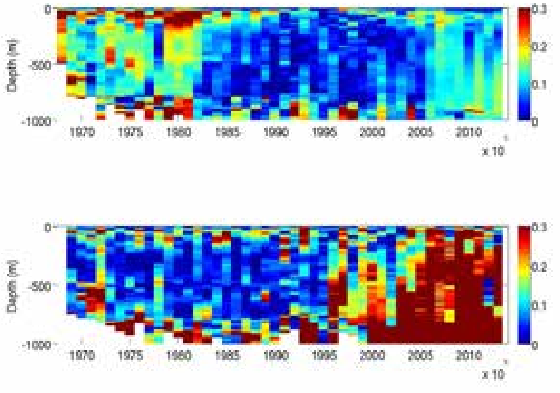

Figure 4 Absolute value of the difference between XBT profiles and reference CTD measurements before (top) and after (bot) the correction by the Hamon et al. (2012) method.

Figure 4 gives the difference between the XBT measurements and the reference temperature before and after the correction. It shows that before 1995, the expected error of adjusted temperature profiles is lower that the uncorrected temperature expected error. After 1995, the lower number of XBT measurements available and a better correction of real time datasets reduce the XBT measurement error and the efficiency of the method.

3. Applications for the products

A core strength of the CORA4.1 product is to provide temperature and salinity profiles covering a large part of the global ocean. Figure 5 shows the evolution of the number of 2×2 degree ocean grids sampled by at least one profile. It shows that the surface ocean sampling increases from 10% in 1950 to almost 80% in surface. This rate varies from 0% in 1967 to almost 80% for measurements acquired between 500 and 550m and between 0% in 1987 to over 50% for measurements taken between 1500 and 1550m depth. The sharp increase of the sampling rate observed in the early 2000 is obviously a consequence of the spreading of the ARGO program (www.argo.ucsd.edu).

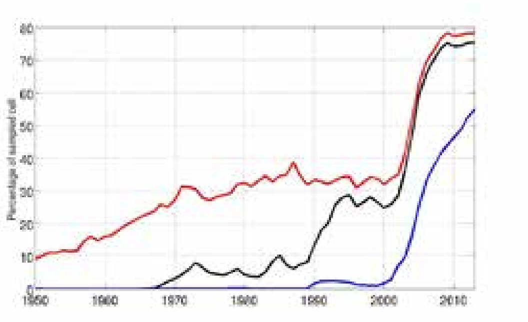

Figure 5 Percentage of 4 degree squares ocean cell sampled by at least one temperature sample between 0 and 50m depth (red), between 500m and 550m depth (black) and between 1500m and 1550m depth (blue).

The increase of the surface covered by the CORA4.1 product allows use of this product for research and operational applications such as data assimilation, climate studies or regional studies.

3.1 Data assimilation

One of the goals of the CORA product development is to produce validated datasets for initialization and assimilation of ocean models. As en example: Mercator products (Lellouche et al, 2012), and GLORYS (Global Ocean Reanalysis and Simulation project), Ferry et al, 2010, are global and regional ocean models based on the assimilation of temperature and salinity from CORA products.

3.2 Climate studies

Finally, the development of the ARGO program together with the production of large delayed mode datasets such as CORA4.1 allows the development of scientifical studies of large scales tendencies in the global ocean.

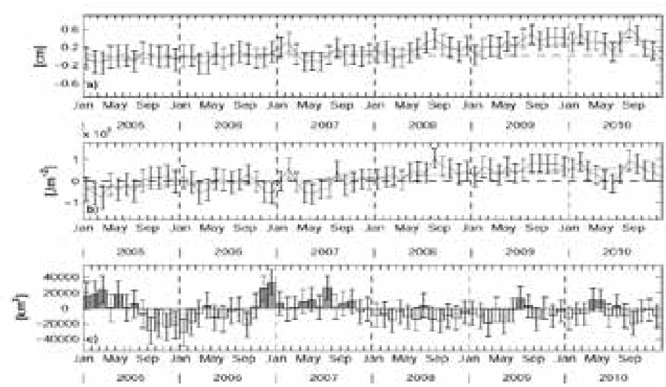

Figure 6 GSSL(a), GOHC (b) and GOFC (c), calculated by Von Schuckmann and Le Traon 2011.

As an exemple: Von Schuckmann and Le Traon 2011 have calculated Global Ocean Heat Content (GOHC), Global ocean Steric Sea Level (GSSL) and Global Ocean Freshwater Content (GOFC). See Figure 6 for an example taken from their manuscript.

4. Conclusion

The CORA4.1 product provides an upgraded version of the CORA dataset (Cabanes et al. 2012) covering the period 1950-2013. This product gathers delayed time validated measurements extracted from the Coriolis database. XBT and CTD measurements extracted from the EN4 dataset (http://www.metofice.gov.uk/hadobs/en4/) together with scientifically validated datasets are also aggregated to provide a high quality delayed time validated temperature and salinity dataset.

Acknowledgements

This work is part of the MyOcean, MyOcean2, MyOcean-FO and Coriolis projects. Additional observations are acquired outside MyOcean and especially by EuroGOOS ROOS institutes at European Scale . Historical products were built in partnership with SeaDataNet2 EU and EMODnet-Physics projects. The contribution from the EN4 dataset of the Met Office Hadley is gratefully acknowledged.

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PLOCAN: a gliderport infrastructure for the East-Central North Atlantic

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Abstract

The use of unmanned autonomous marine vehicles is becoming nowadays normality across world oceans. Significantly more affordable and sustainable than other observing platforms, UAVs, and more specifically underwater (AUVs) and surface (ASVs) gliders, represent a key new technological approach to increase ocean presence in a sustainable and cost-effective way and therefore, improve data quality and derived products in benefit to a wide range of socio-economic sectors related to marine and maritime fields. Gliders are already consolidated as key ocean observing tools for several reasons. A noteworthy variety of commercial models and prototypes developed on the same physical principle (buoyancy) for profilers (AUVs), and the use of marine energies (wind and waves) for the surface (ASVs) versions, offer a broad range of features and capabilities, allowing to monitor the oceans under new spatiotemporal scales due to higher reliability, endurance and affordability. The regular use of these autonomous devices implies dedicated infrastructures (gliderport) availability and highly qualified technical staff that enable such efficiency and sustainability of use. PLOCAN represents a prime example of faithful infrastructure, providing dedicated labs and workshops, equipment, staff and easily accessible operational scenarios addressed to test in a cost-effective and sustainable way new technological developments (test site), while offering highly specialized training through its international glider school for upcoming pilots and technicians under common standards and procedures as emerging job profile.

Keywords: gliderport, AUV, glider, ocean, robotics, training.

1. Introduction

In-situ ocean monitoring platforms (OOPs) technology provides nowadays a large number of options according to end-users needs and operational or budgetary circumstances. In general terms, OOPs are workspaces to accommodate staff (if manned) and/or dedicated payload equipment (manned and unmanned) at the study site and serve as field laboratories. The data collected by OOPs give to end-users the requested information (in many cases as dedicated products) in order to cover specific needs from a wide group of different socio-economic sectors, not only science-research, linked to marine and maritime fields (navigation, fisheries, aquaculture, leisure, tourism, safety and security, search and rescue, archeology, etc,) (Griffiths, 2012).

Despite ocean monitoring is still difficult and costly, current technological advances in key science disciplines (robotics, IT, science materials, electronics, etc.) bring in a permanent improvement way a huge range of options in terms of type, shape, depth capabilities, area of work, payload, telemetry, etc. on how to configure and operate an in-situ OOP (manned or unmanned, moored or drifting, remote or ship-based) in both coastal or off-shore areas.

The availability of such highly specialized observing platforms, allows increase, in a positive way, of data quantity and quality in temporary and special scales not available previously. However, for a safe, efficient and cost-effective management of these OOPs, it's more than necessary to have two important additional components: dedicated infrastructures and highly trained staff for each case and situation.

2. Plocan gliderport facility

The Oceanic Platform of the Canary Islands (PLOCAN) is a public consortium facility located in Gran Canaria (Las Palmas, Spain) engaged to promote long-term, deep-ocean and offshore science and technology activities in the marine and maritime sectors, through a cost-effective and sustainable multipurpose services combination as observatory, test site, underwater vehicles base (VIMAS), highly specialized training and innovation hub (Delory, 2011).

PLOCAN staff operates a wide range of underwater vehicles, with special focus on underwater gliders and ASV, since 2007 both on its own as well as in-partnership with flag-ship national and international technological base institutions and companies within the framework of national and EU projects, technological development cooperation and specific "on-demand" services.

Figure 1 The PLOCAN infrastructure concept (art layout).

More in detail, PLOCAN as a base for underwater vehicles, has and provides cutting-edge dedicated facilities as permanent operational infrastructure able to support a fleet of underwater vehicles (gliders, ROV and AUV) and multidisciplinary ocean observing systems; easy, quick and reliable open-ocean access (1000 m. in less than 5 Nm off); technical and logistical support for trials and operations in tanks, confined or open waters; multidisciplinary and sectorial technology partnership international cooperation with companies and institutions; labs, workshops, boats and control room for test, trials and repairs; highly specialized training program; location well connected by air and sea; etc. (Barrera, 2013)

Figure 2 Gliderport facilities overview.

2.1 PLOCAN Glider School.

The Glider School (http://gliderschool.eu) is a PLOCAN initiative framed within the current demand of new technical profiles on underwater robotics, and more specifically, ocean gliders. The main goal of the school is to provide the right technical and learning framework to potential end-users of these specific OOPs from different socio-economic sectors (private and public) related to marine and maritime fields, in order to bring a first theoretical and practical "touchdown" of existing glider technologies and rest of subsystem components payload.

The school has the direct support from a core group suited by main glider and marine sensors manufacturers, international experts from flag-ship institutions, showing to attendees the glider capabilities and applications, derived from their own background and expertise.

Didactical content refers to technology basics, mission setup, piloting, sea operations, maintenance and vehicle configuration according to end-user needs.

Figure 3 Glider ballasting facility as part of the wet-lab during a glider-school's practical session.

3. Ocean glider technology

From a purist point of view, ocean gliders have been (and still for some people) initially considered only underwater vehicles, leaving ASVs (autonomous surface vehicles) out of this designation. However, ASV are increasingly considered "gliders" as well due to the key contribution they play in different monitoring applications (Alvarez, 2012;)

Underwater gliders have enhanced capabilities, when compared with other drifting platforms like profiling floats, providing some level of maneuverability (piloting) and hence position control (once in surface). Gliders are buoyancy driven autonomous underwater vehicles able to perform saw-tooth trajectories from the surface to depths of 1000 m. (deeper versions are on their way), along reprogrammable routes using two-way communication via satellite (Davis, 2002; Osse, 2007; Testor, 2009; Brito, 2010; Manley, 2010).They achieve forward speeds of up to 40 km/day thanks to wings and rudders, and can be operated for a few months before they have to be recovered. Gliders can record physical and biogeochemical parameters during the dives. Even passive and active acoustic instruments have successfully been used.

At each surfacing, they connect to a computer on land via the bidirectional Iridium satellite phone system in order to send the data they collected and receive new commands from the operator inland, if necessary (at a rate of about 30-60Kbytes in 5 minutes every ~4-5 hours).

Gliders are considered to be less susceptible to damage from fish trawling than moorings and hourly/daily communication by satellite means that if a vehicle is lost or damaged the loss of data can be minimized. Replacing a glider is relatively easy and cheap compared to other OOPs operations at sea in this sense.

Figure 4 Underwater glider starting a downcast.

ASV or surface ocean gliders are a particular group of autonomous marine vehicles powered by renewable marine energies (wind and waves), able to carry on different payload sensor configuration for continuous and long-term and real-time monitoring of meteorological and oceanographic seawater parameters.

Figure 5 ASV or surface ocean glider.

Currently, both groups of vehicles, profilers and surface, are considered by the broad user community as marine gliders in general terms, due to its high sinergetic level.

4. The groom project

Compared with other OOPs, ocean gliders should be considered new generation platforms. However, based on their observing capabilities, the international user community, and more specifically users around Europe, consider it important and necessary to organize, in some way, a dedicated research infrastructure, in order to operate and manage efficiently and sustainably the large European glider fleet.

As a preliminary step before creating the desired ERIC (European Research Infrastructure Consortium), the EU Commission funded, in 2010 within the framework of FP-7 programme, a four-year project under the name of GROOM (Gliders for Research, Ocean

Observation and Management) with a consortium of 12 partners form 8 countries and led by UPMC (University of Pierre et Marie Curie).

Figure 6 GROOM project leaflet, showing number and distribution of potential European gliderport infrastructures.

The GROOM goal is to design a new European Research Infrastructure that uses underwater gliders for collecting oceanographic data. This new infrastructure shall be beneficial for a large number of marine activities and societal applications, which can be related to climate change, marine ecosystems, resources, or security and which rely on academic oceanographic research and/or operational oceanography systems. GROOM will define the scientific, technological, and legal framework of this European glider capacity as key project for building the required observatory network that would allow the Marine Strategy Framework Directive to be implemented. GROOM will develop in line with other European and international initiatives supporting marine in-situ observations, such as in particular Euro-Argo, JERICO, and GOOS.

5. Conclusions

The technology offers nowadays a broad number of platforms, sensors and systems for in-situ ocean observation. To handle all these new capabilities in a safe, efficient and sustainable way requires dedicated infrastructures and specialized technical staff. PLOCAN is a dedicated facility acting as a base for underwater vehicles and more specifically for ocean gliders. PLOCAN gliderport has and offers a fleet of gliders, dedicated logistics and skilled staff, able to support end-users needs regarding ocean monitoring. PLOCAN contributes through FP-7 GROOM project with the design of a European Research Infrastructure addressed to coordinate a gliderport network for a sustainable and efficient use of the European glider fleet in the future.

Acknowledgements

The authors truly acknowledge the Ministry of Economy and Competitiveness by the Spanish National Government and the Canarian Regional Government for funding the PLOCAN infrastructure. A special mention as well to the EU Commission for funding some projects within the FP-7 Framework related to ocean gliders, where PLOCAN is acting as partner. Finally, a special mention to all companies and institutions that, despite difficulties to put into operation this huge and pioneering technological infrastructure, have been and still are providing support for making it a reality.

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Operational Oceanography Products and Services for Maritime Industry

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Abstract

The ultimate goal of modern operational oceanography is an end user oriented product. Beneficiaries are the governmental services, coast-based enterprises and research institutions that make use of the products generated by operational oceanography. Direct users are coastal managers, shipping, offshore industry, ports and harbours, fishing, tourism and recreation industry. Indirect beneficiaries, through climate forecasting based on ocean observations, are food, energy, water and medical suppliers. Availability of updated information on the actual state as well as forecast of marine environment is essential for the success and safety of maritime operations in the offshore industry. Several systems for the collection and presentation of marine data for the needs of different users have been developed and put in operation in the Bulgarian sector of Black Sea. The systems are located both along the coast and in the open sea and the information they provide is used by both the maritime industry and the widest range of users. Combining them into a national operational marine observational system is a task that has to be solved, and that will allow to get a more complete and comprehensive picture of the state of the marine environment in the Bulgarian sector of the Black Sea.

Keywords: observing systems, Black Sea

1. INTRODUCTION

The ultimate goal of modern oceanography is an end user oriented product. Beneficiaries are the governmental services, coast-based enterprises and research institutions that make use of the products generated by operational oceanography. Direct potential users and customers are coastal managers, shipping, offshore industry, ports and harbors, fishing, tourism and recreation industry, and scientific community. Indirect beneficiaries, through climate forecasting based on ocean observations, are food, energy, water and medical suppliers. Five general classes of users for data and information are specified: (1) operational users that analyze the collected data and produce different forecasts serving to impose regulation measures; (2) authorities and managers of large-scale projects needing timely oceanographic information, including statistics and climatic trends; (3) industrial enterprises, safety of structures and avoiding of pollution; (4) tourism and recreation related users aiming at the protection of human health; (5) scientists, engineers, and economists carrying out special researches, strategic design studies, and other investigations to advance the application of marine data. The analysis of information received during the extensive inquiry among all potential end users reveals a variety of data and information needs encompassing physical, chemical, biological and hydrometeorological observation. Based on our experience the most requested marine characteristics are: sea state (wind, waves and currents), sea level and environmental status. Nevertheless, the common requirement concerns development of observing and forecasting systems providing accurate real-time or near-real time data and information supporting decision making and environmental management (Slabakov *et al.,* 2006).

2. MARINE DATA AND INFORMATION SYSTEMS

As a one of the major users of marine data and information the marine industry extensively needs both real-time data and forecasts. Several observing systems were developed to respond to this demand which include the Bulgarian Black Sea coast as well as the Black Sea as a whole. The systems cover both coastal zone and offshore and provide the essential for the maritime industry marine variables.

2.1 Bulgarian Black Sea Monitoring Programme

Bulgarian Black Sea Monitoring Programme was established to provide an accurate description of the present state of the Western part of the Black Sea, provide analysis and forecasts of the sea state, and set the basis for climate and environmental predictions. The programme started in 1991 with sampling a net of stations planned to cover both coastal zone and the open sea. Main goal of the monitoring programme is to collect reliable data and to provide relevant information to the governmental agencies for taking decisions for protection and recovery activities and that are related to the sustainable development of the coastal zone and Bulgarian part of the Black Sea. As an element of the Global Ocean Observing System, Bulgarian Black Sea Monitoring Programme is a permanent system for observation and analysis of marine variables to support operational ocean services (Palazov *et al.,* 2007).

The main goal of the monitoring programme is to collect reliable data and to provide relevant information to the governmental agencies for taking decisions for protection and recovery activities and related to the sustainable development of the coastal zone in the Bulgarian part of the Black Sea, which affects not only the environment but also the social sphere and economics. The monitoring scheme is planned to cover both coastal zone and the main part of the Bulgarian Black Sea Exclusive Economic Zone, thus a net of sampling stations was established, assuring sufficient information for analyses and predictions. The monitoring scheme is shown in Figure 1.

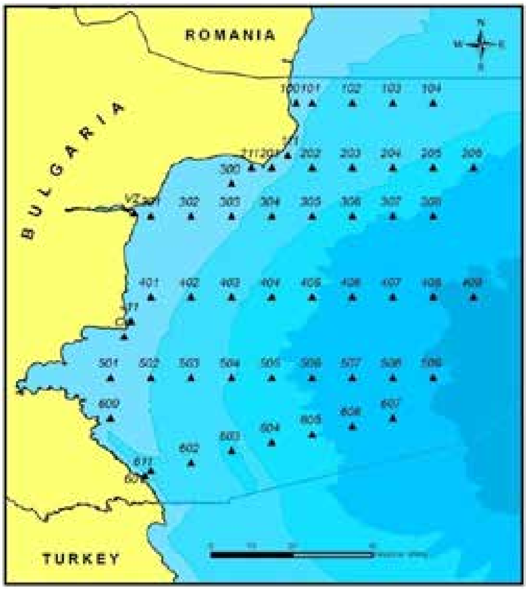

Figure 1 Monitoring scheme

The monitoring programme includes measurement of physical, chemical and biological parameters including: air pressure and temperature, wind velocity and direction, sea water temperature and salinity, transparency and sea water color, dissolved oxygen, pH, hydrogen sulfide, phosphate, nitrite, nitrate and ammonia N, chlorophyll-a, phytoplankton, zooplankton, zoobenthos and macrophytobenthos. The main activity consists of carrying out of one or more CTD casts. Additionally, water samples and/or zooplankton and benthos samples are taken for chemical and biological analyses.

Collected data passes quality control (QC) and quality assurance (QA) procedures according to the international recommendations. Dataset is properly described and documented.

Bulgarian Black Sea Monitoring Programme becomes a sustainable permanent system for observations which provides background information needed for analysis of the sea state, modeling marine variables to support operational ocean services in the Western Black Sea.

2.2 GALATA

A pilot open sea monitoring project was initiated by the Bulgarian Institute of Oceanology and completed in the frame of public-private cooperation between the Institute of Oceanology and gas exploration company Melrose Resources Sarl. The project targets specific elements of regional monitoring system and the development of end-to-end observing capabilities providing internet access to both real time and historical data.

The Galata platform is a fixed, earth gas production platform, owned and operated by a private gas company Petroceltic Sarl. The platform is located in western part of the Black

Sea on the Bulgarian shelf (34 m depth) 26 km east from the city of Varna. The map of platform position is shown on Figure 2. The observing system is designed to collect data with minimum components and to maximize the use of existing facilities. It consists of a measuring system located on the platform, communication system and onshore control and operational centre.

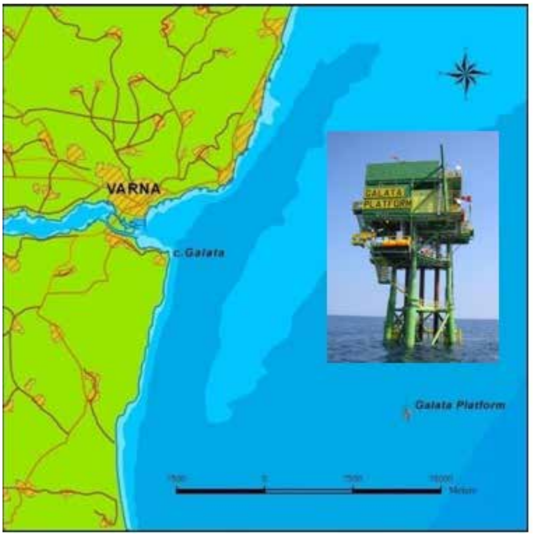

Figure 2 Location of GALATA platform

The measuring system, placed on the platform, consists of 24 sensors distributed in two main groups: meteorological sensors (wind speed, wind direction, air temperature, relative humidity, air pressure , net radiation, visibility) and oceanographic sensors (dissolved oxygen, conductivity, turbidity, water temperature, fluorometer, temperature string-10, doppler current sensor, wave & tide recorder).

There are two data acquisition devises used. One of them collects data from meteorological sensors and part of the oceanographic sensors with samples rate of five minutes. It has 30 channels 27 of which are used and 3 are spare for further use. The second one collects data from wave and tide sensors with samples rate of thirty minutes. It performs data pre-processing and calculates wave parameters (significant wave height, maximum wave height and mean zero crossing period). Thus 31 major oceanographic and meteorological parameters are measured.

Data management provides procedures and technologies to make the processes from data collection to information delivery to the end users smooth and to secure unbreakable functioning of the whole system. Collected data is transmitted to the shore by wifi communication system every five minutes, with the exception of wave and sea level data, which are measured and transmitted every half hour. Data is stored in a central server data base of the Bulgarian National Oceanographic Data Center (BGODC). A WEB interface to database was developed to provide the end users easier access to data.

Galata platform real time data is one of the most important sources of multi-parameter operational information in the Black Sea which serves for monitoring, verification and improvement of modeling results and forecasts, as well as for collecting long time series of data needed for climatic research. It also provides useful real time information for the marine industry and for safety (Palazov *et al.,* 2007-2).

Port Operational Marine Observing System

The Port Operational Marine Observing System (POMOS) is a network of distributed sensors and centralized data collecting, processing and distributing unit. The system is designed to allow for the real-time assessment of weather, marine and environmental conditions throughout the major Bulgarian ports, channels and bays (Palazov *et al.,* 2010). The system architecture is shown in Figure 3.

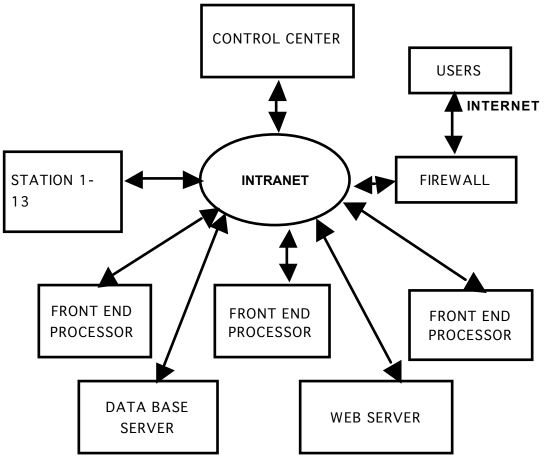

Figure3 POMOS architecture

POMOS includes three main components: measuring stations, communication system and control center. The backbone of POMOS is an integrated system of different types of measuring stations installed at thirteen strategic locations along the Bulgarian Black Sea coast, equipped with a variety of sensors for monitoring the current state of the environment, which measure their data in operational mode as well. The system is designed to monitor 13 important marine navigation oceanographic parameters. POMOS is composed of three main types of measuring stations, which are as follows:

- Eleven weather stations, equipped with instruments for continuous observations of the local weather conditions.
- Seven shore-based hydro stations containing the sea surface water temperature and salinity sensors and highly accurate microwave remote sensors, which provide sea level information. Moreover, two hydro stations located in Varna and Beloslav canals are equipped with two-beam, horizontally oriented Acoustic Doppler Current Profilers (ADCP) which allows obtaining data for currents velocity and direction along the whole width of the canals.

- Two underwater polygons situated in Varna and Burgas bays are equipped with the three – beam vertically oriented ADCPs, providing information for vertical profiles of currents, wave period and significant wave height, water temperature and salinity.

The Data Management System (DMS) used in development of POMOS is designed around a centralized approach to data acquisition, processing, storage, quality control and distribution tasks. The main idea of the DMS is to use retransmitted, over TCP data streams, from RS232 ports of standard metrological and oceanographic instruments to the central real time acquisition software installed on the front–end processors. This approach ensures feedback between control centre and measuring stations for appropriate adjustment, reconfiguration, monitoring and testing of equipment which its company supplied software after installation.

Tailored to the specific needs of the Bulgarian ports, POMOS measures, integrates, disseminates and displays observations of the main weather and sea state parameters in real-time, which support decision- makers for the adequate and timely actions related to ensuring the safe navigation and efficiency of maritime transport. On the other hand, POMOS is a valuable source of the multi parameter operational information in the Black Sea that could be used for oceanographic, coastal and climatic researches, as well as for improvement and verification of the regional models and forecasting. The information generated by the system is also useful for the tourism and recreation industry as well as for sea sports and the general public. The system could be expanded and improved to meet other applications such as ecological monitoring.

2.3 BulSeaL

Systematic sea level measurements started in Bulgaria at the beginning of 20th century and nowadays there are 16 coastal sea level stations in operation (Palazov, 2013). Operators of sea level stations (Figure 4) are: National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences (NIMH) – 6 stations, Cadastre Agency, Ministry of Regional Development (CA) – 4 stations and Institute of Oceanology, Bulgarian Academy of Sciences (IO-BAS) – 1 station plus 5 - PI stations.

Six of them are able to provide real time data. The sea level observations in the network of NIMH, performed at six main Bulgarian ports using standard poles, started in 1910. The program, implemented on the NIMH stations, includes daily measurements of the sea level with water gauges (poles). The position of a zero mark of the water gauge is checked once per year. The sea level network of the CA consists of 4 stations: Varna and Burgas (operational since 1928), Irakly and Ahtopol (since 1971). These stations are equipped with stilling-well tide gauges and with mechanical writing devices which draws sea level changes on paper. Mechanical paper writing instruments were installed in Varna and Burgas during 1928 and in 1971, a new paper writing instrument of type SUM (Russian) was installed in the stations of Irakly and Ahtopol.

Figure 4 Bulgarian sea level measuring stations

A set of five sea level stations in the ports of Balchik, Varna west, Pomorie, Burgas and Oil port Burgas was built during 2009 in the frame of Port Operational Marine Observing System, equipped with high accuracy microwave instruments (PI) and operated by IO-BAS. In 2010 a new sea level station was set up in the IO-BAS coastal research base Shkorpolovtci. The station is equipped with high accuracy microwave instrument. These six stations are providing real time data.

According to the decision of the Council of Ministers in 2012 sea level stations in Varna, Irakly, Burgas and Ahtopol will be operated jointly by Bulgarian Academy of Sciences and CA. Total modernization is planned to make these stations able to produce real time data.

In 2012 high accuracy microwave instruments able to provide real time data were installed at Port Varna and port Burgas. They will perform parallel measurements with the mechanical writing devises in the same places in order to ensure interoperability of new data with historical records.

2.4 MARINEGEOHAZARD

MARINEGEOHAZARD project means “Set-up and implementation of key core components of a regional early-warning system for marine geohazards of risk to the Romanian-Bulgarian Black Sea coastal area”. It is part of the Bulgaria-Romania Cross-border cooperation program Romania-Bulgaria 2010-2013, co-financed by the European Union through the European Regional Development Fund. Bringing together the expertise of the two countries – Bulgaria and Romania, the MARINEGEOHAZARD project aims for the establishment of a joint regional early-warning system and of a common decision tool, which can support in an efficient manner the emergency managers and decision makers in their activity related to protection of the local communities, environment and assets within the cross-border area, from consequences of natural marine geo hazards. This is a first attempt in this area and brings risks with such an innovative approach (Ranguelov *et al.,* 2011).

The general objectiveσ of the project are the implementation of an integrated early warning system accompanied by a common decision-support tool, and enhancement of regional technical capability, for the adequate detection, assessment, forecasting and rapid notification of natural marine geo hazards of risk to the Romanian-Bulgarian Black Sea cross-border area.

According to the work plan of the Project, several systems are integrated in unified clusters of different equipment which are located on Romanian and Bulgarian territory and sea providing information for the two data centres (in Varna and Constanta). These systems are intended to work simultaneously and to provide data to the data centres. The communication systems are using satellite links, INTERNET, radio and telephone lines. The duplication of the centres provides safety and secures data transfer. In case of a major disaster the chance of both systems being destroyed is practically nullified.

The marine part of the system include five moorings: tree in Romanian and two in Bulgarian waters (Figure 5). Each mooring consist of two parts: surface buoy and bottom tsunami meter both equipped with acoustic telemetry. Both of them can be released from the anchor by acoustic releaser. On the surface buoy a set of instruments is installed including: weather station (temperature, relative humidity, wind speed, wind direction, and barometric pressure); chlorophyll sensor, oceanographic instrument (pressure, temperature, conductivity, oxygen, turbidity and current); electronic compass; GPS receiver and IRIDIUM modem. Measured variables are transmitted from the mooring to data centers using satellite communication.

Figure 4 Location of moorings in north-west Black sea

Specially designed software collects, processes and stores marine data from the moorings in two identical databases located in data centers in Varna and Constanta where they can be displayed, processed and used.

3. Data management

Fundamental elements of the success of the marine data and information management system and an effective support of marine and maritime economic activities are the speed and the ease with which users can identify, locate, get access, exchange and use oceanographic and marine data and information. There are a lot of activities and bodies that have been identified as marine data and information users, such as: science, government and local authorities, port authorities, shipping, marine industry (including offshore industry), fishery and aquaculture, tourist industry, environmental protection, coast protection, oil spills combat, search and rescue, national security, civil protection, and general public. On the other hand diverse sources of real-time and historical marine data and information exist and generally they are fragmented, distributed in different places and sometimes unknown to the users. There are several concepts and technologies developed and used to collect, process, display and provide oceanographic data and information to different users (Stefanov *et al.,* 2007, Stefanov and Palazov*,* 2010) but the common approach is marine web portal. The marine web portal concept is to build common web based interface which will provide users fast and easy access to all available marine data and information sources, both historical and real-time such as: marine data bases, observing systems, forecasting systems, atlases etc. The service is regionally oriented to meet user needs. The main advantage of the portal is that it provides a general look “at glance” on all available marine data and information as well as directing user to easy discover data and information of interest. It is planned to provide personalization ability, which will give the user instrument to tailor visualization according its personal needs (Palazov *et al.,* 2012).

4. Nomos an integrated observing system

The Bulgarian National Operational Marine Observing System (NOMOS) is a system of systems designed to allow the real-time assessment of weather and marine conditions in the coastal, shelf and open sea areas of the western part of the Black Sea. NOMOS consists of several independent subsystems: both coastal (POMOS, BulSeaL) and offshore (Galata, MARNEGEOHAZARD, BG Monitoring) (Palazov *et al.,* 2012-2). These subsystems are built for different goals, cover different regions and are targeted to serve different users. They collect real time data using various instruments and sensors placed at different strategic locations. All instruments are connected to communication systems via intranet or internet which provides direct access to the sensors. The measured data is transmitted to the central collecting unit, where the information is processed and stored in database. Access to database is through internet/intranet with the help of browsers. Actual data is controlled by Data Management System and can be displayed on the computer screens using report server supporting thereby the needs of different groups of users.

Thus NOMOS is a system of systems designed to allow real-time assessment of weather and marine conditions in the coastal, shelf and open sea areas of the western part of Black Sea for wide user community. The system includes the all existing subsystems. Integration of the systems is on data and dissemination level. NOMOS architecture is shown on Figure 5.

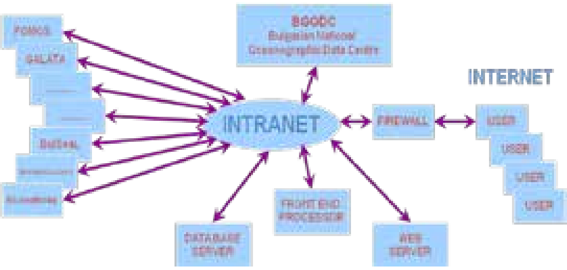

Figure 5 NOMOS architecture

The main goal of NOMOS is to support sustainable development of the Bulgarian Black Sea coast and EEZ, and the main task is to provide operational information for the needs of: national security, civil protection, search and rescue, government and local authorities, port authorities, shipping, marine industry, fishery and aquaculture, tourist industry, environmental protection, coastal protection, oil spills combat and other interests. NOMOS real time data is one of the most important sources of multi-parameter operational information in the Black Sea which will serve for monitoring, verification and improvement of model results and forecasts as well as for collecting long time series of data needed for climatic research, marine physics, chemistry and biology. Free real time data access and developed user friendly WEB and WAP interfaces make the system useful not only for science, marine industry and governmental agencies but also for the general public, especially for fishermen, yachtsmen and windsurfers.

5. Conclusions

NOMOS is a national research project undertaken in cooperation with other EU partners. One of the major applications of the POMOS will be to provide information support to the maritime industry. A WEB centric oceanographic data management system was developed. To provide an encompassing solution the project focusing on the following contributions:

- Central access points to a suite of services tailored to users needs for a range of time-critical tasks built on a generic software platform;
- WEB centric communication system ensuring flexible and operative infrastructure for data and information exchange between partners and end users;
- A managed reporting environment that defines security, caching, distribution, access, and usage reporting, while a single, integrated tool –set allows to manage centrally, the development and delivery of reports;

- GIS data are available on the Web without changing the existing data workflow i.e. how the data is created, maintained, and used by desktop applications. GIS data are kept in its native format without translation or having to maintain yet another copy of that data;
- Prepare necessary organizational, technological and technical prerequisites for integrated and operative Black Sea observing system;
- Uphold European competitiveness in ocean monitoring according to the GOOS and Black Sea GOOS strategic objectives;
- Website has been matured as a prime vehicle for delivery of NOMOS data, information and advisory services

6. LESSONS LEARNED

The main lessons learned during development of NOMOS are:

- To build NOMOS, we need clear strategy and argumentation for funding and development;
- NOMOS should be user driven and should provide useful operational data and information in understandable form;
- NOMOS should be flexible, open for further development, connectable to neighbouring systems and designed and built according international standards.

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Phytoplankton biomass distribution in water column and sediments in the northern Latium coastal area.

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Abstract

Coastal waters represent the 29% of the net primary production and the 40% of carbon sequestration, while constituting only a small fraction of natural waters. Coastal waters have a high economic, social and ecological relevance; whereby the knowledge of the phytoplankton has a key role in the dynamics of the marine ecosystem.

The purpose of this paper is to analyze the variability of the phytoplankton biomass in the Northern Tyrrhenian coast in response to atmospheric and oceanographic forcing.

The implemented observing system integrates data collected by fixed stations, field surveys, satellite imagery and reanalysis data. In particular the seasonal variability of winds was analyzed both through the European Center Medium Weather Forecast (ECMWF) and Civitavecchia weather station data. An oceanographic buoy, moored 1 mile offshore the port, and two fixed coastal station, allowed to acquire and record ecological time series.

Different field surveys were carried out between August 2012 and September 2013; both chemical, physical and biological vertical profiles and Acoustic Doppler Current Profiler (ADCP) profiles were acquired.

During August 2013, sediment cores were collected for chlorophyll a measurements using an Uwitec gravity corer. The study showed that the coastal area is strongly influenced by atmospheric forcing, which contributes predominantly to the seasonal distribution of phytoplankton biomass. During the summer season the sea-breeze events control the biological activity of phytoplankton biomass.

Keywords: multi-platform approach, atmospheric forcing, coastal dynamics, phytoplankton dynamics

1. Introduction

Coastal waters represent only a small fraction of natural waters around the planet, but they have a high economic, social and ecological relevance.

These are regions of high biogeochemistry activity (Gattuso et al., 1998); consequently, the coastal areas are a valuable biome for ecosystem services (Costanza et al., 1997), supporting both the population and human activities. (Walsh, 1988; Chen, 2010)

Coastal areas represent 29% of the net primary production (Ducklow and McCallister, 2005), 40% of carbon sequestration in marine sediments (Muller-Karger et al., 2005; Arrigo, 2005) and also represent a significant component of the carbon and nutrient cycle (Falkowski et al., 2000; Liu et al., 2010).

The knowledge of the phytoplankton therefore has a key role in the dynamics of the marine ecosystem because it is the lowest level of the food chain.

Phytoplankton strictly depends on the light and nutrients; indeed the spatial separation between the light (surface) and nutrients (increasing under the pycnocline) limits the primary production in the ocean. Therefore, the phytoplankton is strongly affected by the physical processes, which tend to generate the optimal conditions for the growth and development. In addition the physical processes on the ocean surface are strongly coupled to the phytoplankton dynamics (Dickey, 1991); especially synoptic weather events as observed in other studies (Marra et al, 1990; Largier et al 2006).

In this context, greater importance has been given to the safeguard of coastal ecosystems, which are particularly sensitive to climate change and human impact; consequently, they need to undergo time series observation programs (i.e. The Long Term Ecological Research Network, L-TER) and monitoring activities as proposed by Marine Strategy Framework Directive (2008/56/EC).

The integration of the monitoring activities of the historical series is recognized as a priority in national and international scientific programs to better understand how marine ecosystems change. So the multi-platform approach for the coastal environment monitoring allows to highlight the changes in marine ecosystems, identifying specific trends in their natural evolution.

The purpose of this paper is to analyze the seasonal and summer variability of phytoplankton biomass in response to atmospheric and oceanographic forcing, with different measurement platforms along a coastal area.

2. Materials and method

2.1 Study area

The coastal area of Civitavecchia is an example of a coastal ecosystem affected by multiple human activities as one of the biggest European harbors, a power plant and aquaculture plants.

The study area is located in the Northern Tyrrhenian Sea, eastern margin; enclosed on the physiographic units extended from Argentario Mount to Capo Linaro (La Monica e Raffi, 1996; Brondi et al 1996).

The circulation of Tyrrhenian basin is affected by mesoscale and seasonal variability (Hopkins, 1988; Pinardi and Navarra, 1993; Vetrano et al. 2010). The Tyrrhenian dynamics show a cyclonic circulation with a very pronounced barotropic component.

The importance of the barotropic component in the Tyrrhenian circulation suggests that the wind plays a key role as forcing agent (S. Pierini, and A.Simioli 1998, Bakun 2001) in coastal circulation.

The mean coastal currents are supposed to be a part of the large-scale thermohaline driven circulation of the western basin of the Mediterranean Sea, and they are thought to flow along the West coast of Italy towards the North-West, with a speed of around 5 cm/s (Elliot 1980).

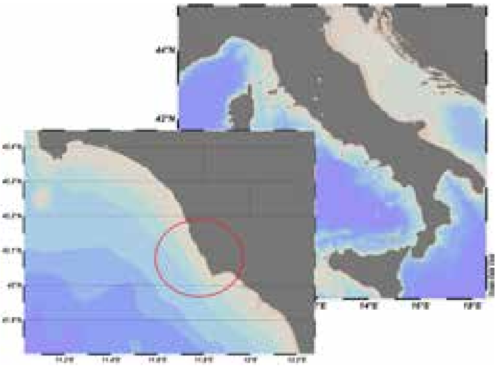

Figure 1 Study area

2.2 Meteorological data

To understand the synoptic atmospheric circulations the ERA-INTERIM (ECMWF) data were analyzed. Moreover real time meteorological data acquired by the Port Authority weather station placed within the Civitavecchia harbor which measures wind speed and direction, atmospheric pressure, temperature, relative humidity and solar radiation.

2.3 Sea water data

An oceanographic buoy, moored 1 mile offshore the port, and two fixed coastal stations, equipped with a multiparametric probe allowed to acquire and record long time series (temperature, conductivity, dissolved oxygen, turbidity and chlorophyll a fluorescence).

Field surveys were carried out Between August 2012 and September 2013; both chemical, physical and biological vertical profiles and Acoustic Doppler Current Profiler (ADCP) profiles were acquired.

During summer period high resolution yo-yo time-series were performed in order to understand the water column variability in response to the breeze circulation. They were performed with a multiparametric probe during August 2012.

In each station seawater samples were collected to analyze chlorophyll a (chl_*a*) concentration according to the spectrophotometric method (Lorenzen, 1967, Lazzara et al, 1990), using a Shimadzu spectrophotometer UV mini 1240 model.

On August 2013 sediment cores (approximately 20 cm length) were collected by a Uwitec gravity corer to analyze chl_*a* concentration. The top 10 cm of each core were cut at 1 cm interval and so were obtained 10 sections for each core. For each section chl_*a* and pheopigment contents were analyzed by spectrophotometric technique.

Maps of surface chl_*a* a and temperature were generated daily. Satellite data for this work were from MODIS sensor.

The satellite Acqua, orbits daily on our interest area in a ranging time from 12:00 am to 13:00 am. Seventy-nine days, between August 2012 and August 2013, were processed, using the Med OC3 algorithm.

2.4 Data analysis

The atmospheric data recorded by weather stations were analyzed in order to detect the wind speed and wind directions frequencies (Figure 2).

Satellite data (www.oceancolor.gsfc/nasa.gov) are processed through the software Seadas 6.

Satellite data were represented in iso-surface form through the use of ODV software (Ocean Data View 4.6.2, Alfred-Wegener-Institute for Polar and Marine Research).

Wind speed, sea temperature and chl_*a* data, recorded by fixed stations, (Figure 9) were detrended using a linear fit and multiplied by Hanning window to compute power spectra. Similar procedures were used for coherence and phase calculations between wind speed, Chl_a and water temperature data. Statistical significance in coherence was calculated with the Goodman formula using the same methods as Woodson et al. (2007).

3. Results

3.1 Annual variability

A monthly analysis of the distribution of wind directions between 2008 and 2013 was performed, the graphs (Figure 2) show that the predominant winds are those from N and SE. Instead the summer period is characterized by a different anemometric regime, especially in August, identified by a cyclical daily oscillation.

The alternation of this kind of atmospheric circulation at seasonal scale with northerly and southwesterly winds, strongly affects the coastal dynamics and can generate upwelling and downwelling phenomena.

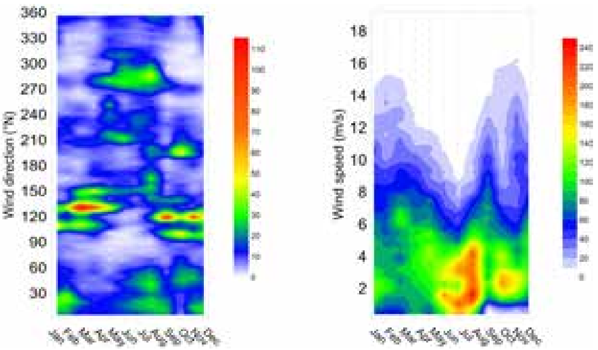

Figure 2 Wind speed and wind direction frequecies from Civitavecchia weather station (2008/2013)

Figures 3 shows wind speed and direction frequencies acquired and processed during this kind of events occurred during the surveys.

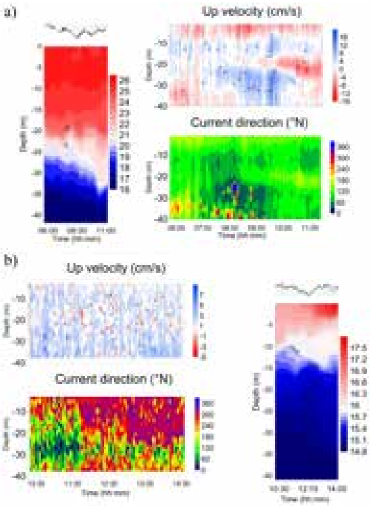

Figure 3a b: ADCP and Temperature time-series collected at 40m deep, during downwelling (a, 04/09/2013) and upwelling (b, 03/09/2014) favorable winds.

It is possible to observe (Fig 3a) how in the presence of southerly winds, occur both a heating of the whole water column and a surface transport in the direction of the coast, which is typical of coastal downwelling condition.

Instead, in the presence of a northerly wind (Fig 3b) there is an offshore surface transport and an onshore bottom transport, with a decrease in water temperature which affects the whole water column. This condition is typical of coastal upwelling.

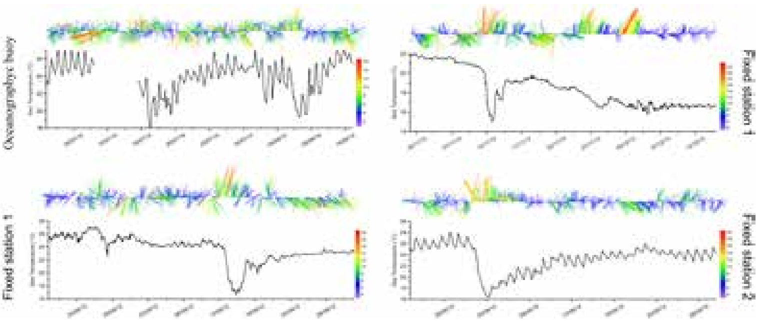

Figure 4 Time series of sea temperature and wind field

The analysis of time series recorded by the fixed stations (Fig 4) highlights a water temperature decrease which occurs together with the upwelling favourable winds.

The analysis of time series recorded by the fixed stations (fig 3) highlights a water temperature decrease which occurs together with the upwelling favourable winds.

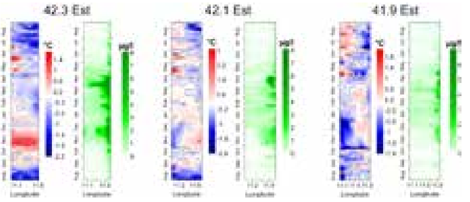

Figure 5 Hovmöller diagram based on August 2012-August 2013 satellite data analysis in three different sections of study area

Water temperature and wind field analysis show that in the presence of northerly winds a cooling of the temperature is more frequent. The temperature decrease observed by the fixed stations is confirmed by satellite images analysis (Figure 5). The Hövmoller diagram shows both temperature anomaly and chl_*a* variations obtained by satellite data in the period between August 2012 and August 2013 and represented in three longitudinal sections (Figure 5).

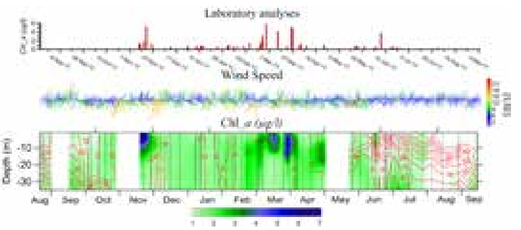

Figure 6 On top: Chl_a by laboratory analysis; on bottom annual distribution of temperature (red line)and phytoplankton biomass (colour scale) between August 2012 and September 2013

The higher values of chl_a occur between October and May; during the year the coastal surface chl_*a* concentration rarely presents values less than 0.5 μg/l.

During, September, October, February, March, May and June chl_*a* shows the highest values. The summer season shows the highest values of chl_*a* below the thermocline that persists throughout the period.

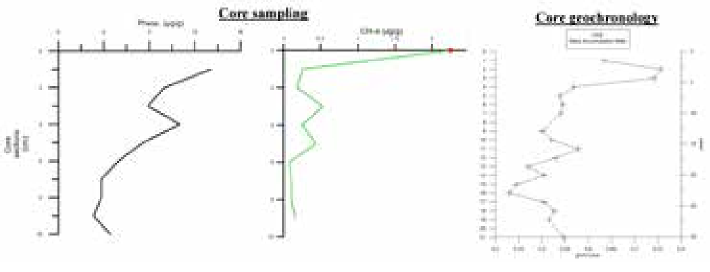

Figure 7 On left sediment Chl_a distribution; on right geochronological dating (Pb210)

Geochronological measures (Fig 7) were inferred from literature data in which a core sample in front of Mignone river delta (50 mt depth) shows an accumulation rate of about 0.7 g/cm2/yr.

For this work we consider a mass accumulation rate of about 0.35 g/cm2/yr which is equal to a sediment accumulation rate of about 3 mm/yr, because of the

core distance from the Mignone river delta.

The values obtained in this paper are quantitatively comparable to the other work made on Tyrrhenian sea. (Pusceddu et al 2009).

3.2 Summer Period

The water column during the summer period is characterized by the presence of a marked thermal stratification (Fig 10) and wind field does not present the typical characteristics of the study area. Indeed along the Tyrrhenian coast the climate conditions of summer season allow to generate the high frequency of land-sea breeze events (Mastratonio et al 2008; Martellucci et al 2013).

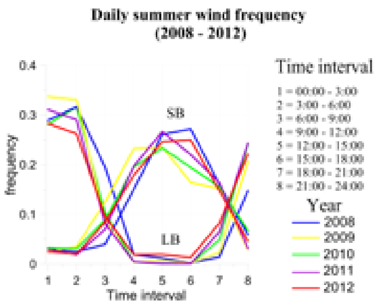

Figure 8 Daily summer wind distribution from 2008 to 2012.

In summer season it is possible to observe high recurrent of cross-shelf events attributable to breezes (Fig 8).

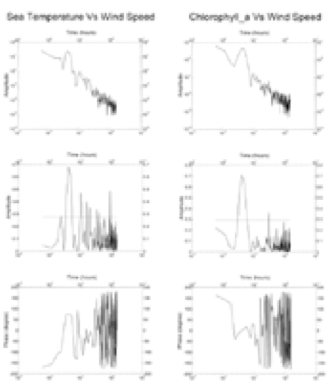

Figure 9 Spectral analysis performed on sea temperature and wind speed (left) and Chl_a and sea temperature (right)

Spectral analysis performed for wind speed and sea temperature (Fig 9) shows that significant peaks occur with daily frequencies; moreover, there is a strong coherence in between the two variables, with a lag time of five hours between the two series in correspondence to the peak at 24h.

Temperature analysis highlight stratification of water column and a well-defined thermocline, in proximity of which temperature oscillations are evident. These fluctuations also appear in chl_*a* diagram. In Figure 10 it is possible to observe that the distribution of isotherms (red line) matches the distribution of chl_*a* (Lennert-Cody and Franks, 2002).

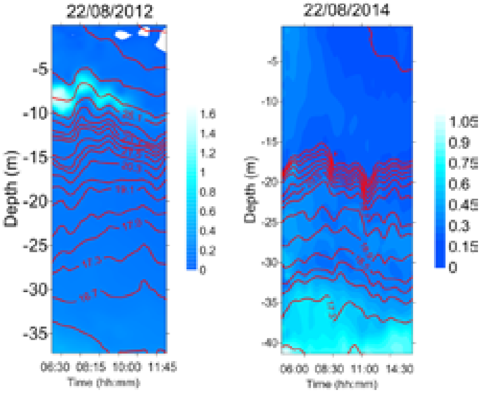

Figure 10 shows Phytoplankton fluorescence (color scale) and temperature (red lines) at 40m deep

It is also possible to observe a decrease in the chl_a concentration between the first and the last station, for both the surface and the bottom layer; furthermore high chl_*a* concentrations (> 1 μg/l) near the thermocline are present during 22/08/2012.

4. Conclusions

Multi-platform systems for coastal environment monitoring are important tools which allow to better understand the dynamics of the coastal ecosystems at different time scale.

This work shows how the study area is strongly influenced by atmospheric forcing. The observations show that in this area upwelling favourable winds occur during the year. In addition, the dynamic phenomena associated with meteorological forcing contribute predominantly to the seasonal distribution of phytoplankton biomass.

During the summer, the coastal dynamics of the study area is strongly influenced by local weather and the breeze regime strongly affects the daily mixing processes that occur along the water column. Furthermore, the oscillations of temperature observed during the oceanographic surveys could be considered as internal waves, as observed in earlier studies conducted in the Tyrrhenian Sea.

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CALYPSO
an operational network of HF radars
for the Malta-Sicily Channel

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Abstract

An HF radar observing system composed of three CODAR SeaSondes is providing real-time surface current pseudo-Eulerian maps every hour in the strip of sea dividing Malta and Sicily. This initiative forms part of the CALYPSO project that principally aims to support the efficient response against marine oil spills in this busy area of maritime transportation in the Mediterranean. In combination to numerical models, an operational chain of activities provides essential data to a spectrum of applications and addresses the needs of a number of responsible entities in Malta and Sicily, targeting the better control of the trans-boundary maritime space and greater efficiency for security and safety at sea.

The usefulness of this effort is measured by the level of usage of the data provided by CALYPSO through dedicated web services with browsing, viewing, and user-defined download of data. The project comprised several validation and system performance tuning exercises through the matching of radar data with direct sea current measurements using drifters and ADCP deployments.

The spatial coverage and high temporal resolution of the HF radar data collected since September 2012 is permitting a unique and detailed characterization of the surface circulation variability in the area at sub-to-mesoscale and seasonal scales. Substantial eddy field structures are evidenced; their origin, dynamics, evolution and linkages to biological processes and the location of fisheries is the subject of ongoing research.

Keywords: observing networks, HF radars, real-time, mesoscale circulation

1. Introduction

The Malta-Sicily Channel (MSC) is a dynamically active stretch of sea within the shelf area connecting the Maltese Islands to the southern coast of Sicily. As with the rest of the Sicily Channel, this area is characterized by important dynamical processes encompassing a wide spectrum of temporal and spatial scales, with significant impacts on ecosystem characteristics as currents contribute to dispersion, transport or retention of nutrients, fish larvae and ichthyoplanktonic products of primary importance in the area (Lafuente et al., 2000).

The MSC is also under pressure due to the intense traffic of commercial vessels, shipping activities, fisheries and tourism. In particular, the maritime transport of oil crossing this region accounts for 25% of the global maritime traffic and for nearly 7% of the world oil accidents over the last 25 years. In combination with localized oil extraction plants existing in the shelf zones this situation presents a serious threat to both the open sea and coastal zone habitats, with consequent impacts on local economic activities such as tourism and fisheries, impacts on ecosystems and losses in revenue. In the case of accidental/deliberate oil spills or drifting-vessel emergency, an operative response chain must include both the detection and the trajectory prediction steps, that take advantage of the most appropriate methodologies and data availability such as: updated meteorological information, near-surface current measurements, and hydrodynamic models with oil spill weathering processes modules.

In a joint effort conducted by Maltese and Sicilian partners in the CALYPSO project (www.capemalta.net/calypso), under the partial funding of the European Union's Italia-Malta Programme – Cohesion Policy 2007 – 2013, a high-frequency (HF) radar network has been set up in 2012 to monitor sea surface currents in the Malta Channel. Radar data aim at supporting applications to optimise intervention in case of oil spill response as well as to endow tools for search and rescue, security, safer navigation, improved meteo-marine forecasts, monitoring of sea conditions in critical areas such as proximity to ports, and better management of the marine space between Malta and Sicily. HF coastal radars provide useful information to support sea safety and monitoring, as they are capable of measuring sea-surface currents with high temporal (10min – 3 hours) and spatial (500m – 6km) resolution. Designed originally for research purposes, the use of HF radars is nowadays well established worldwide and their capabilities have been extensively proven [e.g. Emery et al., 2004, Shay et al. 1998, Cosoli et al., 2013].

We present here the preliminary results of the measurements made by the CALYPSO radar system so far, the identification of near-surface circulation structures that had not yet been observed before, and preliminary results of the data validation. The radar network is introduced and described in Section 2; the data delivery services are described in Section 3, Section 4 deals with the system validation, while Section 5 discusses the main results.

2. The HF radar network

The CALYPSO network consists of three CODAR SeaSonde radars deployed in the MSC (Figure 1). During the first phase of the project, two stations were installed on the Maltese side close to Sopu Tower in Nadur on the island of Gozo and at Ta' Barkat limits of Xaghra in Malta. A third station was added on the Sicilian side at the Pozzallo Harbour. The three radar stations transmit the same frequency (13.50MHz) using a GPS-synchronization module for time synchronisation and frequency management.

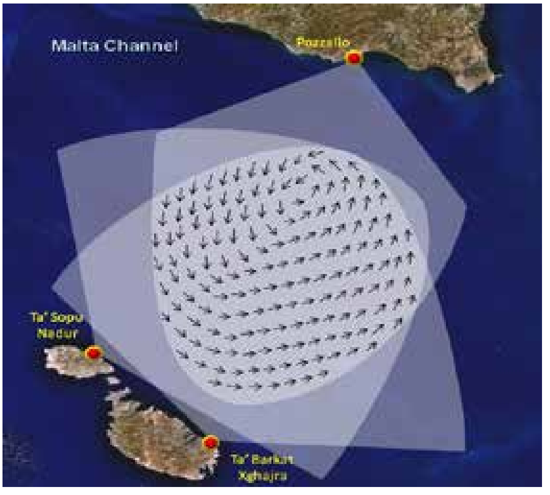

Figure 1 Radar locations on the Malta and Sicily sides

The wave peak period in this part of the Mediterranean region (3 seconds on average) determined the operating frequency in the range of 11MHz to 14MHz to guarantee a high degree of data availability. Thus the final working frequency was set to 13.5MHz according to the wave characteristics and accordingly to the International Telecommunications Union (ITU) frequency bands identified for HF radars.

Operation of the radars relies on the Bragg Scattering of electromagnetic waves by the surface gravity waves. This renders two sharp peaks in the Doppler Spectrum. Due to the underlying ocean currents, the detected peaks do not have a constant Doppler shift. Once the theoretical wave speed is computed from the dispersion relation and subtracted from the Doppler frequency shift, the radial velocity component of the surface current can be found. By installing more than one radar at different locations with an overlapping beam pattern, the same patch of water can be viewed from different angles, and the surface current radial velocity components can be summed to determine the total surface current velocity vector. Radial data from all three stations is transferred to a server at the University of Malta and combined to produce hourly maps of current vectors over a regular grid (Figure 2).

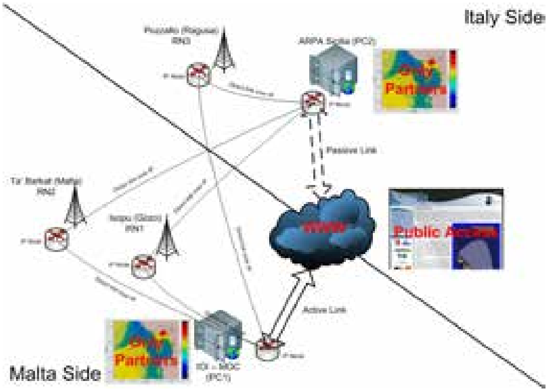

Figure 2 CALYPSO HF Radar Network Schematic

The network operates with a resolution of 1.6km and a 5° angle. Following (Stewart & Joy, 1974), in such a setup the radars are providing current measurements of the upper 1m ocean layer thus representing images of the upper layer of the water column.

A second derived measurement from each radar station is the significant wave height and the wave direction, which are extracted from the second order Doppler spectrum. When there is an increase in wave height, there is no corresponding increase in the height of the first order spectrum (Bragg peaks) since these are generally fully developed. However, there is an increase in the height of the second order peak energy which is proportional to the energy in the longer sea waves.

Due to the size of the Maltese islands, highly variable topography, competition of coastal usage and need to minimise visual and ecological impacts, the limitation of the footprint of all antenna elements was a base requirement from the Malta Environment and Planning Authority. As required by the ITU and FCC regulations, the medium radiated power from each radar is set such as to never exceed 40 watts. The HF Radar antennas have a height of about 7m to 10m. In all sites, low attenuation coaxial cables connect the radar to the electronic equipment housed in a safe location some distance away. The antennas are placed very close to the coastline and are not obstructed by any large scale structures within one wavelength (approximately 30m).

The CALYPSO HF Radar Network also makes use of new state-of-the-art technology that allows for 2D current maps to be rendered as close to the coast as possible. In particular, the radars at Ta' Barkat and Pozzallo are equipped with bistatic/multistatic modules to improve their functionality. The radar in Malta is able to process not only its own monostatic signal, but also the signals transmitted by the Gozo and Sicily stations. To this aim, all radar beams must be synchronized and all stations must share the same processing software. In regions close to the islands, a total vector made up from three or four individual vectors is constructed thus increasing the quality of the final 2D vector map. This also improves the quality of the data in the central region of the domain

The selection of the radar sites was done while keeping electricity supply and data connection in mind. Around 1.5 kW of electrical power are required to power the radar, electronics and cooling systems. At low temperatures, the cooling can be turned off and the power consumption reduces to 0.6kW. Each site is also equipped with a power stabiliser for safer and smoother electrical supply. Real-time transmission of data requires a network bandwidth in the order of 256 Kbps (upload speed). A GPS antenna is also installed on the roof of the building hosting the control unit.

3. Delivering data to the users

The value of an ocean observing system is measured by the quality of the data it delivers, the reliability of the data flow to minimize interruptions and timely publishing, the ease of access and referencing of data files, as well as the production of data dependent services that target the user needs. The CALYPSO data delivery is executed through a dedicated web interface developed within the project to give data access to users in an enhanced format that is readable and fitting to their own systems. The service further provides regular synthesis of data and value-added information to aid direct usage.

The data interface is composed of two main sections, namely: the Public Interface – targeting the public users by showing plots and statistics over nine different sub-regions in the MSC; and the Professional Interface – targeting the professional users by the presentation of quick-view plots, and allowing the download of data, and the handling of special data requests.

Apart from the nowcast sea surface currents generated by the CALYPSO HF-radar system, the data interface further makes use of forecasted sea currents data generated by the ROSARIO-6420 Malta shelf forecasting system (www.capemalta.net/MFSTEP/results0.html). The domain of data coverage has a spatial resolution of 0.03° (approx. 3Km) in the case of the observation nowcasts, and 0.0163° (approx. 1.6 Km) for the forecast fields. Data is provided with a temporal resolution of 1 hour.

The Public Data Interface (Figure 3) synthesises the hourly data fields by spatial averaging over 9 sub-regions and presents the information on sea surface currents averaged for each sub-region for a time span of 13 hours, namely: the present hour conditions; the previous 6 hours generated from HF radar observations; and the next 6 hours generated by the ROSARIO6420 forecast. The information displayed for each selected sub-region includes: the average current magnitude and direction in that sub region; the maximum and minimum current magnitude; the maximum current magnitude over the last 6 hours; and the maximum current magnitude expected in the coming 6 hours.

The Professional Data Interface (Figure 4) consists of three main components, namely: the Data QuickView section; the Data Daily Download section; and the Data Aggregated Download section.

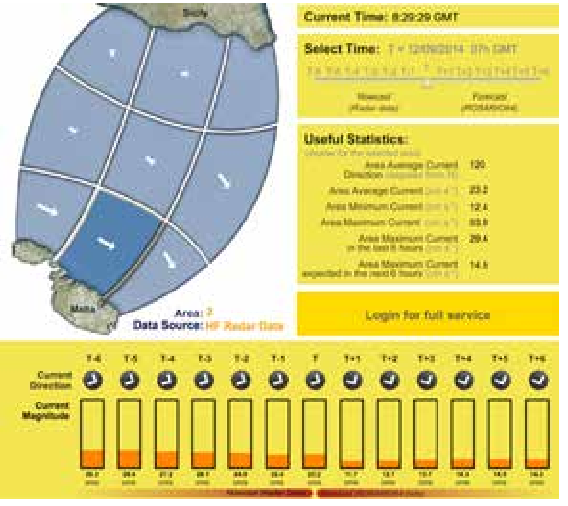

Figure 3 The CALYPSO Public Data Interface

The Data QuickView section allows the viewing and downloading of data on an hourly basis for the entire domain. The user selects the date of interest, and is presented with a set of images of the currents for the selected date and time. The user is allowed to download the data (as NetCDF or ASCII) for any specific hour. Apart from all this, the user may also view an animation of the currents for the selected day.

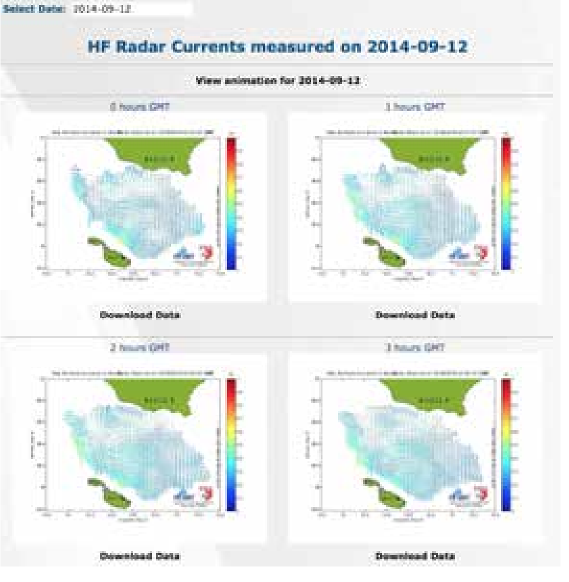

Figure 4 The CALYPSO Professional Data Interface (Data QuickView)

The Data Daily Download section presents the data for download for any month selected by the user. The data is aggregated on a daily basis. Hourly NetCDF files are concatenated together to create the daily files, whilst the ASCII files are aggregated as daily RAR archives. After the user selects the month of interest, the system shows the list of days for which there is data available.

The Data Aggregated Download section allows the aggregation and download of data over a range of user selected days. The user selects the start date and the end date of the period of interest, and the desired data format. The system performs the aggregation of data files for the selected time period up to a maximum span of 100 days. Once the aggregation is completed, the system outputs a link to the resulting aggregated file, with a summary description of the chosen dataset.

4. Performance of the system

The validation of the system was performed by comparing the HF radar observations to independent *in situ* near-surface velocity measurements, collected from Lagrangian drifters and from current profiles, acquired at selected locations within the CALYPSO radar domain. Surface Velocity Profiling (SVP) drifters were launched along a transect between the island of Gozo and Sicily in December 2012, June 2013, September 2013 and October 2013), in collaboration with the Mediterranean Surface Velocity Programme (MedSVP) of the Mediterranean Operational Oceanography Network (MOON).

They had a drogue centred at 15 m below the sea surface, with a surface buoy containing batteries, electronics, data telemetry (GPS) and a sea-surface temperature sensor. Drifter velocities were estimated as central-valued finite-differences of the interpolated positions (Hansen and Poulain, 1996; Gerin and Bussani, 2011). The SVP drifters measure quite accurately the near-surface currents, as wind-induced slip is limited (Niiler et al., 1995; Poulain et al., 2009). Hourly drifter velocity data were finally mapped on the radar grid for further analyses and comparisons. Sea current profiles were acquired by a downward looking Sontek Acoustic Doppler Current Profiler (1 MHz) attached to the side of a boat at 1 m vertical resolution.

Results of the validation of the CALYPSO radar data were consistent with those from similar installations elsewhere (Emery et al., 2004). Correlation between radar and drifter radial velocities were R = [-0.03, 0.7], and were R = [0.25, 0.79], R = [0.27, 0.89] for the U- and V-components. The comparison of ADCP measurements against the radar current vectors (Figure 5 and Figure 6) highlighted an underestimation of the velocities acquired by the radars (around 15%) whereas the agreement in terms of directions was almost perfect.

Hardware failures, software limitation or external radio-frequency interferences (RFI) determined different radial coverage between the threes radars. The latter, in particular affected the three systems after an initial period of good signal-to-noise ratio conditions radar, determining a reduction in operating range and introduction of spurious current vectors.

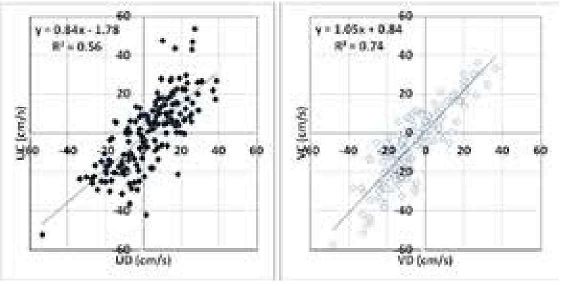

Figure 5 Comparison of drifter measured current components (UD and VD) and the corresponding values from the HF radar (Uc and Vc) (all the available drifter releases).

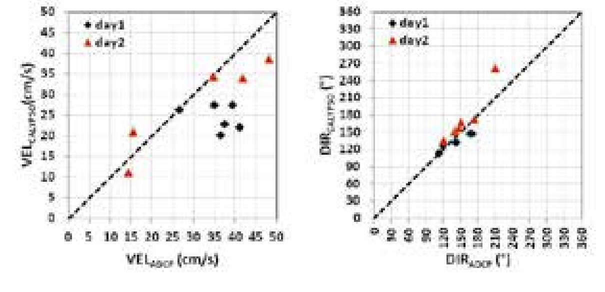

Figure 6 Comparison of magnitude (VEL) and direction (DIR) of the HF radar currents against the ADCP measurements at depth 3.5 m

5. Mesoscale circulation in the MSC

The sequence of monthly-averaged radar current maps in the MSC confirm the dominant presence of an energetic jet throughout the year, associated with the Atlantic Ionian Stream (AIS), with average currents reaching 30-40 cm/s, and directed towards SSE as it exits into the Ionian Sea. The most pertinent circulation pattern revealed by this study concerns the presence of a quasi-permanent mesoscale anticyclonic eddy in the middle of the MSC, bounded on its northern extremity by the AIS current (Drago et al., 2013). The circulation follows a seasonal pattern in which the AIS flow shifts closer to the islands of Malta during Summer and the SE flow along the northern coast of the Maltese Islands becomes particularly intense, tending to swerve against the SE tip of Malta; in Winter the AIS vein is displaced northward towards Sicily, the anticyclonic eddy formation comes into action to the extent of even tending to reverse at times the coastal mean flow along the Malta/Gozo coast to a NW direction. Similarly to the AIS, the mesoscale anticyclone follows a seasonal modulation with zonal shifts in the MSC. As evidenced by the tracks of the drifters deployed in December 2012 (Figure 7), this eddy in fact almost occupied the entire channel consequently trapping the drifters in its interior with a permanence time of 4 to 40 days depending on the point of the drifter release.

A rotary spectral decomposition of surface currents gave evidence to the main periodic oscillations in the radar currents. An example is given in Figure 8 for the grid point having the longest data return. Despite the tidal signal in the MSC is weak and mainly associated to the semidiurnal tidal components, a strong semidiurnal peak is evident at the M2 frequency with a secondary peak at the S2 frequency, which is however almost one order of magnitude smaller than the M2 signal. Near-inertial and inertial oscillations, occurring at period of approximately 15^h at 36° latitude, can be clearly seen in the rotary spectrum, as well as significant energy is observed within the diurnal frequencies. While inertial motions show a clear predominance of the anticyclonic (clockwise rotating) component over the cyclonic component, this predominance is present to a smaller extent also in the diurnal frequency band.

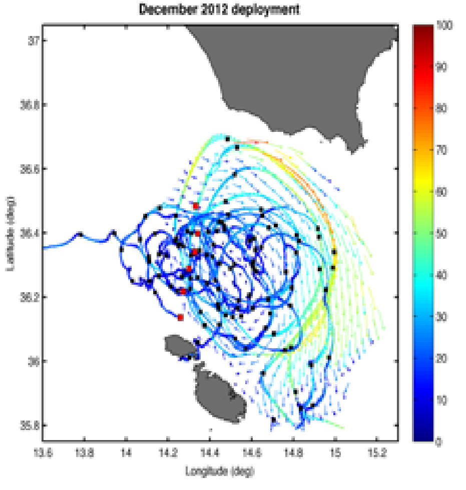

Figure 7 Time-averaged radar current pattern for the December 2012 – January 2013 drifter deployment, overlapped to the along-track instantaneous drifter velocites. Red squares show the deployment locations, black squares show the daily distance travelled by each drifter

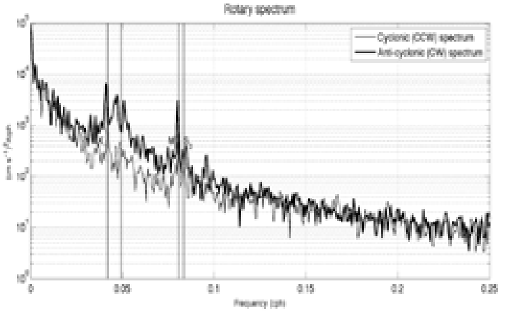

Figure 8 Rotary spectrum for radar surface currents showing current energy distribution over frequencies. Thin line represents the cyclonic (or, counter-clockwise rotating) spectrum, thick line represents the anti-cyclonic (or, clockwise rotating) spectrum. Units are (cm s-1)2 cph-1 for current variance, cycles-per-hour (cph) for frequencies

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Oceanographic data management at the Balearic Islands Coastal Ocean Observing and Forecasting System (SOCIB)

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Abstract

The Balearic Islands Coastal Ocean Observing and Forecasting System (SOCIB, http://www.socib.es), is a multi-platform Marine Research Infrastructure that provides data from the near-shore to the open sea. According to SOCIB principales, data are discoverable and accessible, freely available, quality-controlled standardized and interoperable.

With these objectives in mind, the Data Centre manages the different steps of data processing: from sensors to visualisation by users: 1) the acquisition using SOCIB platforms (gliders, drifters, HF radar, …), numerical models (hydrodynamics, waves, …), or even information generated by other divisions, such as the Division of Strategic Issues and Applications for Society; 2) the archiving and processing, in order to guarantee the data quality; 3) the distribution through dedicated web applications; 4) the dynamic visualisation through SOCIB website or through applications designed for mobile devices.

This paper describes the data processing chain and presents some of the web applications developed in order to improve their visualisation and access. Applications for smart-phones have been also developed to enhance the data access by the general public.

Keywords: multi-platform system, ocean forecast, glider, HF radar, marine research infrastructure.

1. Introduction

The Balearic Islands Coastal Ocean Observing and Forecasting System, is a multi-platform Marine Research Infrastructure located in the Mediterranean Sea (Tintoré et al., 2013). It responds to a paradigm shift in the field of oceanic and coastal observations: instead of single-platform systems, the central element of which is the research vessel, new systems rely on a variety of platforms to provide free, open and quality-controlled data from near-shore to the open sea. SOCIB objectives follow three main lines: scientific priorities, technological developments and response to societal needs. The system is made up of three major infrastructure components: 1) a distributed multi-platform observing system, 2) numerical forecasting system, and 3) a data management and visualization system. To collect the necessary data, the SOCIB system is made up of: a research vessel, a high-frequency (HF) radar system (Lana et al., 2014), weather stations, tide gauges, moorings, drifting buoys, ARGO profilers, and gliders (autonomous underwater vehicles, Heslop et al., 2012; Cusi et al., 2013). In addition, the system has recently begun incorporating oceanographic sensors attached to sea turtles. High resolution model provides ocean forecasts in the western Mediterranean Sea (WMOP, Juza et al., 2015) and waves (SAPO based on the SWAN model). The variety of platforms, instruments and sensors provides data of various types (grid, time series, trajectory, mesh, point, images) related to ocean (temperature, currents, traffic, ...), atmosphere (air pressure, rainfall, …) and land (coastline, erosion, …) as well as in different formats (comma-separated values, NetCDF, JSON, …) makes it essential to have a scalable and integrated data system. In addition to the information provided by the observing platforms and numerical model, the Strategic Issues and Applications for Society (SIAS) division constitutes another source of data that has to be specifically taken into account, for instance for displaying cartographic data.

2. SOCIB DATA CENTER

One of the main challenges for the SOCIB Data Centre (DC) is to deal with this variety of data (i.e., in terms of sources, typologies and formats) and also allow users (scientists, technicians, and the general public) to access the data of interest and to visualize the corresponding information in an easy and attractive way. According to SOCIB principles, data should be: discoverable, accessible, freely available, interoperable and standardized. For these reasons, the data management system implemented aims to meet international standards for quality assurance and interoperability. The system's main components are: 1. An instrumentation application to manage all platforms through a web interface. 2. A processing application to deal with all collected data, performing data calibration, derivation, quality control, and standardization. 3. A data server to provide metadata and data access through standard and open web services (e.g., OPeNDAP, OGC services, HTTP, ncISO). 4. A layer of RESTful web services to ease the development of both internal and external applications, such as web or mobile applications. 5. A set of tools for data visualization and real-time monitoring.

The data management system is implemented using various open source solutions. The data comes from different sources, and according to them, different procedures are applied, employing applications in Java, Matlab, R, Python or geographic information system (GIS). Data from observing platforms or numerical models are stored in NetCDF, while vectorial data are stored in databases implemented in PostGIS. For the metadata, an internal application (see Section 3.1) allows their management and registration into the NetCDF files. The rest of the metadata are edited and stored using Geonetwork application (http://geonetwork-opensource.org/). Data distribution and access is facilited by OGC services, such as Web Map Service (WMS) carried out in Thematic Real-time Environmental Distributed Data Services (Thredds) or Geoserver (http://geoserver.org) applications. Furthermore, DC developed a RESTful web services, *DataDiscovery,* with the objective to make easier the data integration either by internal applications or by a third party, thus providing interoperability to the system.

On top of the described services, SOCIB DC has been developing various applications, as detailed in the next section, allowing users to visualise, access and use the data.

3. APPLICATIONS

Several specific applications have been designed in order to facilitate the access to the data by a wide range of users. The most relevant applications are described in the next sections.

3.1 Applications for data acquisition and processing

Two main applications are used in the first steps of the data cycle. First, the "*Instrumentation*" application, in which all the information related to the platforms managed by SOCIB are registered. Secondly, a "*Processing*" application that performs a series of operations of the data from the considered platforms. These successive operations are : 1) the data ingestion, which requires the knowledge of the data access method and the format ; 2) the data calibration based on the information indicated in *Instrumentation* ; 3) the generation of new data, which requires the method to derive the new variables (for instance, the salinity computed from the conductivity and temperature provided by the instrument) ; 4) the data quality control, based on criteria provided by the facility responsible for the instrument.

3.2 Applications for data acquisition and processing

The Deployment Application (DAPP, http://apps.socib.es/dapp/) displays all the active and completed deployments on a map, with the possibility to obtain the measurements or the data files themselves in one click. For example, on November 27, in addition to the research vessel, 2 gliders, 38 drifters, 6 Argo profilers, 2 moorings, and 2 turtles were deployed. Additional information, such as bathymetry, numerical model results or satellite images, can be provided in the form of additional layers served through a web map service (WMS) interface. A click on the deployment icons opens a window showing basic information (time, positions, speed…) and according to the platform type, links to images generated with the latest data. Direct links to the thredds catalog are also available. The main technologies for this applications are: J2EE, GXT, OpenLayers, GeoJSON and THREDDS (ncWMS).

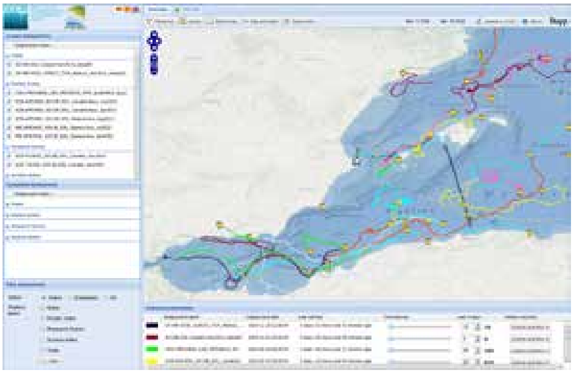


Figure 1 The Deployment Application (DAPP) provides access to both the active and archived deployments of the mobile platforms: surface drifters, profilers, gliders, research vessel and animals (turtles).

The *Lightweight for NetCDF viewer* (LW4NC2, http://thredds.socib.es/lw4nc2/?m=radar, for HF radar in this case) is web client that allows users to browse through gridded fields (numerical model results, HF radar velocities, satellite data) by variable or date, through requests to a web map service such as the ncWMS integrated in the THREDDS server. Additional functionalities of the tool include the extraction of time series at selected locations or along a section drawn on the map, or the animation of layers. The style is easily customisable by modifying these elements: colormap, vectors, minimal and maximal displayed values. The main technologies underneath LW4NC2 are: Ext JS 3, OpenLayers, THREDDS (ncWMS).

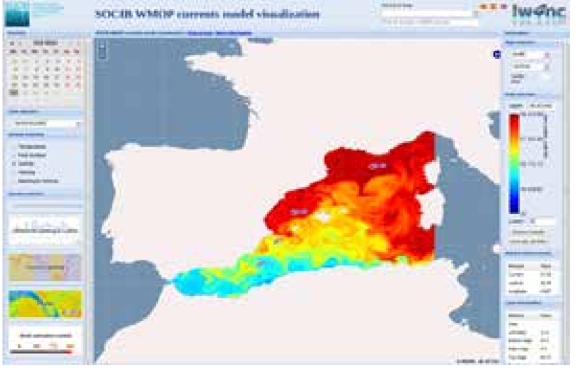


Figure 2 Salinity generated by the hydrodynamic model in the Balearic Sea, viewed through the LW4NC.

The *Environment Sensitivity of the Coastline* (SACosta, http://gis.socib.es/sacosta/composer) is a web-based map viewer for the display of cartographic data related to the environmental sensitivity of the coastline of the Balearic Islands. The spatial data were obtained in 2005-2006 via a formal agreement between the Department of the Interior of the Government of the Balearic Islands and the University of the Balearic Islands. The data have been revised and updated by SOCIB. The viewer was developed to be a decision-making tool to support responses to potential oil spills. The categorization of the coastline is based on the standards defined by Petersen et al. (2002) and is made up of three main components: 1) geomorphological classification of the coast; 2) biological resources (coastal protected areas); and 3) human use (i.e., infrastructures, services, cultural and historic resources). The SACosta tool complies with OGC interoperability standards and the criteria of the INSPIRE directive. The data can be accessed directly through the map viewer, via Google Earth (metadata window), or via a WMS. The descriptions of the data are available in the metadata catalogue of SOCIB (http://gis.socib.es/geonetwork). Recently, a tool has been added to obtain the environmental sensitivity within a polygon selected by the user in the area. A detailed analysis describing the type of coastline with the corresponding length, as well as photographs of the concerned beaches, is automatically generated in the form of a report. The main technologies used for SACosta are PostGIS, Geoserver, GeoExt, Geonetwork, Flask, d3.js.

3.3 Applications for general public

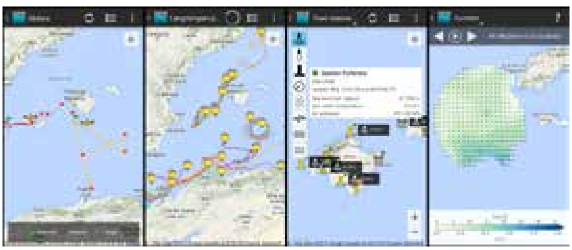
Figure 3 SACosta tool applied to the northeastern coast of Mallorca: an automatic report of the coastline sensitivity and its degree of protection is generated for the shaded polygon drawn by the user.

he applications presented in the previous sections are of particular relevance for scientists and other stakeholders. In order to build the bridge between ocean data and the general public, more specific tools were designed. They aim to present the same data, but in a more user-friendly way.

The SeaBoards (http://seaboard.socib.es/) consist of dashboard visualizations of real-time and forecast ocean data. Seaboards have been primarily designed for the tourism sector and are now installed in several collaborating hotels, providing useful information about the ocean and coastal state in real-time, as well as weather and wave forecasts. Other SeaBoards have been developed, for instance for the HF radar system (http://seaboard.socib.es/galfi) or for the SOCIB research vessel (http://seaboard.socib.es/vessel). Therein, the vessel trajectory and the last data measured by the thermosalinometer (temperature, salinity, fluorescence) and by the weather station (temperature, pressure, wind) are displayed and updated every 10 seconds. Overall, the SeaBoards fulfil the will to enhance public knowledge about science-based beach management and environmental preservation, while providing realistic and consistent measurements in real-time. The SeaBoards are implemented in Django and Dashing widgets, along with the SOCIB RESTful web services.

Figure 4 SeaBoard located in Son Bou (Menorca). Along with real-time images of the nearby beach, swimming and weather conditions and forecast are displayed.

With the increasing use of smart-phone by the general public, the development of applications specific to this support was a quite natural step. The main goal was the capability to provide an easy and quick access to all the platforms and data managed by SOCIB. Concretely, SOCIB App allows users to visualize the information provided by all the observational systems (Figure 6, top panel) or the numerical forecast models (Figure 6, top panel). The general concept of "*Data in one click*" used in the SOCIB web is also applied for the application. Once the app is launched, the user should be able to navigate between the different platforms and find data of interest. Up to now, the app runs under Android (https://play.google.com/store/apps/details?id=com.socib&hl=en) and iOS (https://itunes.apple.com/us/app/socib/id482542716?mt=8). The technologies used for these applications are : Objective-C, MapKit, YAJL, along with the RESTful web services, in particular "*DataDiscovery*" (http://apps.socib.es/DataDiscovery/index.jsp), which provides information and data of SOCIB platforms.



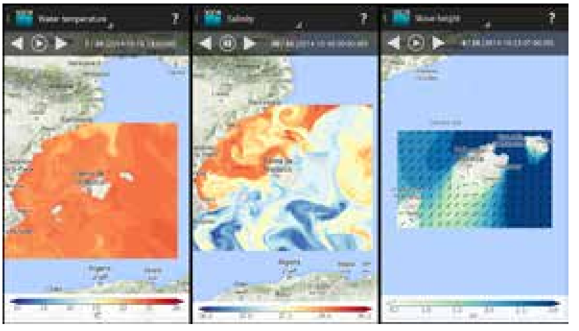


Figure 5 Smart-phone application (Android version): the first four screens show from letft to right: the Glider, Lagrangian platforms, Fixed station and HF radar data. The last three screens shows information related to numerical models: sea surface temperature, salinity and wave height.

4. Conclusions and future work

Over the last years, SOCIB Data Centre has developed several applications aimed at different types of users, ranging from scientists to the general public. In keeping with the objective of bringing relevant data to all kinds of users in a free and easy way, the future plans include the redesign of the applications to improve the user experience, along with the creation of applications specific to different groups of users, including tourists, sailors, surfers, and others. A specific application programming interface (API) is also under construction, with the objective of improving the data access to developers of applications.

Acknowledgements

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The Spanish Institute of Oceanography Observing System, IEOOS

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Abstract

The Spanish Institute of Oceanography (IEO) maintains a large and coherent ocean observing system around the Iberian Peninsula, the Canary and the Balearic Islands. The Spanish Institute of Oceanography Observing System (IEOOS) provides quality controlled data and information about Spanish surrounding waters and comprehends several subsystems.

Tide gauges time series go back to 1943. The coastal time-series observation system, that includes physical, biogeochemical and plankton variability have been monitoring north and northwest Iberian shelf and the Western Mediterranean since 1988. The oceanic time-series observation system monitors slope and oceanic waters since 2000 in Galicia, the Cantabrian Sea, the Canary region, the Gulf of Cadiz and the Western Mediterranean. The IEOOS complements the Spanish contribution to international ocean observing system as Argo, and the Global Drifter Program. Thermosalinographs, an ocean-meteorological buoy in the Bay of Biscay and modelling complete the system.

From traditional oceanographic ships to modern automatic systems such as buoys or Argo floats, are used for the data acquisition. After transmission, data quality procedures, calibration and management, different products as mean sea level, beaches temperature, red tides possibilities, temperature or salinities anomalies, are elaborated on different time scales and delivered at IEO web pages, or on regional alliances as IBIROOS. Databases harmonization (OGC standards) is being implemented. IEOOS contributes to several EU projects as FixO3, Ferrybox, E-AIMS, MyOcean2, ASIMUTH, ECOOP, SeaDataNet, EMODnet, PERSEUS or IRIS-SES.

The IEOOS allows the IEO to fulfil, among other things, the Spanish responsibilities in establishing the Good Environmental Status for the Marine Strategy Framework Directive.

Keywords: observing systems, operational oceanography, Spanish waters.

1. Introduction

Since its foundation a century ago, the Spanish Institute of Oceanography (IEO) has been observing and measuring the ocean characteristics. Some systems like the tide gauges network has been working for more than 60 years. The IEO standard sections began at different moments depending on the local projects, and nowadays there are 181 shelf and slope stations and 50 deep ones that are systematically sampled, taking physical as well as biochemical measurements. At this time, the IEO Observing System (IEOOS) includes 5 permanent moorings equipped with currentmeters, an open-sea ocean-meteorological buoy offshore Santander and an SST satellite image reception station. It also supports the Spanish contribution to the ARGO international program with 47 deployed profilers, and continuous monitoring thermosalinometers, meteorological stations and ADCP installed on the IEO research vessels.

The system is completed with the IEO contribution to the RAIA and Gibraltar observatories, and the development of regional prediction models. All these systematic measurements allow IEO to give responses to ocean research activities, official agencies requirements and industrial and main society demands.

All these networks are linked to international initiatives like SeaDataNet, EMODnet, IBI-ROOS and MONGOOS.

2. Components of the ieo observing system

2.1 TIDE GAUGE NETWORK

Working since 1943, it is the oldest Spanish tide gauge network. It has 12 stations and meets the requirements established by international services and programs as Permanent Service for Mean Sea Level (PSMSL) or Global Sea Level Observing System (GLOSS). The sea level time series have been used in local and regional studies of mean sea level trends and it is relevant for the estimation of extreme sea levels (e.g. García *et al*, 2012).

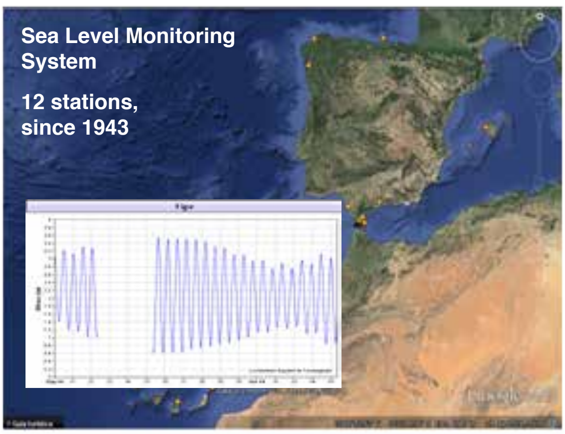


Figure 1 Tide gaudes1943 network since and a mareogram.

2.2 HYDROGRAPHIC MONITORING SECTIONS

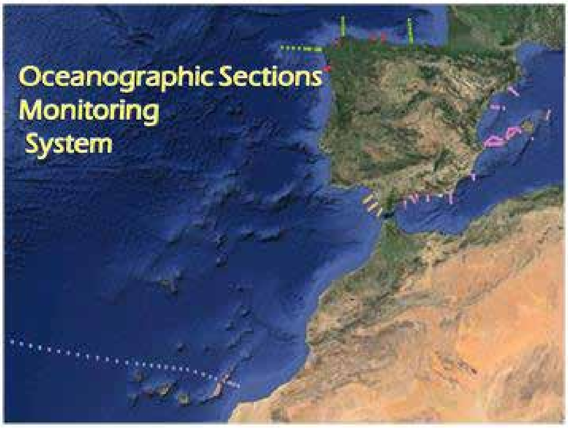


Figure 2 Hydrographic monitoring Shelf and Slope and Deep Sections in the Atlantic Ocean and Mediterranean Sea.

2.2.1 Shelf and Slope Sections

Since 1990, 181 stations are sampled over a regular grid to get information on the shelf-slope gradient. They conform the longest multi-disciplinary oceanographic dataset in Spain and attempt to characterize the ocean variability at different scales, seasonal, inter-seasonal and decadal ones, including plankton behaviour and the ecosystem responses. It covers Galicia (9 stations) and Bay of Biscay (13 stations), Gulf of Cadiz (16 stations) (Monteiro *et* al, 2015) and Mediterranean Sea (85 coastal, shelf and deep stations), including Balearic Islands (Balbín et al., 2014).

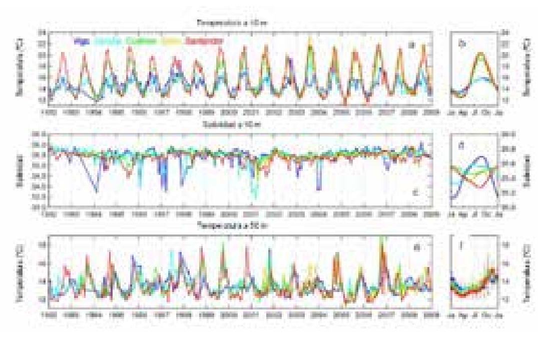
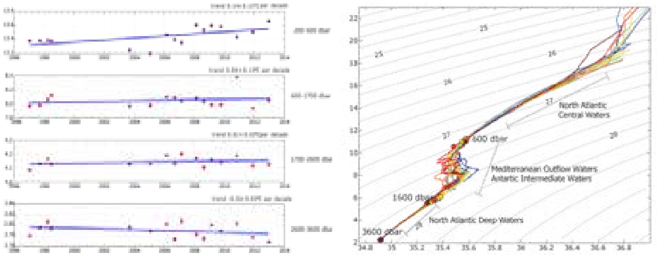


Figure 3 Temperature (10 y 50m) and salinity (10m) variability for the last two decades in Vigo, Coruña, Cudillero, Gijón and Santander shelf sections of Galicia and Bay of Biscay.

2.2.2 Deep Sections

Deep hydrographic sections are sampled in the Canaries basin (2006) and N-NW Spain (2003). Sections have been occupied semiannually or at least annually. The complete deep sections in the Cantabrian Sea have been discontinued recently while some deep stations have been included for the monthly sampling. The aim is to establish the scales of variability in the range decadal/subdecadal. Its information contributes to the knowledge of the oceanographic climatic variability and global change monitoring (Prieto *et al*, 2015)



Mean Temperature for stations 6-17 Canary section

Figure 4 Changes in Temperature and Θ/S diagram for stations in the Canary Basin (RAPROCAN)

2.3 Permanent Moorings

In the Atlantic Ocean, the IEOOS comprises two deep stations in the RADPROF monitoring of N/NW Iberia since 2004 Finisterre and Santander. The second one is not working nowadays. Mooring lines with current-meters and hydrographic sampling at the cores of main water masses have been operative with some interruptions from 2003 at the western Iberian margin and in southern Biscay. The aim is to maintain permanently at least one mooring line at each region.

In the Canary Basin a permanent mooring has been placed in the eastern Boundary Current EBC4 to quantify the water masses variability of these currents as well as the Canary Current.

In the Gibraltar Strait, the IEO is involved in the Gibraltar monitoring system with a mooring, the INGRES mooring in collaboration with the University of Malaga. This mooring is included in the HydroChanges program. In the Mediterranean Sea, the HYDROCHANGES program comprises an international set of deep moorings for the long-term monitoring of the hydrological variability (Schroeder *et al*. 2013). The IEOOS contributes to this program with a mooring in the continental slope at the north of the Ibiza channel. Additionally, a second mooring will be installed in the next few months at the NE of Menorca. The mooring maintenance is planned to be every 6 to 12 months within the RADMED monitoring program (Balbín *et al*., 2014)

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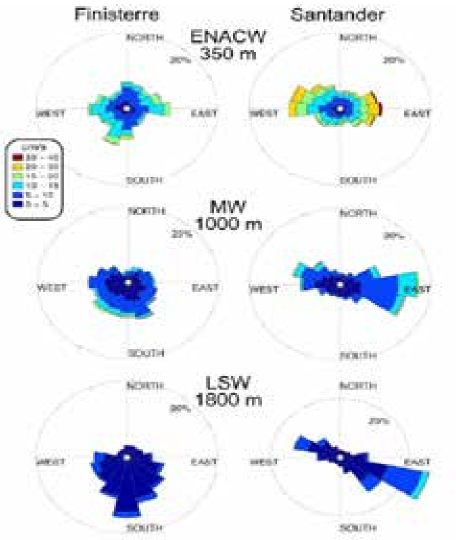
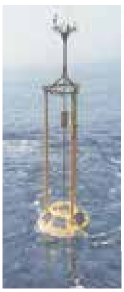
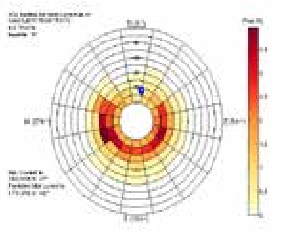


Figure 5 Currents roses of eastern North Atlantic Central Water (ENACW), Mediterranean Water (MW) and Labrador Sea Water (LSW) at Finisterre and santander mooring.

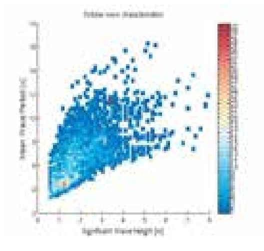
2.4 Ocean-meteorological BUOY

Deployed in 2007, 43º50'N 3º47'W, the Augusto Gonzalez de Linares (AGL) buoy is located 22 miles North of Cape Mayor, off Santander (southern Bay of Biscay). Water depth at the buoy site is 2850m. The obtained information is of great importance for the scientific, meteorological, environmental, fishery, maritime and tourist activities which have a real-time marine information source. The Biscay AGL buoy is the IEOOS contribution to the EU FixO3 project.





A. Sea Current against monthly climatology



B. Wave state against monthly climatology

Figure 6 AGL buoy. Products in www.boya_agl.st.ieo.es : A Value of Sea Current at 5 m depth against monthly climatology. B: Value of Sea State against monthly climatology.

