Organised by:

EuroGOOS
European Global Ocean Observing System

Foras na Mara
Marine Institute

10th EuroGOOS International Conference

3-5 Oct 23
Galway, Ireland

European Operational Oceanography
for the Ocean we want – addressing the UN Ocean Decade Challenges

Conference Proceedings

December 2023

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

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Conference Statement

10th EuroGOOS International Conference statement

In its nearly 30 years of existence, EuroGOOS has become the leading forum for European operational oceanography. The EuroGOOS community is strongly positioned to meet the challenges required by operational oceanography today and into the future, including the needs of the Green Deal and other European initiatives or directives, and to meet national policy needs. Thanks to well-developed networks facilitating regional and international cooperation, European institutions and agencies together have world-leading capacity across the ocean knowledge value chain. On 3-5 October 2023, the 10th EuroGOOS International Conference, the primary gathering for operational oceanography in Europe, brought together more than 160 ocean experts to exchange ideas and recent developments, and to discuss priorities in the context of the UN Decade of Ocean Science for Sustainable Development 2021-2030.

The diversity of Europe and the European operational oceanography community is a great strength. However, it can also lead to fragmentation and associated challenges. Continuing to strengthen coordination at national levels, aligning with the European frameworks, such as the European Ocean Observing System (EOOS), and global efforts, will be essential for the community to meet its ambitions and the needs of users in all sectors of society.

Key priorities and messages from the 10th EuroGOOS International Conference

Operational oceanography in Europe must develop with a holistic Earth system approach. The operational oceanography value chain must be better connected to those of other environmental domains (terrestrial, hydrological, atmospheric, cryospheric, climate, etc.), as well as socio-economic information systems, to deliver fit-for-purpose products and services. This must be simultaneous with the continuous efforts to strengthen the ocean-specific capabilities that are the core of the European operational oceanography community.

Without observations, ocean services and products are not possible. Ocean observations play a crucial role in delivering essential marine services and products relied upon by users in Europe and worldwide, including forecasts, data products, and model outputs on the frequency that is needed by the users. Ocean observations must be sustainable (in all regards), cost-effective and with sufficient coverage. The continued development of the European Ocean Observing System (EOOS) is therefore a collective ambition of the highest priority.

EuroGOOS activities are an important asset contributing to the UN Ocean Decade Challenges for collective impact. Alignment with Decade activities and objectives will further reinforce the impact of EuroGOOS, helping to realise its vision at a global level. The continued engagement of EuroGOOS and its community in the Decade activities will be crucial to the Decade's success in Europe and beyond. The participation of EuroGOOS in Decade Collaborative Centers and in other relevant Decade Actions is the manifestation of this. EuroGOOS collaboration and alignment with GOOS is a cornerstone for enhancing the collective impact of our activities in this context.

Genuine co-design of operational oceanography with users and stakeholders, including policymakers, is essential to ensure their needs are met. For operational oceanography to be fit for purpose and truly meet societal needs, stakeholder engagement, and co-design of the system with users from the outset must become the standard practice. Realising the benefits of operational oceanography for Europe and the world can only be done by embracing well-structured and adequately funded engagement and co-design activities, while also continuously reviewing and adapting to emerging needs.

There is no operational oceanography without people - the skilled individuals without whom there would be no ocean observations, infrastructure and data management, or forecasts and services. Observing platforms or data by themselves cannot deliver the ocean knowledge, products and services Europe needs. Providing adequate resources to the human capacities is key to enable high qualified observations. Enhanced training and education are needed, along with opportunities to ensure operational oceanography is an attractive career path, whether in a scientific, technical, managerial, or other domains.

It is imperative to boost and demonstrate the value of ocean observing and operational oceanography to all stakeholders across the marine knowledge value chain. Understanding of the value of ocean observing and operational oceanography, and their interdependency, must not be taken for granted. Communication, awareness raising, and the ongoing demonstration of economic value are needed to strengthen the case for observations. These are an essential part of Europe's efforts to meet the needs of users in the blue economy and deliver on climate and biodiversity targets.

Beyond these overarching priorities, several specific recommendations emerged as outcomes of the 10th EuroGOOS International Conference, in the areas of ocean observations, modelling, forecasting, Digital Twins of the Ocean and data, as well as engagement and ocean literacy.

Ocean observations: Observations are the foundation of ocean knowledge. To develop EOOS as the coordinated Europe-wide ocean observing system, national level coordination must be strong, observing plans must be guided by user needs and shared to facilitate cooperation. Particular needs for ocean observing in Europe are:

- Tackle fragmentation of observing capacities by strengthening coordination of ocean observing at a national level, aligned with the Europe-wide context of the EOOS Framework.
- Greater recognition of the human resources, the people, who operate the observing systems, and development of Europe-wide skills development and training actions for technicians.
- Improve the sustainability of European operational oceanography in all regards, including environmental impacts and funding. Efforts must be made to minimise the environmental impacts of ocean observing platforms and infrastructures. This includes improved retrieval of equipment, further development of autonomous, smart and low-impact platforms, and greater efficiency through new technologies, improved planning coordination and cooperation.
- Simplify processes to obtain permissions for transnational oceanographic activities to greatly improve efficiency in planning and operations, benefiting the community and facilitating better coordinated and seamless observing campaigns.
- Improve resources for the analysis of the obtained observations and operation and maintenance of the observing systems.

Modelling, forecasting, Digital Twins of the Ocean and data: Ocean modelling and forecasting must continue to advance for many applications, including to support the development of Digital Twins of the Ocean, and must continue to develop through a co-design with users and stakeholders.

- Advancements in ocean modelling capabilities require a special focus on developing improved coastal and biological applications.
- Ensemble prediction and forecasting capabilities, improved ocean-wave-ice coupling, and assimilation of biogeochemical data are particular targets for development.
- Europe's expertise and capacities in modelling must be shared and strengthened, including the development of new techniques and applications involving artificial intelligence.

- To advance services, including the Digital Twins of the Ocean, we must build upon existing European achievements and continue to promote FAIR data standards, and we must maintain data traceability and ensure proper credit is provided to its origin.

Engagement and ocean literacy: To unlock the full potential of operational oceanography in Europe, it is essential to prioritise awareness-raising and active citizen engagement. Developing an ocean literate Europe across all sectors, disciplines, and communities will foster innovation and new applications of ocean knowledge and information, further raising the value of operational oceanography and ocean observing to society.

- Stakeholder engagement and Ocean Literacy should be targeted, properly planned, and well resourced (personnel and activities) and include regular impact assessment. Ocean Literacy should incorporate socio-economic, artistic and creative disciplines to truly promote behaviour change towards sustainability. Cross-disciplinary partnerships are needed.

- Citizen science activities should be fostered in all areas of oceanography through partnerships.

- Further capacity sharing and best practices in engagement and ocean literacy should be promoted across Europe and beyond.

EuroGOOS represents the collective voice of the European operational oceanography community and will continue to serve as the primary forum for its coordination and development, to meet the needs of all users of marine knowledge, information, products and services. The EuroGOOS Community looks forward to addressing the UN Ocean Decade Challenges and meeting its objectives. Results of these efforts will advance Europe as a leader in operational oceanography and ocean observing globally.

Programme

Tuesday 3 October

08:00 - 08:45 **Conference registration (also available on 2 October, 18:00-20:00)**

09:00 - 10:20 **Operational Oceanography for EU and global societal needs** - Room: Lettermore

09:00 - 09:10 Welcome - Henning Wehde, Chair, European Global Ocean Observing System (EuroGOOS)
09:10 - 09:20 Welcome from Conference host - Michael Gillooly, Interim CEO, Marine Institute (Ireland)
09:20 - 09:30 UN Decade of Ocean Science for Sustainable Development - Vladimir Ryabinin, Executive Secretary, IOC-UNESCO
09:30 - 09:40 Ocean observation - sharing responsibility - Delilah Al Khudairy, Director, Maritime Policy & Blue Economy, European Commission DG MARE
09:40 - 09:50 Ocean knowledge for the EU Missions - Elisabetta Balzi, Head of Unit Healthy Seas and Ocean, European Commission DG Research and Innovation
09:50 - 10:10 Key achievements since the last Conference - Inga Lips, Secretary General, EuroGOOS

10:20 - 11:00 Break

11:00 - 12:30 **Operational Oceanography in the Ocean Decade** - Room: Lettermore

Moderator: Holger Brix, Hereon (Germany)

11:00 - 11:20 **Keynote:** Co-designing marine science for the ocean we want - Emma Heslop, IOC-UNESCO
11:20 - 12:30 **Panel discussion**
Decade Collaborative Centre on Ocean Prediction - Enrique Álvarez, Mercator Ocean International
Decade Collaborative Centre on Coastal Resilience - Andrea Valentini, University of Bologna (Italy)
Decade Programme SciNMeet - Rosalia Santoleri, CNR (Italy)

12:30 - 14:00 Lunch

14:00 - 15:30 **Digital Twin of the Ocean for Europe** - Room: Lettermore

Moderator: Henning Wehde, IMR (Norway)

14:00 - 14:20 **Keynote:** Data, science and evidence needs to deliver net gain for fisheries, marine eco-systems and offshore renewable energy - Colm Lordan, Marine Institute (Ireland)
14:20 - 15:30 **Panel discussion**
EuroGOOS Baltic Operational Oceanographic System (BOOS) - Jun She, DMI (Denmark)
EuroGOOS North West European Shelf Operational Oceanographic System (NOOS) - Sebastien Legrand, RBINS (Belgium)
EDITO-Infra - Conor Delaney, EMODnet
EDITO-Model Lab - Marina Tonani, Mercator Ocean International

15:30 - 16:00 Break

16:00 - 17:30 **EOOS - boosting in situ observing capacity** - Room: Lettermore

Moderator: Glenn Nolan, Marine Institute (Ireland)

16:00 - 16:20 **Keynote:** Vision for EOOS - George Petihakis, EOOS Steering Group / HCMR (Greece)
16:20 - 17:30 **Panel discussion**
Italian Integrated Environmental Research Infrastructure System - Rosalia Santoleri, CNR (Italy)
French Ocean Observing System (FrOOS) - Lucie Coquempot, Ifremer (France)
Future Marine Research Infrastructure - Leigh Storey, Natural Environment Research Council, NERC (UK)
Developing observing capacity for ocean biology - Luis Felipe Artigas, Jerico-RI

17:30 - 18:30 **Poster session and group picture** - Room: Ballyvaughan

19:00 - 21:00 **Networking reception at Galway Atlantaquaria**

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Wednesday 4 October

09:00 - 10:30 **Parallel sessions**

A: Towards digital twins of the ocean - Chair: Manuel Ruiz, IEO-CSIC (Spain) - Room: Lettermore

EDITO: two innovative projects for an operational European Digital Twin of the Ocean
Yann Drillet, Mercator Ocean International

Piloting the concept of an Information Management Framework for Environmental Digital Twins (IMFe) and connecting the results to the UN decade DITTO programme
Justin Buck, National Oceanography Centre, British Oceanographic Data Centre (UK)

Ireland's Digital Twin of the Ocean
Michael Arrigan, Marine Institute (Ireland)

Serverless QC for Ocean Gliders: A Sea Change
Thomas Gardner, National Oceanography Centre (UK)

In the shoes of a Marine Data Manager in an autonomous world
Emma Gardner, National Oceanography Centre (UK)

EOSC-FUTURE – ENVRI-FAIR Dashboard of the State of the Environment
Dick Schaap, MARIS (Netherlands)

B: Strategic developments in ocean observing - 1 - Chair: Vanessa Cardin, OGS (Italy) - Room: Inishmaan

The Science We Need for the Mediterranean Sea We Want (SciNMeet) Programme: the Mediterranean Region's contribution to the UN Decade of Ocean Science for Sustainable Development (2021-2030)
Lorenza Evangelista, National Research Council (Italy)

EuroGOOS Scientific Strategy: Advancing a Seamless Earth System Approach for European Operational Oceanography
Jun She, Danish Meteorological Institute (Denmark)

Eurofleets: Long-term sustainable development of capacity sharing through multidisciplinary research cruise funding programmes
Niamh Flavin, Marine Institute (Ireland)

Future Marine Research Infrastructure – defining the scope, scale and pace to help identify and accelerate international partnership opportunities
Leigh Storey, Natural Environment Research Council (UK)

Advancing European Ocean Observing System: Fit-for-Purpose Monitoring Integration, Cost-Effectiveness, Shared Responsibility and network optimization
Lucie Cocquempot, Ifremer (France)

Towards a new phase for Argo at the European scale: Euro-Argo RISE contribution
Estérine Evrard, Euro-Argo ERIC

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C: Enhancing capacity in ocean observing and services - Chair: Henning Wehde, IMR (Norway) - Room: Inishturk

Applications of ocean gliders for climate change monitoring of Essential Ocean Variables (EOVs) in the North East Atlantic
Céline Burin, Earth and Ocean Sciences, School of Natural Sciences and Ryan Institute, University of Galway (Ireland)

Copernicus Observations In Situ Networking and Sustainability (COINS) – Arctic Data
Ole Krarup Leth, Danish Meteorological Institute (Denmark)

Capacity sharing: Provision of data to The Met Eireann integrated Coastal Flood Forecast Service (ICFFS)
Guy Westbrook, Marine Institute (Ireland) (Presenting: Rosemary Lawlor, Met. Eireann)

Demonstration of a transnational cooperation for harmonized chlorophyll a monitoring in the North East Atlantic Ocean
Tamara Rodríguez Ramos, Instituto Español de Oceanografía, CSIC (Spain)

10:30 - 11:00 Break

11:00 - 12:30 **Parallel sessions**

D: Advances in ocean forecasting - Chair: Sebastien Legrand, RBINS (Belgium) - Room: Lettermore

The Copernicus Marine Service: recent achievements and future plans
Pierre-Yves Le Traon, Mercator Ocean International

Forecast uncertainty and ensemble spread in surface currents from a regional ocean model
Martina Idzanovic, MET Norway (Norway)

Forecasting the sea level in the Mediterranean Sea using the assimilation of coastal tide-gauge data
Marco Bajo, National Research Council, CNR-ISMAR (Italy)

The Baltic Sea model system and products delivered into the Copernicus Marine Service
Vibeke Huess, Danish Meteorological Institute (Denmark) (Presenting: Laura Tuomi, FMI (Finland))

Developing coupled wave-ocean model to improve Baltic Sea forecasts
Laura Tuomi, Finnish Meteorological Institute (Finland)

Copernicus Marine forecasting systems: current configurations and future developments
Marina Tonani, Mercator Ocean International

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Wednesday 4 October

E: Strategic developments in ocean observing - 2 - Chair: Holger Brix, Hereon (Germany) - **Room: Inishmaan**

ITINERIS - Italian Integrated Environmental Research Infrastructures System: Marine Domain
Rosalia Santoleri, National Research Council (CNR) (Italy)

The iFADO PAAnoramic mission: the first European Atlantic area international multi-platform ocean monitoring mission
Francisco Campuzano, +ATLANTIC CoLAB (Portugal)

Implementation of the oceanographic platform "ZIPIHUS" at the Al Hoceima Marine Observatory: towards operational oceanography in Morocco for a sustainable management of marine resources
Asma Damghi, Research Laboratory in Applied and Marine Geosciences, Geotechnics and Geohazards, University Abdelmalek Essaadi (Morocco)

EMSO ERIC progress in data harminization and physical access for the benefit of marine science and technology
Juanjo Dañobeitia, EMSO ERIC

F: Strengthening Europe's oceanographic fleet - Chair: Carlos Fernandes, Hydrographic Institute (Portugal) - **Room: Inishturk**

Mediterranean Sea Ship-based Hydrography Programme (Med-SHIP)
Vanessa Cardin, National Institute of Oceanography and Applied Geophysics (OGS) (Italy)

EuroGOSHIP: A potential new research Infrastructure supporting European hydrography
Richard Sanders, NORCE (Norway)

The contribution of Eurofleets RI to respond to the European societal needs
Lorenza Evangelista, National Research Council (CNR) (Italy)

Eurofleets+ Joint Research Activities Advanced Innovative Integrated Services
Arturo Castellón Masalles, National Research Council (CSIC) (Spain)

Norwegian Ships of Opportunity Program for marine and atmospheric research
Helene Frigstad, Norwegian Institute for Water Research (NIVA) (Norway)

G: Scientists for ocean literacy - Chair: Dina Eparkhina (EuroGOOS) - **Room: Inisheer**

Ocean of changes. Modern approach to ocean knowledge transfer
Paulina Pakszys, Institute of Oceanology Polish Academy of Sciences (IO PAN) (Poland)

Ocean Literacy and EU Blue Schools Network as tools for integration of ocean issues into schools curricula
Panayota Koulouri, Hellenic Centre for Marine Research (HCMR) (Greece)

Galway Atlantaquaria & the Irish Ocean Literacy Network – The role aquariums can play in fostering global Ocean Literacy (OL)
Maria Vittoria Marra, Galway Atlantaquaria (Ireland) (Presenting: Noirin Burke)

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12:30 - 14:00 Lunch

14:00 - 15:30 **Parallel sessions**

H: Ocean data assimilation trends and challenges - Chair: Pierre-Yves Le Traon, Mercator Ocean International - Room: Lettermore

Use and impact of in situ observations in global and regional ocean monitoring and forecasting systems
Elisabeth Remy, Mercator Ocean International

The Met Office Forecast Ocean Assimilation Model (FOAM) using a 1/12 degree grid for global forecasts
Ana Aguiar, Met Office (UK)

Recent data assimilation developments in the Mediterranean Sea Analysis and Forecasting System (MedFS)
Jenny Pistoia, CMCC (Italy)

Integrating data assimilation and deep learning to maximize the impact of BGC-Argo observations in the Mediterranean Sea biogeochemical forecasting system
Gianpiero Cossarini, National Institute of Oceanography and Applied Geophysics (OGS) (Italy) (Presenting: Anna Teruzzi)

Direct Assimilation of Sentinel-1 C-SAR Backscatter Data to Update a Baltic Sea Ice Forecasting Model using 4D EnVar Data Assimilation
Lars Axell, Swedish Meteorological and Hydrological Institute (Sweden)

European Sea marine forecast for maritime service by aggregating multi-forecasts and observations
Jun She, Danish Meteorological Institute (Denmark)

I: Ocean observing co-design and stakeholder engagement - Chair: Enrique Alvarez, Mercator Ocean International - Room: Inishmaan

Co-development of an Ocean Observatory with the Aquaculture Industry
Martha Bonnet Dunbar, Institute of Marine Sciences of Andalusia (ICMAN-CSIC) (Spain)

Talking with the potential end-users of the Observatorio Costeiro da Xunta de Galicia as a starting point of their engagement: perceptions and necessities
Clara Almécija Pereda, CETMAR (Spain) (Presenting: Pedro Montero, INTECMAR)

Copernicus Marine and EU Member States: towards new services and co-designed solutions
Tina Silovic, Mercator Ocean International

An open source user-focused technology to process, visualise and automate publication of quality controlled CTD data
Denise O'Sullivan, Marine Institute (Ireland)

MARine Biodiversity and Ecosystem Functioning leading to Ecosystem Services (MARBEFES): Stakeholder Engagement in Heraklion Gulf, Crete, Greece
Panayota Koulouri, Hellenic Centre for Marine Research (Greece)

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J: Operational oceanography in the coastal zone - Chair: Ghada El Serafy, Deltares (Netherlands) - Room: Inishturk

Synthesis of JERICO-RI coastal Pilot Supersite implementation: towards integrated pan-European multiplatform coastal observations
Jukka Seppälä, Finnish Environment Institute (SYKE) (Finland)

Integrating Coastal and Riverine Research – A Case Study for the German Bight and the Elbe River
Holger Brix, Helmholtz-Zentrum Hereon (Germany)

Climate-Proofing Coastal Cities: The SCORE Project's Triple-Win Approach
Salem Gharbia, Atlantic Technological University

High resolution coastal ocean model of Galway Bay, Ireland, supporting oyster aquaculture and native oyster restoration
Diego Pereiro, Marine Institute (Ireland)

New initiatives for multidisciplinary and integrated oceanography in the SE Bay of Biscay
Anna Rubio, AZTI (Spain)

15:30 - 16:00 Break

16:00 - 17:30 **Parallel sessions**

K: Evolution of ocean modelling - Chair: Jun She, DMI (Denmark) - Room: Lettermore

Automatized generation of user oriented ocean model configuration with varying resolution in Baltic Sea – North Sea
Vilnis Frishfelds, Danish Meteorological Institute (Denmark)

Ocean Model products for efficient monitoring of undersea cables
Jens Murawski, Danish Meteorological Institut (Denmark)

Evolution of the Copernicus Marine Service global ocean analysis and forecasting high-resolution system: potential benefit for a wide range of users
Jean-Michel Lellouche, Mercator Ocean International

The Syrian oil spill predictions in the Eastern Mediterranean using SAR images, CMEMS and CYCOFOS forecasts
George Zodiatis, ORION Research (Cyprus)

The MANIF TS project or how to assess acute risk by volatile, gaseous, and explosive Harmful Noxious Sub-stances?
Sebastien Legrand, Royal Belgian Institute of Natural Sciences (Belgium)

Can biophysical models of small pelagic fish be used for fish stock management? An example of the European Iberian sardine
Manuel Ruiz Villarreal, Instituto Español de Oceanografía, IEO-CSIC (Spain)

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L: Ocean observing meeting societal challenges - Chair: Lucie Cocquempot, Ifremer (France) - Room: Inishmaan

The Northwest European Ocean Climatology Product (NEOClime)
Eoghan Daly, Marine Institute (Ireland)

A biophysical model of the Celtic Sea for hindcasting and climate services
Joe McGovern, Marine Institute (Ireland)

Development of a storm surge forecasting model for the NW of Ireland and its validation and calibration using low-cost sensors
Tasneem Ahmed, Atlantic Technological University (Ireland)

Organic carbon dynamics and darkening of Norwegian coastal waters assessed from Ferrybox continuous measurements and earth observation satellites
Therese Harvey, Norwegian Institute for Water Research (Norway)

OLAMUR: offshore low-trophic aquaculture in multi-use scenario realisation
Beatrice Maddalena Scotto, ETT S.p.A. / University of Genoa (Italy)

Subsurface temperature anomaly observed by Argo floats during the 2022 Mediterranean Marine heatwave
Annunziata Pirro, National Institute of Oceanography and Applied Geophysics (OGS) (Italy)

M: Oceanographic services for ocean health - Chair: Urmas Lips, TelTech (Estonia) - Room: Inishturk

Improving ocean ecosystem predictions by coupled data assimilation of physical and biogeochemical observations
Lars Nerger, Alfred Wegener Institute (Germany)

MARBEFES – comprehensive approach to understanding reasons and sharing knowledge on biodiversity changes in European seas
Tymon Zielinski, Institute of Oceanology Polish Academy of Sciences (IO PAN) (Poland)

Resolving the bloom dynamics and ecological role of Noctiluca scintillans in the southern North Sea
Katharina Kordubel, Helmholtz-Zentrum Hereon (Germany)

Potential of CMEMS products for assessing eutrophication status of the Baltic Sea sub-basins
Oliver Samlas, Tallinn University of Technology (Estonia)

Multiscale harmonised automated observations of phytoplankton biomass, diversity and productivity dynamics in the English Channel and North Sea as part of the coastal Pilot Super Site approach (JERICO-RI)
Luis Felipe Artigas, CNRS - ULCO LOG (France)

17:45 - 19:00 **Programme committee and session chairs meeting** - Room: Inishmaan

19:00 - 19:30 **Drinks reception** - Room: Lounch

19:30 - 21:00 **Conference dinner** - Room: Lettermore

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Thursday 5 October

09:00 - 10:50 **The future of operational oceanography** - Room: Lettermore

Moderator: Ghada El Serafy, Deltares (Netherlands)

09:00 - 09:20 **Keynote:** What's next for the operational oceanography - perspectives of the global and European communities - Toste Tahnua, EuroSea / GOOS / GEOMAR (Germany)

09:20 - 09:35 The future of cloud services to deliver FAIR & Open data and analytical services, instrumental for the Digital Twins of the Oceans - Dick Schaap, MARIS (Netherlands)

09:35 - 09:50 European contribution to the OneArgo array - Yann-Hervé DeRoeck, Euro-Argo ERIC

09:50 - 10:05 Towards a network of Operational Marine Biology - Jaume Piera, ICM-CSIC (Spain)

10:05 - 10:20 European maritime regions - knowledge transfer and international dimension - Julien Mader, EuroGOOS IBI ROOS / AZTI (Spain)

10:20 - 10:35 FAIR data - New European data policy - Thierry Carval, Ifremer (France)

10:35 - 10:50 European ocean science 2030 - ocean observing supporting future marine science needs - Fiona Grant, Marine Institute (Ireland)

10:50 - 11:10 Break

11:10 - 13:00 **Reports from parallel session chairs** - Room: Lettermore

Moderator: Glenn Nolan, Marine Institute (Ireland)

11:10 - 11:45 Panel 1: Strategic developments and priorities - Vanessa Cardin (OGS, Italy), Holger Brix (Hereon, Germany), Carlos Fernandes (IH, Portugal), Urmas Lips (TelTech, Estonia)

11:45 - 12:20 Panel 2: Digital Twins, modelling and forecasting - Manuel Ruiz (IEO-CSIC, Spain), Sebastien Legrand (RBINS, Belgium), Pierre-Yves Le Traon (MOi), Jun She (DMI, Denmark), Ghada El Serafy (Deltares, Netherlands)

12:20 - 12:55 Panel 3: Enhancing capacity and co-design - Enrique Alvarez (MOi), Lucie Cocquempot (Ifremer, France), Henning Wehde (IMR, Norway), Dina Eparkhina (EuroGOOS)

13:00 - 13:40 Lunch

13:40 - 15:00 **Closing Session** - Room: Lettermore

13:40 - 14:10 **Conference statement** - Inga Lips, Secretary General, EuroGOOS

14:10 - 14:20 **Early career presentation prizes** - Caroline Cusack, Marine Institute (Ireland)

14:20 - 15:00 **Closing** - Henning Wehde, Chair, EuroGOOS

Side events

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Oral Presentations – Session A

Towards digital twins of the ocean

EDITO-MODEL LAB: the next generation of numerical models for the European Digital Twin Ocean

Authors

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Abstract

February 2022 saw the launch of the development of the **European Digital Twin of the Ocean** (European DTO) under the EU Mission Restore our Oceans and Waters, announced by President von der Leyen at the One Ocean Summit in Brest. The European DTO will be a virtual, dynamic representation of the ocean. Its main goal is to make ocean knowledge readily available to all - citizens, entrepreneurs, scientists, and policymakers - so that our society can better understand the complexities of the marine world and make informed decisions to safeguard the ocean and coastal environments.

To develop the operational core of the European DTO, the European Commission has invested about €10 million in two Horizon Europe research and innovation interdependent projects that will build the public infrastructure and digital framework (EDITO-Infra) and core modelling suite (**EDITO-Model Lab**). It will further construct and evolve a thriving digital ecosystem through a number of other relevant, complementary actions, aiming for an operational Digital Twin of the Ocean by 2024.

Started in January 2023, EDITO-Model Lab is designing the next generation of ocean models. By bringing together advanced numerical modelling, artificial intelligence, machine learning and high-performance computing, it will generate the prediction models and the simulation environment needed to test and design the most effective and sustainable ways of protecting marine and coastal habitats, supporting a more sustainable blue economy, and mitigating and adapting to climate change.

Fed by continuous real-time and historical observations, including thousands of *in situ* sensors across the world's ocean and numerous satellites in space, EDITO-Model Lab will allow the integration of alternative data flows in simulations of ocean processes that are performed in operational frameworks (reanalysis and forecasting) as well as in research projects (reference simulation, climate change projection, etc.).

Figure 1: EDITO-Model Lab in a complex environment, the Virtual Ocean Model Lab will allow users to access computing resources, a large diversity of models, tools, data set and products.

The project will ensure access to required input and validation data (from Copernicus Services, EMODnet, EuroGOOS, ECMWF and Sentinels satellite observations) and to high-performance and distributed computing facilities (from EuroHPC for HPC and other cloud computing resources) It will complement the Copernicus Marine Service and will contribute to consolidate Destination Earth (DestinE).

Led by Mercator Ocean International (MOi), the project involves 14 European partners (MOi, IMT, FONDAZIONE CMCC, CNRS, DELTARES, UNIBO, DMI, HEREON, CINECA, BSC CNS, SOCIB, NERSC and +ATLANTIC) bringing their complementary expertise and key skills needed to **develop the underlying model suite to be integrated into the European DTO**, including:

- **Ocean numerical modelling**, from global scale to coastal, for ocean physics, biogeochemical and marine environments, a large diversity of models will be used in the project and made available in the Virtual Ocean Model Lab. NEMO, which is the model mainly used in the framework of the EU's Copernicus Marine Service, will be used for global, regional, and downscaling applications (Figure 2), but other physical models will also be used, including specificities such as unstructured grid (SHYFEM) and coastal models (HBM, SCHISM and Delti3D). Wave models (WAM and WW3) and ocean biogeochemistry and marine environments (such as PISCES, ECOSMO, BFM, WAQ, VEG, and XBEACH) will also be used;

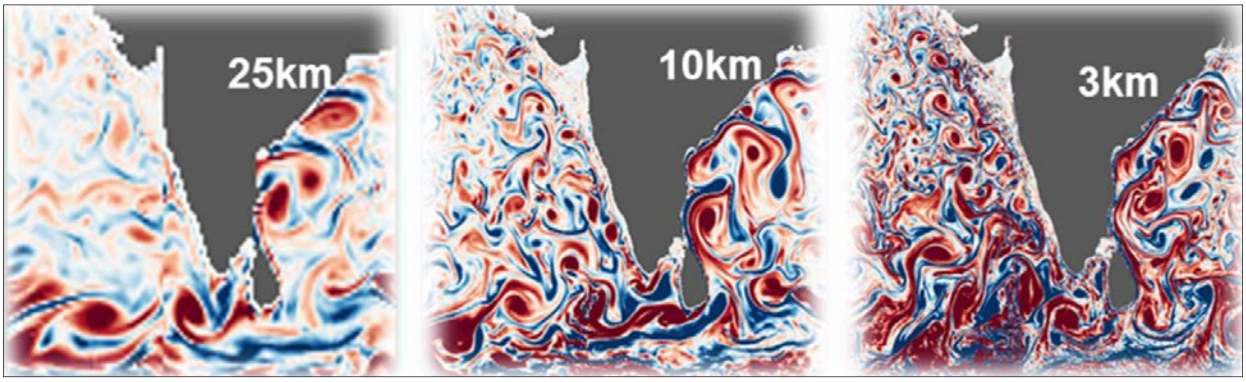

Figure 2: Example of global ocean simulations that will be accessible on the EDITO platform to be used for a large diversity of application as for regional to coastal downscaling and to train neural network.

- **Supercomputing:** BSC and CINECA High performance Computing Centre will be used as EUROHPC components, with the possibility of connecting to other computing facilities to optimise the EDITO numerical models and demonstrate interoperability. The cloud computing platform also used in the Copernicus Marine and WEkEO frameworks will be available through EDITO-Infra and used for different applications in the EDITO-Model Lab;

- **Artificial Intelligence and Machine Learning** applied to ocean applications: Deep Differentiable Emulators (Figure 3) will be developed, addressing three main objectives: optimisation of model parameterisation, ocean field reconstruction and forecast, and data assimilation;

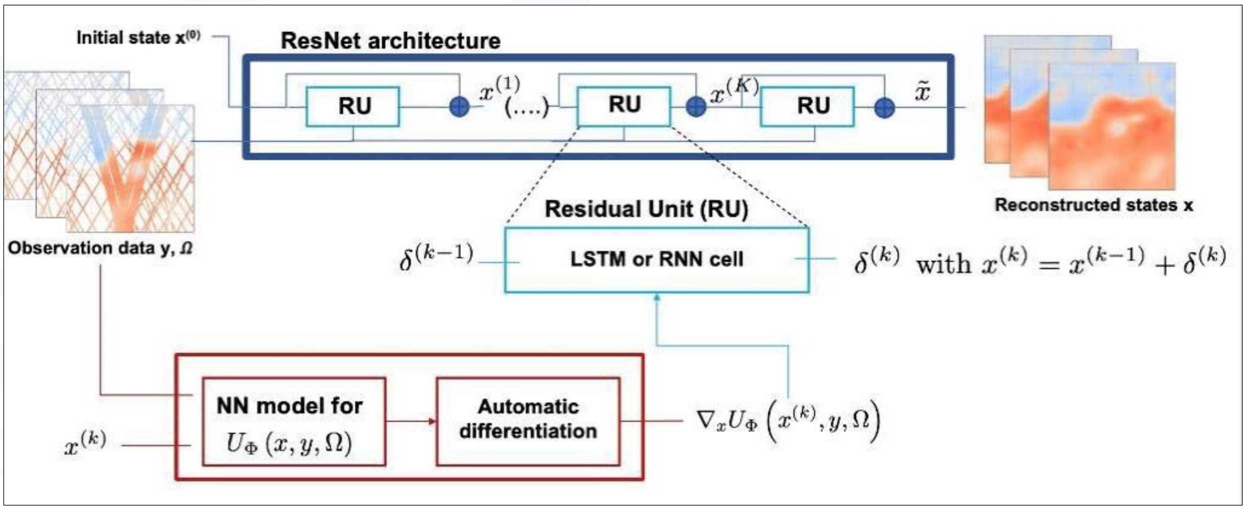

Figure 3: Example of Neural Network (Fablet *et al.*, 2021) that will be used to build Deep Differentiable Emulators to emulate and forecast Lagrangian trajectories, surface velocities or ocean turbidity.

- Software development, numerical models, and tool co-development in the framework of a **Virtual Ocean Model Lab** providing facilities for models and tools co-development and for the usage of the models. Specific tools as validation tools, workflow managers, and a graphic user interface will be made available on the platform and connected with the different models to build the core model suite of EDITO-Model Lab;

- **Operational oceanography** with strong links with the Copernicus Marine Service, OceanPredict, and the UN OceanPrediction Decade Collaborative Centre;

- Developing intermediate to final user applications (Figure 4) to demonstrate feasibility and provide concrete examples of **Focus Applications** addressing Marine Protected Areas for biodiversity, ship routes for zero carbon and pollution sources for zero pollution. **What-If Scenarios** developed will answer key questions about nature-based solutions for biodiversity and coastal hazards, aquaculture for zero carbon and marine plastic for zero pollution.

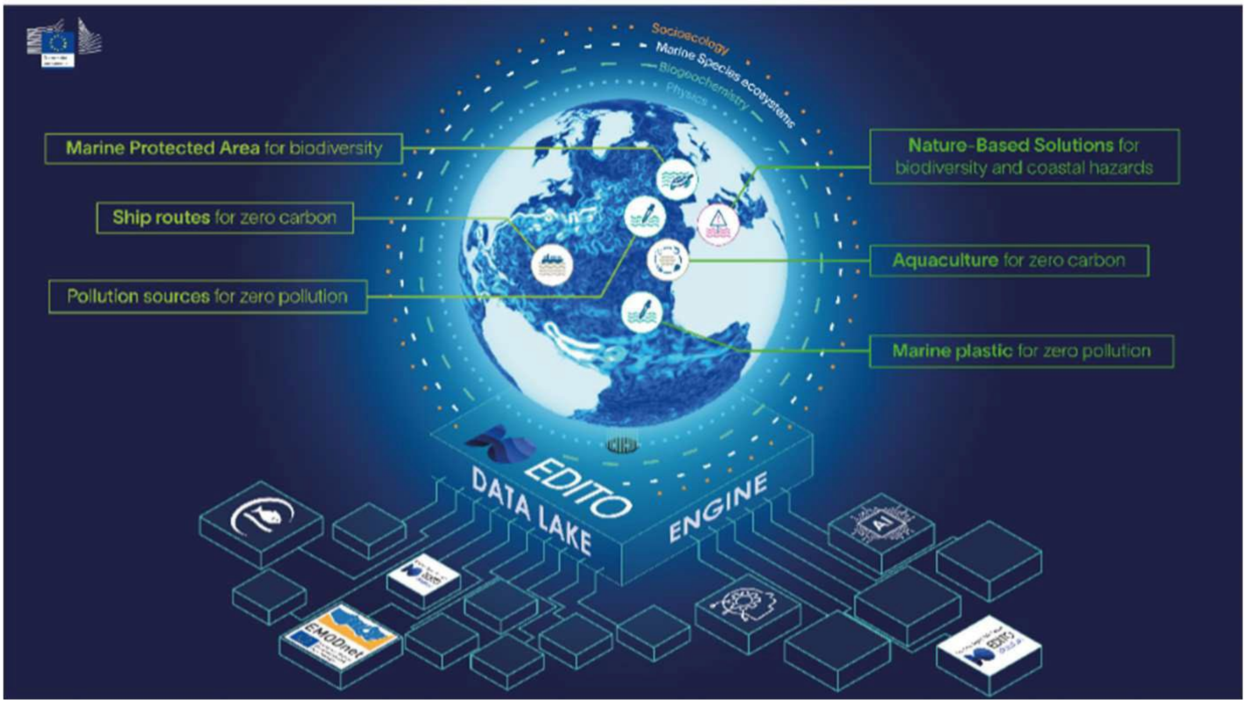

Figure 4: EDITO-Model Lab contribution to the EDITO Platform including new data set accessible on the DATA LAKE and dedicated demonstrator running on the EDITO Engine as Proof of Concept for specific topic such as Marine Protected Area, Ship routes, Pollution sources, Nature Based Solutions, Aquaculture and Marine Plastic.

The whole EDITO initiative will enable a **large diversity of users** (EDITO intermediate users, other EU projects such as ILIAD or Mission Ocean Lighthouses, numerical model developers, ocean and coastal researchers, etc.) to become partners in knowledge generation, explore desirable future, develop ocean management scenarios and assemble their own digital twins. This way, the initiative will engage a wide global community to help ensure a safe, healthy, and productive ocean.

In June 2023, the second edition of the **European Digital Ocean Forum** was the opportunity to define the other (Figure 5) that will be proposed by EDITO with the Explore capacity to use the Digital Twin Ocean platform, the Create capacity to build external third party services and the Contribute capacity to add data & services to the Digital Twin Ocean platform.

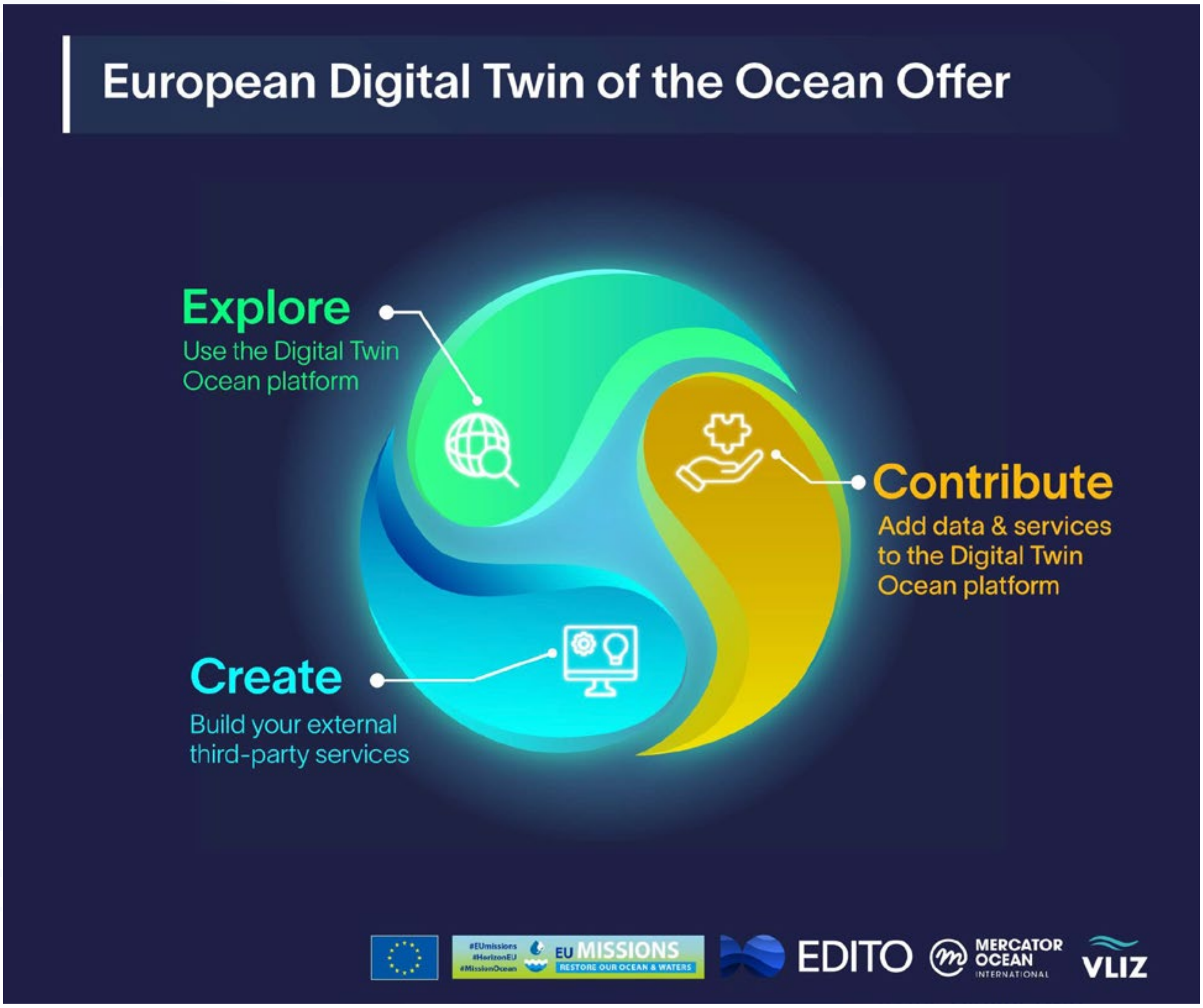

Figure 5: Presentation of the EDITO Offer including Explore, Create and Contribute capacities

https://edito-modellab.eu/

https://www.linkedin.com/company/edito-dto/

https://twitter.com/edito_dto

Piloting the concept of an Information Management Framework for Environmental Digital Twins (IMFe) and connecting the results to the UN decade DITTO programme

Authors

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Keywords

Digital Twin, Information Management Framework, Environment

Abstract

Environmental science is concerned with assessing the impacts of changing environmental conditions upon the state of the natural world. Environmental Digital Twins (EDT) are a new technology that enable environmental change scenarios for real systems to be modelled and their impacts visualised. They will be particularly effective with delivering understanding of these impacts on the natural environment to non-specialist stakeholders.

EDT have been made possible by the emergence of increasingly large, diverse, static data sources, networks of dynamic environmental data from sensor networks and time-variant process modelling. Once combined with visualisation capabilities these provide the basis of the digital twin technologies to enable the environmental scientists community to make a

step-change in understanding of the environment. Components may be developed separately by a network but can be combined to improve understanding provided development follows agreed standards to facilitate data exchange and integration.

1. INTRODUCTION

Environmental science is primarily concerned with assessing the impacts of changing environmental conditions on the state of the natural world. Environmental Digital Twins (EDT) are new technology that significantly improves our understanding of the natural environment and, in particular, delivers the capacity to visualise the impacts of environmental change scenarios upon the environment.

The UK Natural Environment Research Council (NERC) has recently published its first digital strategy , which sets out a vision for digitally enabled environmental science for the next decade. This strategy places data and digital technologies at the heart of UK environmental science. EDT are one such technology. These are needed to demonstrate the complex impacts of anthropogenic changes on the natural environment to non-specialist stakeholders in a form where these impacts can be effectively understood and, hopefully, aid planning to remediate those impacts.

The capacity to build EDT are an outcome of the increasing availability of large and diverse, baseline data sources, combined with real-time monitoring data from dynamic environmental sensor networks and time-variant process modelling. When integrated with visualisation technologies, they provide the components necessary to build EDT technologies and deliver the capability for the environmental science community to make a step-change in our understanding of the environment. Whilst the components may be developed separately but can act collectively as a wider network that can be combined to deliver environmental digital twins.

Enabling this interoperability requires procedures and rules that specifies the components necessary for effective information management within and across the EDT ecosystem. It must enable secure, resilient interoperability of data, and is a reference point to facilitate data use in line with security, legal, commercial, privacy and other relevant concerns. Our recommendations for the development of an information management framework for EDT (IMFe).

Replicating the behaviour of environmental systems is inevitably a multi-disciplinary activity. Therefore, components will need to be developed following agreed standards to make sure the information can be trusted by the user, and that they are semantically interoperable so that data can be shared. A digital Asset Register will be showcased to provide access to and enable linking of such components.

This conceptual project has developed into a project aiming to define the architectures, technologies, standards and hardware infrastructure of the IMFe. These will then be tested by develop a fully functioned pilot environmental digital twin for the Haig Fras Marine Conservation Zone (MCZ). Not only will this test the applicability of the conceptual IMFe but will also provide a clear demonstration of the power of EDT to monitor and scenario test a complex environmental system for the benefit of stakeholders. As a UN Decade Digital Twin of the Ocean (DITTO) project the Haig Fras EDT pilot is trailing the Ocean Data Interoperability System (ODIS) standards. This presentation will show the results of the Haig Fras EDT pilot, sharing its findings and the first results on connecting an EDT to ODIS and by extension DITTO.

2. ENVIRONMENTAL DIGITAL TWINS AS TOOLS TO DELIVER INTEROPERABLE SCIENCE

Environmental science is primarily concerned with assessing the impacts of changing EDT could be a transformational technology to deliver scenario based science to stakeholders. EDT will help to explain complex environmental process interactions to owners of infrastructure. With the advent of scientific data routinely conforming to FAIR principals and as models are increasingly being openly shared through code repositories so the barriers to entry are decreasing.

Domain experts can create components for their own expertise by using common standards for data development these can then be shared gaining greater value for the development efforts and community peer-review and iterative improvements. Such a community of EDT creators need access to common utilities.

The Pilot iMFE project was created to define the facilities necessary to empower the environmental science community with the capability to build EDT and make them interoperable.

3. PROJECT OBJECTIVES

The overarching objective of this project is to develop an Information Management Framework for digital twins of the environment (IMFe) as described in Figure 1 and scoped in Siddorn et al (2022). To build a community of stakeholders around the IMFe work, and an improved understanding of the impact of Digital Research Infrastructure for digital twins:

1. To establish an IMFe development framewor;
2. To conduct pilot studies which test and challenge the framework;
3. To deliver an IMFe which addresses all of these elements;
4. To define and develop the infrastructures necessary to deliver an IMFE.

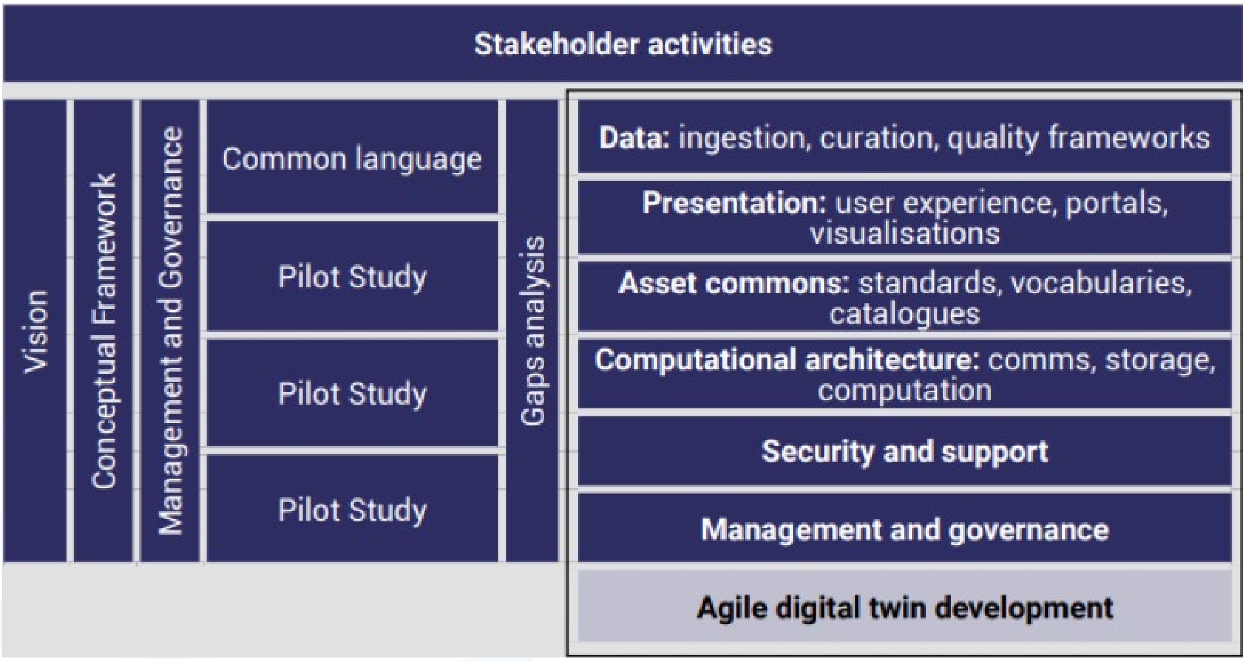

Figure 1: Mapping of the principal elements needed to deliver an Information Management Framework for Environmental Digital Twins

4. INFRASTRCUTURES NEEDED TO DELIVER EDT

Synthesising whole environmental systems in Digital Twins means sharing specialist knowledge between partners and linking them to understand the complete system. Tools are needed to share data and code for common good serve to this community and what do they need? The solution is the "Asset Register" (see Figure 2) a portal and single access point to federated repositories for NERC environmental science discipline by:

- Providing a minimum metadata framework for potential Digital Twin assets;
- Enabling sharing and reuse of modelling components to maximise their value;
- Using common principals: Open Science concepts, FAIR data structures and semantics;
- Enabling interoperable collaborative development of digital twins and their components through sharing of technology, incorporating best practice and making it comprehensible to non-technical users;
- Sustainable after the life span of the project;
- Contents and underlying technology used to deliver this will evolve through time.