2.5 IEO research vessels underway monitoring

Nowadays the IEO maintains continuously working 5 thermosalinometers, 4 meteorological stations, 4 marine data management systems on board the R/V fleet.

Collected data are routinely sent to the IEO datacenter for QA, dissemination and archive. These systematic measures had allowed some climatological products based on repeated shiptracks in Cantabrian Sea (Viloria *et al*.,2012, Viloria, 2012) and Galician Rias (Tel *et al*., 2014). These are very coastal areas where the interseasonal variations have consequences as algae blooms.

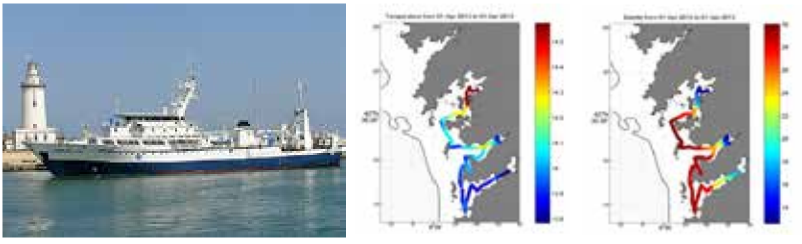


Figure 7 R/V Ramon Margalef, Thermosalinograph plots in Galician Rias: A: Temperature, B: Salinity

2.6 IEO CONTRIBUTION TO ARGO INTERNATIONAL PROGRAM

The IEO supports the main Spanish contribution to the ARGO international program with 47 deployed profilers since 2003.

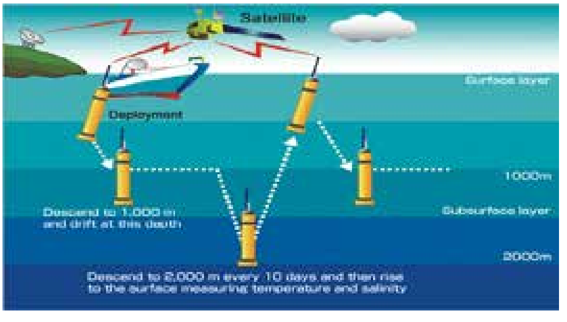


Figure 8 Argo floats functioning.

2.7 IEO SATELLITE RECEPTION STATION

In August 1998 a satellite reception station was mounted at the IEO Santander Centre to receive SST images. Because of technical problems the station stopped working in 2007, but a new reception station was mounted in 2010, with FEDER funds and SST images of the surroundings areas are now available

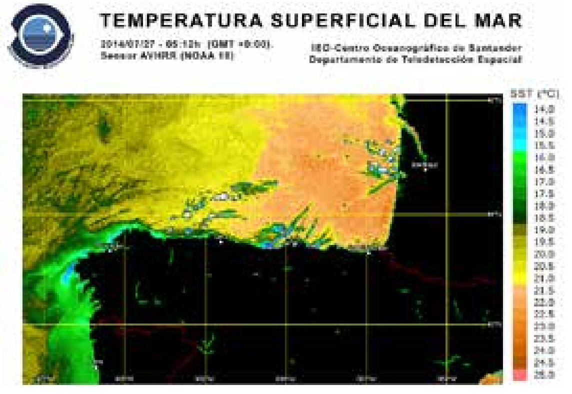


Figure 9 Sea Surface Temperature AVHRR sensor (NOAA 19) Bay of Biscay July 27, 2014

2.8 HYDRODINAMICAL MODELS

The IEO runs high resolution models in the N-NW Iberian Peninsula to give response to the oceanographic water conditions, upwelling system variability and harmful algal bloom prediction, among others.

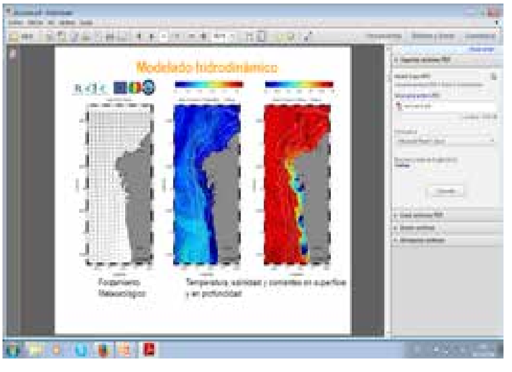


Figure 10 RAIA Project IEO model. Mean Winds Stress (left), Mean current and Temperature (Centre) and Salinity (right)

3. CONCLUSIONS

The Spanish Institute of Oceanography (IEO) maintains a large and coherent ocean observing system around the Iberian Peninsula, the Canary and the Balearic Islands. The Spanish Institute of Oceanography Observing System (IEOOS) provides quality controlled data and information about Spanish surrounding waters and comprehends several subsystems. The IEOOS is already conducting many of the evaluations required under the MSFD.

Furthermore, all the information obtained from the IEOOS is actually providing valuable information to study the biological resources and their dependence on the physic-chemical variables (e.g. Alemany *et al*. 2010), and also physical effects like deep and intermediate water masses formation (e.g. Somavilla *et al*, 2009, Vargas-Yañez *et al*., 2012) modification and transport (e.g. López-Jurado *et al*., 2005), and oscillations and trends in environmental variables (e.g. Prieto *et al,* 2015, Vargas-Yáñez *et al*., 2010).

Acknowledgements

The monitoring program of the IEO, the IEOOS is mainly funded by the Instituto Español de Oceanografía, but some components has been occasionally funded by European Sea Level Service Research Infrastructura (ESEAS-RI) EVR1-2001-00042, the VACLAN (PN I+D+I REM2003-08193-CO3-007MAR), COVACLAN (PN I+D+I CTM2007-646007MAR), RAIA Interreg IV A Galicia N Portugal, EU Infrastructure FixO3, INGRES 3 (PN I+D+I, CTM2010-21229-C02) DESMOND project (PN I+D+I CTM2008-05695-C02-01) the PERSEUS project (FP7-287600) and the IRIS-SES project (FP7-07.0335/2013/659540/SUB/C2.).

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Sea Wave Italian Measurement System

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Abstract

The Italian National Wave Measurement Network (RON Rete Ondametrica Nazionale) run 15 real-time directional buoys uniformly distributed along the Italian coasts. Buoys provide, every 30 minutes, the main physical parameters useful in defining the sea state such as significant and maximum wave height, peak and mean period, wave direction, sea surface temperature, air temperature, wind speed and direction, atmospheric pressure, relative humidity. This kind of data is very useful for all tasks and scientific activities of national interest for the protection, enhancement and improvement for the marine environment. In this work attention has been focused on statistical analysis of wave data in order to define the wave climate and the extreme events.

Keywords: RON, Wave Climate, POT, GPD

1. Introduction

Meteo-marine data are necessary and useful for all tasks and scientific activities of national interest aimed to the protection, enhancement and improvement for the marine environment.

In this framework ISPRA maintains and manages two measuring networks in order to gather all physical parameters needed in defining the sea state for Central Mediterranean Sea: the Sea Level Measurement Network (Rete Mareografica Nazionale, RMN) and the Sea Waves Measurement Network (Rete Ondametrica Nazionale, RON).

In this work wave data have been deeply investigated and analysed.

The RON run 15 real-time directional buoys uniformly distributed along the Italian coasts. From 2010 all buoys are equipped with meteorological instruments; they collect the main physical parameters such as significant and maximum wave height, peak and mean period, wave direction, sea surface temperature, air temperature, wind speed and direction, atmospheric pressure, relative humidity. The monitoring networks provide the technical and scientific support to the better environmental governance, providing a wide range of information in several key areas such as: collection, processing, management and diffusion of marine data; protection of water resources, marine and coastal areas; monitoring of marine environmental quality; prevention and mitigation of impacts of polluted marine and coastal sites; climate change; sustainable use of inland and marine waters; study and evaluation of physical and human factors influencing marine conditions.

In this study, attention has been focused on statistical analysis, in order to define wave climate and extreme events. The statistics considered are mainly the joint frequency distribution of significant wave heights with respect to directions, and with respect to peak periods and mean periods. Extreme Events Analysis has been made through the Peak Over Threshold (POT) method and the Generalized Pareto Distribution (GPD). Moreover, for each time series, a set of statistical parameters has been evaluated, such as the average number of storms per year, the return period corresponding to the maximum value of observed Hs, the return level corresponding to a period of 20 to 50 years depending on the availability of data.

2. Data and observational systems

Wave, tide and wind measurement information are fundamental to all studies, design and management of coastal and offshore works (harbours, beach protection, sealines) as well as to the analysis of relative environmental impacts. Instrumental monitoring is a fundamental requirement in order to hold an accurate and complete knowledge of meteo-marine parameters.

In the marine observation framework, ISPRA is the national data provider on sea level and waves. Data gathered are used for analysis and re-analysis and they are the core of Mediterranean, national and local forecasting. ISPRA provides, comprehensively and systematically, the high-resolution estimation of the physical state of Italian seas as well as real time monitoring.

2.1 The RON

The RON was designed to acquire real-time measurements of physical parameters crucial in defining the sea state, and actually consists of 15 Watchkeeper™ buoys uniformly distributed along the Italian coasts. Data have been collected since 1989 at 8 measurement stations; in 1999 two other stations were added and the remaining five buoys were moored in 2001. From 2010 all stations are equipped with meteorological instruments. Buoys provide, every 30 minutes, the main physical parameters useful in defining the sea state such as significant and maximum wave height, peak and mean period, wave direction, sea surface temperature, air temperature, wind speed and direction, atmospheric pressure, relative humidity.

The buoys, provided by AXYS Technologies Inc., are deployed in approximately 100 meters of water and are outfitted with a series of oceanographic and meteorological sensors. These are particle following buoys, the sensing package consists of accelerometers, rate gyros, and compass as well as uses a compliant mooring system. An algorithm for a 6-degrees of freedom non-linear equation of motion and a Maximum Entropy Method are used to derive wave height and directional frequency spectra.

Very deep procedures have been implemented in order to validate data (quality control QC): L1 and L2 algorithms have been applied in order to make data compliant with international standards.

Only data that have passed all automated QC checks and manual review, and have met WMO standards for accuracy, are archived and they will soon be published in a special data collection of ISPRA.

3. Results

Wave data, collected on the 15 RON locations, represent one of the most accurate and complete oceanographic database in the Central Mediterranean Sea for many environmental issues such as, studies on climate changes and variability and assessment of marine environments.

In this study extreme events and climatology has been fully investigated.

3.1 Extreme Events Analysis

The first step in the extreme events analysis consists in extracting a set of independent wave events using different methodologies, such as POT and annual maxima methods.

Attention has been focused on the determination of the historical storms in terms of the return times and the expected values of the wave heights over several decades. For this purpose an investigation on several statistical distribution has been carried out for each measurement station. As is well known there are many distribution function candidates for extreme wave analysis.

In this study, extreme events analysis has been made through the GPD that provides different kind of distributions such as Gumbel, Frechet and Weibull, depending on the values of the estimated parameters. These distributions have been used in order to evaluate the wave height return level and return times up to 50 years.

These theoretical considerations suggest that when we have data from unknown underlying severity distributions we may be able to successfully approximate the distribution of excess amounts over sufficiently high thresholds by a generalized Pareto distribution, $G_{z,s}$ (x) for some values of z and s.

This approach presupposes that we can find a suitable high threshold above which the GPD is the limiting distribution for the distribution of the excesses and above which we still have sufficient data to give accurate estimates of unknown parameters of the distribution. Even though the series are 25 years long, the analysis gives valuable information about the spatial distribution of the storms and their variability on a decadal time scale in the Central Mediterranean Sea.

For each time series, a set of statistical parameters has been evaluated, such as the average number of storms per year, the return period corresponding to the maximum value of observed Hs, the return level corresponding to a period of 20 to 50 years depending on the availability of data.

3.2 Wave Climate

Wind Wave Climate indicates the statistical characteristics of synthetic wave parameters recorded for a number of years averaged on a yearly basis; it is very useful information in the analysis of coastal morphodynamics and in coastal protection studies while the second gives useful indications in harbour design, and coastal protectionas well.

It has been performed mainly through the joint frequency distribution, represented in tables and wind roses plot.

The considered statistics are mainly the *Joint Frequency Distribution* of significant wave heights (Hs) with respect to directions as shown in the wind roses (Tab. 1), and with respect to peak periods and mean periods.

Figure 1 Extreme events analysis

Significant Wave Height Hm0 (m)	Wave Direction - Dir (deg N)																								
	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	
0.5	313	108	80	48	46	45	45	33	39	45	64	345	833	1119	780	680	784	844	824	1338	1935	1739	1181	883	13864
1.0	161	61	27	20	16	6	3	13	5	4	15	155	446	433	285	604	217	446	408	629	1611	1125	389	315	7417
1.5	52	9	7	3	3	3	1	1	2	3	6	52	144	150	149	509	359	361	342	324	1330	949	131	116	4661
2.0	13	5	-	-	-	-	-	-	-	-	4	9	24	52	61	117	287	238	129	267	1029	717	90	46	3088
2.5	9	-	-	-	-	-	-	-	-	-	-	1	5	7	21	66	209	126	102	137	799	296	44	11	2125
3.0	1	-	-	-	-	-	-	-	-	-	-	-	-	1	8	32	90	68	29	71	292	421	18	3	1400
3.5	-	-	-	-	-	-	-	-	-	-	-	-	1	2	1	8	30	42	30	60	437	347	11	2	971
4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	3	13	11	17	25	399	228	4	3	709
4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	12	14	6	14	172	152	1	-	375
5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	2	4	7	7	131	99	1	-	254
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	3	2	78	75	-	-	161
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	44	40	-	-	85
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	32	40	-	-	74
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	20	13	-	-	34
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	9	-	-	17
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	1	-	-	5
8.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	2
9.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	2
9.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
>=9.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	579	183	114	71	65	54	49	47	49	52	89	469	1443	1772	1309	1525	2205	2168	1857	2824	8483	6269	1770	1388	32538

Tab. I. The Joint Frequency Distribution of significant wave heights (Hs) with respect to directions

Occurrence frequencies can easily be calculated by dividing the value interval of all measurements taken into different classes. The frequency, for each class, is the ratio between the number of events falling within the considered class and the total number of data. To calculate the joint frequency of wave/dir, sea state with wave height above 0.25 m have been defined as calm and not considered in the statistical analysis. The interval of wave measurements have been divided into 5 classes, while each direction sector covers an angle of 15. In order to achieve the statistical analysis, very hard work of validation, and quality control of the raw data from RON has been made.

It is important to highlight that the statistical analysis is representative for the sea areas surrounding the measurement point and having similar meteo-marine exposure.

Any extrapolation to locations far away from the buoy must be verified and carried out by means of transposition models, numerical models and so on.

The *Joint Frequency Distribution* of significant wave heights (Hs) with respect to directions is also represented in the wind roses plot (Figure 2).

The information represented with polar diagrams enable immediate visual identification of the most frequent wave direction, and of the direction of the sea state with the most frequent highest waves.

Italian wave climate illustrated by wind roses (Figure 2), shows two main behaviors: focused on one directional sector (for example at La Spezia) or spread in two or more directional sectors (for example at Monopoli).

In the Tyrrhenian Sea there is a marked directionality in the wave climate, while in the Ionian and Adriatic Seas there are generally bimodal climates.

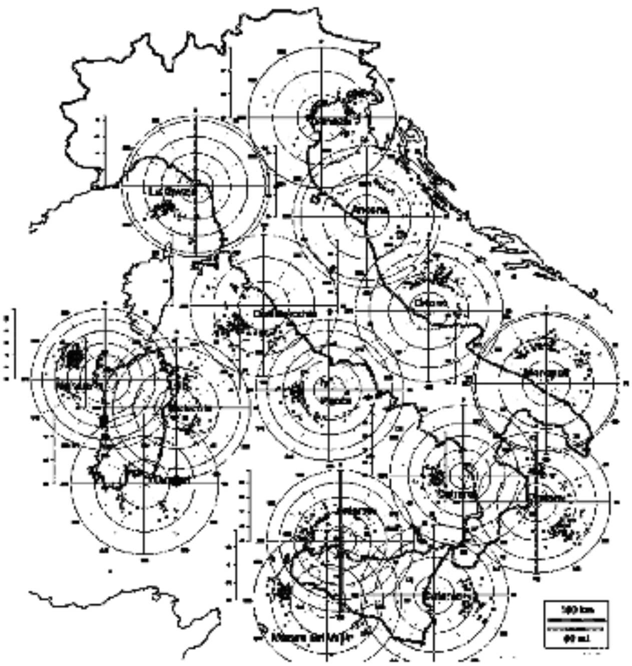
Extreme Events Analysis was applied using the Peak Over Threshold Method and the Generalized Pareto Distribution, giving Return Levels and Return periods. The POT was applied on the sets of independent events extracted from the buoys time series. Only series having at least five years of data have been considered.

Main results have been summarized in Figure1 shown below. For each time series is shown the average number of storms per year, the return period corresponding to the maximum value of observed wave height, the return level corresponding to a period of 20 to 50 years depending on the availability of data. The maxima observed at Alghero, Cetraro and Ponza belong to the same event, the December 1999 storm (also called "Storm of the Century").

4. Discussions and conclusions

The results here summarized have outlined the existence of two different behaviors of wave climates related to different geographical areas of the Italian coasts.

The western group (Alghero, La Spezia, Ponza, Mazara etc.) and the Eastern group (Pescara, Monopoli, Crotone, Catania etc.). The first cluster has typically unimodal annual directional climates characterized by high waves mainly originating from west while the second one often shows bimodal annual directional climates, characterized by smaller waves mainly coming from North. The frequencies of waves coming from South are low in the Western group and high in the Eastern one.



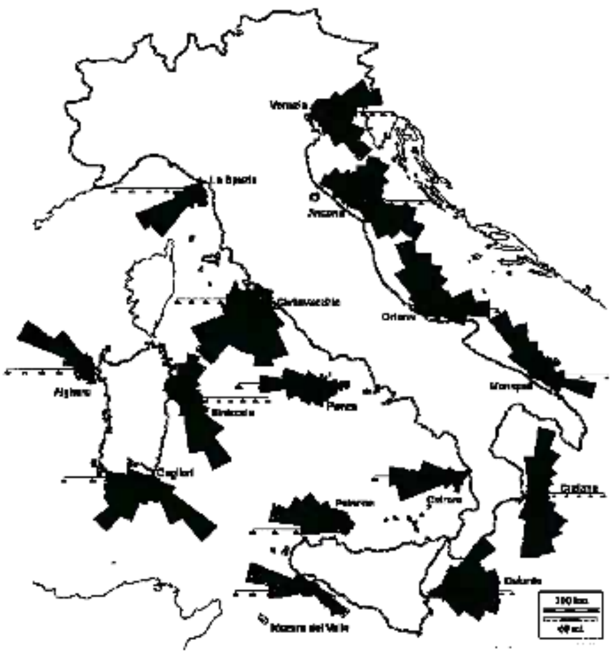


Figure 2 Storm events distribution at each location and wave climate at each location.

The sea level analysis provides useful information on the one hand on sea level variation and storm surge detection but moreover in terms of methodology to be integrated in a tsunami warning system.

In order to carry on these studies it is fundamental to have very long time series with dense spatial coverage. It is well highlighted the importance of collecting data continuously and systematically all along Italian coasts, in order to achieve analysis in terms of sea state variation useful for marine environment assessment.

This is possible thanks to the development and the improvement of the Italian measurement networks that have been providing data forthe last 20 years.

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Greek Argo: Towards monitoring the Eastern Mediterranean – First deployments preliminary results and future planning

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Abstract

The Greek Argo initiative commenced operation in 2010 with the first successful Greek float deployment in the Cretan Sea. During the last two years, the Greek-Argo infrastructure has become a member of Euro-Argo ERIC and therefore fully aligned with the key objectives of the European infrastructure. In the forthcoming years Greek Argo aims to fill gaps in under-sampled sea areas of the Eastern Mediterranean basin such as the Aegean, Ionian and Western Levantine Seas. Within this work Greek Argo's new monitoring capacities and future planning are presented. We additionally present preliminary results from previous deployments showing the level of variability and signals of different origin water masses at subsurface and deep layers for Ionian and Cretan Seas. Furthermore, additional features of these areas are described as data analysis reveals intermediate layers circulation subsystems, a dynamical behavior of the basin's upper thermocline and intermediate/deep water masses spatial variability. A first assessment is also presented regarding biochemical profiles recorded from the float in the Cretan Sea which is the first autonomous profiler with a dissolved oxygen sensor in the basin.

Keywords: Regional seas, hydrology, profiling floats, TS profiles.

1. Introduction

Being the first in-situ, global ocean-observing network in the history of oceanography, autonomous profiling floats have been expanding into regional seas providing crucial information for their dynamic processes. Lately, the expansion of the so-called Argo Network into Regional Seas has upgraded monitoring and forecasting activities in enclosed sea basins giving the opportunity of more enhanced studies of the mesoscale and sub-mesoscale dynamics dominating in such areas. This evolution is the outcome of the combined efforts of the newly formed Euro-Argo Research Infrastructure www.euro-argo.eu and several multinational initiatives. Since 2012, Greece has contributed nationally to the ARGO project. The Greek Argo infrastructure www.greekargo.gr is funded by the National Strategic Reference Framework (NSRF) while it is a member of the Euro-Argo ERIC and therefore fully aligned with the key objectives of the European infrastructure.

The Greek Argo initiative aims to contribute to an enhanced monitoring over the Aegean and Ionian seas as well as the Eastern Mediterranean region in general. The Aegean and Ionian basins present high variability and transitional characteristics as water masses of different origin meet and interact. The physical characteristics and circulation patterns of the wider area have been studied since the 80's, and the results reveal the significant role of these two basins in the hydrology of the Eastern Mediterranean which affects the circulation and balance of the wider region in both seasonal and inter annual timescales (Georgopoulos et al., 1989; Theocharis et al., 1990; The POEM Group, 1992; Robinson and Malanotte-Rizzoli 1993; Theocharis et al., 1993; Roether *et al.,* 1996; Pinardi and Masetti 2000). The three major water masses of the area are namely: the Modified Atlantic Water (MAW), that can usually be identified as a subsurface minimum of salinity between 30 and 200m depth, the Levantine Intermediate Water (LIW), that is identified by its salinity maximum in the layer between 200 and 600m depths and a colder and less saline transitional water mass in the layer between 700 and 1600m. The interaction between these two basins is also important for the dynamics of the area and a subject of study. Research in the past showed that the Levantine origin Cretan Intermediate Water (CIW) which is formed in the South Aegean basin and is slightly denser than (LIW), enters Ionian basin by a northward flow through the west Cretan Arc Straits. (Nittis et al., 1993; Zodiatis 1993b; Astraldi et al., 1999; Kontoyiannis et al., 1999; Lascaratos et al., 1999; Theocharis et al., 1999a; Tsimplis et al., 1999; Vervatis et al., 2011). During 2009 and 2010, an incident of high salinity intermediate water branches reaching into the Ionian Basin was indicated with characteristics similar to the CIW (Kassis et al., 2012).

2. Operational plan - activities

The operational action plan of Greek Argo infrastructure included the purchase and deployment of 25 new floats for the next 5 years, covering in that way semantically the future medium term monitoring needs of the whole region. In this plan many factors were taken into account in order to achieve the best monitoring results. The deployments were planned to cover understudied basins of the region such as Aegean, Eastern Ionian and Western Levantine, with the complex topography of each area and its general circulation features that are the main factors of float losses taken into account. An interesting statistical outcome of the Greek Argo strategic planning was that the lifetime expectancy of the floats for the wider region of the Eastern Mediterranean Sea appeared to be 20% less than of those in the Western part, mainly due to complex bathymetry and topography of the region.

2.1 Float deployments

In 2010, the Hellenic Center for Marine Research procured (using internal funds) and deployed a PROVOR-CTS3 float initiating the Greek Argo programme. The float was deployed in the Cretan Sea during June 2010 and its lifetime ended in May 2012 after a successful recovery and redeployment operation in November 2011. Between October 2013 and November 2014, 7 new deployments were achieved from HCMR's Argo operational team. The first deployment took place in October 2013, under the framework of PERSEUS FP7 project, in the Cretan Sea at approximately 15nm north-west of Heraklion port. The float was lost 6 months after in the South-east straits of Aegean basin but it was detected and recovered by the port authorities under the guidance of Greek Argo operational team. The float is a PROVOR DO type being the first float in Aegean equipped with a dissolved oxygen sensor additional to standard CTD float's instrumentation and is to be redeployed in the same region. In November 2013 and March 2014, two NOVA type standard CTD floats were deployed in the Northern and Central Ionian basin in the framework of IONIO Interreg-III project, being the first Greek Argo floats in Ionian Sea. During the last 3 months of 2014, 4 additional deployments were accomplished by the Greek-Argo team. The floats were purchased by the Greek Argo RI and were deployed in the North, Central, South Aegean and South Ionian accordingly. All floats integrate an Iridium satellite telemetry system which provides a dual telecommunication capability allowing modification of the configuration in real-time, while the one in Central Aegean comprises an additional Dissolved Oxygen sensor. The deployments information and location of the 6 operating Greek floats are presented in table 1 and figure 1.

All floats are following the recommendations of MedArgo (Poulain et al., 2007). More specifically, the drifting depth is 350 m which is near the depth of the Levantine Intermediate Water (LIW) core. The cycle length is set to 5 days in order to obtain useful estimates of currents, as longer cycles are not able to represent the circulation in the vicinity of the intricate coastlines of regional Mediterranean Seas.

Table I Deployments of the active Greek floats in the Aegean and Ionian basins

TYPE	WMO	DATE OF DEPLOYMENT	LAT	LON
NOVA	6901887	13/11/2014	36.25	21.50
NOVA OXYGEN	6901886	12/11/2014	37.08	23.91
NOVA	6901885	08/10/2014	35.79	25.12
NOVA	6901884	07/10/2014	36.92	24.25
NOVA	6901883	14/03/2014	38.14	20.24
NOVA	6901882	28/11/2013	39.91	19.32

Figure 1 Active floats in the Eastern Mediterranean (Greek floats with blue dots) www.greekargo.gr (February 2015)

Moreover, the assimilation of profiler displacements becomes inefficient to correct modelled velocities if the cycle length is longer than the typical Lagrangian integral time scale characteristic of the circulation at 350m (Molcard et al., 2003). The profiling depth for this configuration is set to 1000m and due to irridium telecommunication technology a maximum time of 30min is estimated to be the surface time for the localization and data transmission.

3. Features presented

The analysis of the so far acquired profiles and trajectories shows a variety of hydrodynamic features of the monitoring areas. In the Cretan Sea, the recorded trajectories depict complex circulation patterns with a number of differences in size and intensity mainly cyclonic subsystems.

3.1 Deployments in the Cretan Sea

Regarding mesoscale circulation in the basin, the dominant eddies of the upper layers are the West Cretan anticyclone and the Cretan cyclonic gyre forming a dipole that converge in the centre of the basin (Theocharis et al., 1999a). The latter is recorded from the 1st Argo float's orbit after its deployment during the summer of 2010 which follows a cyclonic path with an approximate 30 km radius thus indicating a significant westward displacement of the eastern cyclone. The perfect fit of the float's path after a comparison against satellite altimetry and the derived geostrophic velocity field, confirms the existence of the cyclone with a signal from surface down to deeper intermediate layers where the float was drifting (350m). After a similar comparison with the Aegean Sea hydrodynamic model output, on a run that is not assimilating data from this specific float, a good representation of the cyclone is shown (figure 2).

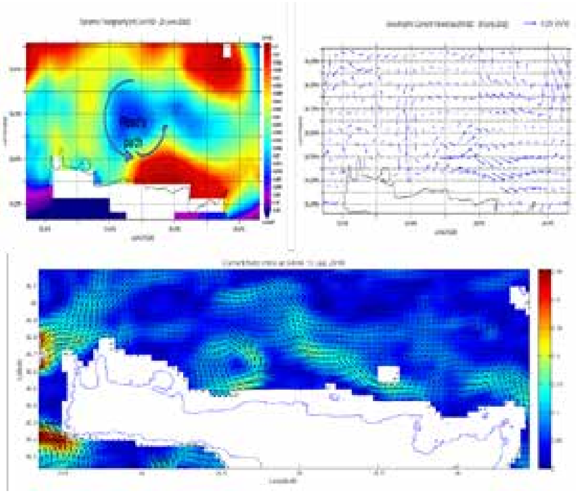

Figure 2 Satellite SSH vs 6900795 trajectory (upper left); Sea Surface Geostrophic Velocities (upper right); Poseidon hydrodynamic model output of monthly average current field at 340m depth during July 2010.

The model is based on the Princeton Ocean model (POM) and was initially developed as part of the Poseidon-I system (Korres et al., 2002). The altimeter products were produced by Ssalto/Duacs and distributed by Aviso, with support from Cnes (http://www.aviso.altimetry.fr/duacs/)

The second float deployed in the area was a PROVOR-DO type (WMO 6901881), which operated for 6 months (November 2013 – March 2014) before its signal was lost in the Eastern straits of the Cretan basin. During the first two months of its operation, its trajectory overlapped with the path of 6900795 float. A comparison of the measured profiles for two sub-regions (South-center and South-east) between 2011 and 2013 shows significant alternation of the physical properties. In 2011, the intermediate layers (100 – 600m) are presented saltier and slightly warmer than what has been recorder in the end of 2013. At surface and subsurface layers, the picture is reversed with higher salinity values recorded in 2013 especially in the South-central part of the basin (figure 3). The large salinity averaged differences (~0.1 psu) of the intermediate layers between the two periods, result in the discrete water masses signals in the T-S diagram constructed using the profiles of each float in the two different sub-regions (figure 4). The high-salinity core water (S > 39.1) with characteristics similar to CIW, that occupied these layers during 2011, is replaced by water masses in the same density range (29.10–29.2 kg·m−3), indicating a LIW intrusion which is associated with temperature and salinity in the ranges of 14–15 ^{o}C and 39.02-39.07 psu, respectively. This is also supported from the comparatively low dissolved oxygen concentration recorded in the layers below 100m during November-December of 2013 from the PROVOR-DO float which conducted a West-east transect following the Cretan coastline. A spur of dissolved oxygen maximum (215-220 μmkg^{-1}), highly correlated with the boundaries of the halocline, is recorded while the underlying layers present values below 205 μmkg^{-1} (figure 5). This can be associated with inflowing LIW from the northwestern Levantine Sea which is poorer in oxygen, than the intermediate and deep waters of the Cretan Sea (Souvermezoglou et al., 1999).

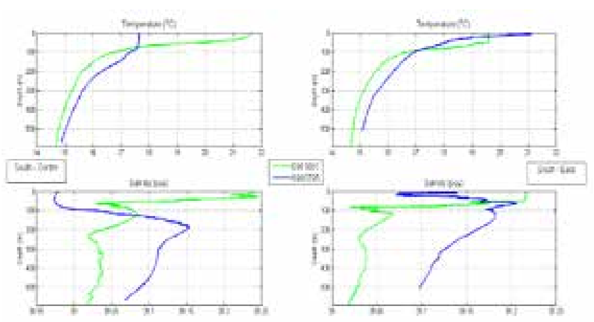

Figure 3 Average Temperature (up) and Salinity (down) profiles for the years 2011 (blue) and 2013 (green) for the Central (left) and the Eastern (right) part.

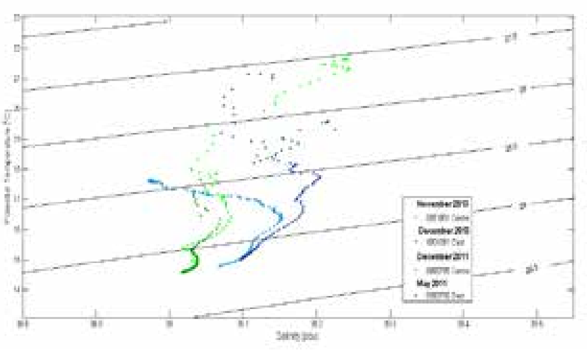

Figure 4 Θ-S diagram for the Central (2011 light blue, 2013 light green) and the Eastern (2011 dark blue, 2013 dark green) part.

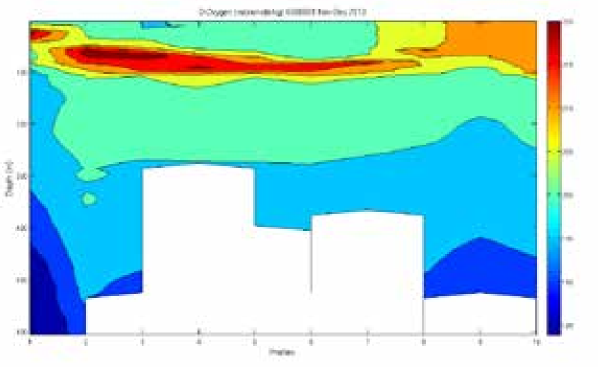

Figure 5 Dissolved oxygen concentration measured by 6901881 float during a centre to east transect along the Cretan coastline.

3.2 Deployments in the Ionian Sea

The two floats, deployed in the Northern and Central Ionian basin at the end of 2013 and the beginning of 2014, performed a northward movement along the coastlines of Albania and Greece respectively that intensified during the second half of 2014. This cyclonic circulation in the Ionian is bringing saltier waters to the southern boundaries of Adriatic that originate from the Aegean and Levantine basins. This is confirmed from the comparison on these two floats averaged profiles for a 6-months period (March-August 2014) that shows differences in both temperature and salinity vertical distribution. Regarding salinity a strong LIW signal is presented in the central part that exceeds 39 psu at 200 m depth while at the northern boundaries this is still present reaching a maximum of 38.9 psu at 300 m (figure 6). The largest temperature differences (~1.3 °C) are shown within the 100 m depth zone which is also depicted in the density field with the northern part presented denser in these layers (figure 6). A Θ-S diagram was constructed from all the profiles between 100 and 1000 m depth in two discrete depth layers (figure 7). The

Northern Ionian waters are denser in the 100-500 m layer while in the 500-1000 m layer this picture is reversed due to the saltier deep waters of the central part. Near 1000 m depth, the northern waters are presented denser (>29.2 kgm^{-3}) with characteristics similar to Adriatic Dense Water (AdDW) which is very likely to reach the Ionian in these depths. The 29.18 kgm^{-3} isopycnal at approximately 1100 m depth can be considered as the lower limit of the AdDW density in the Ionian (Gacic et al., 2014).

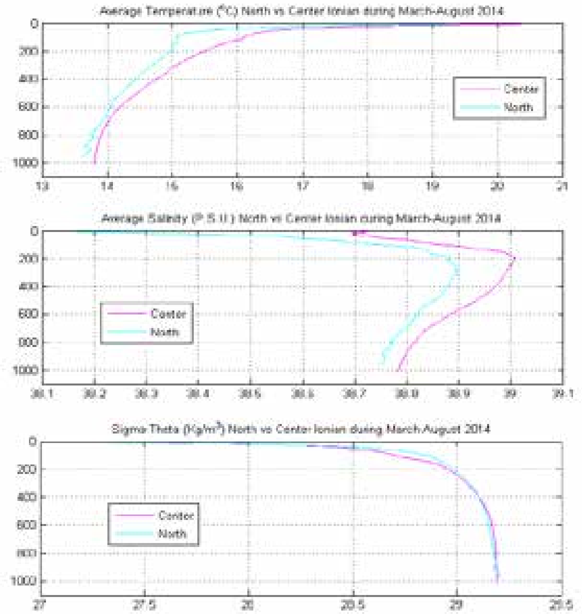

Figure 6 Average profiles of temperature (up), salinity (middle) and density (down) for the floats 6901882 & 6901883 (March – August 2014).

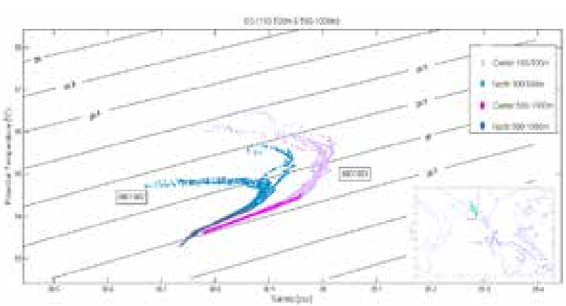

Figure 7 Θ-S diagram from the floats 6901882 (blue) and 6901883 (magenta) during March-August 2014 in the northern and central parts of the basin respectively. Light colors denote the 100-500 m zone; dark colors denote the 500-1000 m zone.

4. Conclusions

The measurements of the Greek floats in the two basins show significant variability with signals of different origin water masses at subsurface and deeper layers. In the Cretan basin, mesoscale circulation patterns together with a number of smaller mainly cyclonic subsystems are traced in the floats trajectories. Regarding the upper layers, the westward displacement of the Cretan cyclone together with an inter-annual variability in the salinity signal, traced all along the central part of the basin until the South-east, are the most important presented features. For the Ionian basin, the presence of a strong salinity core, with characteristics similar to what was observed during 2009 and 2010 in the south part (Kassis et al., 2012), together with a northward circulation in intermediate layers, depict the transfer of LIW in the basin towards its northern boundaries coinciding with the presence of a deep-layer dense water similar to AdDW.

The new-formed Greek Argo RI can play a significant role through additional float deployments that will fill gaps in under-sampled areas of the Eastern Mediterranean such as Aegean and Ionian basins. This network of profiling floats is, for the first time, providing continuous profiles of physical and biochemical parameters from these enclosed basins. The use of this data will have short and long term benefits such as more comprehensive surveys of sea water processes and interactions together with more enhanced operational forecasting and climate studies.

Acknowledgements

This work has been supported by the "Greek Research Infrastructure for Observing the Oceans – GREEK ARGO" project (ERDF 2007-2013) and the IONIO Interreg-III project funded by the European Territorial Cooperation Operational Programme "Greece-Italy" (2007 – 2013).

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Analysis of maritime-coastal severe events in Basque Country during 2014 winter

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Abstract

During the winter of 2014 many deep Atlantic depressions are formed northwest of the British Isles, deepening and moving eastward, promoting areas of high winds and generating high waves that affect large areas of the est European coast. In particular, they affect severely the Irish, Britain, French and Iberian coasts.This paper describes the most significant episodes of maritime storms that have affected the Basque Country during the winter of 2014. Meteorological situation giving rise to strong waves, its characteristics and its effects at local level are analysed.

Keywords: swell severe events, coastal damages, energetic waves, deep low, Basque Country

1. Introduction

During January, February and March of 2014, eight main wave episodes, with high significant wave heights and long peak wave periods, affect Basque coastal area. (#1) In the January 3-4 event, significant wave heights (Hs) above 5 meters were registered. (#2) In the January 6-7 event, Hs above 8 meters with wave period (Tp) over 20 seconds were registered. (#3) On January 27-28, Hs werearound 7-8 meters. (#4). On February 1-2 Hs werearound 7-8 meters concurring with spring tides. (#5) On February 5 and (#6) 8-9 events, Hs of 9-10 m reached the Basque coast. At the end of the winter season, two consecutive episodes affected the area, the first one (#7) taking place on February 28 - March 1 and the last one (#8), which hadthe highest Hs of the whole studied period, taking place on March 3-4 (see Fig 1 and Tab I).

#	Date	Synoptic features	Maritime features	Severe weather clasification	Hs max (m)	Peak Period (s)	Energy (Kw/m)	Wave direction	Max tide level (m)	Hs max at high tide (m)	Peak period at high tide (s)	Barometric component (cm)	Euskalmet warning level	Effects	Stimated Damages (k€)
#1	3-4/01/2014	Z, BL	OW S	High swell	7,2	16-18	432	NW	4,8	6,9	16,0	0	orange	strong	5.005
#2	6-7/01/2014	Z, BL	OW S	High swell	10,1	23	1150	NW	4,0	9,5	23,0	-2	orange	moderate	270
#3	27-28/01/2014	Z, BL	SMW HF	NW Gale	7,9	16-17	505	NW	3,7-4	6,6	17,0	4	orange	moderate	608
#4	1-2/02/2014	Z, AH	SMW HF	High swell	8,5	20	708	NW	4,9	8,1	19,0	-4	red	strong	18.559
#5	05/02/2014	Z, BL	OW S	High swell	9,5	17-18	774	NW	3,9	8,0	17,5	0	orange	light	
#6	8-9/02/2014	Z, BL	SMW HF	High swell	10,5	20	1080	NW	3,3	10,3	18,5	2	orange	light	
#7	28/02-01/03/2014	Z, BL	SMW HF	Wind storm	8,9	15-17	821	NW	4,4-4,8	6,1	18,5	0	orange	moderate	
#8	3-4/03/2014	Z, BL	SMW HF	NW Gale	11,1	19	1147	NW	4,6-4,8	8,6	18,5	3	red	strong	821

Z: Zonal, M: Meridian SMW HF: Strong maritime wind with high fetch, SMW LF: Strong maritime wind with low fetch, OW S: Offshore wind with swell, WW HS: Weak wind and high fetch
BL: Britanic low, BBL: Bay of Biscay low, AH: Azores High

Table 1 Characteristics of events.

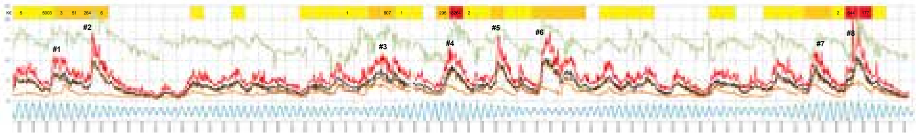

Figure 1 Daily evolution of wave height parameters in m(Hs in black, swell and wind component in brown, Hs max in red) and peak period in second (Tp in greens), including damages cost (in K€) and warning level issued (yellow, orange, red).

2. Analysis

2.1 Meteorological

In general, synoptical characteristics of analyzed events are very similar (see Tab I). They are produced under very intense zonal circulations, sometimes with some light undulation, but usually quite rectilinear. Under these intense circulations, deep low pressure systems are formed (many times as explosive cyclogenesis) with general eastward movement.

2.2 Maritime

General characteristics of waves reaching the Basque Country coast during analyzed events are also quite similar mainly related to strong maritime wind and high fetch (see Table I). Swell episodes from NW with Hs above 7 m and Tp surpassing 15s are registered. Differences among episodes deal with coincidence of high waves with spring tides (in some cases), peak periods and wave energy. In general, all spectra maximum energy is at low frequencies, reflecting that the main component is the Northwest swell that reaches the Basque Country at high periods (see Fig 2).

2.3 Effects and damages

This unusual winter with numerous and continuous coastal-maritime severe events left 44 days with some kind of maritime-coastal warning level issued, 3 days for red level, 14 days for orange level and 27 for yellow (see Fig 1). Warnings, alerts and alarms issued by Euskalmet and Emergencies Authorities (see Tab I and Fig 1), mass media information and preventive measures taken by municipalities and Basque Government authorities minimized human losses to just one person.

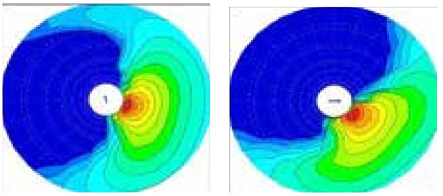

Figure 2 Energy wave spectral distribution for Donostia buoy (BDO) location during #2 and #4 events.

This accident occurred when a person was dragged and beaten by a wave while walking in a public closed area of Bermeo harbor during event #3. On the other hand, 2014 winter coastal-maritime severe events left widespread material damage along the Basque coast. The most devastating event considering economic losses is #4. During this event damages were generalized and affected more than twenty different municipalities in the Basque coast. This event is one of the most severe that ever happened in the area, with damages more than 18 million euros.

3. Summary and conclusions

The generation location, depth and path of deep low pressure systems formed in the Atlantic at northwest of British Islands configure the weather characteristics and waves that affect Basque Country. As it is well known, waves characteristics during those severe events arethe result of the fetch and the intensity and duration of the wind in the generation area.

In the case of events #2 to #6 deep depressions (Christina, Lilli, Nadja, Petra and Ruth) were generated by explosive cyclogenesis with trajectories at lower latitudes than usual, generating very energetic waves that reached the Cantabric and Basque coast. During the studied episodes, storm surges were insignificant on the Basque Coast, since trajectory of storms was far enough (generally through the British Islands).

Severe weather, related to maritime-coastal aspects during winter 2014, are exceptionally adverse for the Basque country. Coincidence of high waves with spring tides (in some cases), high peak periods, wave energy, and clustering and persistence of severe episodes are exceptional. Mean significant wave height and mean peak period for this winter are higher than in the past ten years.

February 2 event is the worst episode, due to waves, ever recorded. It is complicated to link damages and events that occurred after February 2.

In the March 3-4 event, the highest wave heights of all analyzed events are registered, damages are important but not catastrophic because maximum waves did not arrive exactly at maximum spring tide time. At the west of Basque coast in the western Spanish Cantabrian coast maximum waves are coincident with high tide time during the afternoon of day 3, generating many more problems.

Economic losses during this winter are estimated moreat than 50% of losses for the last ten years. The distribution of damages along the Basque coast is variable, although more than 90% corresponds to Bermeo (39%), Donostia (30%), Zarauz (8%), Orio (8%) and Ondarroa (7%). Damages correspond mostly to harbors (55%) and shops, stores, houses and offices (31%).

Acknowledgements

The authors would like to thank the Emergencies and Meteorology Directorate - Security Department - Basque Government for public provision of data and financial support. We also would like to thank all our colleagues from EUSKALMET for their daily effort in promoting valuable services for the Basque community and the Insurance Compensation Consortium for damages-cost data provision.

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Destructive combination of strong waves and tides in the Basque Country: 2 February case.

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Abstract

On 31 January a deep depression was generated in the Atlantic, northwest of the British Islands, which deepened rapidly with a minimum pressure value around 940 mb. This storm moved tothe east to reach the northwest of Britain and then moved northward. This storm generated strong waves traveling along the Atlantic reaching the Basque coast as swell, especially during the morning of February 2. The significant wave height exceeded 7 meters with peak wave periods of about 20 seconds at the most critical moment. In previous wave storms have been recorded wave heights similar to this event, but the singularity of this episode was the coincidence of the height of the waves with the extraordinary height of the tide. The waves reached its maximum value at the same time when high tide occurred, causing the waves to easily surpass structures, showing unusual strength and creating widespread damage at different points along the Basque coast. In this paper we analyze the synoptic situation which leads to strong waves, wave characteristics that affect the Basque coast and its coincidence with spring tides. We also describe the widespread damage caused by this storm, which can be considered as one of the worst wave storm occurred in the Basque Country.

Keywords: swell, high tide, explosive cyclogenesis, significant wave height, Basque Country

1. Synoptical analysis

On January 31, 2014 a deep storm (Nadja) was generated in the Atlantic northwest of the British Islands, which deepened rapidly, meeting the criteria of explosive cyclogenesis, reaching in its center about 940 mb. It moved eastward until reaching the northwest of the British Islands and later on northward (see Fig 1).

This depression formed within the strong zonal circulation that prevails during most part of the 2014 winter. The February 1-2 event, synoptically could be classified as maritime type, with westerly winds, zonal circulation, and pressure patterns dominated by the Azores anticyclone. Although the swell that affects Cantabric area these days is generated by Nadja, which is situated in the vicinity of the British Islands 24-36 hours before swell arrival at the Basque coast. However?, in this case, adversity is determined just by swell.

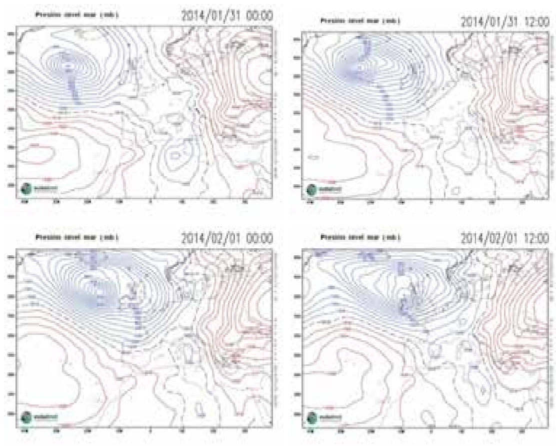

Figure 1 Evolution of sea level pressure (31/01 to 01/02 at 00:00 and 12:00 left to right, top to down).

2. Wave characteristics

onFebruary 1 in the afternoon, the significant wave height starts rising, the first prevailing wind wave, due to the strong westerly wind blowing during the middle hours of the day. But quickly the swell component began to be the most relevant component. At the time of high tide, in the afternoon of day 1, when the sea level is relevant (Puerto de Bilbao 4.61 m), the significant wave height began to approach 6 meters, although still with relatively low periods (peak periods about 11-12 seconds). At night, the significant height continued to rise. At the end of the day significant height reached 8 meters and peak wave period 15-16 seconds. The worst part of the episode happened during the morning of day 2, when the significant wave height, due to the swell, reached over 8 meters and the peak wave period reached 20 seconds (see Figure2). The arrival of this high-energy wave coincides with an exceptionally high tide (4.94 m Puerto de Bilbao), one of the highest in the year making this event the most severe and harmful in recent years.

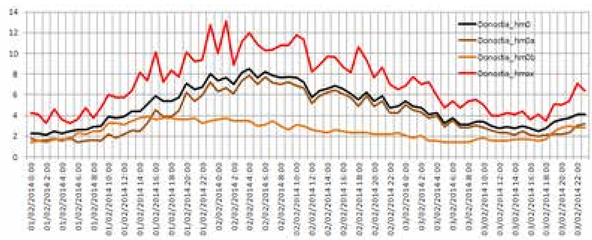

Figure 2 Evolution of significant wave height (hm0), swell (hm0a), wind wave height (hmob) and wave maximum height (hmax).

During day 2 the wave height and period decrease. Although sea level at the time of high tide in the afternoon remained high (4.54 m Puerto de Bilbao) it was 40 cm lower than in the morning. This fact combined with lower heigh waves and periods in the afternoon does not create major problems.

In summary, the waves that affect Basque country coastal area, comes in the form of swell, generated far away from our area, coming with high periods and therefore with high energy. The wave height is not exceptional, but coincidence with exceptional high tides produces devastating consequences.

In the wave spectrum at Donostia buoy, we can see a narrow range in which the energy is concentred at low frequencies, indicating that the wave is determined by swell with high period and high energy (see Figure 3). This swell comes from a northwest direction (290-300 º).

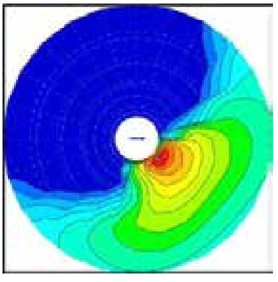

Figure 3 Wave spectrum at Donostia buoy through Euskalmet wave operational modelling system (Wavewatch-III based).

On other episodes affecting the study area, the wave heights have been superior to the values of this event, but exceptionality of this episode is the time coincidence of strong waves and high periods with the extraordinary tidal height, since this is one of the highest tides of the whole year. The waves reached their greatest height and period at the same time that high tide occurred, causing the waves to hithard on the coast, easily bypassing structures, roads and promenades, creating extensive damage on many parts of the coast (see Fig 4).

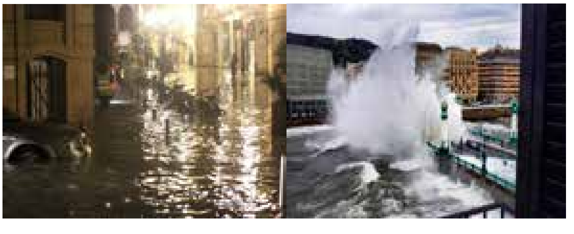

Figure 4 Waves affecting Donostia during the episode.

3. Summary and conclusions

The prediction of wave characteristics in advance and activation of red alert during 6 hours, centered on high tide time in the morning of day 2 are entirely appropriate, minimizing damage especially for human. Damage to coastal infrastructure is inevitable when strong waves and tides bind.

Regarding the effects, this is the worst event of the last 10 years. The unique event closer to this one, but with lower registered damages, is 10-11 March 2008 event, when the wave height was higher but coincident with lower spring tides, and lower periods.

A combination of high enough wave heigth, without being exceptional, with high peak wave periods and high tides are much more destructive than extreme wave heigth matching neap tides.

Acknowledgements

The authors would like to thank the Emergencies and Meteorology Directorate – Security Department- Basque Government for public provision of data and financial support. We also would like to thank all our colleague from Euskalmet for their daily effort in promoting valuable services for the Basque community and the Insurance Compensation Consortium for damages cost data provision.

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Euro-Argo : a new European Research Infrastructure for climate change research and operational oceanography

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Abstract

In May 2014, the Euro-Argo research infrastructure became a new European legal entity (Euro-Argo ERIC). The objective is to organize a long term European contribution to the international Argo array of profiling floats. Argo is now the most important global in-situ observing system required to observe and understand the role of the ocean on the earth climate. Euro-Argo is also an essential component of the in-situ infrastructure required for the Copernicus Marine Core Service and its MyOcean and MyOcean2 projects (operational oceanography). Euro-Argo will thus develop European contribution to the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS).

Keywords: Argo, In Situ, ERIC, Operational Oceangraphy, Climate Research

1. Introduction

The Argo system is based on an array of profiling floats which measure, every 10 days, temperature and salinity throughout the deep global oceans, down to 2,000 meters and deliver data both in real time for operational users and, after careful scientific quality control, for climate change research and monitoring. Argo data policy is fully open and guarantees a free access of the data to all interested users. Argo is now the major, and only systematic, source of information and data over the ocean's interior. Argo aims to establish a global array of in-situ measurements integrated with other elements of the climate observing system (in particular satellite observations) to:

- detect climate variability from seasonal to decadal scales and provide long-term observations of climate change in the oceans.
- provide data to constrain global and regional ocean analysis and forecasting models
- provide data to initialize seasonal and decadal forecasting ocean/atmosphere coupled models and to validate climate models.
- provide information necessary for the calibration and validation of satellite data.

2. The EURO-ARGO ERIC

The Euro-Argo research infrastructure organizes and federates European contribution to Argo.

Euro-Argo carried out from January 2008 to June 2011 a preparatory phase project, funded through the EU 7th Framework Research Programme, whose main outcome was to agree on the legal and governance framework under which to establish the research infrastructure (i.e. as an ERIC), and to draft an implementation plan for the first years of operation.

The Euro-Argo Research Infrastructure (RI) is a distributed facility (see http://www.euro-argo.eu). It comprises a central facility (C-RI) based in France (Ifremer, Brest) and distributed national facilities. The C-RI was officially set up as an ERIC (European Research Infrastructure Consortium) on the 5th May 2014 and signed by 9 European countries (Finland, France, Germany, Italy, Netherlands, Greece, UK, Norway, Poland,) which have agreed to form this new legal European entity to organize a long-term European contribution to Argo as well as the data processing of all these European floats

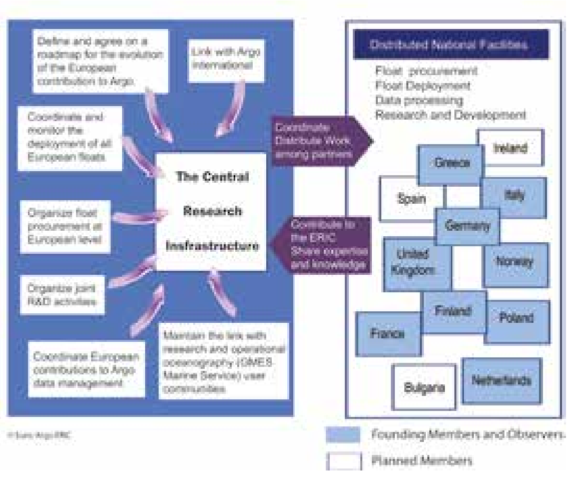

Figure 1 The EURO-ARGO distributed Research Infrastructure

3. EURO-ARGO ERIC role and development

The Euro-Argo ERIC priorities are:

- Priority 1 : maintain and consolidate the global array and regional coverage for European seas. Increase European contribution from 150-200 floats to 250 floats/year and consolidate the data processing system.
- Priority 2: prepare the evolution of Argo to address new scientific and operational challenges. Start implementing the new phase of Argo (biogeochemistry, deep ocean, Arctic).

It will develop in two phases. In the ramping up phase (2014-mid 2015) the central entity (i.e. the Euro-Argo ERIC) will work with a reduced budget funded by the Members and Observers. This budget will allow to fund a programme manager a project assistant at 25% and one full time position (project scientist), and to provide basic support to the Euro-Argo RI (e.g. organization of workshops, maintenance of WWW sites including educational WWW site). In the second phase (2015-onwards) we expect a significant development of the Euro-Argo ERIC up to five persons. In line with the European nature of the infrastructure, a direct EU funding should be set up to complement national contributions and to ensure that Euro-Argo fulfils its objectives: deploying 250 floats/ year (i.e. 25% of the overall international effort), providing high quality observations for ocean and climate research and the GMES/Copernicus Marine Service, preparing the European contribution to the next phase of Argo.

4. Benefit for the European community

Thanks to a stronger European coordination of float deployments EURO-ARGO ERIC will ensure that certain areas are not overpopulated at the expense of other regions or the global array. Euro-Argo will deliver a stronger and more coherent European contribution to float technology development, with particular emphasis on European needs (e.g. sampling under ice, bio-geochemical sensors) leading to improved capability, performance and lifetime.

Figure 2 In blue Euro-Argo RI contribution to Argo (Nov 2014)

The two European Argo data processing centres (Coriolis and BODC) will be strengthen to (i) ensure they are able to process all European floats and deliver the data to users, and (ii) ensure that Europe is able to fulfil its data processing commitments to the global programme (Coriolis GDAC, North Atlantic and Southern Ocean Regional Centres).

Euro-Argo will provide a mechanism for developing consistent inputs and a more concerted European voice into the international Argo programme, resulting in a stronger European influence on how Argo develops in the future.

It will also provide the means to sustain important outreach activities (web-site, brochures, educational materials etc.) needed to explain to school children and the general public the importance of observations from the oceans towards dealing with climate change and other environmental issues.

5. Dual Use : Research and Operational Oceanography

The oceans have a fundamental influence on our climate and weather, both of which are affected by changes in the currents and heat content of the ocean. Argo is a unique system to monitor heat and salt transport and storage, ocean circulation and global overturning changes and to understand the ability of the ocean to absorb excess CO2 from the atmosphere.

Argo is the single most important in-situ observing system required for the Copernicus Marine Core Service (MCS). Argo and satellite data are assimilated into MCS models used to deliver regular and systematic reference information on the state of the ocean for the global ocean and the main European seas

6. Future extensions

Euro-Argo has set up the following priorities for the next five years

- Contribute to the global array and sampling of European regional sea. and improve European coordination.
- Work with DG MARE and Emodnet to set up a long term (7-year) EU funding for Euro-Argo
- Maximise the relevant knowledge of the Seas and Oceans, e.g. their role in a changing climate (towards deeper measurements).
- Continue working with the user communities Develop/extend the user base. Education and outreach
- Maintain strong links with Copernicus and Emodnet.
- Prepare high quality delayed mode data sets required by ocean and climate change research.
- Improving float technology (e.g. extend life time, new sensors) and interactions with float manufacturers.
- Prepare the implementation of the new phase of Argo at European level: deep ocean, biogeochemistry and Arctic. Pilot projects, evolution of national roadmaps and new agreements at European level.
- Integration of Euro-Argo with other marine research infrastructures: towards an European Ocean Observing

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Active and Passive Acoustics for In-Situ Observations of the Ocean Status

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Abstract

Recent European policies underlined the need to improve the integration between methods and platforms used for ocean monitoring in order to overcome the disadvantages of each type of instrument and to emphasize their complementarity. Indeed, the development of methodologies for the full use of all information that can be extracted from existing measurement systems represents a promising frontier for improving the knowledge of the ocean. In particular, the use of instruments installed on moorings or floats able to listen to ambient noise could contribute to enhance the monitoring capacity of meteorological phenomena also in open ocean without the need of fixed platforms. Oceanic ambient noise measurements can be analyzed to obtain qualitative and even quantitative information about meteorological phenomena whilst backscatter echoes can describe biological activities.

The paper explores the potentiality of available acoustic data analyzing long time series of acoustic measurements acquired in the North-Western Mediterranean Sea and in Tethys Bay (Antarctica).

Keywords: in-situ observations, ocean monitoring, underwater acoustic.

1. INTRODUCTION

An effective monitoring of the status of the ocean requires the integration of available observations into an overall system capable of assimilating data originated through a variety of different and multidisciplinary approaches (European Commission, 2013).

Remote sensing techniques give a noteworthy contribution to ocean forecasting models and, in general, to operational oceanography, and equipped buoys, moorings and floats are an effective resource to acquire in-situ measurements for characterizing the ocean status.

Well consolidated methodologies are available for global monitoring of physical ocean properties, whereas knowledge on biochemical characteristics and meteorological phenomena over the ocean is far from thorough (Ducklow et al., 2009).

An answer to this need can be found by exploiting the potentiality of underwater acoustic systems, both active and passive, to listen to ocean noise and to interpret the sound or the received echoes in order to improve knowledge on biological activities, meteorological phenomena at sea and the potential harmful impact of human activities on the ecosystem (Ross, 1993).

2. Data and methods

In order to assess the capability of revealing and characterizing ocean surface processes through measurements of ambient noise in open sea, an autonomous passive acoustic device was deployed on the off-shore buoy W1-M3A (Pensieri et al., 2013) moored in the Ligurian Sea, a deep basin showing peculiar hydrodynamic and meteo-oceanographic features and which is subject to autumnal flood hazard.

Spectral features of acoustic data were used to detect, classify and quantify the processes responsible for ambient noise in the ocean such as wind speed, rainfall and ship passages.

Passive and active acoustics data can be used to monitor marine animal populations, in particular species that use sound to communicate and hunt, and for deepening the knowledge of migratory processes of zooplankton population.

For this twofold aim, passive measurements of ambient noise were performed in Tethys bay (Antarctica region) and an acoustic doppler current profiler was moored in the Ligurian Sea.

In addition, the potentiality of active acoustic devices to monitor the sea state was proven through the development of a system based on a triplet of upward looking echosounders to measure sea waves statistics from a spar buoy in open ocean.

3. Applications and results

3.1 Wind field and rainfall inferred from underwater sound

Wind is the most common physical phenomenon producing sound at the ocean surface and its spectral characteristics cover a wide frequency band from below 1 Hz up to 50 kHz. On the other hand, precipitation events over the oceans contribute to underwater ambient noise in the frequency band between several hundred of Hertz to more than 20 kHz. To estimate type and amount of rainfall in open ocean using sound produced by drops splashing at the surface, and to infer wind regime blowing over sea, acoustic data were simultaneously acquired to high resolution rainfall and wind in-situ observations. The direct comparison showed a very good correspondence between the recorded high values of pressure levels and rain episodes for all analysed frequency bands and the same, but at lower frequency ranges, for wind speed.

3.2 Ocean waves statistics estimation

Several methods are usually employed to estimate ocean waves in shallow water but due to the difficulties of managing any device with extension in deep waters, wave height measurements in open sea are often collected through remote sensing techniques instead of in-situ measurements. An innovative method based on the use of a triplet of echosounders in an upward looking configuration deployed on a spar buoy was developed.

Obtained estimates were compared to co-located Wave Wacht III model forecasts showing very good correlation, with an overestimation of the model for wave higher than 2 m and an underestimation for calm sea state (Figure 1).

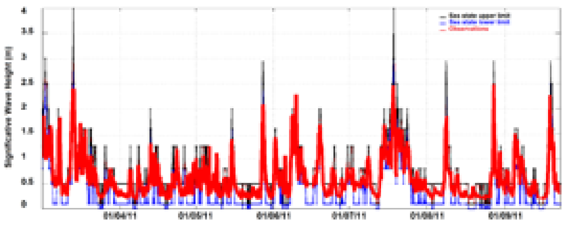

Figure 1. Time-series of in situ sea wave observations (red line) compared with the upper (black line) and lower (blu line) limit of the corresponding Wave Watch III model forecasts.

3.3 Biological activities monitoring

Passive and active acoustic measurements can contribute to listen to and to interpret ocean noise related to biological activities such as the sound emitted from marine mammals and the behaviour of zooplankton.

In order to exploit the potentiality of acoustics for biological studies, a hydrophone was deployed in the uncontaminated area of Tethys Bay (Antarctica). Measurements allowed to identify the presence of Weddell and Crabeater Seals and to detect their calls diversified for pattern, frequency band, duration, rhythm and shape.

Backscatter echoes and the corresponding vertical velocities provided by an acoustic current doppler profiler moored in the open Ligurian sea were analysed in order to deepen the knowledge about zooplankton migration.

The main pattern pointed to a nocturnal migration, with zooplankton organisms occurring deeper in the water column during the day and shallower at night, but also, twilight migration was observed.

3.4 Ship and boat noise monitoring

Ships and boats are the main source of anthropogenic background sound levels in the ocean. Larger ship signatures show louder noise at lower frequencies with broad spectral bandwidths whereas the highest frequency content is lower for ships at longer ranges from the receiver, as higher frequencies attenuate more with range.

Underwater acoustic measurements were correlated to ship traffic provided by the Automatic Identification System (AIS).

Results showed that signature of ships passing close to the listening point had greater received levels with an increase in the higher frequency content of the signal. Signature of ships passing at larger distances from the listening point showed lower levels with less higher frequencies in the signal (Figure 2).

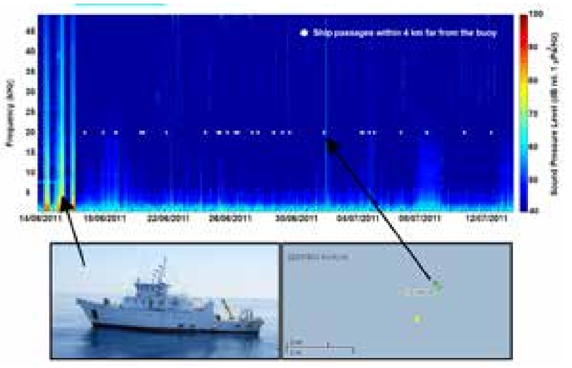

Figure 2 Time series of sound pressure levels acquired from June 2011 up to July 2011 in the open Ligurian Sea. White dots correspond to ship passages within 4 Km far from the listening point.

Acknowledgements

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New Tools for Dissolved Oxygen, Fluorescence and Turbidity Sensors Testing and Intercomparison

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Abstract

The protection and management of the oceans require a comprehensive understanding of processes and conditions that affect the state of the marine environment. Long term in-situ monitoring of bio-geo-chemical properties of the ocean is a challenging task, not only due to “hostile” marine environment, but also due to the instruments accuracy and precision needed to obtain useful data for processes analysis as well as for assimilation into forecasting models. Thus, it is fundamental to develop and test comparison and validation tools for assessing the performance of bio-geo-chemical sensors at each laboratory managing ocean observing systems.

To this aim, two different tools for testing and comparing multiple dissolved oxygen and fluo-turbidity sensors at the same time have been developed and tested at the HCMR calibration facility in Crete within the framework of the European Commission project JERICO.

Keywords: calibration, dissolved oxygen, fluorescence, turbidity.

1. Introduction

The ocean monitoring strategies carried out by the European countries differ widely in terms of observed variables, temporal and spatial resolution making difficult to obtain an overall picture of the state of the european seas. Several efforts were carried out in the past to deepen the knowledge of the pysical properties of sea-water and to develop instruments and methodologies to be used in the field of operational oceanography.

Technologies and methods to assess biogeochemical properties of the ocean are not so mature to be used on long term basis although some parameters can be measured through non-intrusive and automatic, partially miniaturized, relatively low-power, in-situ sensors (Lindstrom et al., 2012). Among the other parameters, dissolved oxygen, fluorescence and turbidity have a strong scientific relevance and are among the most important “bio” variables on which the implementation of ocean observing systems must rely on (Mowlem et al., 2008).

To this aim new tools and procedures, devoted to the intercomparison and intercalibration of dissolved oxygen sensors and fluo/turbidimeters were jointly developed by the National Research Council of Italy in Genoa and the Hellenic Center for Marine Research in Crete (Greece). This work also optimizes the management of sensor pool to be deployed on the offshore W1M3A and E1M3A infrastructures, part of an international network of fixed open ocean operational platforms (Bozzano et al., 2013).

2. Technology

Two innovative different software and hardware tools for laboratory calibration/intercomparison of dissolved oxygen and fluorescence/turbidity sensors were developed. Both tools are based on the same hardware acquisition system capable of collecting simultaneously analogue and serial signals.

For dissolved oxygen tests, the hardware equipment comprised a calibration tank equipped with an immersion circulator and two aerators, two optical oxygen probes used as reference, a submersible pump and an acquisition system (Figure 1a). The developed software tool allowed the acquisition of analog and serial data, also checking in real-time oxygen saturation in the tank. It was developed to compare up to 8 probes arranged in different configurations for several calibration points.

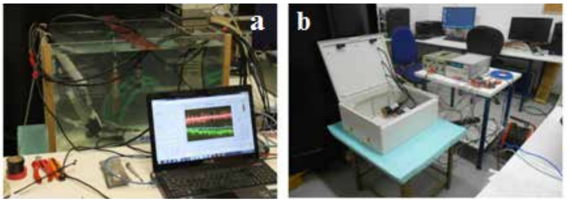

Figure 1 Instrumental set-up for the test of (a) dissolved oxygen probes and (b) fluorescence/turbidity sensors.

The equipment for the fluorescence and turbidity tests was based on a new chamber specially designed to host up to 5 sensors, a recirculation system controlled by a pump and an acquisition system (Figure 1b). The implemented software tool was capable of retrieving analog and serial measurements from different probes operated in the same chamber with the same known concentration but at slightly delayed temporal intervals to avoid possible errors due to multiple reflections.

3. Dissolved oxygen test

Dissolved oxygen concentration in water is often used as a benchmark indicator of water quality since it is critical for the life processes of nearly all organisms.

Often laboratory tests are made in a very controlled environment with a set-up different from the real one in which the sensors will be deployed. To test sensors as close as possible to the operational conditions, several possible deployment configuration were tested during the experiment.

The tank was filled with sea water made homogenous through an immersion circulator. Two aerators were switched on to increase oxygen concentration and turned off to facilitate low dissolved oxygen concentrations. Two pairs of dissolved oxygen sensors each flushed by a submersible pump and two optical dissolved oxygen sensors positioned as close as possible to the water intake of the duct completed the set-up. The simultaneous acquisitions of analogue voltage provided by the oxygen probes allowed the real-time processing and visualization of the concentration and saturation and a real-time comparison with the reference probes. Water samples were taken at stable oxygen concentration to be analyzed through Winkler tritation in order to have reference values. Results obtained with different configurations at the same concentration point were compared to minimize the gap between real-time dissolved oxygen concentrations and reference values.

4. Fluorescence and turbidity test

Fluorescence provides information on growth rates of phytoplankton communities. The practice of such sensors to estimate chlorophyll concentration for long term in-situ deployments is extremely inaccurate unless precise calibrations are made in laboratory.

Turbidity can be defined as the phenomenon where a specific portion of a light beam passing through a liquid medium is deflected from undissolved particles. The deflection is generally a function of size and shape of the particles and for this reason field calibration is highly recommended.

In order to quantitatively compare fluorescence and turbidity observations acquired by the W1M3A and the E1M3A observatories, a new methodology for fluorometer intercomparison was developed. The specifically designed chamber was filled with deionized water, the pump was switched on for 1 minute before measurements to guarantee an homogenous mixing and the temperature was controlled at each calibration point. Different quantities of Chlorella culture and volume of solutions of Disodium salt form of fluorescein were tested acquiring simultaneously voltage and raw count. Test for turbidity were made progressively pouring different volumes of a Formazine primary standard at 500 NTU.

5. Results and conclusions

The tests evidenced that optical dissolved oxygen sensor used as reference were generally in a very good agreement with oxygen concentration determined by the Winkler method although probes under test showed an increasing offset as oxygen concentration increases.

Fluorescence tests evidenced higher values with respect to those reported in the datasheet, and using the Uranine a scale factor of about one order magnitude higher was found (Figure 2a).The use of the new calculated calibration coefficients for turbidity measurements provides a better match between reference and measured values with no dependence on turbidity value whereas the use of manufacturer coefficients introduces a linear trend (Figure 2b).

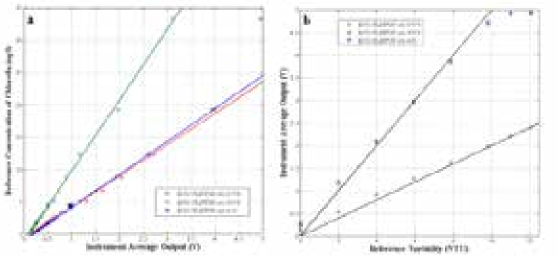

Figure 2 Results of the intercomparison between (a) refererence concentration of Chlorella and instrument analogue output voltage, (b) instrument output as reference turbidity varies.

Results demonstrated the usefulness of the developed calibration tool since it was possible to dynamically configure each sensor and to log simultaneously analogue and serial data. The new designed chamber was also capable of guaranteeing mixed water in a few seconds assuring very stable and repeatable conditions of measurement.

Acknowledgements

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 262584, JERICO.

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The W1M3A Meteo-Oceanographic Data Centre

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Abstract

Since the last decades, huge efforts were performed in the marine domain towards standardisation of data format and data exchange protocols asserting the increasing role in the society and a strong impact on science, technology and business that information systems have.

To this aim, a data centre collecting about 15 years of meteorological and oceanographic observations in the Ligurian Sea has been designed.

The information system, developed using open source tools (e.g., mySQL, PHP) contains historical data as well as measurements collected in near real-time from the fixed buoy of the W1M3A observatory. Different procedures are applied to near real-time and delayed mode data set in agreement with the WMO/JCOMM recommendations. The overall data centre is also capable of producing different types of downstream services to users and to distribute subsets of data on request or in an automatic way in different formats (e.g., MEDATLAS, BUFR, NetCDF, etc.).

Keywords: oceanographic data centre, meteo-oceanographic measurements, web-service, system architecture, data standardization.

1. Introduction

Scientific impact of data collected in the ocean by different types of platforms (fixed buoys, drifters, research or opportunity vessels, etc.) can be limited by the absence of a coordinated and agreed-upon standards for data management covering the complete life cycle of data from (near) real time acquisition of measurements to their long-term archiving (Baker e Chandler, 2008). Acquired data can be useful at the highest level only if quality checked measurements can be discovered, viewed, evaluated, accessed and retrieved by users in standard formats (Cummings, 2011).

A real time thematic assembly center containing atmospheric, oceanographic and bio-geochemical in-situ observations collected in the Ligurian Sea since 2000 has been designed and developed. Measurements were acquired during research cruises periodically carried out in the basin and collected by the W1M3A off-shore observing system.

2. The W1M3A measurements

W1M3A observatory is a multidisciplinary research platform permanently moored in the Ligurian basin, on a deep sea bed of 1200 m, 80 km from the coasts and is constituted of a surface buoy and a sub-surface mooring periodically deployed near-by the main surface buoy (Pensieri et al., 2013).

The platform monitors in a continuous and affordable way, the lower atmosphere processes and the near surface down to the ocean interior physical and biogeochemical properties fulfilling the concept of Essential Ocean Variables monitoring (Bojinski et al., 2014). The onboard acquisition system collects high resolution data that are hourly averaged on board and partly transmitted in near real-time to the receiving station ashore. Oceanographic measuring devices/sensors stores measurements internally and periodically transmits them to the acquisition system on board by means of cable when the sensors are installed on the body of the spar buoy or by acoustic link if they are installed on the subsurface mooring. The scientific payload comprises also a wave meter system and a suite of sensors to monitor biodiversity.

A subset of hourly data is transmitted in near real time and collected at the W1M3A in-situ thematic assembly center (TAC) where data are decoded and automatically quality controlled following the procedure established during the European project in which the platform was involved (such as MFSTEP, MERSEA, EuroSITES, FixO3).

All time series are retrieved during the periodical visit to the system and processed following both automatic delayed mode quality control procedures and data manager intervention to correct measurements for sensor drifting or doubt values.

Once the real time data are successfully quality controlled, they are formatted into common oceanographic standards (MEDATLAS, BUFR, netCDF) and distributed with a restricted access, to be of support to operational oceanography programs (OceanSITES, MyOcean).

3. The W1M3A database

The W1M3A data repository is a Mysql relational database used for data archiving and metadata storing to be published through the observatory portal. Near real-time raw data are processed and inserted into the database using java routines whereas php modules are used to query the database for accessing data and to visualize the measurements. The system allows the inclusion of numerical and alpha-numerical data, as well as images or multimedia files being specifically organized for managing different kind of measurements (times series and casts) and metadata (instrumentation details, sensor configuration, notes, etc.).

The base element aggregating the information is the “observation” record (single measurement of a time series, or a vertical profile) since it contains parameters having a temporal and/or spatial variability.

Each “observation” can be associated to a different number of attributes and can reside in local or remote servers (Figure 1).

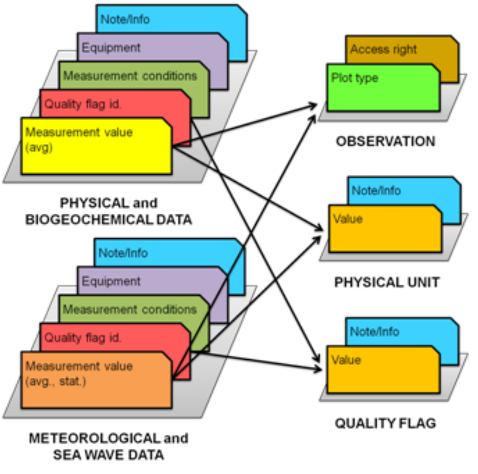

Figure 1 Scheme of the W1M3A database

The W1M3A database allows the organization of information in a flexible way, extending the number of parameters and optimizing the storage. The data base is linked to the W1M3A web server and php procedures are applied in order to manage database and tables content by the system administrator and to provide discovery, view and download services.

4. The W1M3A web-service

The thematic assembly center includes a web based application service allowing users to access data/information through the observatory portal http://www.odas.ge.issia.cnr.it. Web service data consultation is granted at two levels: a free access for generic public users and a reserved one for the data managers of the W1M3A observatory.

Public users can access the time series containing last month of near real-time measurements as well as products analysis and query the data base to visualize historical observations through temporal interval, single/multiple parameters and typology of measurement (Figure 2).

The data manager is authorized to visualize all acquired data with zoom, axes properties and download possibility, to update/modify tables inserting new parameter and to change the public access visualization. The W1M3A data base accomplished the INSPIRE Directive (European parliament, 2007) for user requirements in terms of: long term maintenance of the services, reliability of products provided, use policy: mission, quality and business rules are described.

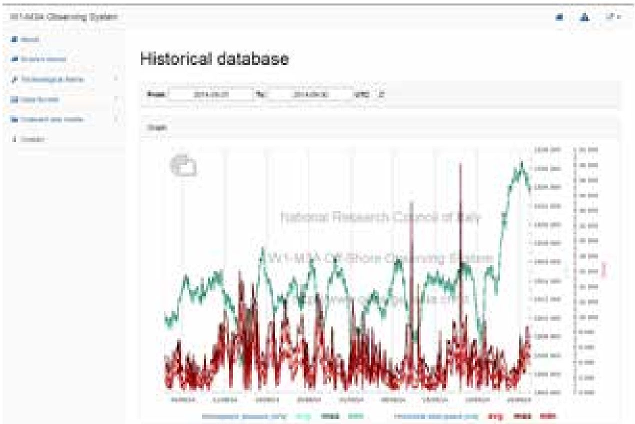

Figure 2 Example of the result of queries made by a public user for one month of atmospheric pressure and wind speed data.

Acknowledgements

The research leading to these results was partially carried out within the framework of the project FixO3 which has received funding from the European Union Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 312463.

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Progress towards the harmonization of oceanic observations from different platforms

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Abstract

The European Station for Time-series in the Ocean, Canary Islands (ESTOC) was initiated in 1994 about 100 km north of the Canary Islands at nominal position 29º 10'N, 15º30'W and 3618 m water depth. The goal was the creation of an Eulerian long time series on inter- and multidisciplinary basis, in order to monitor and help understand oceanic long-term variability in the eastern North Atlantic subtropical gyre. Time-series through monthly observations from ships, hydrographic and biogeochemical moorings, XBT and drifter launchings and glider campaigns has been collected in the area for the last 20 years. As a consequence of that, large and diverse data sets have been generated during this period of observations due to different scientific approaches. Observations from CTDs and bottle sampler, XBT probes, drifters, meteorological and biogeochemical moored sensors, ARGO floats and gliders have been collected in order to satisfy particular project objectives. Each data set has been individually essential to accomplish the project aims; but the compilation and harmonization of these data sets is essential to be used together. Our aim is the creation of standardized data sets (netCDF format) to favor its dissemination to the scientific community.

Keywords: Oceanic observation, Eastern North Atlantic Ocean, ESTOC, Hydrography and Biogeochemistry

1. Introduction

Time-series help to progress in the knowledge about the short- and long-term changes in hydrography and biogeochemistry at selected sites in the Ocean. These sites are test beds for hypotheses regarding biogeochemical processes, climate links and model configurations. Several time-series stations were established during the international Joint Global Ocean Flux Study (JGOFS) program in the late eighties and early nineties, some of them in subtropical latitudes.

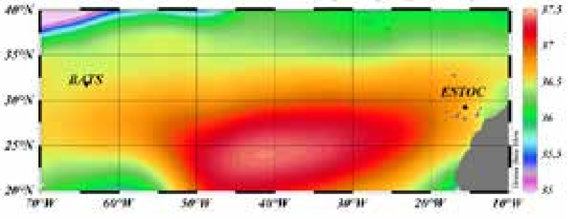

Figure 1 Location of BATS and ESTOC superimposed on an averaged distribution of the surface distribution of salinity contained in the World Ocean Atlas 2009 (20°-40ºN and 10°- 70ºW)

Time-series observations at ESTOC started in February 1994 through a monthly ship-based program and a physical array of sensors. The purpose was the creation of an Eulerian long time series on inter- and multidisciplinary basis (Cianca et al. 2007). As a consequence of this time series existence new observational programs based on oceanographic campaigns took place in the region, in order to face particular aims using the support of the ESTOC data sets. The progress in the development of biogeochemical sensors permitted to perform observational programs based on mooring arrays with higher observational time-resolutions than those based on ships. Thus, the original aims of ESTOC were extended through the different EU projects such as ANIMATE (Atlantic Network of interdisciplinary Moorings and Time-Series for Europe, MERSEA (Marine Environment and Security for the European Area), EuroSITES (European Ocean Observatory Network) and FixO[3] (Fixed point open ocean observatories). Recently the ESTOC program has added glider missions around the site, increasing strongly the observations in the region. Consequently, ESTOC currently has the widest time-series data of physical and biochemical observations in the central-eastern North Atlantic Ocean.

2. Data harmonization and dissemination

TYPE OF OBSERVATION	PROGRAM NAME	PARAMETERS	INSTITUTIONS INVOLVED	TIME RANGE
Ship- based	ESTOC time-series	T, S, DO, Chl. a, DIN, DIP, DIS, Alcalinity, pH, total CO_2, PCO_2, DIC and Pigments	ICCM, ULPGC, IEO and PLOCAN	1994- present (Carbon parameters from 1996 and pigments from 2008)
	Oceanographic cruises and process studies (CANIGO,….)	T, S, DO, Chl. a, DIN, DIP, DIS, Alcalinity, pH, total CO_2, PCO_2, DIC, Pigments and others	Diverse	Variable from 1994
Surface buoy and mooring	Canary Islands Sediment traps	PON, POC and sinking particle flux	Bremen University	1995- 1999 and 1991- 2007
	Hydrography (current and transport)	T, S and currents	IFM Kiel	1994- 2000
	Weather, Hydrography and biogeochemistry (ANIMATE, MERSEA, EuroSITES and $FixO_3$)	T, S, DO, Chl. a, Nitrate, pH, PCO_2	ICCM, IFMK, UB, NOCS, ULPGC and PLOCAN	2002 -present
Drifters	Canary Islands surface circulation	T and current	ICCM, PLOCAN and NOAA	1997- present
XBT launching	ESTOC section	T	ICCM	1996- 2004
ARGO float	Canary Islands region	CTD	IEO	2012- present
Glider	ESTOC section	CTD, DO, Chl. a, turbidity and current	PLOCAN	2012- present

Table I Summary of the main observation programs carried out at ESTOC from the beginning to present.

ESTOC time-series consist on physical and biogeochemical observations measured from 1994 (see table I). The oceanographic variables acquired from the ship-based program are mainly temperature, salinity, dissolved oxygen, chlorophyll a, nutrients, parameters of carbon system and pH. In addition, there are other parameters which were sporadically taken or were measured by other institutions through parallel programs (e.g. Particulate Organic Carbon, Particulate Organic Nitrogen, etc). Time-series from variables such as current, meteorology and some other previously mentioned, were acquired by arrays of sensors and oceanographic buoys. Finally, other platforms used to take ocean information are expandable bathitermograph (XBT), drifters and gliders.

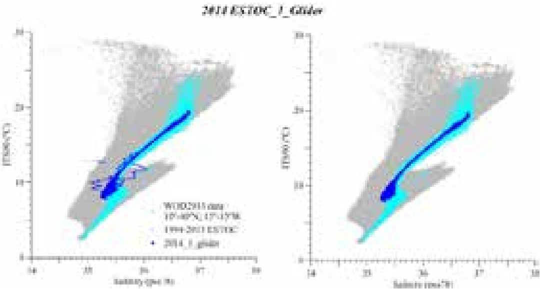

Figure 2. Glider data checked by comparison with WOD2013 data and historical ESTOC data.

The procedures to get the harmonization started with, revisions of metadata and the existing supplementary information from the data sets. The purpose of this task was to know what kind of modifications were applied from the raw files, and if the data had quality control flags allocated. Afterwards, tests of validation and comparisons with historical data sets are being done for the validation prior to generate the netCDF files. For instance, temperature observations were measured using different platforms (CTD, XBT, glider, etc). Metadata were revised, the data was checked and compared to historical records downloaded from the World Ocean Database 2013 (Figure 2). Another example is the meteorological data during 2014. This data set was compared with previous data acquired at ESTOC since 2003 (Figure 3) and quality controlled by use of the specific tests

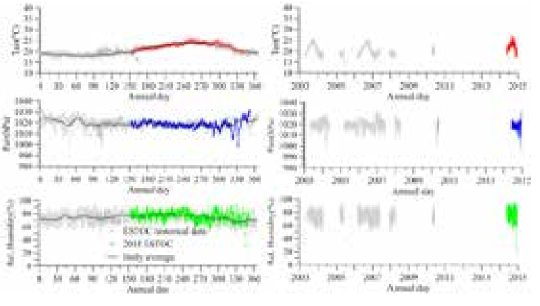

Figure 3 ESTOC meteorological data during 2014 compared to historical observations at site

Finally, the data are converted to OceanSITES netCDF format and the files catalogued using a THREDDS data server to be disseminated.

Acknowledgements

We are especially grateful for the dedicated work of the many scientists and technical staff involved in the data collection and analysis

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Measuring surface currents in the Canary Region with Fifteen years of drifting buoy data.

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Abstract

Drifter data are applied in the study of the surface circulation in the Canary Region. 131 drifter trajectories, distributed within 15 years (1998-2013), have been deployed at the ESTOC site (European Station for Time-Series in the Ocean, Canary Islands), located in the North Atlantic (29º10´N, 15º30´W). The results of the annual surface circulation in the Canaries archipelago obtained from drifting buoys have provided a good knowledge of the surface current system in this area. The Canary Current is strongly influenced by the seasonal variation of the trade winds and the resulting upwelling of northwest Africa. The study also confirms the variability in current direction as an indicator of the tendency for gyres to appear in the centre of the Canary Current. Two clear routes have been confirmed, one flowing southwards, in the lee of the archipelago, which coincides perfectly with classic descriptions; and another less known westward route, which would channel part of the volume of water flowing out towards the west without crossing the archipelago. An Operational Oceanography System is being implemented, based in the combination of observations and analyses of oceanographic data with numerical simulation, in order to try predicting the drifting object trajectories.

Keywords: drifters, surface current, numerical model, Operational System.

1. Introduction

Studies of ocean surface currents play a vital role in our present day understanding of weather and climate through the dynamics of ocean-atmosphere interaction. For many years, ocean currents have been estimated by how they carry objects. Drifting buoys have a long history of use in oceanography. The Data Buoy Cooperation Panel (DBCP) has been working for decades to design standardised drifting buoys to suit observational requirements for meteorological and oceanographic applications. Lagrangian drifters were first designed and deployed in the world oceans in the context of the Surface Velocity Program (SVP) of the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean and Global Atmosphere Program (TOGA), which became the Global Drifter Program (GDP). These SVP drifters were standardized in 1991, with small spherical hull and floats and large Holey-Sock drogue centred at 15 meters below the surface. The Drifter is now commercially available at low cost, and meets both oceanographic requirements (research: measurements of sea surface currents and sea temperature) and meteorological requirements (operational: sea surface temperature and air pressure). Currently all the data collected with these buoys are being processed to establish the patterns of subsurface currents, studying their seasonality and variability in the environment of the Canary Islands. These data can be integrated into predictive models of drifting objects, in order to provide assessment in the possible events of human or material loss due to maritime accidents.

In the eastern Atlantic, the circulatory flow of the subtropical gyres recirculates a considerable amount of water that enters this eastern basin across the central Atlantic ridge, mostly to the south and, to a lesser extent, to the north of the Azores. The main transport is concentrated in the Azores current and continues towards the east following the zonal currents of the Azores Front, where the anticyclonic flow turns and branches into three currents in the Canary Basin. The firs branch flows very close to the eastern flank of the central Atlantic ridge; the second is located in the central Canary Basin; and the third circulates around Madeira and constitutes the Canary Current.

2. RESULTS

The results of the buoys trajectories in the Canary Islands have provided a good knowledge of the surface current system in this area. The study also confirms the variability in the current direction as an indicator of the tendency for gyres to appear in the current. The buoys trajectories are used for the calibration of the results obtained by the models.

In the particular case of Canary Islands and during the last fifteen years, 131 NOAA drifters have been deployed at the ESTOC site (European Station for Time-Series in the Ocean, Canary Islands), located in the North Atlantic (29º10´N, 15º30´W). The ESTOC is submerged in waters of the Canary Current, a weak eastern boundary current in the subtropical gyre, with an extent of about 1000 Km and a speed of 10-30 cm/s. The Canary Current is strongly influenced by the seasonal variation of the trade winds and the resulting upwelling of northwest Africa. In Winter (February, March and April) the trade winds spread towards the south. In Summer (August, September and October) the centre of the high system drifts towards the north, hence moving to the north the southern boundary of the trade winds.

The result of annual surface circulation in the archipelago of Canaries obtained from drifting buoys, confirm the variability in current direction as an indicator of the tendency of gyres to appear in the centre of Canary Current. Data are binned into a 1° x 1° grid and splitted in different seasonal scenarios. Analyses are focused in the surface circulation and aim to estimate parameters such as mean intensity and standard deviations. Mean intensities estimated is 13 cm/s, have reached maximum speeds of 100 cm/s in summer. Standard deviations reached the same magnitude order, highlighting the great variability in the region's circulation.

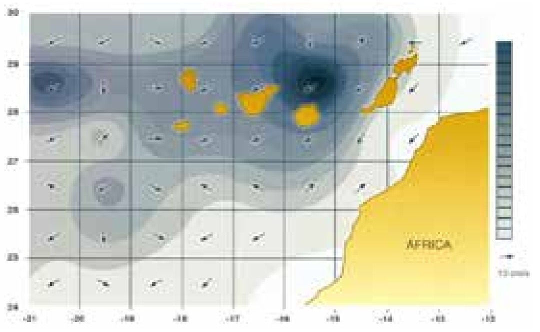

Figure 1 . Mean observations for the period 1998-2013, for each 1° x 1° longitude/ latitude grid cell. Presence of buoys (colour scale) and average current (size and direction of the arrow).

Two clear routes have been confirmed with this study of drifting buoys: one flowing southwards, in the lee of the archipelago, which coincides perfectly with classic descriptions; and another less known westward route, which would channel part of the volume of water flowing out towards the west without crossing the archipelago.

A significant number of mesoscales structures change the typical flow of the current due to the influence of the upwelling present in the African coast and the obstacles that represent the islands in the mean Circulation make. Stationary cyclonic and anti-cyclonic eddies are visible to the south of the islands. These structures can be estimated by making use of satellite altimeters (T/P-ERSJason). This information has allowed us to compare the structures observed from satellites with drifting buoys deployed in the area.

3. APLICATIONS

An Operational Oceanography System is being implemented, based in the combination of observations and analyses of oceanographic data with numerical simulation, in order to try predicting the drifting object trajectories. It is intended to cover marine emergency situations in the Canaries Archipelago waters.

Some practical exercises are being carried out with the local Search and Rescue team. The objective intended is to provide emergency teams with a probable trajectory of the drifting object. The next figure shows simulation results using one numerical model. This model predicts the drifting object trajectory, considering the wind and current effect at the exact moment. The data buoys are being used to correct the model.

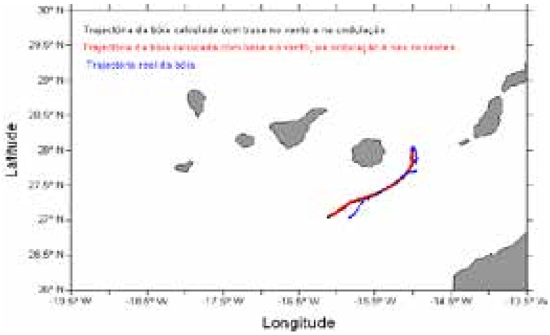

Figure 2 Buoy trajectory (in blue) and trajectory obtained of the model (in red).

Acknowledgements

The authors want to give special thanks to the Drifter Data Assembly Center (DAC) from the AOML/NOAA, for the availability of the data used to do this work, as well as the quality and control analysis of the data before was distributed. Special gratitude to Shaun Dolk and Dr Rick Lumpkin from AOML and to Mayra Pazos from the NOAA/AOML's drifter Data Assembly Center (DAC).

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R3M: The Ocean-Monitoring Strategy for the Macaronesia

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Abstract

Macaronesia region is a vast area in the East Central North Atlantic with an important interest already known for key marine and maritime sectors like research, technology, navigation, energy, border security, tourism, among others. However, logistics and support level to develop and maintain an accurate, useful and sustainable ocean monitoring strategy programme is still clearly below the needs. Despite technology advances addressed to monitor the ocean have been significantly improved during last two decades, there are still many gaps in terms of data quality, reliability, efficiency and sustainability, being significant in large ocean regions with archipelagos located notably far away one to each other. Based on particular and common initiatives for many years ago from several institutions across the region, nowadays there is a multidisciplinary group of universities, companies and institutions aiming in partnership to consolidate a regional ocean observing strategy under the name of R3M (Macaronesian Marine Monitoring Network). R3M is the reference framework to gather and manage the information collected by all existing in-situ (fix and mobile) observing platforms in the area, according to needs from specific end-users and the general public. R3M's aims, standards, formats and rules are always in line with the main international flag-ship initiatives and programmes concerning ocean monitoring.

Keywords: ocean monitoring, database, network, end-user, marine.

1. INTRODUCTION

The Group on Earth Observations (GEO) is still coordinating efforts to build a Global Earth Observation System of Systems, or GEOSS. GEO was launched in response to calls for action by the 2002 World Summit on Sustainable Development and by the G8 (Group of Eight) leading industrialized countries. These high-level meetings recognized that international collaboration is essential for exploiting the growing potential of Earth observations to support decision making in an increasingly complex and environmentally stressed world. GEO is coordinating efforts to build a Global Earth Observation System of Systems, or GEOSS. GOOS (Global Ocean Observing System) is the oceanographic component of GEOSS, being a key component the regional contributions as GRA (GOOS Regional Alliances).

2. R3M. CONCEPT AND GOAL

R3M (Macaronesia Marine and Maritime Network) is a regional -globally linked-initiative aimed to increase the quantity and quality of marine environment observations, in order to understand and predict both the phenomena that take place on it and the related environmental and socioeconomic impact. R3M is an integrative and synergic tool, making compatible and accessible to potential end-users all the marine environment observations regardless of the institution or company that carry them out. The initiative includes technological developments for all types of required instruments and tools, aiming to make them more accessible both on a technical and economical point of view. R3M has been built "from base to top", starting from the specific end-users towards general users, while keeping the goals and rules established by national and international agencies. R3M initiative is led and supported by a core group of institutions from Portugal (IH, UAC, APRAM, OOM), Cape Verde (INDP and ENAPOR) and Spain (ULPGC, PLOCAN, AEMET, IEO, Puertos del Estado), as well as by associtaed partners from other european countries (France, Germany and UK, mainly).

3. OCEAN MONITORING TECHNOLOGIES

Across the Macaronesia region, R3M integrates nowadays a large group of different autonomous platforms technologies -Eulerian and Lagrangian- (Figure 1) addressed to monitor, according to capabilities and needs, the maximum number of environmental parameters.

The large set of existing devices are managed and supported by local, regional and national governmental bodies, agencies or research groups, through particular or joined actions as networks or single platforms.

Figure 1 Some of the main ocean observing platforms that nowadays R3M incorporates.

During the last two years, R3M has experienced significant updates regarding data management and display (Figure 2), with a set of independent but compatible applications to process, store and disseminate information gathered through different oceanographic platforms, following well-known international standards and protocols (i.e. SeaDataNET).

Figure 2 R3M's web portal as access tool to all data observations and related information.

This representative and multidisciplinary large set of autonomous observing platforms and tools currently comprising the R3M is one of the derived results from more than 15-years of work in partnership, carried out through regional and international projects mainly funded by the EU-INTERREG and EU-Framework programs since the late nineties.

4. End users

Currently, R3M has a wide group of direct end-users, from key marine and maritime sectors (i.e. commercial and recreational navigation, health, defense, harbours, educational, safety and security, oil and gas, aquaculture, wastewater, tourism, marine research, water sports, ocean energies, weather agencies, governments, etc.) that use for their own specific activity aims, the useful information provided, most of them in a dedicated product format, making more efficient and cost-effective their performed business activities.

5. Conclusions

The need, importance and specific difficulty to monitor ocean regions like the Macaronesia, in a coordinated, efficient and sustainable way is reflected with the evolution and current status of the R3M, after more than fifteen years of cooperative effort from a wide and multidisciplinary group of entities, both public and private institutions, linked to marine and maritime sectors. This path has allowed to share and bring closer common and specific needs and experiences, based on their activity in the ocean space, both coastal and offshore, being one of the most important to develop a common framework (R3M) where to display and manage useful information. However, despite significant advances in technological and cooperative terms, they are still gaps to accordingly cover based on current and further end-user's needs.

Acknowledgements

The authors truly acknowledge to the EU-INTERREG and EU-Framework programmes for founding during the last fifteen years (and still) a large number of projects and specific actions at regional, national and international level, enabling to setup, improve and keep ongoing in a sustainable way this challenging and useful initiative for the Macaronesia region as is the R3M initiative.

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Monitoring Network Flemish Coast to investigate new techniques for coastal protection

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Abstract

A dedicated 'Monitoring Network Flemish Coast' has been set up to investigate the impact of sandbanks on wave energy dissipation and therefore also on the reduction of wave impact on the coast. At the same time a coupled wave-current model, has been implemented for the study area. The data obtained from the monitoring network are in the first place used to fine-tune parameter values for the physics already implemented in the model. However it also opens perspectives, in the long term, to verify new developments in formulations for the model physics. A well tested numerical model will allow to investigate the effect of alternative or supplementary techniques for coastal protection, like creating underwater sand reefs, bars or artificial sandbanks instead of or in support of the more conventional, but more expensive, beach nourishments.

Keywords: Coastal defence, Wave monitoring, Wave modelling, Wave model calibration

1. Introduction

A Masterplan Coastal Safety has been set up, by the Government of Flanders, to protect the coastal area in Belgium from flooding for a 1/1.000 year storm event. The Belgian coast is sandy but has on different sections an erosive character. Part of the coast is protected by dikes, but on many stretches the beach-dune system serves as coastal protection. The current management strategy is to keep the line and to use where possible soft techniques, such as beach nourishments, to restore the natural beach profile in order to provide adequate protection levels.

There is however considerable interest in using new and innovative techniques for coastal protection. One of them is creating artificial sandbanks or topping up existing sandbanks, with the expectation that the frequency of beach nourishments will be considerably reduced leading to a possibly more cost effective measure. In order to investigate in detail the impact on wave energy reduction by sandbanks and therefore also on the reduction of wave impact on the coast, a monitoring network of 7 wave buoys was established from offshore (open sea) to near-shore (Figure 1). The buoys are more or less aligned and cross several existing sandbanks. The measuring campaign started at the end of November 2013 and the intention is to continue for at least two winter seasons. Preliminary results show that the first winter season (2013-2014) was successfully monitored. These data are now analysed in detail. At the same time a coupled wave-current model is used to hindcast the wave propagation towards the coast and to investigate in detail the sensitivity to different formulations and parameter settings of the physics. In a later phase this set of models can then be used to investigate the impact of creating artificial sandbanks to reduce the wave load on the coast, and the consequent reduction of erosion rates and enhanced protection against flooding.

2. MONITORING NETWORK

The wave data used to study the wave energy propagation from the offshore location Westhinder (some 30km offshore) towards the coast, are delivered by 2 wave buoys of the existing 'Monitoring network Flemish Banks' and by 5 wave buoys of the dedicated 'Network Flemish Coast'. Along that path there are several sandbanks (Figure 1).

The 'Monitoring Network Flemish Banks' delivers already more than 25 years oceanographic data including wave data on several key locations on the Belgian section of the Southern North Sea (www.meetnetvlaamsebanken.be). Data are transmitted in real-time by radio communication. Data from the measuring locations Westhinder (directional Waverider©) and Trapegeer (non-directional Waverider©) are used for this project.

The 'Monitoring Network Flemish Coast', specifically set up for this project, delivers data of 2 directional Waveriders© and 3 non-directional Waveriders©. A reduced data set from these wave buoys is transmitted by satellite communication (Iridium). The Iridium satellite communication is not always 100%, resulting in data gaps of several hours. All raw data however are also stored on an on-board memory card. At the occasion of maintenance, the memory cards are recovered and replaced by a blank memory card. Data recovery from the memory cards was 100% for the first winter period providing a very interesting data set for further study.

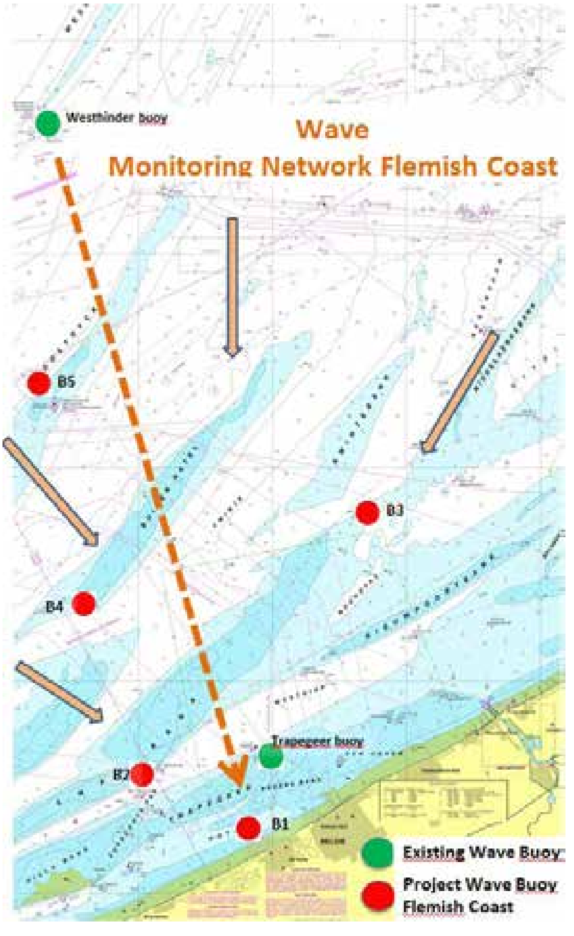

Figure 1 Wave buoy locations for this projects. This zone is also indicated on Figure 2

3. MODEL CONCEPT

A model train of nested and coupled hydrodynamic model (Coherens – Luyten, 2013) and wave models (WAM V4.5.3 (H. Günther and A. Behrens, personal communications, May 2012) and SWAN Version 40.91) has been set up. ERA-interim (Dee et al., 2011) 10m wind fields are used for the hindcast runs. These wind data can be freely downloaded from the ECMWF data server. The set-up is illustrated in Figure 2. A relatively coarse domain is used to generate the necessary boundary conditions for an intermediate resolution model that covers the North Sea. In that North Sea model a fine resolution model is nested for the detailed study of the wave propagation. In order to allow using measured wave spectra as 'near perfect' boundary condition for coastal modelling, a coast parallel wave model implementation has been made as well.

In a first stage, measured data are compared with model data in order to better tune some model parameters. A sensitivity study is currently being carried out on different modelling formulations and on parameter settings of the physics. Further study focusses on dissipation processes, in particular the sensitivity of model results to bottom friction and depth induced breaking. Attention will be paid to the behaviour of the full spectrum and not only to the values of the integrated wave parameters. Attention is also given to sensitivity to local wind forcing.

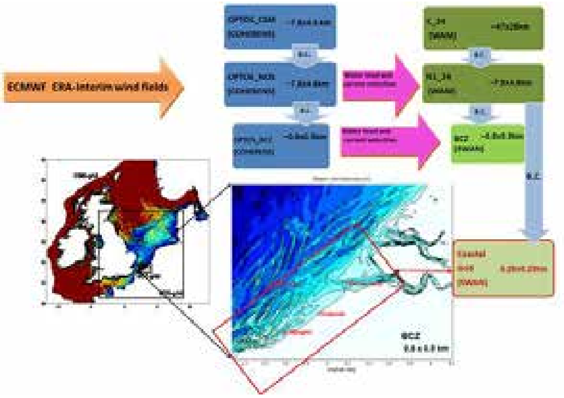

Figure 2 Nested model set up. The black box indicates the zone displayed in Figure 1.

4. END RESULT

At the end, this project will deliver a well calibrated model train to simulate hydrodynamics and waves for the near shore zone of the Belgian Coast. This model train will be a tool to model and study the reduction of wave impact by heightening existing sandbanks, by sand disposal for bars or other alternatives for coastal protection. The model train will be able to deliver high quality hydrodynamic and wave forcing fields for morphodynamic models (e.g. using the Coherens sediment transport model) and/or to supply high quality boundary conditions for specific wave dynamics programs like SWASH or Mildwave, or beach morphodynamic models like XBEACH.

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The RADMED monitoring program: towards an ecosystem approach

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Abstract

The Marine Strategy Framework Directive aims at achieving the Good Environmental Status by 2020. The IEO-RADMED monitoring program is already conducting many of the evaluations required to assess the Environmental Status under the MSFD Descriptors 5 and 7. The different aspects of the ecosystem that are regularly sampled under the RADMED monitoring program are the physical environment and the chemical composition of the water column that condition the primary production. Data is managed by SeaDataNet and stored under the IBAMar database

Keywords: Operational Oceanography, MSFD, ecosystem monitoring

1. Introduction

The IEO-RADMED monitoring program has already conducted many of the evaluations required under the MSFD Descriptors 5 (eutrophication) and 7 (hydrographical conditions) along the Spanish Mediterranean coast. The physical environment and the chemical composition of the water column that condition the primary production are regularly sampled. Primary producers are studied by microscopy, flow cytometry and total chlorophyll-a analysis. The photosynthetic activity, the respiration and the degradation of organic matter determine the gas interchanges with the atmosphere, being the CO2 interchange one of the most important in the actual context of climate change. This is sampled continuously using a SUNDANS system. The relations with the next trophic level can be estimated from the zooplankton studies. The higher trophic relations with zooplanktivourous and tertiary consumers are actually not being considered. The heterotrophic bacteria are essential for the decay of the organic matter to close the cycle. Bacteria are also included in the RADMED monitoring program. Finally, it would be very interesting to study the transference of organic matter to the benthos and also the CO2 content of the sediment. The future implementation of this aspect by sediment traps installed in the HYDROCHANGES moorings or by dredges is under study.

2. Material and methods

The RADMED program samples seasonally a fixed grid of stations, distributed on transects normal to the coast, from Barcelona to the Alboran sea alongside the Spanish Mediterranean coast, and around the Balearic Islands to visit oligotrophic and productive areas with different large scale oceanographic condition. The station distribution is shown in Figure 1. Coastal, shelf and deep stations are sampled to get information on the shelf-slope gradient. Water column temperature, salinity, dissolved oxygen, fluorescence and turbidity are sampled with CTDs and additional sensors in every oceanographic station. Chlorophyll-a and inorganic nutrients along the water column are sampled using a carousel water sampler. pH, total Alkalinity and partial pressure of carbon dioxide in air have been included in the RADMED sampling since 2010. Bongo nets sample phytoplankton and zooplankton to determine abundance and taxonomic composition. Sampling is done under standard protocols

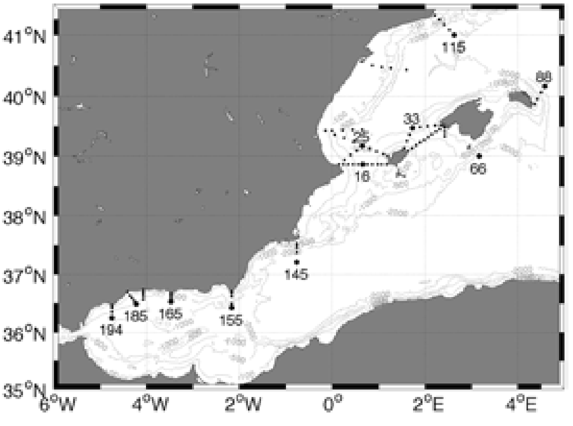

Figure 1 RADMED program sampling stations. Thicker and numbered dots refer to deep stations used for water masses climatological 275 studies. Light gray lines denote isobaths (100 m, 500 m, 1000 m, and 276 2000 m).

3. Data management

All RADMED CTD and biogeochemical data are sent to SeaDataNet (http://www.seadatanet.org/) through the IEO data centre (CEDO, Centro Español de Datos Oceanográficos). At the same time all data are included in the IBAMar database.

IBAMar is a regional database (López-Jurado et al. 2014, and Aparicio-Gonzalez et al. 2015) that brings together all the physical and biochemical data provided by multiparametric probes and water samples, taken during the cruises managed by the Balearic Oceanographic Centre of the Instituto Español de Oceanografía (COB-IEO) during the last four decades. Independent teams used different technologies and methodologies during the four decades of data sampling. However for the IBAMar database, data have been reprocessed using the same protocols, and a standard quality control methodology has been applied to each variable. The result is a homogeneous and quality controlled data regional database. IBAMar database at standard levels is freely available for exploration and download from http://www.ba.ieo.es/ibamar/

4. Some results

One of the main advantages of RADMED is that the sampling is always done over a regular grid. This fact helps the development of studies related to the annual cycles of different variables, their seasonal and interannual variability, the effects of winter convective processes, the presence of water masses, mesoscalar structures, transport and exchange between basins, cycles, trends and possible climate changes, as well as environmental and ecological studies of species.

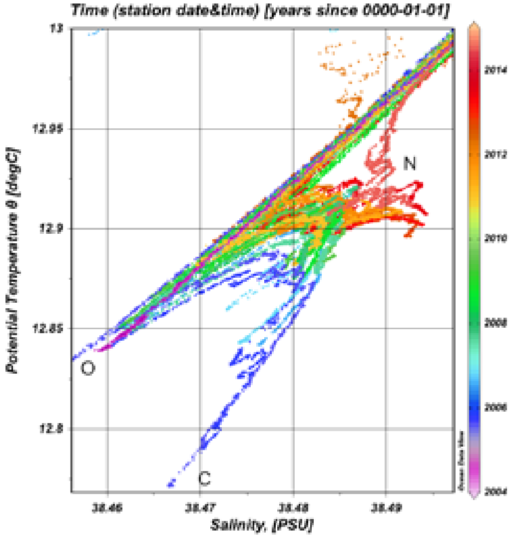

Figure 2 Theta-S diagram at RADMED station 88, NE of Menorca Island from 2004 to 2014.

For example, RADMED has allowed monitoring the evolution of the termohaline anomaly of the deep waters in the West Mediterranean (WMED), first observed in 2005 (López-Jurado et al., 2005) and that now affects the whole Western Mediterranean basin. Figure 2 shows the temporal evolution of the potential temperature versus salinity at a deep station NE of Menorca (number 88 in the map of Figure 1) from 2004. It is possible to observe the contribution of three water masses, the old WMDW, O, that has been shifted upwards from hundreds to thousands of meters by the new WMDW, N, and the waters originated by cascading, C, that occupy the bottom of the water column after the termohaline anomaly originated in 2005 (CIESM, Malta, 2009).

Figure 3 shows the seasonal evolution of hydrographic and biochemical parameters around the Balearic Islands as an example of the kind of studies that can be done under the RADMED monitoring program.

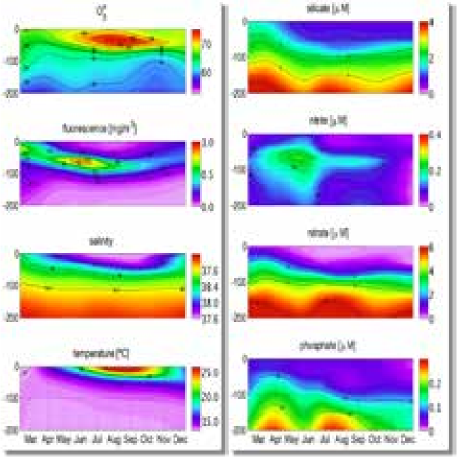

Figure 3 Seasonal evolution of different biochemical variables around the Balearic sea. .

Acknowledgements

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Multifunctional and interoperable sensors for a changing ocean

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Abstract

The NeXOS project is developing new multifunctional sensor systems supporting a number of scientific, technical and societal objectives, ranging from more precise monitoring and modelling of the marine environment to an improved management of fisheries. Several sensors will be developed, based on optical and passive acoustics technologies, addressing key environmental descriptors identified by the European Marine Strategy Framework Directive (MSFD) for Good Environmental Status (GES). Two of the new sensors will also contribute to the European Union Common Fisheries Policy (CFP), with a focus on variables of interest to an Ecosystem Approach to Fisheries (EAF). An objective is the improved cost-efficiency, from procurement to operations, via the implementation of several innovations, such as multiplatform integration, greater reliability through better antifouling management, greater sensor and data interoperability and the creation of market opportunities for European enterprises. Requirements will be further analysed for each new sensor system during the first phase of the project. Those will then be translated into engineering specifications, leading to the development phase. Sensors will then be tested, calibrated, integrated on several platform types, scientifically validated and demonstrated in the field. Translation to production and broad adoption are facilitated by participating industry.

Keywords: multifunctional, sensors, multiplatform, interoperability, GES, MSFD

1. NeXOS innovations

1.1 Optical sensors

To meet the requirements of increasing environmental awareness, optical techniques offer a good opportunity for a wide range of application requiring spatio-temporal measurements. Within NeXOS a number of innovative, compact and cost efficient multifunctional sensor systems for optical measurements are under development:

Carbon sensor system: For the understanding and quantification of the carbon system in the ocean, a minimum of two of the following variables need to be assessed; pH, total alkalinity (AT), inorganic carbon (CT), carbonate ion (CO32-), and the partial pressure of CO2 (pCO2). Within NeXOS, a new compact autonomous sensor system combining high precision sensing of pH, AT, and the carbonate ion together with a membrane-based pCO2 sensor will be developed. This system should offer reliable measurements under varying conditions in terms of stability and precision to allow long-term observations without time-consuming maintenance (Figure 1-A).

Matrix-fluorescence sensor: Fluorescence is a sensitive and very specific technique that is widely available as single wavelength fluorometers for in situ applications. The development of multi-wavelength fluorescence sensors has gained interest due to a broader application range while limiting the integration costs. Inspired by the success of laboratory based excitation-emission-matrix fluorescence spectroscopy (EEMS), NeXOS will proceed from multi-wavelength to matrix-fluorescence in situ sensing (Figure 1-B).

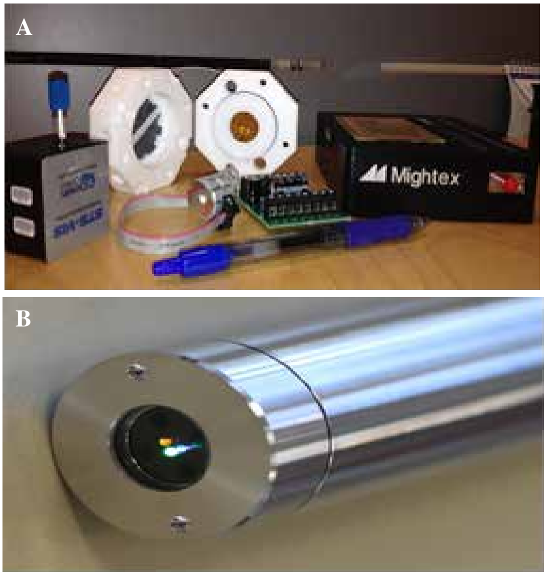

Figure 1 Carbon Sensor System (A); Matrix-fluorescence Sensor (B)

Hyperspectral cavity absorption sensor: Hyperspectral light absorption measurements provide information about relevant water constituents such as dissolved organic matter, suspended material and phytoplankton. Combined with a spectral analysis, a discrimination of different water constituents (including many parameters of water quality assessment) and phytoplankton taxonomic groups is made possible. Within NeXOS an optimization of the Online Hyperspectral integrating cavity absorption meter to fit the needs of a continuous measuring flow-through system (ft-PSICAM) is planned (Figure 2).

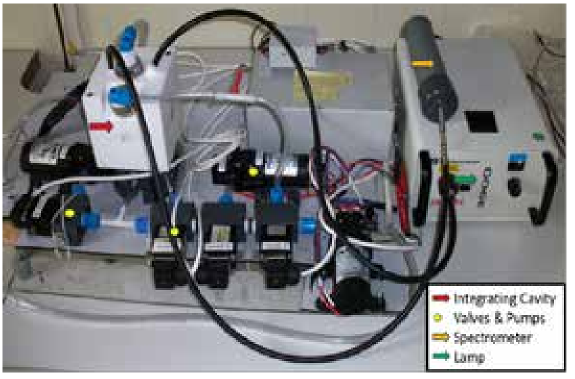

Figure 2 Hyperspectral Integrating Cavity Absorption Sensor.

1.2 Innovative Biofouling Protection

NeXOS proposes an innovative scheme using active protection, controlling biocide generation with a biofilm sensor. This will have high efficiency for optical sensors, low power consumption and negligible environmental impact. The scheme will involve the application of a conductive coating on the transducing interfaces of the sensors. This coating will allow micro-surface-electrolysis, and very little biocide will be produced over the entire sensor.

Figure 3 Biofouling effect on optical sensors.

1.3 Passive Acoustics Sensors

The MSFD and the increasing need to monitor underwater noise for Environmental Impact Assessments of marine activities have increased demand for cost-effective multipurpose acoustic instrumentation. In the framework of NeXOS, a novel, cost-efficient compact and integrated sensor system for passive acoustic measurements is under development focused on the pre and post-processing of acoustic information and improved transducer integration, reducing size and cost while increasing functionality (Figure 4-A).

1.4 Ecosystem Approach to Fisheries

Wireless miniaturized sensors are of interest to fisheries managers, fishermen, fisheries research institutes and oceanographers. Faced with the lack of data to assess precisely the spatial distribution of catch and fishing effort and for the environmental characterization of the fishing area, IFREMER has implemented the RECOPESCA project. The project consists in fitting out fishing vessels with sensors on fishing gears (Figure 4-B) and aboard the vessel itself. These sensors record data on fishing effort and physical parameters such as depth, temperature, salinity or turbidity. Within NeXOS a prototype sensors for oxygen and chlorophyll measurements are under development for their applications to fish population assessments. These parameters have been reported as Essential Ocean Variables by the operational oceanographic community.

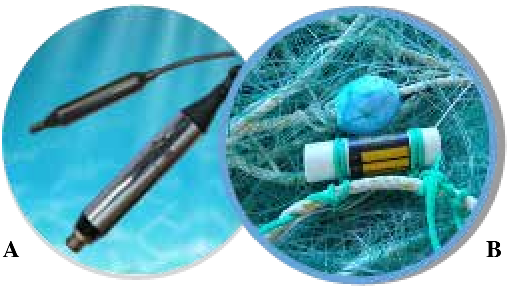

Figure 4 Passive Accoustics Sensors (A); Fishing Gear Sensors (EAF) (B).

1.5 Smart Sensor Interface and SWE

The variety of systems, sensors and platform types calls for a standard approach to collect data from instruments. This is the objective of the SEISI (Smart Electronic Interface for Sensors and Instruments) for the instrument side, and the NeXOS Sensor Web architecture for the client side.

SEISI will employ a set of standards and functionalities that the NeXOS instruments will incorporate in order to harmonise the way of accessing instruments data and metadata. Manufacturers, observatory operators and platform designers will be encouraged to apply this set of standards and functionalities.

2. INTEGRATION, VALIDATION AND DEMONSTRATION

NeXOS promotes a multi-platform strategy shifting traditional sensor use on a dedicated platform to the use of multifunctional sensors on several types of platforms. The innovative aspects of NeXOS include the platform integration process and novel methods of sensor management including two-way communication (SEISI smart sensor interface) and direct data dissemination (Sensor Web) to end users. NeXOS will demonstrate the new sensor developments in real operational scenarios on various platforms.

FP7 Ocean -SCHeMA: integrated in Situ Chemical MApping Probes

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Abstract

Marine environments are vulnerable and influenced by a diversity of anthropogenic and natural substances and organisms that may have adverse effects on the ecosystem equilibrium, on living resources and on human health. Identification of relevant types of hazards at the appropriate temporal and spatial scale is crucial to detect their sources and origin, to understand the processes governing their magnitude and distribution, and to evaluate and manage their risks and consequences preventing economic losses. SCHeMA aims at providing an open and modular sensing solution for in situ high resolution mapping of a range of anthropogenic and natural chemical compounds that may have feedback (synergic) interaction: toxic and/or essential Hg, Cd, Pb, As and Cu trace metal species; nitrate, nitrite, and phosphate nutrients; species relevant to the carbon cycle; volatile organic compounds; potentially toxic algae species and toxins. The SCHeMA system will consist of a plug-and-play adaptive wired/wireless chemical sensor probe network serving as a front-end for gathering detailed spatial and temporal information on water quality and status based on a range of hazardous compounds. An ad-hoc ICT wireless networking solution and web-data information system will allow system localization and reconfiguration; data transfer, logging, storage, standardization, evaluation, modelling, and user-friendly accessibility

Keywords: water quality, plug-and-play, standardization, ecosystem, web-data

1. Introduction

Marine environments are highly vulnerable and influenced by a wide diversity of anthropogenic and natural substances and organisms that may have adverse effects on the ecosystem equilibrium, on living resources and, ultimately, on human health. Identification of relevant types of hazards at the appropriate temporal and spatial scale is crucial to detect their sources and origin, to understand the processes governing their magnitude and distribution, and to ultimately evaluate and manage their risks and consequences preventing economic losses.

SCHeMA aims at providing an open and modular sensing solution for in situ high resolution mapping of a range of anthropogenic and natural chemical compounds that may have feedback (synergic) interaction: toxic and/or essential Hg, Cd, Pb, As and Cu trace metal species; nitrate, nitrite, and phosphate nutrients; species relevant to the carbon cycle; volatile organic compounds; potentially toxic algae species and toxins. The SCHeMA system will consist of a plug-and-play adaptive wired/wireless chemical sensor probe network serving as a front-end for gathering detailed spatial and temporal information on water quality and status based on a range of hazardous compounds. An ad-hoc ICT wireless networking solution and web-data information system will allow system localization and reconfiguration; data transfer, logging, storage, standardization, evaluation, modelling, and user-friendly accessibility.

2. Methods

The SCHeMA system will be designed so that it can operate from different facilities, i.e.: platform, moored buoy, boat, unmanned surface or submersible vehicles, and landers. It will acquire a wealth of information, at high spatial and temporal resolution, on a range of chemical hazardous compounds coupled to environmental master variables. Such a rich database offers the possibility to gain insights into phenomena that are currently poorly understood but are significant for understanding aquatic ecosystems functioning, for predictions of toxicological impact and, ultimately, for sustainable management based on scientific knowledge.

SCHeMA will contribute to enhance ocean observing capabilities and support policies of several EU directives.

2.1 SCHeMA specific objectves

SCHeMA is structured according to a fourfold objective:

> Development of an array of novel chemical sensors taking advantage of various innovative analytical solutions such as:
- (bio)polymer-functionalized gel-integrated sensors for direct, reagent-free, voltammetric detection of toxic/essential fractions of a range of trace metals (inorganic and methyl mercury; inorganic arsenic species; dynamic fraction of cadmium, lead and copper);

- solid state ion-selective membrane sensors for i) direct detection of CO2, CO32-, total alkalinity; and ii) reagent-free, potentially calibration-free, detection of nutrients (nitrate, nitrite, phosphate) when coupled to an on-line desalination module;
- mid-infrared optical sensors for the detection of harmful VOCs;
- optical devices involving selective reversible immobilization of target molecules to sense relevant algae species and biotoxins (saxitoxin, ovatoxin/ palytoxin).

> Incorporation of the novel sensors into miniature, low power consumption, multichannel probes based on Eco-Design-ISO/IEC standards and EnOcean technology as well as energy harvesting devices.

> Development of dedicated wired/wireless communication network and web-based front-end system compatible with EU standard requirements (OGC-SWE, INSPIRE, EMODnet, sensorML, SEIS).

> Evaluation, optimization, validation and demonstration of the SCHeMA sensing tools and integrated system via short and long-term field applications in Atlantic and Mediterranean coastal areas.

3. Outcomes

> Product-based – a suite of powerful field-validated submersible chemical sensor probes and a smart multi-sensor probe Hw/Sw interface platform ready for post-industrial production;

> Applied – water quality assessment of various marine ecosystems and identification of the critical parameters considered relevant for successful management of water quality;

> Scientific – a better understanding of the bio-geochemical processes occurring in selected EU coastal areas that is fundamental to predict the impact of land-based pollution on water quality of vulnerable coastal ecosystems and for the development of knowledge-based protective policies for the marine environment;

> Socio-economic – promotion of new skills and jobs; new collaborations and business opportunities in the world market of marine sensing and monitoring.

www.schema-ocean.eu

Acknowledgment

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From regional seas to global ocean observations: the national capacity of the UK science community

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Abstract

This paper presents case studies of some of the key UK marine science programmes highlighting their successes in increasing the coordination, capacity and knowledge exchange of science at national, European and global scales.

Keywords: sustained observations, time-series, UK

1. Introduction

Sustained marine environmental observations are required at regional and global scales to document seasonal cycles, extreme conditions, environmental change and anthropogenic versus natural variability. The data gathered is vital for informing policy at both national (e.g. Marine Protected Areas) and international level (e.g. Marine Strategy Framework Directive). In order to ensure that the observations are fit for purpose they need coordination and management. The projects presented in this paper have contributed to coordinated national programmes, including UK Integrated Marine Observing Network (2012-present), connecting shelf seas sampling and Atlantic Ocean observations.

2. Western channel observatory

The Western Channel Observatory (WCO; 1903-present) is an oceanographic time-series and marine biodiversity reference site in the Western English Channel. Run jointly between the Marine Biological Association and Plymouth Marine Laboratory, the WCO is funded through NERC National Capability. In situ measurements are undertaken weekly at coastal station L4 and fortnightly at open shelf station E1. The WCO contributes to a network of ~50 time series sites across the North Atlantic and European shelf, coordinated by ICES (International Council for the Exploration of the Sea).

Measurements undertaken across the WCO include (with ~ start date), real time data from 2 operational moorings (L4 and E1; 2009), zooplankton (1988), phytoplankton (1992), nutrients (1934), CTD profiles (1903), pigments including chlorophyll (1992), optics (~2000), CHN (2000). WCO scientists are actively involved with ICES and contribute to the Zooplankton and Phytoplankton Status Reports, which provides comparisons of the long-term change in the plankton across the Atlantic.

3. Extended ELLETT line

The Extended Ellett Line (1975-present) is organized jointly between NOC & SAMS investigating the dynamics and variability of the northward-flowing warm saline water that contributes to the Atlantic Meridonal Overturning Circulation. The section between Scotland and Iceland is repeated annually using both ships and gliders to examine the variability in the hydrography, biogeochemistry and ecosystems.

Data is used in climate assessments by DEFRA, the EU, OSPAR, the IPCC assessment and by the International Council for the Exploration of the Sea (ICES). Data collected has shown upper ocean temperature and salinity to vary with subpolar gyre dynamics and that recently observed warming in the region propagates into the Arctic Ocean. Southward overflow water in the Rockall Trough influences temperature & salinity between 800 and 1200 m (the depth of the permanent pycnocline), highlighting the importance of accounting for this episodic flow when calculating heat transport.

4. RAPID-AMOC

RAPID-AMOC (2014-2020) builds on two previous programmes, which began in 2004. It provides a 10-year continuous data set to monitor changes in the Atlantic Meridional Overturning Circulation (AMOC) and understand its role in climate and ocean circulation variability due to climate change. Data are collected from fixed moorings at 26°N, and used with Argo data and occasional hydrographic surveys, the latter building on observations made intermittently across standard sections dating back to the 1950's. RAPID-AMOC is carried out in close collaboration with international programmes, for example US-AMOC.

The observations show significant decrease in the AMOC strength in 2009-10, coinciding with a cold winter in Europe, suggesting a previously unsuspected role for the AMOC in interannual variability. Climate model predictions for 2000-2100 suggest a slowdown of AMOC over the century. Observations show the decline over 2004-2014 has been faster than predicted (although a longer data series is needed to determine if this is an ongoing trend). Future work with the RAPID array will include adding new sensors to measure biogeochemical parameters. RAPID observations at a single latitude may not fully characterize changes in the AMOC. Therefore OSNAP (2013 – 2018) measuring the AMOC in the North Atlantic sub-polar gyres will complement RAPID.

5. Atlantic meridonal transect

The Atlantic Meridional Transect (AMT; 1995-present) is a long-term multidisciplinary ocean programme, observing biological, chemical and physical oceanography on an annual voyage between the UK and destinations in the South Atlantic. AMT has involved 242 scientists from 20 countries across 24 research cruises. AMT provides a platform for national and international scientific collaboration, training arena and a facility for validation of novel technology.

Some of the research outputs of AMT data include: development of accurate satellite maps of primary productivity, quantification of the effects of excess CO_2 in the oceans & implications for marine life, biogeochemistry, conceptual model development describing phytoplankton size structure changes in relation to chlorophyll concentration, improved understanding of Organic Volatile Oxidised Compounds (including methanol), the evolution of open ocean zooplankton, and the composition and abundance of mycosporine-like amino acids.

6. FixO3

The Fixed point Open Ocean Observatory ($FixO_3$) network (2014-2018) coordinated by the National Oceanography Centre, UK, seeks to; integrate European open ocean fixed point multidisciplinary observatories and improve access to the installations for the broader community. $FixO_3$ builds on the significant advances made in the FP7 programmes EuroSITES, ESONET and CARBOOCEAN.

The Porcupine Abyssal Plain Sustained Observatory (PAP-SO) is one of the $FixO_3$ observatories that the UK is responsible for maintaining & operating. Providing >20 years of data the PAP-SO investigates the effects of climate change on open ocean and deep-sea ecosystems. Data collected includes atmospheric variables (NERC-UK Met Office) temperature*, salinity*, nitrate*, chlorophyll*, dissolved oxygen, CO_2*, dissolved gasses*, radiance*, currents, particle fluxes and benthic imagery (* real time data). PAP-SO data have been used to advise the Department of Environment, Food and Rural Affairs & the European Commission on ocean governance, environmental management, deep sea biodiversity, Marine Protected Areas & observatory development.

7. ARGO

UK Argo (2014), funded by DECC, NERC and the Met Office, has contributed to the 2007 achievement of 3000 active profiling floats globally, measuring temperature and salinity profiles between the surface and 2km depth. The UK has recently invested in 4 Deep Argo floats, capable of profiling to 6km depth. The British Oceanographic Data Centre (BODC) handles the real time data from the UK Argo program, undertaking delayed-mode quality control.

The Met Office uses Argo data for operational purposes as part of their forecasts of ocean conditions over the forthcoming season, thereby improving long term climatological and weather forecasting services. Argo data from both standard and deep profilers also complement AMOC research within programmes such as RAPID-AMOC.

Dissolved oxygen sensors are also being developed for deployment on Argo, enhancing understanding of ocean biogeochemistry.

Acknowledgements

The programmes discussed have received funding from NERC, DECC, Met Office and the EC.

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Real-time quality control of biogeochemical in-situ measurements

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Abstract

The use of biogeochemical sensors in ocean science is increasing fast. New parameters can be monitored but also new monitoring platforms are made available leading to the emerging need of standardized procedures and quality assessments. Nomenclatures, units in use, meta data, sensor calibrations and unattended continuous real-time quality control algorithms have been key topics and development areas. Spatial and temporal variability and the relatively noisy nature of biogeochemical sensors have led to the development of unified algorithms for applications within automatic quality control.

Keywords: in-situ, biogeochemical, quality control

1. Introduction

The use of biogeochemical sensors in ocean science is increasing fast. New parameters can be monitored but also new monitoring platforms are made available. These factors do not only lead to a larger volume of biogeochemical data, but also the emerging need of standardized procedures and quality assessments.

NIVA has been involved in biogeochemical measurements since it was created, both in fresh water and marine science. In the field of sensors and platforms developments and testing, NIVA has been contributing actively in a very large number of projects like the EU-projects Ferrybox, Jerico, MyOcean, MyOcean2, Nexos and MariaBox. Its own network of Ferryboxes extending from Germany into the Arctic is regularly used as a platform for testing new biogeochemical sensors.

In the frame of the project MyOcean, NIVA has been responsible for the implementation of stronger standards for biogeochemical data acquired from any supporting platform, as well as assemble and quality assess measurements from pan-European Ferryboxes in near real-time. Nomenclatures, units in use, meta-data, sensor calibrations and unattended continuous real-time quality control algorithms have been key topics and development areas. Spatial and temporal variability and the relatively noisy nature of biogeochemical sensors have led to the development of unified algorithms for applications within automatic quality control.

Biological measurements involve monitoring of living species and may hereby depend to a large extent on day light, seasons or measured species.

Geochemical measurements involve monitoring of chemical equilibrium which is subject to the chemical reactions taking place at the time of the observations.

Both types of measurements can be much localized in time and space as illustrated in Figure 1. This makes it difficult to monitor biogeochemical parameters.

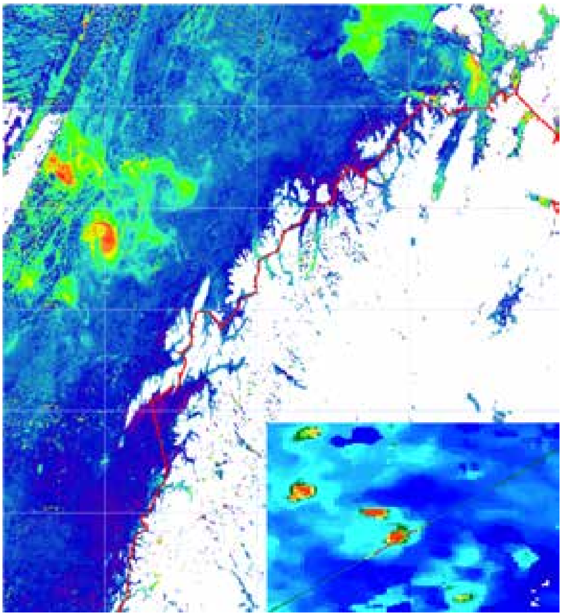

Figure 1 Ocean Color data illustrating the patchiness and variability along the Norwegian coast. In the lower right corner, a Ferrybox is crossing a patch of Chl-a fluorescence. The patch size is of the order of 1 nm.

2. Chl-a FLUORESCENCE

These sensors provide a proxy of Chl-a concentration. These two parameters may differ in different ways. For example, algae species used for calibration or day light variations and concentration will affect measurements. Figure 2 shows how measurements of Chl-a fluorescence are much higher during night. Day and night differences are also larger during bloom events.

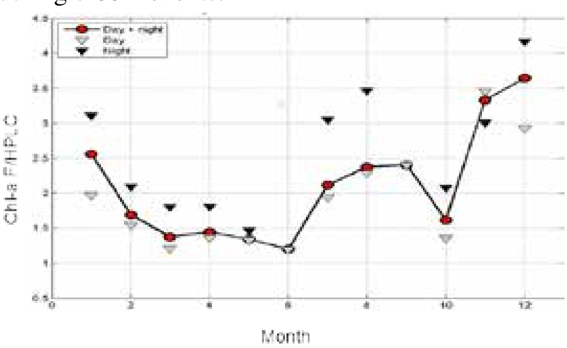

Figure 2 Mean monthly ratio of Chl-a Flu/HPLC. Data has been collected from a Ferrybox line from 2003 to 2008.

The effect of the choice algae for the calibration of sensors is depicted in Figure 3. A factor of 3 can be expected with typical species found in Norwegian waters, while a factor of 6 can be expected globally.

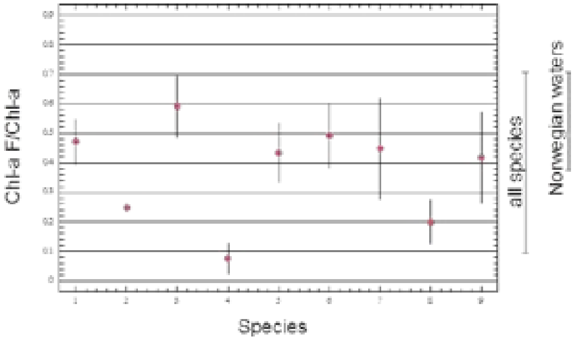

Figure 3 Ratio of Chl-a fluorescence to HPLC measurements performed with different algae species. The species are numbered and listed in Table .1

Table 1 Species used in Figure 3.

No	Alga
1	Chrysochromulina polylepis
2	Dunaliella tertiolecta
3	Emiliania huxleyi
4	Oscilatoria agardii
5	Prorocentrum minimum
6	Prymnesium parvum
7	Phaeodactylum tricornutum
8	Selenastrum capricornutum
9	Skeletonema costatum

Therefore, measurements of Chl-a fluorescence must be provided with information on (i) the type of fluorometer used, (ii) the calibration method and algal culture used and (iii) the validation procedure applied.

3. Oxygen

Saturation is an indicator for production. It is usually used for calibration of optodes (at 0% and 100%). However, optodes measure oxygen concentration. T and S are required to convert from one to the other.

Optodes have an embedded T sensor, but S is constant and stored in the sensor (0‰ by default). Moreover, it has been shown that T from internal sensor can be a major source of uncertainty (Hydes et. al, 2009).

Hence, oxygen measurements must be delivered as concentration in μM (μmol/l) and specify T and S to be used for the calculation of saturation.

4. Quality control

Quality control on these parameters include (i) range test on global and regional scales as well as seasonal scales, (ii) spike test (iii) Instruments comparison test and (iv) parameter relationship test. Note that no gradient test is applied due to the specific features of biogeochemical measurements.

For the same reason, spike test is one of the most challenging one. Moreover, different sensors and platforms provide measurements with different noise structures. In order to overcome this problem and apply a uniform spike test, measurements are normalized and focus is given to high frequencies in order to estimate mean noise energy contained in the signal. This information is used to derive threshold values for potential spikes which are then analyzed in the original measurements using a simplified AIC function on *z-scores* subsets (based on Takeuchi, Ueda).

This algorithm resolves issues of inherent oscillations in data, parameter dependency, climatology and technology. It can therefore be applied to a large number of parameters.

Acknowledgements

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Combining autonomous observations and sampling for operational environmental assessments

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Abstract

Autonomous measurement and sampling systems, e.g. ferryboxes and moorings are increasingly used for operational environmental assessments. In the Gulf of Finland, such an operational assessment system is applied by combining data from a ferrybox, profiling buoy stations and fast laboratory analyses of water samples. Laboratory analyses are essential for calibration of autonomous sensors and needed for those parameters where reliable sensors are not available yet. We demonstrate how this combination of methods is used for fast assessments of eutrophication effects and further studies of the functioning of pelagic ecosystem. Adaptive sampling in connection to high-resolution profiling allows studying in more detail the biodiversity of primary producers associated with different forcing and background conditions, and their functional role in nutrient cycling and/or export-import.

Keywords: ferrybox, profiling buoy, nutrients, phytoplankton, environmental assessment

1. INTRODUCTION

The traditional marine environment monitoring, when only research vessels are used, would result in low spatial coverage and temporal resolution of data and, hence, incomplete assessments. Employment of new technologies and high-resolution horizontal and vertical sampling in the Baltic Sea has enabled to better understand the processes, and link dynamics in chemical and biological fields with the environmental conditions and physical forcing (Lips e Lips, 2014; Lips *et al*., 2011; Lips e Lips, 2008; Jaanus *et al*., 2006). The main aim of this short paper is to give an example how the combination of different autonomous systems, together with conventional sampling, would enable operational environmental assessment in the Gulf of Finland.

2. MATERIAL AND METHODS

The study was conducted in 2014 in the Gulf of Finland, Baltic Sea. Horizontal measurements and sampling was done using the ferrybox system installed abroad "Baltic Princess" plying between Tallinn and Helsinki. The autonomous profiler (Flydog Marine) was deployed close to the ferry line for vertical measurements of temperature (T), salinity (S), chlorophyll *a* fluorescence, oxygen and turbidity at depth of 2-80 m with time interval of 3 hours. Sampling abroad RV SALME was conducted close to the buoy station for inorganic nutrient, chlorophyll *a*, phytoplankton community composition (methods described, ferry line and buoy station AP5 shown in Lips *et al*., 2014) and flow-cytometry (Accuri C6, Becton Dickinson) analysis. Samples for flow-cytometry analysis were fixed with paraformaldehyde (1% FC) and glutaraldehyde (0.1% FC).

3. RESULTS AND DISCUSSION

Ferrybox flow-through measurements of T and S (Figure 1) provided a good background data for understanding the water mass movements. High salinity values, observed at certain time intervals and parts of the cross-section, indicated the inflow of Baltic Proper waters (transport from west to east) while low salinity recordings indicated the outflow of gulf waters in the surface layer from east to west.

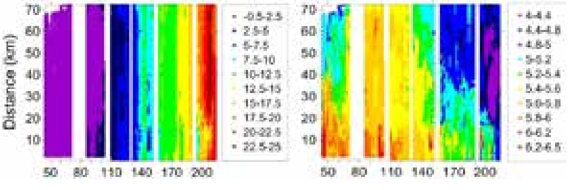

Figure 1 Temperature (left; °C) and salinity (right; psu) dynamics along the ferry route between Tallinn and Helsinki (x-axis: Julian day).

The high-resolution sampling using automated sampler enabled to follow the nutrient depletion during the spring bloom in the surface layer (Figure 2).

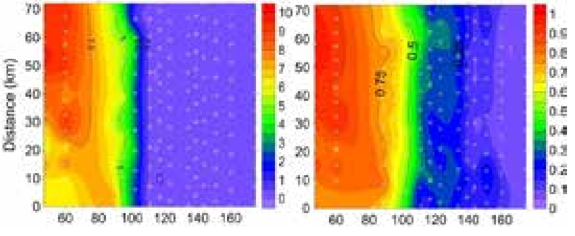

Figure 2 Nitrite+nitrate (left) and phosphate (right) dynamics (in μM) along the ferry route between Tallinn and Helsinki (x-axis: Julian day; dots – sampling stations).

The nitrates in the surface layer were under the detection limit by 22 April while the depletion of phosphates was observed 7 weeks later. The proportion and shift of different microplankton trophic groups in spring summer progression was well related to changes in inorganic nitrogen concentration in the upper mixed layer. There was a clear increase in vertically migrating species (*Peridiniella catenata* and *Mesodinium rubrum*) and a switch in phytolankton community composition from strict autotrophs to mixotrophic species (mainly autotrophic ciliate *Mesodinium rubrum*) after the depletion of nitrates in the upper mixed layer.

High-resolution vertical measurements using autonomous buoy systems were valuable to follow e.g. the dynamics of near bottom layer oxygen concentration, which is very often associated with high turbidity in the same layer (Figure 3).

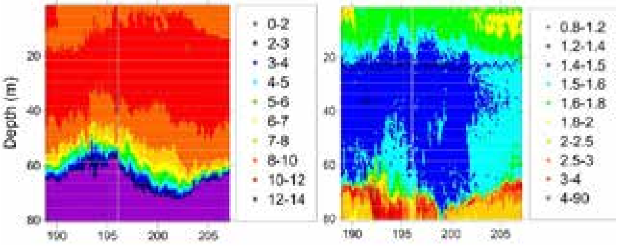

Figure 3 Dynamics of oxygen content (left; mg/l) and turbidity (right; NTU) at the buoy station on 9-26 July 2014 (x-axes: Julian days).

Flow cytometry analysis enabled rapid enumeration of bacterioplankton and picophytoplankton cells throughout the water column. The examples here are for 16th and 25th July (Figure 4). Pico size primary producers are often neglected in the community and biomass analysis. The increase in microbial community density at 10 - 15 m depth on 25th July coincided with changes in turbidity profile (Figure 3).

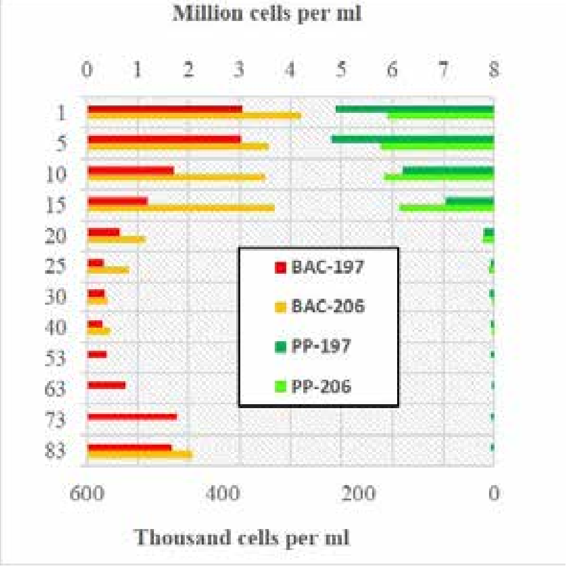

Figure 4 Bacterioplankton (BAC; upper x-axis) and picophytoplankton (PP; lower x-axis) community density profiles on 16th (day 197) and 25th (day 206) July (y-axis: depth). Depths 53 to 73 m were not sampled on 25th.

At suboxic near-bottom layer high side-scatter group emerged (detailed data are not presented here) in bacterial community. This cluster has been found to be responsible for dark CO_2 fixation (chemolithoautotrophic bacteria) in the Gotland Deep (Jost *et al.*, 2008). The detailed information about functionally different bacteria in the near bottom layer is valuable information in understanding the character and intensity of microbial processes in deep layers and impact of these processes to the overall nutrient cycling in the ecosystem.

4. CONCLUSIONS

Using several marine environmental real-time observation systems together with high-resolution sampling can create system networks that collect, store and exchange environmental data. These high-resolution data are essential to end-users who need to understand and/or model ecosystem behaviour.

Acknowledgements

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Modelling and Forecasting Systems

Assessment and intercomparison of numerical simulations in the western Mediterranean: a multi-variable and multi-scale approach

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Abstract

The Mediterranean Forecasting System and Mercator-Océan simulations are evaluated at various spatial and temporal scales using multi-platform observations in the western Mediterranean Sea. The quantitative assessment has shown the general realism of the simulations in terms of surface circulation and variability as well as water masses properties. The sub-basin scale approach has allowed to highlight local and regional errors, which might have a critical impact when using the simulations to initialize and constrain regional models.

Keywords: numerical simulations, sub-basin scale assessment, multi-platform observations, western Mediterranean

1. Introduction

The Mediterranean Forecasting System (MFS, 1/16º, Tonani *et al*., 2014) and Mercator-Océan simulations (Mercator, 1/12º, Lellouche *et al*., 2013) are "eddy-permitting" simulations over the Mediterranean Sea. They are used as initial and boundary conditions of higher resolution regional simulations, such as WMOP (~2km, Juza *et al*., 2015a) in the western Mediterranean (WMed) which is developed at the Balearic Islands Coastal Observing and Forecasting System (SOCIB, Tintoré *et al*., 2013). These high resolution regional simulations aim at reproducing (sub-)mesoscale features that are key in the Mediterranean since they interact with the basin and sub-basin circulations.

In this study, the MFS and Mercator hindcast simulations are evaluated using multi-platform observations in the WMed over 2009-2012. A quantitative comparison is necessary to (1) evaluate the capacity of the simulations to reproduce observed ocean features, (2) quantify the possible simulations biases, (3) improve the simulations to produce better ocean forecasts, to study ocean processes and to address climate studies. To this end, various statistical diagnostics have been developed to assess the simulations at sub-basin scale in terms of surface circulation and variability as well as hydrographic properties.

2. Methodology

(1) Use of available multi-platform observations:

- Sea Surface Temperature (SST): daily satellite products provided by CNR-ISAC (MyOcean, OSI-TAC), interpolated on a regular 1/16º grid.
- Mean Absolute Dynamic Topography and associated geostrophic currents: daily map from altimetry products, interpolated on a regular 1/8º grid (AVISO-CLS SSALTO/DUACS, 2014).
- Temperature (T) and Salinity (S) profiles, from Argo floats, XBTs, CTD transects, provided by ENACT-ENSEMBLES (Good *et al*., 2013).
- High resolution T/S data, from SOCIB gliders, in the Ibiza Channel (Heslop *et al*., 2012).

(2) Systematic spatial and temporal interpolation of simulations at the observations points.

(3) Definition of sub-regions (Fig. 1), as in Manca *et al*. (2004), with typical sub-basin surface dynamics.

(4) Statistical metrics to assess simulations at various spatial and temporal scales.

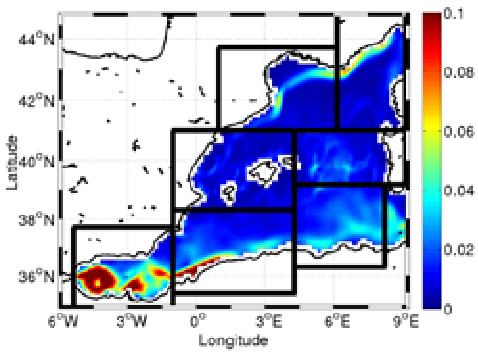

Figure 1 Mean Kinetic Energy (m^2/s^2) from altimetry over 2009-2012. Boxes indicate sub-regions division.

3. Surface circulation and variability

SST analyses have shown that the spatial structure of the SST mean and variability is reasonably well reproduced in MFS and Mercator, as well as the seasonal and interannual variability at basin and sub-basin scales. Although SST data is assimilated in both systems, persistent differences have been found in areas with high mesoscale activity (Alboran Sea and Algerian current), with strong river inputs and air-sea interactions (Gulf of Lion), and with high SST variability (Balearic Sea).

The geostrophic currents are weaker in the simulations than in altimetry products, especially in high mesoscale regions (Alboran Sea, Algerian and Northern Currents).

Mean circulation differences have been found, especially concerning the Balearic Sea circulation in MFS and the western Corsica Current in Mercator.

The most energetic mesoscale activity is observed in the Alboran Sea (Fig. 1). In this region, (1) the first Empirical Orthogonal Function (EOF) of the observed Sea Level Anomaly (SLA) represents the steric contribution of the seasonal cycle, associated to the Western and Eastern Anticyclonic Gyres (WAG and EAG) intensification (weakening) in spring-summer (winter-fall). (2) The second EOF represents the WAG intensification (weakening), the EAG weakening (intensification) in opposite phase, and the apparition of a cyclonic eddy east of the EAG, separated by the Almeria-Oran Front. (3) The observed Kinetic Energy (KE) is stronger in WAG than in EAG, and stronger the second half of the year for both gyres. The WAG is quasi-persistent whereas the EAG disappears in winter, replaced by the cyclonic eddy to the east. The main observed modes of SLA variability are reproduced by both simulations. The WAG KE is weaker in the simulations than in altimetry. MFS better represents the WAG persistence and annual periodicity than Mercator. The EAG KE amplitude is well simulated, but quasi-persistence is found in MFS.

4. Hydrographic properties

Vertical structures of T/S misfits using Argo floats and XBTs profiles have revealed regional and sub-regional biases. At basin-scale, strong surface T/S biases in MFS and Mercator have been found (warm in summer, fresh throughout the year). In the deep layer (>600m), significant cold and salt biases persist in MFS. At regional-scale, seasonal and regional surface T biases are found in both simulations, as well as surface fresh biases in all regions. In the intermediate and deep layers, general findings over the basin are persistent in all regions.

Considering the glider section in the Ibiza Channel (IC) in March-April 2011, the observed T/S diagram and vertical sections reveal the typical water masses of the WMed, as well as the presence of Winter Intermediate Water (WIW), formed in the North WMed (Juza *et al.*, 2013). MFS has strong surface T/S biases, does not properly represent the T maxima associated to the Levantine Intermediate Water and does not reproduce the WIW. On the contrary, Mercator represents the presence of WIW. The high-resolution simulation WMOP, which has been initialized and nested in Mercator, better reproduces the water masses in the IC.

5. Conclusion and perspectives

The multi-variable and sub-basin scale assessment has allowed to highlight sub-regional errors in the MFS and Mercator simulations. This work is reported in Juza *et al.* (2015b). Quantitative comparisons between WMOP (nested in MFS and Mercator) and parent models are under investigation, as well as process studies based on historical observations and hindcast simulations.

Acknowledgements

We greatly acknowledge the Mediterranean Monitoring and Forecasting Centre and Mercator-Océan for performing and providing simulations. Observations products are provided by MyOcean (www.myocean.eu), SOCIB (www.socib.es), AVISO (www.aviso.altimetry.fr), and ENACT-ENSEMBLES (www.metoffice.gov.uk/hadobs).

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Contribution to the harmonization of operational systems: data validation and dissemination through SOS and NetCDF

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Abstract

In this paper we describe the improvementsof the system developed to harmonize the data management practices implemented in different European operational systems. It is used for storing, validate and disseminate the data collected by the meteo-oceanographic MAMBO1 buoy (in the North Adriatic Sea) and the observatory site E2M3A (in the South Adriatic Sea) in (near) real-time. This system includes the collection of marine (near) real-time data with different formats, the conversion in a homogeneous and standard format, the structuring in a database and the validation using XML and OGC (Open Geospatial Consortium) standards. To meet the needs of different scientific communities as (RITMARE, Jerico, MyOcean, ODIP, FixO3), the dissemination follows different paths: through the adoption of Sensor Web Enablement (SWE) we answer to the needs of interact with data in near real-time (using SensorML and O&M standard in a Sensor Observation Service - SOS (http://nodc.ogs.trieste.it/SOS/sos) and a SOSClient (http://nodc.ogs.trieste.it/SOSclient) while to answer to the necessities of ocean monitoring and forecasting community we disseminate data using a NetCDF Oceansite standard. The requirements of interoperability (as suggested by the MSFD), as ability to cooperate and exchange information, and resilience, led our technological choices.

Keywords: Sensor Web Enablement, operational oceanography, ocean monitoring, MSFD.

1. Introduction

In this work we describe the improvements to the system used to archive, validate and deliver data in (near) real-time from marine stations (Partescano et al., 2014). This system was developed to harmonize and disseminate the heterogeneous marine data, collected by different sensors and with different formats, using a NetCDF Oceansite standard and a SOS service (52°North), to meet the needs of different scientific real-time marine data communities, as the Join European Research Infrastructure Network For Coastal Observatories (JERICO), the Fixed point Open Ocean Observatory network (FixO3), the Ocean monitoring and forecasting services (MyOcean) and Italian Flagship Project RITMARE.

The method described in this paper was developed using open technologies and standards to get a flexible tool, easily adaptable to new needs.

2. Methodology

The data flow (Fig.1) of the automatic data management has at the top two different devices that acquire data in (near) real-time: the meteo-marine buoy MAMBO1 (Monitoraggio AMBientale Operativo), located in the Gulf of Trieste, equipped with a meteorological station and two multi-parametric probes, and the E2-M3A, located in the South Adriatic Sea, hosting the meteo station including a radiometer aimed, to collect air-sea interaction measurements, and a mooring with sensors for physical and biochemical parameters (Ravaioli et al., 2014). The real-time heterogeneous data coming from different kind of instruments and with different formats are stored in a database through the RTLoader (Real-Time Loader).

In a second step, the DBValidator (Database Validator) validates the data with a data quality control procedure and assign a quality flag to the data values, following European quality check protocols (UNESCO, 2010).

The RTWs (Real-Time Web Service) is a RESTful Web Service that accepts simple requests to extract the data from the database. These requests can be parametrized with temporal range and output format to guarantee the flexibility of the system.

The data are then disseminated using:

the RTSOS (Real-Time Sensor Observation Service), is an OGC (Open Geospatial Consortium) SOS service, using 52°North implementation (http://52north.org/) version 4.0, that allows to integrate real-time observations of heterogeneous sensors, into a Spatial Data Infrastructure. The SensorML adopts SeaDataNet standard vocabularies (Fichaut et al., 2013) to code: measured parameters using the P01 vocabulary, the instruments with the L05 codes, originators (EDMO codes) and platforms (EDIOS), to guarantee easy integration with the Pan European data management infrastructures. A PostgreSQL/PostGIS database is used, by standard requests. In order to access observations, an SDI (Spatial Data Infrastructure) client displays the sensors position, SOSClient (http://nodc.ogs.trieste.it/SOSclient).

The RTWeb (Real-Time Web interface) is the web interface that the user can use for querying the database using the RTWs;

the NetCDF, Oceansite standard (http://www.oceansites.org/docs/oceansites_user_manual.pdf), is used to answer to the needs of ocean monitoring and forecasting community.

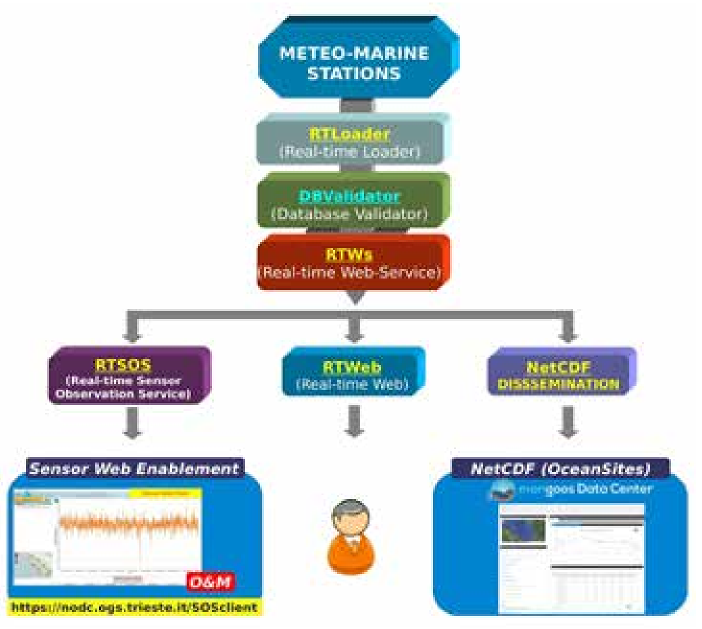

Figure 1 Figure shows the system workflow.

3. Conclusion

To include the data collected by two meteo-marine fixed stations, managed by OGS (MAMBO1 and E2-M3A), into the European infrastructure network forecast and open ocean observatories (JERICO, FIXO3), is created an automatic procedure for the harmonization, validation and standardization of marine data in near real-time. Ongoing European efforts in marine data management (SeaDataNet, EmodNET) and the existing nodes for data assembling (MyOcean In-situ TAC), were implemented and, if necessary, developed, following the perspective of maximizing synergies and avoid duplication of efforts.

The primary aim of this system is data sharing, maintaining interoperability and resilience.

The integration of several activities developed in national and international projects, as RITMARE, JERICO, MyOcean and FixO3, on the one hand has provided the opportunity to share open access and standardized data and on the other hand, gave us the chance to cooperate, analyze and use new technologies such as the Sensor Web Enablement (SWE), using SensorML and O&M standard in a Sensor Observation Service. Furthermore, this approach represents a first attempt to standardize data sharing in real-time adopting the experience maturated during the SeaDataNet project, and it is the first step toward the integration between the real-time and the delayed mode data environmental.

Acknowledgements

This work was supported by the Ministry of Education, Universities and Research (MIUR) under RITMARE Project. We also acknowledge funding from the European Programme (JERICO, FixO3 and SeaDataNet II). The authors are thankful to Paolo Mansutti and Giuseppe Siena for technical support in SensorML developing.

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Biogeochemical Modelling

OSS2015 – Forerunner of the “Green” Ocean Services beyond FP7

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Abstract

OSS2015 fills the “green gap” of the COPERNICUS Marine Service, the goal being to provide reliable now-cast, forecast and climatological trends of bio-chemical properties of the ocean.

The OSS2015 research program focused on the merging of satellite ocean colour data (multispectral radiance of the sea surface) and in situ autonomous measurements (on buoys, drifters, gliders…) through assimilation into bio-geophysical models. Data are ingested into numerical optical, biological and biogeochemical models which are linked to dynamical models of the ocean; concurrently, new empirical/analytical models/algorithms have been developed to retrieve integrated upper ocean parameters (Chlorophyll, Net Primary Production, Particle Size Distribution, Particulate Organic Carbon, and Phytoplankton Functional Types); extrapolation of ocean-downward distribution is targeted in both cases. The programme also included the optimization of sampling strategies.

Two pilots sites have been selected for tests of biogeochemical assimilations of EO and in-situ data, one in the Liguria Sea (a dedicated experiment carried out in March 2013) to qualify bio-optical assimilation techniques with HOPS, the other in the North Atlantic Ocean for comparison of bio-profilers data and ocean colour data with PISCES.

The 2015 outcome is a data service prototype, including a new web-based platform for “on-demand” processing which, on the side line, opens the door to an ocean colour collaborative platform.

Keywords: remote sensing, biogeochemistry, service

1. INTRODUCTION

The OSS2015 project, within the frame of “environmental services”, was set up to help specify and design the “Marine Biology” component of the COPERNICUS Marine Core Service (MCS), further to the MyOcean progress within the FP7 framework and in advance of a new era of global multispectral observations of the ocean (through COPERNICUS). It supports the endeavour of the scientific community dealing with ecology and climatology, and public action through policy makers & enforcers in charge of socio-economic challenges, in particular the European blue growth strategy.

Due to its vastness, to its dynamics variability, to its interactions with land and atmosphere at turbulent boundary layers, to its ecology complexity, to its geomorphology specificities and its strains under anthropogenic stresses, the Ocean deserves a complete, efficient and comprehensive observation and monitoring system built upon in situ measurement networks and remote sensing from satellites, using equations and laws to interpolate between measurements that are always too sparse to resolve all processes and to extrapolate all parameters. OSS2015 research was dedicated to a better understanding of the upper ocean biology, the production of relevant and reliable information and the organisation of data dissemination.

The success of the project is assessed by the delivery of accurate values of bio-geochemical parameters which are relevant for the study of the marine ecosystems and of the carbon cycle, and the prototyping of a Collaborative Platform for scientific exploitation of Earth Observation (EO) data (i.e. to facilitate the data handling by scientists and to spur algorithm development). Some of the information has been evaluated and provided for the first time. Specific dissemination and exploitation methods and exploitation methods have been implemented to promote its use.

2. PROJECT OBJECTIVES AND MAIN SCIENTIFIC ACHIEVEMENTS

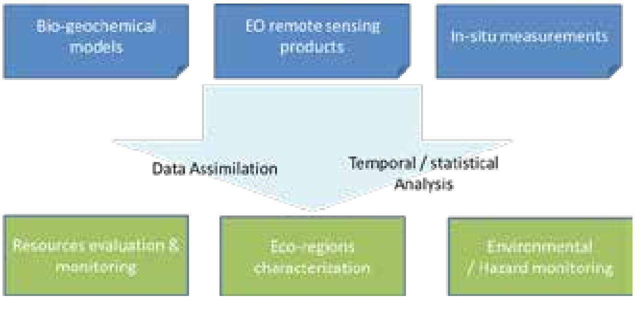

Figure 1 OSS2015 service overview

As summarized in the figure above, the aim of OSS2015 is to deliver marine "green" services including:

- Marine bio-resources evaluation and changes' monitoring
- Eco-region characterizations
- Environmental and hazard monitoring

These services are performed using primary data coming from Earth Observation remote sensing data, in-situ measurements and bio-geochemical models, using various data processing techniques (data assimilation in models, temporal and statistical analysis of time series). OSS2015 improved each component of this information's production line.

Improvements of primary data collection and production include new bio-optical and bio-geochemical models, innovative satellite-derived environmental data, new in-situ measurement techniques and methodologies. The progress also concern validation and quality control methodology, for both in-situ and EO data.

Bio-geochemical models complement primary data by extending the spatial and temporal coverage and introducing a forecasting capability. However models alone have poor prediction capabilities and OSS2015 has particularly studied the impact of assimilation of in-situ and EO data in models.

Data exploitation techniques such as clustering and time-series analysis have been used to improve the characterization of the Ocean (trend detection, bio-region identification).

New or improved user services have been implemented for the distribution of the new EO products. In particular, an on-demand information production service has been implemented.

Together, these advances contribute to the design of a performing Copernicus Ocean "green" service, a component or an adjunct to the MCS.

Some significant achievements of OSS2015 are further developed in the next sections.

2.1 Bioregions and optimisation of float deployment

The segmentation of the global ocean in bio-regions (ecosystems) allows to better model the climate modes' variability, and, practically, to optimise the in-situ and EO sampling strategy.

The method is based on the approach of d'Ortenzio et d'Alcala (2009) to identify clusters in Ocean Colour time series. However, instead of applying it on a pixel-by-pixel basis, we derive time series by sampling OC images along trajectories obtained from model simulations. These trajectories mimic the behaviour of a Bio-Argo profiling float and they are dispersed following the current velocities calculated by a model. Every 5 days, we sampled OC corresponding satellite images over the actual position of the numerical particles, to extract CHL (i.e. match up analysis). To each particle is associated a CHL time series over one year, and the ensemble of time series are finally grouped with the DR09 cluster analysis, giving a bio-regionalisation of the area. This method has been successfully implemented in the North Atlantic.

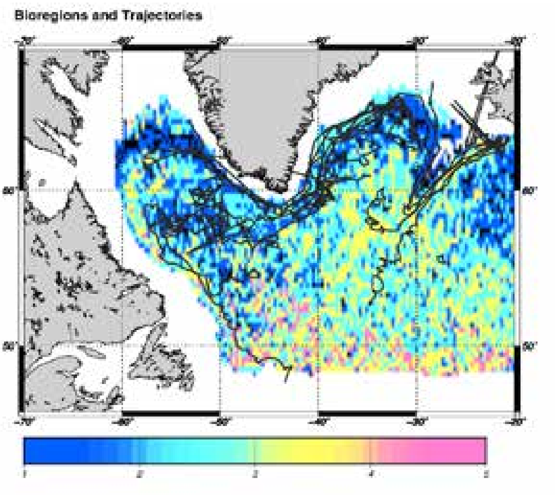

Figure 2 “Lagrangian” Bio-regions in the North Atlantic. The float trajectories (black curves) generally remain inside the same Lagrangian bio-region.

One application of the new bio-regions is to support the optimization of in-situ sampling strategies. Indeed, it has been shown that the trajectories of a float remain generally inside the same bio-region after deployment. This is especially true for Lagrangian bio-regions in the North-Atlantic. Floats deployed inside the same bio-regions are likely to provide similar measurements time series. The deployment strategy should therefore try to sample evenly each bio-region and avoid redundant sampling of the same bio-region. In addition, measurements inside intermittent bio-regions in the Mediterranean (occurring most but not all years) are particularly valuable. An optimal sampling strategy should put a specific focus on these regions.

2.2 Identification of key factors driving marine ecosystems

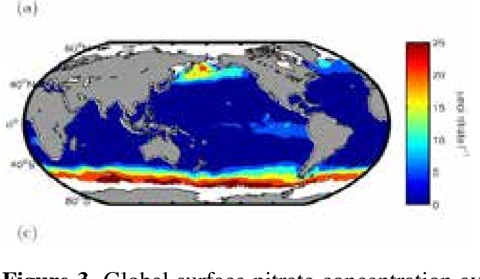

Figure 3 Global surface nitrate concentration average for the period 2005-2010, estimated from Sea Surface Temperature, Chlorophyll, and mixed layer depth.

A new algorithm has been developed for estimating surface nitrate concentration from satellite and operational-model derived data (Arteaga et al., submitted). The algorithm employs local multiple linear regressions of observed nitrate concentration vs. satellite-derived surface temperature and chlorophyll concentration and mixed-layer depth obtained from an operational ocean-circulation model.

The main findings of this research are:

- The new algorithm has been calibrated and validated with independent datasets for different time periods.
- While seasonal variability is somewhat underestimated, the algorithm successfully reproduces observed inter-annual variability in surface nitrate concentration at time-series sites, even for values well outside the range of the calibration data.

The optimality-based variable-stoichiometry phytoplankton model (Pahlow et al. 2008) has been the focus of further developments in the context of OSS2015. These developments contribute to better understand and predict the behaviour of the "living Ocean".

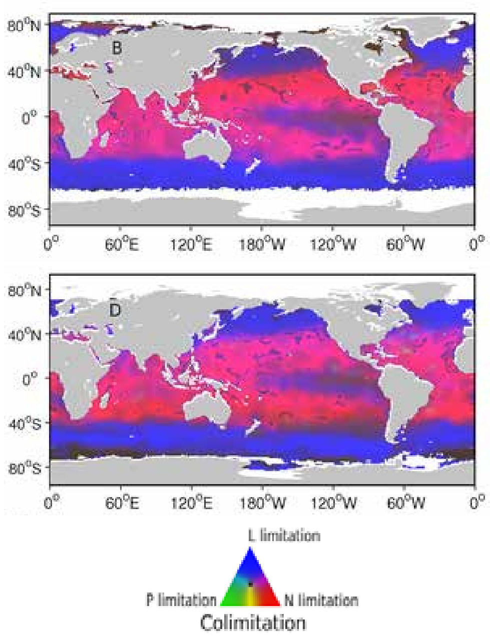

Figure 4 N, P, and light colimitation patterns in the world ocean grouped by season. The maps are Red-Green-Blue (RGB) composites of N limitation (red), P limitation (green) and light (L) limitation (blue), where limitation is defined as the complement to saturation. Colimitation is reflected by the combination of colours: Purple (N-light limitation), Yellow (N-P limitation) and Cyan (P-light limitation). Bright colours indicate limitation, whereas dark colours indicate saturation. Bright areas indicate colimitation by all three factors, while complete saturation is shown by black areas. The seasonal images are composites of 3-month averages: April-June (Top), October-December (Bottom).

The phytoplankton model has been calibrated to represent an 'average' phytoplankton community and solved for ambient conditions derived from satellite and World Ocean Atlas data in order to identify the main factors limiting phytoplankton growth (Arteaga et al. 2014). More precisely, the purpose is to determine quantitatively for each season and each region of the global Ocean, how far phytoplankton growth is limited by the availability of light, phosphorus (P) and nitrogen (N). The main output of this research is to produce monthly maps identifying limiting factors, as aggregated into seasonal averages in the figure below. The main conclusions are:

- Northern high latitudes display seasonal variability of N-light co-limitation, with predominant N limitation during July–September.
- P limitation is negligible in most of the ocean. The Southern Ocean appears as a mainly light limited area.

2.3 Production of Biogeochemical data/INDICATORS time series

A major achievement of the OSS2015 project is the expansion of bio/physico/chemical/optical indicators of the state of the Ocean beyond the traditional parameters such as Chlorophyll, yellow matter and total suspended matter, cloud fraction etc. and the delivery of 15-year time series of this information. These new EO products are available on the webserver of the OSS2015 service line (http://hermes.acri.fr). This work has involved the ULCO, UPMC and CNRS teams (on behalf of the GIS COOC) for the selection and definition of the new products and ACRI for the generation and delivery of the products.

a- Optical characterization of the ocean

Product type	Examples
Biological	Chlorophyll Color Index Algorithm, Particulate Organic Carbon, Particle Size Distribution, Primary Production…
Optical, Atmospheric	Aerosol Optical Depth and Angström coefficient…
Optical, Ocean surface	Reflectances, Photosynthetically available radiation
Optical, Ocean subsurface	Sechi Disk Depth, Light diffuse attenuation coefficient…

Table I. Example of bio-geochemical parameters available from the OSS2015 service.

b- Time series for climatology

The availability of long time series is particularly interesting to study evolutions of the marine environment in response to climate change. OS2015 made significant progress regarding the methodology for the detection of trends in time series of Ocean products such as Chlorophyll. In particular, the impact of the choice of the binning method and temporal period has been analysed with an appropriate statistical tool, the X11 Census method (Verpoorter et al., submitted).

2.4 DATA ASSIMILATION

The Harvard Ecosystem-Physical model (HOPS), currently maintained at MIT, has been used to carry out real time forecasting of physical-biochemical variability (T, S, NO3, NH4, detritus, phytoplankton and zooplankton) in the Liguria Sea during the LLOMEX'13 experiment –atmospheric forcing by embedment of MM5 in COAMPS.

Critical for the biogeochemical module is the mixed layer depth, (calculated through estimated turbulent quantities), and the distribution of light in the water column, (using the Kd(Par)). Surveys by gliders equipped with bio-optical sensors, outputs from the HYCOM model, SST fields and statistics from SeaDATANET were used for model initialisation whereas Chlorophyll concentration, as assessed from MODIS, was assimilated during the whole experiment.

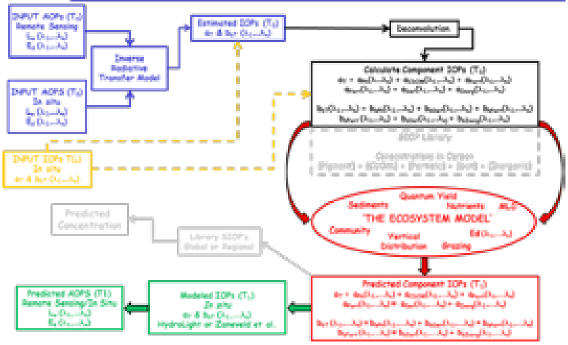

Figure 5 OPERA assimilation scheme

Results are shown in another paper by S. Besiktepe which was also delivered at the 7th EuroGOOS Conference.

3. Infrastructure and Tools : rise of the Collaborative PlatformS

A Collaborative Platform providing algorithm development, processing and validation functions have been developed for the purpose of OSS20125. This "Platform as a Service" approach brings innovation in the field of Earth Observation data processing, and creates the basis of a virtual research centre which allows scientists working together, reviewing their results, standardising the data processes, etc.

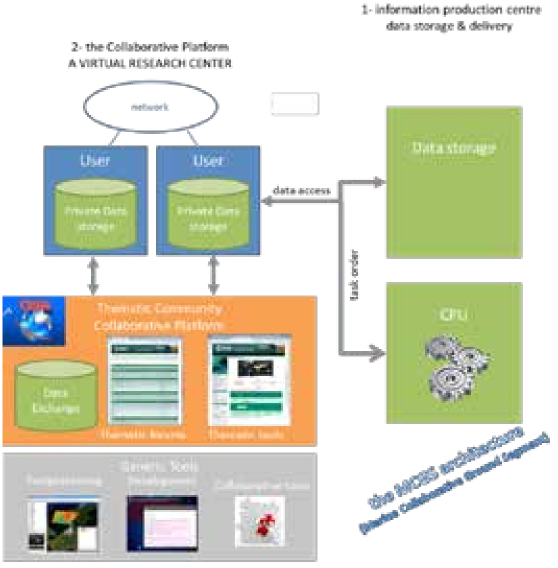

Figure 6 The OSS2015 Collaborative Platform supports the implementation of a virtual research centre for the production of new biogeochemical information.

4. CONCLUSION and outlook

OSS2015 results led to recommendations on a COPERNICUS “green” offshore marine service to be taken into account for the next building step of the Copernicus Marine service. After this prototyping phase, the OSS2015 service might be set-up in the framework of a Public-Private Partnership (in support not only of climatology, adaptation and mitigation of climate change, but also of sustainable and responsible development of marine resources, by optimal deployment of observation means).

In the course of the project, and aside to Science, OSS2015 consortium members have opened several additional perspectives:

- of industrial consolidation, by the gathering of SMEs interested in further developments of the OSS2015 demonstrator and its commercialisation to feed EO downstream services like algal blooms’ forecast or optimisation of aquaculture;
- of socio-economic benefits by the expansion of OSS2015 to coastal areas, using High Resolution and Very High Resolution satellite-borne sensors such as Sentinel 2/MSI or intelligence gathering satellites such as PLEIADES;
- in the digital/knowledge-based economy of Big Data analytics for the “green” ocean monitoring

Acknowledgements

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Modelling the biogeochemical and physical state of the North and Baltic Seas

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Abstract:

A renewal of the operational model system is taking place at the Federal Maritime and Hydrographic Agency in Germany. The new hydrodynamical model component HBM (HIROMB-BOOS-Model) was coupled to the biogeochemical model ERGOM. The model system has been validated extensively and shows altogether a good representation of the physical and biogeochemical properties of the North and Baltic Sea. After a pre-operational test phase the HBM is planned to become operational. The biogeochemical model will be completed by a data assimilation module. The generation of products for the support of decision strategies and reporting for the European Marine Strategy Framework Directive will be among the key applications.

Keywords: ocean model, ecosystem modelling, North Sea, Baltic Sea, MSFD

1. INTRODUCTION

Reliable forecasts of the ocean state provide an important aid for a variety of maritime services ranging from storm surge warnings and search-and-rescue applications to the support of offshore construction and tourism. Operational model systems have become the backbone for many of these tasks. During recent years the field of applications and operational products has even been extended towards biogeochemical state estimates, e.g. in the MyOcean (www.myocean.eu.org) framework. These products are, e.g., able to support reports following the demands of European directives such as the Marine Strategy Framework Directive (MSFD).

A comprehensive operational model system with focus on German territorial waters has been developed and applied at the Federal Maritime and Hydrographic Agency (BSH) over the last decade. An ocean state forecast including the variables water level, currents, temperature, salinity and sea ice is provided on a daily basis. The system consists currently of 2D and 3D ocean models, drift and dispersion models as well as model components for the simulation of ecosystem dynamics. The latest model developments, including the transitioning towards the new HBM (HIROMB-BOOS-MODEL) model code and the ecosystem component ERGOM will be highlighted. A special focus is laid on the implementation, coupling and validation of the hydrodynamic-biogeochemical model setup. While the BSH has a long experience in operational hydrodynamical modelling, the ecosystem modelling is a rather new field of work.

Germany is connected to two sea regions, the North and the Baltic Sea which therefore fall into the responsibility of the BSH. These two regions exchange water via the Skagerrak and Kattegat but differ considerably in their physical and biological environment. While the salinity of the North Sea ranges from 32-35, the salinity of the brackish Baltic Sea varies around 2-15. The North Sea is highly influenced by tides, while the Baltic Sea is permanently stratified in deeper regions. The North Sea is generally more phosphate limited while the Baltic Sea is prone to nitrogen limitation, promoting strong cyanobacteria blooms. In order to obtain consistent information, the challenge to model these two ecosystems in one coupled biogeochemical-hydrodynamical model system is accepted.

2. MODEL SETUP

The model is forced by hourly meteorological fields provided by the German Weather Service (DWD).

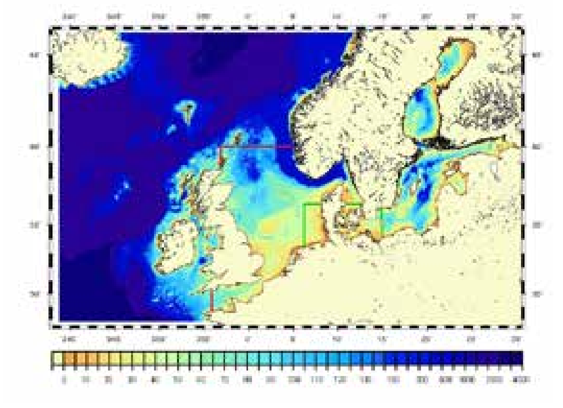


Figure 1 Model domain and bathymetry. The boundary of the fine grid (900 m) is indicated by the green line and the boundary of the coarse grid (5 km) is indicated by the red line. Outside of the coarse grid a North-East-Atlantic model (10 km) is used to generate the physical boundary conditions for the coarse grid. The scale is showing the water depth (m).

Physical boundary conditions at the open boundaries to the North Atlantic are provided by the BSH North-East-Atlantic model. Freshwater discharge originates from the HBV model run at SMHI for the Baltic Sea, from the German Federal Institute of Hydrology (BfG) for the German rivers, and climatological values for the remaining rivers. The biogeochemical river loads for the North Sea stem from Pätsch and Lenhart (2008), while the loads for the Baltic Sea were provided by IOW (Leibniz Institute for Baltic Sea Research Warnemünde, pers. comm. Thomas Neumann). The biological boundary conditions at the North Atlantic open boundary stem from the World Ocean Atlas (Conkright et al., 2002). Atmospheric deposition of nitrogen and phosphor loads is set to a constant background concentration. The model was initialized with data from an ERGOM model run at 1.1.2008 provided by DMI and calculated the whole year 2008 as basis for validation.

2.1 The hydrodynamical model HBM

The model region covers the whole North and Baltic Sea. The German Bight and the western Baltic Sea is simulated with a 2-way nested grid (Figure 1).

The water column is divided into 36 vertical layers for the coarse grid and 24 vertical layers for the fine grid. The vertical layer thickness is calculated dynamicaly during simulation time. The hydrodynamical model is described in detail in Brüning et al. (2014).

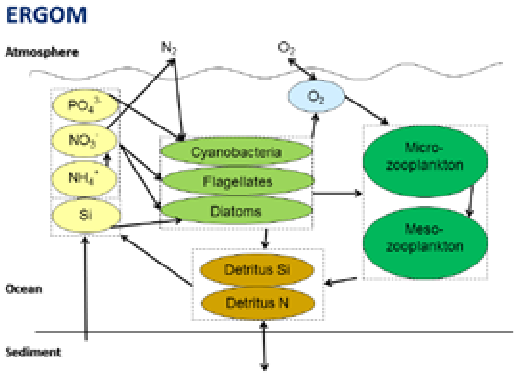


Figure 2 The ecosystem model ERGOM. The relationship between the different state variables is indicated by an arrow showing a flux from one state variable to the other.

2.2 The biogeochemical model ERGOM

The biogeochemical model ERGOM (Figure 2) was originally developed for the Baltic Sea ecosystem (Neumann, 2000) but has recently been extended to the North Sea (Maar et al., 2011). The applied version of ERGOM is a combination of the version of Maar et al. (2011) and the ERGOM version further developed at the Danish Meteorological Institute (DMI), which is, e.g., described by Wan et al. (2012) with some additional features and changes. A new state variable was added, the detritus silicate, to improve the representation of post-bloom silicate limitation of diatoms. In contrast to Wan et al. (2012), and due to the lack of data to satisfactorily describe variable N/P ratios for the whole area and the whole year 2008 a fixed Redfield N/P ratio is used. The fine grid configuration close to the German Coast and the fact that some rivers, e.g. the Elbe are resolved quite far into the land led to unwanted blooms and biological processes in the rivers, despite the fact that ERGOM is not an estuarine or even limnic ecosystem model. Therefore, the calculation of biological processes in rivers is switched off, allowing only passive transport of riverloads into the coastal regions. Following the formulation of (Doron et al., 2013) a diagnostic calculation of chlorophyll concentration was introduced into ERGOM. A new module was therefore implemented which calculates chlorophyll directly in the model by taking the instantaneous light availability and phytoplankton biomass into account.

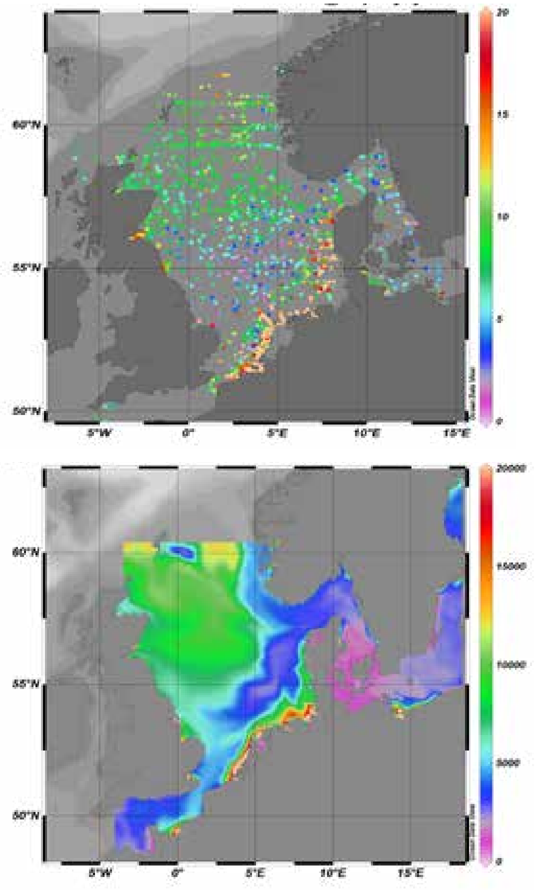


Figure 3 Comparison of NOWESP data climatology for February (upper panel) with model mean of February 2008 (lower panel) for nitrate [mmol/m³] in the North Sea.

3. Validation

We use several data sets to compare model results and observation data: data from the ICES database (www.ices.dk), data from the German oceanographic database (DoD, BSH), data from the NOWESP project (Radach and Gekeler, 1996) and data from HELCOM (www.helcom.fi) observational stations. We follow a hierarchical validation strategy starting from an overview by comparing surface data as a whole to ongoing finer resolution by comparing boxed values, and going down to point measurements of single profiles to get a good overview of the overall model behaviour, strengths and weaknesses. The model generally represents most of the features of the ecosystems quite well, although there is still room for improvement. The general surface patterns (Figure 3) as shown for the example of nitrate, agree with climatological data.

The ICES and DoD data were combined into one single dataset. The model domain was split up into 46 boxes (Figure 4). For each box, matchups between data and model results were identified, meaning that time and spatial position of both data sources must match; otherwise model data were not used. Then a monthly and horizontal mean was calculated for each box using only matching data points. Some examples are given in Figure 5. The general annual cycle is represented quite well for all state variables and the diagnostic chlorophyll, although overall model performance is slightly better in the Baltic Sea boxes in comparison to the North Sea boxes. This could be expected because of the model's history as a former pure Baltic Sea ecosystem model. There seems to be an imbalance between too high nitrate concentrations and too low ammonium concentrations in the overall picture, pointing to the fact that the nitrification rate might still be too strong.

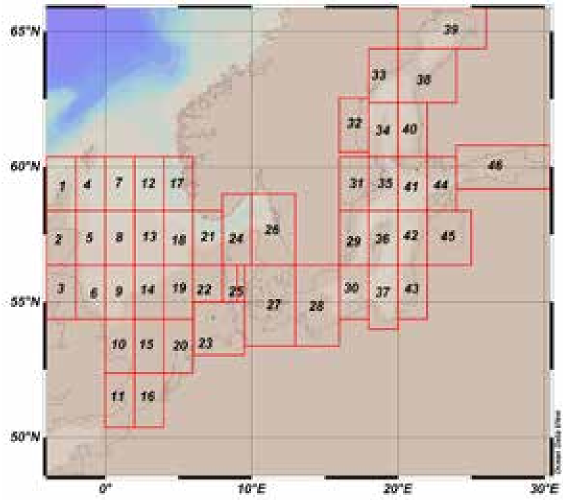
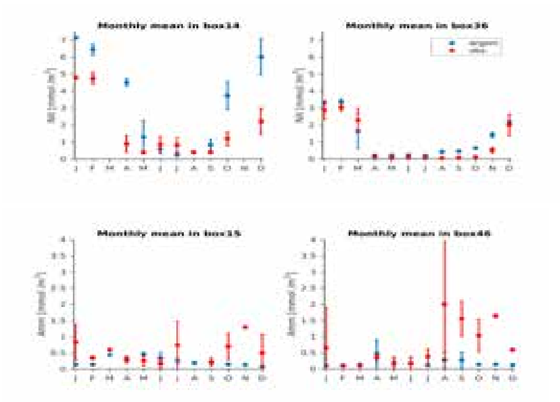


Figure 4 Box setup used for model validation.



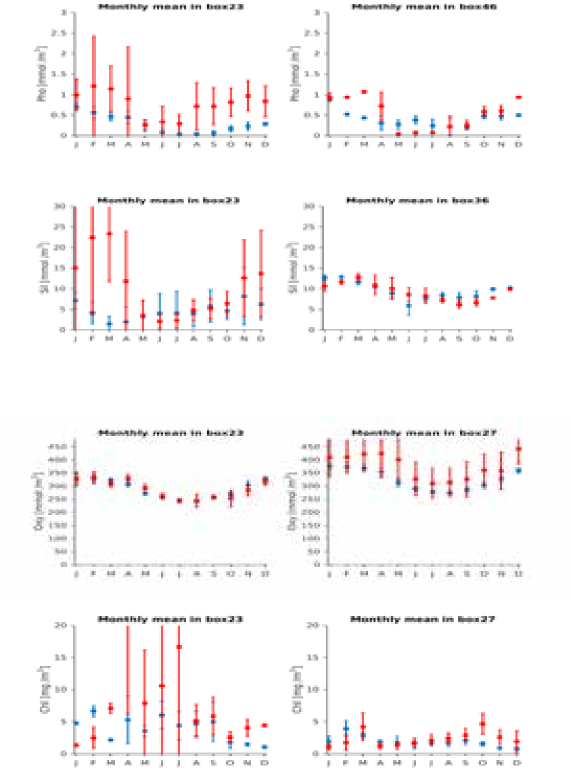


Figure 5 Validation of model results averaged over one box and one month. From the top to the bottom nitrate, ammonium, phosphate, silicate, dissolved oxygen and chlorophyll are displayed. The model results are compared with a combination of DoD and ICES data. Positions of the boxes are given in Figure 4.

Model results for the HELCOM stations were extracted from the full data set and compared directly with the observation data. In Figure 6 one example for station BMPR6, located in the Kattegat, is given. Although the initialized oxygen concentration is too high at 30 m depth, the model is able to simulate the rapid decrease in oxygen concentration in summer 2008. The surface oxygen concentration is represented well at BMPR6. The chlorophyll surface observation data show high values in the end of 2008 which might be unrealistically high. The spring bloom is well represented while chlorophyll at 30 m depth in the model is too high compared to data. The temperature and salinity properties of the station are well represented.

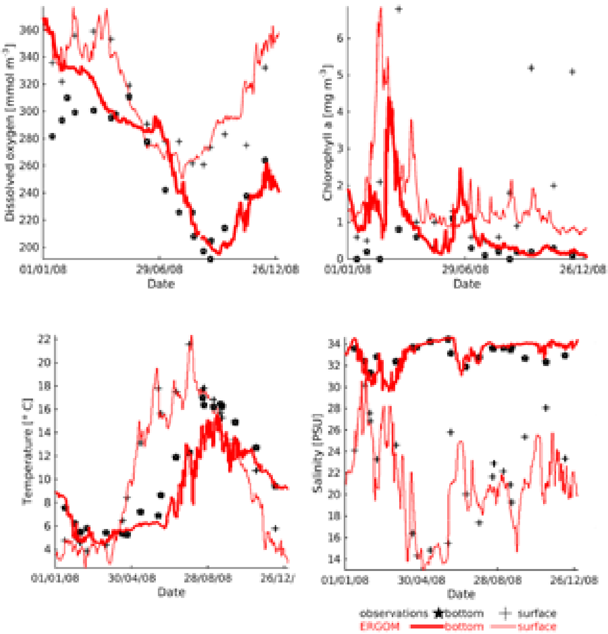


Figure 6 Comparison of HELCOM Station data for 2008 at station BMPR6 (57.2°N 11.67° E) for dissolved oxygen, chlorophyll, temperature and salinity at the surface and at 30 m depth.

4. Summary and outlook

The new pre-operational BSH model system is technically in place and producing reasonable results. The validation shows an overall good agreement with data although there is still need for further improvements in the representation of biogeochemical fields in the North Sea and the balance between nitrate and ammonium. The ecosystem modelling development will be ongoing and directed to supporting decision strategies and reporting for the MSFD. A data assimilation component for satellite derived chlorophyll will complete the model system in near future. Additionally the implementation of a nutrient tagging module is planned to help tracking nutrients from the source to their final sedimentation area.

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A new modelling tool for chemical spill modellers and responders

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Abstract

The increasing volume of chemicals transported by sea and the potentially dramatic consequences of chemical spills, raise the global awareness about the need for implementing better planning and response tools regarding chemical spills. A new 3D chemical / HNS spill fate and behaviour model was developed in MOHID.

The chemical spill model uses the lagrangian parcel method, estimating the distribution of chemical on water surface, shorelines, atmosphere, water column, sediments and seabed. Spilled mass is tracked through phase changes and transport. Model tracks separately evaporated or volatilized parcels, floating chemical, entrained droplets or suspended particles of pure chemical, chemical adsorbed to suspended particulates, and dissolved chemical.

MOHID HNS was simulated under different modelling scenarios, including different release depths, wind velocities, suspended sediments concentration and chemical products - one per behaviour class. Results reflect correctly the expected chemical behaviours.

HNS model development in MOHID platform provides the possibility of taking advantage of existing methods, properties, processes, user interfaces and operational services already developed and tested for this modelling system, shortening the effort needed to further implement an operational chemical spill modelling system in the near future, or to adapt the model to study the biological effects of released chemical substances.

Keywords: HNS, chemical spills, chemical spill model, MOHID, lagrangian

1. Introduction

One of the main pressures affecting the marine environment today results from chemical pollution: the release and effects of chemicals, particles, industrial, agricultural and residential waste, in marine environments. Worldwide, the production of chemicals is increasing with a total production volume expected to double in comparison with 2000 levels by 2024. Consequently, the volumes shipped increases every year, with maritime chemical transport having more than tripled in the past 20 years (CEDRE and Transport Canada, 2012), with some of these substances ending up in the marine environment. The threat of a chemical spill at sea concerns many public and private interest groups as the pollution caused is often invisible and may appear difficult to manage.

Like oil spills, chemical marine pollution may also result in harmful effects on aquatic species and wildlife. Although spill accidents with hazardous and noxious substances

(HNS) are not as frequent as oil spills, they carry additional challenges and difficulties to responders, environmental managers and modellers, due to a variety of reasons: a) HNS can affect human health; b) the wide panoply of different products transported (Häkkinen and Posti, 2013); c) the differences in physical and chemical properties between substances; d) their different behaviour in the environment.

The increasing awareness for these problems (EMSA, 2007), reinforced by some high impact pollution events in the past, is resulting in the need to develop policies and measures to protect the marine environment from chemical pollution.