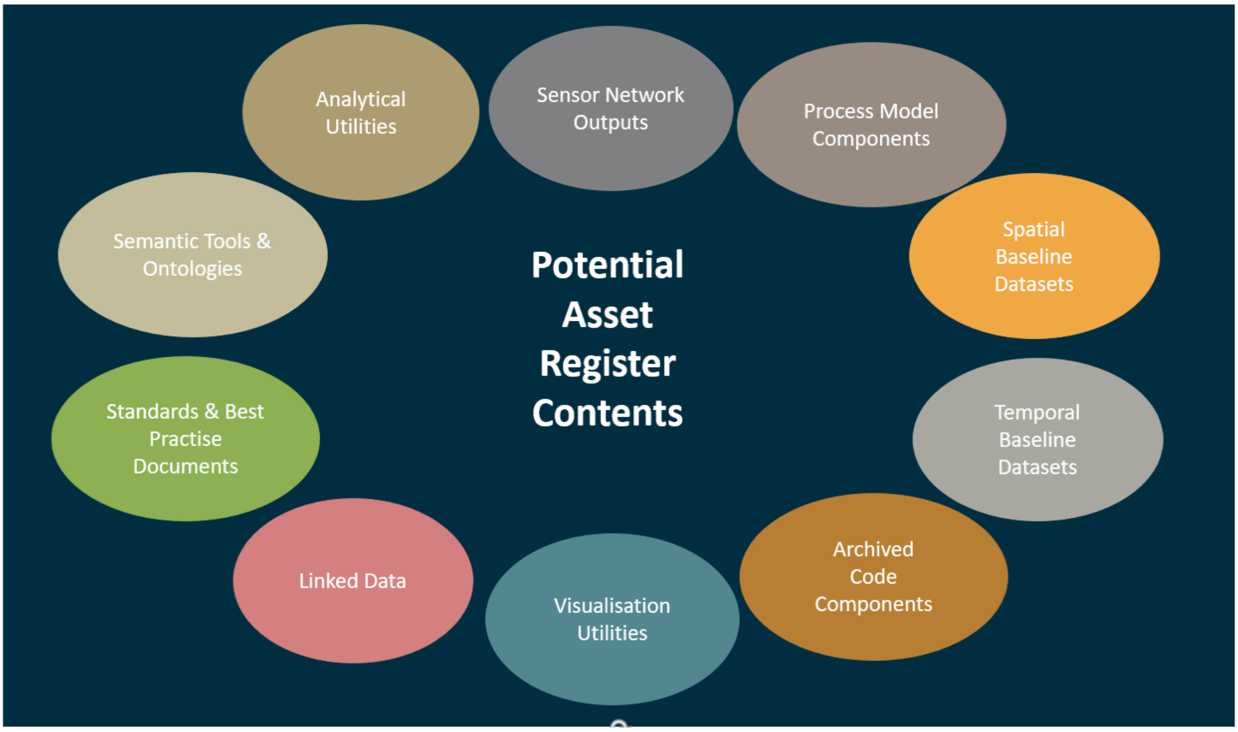

Figure 2: Mapping of the potential components necessary to build an EDT.

5. NEXT STEPS

Full roll out of the Asset Register to a wider user community and its population with:

- Relevant code components;
- Standards;
- FAIR datasets;
- Defining the templates required to enable the asset register to be indexed by the Ocean Data Interoperability System to enable visibility as part of the Ocean Decade;
- Other utilities to enable widespread EDT development.

ACKNOWLEDGEMENTS

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We would like to thank the many contributors to this work. The case studies would not have been possible without the engagement of Aaron Hopkinson and Kirstine Dale from the Met Office, Scott Hosking, James Byrne and Maria Fox from the British Antarctic Survey and Ian Bailey and Steve Kochli from Telicent.

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Additional thanks go to Aaron Hopkinson for his particularly active and helpful engagement and his contribution reviewing the report.

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Serverless QC for Ocean Gliders: A Sea Change

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Keywords
Quality control, container, serverless, vocabulary, code

Abstract
The paper delves into the application of serverless quality control (QC) for ocean gliders, which are autonomous underwater vehicles responsible for gathering oceanographic data. Given the critical role of the data collected by these gliders in understanding ocean dynamics, the need for effective QC is evident. Serverless QC, an innovative method, employs local or cloud-based services to identify and rectify data errors, offering scalability, cost-effectiveness, and reliability advantages over traditional approaches. The paper outlines the challenges in implementing QC models for ocean glider data, proposing solutions through serverless QC. Linking QC methods to the NERC-controlled Vocabulary Server (NVS) addresses the challenge of tracking applied QC, enhancing method definitions and data product traceability. Leveraging OCI-based containers boosts uptake and interoperability of QC modules, ensuring accessibility through hosting platforms like Docker Hub and GitHub. The combined use of serverless QC, NVS, and OCI-based containers is poised to elevate oceanographic data quality, facilitating its sharing and utilization.

1. INTRODUCTION

The way quality control (QC) code is written and shared has had an evolution of late, thanks in part to services like Zenodo, allowing code to be shared via a Digital Object Identifier (DOI). However, as a brief review, the standard practice was to either (re)write a QC routine every time that check was needed or ask around and see if someone knew if there was a routine already coded that could be shared. This is shown in the left-hand stage of Figure 1. QC code sharing transitioned as tools like GitHub and GitLab grew in popularity as shown in the middle stage of Figure 1. Code is shared from a single source and changes could be tracked and discussed. The final stage as shown on the right-hand side use the DOI system to produce a 'read-only' zipped version of the code which can be retrieved regardless of access to the main code repo.

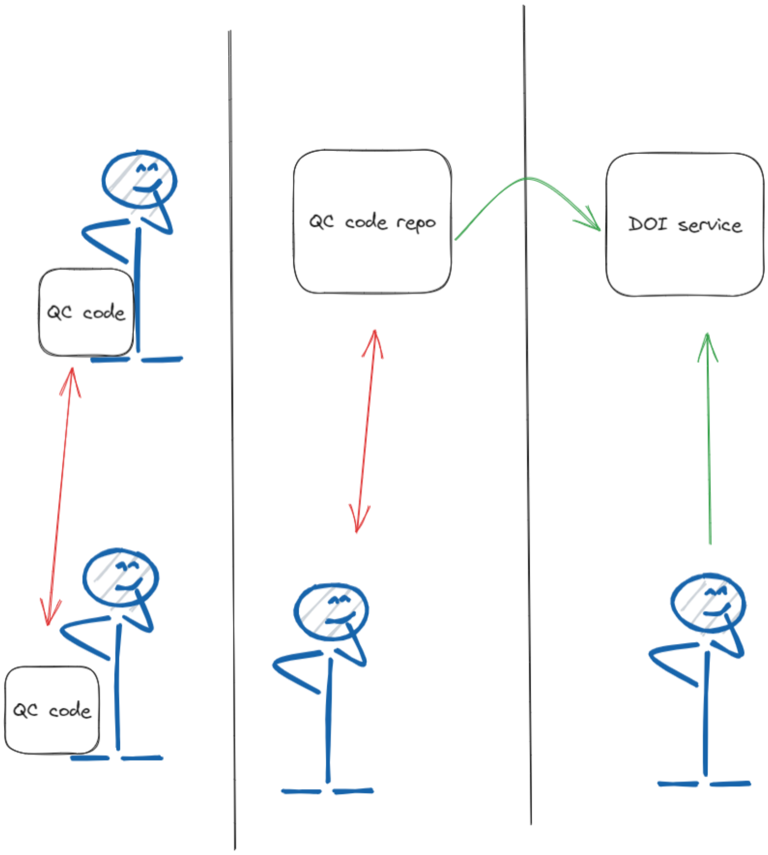

Figure 1: Figure showing the different stages of code sharing.

There are issues with all 3 stages, primarily it is very easy to make 'small' changes to any of the mentioned ways of sharing. The question is why users make changes; one main reason is getting code to run 'locally'. Another reason arises where there is ancillary data required, which might be missing, or the user might feel is 'outdated'. Users may also make changes to reduce the amount of work required to make their data 'fit' the requirements of the QC code. All these potential changes mean there is no guarantee the code now functions as intended and it is due to the possibility for change that we cannot have strong traceability from the QC'ed data back to the QC code run.

There are ways to improve the current practice of code sharing beyond just assigning a DOIs. These enhancements overcome these issues discussed.

2. CONTAINERISED QUALITY CONTROL SERVICE

We have set out the issues with the current style of working with any QC code. The rest of this paper will layout a proposed solution that will address these issues and bring wider benefits to how QC code is run.change scenarios upon the environment.

2.1. Concept

As Figure 2 shows, our solution is to make all QC code accessible via simple web calls (http/https), the QC code is containerised including all the ancillary data that might be required to run the code. We refer to this as Containerised Quality Control (CQC). These containers expect that data will be transmitted to them via JSON objects. To increase the findability and interoperability these QC containers will be referenced within a controlled vocabulary, marked up to indicate what is expected as input and what will be outputted, be that changed data values or details of the flagging system used.

We will first look at what the solution is in general terms, explaining each section before moving into the real-world system the BODC has built on this concept.

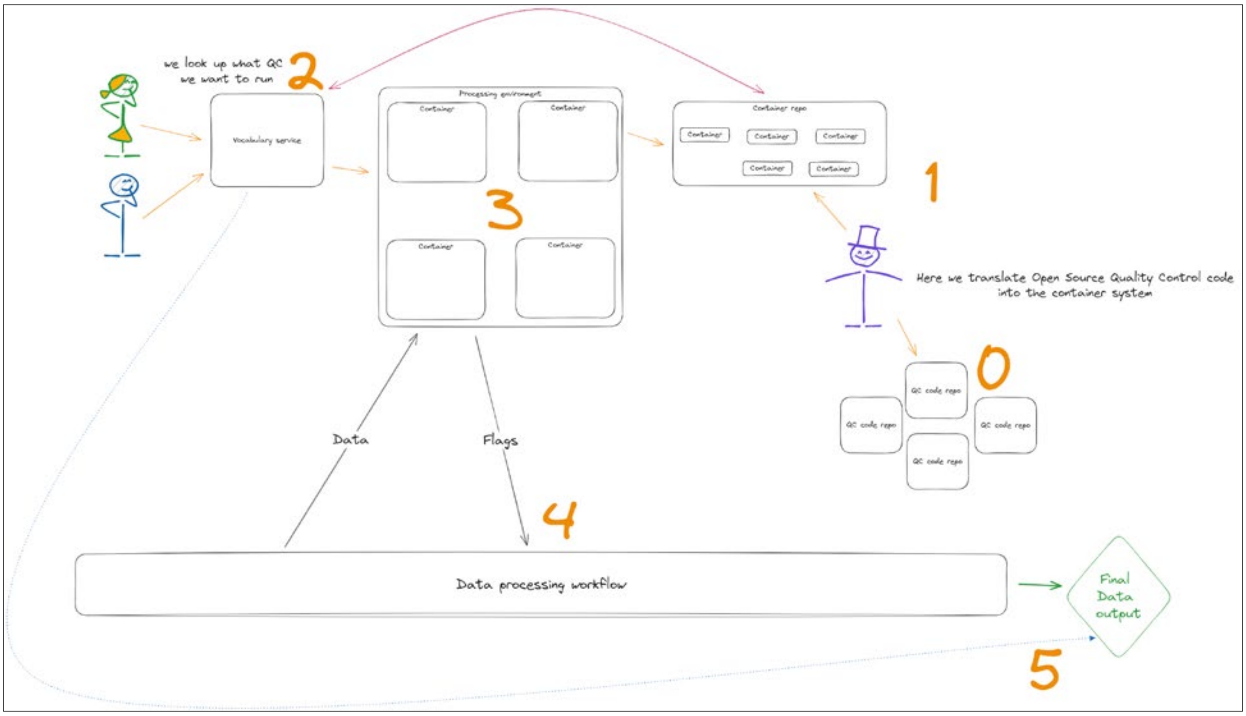

Figure 2: Figure showing a conceptualised workflow of containerising QC code and integrating into a processing workflow.

Step 0 Either find or write (new) QC code. If we are starting from scratch, then we can skip this stage and move to step 1. For those who are reusing code from an online repo (GitHub/GitLab) then we need to make sure the license is permissible for reuse.

Step 1 Once the code is obtained, we can look to build the container. We are building these using the Linux foundation Open Container Initiative standard, this makes them runnable under all modern container systems (docker/lxc/ContainerD). This stage is also where the transfer takes place from the incoming JSON object to the internal format required by the QC code. Once written and tested the whole project is deployed into a container repo (docker hub / GitHub container space).

Step 2 Once we have the containerized QC code, an entry needs to be submitted to the vocab governance group over seeing this controlled vocabulary. Please provide a title and description, which provides a concise overview. In cases where the QC code relies on external data, disclosure of the data's source is required. Additionally, if the QC process spans a specific timeframe, that temporal range must be specified. The inputs for the QC code are a crucial aspect, and it is recommended to define them using appropriate vocabulary terms (NVS P02 collection being highly endorsed). Outputs, any alterations made to values during the QC process need to be documented, including the specifics of the changes. If there's a flagging process involved, the schema employed for flagging must be articulated. The container repository location is another imperative component, to ensure controlled access, a versioned link is advocated to prevent inadvertent access to updated containers. Lastly, if the container is intended for open/public usage, the entry should include an HTTP(S) link enabling data transmission.

Step 3 Now that the code is written and findable, we need to deploy the code to an environment in which it can be run. As the container is based on the OCI, there are a multiple of choices all of which will result in functionally the same system being deployed. Some examples here could be a docker run command, a docker compose file or to use a ContainerD setup.

Step 4 This is the stage 90% of users will interact with, calling the container QC from within their processing chains. This is a simple as making a web request to the container's endpoint. MatLab/Python/Fortran all have functions for making this type of program call.

Step 5 This final stage increases the transparency of the user's output. We can now include the vocab term in the QC field of the output file. This works extremely well for NetCDF based formats where we can add attributes to our variable. However, we can still link to the vocab (and hence the QC) in other file types like CSV's where the vocab name can become the column header.

2.2. BODC implementation

The BODC has implemented the CQC system using open-source off-the-Shelf technology (Figure 3). Given our status as a glider data assembly centre, we made the choice to work with serverless technologies to allow for the overall system to be used by our near real time processing system APDS. This uses CQC as a service and thus CQCS was born.

The technology we used is called Knative (Cloud Native Computing Foundation, 2023). This allows for serverless functions to be built from multiple languages, converted to an OCI based container and deployed into a Kubernetes instance. The BODC has a collection of legacy (Java) and operational (MatLab and python) code, picking a system that was language agnostic was important for us to get maximum benefit.

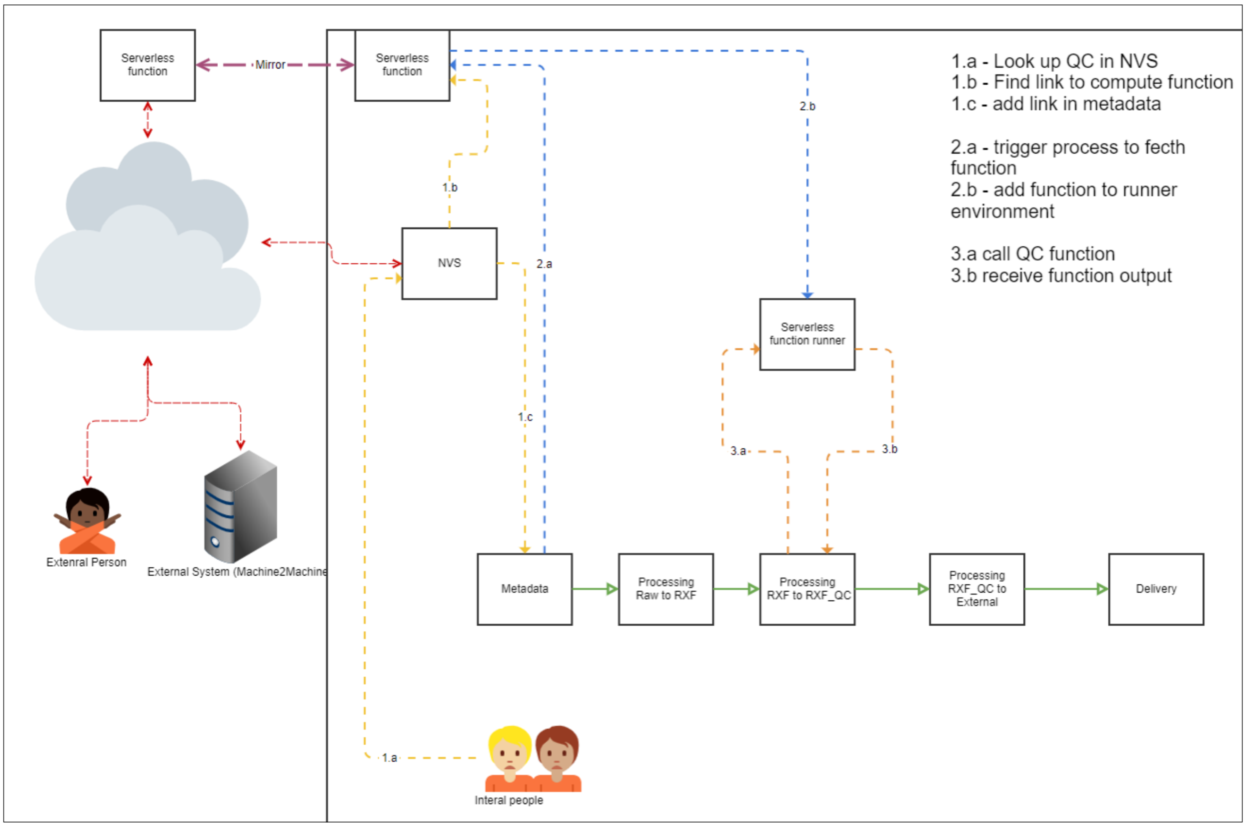

Figure 3: Figure showing BODC's implementation of CQCS and how it links into our APDS processing system.

Given that APDS is written in python we used the knative language pack for python (Ball & Garg, 2023).

This is where we write the translation between already written QC code and the serverless system. Fundamentally this is within the file func.py, this file is created by knative, when you create a new project. It is a template with the required access points to process incoming web requests. All we (the user) need to do is import the external libraries (QC code) and translate the JSON object coming into whatever the QC code needs and pass the QC code output back to the user via the outbound request.

BODC have incorporated this system into the wider glider workflow, where we can send any data that need to be QC'ed and add the resulting flags into the new QC internal file. This internal file also contains all the metadata about the QC run.

Currently BODC have made serverless QC function using open tools such as CoTeDe (Castelao, 2020) and others. These cover deepest pressure, location, regional range (salinity and temperature), climatological (salinity and temperature).

3. BENEFITS

The proposed system has several benefits, including making QC code runnable anywhere a container can be deployed or even anywhere just a network connection is possible, this removes one of the largest reasons for editing QC code when accessed via DOI or GitHub repos. The second point highlights a benefit of bringing 'complex' QC into areas where beforehand there was neither the processing bandwidth nor storage level for QC to be performed.

By linking these CQC components to vocabulary terms, we have built a searchable collection of QC code, thus increasing the FAIR of these functions. The vocab terms also increase trust in the final output adding one of the last missing provenance links.

4. NEXT ACTIONS

BODC have started this system and will continue to grow its use internally, we are looking for others to join us and form part of the community, as ultimately, we would like a governance board for the vocabulary collection for QC code.

Currently the system works over http(s) requests, we would like to investigate the option for cloudevent(s), these would potentially serve IOT sensors better.

We also have an open question for the QC community. Would you like an identifier to link a particular run of a QC container back to the service it was run on? This would act as a guarantee that the stated QC was indeed run at the given address for the given service.

ACKNOWLEDGEMENTS

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In the shoes of a Marine Data Manager in an autonomous world

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Keywords

Gliders, groom, data, management, autonomous, metadata

Abstract

Ocean gliders, are increasingly being used by the community to answer the oceans' big questions. The UK Research and Innovation (UKRI) and the Natural Environment Research Council (NERC) have a 2040 net zero target. To meet this target, NERC are planning to grow their marine autonomy capabilities, with an expectation that there will be a total fleet of 200 gliders available in the national marine equipment pool by 2035. To accommodate this pace of change, Data Assembly Centres (DACs) are required to have automated processing workflows that are reliant 24/7, all year round. Their data systems also need to be capable of scaling out to operate for multiple deployments and deliver data in a timely fashion for use in operational centres and at Global Data Assembly Centres (GDACs). The UK DAC for gliders (the British Oceanographic Data Centre, BODC, based at the UK's National Oceanography Centre, NOC) see this as a big challenge to overcome for the marine data management community. This paper aims to cover how we are trying to make glider data Findable, Accessible, Interoperable, Reusable (FAIR) and improve data management efficiencies for marine autonomy in alignment with the EuroGOOS 2030 strategy vision for sustained ocean observing.

1. INTRODUCTION

The British Oceanographic Data Centre (BODC) would like to take this opportunity to present the data management life cycle for operating an autonomous data system in the context of glider missions.

Ocean Robots called gliders are being used more routinely to collect data about the health of our oceans. The technology of these platforms has been welcomed by scientists who wish to explore areas and at times of the year that are challenging or not possible using traditional equipment.

2. GLIDERS IN BODC AND THE INTERNATIONAL COMMUNITY

The BODC have records of glider data dating back to 2009. The first mission being from the Extended Ellett Line (occupation #1) operated by the Scottish Association for Marine Science (SAMS). Going back to 2009, there was a need to agree on a standard internationally on how to manage data from gliders. December 2012 saw the first publication of the Everyone's Gliding Observatories (EGO) user's manual. This manual details the NetCDF conventions and structure the glider community should follow to create a common exchange file format within Europe (EGO gliders data management team, 2023). The BODC have been a member of the EGO group since its conception, using it as a basis for international collaboration, building glider capacity, knowledge sharing and providing guidance to others. From the development of a common format, the BODC have looked at how we manage the data from the platform. In 2019, the international glider community agreed that globally we needed to be more interoperable. A key decision, being that we needed a globally agreed common exchange file format for glider data.

Looking ahead, the BODC are expecting to be handling more glider deployments and data from other autonomous platforms in the future as the capability in autonomous platforms expands. This will help UKRI and NERC reach their net zero target.

The Glider for Research and Operational Ocean Monitoring Infrastructure and Innovation (GROOM II) project aims to scope a research infrastructure (RI) for Marine Autonomous Systems (MAS) and has set out a data management roadmap with key recommendations for the next 1-2 years, 5 and 10 years. Key areas include the data infrastructure, tools and services, network management and evolution, and skills and training. The purpose of this roadmap is to ensure RI's can sustain the evolution and growth anticipated in MAS platforms and sensor advancements (Turpin *et al.*, 2023).

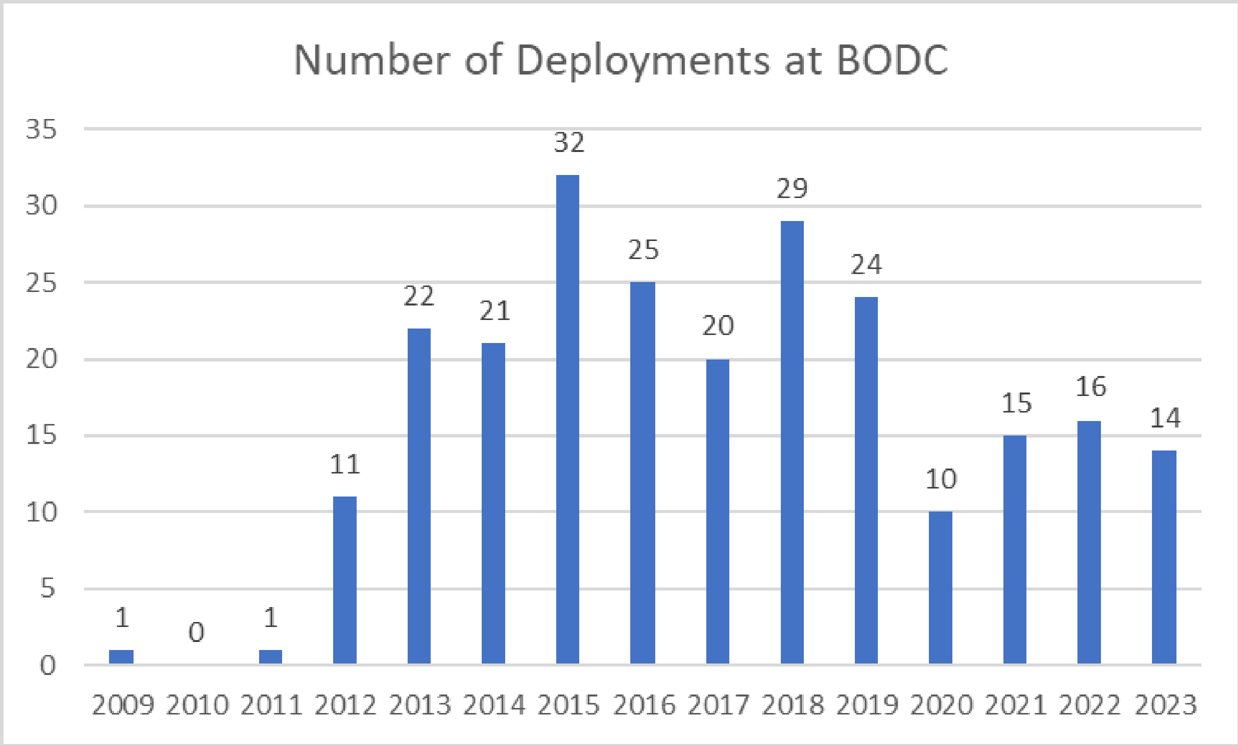

Figure 1: Glider deployments with the UK Glider Data Assembly Centre, the BODC.

3. METADATA

The BODC are using innovative solutions to ensure the data from autonomous platforms are annotated consistently and are discoverable and re-usable. This includes registering sensor and platform metadata from autonomous platforms in the Semantic Sensor Network (SSN) database. This database was created initially as part of the European Union project, SenseOCEAN and uses OGC SWE (Sensor Web Enablement) standards such as Sensor Model Language (Sensor ML) to describe sensor metadata (Alexandra Kokkinaki *et al.*, 2016). By following such standards, the aim is to make all sensor data repositories discoverable, accessible and useable via the Web.

The SSN database approach distinguishes between two main categories: platform and sensor models, as well as platform and sensor instances. A sensor or platform model represents a set of defining characteristics for a group of similar devices, typically mass-produced, akin to a prototype. In contrast, a platform or sensor instance refers to the physical, operational unit itself, with additional specific metadata such as its serial number. A key feature within the database is the model/instance relationship and registering the instances on a particular event at a particular timestamp. Sensor and platform instances are interlinked via deployments and events. Several sensors can be attached on these platforms measuring and observing properties of a 'feature of interest'. These sensors and platforms are held by an organization and are funded to be operated through awards from grants/projects.

The SSN tables have evolved under the Oceanids C2 project (Harris *et al.*, 2020) to add in engineering parameter mapping tables which provide a link between incoming source names to NERC Vocabulary Server (NVS) concepts such as observable properties originating from the BODC Parameter Usage Vocabulary P01s (British Oceanographic Data Centre, 2023). These mappings enable the data to be processed by our code base automatically enabling the near real time data transmission needed for the operational oceanography community.

This database is exposed via webapi created in Oracle REST Data Services (ORDS). These ORDS endpoints are being primarily used by the BODC data managers to annotate glider data with appropriate metadata before it is shared wider in the community. Once inserted into the database, the contents can be accessed via ORDS endpoints resolving in JSON. Below are some examples of the returned JSON snippets.

Raw | Parsed


```
{
  "EGODeployment": [
    {
      "DEPLOYMENT_ID": 603,
      "DEPLOYMENT_START_DATE": 20230512,
      "SUMMARY_REPORT": "This campaign involved the deployment of one seaglider, in the North East Atlantic as part of the Natural Environment Research Council's (NERC) National Capabilty CLASS project and continues the observations carried out along the Extended Ellett Line. The glider is planned for deployment in April 2023.",
      "BASE_STATION": "available in the raw data",
      "EMAIL": "mark.inall@sams.ac.uk",
      "NAME": "Mark Inall",
      "ACTIVE": 1,
      "CAMPAIGNNAME": "Ellett Array 10",
      "PROJNAME": "CLASS",
      "PLATFORMMODEL": [
        {
          "MODEL_VERSION_ID": 125,
          "MODEL_ID": 360,
          "CATEGORY_TYPE": "platforms",
          "DDESC": "M1",
          "PLATFORM_MAKER": "iRobot",
          "UNIQUE_ID": "B7600025",
          "PLATFORM_TYPE": "seaglider",
          "MODEL_NAME": "M1",
          "PLATFORM_FAMILY": "open ocean glider",
          "WMO_INST_TYPE": 830
        }
      ],
```


Figure 2: JSON snippet from Ellett Array mission 10 containing project, campaign, deployment and platform model metadata.

```
"PLATFORMINSTANCE": [
    {
        "PLAT_INSTANCE_VERSION_ID": 903,
        "PLAT_INSTANCE_ID": 445,
        "DATA_TYPE": "EGO glider time-series data",
        "GLIDER_SERIAL_NO": "sg550",
        "PLATFORM_CODE": "Eltanin",
        "GLIDER_OWNER": "SAMS",
        "WMO_PLATFORM_CODE": 6800987,
        "PLATFORM_FAMILY": "open ocean glider"
    }
],
```


Figure 3: JSON snippet containing example platform instance metadata.deployment and platform model metadata.


```
{
    "OBJECTTYPE": "parameter",
    "SDN_PARAMETER_URN": "http://vocab.nerc.ac.uk/collection/P01/current/
    PTCHFG01/",
    "PREFLABEL": "Orientation (pitch) of measurement platform by triaxial
    fluxgate compass",
    "SDN_UOM_UM": "SDN:P06::UAAA",
    "OG1_PARAMETER_URN": "GLIDER_PITCH",
    "OG1_UOM_UM": "deg",
    "VALID_MIN": -180,
    "VALID_MAX": 180,
    "FILLVALUE": -999,
    "SOURCENAME": "eng_pitchAng"
},
```


Figure 4: JSON snippet containing example parameter and NERC Vocabulary Server (NVS) metadata.

Figures 1, 2 and 3 show the JSON snippet outputs from the SSN schema. As data managers we interact with glider operator technicians and scientists to obtain information on the project that is funding the deployments and the sensor instances and platform instance being used for a particular deployment. This liaison and mapping to NVS concepts takes some time for data managers to compile. The National Oceanography Centre (NOC) as well as working together with UK operators and international partners are looking for ways to make this process more efficient and ensure the BODC as the UK glider data assembly centre can scale data management practices for these platforms.

4. DATA INFRASTRUCTURE EVOLUTION

When the BODC started managing glider data, submissions were done via file transfer protocol (FTP) and data was processed using large and complex configuration files and there was no data delivery mechanism. Typical glider deployments took several days to process into EGO NetCDF format. Fast forward through several grant awards and the Oceanids C2 project, the BODC have implemented an application in which glider operators can push files to the BODC securely. This method negates the need for data managers to manually create an archive and copy files to this archive for processing. The BODC also now have a system called APDS which is based on events which is capable of processing raw source files from multiple deployments in parallel and all within minutes of the files being received. This has been achieved by knowledge contained from data managers and coding this into the transfer section of APDS, reducing data manager interactions down to a minimal amount. The shift of data management to pre-deployment activities such as collection of metadata is vital for allowing such fast data processing. Looking to the future, the BODC are working with key partners to make the pre-deployment stage in the process as automated as possible as we look to a NetZero world containing 100s of gilders sending back data at any one time. There is also a glider inventory web interface allowing users to look up glider deployments, view metadata and have access to raw files and the community standard format files via a one-click download.

Within the BODC we are utilising community open-source tools to help plug the gaps such as ERDDAP (Simons, R.A., and Chris John. 2022) and established community-maintained quality control toolboxes for example CoTeDe (Castelão, G. P., 2020). With the help of the GROOM RI framework, further areas within the workflow are being identified to be tackled collectively and apply best practices to such as efficient metadata sharing, real time and delayed mode. There is also a need for a link between the versions of autonomous data and the reference useful related data such as CTD calibration casts.

5. LESSONS LEARNT

Through several years of managing data from autonomous platforms, the BODC have learnt many lessons. Metadata management is a critical step to ensure interoperability of European Ocean Observing System (EOOS) datasets and the implementation of controlled vocabularies for annotating data is a key step. We are also expanding our stakeholder engagement by working with technicians and engineers to analyse the end-to-end data life cycle and looking for improvements and efficiencies. As data managers, we are seeing this as a big benefit to enable us to delivery data in a timely fashion to the glider community.

As we look to the future and a NetZero world we have to be ready to manage more advanced sensor and platform technologies powered by real time configuration changes and as such we as data managers need to look for common solutions to handle the expected pace of change.

ACKNOWLEDGEMENTS

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EOSC-FUTURE – ENVRI-FAIR Dashboard for the State of the Environment

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Keywords

Dashboard, EOVs, datalakes, subsetting API, ocean viewer

Abstract

In the EOSC-Future project, ENVRI-FAIR partners are involved in the Dashboard for the State of the Environment Science Project. The Dashboard should provide easy means to users to determine the state of the environment and follow trends of our Earth system for a selected number of parameters within the Earth components of Atmosphere, Ocean, and Biodiversity. MARIS leads the development of the Ocean component of the Dashboard in cooperation with IFREMER, OGS and NOC-BODC. It consists of two components, 1) a Marine Data Viewer that displays *in situ* measurements of selected Essential Ocean Variables (EOVs) including temperature, oxygen, nutrients and pH and 2) dynamic trend indicators for European sea regions based on these in situ measurements. In order to facilitate input to the Marine Data Viewer and dynamic trend indicators, an analytical workflow is established that enables aggregation and harmonization of data related to the EOVs using a newly developed software system called 'Beacon' with a unique indexing system that can, on the fly, extract specific data based on the user's request from millions of observational datafiles containing multiple parameters in diverse units.

1. INTRODUCTION

1.1. EOSC-FUTURE Project

EOSC-Future is an EU-funded H2020 project that is building on the European Open Science Cloud (EOSC), aiming to deliver a platform with a set of components that links other research portals, resources and services together in order to serve the data needs of researchers. Within this project science clusters with corresponding science projects (SPs) are included to show the impact that these joint open data projects can have. On the one hand these SPs can drive the integration of services and data across multiple domains and showcase the role of EOSC, while on the other hand they help shape EOSC by including researcher's requirements.

1.2. Dashboard of the State of the Environment

In the EOSC-Future project, ENVRI-FAIR partners are involved in developing two SPs, one about Invasive Species, and one about a Dashboard for the State of the Environment. The ENVRI (Environmental Research Infrastructure) community is composed of a number of research infrastructures and networks, all of whom work on different aspects relating to environment research (atmosphere, marine, solid earth, biodiversity / ecosystems). They gather and manage a wealth of information, like environmental data and model results. The Dashboard for the State of the Environment SP is a collaboration between different research infrastructures within the ENVRI community, and brings together the three scientific domains Biodiversity, Atmosphere and Ocean.

The Dashboard should provide easy means to users to determine the state of the environment and follow trends of our Earth system for a selected number of parameters within the Earth components of Atmosphere, Ocean, and Biodiversity (Vermeulen, *et al.*, 2023).

MARIS leads the development of the Ocean component in cooperation with IFREMER, OGS and NOC-BODC. It consists of two components, 1) a Marine Data Viewer that displays *in situ* measurements of selected Essential Ocean Variables (EOVs) including temperature, oxygen, nutrients and pH and 2) dynamic trend indicators for European sea regions based on these *in situ* measurements. The measurements are retrieved from a data lake of selected Blue Data Infrastructures (BDIs) such as Euro-Argo and SeaDataNet CDI using tailor-made APIs for fast sub-setting at data level.

2. ANALYTICAL WORKFLOW

In order to facilitate input to the Marine Data Viewer and dynamic trend indicators, an analytical workflow is established that enables aggregation and harmonization of data related to the EOVs. Figure 1 shows a more elaborate overview of the different steps required for the viewer and trend indicators, for the Blue Data Infrastructure SeaDataNet. The different components are explained in more detail below.

The focus within this Science Project lies on the Essential Ocean Variables (EOVs) Oxygen, Temperature, Nutrients and pH, where the nutrients are divided into Silicate, Phosphate and Nitrate. Each of these six EOVs will follow the technical framework individually.

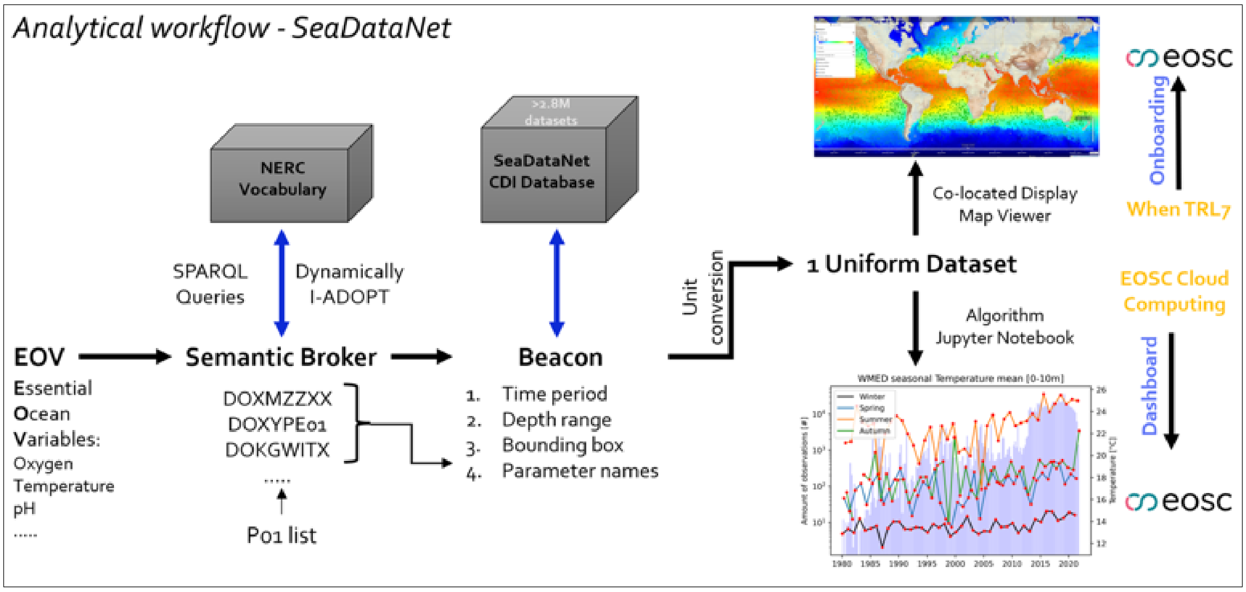

Figure 1: Analytical workflow SeaDataNet.

2.1. Semantic Broker

The semantic broker uses "smart" mappings: i.e., a SPARQL query that relies on the correspondences between A05, P01 and R03 vocabularies (Argo parameter codes, 2023; AtlantOS Essential Variables, 2019; BODC Parameter Usage Vocabulary, 2023) based on the decomposition of observable properties according to the I-ADOPT ontologies. These vocabularies are listed on the NERC Vocabulary Service (NVS) that gives access to standardised and hierarchically-organized vocabularies. The I-ADOPT properties are used as query criteria to the NVS to retrieve the P01/R03s related to each EOV. For example, EOV Oxygen has the following properties, "hasMatrix" water body, "hasObjectOfInterest" oxygen and "hasProperty" concentration.

Summarizing, the SPARQL query gives the relevant P01/R03s depending on SeaDataNet (P01) or Euro-Argo (R03), which are then used as input to Beacon or the Euro-Argo API to retrieve data related to the EOVs.

2.2. Beacon

For this Dashboard and many other societal and scientific challenges, such as Digital Twins of the Oceans, access to a large number of multidisciplinary data resources is key. However, achieving performance is a major challenge as original data is organized in millions of observation files which makes it hard to achieve fast responses. Next to this, data from different domains are stored in a large variety of data infrastructures, each with their own data-access mechanisms, which causes researchers to spend much time on trying to access relevant data. In a perfect world, users should be able to retrieve data in a uniform way from different data infrastructures following their selection criteria, including for example spatial or temporal boundaries, parameter types, depth ranges and other filters.

Therefore, as part of the EOSC Future and Blue-Cloud projects, MARIS has been developing a software system called 'Beacon' with a unique indexing system that can, on the fly, extract specific data based on the user's request from millions of observational datafiles containing multiple parameters in diverse units.

The beacon system and its data can be accessed via a REST API that is exposed by Beacon itself meaning clients can query data via a simple JSON request. The system is built in a way that it returns one single harmonized file as output, regardless of whether the input contains many different datatypes or dimensions. It also allows for converting the units of the original data if parameters are measured in different types of units. It is important to mention that the system can be applied to different data infrastructures and is not tailor made for one specific type of database. As part of the Environmental Dashboard, the beacon API is applied to the SeaDataNet CDI database and the ERA5 dataset from the Climate Data Store, to showcase its performance and user friendliness. For CDI, it is possible to obtain specific data based on the filter options (parameter selection, bounded box with minimum and maximum longitudes and latitudes, depth range and time period).

For the parameter selection, the P01 vocabulary from the NERC Vocabulary Server is used, as the data within the SeaDataNet CDI is mapped with these elements that are identifiers of physical parameters such as Temperature or Oxygen. The data can be retrieved in formats such as one single flattened NETcdf or JSON with dimensions LONGITUDE, LATITUDE, PARAMETER VALUE, TIME and DEPTH.

Summarizing, the SPARQL query gives the relevant P01/R03s depending on SeaDataNet (P01) or Euro-Argo (R03), which are then used as input to Beacon or the Euro-Argo API to retrieve data related to the EOVs.

2.2. Unit conversion

The data measurements stored within the SeaDataNet CDI have a wide range of different units and in order to display these measurements simultaneously they require the same unit. For each of the six EOVs a preferred unit is selected that corresponds to the CMEMS model background layers used in the Marine Data Viewer (see table below). For example, for EOV Oxygen, measurements can be in μmol/kg, mol/kg, μmol/L, etc.., which then have to be converted to the desired unit: $mmol/m^3$.

Table I. Preferred units for EOV's

Temperature	Oxygen	Phosphate	Silicate	Nitrate	pH
[°C]	[mmol/m³]	[mmol/m³]	[mmol/m³]	[mmol/m³]	[-]

In order to obtain the required conversion factors and consequently enable harmonizing of the units, the P24 vocabulary (Units of measure dimensions, 2022) from the NVS is used. Each P24 concept is a classification concept for units of measure based upon the fundamental SI quantities. In the NVS, P24 is linked to BODC's units of measure vocabulary P06 (BODC-approved data storage units, 2023) and hence P24 groups units of measure of identical vector dimensions. The relevant P24 dimension vectors are linked to each of the six EOVs listed above, such that all the units of measure can be selected that could be associated with data targeting that EOV including the observable properties defined in P01. Each unit is also uniquely mapped to a QUDT unit through the owl:sameAs property. So, each P24 concept is associated to a list of valid units in the NVS which are linked to their equivalent in QUDT, giving us access to QUDT's conversion algorithms from the QUDT SPARQL endpoint.

For example, for EOV Oxygen for each P24 dimension it will retrieve the relevant P06 units and using the owl:sameAs property it will provide the associated QUDT units as shown in the diagram below. Having acquired the QUDT unit, we can federate to the QUDT SPARQL endpoint to extract the unit conversions.

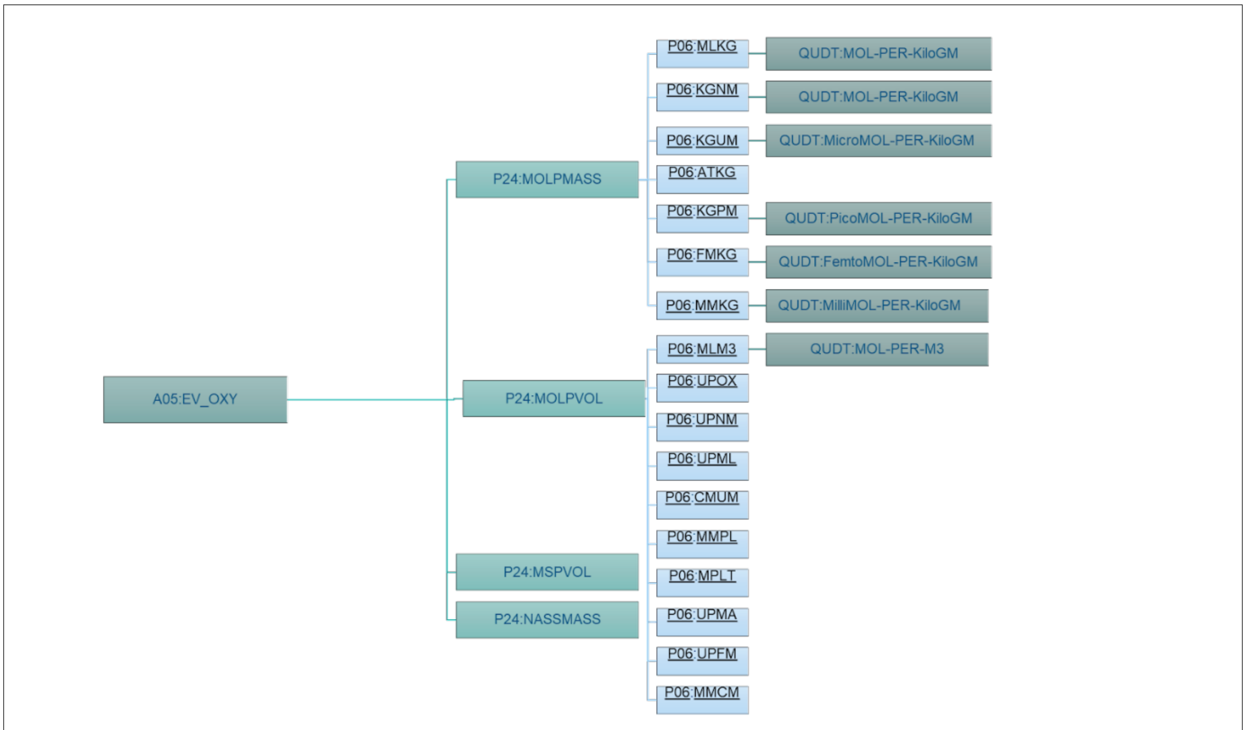

Figure 2: Dependency of vocabularies

At this point of the technical framework, the data that is obtained from the Euro-Argo and SeaDataNet databases should include the preferred unit. This data can then be used as input towards 1) the Map-Viewer and 2) the Ocean Indicators that are both discussed in more detail below.

3. MARINE DATA VIEWER

The user interface of the map viewer is designed for (citizen) scientists and allows them to interact with the large data collections retrieving parameter values from observation data by geographical area and using sliders for date, time and depth. At present, the ocean indicators concern temperature, oxygen, nutrients and pH measurements, from Euro-Argo and SeaDataNet. The *in situ* values are co-located with product layers from Copernicus Marine, based upon modelling and satellite data.

The related *in situ* data sets concern single observations such as profiles, tracks, analysed water samples, etc which are not available as continuous timeseries. Moreover, the spatial coverage varies in time, density, and numbers. The *in situ* observations can be plotted on the map by selecting an EOV, time period (years or months) and depth range (e.g., [0, 5] m). The user can also select multiple EOVs at once, creating an aggregated data collection.

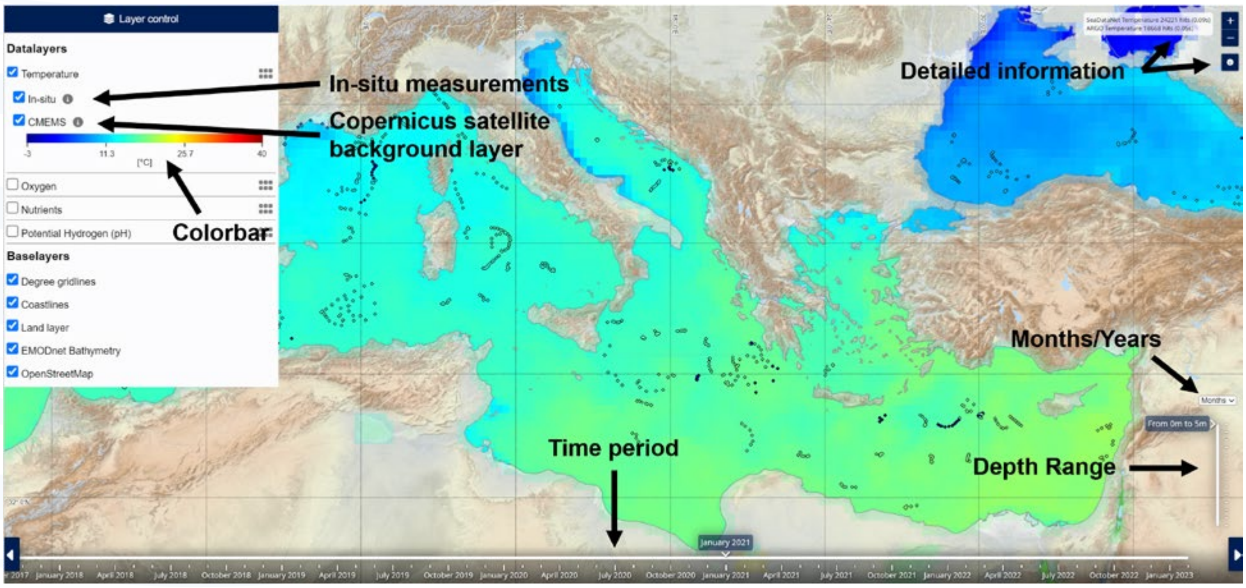

Figure 3: Marine Data Viewer

A colorbar is displayed with a clear colour scheme, depicting the unit of the EOV and the corresponding values. Depending on the EOV a linear or log scale is used for visual purposes. There is a layer system in place where the user can choose the desired hierarchy that determines which data should be shown if different parameters are at the same location.
After the user has selected the parameters, the number of measurements retrieved from the SeaDataNet and Euro-Argo databases can be seen in the top right corner. Here, users

are also able to click on the information icon in the top right and then click on the map near measurements to get more detailed information.