In this context, improving models to properly simulate the fate and behaviour of chemical substances in the marine environment can feed decision support systems to help managers, decision-makers and authorities in the assessment of environmental risks associated with these types of marine pollution. It may also improve preparedness and response to accidental chemical pollution episodes, enabling marine pollution authorities to anticipate the environmental impacts, and therefore providing shorter response times to these types of accidents, which are very hard and complex to manage.

Few chemical spill modelling tools are available for investigating processes and environmental impacts, or planning and contingency arrangements, when compared to oil spill modelling software.

2. Methodology

A new 3D chemical spill fate and behaviour model was developed and integrated in MOHID water modelling system.

2.1 Integration in MOHID

MOHID (www.mohid.com) is a public-domain / open-source modular finite-volumes water modelling system, with the ability to study the water cycle in an integrated approach or in an isolated fashion. This modelling philosophy allows the integration of processes (physical and biogeochemical), as well as of different scales (allowing the use of nested models) and systems (estuaries, watersheds, open-sea, rivers, drainage basins, and reservoirs), due to the adoption of an object oriented programming philosophy (Neves, 2013). The main purpose of developing the model in the MOHID framework is to take advantage of several different properties, processes and features already developed and tested in other types of modelling applications.

The chemical fate and behaviour model was integrated in MOHID's lagrangian module, which uses the concept of tracer, assuming that the spilled contaminant can be represented as an amount of several different small tracers / spillets, and tracked as they move in three-dimensional space over time.

MOHID lagrangian module (Ascione Kenov, et al., 2014) can be run simultaneously with the hydrodynamic model (currents, water temperature, salinity, etc.), or in "offline" mode. In both modes, this model is able to digest currents, water properties, wave parameters and atmosphere properties from different model providers. Additionally, MOHID lagrangian module allows backtracking / modelling, as well as a multi-solution approach (Fernandes, 2013) (generating computational grid on-the-fly, and using the available information from the multiple metocean forecasting solutions available).

The user interaction with MOHID lagrangian module is presently available through different platforms, including MOHID Studio, EASYCO Web Bidirectional Tool and Aquasafe Platform / ARCOPOL Oil Spill Simulator (Fernandes, 2013). Although MOHID Studio is a classical desktop GIS system, the other referred platforms run in web browsers or standard PC, allowing users to define scenarios for model simulations, integrating updated metocean forecasts and generating results in seconds.

The diversity and capacity in the integration of MOHID lagrangian module with powerful and yet simple simulation tools (Fernandes, 2013) is also a main advantage and was also taken into consideration on the adoption of this modelling software for the integration of chemical fate and behaviour modelling system.

2.2 Mass Balance

The spilled mass is tracked through phase changes and transport, with all reaction products assumed to move together – chemical reactions are not specifically addressed in the model. The loss of chemical by reaction to some other form no longer of concern is included in degradation, which is estimated assuming a constant rate of "decay" specific to the environment where the mass exists (i.e., atmosphere, water columns, or sediment). The model estimates the distribution of chemical (as mass and concentration) on the water surface, on shorelines, in the water column, in the sediments and at the bottom. The model separately tracks surface floating chemical, entrained droplets or suspended particles of pure chemical, chemical adsorbed to suspended particulates, and dissolved chemical. The phase changes are computed independently for each particle every time-step, and the probabilities of one particle change from one phase to another (e.g. entrained to dissolved) is (pseudo-)randomly obtained, based on the algorithms that quantify the mass balances in the different processes. Therefore, correct modelling using this kind of approach obviously requires a large amount of particles in the simulation, in order to properly reproduce phase changes when slow processes / small mass transfers are involved.

2.3 Transport

Chemical mass is transported in 3D space and time. The horizontal movement is controlled by currents, wave-induced velocity (Stokes Drift), wind-drift velocity in the surface layer (for floating substances), spreading, and horizontal turbulence. The vertical movement is estimated in accordance with vertical advection from currents, rising velocity, sinking velocity, and turbulent dispersion.

These processes were already implemented in MOHID's lagrangian module, and they are also used in the simulation of oil spills. MOHID can simultaneously simulate currents (in the hydrodynamic module), or use an imposed solution (which is called the "offline" solution) from a previous run, or from a different model (or set of models), as long as the outputs accommodate the time period to simulate.

Since MOHID computes the chemical spills using independent lagrangian particles, surface spreading is modelled at three different levels: a) the initial area of the surface slick (based on Al-Rabeh, et al., 2000), which is randomly populated by MOHID with lagrangian particles; b) the increasing surface area of individual particle (adapted from Mackay, et al., 1980); c) the random movement of individual particles position to reproduce the increasing area of the surface slick (random velocities using diffusion coefficients from Al-Rabeh, et al., 2000).

The vertical velocity of chemical tracers inside the water column (entrained droplets due to breaking waves) will be a balance between their intrinsic buoyancy, advection and turbulence. The rising velocity can be estimated by two alternative approaches: a) assuming a double regime (spherical-cap bubble and small spherical droplets) as used by Liungman and Mattsson (2011); b) three-regime formulation, as proposed by Zheng and Yapa (2000).

2.4 Weathering

Weathering processes simulated include the vertical entrainment from breaking waves, evaporation from the surface, and volatilization from the water column, dissolution, partitioning / sedimentation (adsorption to sediments), resuspension and degradation.

The entrainment of the chemical in the water column can be estimated by the approach of Delvigne & Sweeney (1988) and Delvigne and Hulsen (1994). Entrained droplet diameters can be optionally estimated based on a) user-defined definition (unique value); b) half of the mass median droplet diameter (Spaulding, 1992) or c) pseudo-randomly chosen diameter based on a diameter class distribution computed using the Delvigne and Sweeney (1988) formulation. Particle depth is randomly chosen between Surface and maximum intrusion depth (Tkalich and Chan, 2002).

The evaporation rate from surface floating slicks from chemicals is computed with Kawamura and Mackay, 1985, and assuming that the transfer of mass from liquid to the air is limited by molecular diffusion across a stagnant boundary layer in the air above the chemical's surface (Mackay and Matsugu, 1973). A correction for evaporation rate is included for volatile chemicals, according to Brighton, 1985.

Volatilization of dissolved components from the water column to the atmosphere occurs as they are mixed and diffused to the sea surface boundary and enter the gas phase. This process is computed from the chemical's vapour pressure and solubility, as outlined by Lyman et al., (1982), based on Henry's Law and mass flux being controlled by diffusion in both the water and the air near the interface (Hines and Maddox, 1985).

Dissolution is estimated for spillets in the surface and in droplets dispersed in the water column. Surface slick dissolution is based on the hypothesis of a flat plate (the slick), and the droplets in the water column are assumed to be spherical, with the dissolution treated as a mass flux across the surface areas, according to Mackay & Leinonen, 1977. The dissolution from entrained small droplets is much faster than from surface slicks in the shape of flat plates (which is insignificant), because the surface area to volume ratio is higher for smaller spherical droplets.

Contaminants in the water column are carried to the sea floor primarily by adsorption to suspended particles and subsequent settling. Dissolved chemical in the water column is assumed to adsorb to natural particulate matter based on linear equilibrium partitioning theory, with constant proportions between dissolved and adsorbed concentrations, and dependent on suspended particulate concentration. Substance adsorbs to "silt" particles, and the adsorbed fraction is transported by Stokes Law, and subject to other vertical forces in the water column (e.g. turbulence).

Chemically contaminated particles deposited at the bottom can be re-suspended if bottom current velocity is above a specified threshold (default = 0.2 m/s).

Degradation of a chemical can occur in different environments (atmosphere, water column and sediment) by different processes (biological, chemical or photochemical). Since these degradation processes are not specifically addressed in this model (spilled mass is modelled in terms of transport and phase changes), a constant decay rate specific to the environment where the mass exists is assumed, in order to determine the degradation / loss of chemical to some other form no longer of concern.

The outputs of the chemical spill software developed include the evolution of particles position and state over time, as well as different parameters in 3D or integrated over the vertical column (e.g. mass, concentrations and maximum concentrations).

3. Results

A battery of different modelling scenarios was chosen to evaluate the model response to different substances and responding as expected to variable conditions: 9 different substances - one per physical-chemical behaviour class (gas category was not simulated); different wind velocities (3 m/s and 8 m/s); different release depths (0m and 50m); different suspended sediments concentration: 10 mg/L and 0 mg/L. In this paper we will analyse a selection of results to illustrate the model response to some of these parameters.

The spatial geometry used for the simulations is based on a tank with a constant depth of 96.5m. A constant horizontal spatial step of 100m (dx = dy) was used for the whole domain, as well as 51 vertical layers with a variable depth (starting with approximately 10 cm at the surface layer and with 3.86m at the bottom). Current velocity is not included, and only surface advection due to wind (wind drag effect) is included in the simulations. Turbulent dispersion and wave-driven velocities (Stokes Drift) were also disconnected; therefore, wind is the only horizontal force that controls the particle trajectories. A constant water salinity of 36 ppt was used, as well as a constant temperature of 16ºC. The degradation process was turned off by default.

The schematic and simplistic approach followed for the modelling scenarios was adopted to clearly reduce the number of variables controlling the results, and isolating the influence from the chemical specific parameters and processes programmed.

Changes in wind speed can affect different processes. It will increase the mass transfer in the evaporation process over the surface slick (Figure 1), but will also increase indirectly the wave height (which in these simulations is computed directly from wind speed) and consequently the diffusive mixed depth (obtained from the wave height). These changes will increase entrainment in the water column (due to higher energy from breaking waves), and consequently the dissolution rate (Figure 2).

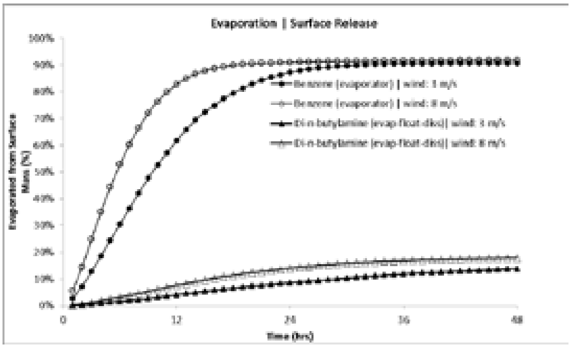

Figure 1 Mass Evaporated from surface for benzene and di-n-butylamine released in surface waters using different wind speeds (no degradation; suspended sediments concentration = 0 mg/L)

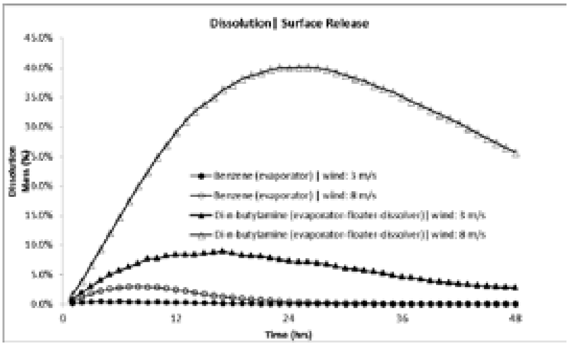

Figure 2 Mass dissolved from a surface spill of benzene and di-n-butylamine under variable wind conditions (no degradation; suspended sediments concentration = 0 mg/L)

The influence of the release depth was also analysed and compared (Figure 3 and Figure 4). If released in subsurface layers (5m depth), the typical behaviour of floating substances (with density lower than water) with any kind of solubility is the increase in dissolution rates, as buoyant liquid rises through the water column. Model results reproduce the increasing dissolution for subsurface releases.

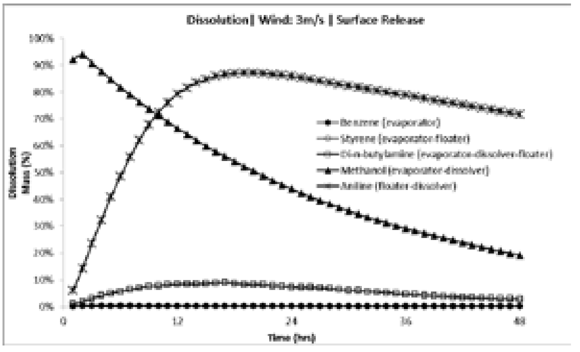

Figure 3 Mass dissolved from different chemical substances spilled on water surface (wind speed = 3 m/s; no degradation; suspended sediments concentration = 0 mg/L)

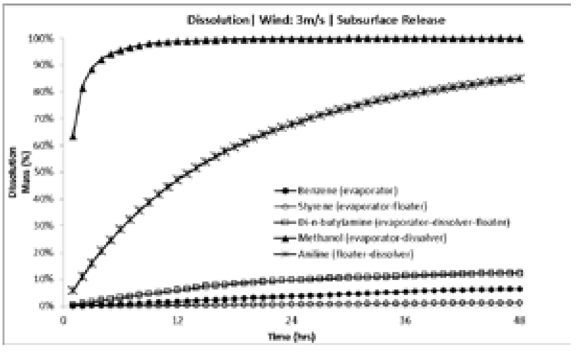

Figure 4 Mass dissolved from different chemical substances spilled at a 5 meter depth (wind speed = 3 m/s; no degradation; suspended sediments concentration = 0 mg/L)

The adsorption of chemical substances to suspended sediments in the water column reduces the amount of dissolved parcel available to be volatilized, as can be seen in the Figure 5 and Figure 6, with the release of an evaporator-dissolver-floater in waters with different suspended sediments concentration).

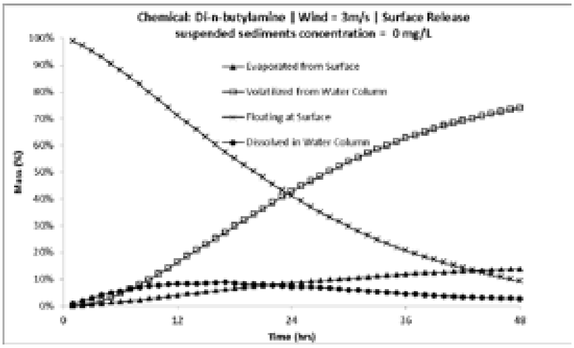

Figure 5 Mass balance from a surface spill of di-n-butylamine (wind speed = 3 m/s; no degradation; suspended sediments concentration = 0 mg/L)

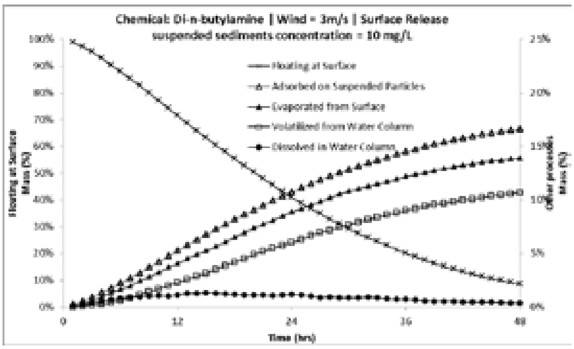

Figure 6 Mass lost from a surface spill of di-n-butylamine (wind speed = 3 m/s; no degradation; suspended sediments concentration = 10 mg/L)

4. Concluding remarks

The results obtained correctly reproduce the expected variations based on the different modelling scenarios deployed. Further tests must now be performed to verify the sediment interactions at the seabed (bottom deposition and re-suspension), as well as to apply the whole model in real test cases including 3D hydrodynamic fields and turbulence. The modelling approach adopted requires a large number of lagrangian particles, however lagrangian model performance was recently improved, and future parallelization will be studied in this context. The developed model is now available to be used by modellers in the scope of environmental studies and planning stages. The ongoing integration with available decision support tools implemented for oil and inert spills will provide an effective answer to emergency responders, and more reliable than simply generalizing different behaviour classes to reproduce the whole panoply of chemicals transported at sea.

Acknowledgements

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Reanalysis of Mediterranean Sea biogeochemistry and the quest for biogeochemical seasonal forecasts

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Abstract

In the frame of MyOcean2 and OPEC projects, OGS produced a reanalysis simulation of Mediterranean Sea biogeochemistry (1999-2010) with assimilation of satellite chlorophyll observations. Results have been analysed comparing the outputs with a control-hindcast simulation, with satellite observations and with available in situ data. Assimilation improves the model skill by better representing both the mean chlorophyll concentrations over the Mediterranean sub-basins and the spatial-temporal definition of local bloom events. The comparison with nutrients climatology based on in situ measurements shows that the non-assimilated variables are consistent with observations. Results concerning potential applications for seasonal forecasts are also discussed.

Keywords: Mediterranean Sea, biogeochemistry, reanalysis, seasonal forecasts

1. Introduction

European Commission clearly highlighted (2014) that innovative actions throughout all the blue economy sectors are crucial to fully realise their growth and jobs potential, without affecting the marine environmental state. Operational Oceanography is asked to contribute to this effort providing products and insight to the implementation of recent EU directives (e.g. 2008/56/EC Marine Strategy Framework Directive, 2014/89/EC Marine Spatial Planning). As a consequence, the interests for feasible climatological data sets of the present conditions of Mediterranean Sea biogeochemistry are constantly growing, and arise both at European and at national level, where MSFD requirements are added to national marine ecosystem management regulations already in force.

In parallel, as demonstrated within the FP7-OPEC project, demands for reliable ecosystem services, often oriented to seasonal forecasts with socio-economical impacts, are emerging from stakeholders and end-users.

On this basis, given the scarcity of spatially and temporally homogeneous biogeochemical observational data in the recent past, a model-based climatology extracted from a reanalysis simulation represents a synoptic description of the present state of the biogeochemical properties of the Mediterranean basin, and it can provide suitable boundary conditions for sub-basin and coastal models. Model-based climatology is indeed built on 3D dynamics and can offer information on the horizontal and vertical structure, integrating the information provided by data in open ocean areas typically not covered by observational surveys.

Further, such reanalysis can be used to initialize experimental biogeochemical seasonal forecasts that may give information on possible future anomalies with respect to present conditions. As an example, seasonal forecasts of low trophic levels fields (e.g. primary producers) can be linked to scenarios of high trophic level fields or other user-driven socio-economic derived quantities.

This communication presents preliminary results of a biogeochemical reanalysis simulation carried out during MyOcean2 and OPEC FP7 projects along with a test run of a seasonal forecast for the period of winter 2013.

2. Methodology

The reanalysis run for the biogeochemistry of Mediterranean Sea at 1/8° horizontal resolution for the period 1999-2010 was carried out with the OGSTM-BFM 3D off-line coupled physical-biogeochemical model (Lazzari et al. 2010, 2012, 2014, 2015). OGSTM-BFM is a biogeochemical model that describes the biogeochemical cycles of 4 chemical compounds: carbon, nitrogen, phosphorus and silicon through the dissolved inorganic, living organic and non-living organic compartments. For this simulation, OGSTM-BFM was embedded in the MyOcean Med-MFC-biogeochemistry subsystem, which uses physical forcing fields extracted from MyOcean Med-MFC-currents products and assimilates satellite surface chlorophyll concentration.

The assimilation scheme uses a 3D variational method that integrates satellite surface chlorophyll to update the phytoplankton groups (Teruzzi et al., 2014).

Initial conditions on nutrients are based on MEDAR-MEDATLAS climatological data sets; boundary conditions on nutrients at rivers, Strait of Gibraltar and atmosphere are respectively based on works by Ludwig et al. (2009), MEDAR-MEDATLAS, Ribera d'Alcalà et al. (2003).

The reanalysis run (RR) is based on a weekly assimilation of surface chlorophyll and a post-processing that produces as output 3D monthly fields of chlorophyll, nutrients (phosphate and nitrate) and dissolved oxygen concentrations, net primary production and phytoplankton biomass.

A control hindcast run (HR) has been performed as the RR but without assimilation.

The model system used for the seasonal forecast test (SF) was the same employed for the RR. Initialization of SF test consists of the final conditions of RR (successively continued until December 2012), with climatological boundary conditions, and physical forcings derived from MyOcean forecast system. Data assimilation was not performed since no observations are expected to be available in a forecast run.

The chlorophyll satellite data used for assimilation and validation consist of SeaWiFS data provided by the MyOcean Ocean Colour Thematic Assembly Centre.

Reference data for model validation consist of in situ observations (OBS) gathered from two international data sets: the historical 1980-1999 data set EU/MEDAR/MEDATLAS II (Manca et al., 2004) and the NODC-OGS databases, which covers the period 1999-2010.

3. Results

Results are presented first with the reanalysis run (RR) validation and then with the test on seasonal forecast (SF).

3.1 Reanalysis validation

The mean surface chlorophyll for the pelagic area of the Mediterranean Sea of Fig. 1 is consistent with current knowledge and previous published results (see references in Lazzari et al., 2012), which indicate that the Mediterranean Sea can be considered as oligotrophic (mean surface concentration of less than 0.1 mg chl/m^3) with the presence of some areas characterized by high values of chlorophyll (specifically the Gulf of Lions, the Alboran Sea, and the Northern Aegean Sea).

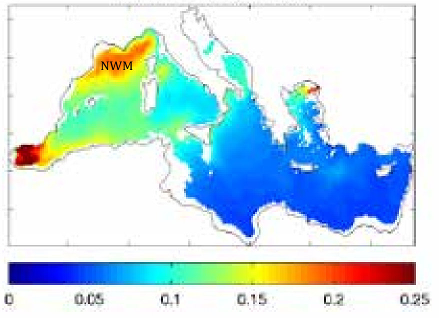

Figure 1 Map of mean surface chlorophyll (mg/m^3). Areas shallower than 200 m are masked. Mediterranean Sea sub-regions used for the metrics evaluation are also shown.

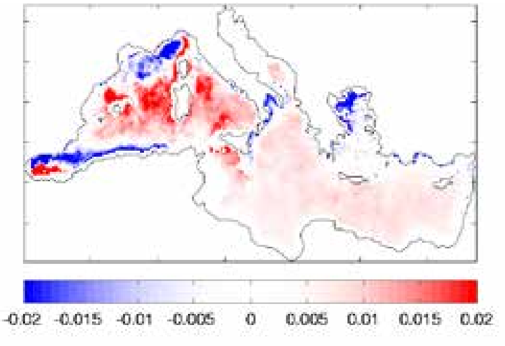

Figure 2 Map of error (model minus reference) of mean surface chlorophyll (mg/m^3). Areas shallower than 200 m are masked.

Through a comparison of our results with the semi-independent reference data set of surface chlorophyll retrieved from SeaWiFS satellite (i.e. though data were assimilated during RR, the validation was performed using the model results before a new assimilation event), we see in Fig.2 that model tends to underestimate high production areas (e.g.

northern sectors of western Mediterranean and northern part of ALB) and to slightly overestimate oligotrophic areas (e.g. Levantine Sea). Nevertheless, the assimilation improves all the indexes of skill performance of the model with respect to the control run (Table I). Results demonstrate that the combination of assimilation and dynamical model is an optimum interpolation method of the satellite data, by correcting and integrating spatial and temporal lacks.

	mean	std	correl	bias %	RMS
REF	0.082	0.049			
RR	0.087	0.043	0.96	9.4	0.015
HR	0.083	0.031	0.86	13.2	0.027

Table 1 Skill assessment indexes for surface chlorophyll (mg/m^3) for RR and HR ("REF" denotes SeaWiFS satellite data).

Table I summarizes the skill assessment of the RR, showing the overall satisfactory capability of our model to correctly represent the surface chlorophyll mean field, taking also into account that target accuracy for the bio-optical algorithms in use at international level is 35% (see Brasseur et al., 2009; Volpe et al., 2007).

Because of the specific characteristics of the different sub-regions of the Mediterranean Sea, the evaluation of model performance in reproducing the chlorophyll seasonal cycle has been done on 9 different sub-regions (Fig. 1). We restrict our results here to just two exemplary sub-regions: North-Western Mediterranean (NWM) and Ionian Sea (ION), showing also the output from the HR to demonstrate the improved model performance due to the data assimilation (Fig.3).

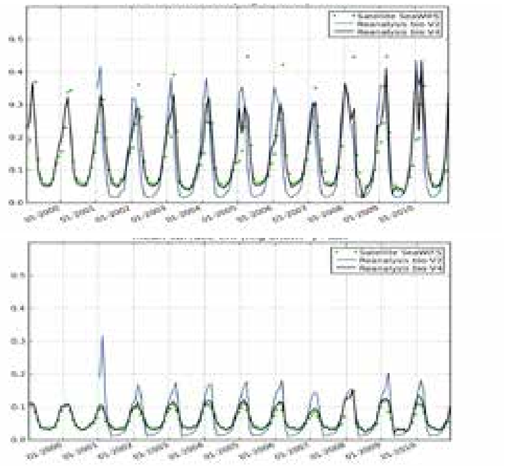

Figure 3 Time series of the monthly mean surface chlorophyll concentration (mg/m^3) for RR (black line), SeaWiFS satellite (green points) and reference HR (blue line) for NWM (top) and ION (bottom) sub-regions.

The time series of the monthly mean concentrations of chlorophyll produced by the RR correctly reproduce the typical seasonal cycle of surface chlorophyll and the east-west gradient. As expected, the RR results are significantly closer to the satellite observations than those of the RR for both sub-regions in terms of field intensity and bloom timing (similar considerations hold for the others sub-regions, not shown).

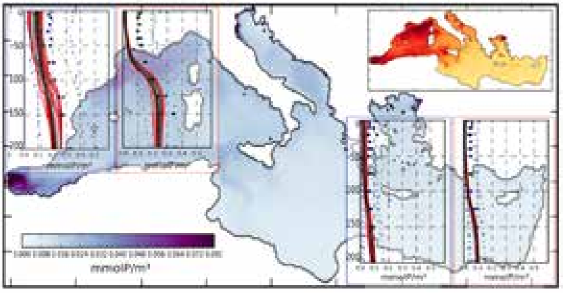

Figure 4 Mean annual field of surface phosphate concentration (main map) and standard deviation (upper-right map). Monthly (red lines) winter (blue framed box) and summer (red framed box) vertical profiles for NWM and LEV sub-regions and relative observations with 2 observational data sets (blue and green dots).

In the Mediterranean Sea, phosphate (PO4) is the main limiting nutrient (Krom et al. 1991), and Figure 4 shows that RR correctly reproduces the mean field and the variability of PO4 (which is generally larger in the western Mediterranean), as reported in literature (see also Lazzari et al., 2015). Figure 4 also shows that vertical profiles are within the observed variability, which is generally larger than the model one. This is clearly due to the different temporal discretization of model output (monthly means) compared to observations: reprocessed model outputs filter out the extreme values that can be captured during a short-term field experiment.

An alternative skill analysis is a space-time matching of the observations with the corresponding RR results. This skill assessment is much more stringent and has been performed for nutrients and Dissolved Oxygen (Tab.II). Results, which are clustered for 2 layers (upper and deeper than 200m), represent both a first attempt of a quantitative assessment of a regional biogeochemical simulation and a benchmark for next developments.

Variable	n. of observations	Unit	Model Efficiency	% Model Bias	Correlation	RMSE
DISSOLVED OXYGEN upper	534	mmolO_2/m^3	-0.05	5.46	0.67	18.05
DISSOLVED OXYGEN deeper	1635	mmolO_2/m^3	0.11	0.22	0.33	20.18
NITRATE upper	2546	mmolN/m^3	-0.18	27.37	0.26	3.10
NITRATE deeper	3593	mmolN/m^3	0.21	5.17	0.46	2.57
PHOSPHATE upper	4676	mmolP/m^3	0.22	41.19	0.65	0.11
PHOSPHATE deeper	6685	mmolP/m^3	0.23	6.70	0.50	0.14

Table II Skill assessment indexes for nutrients for RR.

Model efficiency, which verifies the predictability power of the model, is positive or close to zero, showing that RR results are at least as accurate as the mean of the OBS data. Biases are generally better in the deeper layer, where variability is much lower. PO4 and dissolved oxygen in upper layer show correlation higher than 0.60, while other correlation coefficients remain generally not very high due to the sparse distribution of OBS with respect to the model resolution. It is also worth noting that a 41% PO4 concentration bias in the oligotrophic upper layer is related to very low PO4 values (see Fig. 4), proximal to the operational accuracy of experimental methods. Analogous consideration can be drawn also for upper layer nitrate. Skill assessment indexes for dissolved oxygen should be considered with some caution since the available observations correspond to only two cruises.

3.2 Seasonal forecast test

To investigate the capability of the OGSTM-BFM model system to provide feasible basin-scale seasonal forecasts, we used the preliminary results of a test on winter 2013 (SF). In particular, we investigated the predicted monthly anomalies over a reference climatological data set.

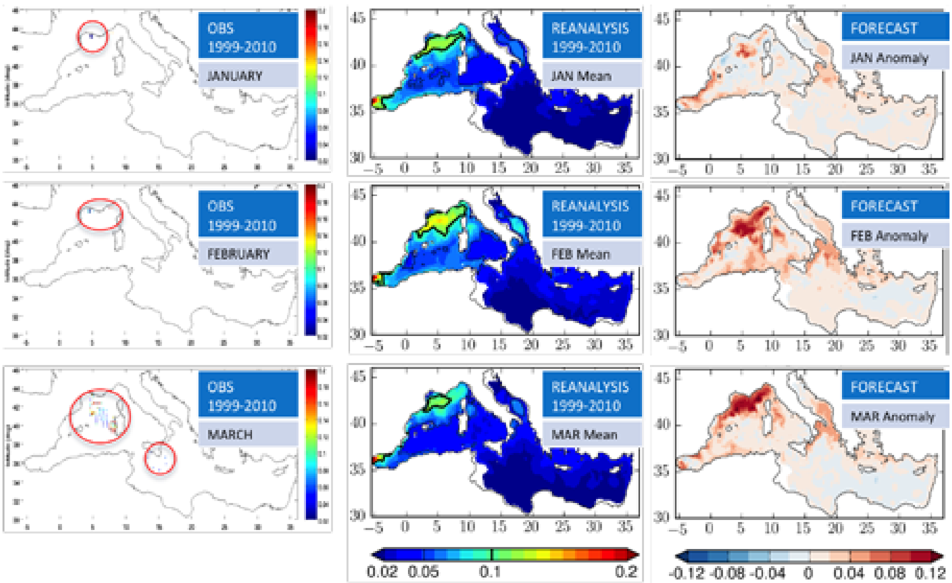

Figure 5 Overview of SF test for PO_4 (mmol/m^3) in the 0-50m layer for January, February, March 2013. Left column: OBS data with monthly mean measured P concentrations. Central column: RR monthly means. Right column: SF monthly mean anomalies.

Main pre-requisite is the availability of the reference climatological data set. Considering the OBS data set, the total amount of data appeared too limited to efficiently build the reference climatology (data not covering the whole Mediterranean basin and mainly concentrated in spring/autumn seasons). As an example, PO4 data gathered in April were among the most numerous (about 600 single measurements) but were spatially concentrated on a very limited area (NWM), so the anomaly could be evaluated, even partially, only for that sub-region.

Therefore, the only feasible alternative is to perform the SF test using as reference the gridded climatology derived from RR, provided that RR had the sufficient skill to be representative of the present conditions. Figure 5 presents the overview of the experiment for the average PO4 concentration in the layer 0-50m; as a comparison, we also included the available observations of the referred months.

Monthly means estimated from RR show a typical east-west basin-scale gradient, with higher values in the ALB and NWM sub-regions.

A qualitative comparison with OBS is possible only for March and in a very limited area (NWM), showing a reasonable agreement on open ocean areas and a model underestimation in the Gulf of Lions and close to Sardinia. Therefore, a basin-scale seasonal forecast can be compared only with a climatology produced by a reanalysis. The results of the SF test show a positive anomaly in NWM, which indicates an increase in intensity of vertical mixing during the simulated period and a higher surface concentration of PO4.

	Jan 2013	Feb 2013	Mar 2013
SF – satellite map: Bias	0.22	0.14	0.03
RMS	0.10	0.12	0.12
Corr	-0.13	0.48	0.56
RR – satellite map: Bias	0.11	0.14	0.04
RMS	0.05	0.06	0.15
Corr	-0.22	0.25	-0.19

Table III Skill assessment of SF and RR-based climatology versus satellite monthly maps (sat) for Jan-Feb-Mar 2013.

As a consequence, during the simulated season the productivity of the area is higher, as well as the concentration of surface chlorophyll.

As a verification test of the validity of the seasonal forecast, the skill between the FS and the MODIS satellite chlorophyll data (which would become eventually available at the end of the period) is compared with the skill between the climatology derived from the RR and the MODIS satellite data (Table III). Results in the Table III show that the SF skill is slightly better than that of the climatology derived from the RR. This is related to the consistency of the spatial structures of surface chlorophyll with those used for the initialization (i.e. the last assimilation event occurred at the end of December 2012), and to the specific forcings which drive the evolution of the surface spatial structures of the FS run.

4. CONCLUSIONS

The present contribution gives some preliminary results on the first reanalysis simulation performed for the biogeochemistry of the Mediterranean Sea for the period 1999-2010, in the frame of MyOcean2 and OPEC FP7 projects. A gridded climatology was extracted from the reanalysis and validated against a control-hindcast simulation, a satellite-derived surface chlorophyll data and an observation-derived dataset including nutrients and dissolved oxygen. The model has a good skill for the assimilated variable (surface chlorophyll), and shows that the results of non-assimilated variables (nutrients and dissolved oxygen) are consistent with observations.

An experimental test on seasonal forecast was carried out, evaluating the mean monthly anomalies with respect to the reanalysis-based climatology. Operational seasonal forecasts are presently at a very experimental stage (e.g MetOffice research and development activity[1]), even if their potential impact on marine resources management has been long recognized. Our tests show that biogeochemical models, meaningfully integrated with observations, are on the right track to provide experimental seasonal forecasts that can support relevant information on scenarios of lower and high trophic level fields or other user-driven socio-economic derived quantities.

Acknowledgements

The material present in this contribution was generated using MyOcean products. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement No. 283291 for the project Operational Ecology: ecosystem forecast products to enhance marine GMES applications (OPEC).

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OPEC project, http://marine-opec.eu/ (website visited on January 2015)

An integrated forecasting system of hydro-biogeochemical and waves in the Tagus estuary

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Abstract

This work describes an integrated forecasting system of hydro-biogeochemical and waves in the Tagus estuary (Portugal). The wave model is based on the WAVEWATCH III (WWIII), while the hydro-biogeochemical model is based on the MOHID modelling system. The integrated forecasting system is running operationally and providing online daily forecast results of hydrodynamics, waves, and water quality (http://forecast.maretec.org/).

Keywords: modelling, hydrodynamic, biogeochemical, waves, forecasting

1. INTRODUCTION

This work describes the implementation of an integrated forecasting system for the Tagus estuary (Portugal), coupling a hydro-biogeochemical with a wave model. The wave model has the physics appropriate to shallow waters, as well as to current-wave interactions. In coastal waters, currents can become important to the growth and decay of waves. Thus, the hydro-biogeochemical model provides currents and water levels to the wave model. On the other hand, the wave model provides wave parameters to the hydro-biogeochemical model. The wave action contributes to increase the bottom shear stress and can be important to the erosion of sediments. The waves can reach different parts of the intertidal zone of the Tagus estuary depending on the tidal cycle, remobilizing the sediments trapped in low velocities areas (Franz et al., 2014a). The turbidity caused by suspended sediments reduces light penetration in the water, affecting photosynthesis and food availability.

2. Model Setup

2.1 Atmospheric Boundary Conditions

The atmospheric forcing for the Tagus Estuary modelling system is provided by the Weather Research and Forecasting (WRF) model, from IST meteorological team (http://meteo.ist.utl.pt/), with a spatial resolution of 3 km x 3 km.

2.2 Wave model

Following the approach of the operational wave modelling forecasting system for the Portuguese Coast, previously implemented by the MARETEC research group, the Tagus estuary wave model is based on the WAVEWATCH III (WWIII). The latest version 4.18 was selected (released by NOAA in March, 2014), which considers an additional important physical process for shallow waters (triad wave-wave interactions). The spectral domain has been divided into 50 frequency (range of 0.035–0.963) and 36 directional bins (directional resolution of 10º).

The open boundary conditions for the wave model have been provided by the operational wave forecasting system for the Portuguese Coast, which has a grid resolution of 5 km x 5 km. An intermediate domain was created for the central zone of Portugal with a grid resolution of 1 km x 1 km. For the Tagus estuary the grid resolution is 200 m x 200 m (Fig.1). To avoid numerical instabilities, the resolution between the father and son grids were improved at most five times.

2.3 Hydro-biogeochemical model

The hydro-biogeochemical model is based on the MOHID water modelling system. The vertical discretization of the hydro-biogeochemical model consists of 14 Cartesian layers overlapped by 7 Sigma layers, with a vertical resolution close to 1 m at the water surface. More details about model setup and validation can be found in Franz et al. (2014b). The open boundary conditions for hydrodynamics and water properties are provided by the Tagus Mouth operational model. The Tagus Mouth model was implemented by the MARETEC research team mainly for the study of the estuary mouth and covers a larger area with a lower resolution (ranging from 2 km to 300 m). This model is also a downscaling of the Portuguese Coast model.

3. Operational System

The integrated forecasting system is running operationally and providing online daily forecast results of hydrodynamics, waves, and water quality (http://forecast.maretec.org/). A scheme of the

system is presented in Fig.2. The hydro-biogeochemical model produces 48h forecasts. Previously, the day before is run with the best ocean and atmospheric conditions, and flow measurements from the hydrometric station of Almourol (http://snirh.apambiente.pt), located in the Tagus river. The hydro-biogeochemical model provides water level and currents for the wave model that currently produces 24h forecasts. In the near future, the wave results will be used by the hydro-biogeochemical operational model for improving the water quality nowcast.

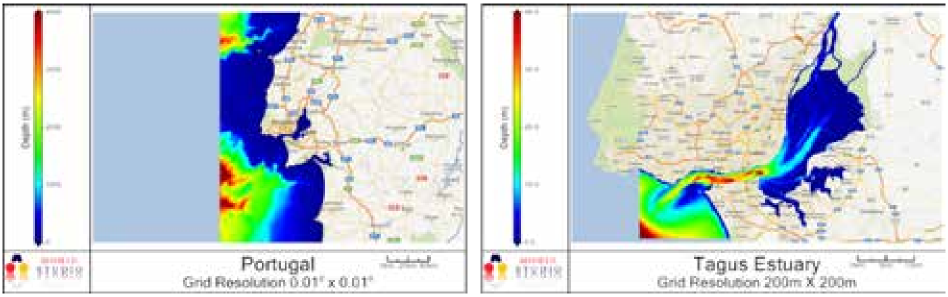

Figure 1 Bathymetry of the Central Portugal and Tagus Estuary domains

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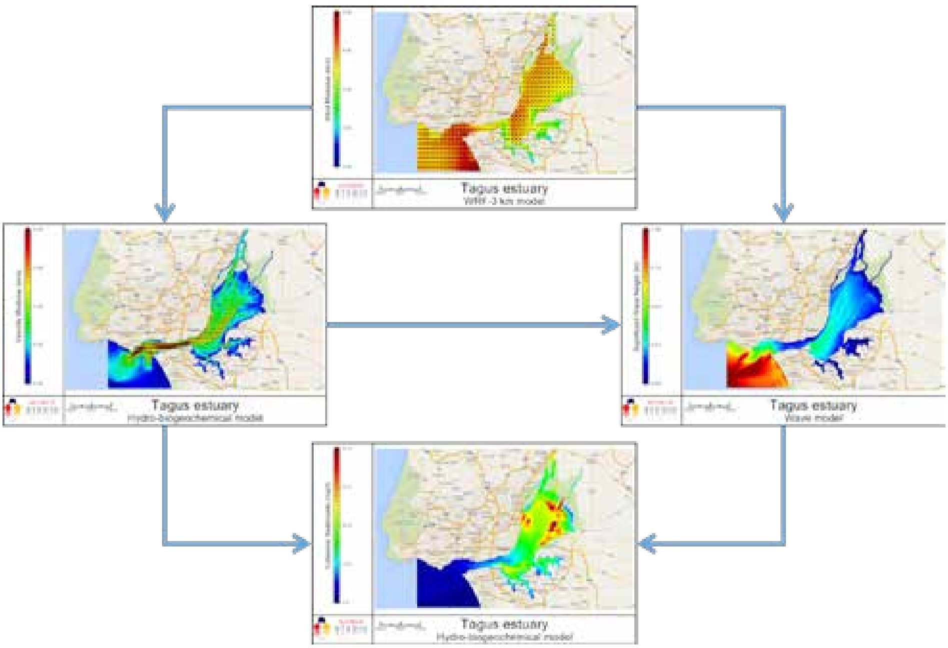

Figure 2 Scheme of the integrated forecasting system

This work was partially supported by the ISDAMP project - Improving Shorelines Defences Against Marine Pollution (Grant Agreement No. 638516/2012/ECHO/A5/SUB), co-funded by the EU Humanitarian Aid and Civil Protection.

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Atmospheric nutrient supply impact on the planktonic community of a Low Nutrient Low Chlorophyll marine ecosystem (1-D Modeling study)

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Abstract

Atmospheric deposition is known to be a significant source of nutrients for the marine environment. Especially for N, anthropogenic emissions to the atmosphere have strongly increased during the last century. The Mediterranean Sea is a unique ecosystem presenting a well-defined decreasing trend in chlorophyll-a from west to east, while the N/P ratio has been measured to increase in the same direction following the oligotrophic character of the sea. The Mediterranean atmosphere is a cross road for air masses of distinct origin, highly affected by both natural and anthropogenic emissions into the atmosphere that strongly interact chemically, leading to the formation of nutrients such as nitrogen compounds. In the present study, the impact of atmospheric deposition of inorganic nitrogen and phosphorus on the Eastern Mediterranean's marine ecosystem is investigated by using a 1-Dimensional marine model. The impact of the atmospheric deposition on the pelagic planktonic ecosystem is calculated. The contribution of human activities in these impacts is estimated. The results show that atmospheric deposition can be the main mechanism responsible for the observed high N/P ratio in the seawater.

Keywords: Mediterranean Sea, Atmospheric deposition, nutrients, plankton

1. Introduction

The atmospheric transport of nutrients to the ocean has been investigated for the past century and has been identified as a critical source of nutrients to the marine ecosystem. After the industrial revolution, human activities, largely associated with food production and fossil-fuel combustion, have caused changes in the pattern of ecological nutrient regulation in marine ecosystems. The Mediterranean Sea is one of the world's most oligotrophic ecosystems and presents an unusually high Nitrogen-to-Phosphorus analogy (N/P) in the eastern basin (28/1). In this basin where riverine nutrient inputs are negligible, N and P atmospheric deposition is believed to be the main source of nutrients in the euphotic zone of the open sea. In the present study, we show how dissolved inorganic nitrogen (DIN) increased atmospheric deposition over the past 150 years, related to an increase in atmospheric dissolved inorganic phosphorus (DIP) load in the surface seawater, as a result of higher atmospheric inputs, affected the Eastern Mediterranean marine ecosystem. The impact of the DIN and DIP atmospheric deposition over time on marine primary production and biomasses is calculated by means of a one- dimension marine model. The effect of the anthropogenic component of nitrogen and phosphorus atmospheric deposition to the N/P analogy in the sea is also investigated.

2. Model description – data

The model used is a coupled physical/biogeochemical 1-D water column model, adapted to simulate the entire Eastern Mediterranean Basin. The model is set for the Cretan Sea as a representative area of the Eastern Mediterranean Basin. It extends down to 1000m depth while is discretized in the vertical by 25 layers, with a finer resolution in the euphotic zone. The hydrodynamic properties of the water column were obtained (off-line) on a daily basis from the Poseidon operational 3-D hydrodynamic Mediterranean basin scale model (www.poseidon.hcmr.gr).

The biogeochemical model is based on ERSEM-2004. It consists of modules describing all the important biological and chemical processes that affect the flow of carbon, nitrogen, phosphorus and silicate, in the water column. It accounts for seawater stratification or mixing. The food-web representation considers functional groups. A detailed description of the model can be found in Christodoulaki et al. (2013).

For the purposes of this study two different simulations are performed (past and present) for a 50-year period each. The first 5 years have been used as spin up time and not analysed here. The two simulations are initialized and forced with the same fields with the only difference between them being the DIN and DIP atmospheric deposition fluxes, used as inputs to the model. For the present simulation (2000) monthly mean values over a 5-year period measurements of DIN and DIP (Kouvarakis et al., 2001, Markaki et al., 2003) in Finokalia, are used. For the past simulation (1860), atmospheric inputs of DIN and DIP are reduced by 90% and 15% respectively, as been suggested by Duce et al. (2008) and by Mahowald et al. (2008), maintaining the seasonal variation of the 2000 simulation. The annual mean DIN to DIP ratio in atmospheric deposition is higher by a factor of 8 with respect to the past simulation (Fig. 1), indicating the importance of human activities in the deposition of nutrients in the Eastern Mediterranean marine ecosystem.

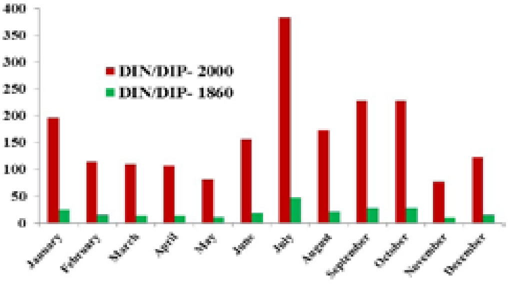

Figure 1 Dissolved Inorganic Nitrogen (DIN) to Dissolved Inorganic Phosphorus (DIP) ratios in the atmospheric deposition for the present and past conditions simulations.

3. Results – discussion

The impact of the atmospheric deposition of DIN and DIP in the Eastern Mediterranean Sea and their effect on the marine primary production and biomasses has been investigated by comparing the two 50-years simulations.

Anthropogenic nitrogen and phosphorus entering the seawater from the atmosphere have enhanced phytoplankton biomass in the upper 100m of the water column by 4-20% in the 150 past years (Table I). Primary production rate has also increased by 7-26% depending on the season. Anthropogenic N and P deposition also lead to a bacterial biomass increase of 4.5%.

Table I Percentage changes (%) and monthly mean values (integrated in the upper 100m of the water column) in phytoplankton biomass, primary production rate and bacterial biomass, due to anthropogenic inputs to the ocean.

	1860	2000	Difference(%)
Phyto Biomass (mg C/m^2)	548 - 1750	600 - 1850	4 - 20
Primary Production (mg $C/m^2/d$)	150 750	200 890	7 - 26
Bacterial Biomass (mg C/m^2)	1040 - 1210	1040-1220	Up to 4.5

Comparing the DIN/DIP model results from the present and the past simulation (Fig. 2), it is obvious that anthropogenic atmospheric deposition increased DIN/DIP over the past 150 years by about 20 – 45%. Another noticeable feature is that in the 1860 simulation the DIN/DIP ratio in the seawater is decreasing and reached an equilibrium value close to the Redfield ratio (16/1).

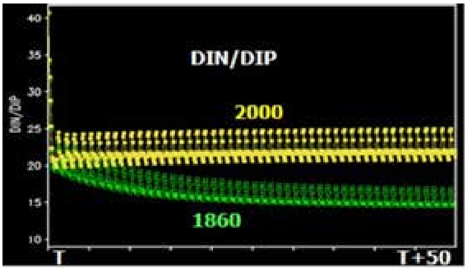

Figure 2 Monthly variation of the DIN/DIP ratio integrated in the upper 200m seawater column, as computed by the 50-year simulations for the present (yellow) and for the past conditions (green).

Acknowledgements

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Modelling and Forecasting Services

The HBM-PDAF assimilation system for operational forecasts in the North and Baltic Seas

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Abstract:

The HIROMB-BOOS Model (HBM) has been coupled with the Parallel Data Assimilation Framework PDAF (http://pdaf.awi.de) in order to improve hydrographic forecasts in the North and Baltic Seas. The coupled forecast system assimilates satellite sea surface temperature as well as in situ data of temperature and salinity profiles to initialize forecasts up to 5 days. The assimilation uses an ensemble Kalman filter, which dynamically estimates the uncertainty of the state estimate with an ensemble of model states and applies spatially localized updates to improve the ocean state. The structure of the assimilation system, which can analogously be used to extend other forecast models for data assimilation, is discussed. Applying the assimilation reduces errors of the surface temperature by about 0.2°C.

Keywords: data assimilation, ensemble Kalman filter, North Sea, Baltic Sea

1. INTRODUCTION

The German Federal Maritime and Hydrographic Agency (BSH) has a large need for ocean forecasting data to run its internal operational services, like the sea level prediction, storm surge warning service, the ice service and to support external customers like the national search-and-rescue centers, the Central Command for Maritime Emergencies or the German Navy. In order to fulfill all these operational obligations, the BSH runs and maintains a comprehensive numerical ocean forecasting system that is under permanent revision. A fruitful cooperation in the Baltic area led to a spread of the original circulation model code developed at the BSH – called BSHcmod (Dick, 1997, Dick *et al.*, 2001, Kleine, 1994) – in the Baltic Sea community. Branches were installed at the Swedish Meteorological and Hydrological Institute and at the Danish Meteorological Institute (DMI). The three model lines have been actively developed over several years and somehow diverged over time. During recent years and with support of the MyOcean projects an effort has been made to merge the three development lines into one. The outcome of this effort is the HIROMB-BOOS Model (HBM, see Berg and Poulsen, 2012) nowadays jointly developed and operationally used by BSH, DMI, the Finnish Meteorological Institute and the Marine Systems Institute of Tallinn University. At the BSH the complete transition from the current operational model code BSHcmod towards HBM should be finished in 2015.

To improve the forecast skill of the HBM, information from observations can be taken into account by means of data assimilation. In data assimilation, the information from a numerical model and from observations are combined to generate an improved estimate of the modeled state. By now the operational forecasts at the BSH are computed without the application of data assimilation. At the DMI, both optimal interpolation (Fu et al., 2011) and 3D-Var methods (Fu et al., 2012) have been applied.

Methods like optimal interpolation and 3D-Var use a single state realization and parameterized covariance matrices or weight matrices to prescribe the weight of deviations of the model state from observations. Current state-of-the-art data assimilation algorithms use an ensemble of model forecasts to estimate the uncertainty of the model state. These methods are typically called sequential data assimilation algorithms and are based on the original ensemble Kalman filter (EnKF, Evensen, 1994). Several new and computationally more efficient methods have been developed, that are classified as ensemble square-root Kalman filters (Tippett *et al.*, 2003, Nerger *et al.*, 2012) or error-subspace Kalman filters (Nerger *et al.*, 2005). Here, the aim is to extend HBM for data assimilation with state-of-the-art ensemble filters. This goal is achieved by coupling HBM to the parallel data assimilation framework (PDAF, *Nerger et al.*, 2005). For the validation of the resulting assimilation system, the SEIK filter (Pham, 2001) is used in combination with a local analysis that builds the LSEIK filter (Nerger *et al.*, 2006).

2. Hiromb-boos model

The HBM is a three-dimensional hydrostatic circulation model using the primitive equations. It uses spherical horizontal and generalized vertical coordinates (Kleine, 2003). The model domain extends from 4°W to 30.5°E and from 48.5°N to 60.5°N in the North Sea and to 66°N in the Baltic Sea. The horizontal grid spacing is ~5 km (5' in longitude and 3' in latitude). In the vertical, the model is discretized using 36 vertical layers. The layer thickness is about 2 m at the surface, up to 3 m in the upper 50 m of the water column. Below 50 m it increases up to a thickness of 100m, whereas the bottom layer thickness is always about 3m.

In the North Sea, the model configuration has a northern open boundary, which is closed with a sponge layer. Within this layer, the temperature and salinity are restored towards monthly mean climatological values. A similar sponge region is included at the entrance to the English Channel.

A two-dimensional model for the North East Atlantic, which is run separately by the BSH, provides information on external surges at the open boundaries. Tidal forcing is implemented using 14 tidal constituents and flooding and drying of tidal flats is applied. The atmospheric forcing at the surface is based on meteorological forecast data provided by the German Weather Service (DWD). River runoff is prescribed as freshwater fluxes at the boundaries opened in the regions of main rivers. HBM includes a sea-ice model component, which describes sea ice thermodynamics and incorporates Hibler-type dynamics (Hibler, 1979).

3. The data assimilation frame-work PDAF

The parallel data assimilation framework PDAF (Nerger et al, 2005, Nerger and Hiller, 2013, http://pdaf.awi.de) is a software framework that allows extending a numerical model with data assimilation functionality for ensemble-based Kalman filters. The framework provides support for ensemble forecasts within a single model program and several different ensemble square-root filters to compute the actual data assimilation (called 'analysis step') in which the forecast ensemble is combined with observations. The extension of the HBM for data assimilation is described in the following section. The assimilation framework uses a parallelization with the Message Passing Interface (MPI, Gropp et al., 1994) to allow for the ensemble integrations. Thus, while running a single program it is logically split into as many model tasks as there are ensemble states. The filter algorithms are parallelized using both MPI and OpenMP (see, e.g. Chandra et al., 2000).

For the setup of a data assimilation system, PDAF follows a strict logical separation of the program into three parts. These are the numerical model, the observations, and the data assimilation method. PDAF implements the data assimilation method such that it is completely independent from the model and the observations. In particular, the assimilation methods only consider so-called state vectors, i.e. the different model fields are combined in a single vector. With these state vectors, the analysis step can be performed by means of linear algebra without considering the different variables of the model. The data assimilation methods are part of the core of PDAF, which can be compiled as a program library as a user does not need to modify these functions. The information exchange between the model and PDAF is conducted through two subroutines that write the model fields into the state vector and vice versa. These routines are model-specific and coded upon the implementation of the assimilation program. The information about observations is handled in a set of subroutines that are used by PDAF as 'call-back' routines. Thus, these routines called by the core routines of PDAF through specified interfaces. These routines are implemented when the data assimilation program is created and have to be consistent with the model grid and the particular observations to be assimilated.

4. Coupling HBM and PDAF

The data assimilation system is implemented by coupling HBM to PDAF through the insertion of subroutine calls to functions of PDAF into the source code of HBM. The program flow is shown in Figure 1. The blue fields show the parts of HBM that are executed. Without the data assimilation the model is first initialized, e.g. by reading the configuration of the model mesh from files and by reading initial model fields. Subsequently, the time stepping of the model is computed in which a prediction of the model state is computed. After the time stepping, the model can perform post-processing before the program ends.

For the data assimilation extension three different subroutine calls are inserted into the source code of HBM. The first call 'init_parallel_pdaf', executes a routine that sets up the parallelization of the data assimilation program. HBM has options to use both MPI and

OpenMP for its own parallelization. In this study, we only used the OpenMP parallelization of HBM and used MPI to distribute the ensemble members. The parallelization is configured such the number of generated model tasks is equal to the ensemble size.

The second call 'init_pdaf' executes a subroutine that reads the configuration for the data assimilation. Further the subroutine itself executes the PDAF core routine 'PDAF_init', which initializes the assimilation framework internally and calls a call-back routine to initialize the ensemble of model states at the initial model time.

The third subroutine that is called 'assimilate_pdaf' executes the PDAF core routines for the analysis step. The routine can check if an analysis step should be performed at the time when it is called, if not, the time stepping of HBM continues.

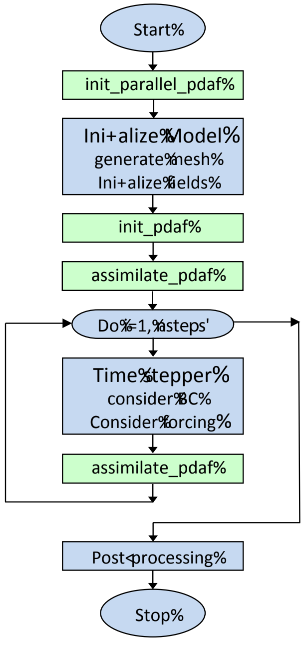


Figure 1 Program flow of the HBM model (blue) with extension by subroutine calls to couple to the data assimilation framework PDAF.

During the analysis step, the PDAF core routine for the analysis step calls several call-back routines that perform the observation handling. As the filter algorithms needs to compute the difference between an observation and its model estimate, one of these operations is the so-called observation operator. This is a model- and observation-specific operator to extract the observed part of a state vector. Other operations are, for example to fill the vector of observations by reading them from a file and the computation of the distance of an observation from a grid point of the HBM model grid. For the analysis step, two options are implemented. In an operational setting, the analysis step is usually computed at the initial model time, and subsequently a long forecast of up to 72 hours is computed. In contrast, for hindcast experiments that are used to optimize the parameter settings for the data assimilation, the analysis step is usually not computed at the initial time, but after (fixed) intervals of time steps (e.g. after each 12 h). The two options are realized by placing the call to the routine 'assimilate_pdaf' both just before the time stepping loop and within it. By choosing a parameter at run time, one can then choose the mode in which the data assimilation is performed.

5. VALIDATION OF THE ASSIMILATION SYSTEM

5.1 Configuration of the assimilation system

The behavior of the assimilation system obtained by coupling HBM and PDAF is assessed with a realistic configuration that follows the operational forecast configuration at the BSH. However, while the operational forecast is computed without data assimilation, we here apply data assimilation to assess its impact on the forecast skill in a hindcast experiment. Following Losa *et al*. (2012, 2014), observations of the sea surface temperature (SST) from NOAA satellites are assimilated. This type of data is received by the BSH as level-2 data and further processed by the BSH. Thus, it is usable for operational purposes. An example of a 12-hour composite of SST data is shown in the upper panel of Figure 3.

The assimilation was performed as a cycling experiment with an analysis step after each forecast of 12h over the full month of October 2007, which was chosen for consistency with Losa *et al*. (2012). Analogous to this study the LSEIK filter was applied. For the local analysis an observational influence radius of 100 km is used within which the observation influence decreases exponentially. Further it is assumed that the errors in the SST observations are uncorrelated with an error of 0.8°C. This rather high error takes into account the representation error, i.e. the inability of the model to exactly represent the observation, e.g. due to the model resolution of 5km. The initial model state estimate at October 1, 2007 was taken from the model forecast without data assimilation. The initial uncertainty that is represented through the ensemble spread is generated from the model variability by means of second-order exact sampling (Pham, 2001).

5.2 Assimilation results

Figure 2 shows the root-mean square (RMS) error between the modeled SST and the satellite observations. The RMS errors for the assimilation show the typical shape with error increases during the forecasts and an error reduction at each analysis time. For the 12h-forecasts from the analysis states, the RMS error is about 0.2°C lower than for the model without assimilation. Exceptions are at October 11, 22 and during October 24-26. Here, the model dynamics drive the error in the state estimate, computed as the mean of the ensemble, very close to the error from the free running model. On October 24 and 25, the forecast errors are slightly larger than the error from the free-running model without data assimilation. Over the full month, the data assimilation reduces the RMS error from 0.87°C for HBM without data assimilation to 0.67°C for the 12-hour forecasts. For the state estimates directly after the analysis step the RMS error was reduced to 0.59°C.

The upper panel of Figure 3 shows the 12-hour composite of SST data on October

30, 2007 centered at midnight. Data is only available in regions without clouds. The weather conditions lead to a situation in which most of the Baltic Sea is unobserved. As the assimilation can only utilize the observational information in regions close to observations, most parts of the Baltic Sea will be not influenced by the assimilation on October 30.

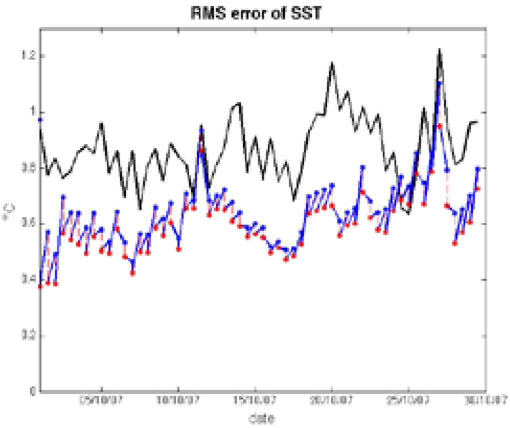


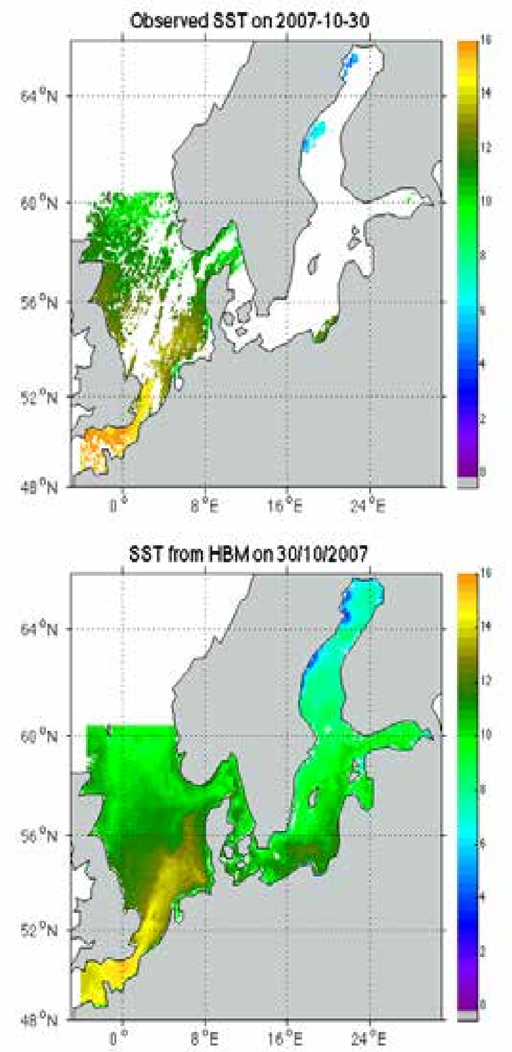
Figure 2 RMS deviation of the modeled SST from the assimilated observations: (black) model without data assimilation, (blue) error of each 12h forecast, (red) error directly after the analysis step.

The middle panel of Figure 3 shows the prediction of SST from HBM without data assimilation. Compared to the SST observations, it is visible that the SST in the northern part of the North Sea is too low. Further, the SST in the English Channel is underestimated. By applying the LSEIK filter throughout the month, the estimates of SST are improved with data assimilation (bottom panel of Figure 3). In particular the SST estimates are higher in the northern North Sea and the English Channel. Also, the SST in the Baltic Sea around the Bay of Gdansk at about 55°N appears to be better represented by the assimilation estimate. However, along the Norwegian Coast in the Skagerrak, the assimilation underestimates the SST.

6. Summary

A data assimilation system has been generated by coupling the HIROMB-BOOS Model (HBM) with the Parallel Data Assimilation Framework (PDAF). The HBM will be used as the next operational model code at the German Federal Maritime and Hydrographic Agency (BSH) to compute forecasts of the North and Baltic Seas. PDAF is a software framework to build ensemble-based data assimilation frameworks. It provides support for the ensemble integrations and provides fully implemented filter methods for data assimilation. Coupling PDAF and the numerical model into a single program results in the most efficient combination as the different parts of the data assimilation program can utilize the parallelization of both the ensemble integrations, the model, and the filter methods.

The coupled data assimilation program was validated with the assimilation of surface temperature observations from NOAA satellites over the month of October 2007. Using the same assimilation parameters as in Losa *et al*. (2012), where the assimilation was applied with the older model version BSHcmod, the RMS deviations of the model forecasts from the observations are reduced by the data assimilation by about 0.2°C. However, at several times, the errors in the assimilation estimates of the SST are very close to those of the HBM without data assimilation and in some instances, the assimilation estimates showed larger errors. This shows that further tuning of the assimilation parameters is required with the HBM model to obtain optimal assimilation results.



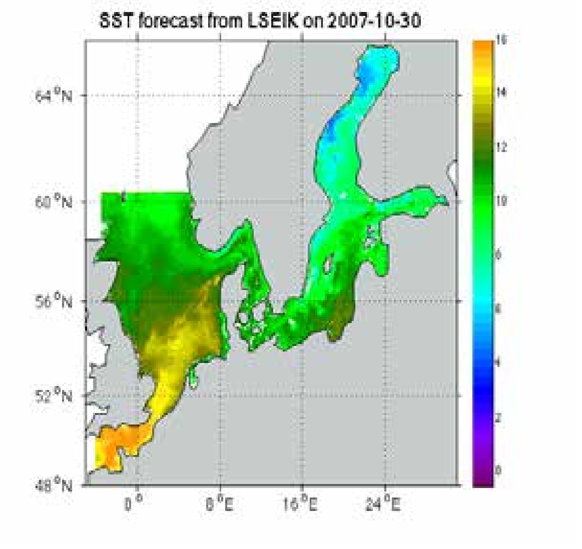


Figure 3 SST on October 30, 2007, 00:00h: (top) Composite of satellite observations. (middle) SST estimate from HBM without assimilation. (bottom) Improved SST estimate from LSEIK assimilation.

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WMOP: Western Mediterranean SOCIB high-resolution ocean forecasting system

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Abstract

The Balearic Islands Coastal Observing and Forecasting System (SOCIB) is a multi-platform distributed oceanic observatory providing both oceanographic data and modelling services to support the operational oceanography in the European and international framework. The Modelling and Forecasting Facility contributes to SOCIB objectives by both developing and maintaining operational forecasting systems and conducting scientific research to continuously support their improvement. Among these systems is the western Mediterranean high resolution operational ocean forecasting system WMOP, which provides temperature, salinity, sea level and currents predictions every day with a 2km and 3h resolution. Monitoring and validation procedures have been developed using multi-platform observations to systematically assess the model performance and to detect model errors at local, sub-basin and basin scales. The systematic validation routine allows to highlight both the general realism of the WMOP ocean forecasting system and sub-regional model errors. The 3-day forecast of physical ocean fields, data visualization and validation results are available on-line at www.socib.es.

Keywords: ocean forecasting system, high resolution model, multi-platform observations, validation, western Mediterranean Sea

1. Introduction

The development of ocean forecasting systems contributes to respond to science and society needs. Indeed, global and regional ocean models can enhance the knowledge of the oceanic system through the understanding of physical processes and their impact on the general circulation. They also support decision making in the marine environment (security, transport, economy, protection, resources, fisheries, and tourism).

The Mediterranean Sea is a basin of both societal and scientific challenges with 46000 km of coastline, more than 3300 islands and 22 coastal countries. Additionally, physical processes found in the worlds oceans occur in the Mediterranean Sea making this basin interesting for oceanic and climatic studies (Malanotte-Rizzoli *et al*., 2014). The Mediterranean Sea is a complex and highly variable basin with three dominant and interacting scales (basin, sub-basin and meso-scales) and a small internal Rossby radius of deformation around 10-15km (Robinson *et al*., 2001). Thus, high resolution regional ocean forecasts and observations are required to represent the (sub-)mesoscale features and to understand their interaction with the general circulation, their impact on vertical motions and the ecosystem variability.

In this context, the Balearic Islands Coastal Observing and Forecasting System (SOCIB, Tintoré *et al*., 2013), a coastal ocean observatory located in the Balearic Islands, has been developing both observing and forecasting systems. In particular, the Modelling and Forecasting Facility at SOCIB is developing a high resolution ocean forecasting system in the western Mediterranean Sea, associated with multi-platform validation procedures in order to systematically assess the model performance (Juza *et al*., 2015a). The 3-day ocean forecasts, as well as their visualization, monitoring and validation, are operational, available and published on-line every day on SOCIB website (www.socib.es). Additionally, the improvement of the forecasting system is supported by scientific research, focused on ocean processes and variability studies based on hindcast simulations.

2. SOCIB

2.1 The Balearic Islands

SOCIB activities are mostly centred in the western part of the Mediterranean Sea with a particular interest in the Balearic Sea and its adjacent basins, considering a wide range of spatio-temporal scales, from the near-shore to the open ocean and from the short-term evolution to the interannual and climatic variability. The Balearic Islands are a key biodiversity hotspot in the western Mediterranean Sea, which is largely related to the importance of thermohaline processes of global ocean relevance that are not yet fully understood.

2.2 Multi-platform observing system

SOCIB has been developing a multi-platform observing system by deploying, collecting, and post-processing various observational data from:

- A coastal Ocean Research Vessel dedicated to oceanographic campaigns supported by different European projects
- A coastal High-Frequency radar measuring surface ocean currents in the eastern part of the Ibiza Channel (Lana *et al*., 2015)
- Underwater gliders deployed along a semi-continuous line in the Ibiza Channel (Heslop *et al*., 2012)
- Lagrangian platforms (drifters, Argo floats) deployed in the western Mediterranean Sea
- Atmospheric and oceanic buoys deployed around the Balearic Islands, complementing the Puertos del Estado network along the Iberian coast
- Satellite products collected from different institutions and missions

2.3 Modelling and Forecasting Facility

The Modelling and Forecasting Facility (M&FF) at SOCIB combines operational goals with research oriented process studies to enhance the capabilities of operational systems and to respond to society needs. Its general objectives are to advance the understanding of physical processes (in particular, the mesoscale dynamics in the western Mediterranean Sea and its impact on the general circulation), to detect and quantify changes at different spatial and temporal scales, to understand the mechanisms that regulate them and to forecast their evolution.

The M&FF has been developing a high resolution ocean model in the western Mediterranean which is able to resolve the mesoscale features (Juza *et al*., 2015a). This provides forecasts of ocean conditions and pre-operational services to operational applications such as prediction of oil spill trajectories (Sayol *et al*., 2013), jellyfish or larvae tracking (e.g. Bluefin Tuna sustainable fisheries, Reglero *et al.,* 2012).

The interaction between the observing and modelling systems is necessary. The combination of simulated and observed data provides information on the ocean state, variability and dynamics, and can help to better understand the ocean processes at different scales. Additionally, the use of observations is necessary to assess the model performance, to detect simulation errors and to improve the predictions.

3. The ocean forecasting system

3.1 WMOP

The ocean forecasting system, called WMOP, is a regional configuration of the ROMS model (Shchepetkin and McWilliams, 2005) implemented in the western part of the Mediterranean Sea from the Gibraltar Strait to the Sardinia Channel (Figure 1). The bottom topography is a 30'' database (Smith and Sandwell, 1997). WMOP has a horizontal resolution of 2km and 32 stretched sigma levels on the vertical. The model is initialized from and nested in the larger scale Mediterranean Forecasting System (MFS, daily, $1/16^o$, Tonani *et al*., 2014) which is distributed every day by MyOcean. The atmospheric forcings coming from the Spanish Agency have a high resolution of 3h and 5km. Climatological runoffs of Var, Rhône, Aude, Hérault, Ebro and Júcar rivers are implemented in the system. They are computed from averaged daily values over the period 2009-2013 provided by the French HYDRO database and the Spanish hydrographic confederations of Ebro and Júcar rivers. A weekly model reinitialization is performed using a 3-week spinup from the MFS fields. Because data assimilation is not yet integrated in the system, this spinup avoids too much drift of the ocean model from the observed conditions but allows the WMOP system to generate (sub-)mesoscale features. The operational system runs on a daily basis and provides 3-day forecasts of ocean temperature, salinity, sea level and currents saved every 3 hours.

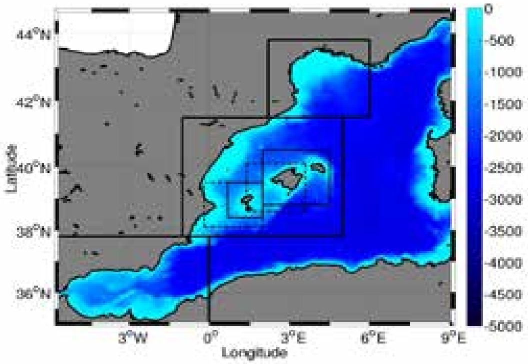

Figure 1 Model configuration. Colour indicates model bathymetry (in m). Boxes indicate regional zooms for data visualization.

3.2 WMOP visualization

Data visualization has been developed and is published on-line. It provides high resolution (3h, ~2km) animations and figures of the 3-day ocean forecasts over the whole western Mediterranean and in sub-regions (Figure 1): Balearic Islands region and specific zooms on Islands (Ibiza-Formentera and Mallorca-Menorca), Channels (Ibiza and Mallorca Channels), and adjacent basins (Gulf of Lion and Alboran Sea). Figure 2 illustrates the WMOP surface temperature and current around the Balearic Islands on 2 October 2014 from the ocean forecasting system.

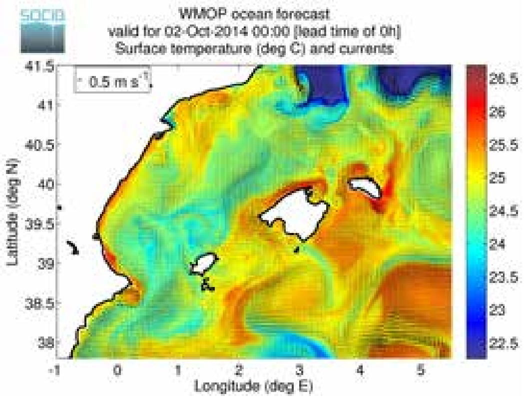

Figure 2 WMOP ocean forecast in the Balearic Islands region on 2 October 2014 at 00:00:00.

Additionally, an interactive application (lw4nc2) has been developed at SOCIB to visualize the model outputs selecting variables (temperature, salinity, sea surface, currents, barotropic velocity) and visualization types (animations, maps, regional zooms, time series at fixed locations, and vertical sections) for past, present and forecast dates.

3.3 WMOP ocean indicators

The model behaviour is monitored following the temporal evolution of ocean indicators (spatially averaged Sea Surface Temperature and Salinity, surface Kinetic Energy; Mixed Layer Depth maximum; total Heat Content within the 0-150m vertical layer) over the whole basin and in sub-regions of particular interest (Balearic Sea, Gulf of Lion, Alboran Sea). Transports in key sections (in particular, Strait of Gibraltar and Balearic Channels) are also computed. All these indicators are computed every day and the last 30-day time series are updated and published daily. They allow to systematically monitor the behaviour of the system and are very useful to detect changes in ocean properties as represented by the model. 3-hourly transports are illustrated in Figure 3 in the Ibiza Channel over the period from 11 December 2014 to 10 January 2015.

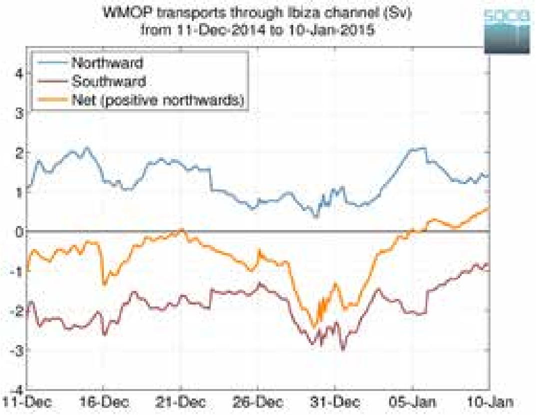

Figure 3 WMOP transport through the Ibiza Channel (Sv) from 11th December 2014 to 10th January 2015.

4. Validation procedures

Validation procedures have been developed to assess the model performance at daily, monthly and seasonal time scales. Multi-platform observations with various spatial and temporal resolution and coverage, including satellite-derived products and *in situ* measurements, are used. Both Near-Real-Time (NRT) and Delayed-Time (DT) model-data comparisons are being performed through statistical metrics and diagnostics. In this way, the validation is multi-variable and multi-scale (from basin to sub-basin and local scales). The ocean forecasts are assessed in terms of large-scale features, surface conditions, circulation and variability, vertical structure and water masses.

4.1 Near-Real-Time validation

The NRT validation, which is published on-line every day, consists in comparing model outputs with available observations for the day before.

- WMOP Sea Surface Temperature compared to satellite products (CNR-ISAC, daily, 1/16°, www.myocean.eu, Buongiorno Nardelli *et al*., 2013)

- WMOP geostrophic currents compared to altimetry products (AVISO-CLS SSALTO/DUACS 2014, daily, 1/8º, www.aviso.oceanobs.com)
- WMOP temperature and salinity vertical profiles compared to Argo floats (www.ifremer.fr)
- WMOP temperature, salinity and currents compared to fixed moorings along the Iberian shelf (Tarragona, Valencia, Cabo de Gata, Cabo de Palos, hourly, www.puertos.es)

The NRT validation allows monitoring of the system performance and provides updated information about the accuracy and the realism of the system. An illustration of the comparison between the observed and simulated SST at Valencia station is given in Figure 4.

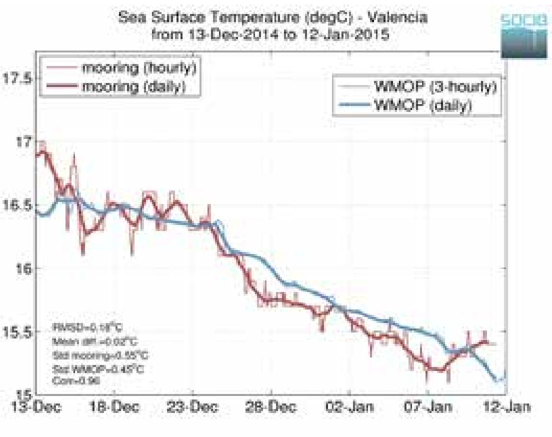

Figure 4 Time series of the fixed mooring and WMOP SST at Valencia station from 13 December 2014 to 12 January 2015.

4.2 Delayed Mode validation

Additionally, a DT validation has been developed to investigate the model errors, to attempt to determine their origin and to improve the ocean forecasts. An intercomparison with the parent model (MFS) is also carried out to evaluate its impact on WMOP outputs and also to highlight the possible benefit of high resolution ocean model for operational applications. Several intercomparisons are performed at various spatial and temporal scales:

- Sub-basin scale assessment over the last year in order to detect regional biases and to improve the representation of physical processes
- Use of new technologies, such as the gliders which provide very high resolution temperature and salinity profiles. They allow monitoring and evaluating mesoscale features and water masses properties at "choke" point (e.g. Ibiza Channel).
- Operational case study: deployment of drifters, comparison of observed and simulated trajectories.

4.3 Process oriented research

The development and improvement of the ocean forecasting system is based on the scientific research carried out in the Modelling and Forecasting Facility in collaboration with other Spanish and international institutions. Numerical and scientific studies have been carried out, combining hindcast simulations and historical data, to better understand the ocean system and the model behaviour. Here are some examples:

- Development of regional circulation hindcast simulations to study western Mediterranean variability
- Sub-basin scale assessment and intercomparison of hindcast simulations in the western Mediterranean (Juza *et al.*, 2015b)
- Mesoscale dynamics studies (Bouffard *et al.*, 2012)
- Water masses formation and propagation (Juza *et al.*, 2013)
- Ecosystem response to oceanic conditions, bio-physical coupling (Oguz *et al.*, 2013, 2014) as well as applications for Bluefin Tuna, jellyfishes, turtles
- Preliminary study on data assimilation including new platforms such as gliders

5. Conclusions

The high resolution WMOP forecasting system is operational, providing daily 72-hour ocean predictions, available and evaluated on-line on SOCIB website. The ocean forecasts are systematically assessed using multi-platform observations (remote sensing data and *in situ* measurements) through Near-Real-Time validation procedures in order to monitor the performance of the system. The systematic routine validation allows to detect regional and local model errors but also to show the general realism of the WMOP system in terms of large-scale surface ocean circulation and variability, as well as vertical hydrographic structure and water masses properties. The operational validation is being extended to other datasets, such as High-Frequency radar, additional fixed moorings and drifters deployed by SOCIB. The improvements of the forecasting system are being pursued through Delayed Mode and long-term comparisons at basin and sub-regional scales as well as sensitivity tests on model parameters. Data assimilation is planned to be implemented in the system, including satellite products, Argo floats, XBTs, CTDs, as well as high resolution data such as gliders and High-Frequency radar. The improvements of the forecasting system are also supported by process-oriented studies using hindcast simulations and historical data.

Acknowledgements

MyOcean Products (www.myocean.eu) from the Mediterranean Monitoring and Forecasting Centre (MED-MFC) which produces the Mediterranean Forecasting System have been used, as well as those from CNR-ISAC which provides optimally interpolated Sea Surface Temperature products. The atmospheric forcings are provided by the Spanish National Institute of Meteorology (AEMET). The altimeter products are produced by SSALTO/DUACS and distributed by AVISO. The Coriolis project (Ifremer) collects and provides the Argo floats. Finally, the data from fixed moorings along the Spanish coast are maintained and provided by Puertos del Estado.

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An algorithm for generation of a hybrid sea surface salinity field

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Abstract

The salinity budget in ocean circulation model experiments is usually not closed. As a consequence, model results may drift due to imballances in the prescribed fluxes at the surface and across open lateral boundaries. This problem may be ameliorated by restoring towards a prescribed sea surface salinity distribution. Here, a method is proposed to produce a 2D salinity field for this purpose, which includes an improvement in the description of fronts when compared to the standard use of a course resolution climatology.

Keywords: salinity, restoration, ocean modelling

1. Introduction

In order to close the hydrological cycle in general circulation models all compartments that influence the fresh water budget must be incorporated. These include cross-compartment fluxes: precipitation from the atmosphere, freezing, run-off from land, melting and calving in the cryosphere and freezing and evaporation from the ocean. In order to model the hydrological cycle correctly, processes such as advection and reservoir retention within each compartment must also be described.

While attempts to accomplish this feat are made with coupled climate models, most modeling activities include prescribed fluxes, either based on observations, parameterizations or results from complementary model simulations. However, in the absence of coupling, the fresh water budget is usually not closed. In the case of ocean circulation models, results for salinity will be affected by any inconsistency in the formulations of fresh water fluxes.

Consider the configuration of most ocean circulation models with respect to salinity and the fresh water budget. Fresh water is exchanged with the atmosphere as precipitation and evaporation. While precipitation can be taken from atmospheric model results, evaporation is usually computed based on local temperatures at the ocean surface and in the atmosphere above it, taking into account the atmosphere's humidity. It is difficult, if not impossible, to adopt such an approach consistently. Run-off to the ocean from land is incorporated as river fluxes which are provided from hydrological models, observations and/or climatology. But these approaches may suffer from incompleteness, *e.g.* due to lack of, or simplistic, inclusion of diffuse run-off. Furthermore, ocean models are frequently configured with open lateral boundaries. Then, prescribed salt fluxes into and out of the regional model may be inconsistent, and the use of non-conserving numerical schemes for open boundary fluxes is another source for concern in the present context. Finally, implementing coupling with a sea ice model additionally complicates the ocean model's ability to correctly describe variations in salinity since most of the processes involved in freezing and melting take place on scales that are much smaller than those resolved by the ocean model.

2. Salinity restoration

One method that may be applied to curb model drift due to inconsistencies in the representation of the salt budget is to restore salinity values towards a prescribed state. This may *e.g.* be implemented as restoration towards a gridded monthly salinity climatology based on observations. Results from an eddy-resolving ocean reanalysis which applied salinity restoration is presented by Schiller *et al.* (2008).

However, this method has significant weaknesses. Two serious weaknesses are that (1) restoration artificially attenuates variability, and that (2) the available climatologies may include a poor representation in regions with strong spatial gradients such as ocean fronts.

In order to reduce the impact of these weaknesses, several methods may be considered. In the context of variability attenuation, restoration may be limited to the salinity at the surface (or the uppermost model layer). The rationale for such a representation to be successful is that most of the processes that may give rise to model drift for salinity results take place either at the surface (evaporation, precipitation), or in the uppermost meters of the water column (river discharge and diffuse run-off). Further, if possible the restoration time scale should be specified with a value that is long enough for variability on the time scale of interest to evolve, and at the same time short enough to restrain the model from drifting.

The topic of the present study is to define and describe a method intended to ameliorate effects of too coarse spatial representation of salinity in the state towards which a simulation is restored. Moreover, due the above reasoning, we will only consider salinity restoration at the surface.

Here, an alternative method to the use of coarse climatological fields for restoration is described. We propose to aggregate *in situ* point measurements on a calendar month basis. Then, the values at the point measurements are extrapolated using results from an ocean circulation reanalysis which is re-gridded onto a fine resolution domain. Thus, relatively large spatial gradients in observations become more accurately described than in the coarser model climatology, as well as the coarser gridded observational products that are available.

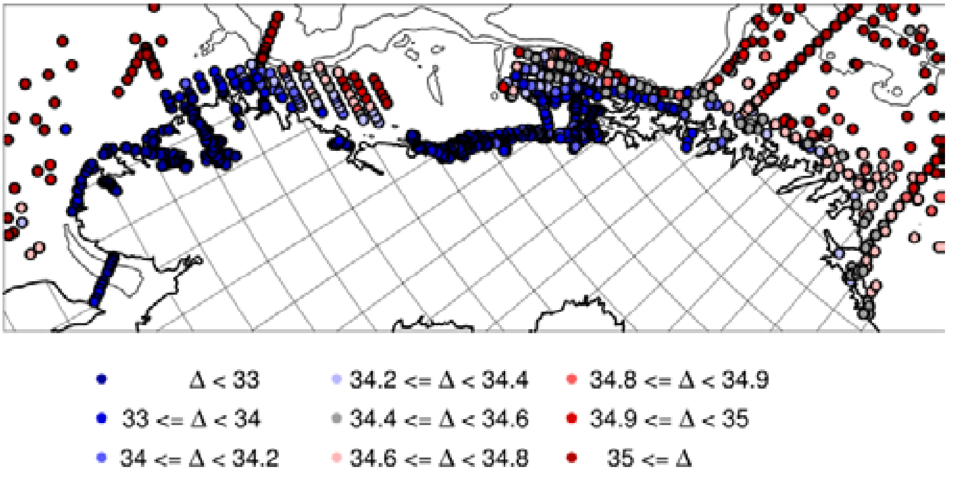

Figure 1 Sea surface salinity observations used in the present study, from March (2006-2013)

A final concern in this context is how to deal with space-time variability in observations, particularly in the vicinity of a front. We recognize that we are not able to produce an exact representation of the front, given the limited number of observations at hand. In order to best accommodate for such variability, we will define a set of salinity categories and use the regions in which the various categories occur as a starting point for our algorithm.

3. Algorithm and example

In brief, the algorithm we propose is given by the following four steps:

(i) interpolate the sea surface salinity (SSS) climatology from an ocean reanalysis onto a high resolution regional grid

(ii) define SSS categories based on the distribution of observations so that each category has approximately the same population

(iii) modify the high resolution representation from (i) by their categorical biases

(iv) adjust the product from (iii) to account for regional biases inside each category

An additional topic that we need to take into account, is that treating each category completely separate from its neighbors will give rise to discontinuities across the boundaries that separate them. These discontinuities must be addressed since they arise from the implementation of the proposed method, and not from the observations.

3.1 Interpolation of SSS

We generate a monthly SSS climatology from the ¼° resolution Forecast Ocean Assimilation Model (FOAM) reanalysis from the UK Met Office (Blockley et al., 2013). Our aim is to improve the representation of the front between the Norwegian Coastal

Current and its adjacent saltier water masses. Hence, the FOAM product is interpolated onto a 0.8 km grid covering our region of interest, using bi-linear interpolation in the horizontal. Hereafter we refer to this limited domain as N.8. This domain is displayed in the figures that follow.

3.2 Definition of SSS categories

First SSS observations within the N.8 domain are collected for each calendar month. We restrict our analysis to observations from the period 2006-2013. The SSS observations from March are displayed in Figure 1. In the cases where there is more than one observation from the same N.8 grid cell, the multiple observations are replaced with their average value.

Next, we sort the SSS values from each month by their magnitude. SSS categories are then defined by requiring each category to include the same number of observations. Here, we choose to work with a set of ten categories. Finally, the model values that correspond to the observations are extracted. The ten category regions for March are shown in Figure 2.

3.3 Modification due to category biases

Next, observations are extrapolated onto the entire model grid by adopting categorical adjustment of model-observation differences for all grids. We start this procedure by averaging the differences for each category and each month, assigning the same weight to all observations. Thus, for each month we have a categorical offset value for each of the ten categories. In order to avoid generation of discontinuities across category boundaries, the modifications due to the category biases are computed by linear interpolation in salinity space as follows:

- the observed categories are mapped onto the SSS space of the model results by identifying the minimum and maximum values in both sets, and retaining the relative distribution of the observation categories in the model space
- if necessary, category offset values are modified to ensure that original categories and modified categorized are not swapped, thus conserving monotonicity
- the arithmetic mean of the span of a category in model space is taken to represent the category in a floating point representation of categories, which is also restricted to a minimum value of 1 and maximum value of number of categories (here, 10)
- each model value is finally adjusted by application of linear weights in model category space when adding the categorical offsets

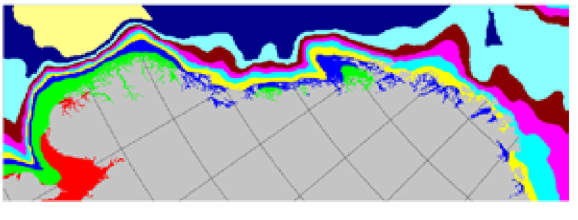

Figure2 A color coded map of the ten categories based on the model mapping of observed sea surface salinity values from March (shown in Figure 1). Red corresponds to category 1, i.e., the region with the lowest observed values.

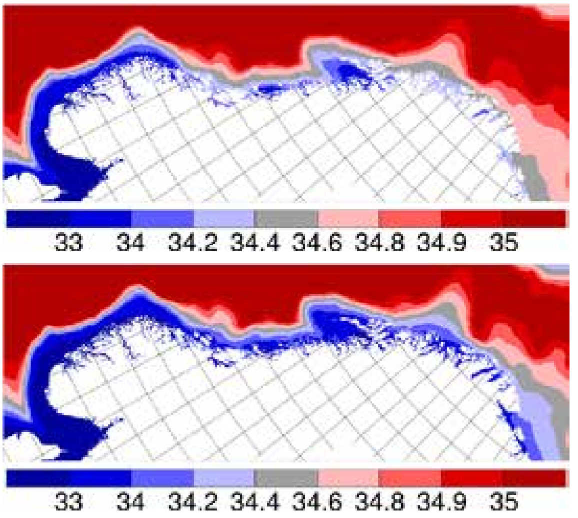

Figure 3 Top: Original model representation of sea surface salinity (SSS), for March. Bottom: Representation of SSS after categorical adjustment.

The model product for March before and after the categorical adjustment is displayed in Figure 3. We note that the region closest to the coast has become less saline, and that the front in some regions becomes stronger. Above, we referred to this process as extrapolation of observations using model results, and the signature of the observed SSS values are evident in Figure 3.

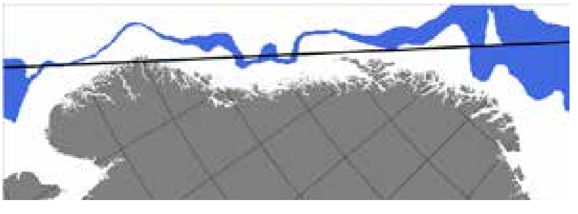

Figure 4 Category 8 regression line. The region in blue corresponds to the domain of category 8 in March. The black line is the least square linear fit to this region.

3.4 Intra-category modifications

In a configuration such as that seen in the present example, each category covers a long stretch of ocean, as seen in Figure 2. In such a case, there may be significant spatial variability in the quality of the results from the model product inside a category. In order to reduce the impact of such a discrepancy, a final step in the proposed algorithm is introduced. The following procedure is applied to this end:

- offsets are re-computed for all observations, as deviations of the modified product from the previous algorithm step

- the (geographical) least squares fit line of each category and for each month is determined; see the illustration in Figure 4
- a (low order) polynomial fit of the deviations to the least squares fit line is determined for each month and each category, with the restrictions that (1) the polynomial does not change the maximum and minimum values expected from the observations, and (2) a constant value is adopted for the ends beyond the positions where corresponding observational values are available; see the illustration in figure 5
- the final adjustment is then made analogously to the adjustment in the previous algorithm step (i.e., in category space)

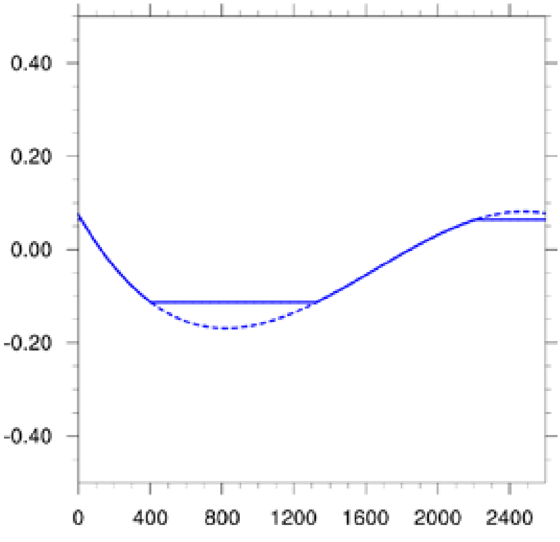

Figure 5 Polynomial fit to remaining SSS deviations after the initial categorical correction. Depicted here is the third order polynomial for category 8 in March (dashed line), and the adjustment that is applied after imposing limits as described in the text (full line, on top). Numbers along the vertical and horizontal axes correspond to temperature anomaly in K and grid node from left boundary, respectively. This illustration is for category 8 in March.

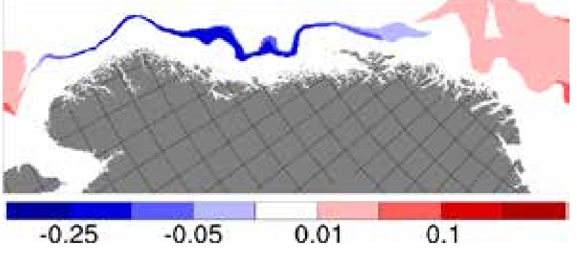

Figure 6 The intra-categorical correction from the final step in the present algorithm. Displayed here are the results for category 8 in March.

The regional correction from this step, for category 8 in March, is displayed in fig. 6. Here, a third order polynomial was used (Figure 5). The results reflect that the model-observation differences had a distinct intra-categorical signature, resulting in an increase in SSS in the north and south, and a decrease in between.

4. Discussion

The SSS field for March that results from the algorithm which is described here, is displayed in Figure 7. The features that we noted had changed from top to bottom panel in Figure 3 are mostly kept in Figure 7, as expected. We observe that the SSS from the final algorithm step is increased in the north and south, and reduced in between (as also seen in the specific category 8 depiction in Figure 6).

In a recent study, this mostly coastal SSS monthly climatology was blended with the original FOAM climatology in regions outside of the domain considered in this presentation. The resulting climatology on a 4km polar stereographic projection was used for SSS restoration, with an exponential decay rate of 180 days. The results are presented and discussed by Røed *et al*. (2015).

It must be stressed that some care needs to be taken when implementing salinity restoration as suggested here. One issue that may become relevant is that when restoring salinity, but not temperature, one may change the static stability of the water column. In the extreme situation, the water column will become statically unstable, leading to un-physical overturning. This problem is likely to be ameliorated if also restoration to a corresponding climatology for (potential) temperature is implemented. This issue has been discussed in detail in the context of results for the Arctic region from coarse resolution global climate circulation model (Zhang *et al*., 1998).

A short-coming of the algorithm described above is that the property in question, here salinity, will generally not be conserved. This is *e.g.* easily seen in the corrections due to the intra-categorical adjustment in the algorithm's final step: There is no areal representation in the polynomial approach, so in Figure 5 we note that the region in which the salinity is increased, covers a much larger area than the region with decreasing values.

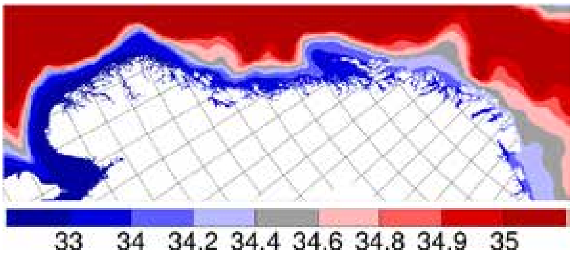

Figure 7 The final product for sea surface salinity in March.

Acknowledgements

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The Tyrrhenian Sea Forecasting System

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Abstract

A high resolution ocean forecasting system is described, based on the Princeton Ocean Model (POM), which covers the whole Tyrrhenian Sea. The system is nested with the Mediterranean Forecasting System and forced by ECMWF data. Here, some examples are given of its performances. The forecasts and re-analysis produced over the last five years have also been used for the investigation of new aspects of the Tyrrhenian Sea circulation and of its variability.

Keywords: Operational models, Tyrrhenian Sea, Mediterranean circulation, mesoscale, altimeter

1. Introduction

The last fifteen years have witnessed a vigorous development of the activities of operational oceanography. During these years, the main Italian scientific institutions active in this field have developed regional operational forecasting systems that cover most of the national seas (Adriatic Sea, Sicily Channel, Tyrrhenian Sea, and the Bonifacio Strait)

Both the research and the operational activities in this field benefit from efficient national coordination, ensured by the "Gruppo Nazionale di Oceanografia Operativa" (GNOO), which was established in 2004. Since 2012, the national activities in the field of operational oceanography are inserted in the Mediterranean Operational Network for the Global Ocean Observing System (MONGOOS), which promotes partnerships and capacity building for GOOS in the Mediterranean Sea.

Here we provide a brief description of the Tyrrhenian Sea forecasting systems, focusing on peculiarities of the model, and giving examples of its validation and use.

2. The tyrem forecasting system

The TYREM system is based on the Princeton Ocean Model (POM; Blumberg and Mellor, 1987). POM is a free surface, sigma coordinate (i.e., terrain following) ocean model that solves the primitive equations under the hydrostatic and Boussinesq approximations. It has been widely used in the last two decades, both for studies of ocean dynamics and for operational purposes.

The implementations here presented are quite standard in that it uses the second order turbulence closure scheme embedded in POM to compute the vertical exchange coefficients, parameterizes the horizontal diffusion following the scheme of Smagorinsky

(1963) and uses the standard POM numerical schemes for the advection of the prognostic variables. TYREM covers the whole Tyrrhenian Sea (TYS hereafter), which is the main Italian sea. The TYS is a deep basin with complex bathymetry, characterized by a rich circulation, which is not yet fully understood.