The information is stored in a table, and when the measurements concern Argo floats, the user is able to click on the profile info to get the information of the whole depth profile. Or when it concerns SeaDataNet measurements the user is redirected to the corresponding CDI landing page.

The viewer also includes background layers from CMEMS that include modelling or satellite products. This is done by using OGC Web Map Service (WMS), which is a standard protocol providing a simple HTTPs interface for requesting geo-registered map images. The *in situ* data can be plotted on top of these products as seen in the figure above, such that a comparison can be made.

4. DYNAMIC TREND INDICATORS

The *in situ* data sets are used in algorithms to generate aggregated values as dynamic trend indicators for sea regions. These are displayed at the Dashboard for the State of the Environment and provide ocean trend indicators for the selected EOVs for designated areas. For more information, users can then click on such an indicator guiding them to the Marine Data Viewer to browse deeper into the data and details facilitating the trends.

A methodology is defined and implemented as an analytical workflow for determining scientifically justified aggregated values for feeding the trend indicators as planned at the first level of the Environmental Dashboard. Natural variability in time and space of parameters and the fact that the availability of data sets also varies in time and space, are major challenges to overcome. The ambition here is to construct the trend indicators based only on the *in situ* data that we have (level 1 indicators).

The focus lies on the European seas, which is divided into different sub-regions as seen in the figure below. For each of the regions listed below, trend indicators are established based on the *in situ* data that is available.

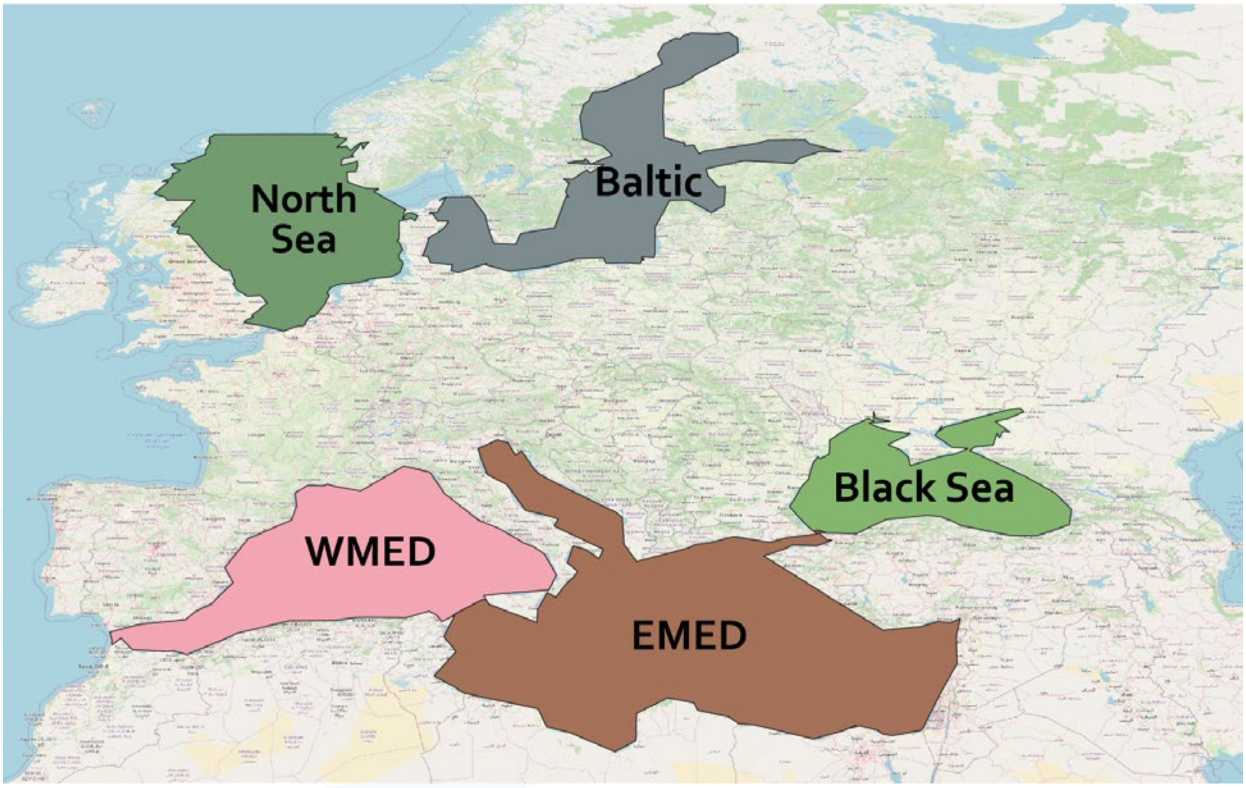

Figure 4: European Sea Regions

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Oral Presentations – Session B

Strategic developments in ocean observing – 1

The Science We Need for the Mediterranean Sea We Want (SciNMeet) Programme: the Mediterranean Region's contribution to the UN Decade of Ocean Science for Sustainable Development (2021-2030)

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Keywords
Mediterranean, Ocean, Decade, science, cooperation

1. INTRODUCTION

The Mediterranean Sea, a semi-enclosed basin, spans only 0.82% of the world's ocean surface but hosts intricate dynamical processes. Encompassed by 22 nations, its coasts are home to over 450 million people spanning three continents - Africa, Asia, and Europe. Boasting an extensive history and a wealth of natural and cultural heritage, the Mediterranean supports 30% of global maritime traffic via the Suez Canal. Hosting approximately 60 offshore oil rigs and serving as the world's top tourist destination, attracting nearly 30% of international tourism, it is a nexus of human activities. However, these pursuits strain its marine ecosystems significantly. Notably, the Mediterranean's vulnerability to Climate Change seems pronounced, reflecting the region's unique dynamics.

In the past century, collaborative efforts such as the Mediterranean Science Commission promoted international marine research, while the need for safeguarding the Mediterranean's marine and coastal environment was emphasised through initiatives such as the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) and the Action Plan for Protection of the Marine Environment and the Sustainable Development of the Coastal Areas of the Mediterranean established under the United Nations Environment Programme (UNEP/MAP), the Strategy of General Fishery Commission for the Mediterranean (FAO/GFCM), the BlueMed Research & Innovation Initiative focused blue economy and jobs. Subsequently, the Mediterranean scientific community collaborated through projects like MedGOOS, MOON, and MONGOOS, leading to the development of regional observing and forecasting systems integrated into global and European marine networks.

As follow up of this context, the Science We Need for the Mediterranean Sea We Want (SciNMeet) Programme seeks to address crucial challenges: the Mediterranean faces significant hurdles, including pollution, climate change, and escalating hazards. SciNMeet aims to establish the Mediterranean as a science hub to confront these issues, deploying observation capabilities for assessing pollution and climate impacts, and proposing adaptive strategies. The objective is to transform the Mediterranean into a "model region," strengthening the science-policy-society interface and its connection with the Blue Economy's sustainability.

SciNMeet intends to demonstrate that long-term collaboration within the Mediterranean Sea community can drive transformative change, contributing to regional and global policies like the UN Sustainable Development Goals (2021-2030), the European Green Deal and the Horizon Europe Mission 'Restore our ocean and waters by 2030'.

2. THE SCINMEET PROGRAMM

The Programme is the result of a journey conducted between January and November 2020 2021, during which two regional consultations were held. These consultations were hosted by the Italian Oceanographic Commission (COI) and co-organized with the UNESCO Intergovernmental Oceanographic Commission (IOC), UNEP/MAP, and the European Commission (EC), with the support of the BlueMed Initiative. The workshop "The Mediterranean Sea We Need for the Future We Want," held from January 21-23, 2020, brought together 159 experts from 32 countries, along with intergovernmental and international organisations and networks. The aim was to discuss the Mediterranean perspective in light of the social outcomes of the Decade: a clean, healthy, and resilient ocean that is predictable, safe, sustainably productive, transparent, accessible, engaging, and stimulating. The virtual session "Co-designing the science and capacity we need for the Mediterranean Region," held on November 11, 2020, with support from the Swedish Ministry of the Environment, gathered 237 experts from 48 countries and over 100 international organisations remotely,

Table I. Specific scientific and capacity development gaps of the Mediterranean region declined for the seven Decade Outcomes (grey circle with white cross) and main interrelations (grey circle). "The Mediterranean Sea we want", Cappelletto *et al.*, 2021.

GAPS	A clean ocean	A healthy and resilient ocean	A predicted ocean
Understanding of primary sources and pathways for the transport of pollutants, including the mapping of pollution hot-spots and their impacts on ecosystem and human health, as well as link with social and economic activities.	(X)	●	●
Linking pollutant fluxes with economic sectors, identifying monitoring indicators and implementing the planning/management measures of the entire water cycle for the terrestrial components, based on appropriate science and technology, as well as all available science/policy interaction.	(X)		●
Better understanding of physical/biogeochemical/biodiversity dynamics on climate time scales, adopting a comprehensive ocean observing system (protection/monitoring), improving the quantitative knowledge of ecosystems (assessing/modelling) and their functioning (including organismal response to environmental stressors) as the basis for their management (increasing MPAs level, integrating MSP and ICZM) and adaptation.		(X)	●
Ensuring systematic observations and continuity of data records in north and south of the Mediterranean and extending the range of observations to include biological and ecological EOVs also in coastal area and including novel observations on marine ecosystems to higher trophic levels, fisheries, genomics, pollutants.	●	●	(X)
Monitoring the coastal-open ocean exchange, mesoscale and sub-mesoscales dynamics on ecosystem functioning and the sea floor morphology in four dimensions in areas characterized by natural (i.e. coastal erosion, deltaic deposition, mass transport) or anthropogenic modification (i.e. infrastructures, dredging).		●	(X)
Adopting numerical models which serve to extrapolate observations in both space and time at the resolution required to understand the coastal and nearshore marine areas and which include marine ecosystem processes and components needed to understand the dynamics of coastal and nearshore marine areas, also nested with open sea models.		●	(X)
Better understanding of the interactions and interdependencies of the environmental conditions and processes, the use of resources, the economy function and sustainability at the ecosystem level (rather than at the species level) and of the inter-relationships between species.			
Data availability by exploiting the synergy of in situ and space observation and forecasting to predict Mediterranean coastal areas in support of multi-hazard early warning systems and of modelling the effects of the mutual interaction of various sources of hazards and environmental changes.		●	
Understanding of the seasonal and interannual variations of HABs events and the changes in their intensity and distribution at the local and regional scales.			
Adequate awareness and involvement of decision makers, communities, citizens, teachers, media, to influence behaviors and perceptions of different actors towards effective sea actions (*sensu* Ocean Literacy).	●		

amid the pandemic. This diverse group included oceanographic and transdisciplinary research institutes, UN partners, NGOs, and the private sector, united in sharing lessons from relevant Mediterranean experiences to co-design Decade actions.

Endorsed in October 2021 as a Decade Action, SciNMeet was promoted by 20 organisations and subscribed by 145 international experts from 27 countries. SciNMeet will address key challenges in the Mediterranean, aiming to better understand and manage the impacts of climate change, pollution, overexploitation of resources, and marine risks on the marine environment. It seeks to contribute to ecosystem functionality and the sustainability of economic operations. By enhancing education, awareness, and international collaboration, mobilising the scientific community, policymakers, the private sector, and society, the Program will tackle the seven outcomes of the Ocean Decade.

A safe ocean	A productive ocean	A transparent and accessible ocean	A inspiring and engaging ocean
	●		
	●		
		●	
●			
	x		
x			
x		x	
●			x

The main goals of the SciNMeet Programme are:

1. Enhancing cooperation for strategic partnerships;
2. Promoting co-design for climate, pollution, and hazard solutions;
3. Keeping marine space under review and ensuring reliable data;
4. Providing integrated observation systems and modelling;
5. Promoting initiatives for sustained *in situ* observations of Essential Ocean Variables (EOVs);
6. Fostering research and innovation for pollution and hazards;
7. Facilitating data access, equipment, and capacity;
8. Increasing awareness, education and regional capacity building;
9. Bridging North-South Mediterranean gaps for cooperation.

3. Operational Plan (1-3 Years)

Building on the results of the above mentioned regional consultations carried out in 2020 to draft the proposal for a Decade Programme targeting the Mediterranean region, a gaps' analysis on the scientific and capacity development issues related to the Seven Decade Outcomes (Table 1) was conducted by the promoting organisations before the submission of SciNMeet. In 2021 the White Paper "The Mediterranean Sea we want" (Cappelletto *et al.*, 2021) was accepted for the Special Issue of Ocean Decade Community White Papers (CWPs) on the Global South at Ocean and Coastal Research Journal and can be considered as the inception step towards an elaboration on the actions to be carried out in the Mediterranean region during the Decade.

The gaps' analysis referred above has driven further reflection on the following priority lines of action to be addressed by SciNMeet during its initial phase, considering a three-year timeframe:

- At thematic level: Climate Change, Marine Pollution, Marine Hazards, Ocean Literacy & Education;

- At cross-cutting level: Ocean Observation & Prediction, Data Sharing, Knowledge Transfer & Capacity Building.

The Operational Plan will address the following Decade Challenges: Understand and beat marine pollution (1), Unlock ocean-based solutions to climate change (5), Expand the Global Ocean Observing System (7), Change humanity's relationship with the ocean (10). It is also expected to make a preliminary contribution to further Challenges such as Develop a sustainable and equitable ocean economy (4), Increase community resilience to ocean hazards (6) and Skills, knowledge and technology for all (9).

4. GOVERNANCE

In the Operational Plan it was set the structure of the Governance, represented in Figure 1.

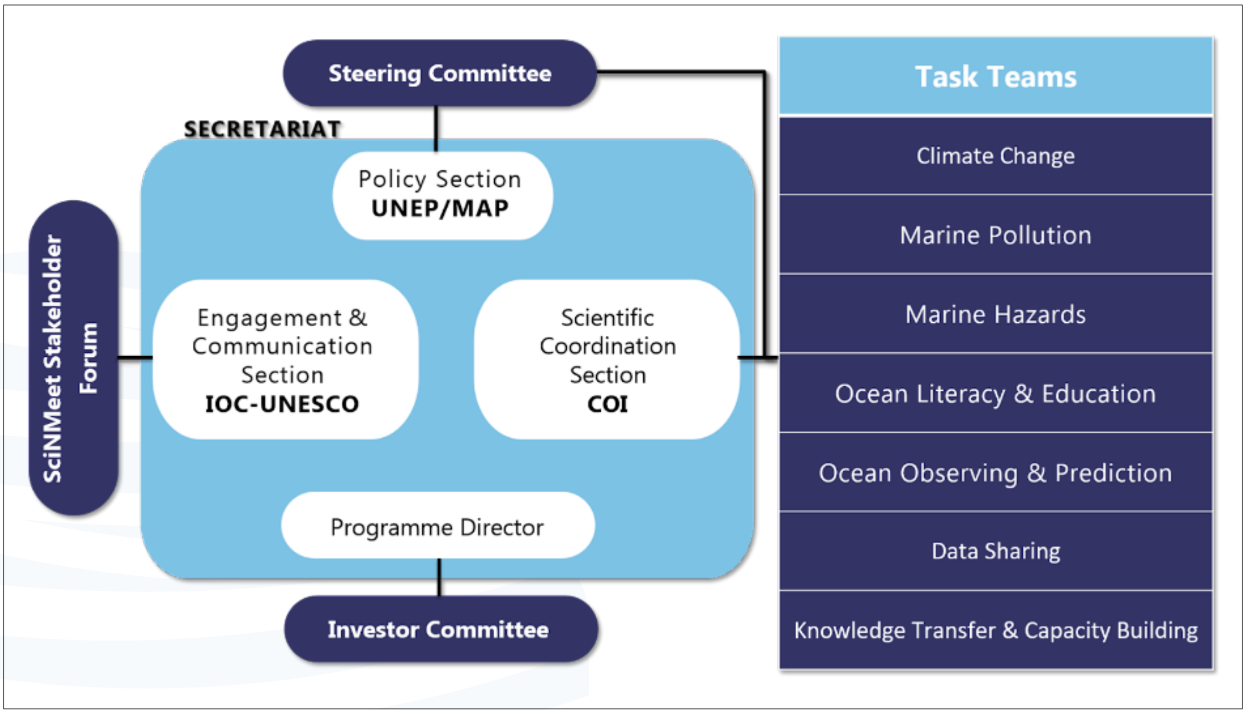

Figure 1: Scheme of the Governance structure of SciNMeet.

SciNMeet is coordinated by a Secretariat, the Executive body in charge of the day-by-day management under the supervision of the Programme Director. The Secretariat is composed of three branches:

1. Policy Section led by UNEP/MAP, responsible for the interaction with the Steering Committee, that is the main strategic body of the Programme since it guides the whole implementation process, including at the scientific, technical and policy level.

2. Scientific Section led by Italian Oceanographic Commission (COI), in charge of coordinating, supporting and monitoring the activities of the Task Teams (TTs), ensuring due contribution to the implementation of relevant Mediterranean Research & Innovation frameworks programmes.

3. Communication & Engagement Section led by IOC-UNESCO, mandated to implement fundraising activities, including by interacting with and animating the Investor Committee, linking with the Decade Global Stakeholders Forum (the group of relevant stakeholders from the science, private, policy and society sectors), and managing the communication.

The TTs are the scientific working groups, corresponding to the 7 thematic and cross-cutting lines of actions of the SciNMeet Programme, that enable its operationalization over a medium term period (3-yrs), ensuring the due achievement of planned results. Each TT is composed of about 15 experts belonging to the organisations hosting the Secretariat as well as to other relevant Mediterranean community stakeholders. The TT members are selected on the basis of their expertise among a shortlist by ensuring a good geographical, gender, age and discipline balance.

The Operational Plan encompasses also the following transversal activities that will be carried out mainly in the first 3 years to start-up a solid process, including at governance level:

1. Launch event (Kickoff meeting);
2. Meeting of the governing bodies;
3. SciNMeet website' design and release;
4. Clustering and mapping the initiatives/projects (including Programmes/Actions endorsed in the framework of the Decade) suitable to contribute and identify possible gaps;
5. Mapping and prioritising the stakeholders to identify further gaps in view of their engagement;
6. Launch of a SciNMeet Stakeholder forum for regular dialogue and consultation;
7. Fundraising strategy.

5. FIRST ACTIONS

The Launch event of SciNMeet was held on the 11th and 12th of July 2022 in Rome and was co-organized by COI, UNESCO/IOC, UNEP/MAP, and GFCM/FAO by engaging 110 participants from 4 continents and 20 countries. In this context, the SciNMeet website was released, as well as the logo that represents the visual identity of the Programme (Fig. 2).

Figure 2: Logo of the SciNMeet Programme, created by graphic designer Elisa Abbadessa and selected through a competition.

The design of the logo is based on the idea that SciNmeet will follow three different paths to achieve its main goals: to bridge the scientific community, the private sector and society at large; to generate data and products; to address new policy requirements and societal demands. The logo is composed of three wavy lines, which represent the waves of the Mediterranean Sea. These waves meet at different points, creating two shapes that resemble a pair of eyes, symbolising the importance of looking to the future of the Mediterranean Sea. At the launch event, following the plenary sessions, were also organised operational parallel meetings of the TTs, addressing contents and rationale, Terms of Reference and roadmap for the smooth running of the activities. One of the key outcomes was the definition of TTs action points that will guide the next activities of the TTs: TT1 Climate Change aims to expand the technical membership to include expertise in climate change financial aspects, experimental biology related to climate change, and representation from assessment agencies; TT2 Marine Pollution focuses on mapping pollution hotspots, harmonising monitoring efforts, and inviting additional members; TT3 Marine Hazards concentrates on addressing diverse marine hazards, finalising expert lists, and establishing a unified framework for hazard descriptions; TT4 Ocean Literacy & Education set to create a stock-take template, devise communication strategies, identify gaps, and generate concept notes for fundraising; TT5 Ocean Observing & Prediction is dedicated to securing sustainable funding, mapping user requirements, enhancing visibility of ocean observing networks, and contributing to international observation systems; TT6 Data Sharing plans to systematise data sharing, expand the team with Southern Mediterranean representatives, and ensure ongoing funding; TT7 Knowledge Transfer & Capacity Building is tasked with evaluating knowledge-sharing initiatives, identifying relevant Ocean Decade Initiatives, engaging key stakeholders, and coordinating events centred on knowledge sharing and capacity building.

6. MOVING FORWARD

Under the strategic guidance of the Steering Committee and with the coordination and
Under the strategic guidance of the Steering Committee and with the coordination and
support of the Secretariat, the TTs will conduct specific activities. Acting as a think tank to deliver innovative ideas for actions on challenging Mediterranean Research & Innovation issues, the TTs will contribute to set-up a long- lasting science-to-policy Regional Cooperation framework. In this framework, a key mid-term milestone will be the delivery of an integrated progress report on the Status of the Mediterranean Sea. SciNMeet will be developed through concrete thematic and cross-cutting projects/activities that will meet the objectives contributing to five different assets, i.e. generating knowledge; monitoring and accessibility; provision of solutions and services for safety and sustainable productivity; integrated governance; inspiration and engagement.

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Future Marine Research Infrastructure – defining the scope, scale and pace to help identify and accelerate international partnerships

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Keywords

Marine, research, infrastructure, autonomous, systems, sensors, end-to-end data, FAIR

Abstract

Science community engagement in the removal of fossil fuels from ocean observations is necessary to both drive change and, most importantly, inform the shape of any future capability. A recent scoping review (Net Zero Oceanographic Capability) conducted by the UK identified the requirement to scale up the use of autonomous systems within a research infrastructure that prioritises interoperability and end-to-end data management and which embeds FAIR data principles. The follow-on Future Marine Research Infrastructure programme (FMRI) is testing the outcomes it needs to achieve over the coming decade and is embarking upon a linked series of development activities and in-water demonstrators aimed at filling specific technology gaps and engaging the user community in the development of novel observational techniques.

The limitations of autonomous systems are outweighed by the benefits if they are considered as a capability which, if integrated with other capabilities (satellites, floats, ships) can be optimised to support sustained and experimental observations including dynamic process studies. Describing the boundaries of the scope, scale and pace of development of this system of systems will help identify and accelerate international partnerships which are themselves influential in maximising any 'network effect' benefits and reducing 'switching costs' often associated with the rapid adoption of new technology.

1. INTRODUCTION

1.1. Observing the ocean is complex because of its vast size and defining characteristics (including extreme pressure at depth, part ice coverage, corrosive nature of sea water, and dynamic and complex interactions on all scales). Those observations are therefore often time consuming, technically challenging, expensive and inherently risky. And it is for those reasons that the ocean is often described as being chronically under-sampled resulting in large gaps in our understanding of its behaviour. This lack of data continues to preclude rapid advances in our ability to accurately forecast changes across temporal and spatial scales and implement sustainable responses.

1.2. In this Decade of Ocean Science for Sustainable Development, relevant technological advancements are such that the opportunity to observe the ocean at significantly increased temporal and spatial levels is within reach if we can both deliver those technological advances and adapt the associated scientific techniques to take advantage of the opportunities presented. Alongside adaptation, increasing compute power, edge computing, big data and AI have the potential to change the way multiple users are able to access FAIR[1] data and how models are increasingly used to inform repeat or new observations.

1.3. However, unless national budgets for marine research infrastructure increase significantly, difficult decisions regarding the optimum mix of research platforms (from global class research ships to hand- held, micro-AUVs) will have to continue to be made by funders and the science community. To date, Marine Autonomous Systems (MAS) have broadly been considered as additional to the foundational capability provided by crewed research vessels carrying science parties. In future, the added requirement to reduce or remove CO_2 emissions associated with marine research will present a new variable that challenges that assumption and drives increased adoption of MAS. Any increasing use of MAS is unlikely to be linear however and phenomena such as 'network effects' and 'switching costs' will impact the pace of change. Those phenomena will also impact upon the scope and scale of MASus e for marine science alongside discrete technology developments, e.g. sensor development or increased battery power, and reducing costs as the market matures.

1.4. A shared understanding of the scope, scale and pace of MAS development and its likely adoption (or not) by the science community is therefore important if we are to deliver the effective integration of this transformational technology into our research ecosystems within a compressed timeframe.

[1] In 2016, the 'FAIR Guiding Principles for Scientific Data Management and Stewardship' were published in Scientific Data to improve the Findability, Accessibility, Interoperability and Reuse of digital assets.

2. GREEN RESEARCH SHIPS

2.1. Research vessel operators will have to respond to both the International Maritime Organisation's (IMO) strategy on the reduction of emissions from shipping alongside the increasing public/science community awareness and concern over CO_2 emissions associated with scientific research. Member states of the IMO, at the recent Marine Environment Protection Committee[2] (MEPC) 80 meeting, adopted the 2023 IMO strategy on the reduction of greenhouse gas emissions from ships with enhanced targets to tackle harmful emissions. The revised strategy includes an enhanced common ambition to reach net-zero emissions "close to 2050", a commitment to ensure an uptake of alternative zero and near-zero greenhouse gas fuels by 2030, as well as indicative checkpoints for 2030 and 2040. It is noteworthy that the MEPC adopted guidelines on the life-cycle greenhouse gas intensity of marine fuels, i.e. the guidelines allow for a well-to-wake calculation of total emissions related to the production and use of marine fuels.

2.2. Research vessels (when state owned and operated) are often provided with exemptions from shipping regulations, e.g. MARPOL. In the UK, whilst those exemptions are available, they have not been applied and have, in the case of CO_2 emissions, been superseded by the UK's funding body, UK Research and Innovation (UKRI), which has declared an intention to be net zero by 2040. The 3 large UK research vessels (the *Royal Research Ships James Cook, Discovery and Sir David Attenborough*) contribute approximately 40% of UKRI's measured CO_2 emissions and therefore present a key obstacle to meeting that intention. The *RRS James Cook* is due to be replaced, after a 25-year life, in 2031 followed by the *RRS Discovery* in 2038. Whilst options include extending the life of both vessels, those dates present opportunities to update technologies and consider alternative options.

2.3. Any replacement ship will have to use a zero-emission fuel such as e-methanol and cannot therefore be considered a like-for-like replacement in either endurance, capability or size. The energy density of methanol is lower than that of traditional fuels, e.g. Marine Gas Oil has an energy density of 36.6 GJ/m^3 compared to methanol's 15.8 GJ/m^3. To maintain the current size and capability, a replacement to the *RRS James Cook* using methanol would have an endurance of 21 days at sea rather than its current 50-day endurance rating. The table below sets out some of the trade-offs that might be practicable and the potential implications on scientific activity for a vessel like the *RRS James Cook*

2.4. Given the implications of switching entirely to zero-emissions research vessels, this paper will hereafter consider research vessels as part of a wider ecosystem spanning remote and *in situ* capability that includes satellites and floats plus a significantly scaled-up autonomous systems capability with all elements operating in support of one another.

[2] The Marine Environment Protection Committee addresses environmental issues under the IMO's remit.

Table I. Endurance, capability and size considerations for a research vessel using e-methanol as the fuel.

	Endurance	Capability	Size
Endurance	Endurance maintained at 50 days	Capability maintained at 30 science berths/ labs/winches etc	Size might increase to 120m and 8000t. Major cost implications for both build and operations including fuel costs.
Capability	Endurance reduced from 50 days to 21 days. Impact upon remote locations, large arrays or extended studies	Capability maintained at 30 science berths/ labs/winches etc	Size maintained at 90m/5000 tonnes
Size	Endurance maintained at 50 days	Up to 20 berths removed, no/size of labs restricted and ship-based equipment limited in size/scope	Size maintained at 90m/5000 tonnes

3. SCOPE (MODELS, DIGITAL TWINS, INTELLIGENT OBSERVATIONS AND DIGITAL RESEARCH INFRASTRUCTURE)

3.1. MAS cannot directly replace research ships and so trying to replicate the methods of observing the ocean or the digital infrastructure that supports research ships will not work. Realising the opportunities presented by a research infrastructure that is both connected and distributed in ways not previously considered requires that its development:

1. Is explicitly linked to the digital infrastructure that will be in place in the future;

2. Can support and deliver new ways of managing data in accordance with FAIR principles;

3. Supports and takes advantage of a trusted data ecosystem that includes machine-to-machine interoperability.

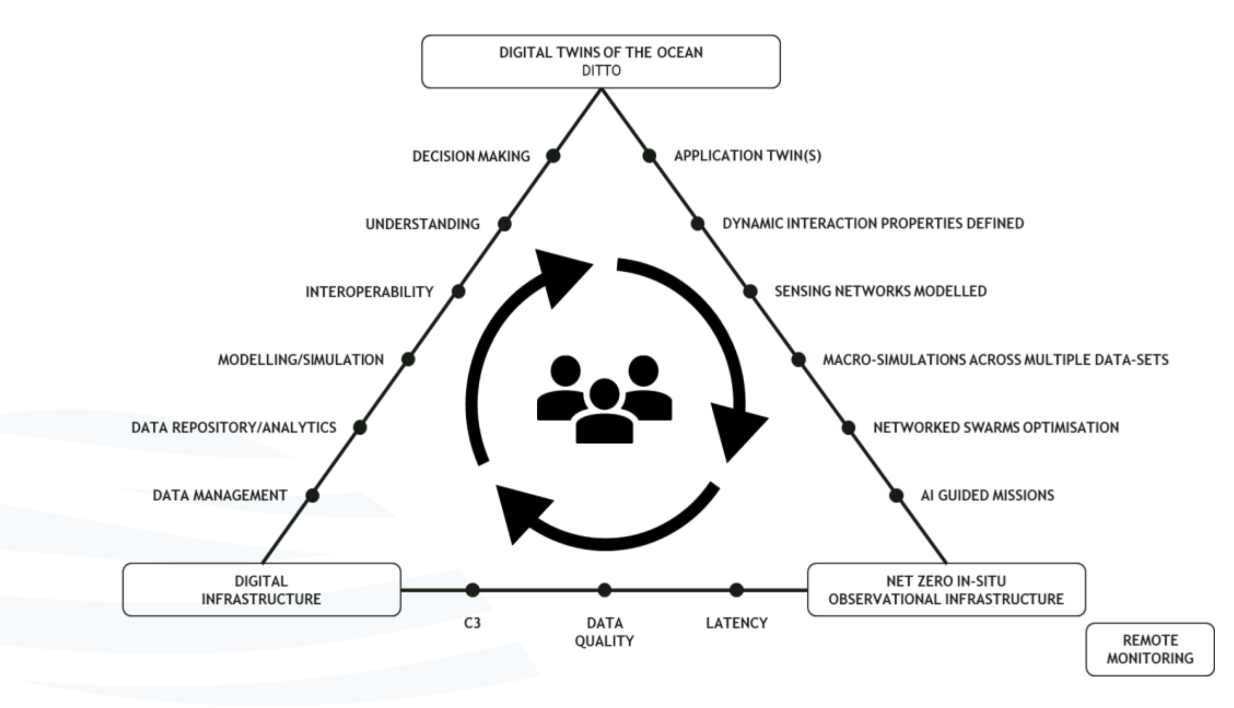

Figure 1. Digitally enabled *in situ* observational infrastructure and key links to the digital infrastructure and DiTTOs that would support effective delivery.

3.2. It is credible to assume that in future the UK might scale up to an autonomous (marine research) capability of 500+ platforms that include various types of gliders, Uncrewed Surface Vehicles (USVs) and long-range Autonomous Underwater Vehicles (AUVs). These platforms might support multiple mission plans whilst at sea, joining up with other platforms for periods of time to undertake a wider range of observations or support specific process studies. This operating model steps away from the temporary 'ownership of data' inherent in the current system and requires instead that 'users' access data via portals that support an agreed level of quality control and quality assurance. To enable this "a shift is needed towards 'data-first' resource mobilization, i.e. not as an add-on for science projects, but to provide the baseline digital capacity for all". (IOC/2023/ODS/45)

3.3. The key enabler for this shift remains the availability of sensors that have the necessary precision, accuracy, reliability and robustness to operate in the marine environment and to be trusted by the science community: "a major transformation in ocean observing will come from the next generation of sensors that provides insights into biogeochemistry, ocean health, and marine life" (GOOS-288 / MTS202304). Progress will remain slow unless we can bring end-users together with engineers and then partner effectively with industry to scale up. That is the precursor to MAS delivering precision and accuracy plus spatial and temporal cover, i.e. to MAS having a measurable impact upon the current under-sampling of the ocean.

4. CALE (AI INFORMED SHAPE/VOLUME AND MISSION OPTIMISATION)

4.1. How to solve the question of how many sensors integrated into how many autonomous platforms equals one research ship? The unknown variables remain the 'what, when and where' the science community will want to observe and how that will change in future. The question might therefore be rephrased as what scale of MAS is required to replicate the inherent capability and flexibility in a research ship and how do we then build upon that to deliver the increased spatial and temporal coverage that is possible through using MAS?

4.2. Imagining a flotilla of 30 autonomous platforms swimming out to an area of interest, taking measurements for 50 days and then swimming home is the wrong way to consider how MAS might work. The Hubble telescope provides a better model with users requesting time to support a particular observation as the telescope orbits the planet. An autonomous platform 'mission' might therefore include collecting data for weather forecasting models during the initial and final stages, then collecting data on a Marine Protected Area within an Exclusive Economic Zone prior to 2 discrete periods in the mid-ocean recording observations alongside other platforms requested by the associated Principal Scientists (data users).

4.3. For an operator this presents a warehousing and scheduling challenge alongside the generic issue of recruiting and retaining a suitably qualified and experienced marine technology workforce. The British Antarctic Survey's AI Lab are leading on research into how AI could optimize the planning of a FMRI-type capability and therefore what scale of 'kit' might be required – the Autonomous Marine Operations Planning project[3] is modelling optimised observational campaigns that include research ships and autonomous platforms launched and recovered from ship and shore. That initial stage will allow us to both optimize the scale of autonomous capability but also start to model options for platform development that might generate efficiencies, e.g range increase of 5% or depth rating to 4000m rather than 1500m. It will also inform plans for warehousing and workforce skillsets in future.

4.4. Optimisation of any national or regional research infrastructure incorporating a scaled-up MAS will include co-ordination but not necessarily centralization. This requires careful consideration against components such as test facilities (lab and in-water), maintenance and servicing centers, warehousing and piloting support – what is the best geographical/workforce split to deliver expertise and resilience within this type of infrastructure?

[3] https://www.bas.ac.uk/project/autonomous-marine-operations-planning/

5. PACE (INERTIA, INEXPERIENCE, INTEROPERABILITY AND INTER-DEPENDENCIES)

5.1. Progress towards a marine research infrastructure that places end-to-end data management at the forefront of its design, is dependent upon novel technology and which still requires the users to conceive of different observational techniques, is unlikely to be linear. The vision, of a research infrastructure that supports precise, accurate measurement across an expanded temporal and spatial range and with equitable access to data across all users, isn't widely accepted nor are the outcomes that would support it fully defined. The Global Ocean Observing System (GOOS) vision includes an intention to "be the vehicle for designing, building and widening the use of the necessary observations and information systems with capability enhanced by new, lower-cost technology" to support a "truly global ocean observing system" by 2030. A first step might be to require Principal Scientists to include plans for secondary usage of their data based upon ocean best practice and GOOS EOV specifications. Alternatively, appropriately formatted and quality-controlled data submitted to GOOS- sponsored digital twins might deliver better data re-use.

5.2. However, there is inertia baked into the system as countries continue to invest £Ms in building new research ships. Any decision to change tack within the 25-year life of those vessels would be both bold and costly. And because the global sustained ocean observing system relies upon key reference programs such as GO-SHIP, which underpin major elements of the wider observing system, a carefully considered transition is necessary. In addition, there is currently a small subset of marine scientists who are experienced in working with MAS which limits consideration of new techniques.

5.3. The GOOS model does however show how interoperable technologies can support rapid advances in marine science with Argo being the exemplar albeit as a somewhat opportunistic program. If the objective remains to "create a fully global, top-to-bottom, dynamically complete and multidisciplinary Argo Program that will integrate seamlessly with satellite and other *in situ* elements" (Legler *et al.*, 2015) then any FMRI should seek to support that objective.

5.4. There are multiple interdependencies in a transition to a research infrastructure that has MAS collecting the percentage of data illustrated in Fig 2 below, but the opportunities are becoming increasingly apparent and are expanding to include adaptive observations which present the next obvious step (Ford *et al.*, 2022). The pace of sensor development sets the baseline and is then dependent upon how scientists might adapt their methods and calibrate new approaches with more established observation technologies. The shock of research ships shifting from fossil fuels to sustainable alternatives and the implications on endurance and capability is yet to be fully considered but has the potential to accelerate and embed that transition.

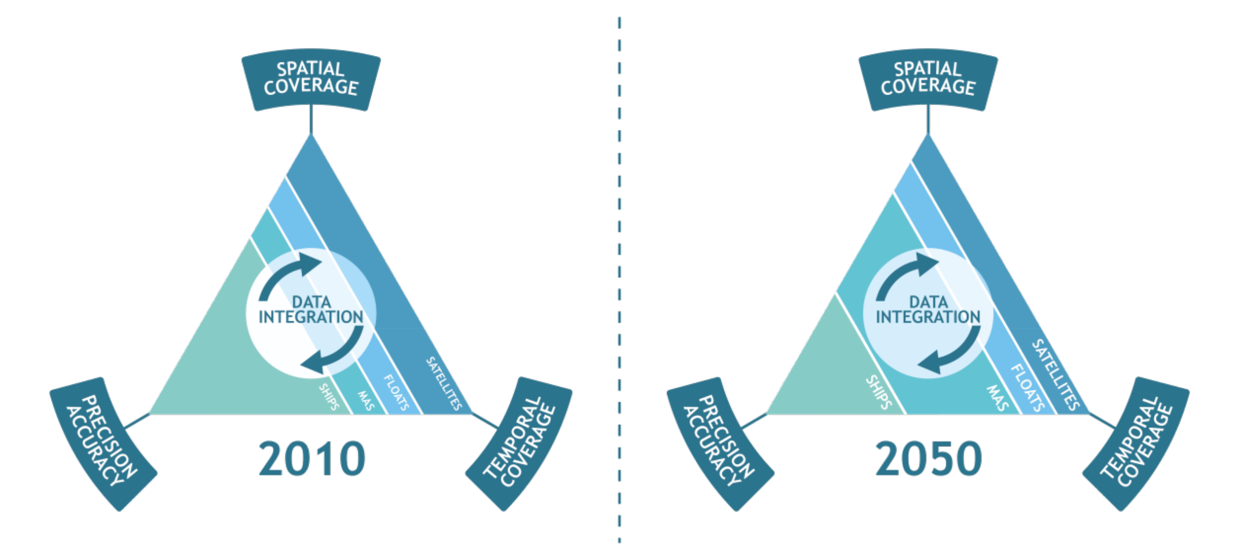

Figure 2. Illustrative comparison of remote and *in situ* observational capabilities relative to precision/accuracy of data and spatial/temporal coverage.

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Towards a new phase for Argo at the European scale: Euro-Argo RISE contribution

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Keywords

In situ ocean observations, OneArgo, Euro-Argo community

Abstract

Consisting of nearly 4000 profilers that dive up and down over the oceans, Argo is a game changer as the first global, real-time *in situ* ocean-observation network and marks a true revolution in global ocean observation. Euro-Argo, aggregated in the form of an ERIC, is the European component of the network, contributing with one fourth of the global fleet. At the OceanObs19 conference in 2019, Argo became OneArgo and aims to expand from core Argo to a global, full depth, interdisciplinary array. The overall objectives of the Euro-Argo RISE project followed this impetus and aimed at sustaining and extending the Argo network at the European level. Through a strong collaboration between 19 partners from 13 countries, this 4-year project helped maturing key topics of the European contribution to OneArgo as technological, data management, services to users and community enhancement.

1. INTRODUCTION

Euro-Argo ERIC aims to provide essential ocean observations for a better understanding of ocean health and of the global warming consequences on the ocean. It coordinates and strengthens the European contribution to the international Argo Programme. To reach this goal and align Euro-Argo ERIC missions with those of the new international OneArgo design, which aims to expand from core Argo to a "global, full-depth, multidisciplinary array", the Euro-Argo RISE project was the key for developing and enhancing the research infrastructure. By pooling together the effort of 19 European partners, this EU Horizon 2020 research and innovation project developed the maturity of the different elements of the Argo network to further develop Euro-Argo contribution towards biogeochemistry, greater depths, seasonally ice-covered and shallow water regions. During 4 years, work progressed through 4 major topics: technological progress, data management, services to users and community enhancement.

2. TECHNOLOGICAL DEVELOPMENTS IN SUPPORT OF ONEARGO IMPLEMENTATION

Euro-Argo ERIC aims to provide essential ocean observations for a better understanding Euro-Argo RISE project has been a key enabler to diversify sensor manufacturers and strove to secure the best sensor performance while matching the required scientific data quality. In parallel to these developments, geographical extension progressed to high latitude regions and to shallower waters of the Marginal Seas.

2.1. Test new sensors on Argo floats

So far, the vast majority of Argo sensors are supplied by a single manufacturer. Euro-Argo RISE has made possible to test available sensors produced by new manufacturers for temperature and salinity as well as some BGC parameters (Fig. 1). Work also contributed to qualify the CTD sensors that meet the requirements, in terms of accuracy and long-term stability, to expand the Argo network to the deep ocean. Thanks to the efforts from Euro-Argo RISE and international partners, it is now possible for Argo to have alternative sensors suppliers (RBR for CTD and TriOS for BGC), and mitigate the risk of a single point of failure in the global program.

While great progress has been made for the deep Argo sensors, it is still necessary to carry out a reference CTD profile at the deployment site to calibrate the measurements deeper than 2000 dbar.

Figure 1. From left to right: Test of the RBR CTD on the Arvor float for the core mission, the two-head prototype to compare the SBE61 and RBR concerto new sensor for the deep mission, and the double irradiance sensor prototype to test TriOS vs Seabird for the BGC mission.

2.2. Expand European geographical coverage

So far, the vast majority of Argo sensors are supplied by a single manufacturer. Euro-Argo RISE provided recommendations, guidelines and tools for operating floats in partially ice-covered areas of the high latitudes (Angel-Benavides *et al.*, 2022). Past experiences, both successes and failures, were assembled and together with the reference datasets gathered give guidance on planning deployments and operating Argo floats in the Nordic Seas and Arctic Ocean. In particular, the Ice Sensing Algorithm (ISA) software is now used with locally adapted configuration parameters, improving the reliability and operating capabilities of Argo. Cheatsheets for operators helped to quickly check the needed steps to operate in seasonally ice-covered regions. Furthermore, open access tools developed and provided in the euroargodev GitHub (see 3.1) assist in planning of operations and using Argo data from these regions.

The potential use of Argo in shallower waters was tested by performing deployments in eight sites of the European Marginal Seas: two in the Baltic Sea, four in the Mediterranean Sea and two in the north-western Black Sea shelf. Specific Argo platform configurations were tested according to the missions' targets. Tests revealed that the most critical configuration parameters are the park pressure, profile pressure and the cycle time: park pressure and profile pressure were set deep enough (even at the sea bed) to try to limit the platform drift and cycle time set between 1 and 5 (7) days in the Mediterranean and Black Seas (Baltic Sea). These test deployments in shallower waters provided demonstration of the potential use of Argo in shallow coastal areas (Notarstefano *et al.*, 2022).

3. IMPROVING THE EUROPEAN CONTRIBUTION TO THE ARGO DATA SYSTEM

Euro-Argo RISE has been central to enhancing the European component to the OneArgo data system through efficient collaborative developments. New delayed mode quality control (DMQC) methods were developed to cover the OneArgo quality requirements.

3.1. A collaborative framework for Euro-Argo: euroargodev

The collaborative framework has been a major pillar to share softwares regarding the improvement of the quality of the Argo dataset and the data stream. Created in December 2019, this collaborative framework can service and be used by the entire Euro-Argo community. This framework is hosted in GitHub and is named 'euroargodev' (Fig. 2).

Structured around three strategic domains, e.g 'software', 'reference dataset', 'data & expertise', this tight collaborative and code-sharing strategy allows for the DMQC process to be more sustainable, transparent, and easier to implement for groups managing modest fleets of Argo floats or simply freshly involved in the complex task of DMQC. Initially created for the development and improvement of DMQC for Argo, the use of the platform has since then expanded and currently hosts tools and materials related to Argo in general, such as argopy, a python library for Argo data beginners and experts (Maze and Balem, 2020), or the Argo online school, an online educational tool on Argo data (Gonzalez-Santana and Velez-Belchi, 2023). Thanks to the collaborative framework, the cooperation between partners and the legacy of the project for the international Argo community and the research infrastructure increased.

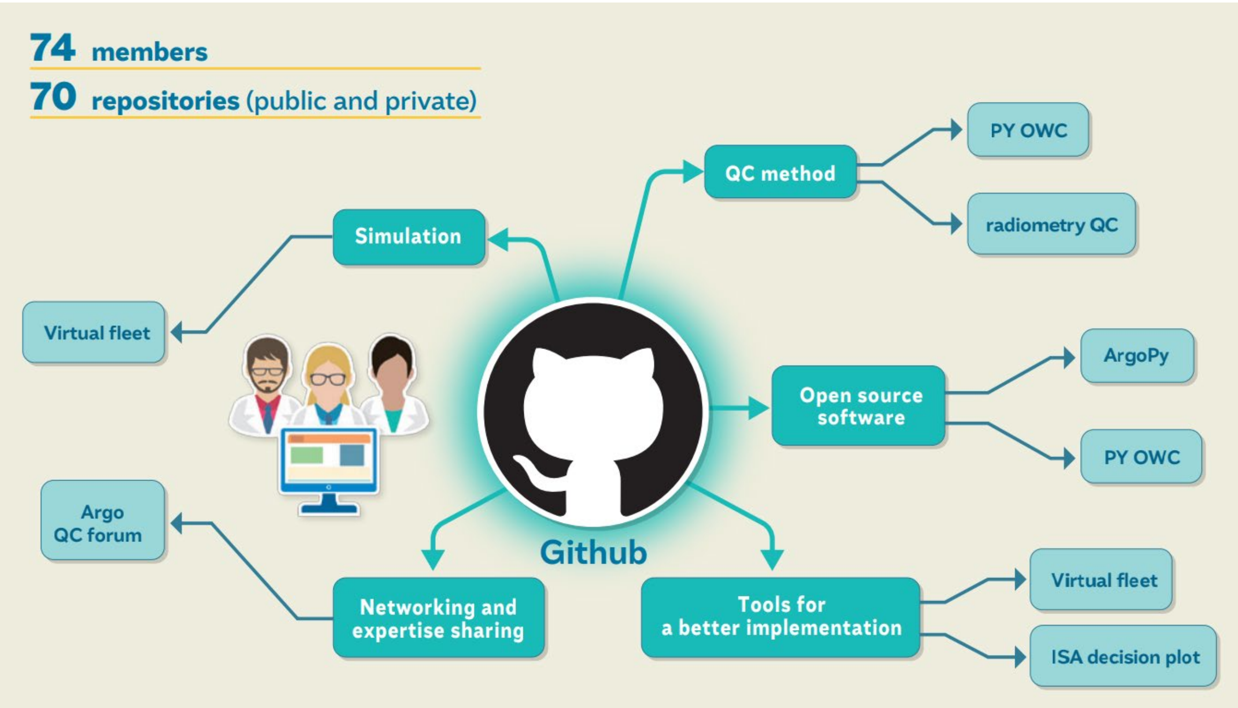

Figure 2. Euroargodev possibilities and current members and repositories as of January 2023.

3.2. Enhancement of quality control processes

Substantial improvements of the existing quality control procedures were carried out, improving algorithms and methods for the three missions (Fig. 3). Adaptations to the quality control in marginal seas were proposed. Specific requirements of the DMQC methods in the deeper European marginal seas (Arctic and Mediterranean) were identified to develop appropriate adaptations that take into account the presence of ice, the complex bathymetry and the scarcity of reference data. The first procedures for quality control of floats in the Baltic were established and will serve as a model for other shallow regions (Klein *et al.*, 2022). The CTD reference database needed for the DMQC was updated in several regions, performing important cleansing work and enhancing the amount and the quality of the reference data.

Table 1. Summary of the improvements for Argo real time and delayed mode quality control performed during Euro-Argo RISE. The green tick means endorsed by Argo international community (Argo Data Management Team).

MISSIONS AND ARGO VARIABLE		PARAMETERS MEASURED AND PROXYS	REAL TIME QUALITY CONTROL STATUS OF PROGRESS	DELAYED MODE QUALITY CONTROL STATUS OF PROGRESS
Core	Temperature and Salinity	Climate change, exchange of energy between atmosphere and ocean, climate and ocean forecasts	Update for RBR QC ✓	Recommendation for DMQC in Baltic shallower waters
Deep	Temperature and Salinity below 2000m	Sea level rise, earth energy budget, deep ocean circulation	Definition of procedures ✓	Definition of Deep DMQC procedures ✓
BCG	6 biogeochemical parameters	Ocean ecosystem health	Robust procedures have been enhanced or developed ✓	Enhanced DMQC procedures developed, tested and for some of the parameters discussed at international level

4. ENHANCEMENT OF SERVICES TO USERS

To facilitate the use of Argo scientific and technical data by users, Euro-Argo RISE has improved and created new tools and services and made them accessible to the Argo community and beyond.

One example is the Argo data selection tool: this online platform was created to display, select sub-sets and download Argo data in several formats (Fig. 4). Updating the former portal, this new version officially released in June 2021 allows users to select small or large sub-sets of Argo scientific data (profiles files) in a fast way through a user-friendly interface. In addition to the usual NetCDF format, the tool offers the possibility to download Argo profiles in .csv format.

Tools were also created to promote and improve data access and usage. Among them, the Argo Online School (AOS) was developed as an e-learning tool to teach the basic foundations to use and understand the Argo programme. As a set of videos, animations and hands-on python driven jupyter notebooks, the AOS is designed to make the Argo programme accessible for high schools or graduate students in any discipline, with no prerequisites. Freely accessible (https://www.euro-argo.eu/argo-online-school/intro.html) and organised

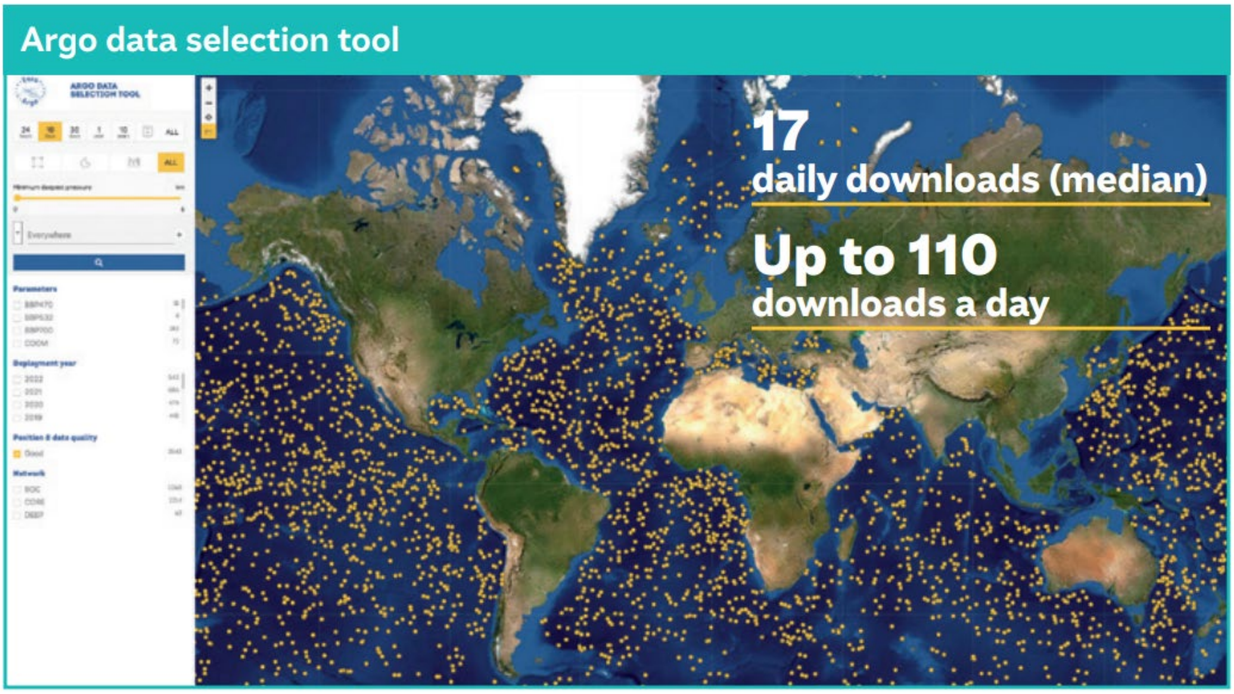

Figure 3. Argo data selection tool, a new tool developed to ease access to Argo data and increase their usage. https://dataselection.euro-argo.eu/

into three main lessons and 2 self-assessment sections, this e-learning tool has the possibility to be expanded to integrate the implementation of new features in OneArgo.

Euro-Argo links were reinforced with key operational users, Copernicus, EMODnet and ECMWF, through MoUs/letter of support and a better integration of available products has resulted. As an example, Argo current product, processed daily at Coriolis GDAC, is now integrated in the Copernicus Marine Service product portfolio.

5. A STRONG COMMUNITY ENHANCEMENT

Euro-Argo RISE project has been an efficient accelerator to enhance the Euro-Argo community and reinforce its integration in European and international landscape.

Thanks to key events to develop new partnerships, engagement with new countries was accelerated. In particular, the Euro-Argo regional workshops, targeting Mediterranean & Black Sea and Arctic & Baltic communities were held in April 2021 and allowed connections between communities sharing an interest for European Marginal Seas. It set up the basis for new collaboration into regional spheres and led to Denmark's application as a candidate Member of Euro-Argo ERIC. Since these workshops, a new forum emerged: the EuroGOOS Argo Task team. Interested countries which want to join the Euro-Argo ERIC have now a place to discuss operational matters and can closely interact with the Management Board of the ERIC. Portugal, Belgium, Cyprus and Turkey are part of this task team to progress towards membership.

Actions were taken for raising awareness among young people. The Ocean Observers initiative was pursued (Rusciano *et al.*, 2021), with the organisation of the 2nd OceanObservers workshop in 2021 and a rebranded website enriched with educational material. This initiative is led by an international educational network made up of different actors involved in marine science outreach activities who are willing to share experience on educational activities related to *in situ* ocean observations. These actions are continuing both at national and European level in partnership with OceanOPS and EuroGOOS.

6. CONCLUSION

Each of the results crucially took Euro-Argo members to a higher level of performance with regard to Argo activities and contributed to improve the overall Argo network and enhance the Euro-Argo community. It also facilitated collaboration with other European Research infrastructures within EOOS (European Ocean Observing System). Finally, Euro-Argo RISE enabled Europe to strengthen its contribution to the development of OneArgo and identify the challenges for the decade to come.

ACKNOWLEDGEMENTS

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Oral presentations – Session C

Enhancing capacity in ocean observing and services

Capacity sharing: Provision of data to The Met Eireann Integrated Coastal Flood Forecast Service (ICFFS)

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Keywords

Operational Monitoring, Flood Forecasting

Abstract

In 2022, the Integrated Coastal Flood Forecast Service (ICFFS) was established. This service is led by Met Éireann and aims to address the national priority issue of coastal flood forecasting. The ICFFS will make use of integrated forecasting approaches, requiring the development of models for tidal, surge, and ocean-wave forecast, as well as expansion of current coastal observing infrastructure. The service emphasises sharing existing national infrastructure, where programs either at or close to operational readiness can provide valuable and critical input. This paper describes a collaboration between Irish sectoral organizations to coordinate and develop existing capacity in the area of coastal observing. The activities involved in making use of shared capacity are described, including levelling up on specification, data handling, operations and maintenance procedures as well as increasing data availability. To date, work has included establishment of national working groups for Waves, Tides and High Frequency (HF) Radars, along with two pilot studies. The first pilot study utilises Aids to Navigation (ATON) buoys for wave observation and the second aims to deploy additional communications, tidal and weather monitoring equipment to existing infrastructure in Galway Port. Details of these trials, results and outputs are discussed.

1. INTRODUCTION

For coastal flood forecasting, Met Éireann (MÉ), as the World Meteorological Organization (WMO) representative and in line with the UN's Ocean Decade goals, are looking to optimise the existing infrastructure with our partners, where possible for multi-purpose usage by the state. A summary is provided outlining the existing coastal observation network below and the approaches being undertaken to integrate the various data feeds to support the high quality, high availability needs of the Integrated Coastal Flood Forecasting Service ICFFS. The work to date has been focused on wave buoy and tidal gauge networks.

The existing network has been developed for Ireland by different government agencies for their own specific uses which have included safety and navigation, aiding marine research, flood relief design and weather forecasting. Ireland's marine territory extends far beyond our coastline at up to 220 million acres (approx. 880,000km^2), an area more than 10 times our land mass. For the ongoing monitoring of our seas this a huge challenge as the area we manage is very extensive.

2 EXISTING COASTAL OBSERVING INFRASTRUCTURE

2.1. Buoy Network

Permanent wave buoy networks are operated by the Marine Institute (MI) and Commissioners of Irish Lights (Irish Lights) in Ireland. The primary purposes of these networks to date have been operational monitoring, ocean energy resource assessment, aiding marine research and safety and navigation.

The Irish Marine Data Buoy Observation Network is managed by the MI in collaboration with MÉ and funded by the Department of Agriculture, Food, and the Marine. The network is designed to improve weather forecasts and safety at sea around Ireland and and consists of 5 metocean buoys measuring both meteorological and oceanographic parameters. The buoy network provides vital data for weather forecasts, shipping bulletins, gale, and swell warnings as well as data for public information and research. Buoy data is also helpful for validating numerical weather prediction models and satellite products. The Atlantic Marine Energy Test Site (AMETS) is being developed by Sustainable Energy Authority of Ireland (SEAI) to facilitate testing of full-scale wave energy converters and floating offshore wind technologies in an open ocean environment.

Irish Lights have over 225 Aids to Navigation in operation around the Irish coast of which 141 are buoys, 22 are beacons and 65 are lighthouses. 70 of the 141 navigation buoys are fitted with AIS to allow data transmission.

2.2. Tidal Network

In Ireland, the main operators of tide gauges are the Office of Public Works (OPW) and the MI; some local authorities and port companies also maintain stations. Currently, 3 tide gauges in Ireland are component stations of the Globel Sea Level Observing Network (GLOSS).

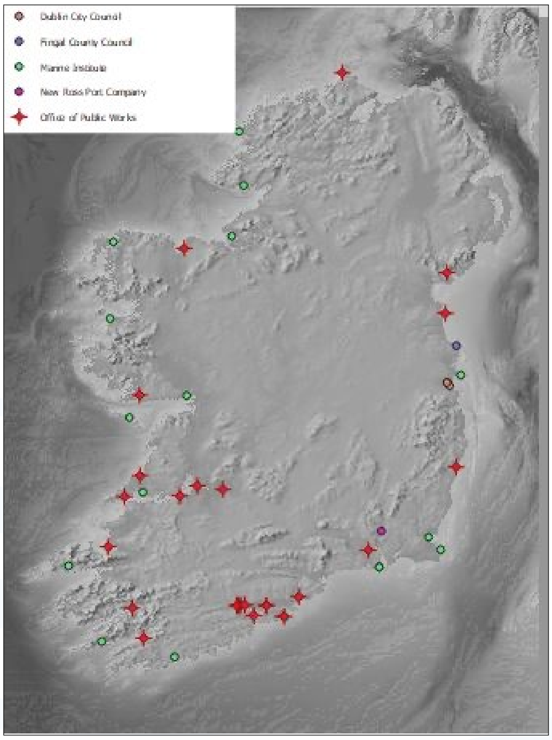

Figure 1. Existing Tide Gauge Network

Owned and managed by the Marine institute, the Irish National Tide Gauge Network (INTGN) is comprised of 19 high quality marine tide gauges plus numerous river gauges. The network is managed and funded on an operational basis now but developed from discretionary funds over a 20-year period. Data is freely available in real-time and delayed modes. Two of the INTGN stations are GLOSS stations - Union Hall harbour (west Cork) and Howth Harbour (County Dublin).

Owned and managed by the Office of Public Works (OPW) there are 66 tide gauges in operation around the Irish coast of which 26 are tidal and 40 are semi-tidal, mostly placed in the last 5 years. This includes a GLOSS station, located at Malin Head (Co. Donegal).

3. PILOT PROJECTS

The establishment of the ICFFS has brought the agencies working together in a coordinated approached where data are shared. The existing wave and tidal network operating in Ireland is described above. Several government agencies/bodies are involved with their own specific objectives and have developed an extensive infrastructure network. The requirements for ICFFS are for an operational, real-time data delivery service producing high quality, high availability data. New infrastructure will be required for various areas, but the initial approach was to optimise the public benefit from existing capacity by expanding the instrument suite deployed to existing infrastructure.

In 2021, a national working group for wave observation was established, including members from the Marine Institute, Irish Lights and Met Éireann, to ensure that optimisation of the Wave Buoys was informed by best practice. Additional working groups on tidal and HF Radar were subsequently established. These working groups bring together experts from public and academic institutions to identify gaps in networks, develop standards for instrumentation and maintenance and optimise existing infrastructure.

3.1. Wave Buoy Pilot Project

The Wave Buoy Pilot Project was a collaboration between Met Éireann with the Irish Lights to trial deploying wave sensors on Irish Lights' Aids to Navigation (AtoN) buoys. The objective of this pilot project was to provide near real-time meteorological and hydrographic data to ICFFS from Irish Lights' buoys who original purpose is for navigation purposes only. The buoys will be providing two services to the State;

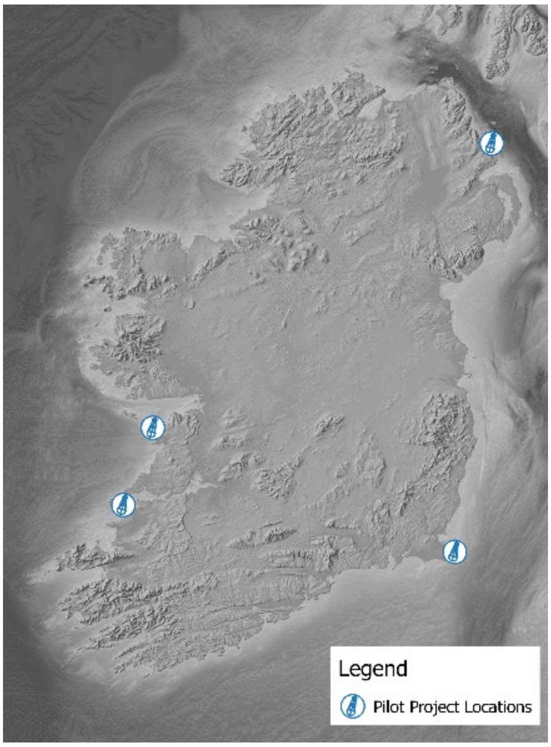

Figure 2. Irish Lights Wave Buoy Location for Pilot Project

firstly, to assist in navigation of the seas around the coast of Ireland and secondly to provide observations for coastal flood forecasts and a sea area forecasting service to be used by Met Éireann. This joint approach utilises the infrastructure twice rather than just once. This was achieved through the installation of a SeaView wave sensor on each buoy to carry out wave observations.

By utilising Irish Lights' existing AtoNs and Automatic Identification System (AIS) infrastructure, Irish Lights can provide meteorological and hydrographic information at strategic locations around the coast of Ireland. The data collected from these sensors is used to populate the fields of the AIS meteorological and hydrographic data message (message 8) as defined in IMO's SN.1/Circ.289 and transmitted directly to mariners.

Four Irish Lights wave buoys were selected for the project: Ballybunnion buoy (Shannon Estuary), Finnis buoy (Galway Bay), South Hunter buoy (Larne) and Splaugh buoy (Rosslare), as shown in Figure 2.

This will provide Met Éireann with wave data at four key locations around the coast where currently wave data is lacking. The parameters required by Met Éireann, and captured by the new instruments are Spectral Significant Wave Height (Hm0), Peak Wave Period (Tp), Mean Wave Direction (qd). The pilot project was divided into three stages, stage one-procurement & testing, stage 2-deployment and stage 3-assessment.

To establish the success or failure of the project with the new wave sensor within the AtoN, the collected data was compared to other available wave data in stage 3. This was carried out initially by comparing the data collected by the wave sensor against the Marine Institute's East Atlantic SWAN model. This process informed us if the wave sensor was working and producing reasonably accurate data. A comparison with model data was useful for an initial check, however, a more in-depth comparison with a Datawell Waverider, considered the industry standard in wave measurement, was subsequently used to verify the accuracy of the wave sensor deployed on a AtoN.

The Marine Institute (MI) were supplied with the initial data from three of the wave sensors at Finnis, South Hunter and Splaugh for November 2021 to mid-January 2022.

The MI operate the East Atlantic SWAN model which encompasses the trial locations of this project. They compared the significant wave height (Hm0), peak wave period (Tp) and wave direction (qd) from the SeaView wave sensor to the model outputs for the same period. The time series from both sources were plotted and a visual inspection of the results was carried out.

The comparison of model and wave sensor data indicated that the wave sensor was collecting reasonably accurate results, noting that modelled data and empirically observed data will by their very nature exhibit differences. After this initial comparison was completed, Waveriders were deployed adjacent to each of the wave sensors to get a more accurate comparison.

The results of the comparison of the Seaview wave sensor and Datawell Waverider indicated excellent agreement for significant wave height, mean wave period and mean wave direction. The Time series of significant wave height for the Datawell Waverider and SeaView wave sensor at Finnis, Splaugh, Ballybunnion and South Hunter sampling locations are shown in Figure 3, straight lines connecting datapoints indicate gaps in the data. Strong correlations were observed at all four sampling locations and bias and RMSE values were low at 3 out of 4 locations.

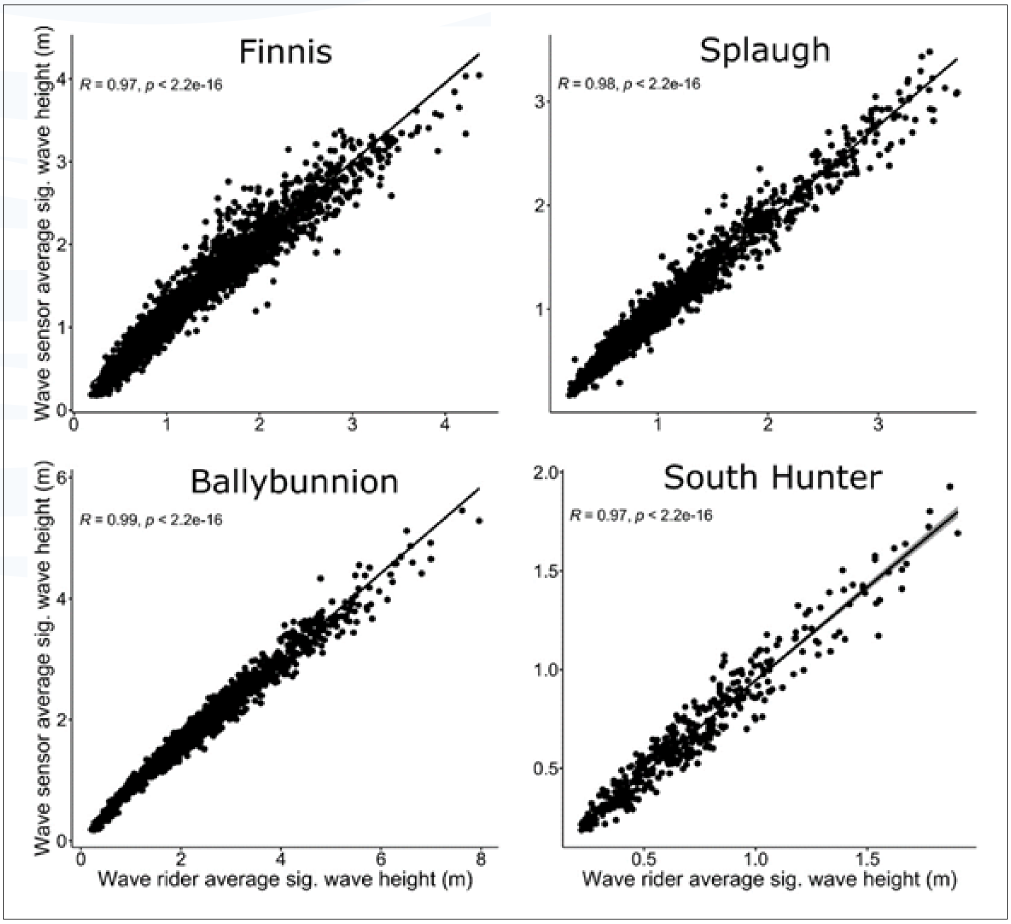

Figure 3. XXXXXXXXXXXXXX

Figure 3: Scatter plot displaying Pearson's correlation coefficient and significance value for hourly averaged significant wave height between Waverider and wave sensor at the Finnis, Splaugh, Ballybunnion and South Hunter sampling locations. Black line indicates linear relationships and shaded area represents 95% confidence intervals.

Overall, the differences between the wave sensor and Waverider were lower or comparable to previous studies comparing wave measurement devices (Andrews and Peach, 2019; Beckman and Long, 2022). This would indicate that the deployment a wave sensor on an existing AtoN does not hinder its ability to collect accurate verifiable data and is a practical and cost-effective alternative to deploying a dedicated wave buoy. It is also important to note that due to differences in data output time intervals between the wave sensor (20 minutes) and Waverider (30 minutes), hourly averaging was required to enable a comparison. If collection intervals were the same, it would enable a more direct and accurate comparison of wave measurement data.

The results of the comparison analysis between the Seaview wave sensor and the Datawell Waverider showed excellent agreement for significant wave height, maximum wave height, mean wave period and mean wave direction at most trial locations. Agreement was weaker for peak wave periods at all sites and mean wave direction at two sites.

The acquisition of near real-time high-quality wave data will be beneficial to the FFD (Flood Forecasting Division) before, during and after coastal flood events and will enhance coastal flood forecasting capabilities. The data will be an important input to any new coastal flood forecast models and the verification of existing models. The proposed next steps are to expand the use of wave sensors on further AtoN within Irish Lights' buoy network with priority in coastal areas most at risk of flooding.

3.2. Tidal Gauge Pilot Study

The objective of the Galway tide gauge pilot project is to establish the measures required to increase water level data real-time availability to the maximum extent that is feasible. Four primary areas were upgraded (1) a second water level sensor and associated components (2) dual data acquisition systems (3) diversified power supplies with failover and (4) dual path telecommunications using different cellular networks.

As part of the work a decision was taken to add a single conductivity temperature and depth sensor as well as dual compact WMO spec. met stations, again providing 100% redundancy.

The upgrade work was a team effort bringing together colleagues from the Marine Institute, Met Éireann, Galway Port Company, PO Maritime, and National Vibration Monitoring Ltd. (NVM).

Currently the new weather stations and additional sensors have been procured. The Marine Institute has upgraded the existing tidal station with a second sensor and the plan is to bring it on stream by the end of 2023 and may form a template for other stations.

The data transmission and reception from this tide station and weather station in Galway will need to be developed in the next stage of the project for dual data acquisition system. At present that data is going to the ERDAP site only.

4. DATA VISUALISATION

An Irish Flood Integrated Communications System (IFICS) which will allow the visualisation, production and dissemination of flood risk information for the Flood Forecast Centre at Met Éireann has been developed over the last two years. Within this system the existing tide and wave networks are displayed together along with available flood risk information. The new observation data collected as part of the pilot studies are visualised here to. This system has been made available to the key stakeholders involved in flood risk management in Ireland.

5. NEXT STEPS

To make full use of high availability data, sourced from the existing networks, situational awareness using wave and tide predictions together with ensemble forecast data, backup systems along with alternative communication will be requiredTo make full use of high availability data, sourced from the existing networks, situational awareness using wave and tide predictions together with ensemble forecast data, backup systems along with alternative communication will be required.

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Eoin Sherlock, Kevin Sheehy, Méabh Nic Guidhir, Dr Ryan McGeady, Met Éireann (ME), Peter Newport, Office of Public Works (OPW), Brian Sheridan, Galway Port Company (GP), Ronan Boyle, Dr Elaine Fitzgerald, Commissioners for Irish Lights (CIL), Alan Berry, Glenn Nolan, Marine Institute (MI)

Oral presentations – Session D

Advances in ocean forecasting

The Copernicus Marine Service recent achievements and future plans

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Keywords

Observations, forecasting, services, networking, users

Abstract

The Copernicus Marine Service provides operational, regular, and systematic reference information on the blue/white/green ocean state for the global ocean and European regional seas. More than 55,000 expert downstream services and users are connected to the service. The Copernicus Marine Service responds to public and private user needs and supports policies related to all marine and maritime sectors. An overview of Copernicus Marine Service recent achievements, service evolution strategy and plans for the coming 5 years will be given. The objective is to further establish Copernicus Marine Service products as a worldwide reference and respond to increasing user and policy needs for improved ocean monitoring and prediction capabilities. This requires preparing the implementation of the next generation of ocean monitoring and forecasting systems while embracing new capabilities of digital services in synergy with the Digital Twin Ocean developments. International cooperation and impact (UN Decade of Ocean Science) is a key element of Copernicus Marine evolution strategy. The cooperation with EuroGOOS and its members is also essential. Of particular importance are the interactions related to ocean observations in the framework of EOOS and the coastal ocean through the links with national coastal forecasting services and downstream applications.

1. INTRODUCTION

The Copernicus Marine Service implemented by Mercator Ocean International (MOi) provides operational, regular, and systematic reference information on the blue/white/green ocean state for the global ocean and European regional seas (see Le Traon *et al.*, 2019). The Copernicus Marine answers to the increasing needs of improved ocean monitoring and prediction capabilities to understand, predict and adapt to climate change, for a sustainable management of the ocean and its resources, a sustainable blue economy and to better protect marine ecosystems and biodiversity. The Copernicus Marine Service is a powerful instrument to support the European Union in the Green Deal, Digital Strategy and the environmental policies implementation.

An overview of Copernicus Marine Service recent achievements, service evolution strategy and plans for the coming 5 years is described below. Section 2 summarizes the Copernicus Marine Service architecture. Status and recent achievements are presented in section 3. Section 4 details service evolution plan up to 2028. The essential role of interactions with EuroGOOS are discussed in section 5. Main conclusions are given in section 6.

2. COPERNICUS MARINE SERVICE ARCHITECTURE

The data collection and data processing are two primary functions of the Copernicus Marine Service ensured by Production Centers. The Copernicus Marine Service architecture relies on production centers both for observations (Thematic Assembly Centers – TACs) and modelling/assimilation (Monitoring and Forecasting Centers – MFCs):

- Eight Thematic Assembly Centers (TACs), with six satellite TACs organized by ocean variables (sea level, ocean colour, sea-surface temperature, sea ice, winds and waves), one TAC for *in situ* observations and one multi-observation TAC (that merges through data driven and AI [Artificial Intelligence] techniques *in situ* & satellite data to elaborate high-level products). These production centres gather observation data from *in situ* networks (e.g. the Global Ocean Observing System (GOOS) and the European Global Ocean Observing System (EuroGOOS)) and from the Copernicus satellite component, through the European Space Agency (ESA) and the European organisation for the exploitation of Meteorological Satellite (EUMETSAT). TACs generate validated data sets directly useable for assimilation and validation in models (MFCs) and high-level products (i.e. gridded multi-sensor products, near real time and long-time series) directly useable for downstream applications;

- Seven Monitoring and Forecasting Centers (MFCs), distributed according to the marine area covered, including Global Ocean, Arctic Ocean, Baltic Sea, North Atlantic West Shelf, North Atlantic Iberia-Biscay-Ireland area, Mediterranean Sea and Black Sea). MFCs generate model-based products on the ocean physical, sea-ice and biogeochemical states, including forecasts, analyses and reanalyses. MFCs also generate initial and/or boundary conditions for nested coastal and ocean/atmosphere coupled modelling systems.

The Copernicus Marine Service distributed architecture of Production Centers responds to the double objective of engaging the best experts from where they are while also creating service value as close to the field as possible. In addition to the Production Centres, the Copernicus Marine Service includes the following elements (Figure 1):

- A Dissemination Unit (DU)/Marine Data Store (MDS), which is the central IT element of the system, where all product data are stored, registered and organized. In Copernicus 2 (2021-2027), the MDS includes and extends the functions of Copernicus 1 DU (2015-2021);

- A Marine Information System (MIS), managing all IT data flows;

- A Marine Open Hub (MOH), which is a one-stop-shop to the service information and a Marine User Gateway (MUG) to manage users' interactions with the service both reachable at https://marine.copernicus.eu/. They ensure the service uptake and service delivery functions.

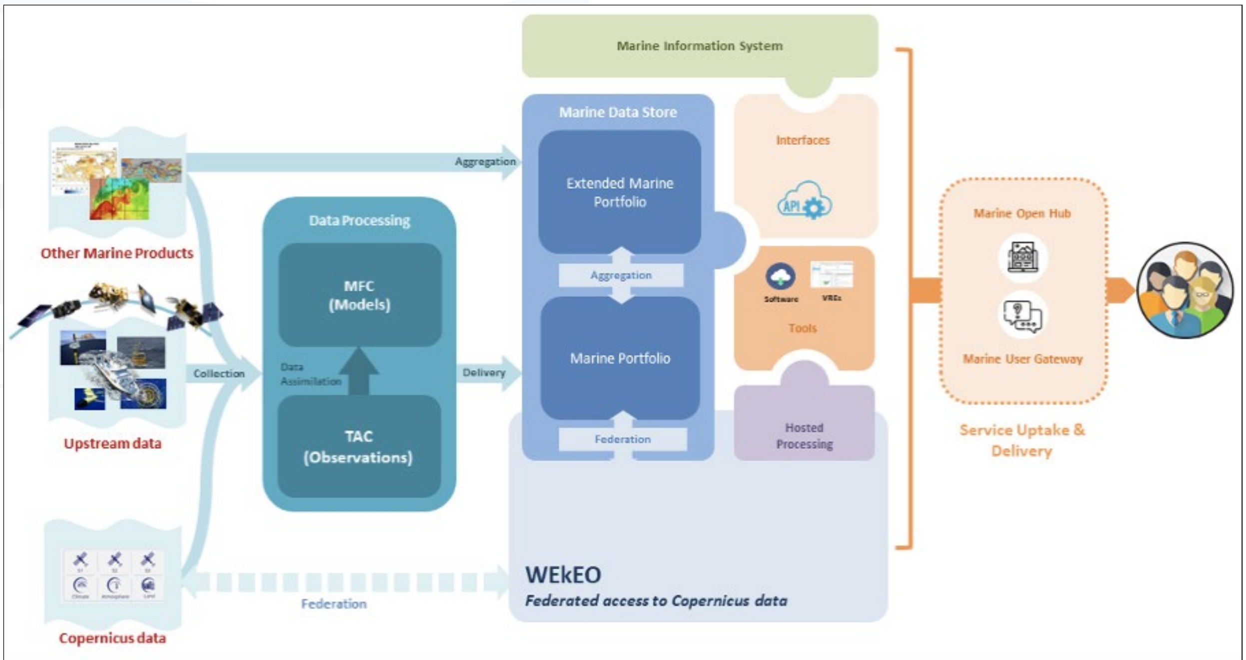

Figure 1. Overview of the main components of the Copernicus Marine Service.

3. STATUS AND RECENT ACHIEVEMENTS

The first operational phase 2015-2021 of the Copernicus Marine Service successfully implemented a unique European Union ocean monitoring and forecasting service. The major advances achieved during the period 2015-2021 are reviewed and detailed in Le Traon *et al.*, (2021). The Copernicus 2 phase of the Copernicus Marine started in July 2021. The first objective was to ensure the continuity of the service with respect to Copernicus 1. This has been successfully achieved. In 2022 and 2023, several important evolutions of the service and its organization have also been implemented:

- A reinforced governance (Member States) has been set up with the Copernicus Marine Forum that gathers representatives of member states to discuss our national collaboration programme, in particular, related to the coastal ocean. Our advisory bodies both for science (STAC) and user (CUAG) have been renewed and set up for Copernicus 2;

- User uptake continues to steadily increase. We now have more than 55, 000 subscribers and our web site has attracted more than 700, 000 different visitors in 2022;

- The new consortia for the production centers have been set up in early 2022. The service relies today on a robust infrastructure of Thematic Assembly Centers (TACs) and Modelling and Forecasting Centers (MFCs) that keep observation and model products at the cutting edge and ensure that they answer to user needs;

- Transfer of UK partner activities to European contractors following Brexit decisions taken by the EC procurement board has been organized and related actions have been implemented;

- Four releases of Copernicus Marine portfolio occurred from the start of Copernicus 2: November 2021, July 2022, November 2022 and March 2023. Observation products (TACs) have focused their efforts in providing improved resolution for coastal applications, increasing the number of *in situ*-observations and providing more biogeochemical *in situ* data in collaboration with EMODnet. Model products (MFCs) accuracy improved thanks to improved model parametrization, resolution, coupling terms, forcings and use of upgraded data assimilation schemes and addition of more observation data. Model portfolio was enriched with new variables (e.g., carbonate and ice variables), multi-year products closer to present and with longer time series. See Tonani *et al.*, (this issue);

- The Sentinel-6 mission has been integrated in the observation and model products with a positive impact on their quality;

- The production of satellite ocean ECVs by the Copernicus Marine satellite TACs for the Copernicus Climate Change Service (C3S) started in February 2023;

- The development and implementation of a completely overhauled Marine Data Store (MDS) system carried out in synergy with the European Digital Twin Ocean (DTO) activities has started. The new MDS will be put in operation from Fall 2023 and will include improved capacities: delivering access to Petabyte-sized datasets, introduction of cloud computing capacities, high availability, scalability and interoperability at lower cost;

- The Copernicus Marine Service product quality dashboard was updated: weekly maintenance and monthly updates were performed to update the contents and to implement new metrics as they became available from the production centres;

- The web catalogue of products was fully revamped for an easier user experience and the viewer interface was updated with more functionalities (see https://marine.copernicus.eu/news/new-release-copernicus-marine-service-catalogue-viewer);

- The Copernicus Ocean State Report has now reached its 8th cycle under refined strategy in response to increasing needs at European and international level for science-based evidence for variations & changes in the Ocean. Ocean State Report 6 was published in 2022, Ocean State Report 7 will be published in 2023 in a new journal (State of the Planet);

- Our post-2024 evolutions are prepared through our Service Evolution R&D programme (Copernicus Marine STAC and Mercator Ocean, 2022). A first call was issued in January 2022 to select projects to carry mid-term (~2-3 years) R&D activities. 14 innovative projects started in July 2022 for 25 months. They cover the following topics: ocean forecasting systems, marine coastal environment, ocean colour derived products, and surface currents and sea level products (see https://marine.copernicus.eu/about/research-development-projects). A second call will be launched end of 2023;

- Long-term scientific and technical evolutions are mainly supported through H2020 and Horizon Europe programmes: IMMERSE (models), ECFAS (links with emergency management service), ACCIBERG (Arctic), NECCTON (biology), FOCCUS (coastal);

- Our User Engagement activities have resumed. A call for tender was issued end of 2022 to develop pilot use cases for marine coastal downscaling monitoring activities. 15 projects have been selected for an 18-month period, aiming to bridge gaps and overcome obstacles for the future seamless integration of Copernicus coastal marine monitoring services from the open ocean to the coast (see https://marine.copernicus.eu/news/2nd-user-engagement-phase-launched) and Silovic *et al.,* (this issue);

- Synergies with the other Copernicus services have been strengthened through the development of thematic hubs. The Copernicus coastal thematic hub was launched in June 2023. The Copernicus Arctic hub launch will take place in Fall 2023;

- On the international level, Copernicus Marine provides a major contribution to the UN Decade of Ocean Science and its programmes. Close links are established with the UN Decade Collaboration Center (DCC) on OceanPrediction.

4. FUTURE PLANS

The objective is to further establish Copernicus Marine Service products as a worldwide reference, continue to foster the Service uptake and respond to increasing and pressing user and policy needs for improved ocean monitoring and prediction capabilities. Our priorities up to the end of Copernicus 2 (2028) will be to ensure the continuity of the service, to progressively embrace the new capabilities of digital services in synergy with the Digital Twin Ocean development (see Drillet *et al.,* this issue) and prepare the implementation of the next generation of ocean monitoring and forecasting systems (improved Arctic monitoring, ensemble forecasting, high resolution) and new services for coastal marine (with Member States) and for marine biology.

The Copernicus Marine will make the best use of future Sentinel missions (C units to be launched between 2024 to 2028) and will prepare the uptake of Sentinel expansion missions, in particular, for an improved monitoring of the polar seas (CIMR, CRISTAL, ROSE-L). Integration of new satellite observations from contributing missions is also planned (e.g., SWOT for swath altimetry, PACE for hyperspectral ocean colour observations). It will follow the evolution of the *in situ* observing system and the improvement in gathering more *in situ* observations from physics to biology.

Continuous evolutions of observation (TACs) and modelling (MFC) products is planned: integration of new satellite missions, improved coupling, improved data assimilation, higher resolution, development of the use of AI for observation and model products. Transition toward ensemble forecasting is prepared as part of a cross-cutting group of Copernicus Marine MFCs. The expectation is that from 2025 to 2028 most, if not all MFCs, will propose ensemble forecasts to their users.

Improved coastal zone (marine) monitoring and forecasting is one of the top priorities for Copernicus Marine in Copernicus 2. The objective is to offer new services for the coastal ocean through a co-design and co-development approach between the EU Copernicus Marine

Service and coastal marine services operated by member states. The coastal extension of the service started in 2023 and will be developed from 2024 to 2028. It will feature:

- New or improved satellite products for the coastal zone (e.g., time evolving bathymetry, waves, winds, sea level, ocean colour…);

- Standardized (freshwater, nutrients, particulate and dissolved matter) modelled river discharges that will be developed in cooperation with the Emergency Management Service;

- More *in situ* coastal observations through improved access to existing data. This will be organized by the Copernicus Marine *in situ* TAC in interaction with EMODnet and JERICO;

- Operational interfaces with coastal monitoring and forecasting systems operated by Member States. This will be organized through our national collaboration programme (see Silovic *et al.*, this issue) in interaction with the Copernicus Marine Forum and related user engagement calls. R&D issues will be addressed through the FOCCUS Horizon European project that will start end of 2023.

Improved offer for marine biology. The objective is to provide a step change in Copernicus Marine capability to inform biodiversity conservation and food resources management:

- Gathering and processing of new biogeochemical/biology *in situ* and satellite observations;

- New processes in biogeochemical models (benthic/pelagic coupling, riverine inputs);

- Advanced data assimilation techniques;

- Ecosystem modelling from low- (plankton), mid- (micronekton) to high- (fish) trophic levels;

- Habitats for key protected species (e.g., marine mammals);

- Assessing scenarios for climate change impacts on stocks and protected species.

These developments are carried out as part of the NECCTON Horizon Europe and depending on progress several elements could be integrated in the Copernicus Marine portfolio from 2025 to 2028.

In addition to the development of climate projection for main exploited fishes and protected species carried out as part of NECCTON, climate projection (physics and biogeochemistry) at regional/coastal scale will also be developed through Horizon Europe and other research projects. These marine climate projection products will build on and complement/extend (biogeochemistry incl. high trophic levels; coastal/regional downscaling) C3S climate projection products.

5. LINKS WITH EUROGOOS

The cooperation with EuroGOOS and its members is essential for the Copernicus Marine success and long-term sustainability. Areas of collaboration exist all along the operational oceanography value chain. MOi and EuroGOOS have signed a Memorandum of Understanding (MoU) to formalize this cooperation and to foster co-operation on ocean observations, ocean forecasting, digital twin ocean and the development and sustainability of downstream services and applications.

The coastal extension of the Copernicus Marine service (see above) is an area where the collaboration with EuroGOOS and its members will be key. Many interactions need to be established between research activities, operational interfaces with national coastal forecasting services and development of downstream applications.

The development of a fit for purpose sustainable *in situ* observing system, extending from global to regional and coastal scales is another area where links with EuroGOOS and its ROOSes together with European research infrastructures are essential and need to be re-enforced. A joint effort is required to ensure the development of the ocean observing system and the related data assembly activities together with the Copernicus Marine *in situ* Thematic Assembly Center and EMODnet. European activities need to be consolidated and developed in the framework of the European Ocean Observing System (EOOS) together with Member States and the European Commission.

6. CONCLUSION

Copernicus Marine in Copernicus 2 is now fully launched with an ambitious plan aligned with the EU Green Deal and Digital strategies. Continuity of service with incremental evolutions is the main priority but the Copernicus Marine must keep evolving to remain state of the art, answer to the increased ocean monitoring and prediction needs and remain a competitive Copernicus service. There is a clear phased implementation driven by user and policy needs, observation, science & technology advances and taking into account budget constraints: embracing new capabilities of digital services in synergy with the Digital Twin Ocean developments, implementing the next generation of ocean and sea ice monitoring and forecasting systems and the new service lines for coastal and marine biology. This ambitious plan relies on the unique expertise of the European operational oceanography community and interaction with EuroGOOS. International cooperation in the framework of the UN Decade of Ocean Science and its programmes is also essential.

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Forecast uncertainty and ensemble spread in surface currents from a regional ocean model

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Keywords

Surface currents, regional ocean forecasting, ensemble prediction systems, forecast uncertainty, high-frequency radar

Abstract

An operational ocean Ensemble Prediction System (EPS) designed for the coastal seas off Northern Norway is compared with high-frequency radar estimates of current speed. Comprising 24 members, the EPS does not perturb nor constrain ocean currents but relies on atmospheric ensemble forcing. The spread in the ocean ensemble arises from variations in wind-forcing history and constraints imposed by data assimilation on sea surface temperature. The primary objective of the ensemble is to capture the true uncertainty in initial conditions, particularly in mesoscale circulation, which remains largely unknown. The findings indicate a noticeable yet limited predictive skill in surface currents, coupled with robust statistical performance. Furthermore, the validation metrics illustrate a degradation in current speed predictions over the forecast range. Notably, the use of high-resolution wind forcing appears to enhance forecast accuracy in currents compared to lower-resolution forcing. Overall, the ensemble demonstrates the capacity to predict forecast uncertainty.

1. INTRODUCTION

We address the challenge of forecasting surface currents, a crucial ocean variable for applications in marine ecosystems, offshore industries, and shipping. Particularly important in coastal seas, accurate predictions are vital for risk assessments, ecosystem models, and emergency response. This study employs an Ensemble Prediction System (EPS) with a regional ocean model to quantify uncertainty in surface current predictions, by examining its performance against high-frequency (HF) radar data.

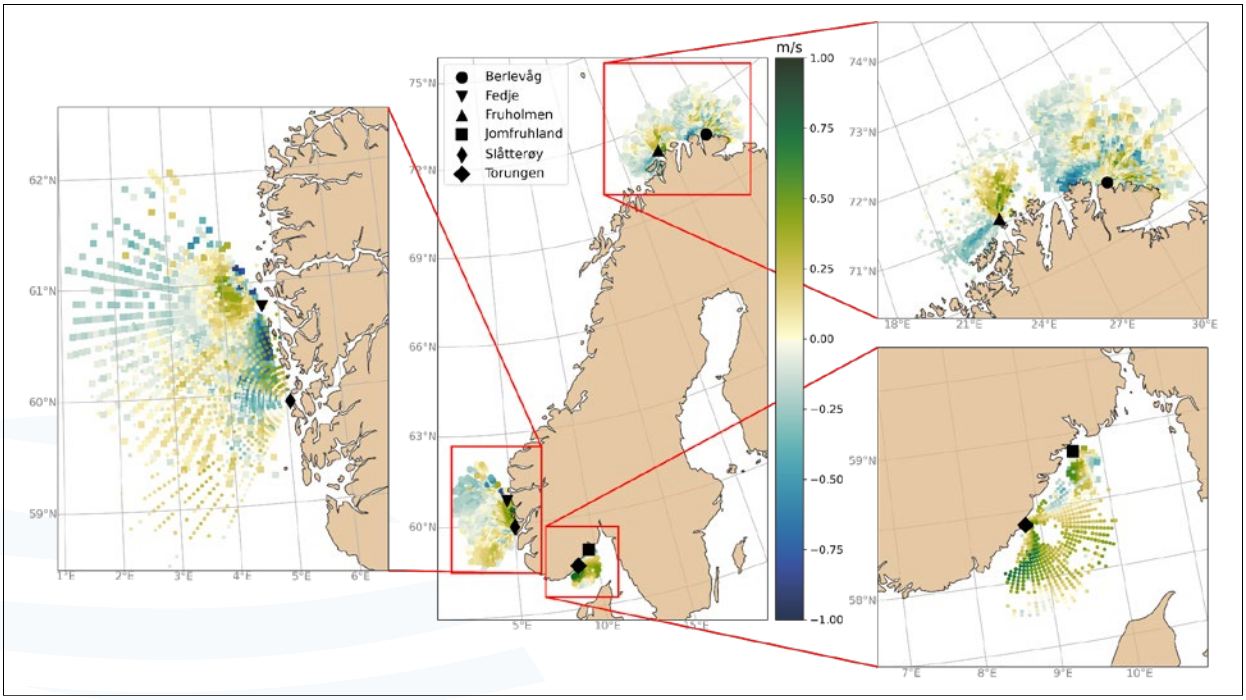

Figure 1. Observation network of HF radars along the Norwegian coast with six operational HF radar stations. We used data from the Fruholmen HF radar in this study. HF radar data is available at https://thredds.met.no/thredds/catalog/remotesensinghfradar/catalog.html.

2. DATA AND METHODS

Surface current predictions from Barents-2.5 EPS (Röhrs *et al.*, 2023) are compared to HF radar data from the CODAR SeaSonde instrument, operating on the Fruholmen island. The radar system, as part of the Norwegian operational system of HF radars along the coast (Fig. 1), offers exceptional spatial and temporal resolution of surface currents. We validate the radial component of surface currents from the regional model against HF radar observations considering three distinct time spans: 0-24h (+24h), 24-48h (+48h), and 48-66h (+66h).

We assess (i) the skill in surface current forecasting by looking into the ensemble's statistics as a function of forecast lead time as well as (ii) the ensemble spread. To look into the ensemble spread, we built reliability diagrams by defining four events: absolute radial current components excess speeds of 0.1, 0.2, 0.3, 0.4 m/s. Forecast probabilities are split into discrete classes, i.e. bins ranging from zero to one. For each probability class, the observed frequency is plotted against the corresponding forecast probability. For a perfectly reliable forecasting system, the points would lie on a diagonal.

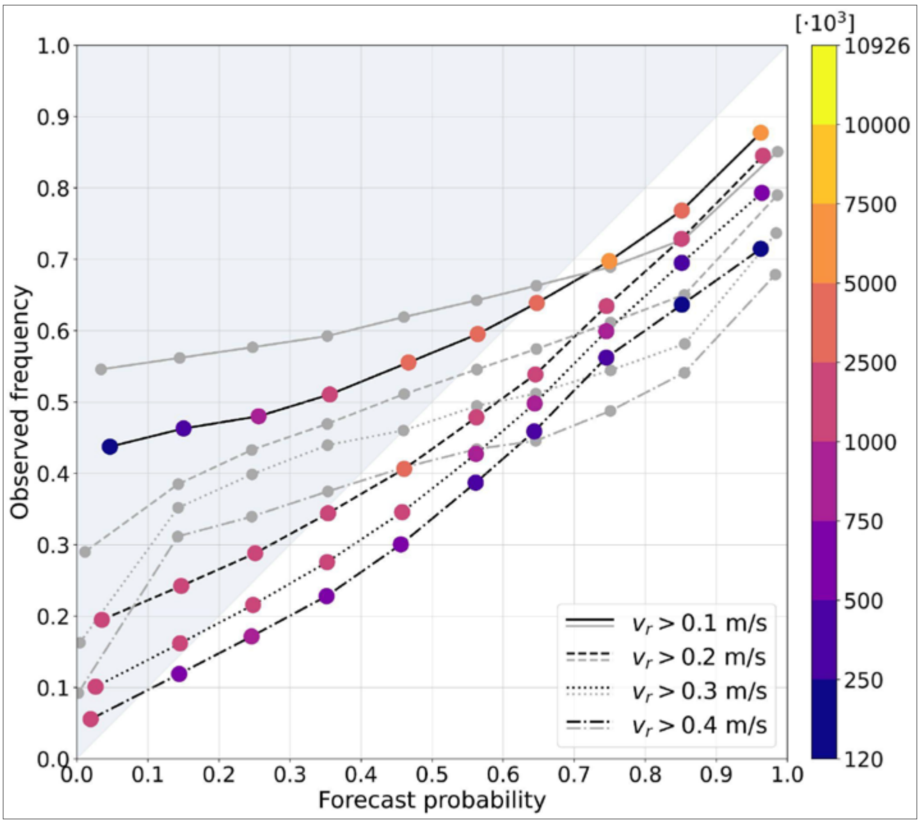

Figure 2. Reliability diagrams for time span +24h for all observation points combined within the period 2021-11-15–2021-12-31. Solid, dashed, dotted, and dash-dotted lines of reliability diagrams show forecast reliability for the observed absolute radial current component for thresholds above 0.1 m/s, 0.2 m/s, 0.3 m/s, and 0.4 m/s, respectively. The horizontal axis is the forecast probability between 0 and 1 from the EPS, and the vertical axis indicates the corresponding observed frequency of occurrence. The different colours indicate the number of observations that exceeded the given threshold for a given forecast probability. For black lines, a normal distributed random error with a standard deviation based on the total observation error was added to all ensemble members (see Sec. 2.1 in Idžanović *et al.*, (2023) for more details).

3. DISCUSSION AND RESULTS

3.1. Surface current forecast skill

We show that the Barents-2.5 EPS exhibits statistical skill in reproducing radial components of surface currents. The spatial correlation between observed and modelled surface current speeds decreases slightly with increasing lead time, but all ensemble members maintain a mean spatial correlation of around 0.5. Metrics such as root-mean-square error and mean absolute error increase almost linearly with time (see Fig. 3 in Idžanović *et al.*, (2023)), indicating a growing discrepancy between model predictions and HF radar observations as lead time extends. The mean bias is approximately 2.6 cm/s for all lead times over all model ensemble members.

3.2. Influence of wind forcing

High-resolution wind forcing (AROME-Arctic) enhances forecast skill compared to ensemble members driven by lower resolution atmospheric fields (IFS). This suggests that high-resolution wind forcing contributes to better accuracy in surface current predictions, especially for situations of strong surface currents constrained by bathymetry, coastline, and winds.

3.3. **Prediction of uncertainty**

The model tends to underestimate low probabilities and overestimate high probabilities (Fig. 2). The study emphasises a lack of ensemble spread, particularly in extreme events, as seen in reliability diagrams and rank histograms (see Fig. 4c in Idžanović *et al.*, (2023)).

4. CONCLUSIONS ON REGIONAL OCEAN MODELLING

This study is motivated by the need for accurate current predictions, especially in coastal regions where pollutants can cause significant damage. We discuss the limitations of ocean general circulation models in predicting mesoscale current fields due to intrinsic chaotic variability. The need for ensemble forecasting to assess model uncertainty and identify predictable features is emphasised. The findings indicate that while the Barents-2.5 EPS demonstrates statistical skill in reproducing surface current magnitudes, its predictive skill is limited. The insufficient ensemble spread raises concerns about the model's ability to capture extreme events; emphasising the importance of initial conditions, lateral constraints, and atmospheric forcing for regional ocean modelling. We see potential in enhancing regional-scale surface current predictions with HF radar and satellite altimetry data, but the assimilation of surface currents into models presents significant challenges. The study contributes to ongoing efforts to enhance the accuracy of surface current forecasts, crucial for various practical applications in oceanography and maritime operations. For more detailed information, see Idžanović *et al.*, (2023).