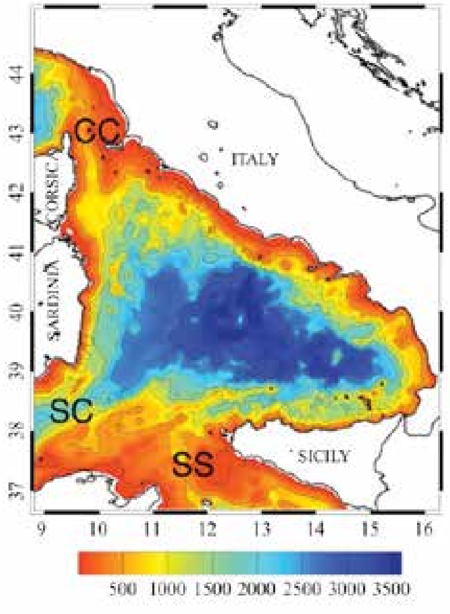

Figure 1 The computational domain of TYREM, including the whole Tyrrhenian Sea. CC, SC, and SS denote the three openings: the Corsica Channel, the Sardinia Channel, and the Sicily Strait, respectively. The basin bathymetry (in meters) is indicated by colors and contours.

The model domain, shown in Figure 1, extends into the Sicily Strait, where is the southern open boundary, at 36.68°N, and, to the west, into the Ligurian Sea and the Sardinia Channel, where two other open boundaries are located, on the 8.81°E line.

The computational grid is made by a regular longitude-latitude grid, with a grid spacing of 1/48°, which gives an average horizontal resolution of about 2 km, and by 40 sigma levels in the vertical, smoothly distributed along the water column, with appropriate thinning in the surface and intermediate layers.

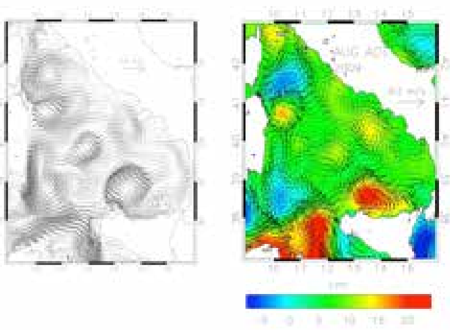

Figure 2 Average circulation for August 2009 from TYREM's hindcasts (left) compared with the geostrophic reconstruction obtained from the AVISO ADT data (right). In the latter panel, the ADT values are indicated by colors.

The bottom topography, interpolated from the DBDV dataset (see http://www.navo.navy.mil/), has been slightly smoothed, to reduce the pressure gradient errors inherent in the use of sigma coordinates over steep topography. As Figure 1 shows, the resulting model bathymetry remains quite realistic, even though some complicated coastal features are not adequately resolved. The model is forced by surface momentum heat and fresh water fluxes computed by bulk formulae (see, e.g., Napolitano ., 2014) from atmospheric data. These are data of air temperature, relative humidity, cloud cover and wind from the forecasts and/or re-analyses of the ECMWF (European Centre for Medium Range Weather Forecast), which have horizontal resolution of 0.25° and a frequency of 6 hours. The model is nested one-way with the Mediterranean Sea operational model MF1671 (Oddo ., 2009); the initial and boundary conditions for the regional model are obtained through linear interpolations of the corresponding fields of the parent model. However, particular attention is devoted to the alignment of the transports through the three open boundaries between the two models, which is achieved through the same treatment for the barotropic and baroclinic velocities described in Zavatarelli and Pinardi (2003). TYREM has been operational since January 2009. The system is initialized, in hindcast mode, on each Tuesday, when analysis simulations from the MF1671 model covering the previous 15 days are produced and made available. A hindcast simulation is performed that starts seven days earlier and uses the analyses of MF1671 and of ECMWF, which is followed by a forecast of seven days. This procedure allows for the elimination of spurious barotropic waves set off after the initialization. A potential disadvantage is that the initialization, which includes the effects of the data assimilation in the parent model, is moved a week back. On the other hand, the method is simple (it avoids the complexities of variational methods), and gives more time to the high-resolution regional model to develop its own dynamics. Between Wednesday and Monday of the following week, seven days forecasts are produced daily, initializing the model with restart fields from the previous day's forecast. Further details on the numerical implementation of the POM model for the TYS can be found in Napolitano . (2014), in which the TYREM outputs have been used to characterize the surface and intermediate TYS circulation of 2009. This was the first year of life of the system, and turned out to be quite typical in terms of both winter and summer surface circulations (see also Iacono ., 2013), where the long dataset of altimetric observations now available, together with results from TYREM and from dedicated numerical simulations, was used to characterize the seasonal variability of the TYS circulation). Figure 2 shows the average August 2009 surface circulation predicted by TYREM (left panel), together with an average map of absolute dynamic topography (ADT) for the same period (AVISO data; right panel, ADT indicated by colors), with a geostrophic reconstruction of the circulation superposed.

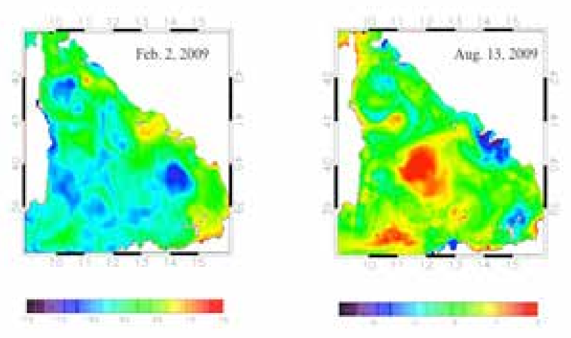

Figure 3 Temperature bias (TYREM SST – observed SST) for typical winter (left) and summer situations.

There is very good agreement between the two circulation fields, which contain well-known cyclonic structures in the western part of the basin (e.g., the Bonifacio dipole, to the east of Corsica), but also some wide anticyclonic vortices in the central and eastern part of the basin. It was shown in Iacono . (2013) that these are robust features of the TYS summer circulation. Examples of the model performance in reproducing the structure of the SST are given in Figure 3, showing the temperature bias in a typical winter (left) and summer (right) situation. The bias is computed taking as a reference the SST measured from satellite (Buongiorno Nardelli , 2013). The bias is small in winter (between -0.5°C and +0.5°C over most of the domain), and somewhat larger in summer, where the model SST is about two degrees warmer than the observed one in the central and southern parts of the basin. This tendency to overestimate the SST in the presence of strong surface heating is a known shortcoming of the Mellor-Yamada turbulence scheme (Mellor, 2001). Further work should be dedicated to improve this aspect of the summer model performance.

Development of TYREM is ongoing, following three directions: inclusion of the main fluvial inputs along the western Italian coast; use of high-resolution atmospheric forcing from limited area models; and development of a very high-resolution (1/144°) ocean forecasting model including the coastal area of the Campania region (in collaboration with the Parthenope University of Naples).

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Downscaling from the ocean to the regional level: an approach to the Portuguese Exclusive Economic Zone

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Abstract

The Lusitania model is a 3D baroclinic regional model covering a wide area of the eastern Atlantic Ocean, including the Portuguese Exclusive Economic Zone (EEZ), and the Western Mediterranean Sea. The model is forced by the MyOcean general circulation model, the FES2004 global tide solution and the atmospheric forcing provided by the NCEP Global Forecasting System (GFS). The Lusitania application is able to represent the main oceanographic processes as temperature and salinity fronts and gradients, and the general circulation patterns of the Eastern Atlantic Ocean and Western Mediterranean Sea. The model domain's limits were set to provide modelling results to the Portuguese EEZ and to supply boundary conditions to more refined regional models for the Portuguese continental coast, Madeira and Azores archipelagos and to areas that could be defined of interest following a cascade downscaling technique. A general description of the Lusitania application will be provided and model results will be shown.

Keywords: Portuguese EEZ model, Operational model, MOHID modelling system, Downscaling technique

1. INTRODUCTION

Portugal is a coastal nation formed by the continental territory and two archipelagos, Madeira and Azores Islands. The Portuguese Exclusive Economic Zone (EEZ) is one of the largest EEZ in the world with 1,727 km^2 and this area can be increased in the near future to 3,877 km^2. Thus, Portugal includes a vast area of the Atlantic Ocean which resources could be exploited economically while, under the EU Marine Strategy Framework Directive (MSFD), its waters should be protected and monitored. Keeping a good environmental standard of the marine and coastal waters is therefore of vital importance for Portugal and its economy.

In order to provide support to the MSFD aims, namely to generate solutions to be used by smaller regional models, an application running the MOHID model (www.mohid.com.) for the current Portuguese EEZ extension was developed. Lusitania model aims to provide hydrodynamic modelling results to the Portuguese EEZ and to improve boundary conditions for the Portuguese regional seas (Madeira, Azores and Iberian zone).

Downscaling of ocean models can be done directly to the regional seas, however the use of an intermediate level has scientific and socio-economic advantages and the Lusitania model aims to take advantage of both. An offline downscaling philosophy will be applied to Lusitania model results in order to provide boundary conditions to the Portuguese continental coast, the Madeira and the Azores archipelago regional models.

2. Lusitania application

The Lusitania application is a system based on the MOHID model (Neves, 2013), an open source numerical model (www.mohid.com). MOHID is a three-dimensional water modelling system, developed by MARETEC (Marine and Environmental Technology Research Center) at Instituto Superior Técnico.

This application covers a wide area of the eastern Atlantic Ocean and the Western Mediterranean Sea. The domain's limits were set to cover the current Portuguese EEZ and also to simulate accurately the water fluxes in the Strait of Gibraltar, as these fluxes affect the water circulation on the southern coast of the Iberian Peninsula.

The Lusitania application is composed of two nested model domains (Level1 and Level2) with 0.08° resolution. The Level1 consists on a 2D barotropic model covering the geographic area 24.63ºN-47.91ºN and 37.83ºW-9.45ºE. Level1 is forced along its open boundaries by tidal components obtained from the FES2004 global tide solution (Lyard et al., 2006) with admittance included. The Level2 consists on a 3D baroclinic model covering an area slightly smaller (26.07ºN-46.47ºN and 36.39ºW-8.25ºE) and vertically discretised in 50 layers, 7 sigma coordinate layers in the top eight meters followed by 43 Cartesian layers with increasing depth thickness.

Two sources of data were combined to obtain the Lusitania model bathymetry: the EMODNet Hydrography portal (http://www.emodnet-hydrography.eu) complemented by the 30" resolution global bathymetry data SRTM30_PLUS (Becker et al., 2009) in the regions where EMODNet data was not available.

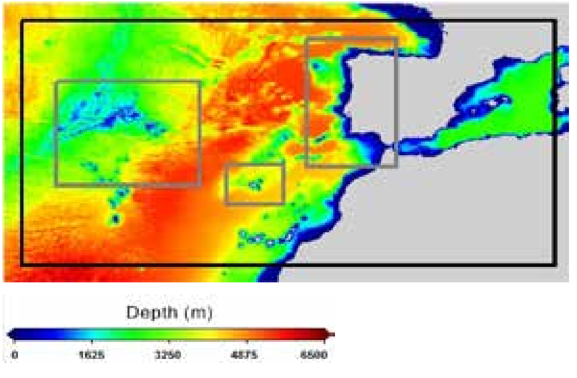

Figure 1 Bathymetry for the Lusitania Level1 grid (whole domain), Level2 grid (area within the black square) and the domains of the regional models (grey squares) for the Portuguese continental coast, Madeira and Azores archipelagos.

The Level2 domain was forced by the tidal computed by Level1domain along with atmospheric forcing provided by the NCEP Global Forecasting System (GFS) and the MyOcean general circulation model results (MyOcean catalogue product ID: GLOBAL-ANALYSIS-FORECAST-PHYS-001-002). The GFS model provides information about the air temperature, atmospheric pressure, wind and solar radiation with a horizontal resolution of 0.5º. Initial and boundary conditions for currents, sea temperature and salinity were obtained from the MyOcean product with a horizontal resolution around 0.083º. For the Level2, temperature and salinity fields were assimilated from the MyOcean model.

An Automatic Running Tool (ART) software was used to manage and to automatize the operational procedures, namely to pre-process the input files needed, execute the model and distribute the model results in several forms. The ART tool allows running models in a cascade scheme, where downstream models wait for a signal from the immediate upstream model indicating the end of the running, and triggers the following model simulation. This procedure reduces the computational time, as the different models can run in separate machines.

3. Lusitania results

The Lusitania is running since January 2013 and is being run to become fully operational. The results of the water levels and 3D fields for currents, salinity and temperature are being produced and published in the portal http://forecast.maretec.org/opmodelcat.

Model results analysis shows that the main water masses present in the domain can be observed in the Lusitania results. The entering of Atlantic water into the Mediterranean through the Strait of Gibraltar as surface water mass can be observed in the surface velocity field results (Fig. 2). In the western basin of the Mediterranean Sea the main circulation patterns are also observed: the inflow of the Atlantic water is first directed north-eastward due to the orientation of the Strait of Gibraltar, then generally describes a clockwise gyre in the east of the Alboran Sea between Spain and Morocco (El-Geziry and Bryden, 2010).

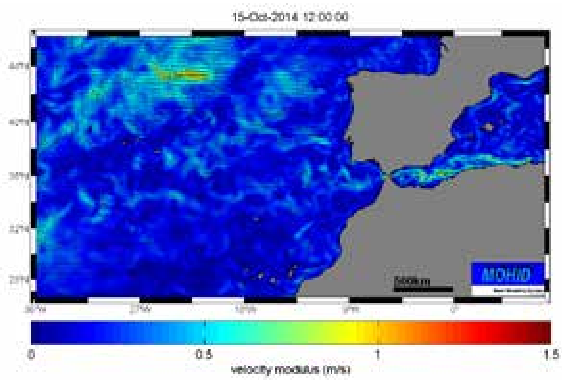

Figure 2 Instantaneous surface velocity field obtained with the Lusitania model for the day 15 of October 2014.

The analysis of one month average surface salinity shows that Lusitania reproduces the salinity gradients between the saltier Mediterranean water and the Atlantic water, and the mixing between these waters (Fig. 3). The one month average water surface temperature results (Fig. 4) display the meridional temperature gradient in the Atlantic side and the more homogeneous temperature distribution in the Mediterranean Sea. Also evident in results is the wind influence on temperature through coastal upwelling along the Western European and African coasts (Fig. 4). In the Mediterranean, near the Straits of Gibraltar lower surface water temperatures can be observed due to the colder Atlantic Waters. Also in the Gulf of Lions, North Western Mediterranean Sea, surface temperature results shows lower water temperature that could be related to the surface cooling due to cold air transported by north-western winds known as mistrals.

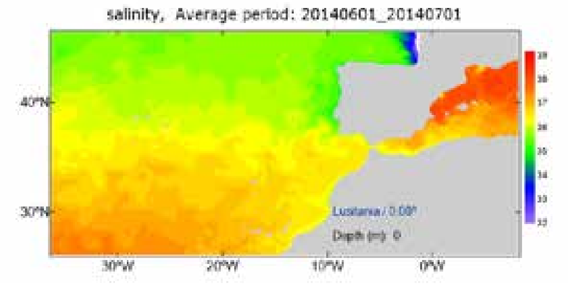

Figure 3 Lusitania average surface salinity. The average corresponds to the model results obtained for the period between 1of June and 1of July 2014.

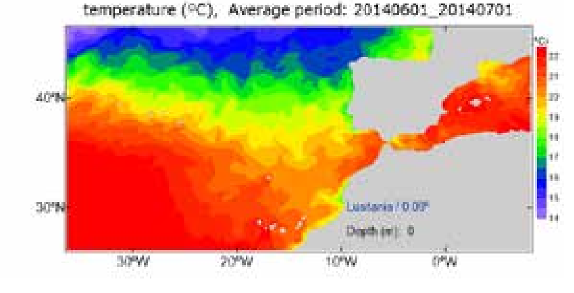

Figure 4 Lusitania average water surface temperature. The average corresponds to the model results obtained for the period between 1of June and 1of July 2014.

3.1 Model validation

Model results validation includes comparisons with data from remote sensing sensors, satellite and ARGO floats, and data from moored sensors, buoys and tidal gauges. Remote sensing allows obtaining observations in remote areas where traditional sampling would be very costly while also covering large areas. Lusitania sea surface temperature (SST) results are being compared with Microwave Optimally Interpolated sea surface temperature data (MW OI SST) produced by the Remote Sensing Systems group. Plots with the difference between model results and remote sensing data are produced and quantitative statistics are calculated to assess model performance. Fig. 5 illustrates an example of this comparison, where the results show good agreement between the model results and the observations.

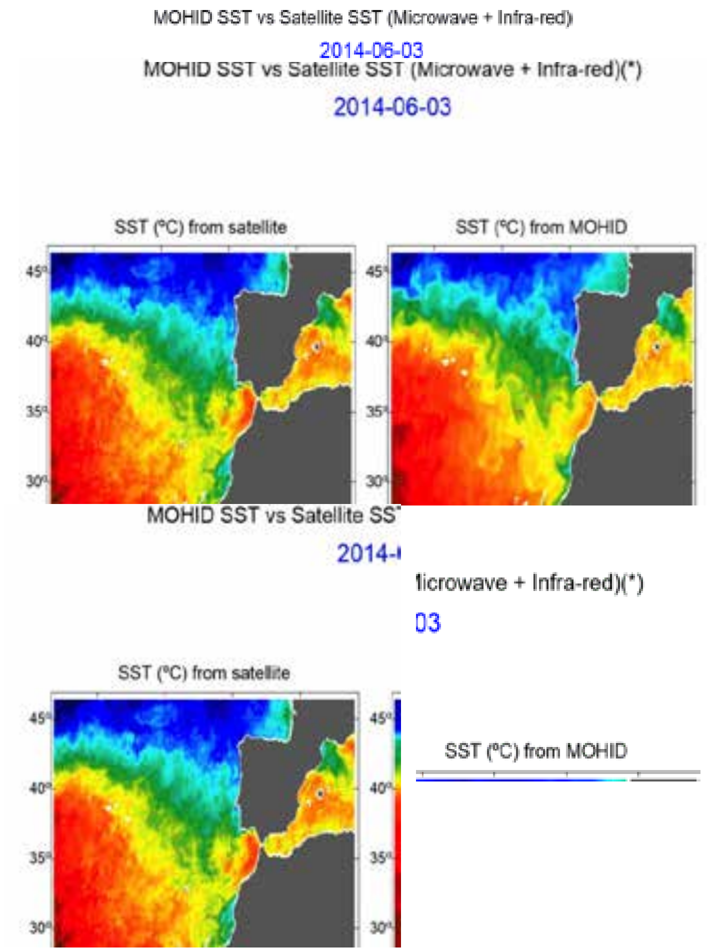

Figure 5 Comparison between Lusitania model (MOHID) and satellite sea surface temperature: SST obtained from the satellite; SST obtained from the Lusitania model results; SST difference between the Lusitania and the satellite; quantitative statistics.

Comparisons between model temperature and salinity profiles and the Argo floats (http://www.argos-system.org/) are also being performed. This comparison shows the correctness of the model water masses vertical distribution, complementing the information provided by satellite imagery. An example of this comparison is shown in Fig. 6, where plots of temperature and salinity profiles from the Lusitania model (red), MyOcean model (green) and Argo floats (blue) are compared. In this case, Lusitania and MyOcean models have similar results and the profiles obtained are similar to the Argo profiles.

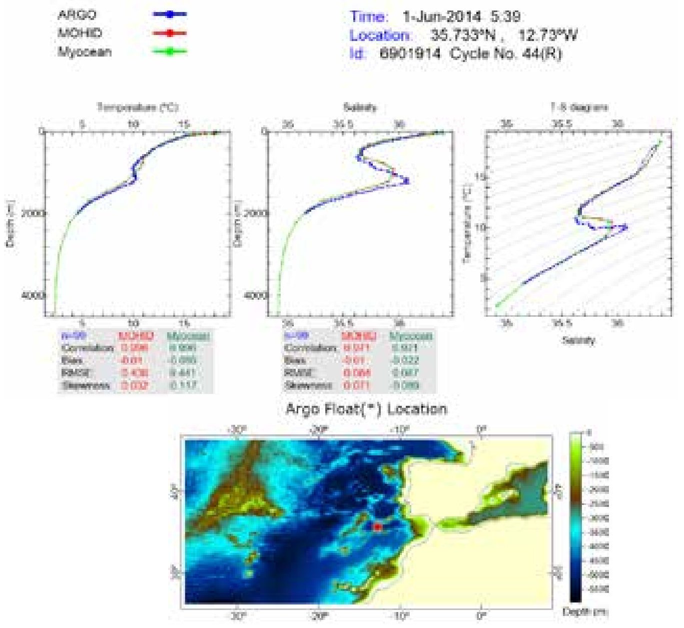

Figure 6 Comparison between the temperature and salinity profiles from the Lusitania model, the MyOcean solution and the Argo float.

3.2 Model downscaling

Downscaling requires the combination of tidal models with the lower frequency solution provided by global circulation models. Normally, this implies the use of simplified approaches at the open boundaries having consequences for the near boundary solution. Thus the model open boundary must be located as far as possible from the end user study area. When nested models are used the open boundary issue has lower consequences because at the boundary between the coarser and the finer models there is only a numerical issue, since both levels simulate the same processes.

A downscaling offline technique will be used in Lusitania model results to provide boundary conditions to the regional models. This approach consists in saving a window of model results from the upstream model (Lusitania model) with a high temporal resolution, able to represent the main processes coming from the open ocean (i.e. the tide signal), and use these results in the local models (Portuguese continental coast, the Madeira and the Azores archipelago models) boundary conditions (Campuzano et al., 2012).

In this cascade downscaling technique the model is waiting for a signal from an upwind model indicating that all the conditions are ready to start running. This synchronization optimizes computing time and reduces operating errors. This technique allows: the local model to run independently; running several downstream models at the same time; and the integration of ecological processes with greater time scales.

4. Conclusion and future work

The Portuguese Exclusive Economic Zone (EEZ) includes a large part of the Atlantic Ocean which resources could be exploited economically in different ways. The EU Marine Strategy Framework Directive (Directive 2008/56/EC) aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend.

Regional models make the link between global circulation models and local coastal and estuarine models that are in fact the most important in terms of socio-economics. At the global scale free surface fluxes are the only relevant forcing, while at the local scale tide is often the most important forcing. Downscaling of global circulation models to force local models needs an intermediate regional model forced at the open boundary by results of a global circulation model and by a global tidal model.

The Lusitania application could be regarded as an important tool for ocean and coastal monitoring, forecast and management of the Portuguese EEZ. Lusitania can provide boundary conditions to more refined regional models, i.e. Portuguese continental coast and the Madeira and Azores archipelagos, and to areas that could be defined of interest following the cascade downscaling technique.

The Lusitania application is able to represent the oceanographic processes as temperature and salinity fronts and gradients, and the general circulation patterns of this area of the Atlantic and the western Mediterranean basin. The validations performed show a good agreement between the model results and the observations.

The described pre-operational model will be continuously simulated until the present to become an operational application. Future version of Lusitania application will include the biogeochemical processes to increase its performance, and also the use of MPI to improve the computational time.

Acknowledgements

This study has been conducted using MyOcean Products. The bathymetric metadata and Digital Terrain Model data products have been derived from the EMODNet Hydrography portal - http://www.emodnet-hydrography.eu. Microwave OI SST data are produced by Remote Sensing Systems and sponsored by National Oceanographic Partnership Program (NOPP), the NASA Earth Science Physical Oceanography Program, and the NASA MEaSUREs DISCOVER Project. Data are available at www.remss.com.

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WIFF a nowcast-forecast system for high-resolution coastal applications

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Abstract

Coastal and offshore oil spill events have huge social, economic and environmental impacts, which can ultimately damage an entire coastal area for long periods of time. Simultaneously, adequate preparedness of harbor and maritime authorities to potential oil spills requires significant material and human resources. Timely hazard forecasting is an essential part of risk management for vulnerable communities, providing the necessary information for pollution protection resources allocation and efficient management of emergency personnel.

This work presents a nowcast-forecast information system, tailored for coastal applications, which integrates a suite of high-resolution numerical models for distinct purposes like circulation, waves, oil spills, morphodynamic and water quality. The present study will focus mainly on the oil spill modeling system. A brief explanation of the numerical model including all the oil weathering processes and also of the WebGIS platform is made.

The Water Information and Forecasting Framework (WIFF), due to the use of non-structured simulation grids, is well suited for cross-scale applications that can range from the ocean to coastal zones and estuaries. This feature provides the stakeholders and port authorities the capability to have all the information (in-time and with high-resolution) needed to support them in the combat of a real crisis event.

Keywords: oil-spills, nowcast-forecast, monitoring, WebGIS

1. Introduction

Natural and man-made disasters worldwide cause widespread destruction of property, human injuries and deaths. Even if disasters have unpredictable occurrences or consequences, many mitigation actions can be done to diminish the resulting damages or their severity. Preventive measures are currently under improvement and their effectiveness aims at decreasing the impact of the hazards. Thus, the protection of important environmental and social assets in river and coastal regions requires the early warning for potential hazards, such as floods, pollution events and tsunamis. Timely hazard forecasting is an essential part of risk management for vulnerable communities, providing the necessary information for population evacuation, pollution protection resources allocation and efficient emergency personnel management. Forecast systems combine our ability to measure and to simulate the behavior of water bodies by integrating numerical models, monitoring networks and information technology systems. These systems provide real-time short-term predictions of the main physical and chemical parameters.

This work presents a nowcast-forecast information system, tailored for coastal applications. The information system is based on the custom deployment of a generic forecasting platform, modified for short to long wave predictions, and implemented in a modular way to accommodate future developments. It integrates a suite of high-resolution numerical models, for distinct purposes like circulation, waves, oil spills, morphodynamic and water quality.

The present study will focus mainly on the oil spill modeling system. A brief explanation of the numerical model and all the oil weathering processes is made. The present study acknowledges that one of the easiest and friendliest ways of reaching a broad spectrum of stakeholders, from the coastal managers to the avid recreational user, is to produce images and animations integrating the products of the running forecast models, taking advantage of the several visualization tool boxes, many of which support GIS (Geographic Information System) capacities. Therefore, the present work will also provide a brief description of the several derived products generated by the oil spill forecast system and their integration/presentation in a WebGIS platform.

The WIFF system, due to the use of non-structured simulation grids, is very well suited for cross-scale applications that can range from the ocean to coastal zones and estuaries. This feature provides the stakeholders and port authorities the capability to have all the information (in-time and with high-resolution) needed to support them in the combat of a real crisis event.

2. VOILS – OIL SPILL MODEL

VOILS is a 2D/3D Eulerian-Lagrangean transport and weathering oil spill model (Azevedo et al., 2009; Azevedo et al., 2014). All the major oil weathering processes are implemented, such as: advection, spreading, evaporation, emulsification, dispersion, dissolution and shoreline retention (including oil reposition). Several weathering formulations were implemented for the spreading (Lehr *et al.,* 1984 and Lehr, 2001), evaporation (Stiver e Mackay, 1984; Fingas, 2004 and Jones, 1997), and emulsification (Mackay *et al*., 1980 and Rasmussen, 1985). The evaporation, emulsification, density and viscosity formulations were calibrated and validated against laboratory tests made in CEDRE, in the scope of the European SPRES project (http://www.spresproject.eu).

VOILS solves a transport-type equation for the thickness of the oil at the surface. The equations are solved with a combination of finite volumes and Eulerian-Lagrangian methods, which provide efficiency and mass conservation.

VOILS also takes advantage of unstructured horizontal grids to efficiently represent complex coastal boundaries, enhancing the capabilities of the modeling system for cross-scale applications that can range from ocean to coastal zones, estuaries and ports. Besides regular outputs, VOILS also produces several indicators for risk management. Examples are exposure time, time for first oil arrival, oil density and viscosity evolution, evaporation and emulsification rates, oil mass and shoreline retention areas.

3. WIFF NOWCAST-FORECAST SYSTEM

The nowcast-forecast information system proposed herein is based on the deployment of a generic forecasting platform, adaptable to any geographical location, and customizable for coastal applications, which was originally developed at CMOP (Center for Coastal Margin Observation & Prediction, U.S.A. – Baptista, 2006) and was adapted and extended by LNEC (Jesus et al., 2012; 2013). The system integrates a set of numerical models that run in parallel automatically in a high-performance environment.

The WIFF platform is capable of coupling waves, tides, storm surges, river flows, precipitation and winds, providing forecasts of water levels, currents, water temperatures, salinity and waves for a target area. The WIFF forecast platform is composed by the following numerical models: a wave model (WaveWatchIII, Tolman *et al*., 2002), a hydrodynamic model (SELFE, Zhang e Baptista, 2008), an oil spill model (VOILS) and also an ecological model ECO-SELFE (Rodrigues *et al*., 2009).

Circulation is simulated with the community model SELFE (Zhang and Baptista, 2008). SELFE solves the 3D baroclinic shallow water equations for elevations, velocities, salinity and water temperature. The domain is discrete with finite elements in the horizontal and mixed S-Z coordinates in the vertical. A semi-implicit time stepping algorithm combined with an Eulerian- Lagrangian treatment of the advective terms in the momentum equations provides a robust and spurious-free solution, free of Courant number restrictions. Moreover, SELFE is fully parallelized.

During SPRES and PAC:MAN projects the WIFF system was applied to the Aveiro lagoon. For that particular case of the Aveiro lagoon, SELFE was forced by water elevations, temperatures and salinities from a regional model (www.myocean.org) at the ocean boundary, quasi-real time river flows (www.snirh.pt) and atmospheric forcings (NOAA: www.ncdc.noaa.gov/data-access/model-data/model datasets/global-forcast-system-gfs and University of Aveiro: http://climetua.fis.ua.pt).

The platform provides daily hydrodynamic forecasts for the next two days. These hydrodynamic predictions are then used to forecast the evolution of six predefined spills, using VOILS. This system has also the capability to forecast on-demand oil spills, using the hydrodynamic forecasts and the spill information provided by the user (e.g., spill time, amount and type of oil). The products of the WIFF system are available in a webGIS platform. This platform can be used to: display maps of several variables (elevation, salinity, temperature, oil spill trajectories, oil exposure time – which is the period of time that a particular point of the domain is contaminated with oil; see Figs. 1-3), automatically compare model results with data retrieved from real time field sensors (Fig. 4), extract sensor data time series or predictions time series at any location defined be the user (Fig. 5) and display environmental sensitivity/vulnerability maps for risk assessment purposes (Fig. 6 and Fig. 7 from Section 4).

The access to the site of this project is restricted, therefore the users should ask for a user name and password to the site administrators.

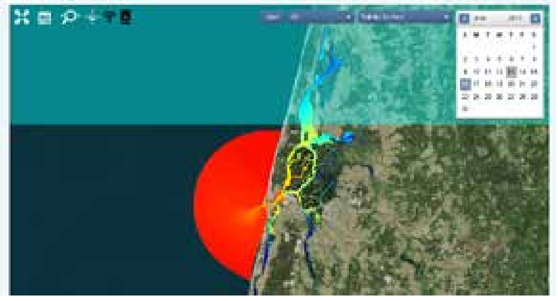

Figure 1 Example of a predicted salinity map.

Figure 2 Example of an oil spill simulation (oil thickness is represented in red).

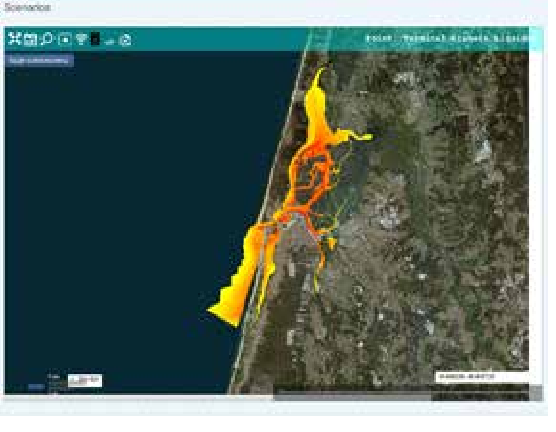

Figure 3 Example of an oil spill exposure time map, where the yellow-red colormap correspond to a 1-24 hours of oil contamination period, respectively.

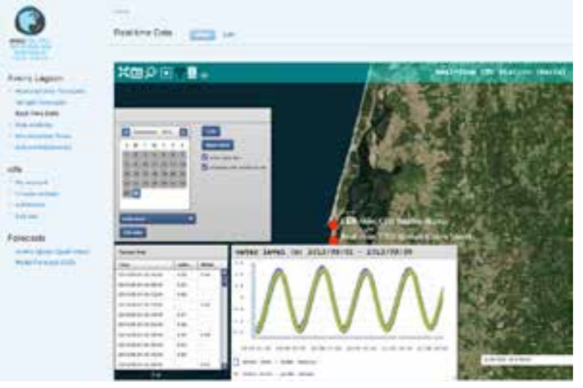

Figure 4 Automatic comparison of model results with data from sensors (model results: blue line; sensor data: green dots).

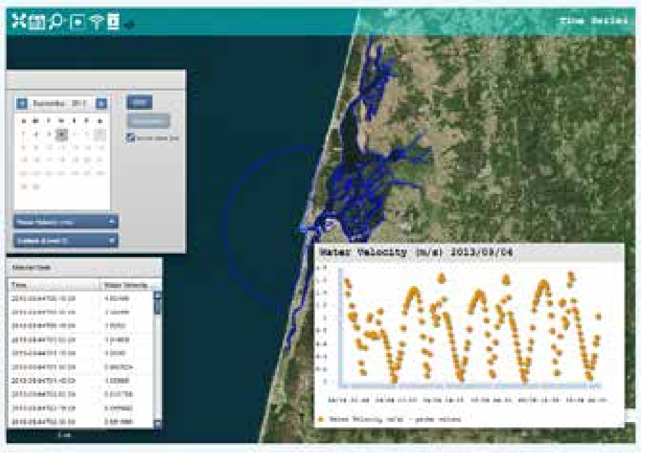

Figure 5 Probing of the model predictions (water velocity) at a location defined by the user.

4. RISK MANAGEMENT PORTAL

The oil risk WIFF platform was conceptualized for emergency management through pre-defined hot spots for oil spills, where a plume of 10 tons of RFO/HFO N.6 oil is released, all defined with the collaboration of the Port Authority. Oil spill predictions for all spots and all scenarios are run in parallel processors, to provide the fastest availability of results. These results are then processed into indicators for oil impact analysis, such as the time of exposure to oil at every node of the domain for each oil spill model simulation. From the analysis of Fig. 3 one can evaluate the areas affected by the oil for a particular simulation. Information on the surface slick and on the beached oil can be processed and visualized as different GIS layers, allowing for the quick specification of the most adequate response or mitigation action.

A detailed risk assessment, based on georeferenced hazard and vulnerability maps, can also be visualized in the interface. A multi-scenario approach, based on the most likely environmental scenarios for accident-prone conditions (wind, waves and tides) was used to generate hazard maps (Boer *et al*., 2014). To facilitate the oil pathways analysis, the platform provides a filtering service for each forcing factor and for the probability of the combination of factors, allowing a quick access to specific simulations.

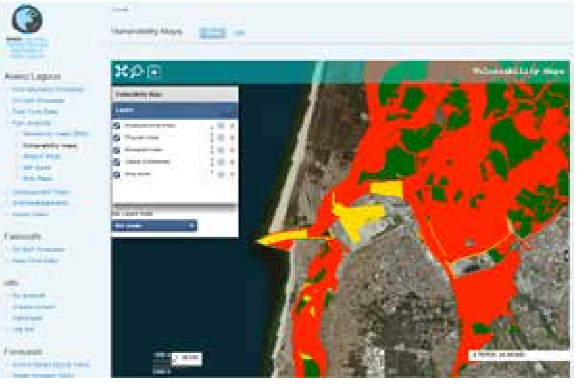

Figure 6 Example of the representation of the distinct vulnerability maps produced for the Aveiro lagoon.

The oil spill emergency component is closely linked to the formal risk management tool. While oil forecast runs are ongoing, a preliminary estimate of the potential oil pathways can be inferred, as the platform automatically selects and highlights the pre-run scenario closest to the forecasted environmental conditions. Likewise, the oil spill forecasts also contribute to progressively enrich the database of scenarios. Every day, each new set of oil runs is integrated in the risk analysis database and made available at the filtering menu. This closed loop will continuously increase the completeness of the platform and consequently its usefulness for real accidents.

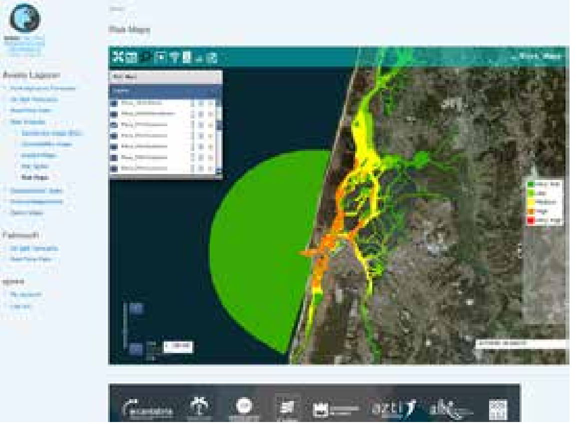

Figure 7 Example of the risk maps produced within the SPRES project for the Aveiro lagoon.

The flexible and generic nature of the platform will enable at a later stage the possibility to combine, in a single screen, different layers of sensitivity, vulnerability and hazard maps, as well as relevant oil indicators at selected locations – receptor points (Fig. 6 and Fig. 7). Receptor point information will be readily available as data time series for visualization, analysis and download. For the same points, the platform will provide the mitigation and response action fact sheets under development in the SPRES project.

5. Concluding remarks

Herein, an interactive and flexible computational GIS-based platform is presented, which takes advantage of novel technologies to provide on-line, intuitive and geographically-referenced access to real-time data and model predictions. This platform also allows producing on-demand services in support of coastal resources and harbor operations management as well as emergency procedures. The forecasting engine behind the platform is supported by multi-scale high-accuracy numerical models for both hydrodynamics and oil transport and weathering, which handle all relevant processes both in the water column and intertidal areas.

The platform, generally denoted as WIFF, was customized for oil spill risk management and successfully applied to the risk of an oil spill within the Port of Aveiro jurisdiction area. Nevertheless, the WIFF system can be easily applied to other locations (in coastal and estuarine areas or offshore) in order to support national authorities, port administrations or private corporations in the oil industry.

Acknowledgements

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Analysis on research priorities for European operational oceanography

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Abstract

This paper analyses research needs for European operational oceanography in European coastal and shelf seas, with a time frame of 5-10 years. Following the value chain of operational oceanography, research priorities in four knowledge areas have been addressed: operational ecology, coastal operational oceanography, European Ocean Observation System and European ocean modelling framework. The intention of the paper is to provide a basis for further developing EuroGOOS scientific strategy and research priorities in 2014-2020.

Keywords: Operational ecology, Coastal, EOOS, next generation model

1. Introduction

EuroGOOS is a community formed with national institutions which have operational oceanography obligations. Such obligations have a common value-chain, i.e., user-driven, knowledge-based, operationally featured and service-oriented (Fig. 1).

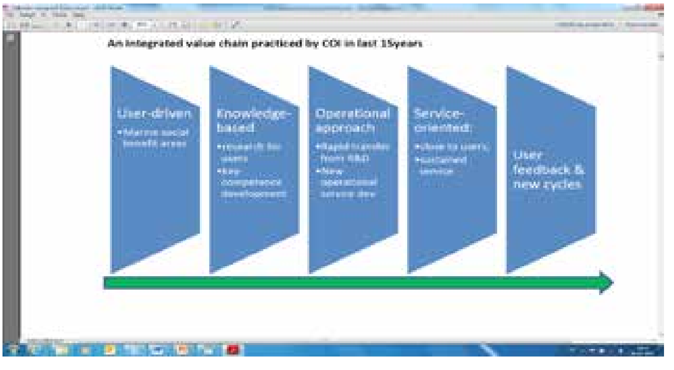

Figure 1 Value-chain of operational oceanography

Research is a key in this value chain, which leads to transformation of the user-needs into the operational production and service. With this understanding, the EuroGOOS community has been promoting and performing the research with an integrated modelling-monitoring approach, aiming at provision of high quality and timely operational information service for supporting applications in a wide range of Social Benefit Areas (SBAs). Therefore EuroGOOS research shall focus on improving the modelling and monitoring platforms, as well as the performance of the integrated modelling-monitoring for supporting the targeted SBAs.

Over the past 20 years, significant advancements have been made in operational oceanography, benefited from community research supported from European Commission (EC) Operational Forecasting Cluster projects (Cieslikiewicz et al. 2004) and GMES (Global Monitoring for Environment and Security, currently referred as Copernicus) Marine Service program (Bahurel et al. 2010). Copernicus Marine Service (CMS) is used as background for this paper.

With the EC Framework Program support in the last 20 years, European operational oceanography has become one of the world leaders in operational marine service in global, regional and national scales. At national level, existing national services (e.g., in France, UK and Germany etc.) have been further developed and extended; New national service capacities have been established and advanced in many countries (e.g., Italy, Denmark, Estonia etc.). At the European level, an integrated capacity – MyOcean System of subsystems for operational monitoring and forecasting for global, Arctic and European Seas have been established.

Major scientific advancements made in the EC Operational Forecasting Cluster and CMS have been on the development of Earth Observation (EO) data management, short-term forecasting systems (including data assimilation) and reconstruction of long-term historical database through reanalysis and reprocessing. Other important issues, such as long-term prediction, ecosystem prediction, coastal service and optimisation of European marine monitoring systems etc., have also been supported by EC and national research projects but with much lower level of maturity and integration (in terms of operational service) in comparing within the CMS (e.g., short-term forecasting on physical ocean).

The purpose of this paper is to analyse future research priorities of operational oceanography in the European regional Seas, in a time scale of 5-10 years, with targeted service areas in

- Blue Growth in Europe
- Ecosystem-based management
- Climate change adaptation and mitigation, and disaster prevention
- Integrated Coastal Zone Management (ICZM)
- Copernicus long-term research
- Ocean monitoring activities

It is expected that the paper will also contribute to the EuroGOOS scientific strategy development. Four knowledge areas are selected for the analysis:

- Operational Ecology
- Coastal Operational Oceanography
- European Ocean Observation System (EOOS)
- European Operational Ocean Modelling

The global and Arctic-North Atlantic scale are also key service areas of European operational oceanography, they are however out of the scope of this paper.

2. Operational ecology

2.1 Background and objectives

Similar to operational service of physical ocean for maritime safety and offshore energy, an operational service of ecological indicators is also urgently needed for the ecosystem-based management, e.g., implementation of EU regulations in Marine Strategy Framework Directive (MSFD), Water Framework Directive (WFD) and Common Fishery Policy (CFP) etc. Although the short-term forecast (in days) is important, longer scales (seasonal to decadal) are even more relevant to the ecological service. The operational ecological service shall provide a range of high quality and timely data products describing the past (historical reanalysis simulations and reprocessed observations), present (for the past year or two) and future (seasonal forecast, scenarios) states of the marine ecosystems. These products will make ecosystem-based management more reliable, operational, efficient and timely in e.g.

1. More frequent update of the environment state assessment from the current 3-5 year cycle to a yearly one.
2. More reliable and efficient assessment based on integrated model-EO approach
3. New capabilities for ecosystem outlook in seasonal to decadal scales
4. Flexible operational tools for scenario-based ecosystem management through end-to-end modelling (Rose et al., 2010)
5. Provision of operational high trophic level service for fishery management
6. More reliable forecasts of biohazards such as harmful algae bloom, hypoxia etc.

To address scientific and technological challenges for the provision of operational ecological services, a complete knowledge base on the “Operational Ecology” is needed. Although recent scientific developments and breakthrough have provided a preliminary knowledge base for addressing above issues (e.g. in EU project OPEC), significant knowledge gaps still exist and efficient operational tools for the provision of the ecological service are yet to be developed and/or matured.

2.2 Implementation platform and research priorities

In order to build up European world-leading capacity of Operational Ecology, an Operational Ecology European Experiment (OEEE) is called for

- Identifying and filling major knowledge and technological gaps in operational ecology
- Identifying and filling major data gaps in operational ecology (incl. monitoring)
- Bringing multi-disciplinary knowledge, data and products together for operational ecology service

As the first phase towards operational ecology in Europe, OEEE will bring the existing knowledge, data and models together to develop and demonstrate an integrated operational service platform (both monitoring and modelling) for the ecosystem-based management in European scale to serve dedicated stakeholders such as EEA, ICES, Regional Conventions and Member State environmental agencies for the implementation of WFD, MSFD and CFP etc.

The research priorities in OEEE are as follows:

- To develop modelling techniques for Good Environment State assessment and operational fishery management
  - Develop and optimize flexible end-to-end models/tools for scenario-based service
  - Develop fully coupled atmosphere-ocean-ice-biogeochemical-IBM-food web models for ecosystem outlook in seasonal to decadal scale
  - Improve understanding of nutrient cycles and key parameterizations to improve forecasts of biohazards (through integrated monitoring and modelling approach)
- To explore fully use of existing biogeochemical data for operational ecology (data assimilation, model calibration and validation)
- To design and implement new monitoring activities for key process studies in order to reduce major uncertainties in operational ecology products
- Preoperational demonstration (Multi-model ensemble approach) on Rapid Environment Assessment, seasonal to decadal forecasting/projection for ecosystem components with the highest predictability and fishery service

3. Coastal oceanography

3.1 Background and objectives

One third of the EU population lives within 50 km of the coast. The GDP generated by this population amounts over 30% of the EU. The economic value of coastal areas within 500 metre from the European seas totals between €0.5-1 trillion, therefor a key area of European Blow Growth. Multiple pressures - including habitat loss and degradation, pollution, over-exploitation of fish stocks, climate change and natural hazards- affect the coastal ecosystems. In the past decade, Europe has endeavoured to establish a knowledge and indicator-based objective approach for ICZM and WFD, as well as an integrated coastal and shelf sea operational oceanography (She and Buch, 2003). For the ICZM, EU Working Group on Information and Data (WG-ID) proposed a list of indicators for assessing the ICZM progress and sustained development in 2003. The 27 sustainable development indicators, established by EU have been widely applied for ICZM in many European coastal regions. It is recognized that the indicator-based approach has to provide the reliable information on state of the coastal zone in each separate region, thus supporting the quality of coastal management decisions. The current information flows for the coast, however, are still fragmented, and do not support an integrated understanding of the coastal system as a whole nor do they support well-balanced decisions that ensure appropriate management.

Next generation European coastal operational oceanography shall aim to establish standardized methodology for the provision of necessary data and information flows in European coastal zones on an operational basis in order to support the Blue Growth in coastal regions, indicator-based ICZM and WFD implementation. It is expected that, by making this coastal service operational, huge benefits will be realized to the European society.

3.2 Implementation platform and research priorities

A European Costal Operational Oceanography Project (ECOO) is needed for building up European capacity on Coastal Operational Oceanography to

- establish standardised methodologies for mapping European coastal sediment cells and risks of shorelines
- establish an operational production chain of a list of indicators to support an indicator-based approach for ICZM implementation
- develop downstream services to boost the Blue Growth in coastal and offshore regions

On-going Copernicus Services have already provided or will provide large sets of relevant operational data and information flows in regional sea scale. Such services can be further integrated and extended from offshore to coastal zone, which shall provide spatial-temporal distributed data and information for following areas:

- Forecast of coastal natural hazards e.g., storm surge, flooding, high seas and coastal erosion
- Water management and flooding management.
- Coastal climate change adaptation and mitigation
- Operational mapping of the boundaries of European coastal sediment cells and sediment transport, and the status of the European shoreline risk levels
- Coastal water quality assessment (nutrients, transparency, dissolved organic matter, pollutants etc.)

Research priorities

- Improve integrated monitoring of coastal conditions through combination of satellite, HF radar, other coastal observatories and models
- Develop coupled ocean-wave-ice-sediment-ecosystem-riverine models in a few hundred meter or higher resolution for the coastal seas, and calibrate them for operational usage
- Understanding estuary and coastal dynamics and their role in nutrient cycle and pollutant transportation, and advancing the relevant processes in models: wave-current-sea level interaction, river plume, coast-estuary interaction, fate of river loadings
- A demonstration experiment for a Targeted Operational Period by downscaling the Copernicus data and information and integrating them with existing coastal data and information. The purpose is to provide data and information products for short-

term operational prediction and yearly assessment of the coastal environment and ecosystems.

- Establishing Europe-wide standardized methodologies for delineating coastal sediment cells, including methodologies relating to the production or modelling of datasets required for delineating such sediment cells, and towards shoreline economics.
- Establish standardized methodologies and production chain for calculating value-added products and the indicators for the ICZM and WFD implementation, e.g., indicators of anthropogenic pressure (riverine inputs, shipping, oil spill etc), climate change (sea level rise, sea ice, warming, sea state and currents etc), coastal erosion, nutrient and eutrophication, coastal sediment transport, hydrography and water quality etc.
- High resolution climate simulations for the coastal and transitional waters with resolving inter-basin exchange through Straits as well as extreme events
- Advancement of forecasting skills: multi-model ensemble prediction combining with observations

4. European Ocean Observing System (EOOS)

4.1 Background and objectives

Since the establishment of EuroGOOS, the ocean observation system has always been a central focus (Prandle et al, 2003, Nittis et al., 2014). Aiming at optimising existing European marine monitoring networks, comprehensive metadata and/or database of the European marine observations have been established in EU projects EDIOS, SEADataNet, EMODNET and MyOcean. A variety of assessment and optimal design research have been carried out. FP5 project ODON developed quantitative statistical assessment and optimal design methods for Baltic-North Sea satellite-in situ temperature and salinity monitoring networks (She et al., 2007). ODON method was later applied to assess the pan-European Sea T/S monitoring networks in FP6 project ECOOP (Fu et al., 2011) and biogeochemical monitoring networks in FP7 project OPEC (http://www.marine-opec.eu/documents/deliverables/d5.2.pdf). The Observing System Simulation Experiments (OSSEs) have been extensively applied in assessing physical monitoring networks in FP7 project JERICO. Currently DG-MARE and EMODNET have initiated a series of European Basin Checkpoint projects (for Mediterranean, North Sea, NE Atlantic, Black Sea, Arctic and Baltic Sea) to perform fit-for-purpose assessment of the European marine observations. The existing assessment work has led to identification of the gaps and availability of the existing networks and recommendations to future monitoring networks. However, existing research focuses more on the method development rather than implementation of recommended changes. Optimisation of EOOS remains as a focus for both EuroGOOS and CMS so that EOOS provides improved datasets for operational oceanography.

4.2 Implementation platform and research priorities

An EOOS optimisation project is needed as the instrument for implementing the needed research for the EOOS. The EOOS R&D shall aim at a sustainable end-to-end delivery of values of data, i.e.

1. Data-to-products: 1) identify and exploit full usage of existing data for forecasting and reanalysis; 2) ensure timely delivery of available observations for operational use
2. Data-to-knowledge: promote case studies by using observations together with models to understand physical and ecosystem processes and improve model parameterisations/forecasts
3. Data-to-social-economic benefit: identify and carry out innovative fit-for-purpose social-economic applications by using observations together with models.
4. Optimisation: optimally design and implement new cost-effective component of EOOS as necessary, either as an adjustment and mobilisation of the existing monitoring resources or as new investments. The optimisation has to adopt an integrated, user-driven approach by combining scientific, technological and management designs.

5. European Operational Ocean Modelling Infrastructure

Operational ocean modelling has been largely advanced in the last 20 years in Europe. In recent years a very strong movement is the NEMO model development, with supports from both national and European level. More and more countries start to use NEMO as their operational model. However, more than a dozen ocean models are stilled used in operational modelling such as HBM, HYCOM, ROMS, POM, MOM, MITGCM etc. It is also noted that key "ocean model developers" are just a very small portion of the ocean modelling community. One reason is due to lack of resources and another is, unlike NEMO and HBM, many of these operational models are originated outside Europe.

Due to lack of modelling resources in national level, for EuroGOOS partners, it is of the same importance for sharing best practice of operational modelling as for making new model development. One way for sharing best practice is through Community model development such as NEMO. On the other hand, using different models in Europe for operational forecasting are also necessary as it is true that one model cannot solve all problems. EuroGOOS has initiated a Coastal and Shelf model Working Group to promote the model knowledge exchange and best-practice sharing. To this end, following network and support activities are suggested:

- Design a EuroGOOS ocean modelling framework strategy (e.g., standard, selection of models, way of work in model development etc)
- Facilitate efficient use of European ocean modelling resources and share best practice
- Building up test-bed and permanent provision of forcing data – weather forcing, river runoff, loadings, tidal boundaries, dynamic boundaries, climatological boundaries and bathymetry
- Building up capacity of mobility of common models: flexible implementation of common models for new applications such as different areas, setups (nesting and resolution) and computing platforms
- Common coupling framework development: OASIS, ESMF etc
- Common standards of Cal/val and uncertainty estimation

- Promote community modelling framework: inter-comparison of European community models; common framework of using multi-model products

The next generation European operational model can be ideally featured as follows:

1. Fully coupled atmosphere-ocean-ice-wave-ecosystem models with data assimilation and ensemble forecast
2. Flexible grids: to resolve pan-European Sea coverage and straits
3. "Green" model: can run efficiently in multi-core and many-core super-computing platforms so that the system upgrade can be sustainable in terms of cost-efficiency.

The first feature has been proposed as the future goal of the CMS systems. Although a few meteorological agencies have started to move in this direction, significant challenges remain.

The second feature addresses the weakness of existing operational ocean models in resolving long-term inter-basin exchange through the Straits (e.g. Bosporus, Belts) and response to EU agencies' request on pan-European products. Such a feature has been recently implemented tested by using DMI's HBM model (She et al. 2014)

The third feature addresses the conflict between the fast increasing computational needs and lack of good code for advanced supercomputing. DMI's HBM model has been optimised with this green feature for running efficiently in both multi- and many-core platforms (Poulsen et al. 2014).

To develop next generation European operational model system, following Joint Research activities (priority areas) are recommended:

- Optimising forcing in models: surface flux parameterizations and boundary conditions
- Optimisation of key processes such as turbulence mixing
- Develop common model code standards and relevant impact studies, e.g. run2run reproducibility, drift test for climate simulations, assessment impacts of using inhomogeneous observations and assimilation schemes in estimating the trend
- Model code engineering for next generation high performance computing: multi-core and many-core platforms
  - Improving scalability
  - Optimal combination of hardware and model codes, e.g. SIMD
  - Optimisation of numerical algorithms
  - HPC cost-benefit analysis in terms of "green" model standards
- Develop Pan-European models: one executable for entire pan-European Seas
  - High resolution (1nm or higher)

    - High computing efficiency
    - Properly resolving all main straits
    - Compatible or better performance comparing to single basin model
- Develop Common Assimilation Framework

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Validation of a Barotropic Tidal Model of Northern Adriatic using High Frequency Radar and Tide Gauge Measurements

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Abstract

The Gulf of Trieste (GoT) in the northern Adriatic is a region with the most pronounced tidal dynamics in the Mediterranean. Tidal prediction is therefore of substantial interest to the local communities. We estimate tidal prediction skills of two numerical models (OTPS tidal model and Northern Adriatic setup of POM) as compared to high resolution (1 h temporal resolution, 0.6 km horizontal resolution) and high frequency (HF, 25 MHz operating frequency) radar surface current observations (1 h temporal resolution, 1.5 km horizontal resolution) in the Gulf of Trieste (GoT) and to three years of tide-gauge data.

Keywords: HF radar observations, barotropic tidal modeling, tide-gauge observations, model validation

1. Introduction

The Gulf of Trieste (GoT) in the northern Adriatic (see Figure 1) is a region with the most pronounced tidal dynamics in the Mediterranean. Tidal prediction is therefore of substantial interest to the local communities. We estimate tidal prediction skill of two numerical models as compared to high resolution and high frequency (HF) radar surface current observations in the Gulf of Trieste (GoT) and to several years of tide gauge observations. The models compared are 1) a barotropic (vertically averaged 2D) tidal model OTPS, set up on the Northern Adriatic domain, which solves shallow water equations using constituents from OTIS inversion of Topex SSH data, 2) a general ocean circulation model NAPOM (Northern Adriatic setup of POM), where the tide is implemented as the open boundary forcing during POM external integration loop (Malačič et al. 2012, Cosoli et al. 2013). Tidal ellipses were calculated from vertically averaged NAPOM current velocities.

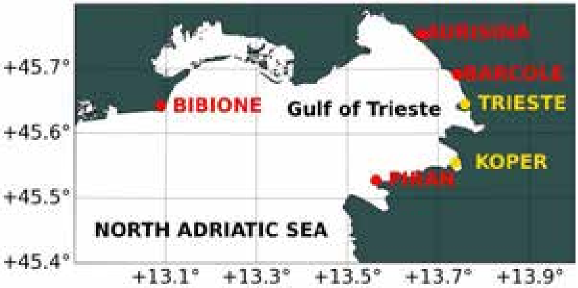

Figure 1 HF radar observation sites (red dots) that were covering the Gulf of Trieste in Northern Adriatic sea in years 2011-12. Tide gauge is located in Koper.

2. Tidal ellipse analysis

Tidal ellipse analysis was performed on observed surface currents and tidal model currents. NAPOM tidal ellipses were calculated from vertically averaged NAPOM current velocities (Cosoli et al. 2013). OTPS capably reproduces the HF radar semidiurnal components within the GoT's interior and also depicts the Kelvin-wave propagation offshore Grado (Figure 3). Dominant M_2 components from HF radar and OTPS compare favourably, as shown in Figure 2. Larger discrepancies were observed in the K1 band, most likely due to radar data contamination by wind energy. OTPS model estimations for M_2 and S_2 semi-major axes agree with HF observations to 0.2 cm/s.

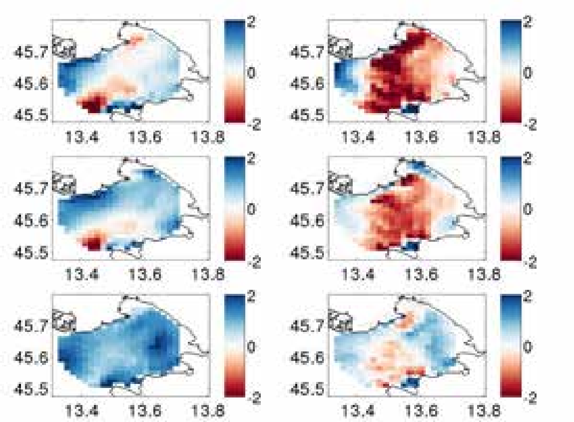

Figure 2 M2 (top), S2 (middle) and K1 (bottom) semi-major axis differences [cm/s] between HF radar and OTPS tidal model (left column) and between HF radar and NAPOM model (right column).

NAPOM model overestimates M_2 semi-major axis by roughly 3 cm/s and S_2 semi-major axis by 2 cm/s, but performs somewhat better in the estimation of K_1 component.

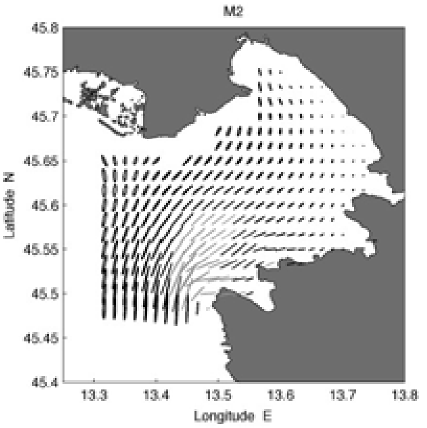

Figure 3 Tidal ellipses of the M2 tidal constituent, calculated from the OTPS tidal model of northern Adriatic. Semi-major axes of the ellipses outside of the Gulf of Trieste are oriented predominantly along the N-S direction, except outside the northwestern gulf entrance where they elongate along the NW-SE axis, indicating a tidal Kelvin wave. Black (gray) ellipses have counter-clockwise (clockwise) sense of rotation.

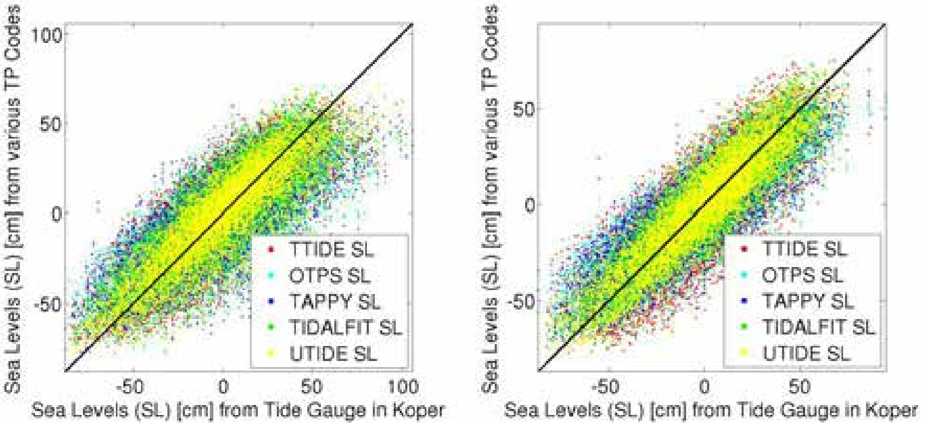

Figure 4 Top: Astronomic tides from several tidal packages as compared to tide-gauge observations in Koper (Slovenia) in year 2010. Bottom: the same for the year 2011. (Year 2012 not shown.)

3. Tide-gauge comparisons

Tidal analysis is performed on model tidal elevations in Koper (Slovenia, see Figure 1 for location of Koper) and *in-situ* measurements from the coastal tide-gauge in Koper. Comparisons of several tidal packages (*t_tide*, *utide*, *TAPPY*, *OTPS*, *tidal_fit*) to multi-year (2010-2012) tide-gauge observations in Koper were performed. They indicate that *OTPS* SSH forecast skill for Koper location is comparable to forecasts produced by packages like *t_tide* or *utide* (based on actual Koper tide-gauge observations from the past year). Multi- year total residual sea levels in Koper are roughly 18 cm for *OTPS*, 14 cm for *utide* prediction from analyzed data, and 19 cm for *t_tide* prediction from analyzed data, as shown in Figure 4. Large residuals stem mostly from local meteorological forcings, and, in case of OTPS and NAPOM models, from the coarse model grid and imprecise bathymetry, but perhaps also from the limited input satellite data (Topex SSH) available for tidal inversion.

4. Conclusions

Northern Adriatic sea is one of the areas in the Mediterranean which is most exposed to tidal dynamics, seiches and storm surges. Reliable sea- surface elevation modeling is therefore of significant value to local communities. We have verified performances of several operational tools that are currently being used in the region to model tidal currents and elevations in the Northern Adriatic. OTPS barotropic tidal model has been compared to several other tidal analysis and prediction codes, to the tidal components extracted from baroclinic general circulation ocean model NAPOM and to the tidal components extracted from the HF measurements of surface currents in the Gulf of Trieste. It has been demonstrated that the OTPS barotropic tidal model performs comparably well with all of the above and thus represents a suitable tidal forcing for future general circulation models. Additional efforts have been made to incorporate the atmospheric sea-level pressure component in the operational circulation models for the northern Adriatic, thus ensuring a more reliable forecasting of residual sea-levels due to meteorological forcings, and consequently higher levels of safety for coastal populations.

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Estimation of regional significant wave height observation error using a triple collocation method

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Abstract

Triple collocation methods, where data from three different measurement sources are collocated and compared have been carried out previously on a global scale. The three separate estimates of the truth can be used to estimate the error associated with each different measurement method. A regional triple collocation study has been carried out in two regions, the North Sea and the North European Atlantic Margin (NEAM), where a high density of in-situ data is available.

Keywords: waves, model validation, satellite observations.

1. Introduction

Regional triple collocation assessments of observation errors were carried out for two European sea areas:

- North Sea (3^0W – 10^0E, 51^0N – 63^0N)
- North European Atlantic Margin (NEAM, 20^0W – 0^0W, 30^0N – 65^0N)

The two regions have contrasting wave climates, with the North Sea being a semi-enclosed shelf sea with moderate fetches, whilst waves in the NEAM often develop over a longer distance and comprise of a mix of developing and mature wind-seas plus swell

It is desirable to locate the three independent measurements as closely in space and time as possible. However it is also essential to achieve enough collocations to create a statistically robust data set. To establish a suitable spatial scale for collocation, a study using the background error covariance matrix was carried out. This was used to establish the spatial distances at which the background error correlation was greater than 0.8. The results supported using a collocation distance of 50km.

Data was used from three independent sources, model, in-situ and satellite altimeter. The study covers the period 2010 – 2012 inclusive.

- 8km resolution hindcast using WAVEWATCH III™ (Tolman, 2009)
- Hourly in-situ observations from WMO/IOC Joint Commission on Marine Meteorology (JCOMM) (Bidlot et al., 2007)
- Envisat, Jason-1, Jason-2 from GlobWave project (Globwave, 2012)

2. Error estimation model

A triple collocation essentially provides three estimates of the truth *X, Y, Z*. These comprised in-situ observations, satellite soundings and a wave model. The error model of Janssen et al. (2007) was used to estimate the errors of the three measurements.

It is assumed that the measurements depend on truth *T* in a linear fashion (equation 1).

$$
\begin{aligned}
X &= \mathrm{b}_x T + e_x, \\
Y &= \mathrm{b}_y T + e_y, \\
Z &= \mathrm{b}_z T + e_z.
\end{aligned}
\qquad (1)
$$

Where e_y, e_x, and e_z denote the residual errors in the measurements, *X, Y, Z*. β is the linear calibration constant for each respective measurement. If the linear model is valid and the errors from the different measurements are uncorrelated the linear calibration constant (ß) can be estimated using the following equation (2).

$$\beta_y = (-B + \sqrt{(B^2 - 4AC)})/2A \qquad (2)$$

Where:

$$A = \gamma\langle XY\rangle \quad B = \langle X^2\rangle - \gamma\langle Y^2\rangle \quad \gamma = \langle e_x^2\rangle / \langle e_y^2\rangle \quad C = -\langle XY\rangle$$

The truth is unknown, so only two of the three calibration constants can be obtained. One, say *X*, is chosen as the reference. The calibration constants for *Z* and *Y* can be obtained using neutral regression (Marsden 1999), *Y* can be replaced with *Z* to give the regression constant for *Z*.

3. Results

3.1 Time Stability

The Jason-2 satellite data extended over the entire three year period, therefore this was used to examine the temporal stability of the error estimates from the error model. Figure 1 shows the changes in error estimates of a rolling 12 month period for the 3 study period in the NEAM. It can be seen that there were large estimated errors in the in-situ observations during 2010. These drop sharply at the beginning of 2011. The reasons for this were investigated and found to be due to a single wave buoy near Brittany that produced anomalous results during 2010 which had not been identified by the standard quality control checks. The 4 outliers in the data set were removed and the analysis re-run, the results are shown in figure 2. It can be seen that these data values were responsible for the large estimated errors in 2010.

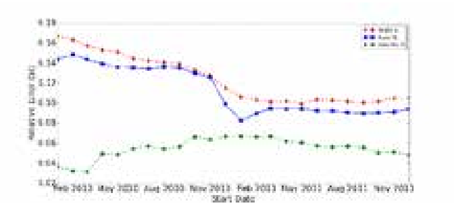

Figure 1 Error estimates for a rolling 12 month period in the NEAM.

Figure 2 Error estimates for a rolling 12 month period in the NEAM with outliers removed.

In figures 2 and 3 a gradual downward trend in the estimated model error can be seen. In the hindcast used for the study a change was made to the wind data source in January 2011 from a downscaling atmospheric model run using ERA-Interim boundary conditions, to operational Met Office global atmospheric model analysis winds. This appears to have improved the performance of the model and reduced the error measured against the observations. This reduction in model error is seen in both the NEAM and the North Sea.

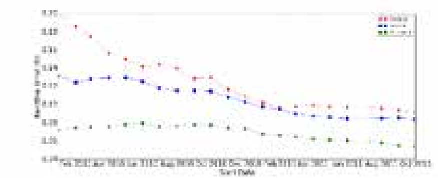

Figure 3 Error estimation for a rolling 12 month period in the North Sea.

In figure 3 some changes over the three year period are seen in the in-situ measurements for the North Sea. These may have been caused by some changes in the in-situ network over the study period. The occurrence of some particularly large storm events in the sample may have also influenced the errors from January 2011 onwards

3.2 Sensitivity Testing

To test the robustness of the error estimates a number of sensitivity tests were carried out. One test looked at the effect of the number of satellite soundings averaged to provide the matchup satellite value (referred to as a 'super-observation'). Error estimates were calculated using three and 5 satellite soundings in each super-observation. A control dataset with only a single satellite sounding in each matchup was also used. There was a significant sensitivity to the number of satellite observations used for a single matchup. The estimated error for the satellite observations is shown in table 1. In both the NEAM and the North Sea the error is reduced when the number of soundings is increased

Table 1 Satellite error for different numbers of soundings in each super –observation

Soundings	NEAM	NS
1	0.08	0.09
3	0.06	0.07
5	0.04	0.06

4. Conclusions

This study has demonstrated that robust triple collocation estimates can be generated on a regional basis using the method of Janssen et al. (2007). Key sensitivities that have been discussed here were changes to the in-situ data and in the case of the satellite errors changes to the averaging in the super observations. Within the regions that were analysed differences in the error. The results can be particularly sensitive to outliers and given the relatively small number of in-situ data points in a regional sample any changes in the in-situ network are likely to affect the results. Significant effort should be made to quality control the in-situ data, in this case standard quality control was not sufficient to identify a small number of in-situ errors.

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Tolman, H.L., 2009: User manual and system documentation of WAVEWATCH III™ version*3.14*. *NOAA / NWS / NCEP / MMAB Technical Note* 276, 194 pp + Appendices

The W1M3A Meteo-Oceanographic Data Centre

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Abstract

Since the last decades, huge efforts were performed in the marine domain towards standardisation of data format and data exchange protocols asserting the increasing role in the society and a strong impact on science, technology and business that information systems have.

To this aim, a data centre collecting about 15 years of meteorological and oceanographic observations in the Ligurian Sea has been designed.

The information system, developed using open source tools (e.g., mySQL, PHP) contains historical data as well as measurements collected in near real-time from the fixed buoy of the W1M3A observatory. Different procedures are applied to near real-time and delayed mode data set in agreement with the WMO/JCOMM recommendations. The overall data centre is also capable of producing different types of downstream services to users and to distribute subsets of data on request or in an automatic way in different formats (e.g., MEDATLAS, BUFR, NetCDF, etc.).

Keywords: oceanographic data centre, meteo-oceanographic measurements, web-service, system architecture, data standardization.

1. Introduction

Scientific impact of data collected in the ocean by different types of platforms (fixed buoys, drifters, research or opportunity vessels, etc.) can be limited by the absence of a coordinated and agreed-upon standards for data management covering the complete life cycle of data from (near) real time acquisition of measurements to their long-term archiving (Baker e Chandler, 2008). Acquired data can be useful at the highest level only if quality checked measurements can be discovered, viewed, evaluated, accessed and retrieved by users in standard formats (Cummings, 2011).

A real time thematic assembly center containing atmospheric, oceanographic and bio-geochemical in-situ observations collected in the Ligurian Sea since 2000 has been designed and developed. Measurements were acquired during research cruises periodically carried out in the basin and collected by the W1M3A off-shore observing system.

2. The W1M3A measurements

W1M3A observatory is a multidisciplinary research platform permanently moored in the Ligurian basin, on a deep sea bed of 1200 m, 80 km from the coasts and is constituted of a surface buoy and a sub-surface mooring periodically deployed near-by the main surface buoy (Pensieri et al., 2013).

The platform monitors in a continuous and affordable way, the lower atmosphere processes and the near surface down to the ocean interior physical and biogeochemical properties fulfilling the concept of Essential Ocean Variables monitoring (Bojinski et al., 2014). The on-board acquisition system collects high resolution data that are hourly averaged on board and partly transmitted in near real-time to the receiving station ashore. Oceanographic measuring devices/sensors stores measurements internally and periodically transmits them to the acquisition system on board by means of cable when the sensors are installed on the body of the spar buoy or by acoustic link if they are installed on the subsurface mooring. The scientific payload comprises also a wave meter system and a suite of sensors to monitor biodiversity.

A subset of hourly data is transmitted in near real time and collected at the W1M3A in-situ thematic assembly center (TAC) where data are decoded and automatically quality controlled following the procedure established during the European project in which the platform was involved (such as MFSTEP, MERSEA, EuroSITES, FixO3).

All time series are retrieved during the periodical visit to the system and processed following both automatic delayed mode quality control procedures and data manager intervention to correct measurements for sensor drifting or doubt values.

Once the real time data are successfully quality controlled, they are formatted into common oceanographic standards (MEDATLAS, BUFR, netCDF) and distributed with a restricted access, to be of support to operational oceanography programs (OceanSITES, MyOcean).

3. The W1M3A database

The W1M3A data repository is a Mysql relational database used for data archiving and metadata storing to be published through the observatory portal. Near real-time raw data are processed and inserted into the database using java routines whereas php modules are used to query the database for accessing data and to visualize the measurements. The system allows the inclusion of numerical and alpha-numerical data, as well as images or multimedia files being specifically organized for managing different kind of measurements (times series and casts) and metadata (instrumentation details, sensor configuration, notes, etc.).

The base element aggregating the information is the “observation” record (single measurement of a time series, or a vertical profile) since it contains parameters having a temporal and/or spatial variability.

Each “observation” can be associated to a different number of attributes and can reside in local or remote servers (Figure 1).

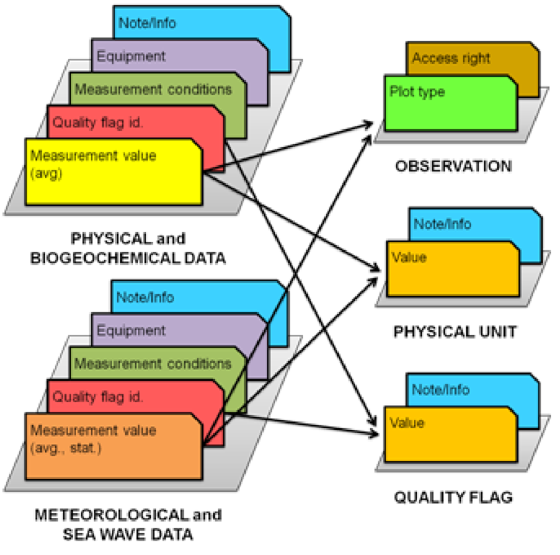

Figure 1 Scheme of the W1M3A database

The W1M3A database allows the organization of information in a flexible way, extending the number of parameters and optimizing the storage. The data base is linked to the W1M3A web server and php procedures are applied in order to manage database and tables content by the system administrator and to provide discovery, view and download services.

4. The W1M3A web-service

The thematic assembly center includes a web based application service allowing users to access data/information through the observatory portal http://www.odas.ge.issia.cnr.it. Web service data consultation is granted at two levels: a free access for generic public users and a reserved one for the data managers of the W1M3A observatory.

Public users can access the time series containing last month of near real-time measurements as well as products analysis and query the data base to visualize historical observations through temporal interval, single/multiple parameters and typology of measurement (Figure 2).

The data manager is authorized to visualize all acquired data with zoom, axes properties and download possibility, to update/modify tables inserting new parameter and to change the public access visualization. The W1M3A data base accomplished the INSPIRE Directive (European parliament, 2007) for user requirements in terms of: long term maintenance of the services, reliability of products provided, use policy: mission, quality and business rules are described.

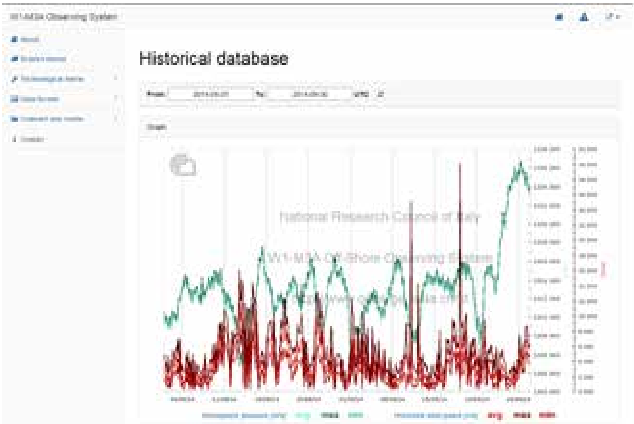

Figure 2 Example of the result of queries made by a public user for one month of atmospheric pressure and wind speed data.

Acknowledgements

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Long Term Assessment of the Met Office FOAM-NEMO System

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Abstract

An investigation into the long term accuracy and forecasting skill of the Met Office 1/4 degree open ocean FOAM-NEMO system. Using the GODAE OceanView Class4 metrics, time series of summary statistics for regions of interest and the full model domain have been produced for temperature profiles, Sea Surface Temperature and Sea Level Anomaly. This work has been undertaken to show how various model changes since March 2010 have impacted the FOAM-NEMO system.

Keywords: FOAM, Verification, GODAE

1. Introduction

The verification of the Met Office Forecasting Ocean Assimilation Model (FOAM) has traditionally focused on short term skill and 1-2 year hindcasts used to assess system upgrades. This work is an attempt to understand how the model has improved over time, which changes have had the largest impact and where future work should be focussed.

The time series begins in March 2010 when the FOAM system was upgraded to use NEMO (Storkey et al., 2010). Major changes to the system took place in November 2010 (Storkey, 2011) and in January 2013 (Blokley *et al.,* 2014) (Waters *et al.,* 2014). Table I lists all of the changes made to the system.

Change Number and Date	Upgrades
PS25 02/11/2010	New Mean Dynamic Topography Seasonally varying error covariances Upgrade to NEMO Vn3.2 Use of 3 hourly heat and wind stress fluxes
PS28 17/01/2012	Profile assimilation south of 60S Half-slip lateral boundaries

PS31 16/01/2013	Introduction of the NEMOVAR data assimilation system SST Bias correction to use 1m top box Change of sea ice model from LIM to CICE Increase in the number of vertical levels to 75 Bulk formulae surface boundary conditions Salinity dependent freezing
PS32 30/04/2013	Changes to salinity in Black Sea
PS33 04/02/2014	Black list Indian Ocean ASIRI ARGO Equivalent obs Diurnal SST parameterisation updated

Table I Summary of the changes made to the FOAM-NEMO system

2. METHODOLOGY

The time series has been produced using the GODAE OceanView Class4 metrics. For each observation an offline observation operator maps the forecast systems to observation space (Ryan, 2015). Root Mean Square Error (RMSE) and Bias are then calculated for each observation type and area.

The observation data used for the comparison are; Sea Level Anomaly (SLA) from Coriolis, Sea Surface Temperature (SST) from USGODAE and temperature profiles (0-500m) from MyOcean.

3. RESULTS

The RMSE of globally averaged SLA has reduced by ~0.05m and the bias has reduced by ~0.01m. We see a steep drop in RMSE in January 2012. This is as a result of the change to half-slip lateral boundaries. This was made to remove spurious coastal currents. Removing these currents has had a dramatic impact on the global statistics for SLA.

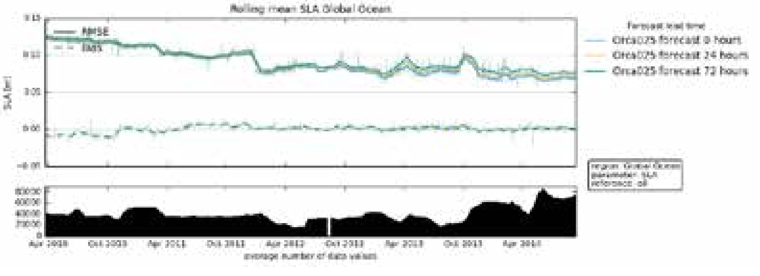

Figure 1 30 day rolling mean of RMSE and Bias for depth averaged (0-500m) temperature profiles across the Global Ocean

The increase in the spread of RMSE over the forecast cycle, see in Fig 1, after January 2013 is also present in the SST, see Fig 2. The most significant change made at this time was the introduction of the NEMOVar assimilation system. NEMOVar has a significant positive impact on both the RMSE and bias. These improvements have a larger impact on the early part of the forecast cycle and so, there is an increase in the spread of errors between forecast days.

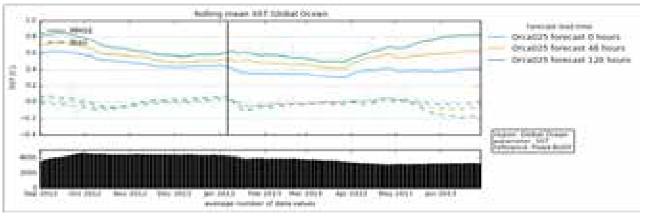

Figure 2 30 day rolling mean of RMSE and Bias for Fixed Buoy SST across the Global Ocean from September 2012 to July 2013.

The profile temperature has the smallest change in RMSE and Bias over the time series and in some regions, such as the Tropical Pacific (see Fig 3), we see a worsening of the RMSE.

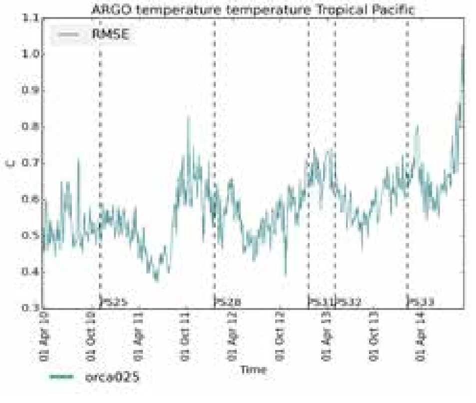

Figure 3 Median filtered RMSE for the 1 day forecast of depth averaged temperature (0-500m) in the Tropical Pacific

The Fixed Buoy SST and the profile temperature show a clear reduction in the seasonality fluctuation of RMSE (see Figs 4 and 5) during the northern hemisphere summer.

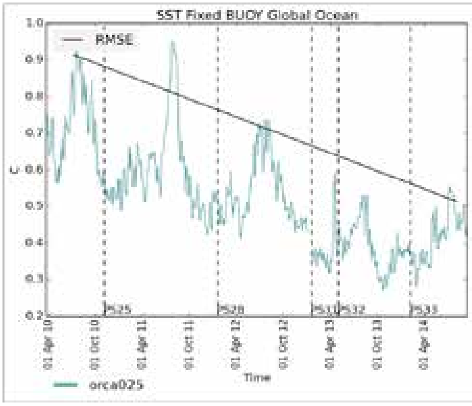

Figure 4 Median filtered RMSE for the 1 day forecast of fixed busy SST across the Global Ocean.

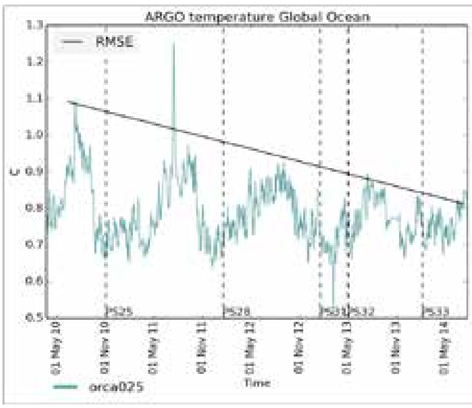

Figure 5 Median filtered RMSE for the 1 day forecast of depth averaged temperature (0-500m) across the Global Ocean.

4. Conclusions

There has been an overall improvement in both RMSE and Bias of the FOAM system for SST, SLA and temperature profiles. However not all regions have improved to the same extent and there may be compensating errors when looking at global statistics.

The increase in the spread of errors over the forecast cycle is seen in all observation types and is almost certainly due to the introduction of NEMOVar.

The seasonal variation in temperature RMSE, both at the surface and in the water column, has decreased considerably.

We see that small changes to the system, such as the free slip to half slip boundary conditions, can have a large impact on the quality of the forecasts.

Acknowledgements

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Operational modelling for supporting and characterising the Marine Renewable Energies in Western Iberia

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Abstract

Marine renewable energies comprise a vast number of technologies including tidal, waves and offshore wind technologies. Operational modelling could contribute to support the development of such activities in several ways. An implementation of the WaveWatch III ® model for the Portuguese Continental Coast for the period 2000-2010 was validated and used to estimate the wave power resource. The same configuration has been used to provide forecasts for marine renewable energy for the Energymare and Turnkey projects.

Keywords: Marine Renewable Energies, waves, operational modelling, forecast, resource assessment

1. Introduction

Marine renewable energies comprise a vast number of technologies including tidal, waves and offshore wind technologies. Operational modelling could contribute to support the development of such activities in several ways. Through atmospheric, wave and hydrodynamic models, the areas with enough energetic resource for these industries could be identified. Furthermore, operation and maintenance services rely on the sea conditions that operational modelling is able to provide through forecast services. These forecasts could also be valuable for the survivability of the installed devices as extreme events could be identified and thus the possible damage could be reduced by taking measures. Moreover, operational modelling could evaluate the amount of energy that would be available and how much could be produced by the devices thus the electric system would be more efficient in accommodating the generated energy. Due to the limited scope of this paper, only the main results for the wave energy resource evaluation will be discussed here.

2. Waves modelling

In order to model the wave generation, propagation and dynamics the NOAA WAVEWATCH III (R) Model V3.18 was used.

2.1 Modelling domains

In the case of the Portuguese coast, swell waves are generated on the western side of the Atlantic Ocean. For that reason, three nested levels with increasing resolution -0.5, 0.25 and 0.05 degrees- were defined to simulate the waves arriving to the Portuguese coast (Figure 1). Covering, the North Atlantic Ocean (Nat), the southwest part of Europe (SWE) and the Portuguese continental coast (PCC) respectively.

Two bathymetric sources were combined to populate all levels grids: the EMODNet Hydrography portal (http://www.emodnet-hydrography.eu) completed by the 30" resolution global bathymetry data SRTM30_PLUS (Becker *et al.*, 2009) for regions where EMODNet data were absent.

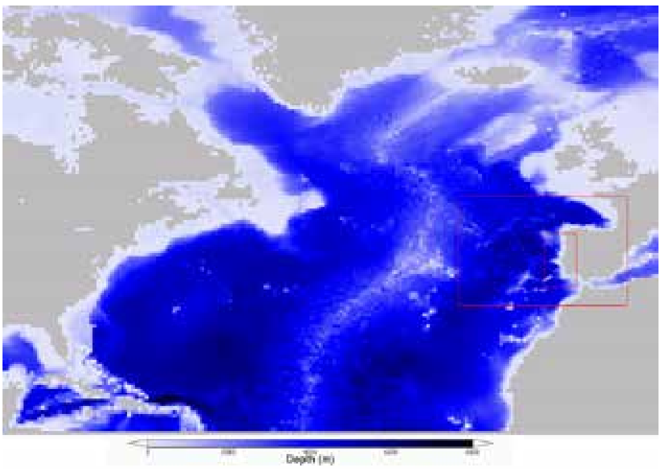

Figure 1 Grids used for modelling the waves arriving to the Continental Portuguese coast. Nested domains are indicated by the red squares.

2.2 Meteorological forcing

The wave energy resource was evaluated for the period 2000-2010. The NCEP FNL Operational Model Global Tropospheric Analyses, continuing from July 1999 with 1 degree of horizontal resolution (NCEP/NWS/NOAA/U.S. Department of Commerce, 2000)) was used to feed the wave model with winds intensities and direction.

3. Results

3.1 Model Validation

Historical wave parameter observations are scarce in the Portuguese coast. For the selected period, three stations were used from the Instituto Hidrográfico (IH) from Portugal and five stations from Puertos del Estado (PdE) in Spain covering different periods (Table I).

The observed data were compared with hourly model time series. Coefficients of determination (R^2) were obtained for each station and for significant wave height (H_s) and for wave average period (T_m) (Table I). The obtained values show a great agreement for the H_s variable for the entire area of study with R^2 values comprised between 0.79 and 0.92. On the other hand, the model, with the current version and configuration, showed a lower capacity for calculating the average period with R^2 values from 0.75 to 0.20. The capacity of the model to estimate both variables is better in open exposed coastal areas while decreased in wave sheltered areas.

3.2 Wave Energy

Wave power (P) was estimated using the formula for deep water (Figure 2):

$$P = 0.49 * H_s^2 * T_m$$

obtaining kilowatts (kW) per meter of wavefront length. Once this formula is applied to the PCC domain for the 2000-2010 period, we obtain the wave power distribution for the study area.

4. Discussion

Wave power distribution shows a clear gradient with a NW-SE orientation. Maximum values around 50 kWm^{-1} are found in the open ocean off the Northern coast while minimum values are located in the areas sheltered by geographic features from this direction i.e. the Tagus and Sado estuarine mouths and the Algarve southern coast. On average the Portuguese coastal area has a wave power around 30 kWm^{-1} though this value presents a strong seasonality. Values obtained were in agreement with the ones obtained by Pontes *et al*. (2003). Regarding the difficulty to forecast the period and with H_s being more relevant to the wave power estimation and the area of interest for wave energy in areas exposed to the coast we consider that the current approximation is valid for characterizing the waves resource in the Portuguese continental coast.

Table I List of observing stations and its source (PdE: Puertos del Estado and IH: Instituto Hidrográfico), location in terms of latitude and longitude, validation period and coefficient of correlation (R^2) for the significant wave height (H_s) and the average period (T_m)

Station Name	Domain	Latitude	Longitude	Data Period	H_s R^2	T_m R^2
Estaca de Bares (PdE)	SWE	44.06 N	7.62 W	Jan 2002-Dec 2009	0.92	0.75
Cabo de Peñas (PdE)	SWE	43.73 N	6.19 W	Jan 2002-Dec 2009	0.89	0.71
Villano-Sisargas (PdE)	SWE	43.49 N	9.21W	Jan 2002-Dec 2009	0.90	0.74
Silleiro (PdE)	PCC	42.12 N	9.40 W	Jan 2002-Dec 2009	0.91	0.69
Leixoes (IH)	PCC	41.18 N	8.70 W	Jan 2008-Dec 2009	0.91	0.61
Sines (IH)	PCC	37.95 N	8.89 W	Jan 2008-Dec 2009	0.90	0.61
Faro (IH)	PCC	36.90 N	7.90 W	Jan 2008-Dec 2009	0.80	0.20
Cadiz (PdE)	SWE	36.84 N	6.98W	Dec 2008-Dec 2009	0.79	0.31

The same configuration has been used to implement a forecast wave service using a GFS forecast product with higher resolution and which results can be accessed at http://forecast.maretec.org/

Acknowledgements

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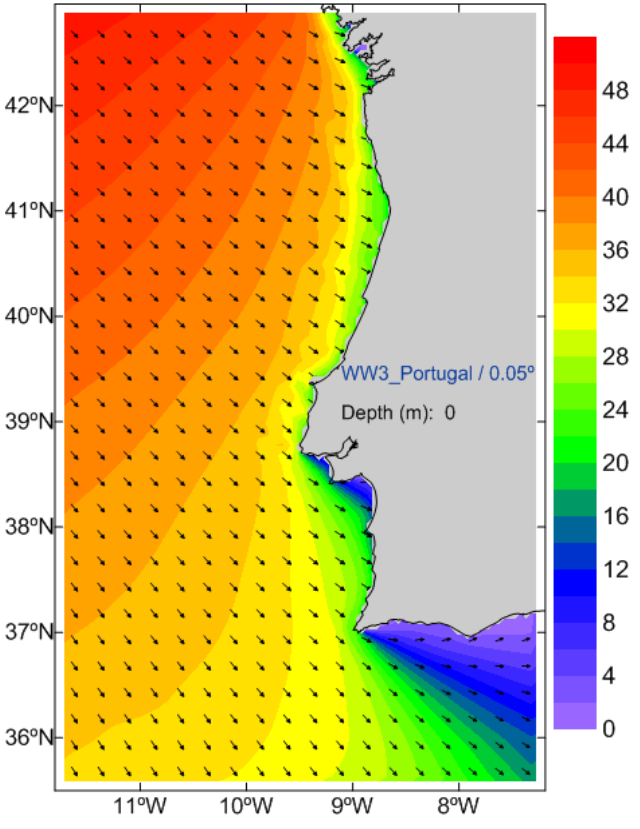

Figure 2 Wave power in kWm^{-1} for the PCC domain, mean wave direction is indicated by the arrows.

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Adapting NEMO for use as a storm surge forecasting model

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Abstract:

In this work we present the preliminary results and future plans of a joint Met Office and NOC project to develop a storm surge forecasting model using a configuration of the Nucleus for European Modelling of the Ocean (NEMO) code (Madec, 2008). This configuration will eventually be used for operational storm surge forecasting within the UK. The effect of vertical resolution on barotropic tide-only simulations are investigated, with additional vertical levels shown to have limited effect for this particular set up. The effect of varying bottom friction is assessed in a one-layer model run. The coefficient used within the non-linear formulation implemented in the model is shown to have an important impact on the resulting tidal amplitudes, which are of particular interest for surge modelling due to surge-tide interactions.

Keywords: Storm Surge, NEMO, model development

1. INTRODUCTION

Accurate forecasting of storm surge events is crucial to enable government agencies to assess the risk of overtopping or breach of coastal defences so they can respond appropriately; minimising risk to life and infrastructure.

The Met Office and NOC have begun transitioning the UK's storm surge forecast system, based on the Proudman Oceanographic Laboratory's CS3X model (Flather, 1991), to a configuration based on the Nucleus for European Modelling of the Ocean (NEMO) code base. This work involves adapting NEMO to add functionality, such improvements to bottom friction coefficients and surface forcing, and making changes that allow NEMO to run efficiently as a two-dimensional, barotropic model.

This project enables interesting scientific comparisons to be made between a NEMO based surge model and the full three-dimensional baroclinic NEMO configurations currently run within the Met Office, facilitating assessment of the impact of baroclinic processes and vertical resolution on sea surface height forecasts. Moving to a NEMO code base will also allow future developments to be more easily implemented within the storm surge model, due to the wide range of options which currently exist within NEMO or are planned for future NEMO releases, such as data assimilation and atmosphere-ocean-wave coupling.

This paper begins by looking briefly at the effect of reducing vertical level on the propagation of tides within a NEMO based coastal configuration in part 2. Part 3 then assesses the impact of varying the coefficient used in the bottom friction calculations on the tides, this time in a one level configuration. Finally part 4 discusses future plans of this project.

2. Sensitivity of sea surface height to vertical resolution

The sensitivity of the model to the vertical resolution has been assessed with respect to the impact on SSH (Sea Surface Height). Barotropic model simulations of 10 days were run with varying numbers of vertical levels; all runs were started from rest with constant temperature and salinity, no heat or freshwater fluxes were applied and momentum fluxes were applied using the CORE bulk formula. Atmospheric pressure effects were applied using an inverse barometer formulation. Tidal SSH (sea surface height) and barotropic velocities were applied at the open boundaries. Simulations were run with 2, 3, 5, 10, 30 and 50 evenly spaced vertical levels. Figure 1 shows the variation in SSH between the runs at various points in the domain on the 10th day of the run.

The results indicate that changes to the number of vertical levels results in a small phase shift for all runs with three or more vertical levels, and a larger phase shift for the 2 level model. The impact on amplitude is negligible for all but the 2 level case.

These runs used NEMO's implicit bottom friction formulation with a coefficient derived using a log layer approach. This formulation is sensitive to the number of vertical levels. The parameterisation is identical in all runs, and is tuned to the 50 level configuration. As such it is expected that the model would not necessarily perform as well with coarser vertical resolution, when compared with runs undertaken using 50 vertical levels.

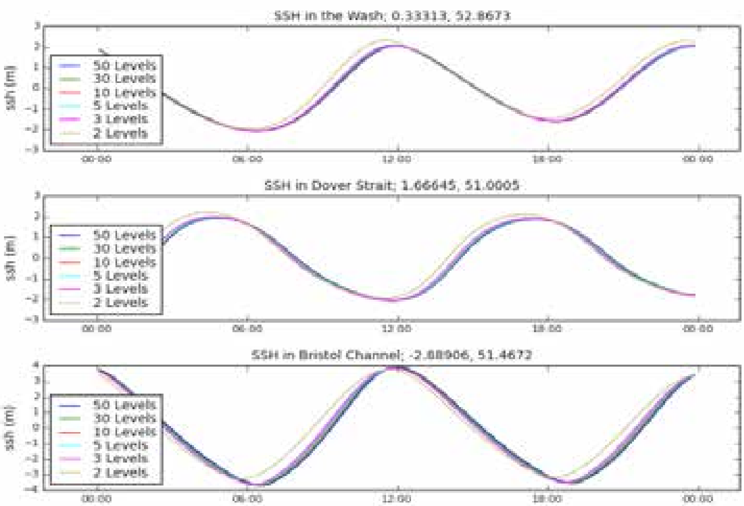

Figure 1 SH variation after 10 days

3. BOTTOM FRICTION

Within NEMO the bottom friction is included as a vertical diffusive flux, F. As the logarithmic boundary layer is not resolved within ocean models, this downward momentum flux is parameterised. Various parameterisations are available but, due to the overall simplicity of the model along with the need to model tidal flows, it was felt the non-linear parameterisation was most appropriate for the initial configuration. This scheme assumes the flux due to bottom friction is proportional to the velocity of the bottom layer (the barotropic velocity in this one layer model) using , where r is a drag coefficient and h is the height of the bottom box (the height of the entire water column in this one layer set up). The non linear formulation for bed stress which is used assumes that r is correlated to current speed by the equation , with A a user defined coefficient.

The detail of the application of bottom friction, particularly the choice of the coefficient A, is likely to have a large impact on the ability of the model to accurately represent the propagation of tides and surges. A number of runs were undertaken with varying values for the coefficient A. The runs were forced with the M2 tidal component on the boundaries and no fluxes. The model was run for 9 months, with output compared to a tidal harmonic series of the M2 tidal constituent based on observational data at a number of UK ports.

Statistical results from this experiment are shown in figure 2. The choice of coefficient has an impact on tidal amplitudes, more notable for large amplitudes, as well as having an impact on the timing of the tide, with lower coefficients showing a closer fit to the observations for these limited experiments.

4. FURTHER WORK

Further work is required to determine the most suitable bottom friction parameterisation and coefficients. Use of a 2-dimensionally varying coefficient may also be assessed. The overall aim is to optimise the tidal performance of the model. Whilst only the surge residual from this model is used by operational forecasters (who combine this with astronomical tidal predictions calculated from tidal harmonic series), the ability of the model to accurately represent the tides is essential in order to limit errors in calculation of tide-surge interaction, and therefore limit errors in the overall surge residual forecast.

After tuning the bottom friction in tide only mode, the surface forcing used to apply momentum fluxes within the model will be assessed. Existing Met Office coastal ocean models apply surface fluxes using a drag coefficient calculated with the CORE bulk formulae (Large and Yeager, 2004). Thus far runs with surface fluxes have applied momentum using drag coefficients calculated this way. The option to calculate a drag coefficient using the Charnock formula (Charnock, 1955) will be developed for use in NEMO and this will be tested and compared with the CORE formula. Testing and validation will ensure that the model performs well during average conditions, which dominate when looking at long term statistical assessments, but will focus on model performance during the extreme events which it is designed to forecast. As such a long run will be completed, which will be statistically verified against observations, including case studies of a number of high surge events. For example, some of the extreme storms which caused damage over the 2013/2014 winter period.

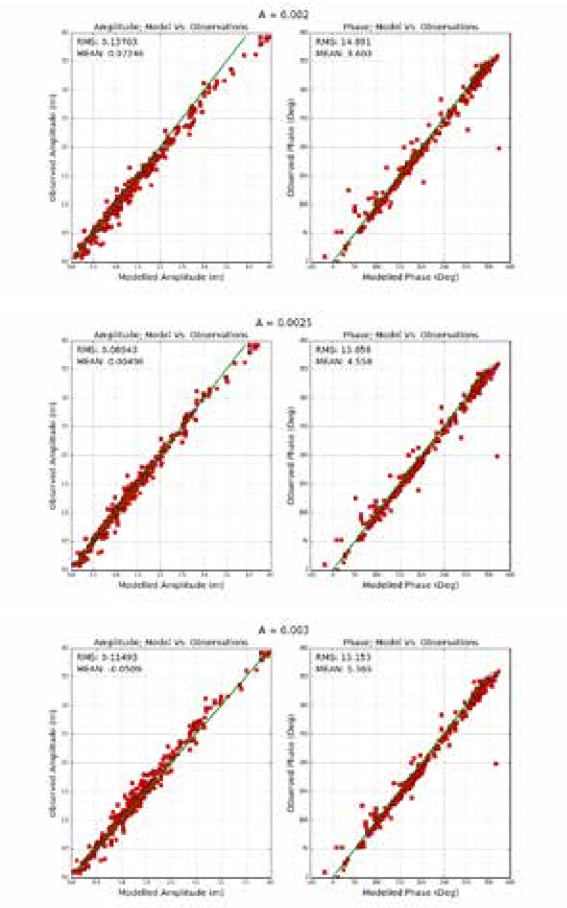

Figure 2 Effects of varying bottom friction coefficient

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Recent development and assessment of the Met Office operational global ocean forecasting system (FOAM)

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Abstract

The Forecast Ocean Assimilation Model (FOAM) is an operational ocean analysis and forecast system run daily at the Met Office. The FOAM system uses the NEMO ocean model as its dynamical core coupled to the Los Alamos CICE sea ice model. Satellite and in-situ observations are assimilated by FOAM each day using the NEMOVAR 3D-Var data assimilation scheme. In this paper recent upgrades to the model and assimilation components of the Global FOAM system are introduced and improvements to the model are shown.

Keywords: FOAM, operational oceanography, NEMO, NEMOVAR, data assimilation

1. Introduction

The Global FOAM configuration has been running operationally at the Met Office since 1997 and produces daily analyses and 7 day forecasts of ocean tracers, currents and sea ice at 1/4° resolution. Satellite and in-situ observations of temperature, salinity, sea level anomaly and sea ice concentration are assimilated each day using the NEMOVAR 3D-Var FGAT scheme (Waters et al. 2014). As well as providing ocean forecasts to the Royal Navy, Global FOAM is used to initialise medium-range and seasonal forecasts using the Met Office's GloSea5 coupled prediction system of MacLachlan et al. (2014). Ocean analyses and 7-day coupled forecasts are freely distributed each day through the MyOcean project.

In early 2013 the FOAM system underwent a major upgrade which involved implementation of the NEMOVAR FGAT 3D-Var data assimilation scheme, the multi-category CICE sea ice model, CORE bulk formulae surface boundary conditions and an increased vertical resolution for Global FOAM from 50 to 75 levels (Blockley et al., 2014). Assessment of the upgraded FOAM system (termed FOAM v12) showed considerable improvement in the near-surface tracer fields, sea ice extent and sea ice volume. There were also improvements to the near-surface current forecasts as well as a better representation of mesoscale eddies in areas of high variability. Although tracer fields were improved in the top 80m there was a reduction in skill in sub-surface tracer fields. These problems were thought to be caused, in part, by the shorter horizontal length-scales used by NEMOVAR failing to constrain the deep ocean where observations are sparse. There was also evidence of too much vertical mixing in the system with a pronounced warm bias around 100m depth and an increased sea surface temperature error growth during the model forecasts.

2. THE GLOBAL FOAM v13 UPGRADE

In order to address the problems raised by Blockley et al. (2014) an updated FOAM system, version 13, was developed during 2014. This section provides details of the changes that were made to the various component parts of FOAM.

2.1 Ocean model changes

The NEMO ocean model component was upgraded to use the UK's Joint Ocean Modelling Programme (JOMP) Global Ocean configuration version 5.0 (GO5). The main focus of this GO5 configuration was to provide a more realistic representation of near-surface mixing achieved by tuning the TKE vertical mixing scheme. Additionally the NEMO base code was upgrade from vn3.2 to vn3.4 and the model bathymetry was updated. Further details of the GO5 configuration can be found in Megann et al. (2014).

2.2 Ice model changes

The CICE sea ice model component was upgraded to use the UK's Joint Sea Ice Modelling Programme (JSIMP) Global Sea Ice configuration version 6.0 (GSI6) as described in Rae et al. (2015). The focus of these sea ice changes is on increasing the Arctic sea ice thickness to create a more realistic ice volume distribution.

2.3 Data assimilation changes

The NEMOVAR data assimilation scheme used in FOAM has been upgraded to use dual horizontal correlation length-scales for sub-surface tracer assimilation to allow the data assimilation to better constrain the deep ocean tracers. Implementation of dual correlation length-scales in Global FOAM is further described in Mirouze et al. (2015).

3. IMPROVEMENTS AT FOAM v13

The GO5 NEMO changes and dual length-scale NEMOVAR changes have had a considerable impact on the near-surface tracer biases present in the v12 system. Error profiles calculated from innovations show that the warm bias at 100m has been considerably reduced and the model maintains a better representation of salinity in the upper 500m (see Fig. 1). The improved near-surface mixing has also led to a considerable reduction in mean SST error growth through the forecast (not shown).

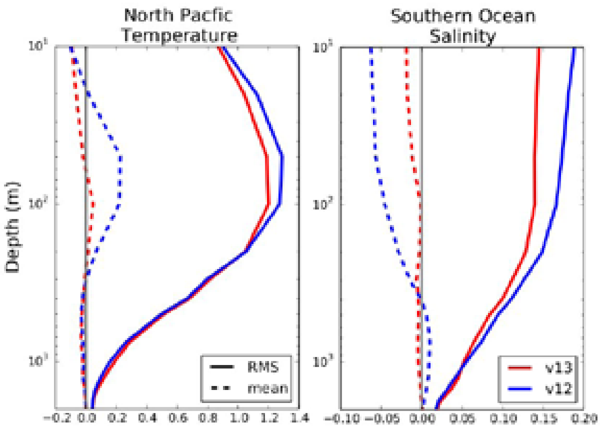

Figure 1 Plots of subsurface RMS (solid lines) and mean (dashed lines) error profiles for temperature in the North Pacific (left) and salinity in the Southern Ocean (right). Mean errors are plotted as modelled-observed so positive temperature (salinity) values indicate that the model is too warm (salty). Depth in metres is plotted on a log scale.

The GSI6 sea-ice model changes have also had a positive effect (see Fig. 2). An assessment of ice volume shows that Arctic ice is now much closer to the PIOMAS volumes of Schweiger et al. (2011). This improvement to ice volume has also had an effect on the quality of ice concentration forecasts – particularly during the melt seasons. This is most notable in the Arctic where 5-day forecasts remain considerably closer to the corresponding FOAM analyses and OSTIA/OSI-SAF observations.

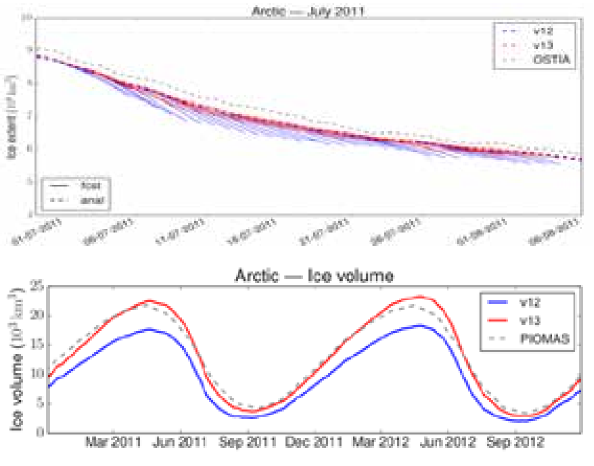

Figure 2 Upper: Arctic ice extent 5-day forecasts (solid lines) during July 2011 compared with corresponding FOAM and OSTIA analyses (dashed lines). Lower: 2-year time series of Arctic sea ice volume compared with PIOMAS. Grey dashed lines in are daily OSTIA (Donlon et al., 2012) sea ice extent derived from OSI-SAF ice concentrations and monthly PIOMAS (Schweiger et al., 2011) ice volume data.

Acknowledgements

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The Mid Atlantic Current Hindcast for the Oil and Gas Industry

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Abstract:

The Mid Atlantic Current Hindcast (MACH) is a 20 year high resolution hindcast for the oil and gas industry. The key aim of the initiative is to produce a high quality hindcast of ocean currents near the West Coast of Africa to assist in engineering design and reduction of operational risk in the area. This project provides a major update to previous hindcast studies in this region and is a significant resource for the oil and gas industry.

Keywords: oil and gas industry, West Africa, Currents

1. Introduction

The waters off the West African coast are of significant interest for oil and gas extraction and exploration. For sea based oil and gas operations it is important to have accurate information on ocean currents. This data is crucial for assessment of worst case design loading conditions and dynamic loading, optimizing seismic explorations, operational planning for shuttle tanker offloading and oil spill contingency planning.

The Mid Atlantic Current Hindcast (MACH) product is a high resolution hindcast of currents and other ocean parameters developed specifically for use within the Oil and Gas Industry. This project is a collaboration between the Met Office, OceanWeather Inc. and BMT ARGOSS. The MACH modelling system uses the Forecasting Ocean Assimilation Model (FOAM, Blockley *et al.,* 2014) and consists of a series of three nested model grids. These model grids range from a coarser global domain to a high resolution grid covering the coastal waters off West Africa from the Gulf of Guinea to Namibia.

In this paper we describe the MACH model and show some validation results which illustrate its capabilities.

2. Model description

The coarsest model used in the MACH system is ORCA025, a global ¼ degree model (Blockley *et al.,* 2014). This provides boundary conditions for the $1/12^{th}$ degree Equatorial and South Atlantic model (ESA12). The ESA12 domain is shown in Figure 1 and provides the boundary conditions for the $1/36^{th}$ degree North Equatorial and West

Africa Model (NEWA36), shown by the red box in Figure 1. The NEWA36 model is the MACH product domain. All three models use the hydrodynamic model NEMO vn3.2 (Madec 2008) and have 75 vertical levels with a vertical resolution of approximately 1m near the surface and 200m at depth. The two outer models are both coupled to the CICE (Hunke and lipscomb, 2010) sea ice model and use the variational data assimilation scheme, NEMOVAR (Waters *et al*.. 2014), to assimilate observations of temperature, salinity, sea surface height and sea ice concentration. The two inner models are forced with hourly wind fields from Oceanweather Inc and 3 hourly heat and freshwater inputs from ERA-INTERIM (Dee *et al*. 2011). All models use a climatological river data set (Bourdalle-Badie and Treguier, 2006).

The MACH dataset is produced over a 20 year period from 1st of January 1993 until the 31st of December 2012.

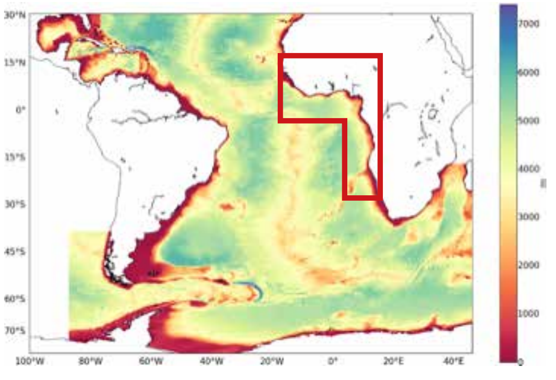

Figure 1 Bathymetry for the ESA12 model domain. The NEWA36 model domain is shown in red.

3. Model assessment

The MACH model is assessed against individual ADCP moorings, surface drifter trajectories and surface drifter climatologies. Here we present a small sample of the validation results used in the MACH project.

Figure 2 shows Rose current plots for the NEWA36 model and an ADCP observation. At this location the model and observation's Rose plots compare well, with both showing currents travelling predominantly towards the East-South -East.

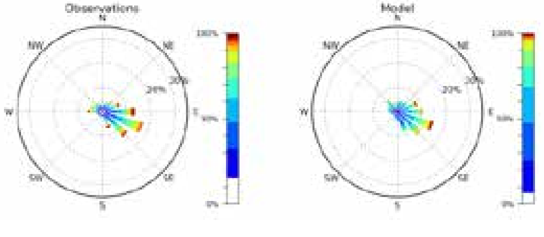

Figure 2 Rose surface current plots for an ADCP mooring (top plot) off the coast of Nigeria and the model (bottom plot) for a concurrent period and location.

Figure 3 compares observed drifter trajectories with modelled trajectories computed using the TRACMASS particle tracking code (Döös, 2009), for June 2009. The model trajectories presented are from the NEWA36 model, the ESA12 model and the HYCOM GLBa0.08 model[1] (Bleck, 2002). In many cases the trajectories compare well between the models and observations. Quantative comparisons were also made by calculating the normalised cumulative separation distance (Liu and Weisberg, 2011) for the period between 2009 and 2012. These results (not presented) determine that both the MACH models outperform HYCOM with NEWA36 performing marginally better than ESA12.

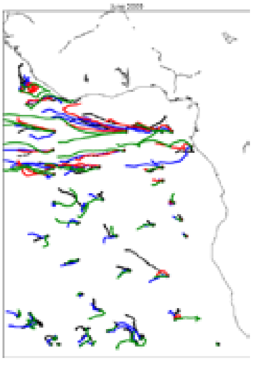

Figure 3 Observed drifter trajectories, and model trajectories for June 2009. Black: observed drifter tracks, Blue: ESA12 tracks, Red: NEWA36 tracks, Green: HYCOM tracks.

Figure 4 shows surface current climatologies from surface drifters and the NEWA36 model. These plots illustrate that the large scale features are well represented in the model. For example, a separation of the South equatorial current is seen in both plots.

4. Mach product advantages

The MACH hindcast data uses advanced modelling techniques and provides a validated long-term spatial ocean profile hindcast at reduced costs and short lead-in time. The validation of MACH has shown it to be an accurate and competitive product and therefore a significant resource for the oil and gas industry.

1 http://hycom.org/dataserver/glb-analysis

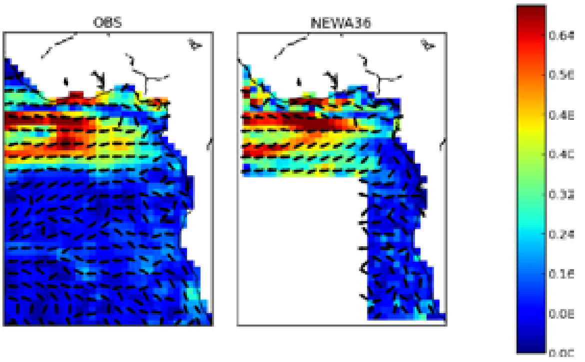

Figure 4 Observed and modelled surface currents for June. Left plot is a climatology derived from surface drifters (Lumpkin and Garraffo, 2005). Right plot is the monthly mean June 2009 currents from MACH. The colours show current speed, and the arrows show direction.

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Implementation and validation of a wave forecasting system for the Portuguese Coast

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Abstract

This work describes the implementation and validation of a wave forecasting system for the Portuguese Coast based on the WAVEWATCH III (WWIII) model. The wave forecasting system was implemented following a downscaling approach (multi-grid) and was validated by using wave buoys data.

Keywords: modelling, waves, downscaling, validation, forecasting

1. Introduction

The MARETEC wave forecasting system for the North Atlantic and Portuguese Coast based on the WAVEWATCH III (WWIII) model was updated to the released version 3.14 with the development of new operational tools. The system's main aims are to provide wave forecasting results to assist in the management of wave energy devices, verify appropriate conditions and best locations to deploy floating barriers to contain oil spills, force local high resolution wave models and assess the sediment transport on the coast, through the coupling with hydrodynamic models.

2. Methodology

The system was implemented following a downscaling approach (multi-grid) to properly represent the propagation of waves generated in the North Atlantic into the regional and local higher resolution domains (Fig.1). The grid resolutions range from approximately 0.5° x 0.5° in the North Atlantic domain to 0.05° x 0.05° in the Portuguese Coast domain. The wind forcing is provided by the Global Forecast System (GFS), from the National Oceanic and Atmospheric Administration (NOAA), with a spatial resolution of 0.5° x 0.5°.

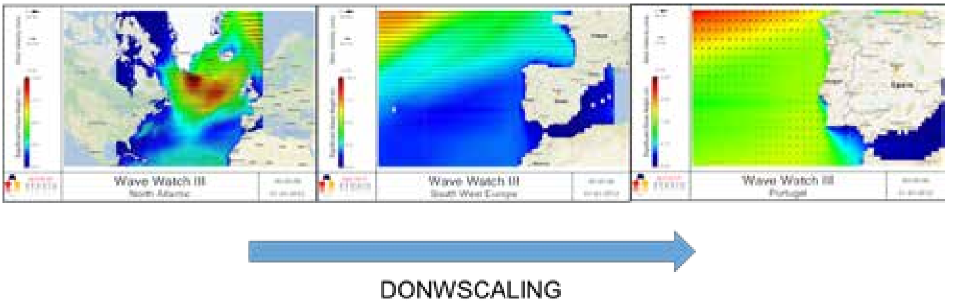

Figure 1 Nesting from the North Atlantic domain to the Portuguese Coast domain

3. Operational Tools

The standard input/output format of spatial data sets used by MARETEC is the Hierarchical Data Format (HDF5), which makes possible the management of extremely large and complex data collections. A tool was developed to convert HDF5 files into WWIII input format (HDF5_to_WWIII). This tool allows forcing WWIII with wind results from different meteorological models (GFS, MM5, WRF) already used by MARETEC to force MOHID modelling system applications. Therefore, currents and water level simulated by MOHID can be converted with the same tool in WWIII format and used as input for the wave simulations. On the other hand, WWIII wave results can be considered in the MOHID applications by using another tool to convert WWIII output format to HDF5 (WWIII_to_HDF5).

3.1 Automatic Running Tool

In order to run WWIII automatically and in operational mode, the Automatic Running Tool (ART) previously developed to allow automatic simulations of MOHID applications was adapted for the operational wave forecasting system. The daily forecast of waves is currently published online at http://forecast.maretec.org/.

4. Validation

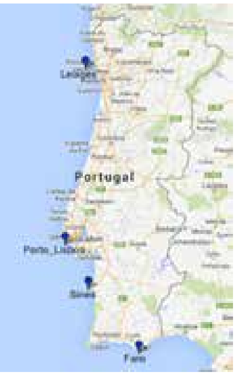

Figure 1 Location of the wave buoys

The wave modelling system was validated on the Portuguese Coast for the entire year of 2012 by using data of wave buoys presented in Fig.2 (Leixões, Lisbon, Sines, Faro). The analysed wave parameters were: significant wave height (Fig.3), mean wave period (Fig.4) and mean wave direction (Fig.5). Statistics are shown in tables I, II and III.

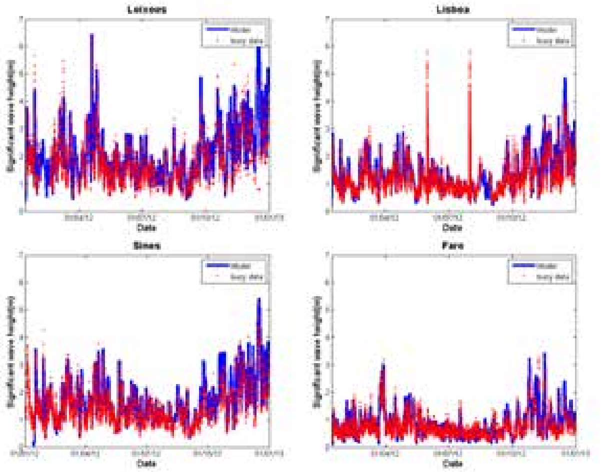

Figure 3 Time series of significant wave height

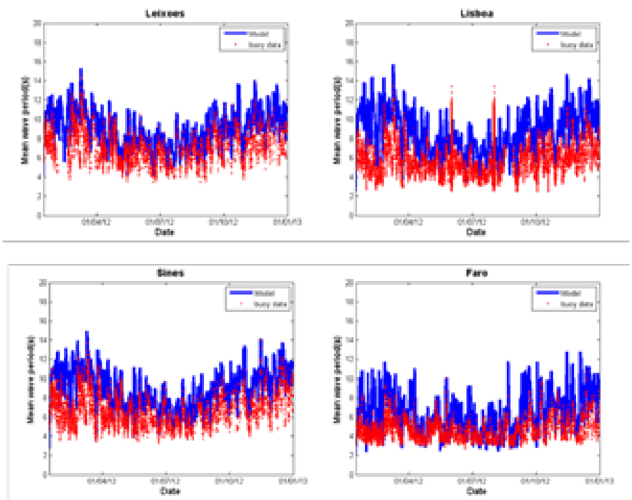

Figure 4 Time series of mean wave period

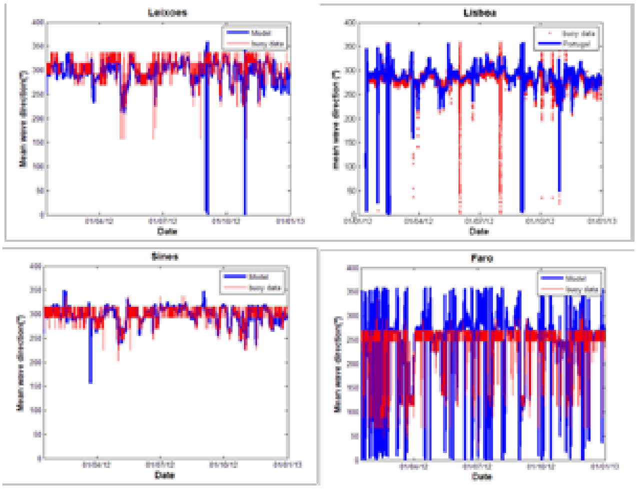

Figure 5 Time series of mean wave direction

	Pearson	RMSE	Bias
Leixões	0.93	0.39	0.18
Lisboa	0.92	0.29	0.10
Sines	0.93	0.34	0.17
Faro	0.88	0.23	0.05

Table I Statistics for significant wave height

	Pearson	RMSE	Bias
Leixões	0.82	2.23	2.00
Lisboa	0.70	3.44	3.05
Sines	0.76	2.74	2.38
Faro	0.62	2.16	1.40

Table II Statistics for mean wave period

	Pearson	RMSE	Bias
Leixões	0.64	24.4	-9.41
Lisboa	0.47	30.00	3.80
Sines	0.68	14.17	-2.07
Faro	0.59	68.30	3.52

Table III Statistics for mean wave direction

The wave forecasting system results showed a good agreement with data. However, the results can be improved locally with the nesting of higher grid resolution domains, especially for the wave direction obtained in Faro. The consideration of currents and water level in these domains may also improve the results. Furthermore, a better spectral resolution will be tested, with 50 frequencies instead of 25 and 36 directions instead of 24 used in this study.

Acknowledgements

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Upwelling patterns and coastal vulnerability to oil spills in the South Iberian coast

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Abstract

The South Iberia oceanography, characterized by several mesoscale processes, is tied up to the large scale climatological variability between the Azores high pressure cell and the Iceland low. Seasonal patterns from spring to late summer and during winter influence and characterize the region circulation. As the region lies on one of the world's busiest maritime routes, with tankers representing a significant part of the vessel traffic, the effects of upwelling patterns in oil spill trajectories are investigated, with the main goal of exploring the role of these mesoscale features on coastal vulnerability to oil spills. Using five years worth of SST images, retrieved form both MODIS Aqua and METOP-A satellites, four different types of upwelling events were identified and considered as the typical upwelling patterns of the region. An operational oil spill model implemented for the South Iberian coast was used to reproduce these events and to access the evolution of a hypothetical oil spill in each of them. Results obtained allows to infer the model ability to correctly reproduce these regional patterns while, at the same time, providing useful clues about the effects of this mesoscale circulation in the region's coastal vulnerability to oil spills.

Keywords: SW Iberia**;** Upwelling system; Remote sensing; mesoscale patterns; modelling; oil spills

1. Introduction

Several research studies have focused on the western Iberian oceanography, with Relvas et al. (2007) presenting an extensive review on the physical oceanography of the western Iberia system and charaterizing the main mesoscale features described for the region. A succession of mesoscale structures such as jets, meanders, ubiquitous eddies, upwelling filaments and countercurrents, superimposed on more stable structures with seasonal variations have been suggested by several authors (e.g. Torres et al., 2003; Relvas and Barton, 2005). In this study, focusing at the surface, we looked for regional sea surface temperature (SST) patterns captured by remote sensing techniques, relating them with the trajectory of hypothetical oil spills using the SOMA operational model running for the region (Janeiro et al., 2012).

2. Results

Seasonal mesoscale circulation patterns were identified using five years of satellite images from both MODIS Aqua and METOP-A between 2009 and 2013. To identify the several events, a visual review of the combined MODIS – METOP SST image dataset was done. Based on the SST images, Figure 1 resumes the five topologies of mesoscale events considered the most representative of the South Iberian coast.

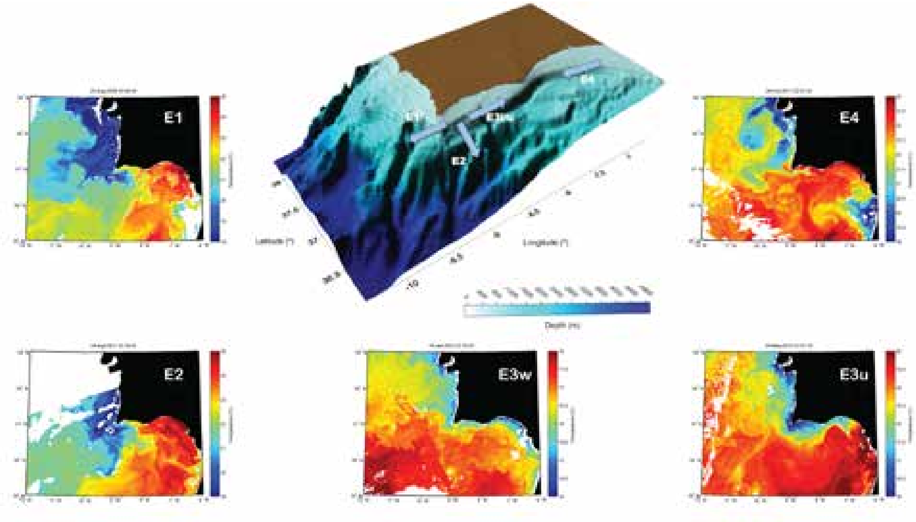

Figure 1 Mesoscale events considered the most representative of South Iberian coast and classified from the available MODIA-Aqua e METOP-A SST images

Following the classification of the SST dataset into representative events, this information was used to generate a battery of simulations with the objective of assessing how effectively the model simulates the mesoscale features. The simulations were performed by the SOMA operational forecasting system running in hindcast mode. The system encompasses a hydrodynamic model and an oil spill model running online and exchanging information in real-time. The SKIRON model (Kallos, 1997) results are used in the operational system as atmospheric forcing fields for the hydrodynamic and lagrangian models. A quantitative assessment of model ability to correctly reproduce the events simulated was done relating the model results of SST with operational observations from three buoys along the study area. The assessment method proposed by O'Donncha et al. (2015) was followed. In general, the model presents a reasonably good ability to reproduce the events. Nevertheless, there was a noteworthy bias in most of the comparisons, not shown, although it was a clear tendency. In fact the model overestimates and underestimates SST during different events and locations. In order to better identify and relate the SST patterns from both satellite images and model, in each event, an average bias for the three buoys was calculated and retrieved from the model SST. To assess the influence of the identified regional mesoscale features in the trajectories of oil spills, several hypothetical spills were simulated during two days in the period of each event. The position of each spill was chosen based on the major shipping routes crossing the study area and the presence of major ports. The oil spills are only influenced by the hydrodynamics, which accounts for the wind effect. Figure 2 resumes the results obtained. The oil trajectories present a good correlation with the main patterns identified in the model SST distribution

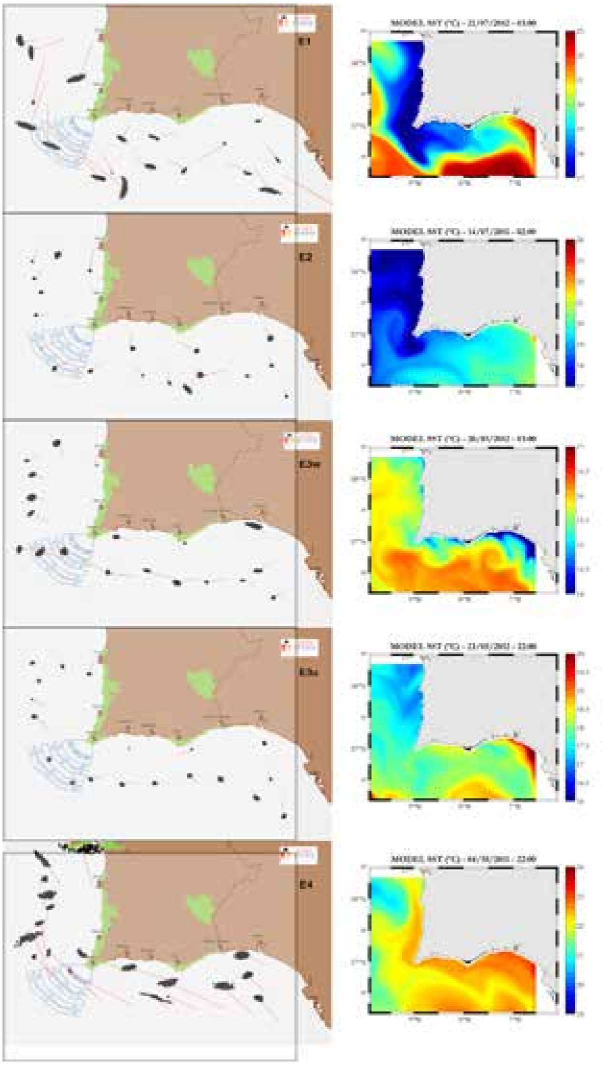

Figure 2 Oil spill scenarios simulated for each classified upwelling event (left). The orange dots correspond to the initial position of the spill while the red line shows the trajectory associated with each spill (in black). The grey rectangle marks the Northern and Eastern limits of level 1, the outer model grid. In green it's represented the protected areas established for the region. To the right the correspondent SST distribution in the study area is presented.

3. Discussion

The main mesoscale features present in the region, observed and described by several authors, were clearly identified by observing the remote sensing SST data. Also, the temporal coverage of the database, combining both MODIS and METOP-A satellites, allowed us to perceive the mesoscale patterns that occur in the region. This is regarded as useful information not only for the present work, but also for future research focused on relating and explaining these regional patterns with the main driving forcing mechanism defining the oceanography of the Iberian Peninsula. While differences in SST exist between satellite images and model results, nonetheless, in general the model represents, to a good extent, the major features observed from space. With this study, the importance of regional mesoscale features in the dynamics of oil spills is emphasized, not only by their direct effect in driving 'event-specific' spills but also the potential use of the patterns associated with these events in the regional 'exposure degree' to oil spills. All the above highlights the importance to better understand these mesoscale patterns, identified as a key challenge by Relvas et al. (2007).

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Remote Sensing

Use of operational oceanography satellite products to develop environmental indicators for the European MSFD

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Abstract

Operational oceanography products were used to define different indicators useful for the Marine Strategy Framework Directive Good Environmental Status (GES). Satellite chlorophyll data have been used to detect chlorophyll concentration trends in the Mediterranean Sea, aiming to identify the areas subject to eutrophication problems. Moreover satellite Sea Surface Temperature and wind data have been used to define upwelling indices to identify the regions more subject to upwelling events.

Keywords: Chl trend, upwelling index, operational oceanography, MSFD

1. Introduction

The aim of the Marine Strategy Framework Directive is to achieve and to maintain the Good Environmental Status (GES) of European marine waters by 2020 (MSFD; 2008/56/EC, http://www.msfd.eu/). The Directive defined 11 qualitative descriptors that are further divided into 26 criteria and 56 associated indicators, which describe what the environment will look like when the GES has been achieved (http://www.msfd.eu/knowseas/ges.html).

This work describes how operational oceanography products have been used to develop some of these indicators. The indicators here described fit with the needs of descriptors 5, which is focused on eutrophication problems, and 7, which refers to alterations of hydrographical conditions.

Eutrophication occurs when waters are subject to an increase of nutrient input, typically nitrogen and phosphorus, that can induce an excessive growth of phytoplankton concentration and a consequent degradation of the marine ecosystems. Eutrophication can be monitored by studying the spatial and temporal variation of the chlorophyll (Chl) concentration. In particular, Chl trends are an efficient tool to understand the response of the marine ecosystem to human pressures. The first indicator here described is the Chl trend over the Mediterranean Sea obtained by applying the Mann-Kendall test and Sen's method (Mann 1945, Kendall 1975, Sen 1968) to the de-seasonalized time series of satellite Chl concentration data.

Additionally, identifying the areas of Mediterranean Sea with frequent upwelling phenomena is particularly important due to the fact that coastal upwelling modulates the natural distribution of nutrients, naturally increasing primary productivity in the regions in which it occurs. For this reason we also developed two coastal upwelling indices, based on Ekman theory, from satellite scatterometer wind data (Ekman 1905, Alvarez et al., 2008, Lluch-Cota, 2000, Schwing et al., 1996) and Sea Surface Temperature data (Demarcq et al., 2000, Marullo et al., 1989, Nykjær et al., 1994).

In section 2 we describe the dataset and methods we used to develop the above mentioned indicators; the results are presented in section 3 and conclusions are given in section 4.

2. Materials and Methods

2.1 Chl data

In this study we examine the Mediterranean Sea merged Case1-Case2 chlorophyll product produced by CNR-ISAC (Volpe et al., 2012). The dataset used covers the 1998-2009 period with a monthly temporal resolution and a spatial resolution of 1 km.

2.2 SST data

The SST data analyzed here are the Mediterranean Sea near real-time (NRT) MyOcean Sea Surface Temperature products (http://www.myocean.eu). These consist of daily optimally-interpolated 1/16° horizontal resolution merged maps relative to the 2009-2011 period.

2.3 Wind data

The dataset studied in this work is the Cross-Calibrated Multi-Platform Ocean Surface Wind Vector L3.0 First-Look Analyses (http://podaac.jpl.nasa.gov). In this work we used the 2009-2011 6-hourly wind maps at 25 km spatial resolution.

For more details about the SST and wind dataset used, see Rinaldi et al. (2015).

2.4 Chlorophyll Trend

To estimate the magnitude of the trend ($mg \cdot m^{-3} \cdot yr^{-1}$) and its significance we applied the Mann-Kendall test and Sens's method (Mann, 1945, Kendall, 1975, Sen, 1968) to the de-seasonalized monthly mean Chl values. To remove the seasonal signal we use the X-11 seasonal adjustment method (Rinaldi et al., in preparation, Dagum 1980, Pezzulli et al., 2005) .

2.5 SST upwelling index (SST_{index})

Daily SST_{index} were computed along 49 cross-shore coastal sections (Fig. 1) as:

$$SST_{index} = \frac{\left(SST_{dayMAX} - SST_{dayMIN}\right) - \left(SST_{c\lim MAX} - SST_{c\lim MIN}\right)}{\left|SST_{c\lim MAX} - SST_{c\lim MIN}\right|}$$

Here, SST_{dayMIN} is the minimum SST found within 2 internal Rossby radii of deformation from the coast and inshore of the maximum SST gradient value in the same (0, 2Rd) section segment. SST_{dayMAX} is the mean SST value relative to all section pixels seaward of the maximum SST gradient location. Finally, $SST_{climMIN}$ and $SST_{climMAX}$ are the equivalent of SST_{dayMIN} and SST_{dayMAX}, but relative to the 2009-2011 monthly climatology SST maps, for the month relative to the examined day. A 2009-2011 time series of daily SST_{index} was thus obtained and normalized for each section (Fig. 2). Positive SST_{index} values are assumed to be indicative of upwelling events, with significantly colder water inshore. Upwelling event frequencies f_{SST} were also computed as the ratio between the number of (upwelling) events with normalized $SST_{index} > 0.1$ and the total number of daily SST_{index} values at a given section. That is, an upwelling event was considered as such when SST_{index} was "significantly" positive. This 0.1 threshold is subject to revision and was qualitatively chosen by looking at SST maps that show evident upwelling conditions (see also Rinaldi et al., 2015).

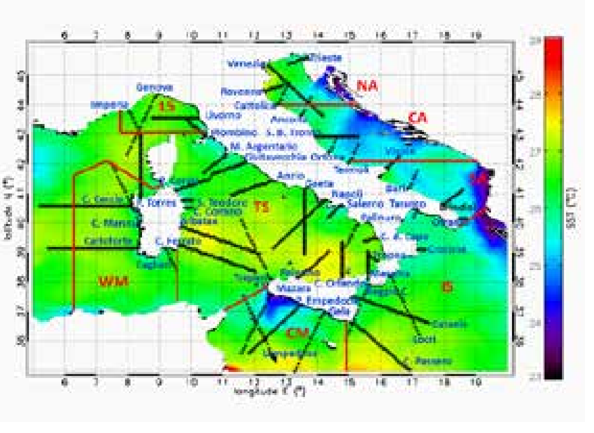

Figure 1 SST map of the study area with sections for SST_{index} computation, location names among which the RMN stations (names in purple). MSFD Italian Sub-regions are also shown, divided by colored segments: Ligurian Sea (LS), Tyrrhenian Sea (TS), Western Mediterranean Sea (WM), Central Mediterranean Sea (CM), Ionian Sea (IS), Northern, Central and Southern Adriatic Sea (NA, CA and SA respectively).

2.6 Wind upwelling index

The 6-hourly satellite wind data were averaged into daily maps that were used to compute surface wind stress and Ekman transport (Ekman, 1905, Schwing et al., 1996 and references therein). The wind upwelling index W_{index} was defined as the component of Ekman transport perpendicular to the coast at each location. Daily W_{index} time series were computed and normalized at each section and upwelling-favorable conditions were defined by $W_{index} > 0.1$ this threshold value being a preliminary choice, as for SST_{index}. Finally, the upwelling frequency f_W was defined as the number of upwelling-favorable days ($W_{index} > 0.1$) divided by the total days (Rinaldi et al., 2015).

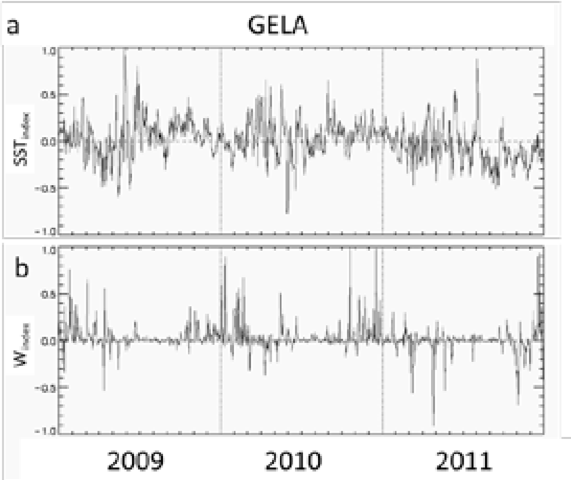

Figure 2(a) SST_{index} and (b) W_{index} time series for Gela (southern Sicily, Fig. 1).

3. Results

3.1 Chlorophyll Trend

In line with the ocean primary production trend (Behrenfeld et al., 2006, Doney, 2006) the open ocean (Case 1) waters of the Mediterranean Sea are characterized by a lightly decreasing Chl trend. This is due to the increased stratification of the basin, caused by global warming, with a consequent reduction of vertical mixing between the surface layer and underlying nutrient-rich waters (Barale et al., 2008).

On the contrary, the most intense trend signals, both negative and positive, are found in coastal waters (Case 2) near lagoons, river deltas, and/or large urban areas (Fig. 3). In particular, negative Chl trends characterize the Ebro, Po, Rhone and Tiber river plumes and the northern Aegean Sea. These trends are linked to the measures taken by the European Union since the 1990s, aiming to reduce nutrient discharge in the coastal waters and to improve the water treatment and land management along river basins (Torrecilla et al., 2005, Ludwig et al. 2010, Romero et al., 2012,).

On the contrary, the most evident increasing trends are found in the coastal regions subject to intense anthrophic pressure and in correspondence with particularly polluted rivers the waters of which were used for irrigation and domestic and industrial purposes. In particular we detect eutrophication problems off the Nile Delta region, in the region between Sfax-Chebba cities and Kerkennah Island (Gulf of Gabes, Tunisian coast of the Sicily Channel) and in confluence of the Volturno and Tirso river mouths in the Tyrrhenian Sea and in the Sardinian Sea, respectively (Fig. 2).

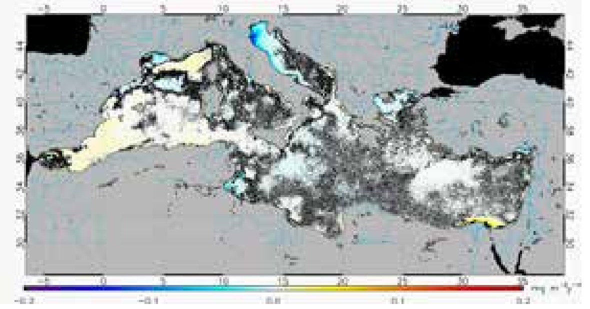

Figure 2(b) Chl trend over the Mediterranean Sea with a significance greater than 70%. Black pixels refer to no significant trend.

3.2 SST Upwelling index

The Central Mediterranean Sea (Fig. 1) is among the sub-regions with most frequent upwelling in 2009-2011. Indeed most of the stations located there have 35% < f_{SST} < 45% (i.e the top 10% of the f_{SST} range). Other stations with frequent upwelling events are in the Ionian Sea (Taranto and Crotone, Italy), and in the Tyrrhenian Sea (Palinuro and Naples, Italy). Our results are supported by literature (see for example Piccioni et al., 1988, Béranger et al., 2004, Marullo et al., 1994, Bakun and Agostini, 2001), thus encouraging according to the methodology adopted to compute SST_{index}, even though we do not find work that support our results for the Ionian Sea, which calls for further investigation.

The stations with rare upwelling (f_{SST} < 20%) are along the Sardinian coasts in the Western Mediterranean and Tyrrhenian Sea (Arbatax, Porto Cervo, Carloforte, Trapani; Fig. 1), in the Northern and Southern Adriatic Sea (Venice and Vieste, respectively) and include also Locri in the Ionian Sea. The Tyrrhenian Sea having high and low f_{SST} is therefore a site of high spatial variability in upwelling frequency.

3.3 Wind Upwelling index

As found for f_{SST}, the MFSD sub-regions most subject to upwelling events, according to the scatterometer wind index W_{index}, are the Central Mediterranean Sea (Porto Empedocle, Gela and Mazara) and the Tyrrhenian Sea (Anzio, Civitavecchia and Monte Argentario), even though with much lower frequencies f_W than f_{SST} (10% < f_W < 16%, Table 1). On the other hand, the Western Mediterranean and the Northern and Central Adriatic Seas seem less subject to upwelling according to W_{index}, with f_W < 5%, the low values for the Western Mediterranean Sea calling for further investigation on W_{index}, given the intense northwesterlies that persistently blow in the Sardinian Sea (Olita et al., 2013). Finally, f_W in other basins such as the Tyrrhenian and Southern Adriatic Seas are spatially variable.

4. Discussion and Conclusions

This work describes the chlorophyll trend over the Mediterranean Sea and coastal upwelling in the Italian Seas inferred with two indices derived using satellite oceanographic observational products.

Chl trend results highlight that the most intense positive or negative trend signals are found in Case 2 waters linked to the enhanced/reduced nutrient load carried by rivers and to anthropic pressure along the coastline.

The two upwelling indices correctly identify the southern Sicilian coast as one of the sites more subject to coastal upwelling, in agreement with literature, albeit with different event frequencies. However, some regions are not uniformly identified as high or low upwelling occurrence sites, in that frequencies f_{SST} and f_W are very different.

Fig. 2 shows SST_{index} and W_{index} time series for Gela in the Central Mediterranean sub-region SST_{index} and W_{index} do not always simultaneously identify upwelling. The discrepancies between indices require further investigations. For this reason future work will be dedicated to devising a combined thus more robust wind-SST upwelling index, e.g. also taking into account the ocean's inertia, i.e. how long the wind must blow so that significant upwelling may occur.

We feel that this work has given a good suggestion as to the important contribution that operational oceanography can give the to the successful assessment and achievement of the European waters' GES.

Acknowledgements

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Spatio-temporal variability of Phytoplankton Size Classes in the Mediterranean Sea from Ocean Colour data

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Abstract

Satellite-borne optical sensors can detect Phytoplankton Size Classes (PSCs) and Functional Types (PFTs). Several physical and biological models have been proposed to quantify their contribution to the total phytoplanktonic biomass. Three models were selected: Brewin *et al*. (2010; 2011), Hirata *et al*. (2011) and Kostadinov *et al*. (2009), henceforth referred as B11, H11 and K09. B11 and H11 are empirical algorithms, based on the chlorophyll concentration, whereas K09 is a model based on the theoretical relation between the particles backscattering coefficient and the Particle Size Distribution (PSD) slope. We evaluate how these models describe the spatio-temporal variability of three dominant PSCs (micro-, nano- and pico-phytoplankton), in the Mediterranean Sea, during the SeaWiFS mission (1998-2010). The algorithms were ground-truthed against the Mediterranean subset of the SeaBASS dataset (Werdell, P.J. and S.W. Bailey, 2005). The subsequent analysis by B11 and H11, suggested that pico-phytoplankton dominates the chlorophyll all year round with maxima during summer and minima in late winter – spring, in open sea regions. Coastal areas, instead, show the dominance of nano- and micro- phytoplankton, so as in the intense bloom regions, in the late winter – spring months. K09 provides complementary information on the particles size distribution.

Keywords: Phytoplankton, Size-Classes, Mediterranean Sea, Ocean Colour, Particle Size Distribution

1. Introduction

Phytoplankton represents the first step of the food chain. These microalgae are similar to the plants, which require the sunlight to produce oxygen, thus supporting the respiration of the heterotrophic marine organisms. In the marine system, phytoplankton provides for approximately half of the global net primary production (Gregg *et al*., 2003), thus having a direct role in the carbon and nutrients recycling.

The distribution of phytoplankton communities is related to biotic and abiotic processes, of which the most important are the light and nutrients availability, followed by the environmental conditions, interspecific relationships (e.g. predation and competition) and dispersal (Follows *et al*., 2007). A different configuration of the community's structure derives from the interaction of these factors. Whatever environmental change or anomaly can be reflected in the phytoplankton assemblage dynamics.

Over the years, several techniques have been developed for the algal biomass monitoring. Most of them are based on laboratory methods, but, recently, also the use of satellite-borne optical sensors has become widespread.

Depending on the groups or taxa, thus varying the pigment composition (Chl-*a*, carotenoids, biliproteins) and pigment packaging, the phytoplankton affects the optical properties of water.

One of the most useful satellite product is the chlorophyll concentration; this is the essential pigment for the photosynthetic activity, and is strictly connected to the phytoplankton biomass concentration at the sea surface.

Any specific dynamics of the algal community is reflected in a particular absorption pattern or backscatter spectrum, and this is the reason why further bio-optical models consider not only the chlorophyll concentration, but also, different optical variables, such as the absorption and/or backscattering coefficients.

Considering the several approaches, used to identify phytoplankton groups from space, they are usually divided in: spectral-response based approach (Alvain *et al.*, 2005; Fujiwara *et al.*, 2008; Navarro *et al.*, 2014; Sathyendranath *et al.* 2004); abundance based approach (Hirata *et al.*, 2011; Brewin *et a*l., 2010; Kostadinov *et al.*, 2009) and ecological based approach (Raitsos *et al.* 2008), (Brewin *et al.*, 2010). Among them, some are empirical models, such as the chlorophyll-based ones, and others are semi-analytical, as Kostadinov *et al.* (2009).

When we talk about the phytoplankton community, studied from space, it is usually classified in: Phytoplankton Functional Groups (PFTs), referred to a grouping of different species with a common ecological function; or in Phytoplankton Size Classes (PSCs), as micro (>20 μm), nano (2-20 μm) and pico (<2 μm) (Sieburth *et al.*, 1978).

Here, we will concentrate on the identification and description of the spatial and temporal evolution of PSCs, in the Mediterranean Sea.

2. Methods

2.1 PSCs and PSD algorithms

In this work, the phytoplankton biomass distribution was investigated, at first, applying two PSCs bio-optical algorithms: Hirata *et al.,* (2011), and Brewin *et al.*, (2010; 2011), both based on chlorophyll concentration. Secondly, the particle size distribution was analysed following the Kostadinov *et al.* (2009) model. Indeed, assuming that in open ocean (Case 1 water), the particle assemblage is strongly dependent only by the biogenic material; the PSD can be related to the PSCs distribution. In this way, it can describe the contribution of the three size classes (micro, nano, pico), in terms of biovolume or cell L^{-1}.

2.2 In situ data

To test the applicability of the two PSCs global models (Hirata *et al*. 2011 and Brewin *et al*. 2010; 2011) on our basin, a Mediterranean subset of SeaBASS dataset of phytoplankton pigments was selected.

The *in situ* PSCs classification was pursued by following the method described respectively in the two models and using the Vidussi *et al*., (2001) and Uitz *et al*., (2006) theory, based on the use of Diagnostic Pigments Analysis (DPA) (for the details see Vidussi *et al*., 2001 and Uitz *et al*., 2006).

2.3 Satellite data

Daily chlorophyll fields of SeaWiFS time series (1998-2010) were used to infer the PSCs distribution. This chlorophyll product, named Chl_Case1-2, was produced by the GOS-ISAC group of the National Research Council. They derive from the combined use of two algorithms, one specifically for Case 1 water and a second used for the Case 2 water (for the details of data processing see Volpe *et al*. 2012). Daily chlorophyll fields were then averaged in order to produce monthly and climatological maps.

3. Results

3.1 Spatial PSCs variability

The two types of algorithms, chlorophyll based and PSD slope based, describe respectively the phytoplankton and particles distribution, in a complementary way.

In this work, we will focus the attention on the results coming from the chlorophyll based algorithms, as Hirata model.

Over the entire basin, our analysis demonstrated that: in the coastal zones, micro-phytoplankton dominates almost all year, followed by the nano fraction.

Micro component, also, reaches high values in the strong dynamic zones in which the upwelling events involves the deepest layers of the water column, determining the nutrients rise up to the surface and, thus, supporting the biggest cells growth. Instead, the nano fraction appears widespread, over the basin, with quite constant percentages (about 30-50%), all the year. Pico-phytoplankton follows the nano-phytoplankton spatial distribution, becoming, in summer, predominant on the TChl a, above all in the Eastern basin, where the ultra-oligotrophy is more marked.

At local scale, the most interesting areas, for the monitoring of phytoplankton biomass variability, are the more dynamic ones, like e.g. the Gulf of Lyon and generally the Northwestern Mediterranean Sea (NwMed). Here, considering two opposite months, April and August, the three PSCs show a specific spatial and temporal succession. In spring, the NwMed, is characterized by several processes that induce the deep water formation, causing strong convective phenomena and the uplift of nutrients from the bottom layer. The availability of nutrients in high concentration and the photoperiod length, create the ideal condition to sustain a spring bloom. Indeed, in April, the micro-phytoplankton contribution to chlorophyll a is very high, reaching the 57-58% (Fig. 1c). At the boundary of the area in which the micro fraction is high, the nano component reaches percentage of about 47-50% (Fig. 1b).

Differing from the other two PSCs, Pico-phytoplankton shows the major contribution to TChl *a* in summer. Indeed, in August, its contribution to chlorophyll *a*, is about 60-68% (Fig. 1d); while nano but, above all, micro fractions remain restricted to the coastal zone (Fig. 1e-f).

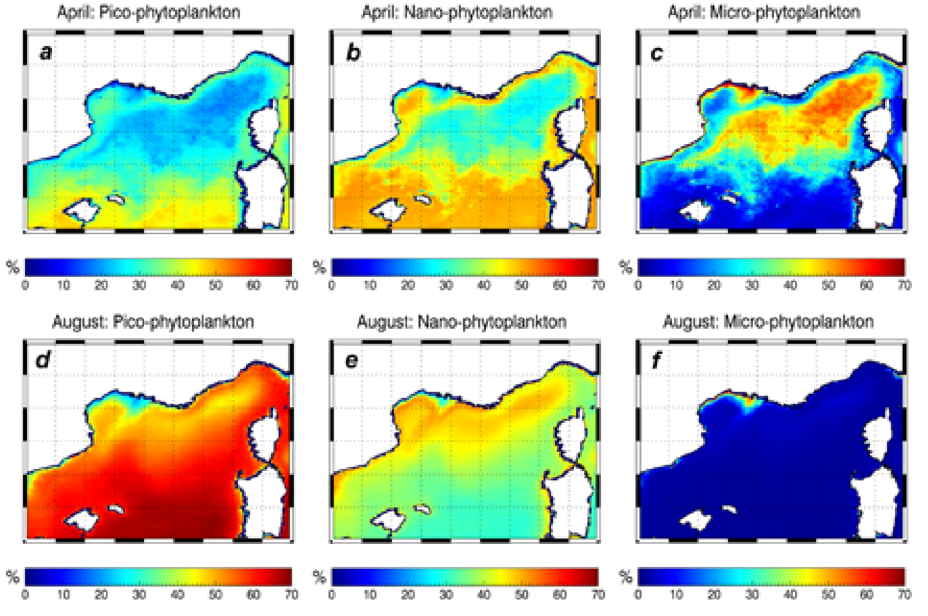

Figure 1 Climatology maps of micro-, nano- and pico-phytoplankton for SeaWiFS Era (1998-2010) in the Northwestern Mediterranean Sea, (a-d, April; d-f, August).

A particular dynamics of phytoplankton assemblage is observed also in the Alborán Sea. Here the Atlantic inflow establishes a specific and complex system of currents and fronts. In particular, the coastal currents cause intermittently upwelling events along the Spanish coast (Sarhan *et al*. 2000) supporting the widespread of the major class as micro-phytoplankton (Fig. 2c). In August, this phenomenon is less pronounced (Fig. 2f) with respect to April, in which the signal of micro component extends over all the northern boundary of the two gyre, the West and the East ones (Fig. 2c).

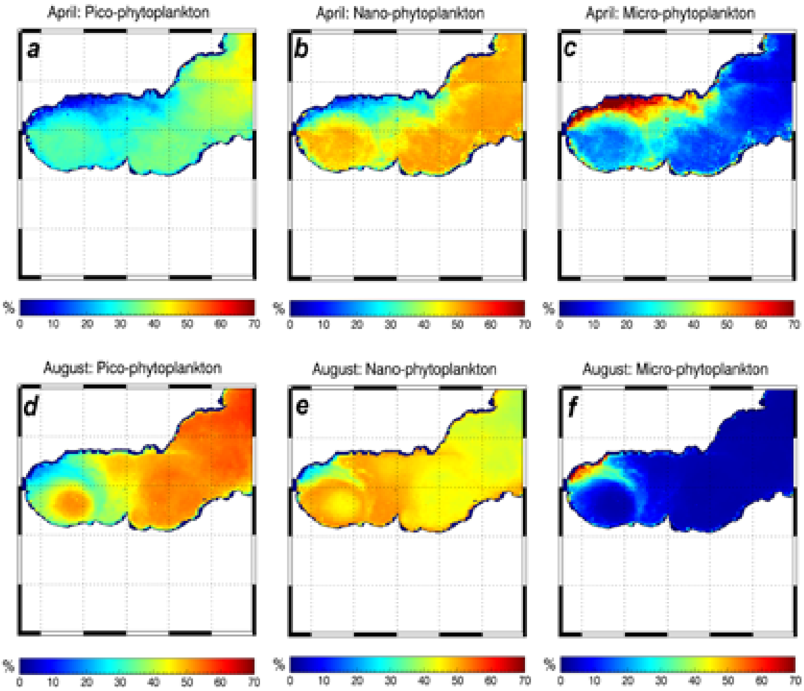

Figure 2 Climatology maps of micro-, nano- and pico-phytoplankton for SeaWiFS Era (1998-2010) in the Alboràn Sea, (a-d, April; d-f, August).

In August, the nano fraction is of about 40-50 % on the TChl *a*, and it is concentrated along the front between the two gyre (Fig. 2e). In the same months, pico-phytoplankton reaches high percentages of about 50-55% in all the Eastern Alborán gyre, while in the Western Alborán Sea, it shows a single core located in the centre of the gyre (Fig. 2d).

3.2 Temporal PSCs variability

At local scale, because of their peculiarity, we have focused the attention on two areas: the Levantine Sea and the North Adriatic Sea.

The seasonal variability in the Levantine basin (Fig. 3) is related mainly to the pico-phytoplankton signal.

Indeed, the very low values of the micro contribution on TChl *a* are affected by the oligotrophy of this area (Fig. 3). The higher values of pico and nano fraction occur from autumn to late winter, while a decreasing is observed in summer, in which the discard of pico from the other two PSCs is enhanced (Fig. 3).

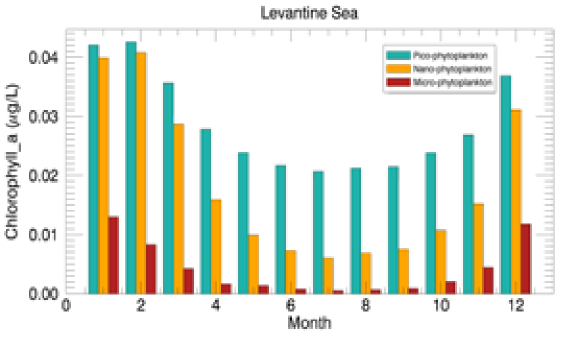

Figure 3 Climatology of micro-, nano-, pico-phytoplankton fraction on total chlorophyll in the Levantine Sea (SeaWiFS time series 1998-2010).

An opposite extreme case is the North Adriatic Sea. In this area, the major contribution to the TChl *a* is due to the micro fraction, which predominates in the late spring and autumn (Fig. 4). Here, nano- and pico-phytoplankton show a low seasonal variability with a quite constant contribution to TChl *a*, over the year.

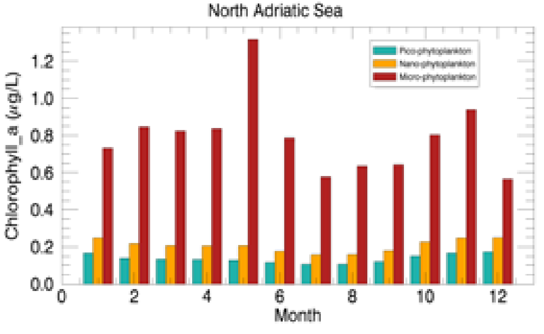

Figure 4 Climatology of micro-, nano-, pico-phytoplankton fraction on total chlorophyll in the North Adriatic Sea (SeaWiFS time series 1998-2010).

4. Discussion and conclusions

In this work, we have described, for the first time, the spatial and temporal variability of the phytoplankton size classes in the Mediterranean Sea, starting from the use of ocean colour data.

Our results have shown that, in rich nutrient condition, micro-phytoplankton provides the major contribution to the TChl *a*. Moreover, micro component reaches high percentages in coastal zones, such as in the North Adriatic Sea (Fig. 4). Here, every year, several big rivers, as Po, Brenta, Livenza etc., brought a big amount of nutrients into the sea (Malej *et al.*, 2005), supporting the fast growing of the biggest algal cells.

In our analysis, nano-phytoplankton is widespread over the entire basin with quite constant percentages, following in the most cases the seasonal variability of micro in the Western basin and that of pico in the Eastern one.

At the same time, our results confirmed that, in poor nutrients condition, the ability of the smallest cells to survive better than the biggest ones (Le Querè *et al*., 2005), makes the pico-phytoplankton the most suitable to live in the ultra-oligotrophic waters, like those of the Eastern basin, especially of the Levantine Sea (Fig. 3).

Concluding, our analysis demonstrated that the use of this new remote technique, for the identification of phytoplankton groups, represents an innovative and synoptic tool for monitoring the algal biomass and consequently the marine system. Taking into account that, the phytoplankton assemblage is the result of the synergy of several environmental forces, it can be a mirror of the consequences that the climate change could have on the marine ecosystem.

As a future perspective we want to test others global PSCs/PFTs bio-optical algorithms and even if it is possible recalibrate/validate them for the Mediterranean Sea.

Acknowledgements

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Jason Continuity of Services: Continuing the Jason Altimeter Data Records as Copernicus Sentinel-6.

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Abstract

The Sentinel-6 mission is proposed as a multi-partner programme to continue the Jason satellite altimeter data services beyond the Jason-2 and Jason-3 missions. The Sentinel-6 mission programme consists of two identical satellites flying in sequence to prolong the climate data record of sea level accumulated by the Topex-Poseidon, Jason-1, Jason-2 and Jason-3 missions beyond 2030. The Sentinel-6 mission intends to maintain these services in a fully operational manner. A key feature is the simultaneous pulse-limited and synthetic aperture radar processing allowing direct and continuous comparisons of the sea surface height measurements based on these processing methods and providing backward compatibility. The Sentinel-6 mission will also include Radio Occultation user services.

Keywords: Altimetry, sea surface height, radio occultation

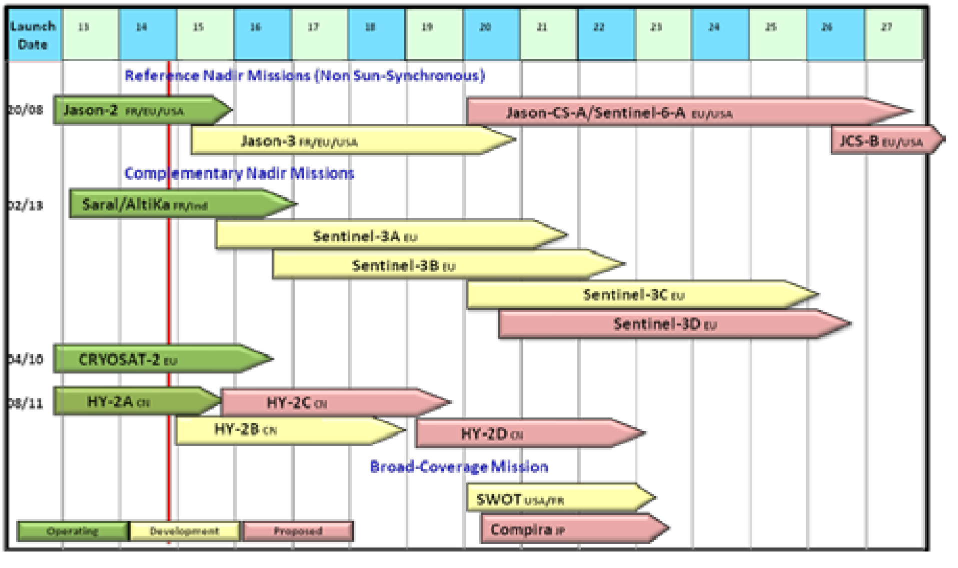

Figure 1 Overview of the near future altimeter satellite missions (Source: CEOS).

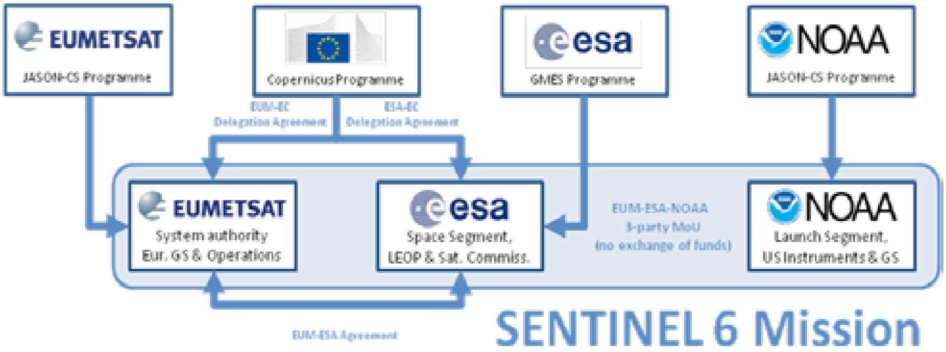

Figure 2 The multi-partner programme and agreement set-up underlying the Sentinel-6 missions.

1. Introduction

The Sentinel-6 mission is proposed as a multi- partner program to continue the Jason altimeter data services beyond Jason-2, currently fully operational, , and Jason-3, planned to be launched in summer 2015. The Jason- Continuity of Service programme constitutes EUMETSAT's contribution to the Copernicus Sentinel-6 mission to be developed and implemented through a partnership between the EU, ESA, EUMETSAT and NOAA. The mission will uniquely extend the climate record of sea level measurements accumulated since 1992 by the Topex-Poseidon (e.g., Fu et al. 1994), Jason-1 (e.g. Menard and Fu, 2001), Jason-2 (e.g., Lambin et al 2010) and Jason-3 missions beyond 2030. A prime mission objective is to continue these global sea level time series with an error on sea level trend of less than a 1 mm/year. The sentinel-6 mission will also be an essential observing system for operational oceanography and seasonal forecasts in Europe and beyond. As its predecessors the proposed mission will provide key user measurement services for sea level rise monitoring, operational oceanography and marine meteorology. These services will be aligned with those of the Sentinel-3 missions, see e.g., Donlon et al. (2012), which will be operational in the same era, see Figure 1.

The Sentinel-6 mission programme consists of two identical satellites (Jason-CS A and Jason-CS B) with each a nominal lifetime of 5.5 years. The satellites will be launched sequentially in the 'Jason orbit' to take over the services of Jason-3 when this scheduled mission becomes of age. Currently the launches of Jason-CS A and B are planned for 2020 and 2026, respectively.

2. Programmatic set-up

Figure 2 outlines the multi-partner programme and agreement set-up underlying the Sentinel-6 missions. The European contribution will be implemented through the combination of the ESA GMES Segment 3 programme (GSC-3), the optional EUMETSAT Jason-CS programme and the EU Copernicus Programme, for the joint benefits of the meteorological and Copernicus user communities in Europe. In addition, on behalf of the United States, NOAA is developing a dedicated Jason-CS programme. The following high level sharing of responsibilities is envisaged (which may still be subject to some changes):

EUMETSAT is the system authority and is responsible for the Sentinel-6 ground segment development and operations preparation. EUMETSAT will also carry out the operations build up and operations of the Sentinel-6 system including both satellites and delivery of data services to Copernicus Service Providers and users on behalf of the EU.

ESA is responsible for the development of the first Jason-CS satellite and the instruments prototype processors as well as for the procurement of the recurrent satellite on behalf of EUMETSAT and the EU.

NOAA will deliver the US payload instruments for both satellites and will provide ground segment development support, launch services, and contributions to operations. The three space agencies will share the responsibility of and the science team coordination and the calibration/validation activities, with EC being involved in the interactions with the science teams. In addition, agreements will be concluded between EUMETSAT and CNES and between NOAA and NASA for system and science expertise support.

3. Mission characteristics

The Sentinel 6 Space Segment consists of two successive Jason-CS satellites (A and B), based on the CryoSat-2 heritage platform, with some tailoring to specific needs of the Sentinel 6 mission. The satellites will embark the following main payload:

- a Ku/C band altimeter (Poseidon-4);
- a microwave radiometer (AMR-C);
- a GNSS receiver (GNSS-POD);
- a DORIS instrument;
- a Laser Retroreflector Array;
- a Radio Occultation instrument (GNSS-RO).

The latter instrument is added for the Sentinel-6 mission to include a secondary mission to provide radio occultation observation services to meteorological users.

It is important to remark that the Poseidon-4 radar altimeter has evolved significantly from the Poseidon-3A and -3B instruments on board Jason-2 and 3, respectively. In addition to a pulse-width limited processing, loosely termed Low Resolution Mode (LRM), the Poseidon-4 on board the Jason-CS satellites will also have the facility of a simultaneous Synthetic Aperture Radar processing (loosely called SAR mode), see also section 5. The SAR mode will provide further service alignment with those of the Sentinel-3 SRAL mission.

The Jason-CS satellites will fly in the same orbit as Jason-2 and Jason-3. This is a non-sun-synchronous orbit with nominal altitude of 1336 km and 66°inclination. The orbit period is 112 minutes and 26 seconds and the ground track cycle repeats every 10 days, shifted by approximately 2 hours.

The Sentinel-6 mission will include 5 main operational user product services: 1) A Near Real Time Altimetry Service (ALT-NRT) will consist of delivery of altimeter Level 2 data products in less than 3 hours after data acquisition. These products are mainly used for marine meteorology, ocean-atmosphere gas transfer studies and real operational oceanography services. 2) A Short Time Critical Altimetry Service (ALT-STC) will consist of a delivery of level 2 user data products within 36 hours based on preliminary restituted orbit data. 3) A Non Time Critical Altimetry Service (ALT-NTC) will consist of a delivery of level 2 user data products within 60 days after data acquisition based on final restituted orbit data. The main objective of the ALT-NTC service is to provide global and regional mean sea level time series for ocean climate monitoring.

Finally, the NRT and NTC Radio Occultation services will deliver Level 1b and Level 2 RO data products with the same timeliness as of their altimeter counterparts to serve the atmospheric (Numerical Weather Prediction and Climate) user communities.

4. Mission objectives

Sentinel-6 shall be an operational mission for all its main services. Hence, full emphasis is put on lack of down-time, reliability, and timely distribution of data products. It will also include support to information service providers and major reprocessing activities.

Sentinel-6 products shall be of sufficient quality to serve as the high precision reference mission for other altimeter missions. It has been formally required that the mission performance shall not be worse as the known performance of Jason-2. With the current design however the expectation is that the Sentinel-6 mission will outperform Jason-2 on many aspects and will form a reliable state of the art reference for various other altimeter missions in the near future.

The exact Sentinel-6 products and product suite are not detailed out yet. The mission however shall provide a product suite enabling an optimal combination with products from other altimeter missions. This is particularly pursued for combining Sentinel-6 with the Sentinel-3 SRAL missions. Also the generation of higher level single mission products (L2P and L3) are supported.

The Sentinel-6 products shall maintain their quality closer to the coastline than products from TOPEX/Poseidon, Jason, Jason-2, and Jason-3. This, among other techniques, will be facilitated by the SAR mode capabilities.

Sentinel-6 services shall provide significant wave height and wind speed products in near real-time.

5. Interleaved sar mode

As indicated in section 3, the Poseidon-4 radar altimeter system can operate in a pulse-width limited (LRM) and a synthetic aperture Radar (SAR) processing simultaneously. Hence both Brown echoes and SAR radar echoes will be generated simultaneously in the ground processing. This is loosely called the interleaved mode. This mode has the following advantages: The original (Jason-2/3) low resolution processing is maintained simultaneously to higher resolution products, thereby ensuring full continuity of services with Jason-3, based on pulse-width limited processing with an along-track resolution of approximately 7 km. The availability of much higher along track resolution (300m) and, when averaged, a lower range measurement noise will enable an enhanced use especially in coastal areas. The enabled continuous and direct comparison of LRM and SAR measurements (which is neither available from Sentinel-3 or Cryosat-2) makes Sentinel-6 a reference for all SAR altimetry missions. More details and background of the interleaved mode can be found in, e.g., Phallipou et al. (2012) and Gommenginger et al. (2013).

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The EUMETSAT Sentinel-3 Marine Centre

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Abstract

The EUMETSAT Sentinel-3 Marine Centre as part of the Sentinel-3 Payload Data Ground Segment and as integrated in the EUMETSAT overall satellite ground segment set-up is explained in summary. In addition, an overview of the essential sentinel-3 marine user products and the related user services is provided. The first Sentinel-3 satellite is expected to be launched in Autumn 2015.

Keywords: Sentinel-3, satellite observations, data processing, marine user data products.

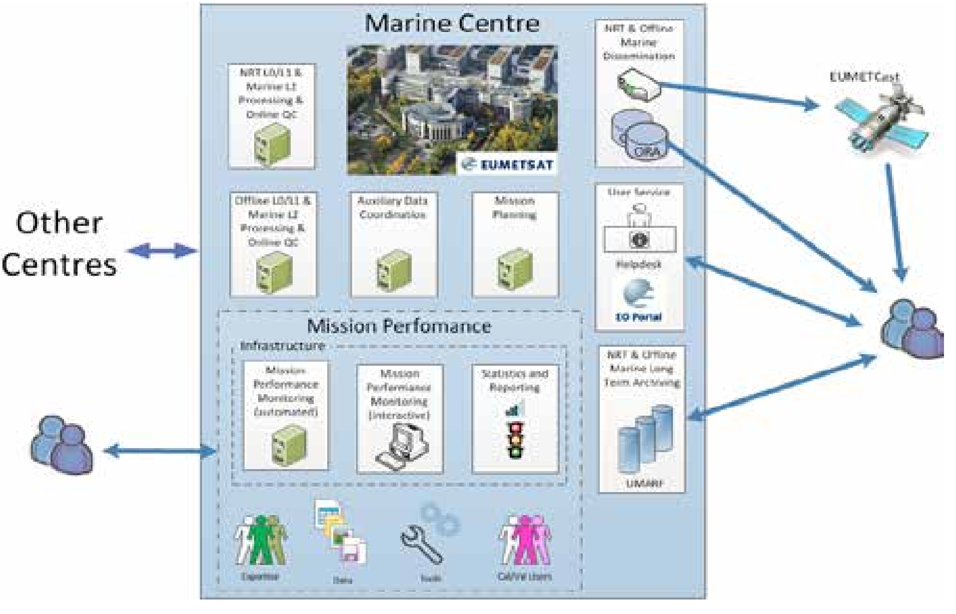

Figure 1 Overview of the EUMETSAT Sentinel-3 Marine Centre.

Product	EUMETCast	ODA	Data Centre (UMARF)	Timeliness	Dissemination Unit size	Size per orbit (GB) (likely compressed sizes)
OLCI L1 EFR	✓	✓	✓	NRT	Frame (3 min)	21.4
		✓	✓	NTC	idem	idem
OLCI L1 ERR	✓	✓	✓	NRT	Full Orbit Daylight (2666 sec)	1.7
		✓	✓	NTC	idem	idem
OLCI L2 WFR		✓	✓	NRT, NTC	Frame (3 min)	14.1
OLCI L2 WRR	✓	✓	✓	NRT	Full Orbit Daylight (2666 sec)	1.19
		✓	✓	NTC	idem	idem
SLSTR L1B		✓	✓	NRT, NTC	Frame (3 min)	18.5
SLSTR L2 WST	✓	✓	✓	NRT	Full orbit: dump	0.7
		✓	✓	NTC	Full orbit: South Pole to South Pole	Idem
SRAL L1B	✓	✓	✓	NRT, STC*	Full orbit: dump	0.4
		✓	✓	NTC	*Half Orbit: Pole to Pole	idem
SRAL L2 WAT	✓	✓	✓	NRT, STC*	Full orbit: dump	0.2
		✓	✓	NTC	*Half Orbit: Pole to Pole	idem

Table I High-level overview of Product Dissemination from the EUMETSAT Marine Centre.

1. Introduction

The Sentinel-3 mission is part of a series of Sentinel missions, under the umbrella of the Copernicus programme.

Sentinel-3 main objective is to determine parameters such as sea-surface topography, sea- and land-surface temperature, as well as ocean- and land-surface colour with high-end accuracy and reliability. Near-real time data processing and delivery will allow a broad range of Copernicus services for both the marine and land environment to continuously profit from the mission.

Within the Coperniucs programme, EUMETSAT will be responsible for the operation of Sentinel-3, 4 and 5 and 6, the latter depending upon approval of all the underlying programme (see, e.g., Bonekamp et al. these proceeding). ESA will be responsible for the development of the satellites and payload and the operation of Sentinel-1 and -2. Sentinel -1 A was already launched in 2014 (ref).

The first Sentinel-3 satellite (Sentinel-3 A) is currently scheduled for launch, from Plesetsk Cosmodrome, Russia, in autumn 2015. Sentinel-3 B should follow 1-1,5 years later, in order to fully meet the set user requirements with a tandem mission.

For the generation of the Sentinel-3 user data products, the so-called Payload Data Ground Segment (PDGS) was developed by ESA. This development is managed jointly by ESA and EUMETSAT. A central element of the PDGS is the EUMETSAT Sentinel-3 Marine Centre (MC) which will be fully and directly operated by EUMETSAT, including, e.g., mission planning, auxiliary data coordination and a mission performance capability.

ESA will operate counterpart PDGS centres for the land prodcut services.

Figure 1 provides a schematic overview of the EUMETSAT MC. The objectives of this paper are to briefly explain this MC and to explain the related services which will originate from the MC.

2. Main payload and level 1 products

First, the main instrument (payload) and related low level (level 1) measurements are mentioned and explained. Further details of the Sentinel-3 payload and these measurements can, e.g., be found in Donlon et al. (2012). The Sea and Land Surface Temperature Radiometer (SLSTR) level 1 products include calibrated and geo-located radiances and brightness temperatures computed from instrument source packets in the thermal, short wave and visible channels. The Ocean and Land Colour Instrument (OLCI) Level 1 products include calibrated top of the atmosphere radiance values in the OLCI spectral bands, computed from the instrument digital counts applying the radiometric processing and the stray-light effect correction. Synthetic Aperture Radar Altimeter (SRAL) Level 1 products include geo-located and calibrated radar echoes (i.e. waveforms) with all ancillary information annotated. The Sentinel-3 altimetry payload will also a dual frequency passive microwave radiometer (MWR) for wet-tropospheric correction and a Precise Orbit Determination package including a GPS receiver, a DORIS instrument and a laser retro-reflector.

During operations, Level 1 Products will be made available to the users, see Table 1. They will be kept identical for the sentinel-3 land and marine services.

3. Marine level 2 user products

Table 1 also lists the baseline for the operational marine level-2 products. From SLSTR the MC will provide Level 2 Sea Surface Temperature in the GHRSST L2P format (SLSTR L2 WST). OLCI will deliver the Ocean Colour products in a reduced and full resolution version (OLCI L2 WRR and OLCI WFR, respectively). These products contain the following parameters: Normalised water surface reflectance; Algal pigment concentration for open and for coastal waters; Total suspended matter concentration; Diffuse attenuation coefficient; Coloured dissolved matter absorption; Photosynthetically active radiation;Integrated water vapour;Aerosol optical depth; Aerosol Angström exponent. The SRAL marine Level 2 products (SRAL L2 WAT) contain the 1 Hz and 20 Hz measurements of sea surface height, significant wave height; Surface wind speed as well as the measurement of height and freeboard of sea ice.

Table 1 contains some additional information on the disseminated from the MC. Estimated product sizes are provided in the last column. All Level 1 and level 2 products will be formatted in NetCDF. Further details of these products can be found on the ESA Sentinel-3 web pages (ESA web).

4. Processing and product services

Three type of processing timeliness and related user services are identified for the Sentinel-3 mission. These are: 1) The Near Real-Time (NRT) service: User Products are delivered less than 3 hours after data acquisition and mainly used for marine meteorology and operational oceanography 2) The Slow Time Critical (STC) service: Products are delivered within 48 hours after data acquisition, due mainly to the consolidation of some auxiliary or ancillary data (e.g. preliminary restituted orbit data). 3) The Non-Time

Critical (NTC) service: The products are typically delivered within 2 months after data acquisition. This additional delay allows consolidation of some auxiliary or ancillary data (e.g. precise orbit data) and the data are mainly used for geophysical studies and operational oceanography. All the level 1 and level 2 user products are delivered under these services. Reprocessed products, although a key element in the overall service will be provided from off line activities.

5. Mission performance

ESA and EUMETSAT are working together on the performance monitoring, calibration and validation and the product evolutions in what is informally called the mission performance framework. These activities fall under the MC perimeter, see Figure 1. The objective is to provide the highest quality and the best understanding of the user products as provided under the indicated services. A Cal/Val plan was jointly written. ESA is procuring a Mission Performance Monitoring Facility to be fully integrated in the MC in order to facilitate the routine monitoring of instruments, processing system and products. Expert Support Laboratories and in-house experts are tasked for more interactive monitoring and the execution of Cal/Val tasks. Contribution, feedback and requests from the user and science communities are organized in a dedicated joint Sentinel-3 Validation Team and joint Quality Working Groups. Major changes of the MC services have to be agreed with the EC in the framework of the Copernicus programme.

Dissemination and archiving

The EUMETSAT Sentinel-3 Marine Centre interfaces with the multi-mission integrated facilities for dissemination and archiving at EUMETSAT. These facilities are already providing for the meteorological satellite services of Europe (e.g., for Meteosat and Metop).

The core set-up for dissemination of the NRT and offline (STC and NTC) products is the Online Data Access (ODA). This is a rolling archive of the products stacking the last 30 days. The ODA is accessible using FTP and HTTP protocols. In addition, as can be seen from Table 1, several products will also be disseminated using EUMETCAST. EUMETCast is a multi-service dissemination system based on standard Digital Video Broadcast (DVB) technology. For the near future also terrestrial broadcasting methods for the MC product dissemination are envisaged.

All the level 0, level 1 and Marine level 2 products are archived in the EUMETSAT Data Centre. From this centre the level 1 and level 2 products can be ordered in a variety of delivery formats.

User support services will be integrated in the wider Earth Observation Portal (EOP) at EUMETSAT. These services include cataloguing of the products, user registration, user notifications, helpdesk and training on use of the products. Upcoming users of the sentinel-3 Marine products are invited to familiarize themselves with the dissemination and user interfaces.

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Esa Web

sentinel.esa.int/web/sentinel/missions/sentinel-3

Ocean colour products from geostationary platforms, opportunities with Meteosat Second and Third Generation

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Abstract:

Ocean colour applications from medium resolution polar-orbiting satellite sensors are maturing and have provided the justification for the Sentinel-3 OLCI mission in the framework of the European Earth Observation Copernicus programme. Key drivers for Copernicus are the national obligations of the EU member states to report on the quality of coastal and inland waters for the EU Water Framework and Marine Strategy Framework Directives. Further applications include CO_2 sequestration and carbon cycling, fisheries and aquaculture management, near real time alerting for harmful algae blooms, and the assessment of sediment transport in coastal waters, particularly as related to human activities such as dredging, and offshore construction. Nevertheless. ocean colour data from satellite polar-orbiting platforms suffer from lack of coverage during cloudy periods and in-between the consecutive swaths, and from inadequate resolution of quickly varying processes. Ocean colour remote sensors on geostationary platforms can provide an enormous improvement in sampling frequency which will bring major advantages and new applications and services. The paper focuses on ocean colour products that are being developed from the EUMETSAT's SEVIRI instrument on the geostationary MSG platform. The products will enable monitoring of coastal sediment transport, water turbidity, tidal dynamics and water clarity. Further products and services are investigated from the EUMETSAT's FCI instrument on MTG.

Keywords: geostationary, ocean colour, water turbidity, SEVIRI, FCI, Meteosat

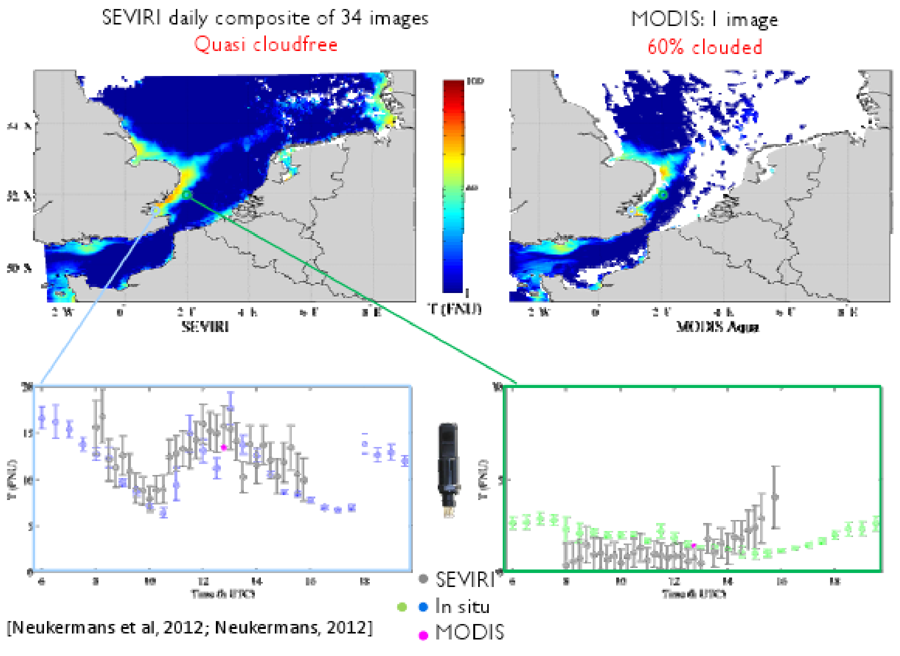

Figure 1 Daily composite of the SEVIRI turbidity in the southern North Sea and its diurnal dynamics at two sites compared to a single daily MODIS scene (pointed as a red dot in the daily time series).

1. Introduction

There is an established user need for a range of water clarity and bio-geochemistry information services to support reporting requirements of the European Union within Water Framework and Marine Strategy Framework Directives. Global optical coverage of marine, coastal, estuarine and lake water clarity and bio-geochemistry provided by polar orbiting sensors is however significantly reduced due to clouds, as well as gaps between orbits and sun glint. For example, at 4 km spatial resolution, polar instruments provide typically between 4 and 8% coverage of the global ocean per day, depending on the swath-width and glint avoidance capabilities (IOCCG, 2007). Merger of data from multiple polar missions increases the global coverage but is not straightforward because of systematic biases between instruments at the level of accuracies of ocean colour products due to instrument calibration and algorithm differences (Kwiatkowska and McClain, 2009). Many high spatio-temporal marine processes cannot be adequately resolved by infrequent observations from polar platforms (Antoine et al., 2012).

Recurrent daily observations from a geostationary platform significantly increase the coverage of the water optical processes. For example, the first geostationary ocean colour instrument GOCI from Korea (Ryu, 2013) provides a three-fold improvement in coverage of the waters around the Korean peninsula just with 8 scenes per day in comparison with a single daily geostationary coverage. A high-temporal monitoring could provide information on fast varying processes in coastal ocean, estuarine zones, and lakes which are of special interest to the majority of data users. It would also provide the required input to coupled models to meet operational needs for marine and coastal nowcasts and forecasts. These processes include:

- Tidal dynamics, eddies, fronts;
- Exchange of materials at the land-sea interface, sediment transport, particle tracking, coastal erosion;
- Rapidly evolving phenomena such as river plumes;
- Hazards, for example tropical storms, tsunamis, chemical/oil spills, flooding/river runoff, icebergs, sediment plumes, ship waste disposal.

2. Meteosat second and third generation

The Meteosat Second Generation (MSG) series comprises four satellites in geostationary orbit 36,000 km above the equator. Meteosat-8, -9 and -10 operate over Europe and Africa and Meteosat-11 is planned to be launched in 2015. Meteosat-10 (launched from the Guiana Space Centre in Kourou in 2012) is the prime operational geostationary satellite, positioned at 0 degrees longitude providing full disc imagery every 15 minutes. Meteosat-9 (launched on 2005) provides the Rapid Scanning Service, delivering more frequent images every five minutes over parts of Europe, Africa and adjacent seas. Meteosat-8 (launched in 2002) serves as a back up to both spacecraft. Meteosat-7 (launched in 1997) is the last of the first generation of Meteosat satellites and operates over the Indian Ocean, filling a data gap over the region until it is de-orbited in 2017.

EUMETSAT's MSG satellites carry an optical imaging radiometer, SEVIRI, with solar bands in the range of 0.635 μm, 0.81 μm, and 1.64 μm, which are suitable for ocean colour retrieval (MSG Documents, 2014). SEVIRI's frequent imaging of the Full Disk at High Rate every 15 min has been demonstrated to improve temporal coverage of coastal, estuarine and lake water clarity variability, including tidal effects, sediment transport, and environmental impacts of human activities and hazards (Ruddick et al., 2014; Neukermans et al., 2012). Figure 1 presents diurnal dynamics of water turbidity at two sites in the southern North Sea captured by SEVIRI and buoy measurements and compares it to a single daily scene from a polar-orbiting instrument, MODIS. SEVIRI imaging has been also shown to be capable of distinguishing specific bio-geochemical features, such as coccolithophore blooms, as for instance demonstrated in the Bay of Biscay (Vanhellemont et al., 2013).

EUMETSAT's Meteosat Third Generation (MTG) Imaging satellites will carry Flexible Combined Imager (FCI) instruments, which are the upgraded continuation of MSG SEVIRI with additional spectral bands in the visible blue and green wavelengths, 0.444 μm and 0.51 μm, both potentially suitable for additional ocean colour products (MTG

System Requirements Document, 2013). Frequent imaging of the Full Disk High Spectral resolution Imagery every 10 min has an evident potential to further improve temporal coverage of marine, coastal and estuarine and lake bio-geochemical processes. The better spatial resolution of 1 km at nadir is an improvement on SEVIRI's 3 km resolution and is suitable for global ocean observations and coastal and lake studies.

3. Ocean colour feasibility studies

A feasibility study for geostationary ocean colour products using MSG SEVIRI has been accomplished by Remote Sensing and Ecosystem Modelling (REMSEM) team at the Operational Direction Natural Environment (OD Nature) – department of the Royal Belgian Institute of Natural Sciences (RBINS). The team used SEVIRI to show capabilities for tracking of high spatio-temporal events and for cloud avoidance (Neukermans et al., 2012; Ruddick et al., 2014). SEVIRI spectral bands in red and NIR allowed deriving suspended sediment, turbidity and Kd_PAR, which are used for sediment transport, tidal dynamics, and ecosystem monitoring. The critical proof-of-concept demonstrated that atmospheric correction and in-water algorithms can be adapted to the SEVIRI sensor for these specific products. The method has been implemented for Belgian coastal waters where the in-water sediment signal is relatively strong in the red band but the atmospheric correction is fairly demanding at the 3.4 to 5.4 range of airmass. The coarse spatial resolution of 6 km at the Belgian coast is also not optimal.

The concept study showed that SEVIRI could be used as an effective substitute to ship campaigns to acquire the turbidity measurements required by the Water Framework Directive.

4. Initiatives towards operational processing

Recently, EUMETSAT have started two initiatives towards operational processing of ocean colour products from geostationary platforms, one for MSG and one for MTG.

This MSG initiative is a study with several objectives. These are: to collect and analyse user requirements for SEVIRI ocean colour products for monitoring, forecasting and real-time warning applications; to conduct scientific development of SEVIRI ocean colour algorithms that will operate over the full disk coverage and be suitable for real-time applications; to specify an operational product definition; and to prototype a processing chain suitable for near real time processing, including product quality and validation assessment.

SEVIRI ocean colour products include water turbidity, diffuse attenuation of photosynthetically active radiation (Kd_PAR), euphotic depth and, potentially, coccolithophore blooms and Total Suspended Matter (TSM) concentrations. The important scientific issues are related to the actual spectral, spatial, and radiometric limitations of the SEVIRI sensor as well as to the atmospheric correction of geostationary data. Algorithm error budgets include assumed atmospheric model (plane parallel or spherical shell), airmass extremes over daily and annual coverage, and other uncertainties, such as straylight from land and clouds, sunglint,and backscattering geometry.

The MSG study has kicked off in the first quarter of 2015. If successful, the study will be followed by the implementation of SEVIRI's ocean colour operational system and the demonstration of services. A potential follow-on activity can also generate a multi-year time series of ocean colour products from SEVIRI's full historical data record for climate applications.

The second planned initiative is also a study. The objective is to evaluate MTG FCI capabilities to provide additional ocean colour products enabled by new bands in the blue and green. These products include chlorophyll-a concentrations, the main photosynthetic pigment of in-water phytoplankton used as an index of phytoplankton biomass. The applications of the chlorophyll products are very diverse, from fisheries, water quality and harmful algal bloom forecasting to managing marine and coastal ecosystems and to climate and Earth system science. Regular measurements of coastal and in-land water chlorophyll levels are required by the European Commission towards its Maritime Strategy Framework Directive and the Water Framework Directive for achieving the Good Environmental Status.

The study will extend the user requirements and atmospheric correction developments following the MSG work. It will then evaluate suitability of FCI's spectral and radiometric characteristics, calibration accuracies, SNRs as well as air mass extremities to retrieve ocean colour products from open ocean, coastal and lake environments. A proposed chlorophyll-a concentration product will be studied for its detection limits and matched against user requirements. The study can also provide possible FCI characterization and ground processing recommendations that could improve ocean colour products and match them closer to user needs.

5. Conclusions

Ocean colour observations from a geostationary platform provide potentially major benefits compared to the current monitoring from polar orbits. It would significantly increase the coverage availability through the delivery of gap free data and it would allow monitoring and understanding of the high-frequency diurnal processes. Geostationary ocean colour would then open a capability for new applications and services. Considerable improvements in radiation budget products, such as of photosynthetically active radiation (PAR) are also expected. The paper introduces EUMETSAT's efforts to develop operational ocean colour services from its second and third generation of Meteosat missions. Despite the fact that the missions are not designed with ocean colour goals as requirements, the service potential is encouraging.

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Users and New Services

Characterization of coastal-maritime severe events in Basque Country

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Abstract

In this paper we present a study of coastal-maritime adverse events in Basque Country, taking into account different meteorological and oceanographical aspects, including the analysis of available parameters in the area from observation networks, models, warnings and damages data in Basque coastal area. We also present some conclusions for a better characterization of potential severity of adverse coastal-maritime events in Basque Country.

Keywords: waves, severe events, coastal damages, flood level, Basque Country

1. Introduction

The wave climate along the Cantabrian coast is related directly to its geographical setting within the Bay of Biscay and the northeastern Atlantic (Gonzalez et al. 2004). Due to its orientation and location, in relation to the low-pressure systems, which develop in the transitional area between the high-pressure region of Azores and the sub-arctic low pressures, the Basque coast is exposed to large fetches. Such fetches extend to distances of more than 1,500 km, from the centre of the low-pressure areas; as such, they are located frequently to the northwest of the British Isles and Iceland. The southern part of the continental shelf of the Bay of Biscay is exposed to a large range of possible sea states, in relation to wave height (Hs) and period (T); as such, it is considered a high-energy environment. Most registered wave periods range from 5 to 22 s, standing most frequently between 8 to 12 s.

In this work, we include the study of parameters available in the area from local observation networks, information from oceano-meteorological models and data about damages in the Basque coastal areas caused by coastal maritime adverse events. A first selection of events based on severity, representativeness and data availability is made. Then, after data analysis, a characterization of the main characteristics of episodes is made, based on different direct and derived parameters.

The ultimate goal of this study is to provide background and inputs for the update of the Basque Meteorology Agency (Euskalmet) coastal-maritime warning system.

2. DATA SOURCES

Different data sources are available in the area and are included in this study, particularly in-situ observing systems, models and impact-damages data.

2.1 Instrumentation

In the Basque Country area different observing systems are available from the Basque Government:

- Two buoys located in front of Donostia-San Sebastián (Donostia Buoy - DB) and Cape Matxitxako (Matxitxako Buoy - MB), over the slope (550 and 450 m isobaths, respectively), which provide, since 2007, hourly data of meteorological and oceanographic variables at the sea surface. In addition, a downward looking ADCP and a CTs chain measure currents and provide temperature and conductivity data, respectively (Ferrer et al. 2009).
- Six coastal stations (water depths <30 m) that provide, since 2004, 10-minute data of temperature, currents, tides and waves at six strategic points on the Basque coast (González et al. 2007, Fontán et al. 2009, Ferrer et al. 2007, 2009).
- A high frequency (HF) radar array with two stations (operating at ~4.5 MHz), located at the Basque coast, which provide hourly surface current fields, since January 2009 (Rubio et al., 2011, Ferrer et al., 2009).
- An Automatic Weather Stations (AWS) network on more than 100 AWS distributed all along the Basque Country territory (Gaztelumendi et al 2002).
- Others (Wind profiler, Meteorological Radar, electrical discharges detection system, radiosounding, etc.)