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Forecasting the sea level in the Mediterranean Sea using the data assimilation of coastal tide gauge data

Authors

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Keywords

Data assimilation, ocean modelling, tides, surge, seiches

Abstract

Tides, surges and seiches, often in conjunction, are responsible for flooding events in the Mediterranean. These events have a time scale that requires a short-term forecast (up to 5-10 days), which is linked to the weather forecast. To do it, we used a finite element hydrodynamic model and the data assimilation of sea level from coastal stations. The assimilation of coastal data significantly improves the storm surge forecast, especially when pre-existing seiche oscillations are present. Moreover, computing only the astronomical part, the assimilation of tidal data, strongly improves the tidal reproduction, even in areas far from the assimilated stations, such as the south-eastern basin of the Mediterranean Sea. Adding the forecast storm surge to the computed tide, we obtain a total sea level to force three coastal areas in the Adriatic Sea. These areas are the Venice Lagoon, the Marano Lagoon, and the Po Delta. In the case of Venice, this system allows a local forecast of the sea level in the Venice centre, which can be used to alert the population and/or to manage the flood barriers in case of strong storm surge events.

1. INTRODUCTION

The Mediterranean Sea is subject to frequent storm surge events, especially in Autumn. The stronger are in the Adriatic Sea, due to the shallowness of the northern part and to the direction of the winds that are prevalent in this season, the Scirocco (south-east). The city of Venice, located in the northern Adriatic Sea, is subject to frequent floodings, due to these factors and to the sea level rise of the last decades, which increases the mean sea level of the tidal signal.

A further factor affecting the sea level extremes in this area are the seiche oscillations, which can be very energetic (Cerovecki *et al.*, 1997). When these oscillations happen in conjunction with a new storm surge and with a spring tide the total sea level can reach remarkably high extremes (Bajo *et al.*, 2019).

In the rest of the Mediterranean Sea, the sea level reaches smaller extremes (Schwab & Rao, 1983), but these components are still present, and their correct reproduction is necessary to obtain a good forecast. In this extended abstract we present an operational system for the sea level forecast in the Mediterranean Sea, with a focus on the Italian coasts, which uses a data assimilation (DA) procedure based on the Ensemble Kalman Filter - EnKF (Evensen, 1994, 2003). All the available data from the Italian Institute for Environmental Protection and Research (ISPRA) tide gauge stations (https://www.mareografico.it/) are assimilated after passing a quality check. The operational system runs also three more simulations in coastal basins, located in the Adriatic Sea. The methodology followed in the creation of such an operational system is based on a more general work on the sea level reproduction in the Mediterranean Sea that we recently published (Bajo *et al.*, 2023).

The following section will provide the methods, then the results and conclusions.

2 METHODS

2.1. Model description and set-up

In this work we used a finite element hydrodynamic model named System of HydrodYnamic Finite Element Modules – SHYFEM (Umgiesser & Bergamasco, 1993). The model is open source (https://github.com/SHYFEM-model/shyfem) and was used in the past in several coastal and open ocean applications. In this work, we use a simple and fast formulation, two-dimensional and barotropic, with surface wind and mean sea level pressure as forcing. The wind stress is prescribed with a Charnock-like formulation (Hersbach, 2011), while the bottom stress has a hybrid linear-quadratic formulation (Bajo *et al.*, 2019). The lateral boundary conditions are closed everywhere except in the Atlantic Ocean where they are open, with the sea level prescribed.

The atmospheric forcing is provided by the BOLAM meteorological model, running at ISPRA, with a resolution of 8km and a temporal step of one hour (Mariani *et al.*, 2015). The sea level boundary conditions are provided by the Copernicus de-tided sea level from the Mediterranean Sea Physical Analysis and Forecast system (Clementi *et al.*, 2021) in the case of the storm surge simulation, while the tidal level from the FES2014 (Lyard *et al.*, 2021) has been used in the tide simulations.

The first storm surge operational run of the model is over a Mediterranean computational grid of about 163,000 triangular elements with a maximum resolution of about 500m (Figure 1). The same grid is used for the run with the astronomical tide. The runs of the model in the three coastal areas are nested, using as boundary conditions a total sea level field computed by adding the astronomical tide to the storm surge component and adjusting the mean sea level to the current value in Punta della Salute (a station in the Venice centre). The three nested simulations used three different grids for the Marano-Grado lagoon, for the Venice lagoon and for the Po Delta (Figure 2).

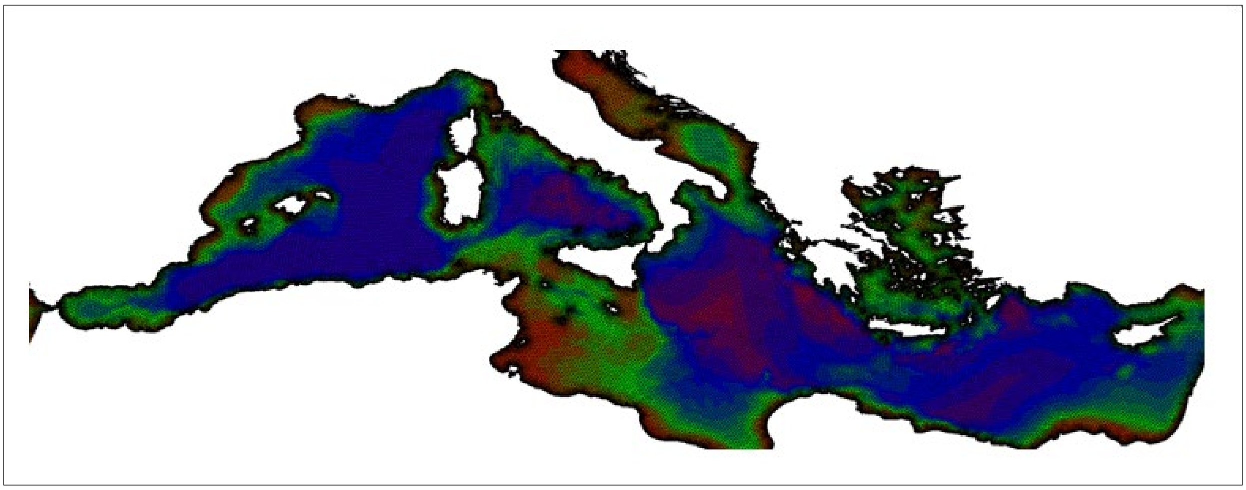

Figure 1. Computational grid of the Mediterranean Sea

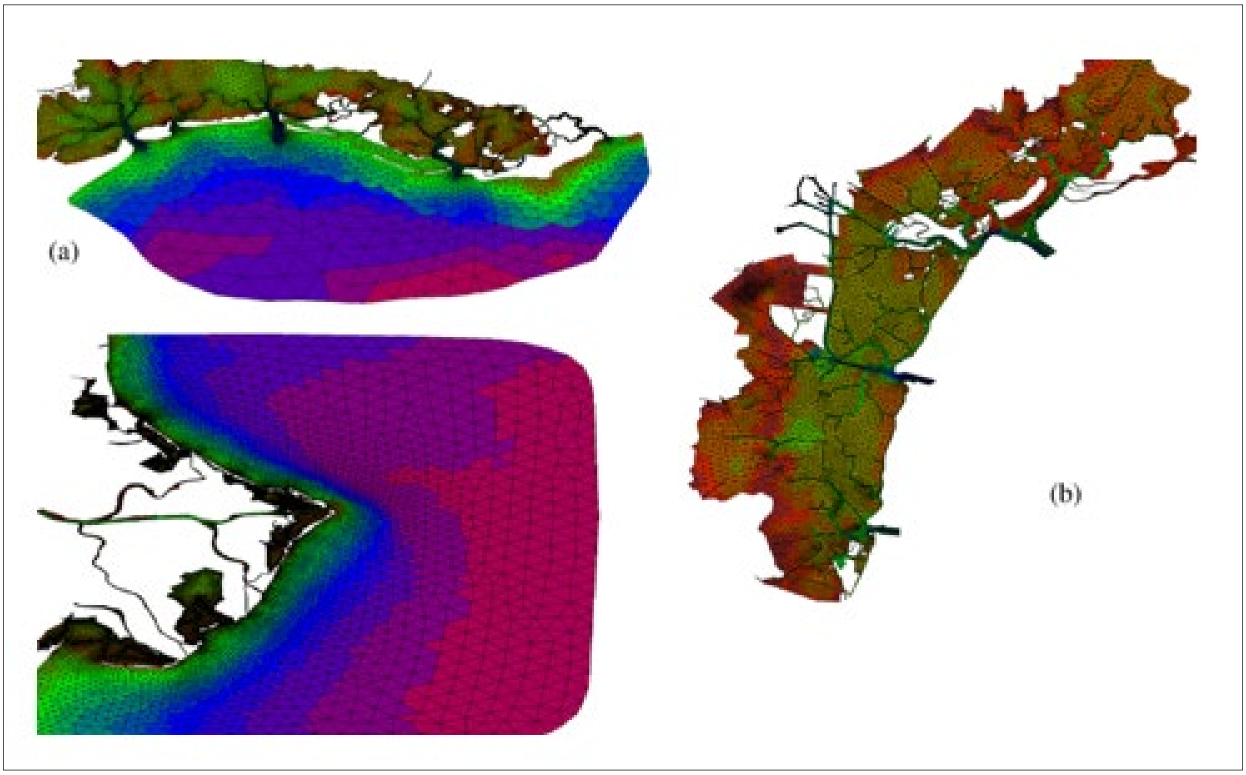

Figure 2. The three coastal grids used in the simulations. The Marano-Grado lagoon (a), the Venice lagoon (b) and the Po Delta (c).

2.2. The data assimilation system and set-up

The DA system used in this work is based on the Ensemble Kalman Filter, with a code adapted from the Geir Evensen's code (https://github.com/geirev/EnKF_analysis) and developed to work with the SHYFEM model. The code allows to choose between different analysis methods, the use of adaptative inflation scheme, the local analysis, and other parameters. For a detailed description of the method and of its calibration we refer to the published paper (Bajo *et al.*, 2023). The final configuration uses eighty-one ensemble members, without localisation. The system has an adaptative inflation with a penalty system for the large departures. The analysis solution is relaxed to the deterministic one approaching the lateral open boundary conditions.

Both the lateral boundary conditions and the surface conditions, which are the wind and the pressure fields, are perturbed with a pseudo-gaussian method (Evensen, 2004). The perturbations are maintained along the whole assimilation window. Then, the system computes the ensemble analysis mean and starts a forecast simulation from this state. This procedure is followed by the surge simulations, while the tide simulations have not the forecast. In this case, harmonic analyses are computed in the assimilated stations to produce timeseries of astronomical tide. Then, these timeseries are used as observations to be assimilated. This method allows to correct the spatial fields of astronomical tide using the information from the harmonic analysis.

The reanalysis fields of tide are summed to the surge forecast fields to be used as lateral forcing in the coastal simulations.

3. RESULTS

In this section we analyse the results of the operational system in a period from the 1st of June 2023 to the 1st of October 2023, excluding some short periods where the system did not work for some technical problems. The system runs both in a deterministic way, without and with DA. In this case the forecast starts from an initial state given by the analysis ensemble mean. In Table I we show the correlation and the RMSE of the modelled data with respect to the observations in two stations, Venice and Ancona.

Table I. Correlation and RMSE in two stations, Venice, and Ancona, for the results without DA (d) and with DA (a). The first, second and third-day forecasts are reported.

1st Day forecast				
Station	**$Corr_d$**	**$Corr_a$**	**$RMSE_d$ [cm]**	**$RMSE_a$ [cm]**
Venice	0.984	0.998	4.65	1.58
Ancona	0.978	0.984	3.10	2.64
2nd Day forecast				
Station	**$Corr_d$**	**$Corr_a$**	**$RMSE_d$ [cm]**	**$RMSE_a$ [cm]**
Venice	0.979	0.986	5.40	4.43
Ancona	0.964	0.965	3.93	3.92
3nd Day forecast				
Station	**$Corr_d$**	**$Corr_a$**	**$RMSE_d$ [cm]**	**$RMSE_a$ [cm]**
Venice	0.971	0.970	6.41	6.96
Ancona	0.937	0.934	5.26	5.57

The results show a substantial improvement of the DA the first day of forecast. Although in this period, which are the first months in which the system is operating, there was no intense storm surge event, as is normal in Summer, the improvement is still good. We expect from previous works (Bajo *et al.*, 2019, 2023), that the impact of DA will be higher in case of strong storms and with pre-existing seiche oscillations. The only minor event in this period is shown in Figure 3, when a weak perturbation caused a small storm surge in the northern Adriatic on August 28. The figure shows the forecast with and without DA, one, two and three days before. In the third day forecast the effect of DA is small, sometimes improving sometimes worsening but of tiny amounts. The DA improvement is more evident the second day forecast both in the reproduction of the main peak and of the minor peaks. The first day forecast the DA provides a very good forecast, as seen also by the statistics in Table I, but also the normal forecast is quite good, as the event was not very strong and the errors of the wind forcing was probably low.

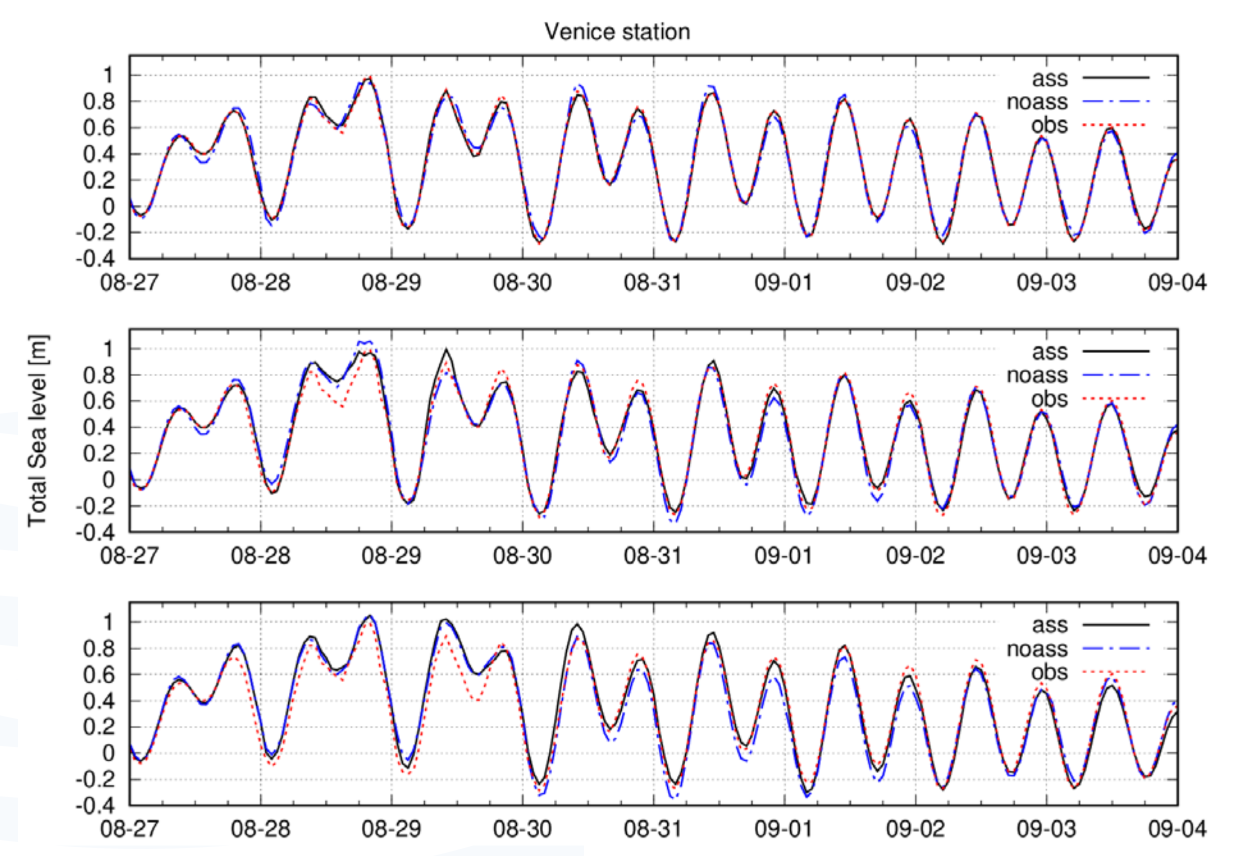

Figure 3. Forecast of the total sea level in Venice (outside the lagoon). The First (first panel), second (second panel) and third day (third panel) forecast with (ass) and without (noass) DA are shown.

4. DISCUSSION AND CONCLUSIONS

In this extended abstract we presented a new operational system for the storm surge forecasting along all the Italian coasts. The system is running at ISPRA and uses an EnKF to assimilate the sea level from coastal stations. The system also runs a reanalysis of the astronomical tide over the Mediterranean Sea. These two products are used to force three simulations of coastal areas (the Marano-Grado lagoon, the Venice lagoon, and the Po Delta). Here we have shown some preliminary results, obtained in the first months of the total sea level forecast in the Mediterranean Sea. As expected, the effect of DA is positive and stronger in the first days of forecast.

Future works on this operational system will consist in adding other sea-level stations to the DA, from regions outside Italy, and the possible use of parameter estimation techniques. Other improvement not related to the DA are the possible use of different wind forcings and the coupling with waves.

ACKNOWLEDGEMENTS

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Developing coupled wave-ocean model to improve Baltic Sea forecasts

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Keywords

WAM, NEMO, coupling, Baltic Sea

Abstract

The Baltic Monitoring and Forecasting Centre (BAL MFC) of the Copernicus Marine Service has in recent years improved the 3D ocean and wave forecasting systems by introducing coupling between the models. At present the BAL MFC wave forecasting system utilises pre-calculated surface current, sea surface height and ice concentration fields from the BAL MFC 3D ocean forecasting system NEMO. The most significant impact of coupling on the wave forecast accuracy was seen by the varying ice conditions during the forecast if they are sufficiently well represented by NEMO. Surface currents and SSH variation only occasionally influence the wave conditions and the effects are mostly limited to coastal areas. However, the validation carried out showed that in case of strong coastal currents or high sea level events, the coupling between wave and ocean models positively affected the quality of wave forecast in the Baltic Sea. Currently only surface Stokes drift calculated by WAM is considered in the BAL MFC NEMO model. This was found to have relatively small effects on the results. To enhance the coupling, the effects of water-side-stress modified by the wave field are currently being studied. The preliminary results show changes in the surface currents, SSH and surface mixed layer depth. While it is not clear in all cases, whether the change is for the better, since observations for verification are lacking, the results are promising. However, further research is needed to gain a comprehensive understanding of the impacts introduced by coupling. Additionally, adjustments to model parameterizations, particularly concerning surface layer mixing, may be required.

1. INTRODUCTION

The Baltic Monitoring and Forecasting Centre (BAL MFC) under the Copernicus Marine Service is providing forecasts, hindcasts and reanalysis for physics, waves, ice and biogeochemistry for the Baltic Sea. The work is done by a consortium of five institutes, namely DMI (Coordinator, Denmark), BSH (Germany), FMI (Finland), Taltech (Estonia) and SMHI (Sweden). Behind the products there are state-of-the-art models Nucleus for European Modelling of the Ocean (NEMO), Ecological Regional Ocean Model (ERGOM), the Wave Model (WAM), with dedicated setups to account for the specific features of the Baltic Sea (e.g., Tuomi *et al.*, 2014, Tuomi *et al.*, 2019, Kärnä *et al.*, 2021, Lorkowski *et al.*, 2021).

The BAL MFC model systems are continuously being developed and one of the recent tasks has been to advance the coupling between the models. As a first step the surface currents were introduced for the wave model to account for the current refraction-related changes in the propagation direction of the waves and other current-induced changes in the wave field. Although, the overall effect of surface currents on the modelled wave fields was found small in the Baltic Sea, in certain conditions, it was shown to improve accuracy especially in the coastal areas and in cases with two-peaked spectra (Kanarik *et al.*, 2021). Inducing ice concentration from the 3D ocean-ice model has been shown to have larger effects on the wave field in the Baltic Sea, especially in conditions, where there are large changes in the ice field during the forecast run. However, the quality of the ice forecast may not always be sufficient to provide good enough data for the wave forecasts (Tuomi *et al.*, 2019). Coupling from waves to ocean has been advanced by introducing surface Stokes drift calculated by WAM to NEMO. The impact on results was negligible, although some small improvements were seen in the forecasts of extreme sea levels (Nord *et al.*, 2021).

In this paper we will describe the latest advancements in the coupling of the wave and ocean-ice forecast systems. Section 2 give short introduction to the model systems and Section 3 will demonstrate the effects of the latest coupling activities on the accuracy of the model results.

2. MODELLING SYSTEMS

The BAL MFC wave forecast system (BALTICSEA_ANALYSISFORECAST_WAV_003_010, EU Copernicus Marine Service Product, 2022a) is based on wave model WAM cycle 4.6.2 (Komen *et al.*, 1994), with some modifications and additions to account for specific features of the Baltic Sea (Tuomi *et al.*, 2011 and 2014). The BAL MFC 3D ocean forecasting system (BALTICSEA_ANALYSISFORECAST_ PHY_003_006, EU Copernicus Marine Service Product, 2022b) is based on the open-source ocean circulation model NEMO 4.0. The setup has been tuned and tested within the BAL MFC consortium to fit the needs of the Baltic Sea region.

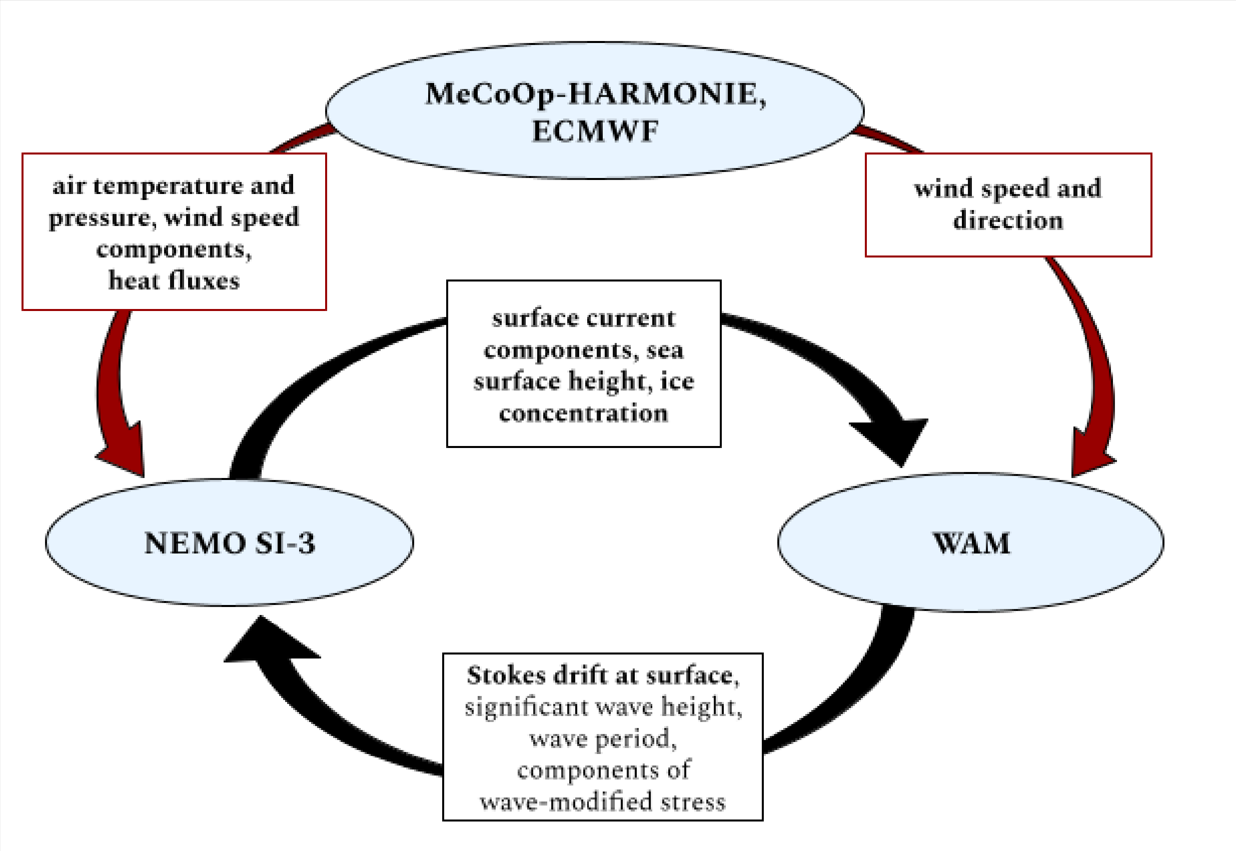

Figure 1. Schematic figure of parameter exchange between the models.

Both systems are run with 1 nmi resolution and using same bathymetry and atmospheric forcing. Presently the coupling between the models is done by exchanging files. WAM uses forcing from NEMO including the following parameters: ice concentration, surface current and sea surface height (SSH). NEMO utilises surface Stokes drift calculated by WAM. The coupling scheme between the models is described in Fig. 1. Further details of the modelling systems can be found in the Product User Manuals (Lindenthal *et al.*, 2022, Tuomi and Kanarik 2022) and Quality information documents (Jandt-Scheelke *et al.*, 2022, Kanarik and Tuomi 2022).

3. WAM-NEMO COUPLING

In the previous update of the BAL MFC WAM system in December 2021, SSH from NEMO was introduced as new forcing. To estimate the effect of variable SSH on the WAM results we run period of 1 Jan 2020 - 31 Dec 2021 with (WAM_SSH) and without (WAM_REF) SSH forcing. SSH data was provided with 15 min temporal resolution and introduced as a change to the water depth used by the wave model. Similar to our earlier findings about wave-current interaction in the Baltic Sea, the changes induced by SSH to the wave field were negligible for most of the time. Differences between WAM_SSH and WAM_REF were seen mostly in the coastal areas, where the shallower water depths attenuate wave energy through bottom friction and depth-induce wave breaking. The high sea level events induced larger changes to the SWH than the low sea level events (Fig. 2). This is in accordance with the fact that water level maxima are typically larger than minima in the Baltic Sea.

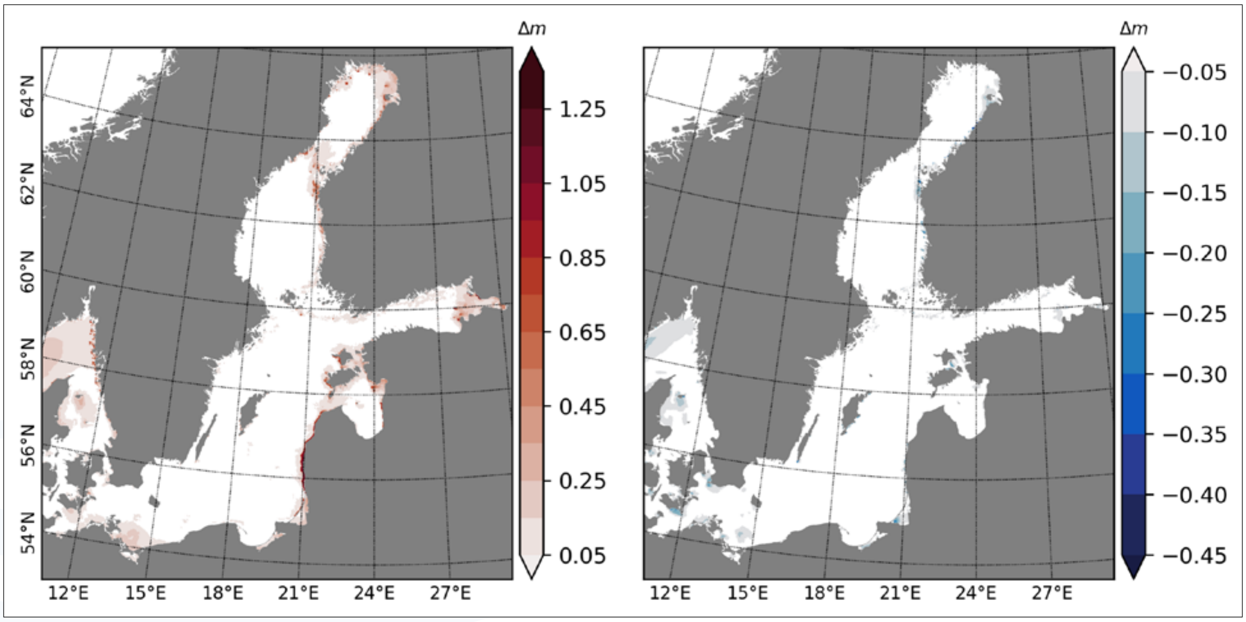

Figure 2. Largest changes in the SWH induced by the SSH (WAM_SSH-WAM_REF). Left panel shows the largest increase of SWH and right panel the largest decrease of SWH caused by changing SSH.

The largest differences in SWH between WAM_SSH and WAM_REF were seen on the eastern coast of the Baltic proper and at the northern and eastern extremities of the Gulf of Bothnia and Gulf Finland, respectively. For example, in the Bothnian Bay the high sea level events caused changes larger than 10 cm to the SWH c. 3 % of time (c. 490 h) within the two years period (Fig 3). The low sea level events had less affect and over 10 cm differences were seen at maximum 36 hours in 2 years in the Bothnian Bay.

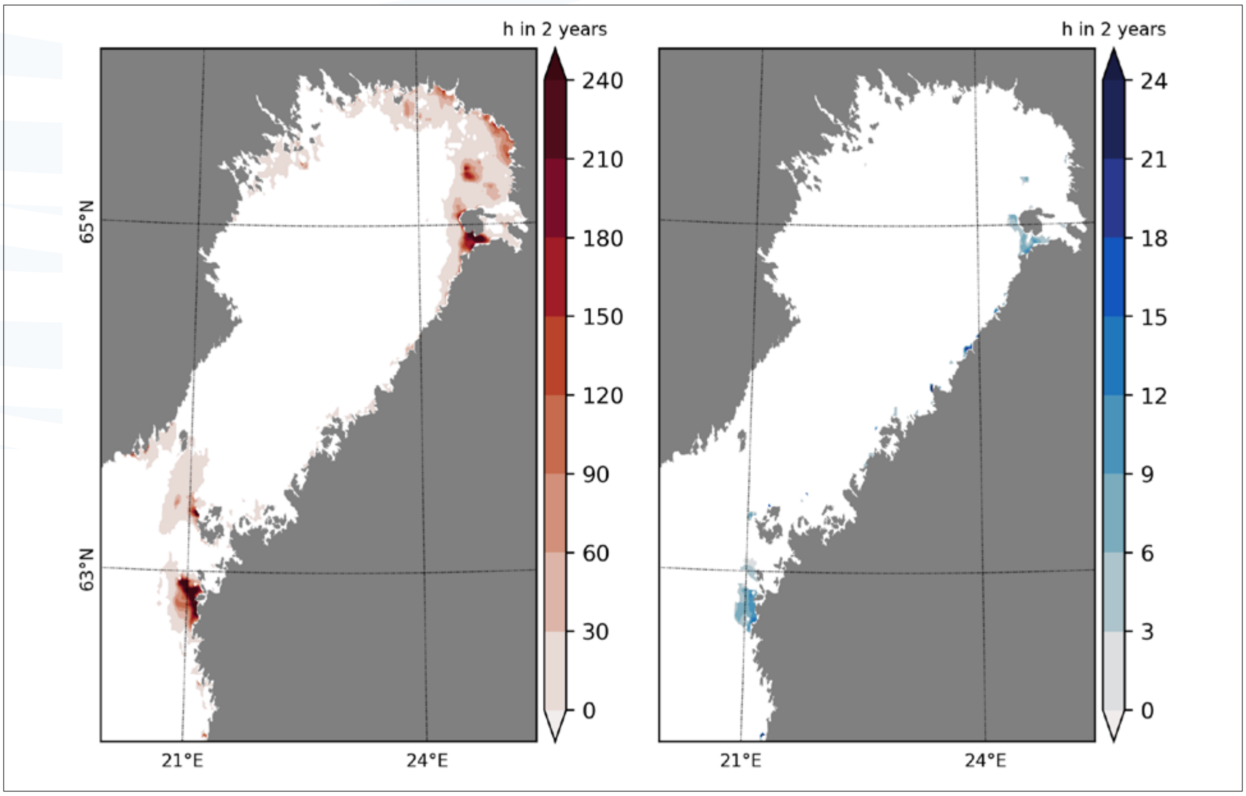

Figure 3. Frequency of differences of over 10 cm of SWH caused by changes in sea level. Colour scale shows the number of hours when run accounting for sea level variability (WAM_SSH) predicted SWH to be over 10 cm higher than the reference run (WAM_REF, left) and the times when it predicted lower SWH (right) during the two-year period (2020-2021).

The present NEMO forecast system uses surface Stokes drift from WAM which is transferred to 3D Stokes drift using parameterisation by Breivik *et al.*, (2015). As Stokes drift was found to have relatively small effects on the model results (Nord *et al.*, 2021) we are now testing how wave modified stress affects the NEMO model results. We run tests with hourly forcing fields from WAM (NEMO_WSTR) for the period of 1 Apr – 31 Dec 2021, using hourly fields of wave modifiedt stress. This was shown to have significantly larger effect on the NEMO results compared to Stokes drift. NEMO_WSTR resulted in an increase of mean surface current speeds throughout the model region and to changes in vertical stratification and mixing, e.g., increase in thermocline depth. Similar to earlier results gained using Stoke's drift, including wave-induced stress impacted the SSH values, especially in case of high sea levels. In some cases, SSH improved compared to measurements, but there were also cases in which the accuracy decreased (Fig. 4). The preliminary results show that some further work is needed to better tune for example mixing parameterisations.

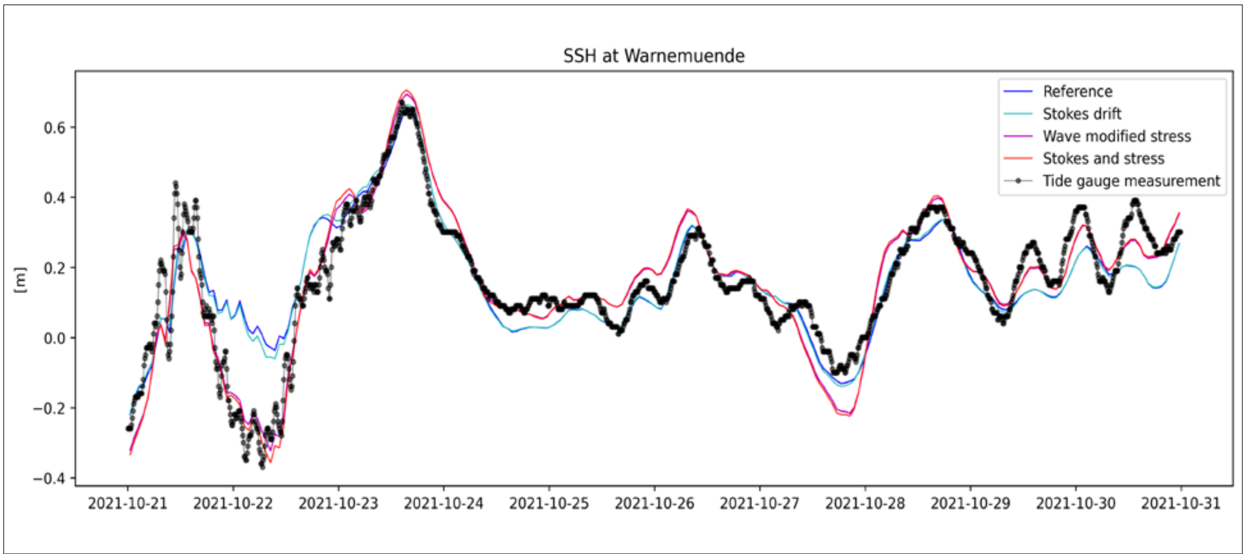

Figure 4. SSH differences between NEMO reference run (no coupling) and runs using data from WAM model (Stokes drift, wave modified stress and their combination) at tide gauge station Warnemünde located in the southern part of the Baltic Sea.

4. SUMMARY AND FUTURE WORK

The BAL MFC consortium is working towards a fully coupled wave-ice-ocean modelling system. The results and experiences gained from the offline coupling of the WAM and NEMO models have been promising. In the current products quality of the wave forecasts has improved in the coastal areas by including the changes induced by varying current and SSH fields and small positive impacts have been seen in NEMO SSH forecast when Stokes drift was added as forcing. Further work is needed to fully account for the wave effects in NEMO.

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Oral Presentations – Session E

Strategic developments in ocean observing – 2

ITINERIS - Italian Integrated Environmental Research Infrastructures System: Marine Domain

Authors

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Keywords

Research Infrastructures, ocean observation, Italian Integrated Ocean Observing System (IOOS), Essential Ocean Variables (EOVs), Data access

Abstract

English abstract with a maximum of 200 words in Times New Roman 10 pt and single spacing.

The ITINERIS Project is creating the Italian Hub for Research Infrastructures for environmental sciences, covering the atmosphere, marine domain, terrestrial biosphere, and geosphere. Its primary objective is to promote interdisciplinary research in environmental sciences by

utilizing and sharing existing and new data and services, to address vital scientific and societal issues such as sustainable resource usage, Nature-Based Solutions, Green and Blue Economy, pollution reduction, and climate change mitigation.

Within ITINERIS, the Marine Domain plays a pivotal role, integrating all marine-relevant RIs with the aim of guaranteeing access to Italian facilities, services, and marine data and ensuring long-term monitoring of Essential Ocean Variables (EOVs), Essential Biodiversity Variables (EBVs), and Essential Climate Variables (ECVs). This will allow the establishment of a Italian Integrated Ocean Observing System (IOOS) able to contribute to European and International efforts on ocean observations (EOOS and GOOS), responding to the major challenge of the UN Ocean Decade of Science for Sustainable Development.

Three additional objectives will complete the IOOS implementation effort: 1) filling the gaps in biological and ecosystem observations, 2) expanding the capability for near-real-time ship-based ocean observations, and 3) developing pilot services to address cross-cutting ocean issues.

1. INTRODUCTION

Most critical issues currently faced by human societies concern key environmental challenges. The effects of pollution, land use, and climate change, and the related impacts on biodiversity and ecosystem integrity need to be urgently addressed, providing quantitative knowledge that should be transformed into actionable management and restoration strategies. Given the multiplicity of space and time scales involved and the complexity and interlinkages between the different challenges, a multi-disciplinary approach at the full Earth System level is paramount.

Environmental research as a whole thus needs comprehensive observations adopting an integrated approach, field, and laboratory analyses and experiments, cross-disciplinary statistical data analysis and modeling tools which altogether provide the information needed for characterizing and predicting the Earth's environmental system.

In the last 20 years, the European Commission, together with Member States and the scientific community has established the Research Infrastructures Programme addressing facilities, and resources sharing, and services implementation for the stakeholders. From the development of marine RIs, it s expected that they become an essential component of the European contribution to the Global Ocean Observing System (GOOS) by ensuring the long-term provision of robust quality control of scientific data. However, since each marine RI has its own priorities and development strategy, there is the need to harmonize and ensure the long-term sustainability of ocean observation.

Italy participates in all main environmental RIs of pan-European interest and hosts other environmentally relevant national RIs. At the strategic level, Italy aims to empower its national infrastructure nodes and integrate them into a system of systems, as envisaged in the National Plan for Research Infrastructures 2021-2027.

The ITINERIS Project is building the Italian Hub of RIs in the environmental scientific domains (atmosphere, marine domain, terrestrial biosphere, and geosphere) providing access to data and services. The main goal is to develop cross-disciplinary research in environmental sciences through the use and re-use of existing (or pre-operational) data and services and new observations, to address scientifically and societally relevant issues such as sustainable use of natural resources, implementation of Nature-Based Solutions, Green and Blue Economy, pollution reduction, critical zone, ecosystem management and restoration, carbon cycle, mitigation of the downstream effects of climate and environmental changes.

The ITINERIS Marine Domain, a crucial component of the system, will start the integration of all marine-relevant RIs' data and services with the aim to guarantee and facilitate the access to Italian facilities, services, and to ensure long-term monitoring of Essential Ocean Variables, Essential Biodiversity Variables and Essential Climate Variables. The final goal of this integration effort is the establishment of the IOOS, to coordinate and harmonize national marine observations and provide a single access point to all Italian marine data, facilities, and services. In this article, the main objectives of the project, the first results on the gaps in the EOV and data access and services will be presented in combination with a plan about how to overcome these gaps, develop and harmonize the future IOOS.

2. BUILDING THE ITALIAN INTEGRATED OCEAN OBSERVING SYSTEM (IOOS)

The ITINERIS Marine Domain will build the IOOS by integrating and expanding existing ocean observation capabilities harmonizing data collected by various Research Infrastructures (RIs). These RIs include Italy's nodes and facilities within the ESFRI EURO-ARGO ERIC, EMSO ERIC, DANUBIUS, ICOS, JERICO, eLTER, EUROFLEETS, SIOS as well as three significant Italian infrastructures: Laboratori Nazionali del Sud, N/R Laura Bassi, and GeoSciences.

This large number of RIs, their heterogeneity and complementarity, and the urgent need for a harmonized approach require a coordinated action to integrate and interlink the different RIs and national integrated systems.

The IOOS will be established to coordinate and harmonize national observations to improve quality and interoperability of ocean data, for three critical themes: climate, operational services, and marine ecosystem health. To centralize Italian marine data, the National Marine Data Center, designed as a distributed system by the Italian Oceanographic Commission, will be implemented.

During the project, critical data gaps in EOVs and EBVs observations will be addressed to enhance the continuity and coverage of biochemistry, biological, and ecosystem data.

Key sites will be upgraded to improve the acquisition of ecosystem-level biological observations, utilizing both automated and innovative technologies.

Italian research vessels will be equipped to provide continuous near-real-time (NRT) ship-based observations, contributing to global full-depth, coast-to-coast transect measurements. Data will be accessible through the IOOS data center, linked to the ITINERIS HUB, ensuring data equity. Furthermore, pilot services will be developed to address major marine challenges and meet stakeholder needs, showcasing the positive impact of data and facility integration and harmonization.

3. ITINERIS MARINE RIS: GAP ANALYSIS OF THE NATIONAL MARINE FACILITIES, EQUIPMENT, AND ACCESS PROCEDURES

The distribution of the Italian fixed facilities (fixed platforms, buoys, moorings, etc.) available in RIs is quite homogeneous along the coast, with minor gaps along the coasts of Sicily and Sardinia (Figure 1). All main Italian Seas (Ligurian, Tyrrhenian, Adriatic, Ionian) and straits (Sicily, Otranto, Messina) have a sufficient coverage of observing stations. In addition to the fixed facilities, the RI Euro-Argo ERIC manages a large fleet of autonomous mobile vehicles, i.e., Argo floats, which allows to extend quite evenly the observations all over the Mediterranean Sea and partially in the Black Sea and Southern Ocean/Antarctica (Deliverable ITINERIS D5.3).

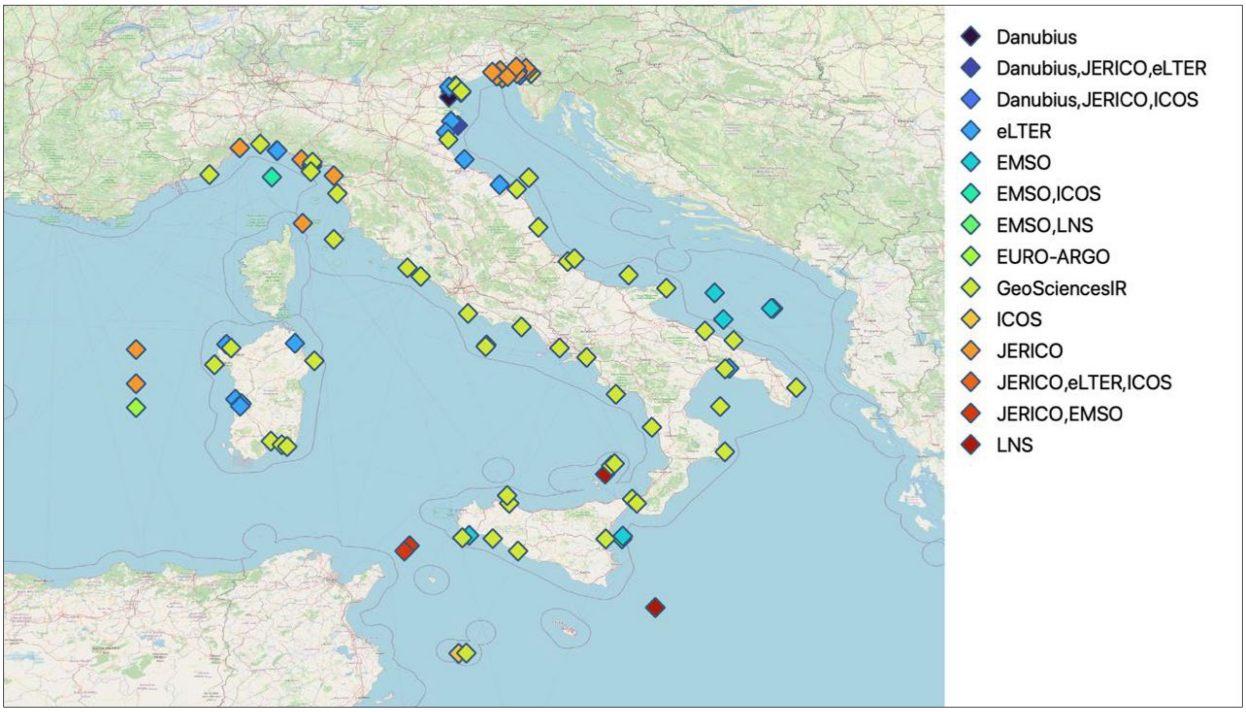

Figure 1. The location of facilities related to the RIs considered in WP5 of ITINERIS, Euro- Argo floats, and JERICO drifters' locations are indicative.

Regarding the availability of EOVs and ECVs, it's noteworthy that the 11 Research Infrastructures exhibit an uneven distribution. While physical variables in the ocean and atmosphere are well-covered (Figure 3), there are noticeable gaps in the representation of biological and biogeochemical variables (Deliverable ITINERIS D5.3).

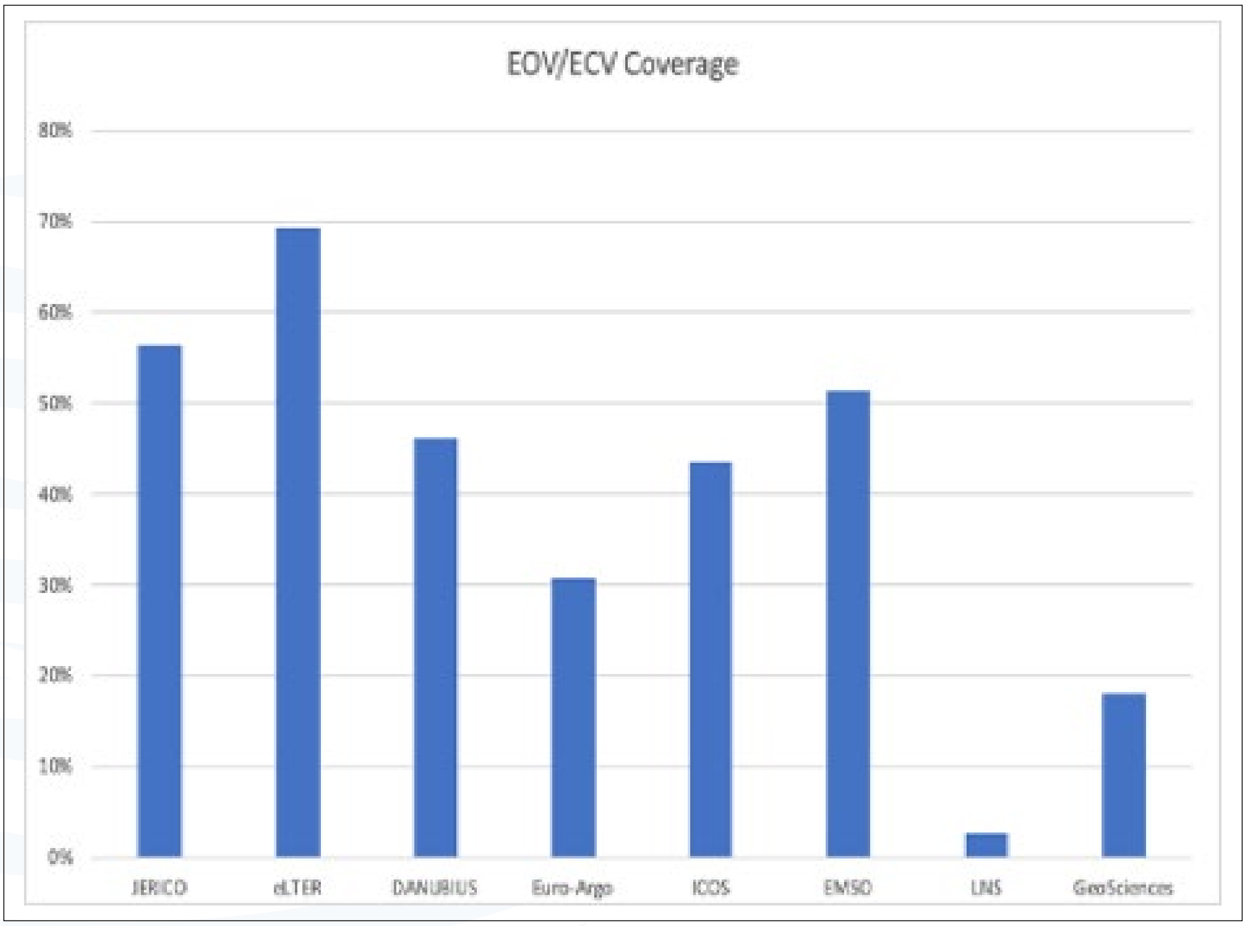

Figure 2. Percentage of EOVs/ECVs measured by each RI on the 39 EOVs/ECVs considered.