Spanish Government also maintains observing systems in the area, particularly a deep water Buoy in Bilbao (BB) from Puertos del Estado and other meteo observing systems from AEMET (Spanish meteorology Agency).

2.2 Models

Different wave operational and research models are available in the area:

- The Euskalmet wave forecast system developed by Tecnalia is based on WAVEWATCH (WW3) model (Tolman et al 1996,2002). The system runs once daily, with four nested domain grids. The system uses previous run fields and last available winds from operational Euskalmet mesoscale prediction systems based on PSU/NCAR models MM5 and WRF. System runs daily for five days in advance (Gaztelumendi et al, 2007, 2008, 2009).
- WAM wave model outputs (1.6 km horizontal resolution) are also available from AZTI-Tecnalia, forced by WRF model wind fields (Ferrer et al 2008, 2009). The conditions applied to the open boundary of the WAM grid are provided by NOAA WAVEWATCH III model using products of NCEP as input.

2.3 Effects-damages data

Effects-damages data consulted in this study originate from different sources. Non-official information (mainly qualitative) from newspapers, internet, social media and experts background. Official information related with damages in coastal areas available from Municipalities, Regional Government, Basque Government and Spanish government.

In any case, the most valuable (quantitative and well time-space referred data) data are provided for the Assurance compensation consortium: 1471 approved insurance reports including cost, damage type, date and precise location information for the period 2004-2014 (total amount of 47.955.000 €).

2.4 Warnings data

At Euskalmet, the weather warning system started as a simple system based on several meteorological fixed thresholds (2004). Later on, it migrated towards a more sophisticated system based on a traffic-lights colour concept with more flexible criteria (2009). Warning issues have moved, during the past years fully away from the fixed thresholds strategy (mainly focused on scientific-technical aspects) towards a more flexible, impact-based approach (mainly focused on civil protection and users) (Gaztelumendi et al 2012).

Coastal-maritime warnings migrated from a pure Hs threshold of 3 m (2004), to traffic-light colour (2009) 3.5, 5, 7 m thresholds (1.5 m less in summer–beach time) considering always significant wave height at coast (0-2 miles) (Gazteluemndi et al 2013).

During the last years, the content of the warning bulletin has also evolved. In the past contained pure Hs forecast information (Oct 2004), including swell wave height, period and direction (Jan 2005) and later on (2012) included tide information. Today, we use some combined criteria considering wave characteristics at the coast, tide and possible impact on the littoral, including short alert and alarm periods coincident with spring tide maximum time.

Date	Synoptic features	Maritime features	Severe weather clasification	Hs max (m)	Peak Period (s)	Energy (Kw/m)	Wave direction	Max tide level (m)	Hs max at high tide (m)	Peak period at high tide (s)	Barometric component (cm)	Euskalmet warning level	Effects	Stimated Damages (K€)
19/04/2004	Z, BL	SMW HF	NW Gale	7,8	14-15	432	NW	4.4	7.2	12,5	9	orange	light	35
18-19/01/2005	Z, AH	SMW HF	NW Gale	10,8	17-20	1057	NW	3.5	7.6	16,0	-12	orange	moderate	65
17/03/2006	Z, BL	SMW HF	High swell	8,3	15-18	557	NW	4.3	7.7	14,5	6	orange	light	39
20/01/2007	M, BBL	SMW LF	Wind storm	5,8	8-10	148	NW	4.2	5.4	9.3	5	yellow	light	238
10/02/2007	Z, BL	OW S	NW Gale	8,7	17	784	NW	3.4	8.1	17,0	0	orange	light	10
12/02/2007	Z, BL	SMW HF	Wind storm	10,1	17	884	NW	3.7	9.7	17,0	5	orange	light	4
7-8/03/2007	Z, BBL	SMW HF	Wind storm	11,1	12-14	813	NW	4.2	10,0	12,0	8	orange	moderate	
19-20/03/2007	M, AH	SMW HF	NW Gale	8,6	12-14	471	NW	5.0	7.1	13,0	4	red	strong	1.030
10/12/2007	Z, BL	SMW HF	NW Gale	11,8	17-18	1154	NW	4.1	9.5	15,0	-3	red	strong	3.125
10-11/03/2008	Z, BL	SMW HF	High swell	11,6	20	1319	NW	4.7	9.7	15,0	8	red	strong	14.517
23-24/01/2009	Z, BBL	SMW HF	Wind storm	13,7	15-17	1471	NW	3.4	12,0	16,0	23	red	moderate	2
10/02/2009	Z, BL	SMW HF	Wind storm	7,1	13-15	340	NW	4.5	6.7	13,0	-2	orange	light	27
05/03/2009	Z, BL	SMW HF	NW Gale	9,3	13-15	583	NW	3.2	8.5	14,0	8	orange	light	
08/11/2009	Z, BL	SMW HF	NW Gale	9,7	15-18	784	NW	4.0	9.1	12,5	5	red	light	11
8-9/11/2010	M, BL	SMW HF	NW Gale	10,6	17-20	1019	NW	4.2	9.2	14,5	33	red	strong	2.993
14-17/12/2011	Z, AH	SMW HF	Wind storm	8,1	15-18	557	NW	4.0	6.3	15,0	-2	red	light	45
18-19/04/2012	Z, BL	SMW HF	NW Gale	8,0	15-17	502	NW	4.4	5.7	15,0	15	orange	light	
23-24/04/2012	Z, BL	SMW HF	NW Gale	8,2	13-15	461	NW	4.2	3.2	14,0	1	orange	light	
28/01/2013	Z, BL	WW HS	High swell	7,3	15-17	441	NW	4.4	4.5	12,5	-7	orange	light	
11-12/03/2013	Z, BL	SMW HF	NW Gale	9,1	15	609	NW	4,5-4,8	6.4	14,5	0	orange	light	
3-4/01/2014	Z, BL	OW S	High swell	7,2	15-16	432	NW	4.8	6.5	16,0	8	orange	strong	5.006
6-7/01/2014	Z, BL	OW S	High swell	10,1	23	1150	NW	4.6	9.5	23,0	-2	orange	moderate	279
27-28/01/2014	Z, BL	SMW HF	NW Gale	7,9	15-17	505	NW	3,7-4	6.6	17,0	6	orange	moderate	608
1-2/02/2014	Z, AH	SMW HF	High swell	8,5	20	708	NW	4.9	8.1	16,0	-4	red	strong	18.559
05/02/2014	Z, BL	OW S	High swell	9,5	17-18	774	NW	3.9	8.0	17,5	0	orange	light	
8-9/02/2014	Z, BL	SMW HF	High swell	10,5	20	1080	NW	3.3	10,3	18,5	7	orange	light	
28/02-01/03/2014	Z, BL	SMW HF	Wind storm	8,9	15-17	621	NW	4,4-4,8	8.1	16,5	0	orange	moderate	
3-4/03/2014	Z, BL	SMW HF	NW Gale	11,1	19	1147	NW	4,0-4,8	8.6	16,5	3	red	strong	621

Z: Zonal, M: Meridian SMW HF: Strong maritime wind with high fetch, SMW LF: Strong maritime wind with low fetch, OW S: Offshore wind with swell, WW HS: Weak wind and high fetch
BL: Britanic low, BBL: Bay of Biscay low, AH: Azores High

Table I Data summary for relevant events.

3. DATA ANALYSIS

3.1 Episode selection

The selection of events is done taking into account three main aspects:

(i) potential severity (based on significant wave height threshold 7m criteria, warning level issued and experts consideration)

(ii) data availability (we need to guarantee enough data information for the in-deep analysis and characterization of the event)

(iii) effects (using direct damages data when available).

We select 28 episodes within the period 2004 to 2014 (see Table I). 19 of these events cover 99,9% of the economic losses declared. 9 extra events without reported damages, but with operational interest and high potential impact due to its wave and tide characteristics are included.

3.2 Meteorological aspects

Considering meteorological aspects, the events can be classified into 2 main groups:

(1) The events related to deep lows travelling through the Atlantic from southwest to northeast, with a marked zonal component in higher latitudes. They are mostly explosive cyclogenesis that do not affect directly the Basque Country.

(2) The intense northwest flows with an extended trajectory over the sea, between the Azores anticyclone and the low pressure systems in the Britannic Islands.

90% of the events correspond to zonal circulations and 75% of events correspond with Britannic lows configurations on surface. If we consider Euskalmet severe weather classification: 46% corresponds to NW Gales, 28% Wind storms and 28% to high swell. 82% damages occurred during high swell episodes, while 18% is related to NW Gales (Gaztelumendi et al 2014).

3.3 Waves aspects

The wave climate along the Cantabrian coast is related directly to its geographical setting within the Bay of Biscay and the NE Atlantic. Due to its orientation and location, in relation to the low-pressure systems, which develop in the transitional area between the high-pressure region of Azores and the sub-arctic low pressures, the Basque coast is exposed to large fetches.

The low pressures generate strong winds over the North Atlantic and large waves from the fourth quadrant (270º to 360ºN). Such waves, arrive at the Basque Country as swell from the northwest, this situation is quite frequent over the area and coexists with local light wind or with strong and relatively persistent winds from different directions.

82% of events are related to episodes of strong maritime winds with high fetch and 14% with offshore wind with swell.

Selected events show great variability with Hs from 5.8 to 13.7 m, directions from 280 to 325 deg, periods from 13.3 to 23.3 s, tide level from 3.5 to 5m and energy flux from 432 to 1471 KW/m. In most part of the selected events significant wave heights surpass 7 m, and peak periods surpass 14 seconds.

The combination of wave height and peak period is basically related to the intensity and distance to the generation area. A closer, but less energetic, storm inside the Bay of Biscay can generate waves with similar size than those coming from much bigger but more distant storms. Anyway, the periods would be much bigger in the second case and so will be the energy of each wave on the coast.

3.4 Tides

Since we are especially interested on the effect of these adverse events on the littoral, we should also take into account the effect of tides. In fact, the most problematic events are not related to the highest wave heights but to situations of high long period waves coincident with high tides, specially, during spring tides. The most harmful events occur with tide levels over 4,5 m.

4. EVENTS CHARACTERIZATION

4.1 Impact analysis

The distribution of dama along the littoral is variable, although it corresponds mostly to damage within harbours (Bermeo 30%, Orio 12%, Ondarroa 5%) and damages to shops, stores, houses offices and motor vehicles (Donostia 37%, Zarautz 6%).

The correlation between the different oceano-meteorological parameters and the registered coastal damages is not straightforward, as we can see examining some cases:

The 19-20/03/2007 event occurs during an exceptional maximum tide level (5 m), conversely, the peak period and maximum wave height during the high tide are weak (13-14 s, 8.6 m,). The importance of the damages generated by this concrete event (>1000k€), illustrate the fact that the mean sea level is a key factor.

During the 23-24/01/2009 (Klaus) event, the significant wave height registered beats the record of the time series (13,7 m), the peak period 16 s. However, the high tide level is only 3,4 m and the damages generated are not so relevant compared to other events (2k€) (Egaña et al, 2009,2010).

During the event of the 6-7/01/2014 the highest peak period of the series is registered (23 s). Maximum tide level is 4 m and significant height is 9.5 m. Damages reported are medium with punctual floodings (270k€).

The two most relevant events (responsible for 70% of the reported damages for the last ten years) are those of 10-11/03/2008 (Hs 9.7 m, Tp 15 s during max tide 4.7 m) and 01-02/02/2014 (Hs 8.1 m, Tp 19 s, during max tide 4.9 m) . They correspond to a combination of tide levels over 4.7 m, significant wave height over 8 m and peak periods over 15 s. In both cases damages are generated by a combination of waves impact and flooding (14.917k€, 18.559k€) (Egaña et al 2014, Gaztelumendi et al 2014)

In order to understand the economic impact of waves on thecoast line we must consider some non-oceano-meteorological factors, including:

- small scale variations of the coastline.
- orientation of seawalls and harbours.
- exposure of some areas to the incident wave field.
- configuration of beaches
- distribution of human population and goods.
- effect of the preventive measures applied.
- previous situation (the economic losses on previously damaged areas tend to be less significant).

4.2 Derived variables

For an accurate characterization of the impact on the coast, we must consider all together with wave characteristics, different physical factors related with shoreline characteristics

We include in the analysis the estimation of extreme run-up (Ru%2) during storm conditions, a well-known parameter that plays a critical role in dune erosion and structure overtopping during storm conditions (Ruggiero et al., 2001).

Here we consider run-up as the height of discrete water-level maxima depending on two different processes; wave setup and total swash excursion. We use Stockdon (2006) empirical parameterization for extreme run-up, defined by the 2% exceedance value (Ru%2), including: the foreshore beach slope (β), offshore wave height (Ho), and the deep-water wavelength (Lo).

$$R_{u\%2} = 1.1\left(0.35tg(\beta)(L_0H_o)^{1/2} + \frac{[H_oL_0(0.563tg^2(\beta) + 0.004)]^{1/2}}{2}\right)$$

In beaches not directly exposed to the deep waters incoming wave direction, it is recommended the use of the wave height at the breaking point (H_b) instead the deep water wave height (H_o). In this study, H_b is calculated transforming with linear wave theory deep waters wave conditions (H_o, T_p, D_o) to breaking wave height in a bathymetry and coastline facing.

$$H_b = \left(0.22\, H_0^2 T_p \cos\,(360 - D_0)\right)^{2/5}$$

Coastal alignment is important for Hs translation from buoys location to littoral level and H_b calculation. The Ru%2 has been calculated along the 3 different orientations of the coast (320º, 340º, 360º) using the Stockdon formulation.

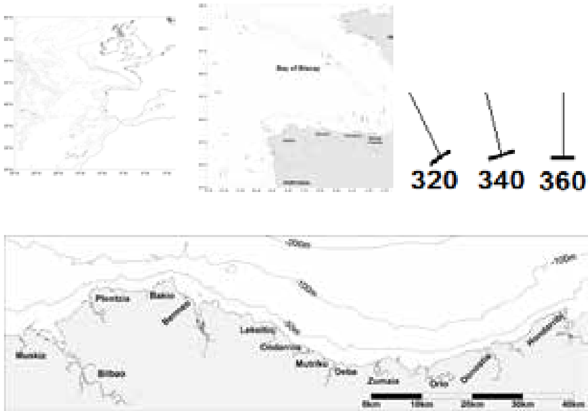

Figure 1 Basque coast.

In order to evaluate potential penetration of water during the storm, we introduce the Flood Level (Fl) a parameter related with flood potential that combines the effects of increased water level at the shoreline due to astronomical and meteorological tide (Sl) and the breaking of waves and transfer of momentum to the water column (Ru2%). At the end, damages are related with maximum extension of water penetrating on the coast during the storm due to the worst combination of run-up extension and tides.

$$Fl = R_{u\%2} + Sl$$

4.3 Statistical analysis

Some statistical analysis are done (including multiple regression) for a better understanding of the relative importance of each parameter in the event characterization, and, particularly, in order to extract relationships with damages occurrence.

The dependent variable is the economic damage value and the independent variables are: sea level (Sl), significant wave height (H_o), peak period (T_p), and direction (D_o) at undefined depths, breaking wave height (H_b), coastal energy flux, T_p/T_{m02} relationship, flood level (Fl) for three different directions (320, 340 and 360) and for dissipative beach slope (β=0.02) and rocky coastline with artificial structures (β=0.09).

As a result of these studies, just four parameters show correlation bigger than 50% with damages; particularly Sl and Fl for dissipative beach slope. Maximum correlation values (67%) are obtained for the Fl with 360° coastal alignment.

For simplification purposes, we choose as representative for the whole Basque Coast the value of Fl in the "worst case" (meaning coastal orientation of 360° and β=0.02).

5. Conclusions and future work

Most part of the adverse events is characterized by swell situations generated by remote deep lows and NW gales, since these configurations favour high fetch and high wave heights.

The combination of high significant wave heights, without being exceptional, with high wave peak periods and spring high tides can be much more destructive than an event of extreme waves coinciding with neap tides.

Storms with a more North peak direction have greater impact on the Basque coast.

Waves characteristics combined with the alignment of the coast and the mean sea level during the peak of the storm, result in very different levels of littoral impact associated to similar wave height condition in deep waters.

Flood Level seems to be a good and relatively simple parameter to take into account coastal effects due to the combination of run-up (setup plus swash) and sea level conditions (barometric and astronomic tides).

From the operational Euskalmet point of view, coastal-maritime warning system must incorporate those aspects, including a new type of maritime-coastal warning oriented to coastal impact. In this case, analysis of wave characteristics during high tide is critical and, particularly, the analysis of flood level.

In the future, we must include other coastal impact indicators, not just € (spatio-temporal damages extension, warnings, emergencies interventions…), and extend statistical analysis. We also need to find operational routines maximizing Hit Ratio and minimizing False Alarm Ratio, to establish warning/alert/alarm thresholds for coastal impact and to incorporate new considerations on numerical guidance model.

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Actual status of operational oceanography at the Mediterranean Sea: The MONGOOS perspective.

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Abstract

The Mediterranean Operational Network for the Global Ocean Observing System (MONGOOS) was established in 2012 to further develop operational oceanography in the Mediterranean Sea. MONGOOS comprises the previous activities of MOON and MEDGOOS. In this framework, a complete survey of Mediterranean Sea countries Operational Oceanography capabilities has been carried out by MonGOOS partners. This survey provides an updated vision of all existing systems in the region, as well as an image of its actual operational status. Modeling, in-situ and remote sensing capabilities have been explored. As a result of the survey, a new specific service has been developed in the MonGOOS web page (http://www.mongoos.eu/). Access to modeling systems and in-situ data is provided through this service. The new product directly links to the services operated by all data providing institutions, being an alternative and complementary approach to the more centralized system being developed at EMODNET and MyOcean. Analysis of the data shows a huge range of data availability and accessibility in the region. Operational forecasting systems in the region can be considered, in general, state of the art. With respect to in-situ data, the study confirms the well-known under-sampling of the African coast.

Keywords: Operational Oceanography, Mediterranean sea, numerical models, networks, real time

1. Introduction

The Mediterranean Operational Network for the Global Ocean Observing System (MONGOOS) was established in 2012 to further develop operational oceanography in the Mediterranean Sea. MONGOOS (http://www.mongoos.eu/) comprises the previous activities of MOON and MEDGOOS. MONGOOS is promoting partnerships and capacity building for GOOS in the Mediterranean Sea and creating a continuous working framework with EuroGOOS and GOOS Africa in order to define common roles and activities in the Mediterranean Sea.

One of the roles of MONGOOS is to assess the status of operational oceanography in the Mediterranean Basin and suggest working lines to be fulfilled in future projects or initiatives. Unfortunately, it was detected that the existing inventories of models, in-situ stations and remote sensing capabilities were not properly updated or complete enough to fulfill this task. Additionally, accessing the data, or the data originators, was a difficult task due to this absence. Finally, in most of the cases, little visibility and credit was achieved by the data originators, often displaying their real time data on their web sites without really being noticed by the community.

In order to overcome these gaps, a new service, *the MONGOOS showcase tool*, was designed and implemented. Access to modeling systems and in-situ data is provided through this service, based on a GIS interface. The new product directly links to the services operated by all data providing institutions.

In parallel to this effort, HCMR has developed the MONGOOS Data Center, now also fully integrated into the MONGOOS web page. This system, developed mainly in the framework of MyOcean project, provides access to real time data from most of the existing operational oceanography instrumentation in the region thanks to a complete access to the MyOcean In-Situ TAC (Thematic Assembly Center). The TAC collects automatically, data from most of the stations station in the region into a single server.

Both products follow radically different approaches and have their own benefits. While the more centralized Data Center provides a consistent access to the real time data in the whole Mediterranean Sea, the de-centralized Showcase presents access to the original data providers, on some occasions including additional or more updated information

The present work describes in detail (sections 2, 3 and 4) the Showcase tool and, for the sake of completeness, the Data Center (section 5). Due to the complex nature of the second product, the related details deserve and require an independent paper. Finally, both products are employed in section 6 in order to diagnose actual status of Operational Oceanography in the region and propose future lines of development.

2. Showcase tool: methodology

The tool was designed with the objectives to:

- serve as a simple and visually attractive GIS based overview of the existing systems for forecasting and monitoring the Mediterranean Sea
- give access to the available real time data (in graphical format and/or numerical) as provided by the data originators
- increase visibility to MONGOOS partners
- provide easy contact with data originators

The technical requirements were:

- to include a simple mechanism to keep the product updated, allowing the inclusion of future new information
- to provide full integration into MONGOOS web page

In order to fulfill these objectives and requirements the Showcase Tool has been designed in the form of maps with clickable information on the existing monitoring system and in-situ stations. The links in the maps connect both with the web page of the originating institution and with the data itself, as provided by the mentioned center.

Technically, the maps obtain all the information from a Mysql data base running in a Linux server. In order to provide all the required information to the data base, an excel file with all the required fields was created. The file was circulated several times to all MONGOOS members, until a satisfactory degree of completion was achieved. Special care was taken in maintaining a consistency of the inputs from all members.

By doing so, a complete survey of Mediterranean Sea Operational Oceanography capabilities has been developed. This survey provides an updated and realistic synoptic vision of all existing systems in the region, as well as an image of its actual operational status.

With respect to satellite data, an inventory of data sources to obtain information in the Mediterranean region has been developed as an independent section of the Showcase Tool

3. Showcase tool: the existing forecast systems

3.1 Waves

Figure 1 shows the existing operational wave forecasting systems in the Mediterranean Sea. There are 33 models in total, some are covering the whole basin while others are nested coastal models, providing solutions to harbours or other small areas. Most of the large scales implementations are based on the WAM model, while the coastal ones are using mostly SWAM. Atmospheric forcing is also different, with origin in models like HIRLAM, WRF or Skiron.

There are similar number of models in the Eastern and Western sub-basins, and an absence of high resolution nested application on the African Coast.

3.2 Circulation and Hydrography

Most of the models (figure XXXX) are nested into the Mediterranean Sea-MONGOOS Marine Forecasting Centre developed by INGV in the framework of MyOcean series of projects. It consists of a 3d-baroclinic implementation of NEMO code, including data assimilation and, since the last version, atmospheric pressure forcing. The forecast horizon is 10 days and it is forced with ECMWF atmospheric fields. Horizontal resolution is 1/16° and employs 72 vertical layers (z-coordinate).

Nested applications are, in most of the cases, POM and ROMS based forecast systems. Usually, do not employ data assimilation. There is a good coverage of both sub-basins. Typical forecast horizon is 5 to 10 days. Usual resolution in 1 or 2 km, being as low as 200 meters in the case of the Puertos del Estado-SAMPA model at the straits of Gibraltar. The number of vertical levels is, very frequently, between 20 and 30 using all kind of coordinate systems.

Almost all the models use NetCDF as output format and are executed once per day.

Only a few models are employing atmospheric pressure forcing, something fundamental to for sea level (storm surge) short term-forecast. A few systems are specialized in this variable and phenomena, working in 2D barotropic mode. In order to distinguish the applications able to deal properly with these phenomena (2D or 3D), they are displayed in another independent map in the tool (not shown here).

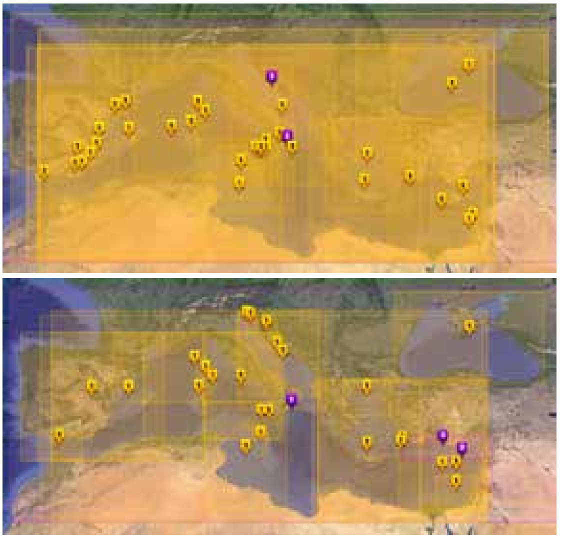

Figure 1 Existing wave (upper panel) and circulation (lower panel) operational models as shown by the Showcase Tool

4. Showcase tool: the existing monitoring systems

The numbers and descriptions presented in this section correspond to the result of several iterations with all the institutions and MONGOOS and, on occasions, with some others with activity in the region and are still not part of the organization. In spite of evident gaps (i.e. no tide gauges reported at Greece) it constitutes the most comprehensive catalog of available oceanographic measurements in the region. Figure XXXX shows the distribution of wave, sea level, SST and salinity sensors.

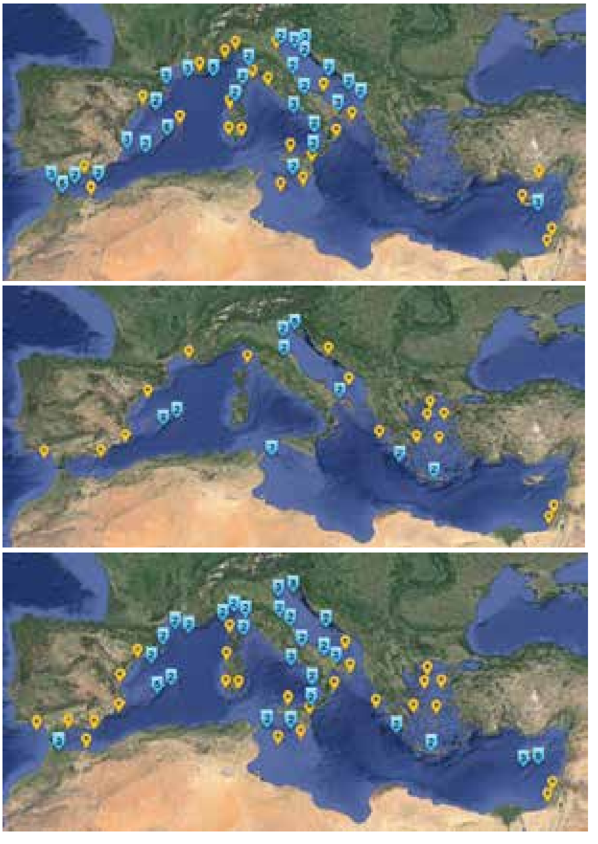

Figure 2 maps of sensors for waves (upper panel), sea level (second panel), current meters (third panel) and water temperature (bottom panel)

As previously explained, the Showcase Tool contains links to the web page section of the data providers that contains the measured data on real time, most of the times in graphical format

It is also important to note that only handles fixed stations, so ARGO floats, gliders and other sources of valuable information are not included yet.

4.1 Waves

In total there are 58 buoys capable of measuring waves, most of them directional. Coverage is more complete in the western basin and there is an almost total absence on the African coast, with the exception of Ceuta and Melilla stations.

4.2 Circulation and Hydrography

Water temperature is the most frequently measured variable on a regular basis, with 113 stations. Only 37 current meters are operational in the whole region. 50 salinity stations are reported. No stations are present on the African coast.

4.3 Sea level

A total of 100 sea level stations are reported in the region. There is a significant gap in Eastern Europe that is due to lack of data in the Showcase Tool, not to absence of stations. MONGOOS community is working on solving this coordination issue. Once more, there is a total absence of stations in the North African coast, except for the ones at the Spanish cities.

4.4 Atmospheric variables over sea

Several buoys and towers are able to measure atmospheric variables' over the sea: The tool contains information of 80 Meteorological stations capable of measuring air pressure, temperature and wind.

5. The mongoos data center

The MONGOOS Data Center, developed by HCMR, collects and processes data from in-situ platforms in the Mediterranean Sea. It is the regional node for the In-situ component of the Copernicus Marine Core Service (MCS).

Distributes added value (quality controlled) data in a unique format. It was built through MyOcean series of projects, but it supports the Mediterranean observing component of major EU projects in Operational Oceanography (Jerico, Perseus, FixO3).

It is fully integrated into MONGOOS web page (see figure 3).

Figure 3 The MONGOOS data center as shown on the web page

6. Discussion

6.1 Forecast systems.

Both, by number and quality of the operational systems, the Mediterranean area is reasonably well covered, as compared to other regions. There are, in general, sufficient "*state of the art*" models for waves, sea level and circulation.

For circulation, the level of coordination between MONGOOS community institutions is remarkable and superior to other European areas, following clearly the well-known Copernicus "butterfly" approach: most of the nested models are getting boundary conditions from the MyOcean system.

A major practical limitation is, as in other seas, the lack of in-situ real time data to be assimilated into circulation models. Due to the limited amount of stations available and the small size of the mesoscale patterns, models do not always locate these in the "right position", in spite of the application of data assimilation algorithms. This problem leads to severe uncertainty in the current forecast at a specific point and time. This is particularly important when trying to apply the model results to certain specific applications, such as search and rescue operations. In any case, this is a problem shared by all circulation models in the world that are not running in regions strongly dominated by barotropic induced processes, such as tides.

6.2 In-situ component

For some variables, and in certain regions, the monitoring system is quite satisfactory. For example, the number of tide gauges in the western European Mediterranean coast is sufficient for most of the applications (study of sea level trends, storm surge monitoring, etc.). A similar situation can be found for wave buoys.

Nevertheless, the absences and limitations of the monitoring system are clear and often dramatic. First of all, the African coast presents an almost total absence of data. There is a radical North-South imbalance. The only exceptions are the stations located at the Spanish cities of Ceuta and Melilla. Even on the European coasts, there is an obvious unequal distribution of sensors as a result of a lack of global planning.

Other variables, like currents, are clearly under-sampled in the whole region. The same situations apply for salinity and water temperature, although for these variables data from gliders and ARGO serve to mitigate the situation. In any case, due to the size of mesoscale structures in the region, the limited number of sensors is clearly insufficient to properly contribute to data assimilation in numerical models, as previously pointed out.

The solution to this problem is complex due to the high cost of maintaining these sensors at sea. Only a proper combination of satellite data (SST and altimeter), additional in-situ stations, an increased glider fleet and HF-radar data could provide the data needed to reduce model uncertainty to a fully satisfactory level for applications such as Search and Rescue.

In any case, almost all the known stations are providing the data to MONGOOS data center, so coordination is not a big issue anymore. The problem is the absence of data.

7. Conclusions and future work

A new Showcase Tool has been developed by MonGOOS in order to directly access numerical forecast systems and in-situ stations. It shows partners existing capabilities. It is available at MonGOOS web page.

In the future, the Tool will be improved with more data.

HCMR has developed the MONGOOS data center, based on the work done at MyOcean series of projects. It is fully integrated into MONGOOS web page and offers an alternative and more centralized approach to the Showcase Tool.

With respect to model forecasting, the situation of the region is satisfactory, with state of the art models running operationally at different scales, and similar to the one existing in other regions. Lack of in-situ data is a limitation for circulation models. This is particularly true in this area due to the small scale and importance of mesoscale structures.

With respect to in-situ data, the number of stations covering certain variables, such as currents, is insufficient, while others like waves are properly addressed in specific regions like the French and Spanish coast.

For all variables, there is a dramatic North-South imbalance. There is an almost total absence of instrumentation on the African coast, except in the Spanish cities of Ceuta and Melilla. Therefore, there is an urgent need to find international collaboration mechanisms to promote implementation of measuring networks in the North African Countries. This activity should rely, from the beginning, on the work of the local technicians. In this sense, the formation needed to install and maintain the equipment should be provided from day zero. By working in this way, the possibilities of long term sustainability would be substantially increased.

One of the MONGOOS roles is to act as a focal point of regional activities, promoting the improvement of existing systems and the development of new ones (special focus in Northern Africa). It is therefore expected, from MONGOOS partners and organization, to be active in this field.

On some occasions there are difficulties for data interchange of data and coordination, but this is clearly not the major problem in the region. The major problem is the absence of measurements. This is a clear message pointed out by MONGOOS communities during its meetings.

Acknowledgements

The authors wish to thank all MONGOOS community for the support provided during this work. Susana Pérez Rubio deal with lots of the co-ordination work while creating the tool. Initial reviews were carried out by Pilar Gil and Begoña Morón. Arancha Amo deal with the problem of formatting properly all latitude and longitude references. The company NoLogin was in charge of the software development associated to this work.

COPERNICUS Coastal Service, the FP7 Space projects prospective

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Abstract

A group of scientists and representatives of companies drafted the scope of a potential operational COPERNICUS Coastal service covering both marine and land aspects (coastal waters, shoreline and hinterland), to be considered in the operational framework of the COPERNICUS programme. The aim is to stimulate the discussion on the extent of a Sentinel satellites-based coastal general service in the COPERNICUS operational phase 2015-2020 and to sum up the current environment monitoring capacity which has been developed through prototype services built on EC FP7 and ESA R&D funds.

"Coastal monitoring" is a short name for the collection, analysis, publication, merging and mapping of observations, whether in-situ or remote sensed measurements (qualitative or quantitative), and observations-derived parameters which can be used as legal evidence for the implementation of EC directives on pollution prevention, water quality enforcement and environment preservation (e.g. Water Framework Directive –WFD, Marine Strategy Framework Directive -MFSD) and as indicators for Coastal Spatial Planning (CSP) and Integrated Coastal Management (ICM).

It requires: - consensus of the parties involved (authorities, scientists) on measurement and assessment methods, -indisputable measurements supported by calibration, inter-calibration and validation, - ways and means to 'expand' spatially, temporarily and causally the measurements and their extrapolation through algorithms and dynamic modelling (data assimilation), and interpolation schemes. Quantitative measurements are usually in-situ ones, used as such or for calibration of remote sensing, and remote sensing is an 'expansion' mean.

This communication informs about the products/information that would be readily available on reference/initial states, trends and events, with their uncertainties assessment so as to draft national regulations on measurements/observations dedicated to policy enforcement. The preliminary architecture of a pan-European general service is outlined, with links to the COPERNICUS land/marine/atmosphere and other public services.

Keywords: Copernicus, Earth Observation, Coastal monitoring, WFD, MSFD, ICM, Copernicus coastal service

1. Introduction

This communication drafts the scope of a potential operational COPERNICUS/GMES *Coastal Monitoring* service to be considered in the operational framework of the COPERNICUS/GMES program. The aim is to stimulate the discussion on the extent of a COPERNICUS Coastal Monitoring Service in the operational phase 2015-2020 (covering both marine and land aspects) and to inform the EC on the coastal service monitoring capacity developed though prototype service built on R&D funds. The main motivation is the successful achievement of several FP7 R&D projects that have paved the way towards operational monitoring services. These projects are FP7 AQUAMAR, FP7 COBIOS, FP7 ASIMUTH… and ESA GSE Marcoast. Based on the COPERNICUS operational services deployment, particular emphasis is made on processing and delivery of products derived from Earth Observation for such a Coastal Assessment and Monitoring service.

In order to enact, enforce and ensure that member states abide by the regulations which derive from relevant European Directives, and also in order to optimise the use of coastal areas in a sustainable development framework, there is a need for reliable monitoring tools of the ecological status of the coast and shoreline.

2. Coastal monitoring for who ?

Due to the fact that coastal areas support a convergence of activities, there is a wide range of users with mandates or requirements to collect information and monitor aspects of the coastal environment. For the three policy areas (Marine Strategy Framework Directive, Water Framework Directive, Integrated Coastal Management) the national level agencies involved in the different member states include:

- National Environmental Protection Agencies
- National Geological Surveys/Resource Management Agencies
- Water Agencies/Authorities
- National Hydrographic/Land Survey Agencies

In addition, in many cases (eg collection of water quality information), responsibility for the day to day monitoring is often delegated to regional or local level organisations, primarily local environmental protection agencies. In these situations, the regional authority may collect environmental data while national agencies then aggregate the information into indicators or higher level customised information layers and indicators.

During the various projects executed under FP7 and ESA funding, many of these users have been exposed to customized information products that would be incorporated into a potential Copernicus service. Their feedback gives a useful perspective on the benefit and impact that such a service could generate. Benefits and impacts cited with respect to demonstrations of prototype services include:

- The capacity of EO based information to fill in gaps (spatial and temporal) in in-situ data collection networks, in particular to provide an extension of the monitoring capability to areas not covered by conventional data collection networks. Data from EO based information have, in many cases, been directly used as part of the national agencies reporting under EU coastal legislation.

- Providing a homogeneous framework against which in-situ measurements can be effectively combined or their significance understood. In-situ measurements provide a local or point measurement and the location may not be optimal for the effective characterization of a particular process or phenomena. However EO derived information can provide contextual information that enables the situation around a measurement to be understood and the measurements from different areas combined in a consistent manner. In a number of cases, the EO based information has also supported a redesign of the in-situ measurement network
- Supporting regional inter-calibration –this issue is related to the previous point – in-situ measurement networks are designed and put in place by regional or national institutions to measure parameters of local importance. These may not always be optimized to support reporting under EU legislation. EO based information provides a baseline against which these different measurements can be inter-calibrated.

3. Proposed COPERNICUS Coastal Service

In the frame of the coastal monitoring, contributors to this communication principally see a need for:

- ***A larger and recognised use of Earth Observation for environmental reporting:*** this is based on two main elements: a further improved and documented qualification of such observations for reliable environmental observations and the upcoming availability of a medium to long-term suite of satellite observations thanks to Sentinels missions. It is believed that a wider acceptance and consideration of Earth Observation by Members states for the benefit of larger and larger environmental monitoring programs and objectives, will trigger a much larger acceptance by other stakeholders.
- ***A pan-European deployment of COPERNICUS Coastal service allowing harmonisation across MS and*** based on experiences gained through ESA and EU R&D projects and supported by a clustering of regional expertise. Beyond the immediate benefit for the European Environmental goals, this would bear the possibility to also reach users outside Europe and hence contribute to a sustainable economic exploitation and would sustain the employment market in Europe.
- ***Optimisation of and best use of complementary observations means.*** Earth Observation cannot stand alone and should go together and consistently with in situ data collection. There is a real opportuniy to optimise observation networks by combining EO, in situ and modelling – such as investigated in FP7 OSS2015.

Because water bodies, and their constituents, cannot be observed independently from its surroundings, a COPERNICUS Coastal Service would be made of:

i. a <u>coastal mapping service</u>, delivering a set of maps of satellite derived parameters of biological and geomorphological features at various temporal and spatial scales, and

ii. a coastal marine characterization service, subdivided in:

- a *water quality service*
- a *hydraulic characterization service*

The proposed coastal service is a mix of three thematic services (land, marine and possibly atmosphere) and can act as an assembly node to serve, among others, the purpose of risk and security core services. In addition it provides services to downstream and directly to targeted users (see dedicated section below). The coastal service shall therefore rely on ocean, land and atmosphere COPERNICUS core services.

It is worth noting that the capacity of EO based information to enhance the process of combining different in-situ measurements has been recognized both at national level for combining data collected by different regional authorities and at European or pan-national level for combining the information reported by different Member States.

4. Initial set of products and service for COPERNICUS Coastal Service (CCS)

For all products listed hereafter, the important aspects for which FP7 projects partners have been very careful has been the validation step. Validation means that all bio-optical quantities derived from Earth Observation (possibly with any types of modeling) is compared with in situ 'truth' when available in order to check and demonstrate that the retrieved quantities is lying within a known, documented and acceptable accuracy. This aspect is particularly important for these products to be eligible for reporting. Therefore, validation is proposed to be an entire part of the CSS (which surprisingly enough is not the case for most of in situ observations used for operational monitoring). Validation is described more specifically in a dedicated section in the following. Moreover, in order to capitalize on the existing large European effort, this validation will rely on EMODnet in situ data collection and, wherever necessary on Seadatanet data.

Lastly, all these products/services have been studied and tuned with existing Earth Observation missions mainly Ocean Colour missions (MERIS, MODIS, SeaWiFs) and high resolution optical sensors (Rapideye, Wordview 1 and 2). Outcomes of these studies are fully applicable with the portfolio of sensors proposed by the GMES/COPERNICUS missions: Sentinel 2 and 3 (and in some specific cases on Sentinel 1).

Chlorophyll-a (Chl-a) surface concentration: This quantity is derived since more than 15 years from the sea surface coloration (Ocean Colour measured from space). It has been proven to be mature enough to be used for operational targets (eutrophication and algal blooms alerts), environmental reporting and climate change analysis. This data is explicitly required for WFD, MSFD, UNEP-MAP and is valuable information for BWD and ICZM. The CCS shall provide regular mapping of Chl-a statistics (e.g. yearly P90 has been chosen for WFD and MSFD reporting).

Turbidity / water transparency: The sediment load in sea water is an indicator of both terrestrial export to the sea (with for some cases pollutant export estimates) and of variability of sea transparency and available light for marine life. Earth Observation has proven to be a reliable means for assessing water transparency and turbidity and its temporal fluctuations at large scale. Monitoring of this parameter (either under the form of light penetration depth or turbidity) is required for WFD, MSFD, UNEP-MAP and indirectly by ICZM. Transparency is also required for regional regulation (such as HELCOM). The CCS shall provide turbidity/transparency maps under the statistical forms (monthly aggregation, trends) required by regulations

Harmful Algal Bloom monitoring: Thanks to the availability and specificities of several recent ocean colors missions, Algal Bloom monitoring on European waters has had significant success and has expanded considerably in the last ten years. Several techniques allow either to detect anomalies in surface composition that point toward a likelihood of blooms or some algae taxa can be directly discriminated from observation from space. This information is particularly relevant for ICZM, BWD, MSFD and UNEP-MAP and could also be of interest for WFD.

Shallow waters sea bed mapping: The mapping of the sea floor is of prime importance to better understand the impact, the remediation and its efficiency, of anthropic pressure on the biodiversity on the sea fixed vegetation and in particular the Algae meadows (such as Posidonia) and coraligens populations. In that respect, high resolution imagery allows, combined or not with ancillary information, to retrieve classification of sea floor occupation which is particularly relevant for ICZM, WFD and UNPE-MAP in addition to regional/local regulations. The CCS shall propose the systematic mapping of sea floor (as being investigated for instance under various spatial scales by the EUSeamap project). The coastal benthic mapping of today is very unequal in quality and extent from one Member State to another. The CCS shall harmonise this mapping. For this application, high resolution missions as Landsat, Rapideye, Worldview shall be used to supplement Medium scale ocean color observations.

Bathymetry / Coastline mapping: As for classification of sea bottom, high resolution imagery is used for bathymetry retrieval. This technique, formerly applicable for very uniform type of sea bottom (e.g. sandy), has become more and more operational for other types of bottom thanks to the availability of specific missions as Worlview-2 that presents the right spectral resolution for this application. The CCS shall apply this technique to support the WFD, the BWD, the ICZM and the UNEP-MAP which explicitly require morphological information and dynamic monitoring. Sea Bed mapping quality and extent is however obviously linked to the light penetration into the waters and so is more adapted to clear waters. This is a typical example where complementarity between in situ observations and EO is fundamental.

Anthropic pressure at coast w.r.t. land usage: The land use classification at coast is mainly required by ICZM, WFD and BWD. Besides some parameters of coastal land use (e.g. number of artificial/anthropic structures along the coastline) which are explicitly required, the primary idea is to support the characterisation of anthropic pressure and its evolution in space and time. Characterisation of coastal watersheds and beaches profiles are also explicitly required by BWD. Such analysis are performed with imagery techniques close to the ones use for pure land classification, except the typology of requested information. On top of classical visible image analysis, SAR information from Sentinel 1 could also be used.

5. Validation

Validation of products and services is crucial for achieving acceptance and for continuously monitor if the required product quality is achieved. Different methods are usually applied to generate the above mentioned parameters, depending of specific physical, chemical and biological conditions of the coastal zone, as well as depending on the instruments (space and ground based, models) involved. The FP7 project Aquamar and the ESA GSE project Marcoast have developed a validation process which has grown over a long time and with close iteration with users. It has been adopted by other FP7 projects. It consists of a set of different thematics to be addressed, namely documentation, product accuracy, service reliability, compliance with SLA. The basic quality analysis has to be done by the service provider, submitted to and reviewed by an independent expert and finally sent for commenting to the user. The whole procedure is highly standardised and should become integral part of a CCS. Users have requested to further develop the validation process towards a certification scheme, which could be done in parallel in the R&D domain (Horizon2020).

6. Status of the Copernicus Coastal Service

The concept of CCS has been documented and is available at the following url (http://oss2015.eu/phocadownload/Comm/White_paper_COPERNICUS_Coastal_Service.pdf).

It has been presented at Workshop on Copernicus Coastal water monitoring services - 17 Oct. 2013 and presented at users GMES User Forum - 20 February 2014. Overall this concept has been very well received and perceived by the audience of these fora.

The team behind this CCS White Paper is asking and expecting to get support from (and to develop links with) Eurogoos, Emodnet and CMS at least for support to validation of EO derived products for coastal monitoring. This team is acting as a representative for further advances of the Copernicus Coastal Service to provide advanced products and service in complementarity with other Copernicus Core Services (Land, Marine, Risk …)

Integration of ecological and socio-economic issues in a Sea-Use Map toward the implementation of the MSFD

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Abstract

European directives, Marine Strategy ahead, are based on the Ecosystem Approach, so they promote the exploitation of natural resources but only when it is considered in terms of ecosystems capabilities. Coastal environment is one of the most ecologically rich - e.g. seagrass meadows - consequently it is one of the most rich in resources. Everyday new possibilities of exploitation get into the market, from marine bioresources to renewable energy. Under the circumstances, there is an urgent need of tools for the management of conflicts between human development and the preservation of the natural capital, as well as between different sea-users, competing for limited spaces and resources. In this work a Sea-Use Map integrating both ecological and socio-economic information is presented, in order to provide an easy-to-use instrument for coastal management and spatial planning.

Ecological issues are mapped as biocenosis distribution and are managed through the point of view of the ecological economy, that is, through the analysis of their ecosystem functions. At this stage no economic valuation is provided, but benefit provision, arising from specific ecosystem functions, is mapped for every coastal ecosystem along with human activities and constraints.

Socio-economic issues are mapped in terms of users distribution on the coast and their space demand. In the end, wave energy converters are used as a case study, simulating the integration of a new use in a coastal area (North-East Tyrrhenian Sea) busy with many strategic human activities but endowed with top-value ecosystems.

Keywords: Ecosystem services, bencthic bioocenosis, sea users, maritime spatial planning, wave power

1. Introduction

Marine coastal environments represent some of the most productive environments on Earth. From the high latitudes to the equator, mangroves, kelp forests, seagrass meadows and coral reefs play a fundamental role in the regulation of the natural equilibrium at the global scale (Dayton 1985, Hutchings 1987, Pergent 1994, Huges 1989). Ecological processes within these ecosystems provide substantial benefits to organisms and other ecosystems through a complex system of interactions and feedbacks in which different species, whatever role they play, provide and exploit benefits. Humankind is no different in this respect and is also intrinsically dependent upon the benefits it enjoys from ecosystems (Butler et al., 2003); food provision, oxygen production and bioremediation are just some of the benefits that play an important role for humans living in coastal areas (Beaumont 2007).

According to Costanza (Costanza et al., 2014), terrestrial ecosystems have an economic value (on a per-hectare basis), which is barely comparable with that of coastal and transitional ecosystems, such as seagrass meadows, coral reef, mangroves, estuaries or even coastal swamps.

In this context, the aim of the European Union's normative action is to promote the sustainable management of ecosystems and natural resources so that the natural equilibrium, as well as the benefits it generates for humans, can be preserved. The EU has taken action through a series of frameworks and administrative measures. For marine coastal systems, the EU has issued the 2008 Marine Strategy Framework Directive, the 2007 Recommendation on the Integrated Coastal Zone Management and the 2014 Directive on Maritime Spatial Planning (MSP).

The present work aims to develop an operational approach for this specific evaluation case. The final output will be a detailed map showing the spatial distribution of the provided natural benefits, along with socio-economic information. The resulting map is realised on the basis of the selected operational framework to ecosystem services and the definition of the relevant spatial unit. In this manner, ecological processes and benefits will be highlighted for every spatial unit. In the end, final information will be displayed on the resulting map. This should also be seen as the building of the theoretical basis to the economic evaluation of those benefits.

We are not interested in the affirmation of a new definition of ecosystem services but, according to Costanza, in his 2008 paper, we have developed our own operational definition, which is suitable for this specific case of benefit assessment from benthic communities. In this framework, we base our strategy on the ability of the benthic biocenosis to provide excellent information on ecological processes from which ecosystem benefits arise.

2. Modules of the Sea-Use Map

The Sea-Use Map is built up on three funding modules: 1) ecosystems 2) socio-economic information 3) ecosystem services.

Information layers in the map are overlapped as shown in Figure 1. With the coastal morphotypes layer, basic information is given, such as soil and sea bottom features, orientation, trend and steepness of the coastline. This is overlapped with ecosystem information and existing sea users, in terms of land/sea coverage, including relative prohibition (e.g., constraints to fishery, navigation, mooring, etc.). Ecosystem services, and the provision of benefits to human well-being in particular, build up the last overlapped information.

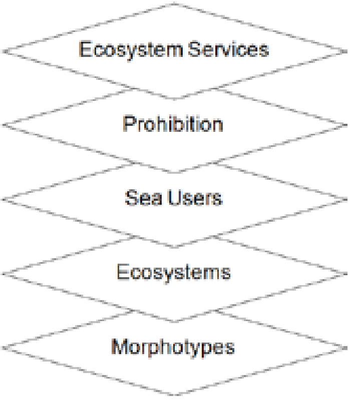

Figure 1 Hierarchic addition of information layers.

2.1 Ecosystems

We have based our ecosystem assessment on the typology of substrate which is likely to remain unchanged on the necessary time scale. A seabed typology usually support a characteristic biocenosis whose composition in species may vary through different facies, but its role and equilibrium should not change consistently.

The benthic life has communities that, more than any other, are intimately tied to the specific conditions of an area and can thus provide information on the ecological status and the evolution of characteristic environmental conditions. The benthic community of a precise area undergoes precise ranges of the ecological drivers, such as penetration of light, hydrodynamics, sedimentation rate, availability of nutrients and organic matter. The set of species that colonise a specific environment, the benthic biocenosis, is the result of the combination of these factors (biotope). When the ecological factors change, on both the long and short term, they generate modifications in the composition of species and in their relative abundance.

The benthos zonation system, and that from Pérés & Picard, in particular, allows to carry out ecological studies based on assumptions which are valid for processes, thus independent from the specific condition of a site. This is what Boudouresque and Fresi (Boudouresque & Fresi, 1976) mean when they call the benthic biocenosis a working tool, that is its capacity to produce ecological information just through its identification: if there is a specific benthic biocenosis there are necessarily those specific ecological conditions. In the end, if we can identify the characteristic species list of a biocenosis we can accordingly know the existing ecological processes and conditions. In this framework, using the benthic biocenosis as the relevant spatial unit allow us to deduce ecological processes in a specific area by the characteristic species list.

Species lists and their distribution along the coast are described through an integration of available data in the study area. As a result, the benthic biocenosis distribution map was drawn and shown in Figure 2.

2.2 Socio-economic information

Socio-economic information can now be overlapped to natural ones. This definition includes main human activities on the coasts, such as commercial ports, agriculture, fishery, power plants etc., but it includes also cultural sites, protected areas, prohibition to navigation or mooring. Information is gathered mainly through land-coverage data, including as sources the Corine land cover project, regional and national databases and atlas.

Results of layers overlapping is shown in Figure 3.

2.3 Ecosystem services

Many authors have tried to define ecosystem services in a unique way so far, often leading to uncertainties and misunderstandings, as the large literature on the issue demonstrates. We have selected the progresses of Fisher & Turner (Fisher & Turner 2008, 2009) and Costanza as the theoretical background of our work. In Fisher and Turner (2008) services are clearly separated from benefits and three funding conditions for their identification are provided: 1) services are not benefits 2) services are ecological in nature 3) services do not have to be utilized directly.

We are not interested in the affirmation of a new definition of ecosystem services. We agree with Costanza 2008 who suggests that a unique definition

of ecosystem services and benefits is not useful, as it has to be shaped for the specific valuation case.

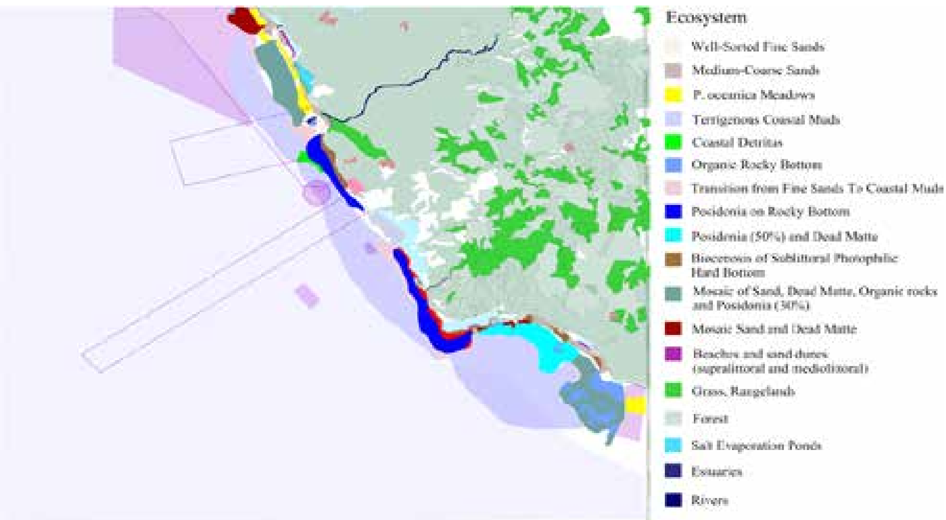

Figure 2 Spatial distribution of benthic biocenosis in the study area.

In this work we consider ecosystem services as ecological processes, but we focus on the distribution of actual benefit people obtain from ecosystems. As we have described in the previous section, the use of the benthic biocenosis as the relevant unit allow us to condense the information on the funding ecological processes that regulate the biocenotic balance, thus generating positive value for human communities, in the definition of the benthic biocenosis. We do not underestimate the services, we just focus on benefits as the services, as ecological processes, are already taken into account when we identify the correct benthic biocenosis through its species list.

We use the list of ecosystem services found in Costanza for standardisation and comparison purposes. We just adapt Costanza's list to our case of valuation of coastal marine ecosystems, as shown in Table 1.

Ecosystem Benefits
Carbon sequestration
Water cleaning
Erosion control
Bioremediation
Food production
Raw materials
Genetic resources
Recreational potential
Cultural/aesthetic
O2 Provision

Table 1 Ecosystem benefits provided by marine coastal ecosystems. adapted from Costanza 2008.

Ecosystem benefit distribution is then overlapped to biocenosis distribution in the map.

As a result of the information layer overlap the final Sea-Use Map is drawn, presented in Figure 3.

In the Benefit Provision Map ecosystems are displaced along with the main human uses of coastal spaces. While uses are identified with an associated colour, ecosystems are shown in a grey scale. Benefits provision in the study area ranges from 2 to 9 and the intensity of black in the scale follows it. Also constraints and restriction to navigation, fishery and mooring are shown, so that forbidden areas are immediately identified.

Now, the Map can be considered as a model to simulate the effect of both natural and human-induced changes in the equilibrium of natural systems, providing an overview on possible effects of these changes on human well-being.

3. Case Study: wave energy converters

The proposed tool is conceived to be used in a range of different applications. I

If we consider the deployment of wave energy converters along the coast (driver of changes) we can use the map to support the site selection, so that effects on ecosystem services, and relative benefits, can be minimized.

If we implement a methodology for the assessment of wave power distribution in shallow waters (Carli et al., 2011), in the same area of the Benefit Provision Map, it is possible to obtain the wave power available at high resolution, as shown in Figure 4.

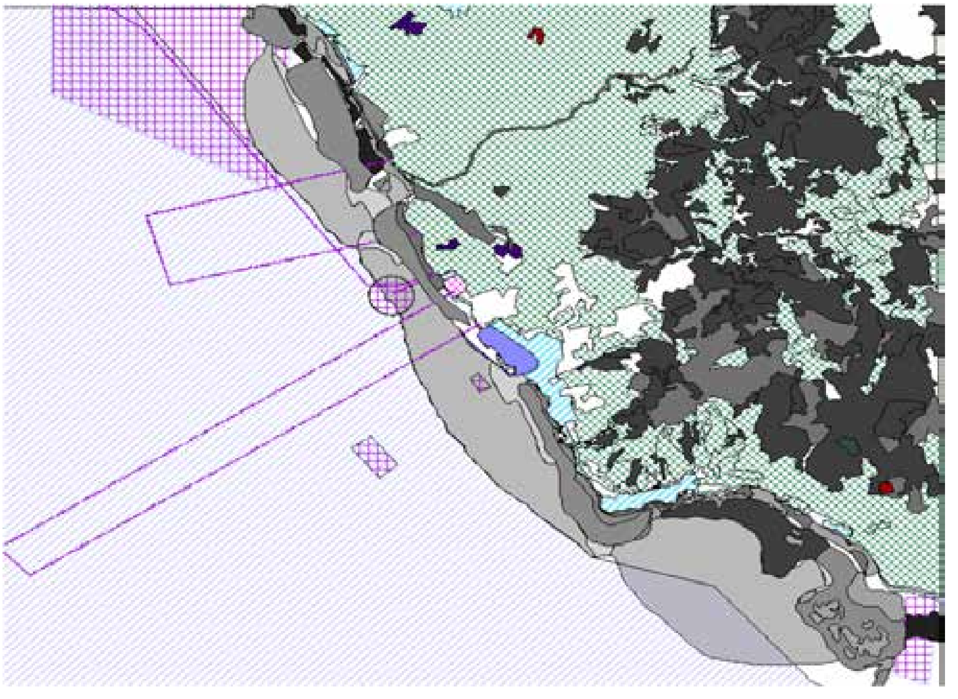

Figure 3 Spatially explicit distribution of the provision of ecosystem benefit to human well-being from marine coastal environment

By map overlay it is possible to identify the most suitable sites for energy exploitation and the benefit provision of the same areas, thus supporting decision-making in coastal management (Figure 5).

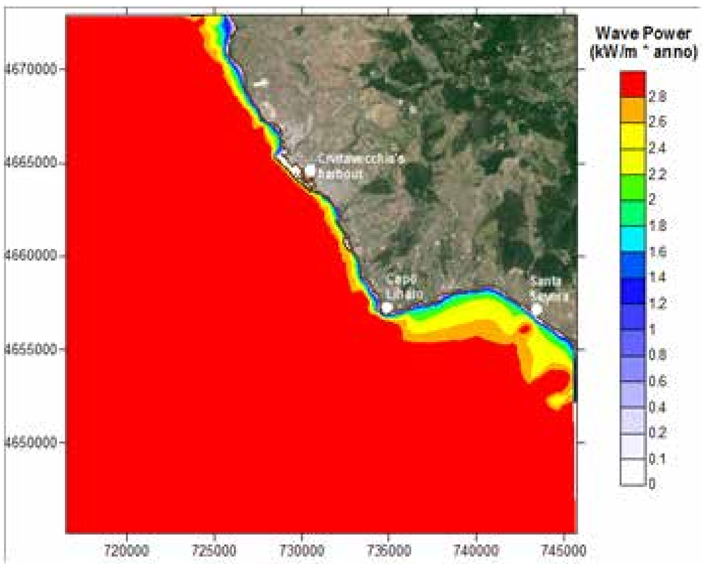

Figure 4 Wave power distribution in coastal water through the implementation of a downscaling methodology

4. Conclusion and future development

If we consider spatial planning as a complex process, the Sea-Use Map can be considered as a supporting tool for coastal managers, as it helps to include harms to both environment and human well-being in an integrated way, supporting this way cost-benefit analyses with pragmatic criteria.

Ecological and spatial data play a funding role in the process. The more accurate the datasets the more comprehensive the map, hence decision making and site selection get empowered in a wide range of coastal issues. Integration of new competitors for spaces and resources and design of conservation projects, as well as the monitoring of effects of major changes are just some of the practical opportunities of implementation for the presented tool. However, public administrations of coastal zones should find usefulness in such an approach in ordinary management too.

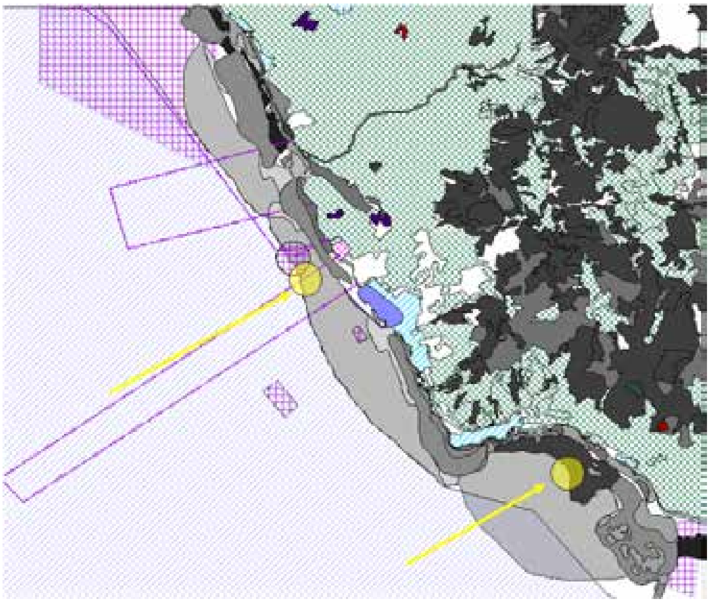

Figure 5 Overlay of wave power distribution upon the ecosystem benefit layer

As a future development, the Map should also work as the basis for a comprehensive assessment of the ecologically-related economic value of a coastal zone. Once benefits are assessed and explicitly displayed, factors that have to be computed to achieve the monetary valuation now get clear. So, if a particular area is found suitable for a new form of exploitation, the spatial distribution of benefit provision's economic value is readily provided. This will not be a definitive criterion, but in a decision-making process it can provide an easy access parameter to carry out cost-benefit analyses.

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A large part of this work is done on the assessment of benthic biocenosis in the study area. The authors wish to thank the Port Authority of Civitavecchia for putting at our disposal its large dataset on benthic communities in the area and for the technical cooperation in the assessment of wave energy along the coast of Civitavecchia.

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EMODnet Human Activities as the entry point to spatial information on the use of our seas

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Abstract

EMODnet Human Activities is a project financed by the EU Commission, which aims to map the spatial extent and intensity of a wide array of marine and maritime activities in EU waters. On account of the heterogeneity of information on the use of Europe seas, Human Activities aims to facilitate access to existing marine data on activities carried out in EU waters, by building a single entry point for homogeneous and standardised geographic information on 14 different themes, which represents possible uses of the marine space. Such a service should (i) reduce uncertainty in our knowledge and ability to forecast the behaviour of the sea, (ii) improving offshore operators' efficiency and costs in gathering and processing marine data for operational and planning purposes, and (iii) stimulate competition and innovation in established and emerging maritime sectors.

Keywords: EMODnet, human activities, marine data, GIS, interoperability.

1. Introduction

The European Marine and Observation Data Network (EMODnet) Human Activities (www.emodnet-humanactivities.eu) is a project financed by the EU Commission, which aims to map the spatial extent and intensity of a wide array of marine and maritime activities in EU waters.

The project is part of a wider long-term initiative, whose purpose is to unlock fragmented and hidden marine data resources across Europe, and to make these available to individuals and organisations (public and private). This should facilitate investment in sustainable coastal and offshore activities through improved access to quality-assured, standardised and harmonised marine data which are interoperable and free of restrictions on use.

There are currently 7 web portals (Bathymetry, Geology, Seabed Habitats, Biology, Chemistry, Physics and Human Activities) that are making available geographic datasets addressing different maritime themes.

The Human Activities portal is being developed by a consortium made up of 6 companies: Cogea, AND International, AZTI Tecnalia, CETMAR, Eurofish International Organisation, and Lovell Johns. The contract will end in 2016, but the project is already financed for a further three years.

2. Context

Traditionally, the collection of marine data in the EU has been carried out in a fragmented and largely uncoordinated way. Institutions and agencies have focussed on addressing their own specific needs, often in isolation with each other. As a result, even though a multitude of reliable data is now available to users across the EU, its usability and interoperability is in some cases limited by the lack of common standards.

The INSPIRE Directive[1],which entered into force in May 2007, represents an EU-level recognition of this situation, and seeks to ensure that the spatial data infrastructures of the Member States are compatible and usable in a trans-boundary context. While the INSPIRE directive has undoubtedly provided considerable improvement as to the interoperability of spatial data in the EU, the overall context is still far from being satisfactory.

Besides the poor level of interoperability, another element that hinders the actual use of marine data is the lack of a single entry point at EU level. While for instance, even non-experts are aware of the existence of EUROSTAT as the EU collector of statistical information, when it comes to the marine domain, available data are scattered across a large number of sources and websites. Accessing data from different sources across the EU may imply having to deal with several different languages and/or geographic reference systems.

On the other hand, it is becoming increasingly evident that easy access to reliable marine data is paramount to:

- Reducing uncertainty in our knowledge and ability to forecast the behaviour of the sea;
- Improving offshore operators' efficiency and costs in gathering and processing marine data for operational and planning purposes;
- Stimulating competition and innovation in established and emerging maritime sectors.

The above are, inter alia, essential preconditions to fostering sustainable economic development from the sea, the so-called 'Blue Growth'[2]

3. Objectives

In light of the above considerations, EMODnet Human Activities aims to facilitate access to existing marine data on activities carried out in EU waters, by building a single entry point for geographic information on 14 different themes:

1. Aggregate extraction
2. Commercial and recreational shipping
3. Cultural heritage

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[1] Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) was published in the official Journal on the 25th April 2007

[2] For further references, please see Marine Knowledge 2020 (http://ec.europa.eu/maritimeaffairs/policy/marine_knowledge_2020/index_en.htm) and 'Blue Growth' (http://ec.europa.eu/maritimeaffairs/policy/blue_growth/index_en.htm).

4. Dredging
5. Fisheries zones
6. Hydrocarbon extraction
7. Major ports
8. Mariculture
9. Ocean energy facilities
10. Pipelines and cables
11. Protected areas
12. Waste disposal
13. Wind farms
14. Other forms of area management / designation

The information provided through the portal is collated from a variety of sources, harmonised and made interoperable.

Data are free and free of any restrictions, in such a way as to ensure their use from a multitude of stakeholders (policy makers, researchers, students, spatial planners, etc.).

Besides making available data for download, the portal also features an interactive map, through which users can have a quick and user-friendly overview of where activities are taking place.

All datasets available on the portal are complemented with INSPIRE-compliant metadata, so as to provide Human Activities users with complete information on the way data are processed.

The overarching objective of the project is to make it easier for the widest possible number of users to access existing information on the spatial extent of human activities at sea. In the long term, this will inform better evidence-based decision making, and reduce the indirect costs related to retrieving data currently scattered across multiple sources.

The general idea is that EMODnet Human Activities users will be empowered with a ready-to-use database, thus spending less time looking for data, while being able to focus more on their final goals.

4. Principles

EMODnet Human Activities revolves around a few key principles:

- It is not a new data collection: the portal simply pools together existing resources. The rationale is that a considerable number of institutions are already collecting reliable data in Europe, and there is no need to duplicate their efforts. Human Activities intends to make the most of what is already available.
- It is entirely voluntary: all data providers share their data and contribute to achieving the project's objective. Data sources are not being financed to share their data
- Data needs to be harmonised and interoperable: the added value of Human Activities

lies in its capacity to provide standardised information, which could not be found elsewhere in a common format.

- Data should stay where they are now: contrary to many projects that aim to build their own database, the principle underlying EMODnet is that primary data sources should remain in charge of their data. This means that, where possible, EMODnet encourages sources to provide their data via machine-to-machine connections. In this way, data are not moved to a centralised database, and are maintained by their originators.

5. CONCLUSIONS

At the time of writing the project is in its second year and will end in September 2016. However, a considerable amount of data has already been made available on the portal for users to view and download.

Albeit not complete, data collection is at an advanced stage, and an increasing number of users are now relying on EMODnet Human Activities as the entry point for spatial information on the use of EU seas.

A thorough users' survey will be carried out in the third year of the project, in order to fine-tune the portal and pave the way for the next phase of EMODnet. However, based on preliminary feedback, it can already be argued that Human Activities are now being used by a multitude of stakeholders from different backgrounds, its main users being researchers, students, and maritime spatial planners.

The reason why users choose EMODnet Human Activities seems to be related to the easier access it gives to information otherwise scattered across different sources.

Compared with the other EMODnet portals, Human Activities tends to have a cross-cutting impact on several marine areas, thus serving a variety of purposes. Its data, for instance, are being used as a proxy for pressures (e.g. to define the footprint of disturbance to the seabed) by experts of various marine disciplines, and this makes Human Activities one of the EMODnet portals with the most heterogeneous user base.

Whether Human Activities will manage to establish itself as the official entry point for spatial information on the use of EU seas is difficult to predict. In the absence of specific regulation, data transmission to EMODnet largely depends on the ability of the consortium running the project, and on data sources' willingness to contribute to the project. While many institutions are endorsing the idea that Europe should develop standardised information on the uses of the sea, several others remain reluctant to share their data for a variety of reasons.

In view of the success of the project, and in order to provide users with increasingly reliable information, it is paramount that a higher degree of cooperation is attained.

Black Sea Argo: history, current status and prospect

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Abstract

A crucial element of the Black Sea restoration and rehabilitation initiatives is the implementation of a continuous monitoring and operational observing system in the region. The Black Sea ARGO is a key component of such a system that since 2002 has provided continuous basin wide real time *in situ* observations of the temperature and salinity profiles and recently of the main biogeochemical parameters from surface down to 2000 m depth. The aim of this study is to provide a comprehensive review of the Argo activities that have been carried out since the first launch of autonomous profiling float in the Black Sea, to highlight the main objectives of the initiative as well as to outline the prospects for its future development.

Keywords: Black Sea, ARGO, observations, *in situ*

1. Introduction

Black Sea is a region of particular interest in terms of its past and present level of ecological degradation by anthropogenic influences among the European Seas and highly dynamic and complex eddy-driven circulation system. The Black Sea receives drainage from almost one-third of the continental Europe (five times its surface area) which includes 17 countries with about 160 million inhabitants. It is relatively isolated from the world oceans, has a limited exchange with Mediterranean Sea through the Bosphorus-Dardanelles Straits System and hence is highly vulnerable to external environmental stresses. Beside, its resources have become unsustainable and its ecological state has deteriorated dramatically. Monitoring and understanding the role of four-dimensional circulation and thermohaline structure on transport and dispersion of biogeochemical properties are therefore a priority among different problems that need to be addressed. In fact majority of *in situ* observations that are commonly used for monitoring of the Black Sea are generally based on near-shore monitoring programmes or irregular oceanographic cruises that provide either non-synoptic, coarse resolution realizations of large scale processes or detailed, but time and site specific snapshots of local features. A crucial element of the Black Sea restoration and rehabilitation initiatives is the implementation of a continuous monitoring and operational observing system in the region. The Black Sea ARGO is a key component of such a system that since 2002 has provided continuous basin wide real-time *in situ* observations of temperature and salinity profiles and recently of the main bio-optical and chemical sea water parameters from surface down to 1500 m depth.

The aim of this study is to provide a comprehensive review of the Argo actives that have been carried out since the first launch of autonomous profiling float in the Black Sea, to highlight the main objectives of the initiative as well as to outline the prospects for its future development.

2. History of the black sea argo

The Black Sea Argo story began in September 2002 when three profiling floats, assembled by the School of Oceanography—University of Washington, were deployed in the southwestern Black Sea, approximately 180 km offshore of the Bosphorus Strait (Korotaev et al, 2006). The US-Turkish-Ukrainian collaboration in the frame of the project "Observing the Black Sea with Profiling Floats" funded by the NICOP program led to deployment in total 7 APEX floats in the Black Sea within the period 2002-2006. The primary aims of this project were to improve the capability for near-real-time temperature and salinity measurements within the entire water column of the Black Sea, and to promote a better understanding of the intermediate and deep circulation and seasonal and inter-annual dynamics of water mass characteristics. The last profile form US-TR-UA floats was obtained in December 2009. Their estimated average life time is about 3 years, but the quality of the data is not always high (Peneva et al, 2011).

This pioneer initiative was followed by several scientific oceanographic programs in the Black Sea aiming to contribute towards development of the regional research infrastructure in support of Euro and Global Argo networks.

In June 2009 Helmholtz-Zentrum Geesthacht and Max-Planck-Institut fuer Marine Mikrobiologie institutes cojointly launched in the Black Sea two NEMO floats (7900465, 7900466) with oxygen sensors during a research cruise with R/V Maria Merian in the frame of HYPOX Project (Stanev et al, 2013). The main scientific goal of the project was to monitor oxygen depletion and associated process in the semi-enclosed basins with permanent anoxia. Both floats ceased operating after 120 and 187 cycles, respectively.

Few months later, in December 2009 and April 2010, within EURO-ARGO programme, French Institute IFREMER deployed two PROVOR floats in the Western Black Sea (Peneva et al, 2011). One of the floats (WMO 5902291) was additionally equipped with oxygen sensors, but stopped operating after only 24 cycles.

In 2011 a BulArgo programme was initiated in Bulgaria. The project was funded by Bulgarian National Science Fund of the Bulgarian Ministry of Education, Youth and Science. The main objectives of the BulArgo project were: 1) to develop national research infrastructure as a Bulgarian component of the Euro-Argo network; 2) to increase sources of the Black Sea *in situ* data and to improve quality of local oceanographic products and forecasts and 3) to promote international collaboration towards establishment of a Black Sea Argo program (A.Palazov, 2012, E.Peneva, 2011). Four BulArgo floats were deployed in the western open Black Sea in March 2011 and August 2013. Apart from the standard CTD measurements, one of the floats (6900804) was equipped with an oxygen sensor. All floats use ARGOS telemetry system, and were programmed to a 5-days cycle, a parking-depth at 750 m and a profile depth at 1500 m. Two of four BulArgo floats (7900590 and 6900803) are still collecting data, one is considered dead (6900804) and one (6900805) stranded on the southeaster Turkish coast after 209 cycles of operation (Fig.1). The float was successfully recovered by Turkish scientists and will be redeployed after its battery replacement.

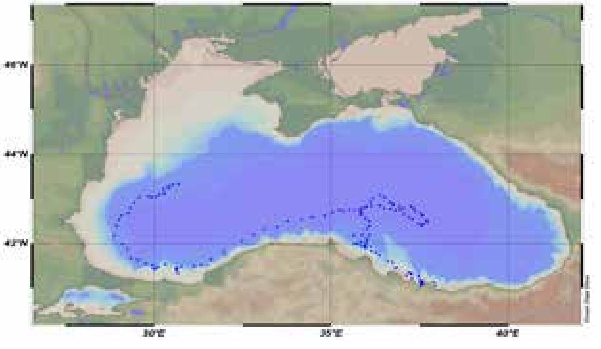

Figure 1 Trajectory of the float 6900805

In August 2013 and May 2014, in a frame of DEKOSIM (Marine Ecosystems and Climate Studies Center) project, scientists from Institute for Marine Sciences (IMS), Erdemly, Turkey deployed four PROVOR floats with DO sensors in the southern Black Sea, as two of them (6901900 and 6901899) have two-ways IRIDIM communication. Since June 2012 in a frame of a collaborative effort with Italy, Institute of oceanology, Bulgarian Academy of Sciences (IO-BAS) has deployed six ARGO floats in the western Black Sea (Fig.2) as contribution to the MedARGO programme. These floats are Arvor-L instruments designed by Ifremer and manufactured by NKE (France), two with IRIDIUM (6901831 and 6901832) and four with ARGOS telemetry (9601959, 9601961, 9601962, and 9601960). They have a parking depth alternating at 200 or 300 m and profiling depth at 1500 m. One of the floats (6901960) stranded on the Southern Bulgarian coast (near the city of Primorsko) in 2012 after 26 cycles of operation. It was recovered and redeployed in 2013 after being refurbished and repaired. All MedArgo floats are still active.

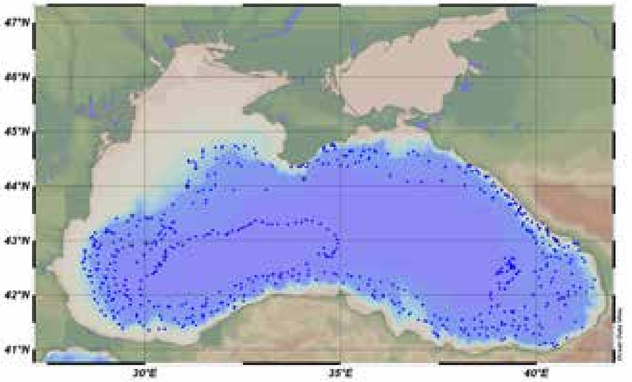

Figure 2 Trajectory of the MedArgo floats (9601959, 9601961, 9601962, 9601960, 6901831 and 6901832)

In December 2013, two biogeochemical PROVOR CST4 floats (basbio001b and basbio002b) were deployed in the western Black Sea by IO-BAS in the frame of E-AIMS, EC 7FP project. In addition to the standard CTD, each float mounted the following set of biogeochemical sensors:

1) Aanderaa oxygen optode 4330;
2) Satlantic Rem-A sensor including a WETLabs ECO-Triplet (with three channels to measure chlorophyll-a fluorescence, and optical backscattering at 532 and 700 nm) and a Satlantic OCR540 (with four channels measuring downward irradiance at 380, 412, 490 nm and a channel for photosynthetically available radiation, PAR).

The Bio Argo floats were programmed to collect data over the top 1000 m. They transmit data via two-ways IRIDIUM/RADICUS satellite communication that allows changes of the floats mission parameters while underway. The main objectives of the Black Sea Bio Argo experiment are: 1) to investigate the seasonal evolution of oxygen in the upper layers, including the subsurface oxygen maximum; 2) to study the seasonal and interannual dynamics of phytoplankton blooms in the deeper Black Sea and 3) to test the bio –optical sensors performance in the Black Sea. The Bio Argo data are processed by Marie Optics and Remote Sensing lab, Villefrance and distributed via Ocean autonomous observations web site (www.oao.obs-vlfr.fr). One of the floats (basbio2d) stopped transmission after 1 year of operation (76 profiles).

In June 2014 a PROVOR CT float (7900593) delivered under PERSEUS EC 7FP was launched in the western Black Se during a research cruise with R/V "Akademik". The parking and profile depth of the float was set up to 750 m and 2000 m, respectively. Until end of the PERSEUS project, three more floats will be deployed in the north western, north eastern and western Black Sea by Romanian, Bulgarian and Russian scientists.

3. Main goal of black sea argo

The main goal of the Black Sea Argo is to provide continues whole-of-basin autonomous near real time monitoring, even though the floats were deployed to serve different research objectives of the various international and national projects. The Black Sea

ARGO specific objectives can be divided into 3 major groups, as each group has several subtasks (Fig.3)

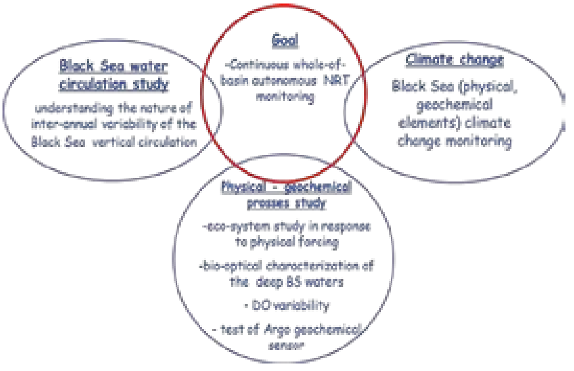

Figure 3 Black Sea Argo goal and specific objectives

4. Current status of the black sea argo

In total 28 Argo floats have been operated in the Black Sea since 2002 and have provided more than 3000 CTD profiles. The number of active floats per year significantly increased from 3 in 2002 to 13 in 2013 and 2014 (Fig.4). According to the recommendations given by P. Poulan et al, 2009, the minimum population of 5 floats is required for monitoring of the Black Sea.

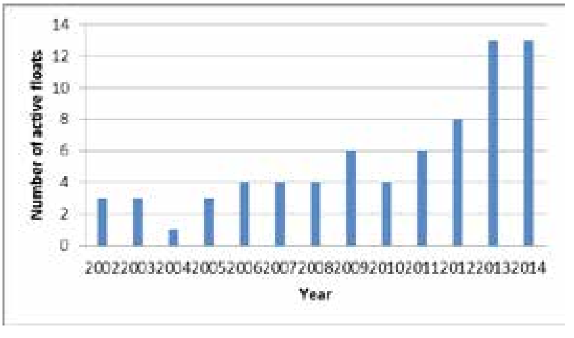

Figure 4 Number of the Black Sea Argo active floats per year

The positions of the Black Sea Argo active floats as of the end of October 2014 are shown on Figure 5. The breakdown of float types being used in the Black Sea is as follows: 10 - APEX, 2 –NEMO, 7- Arvor-L and 9 – PROVOR

Figure 5 Position of the Black Sea Argo active float on 26 October 2014

5. Results and conclusions

For the period 2007-2014 the floats deployment per year in the Black Sea rises about 3 times (Fig.6).

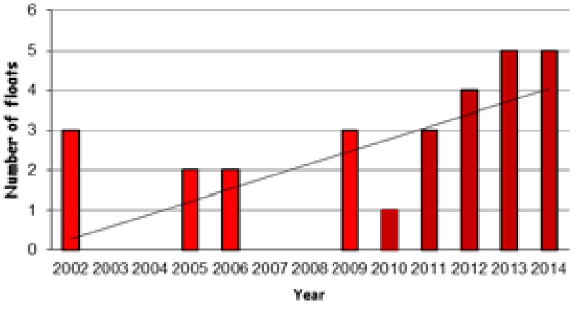

Figure 6 Black Sea Argo floats deployment per year

The individual national contribution of the countries deployed Argo floats in the Black Sea is given on Figure 7.

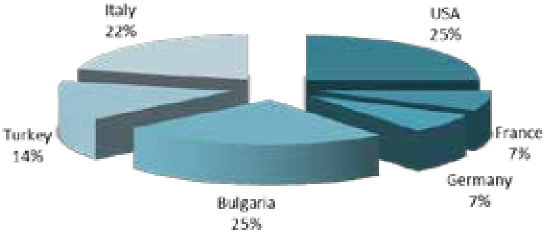

Figure 7 Black Sea Argo national contribution

The Black Sea is considered as a marginal sea and it is important to know the life time of Argo buoys in the basin. The Black Sea Argo experience shows that the average lifetime of the floats in Black Sea is not dramatically different from those in open oceans (Kobayashi at al. 2009) and is about 36 months (Fig.8)

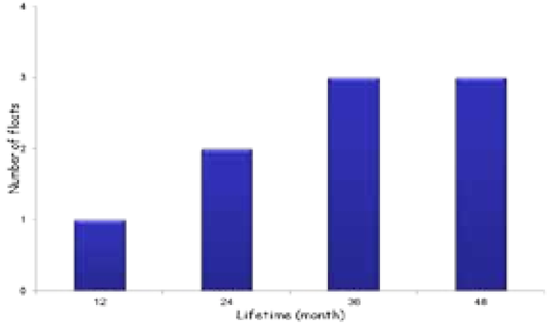

Figure 8 Black Sea Argo floats lifetime

Last year the Black Sea Argo became a very important source of marine data especially from the open sea. The number of T/S profiles per year notably increases from 48 in 2002 to 728 in 2014. As it is shown on Figure 9 last two years more than 600 profiles per year were obtained, much more then with research vessels for the same period.

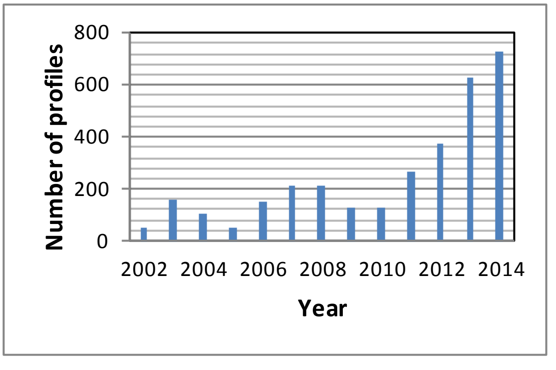

Figure 9 Number of Argo T/S profiles per year

6. BLACK SEA ARGO FUTURE

The strategic plan related to the future sustainability of the Black Sea Argo includes the following actions:

- To strengthen the Black Sea contribution to the EuroArgo programme;
- To support implementation of EU Marine Policy in the Black Sea thought deployment

of biogeochemical floats (DO, CHL, Nitrates)

- To increase the number of floats with IRIDIUM communication;
- To extend contribution of individual BS countries for operational or scientific purposes;
- To apply for financial support via national and EU projects in order to maintain optimal fleet of 10 floats in the Black Sea.

Acknowledgements

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Online monitoring and forecasts of ice resistance supporting winter navigation in ice channels

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Abstract

Winter navigation occurs mostly in ice channels, which icebreakers break into fast or drift ice. Every ship proceeding in such an ice channel experiences ice resistance, which influences the ship's speed and navigational capabilities in general. Operational tools capable of monitoring and forecasting ice navigation conditions in the local sea area are practically absent. We propose an online system to monitor and forecast ship resistance in ice channels. Firstly, we introduce the technology for *in situ* estimation of the ship resistance in ice, based on registration of ship hull vibration intensity. Observations have shown that ship hull vibration is more intensive in more severe ice conditions, both in terms of ice thickness or compression, which we regard to be taken as an integral measure of ship resistance in ice. Next, we define and calculate the ice resistance index for a particular ship navigating in ice. The comparison of acquired ship hull vibration data and ice condition information from satellite images, as well *in situ* observations, showed that the obtained data distinguish ice conditions of differing severity well. In order to supply the system with forecasting skill, a fuzzy logic relational scheme was defined, applied, and validated. The online system to show the *in-situ* ship resistance in ice, as well the forecast, was designed, realised, tested, validated, and is currently pre-operational for the fairway into the Pärnu Port, Gulf of Riga, the Baltic Sea.

Keywords: winter navigation, ice resistance, ship hull vibration, fuzzy logic model

1. Introduction

Maritime safety and smooth and optimised traffic are the main tasks to be kept in mind when organising winter navigation in varying ice conditions. It is characteristic of winter navigation that ships navigate in ice channels where they experience ice resistance which in turn influences the ship speed and her navigational capability. Therefore, for wintertime navigation in an icy environment, in addition to current and forecasted meteorological conditions, the *in situ* knowledge of ice resistance in the fairway and its forecast are essential.

Ice interacting with a moving ship causes ship resistance in ice, which results in reduced speed and in extreme cases the ship gets stuck in ice. Apart from the geometry of the ship hull and ice thickness the ship resistance in ice depends on ice compression (pressure) (Lindqvist, 1989; Riska *et al.*, 1998). The latter is a result of the co-action of wind and currents on drifting ice and forms pressure in the ice field when ice concentration is close to 100%. The measurement and forecasting of ice compression in local ship scale is a complicated task and not entirely solved up to now. In this paper we consider ship resistance in ice as a function of the severity of ice conditions. Ice resistance is dependent on ship characteristics, but in our case we perform measurements on board the most capable ship in ice, the icebreaker, namely IB EVA-316, operated by the Estonian Maritime Administration.

We propose an innovative method for *in situ* evaluation of ship performance in ice through measurements and analysis of ship hull vibrations. The product of measurements, the ship resistance in ice index, is realised as an expert system. A forecast of ice resistance based on a fuzzy logic model was included into the system. The basic forcing parameter, the wind, both measured and forecasted, is also shown in the system together with ice conditions obtained from satellite images and *in-situ* observations. The system was composed as a web-based online expert system to monitor and forecast ice resistance and relevant parameters for a specific ice channel – the fairway into Pärnu Port, Gulf of Riga, the Baltic Sea.

The online knowledge of ice resistance and its forecast will help to plan ship time and routes (to avoid ship stuck in the ice), to improve ship safety in icy winter conditions, and also to lower running costs both for the ice-breaking fleet as well merchant ships, through optimized fuel consumption and better planning of activities.

2. Materials and methods

2.1 Measurements

The system for monitoring ship resistance in ice consists of a recording unit for ship hull vibration and online data transfer capability. The working principle of the system is based on understanding that ice resistance from different sources (plane or ridged ice, presence of compressive ice, etc.) results in ship hull vibrations of varying intensity – higher vibration intensity refers to more ship resistance in ice. Vibration of the ship hull is recorded in terms of a 3D acceleration sensor which is tightly fixed to the ship hull (Fig. 1). There are other sources of vibration – engines, waves, etc. – but these can be detached from vibrations caused by ice resistance. Harder ice resistance (severe ice conditions/ compression) cause more intensive vibrations. A measurement system was designed and built by Marine Systems Institute at TUT, along with local engineering companies, and installed aboard Icebreaker EVA-316 (Estonian Maritime Administration), assisting ships and organising winter traffic in the Gulf of Riga and Pärnu Bay, the Baltic Sea. Measurement data are transferred in real time to the FTP server of the Marine Systems Institute, TUT, using GSM/GPRS protocol.

Figure 1 Instrumentation for ship hull vibration measurements as installed aboard EVA 316 (the instrumentation box before installation (upper panel) and after installation (lower panel)).

Mapping the measured ship resistance to on-board observed ice resistance (in accordance to a predefined ice resistance severity scale) relates measured acceleration data to the ice resistance index (the calibration procedure).

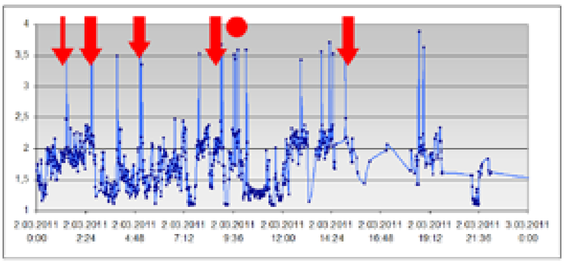

Figure 2 An example of ship hull vibration raw data (measured as acceleration in G units); bold arrows mark peaks, a very strong ice resistance observed on board the IB TARMO. The bold red dot marks the time when a merchant ship nearby IB got stuck because of very strong ice compression.

An example of measured ship hull vibration intensity versus observed ice resistance is presented in Fig. 2.

In this paper the ice resistance severity scale has five ranks: none, weak, average, strong, and very strong ice resistance. An example of validation of the estimated ice resistance index is given in Fig. 3, where IB EVA-316 proceeded first in open water (black on the satellite image) and then met the ice floe, inside which the signal shows varying ice resistance, through the ice floe.

Based on ship hull vibration intensity measurements with 1-minute intervals, the ice resistance index is published in real time as a colour-coded parameter on a special web page (http://on-line.msi.ttu.ee/ship6a/).

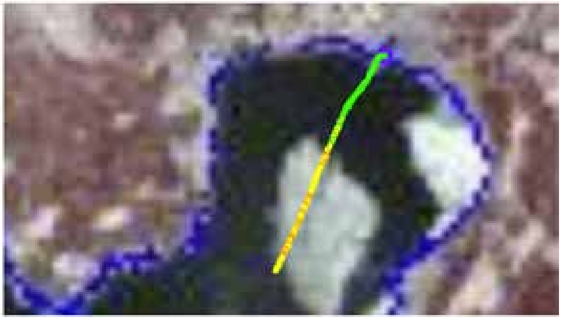

Figure 3 Validation example of the ice resistance index as IB EVA-316 was cruising through different ice conditions. The coloured bar marks respectively none, weak, average, strong, and very strong ice resistances.

2.2 Model

Forecast ability was found to be important and useful in practical navigation; therefore, the system was complemented with a fuzzy logic model to forecast ice resistance. The model's conceptual details are described in Lilover and Kouts (2012). In this research a simplified model for evaluation of ship resistance in ice was developed.

Here we implement this model approach for a specific fairway in Pärnu Harbour. The fuzzy logic model includes two relational systems: integrated ice properties as the potential for ice resistance and the power of forcings (mainly wind) to trigger the scheme (Fig. 4). Firstly, we take into account parameters which comprise the potential (or power) of ice resistance. Among these parameters are ice thickness, ice compactness, and ice categories (e.g. plain ice, ridges, etc.). The ice parameters could be found from regular ice charts, satellite images, visual observations, or as the output of ice dynamics models, and these form the potential for the ice resistance. Secondly, we consider parameters which trigger the potential for ice resistance. For the simplest model, such triggering parameters could be the wind-forcing pattern and especially its change or some other estimates obtained from the relevant model output and/or remote sensing products. A fuzzy logic model considers both the potential and triggering measures for ice resistance and provides a forecast of ship resistance in ice at a given location and time. Model output, ship resistance in ice, is appropriately divided into classes: none, weak, average, strong, or very strong ice resistance. Model calibration and validation was performed using measurements of ship resistance in ice as described above, relevant observations at ship bridges, classical ice maps, satellite images, and ice drifter data. Performed field observations showed that ship resistance in ice is highly dependent on relative angle between the ship course and wind vector (Lilover and Kouts, 2012); therefore, we insert this as an important triggering factor into the model. The calibration and validation of the model was made during icebreaking season 2012/2013 on the fairway into Pärnu Harbour, based on onboard observations of the IB EVA-316 crew, satellite data, as well as estimated ship resistance based on ship hull vibration data.

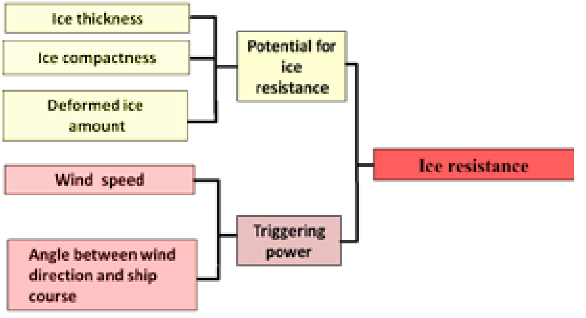

Figure 4 A conceptual fuzzy logic model to forecast the ship resistance in ice.

3. RESULTS AND DISCUSSION

The sensitivity of the fuzzy logic forecast model was studied via experiment in March 2012, during two consecutive days, 20–21 March. There were practically no changes in ice conditions, but estimated ship resistance in ice varies considerably (Fig. 5). Based on observations, the basic hypothesis was set that wind was the main forcing factor for ice compression in the given ice conditions and this was proved by the ship resistance in ice measurements. It was found that wind blowing perpendicular to the ship channel causes more ice resistance to the ship than wind parallel to the channel, because of compressive forces in the ice sheet. Ship hull vibration data also adequately showed ship manoeuvres in ice and the relevant ship resistances. The above concept was the basis for considering the wind forecast data in development and implementation of the fuzzy logic model to forecast the ice resistance in the fairway to the Pärnu Harbour in the Gulf of Riga, where the quasi-permanent ship channel is broken into the ice sheet for the entire season, lasting from 1–6 months, depending on the severity of the winter.

Figure 5 Ship resistance in ice as a function of wind direction (red arrows).

The fuzzy logic model produces 48-hour forecasts of ship resistance in ice along the fairway to Pärnu Harbour for 63 grid points (Fig. 6). Forecast calculations of ice resistance are based on the weather forecast model HIRLAM wind 48h forecast for 63 grid points and ice data deduced for those grid points from MODIS satellite images, ice charts, as well communication with the icebreaker crew.

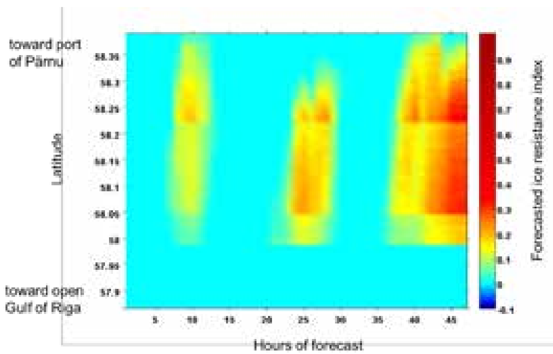

Figure 6 48-hour forecast of the ice resistance index along the fairway to the Pärnu Harbour as a fuzzy logic model output.

Technically, the 48-hour forecast of ship resistance in ice was produced once a day, whereas the ice parameters were also evaluated once a day and regarded to stay fixed for the forecast period. For Pärnu Bay, one could say that fast ice is the prevailing ice type, and ice thickness is comparably stable throughout the entire ice season there. Drift ice prevails at the same time in the outer Gulf of Riga, while still prevailing SW winds push ice into the Pärnu Bay and a stable ice sheet is produced if frozen. From January to March, the main driver for development of ice resistance and also compressive ice situations is wind force, in conditions of a stable ice sheet. In April ice conditions become more unstable and other factors will also play a role, like water level fluctuations, currents, and outflow of the Pärnu River. An example comparison of measured ship resistance in ice and modelled ice resistance is given in Fig. 7, where the reasonably good coincidence between the 48h forecast and measurements is seen.

Online data of local scale ship resistance in ice, with 1-minute time intervals along with the fuzzy logic forecast model, were integrated into web-based system, allowing the ice navigation conditions in particular fairways to be monitored and forecasted. The Gulf of Riga and entrance into Pärnu Harbour was chosen as the test site and the fuzzy logic forecast model was tuned accordingly. In this local sea area ice conditions are better observable and under control (permanent IB EVA-316 attendance). The expert system is freely open to different users *http://on-line.msi.ttu.ee/ship6a/* among which are both ship captains and on shore coordinators of winter navigation.

The online version of the expert system for monitoring and forecasting ship resistance in ice has different layers (options): ship resistance in ice measurements in the fairway categorised into specific ranks; measured and forecasted wind vectors along the fairway; the MODIS satellite data (if available) about the ice coverage; and ice resistance forecast along the fairway for a period of 48h ahead.