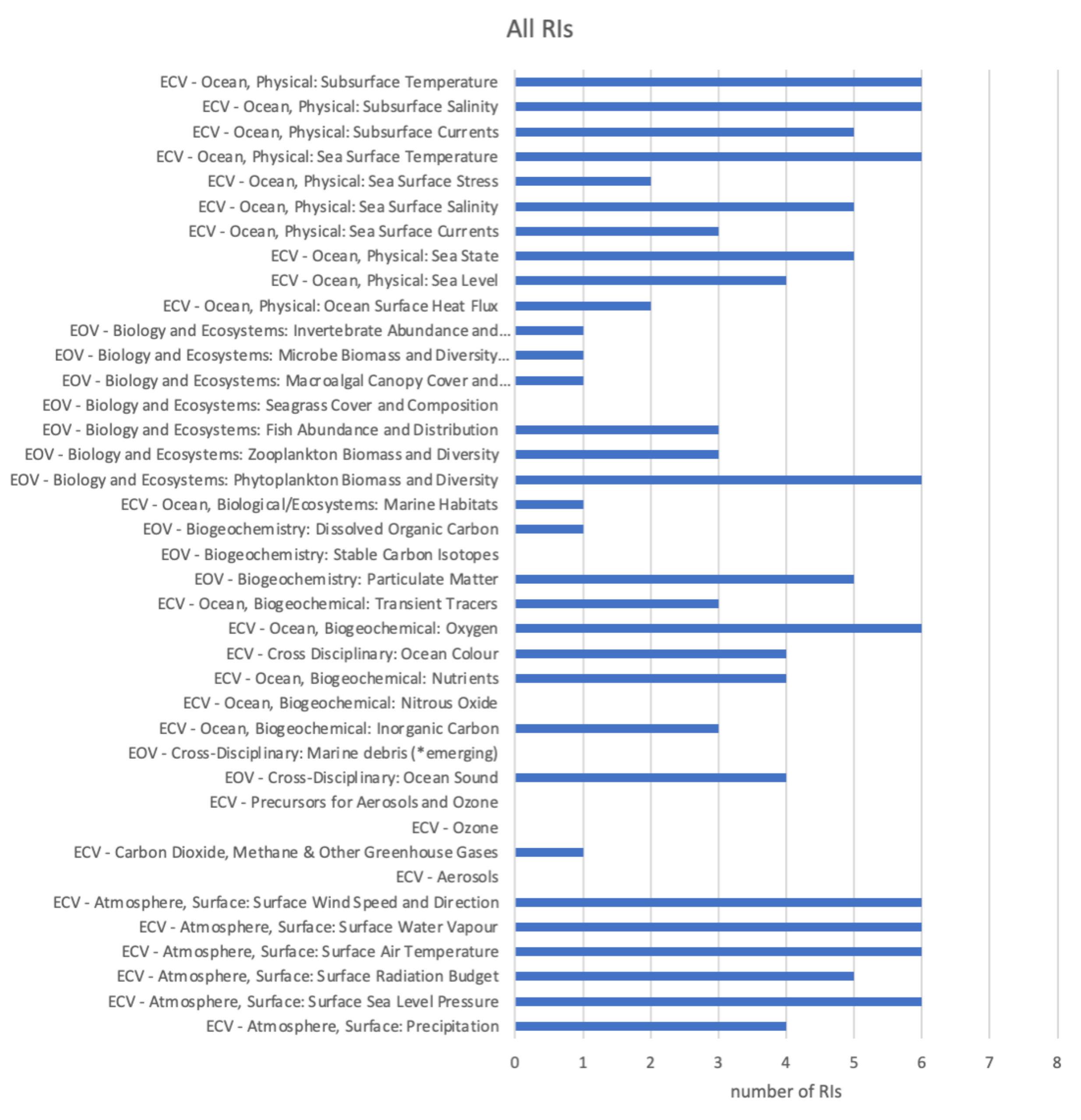

Figure 3. Number of RIs contributing to the measurement of specific EOVs/ECVs (right panel).

In terms of access and data provision, the survey covering all 11 RIs examined (Table 1) reveals the following:

- The 67% of the total ECV/EOV measured across all RIs adheres to the "A" in FAIR principles, as it is accessible through open international databases. This data offers options for visualization, downloading, and subsetting;

- The 20% of the data is available upon request to the data owner;

- The 12% of the data can be accessed through a database link with hybrid access options;

- The 1% of the data is not open, either inaccessible or subject to restricted access.

Table 1. Summary of the data access virtual procedures to the several EOV/ECVs measured by the current RIs facilities. Three main aspects are addressed: the method for delivering the product, access options, and the data release timing.

	JERICO		eLTER		DANUBIUS	
Method of delivery of the product	n. facilities	n of EOV/ECV	n. facilities	n of EOV/ECV	n. facilities	n of EOV/ECV
Upon request to the data owner/manager	4	31	12	35	7	61
accessible on database (by link)	3	37	5	40	2	31
accessible on international database (NOT OPEN)	0	0	0	203	0	0
accessible on international database (OPEN)	17	94	2	111	3	10
accessibile on any other national database (NOT OPEN)	0	0	0	15	0	0
Access Options						
visualization, download, subsetting	20	127	8	128	4	46
visualization, download	3	19	0	0	2	6
download	2	11	0	0	3	11
visualization	0	0	0	0	0	0
not accessible	0	0	2	57	1	4
restricted access	1	5	10	120	4	32
Data release time						
real time (< 2h)	20	136	7	101	6	62
< 24 h	2	10	0	0	0	0
< 7 days	0	0	1	4	1	1
< 30 days	0	0	10	115	4	27
< 365 days	4	16	7	84	4	14
never	0	0	0	0	0	0

The ITINERIS Project will fill the gaps on observation and data access. Efforts will also be made to enhance the ability of RI marine facilities to transmit data from offshore to inshore for real-time data access. Additionally, new instrumentation aligned with digital requirements will be procured and installed.

4. DESIGN THE IOOS MARINE DATA CENTER

Data and products provided by various RIs will be homogenized and unified to create an integrated system capable of ensuring continuous data and service provision. After the standardization procedures, all data will be integrated and made accessible through the IOOS.

The development of a national marine data center, designed as a distributed system by the COI (Italian Oceanographic Commission), will be a collaborative effort involving all relevant entities. It will be interfaces with international intitiative on data portals such as Seadatanet and EmodNet in order to contribute to IODE, OBIS.

The IOOS data center (Figure 4) will establish connections with existing RI data centers and thematic data centers to create a unified access point. It is designed based on the requirements on FAIRness and in order to have a common framework for Access Provision and implementation of a single entry point to the whole national network of environmental RIs (ITINERIS HUB, Deliverable ITINERIS 5.1, 5.2).

Euro-Argo		ICOS		EMSO		LNS		GeoSciences	
n. facilities	n of EOV/ECV	n. facilities	n of EOV/ECV	n. facilities	n of EOV/ECV	n. facilities	n of EOV/ECV	n. facilities	n of EOV/ECV
1	5	2	23	7	38	6	6	0	0
0	0	1	18	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
5	188	4	29	7	79	0	0	43	352
0	0	0	0	1	6	0	0	0	0
0	0	4	40	3	35	0	0	43	352
1	10	1	7	3	41	0	0	0	0
1	5	2	20	7	20	6	6	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	3	14	0	0	0	0
0	0	1	3	0	0	0	0	0	0
0	0	3	35	1	7	0	0	43	352
5	171	2	12	5	31	3	3	0	0
0	0	0	0	1	1	2	2	0	0
0	0	1	10	0	0	0	0	0	0
1	1	2	13	6	57	1	1	0	0
0	0	0	0	3	14	0	0	0	0

Following the LifeWatch ERIC approach,Virtual Research Environments (VRE) will be implemented. VREs are new eScience facilities that address scientific and applied questions requiring serious effort in data harmonization, analysis, modelling and computational power. The pilot services will use and be tested within VREs to address key marine and enviromental scientific question like climate change or envirometal pollution.

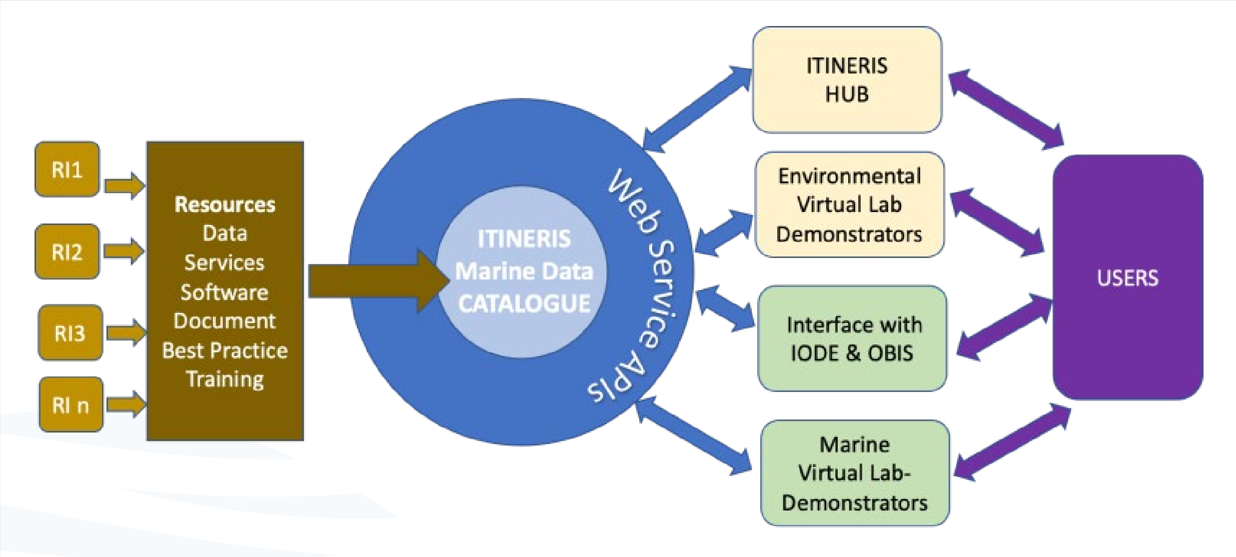

Figure 4. Design of the Italian Integrated Ocean Observing System (IOOS)- Marine Data Store Architecture.

ACKNOWLEDGEMENTS

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Croatian Dissemination of Adriatic Sea Marine Met-ocean Data Buoy Observations to Ships via AIS messages

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Keywords

Adriatic, data buoy network, AIS AtoN, maritime navigation information, maritime safety

Abstract

Automatic Identification System (AIS) is an autonomous broadcast system, operating in the VHF maritime mobile band. It exchanges information such as vessel identification, position, speed, forecast etc. between fixed and mobile stations.

Croatian Meteorological and Hydrological service (DHMZ) contributes to the optimal/ efficient/effective and safe maritime navigation information system at the Adriatic with 5 met-ocean moored data buoys at Adriatic open sea. The each data buoy is radio broadcasting meteorological data in real-time via the AIS system every 10 minutes to the ships in the area.

The use of AIS within marine aids to navigation services is broadcasting of the aids to navigation (AtoN) report message (Message 21) and other AIS messages, in our line of work is Message 8 (weather conditions, wind speed and direction, sea waves, sea temperature, currents, etc.).

Croatian national maritime waterways and radio service company Plovput cooperates with DHMZ on AIS AtoN message quality procedures. AIS messages are collecting via AIS base stations at Adriatic coast operated by Plovput. Plovput ships are also one of the many AIS AtoN users.

The exchange of information between all systems is necessary for cooperation and improvement of each segment in the monitoring of maritime traffic in Adriatic sea.

1. INTRODUCTION

Croatian Meteorological and Hydrological Service (DHMZ) is a state institution of Croatia, who provide support to environment protection, act towards the preservation of life and material goods from natural hazards and disasters. As part of Croatian national obligations as maritime country, DHMZ is authorized for the national operative marine services, provided by the Marine Meteorological Center in Split. DHMZ operates several ranges of observation networks (meteorological, climatological, hydrological, marine), and provides forecasts and meteo and marine warnings.

2. MET-OCEAN OBSERVATION AND AIS (AUTOMATIC IDENTIFICATION SYSTEM)

Since year 2017 DHMZ is running the project of Modernization of the National Weather Observation Network in Croatia (METMONIC). At the summer 2022, a new state network of met-ocean moored data buoys has been established - 5 open sea data buoys at areas between Croatian open sea and internal waters (locations Kvarner, Blitvenica, Viški kanal, Palagruža, Molunat) Data buoys are equipped with dual meteo sensors, oceanographic sensors for sea surface and sea profile measurements, and with 3 types of real-time dissemination systems (GSM, IRIDIUM, AIS telecommunications).

Automatic Identification System (AIS) is an autonomous broadcast system for the purpose of navigation safety. All SOLAS ships and all navigational aid equipment is providing AIS location and ID messages, for the purpose of automatic marine traffic tracking systems. Advanced active systems could provide AIS aids to navigation (AtoN) products, developed by IALA, with ability to broadcast other safety information, ship-to-ship, equipment-to-ship, equipment-to-base-stations The each DHMZ data buoy is radio broadcasting meteorological data in real-time via the AIS system every 10 minutes to the ships in the area of 12NM. The use of AIS within marine aids to navigation services is broadcasting of the aids to navigation (AtoN) report message (Message 21) and other AIS messages, in our line of work is Message 8 (weather conditions, wind speed and direction, sea waves, sea temperature, currents, etc.).For the purpose of marine meteo duties DHMZ cooperate with Croatian national maritime waterways and radio service company Plovput LLC. For the purpose of marine traffic safety Plovput established AIS AtoN service at 2022. System consists of radio acquisition network, central processing system, data base and Web dissemination application. System is linked to the different AIS data sources. Radio acquisition network of AIS base station at 10 Croatian costal peaks (Učka, Savudrija, Razromir, Osorčica, Mala Glava, Žirje, Vidova gora, Ilijino brdo, Hum, Uljenje) is the operative since year 2022. System successfully collecting DHMZ data-buoy AIS AtoN messages, decode binary messages, and save them for the back-up. Even the most distant radio messages from Palagruža buoy are successfully collected. Plovput system is the primary tool for DHMZ monitoring of AIS dissemination.

3. MARINE TRAFFIC AND MARITIME ACTIVITIES AT ADRIATIC SEA

Adriatic Sea is semi-closed Mediterranean sea at the areas between several mountain chains. Weather and climate conditions are very often severe during winter, from the highest sea waves of more than 10 meters, along the 700km long Adriatic fetch, to the severe northern winds up to 35knt. Summers are warm and very warm, but summer storms and gales could developed rapid changes of weather and sea state conditions. Marine traffic of SOLAS ships is intensive toward the northern and mid Adriatic ports (Trieste, Kopar, Venice, Ravena, Rijeka, Split) but also toward the oil and LNG terminals at the northern Adriatic ports. Oil platforms are operating at several locations near international marine waterways. During the summer time more that 100.000 recreational ships and passengers speed crafts are operating at Croatian costs, between 1200 islands. The new data from DHMZ met-ocean state buoy network provide additional help for marine vessel traffic monitoring and is the primary source for open sea marine weather warnings. AIS radio broadcasting of real-time met-ocean measurements enabled efficient update of graphical display of AIS data on board a ships and contribute to marine safety.

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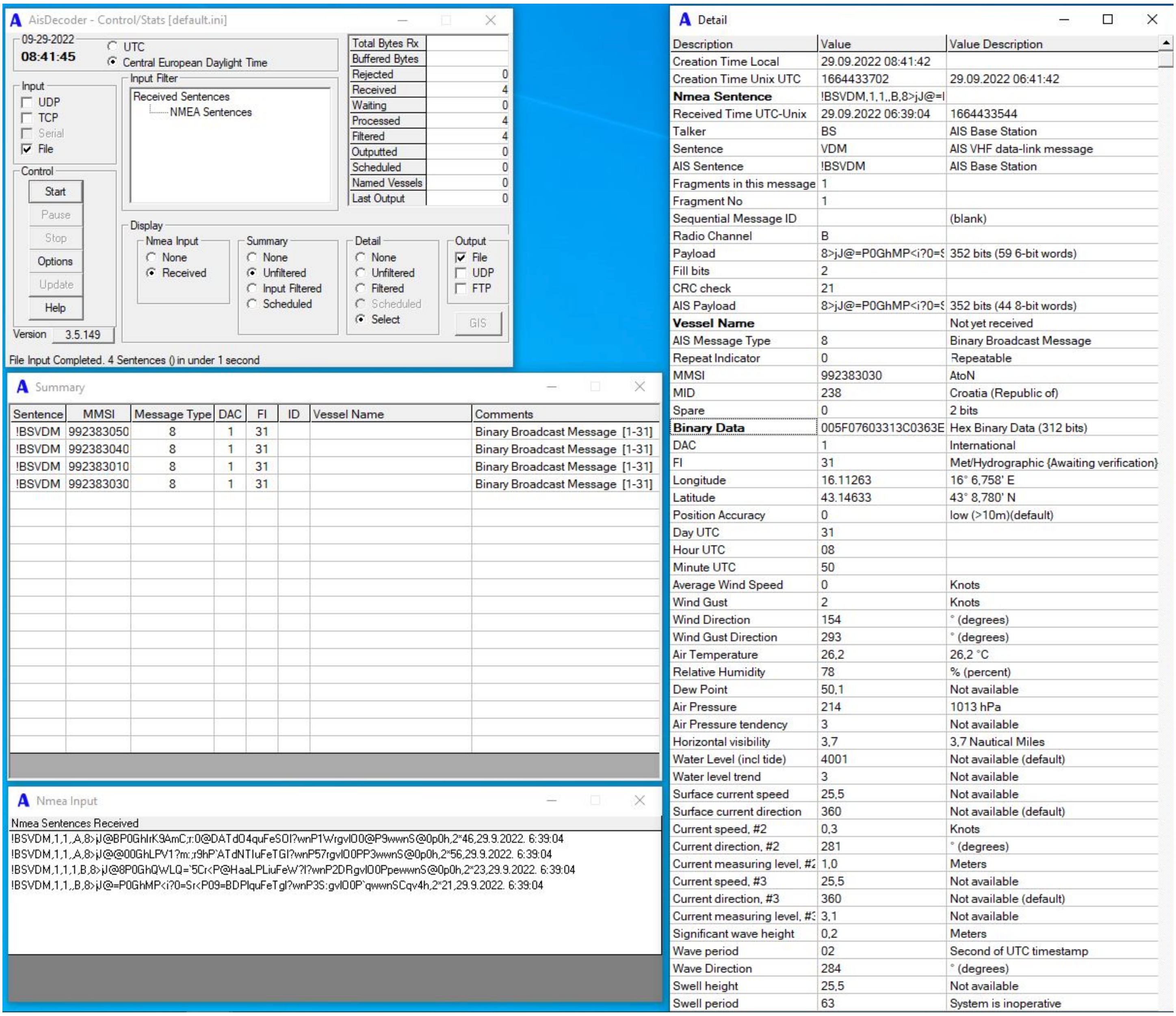

Figure 1. AIS Message 8 DAC 1 FI 31.

EMSO ERIC progress in data harmonization and physical access for the benefit of marine science and technology

Authors

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Keywords

Ocean Observing System, Seafloor observatories, European Research Infrastructure data harmonization

Abstract

EMSO is a European Research Infrastructure (RI) focused on seafloor and water column observations, offering resources to scientists and stakeholders via its Regional Facilities (RFs). Its goal is to enhance research and understanding of global changes in Europe's surrounding regions. EMSO ERIC's data access employs the ERDDAP technology, which streamlines data and harmonized metadata, ensuring access via a single entry point in line with FAIR data principles. Additionally, an API has been designed to enhance ERDDAP's response time and reliability and introduce additional features. EMSO's ERIC physical access is facilitated by the "EMSO Calls for Access" which is geared towards acquiring new data or testing novel sensors and technologies within the RFs. This overview of EMSO's RF Data and Access Services highlights service implementation's challenges, benefits, outcomes, and impacts. It emphasizes the promotion of access to Regional Facilities and the utilization of the EMSO ERIC data.

1. INTRODUCTION

EMSO, European Multidisciplinary Seafloor and Water Column Observatory, European Research Infrastructure Consortium, is a distributed research infrastructure consisting of ocean observing systems across the European seas (Dañobeitia *et al.,* 2023). It serves as a distributed research infrastructure recording a wide range of multidisciplinary data for marine monitoring purposes (Best *et al.,* 2016).

The main objective of EMSO ERIC is to deliver high-quality harmonized data to scientists to support research and understanding deep-sea natural processes and interactions at the seafloor and in the water column over time scales ranging from seconds to decades (Ruhl *et al.,* 2011; Favali *et al.,* 2015).

EMSO ERIC relies upon a variety of oceanographic, physicochemical, and biological sensors and develops specific tools to distribute the acquired data through its Data Portal (https://data.emso.eu/home). As of today, the consortium is participated by 27 European research institutions and centers, which contribute with 11 Regional Facilities (RFs) with fixed instrumentation and 2 test sites. Some of these installations have long time-series and are suitable sites for hosting, testing and validating prototypes of sensors, communications systems and protocols, and for calibration tests (see Fig. 1).

EMSO ERIC promotes the adoption of common standards, vocabularies, software tools, and data services for ocean data management, which are widely adaopted and reradily available through the portal and are widely adopted.

Figure 1. Distribution of EMSO ERIC Regional facilities

2. DATA ACCESS PROVISION IN EMSO ERIC

EMSO ERIC manages and publishes data coming from all RFs, and makes them accessible through a single web service, a federated ERDDAP, facilitating broad and unified access to harmonized data.

EMSO ERIC has developed various tools over time to handle the heterogeneous data produced at the different RFs and test sites, and to distribute harmonized data. The tools were developed jointly by the Data Management Service Group and the ERIC IT staff, and designed to manage the specific data sources from each RF and to make use of open-source libraries and frameworks, such as MOODA (Bardaji *et al.*, 2021). Since the vocabulary and metadata differed for each data source, the harmonization process has become complex and resource-intensive. Moreover, the Quality Control process relied on automated decision algorithms, yet these required slight adjustments for each dataset. Inconsistencies and issues were often found in the data that could only be resolved with a deep understanding of the operation conditions in which the RFs had acquired the measurements. It's important to note that many RFs perform sensor tests, and sometimes, the resulting data aren't intended for scientific purposes and cannot be published as such. Given these challenges, the decision was made that each RF should provide its data already harmonized following EMSO ERIC harmonization protocol.

After a long and intense work, the data discovery and access services are managed through a federated ERDDAP servers. For the EMSO ERIC data portal, an additional API is used for visualization purposes and to extend the ERDDAP´s functionalities.

The data discovery process in EMSO ERIC is designed to be as intuitive and streamlined as possible. Users can search for data based on a variety of parameters, such as the dataset's name, time range, geographic location, or the parameters that the data represents. ERDDAP also provides a clear, standardized metadata description for each dataset. This helps researchers in finding relevant datasets quickly and efficiently, regardless of their size or complexity.

Moreover, ERDDAP provides a user-friendly graphical interface (see Fig.2), which allows users to visually explore the available datasets to find the appropriate data for their research needs.

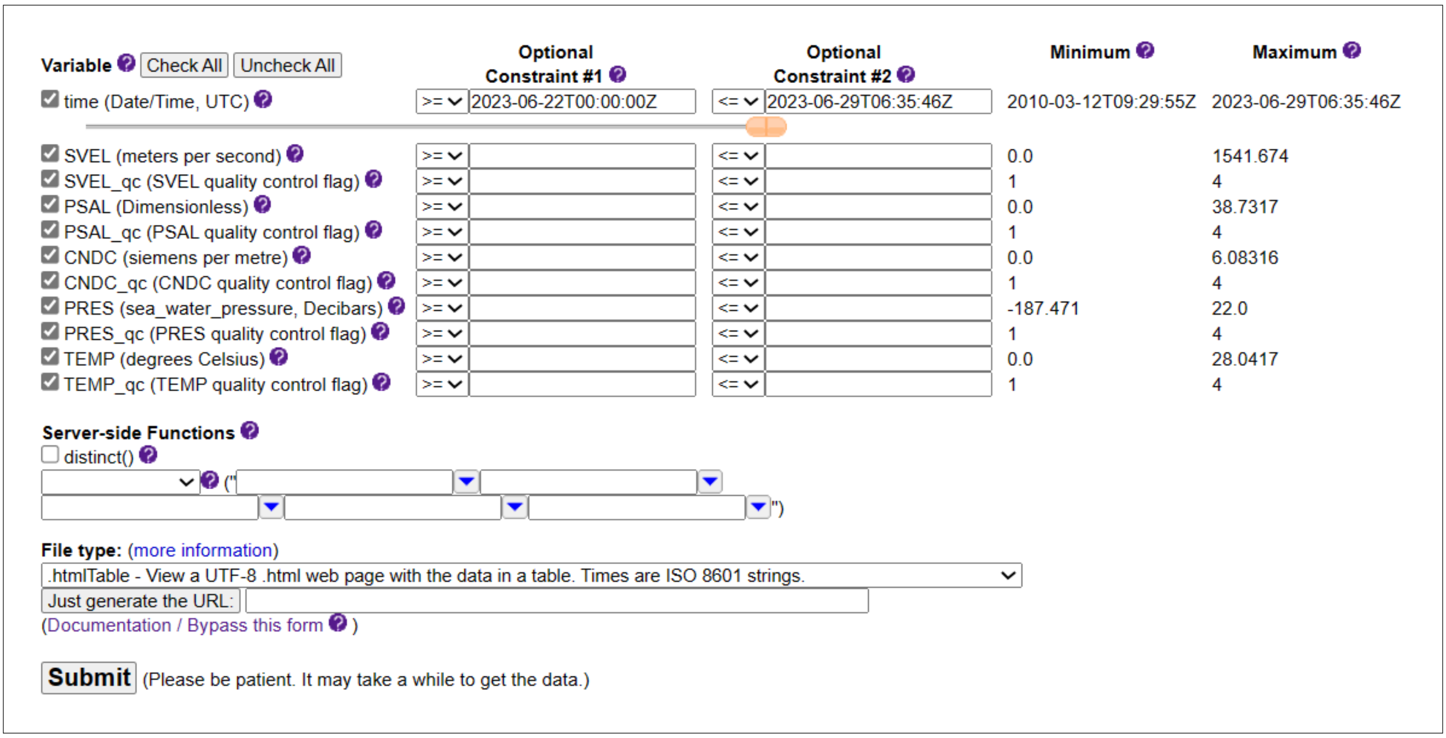

Figure 2. ERDDAP user interface reachable through EMSO data Portal.

3. PHYSICAL ACCESS TO EMSO INFRASTRUCTURE

EMSO ERIC provides physical access to scientists and technologists with a keen interest in marine science and technology research to perform new experiments and ordinary research activities also in a controlled and highly specialized operational environment. The Access service is based on a competitive scheme relying on regularly issued Calls for Access.

The operational status of the RFs ensures the availability of the most advanced scientific and technological capabilities. In 2023 the number of facilities participating in the provision of the physical access service has increased significantly: there are seven in total, up from four the previous year. Two are in the Atlantic Ocean, and five in the Mediterranean Sea.

Scientists and engineers can benefit from high-quality, interconnected instrumented platforms operating in the open ocean for conducting cutting-edge research and/or tests. Beyond the access, the staff at EMSO RFs, including engineers and scientists, can offer qualified capabilities for training services and engineering development, which complement an ideal research work environment. The steps to apply for the call and to implement the project are summarized in Fig. 3.

Collaboration with EMSO RF is undoubtedly a leap forward for marine research and development and a unique opportunity for those seeking to broaden their horizons in this field. Project proposals are evaluated every two months, and the selected ones are funded and granted free access to the selected sites.

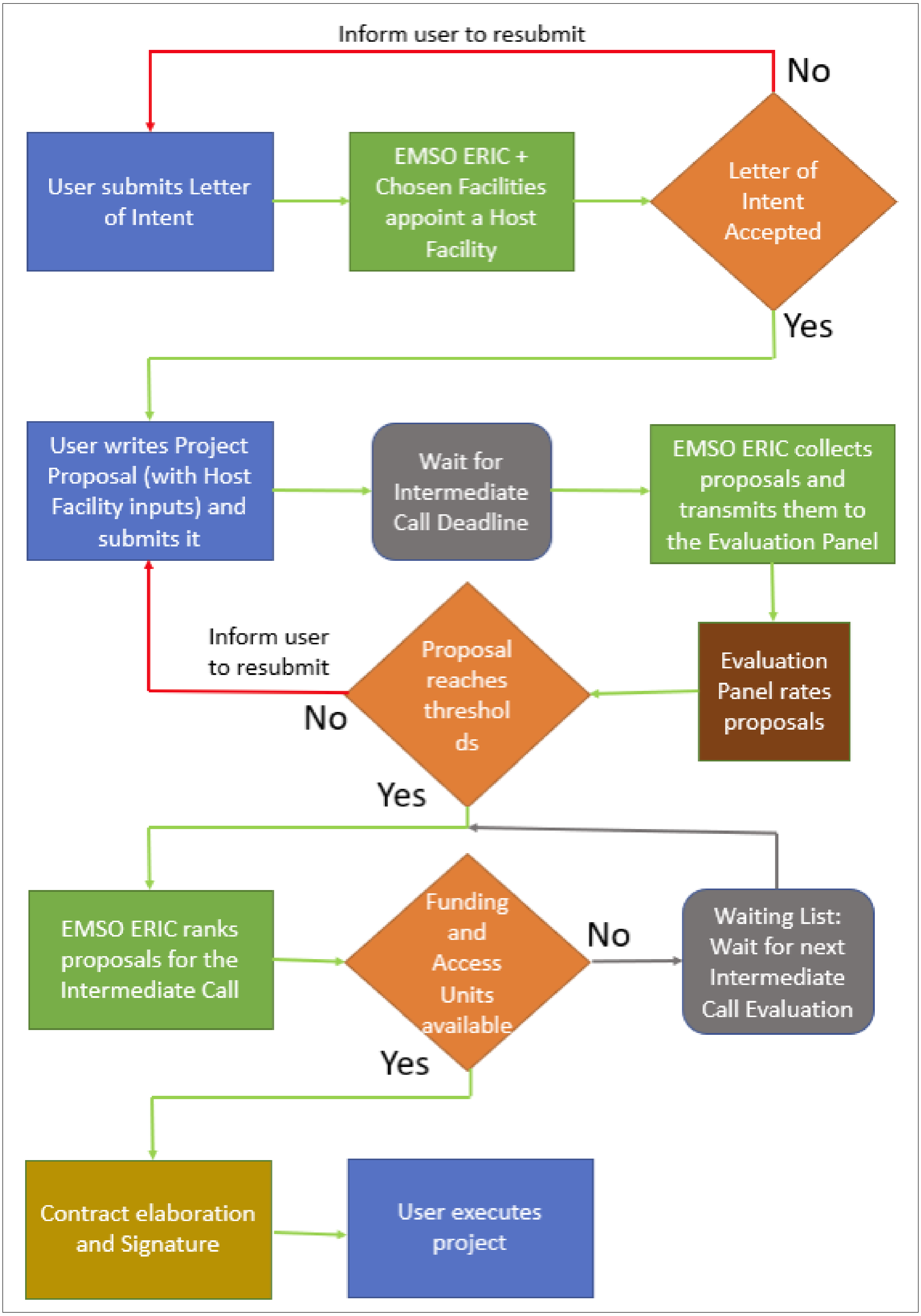

Figure 3. EMSO Physical Access execution diagram

ACKNOWLEDGEMENTS

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The iFADO PAAnoramic mission: the first European Atlantic area international multi-platform ocean monitoring

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Keywords

Atlantic Area, international mission, PAAnoramic, iFADO, monitoring, gliders

Abstract

Implementation of the EU Marine Strategy Framework Directive (MSFD) and extension of periodic monitoring programs to offshore waters is costly and technically challenging. The iFADO (innovation in the Framework of the Atlantic Deep Ocean) project addressed this through integrating fixed point observatories with satellite, modelling, and novel technologies. The consortium proposed a high-impact mission covering the Atlantic Arc using autonomous underwater and surface vehicles as a project extension, and the objective was to demonstrate the collaborative capacity to monitor the Atlantic area with international collaborations using different technologies, vehicles, and sensors. Three institutes deploying gliders in 3 legs of a 'relay' from the Porcupine Abyssal Plain Sustained Observatory (PAP-SO) to the shelf off Ireland (managed by MI, Ireland); then from Ireland to Portugal (covered by NOC, UK); then from Portugal to Gran Canaria (PLOCAN, Spain). This article covers some of the data obtained and lessons learnt from this demonstration of the collaborative capacity to monitor the Atlantic area with gliders.

1. INTRODUCTION

The aim of the European Union's ambitious Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC) is to protect the marine environment more effectively across Europe. Its implementation in the European Atlantic Region (EAR) and the need to extend periodic monitoring programs to offshore waters is very challenging due to its surface extension and large deep-water areas. To overcome these difficulties, the iFADO project (innovation in the Framework of the Atlantic Deep Ocean; https://www.ifado.eu; 2017-2023) combined traditional monitoring with cost-effective state-of-the-art technologies: remote sensing, numerical modelling, and emerging observation platforms such as gliders and oceanic buoys.

After several successful international glider missions, the consortium proposed a flagship action for the project's final year: the PAAnoramic mission. This mission was built on the already established and successful glider endurance line between mainland Portugal and the Canary Islands (Spain) and expanded it Northward into the wider NE Atlantic Area. Since 2018, this endurance line, established during the iFADO project, has been monitoring the southern part of the Atlantic Area on an annual basis. The PAAnoramic mission traversed the European Atlantic using autonomous underwater vehicles combined with *in situ* monitoring cruises and was supported by satellite imagery and operational numerical modelling. This is the first international multi-platform ocean monitoring mission meridionally covering the entire European Atlantic area.

The main goal of the mission was to demonstrate how international collaboration is key for monitoring the ocean, to implement MSFD, achieve Good Environmental Status, and contribute to the UN Sustainable Development goals such as SDG14: Life Below Water. This ambitious action will set a milestone for a future Atlantic Area international unmanned monitoring strategy.

2. PAANORAMIC MISSION PLANNING

The PAAnoramic mission was planned to cover a linear distance of more than 3000 km across three countries' exclusive economic zones (Ireland, Portugal, and Spain) and international waters. Due to the current logistical and budget limitations, the mission was divided into coordinated legs. Teams from different countries designed a suitable approach to cover this large region. The scientific payload installed in the glider (CTD, DO and bio-optics) allowed collection of data related to physical and biogeochemical essential ocean variables. On their way, the gliders crossed various offshore Marine Protected Areas, such as the Savage Islands and the Gorringe Bank among other seamounts and visited open ocean sustained observatories (moored buoys) such as PAP-SO (Porcupine Abyssal Plain Sustained Observatory) and the ESTOC (European Station for Time-Series in the Ocean Canary Islands).

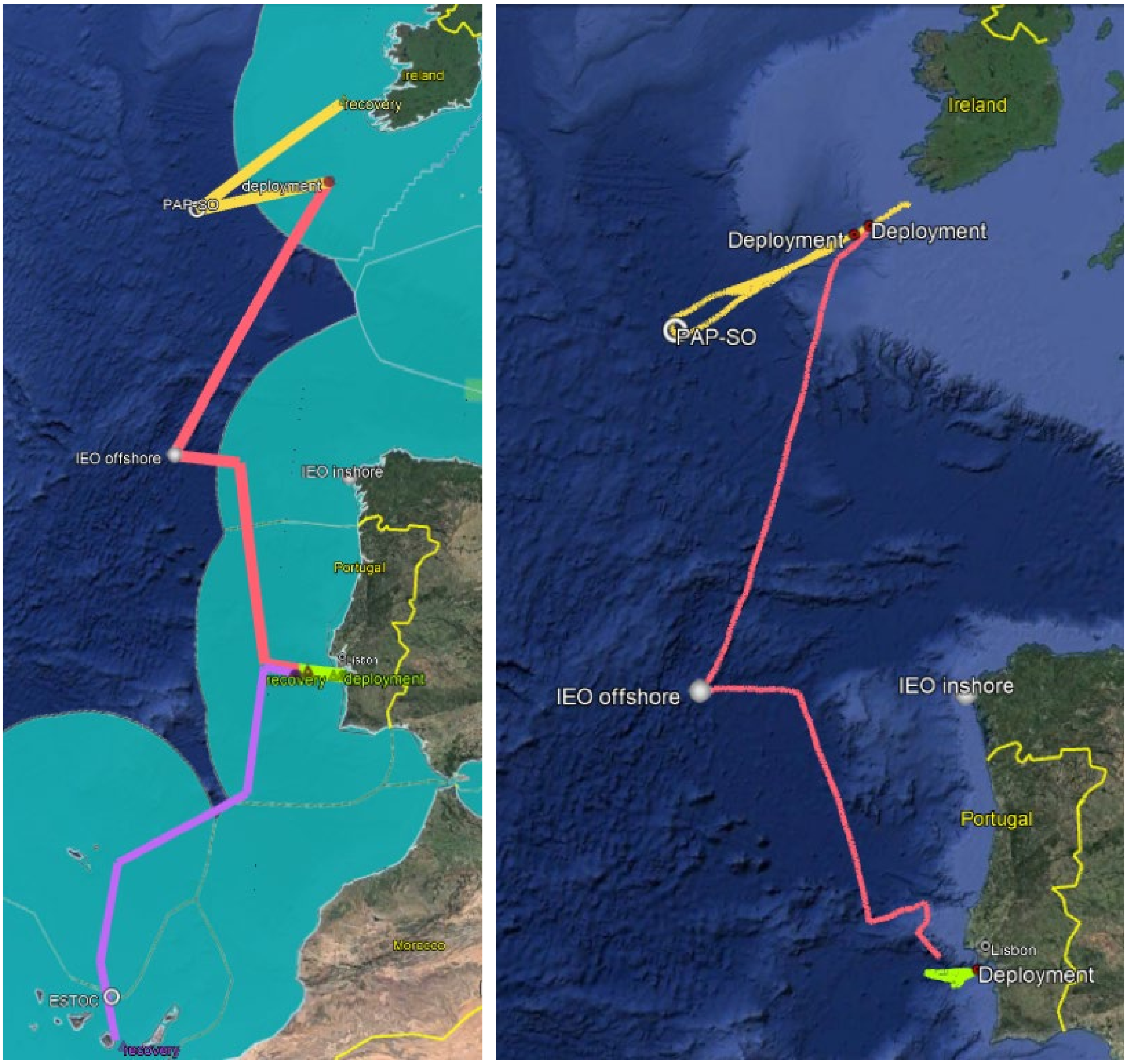

Figure 1. Left: PAAnoramic planned legs on its final configuration: Leg 1 Ireland-PAP-SO (yellow line), Leg 2 Ireland-Mainland Portugal (pink line) and Leg 3 EShed-iFADO (green line) and Leg 4 Mainland Portugal-Gran Canaria (purple line). The exclusive economic zones in the Atlantic Area are displayed in light blue. **Right:** Performed paths for the first three PAAnoramic legs. The deployment location for each leg is indicated with red markers.

2.1. PAAnoramic mission preparation

This was a complex mission both conceptually and logistically. It was a lengthy process given the need to coordinate efforts from many international partners and contend with limited resources in terms of vehicles, budget and available ship time. From the bureaucratic point of view, efforts were made to guarantee diplomatic clearance for the vehicles. +ATLANTIC designed a communication plan to the general public to cover the different tasks performed during the preparation, launch and recovery of the autonomous vehicles through the iFADO social networks (X, LinkedIn and Facebook) and webpage (https://www.ifado.eu/).

2.2. **PAAnoramic mission legs**

The PAAnoramic glider mission was divided into four legs (Fig 1 left):

- **Leg 1 (Ireland-PAP-SO):** Marine Institute covered a two-way transect between Ireland and PAP-SO. This leg took place from the 9th of December 2022 to the 10th of February 2023;
- **Leg 2 (Ireland-Mainland Portugal):** National Oceanographic Centre covered the section from the Irish coast to mainland Portugal. This leg started simultaneously with Leg 1 (9th of December 2022 to the 15th of March 2023);
- **Leg 3 (EShed-iFADO):** IPMA designed a zonal mission to Western Iberia from the coastal area to the deep submarine canyons. The mission performed by PLOCAN took place between the 15th of June 2023 to the 12th of July 2023. This leg named EShed-iFADO ("Eddy shedding monitoring off Setúbal Bay") aimed to achieve a better understanding of the effects of the Lisbon and Setubal submarine canyons to the ocean circulation;
- **Leg 4 (Mainland Portugal-Gran Canaria):** PLOCAN will complete the mission with the route from mainland Portugal to the Canaries. The launch is planned for the 6th of September 2023 and will arrive in Gran Canaria by November 2023.

2.3. **PAAnoramic mission vehicles**

Three gliders were used to perform the PAAnoramic mission (Fig. 2):

- Aisling na Mara from Marine Institute is a 1000m operation rated Teledyne Webb Slocum G3 glider. This glider is part of EirOOS – the Irish Ocean Observing System which is a component of the European Ocean Observing System (EOOS);
- SG152 is a Seaglider® operated by Cyprus Subsea Consulting and Services (CSCS) in coordination with NOC;
- P302 is Seaglider® operated by PLOCAN. This glider performed the two last PAAnoramic legs consecutively. This same glider previously performed the endurance line missions between mainland Portugal and the Canary Islands in 2019, 2020 and 2021.

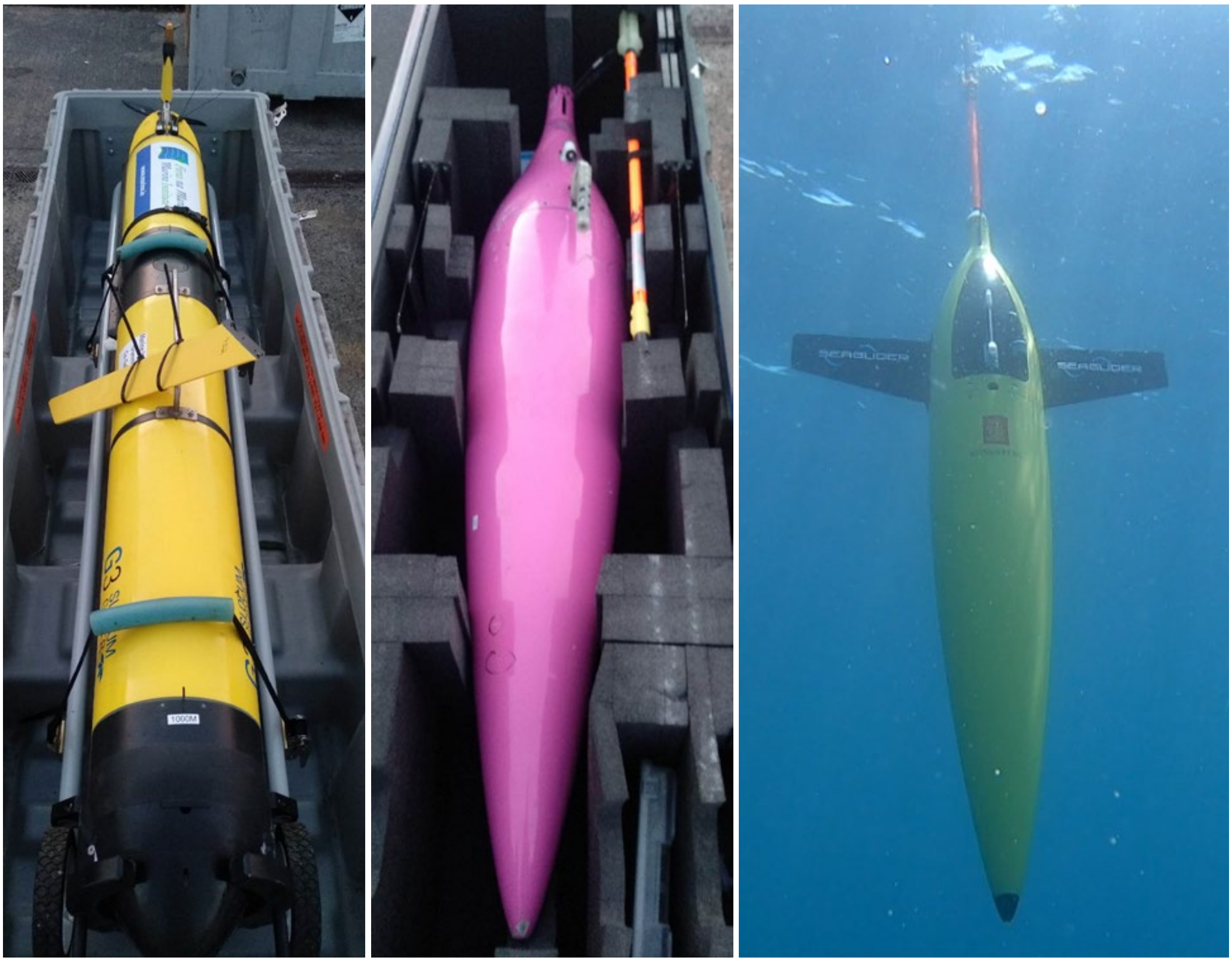

Figure 2. Left: Aisling na Mara Teledyne Webb Slocum G3 glider, **Centre:** SG152 Seaglider and **Right:** P302 Seaglider.

3. PAANORAMIC MISSION DEVELOPMENT

The PAAnoramic mission began on the 9th of December 2022 with the simultaneous deployment of 2 gliders (the Aisling na Mara and SG152) off the southwest Irish coast by the Marine Institute. The first glider, SG152, was deployed around 130 km off the Irish coast (50.8860 °N; 11.4747 °W) while the second glider, Aisling na Mara was deployed about 35 km away to the southwest at coordinates (50.7372 °N; 11.8905 °W). The last glider, P302, performed Leg 3 during June-July 2023 and this same glider will be relaunched in September 2023 for the 4th leg, and complete the PAANORAMIC mission in the Canary Islands with an expected recovery around November 2023. The actual glider paths during the first three legs were close to the original plan (Fig. 1 right). However, logistical constraints in vehicle availability, deployment opportunities (including weather) and technical malfunctions affected the timing of the glider launches. Overall mission modifications to the original paths and dates were needed to ensure glider batteries could provide enough energy to rendezvous with available boats for deployment and collection.

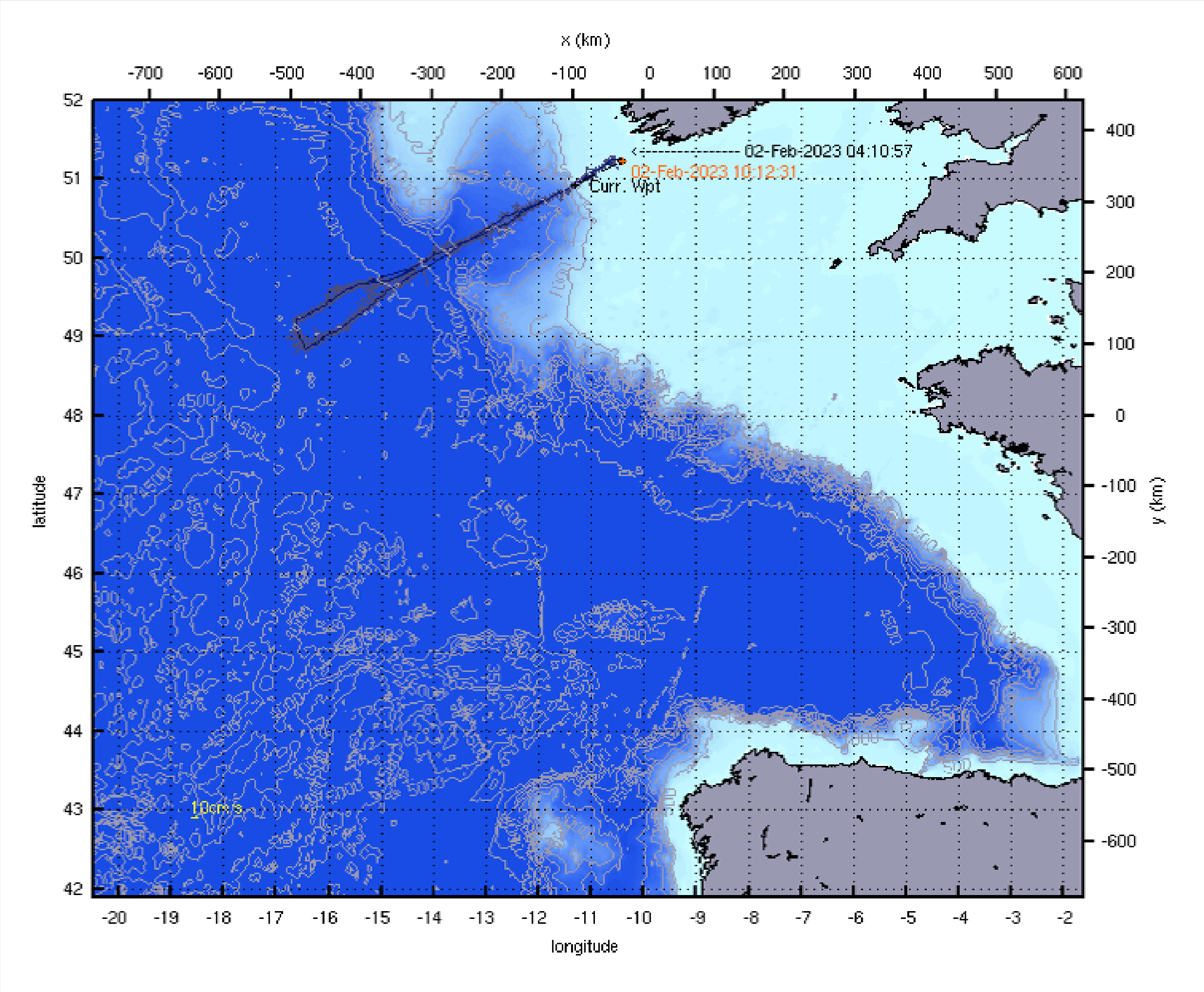

Figure 3. Left: Full path.