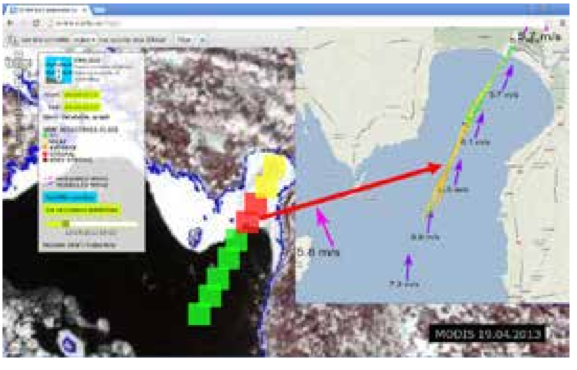

Figure 7 Screen view of the operational web-based expert system for monitoring and forecasting ship resistance in ice. Comparison of measured (right) and forecasted (left) ship resistances in ice along the fairway into to the Pärnu Harbour are given (length of fairway is approximately 30 nm). The satellite image in the background shows actual ice conditions; the ice resistance is highest at the ice edge in conditions when wind is pushing ice into the Pärnu Bay.

4. Conclusions

A method to evaluate and forecast ship resistance in an ice channel was developed, tested, and implemented in the fairway into Pärnu Harbour, the Gulf of Riga.

Ship resistance in ice data was made available for operational use via web-based user interface, as well for further post-processing and statistical analysis.

Ship resistance in real time and its forecast, along with forcing parameters like wind and ice conditions in the form of satellite imagery, are made available through the same web-based user interface: *http://on-line.msi.ttu.ee/ship6a/*.

The forecast method for ship resistance in ice is based on a fuzzy logic relational scheme, which was developed and applied to the Pärnu Harbour fairway. The forecast was integrated into a web-based expert service, complementary to ice-resistance monitoring data.

We conclude that the ship hull vibration measurements applied for detection of ship resistance in an ice channel enable to monitor the ship performance in real time in the local scale. Forecast of ice resistance using the fuzzy logic model allows optimisation of winter traffic along the fairways locally, making it more seamless both operationally and in the longer perspective.

Acknowledgements

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Real-time observatory of the water quality in the Tagus estuary

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Abstract:

A real-time observatory of the water quality in the Tagus estuary is presented. The first prototype was developed and validated to provide early-warnings of fecal contamination in the estuary from combined sewer overflows of the Alcântara outfall, in Lisbon. This observatory, operational since 2013, relies on the Water Information and Forecasting Framework (WIFF), developed at LNEC. The WIFF runs the models automatically in a high-performance environment and includes a WebGIS visualization tool for both data and model results. For the Tagus estuary, WIFF integrates the three-dimensional model ECO-SELFE, which couples the hydrodynamic model SELFE with biogeochemical and fecal contamination models, and the urban drainage model SWMM, providing 2-days forecasts. The model is forced by oceanographic predictions from MyOcean, extrapolations and climatology of the Tagus river flow and atmospheric forecasts. The system also incorporates two on-line monitoring stations, in the sewer and in the estuary. The estuarine monitoring station provides quasi-real-time data of several variables (e.g. suspend solids, salinity, temperature, dissolved oxygen, nitrates) measured by different probes (e.g. UV-Vis spectrophotometric probe). The WIFF and its models are of generic usage, adaptable to any geographical location, and customizable for different estuarine, coastal and oceanographic applications, coupled with urban drainage models if needed.

Keywords: On-line monitoring, Forecast, Fecal bacteria, Urban drainage, Receiving waters

1. INTRODUCTION

The deployment of surveillance and early-warning systems to anticipate potential pollution events and mitigate their impacts has received considerable developments, fostered by recent legislation (e.g. E.U. Bathing Water Directive).

Real-time observatories, combining forecast modelling systems and real-time monitoring networks, are emerging tools to support water quality management. These observatories started being developed in the 1990's, focusing mainly in oceanographic predictions and achieved vast advances in the last decade (e.g., Baptista, 2006).

For water quality, surveillance and early-warning systems are now emerging (e.g., bathingwater.dhi group.comearlywarningsystem.html, Viegas *et al.*, 2009), but challenges still remain for reliable forecasts and early-warnings.

Managing the effective co-existence of urban drainage and recreational activities in bordering water bodies of large cities, in particular, remains a challenge. Integrated modelling approaches, combining models for urban drainage and receiving waters, can help handling these conflicting uses. Indeed, these sophisticated tools are required to cover the full range of the spatial and temporal scales of the processes involved in hydrodynamic and fecal contamination. The communication of the results to a broad spectrum of users, with different needs (e.g., water body managers, utilities, general public) and using different platforms (desktops, mobiles, tablets), is also very important.

An innovative real-time observatory for water quality management, covering both the Tagus estuary and Lisbon's largest catchment (Figure 1), is presented in this paper. Developments are being performed aiming to address water management authorities challenges, such as controlling urban floods and direct discharges of pollutant effluents to receiving waters from combined sewer overflows (CSO) (Matos and Frazão, 2001), in order to minimize potential negative impacts on the receiving water bodies that may limit the uses and activities at the waterfront.

2. Tagus estuary observatory: building blocks

2.1 Study Area

The pilot surveillance and forecast system for water quality was deployed in the Tagus estuary and is being applied for the largest basin in Lisbon city, the Alcântara catchment (Figure 1).

The Tagus estuary, located in the Portuguese west coast, is one of the largest estuaries in Europe with an area of about 320 km^2. The estuarine margins are intensively occupied and support diverse uses and activities (urban, industrial/harbors, agriculture, shellfish harvesting). About 60% of the northern margin is occupied by urban areas and industrial facilities (Rilo *et al.*, 2012). The estuary itself holds diverse recreational activities (e.g. sailing, fishing) and a major natural reserve.

The estuary has a complex morphology, with a deep and narrow inlet channel and a broad and shallow inner basin, with an intertidal area of about 43% of the total estuarine surface (Nogueira Mendes *et al.*, 2012). The tides are semi-diurnal, with tidal ranges varying from 0.75 m in neap tides in Cascais to 4.3 m in spring tides in the upper estuary (Fortunato *et al., 1999*). Tidal propagation within the estuary is complex and its amplitude increases towards upstream due to resonance effects (Fortunato *et al.*, 1999). The main source of freshwater into the estuary is the Tagus river with an average flow of 370 m^3/s (Neves, 2010).

The Alcântara catchment outfall represents the largest urban discharge point into the Tagus estuary, including both treated effluents from the Alcântara wastewater treatment plant (WWTP) and CSO discharges. The system includes a 3200 ha gravity basin and a large riverfront pumping interceptor system. The WWTP serves a population of about 600 000 inhabitants and has a dry weather treatment capacity of 3.3 m^3/s and an additional 3.3 m^3/s capacity for wet-weather flow.

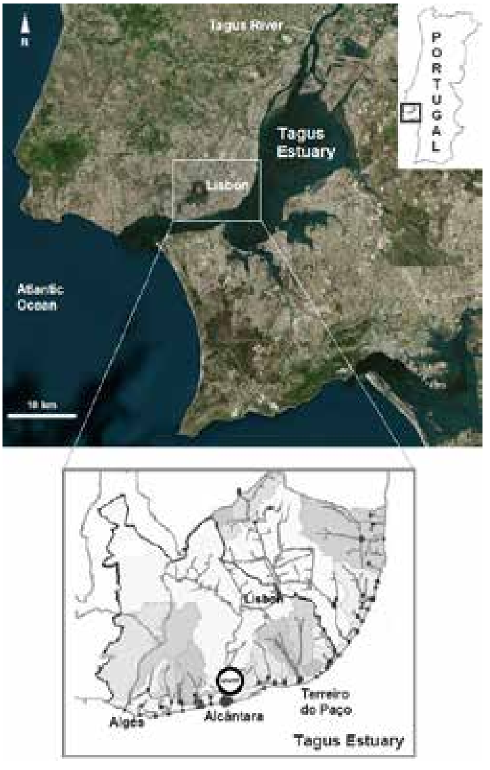

Figure 1 Location and general overwiew of the Tagus estuary and of the Alcântara catchment. The location of the Alcântara wastewater treatment plant (WWTP, marked with the circle) and of the Alcântara outfall area identified.

2.2 Conceptual Approach

The real-time observatory was created for surveillance and decision-making support, envisioning the early-warning of pollution events in the receiving waters. The relevant hydraulic and water quality processes were integrated from the catchment to the receiving waters, at the appropriate spatial and temporal scales. The system integrates real-time on-line monitoring networks and forecasting tools, on both the drainage network and the estuary. The integrated modelling approach is based on a flux of information between the urban drainage network, the WWTP and the estuary models, and the forcing predictions (Figure 2).

2.3 Monitoring Network

The real-time monitoring system includes two water quality stations and a set of rain gauges, flowmeters and water level sensors. The water quality stations are located in the estuary, near the discharge of the Alcântara outfall (Figure 1), and in the sewer main trunk, in the diversion sewer from the CSO to the WWTP. The estuarine station comprises temperature, conductivity/salinity, dissolved oxygen, pH, and ammonium probes, and a UV-spectrophotometric probe, calibrated for total suspended solids – TSS, chemical oxygen demand – COD and nitrates). Publicly available data sources such as the Port of Lisbon and the Direção-Geral do Território pressure sensors are also included.

Experimental surveys were carried out to characterize the physical, chemical and microbiological parameters, for dry- and wet-weather conditions (David *et al.*, 2013, 2014), aiming to assess the quality of the measurements provided by the UV-Vis spectrophotometric probes, to study relationships between parameters that will support the establishment of contamination warnings and to validate the numerical models.

2.4 Tagus Estuary Model

The Tagus estuary hydrodynamics and fecal contamination are simulated using the fully-coupled, three-dimensional, community model ECO-SELFE 3.1d (Rodrigues *et al.*, 2009, 2011, 2012).

The model setup derived from the application of Costa *et al.* (2012). A detailed description of the Tagus estuary hydrodynamics and fecal contamination model setup, calibration and validation can be found in Rodrigues *et al.* (2013). The Tagus estuary model was further extended from this application to account for the relevant urban discharges in the waterfront Algés-Alcântara-Terreiro do Paço (Figure 1).

The domain is discretized with a horizontal grid with about 53000 elements and 28000 nodes (Figure 3) and a vertical grid with 20 *SZ* levels (15 *S* levels and 5 *Z* levels). The spatial resolution of the horizontal grid varies from about 1-2 m in the discharges' areas (Figure 3) to 2 km in the oceanic area. The time step is set to 30 seconds. Two fecal bacteria tracers are simulated: *Escherichia coli* (*E. coli*) and fecal coliforms.

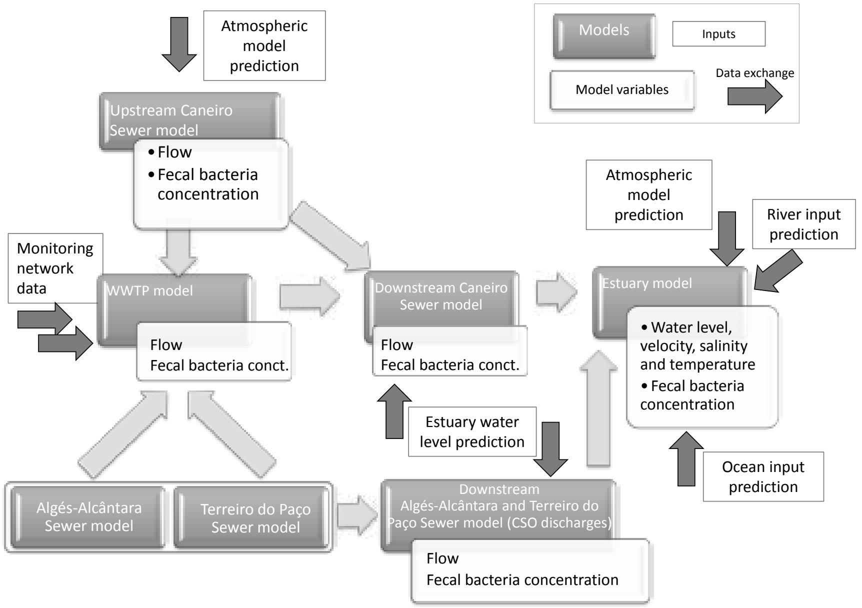

Figure 2 Integrated modelling approach and flux of information between models and input variables.

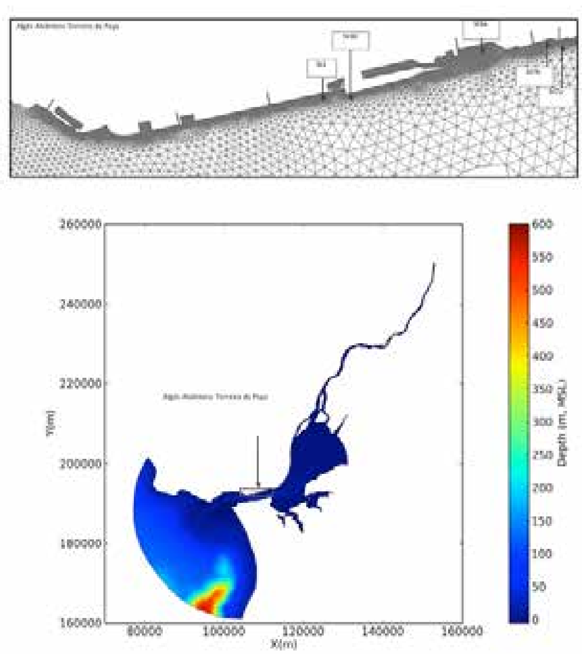

Figure 3 Tagus estuary horizontal grid and detailed view of the discharges along the Algés – Alcântara – Terreiro do Paço waterfront. Location of the sampling stations is presented.

Nine open boundaries are considered: the Atlantic Ocean, the Tagus river, the Alcântara outfall and six additional urban discharges in the waterfront Algés-Alcântara-Terreiro do Paço. Atmospheric forcing is also considered.

The oceanic boundary is forced by water levels, salinity and temperature and constant concentrations of fecal bacteria (set to 0 MNP/100 ml).

The urban discharges to the estuary are calculated using the sewer model, which also accounts for the WWTP in the Alcântara outfall. Numerical simulation of the sewer network is performed using SWMM 5 (Rossman, 2007). The hydraulics of the WWTP is modelled also using SWWM throughout the different components of the treatment plant. A semi-empirical model was developed to simulate the wastewater quality along the WWTP components. The fecal bacteria loads at the six urban discharges, besides the Alcântara outfall, are estimated based on semi-empirical relations.

Model-data comparisons suggest that the model is able to represent the main patterns observed (Rodrigues *et al.*, 2013; Figure 4)

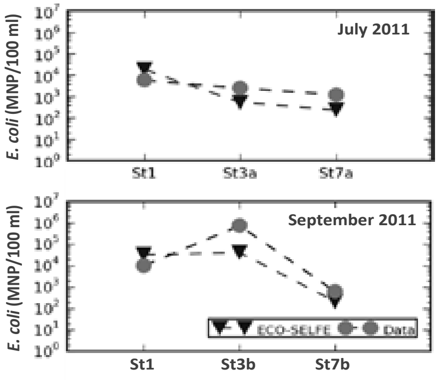

Figure 3 Comparison between data and model spatial variation of average concentrations of E. coli on July 15, 2011, and September 6, 2011 (adapted from Rodrigues et al., 2013).

2.5 Water Information and Forecasting Framework

The real-time observatory of the Tagus estuary is deployed with the WIFF–Water Information and Forecasting Framework (previously denoted as RDFS-PT, Jesus *et al.*, 2012), developed at LNEC.

WIFF integrates numerical models, field data, a set of scripts and programs for data and models management, and an interface for visualization (Jesus *et al.*, 2012). The architecture of WIFF relies on a set of servers integrated in a central system running LINUX. These servers are responsible for running the daily forecasts of the models, which can then be accessed by a Web browser, with WebGIS functionalities. Model forecasts, data access and management tools are stored in the central system. Further description can be found in Jesus *et al.* (2012) and Rodrigues *et al.* (2013).

3. Real-time monitoring and water quality forecasts

the real-time observatory for the water quality in the Tagus provides daily 48-hours forecasts of water levels, velocities, salinity, temperature, fecal coliforms and *E. coli* (Figure 5). In operational mode the circulation is forced by extrapolations from real-time river flow data from SNIRH (snirh.pt), forecasts from the regional ocean model of MyOcean (www.myocean.eu.org/) and forecasts from the urban drainage model. In case of failure of these sources, redundancy schemes were implemented in the system: river flow climatology and/or tidal elevations from harmonic synthesis are used as alternative to force the river and the oceanic boundary, respectively. Atmospheric forecast from WRF 9km are used for wind, air temperature, sea level pressure and specific humidity (available at http://www.windguru.cz), while for shortwave and longwave radiation GFS 50km forecasts are used (available at http://nomads.ncep.noaa.gov/model).

Estuarine model forecasts are continuously validated by automatic comparison with data from the online water quality station and other sources, namely two tide gauges located in Cascais and Algés.

The WebGIS interface allows the user to explore both the model forecasts and the data (Figure 5 and Figure 6). Model forecasts and data comparisons are also available through the WebGIS interface (Figure 6).

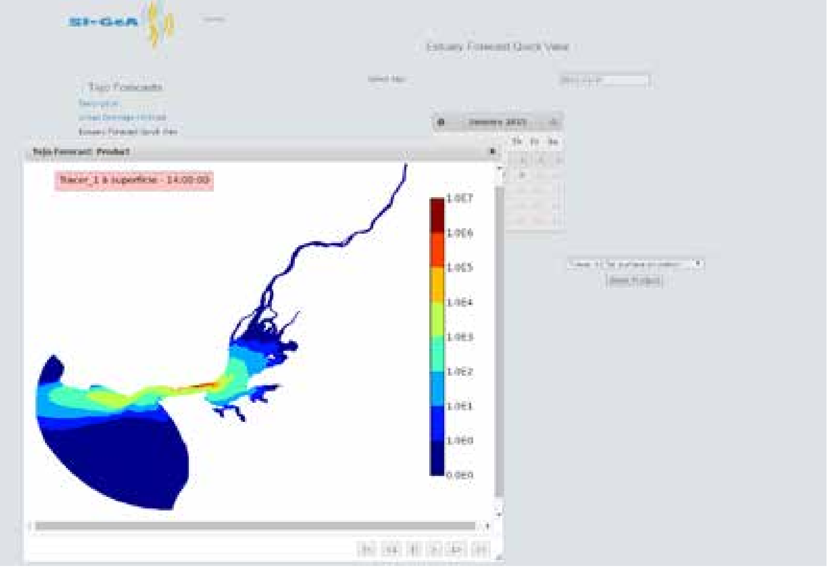

Figure 5 WIFF interface showing fecal concentration forecasts in the estuary.

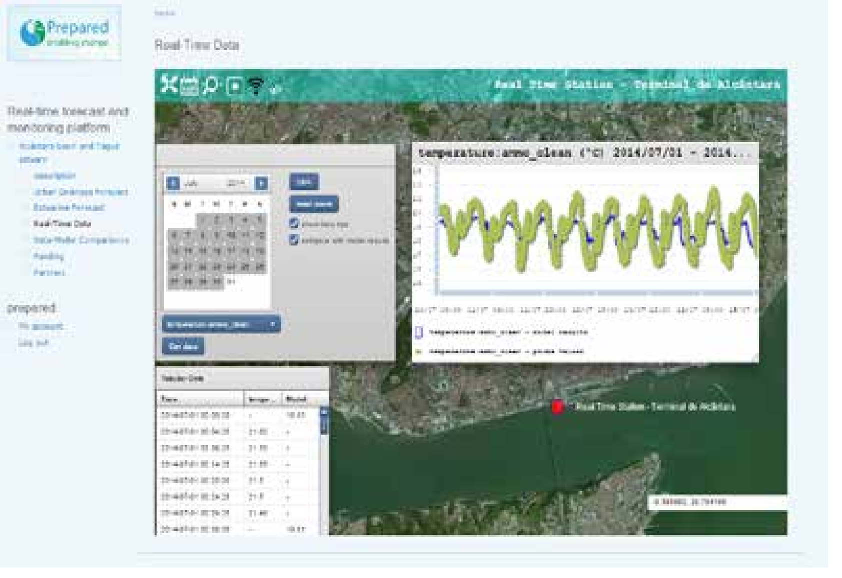

Figure 6 WIFF interface showing the access to data from the on-line water quality station and model-data comparisons.

4. Conclusions

A new real-time observatory provides continuous surveillance and anticipation of pollution events in urban systems through the innovative integration of catchment-to-receiving waters monitoring and predictive modelling, supported by a 2-days forecast platform, automatically validated with on-line data. The analysis of the system shows the ability of the models to represent the main spatial and temporal patterns observed. Its application to Lisbon's largest basin has already provided valuable, real-time information for sustainable and efficient wastewater management. The repository of both data and model predictions constitutes a valuable resource for both scientific and management communities to improve the knowledge of this important estuary and to support further interventions in the interactions between the city and the estuary.

The conceptual approach applied to the Tagus estuary and the WIFF are of generic use. It can be applied to other estuaries worldwide to support the efficient management of these water bodies, providing the maintenance of the uses and activities.

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ASIMUTH: a Copernicus marine downstream service for HAB forecasts in the Galician region

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Abstract:

The project ASIMUTH (http://www.asimuth.eu) aims to develop forecasting capabilities to warn of impending harmful algal blooms (HABs) along the European Atlantic coast. ASIMUTH is a HAB warning service for the aquaculture industry developed as a demonstration of a Copernicus marine downstream service coupled to the MyOcean service. In the framework of ASIMUTH, IEO is developing products to characterize the oceanographic conditions during periods of HABs in the Galician Rías and shelf where aquaculture has a strong socio-economic impact. In this contribution, we will present the ASIMUTH forecast system based on hydrodynamic, biochemical and Lagrangian particle-tracking model results combined with in-situ data and satellite imagery. We will also report on the Galician HAB pilot bulletins that were developed as a product of the ASIMUTH project and are aimed at providing forecasts of HAB events that might induce closures of harvesting areas or, when the areas are already closed, at giving some information on the oceanographic conditions that could favour or hamper the opening of the areas.

Keywords: downstream service, HABs, forecasts, aquaculture

1. Introduction

The project ASIMUTH (http://www.asimuth.eu) aims to develop forecasting capabilities to warn of impending harmful algal blooms (HABs) along the European Atlantic coast (Portugal, Galicia, France, Ireland and Scotland). ASIMUTH is a HAB warning service for the aquaculture industry developed as a demonstration of a Copernicus marine downstream service coupled to the MyOcean service (Mateus et al. 2012). The ASIMUTH consortium brings together public institutes (R&D and monitoring agencies) and SMEs from UK, Ireland, Spain and Portugal, with IEO leading the development of the Galician HAB early warning system.

IEO is a public research institute founded in 1914 and devoted exclusively to marine related studies including fisheries, aquaculture and marine environment studies. IEO routinely performs monitoring of hydrography, plankton, fisheries and pollutants along the Spanish coasts. IEO maintains a large observing system for monitoring of oceanographic and biological properties around the Iberian Peninsula and Islands (Lavin et al., this book).

As a development for supporting users in different domains, a suite of products for the general public, and more specifically for the aquaculture, marine leisure, fishing and commercial users, are available in the web portal http://www.indicedeafloramiento.ieo.es. With downscaled models IEO is producing upwelling indexes, frontal maps for fisheries and beach status information for marine leisure pursuits (http://playas.ieo.es). Data and products are disseminated through web applications some of them ready for smart phones.

Aiming at establishing a downstream service, ASIMUTH partners are developing products to characterize the oceanographic conditions during periods of HABs and to forecast the risk of impending HABs. At the North-western Iberian coast, HAB events (mainly *Dinophysis spp*.) are a recurrent phenomena throughout the whole year, leading to closures of harvesting areas in a region where aquaculture has a strong socioeconomic impact.

In this contribution, we will present the ASIMUTH forecast system based on hydrodynamic, biochemical and Lagrangian particle-tracking model results combined with in-situ data and satellite imagery. We will also report on the Galician HAB pilot bulletins that were developed as a product of the ASIMUTH project and are aimed at providing forecasts of HAB events that might induce closures of harvesting areas or, when the areas are already closed, at giving some information on the oceanographic conditions that could favour or hamper the opening of the areas. The Galician HAB early warning system aims at supporting decisions of the monitoring system managers [INTECMAR, www.intecmar.org] as well as at providing forecasts to the aquaculture industry in Galicia.

2. The forecast system

2.1 The forecast model

Over the past ten years, the Coastal Ocean Modelling Group at IEO has gained wide experience in the simulation of the circulation of the NW and N Iberian shelf and slope using the Regional Ocean Model System (ROMS). In its present forecast configuration, the model is being run routinely with atmospheric data supplied by the regional weather service (MeteoGalicia, http://www.meteogalicia.es). Open boundaries and initial conditions are obtained from a large scale model, the operational forecasting system for the North Atlantic (PSY2V4/Mercator Ocean) in the MyOcean Copernicus Marine Service. The operational grid domain spans from the Atlantic (from Cape S. Vicente, Portugal) to the Cantabrian Sea shelves (up to Gijón, Spain), with a 4 km resolution. A higher resolution 1.3 km grid centred in the Galician coast runs nested. This system provides water temperature, salinity, surface elevation, currents and fluxes with a 3 day forecast range. The model configuration has been extensively compared with data and it has shown skill in simulating the observed variability of shelf and slope processes in the area (Otero et al. 2009, Otero et al. 2013, Marta-Almeida et al. 2014). Another pre-operational configuration, developed during the ASIMUTH project, runs with a 3.5 km resolution and extends to the French shelf. A N2PZD2 biochemical model is run coupled to the physical model and provides results of nutrients, chlorophyll, phytoplankton and zooplankton. We are aware that the use of a simple phytoplankton class is a strong simplification of the complexity of the ecosystem. However, we will show that we can extract useful information from the model results that can be used for experts to issue a forecast and that can be displayed in different formats and viewers.

2.2 OGC web services

IEO and ASIMUTH put strong emphasis on providing open geo-referenced products, following Open Geospatial Consortium (OGC) and INSPIRE directive standards. Since 2012, IEO has been distributing observation and model results in OGC servers to allow possible users to view, discover and download in-situ and model data in the framework of ASIMUTH and RAIA observatory [www.marnaraia.org] projects. A THREDDS (Thematic Realtime Environmental Distributed Data Services) server has been set up during ASIMUTH for distributing model results of hindcast and forecast model simulations. [http://centolo.co.ieo.es:8080/thredds]. Model output (hourly data and daily averages) is available in the THREDDS data server (TDS). Images can be accessed using the THREDDS WMS (Web Map Service) capabilities.

The availability of model output in the TDS allows us to obtain data via OPENDAP, HTTPserver or NetcdfSubset, but also allow us to query the TDS for getting an image using WMS or WCS (Web Coverage Service). In figure 1, we plot the graphics of surface chlorophyll from 20 to 23 April 2006 obtained by sending a query to the WMS server. The development of a bloom on the west coast is clear in the model results.

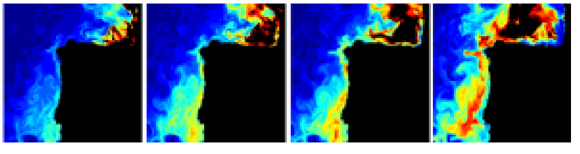

Figure 1 Model surface chlorophyll in the period 20-23 April 2006 obtained by queries to the TDS-WMS

2.3 The web portal: indicedeafloramiento.ieo.es

A web page for disseminating in-situ data, model results and some derived products was launched as a contribution to the RAIA observatory [http://www.indicedeafloramiento.ieo.es]. Results of model temperature, salinity, chlorophyll and currents at different depths can be viewed in the web page. The viewer queries the WMS server and displays plots from the daily hindcast and the forecast and from archived results.

The viewer was upgraded during ASIMUTH to show results in shellfish harvesting areas. The model results are interpolated to the location of shellfishing areas, which include areas where rafts (bateas) are located or where harvesting is done on foot, on boat or diving. As an illustration of this feature, in figure 2 we show results for a period in April 2006. In response to upwelling winds, the model simulates an increase of chlorophyll (in units of mg m^{-3}). The modelled bloom is more intense in the southern-most Rias (Vigo and Pontevedra).

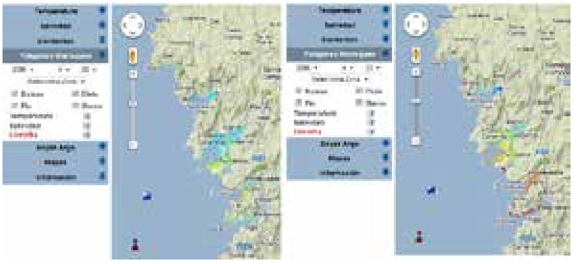

Figure 2 Model results on 20 and 23 April 2006 of chlorophyll displayed on shellfishing areas in Galician Rias.

Another illustration of the capabilities of the viewer is given in Figure 3. The results of the model for two different days in September-October 2006 when *Dinophysis acuta* was detected in monitoring surveys are shown. On the left handside, model results of chlorophyll in shellfishing areas are plotted. There is no bloom in this period and therefore not much information can be obtained from the surface plot of chlorophyll. However, if we click on some polygon, the evolution of daily values of surface temperature, salinity, chlorophyll and currents is displayed. This allow us to detect an increase of salinity on 29-30 September associated with a surface inflow into the ria. In the monitoring cruise on 2 October, a *D. acuta* peak of 6 10^3 cell l^{-1} was measured at 5 m depth in the Ría de Pontevedra (Escalera et al. 2012). Another high concentration peak was obtained on the following weekly monitoring on 9 October, when a subsurface maximum of *D. acuta* 78 10^3 cell l^{-1} (new record density for this species in Galicia) was measured. The results displayed in the viewer indicate again that confinement into the ría occurred. Note that during those days the availability of SST and chlorophyll satellite images is hampered by clouds.

Figure 3 Model results in September-October 2006 displayed in shellfishing areas in Galician Rias

3. Galician hab bulletins

The bulletins for early warning of HAB events in the Galician shelf and rías respond to the demand of specific HAB forecasts, which thus complement the dissemination of oceanographic data and forecasts. Users from monitoring agencies and from the aquaculture industry have emphasised that the availability of forecasts is one of their main priorities.

3.1 HAB and toxin information

In the bulletin, plots of the spatial distribution of the evolution during the last 3 weeks of cell counts of HAB species are presented (data provided by INTECMAR). A weekly summary of toxic species and on the status of closures of harvesting areas due to the presence of ASP, DSP and PSP toxins (data from Intecmar) is written. In this page, the forecast on the evolution of oceanographic conditions is provided to give an estimation of the evolution of the status of harvesting areas (open or closed, http://www.intecmar.org/informacion/biotoxinas/EstadoZonas/Informes.aspx?sm=a2).

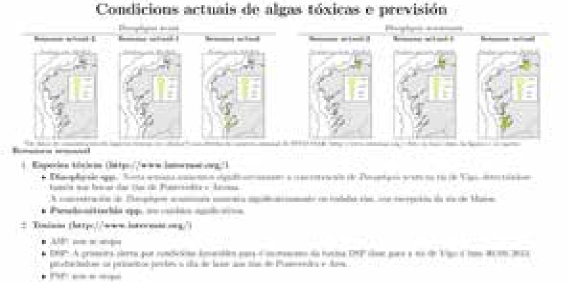

Figure 4 Galician Pilot HAB Bulletin for 4 November 2013 page reporting HAB phytoplankton species counts (showing last monitoring data available on 30 September 2013 and data from two previous weeks) and toxin measurements.

3.2 In-situ and remote sensing data

In-situ and remote sensing data of the oceanographic conditions in the area related with HAB evolution (upwelling index, in-situ temperature and salinity, ODYSSEA sea surface temperature, and chlorophyll) are shown in the pilot bulletin (figure 5). Bulletins are written in Spanish and Galician languages, the two official languages of the Galicia autonomous region.

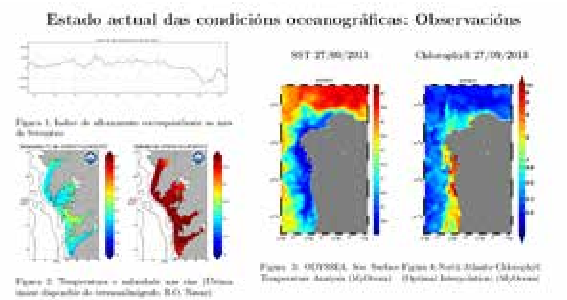

Figure 5 Galician Pilot HAB Bulletin page on oceanographic conditions: upwelling index (top left), T and S from the thermosalinograph on board RV Navaz (bottom left) and chlorophyll and SST from MyOcean satellite products (right)

Upwelling indexes are routinely computed in different locations along the Iberian coast (González-Nuevo et al. 2014). Forecasts and plots of the evolution in the present month and in previous months and years are distributed in the web portal presented in section 2.3. Upwelling index is computed from different data: buoys, operational and hindcast atmospheric models and constitutes a product of interest for the analysis of oceanographic conditions influencing HABs.

In-situ temperature, salinity and florescence measured by the thermosalinometer on board the IEO research vessel *Navaz* performing weekly HAB monitoring in Galician Rias Baixas provide information on freshwater in the rias and on penetration of shelf waters into the rías. Results from other routine monitoring cruises in the area are used to get additional information on oceanographic conditions (stratification, location of fronts...).

MyOcean surface Chlorophyll a measurements (Optimal interpolation Near Real Time L4 product at 1 Km resolution for the North Atlantic) and sea surface temperature (SST, ODYSSEA NWS Sea Surface Temperature analysis) on the closest day to the day of issuing the bulletin are displayed.

3.3 Model forecasts

The bulletin also provides information (Figure 6) of model forecasts on the shelf for the following 3 days, with detailed information about the forecast sea surface temperature and currents. Cross-sections of along-shore currents show the model forecast of along-shore transport which might carry populations from Portuguese waters. Results from Lagrangian simulations of particles emitted on the shelf for the latitudes of the northernmost Portuguese bivalve monitoring areas are plotted for displaying eventual transport of particles from Portuguese areas.

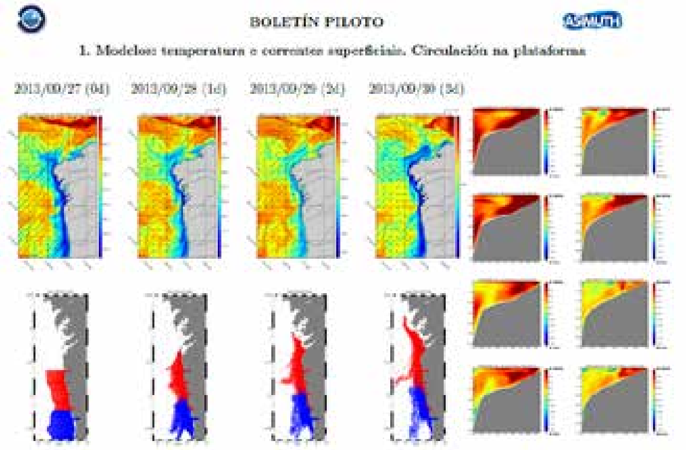

Figure 6 Galician Pilot HAB Bulletin page for Friday 27 September 2013. Top panel: 3-day forecasts of model generated SST and velocities. Bottom left panels: 3-day evolution of particles released from the two northernmost Portuguese bivalve monitoring areas Left panel: 3-day forecast of north-south velocities (red and blue respectively) along cross-shore sections at the central latitudes of the Portuguese monitoring areas (left, Viana, right, Porto)

Forecasts of flows into and out of the Galician rías are also provided by showing cross-sections at the mouth of the rias (Figure 7). Additionally, Lagrangian particles are released in the different rias and tracked for the following 3 days. The aim is estimating retention in the rias and transport among them.

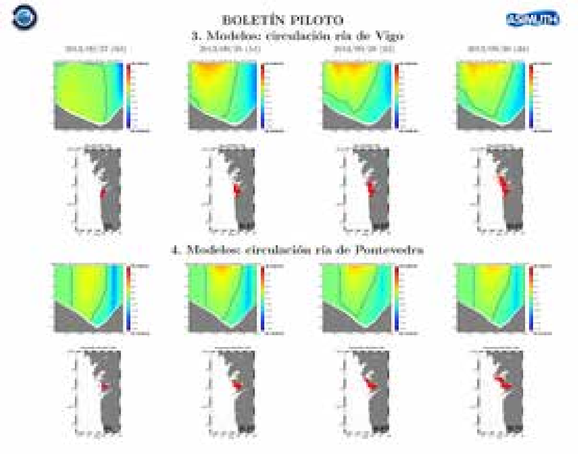

Figure 7 Galician Pilot HAB Bulletin page for Friday 27 Septembr 2013 showing across-channel sections at the mouth of the Rías of Vigo and Pontevedra; and Lagrangian particle tracking simulations of particles released in the rias. Percentage in the figures corresponds to the percentage of particles leaving the Ría.

4. Can the asimuth system provide an early warning of hab events?

The main species causing toxic outbreaks in Galicia are the dinoflagellates *Dinophysis spp*. (*D. acuminata* and *D. acuta*) and *Gymnodinium catenatum;* associated with diarrhetic (DSP) and paralytic shellfish poisoning (PSP) events. *D. acuminata* appears in the rías linked to the beginning of the upwelling season and persists throughout the upwelling season; variations in cell numbers are associated with wind event variability (see a review in Reguera et al. 2012). It is known that highest net growth of *D. acuminata* is observed during relaxation and downwelling following upwelling events. During ASIMUTH we have demonstrated that the forecast model is able to describe in detail the oceanographic conditions in response to upwelling-downwelling cycles and the interplay of different physical forcing (wind events, tides...). The forecast model is therefore able to warn of the conditions favourable for *D. acuminata* growth: upwelling events (favourable for the growth of its prey *Mesodinium spp*.) followed by retention in the rias (favourable for the encounter of *Dinophysis* and *Mesodinium*). Particularly, the model is able to warn of potentially rapid changes in cell densities linked to shifts in winds. Therefore, we can put forth that the forecast model can warn of the risk of a DSP event by *D. acuminata* that might cause the closing of harvesting areas.

In contrast to *D. acuminata*, *D. acuta* and *G. catenatum* are very seasonal and appear at the autumn transition from upwelling to downwelling favourable conditions as sudden blooms that have been linked to along-shore advection of shelf waters (Escalera et al. 2010). Autumn blooms cause high economic losses to the shellfish industry when closures last for several months, including the winter (Christmas) harvest season, when sales are at their peak. During ASIMUTH we have run hindcast simulations of the dinoflagellate blooms during the autumns of 2005 and 2013. The presence of *D. acuta* in 2005 and 2013 and of *G. catenatum* in 2005 on the northern Portuguese shelf in the summer of the two years was detected by the Portuguese monitoring system. In October 2005 and September 2013, these toxic species suddenly appeared in Galicia (see weekly monitoring data at the intense autumn outbreak on 30 September 2013 in figure 4). The ASIMUTH system was able to forecast along-shore advection associated with the arrival of autumn HABs to Galicia in both years. In Figure 6 we can see that the forecast system predicted northwards transport on the shelf on the days before 30 September 2013 able to transport HAB populations from Portuguese waters. This is clearly seen in figure 6 both in along-shore sections and in the results from the Lagrangian simulations tracking particles emitted on the shelf from the latitudes of the northernmost Portuguese bivalve monitoring areas.

5. Summary and conclusions

The Galician ASIMUTH HAB forecast system gathers data on the status of harvesting areas (open or closed) and about the presence of toxic species and also information on the current oceanographic conditions from in-situ measurements and satellite imagery. This is combined with the analysis of the results of high resolution local numerical predictions that help characterise along-shore and across-shore transport. Experts use this information and their knowledge to issue a prediction of where a HAB is "likely" to result in closures of harvesting areas. During ASIMUTH, we have performed hindcast and forecast simulations for different periods that show that the forecast system is able to describe and predict across and along-shore transport affecting harvesting sites in Galicia and their variability and therefore can provide assessment for monitoring agencies and the aquaculture industry to implement protective measures on time.

ASIMUTH has posed emphasis on the necessity of providing free and open geo-referenced products, following OGC and INSPIRE directive standards. The aim is offering final users the possibility of effectively view, discover and download in-situ and model data and also products derived from them. As we have illustrated in this contribution, the ASIMUTH downstream service, apart from HAB forecasts and early warning, incorporates web portals and viewers and OGC web services.

The ASIMUTH experience in Galicia and in all pilot areas along the European Atlantic margin successfully demonstrates the potential of downstream services for users, in this case the HAB monitoring system managers and the aquaculture industry. This aligns with the main objective of the Copernicus program of improving land, atmosphere and marine monitoring services to citizens. ASIMUTH uses MyOcean information (larger scale models and satellite imagery) and exploits it at a regional level with downscaled models and in-situ HAB data for giving service to final users. ASIMUTH is also a clear example of direct use of Earth observations, of operational monitoring of ecosystems and of development of model-based products for analysis and prediction in the benefit of the society. Therefore ASIMUTH is a decision-support tool that contributes to GEOSS (http://www.earthobservations.org/geoss.php) tasks on Oceans and Society: Blue Planet Strategic Targets (monitoring, analysis and prediction).

Acknowledgements

We thank the Galician Monitoring Programme (www.intecmar.org) for weekly reports on HABs and environmental conditions. The ASIMUTH downstream service has been supported by the project ASIMUTH (Fp7-SPACE-261860). Additional funding was provided by the project MyOcean2 (Fp7-Space-2011-1-283367) and by the Axencia Galega de Innovación (GAIN, Xunta de Galicia). Funding for the maintenance of the operational model and for the development of the web services was also received from RAIA Coastal Observatory projects (0313-RAIA-1-E and 0520-RAIA-CO-1-E, POCTEP 2007–2013). Computations were partially performed at CESGA (Centro de Supercomputación de Galicia).

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Lagrangian Modeling of Marine Tracer Transport An application to the case of anchovy dispersal in the Sicily Channel

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abstract

Numerical simulations of Lagrangian tracer trajectories require the knowledge of large scale circulation fields and a suitable parameterization of unresolved, or poorly resolved, small-scale motions. Recently, a modeling tool was introduced (see Palatella et al, 2014) in which the large scale advection is driven by velocity fields provided by the Mediterranean Forecast System, and unresolved chaotic dispersion is modeled by means of Lagrangian kinematic fields. As an application, the dispersal of anchovy eggs and larvae (from the eggs release to the nursery regions), in the Sicily Channel, was studied. Results about the decadal variability (1999-2012) of anchovy dispersion are summarised.

Keywords: Lagrangian trajectories, anchovy dispersal

1. Introduction

Numerical simulations of the marine dispersal of small organisms need large-scale circulation fields and a suitable parameterization of unresolved sub-grid-scale (SGS) motions: indeed, in the absence of the latter small-scale motions, dispersion is unrealistically slow (see Lacorata et al. 2014).

Recently in Palatella et al. (2014) a modeling system was set up, in which the large-scale advection is provided by the Mediterranean Forecast System (Tonani et al. 2009) and the unresolved scale transport is modeled by means of Lagrangian kinematic fields. By suitably tuning small scale, non linear dynamics, meaningful mean transport properties can be obtained on time lags of the order of few days and on spatial distances of the order of few hundreds of kilometers. As an application, we discuss the case of anchovy egg and larva dispersal in the Sicily Channel.

2. Lagrangian statistics

2.1 Theoretical background

To obtain the Lagrangian trajectory of a tracer particle, the equation to solve is:

$$d\boldsymbol{x}(t)/dt = \boldsymbol{U}(\boldsymbol{x},t) + \boldsymbol{u}(\boldsymbol{x},t) \qquad (1)$$

where $\boldsymbol{U}(\boldsymbol{x},t)$ is the ocean velocity field provided by a Global Circulation Model (GCM), which is known on a coarse grid (the typical size of the grid is a few km), and at few sampling times (e.g. daily snapshots). In equation (1), $\boldsymbol{u}(\boldsymbol{x}(t),t)$ is the small-scale and high-frequency term accounting for the velocity fluctuations neglected by the coarse-grid GCM. It is important to note that: *first*, the spatio-temporal interpolation of $\boldsymbol{U}(\boldsymbol{x},t)$ does not give access to these motions, which have their own spectral content; *second*, the missing component $\boldsymbol{u}(\boldsymbol{x},t)$ should be parameterised with suitable techniques.

Before describing the parameterisation adopted here, it is useful to recall what are the relevant motions we are interested in and their characteristic scales. Schematically, upper ocean dynamics can be viewed as the superposition of the contribution of eddies of different sizes, from mesoscale structures down to turbulent eddies. In the Mediterranean Sea, for our purpose, it is enough to use the following rough classification: (i) topographical structures of typical size ~100 km or more (weakly turbulent); (ii) mesoscale structures of the order of the Rossby radius, that is about 20 km (often associated to 2D turbulence); (iii) mixed layer turbulence from the scale of 100 m down to centimeters (much alike to 3D turbulent flow). Hence the modeled dynamics should reproduce the known spatio-temporal statistical behaviour of tracer particles dispersion in a flow with the above characteristics.

2.2 Anchovy eggs and larvae dispersion

Using large-scale velocities only, Lagrangian particles do not mix, unless they are initially at different depths. This is because the coarse velocities are spatio-temporally coherent over large distances and long time lags. To recover the correct dispersion properties, a sub-grid scale kinematic Lagrangian velocity field $\boldsymbol{u}(\boldsymbol{x},t)$ was added to MFS velocity components $\boldsymbol{U}(\boldsymbol{x},t)$, with the following rules: horizontal motions at scale 10-20 km are added (2D-SGS); vertical motions at scale ~ 50 m are also added, when requested (z-SGS). The SGS parameters calibration is done by using the behaviour of the so-called Finite Size Lyapunov Exponent (Lacorata et al., 2014), which measures the statistical relationship between spatial and temporal scales in chaotic-turbulent flows. Moreover, for the anchovy dynamics we considered that: i) eggs are buoyant for age < 1.5 days; ii) larvae are mixed by 3D turbulence and are without Diel Vertical Motion (DVM); iii) in the case of DVM, it is assumed that larvae go to the surface in the daytime and to deeper water at night.

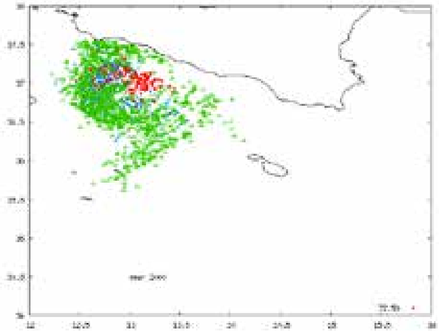

Figure 1 Anchovy positions at day 72, for year 2000. Colors refer to the anchovies' age: red (< 5 days, eggs), blue (5 < age < 10 days, larvae), green (10 < age < 25 days, larvae). B denotes the Belice river delta and CP indicates Capo Passero.

We employed MFS daily snapshots of the velocity fields that cover the months from June to September, for the period 1999 – 2012. Horizontal and vertical resolutions are 1/16° x1/16° degrees (~6.5km) and 72 vertical levels (from 1.5 to 5000 m depth), respectively. In the numerical experiments, from 1 June to 15 September of each year, anchovy eggs are continuously released at the spawning rate of 68.5eggs/day.

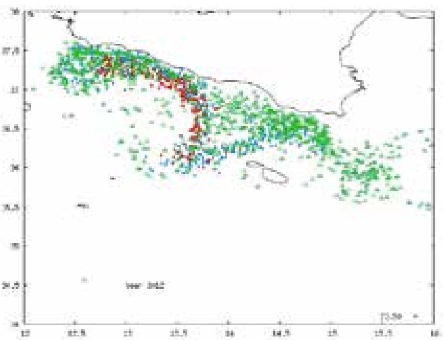

Figure 2 As in Fig. 1 but for the year 2012.

In Fig. 1, we plot a snapshot of the anchovy eggs and larvae trajectories (year 2000). Colors refer to the anchovies' age. As it can be observed, the dynamical conditions are such that most of the eggs and larvae get trapped near the release region at the spawning area (Belice river delta, Fig. 1), and very few are able to get to the nursery area, off Capo Passero. The dynamical situation is different for 2012, as it can be observed in Fig. 2: now the spawning success is very high, since a large number of anchovy larvae reach the nursery region. A useful observable to quantify the variability of the spawning success is the Lagrangian Transport Index, which measures, for each year, the percentage of individuals released at the spawning area and arriving at the nursery area, off Capo Passero (Fig. 3).

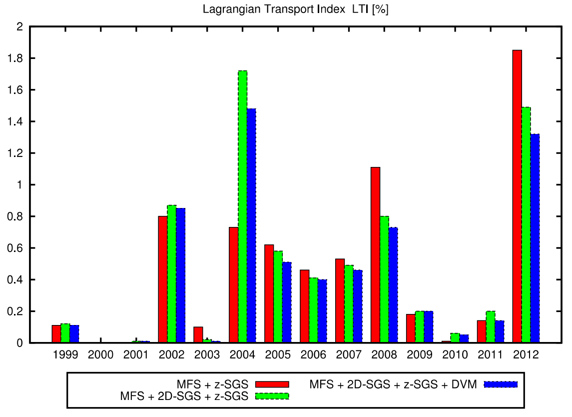

Figure 3 The Lagrangian Transport Index variability. Red bars: MFS plus z-SGS simulation; green: MFS plus 2D-SGS and z-SGS; blue: as the latter case, plus diel vertical migration.

To conclude, the velocity fields given by GCMs are not suitable for Lagrangian simulations on any scales of motion. The use of suitable sub-grid parameterizations (such as the kinematic model here adopted) permits to recover small-scale dispersion properties, otherwise missing. Our results suggest that anchovy egg and larva density fluctuations in the Sicily Channel region can be explained in terms of Lagrangian transport variability as main factor.

Acknowledgements

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Fostering bottom-up capacity in managing and sharing marine observations: the RITMARE StarterKit

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Abstract:

Capacity building by data providers is a fundamental task in the creation of a decentralized infrastructure for marine data in the context of RITMARE, the Italian Flagship Project for marine research. This challenge has been tackled by providing the Starter Kit, a comprehensive set of domain-oriented software components that exposes standard web services for the management of maps and observations from sensors. We report on the characteristics of this toolkit, developed by the National Research Council (CNR) of Italy, particularly with regard to the underlying service-oriented approach and the facilities offered to research data providers.

Keywords: Spatial Data Infrastructure, Catalogue service, marine research, OGC services, interoperability

1. Introduction

RITMARE is a Flagship Project by the Italian Ministry of University and Research, which aims at supporting and improving Italian marine research. RITMARE Sub-project 7 is charged with building the decentralized data sharing infrastructure of the project, employed by data providers (public research bodies and inter-university consortia) and by a variety of stakeholders (public administrations, private companies, and citizens).

Capacity building by data providers (scientists from heterogeneous domains, such as oceanography, ecosystems, geophysics, etc.) is a fundamental challenge in RITMARE, tackled by providing a comprehensive suite of domain-oriented, open-source software components that expose Open Geospatial Consortium (OGC) standard web services for the management of geospatial information.

The software suite, here named RITMARE StaterKit (SK), is a virtual appliance where standards-compliant services allow data providers to easily manage both geographic data and sensor observations; it also enables a uniform mechanism for metadata creation. Individual installations are managed autonomously by the distinct data providers, though metadata are transparently harvested by a centralized catalogue service integrating the distinct contributions to Italian and international marine research.

The SK has been distributed among different communities in RITMARE (mainly geophysics and marine ecologists) to test its features.

This paper reports on the characteristics of the SK (section 2) and discusses the results (section 3).

2. Characteristics of the software suite

The main purpose of the SK is to enable researchers and their related organizations to autonomously contribute their data and metadata to the RITMARE interoperable infrastructure.

By means of the SK, data providers can upload and manage their data (both maps and observations), create the appropriate metadata for both datasets and sensors, and finally perform discovery, visualization, and access according to standard services. In a nutshell, the SK is a web-based application and platform, kick-starting a Spatial Data Infrastructure (SDI), for the purpose of managing geospatial and observation datasets, as well as other categories of resources (see Figure 1).

The focus is on three main strategies:

- to allow data providers to easily and directly manage, publish, and share their geospatial and observation datasets (without requiring specific skills on SDI);
- to foster reuse of the services provided by the SK in other projects and initiatives;
- to simplify as much as possible the installation of the suite.

From an implementation point of view, the components bundled in the SK expose the following OCG services: Web Map Service, Web Feature Service, Web Coverage Service, Catalogue Services for the Web, Sensor Observation Service (SOS).

Besides the software that has been specifically created for the requirements of RITMARE, the SK is partially based on results of the CIGNo project (Bergamasco et al., 2011), and it also features a number of services provided by GeoNode and 52North SOS.

The software that has been customized or created for the SK allows keeping data, metadata, and services tightly coupled. As an example, several metadata items are automatically extracted from datasets at upload-time and passed down to the metadata editor for insertion in the metadata record. The three main extensions/customizations introduced are the following:

SOS Manager It supports editing of sensors' metadata (SensorML) for registering a new sensor and for uploading observations.

SOS Client The application allows the user to graphically explore observations in SOS services.

EDI Client The client-side component of a customizable, semantics-aware metadata editing web service developed from scratch for the SK, in order to assure uniform metadata creation.

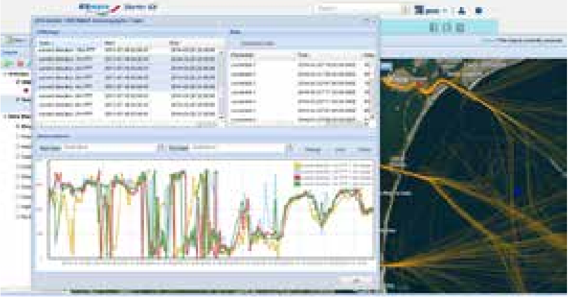

Figure 1 In the SK Map Composer, users create and share interactive maps by combining geospatial and observation services.

Besides maps, the SK is also capable of uploading, storing, and publishing sensor descriptions and observations. To this purpose, the main component that is bundled is the implementation by 52North of the SOS specification and related facilities. The objective is to provide users with interfaces to write the metadata that enable the registration of individual sensors, platforms, and probes, and to upload the observations that are produced by the registered sensors as Comma-Separated Values (CSV) files.

The SOS Client allows to execute standard requests such as Get-FeatureOfInterest and GetObservation using a map as the user interface. After retrieving the data from an SOS endpoint, users can display on the map the Features of Interest (FOI) that are made available by the endpoint (e.g., points, lines, polygons). The FOI can then be queried for the time series that are made available for one or more observed properties: These can then be displayed in traditional tabular mode or charted as shown in Figure 1.

3. Conclusions

This paper has briefly described the software suite proposed in RITMARE to improve capacity building of geospatial data providers. It offers the following features: i) storage and management of the maps and observations resulting from research activities; ii) friendly creation and maintenance of autonomous repositories of the data produced; iii) advanced search and retrieval; iv) interoperable data sharing in RITMARE and other projects, avoiding duplication and data transfer.

The suite is now distributed in beta version and tested by RITMARE researchers as well as international organizations and consortia (IMOS, ODIP). It has been proved that the SK easily integrates geographic data with sensor observations and provides a uniform mechanism for metadata creation. Individual installations can then be managed in isolation by the distinct data providers but are transparently harvested by a centralised catalogue service, which integrates the distinct, distributed contributions to Italian marine research.

Test results are collected and available at the address:

https://github.com/SP7-Ritmare/starterkit/issues?q=is%3Aopen+is%3Aissue

Acknowledgements

The activities described in this paper have been funded by the Italian Flagship Project RITMARE (http://www.ritmare.it).

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Ocean Surface Vehicles (OSV) for maritime security applications -The PERSEUS Project-

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Abstract

The PERSEUS project (Protection of European BoRders and Seas trough the IntElligent Use of Surveillance) goal is the protection of the European seas and frontiers through the use of cutting-edge technology. This 4-years duration pilot project funded by the 7th Framework Program is becoming the flagship initiative in the field of maritime security. Lead by INDRA, the consortium is formed by more than thirty partners from twelve different EU-countries, most of them having maritime frontiers. The project attempts to answer the demand of a European integrated system for border surveillance, being its main goal to develop and test a European system for maritime monitoring through the integration of the already existent local systems and its update and improvement using technological innovations, setting up the standards and bases for its final development. PERSEUS includes technological innovations in the areas of detection and analysis applied to maritime security, aiming to become the first European-scale maritime surveillance system able to detect small ships and low-high flights. The overall technical and operational approach will pool multiple sensors, monitoring platforms and information sources, improving constantly with latest developments in detection, recognition and identification fields, where autonomous unmanned ocean vehicles with specific and dedicated payload sensor configurations will play a key role.

Keywords: Ocean, ASV, surveillance, maritime security, frontier.

1. Introduction

One of the main goals of the European Union (EU) is to create an area without internal borders where people may move, live and work freely, knowing that their rights are fully respected and their security ensured, and where maritime security should be considered as a key part of this borderless area.

Beyond coastal waters, surveillance tools such as Patrol Vessels (PV) and Aircrafts (PA) are used as mobile assets to identify and position targets. However, both technologies have significant operational costs, whilst the lack of regulations to operate outside a segregated air/sea space, impose limits to the utilization of unmanned aerial and ocean vehicles for remote surveillance of marine areas. In addition, the analysis of current operational obstacles faced by the end-users community shows that weaknesses in communications capabilities (in particular related with tactical communications, interoperability and standardization) hinder the detection, identification and tracking of i.e. small boats at the external EU Maritime borders.

A R&D is therefore targeted to extend the portfolio of unmanned and light ocean observing platforms for reduced operational cost, and increased capability in surveillance in high seas and to improve the communication between assets, which is particularly critical in multi-national joint operations, where different systems co-operate in one single operational scenario (to be tested in the context of a real operational scenario, such a FRONTEX or EUROSUR led joint operation).

2. The perseus project

The PERSEUS (Protecting EuRopean SEas and borders through the intelligent Use of Surveillance) is an FP7 demonstration project supported by the FP7 Security Research theme under DG-Enterprise, aiming to build and demonstrate an EU maritime surveillance system integrating existing national and communitarian infrastructures and enhancing them with innovative technologies.

PERSEUS is therefore a key project in delivering comprehensive maritime surveillance from coastal regions to high seas through collaboration across Member States that includes two major demonstration phases between 2013 and 2015 in different operational scenarios. PERSEUS aims to contribute to the EUROSUR roadmap, at feasibility, standards, best practices and regulation levels, facing the following challenges: detection of small boats and low flying target, integration of sensors and capacities, fusion of information and common operational picture at regional and European level, reporting and decision support systems, and interoperability among different institutions and states.

3. Unmanned ocean vehicles

The Wave Glider is a new class of wave-propelled, persistent unmanned autonomous ocean vehicle. The key innovation of the system is its ability to harvest the abundant energy in ocean waves to provide essentially limitless propulsion. The vehicle is a hybrid sea-surface and underwater vehicle comprising a submerged “glider” attached via a tether to a surface float. It is propelled by the conversion of ocean wave energy into forward thrust, independent of wave direction. The wave energy propulsion system is purely mechanical; no electrical power is generated nor consumed by the propulsion mechanism. There is substantial power available in ocean waves, and the Wave Glider harnesses this power to maintain an average forward speed of 1.5 kt in seas with 0.5m - 1m wave height.

Operating individually or in fleets, this OSV technology enables 24/7/365, all-weather operations at a daily cost of up to 90 percent less than today’s data collection alternatives, while complementing and improving the efficiency of ships, buoys, satellites and aircraft.

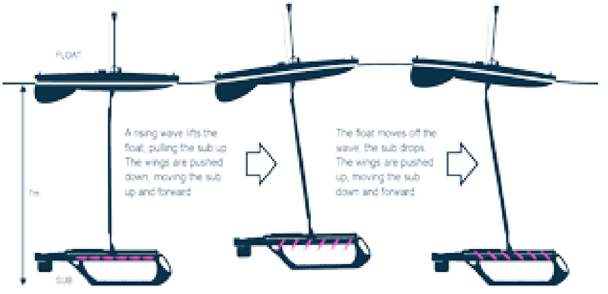

Figure 1 Wave Glider operating principle (Drawing courtesy of Liquid Robotics).

In order to cover the specific technical requirements by PERSEUS, and based on the Wave Glider modular features and capabilities, a Passive Acoustic Module (PAM) has been specifically attached as part of the glider payload.

The proposed technical solution includes to a towed array of hydrophones (towfish), attached to the submerged module. The acoustic signatures detected will be real-time provided to glider pilot. Once the acoustic signature is detected, it could be tracked continuously in order to proceed with decision making by the end-user.

Figure 2 Detail of the Wave Glider with a towed array of hydrophones (towfish), attached to the submerged module.

4. Operational approach

A Western field mission is expected for spring 2015, to be carried out Southwards Canary Islands. PLOCAN will be involved with unmanned autonomous marine vehicles, providing valuable information to the PERSEUS integrated system, in order to cover the end-users (Guardia Civil) needs. The goal of the mission is to deploy in the target area an OSV with a PAM (Passive Acoustic Module) system, addressed to detect potential illegal boats. The information gathered by the OSV will be integrated into the PERSEUS system, in order to provide the best information available to end-users (Guardia Civil) for decision making.

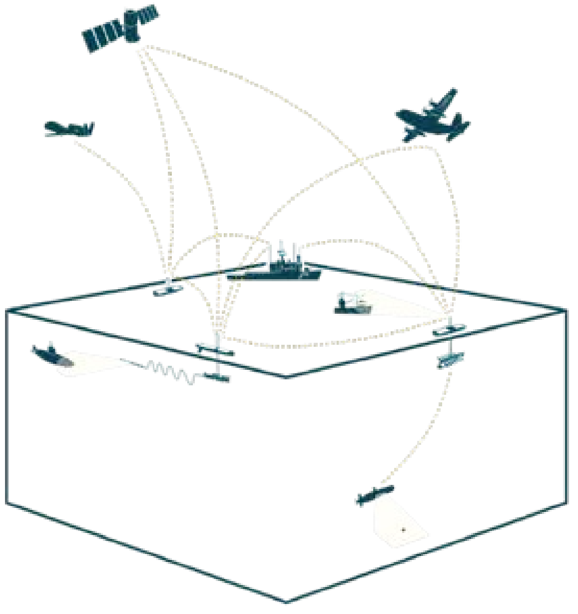

Figure 3 Multiplatform interoperability scenario using unmanned surface vehicles like Wave Glider technology.

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Effect of the river discharge implementation in an operational model for the West Iberia coastal area.

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Abstract

In order to evaluate the relative importance of the nutrients reaching the coast from river watersheds and their impact on the coastal primary production an integrated catchment-estuarine system was incorporated to the Portuguese Coast Operational Modelling System (PCOMS). At the watershed level, the Mohid Land model provided operationally water flow and properties, including nutrients, for the main river catchments of Western Iberia with a 2 km horizontal resolution. Downstream, several operational hydrodynamic and biological estuarine applications used the previous results as fresh water input flows, filling the gaps in the observation network. From the estuarine models, the tidally modulated water and properties fluxes to the coast were obtained. These fluxes were finally imposed in the PCOMS System, a fully 3D baroclinic hydrodynamic and ecological regional model that covers the Iberian Atlantic coast.

Keywords: Numerical modelling, Mohid, Catchment, Estuary, PCOMS, Nutrients

1. Introduction

In the Iberian Peninsula, the largest rivers, with the exception of the Ebro River, discharge on the Atlantic coast draining on its way almost two thirds of the territory. They are an important source of nutrients and sediments to these coastal areas. It is critical to determine the inland waters contribution to the open ocean, in terms of volume and composition.

A watershed model has been applied to the Iberian Peninsula to characterise the river discharges and their influence on the coastal circulation and nutrient processes. By linking this watershed model to a hydrodynamic and ecological model for the Portuguese coastal region the influence of the land inputs were evaluated.

The different interfaces found by the water from the watersheds to the open ocean were reproduced through numerical models for the first time for the Portuguese coast using the different components of the Mohid Water Modelling System (Neves, 2013).

2. Modelling approach

The Mohid Land model provided operationally water flow and properties, including nutrients, for the main river catchments of the Western Iberian Peninsula area. Downstream, several operational hydrodynamic and biological estuarine applications used the previous results as fresh water input flows, filling the gaps in the observation network. From the estuarine models, the tidally modulated water and properties fluxes to the coast were obtained. These fluxes were finally imposed on the Portuguese Coast Operational Modelling System (hereafter referred as PCOMS, Figure 2, Mateus *et al.*, 2012).

This complex system of models is integrated and synchronised through the ART software (Automatic Running Tool), a software for model simulations automation developed at IST. The ART tool pre-processes the boundary conditions from different sources needed to run the model; executes the Mohid water and Mohid Land depending of the application using the configured files and store, graphs and distributes the model results via OPeNDAP, smartphone and Webpages.

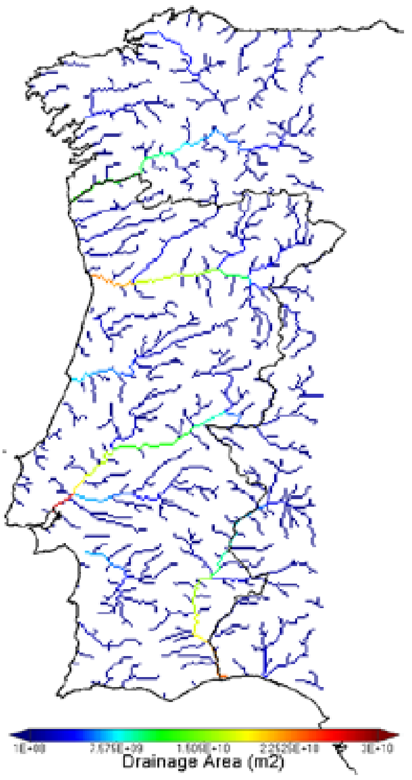

Figure 3 Main water lines in the Western Iberian Peninsula indicating the drainage area obtained for the 2 km resolution.

2.1 Watershed modelling

Two application domains with different resolution and area covered were designed in order to provide high resolution results for Portugal and also able to reproduce the spatial scale of large trans-boundary rivers discharging in Western Iberia such as the Tagus, Douro and Guadiana rivers. Using the NASA digital terrain elevation two domains were constructed

- the Iberian Peninsula domain (IP domain) 10 km horizontal resolution
- the Western Iberia domain (WI domain) 2 km horizontal resolution (Figure 1)
-

Both domains were populated with data from the Corine 2006 land cover and JRC soil database allowing the model to estimates the amount of water flowing in the water lines without taking into account the human consumption, water reservoirs and dams that could influence the river flow and the amount of water reaching the coastline.

2.2 Integration with ocean model

The watershed models are linked through estuarine models that receive the water from the watershed models (i.e. Aveiro, Minho, Lima, etc.) or, when existing, from the SNIRH observing system (Douro, Tagus, Mondego). From these estuarine models, section fluxes are obtained and in the next step introduced in the 3D hydrodynamic and ecological regional model PCOMS. If the estuarine model is 3D, the discharge would be distributed at the corresponding depths, as is the case of the Tagus estuary mouth (Campuzano *et al*., 2012), the rest of the estuarine models are 2D and thus the discharge is imposed in the surface layer. The rest of the river discharges are directly imposed in the regional circulation model PCOMS.

2.3 Ocean modelling

In order to estimate the influence of the river discharges in terms of nutrient fluxes a set of 3D polygons were defined in the PCOMS application. The PCOMS model is a 3D full baroclinic hydrodynamic and ecological regional application that downscales the Mercator-Océan PSY2V4 North Atlantic solution with a horizontal resolution of 0.06º and with 50 vertical levels (43 in Cartesian and 7 in sigma coordinates) with a resolution of almost 1 m near the surface (Figure 2). Tides are forced using the global tide solution FES2004 along the ocean boundary (Lyard *et al*., 2006).

3. Results and discussion

The addition of the estuarine fluxes modifies the coastal circulation and could create sharp haline fronts such as the one observed in June 2012 where the combination of several estuarine discharges created a front that occupies the centre and north of Portugal. Salinity values over 35 psu (Figure 2). This phenomena, named as the West Iberia Buoyant Plume, was observed during summer campaigns by Peliz *et al*. (2002). The same configuration has been used to implement a forecast service the results of which can be accessed at http://forecast.maretec.org/

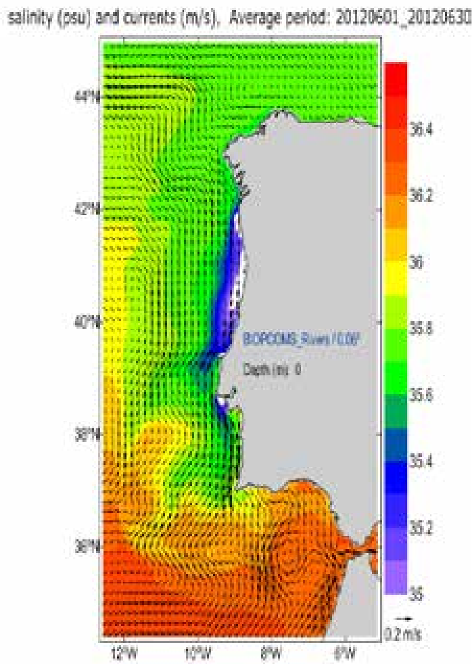

Figure 2 Average sea surface salinity for the month of June 2012 White values correspond to values below 35 psu.

Acknowledgements

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Combining operational models and data into a dynamic vessel risk assessment tool for coastal regions

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Abstract

A combined methodology to estimate time and space variable shoreline risks from ships has been developed, integrating meteo-oceanic and oil spill forecasts with vessel traffic (AIS). The risk rating combines the likelihood of an oil spill occurring from a vessel navigating in the study area – Portuguese Galician Continental Shelf – with the assessed consequences to the shoreline. The spill likelihood depends on dynamic marine weather conditions and historical accident data. The consequences reflect the hypothetical spilled oil amount reaching shoreline and its environmental and socio-economic vulnerabilities. The oil reaching shoreline is quantified with an oil spill fate and behavior model running multiple hypothetical spills from vessels along time. Shoreline risks can be computed in real-time or from historic data. The integration of meteo-oceanic + oil spill models with coastal vulnerability and AIS data in the quantification of risk enhances the decision support model, providing a more realistic approach in the assessment of shoreline impacts. The risk assessment from historic data can help in finding typical risk patterns, "hot spots" or developing sensitivity analysis to specific conditions, whereas real time risk levels can be used in the prioritization of ships, geographical areas, strategic tug positioning and implementation of dynamic risk-based vessel traffic monitoring.

Keywords: risk, oil spills, operational models, risk assessment, ship traffic

1. Introduction

Pollution risks in coastal and marine environments are frequently quantified in a static mode, considering historical data, reference situations, and typical or extreme scenarios, in a planning stage.

Latest scientific and technological developments on coastal monitoring and operational oceanography have provided the opportunity of building more complex and integrative decision support systems for coastal risk management. A novel methodology for dynamic shoreline risk quantification, integrating numerical meteo-oceanic forecasts and oil spill simulations with the existing monitoring tools (e.g. vessel traffic control systems) is presented.

The main purpose is to build a decision support system capable of quantifying time and space variable ship-sourced shoreline pollution risk levels, combining multiple data layers: a) instant vessel information (AIS); b) regional statistics information on vessels accidents history; c) coastal vulnerabilities; d) instant meteo-oceanic forecasting data; e) continuously simulated oil spill fate and behaviour from ships navigating along the coast.

The relevance of integrating the oil spill model and meteo-oceanic data from forecasting systems in the risk algorithm is evaluated.

The whole system is currently implemented in the Portuguese and Galician Continental Shelf - a high shipping density zone. This is also a peripheral zone, where activities in the near-shore area assume a very relevant role in the social and economic context.

2. Methodology

The risk rating combines the likelihood of an oil spill occurring from a vessel navigating in the study area with the assessed consequences to the shoreline. The likelihood is based on dynamic marine weather conditions and statistical information (frequency constants for each accident type) from previous accidents. Variable wind, currents, waves and visibility are taken into account for the likelihood of an accident, which is modified with correction factors adjusted by those meteo-oceanic conditions. These parameters can be imported to system's database in real-time from online internal or 3rd party forecasting systems. Currently the system imports the MARETEC-IST's forecast solutions available in http://forecast.maretec.org and http://meteo.ist.utl.pt.

These meteo-oceanic properties are also used to feed the oil spill fate and behaviour model integrated in the system, which is used to estimate the hypothetical spilled oil amount reaching shoreline. This oil amount in the near-shore and the environmental and socio-economic vulnerability indexes for those affected areas are both used to quantify the shoreline consequences.

The integrated oil spill model is MOHID lagrangian particle tracking system (references). This modelling solution was operationally applied in different incidents (Carracedo *et al.*, 2006), field exercises and studies, and allows the simulation of all major transport and weathering processes, and was recently updated to include full 3D movement of oil particles, wave-induced currents, and oil-shoreline interaction (Fernandes *et al.*, 2013). The dynamic risk tool continuously runs MOHID to simulate hypothetical spills from multiple vessels across the coast, and then taking into account the amount of oil that would approach the coastline.

The shoreline environmental (NOAA-ESI) and socio-economic vulnerability indexes are used in the quantification of the consequences, on risk algorithm.

The simultaneous calculation of the risk posed by each vessel crossing a pilot area is integrated, allowing the generation of a dynamic shoreline risk map for that zone. Variable vessel information is used in the computation of risk: geographical position, cargo type, speed, vessel type, weight (DWT), name and ID (MMSI). Vessels with less than 100 DWT, passenger vessels and fishing vessels navigating outside restricted waters are not considered. The vessel information is obtained from AIS data. The most frequent types of accidents are considered in the system: grounding, foundering and structural failures, collision (with a ship or with port facilities), fire and explosion. The system estimates overall and accident type-specific risk levels.

An alternative risk rating is also computed, without the integration of the oil spill model for estimating the shoreline impact (in this case, using vessel shoreline proximity as impact factor).

3. Results

The decision support system permits visualization of vessel accident risk, shoreline contamination risk and vulnerability indexes, vessel traffic and details, isolated risks caused by specific vessels or isolated risks on specific zones.

Being implemented in a multifunctional GIS desktop system - MOHID Studio, the developed system allows the integrated visualization of previously mentioned layers with meteo-oceanic data, oil spill trajectories, or any other user-added layer. The system can be used to compute risks on live mode (real-time) or on-demand / delayed mode, since all the information needed is available in real-time and is continuously updated and recorded in a database for future use.

Applying this system for risk assessment with historical (or virtual) data allows the identification of typical risk patterns and "hot spots", as well as the development of sensitivity analysis to specific conditions or scenarios (e.g. studying the environmental impact of the increase in the number of vessels). On the other side, the risk assessment from live data provides the possibility of prioritizing individual ships and geographical areas in certain periods, allowing strategic tug positioning or the implementation of dynamic risk-based vessel traffic monitoring.

Figure 1 Shoreline risk levels in Southern Portugal (2014-10-08).

The integration of numerical models (oil spill + meteo-oceanic) with AIS and coastal vulnerability in the quantification of shoreline risk algorithm allows the improvement of the decision support model, in a more realistic approach for the assessment of shoreline impacts. This integrated dynamic approach shows particular relevance in regions with greater variability in marine weather conditions or in vessel traffic – i.e. where risk is more variable. It also provides a different perspective and understanding on risk in specific zones with calm and / or favourable meteo-oceanic conditions with constant high cargo or tanker traffic in the near-shore area. The developed tool shows that those conditions don't necessarily mean high risks for the shoreline – the existence of wind and currents generating oil transport offshore will significantly reduce the shoreline contamination risk.

Acknowledgements

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Operational Metocean Forecast for Port Access and Operations using the AquaSafe platform

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Abstract

The AquaSafe platform has been set up for several ports since 2011: Leixões, Viana do Castelo and Setúbal, in Portugal, and Buenaventura and Tumaco, in Colombia, to support the need to increase productivity and maintain safety. This platform can be used to downscale waves and currents' forecasts to a resolution of the order of 10 m and disseminate modelled and measured data in real time. AquaSafe is also being used to support the evaluation of the water depth in the navigation channels. This data is displayed in real time in control rooms' screens, in mobile Apps and automatic reports via email. One of the desktop clients that connects to the forecast server is the Oil Spill Simulator, used in emergency situations (oil spill or search and rescue related operations).

Keywords: Port access, forecast, downscale, multi-nesting modelling, AquaSafe

1. Introduction

The present economic context of rapid growth in the movement of goods in a lot of ports, and the predicted increase in world seaborne trade in the next decade, is key to justify the need for improved operational systems. Ports need to increase productivity as they need to cope with more demand (increase in trade), different demand (growing size of vessels see Fig. 1) and the capital and time constraints in growing port infrastructures.

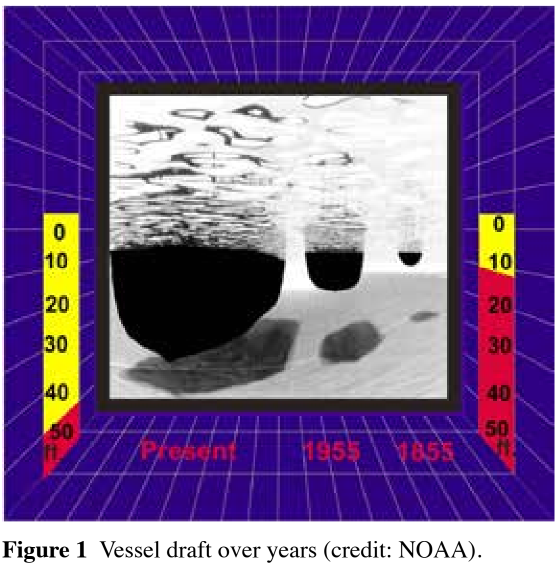

Figure 1 Vessel draft over years (credit: NOAA).

2. Ports scale operational modelling

Operational systems, based in the AquaSafe software (Silva, 2012), with forecasts of hydrodynamics and waves, at scales around 20 to 100 m (see Fig 2.), meteorology, at scales of 4 to 9 km, validated with tidal gauges, meteo stations and wave buoys have been set up in several ports since 2011: Leixões, Viana do Castelo (see Fig. 3) and Setúbal, in Portugal, and Buenaventura and Tumaco, in Colombia.

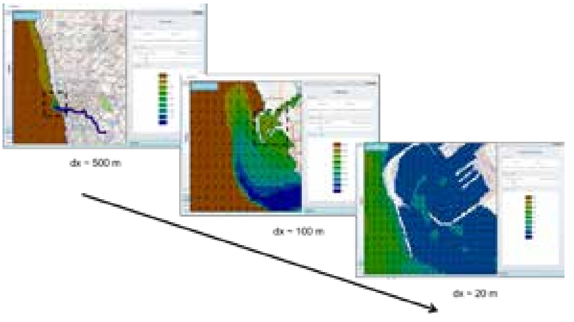

Figure 2 Three MOHID one-way nesting levels – Leixões Port.

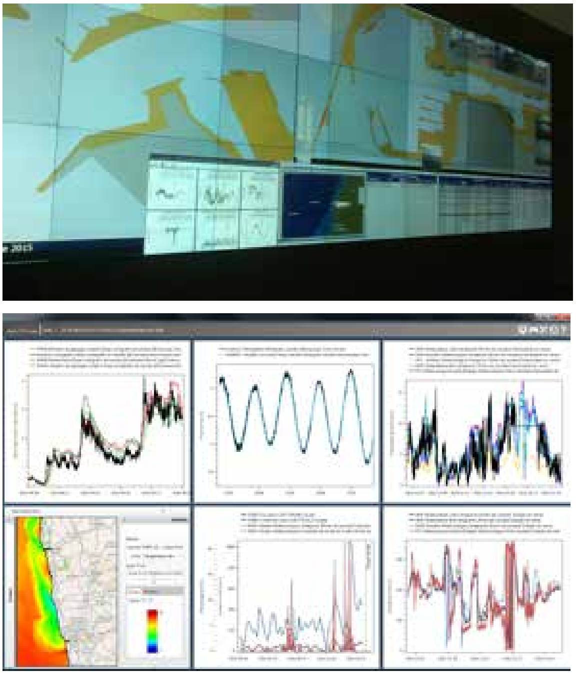

Figure 3 Desktop client that allows access (in real time) to forecasts and observations in screens placed in the control room.

3. AquaSafe software

The design of each of the systems has different modelling strategies, depending on the specific problems of each port. These systems are based on an AquaSafe server that connects to third party models (global models like GFS, RTOFS, MyOcean and regional models like WRF or MM5), to databases or scada systems that manage observations, runs regional or local models, (like MOHID, WW3, SWAN), sends automated reports by email, connects to desktop or web clients to show observations and forecasts. The methodology implemented follows the recommendations of PIANC (2012).

Boundary and initial conditions of coastal scale models are defined using global and regional third party solutions. The coastal scale then is refined to the local scale using multi-nesting approaches. In the case of MOHID, the methodology proposed by HIDROMOD (Leitão, 2005) is followed. For other models, standard methodologies proposed by each modelling community are used.

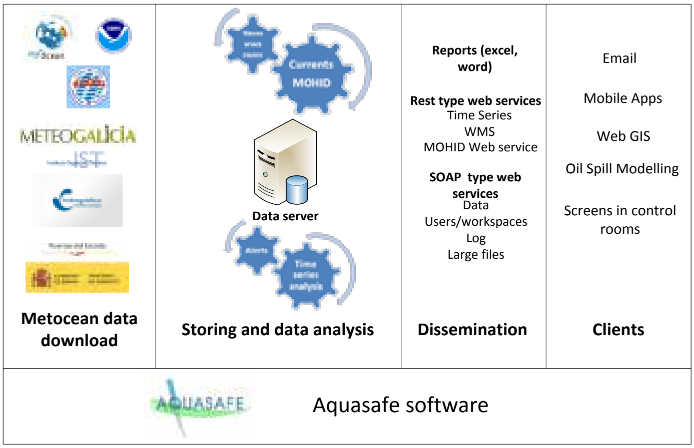

Figure 4 AquaSafe software components.

4. Operational tools focused in Ports

One of the desktop clients that connects to the AquaSafe server forecasts is the Oil Spill Simulator. This software client is an efficient forecast tool for emergency situations (oil spill or search and rescue related operations) as it relies on hydrodynamic forecasts that are used on a day-to-day basis, for navigation purposes. AquaSafe is also being used to assess the available water depth in navigation channels. By means of integration of the most recent bathymetric surveys and model results (water level, currents, waves and meteorological conditions), it is possible to optimize the dredging effort necessary to guarantee safe navigation conditions.

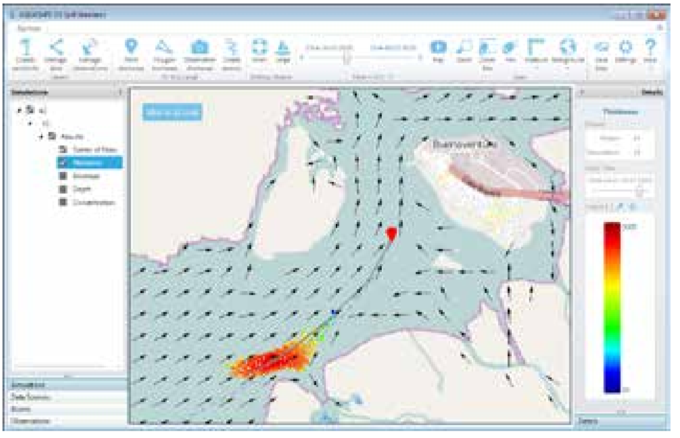

Figure 5 Oil spill - Buenaventura bay Colombia.

5. Conclusions

Operational systems focused in specific needs (e.g. Metocean data at Ports scale) must be implemented and developed in close collaboration with the client. Standards must be used to allow a direct connection to the client's software platforms. Web pages, mobile Apps and desktop clients are efficient channels to disseminate observation and forecast data.

Acknowledgements

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Adriatic marine meteorological center AMMC

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Abstract

Meteorological and Hydrological Service of Croatia (DHMZ Croatia) took a lead in organizing a cooperation of national meteorological services toward the better marine meteorological services at the Adriatic sea area (abb AMMC). The aim of the AMMC is to apply and enhance the World meteorological Organization (WMO) and Joined Commission for Marine Meteorology (JCOMM) standards at regional and national levels in particular at: the integration of meteorological, hydrological and oceanographic in-situ observation systems at Adriatic sea area; improving of the regional observation capabilities by implementation of WMO system of observation planning and integration system and link to WMO Information system (WIGOS/WIS); implementation of geoportal WEB site with the aid of data discovery, download and display functionality according to WIS and INSPIRE standards. At regional level, AMMC should took at steps for harmonization of Adriatic met-ocean forecasting and warning system, cooperate at the establishment of decadal average states /normal for atmospheric -ocean system parameters in order to improve the local and extreme events assessments; standardization of marine meteorological products for tourist and recreational vessels, taking into account the local climate conditions and vulnerability to extreme maritime events in order to improve marine traffic safety.

Keywords: Adriatic, services, meteorological-oceanographic, WMO WIGOS/WIS

1. Introduction

Meteorological and Hydrological Service of Croatia (DHMZ) is the official authority for meteorological, climatological, marine and hydrological service in Croatia, and representing Croatia at WMO and at the other similar European and international associations e.g. ECMWF, EUMETNET, EUMETSAT, and JCOMM.

Recognizing the need for centralized and comprehensive marine meteorological and oceanographic information for the Adriatic Sea area and the necessity to fill the gaps of marine and oceanographic information (data and products) by the cooperation between existing national meteorological and hydrological services (NHMS) and their partners resources, DHMZ, in coordination with WMO and JCOMM, took steps towards the establishment of a WIS-DCPC / WIGOS Marine Meteorological Centre as a Sub-Regional Facility for the Adriatic Sea Area.

In September 2014, during WMO Conference for Basic Systems, DHMZ was approved as Regional marine meteorological Dissemination and Production Center (DCPC) for Adriatic Sea (AMMC), under the JCOMM coordination, where regional coordination between NHMSs of Albania, Bosnia and Herzegovina, Croatia, Italy, Montenegro and Slovenia, for the Adriatic Sea, will serve as a Pilot-project for marine services for small / inner sea / gulf areas.

2. Croatian marine meteorological services

Marine meteorological service in Croatia is provided by DHMZ dedicated division, PMC - national marine meteorological center in Split, the third largest passenger port in the Mediterranean Sea.

PMC is a national marine call service, linked to national data production and WIS center in Zagreb, equipped with resources and trained Marine weather forecasters (MWF) and data and IT operators. MWFs work in 20-24h shifts and provides: marine weather watch, forecast weather and marine phenomena; issues multi language warnings for hazardous phenomena at inner seas and coastal areas; ensures services for Search and Rescue actions (SAR); services for Prevention of, Preparedness for and Response to Major Marine Pollution Incidents in the Adriatic Sea.

DHMZ, with the new role of AMMC host, took the steps toward improvement of capabilities in marine services, in order to become a center of excellence, by: partnership with national oceanographic, hydrographic institutes and Academia; common planning on marine safety products and procedures with the Croatian Maritime Safety Directorate; establishment of Integrated Marine meteorological forecasting and early warning system; partnership with EuTrain on marine forecasting education.

3. Wigos

The WMO Integrated Global Observing System (WIGOS) provides a new framework for WMO observing systems, including the contributions of WMO to co-sponsored observing systems, and other GOOS systems. It is important to recognize that WIGOS is not replacing the existing observing systems, but is rather an over-arching framework for the evolution of these systems which will continue to be owned and operated by a diverse array of organizations and programs. WIGOS will focus on the integration of governance and management functions, mechanisms and activities to be accomplished by contributing observing systems, according to the resources allocated on a global, regional and national level. WMO and JCOMM recognize WIGOS as a future integrated system of observing systems that is shaped in a most efficient way, under agreed standards of data quality management.

4. Ammc functions and partnership

AMMC is a partnership of NHMSs**,** AMMC members that are focal points, coordinating meteorological, hydrological and oceanographic services and institutes at national level. Members are: defining AMMC plans; coordinating national distribution and retrieval actions toward AMMC DCPC (WIS/WIGS); providing national standards and procedures for marine services; proposing and applying common actions on Adriatic Sea marine services; coordinating WIGOS/OSCAR actions on observation network requirements and development.

AMMC DCPC virtual center, hosted by DHMZ, provides DCPC Geo Portal and functionality (maintenance of network, products, users, archive),provides link between AMMC and WIS GISC Offenbach for WIS/WIGOS data harvesting, provides operative Adriatic Sea area products to WIS/WIGOS systems; maintains operative and near-real time Adriatic Sea area products for public and scientific purposes; Provides INSPIRE compabilities and functions (search, view, download, remote harvesting); provides technical support for common actions on Adriatic Sea marine services (http://www.ammc.hr:8080/geoportal/).

The main goal for the Marine meteorological Center for the Adriatic Sea Region , is to enable, enhance, and secure provision of *affordable* and *cost effective* joint service (24/7/365) for the users of the marine meteorological and oceanographic information (data and products) for the Adriatic sea area by: bringing together National Meteorological and Hydrological Services NHMS and their partner organizations such as hydrographic, oceanographic, institutions and Academia (e.g. universities) taking into account and respecting each other's responsibilities and mandates; inventory and utilization of existing marine meteorological and oceanographic infrastructure trough usage of common highly effective DCPC - WIS / WIGOS two way communication system in order to provide standardized, centralized and comprehensive marine and oceanographic information and to avoid duplications of facilities and human resources.

Acknowledgements

AMMC activities has been supported by WMO and JCOMM.

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Environmental Marine Information System (EMIS) – A marine geo-portal to assist in the management of European Seas

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Abstract

The conception, development, implementation and monitoring of EU environmental policies requires the provision of timely, quality assured and easy-to-use data and information. The Joint Research Centre (JRC) of the European Commission (EC) in its role as a marine Competence Centre for Good Environmental Status (GES) has developed an Environmental Marine Information System (EMIS) to assist Member States with the monitoring and assessment of their marine and coastal waters.
The system's operations include i) the provision of continuous, and accurate marine / coastal data as derived from satellite observations and model outputs; ii) the generation of indicators for diagnostic of the coastal state and analyses of changes in marine ecosystems; iii) basic navigation and interrogation tools with time-series and statistical analyses generated automatically in a format ready for reporting.
EMIS is implemented with services compliant with the Open Geospatial Consortium (OGC) specifications and INSPIRE standards to ensure full interoperability. These services are connected to R-written functions, enabling the processing of EMIS data, their analysis and reporting to be integrated in a unique development environment. An application example is given with the analysis of the environmental variability of the Gulf of Sidra (Libya), as part of the EU MEDINA project.

Keywords: Geo-portal, European seas, satellite, ecosystems, indicators

1. introduction

Rapid and often negative changes of the water quality, and subsequent degradation of marine habitats over European continental shelves have triggered the necessity to develop strong political instruments that would preserve the natural resources and biodiversity, while keeping the related economic sectors viable. The success of implementing these policies depends on the nature and reliability of scientific data, the aggregation of these data into appropriate information (indicators) maps, as well as on the degree of harmonization in the methods and monitoring tools, and on the frequency to which this information can be made available with respect to the time variability of marine processes.

Over the last two decades, earth observations from satellite has demonstrated great potential to capture important marine and coastal processes like sediment transport, coastal upwelling, eutrophication, ecosystem shifts, over extensive areas and at timescale ranging from hours to several days or years. Nevertheless, there are still some constraints in using these data operationally, including uneasy access to the data and inadequate analysis and information dissemination approaches to communities outside the research / scientific system. Geographical Information System (GIS) enable the combination of data from multiple and disparate sources, as well as provides an excellent platform to communicate results of scientific analysis to a wider community including policy makers. This work briefly reviews feartures of a Marine Information System (EMIS, http://emis.jrc.ec.europa.eu) , designed to provide the user community at large appropriate information to conduct water quality assessment and resource monitoring in the coastal and marine waters around Europe.

2. Web-gis design and architecture

EMIS web-GIS applications are based on a MapServer engine (v.6.4). Scripts are written in PHP/PHP Mapscript and in Perl/Phython/R programming languages for developing server-side applications and dynamic web content.

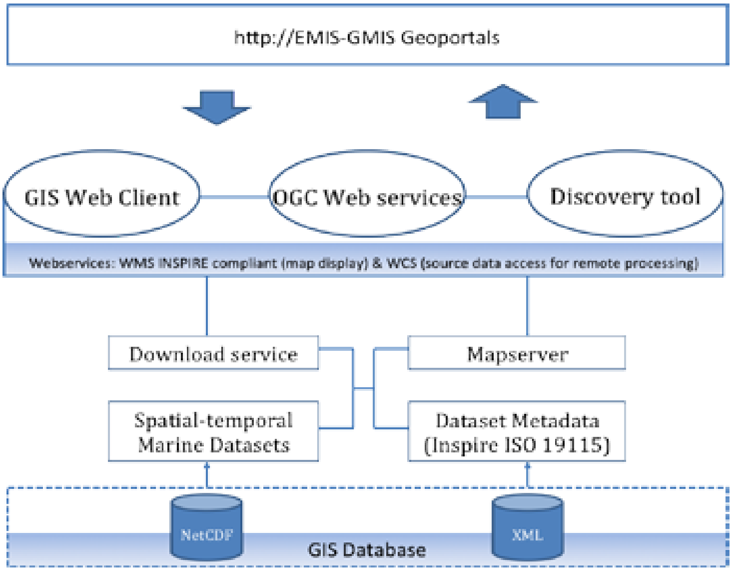

Figure 1 The Service-oriented architecture and technical workflow of EMIS geo-portal.

To ensure full interoperability with other GIS systems, EMIS is implemented with OGC-compliant services and INSPIRE standards. These services are connected to R-written functions, enabling the processing of EMIS data, their analysis and reporting to be integrated in a unique development environment.

3. Gis database and processing

Most of the data populating EMIS are derived from earth Observations satellites, specifically those carrying ocean colour and thermal radiometers. Complementing these data, the geo-portal also includes some aspects of the marine physics issued from numerical model simulating important hydro- and thermodynamic processes in marine and coastal waters.

Satellite data from SeaWiFS, MODIS and MERIS sensors have been processed using the most recent NASA SeaDAS software (Fu et al. 1998), to create monthly biogeochemical products at a resolution of 2 and 4 km. Sea surface temperature (SST) is retrieved from AVHRR and MODIS-Terra, both granting continuous time-series of SST since 1985.

A set of variables describing the marine physics in the water column are generated from the General Estuarine Transport Model (GETM), consistently implemented in all European seas.

Particular attention is paid to the quality of the information provided. Validation exercises are regularly performed to assess the efficiency of satellite data over European seas (Zibordi et al. 2009, 2013).

4. System functionalities

EMIS viewer offers a set of tools enabling navigation and browsing through the data according to spatial resolutions, variables to be analysed, and time period. Specific applications have been developed to query the data and perform automatically basic statistical analysis on the region of interest (i.e., mean, max./min. Values, standard deviation). Additional functions include correlation and time series analysis generated on request and visualized as charts or plots in the display area and available as ASCII file for further processing.

The Discovery tool enables an easy and fast visualisation of EMIS database and a direct access to the listed datasets in three different ways: display (GIS viewer, WMS), download (netCDF, GeoTIFF, WCS), and query of metadata (CSW).

5. Environmental assessment: gulf of syrte (mediterranea)

A pilot case study devoted to Lybian waters was performed using EMIS data, in the framework of the EU MEDINA project (http://www.medinaproject.eu) and focusing on the environmental variability of the Gulf of Syrte. This area is oligotrophic, and characterized by a strong seasonal cycle, both in the biological and physical processes as observed from satellite. The data and indices in EMIS show a good resistance to eutrophication and oxygen depletion for this area, even though the results should still be validated using field measurements.

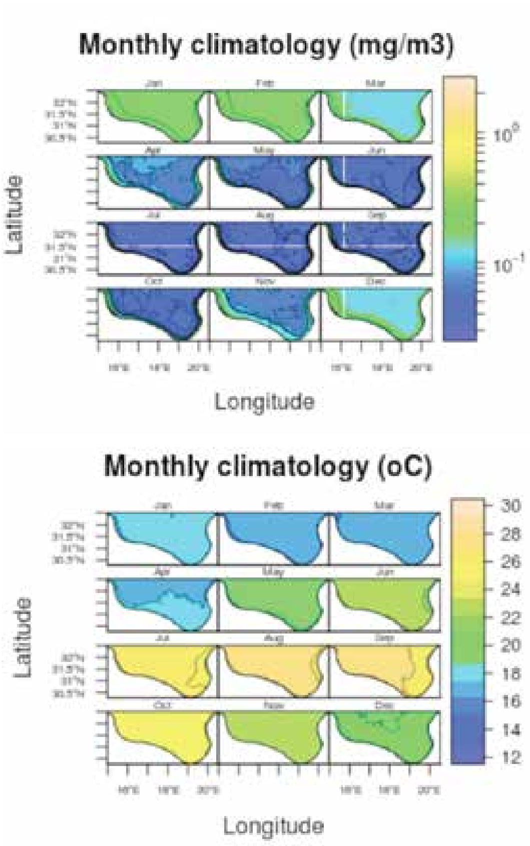

Figure 1 EMIS-derived monthly climatology (2003-2012) of Chlorophyll-a concentration (top) and sea surface temperature (bottom) in the Gulf of Syrte.

The data was used further to partition the area into 9 different sub-regions, differing both in the geography (coastal *vs* pelagic) and in their environmental processes (productive *vs* energetic systems).

Acknowledgements

The authors wish to thank NASA OBPG for granting access to the satellite data, and F. Mélin for processing and analysing these data into a consistent and accurate database of biogeochemical products.

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