Data collected along the mission were distributed using standards and supported by international programmes. The latest position and samples of observed data were distributed in near-real-time through the EGO Initiative (Everyone's Gliding Observatories; https://www.ego-network.org). This initiative provides access to the datasets via Coriolis Data Centre and automatically plots the data collected (see Fig. 3 for Leg 1 plots).

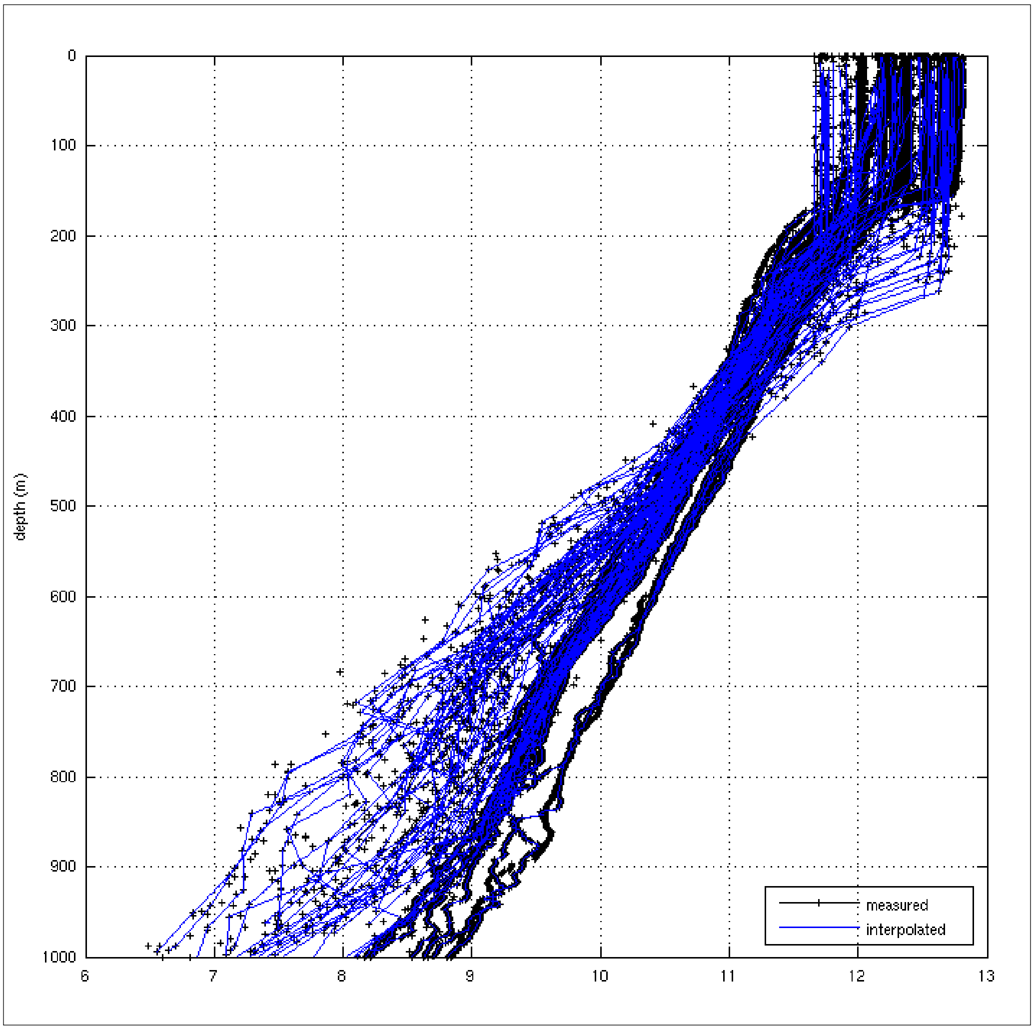

Figure 3. Right: temperature vertical profiles for Leg 1 Ireland-PAP-SO automatically generated and displayed on the EGO initiative webpage.

4. CONCLUSIONS AND LESSONS LEARNT

The PAAnoramic mission will set a milestone for a future Atlantic Area international unmanned monitoring strategy. The ambitious mission can be considered as a best practice for offshore monitoring of good environmental status (MSFD). Regular missions could support scientific data to monitor changes in ocean circulation and water mass dynamics. As an example, Fig. 4 shows potential temperature, salinity and dissolved oxygen for the entire Leg 2 where different water masses can be clearly identified.

This mission involved participation of four Atlantic Area countries (Ireland, UK, Portugal and Spain), including two archipelagos (Madeira and Canary Islands). The mission was also supported by two non-iFADO project partners: Cyprus Subsea (Cyprus) and Instituto Hidrográfico (Portugal). This collaboration demonstrated the capacity to monitor the Atlantic area with gliders though international collaborations using different technologies, vehicles and sensors.

The mission also demonstrated how gliders can reduce logistics, costs, and risks of ocean monitoring and cover remote areas during harsh weather conditions. Future missions could also fit novel biogeochemical sensors, (such as nutrients, pCO_2, biology, particles, radiometry, underwater noise etc) to provide a wider spectrum of observations.

From the technical perspective, the mission was an opportunity to show initiatives, such as GROOM II, that it is possible to have operational data flowing in near-real-time. The EGO data visualization for both Slocum and Seaglider missions' can be regarded as a reference point for tracking progress and collaborating on the results as they come in. The data was distributed through Coriolis and ready to feed numerical models and improve forecasts.

As a principal legacy of the iFADO project, the PAAnoramic mission aimed to demonstrate the possibility to establish a coordinated endurance line between M6, PAP, IEO, ESTOC sites and support cross-calibration. In the future, to have built in capabilities to allow quick response missions would cover both unexpected funding opportunities and/or unplanned natural events that require quick action.data visualization for both Slocum and Seaglider missions' can be regarded as a reference point for tracking progress and collaborating on the results as they come in. The data was distributed through Coriolis and ready to feed numerical models and improve forecasts.

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ACKNOWLEDGEMENTS

The iFADO project was supported with ERDF funds from the INTERREG Atlantic Area Programme under contract EAPA 165/2016.

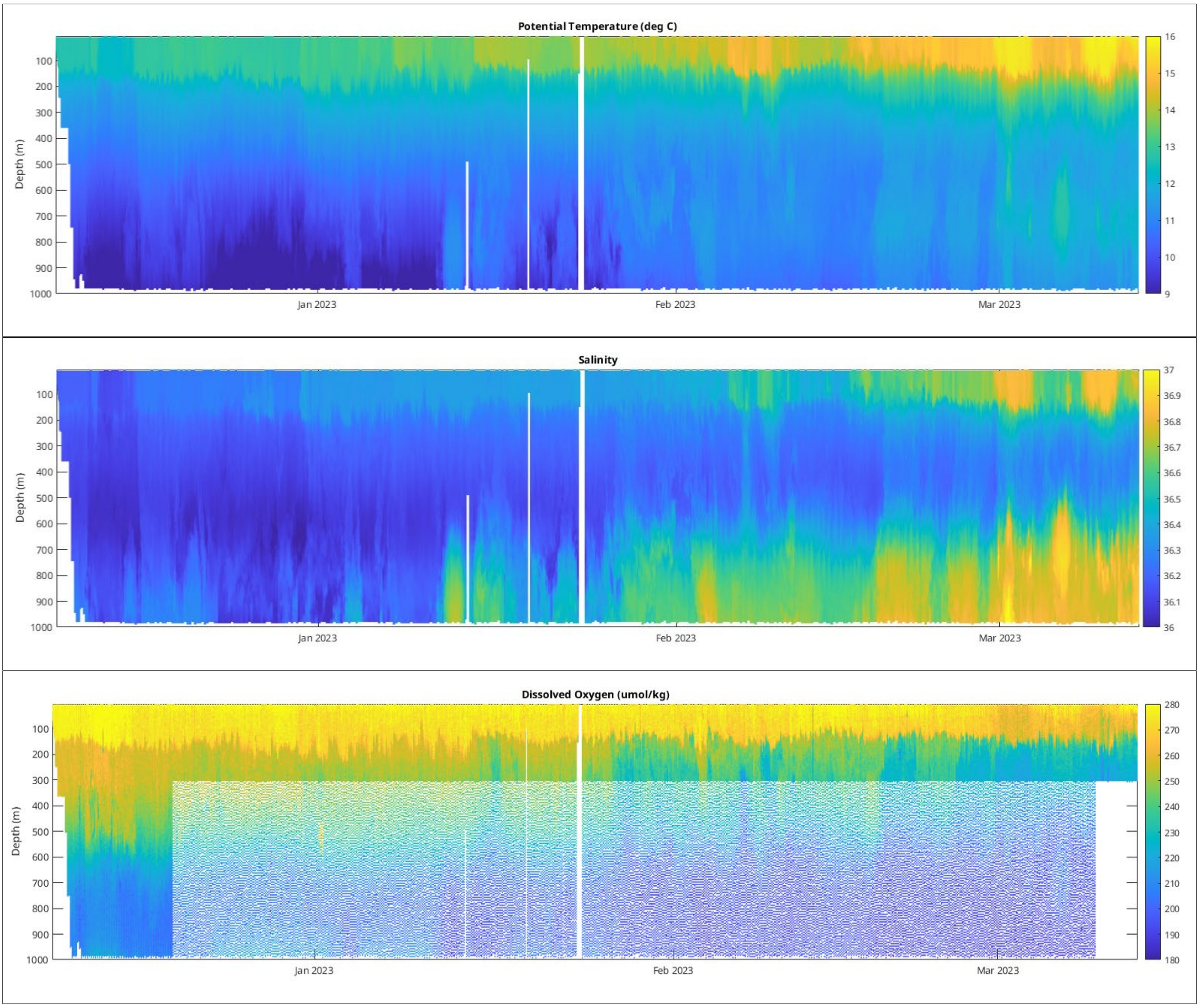

Figure 4. Top: Leg 2 potential temperature; Centre: salinity and Bottom: dissolved oxygen observations. Note: PAAnoramic mission data has not been fully processed yet and the displayed data are raw and thus subject to minimal quality control.

Oral presentations – Session F

Strengthening Europe's oceanographic fleet

Mediterranean Sea Ship-based Hydrography Programme (Med-SHIP)

Authors

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Keywords

Mediterranean Sea, hydrography, biogeochemistry, repeat sections, North-South cooperation

Abstract

The Mediterranean Sea is a "hotspot" for climate and environmental changes, subjected to multiple human pressures. Those factors have consequences on coastal and open ocean oceanography and biogeochemistry. However, observing the Mediterranean Sea is challenging due to geopolitical and economic differences between the coastal countries. MonGOOS (Mediterranean Oceanographic Network for the Global Ocean Observing System) is the Regional Alliance of GOOS, the Global Ocean Observing Network, coordinating the observations in the region. MonGOOS, as well as EuroGOOS, historically lacked a ship-based component to collect essential ocean data. Med-SHIP (Mediterranean Sea Ship-based Hydrography Programme) is an initiative that fills this gap by conducting regular cruises across the to monitor changes in heat, freshwater, carbon, oxygen, nutrients, and transient tracers. Med-SHIP needs support from MonGOOS and EuroGOOS to achieve its two main goals: i) to raise awareness of the importance of Med-SHIP for observing, detecting and

predicting global change risks affecting the Mediterranean Sea ecosystems, and ii) to train researchers from European and Middle East and North Africa countries on topics such as climate change and ocean acidification.

1. INTRODUCTION

The Mediterranean Sea (MedSea) is a hotspot for climate and environmental changes, with more pronounced impacts and risks compared to the global ocean average (MedECC, 2020). The MedSea has densely populated coastal areas with significant economies and activities. Pressures on key climate-related issues in the MedSea, such as warming, sea level rise, salinization, and acidification, are exacerbated by its particular oceanography: it is a relatively small, semi-enclosed basin with limited exchanges, high turnover time with active deep and intermediate water formation, and particular biogeochemistry. The MedSea behaves like a miniature ocean where the temporal and spatial scales of variability are much shorter, allowing observation of climate-driven changes in physical, chemical, and even biological oceanography at the scale of human lifetimes. However, observing the coastal and open MedSea is very complex due to socio-geopolitical and economic differences between the countries of the European Union and those of the MENA (Middle East and North Africa) region. Problems in permitting work in exclusive economic zones (EEZs) and differences in gross domestic product (GDP) and income between northern and southern regions limit observation in several marine areas and, more worryingly, hinder any adaptation or mitigation strategies to address climate and environmental risks.

Ocean operational observations in the MedSea are coordinated by the Mediterranean Oceanographic Network for the Global Ocean Observing System (MonGOOS). For MonGOOS, the addition of a ship-based component is of strategic importance, as a sustained program of regularly repeated coast-to-coast full-depth zonal and meridional cruises to collect Essential Ocean Variables (EOVs) is missing in its portfolio. The Mediterranean Sea Ship-based Hydrography Programme (Med-SHIP) builds on the international program GO-SHIP (Global Ocean Ship-based Hydrographic Investigations Program) and is implemented thanks to ship access provided by individual countries such as Germany (2001, 2011, and 2018) or by EuroFleets Research Infrastructure (RI) (2016 and 2022). Med-SHIP monitors changes in the deep MedSea through oceanographic cruises to document the budget of heat, freshwater, carbon, oxygen, inorganic and organic nutrients, and transient tracers.

The Med-SHIP initiative needs to be directly recognized and supported by MonGOOS and EuroGOOS with two main objectives: i) to raise public and stakeholder awareness of the importance of Med-SHIP for monitoring detecting and predicting global change risks affecting the MedSea ecosystems, and ii) to provide sustained support to the monitoring efforts of the European and MENA countries through capacity-building training on target topics such as climate change and ocean acidification.

2. MEDITERRANEAN PECULIARITIES

The overturning circulation of the MedSea has a shorter time scale than the global ocean (60 years versus >500 years), making the MedSea response to changes faster and more strongly than the global ocean, allowing the signal of change to be detected earlier and with greater magnitude (MedECC, 2020). Therefore, the MedSea is a useful laboratory to understand the role of key processes related to climate change, which allows us to understand these processes on a global scale.

In terms of ocean carbon uptake, the combination of intense deep-water formation and the high-temperature and low ratio of dissolved inorganic carbon to alkalinity and Revelle factor of MedSea waters enhances the uptake and storage of anthropogenic carbon, CANT (Álvarez *et al.*, 2023; Tanhua, 2019; Hassoun *et al.*, 2022). The column inventory of CANT in the MedSea is much higher than in the Atlantic or Pacific oceans (Lee *et al.*, 2011; Hassoun *et al.*, 2022). However, water column CO_2 measurements covering the whole basin are still limited, and the rate and location of the carbon uptake and deep transfer through circulation and the biological pump are still important scientific questions that need to be addressed.
Moreover, the salinity and temperature of the deep MedSea have been rising over time (Schroeder *et al.*, 2016; Borghini *et al.*, 2014; Cardin *et al.*, 2015), and it is necessary to document the changes and understand the processes that caused their increase. In the same context, the weak vertical mixing during the last winter convection events in the Western MedSea (WMED) showed a rapid increase in temperature and salinity and a decrease in dissolved oxygen in intermediate waters. These changes could affect carbon export and the mesopelagic marine ecosystems (Coppola *et al.*, 2018). Models also indicate that oxygen concentrations are decreasing at mid-depths while stratification is increasing. Continuous observations of the changes in the physical and biogeochemical properties of the MedSea are important in the context of the strong water mass modification observed recently, especially the sudden changes in the thermohaline properties of the Western Mediterranean Deep Water (WMDW) observed after the winter of 2004-2005 (Schroeder *et al.*, 2016), which are called the Western Mediterranean Transition (WMT). Schroeder *et al.*,(2016) linked the new deep water properties of the WMDW to the progressive increase of heat and salt content in the Levantine Intermediate Waters (LIW) due to the arrival of water of Eastern origin influenced by the Eastern Mediterranean Transient (EMT). Roether and Lupton (2011) showed that mixing between the different water masses in the Tyrrhenian Sea has increased because of the EMT. Furthermore, EMT deep water episodes hold high salinity, density and oxygen values. However, this system seems to function differently in the Eastern MedSea (EMED) as it has been found that in the Cretan passage a west-to-east gradient of increasing salinity and decreasing oxygen are a result of the propagation of newly water masses from the Adriatic Sea from the Ionian sea to the Levantine basin (Velaoras *et al.*,2019). Thus, the impact of the changes on the MedSea ecosystems remains poorly understood (MedECC, 2022).

3. SCIENTIFIC MOTIVATION

The scientific rationale for Med-SHIP (Figure 1) stems from the remarkable changes in physical and biogeochemical properties detected in the MedSea over the last decades. However, these trends are partly obscured by significant episodic events and regional variability. For example, the salinity and temperature of the deep MedSea have been rising for at least the past 40 years at rates of about 0.015 and 0.04 °C per decade, respectively (Borghini *et al.*, 2014). Moreover, both inorganic and anthropogenic carbon contents are higher in the deep MedSea compared to the global deep ocean.

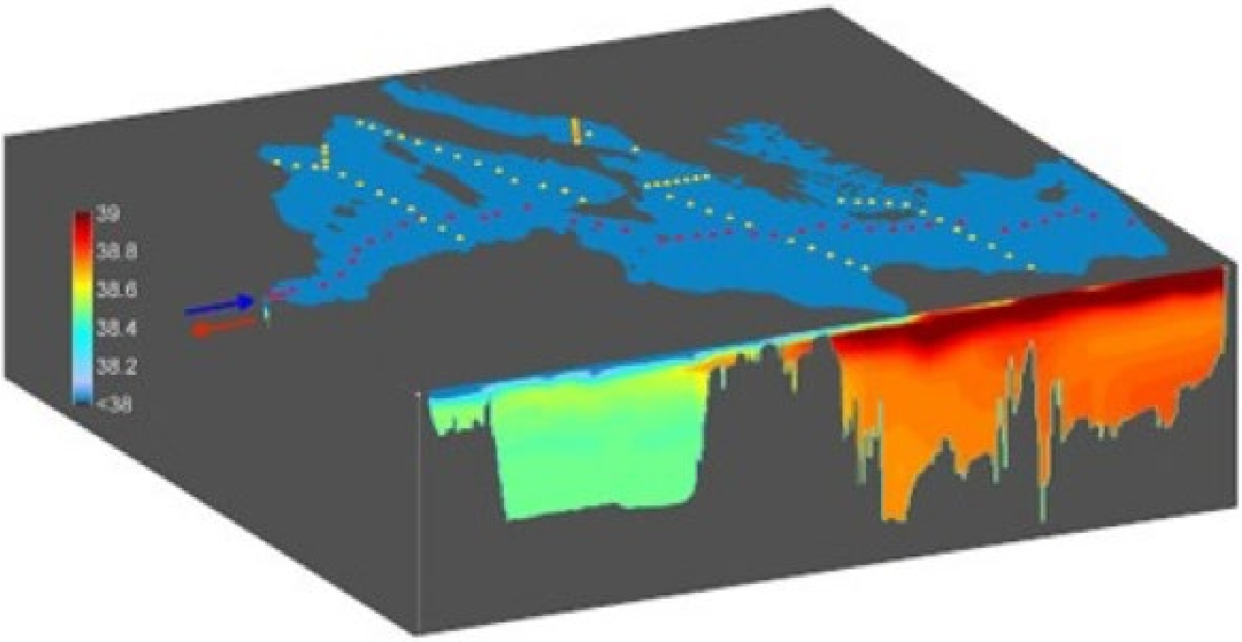

Figure 1. Proposed repeat Med-SHIP hydrographic sections. Red dots indicate the low-frequency zonal section, yellow dots the high-frequency meridional sections. The interior salinity along the zonal section is shown in colour. From Schroeder *et al.*, (2015).

Despite technological advances, ship-based hydrography is still the most reliable method for acquiring high-quality, high spatial and vertical resolution data of various physical, chemical, and biological variables throughout the water column. For example, the global network of Argo profiling floats measures the physical characteristics of the upper 2,000 m of the ocean, but this depth does not cover an important portion of the MedSea (more than 20 % of its volume lies below this depth), where significant changes have been observed (Schroeder *et al.*, 2016).

To monitor changes in the whole water column, and especially for the waters below 2,000 m, it is vital to (1) improve the accuracy of freshwater, heat, and sea level budgets, (2) identify the distributions and patterns of natural and anthropogenic carbon and better understand their drivers, (3) constrain ventilation and circulation pathways, (4) more accurately observe the variability in water mass properties and the processes controlling them, (5) determine the importance of biogeochemically and ecologically relevant properties, (6) evaluate the long-term steric contribution to MedSea sea level, and (7) increase the historical database of whole full water column observations necessary for studying long-term changes.

Regular continuous observations are essential to lower the uncertainties, test ocean models, improve short and long-term projections, and constrain state estimations. Moreover, ship-based hydrographic measurements provide a standard for verifying new autonomous sensor measurements and are a reference dataset for other observing systems such as Argo profiling floats, expendable bathythermographs, and gliders. Hydrographic cruises also offer access to remote ocean areas for deploying these autonomous instruments. Med-SHIP thus provides a full-depth, whole-basin view of changes in the MedSea, a framework that allows regional observations and Argo profiles to be understood from a basin-scale perspective.

4. PROGRAMME IMPLEMENTATION

Figure 2 shows the summary of the implementation of Med-SHIP so far. The zonal section, recognized as the MED01 GO-SHIP line, has been repeated twice by German expeditions in 2011 and 2018. The meridional sections in the WMED were repeated in 2016 and 2022, thanks to ship time funded by the EU Eurofleets2 and Eurofleets+ RI projects. The meridional sections in the EMED have been repeated only once in 2016, also funded by Eurofleets2, and a new occupation is very timely. The meridional, EMED and WMED sections have been submitted to be recognized as Associated GO-SHIP lines.

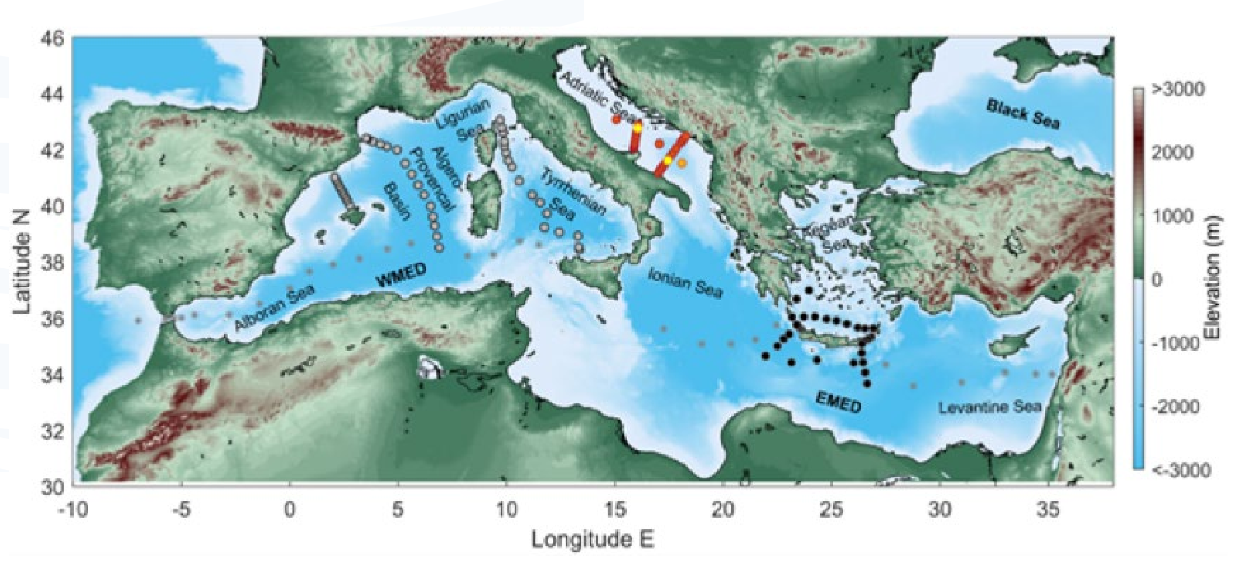

Figure 2. Station map of the Med-SHIP repeated cruises carried out between 2011 and 2022. From Schroeder *et al.*, submitted.

5. FUTURE OUTLOOK

In conclusion and given future directions, we propose that Med-SHIP should be integrated into the Mediterranean sustained observing system as a reference component for long-term studies of processes, events, and changes in the MedSea. It should rely on specific reference lines, along which several core variables (linked to EOVs) are measured, following clear standards/best practices and using certified reference materials. It should adopt an open data policy and define the timelines for delivering the different types of data and products. It would require a regional coordination body and a scientific steering committee and should have a centralised web page where to publish cruise plans, data directories, manuals and reference documents, cruise calendars, as well as calls for participation to improve the diversity of observations and relevance of the initiative to all Mediterranean countries. Ultimately, the proposed Med-SHIP programme should involve the maximum number of Mediterranean countries, including early and mid-career scientists, to sustain these observations by new generations of diverse marine scientists.

Furthermore, to align with the Ocean Decade objectives, new opportunities should be explored to enhance the Med-SHIP programme, such as the addition of biological and ecosystem measurements, the expansion of the real-time provision of data, the collaboration with the MedArgo programme to provide opportunities for instrument deployments and for the provision of calibration data, the expansion of gridded products into biogeochemical parameters, the support and facilitation of multinational voyages, the exploration of new models of funding, and the development of cruise-related access and training opportunities.

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The contribution of EUROFLEETS RI to respond to the European societal needs

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Keywords

Research Vessels, access, excellent research, European Union Missions, EOOS

Abstract

The paper illustrates the progress in the establishment of the new pan-European distributed Research Infrastructure (RI), EUROFLEETS RI, which aims at uniting world-class Research Vessels (RVs) and associated equipment among European partners to facilitate access to unique marine infrastructures for a wide user community, enabling excellent research, increased cooperation in technical development and sharing of knowledge in RV management, as well as increasing ocean literacy. The pan-European relevance of EUROFLEETS RI is to work as a catalyst in the continuous efforts to better coordinate collaboration in marine monitoring and research in national and international waters, in the most cost-effective use of the available infrastructures driven by the need to understand the inevitable impacts of climate and other global changes based on the best scientific knowledge available. EUROFLEETS RI will play a central role in delivering the European Union Missions, advancing the European Green Deal, the Ocean Digital Twin, Sustainable Blue Economy Partnership and the UN Decade of Ocean Science for Sustainable Development (2021-2030). In this scenario, EUROFLEETS RI will enable the delivery of additional key data for understanding climate change, plastic pollution, ocean acidification, impact of blue energy developments, deep-sea mining, tourism and other human activities in the marine environment.

1. INTRODUCTION

The ability of European scientists to conduct research for the advancement of knowledge and technology, and for them to remain at the forefront of their field is dependent on access to state-of-the art infrastructures. In this scenario, built on the achievements of the success of the Eurofleets projects, there is a common understanding among the Research Vessel (RV) operator community that it is necessary to move toward to the establishment of a formal structure for cooperating on a pan- European level.

The approach, under discussion within the community, to achieve this goal is to establish a legal entity, named EUROFLEETS Research Infrastructure (EUROFLEETS RI) that will facilitate access to unique marine infrastructures to enable excellent research in order to sustainably support healthy oceans, increased cooperation in technical development, and sharing of knowledge in RV operations and management as well as increasing ocean literacy.

The proposed EUROFLEETS RI business idea includes the 5 mechanisms/services, each independent of the other, reported in Figure 1, identifying as core activities the ship-access management to continue providing vital necessary EU-funded Transnational Access (TA) programmes utilizing its member's infrastructures to researchers and scientists into the future through funding programmers such as Horizon Europe. Eurofleets RI will work together with the European Commission (EC) in developing other long term sustainable funding support programmes to facilitate planned access to our Seas and Oceans through access, training and data provision.

In the view of providing researchers with TA to RVs and Large EXchangeable Instruments (LEXIs) on behalf of the EC, EUROFLEETS RI will play a central role in delivering the European Union Missions by the provision of access to our Seas and Oceans through facilitation of multidisciplinary science teams tackling changing climate, supporting bio medical research, ocean monitoring, sustainable fisheries and advancing the European Green Deal, the Ocean Digital Twin, Sustainable Blue Economy Partnership and the UN Decade of Ocean Science for Sustainable Development (2021- 20230).

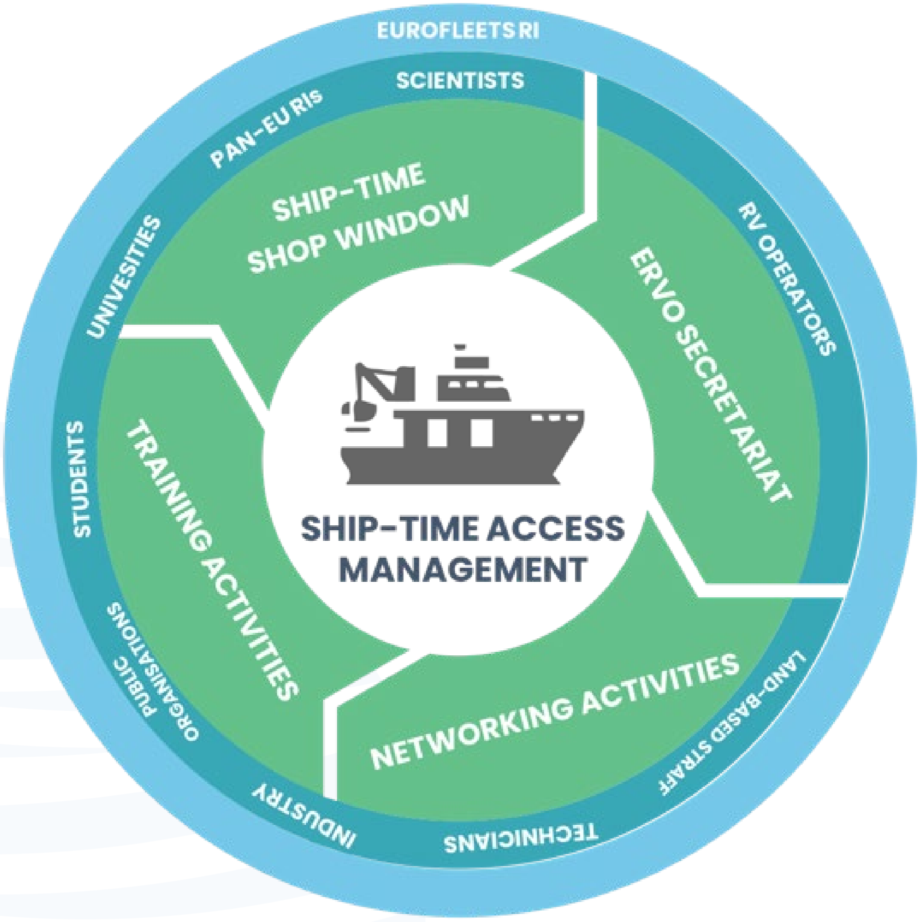

Figure 1. Key activities of EUROFLEETS RI.

2. TOWARD EUROFFLETS RI

The development of the EUROFLEETS RI will follow the ESFRI Lifecycle Approach, beginning in January 2024, with the aim of being operational by January 2029.

During the H2020 funded project Eurofleets+, in order to lay the foundation for the construction of future EUROFLEETS RI, the following aspects have been identified to be of crucial importance and then addressed in depth:

2.1. **The legal structure that will support the core activities of the EUROFLEETS RI** (Magnifico *et al.*, 2020). After examining different legal forms relevant for EUROFLEETS RI, the arguments are strongly in favour of establishing an International non-profit association under the Belgian law, a so-called Association Internationale Sans But Lucrative (AISBL) since the primary objective of a future EUROFLEETS RI is to increase the integration of and broaden access to the existing network of RVs and LEXIs rather than acquiring, owning and operating any new facilities (joint ownership of a common asset) and an AISBL seems to be sufficient to bring together partners to form a legal entity with a simple governance structure, light administration, an international image and a European character.

2.2. The offer and demand of TA at European level

(Magnifico *et al.*, 2023). In collaboration with the European Research Vessel Operator (ERVO) Group, two relevant drivers were investigated to preliminary assess the offer and demand of TA: the spare capacity of the European Research fleets and the volume and the effectiveness of on-going TA initiatives. Between October and November 2021, the ERVO group launched a survey to collect data about the operating days and the spare time for European Research Vessels. In addition, an on-line survey was designed, consisting of 9 main questions, focused on the following 5 main items: 1. TA mechanisms adopted; 2. Number of TA days at sea in the period 2018 -2023 provided for access to a RV or LEXIs, to scientists (either from a different European country or international); 3, Sea area of interest based on the EuroGOOS regions and 5. Benefits of TA initiatives.

In total the spare capacity reported with the current manning of the RVs is 1424 d/y could increase up to 900 d/y if a second crew is employed on six of the RVs which gives a potential total spare capacity of 2324 d/y if all spare capacity was used. This event in practice is impossible, but it gives a clear indication that a better utilization of the European RV fleet is possible if the necessary resources (funding and crew) are made available and an efficient system for European TA is developed and implemented.

The demand for TA initiatives in the period 2018-2023 is mainly due to: 1. the lack of available days on national vessels (due to high demand of supplier, technical problem); 2. insufficient operational capability on national vessels (permanent or technical problem) and 3. Ship operation in areas inaccessible by national research vessel (especially in the Artic Region).

2.3. Securing members from the RV and LEXI communities

A preliminary expression of interest was widely circulated on January 10, 2023, to the Eurofleets+ beneficiary community, as well as to other non-Eurofleets+ RV operators, ERVO and OFEG members. The survey was aimed at exploring the potential commitment of RV and LEXI communities in terms of infrastructure availability, in-kind contribution to secure the operation of the EUROFLEETS RI, and an annual fee amount to set up the RI services and central office, and to secure the financial sustainability during the first year of the RI lifetime.

2.4. Costs for establishing an EUROFLEETS RI support office

(Magnifico *et al.*, 2022). A rigorous approach was adopted to assess preliminarily the operational costs of EUROFLEETS RI referring to the coordination activities required to run the Central Hub, link Eurofleets RI partners, and for the management of the services provided (e.g., personnel, services, equipment, travel, training, buildings, etc.). These costs are split into costs for the TA management and the secondary activities.

2.5. **Establishing commitment for funding for TA from the European Commission (EC)** (Sá *et al.*, 2022). The four-year Eurofleets+ project has provided several opportunities to start a dialogue with the EC to present the EUROFLEETS RI strategy and a summary of achievements and recommendations for policymakers have been produced.

3. EUROFLLETS RI CONTRIBUTION ON SOCIETAL NEEDS

By providing a complementary research platform across the entire Atlantic Ocean and European Seas, EUROFLEETS RI will enable the delivery of additional key data for understanding climate change, plastic pollution, ocean acidification, impact of blue energy developments, deep-sea mining, tourism and other human activities in the marine environment.

EUROFLEETS RI will work with a variety of stakeholder communities to further Europe's capacity to investigate the urgent scientific questions in marine research, critical for understanding the Earth system.

In the framework of the funding programme of the European Commission "Horizon Europe", EUROFLEETS RI potential contribution to the mission areas is reported in Figure 2.

Table 1. EUROFLEETS RI potential contribution to the Mission Areas of "Horizon Europe".

<table>
<tr><th>Cancer</th><th>Adaptation to climate change including societal transformation</th><th>Healthy oceans, seas, coastal and inland waters</th><th>Climate-neutral and smart cities</th><th>Soil health and food</th></tr>
<tr><td rowspan="5">Support BioMedical Research from our oceans</td><td>Monitoring and informing on Climate change</td><td>Monitoring of marine pollution</td><td>Climate change</td><td>Climate change</td></tr>
<tr><td>Managing climate risks such as floods and storms</td><td>Climate change in the ocean</td><td>European Green Deal</td><td>Sea Level Rising</td></tr>
<tr><td rowspan="3">Informing and actively contributing to and supporting scientists to enable goal 14. and associated targets</td><td>Sustainable use of ocean resources</td><td>Greening of RV Fleet</td><td>European Green Deal</td></tr>
<tr><td>Maritime Spatial Planning & Marine Protected Areas</td><td>Climate Neutral harbours</td><td>Sustainable Food</td></tr>
<tr><td>Ocean Governance</td><td></td><td>Monitor effect of Caring for soil mission on oceans</td></tr>
</table>

In the context of the UN Decade of Ocean Science for Sustainable Development (2021-2030), EUROFLEETS RI wishes to be a significant actor in supporting the scientific priorities, as reported in Figure 3.

Table 2. EUROFLEETS RI significance to the scientific priorities of the UN Decade of Ocean Science for Sustainable Development (2021-2030) (Source: Nieuwejaar *et al.*, 2019)

SCIENTIFIC PRIORITY	RESEARCH VESSEL RELEVANCE
1. Comprehensive digital atlas of the ocean	Provision of the means to aquire the data which will underpin the atlas
2. Comprehensive ocean observing system for all major basins	Enabling installation, maintenance and calibration of ocean observation infrastructures, and delivering the monitoring needed for a fully comprehensive ocean observing system
3. Quantitative understanding of ocean ecosystems and their functioning as the basis for their management and adaptation	Key provision of data to enable understanding and analysis
4. Data and information portal	Provision of data, including in real- and near-real time
5. Integrated multi-hazard warning system	Data collection and observation infrastructure support, especially in critical deep-sea and Polar regions
6. Ocean in earth-system observation, research and prediction, supported by social and human sciences and economic valuation	Providing observations but also providing a research vessel operators perspective on social, human and economic valuation of fleet, equipment and infrastructures
7. Capacity-building and accelerated technology transfer, training and education, ocean literacy	Technological innovation to enable new science and research vessels as a great tool for outreach and ocean literacy promotion
8. Provide ocean science, data and information to inform policies for a well-functioning ocean in support of all sustainable development goals of 2030 Agenda	Provision of data conducted in a sustainable manner to the science community, in order to support policy- and decision-making

In accordance with the UN SDGs, EUROFLEETS RI will increase scientific knowledge, develop research capacity and transfer marine technology. EUROFLEETS RI will address key scientific issues like ocean health, marine biodiversity, ocean acidification and others through enhanced scientific cooperation at all levels. The expected impacts address the following UN SDGs and the Paris Agreement: SDG2 – Food Security; SDG3 – Health; SDG4 – Education; SDG5 – Gender Equality; SDG7 – Energy; SDG8 – Economic Growth; SDG9 – Infrastructure and Industrialization; SDG11 – Cities; SDG13 – Climate Change, in addition to SDG 14 – Life below the water.

Additionally, the European Green Deal, launched in December 2019 is a set of policy initiatives by the European Commission with the overarching aim of making the European Union climate neutral in 2050. It aims to cut carbon emissions and achieve economic growth not tied to resource use. EUROFLEETS RI has the potential to meet the objectives through accelerating and navigating the necessary transitions supporting the offshore renewable energy research sector. Other contributions such as the greening of the EUROFLEETS RI vessels and supporting the circular and sustainable management of vessels will further support Europe's aim of being the first climate neutral continent in the world.

4. CONCLUSION

There is a consensus among the RV operators and the scientific community that so far the Eurofleets projects have provided remarkable opportunities for marine research across European Seas. Built on these successful experiences, EUROFLEETS RI wishes to continue providing vital necessary TA programs to respond to the societal needs.

A first step toward the implementation of the above-mentioned service will be to run TA programmes, at both pan-European and Regional level or for thematic areas. This will be done in collaboration with consolidated initiatives in Europe and beyond, to test and enhance the operational and financial model, along with the TA tools.

The list of potential TA programmes is reported below:

- **Regional Operational Programme.** The TA initiative can run in collaboration with EuroGOOS, taking advantage of and improving the already established coordination and development actions towards joint service production in European maritime regions. Working hand in hand, EuroGOOS members and EUROFLEETS RI can jointly enhance the European leadership in ocean observing and integrated services.

- **Ocean Decade-oriented Programme.** The TA initiative can run in collaboration with the IOC-UNESCO to support the implementation of the following Ocean Decade Programmes (list is not exhaustive):
  - Ocean Acidification Research for Sustainability (OARS);
  - Digital Twins of the Ocean (DITTO);
  - Challenger 150 - A Decade to Study Deep-Sea Life;
  - Deep Ocean Observing Strategy (DOOS);
  - The Science We Need for the Mediterranean Sea We Want (SciNMeet).

- **Mission-oriented Programme.** The TA initiative can run in collaboration with EU-funded projects to meet the mission-oriented research and innovation policy adopted by the EC in Horizon Europe programme.

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Oral Presentations – Session G

Scientists for ocean literacy

Ocean of changes – Modern approach to ocean knowledge transfer

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Keywords

Knowledge transfers, effective communication, marine education, ocean literacy

Abstract

Ocean of changes (OoCH) is an ongoing project, coordinated by the CORE (Climate and Ocean Research and Education Laboratory at Institute of Oceanology PAN) in close cooperation with international partners. OoCH is a part of the European educational platform, EU4Ocean Coalition. Since 2021, the Ocean of Changes is an official partner of the UN Decade of Ocean Science for Sustainable Development (2021-2030). Our team consists of people with different background and skills, which allows us to approach various topics with a broad perspective.

The idea of the Ocean of Changes project is to exchange information on matters relating to the seas and oceans in order to build a community operating under the UN Sustainable Development Goals, and in the case of local activities, with particular emphasis on the Baltic Sea.

We organize workshops, ecological and scientific picnics; we take part in interviews, discussion panels, prepare blog notes and articles; we are co-organizers of art competitions, summer schools, as well as conferences for young researchers from students to young doctors and conferences for school youth.

We want to stressed out the challenges in bringing researchers, data managers and educators together to provide consistent, up-to-date messages that can appeal to and can be understood by modern societies. We propose a pathway for improving communication on ocean changes that takes advantage of the technological abilities for environmental data collection and processing, global and regional research, as well as good practices in ocean literacy and climate and ocean education.

Here we present our most popular activity - Not Another Ocean Handbook which is a series of short videos covering all sorts of issues related to the marine environment, from the ocean current system, to relations with the atmosphere, ocean life, ecology, fisheries and the activities of international organizations such as the United Nations. This bottom-up project have been started during COVID pandemic outbreak in Europe, since conducting maritime education in face-to-face form were impossible. So far, our project is very successful and popular, driving its educational value, awakening the sea consciousness and convey ocean literacy. We want to show you not only the history of the Handbook, but also an important aspect of the technological changes that took place during its creation.

1. INTRODUCTION

The Ocean of Changes (OoCH) [1] project, a collaborative endeavor orchestrated by the Climate and Ocean Research and Education Laboratory [2] at the Institute of Oceanology PAN, stands at the forefront of a transformative movement. With a steadfast commitment to unraveling the complexities of our seas and oceans, OoCH exemplifies a resolute dedication to a sustainable future for our planet. In partnership with international allies and as a vital component of the European educational platform, EU4Ocean Coalition, this project has embarked on a journey to navigate the intricacies of our oceans and seas, shaping a collective vision under the United Nations Sustainable Development Goals.

This multifaceted endeavor draws its strength from a diverse and talented team, a remarkable confluence of individuals with varied backgrounds and skills, who collectively explore and address the ever-evolving challenges of our marine ecosystems. The central premise of the Ocean of Changes project is to foster an environment where knowledge flows freely, culminating in a community that actively engages with the UN's Sustainable Development Goals, with particular emphasis on the Baltic Sea and its surroundings.

The Ocean of Changes project doesn't stop at discussions; it is an action-oriented initiative. Through a rich tapestry of events, ranging from educational workshops, ecological and scientific picnics, to informative interviews, thought-provoking panel discussions, engaging blog posts, and enlightening articles, this project is sowing the seeds of change. It also plays a pivotal role in art competitions, summer schools, and conferences, ensuring that the message of ocean conservation and sustainability reaches not only seasoned researchers but also young minds and students, reinforcing the importance of nurturing the next generation of ocean advocates.

The very essence of OoCH is rooted in its mission to bridge the gap between researchers, data managers, and educators. By uniting these diverse disciplines, the project endeavors to present a unified front, offering consistent and up-to-date information that can resonate with modern societies. This approach takes full advantage of technological capabilities for environmental data collection and processing, tapping into the wellspring of global and regional research, and embracing best practices in ocean literacy, climate education, and marine science communication.

A standout aspect of the Ocean of Changes project is the "Not Another Ocean Handbook" [3] initiative, which comprises a series of concise yet informative videos. These videos traverse a wide spectrum of marine-related topics, illuminating subjects such as ocean currents, atmospheric interactions, marine life, ecology, fisheries, and the vital role of international organizations, notably the United Nations. Born out of the challenges posed by the COVID-19 pandemic, this project has garnered remarkable success, transcending traditional face-to-face education and advancing ocean literacy, all while chronicling the technological evolution that underpins its creation.

As we delve deeper into the Ocean of Changes project, we will explore not only its activities but also the profound impact it has had on understanding, conserving, and communicating the importance of our oceans and seas in the pursuit of sustainable development. Together, we embark on a journey to make waves of positive change, aligning with the UN's Decade of Ocean Science for Sustainable Development (2021-2030), and nurturing a deep-seated appreciation for our planet's most vital, yet often underappreciated, ecosystems.

2. METHODOLOGY, OBJECTIVES AND EXPECTED RESULTS

The Ocean of Changes (OoCH) is a bottom-up project that has a multifaceted methodology which combines research, education, and community engagement to achieve its objectives.

Here are the key methods employed:

1. **Collaborative Approach**
   OoCH fosters collaboration among a diverse team of experts, including researchers, data managers, educators, and community stakeholders. This collaborative approach ensures a well-rounded perspective on ocean-related issues.

2. **Education and Outreach**
   The project leverages various educational methods, including workshops, picnics, interviews, discussion panels, blog posts, articles, art competitions, summer schools, conferences and others. These educational events serve to inform and engage a broad audience, from students to young researchers and the wider community.

3. **Digital Media**
   Central to the OoCH methodology is the "Not Another Ocean Handbook" series of short videos. These videos utilize digital media to deliver easily digestible and visually engaging content on marine and ocean-related topics. This approach takes advantage of the convenience and accessibility of online platforms to reach a wide audience.

4. **Technology Utilization**
   The project harnesses technological advancements in data collection, processing, and communication. It takes advantage of data collection tools and platforms, enabling real-time data sharing and communication about ocean changes.

The Ocean of Changes project has several overarching objectives:

1. **Raise Awareness**
   The primary objective is to raise awareness about the critical issues facing our oceans and seas, with a particular focus on the Baltic Sea. This includes promoting knowledge of the UN Sustainable Development Goals and the need for ocean conservation.

2. **Community Building**
   Foster a community of stakeholders, including researchers, educators, students, and the general public, who actively engage with ocean-related topics and work together to address these challenges.

3. **Effective Communication**
   Improve the communication of ocean changes by bringing together researchers, data managers, and educators. This objective seeks to ensure that the messages delivered are consistent, up-to-date, and comprehensible to modern societies.

4. **Education and Empowerment**
   Provide accessible and engaging educational resources and events to empower individuals and communities to make informed decisions and take action to protect the oceans and contribute to sustainable development.

5. **Support the UN Decade of Ocean Science**
   As an official partner of the UN Decade of Ocean Science for Sustainable Development, the project aims to actively contribute to the goals of this international initiative and promote ocean science for the benefit of society.

The Ocean of Changes project anticipates several tangible results:

1. **Increased Awareness**
   A more informed and aware society regarding the challenges and importance of ocean conservation and sustainable development.

2. **Empowered Communities**
   Communities and individuals who are equipped with the knowledge and tools to take action to protect the oceans.

3. **Strengthened Network**
   A robust network of stakeholders, including researchers, data managers, educators, and the public, collaborating on ocean-related initiatives and research.

4. **Informed Decision-Making**
   Informed decision-making at local and international levels with regard to ocean policies and practices.

5. **Positive Impact:**
   Contributions to the UN Decade of Ocean Science for Sustainable Development, advancing the goals of this initiative and promoting positive change in the understanding and conservation of the oceans.

6. **Technological Advancement**
   Leveraging and showcasing the evolution of technology in data collection, sharing, and education, with a focus on improving ocean literacy.

In summary, the Ocean of Changes project employs a comprehensive methodology to achieve its objectives, focusing on education, collaboration, and technological advancement. Its expected results encompass a more aware and engaged community, strengthened networks, and a positive impact on ocean sustainability and conservation efforts.

3. CONCLUSIONS

The Ocean of Changes (OoCH) project stands as a beacon of hope and action in the realm of ocean conservation and sustainability. Through its multi-faceted approach, this initiative has made significant strides in raising awareness, educating communities, and fostering collaboration among diverse stakeholders.

As we draw our conclusions, several key points emerge:

1. **Unified Approach**
   OoCH has demonstrated the power of unity by bringing together a diverse team of experts, ranging from researchers and data managers to educators and the wider community. This collaborative approach has proven to be a formidable force in addressing the complex challenges facing our oceans.

2. **Education as Empowerment**
   Education is at the heart of OoCH's mission. The project's workshops, picnics, interviews, blog posts, articles, and the innovative "Not Another Ocean Handbook" video series have empowered individuals and communities with knowledge, making them better equipped to make informed decisions and take action to protect our oceans.

3. **Communication and Outreach**
   Effective communication has been a cornerstone of OoCH's strategy. By bringing together researchers, data managers, and educators, the project has succeeded in delivering consistent, up-to-date, and accessible messages about ocean changes, thereby enhancing public understanding and engagement with these crucial topics.

4. **Global and Local Impact:**
   OoCH has not limited its ambitions to local concerns but has aligned itself with international initiatives, notably the UN Decade of Ocean Science for Sustainable Development. This alignment has positioned the project to contribute meaningfully to global goals and to promote ocean science for the benefit of society.

5. **Technological Evolution:**
   The project's adaptation to the challenges of the COVID-19 pandemic by launching the "Not Another Ocean Handbook" video series showcases the capacity of technology to deliver education and inspire change, even during the most trying circumstances. This digital innovation has proven highly successful in driving ocean literacy and awareness.

In conclusion, the Ocean of Changes project is a testament to the power of collaboration, education, and technological innovation in addressing the critical issues surrounding our oceans. It has not only informed and empowered communities but has also set an example for how diverse groups can come together to make positive changes in the world.

As we navigate the UN Decade of Ocean Science for Sustainable Development, OoCH stands as a shining example of how collective efforts can contribute to a sustainable future for our oceans and, by extension, our planet. The project's impact goes beyond the dissemination of information; it has sown the seeds of lasting change, nurturing a profound appreciation for our oceans and their pivotal role in the broader context of sustainable development. It is a reminder that, together, we can make a difference and protect the life-sustaining ecosystems that lie beneath the waves.

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Galway Atlantaquaria and the Irish Ocean Literacy Network – The role aquariums can play in fostering global Ocean Literacy (OL)

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Keywords

Ocean literacy, all-island network, local to global collaborations, dialogue

Abstract

Irish Ocean Literacy Network (IOLN) is the working name of an informal network established in 2016, aimed at bringing together individuals and organisations who are currently involved in, or would like to become involved in, working towards the IOLN vision, which is to achieve an Ocean Literate society across the Island of Ireland. Since its inception, the IOLN has hosted many networking events, workshops, etc., including the 'We Are Islanders' national campaign. The Network has also become recognised internationally as an advocate of OL and is involved in large scale initiatives such as the UNESCO Ocean Literacy With All, the EU4Ocean Platform, the EuroGOOS Ocean Literacy Working Group, and is part of both the All-Atlantic and the European Blue Schools Network. Galway Atlantaquaria (GA), National Aquarium of Ireland, is the current Secretariat of the IOLN. In this role, it acts as a central contact and dissemination point for the Network supporting initiatives and collaboration opportunities between the IOLN members and providing a platform for engagement with relevant stakeholders. By showcasing a range of GA and IOLN initiatives, we hope to highlight the role zoos and aquariums can play in improving dialogue and interaction between civil society, decision makers, stakeholders and scientists.restoration and shoreline change mitigation. The results of this study provide important data and information for better scenario coastal planning and management.

1. INTRODUCTION

The need for increased OL, defined as 'an understanding of the ocean's influence on us and our influence on the ocean', has been acknowledged 'to allow society to understand critical issues associated with important ocean-related topics … and developing a sustainable future' (Santoro *et al.*, 2018). However, it is increasingly recognised that awareness and knowledge about the ocean are not enough to encourage effective behaviour changes, and this has led to the development of new OL models which aims at understanding how to foster 'active participation, connection, and engagement from the diversity of audiences across society' (McKinley *et al.*, 2023).

The Irish Ocean Literacy Network (IOLN) is an all-island network of individuals and organisations who are currently involved in, or would like to become involved in, working towards the IOLN vision, which is to achieve an Ocean Literate society across the Island of Ireland. The IOLN was established informally in 2016 to mantain and build up on the all-island network that was developed in the framework of the EU project Sea for Society (2012–2015), a European Mobilisation and Mutual Learning Action Plan (MMLAP) funded by the European Commission's DG Research & Innovation under the theme Science in Society. For the first time in Europe, this project consulted citizens, young people and stakeholders on issues related to the ocean, and this unique and innovative approch obtained a comprehensive and complex picture of the challenges involved in the creation of a 'Blue Society' which recognises 'the importance of the Ocean as a commonly shared resource requiring collective management by all' ('Sea for Society' final report summary, 2015). As a result of their participation in 'Sea for Society', the project partners in Ireland recognised the importance of building, maintaining and integrating networks in order to implement a Blue Society in the future (McHugh & Domegan, 2017), therefore the establishment of the IOLN was felt like the necessary action to take in order to bring forward the legacy of the project and promote the development of a Blue Society on the Island of Ireland.

2. THE IOLN OVER THE YEARS

2.1. The structure of the IOLN

In May 2023 there were 143 members listed for IOLN, representing individuals, community groups, SMEs, semi-state and other state agencies. Membership is currently free and open to any public or private entity on the island of Ireland which has an interest in working towards the vision of the Network. The current governance of the IOLN involves a voluntary Steering Committee (SC) whose main role is to guide the development of the Network. Day-to-day activities are carried out by a part-time Secretariat currently held by Galway Atlantaquaria (GA) which acts as a central contact and dissemination point for the Network and works in conjunction with the Steering Committee to define goals and deliverables to measure the impact and effectiveness of the Network. Part of the role of the Secretariat is to organise regular networking events and workshops for the IOLN members, and to distribute information about projects and initiatives carried on by the same members as well as other opportunities of interest for the whole community of OL champions. Between 2016 and 2021, funding came mainly through contributions from the Marine Institute, supplemented by Bórd Íascaigh Mhara (BIM) in 2020 and 2021.

2.2. The 'We Are Islanders' campaign

One of the major events organised by the IOLN was an all-island social media campaign called 'We Are Islanders' in 2019. The theme was selected after a consultation held with the members of the Network in February that year, whereas the campaign was designed the following May at a co-creation workshop open to all the IOLN members. To join 'We Are Islanders', participants were asked to share their personal connections with the ocean via short videos to be posted on social media with the common hashtag #weareislanders. The campaign was launched on World Ocean Day and saw a large enthusiastic participation by the Network members, as shown in Fig. 1. Despite the abrupt interruption of the campaign caused by the Covid pandemic, the hashtag #weareislanders is still used to connect news and social media posts about the activities carried out by the IOLN members in 2020, when the hashtag #WeAreIslanders trended online.

Figure 1. A selection of pictures of the IOLN members who took part in 'We Are Islanders' taken at different marine-themed events with the photo op frame that was designed for the campaign.

2.3. International collaborations

The work carried out by the IOLN to promote OL on the Island of Ireland has been recognised internationally via the inclusion of the Network in initiatives such as the UNESCO Ocean Literacy With All, the EU4Ocean Platform, and the EuroGOOS Ocean Literacy Working Group. In this view, in 2022 the Network was involved in two major events at European and global scale respectively: in June the IOLN was one of the ten organisations to sign the new Charter for Blue Education in Europe co-developed by the same organisations within the framework of the EU4Ocean Coalition and its Network of Blue schools (Fig. 2a), whereas in October the IOLN participated to the first in-person meeting of the National Coordinators of the All-Atlantic Blue Schools Network during the 2nd Ocean Literacy Dialogues event, which was held in Brazil (Fig. 2b).

2.4. Inclusion in the PREP4BLUE project

Currently, the IOLN is one of the OL networks involved in PREP4BLUE, a Horizon Europe project started in 2022 whose name stands for 'Preparing the Research & Innovation Core for Mission Ocean, Seas & Waters'. In fact, PREP4BLUE will set the foundations for co-creating and co-implementing the research and innovation required to enable the EU Mission: Restore Our Ocean and Waters, and the IOLN will contribute to the project's work focused on enabling stakeholders to empower citizen and community-led action in support of the Mission, through deepening and widening citizen engagement by leveraging participatory innovations. In this view, the IOLN will work until 2025 to increase its reach and connect with potential new members and stakeholders, seed and develop other OL networks across Europe offering mentoring and sharing learnings and materials, and finally the IOLN will be piloting activities associated with other tasks within the framework of PREP4BLUE in order to develop the Network and to promote the Mission's goals.

Figure 2. **a)** Group photo of the representatives of the ten organisations that signed the Charter for Blue Education at the UN Ocean 2022 on June 29 in Lisbon. **b)** The National Coordinators of the All-Atlantic Blue Schools Network who took part in the 2nd Ocean Literacy Dialogues event in Brazil.

3. THE ROLE OF GALWAY ATLANTAQUARIA IN SUPPORTING THE IOLN

Galway Atlantaquaria (GA), National Aquarium of Ireland, was appointed to the role of Secretariat of the IOLN in 2018. Since then, GA has been supporting collaboration opportunities between the Network members and providing a platform for engagement with relevant stakeholders via facilitation and promotion of many initiatives over the years. Here we describe some of the main initiatives promoted by GA to support the IOLN in 2023.

3.1. The series of regional meetings

To stimulate the dialogue within the IOLN and to reach out to potential new members and other stakeholders, GA organised a series of regional members meetings across the four provinces of Ireland, i. e. Connacht, Leinster, Munster and Ulster, between March and June. The aim of these meetings was to give the Network members the opportunity to come together in person to exchange ideas and discuss future plans for common OL initiatives after the long break caused by Covid. Unfortunately, the meeting in Dublin had to be postponed, but the three meetings organised in Belfast, Galway and Cork provided great opportunities to showcase the very cutting-edge and diversified OL work carried on around the country and to discuss how the IOLN could best support the work of its members and contribute to the establishment of new OL-focused initiatives in Ireland. In particular, the discussions held at the meeting in Belfast highlighted the important role that the IOLN can play in fostering cross-border dialogue and collaborations among ocean stakeholders (Fig. 3).

Figure 3. The attendees at the IOLN regional meeting in Belfast held on the 29th March 2023. The group included representatives of a wide range of sectors including academia, government bodies, state agencies, NGOs and SMEs.

3.2. **The support to conservation initiatives**

As part of its role as IOLN Secretariat in the framework of PREP4BLUE, GA is supporting the first specific objective of the EU Mission: Restore Our Ocean and Waters that is to 'protect and restore marine and freshwater ecosystems and biodiversity' (European Commission, 2021) via the establishment of working groups within the IOLN focused on key marine ecosystems under threat, like e. g. seagrass meadows and coastal dunes. Moreover, GA is helping promote both local and nationwide conservation activities via the funding of small grants aimed at supporting and encouraging individuals or community groups working in marine conservation and education.

In this view, last May GA organised a first general meeting aimed at establishing an all-island network of individuals and organisations working on seagrass conservation with the support of researchers from the Smithsonian Institution and the University of Maryland as well as Irish citizen science groups as Seasearch Ireland and Fenit Coast Conservation. GA also awarded five small conservation grants to several projects stretching along the West coast or Ireland which included a citizen science project about skates and rays across the country, a youth marine education programme in Donegal, an art project in a primary school in Galway, and initiatives based in Kerry, i.e. a European oyster reef restoration project and the collaboration among four coastal community organisations to complete the survey of a unique seagrass ecosystem.

4. THE FUTURE OF THE IOLN

The IOLN has been successful in building a large Network of members and stakeholders, showing resilience and adaptability in serving the needs of its members and established a good reputation in Ireland and internationally. However, its informal organisation structure and governance model has been recognised to not be suitable to sustain the growth desired over the next future. For this reason, the IOLN is in the process to form a new Company Limited by Guarantee (CLG), i. e. a type of corporation which will enable the Network to secure medium to long-term funding and to harness the opportunities presented by national, EU and international initiatives. In this way, the IOLN will be able to develop new strategies to further the goals of OL on the island of Ireland and engage with a wider pool of members and stakeholders.

5. CONCLUSIONS

'Educate, Engage and Inspire' is the call of action of GA, and this has been put into practice not only through a wide diversity of exhibits showcasing the world of water, from the river to the sea, but also through the implementation of a large range of formal and informal education activities involving students from pre-school to college level as well as the organisation of a multifaceted programme of public engagement initiatives aimed at promoting OL with the wider public. As part of the latter, GA supports the development of the IOLN promoting dialogue and collaborations among individuals and organisations working in all possible marine sectors with a view 'to conserve ocean health and promote sustainable means of using ocean resources' (Ryabinin, 2019). Therefore, with its work GA shows how aquariums (and zoos) can play a key role in improving dialogue and interaction between civil society, decision makers, stakeholders, and scientists.

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Oral Presentation – Session H

Ocean data assimilation trends and challenges

Integrating data assimilation and deep learning to maximize the impact of BGC-Argo observations in the Mediterranean Sea biogeochemical forecasting system

Authors

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Keywords

Model predictions, deep learning, data assimilation, BGC-Argo

Abstract

As part of the EU Marine Copernicus Service, the Mediterranean Biogeochemical Operational System (MedBFM) includes a multivariate and multiplatform variational data assimilation (DA) scheme for Ocean Color chlorophyll observations and BGC-Argo chlorophyll, nitrate and oxygen profiles. To further increase the benefits of assimilating profiles of biogeochemical variables, a multilayer perceptron deep learning (DL) is used to produce relationships between high-frequency observed variables and low-frequency ones. Using ARGO profiles of temperature, salinity, and oxygen (i.e., the most commonly available BGC sensor), the DL models generate synthetic measurements of nitrate that are integrated into the operational MedBFM system through data assimilation. Synthetic nutrient profiles are quality controlled and merged with measured BGC-Argo profiles and different simulations are used to evaluate the effectiveness of the enhanced observing system in constraining model dynamics and improving model predictions. Results demonstrate the feasibility of integrating DL and DA into an operational model forecast system, and show that the model prediction performances for assimilated variables are improved by the integrated DL / DA system, while no degradation is detected for other variables.

1. INTRODUCTION

In the context of operational oceanography, the biogeochemical modelling component of the Copernicus Marine Service for the Mediterranean Sea (MedBFM) provides analysis, short term forecast (Salon *et al.*, 2019) and long term reanalysis (Cossarini *et al.*, 2021), including the assimilation of satellites Ocean Colour (OC) and BGC-Argo observations (Salon *et al.*, 2019).

The 3DVarBio variational assimilation scheme of MedBFM has evolved over time by including a greater number of observation types and variables. Starting from the first release (Teruzzi *et al.*,2014), the assimilation has progressively included coastal OC observations (Teruzzi *et al.*, 2018), chlorophyll and nitrate profiles from BGC-Argo (Cossarini *et al.*, 2019 and Teruzzi *et al.*,2021, respectively). Given the growing availability of oxygen (O_2) from BGC-Argo, we propose the integration of O_2-based Neural Network (NN) reconstructed profiles of nitrate in the assimilation scheme.

The use of NN to reconstruct biogeochemical variables was introduced by Sauzede *et al.*, (2017), that employed an Multi Layer Preceptor (MLP-NN) to approximate nutrient and carbonate system variables from physical and oxygen in situ data. An updated version by Bittig *et al.*, (2018c) allowed a refining of the previous work for the global ocean, whereas a specific configuration for the Mediterranean Sea region was developed by Fourrier *et al.*, (2020). With the specific aim of using NN to reconstruct vertical profiles of nitrate, a further update of the application of the MLP method in the Mediterranean Sea is provided in Pietropolli*et al.*, 2023).

2. METHODS

A novel combined Neural Network (NN-MLP-MED) and Data Assimilation (3DVarBio) approach is included in the Mediterranean MedBFM model system to integrate BGC-Argo and reconstructed profiles into biogeochemical simulations of the Mediterranean Sea. The MedBFM, which is the biogeochemical component of the Mediterranean Copernicus Marine Service, consists of the OGS transport model (OGSTM), the BFM, Biogeochemical Flux Model and the 3DVarBio variational assimilation scheme (Salon *et al.*, 2019; Cossarini *et al.*, 2021; Teruzzi *et al.*, 2021).

The NN-MLP-MED (Pietropolli *et al.*, 2023) is the evolution of previous MLP architectures developed to predict low-sampled variables (e.g., nutrients) starting from high-sampled ones (e.g., temperature) (Sauzede *et al.*, 2017, Bittig *et al.*, 2018c and Fourrier *et al.*, 2020). Novel elements include: a large training dataset, a two-step quality check process, and changes in neural network architecture to enhance prediction performance by incorporating nonlinear functions. The error of reconstructed nitrate, obtained by using the EMODnet (Buga *et al.*, 2018) as validation dataset, was 0.5 mmol m−3 (Pietropolli *et al.*, 2023). ARGO profiles of temperature, salinity, and oxygen (i.e., the most commonly available BGC sensor) are then used to reconstruct nitrate profiles more than doubling the number of nitrate profiles.

A novel quality control procedure for BGC-Argo oxygen data includes detection of oxygen sensor drifts and comparison with EMODnet climatology and typical variability in deep layers (Amadio *et al.*, 2023).

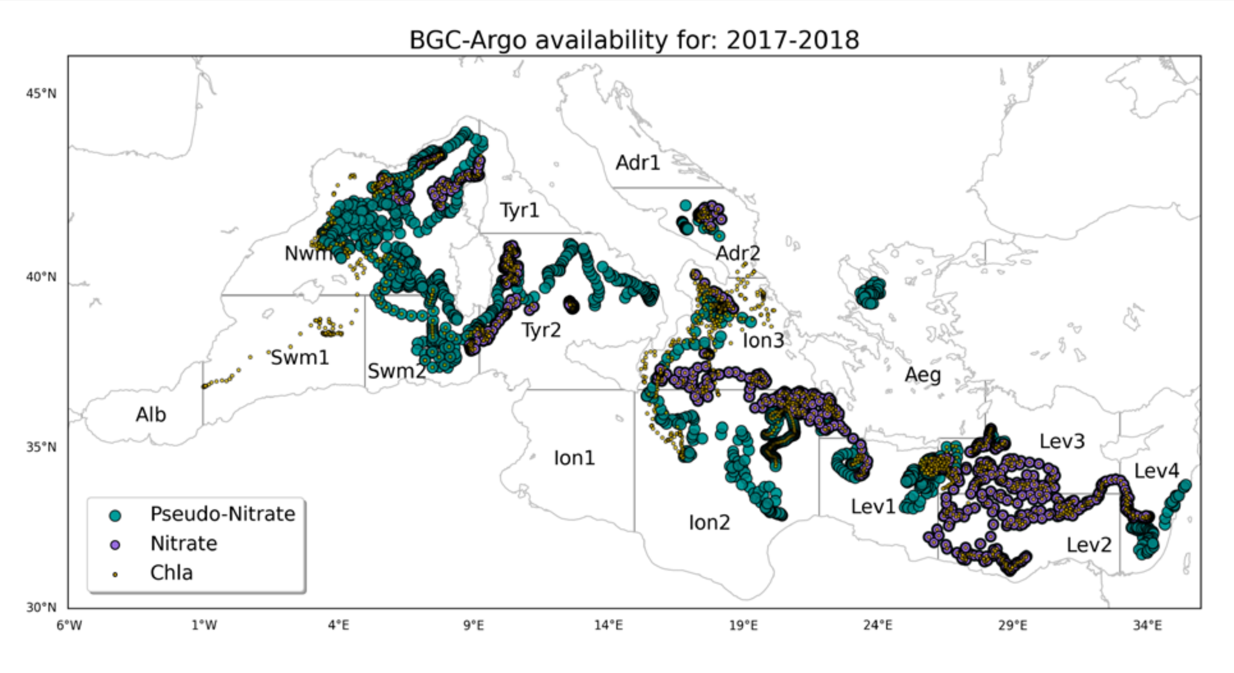

Figure 1. Mediterranean Sea model domain and position of BGC-Argo profiles of chlorophyll-a (red), Nitrate *in situ* (orange) and reconstructed Nitrate (grey).

Three numerical experiments covering the 2017-2018 time range were performed to assess the impact of the integration of real and reconstructed nutrient profiles: an hindcast simulation (REF), a simulation with assimilation of BGC-Argo profiles of nitrate, oxygen and chlorophyll (DAfl) and a simulation which included also the assimilation of reconstructed nitrate profiles (DAnn). The MedBFM setup mostly corresponds to the standard adopted in the Mediterranean Analysis and Forecast biogeochemical system of the Marine Copernicus Service (details are provided in Salon *et al.*, 2019).

3. RESULTS

The RMSD metrics of the simulations based on the comparison between of BGC-Argo data and first guess of simulations are shown in Table 1 for selected layers. It is worth to note that only BGC-Argo profiles are used in the validation (i.e., reconstructed NN profiles are used only for assimilation).

As already shown in Teruzzi *et al.*, (2021), the assimilation of *in situ* BGC-Argo considerably improves the quality of modelled nitrate with respect to the hindcast simulation (Table 1). In addition, the assimilation of the reconstructed profiles further decreases the RMSD. This impact can be directly ascribed to the increased number of reconstructed nitrate profiles that generate more persistent corrections near BGC-Argo nitrate profiles.

Table I. RMSD of nitrate for the three runs: hindcast (HIND), assimilation of BGC-Argo (DAfl) and assimilation of both BGC-Argo and reconstructed profiles (DAnn).

	0-10m	10-30m	30-60m	60-100m	100-150m	150-300m	300-600m
HIND	1.243	1.175	1.060	1.046	1.261	0.944	0.873
DAfl	0.955	0.885	0.696	0.750	0.878	0.571	0.486
DAnn	0.913	0.847	0.658	0.722	0.869	0.619	0.476

The departure of the two assimilation simulations from the reference solution provides insights into the impact of the observing system design. Here, we adopt the data impact indicators described in Teruzzi *et al.*, (2021), which consists in the 0-300 m vertical integration of the absolute difference between assimilation simulations and REF (for each day and grid point). In particular, Figure 2 shows the impact indicator in winter (left column) and in summer (right column) for the two runs: DAfl (first row) and DAnn (second row). The higher the values of the indicator, the higher the impact of the assimilation. In the run with BGC-Argo assimilation (DAfl), the extent of nitrate indicator above 0.1 is 16.5% and 18.7% in winter and in summer respectively, with clear spatial distribution mapping the BGC-Argo density. The introduction of reconstructed profiles in DAnn make it possible to increase the nitrate impacted areas up to about 35% and 39% in winter and summer respectively.

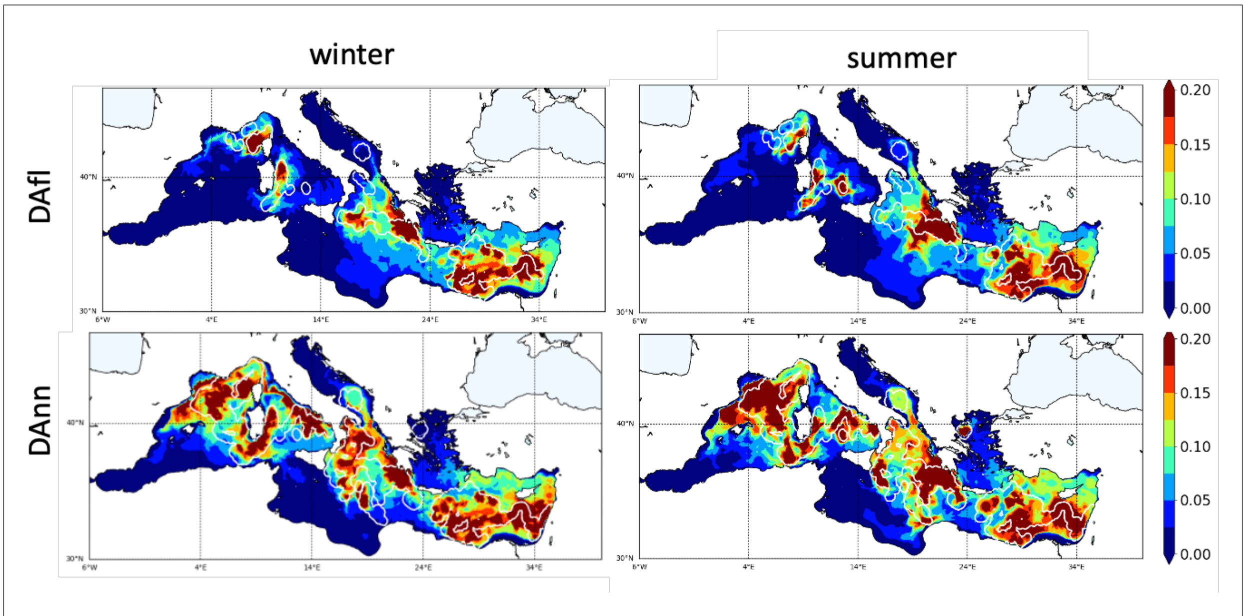

Figure 2. Spatial impact indicator of the assimilation nitrate profiles for the two runs DAfl (upper) and DAnn (lower) in winter and summer.

The positive impact extends to vertical ecosystem dynamics, such as nutricline and deep chlorophyll maximum in summer, as well as ecosystem indicators such as vertically integrated primary production, demonstrating the importance of vertical measurements to constrain simulations of the ocean interior. Details and additional results are described in Amadio *et al.*, 2023.

4. FINAL REMARKS

Our results show that the combining deterministic Feed-Forward Neural Network and Data Assimilation enhances the positive benefits of the multivariate profile assimilation in the Copernicus Operational System for Short-Term Forecasting of the Biogeochemistry of the Mediterranean Sea (MedBFM). This is particularly important considering that the recent evolution of availability of BGC-Argo sensors showed a dramatic decrease in nitrate and chlorophyll after 2020 (Figure 3). Thus, the combination of NN and DA together with enough oxygen profiles will support the positive impact of the BGC-Argo observing system.

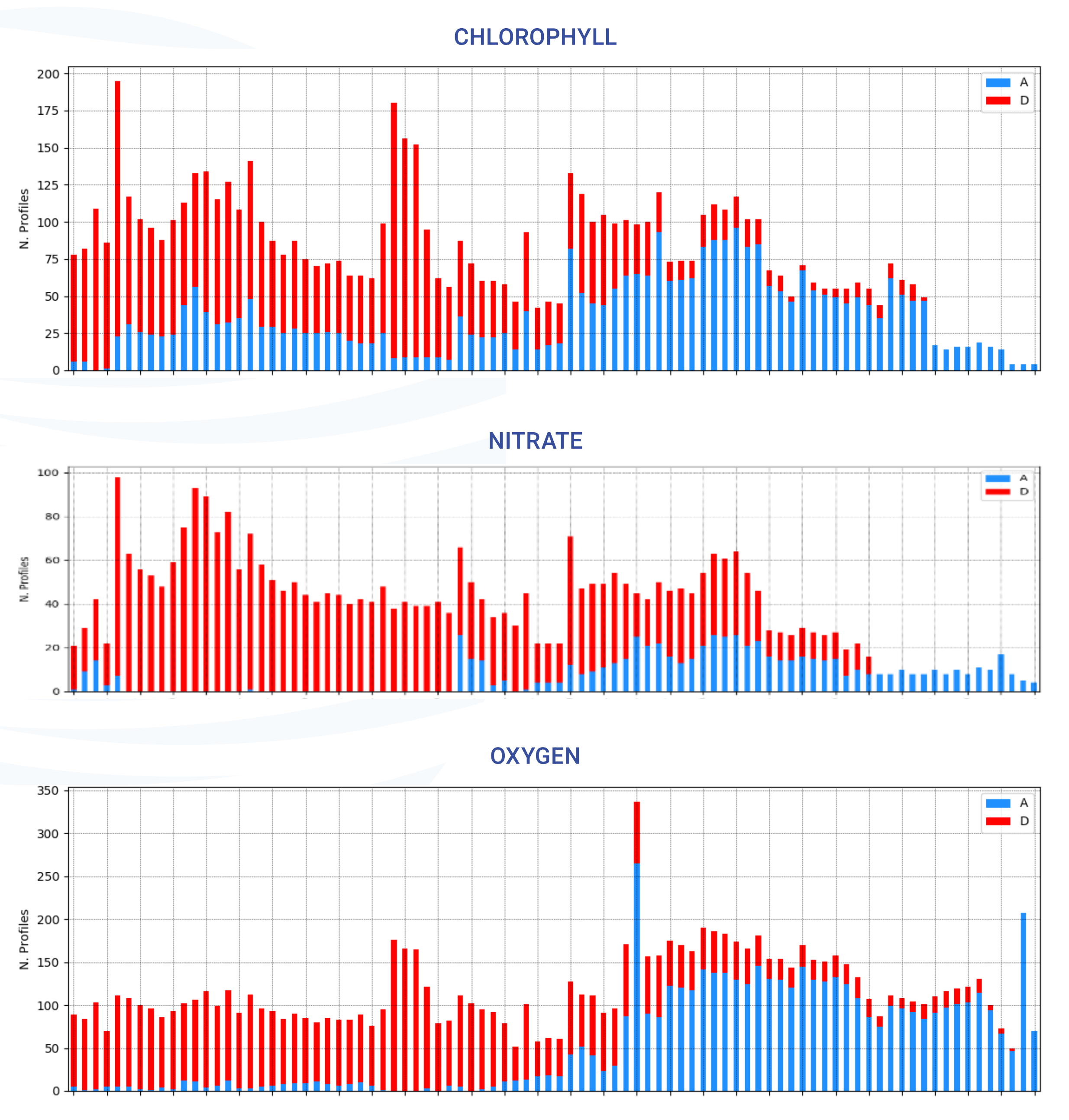

Figure 3. Number of available BGC-Argo profiles for chlorophyll, nitrate and oxygen.

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Oral Presentations – Session I

Ocean observing co-design and stakeholder engagement

Talking with the potential end-users of the *Observatorio Costeiro da Xunta de Galicia* as a starting point of their engagement: perceptions and necessities

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Keywords

Operational Oceanography, Coastal Observatory, Blue Economy, Stakeholder engagement, NW Iberian Peninsula

Abstract

The Observatorio Costeiro da Xunta de Galicia leads operational oceanography in Galicia, offering observation and forecast systems to manage marine ecosystem services and face the challenges of climate change. Through partnerships with government entities and projects funded by the INTERREG V-A España-Portugal Program, as ATLAZUL, the usefulness and demand of the observatory's information by end users is evaluated. In addition, supplementary information needs were identified. The Observatory highlights the importance of the participation of end users to meet the needs of society and improve the accessibility and usability of oceanographic data.high-risk local areas. A storm surge model has been developed for the first time for the NW of Ireland using a finite element hydrodynamic modelling suite called Shallow water HYdrodynamic Finite Element Model (SHYFEM), a 3D hydrodynamic model particularly suitable for application in areas of

complex geometry and bathymetry. This model is validated and calibrated with low-cost water level sensors after the subsequent validation of these low-cost sensors with standard reference instruments. Such a framework could be replicated for development of a storm surge model in any high-risk ungauged coastal areas, especially in face of the rising coastal flooding risk from increasing sea levels. The NW of Ireland has sparse coastal observation systems and hence has been conducive for implementing such a modelling approach using low-cost water level sensors for validation and calibration.

1. INTRODUCTION

Operational oceanography involves the systematic and continuous measurement, interpretation, and dissemination of information regarding the ocean and atmosphere. This valuable data serves as a crucial tool for optimizing the management of marine resources and ecosystem services, enhancing contingency plans for addressing marine accidents and extreme events, boosting the Blue Knowledge and Economy or dealing with climate change challenges.

Therefore, all the geographic areas and socio-cultural identities that are linked to the seas or oceans should implement and strengthen their observational infrastructures and side with societal needs and challenges in order to face them. Stakeholders' viewpoint must be taken into account, as a first step of a co-creation process, to design the forthcoming future of the Observatories.

Observatorio Costeiro da Xunta de Galicia (Coastal Observatory of the Government of Galicia)

Situated in the southwestern part of Europe, the Iberian Peninsula is surrounded by the Mediterranean Sea and the Atlantic Ocean, which embrace its 8000 kilometres of coastline. Nearly 20% of this coastline belongs to Galicia, located in the north western region of the Iberian Peninsula. Consequently, Galicia's 1500-kilometer-long coast holds immense social, environmental, and economic significance for Galician way of life. Galicia's coastal areas not only contribute to vital sectors such as fisheries, aquaculture, shellfish harvesting, shipyards, port activities, and merchant traffic but also play a key role in the development of renewable energies and coastal and maritime tourism.

As a consequence, *Observatorio Costeiro da Xunta de Galicia* (www.observatoriocosteiro.gal) leads the operational oceanography in Galicia carrying out observing and forecasting systems and the implementation of services and products for 30 years.

The *Observatorio* is partnered by three different public institutions as a leading example of interinstitutional cooperation. Firstly, *Dirección Xeral de Calidad Ambiental, sostenibilidad y Cambio Climático (DXCASCC-MeteoGalicia), under Consellería de Medioambiente,* *Territorio e Vivenda* (Ministry of Environment of the Government of Galicia) that maintains meteorological and climatological observation, develops a meteorological and marine forecast and provides a guide to future weather conditions for Galicia. Secondly, and depending on Consellería do Mar (Ministry of Sea of the Government of Galicia), Intecmar that controls the quality of the marine environment and the implementation of the regulations for technical and health control of sea products, and CETMAR, a public Foundation that works to improve the marine environment, its resources and all the sectors involved and to encourage innovation and environmental, social and economic sustainability. Furthermore, *Observatorio Costeiro Xunta de Galicia*, and its partnership, belong to *Observatorio RAIA* (www.marnaraia.org), a leading case of European Cross-Border cooperation in the Galicia-North Portugal Euroregion.

Observatorio Costeiro Xunta de Galicia engages in three main activities: observation, prediction, and implementation of services and products, enabling us to understand and forecast ocean behaviour (Figure 1). All data is available at http://www.observatoriocosteiro.gal and on the main European Data Aggregators as CMEMS, EMODnet and SeaDataNet.

Figure 1. Partnership and main activities of the *Observatorio Costeiro da Xunta de Galicia*.

1.1. Observing System

Different facilities operate concurrently to guarantee the availability of accurate data, after an automatic quality control process, which include physical and historical range tests, spike tests, rate of change tests and a visual checks to enhance the reliability and usability of the data.

The Observatory controls six automated platforms in the Rías Baixas area, with some platforms being in operation since 2007. These platforms gather real-time data on water temperature, salinity, oxygen levels, currents, as well as meteorological parameters like temperature, wind, and humidity. Besides, weekly profiles are carried out at 43 oceanographic stations in the four Rías Baixas and Ártabro Gulf, offering comprehensive data on temperature, salinity, conductivity, oxygen, fluorescence, pH, transmittance, irradiance and density as well as biogeochemical parameters from water samples. These ongoing series of measurements, which began in 1992, represent one of the longest and most extensive in the world. In addition, nearly 50 coastal weather stations gather real-time measurements of wind, temperature, humidity, precipitation, air pressure, and radiation. Moreover, a HF radar network consisting of four stations in Galicia and one in Portugal facilitates the production of surface current maps up to 100 miles, along with wave parameters. This network plays a vital role in monitoring the Finisterre traffic separation scheme, which involves more than 40,000 ship crossings annually.

1.2. Forecasting System

Numerical forecast system, which runs models on a daily basis, is maintained by the Observatory. Hydrodynamic models, such as ROMS for the Galician coast (resolution: 2km) and MOHID for the estuaries (resolution: 300m), are used to predict sea level, currents, salinity, and temperature. The atmospheric WRF model generates forecasts for temperature, wind, pressure, precipitation, and other variables once a day for Galicia, with a resolution of 1km, and twice a day with a resolution of 4km. Wave models, namely WaveWatch III (WW3) for the open sea and SWAN in the coastal zone (non-structured grid, resolution less than 50m), provide predictions for significant wave height, period, and wave direction. In the event of accidental pollution, Lagrangian models are employed to assist maritime authorities. The predictive models are validated and enhanced through ocean observations, ensuring their high reliability, being the observatory end-user of their own data.

1.3. Products and Services

Several value-added products and services are developed by the use of the observatory information. Daily ocean-meteorological forecast bulletins offer comprehensive details regarding weather and sea conditions, as well as, specific forecast viewers that provide information about beaches and ports. Furthermore, specialized services have been developed to help specific end-users, such as the

Percegurú mobile application designed for goose barnacle harvesters, or *Plan Camgal* viewer, aimed for Marine Pollution Fight. These services also include some HF Radar viewers, which not only provide surface current information but also feature HF radar derived upwelling index and waves. Moreover, there is a tool dedicated to detect and show natural underwater noise events like cetaceans or anthropogenic ones, facilitated by a hydrophone installed in one of the automated platforms.

1.4. Methods

In order to assess how well-known, how much used and how useful the observatory information is and which other information could be interesting for end-users, a total of 30 meetings have been carried out with stakeholders. The relationship between stakeholders and the sea is diverse: fishing and aquaculture activities, tourism, ad hoc services and APPs, GIS professionals, competent authorities or marine safety. ATLAZUL Project, financed by INTERREG V-A España-Portugal Program, aims to impulse the Atlantic coastal alliance for blue growth and has provided the ideal context for these interactions.

During these interviews, a large catalogue of oceanographic capabilities in Galicia from the *Observatorio RAIA* has been shown, where specifications as spatial and temporal distribution, parameters and units are included, likewise how to find and handle all data series on the websites www.observatoriocosteiro.gal and www.marnaraia.org. In addition, a large list of new necessities and requirements that could be convenient and suitable for stakeholders to improve their activities has been also gathered during the interviews.

1.5. Results

This section summarizes the Observatory information that is known and used (Figure 2, Table 1), data that are considered interesting for stakeholders' future activities (Table 1) and new necessities of oceanographic information that have been identified (Table 2). All facilities are from the Observatorio RAIA (www.marnaraia.org), the Cross-Border one, while those written in italics are owned by the *Observatorio Costeiro Xunta de Galicia*.

Table I. Table showing the number of stakeholders that knows or uses the facilities of the Observatorio Costeiro da Xunta de Galicia and the number of stakeholders interested in use them (total of stakeholders=30).

Number of Stakeholders that know and use each facility					
	Facility	**Know**	**Occasional use**	**Frequent use**	**Stakeholders interested in each facility**
Observations	Oceanographic Buoys	13	4	2	14
	External HF Radar	4	2	2	10
	HF Radar of Ría de Vigo	7	2	0	8
	Coastal Waters Quality (CTD +Samples)	7	0	0	7
	Transitional Waters Quality (CTD+Samp)	4	0	0	5
	Weekly CTD stations	13	7	3	2
	Weather stations	6	4	20	2
	Monthly radial surveys	4	1	0	1
	Continuous station of Toralla	3	0	0	1
	Weekly biogeochemical sampling	16	4	3	1
	Continuous underwater covering of CSIC	1	0	0	1
Forecast	Oceanographic models from *Xunta*	7	3	2	12
	Oceanographic models from UAveiro	1	1	0	9
	Wave models	5	4	21	3
	Weather model from *Xunta Galicia*	3	4	23	1
Services and Products	Upwelling Index by HF	6	0	0	9
	Plan CAMGAL	12	3	0	8
	HF Wave viewer	4	2	0	7
	HF Currents viewer	4	0	2	6
	Upwelling Index IEO	1	0	1	5
	MarRISK Index	2	0	0	4
	Percegurú	12	4	0	3
	Marine weather Bulletin	5	0	25	1
	Kitesurf	2	2	0	1
	Beach weather Bulletin	11	7	0	1
	Beach waters	8	6	3	1

Table 2. The most required oceanographic information gather after interviewed stakeholders.

	Facility	Nº stakeholders interested
Observations	Temperature in specific areas	5
	Time series of closed offshore rafts for toxic Harmful Algal	5
	Salinity in specific areas (internal zones of estuaries)	4
	Turbidity	3
	High-Frequency Radar with high resolution in other areas	3
	Socioeconomic data associated with the fishing-aquaculture	3
	Presence of faecal discharges (E. coli)	3
	Key contaminants for exploited species (sulfate)	3
Forecast	Improved wave models (specific to zones)	5
	Improved wind models (specific to zones)	5
	Improved current models (specific to zones)	3
	Biological models for exploited species (spawning)	1
Services and Products	Viewer with integrated information in one place	4
	Viewers with accessible metadata, FAIR data	4
	Mobile viewer with integrated information in one place	3

2. DISCUSSION

Regarding to observing systems, models and services and products in Galicia, the external interviewees are aware of the 50% available information, and one fifth of it is used, at least, occasionally (10% frequently, Table 1). In relation to the facilities from the *Observatorio Costeiro da Xunta* numbers pinpoint to an improvement of knowledge: almost 60% of them are well-known and one third are commonly used, especially, predictive models (atmospheric and wave ones). Observing systems -oceanographic Buoys, weekly CTD stations and biogeochemical sampling, weather stations- are widely handling, except for the HF RADAR information that has just been implemented and launched in highly intuitive and user-friendly viewers. In addition, the ocean-meteorological daily forecast bulletin or other specific forecast viewers, which inform about the forecast for beaches and ports, are extensively employed (table 1).

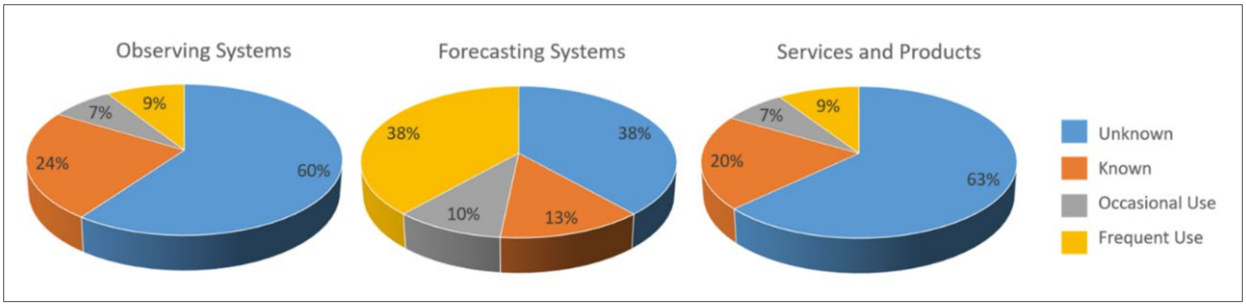

Figure 2. Percentage of Observing Systems (left), Forecasting Systems (centre) and Services and Products (right) that are Unknown (blue), Known (orange), occasionally used (grey) and Frequently used (yellow) by the external stakeholders.

The information that has been presented to the stakeholders has also generated a lot of interest, and a significant part of this data that are not used before has been deemed very useful for their employment in the future (Table 1). Among these, the data from Oceanographic Buoys, oceanographic models (other ones are widely used), the external HF Radar viewers -for current, wave and upwelling index- and *Plan Camgal* -an administration tool for contingency plans to deal with marine accidents or extreme events- have been pinpointed, all of which belong to the *Observatorio Costeiro da Xunta*.

Moreover, the most required oceanographic information by the interviewed stakeholders has been gathered and analysed. Temperature and salinity in specific areas to detect special local particularities or biological events and time series of closed to extraction mussel rafts due to toxic Harmful Algal Blooms (HABs) are the most highlighted, as well as, improved wave and wind models or the union of the whole different viewers in a unique one linking metadata and accessible-usable-reliable data. Some of these specific areas, pointed to be monitored, are just being taken into account for the next actuations of the observatory.

It is striking that some of these required data do already exist, what indicates the need to make an effort on diffusion and dissemination to reach more potential end-users, training and encouraging them to take advance of all this information and services to enhance their professional outcomes and their quality of life. In addition, some progress should be done to improve the accessibility, standardization and harmonization of the data to ensure their usability.

3. CONCLUSIONS

The interaction with stakeholders is decisive to draw up a strategic plan for the *Observatorio Costeiro da Xunta de Galicia* inasmuch as the end-users contribution guides the Observatory to face society necessities and requirements and being the first steps of their active involvement and future engagement.

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Copernicus Marine and EU Member States: towards new services and co-designed solutions

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Abstract
The Copernicus Marine Service, managed by Mercator Ocean International (MOi), is a vital source of global and European regional seas information. It uses satellite and *in situ* observations, along with 3D model simulations, to provide reference marine information on physical, biogeochemical, and sea ice conditions. As one of six pillar services of the Copernicus program, and the European Union service advancing a sustainable use of the Ocean, the Copernicus Marine Service is critical in supporting decision-making processes.

MOi plays a crucial role in the Copernicus Marine Service by providing and enhancing the data and the service but also strives to establish seamless connections throughout the oceanography data value chain. To achieve this goal, MOi aims to foster collaboration and partnership with stakeholders to develop ocean information that aligns with policy and governance needs. Initiatives such as the Marine Forum, Copernicus Thematic Hubs, and User Engagement call for tender, promote synergies, develop new downstream services, and support decision-making in marine and maritime sectors. The Marine Forum facilitates interactions and exchanges between marine stakeholders from EU Member States and MOi to implement the Copernicus program in the marine domain. The Copernicus Thematic Hubs, implemented by MOi, focused on coastal and arctic environments, will facilitate access to Copernicus Information and identify information gaps to stimulate the development of new downstream services. The User Engagement call for tender reinforces collaboration with marine policy and governance stakeholders within EU Member States aiming to develop a seamless marine monitoring service to support the implementation of EU Policies and Directives.

Overall, these initiatives represent a crucial step towards better aligning ocean information with policy and governance needs. By working collaboratively with stakeholders, Mercator Ocean International ensures that its services and data are more relevant and accessible to those who need them the most.

1. INTRODUCTION

1.1. The significance of Copernicus Marine Service and MOi role in oceanography data value chain

The Copernicus Marine Service is a unique operational system that provides operational, regular, and systematic reference information on the physical, biogeochemical, and sea ice state for the global ocean and European regional seas. It strikes a balance between cutting-edge science and operational commitments, utilizing satellite and *in situ* observations along with models to describe, monitor, and forecast the ocean state.

The information that Copernicus Marine Service provides is open and free of charge. Its quality control is based on a documented quality system, and its upgrades are based on the outcomes of short- to long-term Research and Development (R&D) activities driven by user and policy requirements (Mercator, 2016). To that end, the service evolves continuously to meet user requirements and faces scientific and technical challenges to improve products (Drevillon *et al.*, 2018). With an expansive user base (exceeding fifty thousand), alongside corresponding downstream services, the service is tailored to both public and private demands while supporting EU Directives and Policies in various marine and maritime domains encompassing maritime safety, coastal environmental monitoring, fisheries, renewable energy, etc. Its major objective revolves around delivering and sustaining a state-of-the-art European service, while placing a great emphasis on explicitly and transparently engaging users in defining the service delivery (Le Traon *et al.*, 2019; Le Traon, this issue). In order to ensure this ongoing enhancement of Copernicus Marine Services, MOi has formulated a comprehensive two-fold strategy comprising Service Evolution and User Engagement.

The Service Evolution activities aim to prepare future versions of the Copernicus Marine Service by incorporating scientific and technological advancements within its data portfolio. This continuous improvement activities ensure that the data produced by the Copernicus Marine Service maintains its position at the forefront of ocean monitoring and prediction advancements. This concurrently increases the overall value and reliability of the oceanographic data provided.

On a complementary front, User Engagement activities are focused on maximizing the use of the current version of the service, addressing users' needs, and increasing user satisfaction and confidence. Addressing user needs starts with collection of user feedback on the service. This step is crucial for improving services and products to better meet the specific needs and expectations of users. User feedback for the Copernicus Marine Service is gathered through surveys, events, and direct communication with expert users, while the Champion User Advisory Group (CUAG) assesses and enhances service relevance for specific markets and applications (Giunta *et al.*, this issue). Additionally, MOi aims to strengthen its collaboration with intermediate users of Copernicus Marine Service by enhancing awareness and illustrating current and new use cases. This approach facilitates the evolution of products and services through the active engagement of key stakeholders.

These collaborative initiatives and continuous innovation stand as the driving force in connecting oceanographic data producers and the end-users to foster a seamless flow of oceanographic information. As provision of precise and timely information is essential for well-informed decision-making, through these actions MOi is solidifying its position as a global reference in ocean observation and prediction capabilities.

1.2. Fostering collaboration and partnerships for ocean information

Stakeholder engagement is crucial for maximizing ocean monitoring benefits, considering diverse stakeholders with varying priorities. Effective collaboration and interconnected networks lead to improved services and utilization of ocean science globally. Success relies on common goals, effective communication, and co-production of information and knowledge, resulting in more usable outputs for informed decision-making and policy development.

MOi actively fosters stakeholder engagement through various initiatives - i) Copernicus Thematic Hubs, ii) Copernicus National Marine Stakeholder Forum (hereafter Marine Forum), and iii) National Collaboration Programme-, recognizing the importance of diverse perspectives and collaborative efforts to co-design the future Copernicus Marine Service. These initiatives will ultimately contribute to more informed decision-making and effective policy development for our marine environment.

i) Copernicus Thematic Hubs

To that end, Copernicus Thematic Hubs aim to facilitate access to Copernicus thematic information, benefiting various users, implementing EU policies, and promoting innovation and competitiveness in the EU industrial ecosystem. It will offer a centralized platform for accessing relevant data and information products; this aims at easing the use and interaction between users and Copernicus services. Several Copernicus Thematic hubs will be developed by the European Commission and its Entrusted entities, among which the two coastal and arctic hubs that are developed by MOi. The Copernicus Coastal Hub has already been launched in June

2023 during the Copernicus Marine' General Assembly (The Coastal Thematic Hub | COASTAL (copernicus.eu)) (Fig 1) and the Copernicus Arctic Hub is currently being developed and will be launched later in the Fall.

The Copernicus Coastal Hub provides open and free access to a selection of coastal Earth Observation data sourced from the Copernicus Sentinel satellites and all Copernicus Services (marine, land, atmosphere, climate, and emergency). It serves as a centralized repository for Copernicus coastal Earth Observation data, tailored to a wide spectrum of applications, spanning from the implementation of the European Green Deal and Environmental policies to use in academia and industry. The Copernicus Coastal Hub, anticipated to undergo continuous improvement in the upcoming months, is founded upon both Copernicus Services and the Copernicus WEkEO infrastructure. It is dedicated to facilitate data access and utilization, with a particular focus on European coastal zones. This hub not only provides access to a curated selection of open and free Copernicus coastal Earth observation data through a dedicated viewer but also serves as a platform to explore various use cases demonstrating the application of coastal Copernicus products and information, particularly in the context of the EU Green Deal.

Likewise, the Copernicus Arctic Hub will adopt a comparable framework, extending free and open access to a range of Arctic Earth observation data from the Copernicus Sentinel satellites and all Copernicus Services. It will present a collection of Copernicus Arctic data, accompanied by a viewer for seamless access, download, and visualization of the data. Furthermore, it will offer insights into different use cases, showcasing how Arctic Copernicus products and information are employed across various scenarios, notably in the implementation of the EU Arctic Policy.

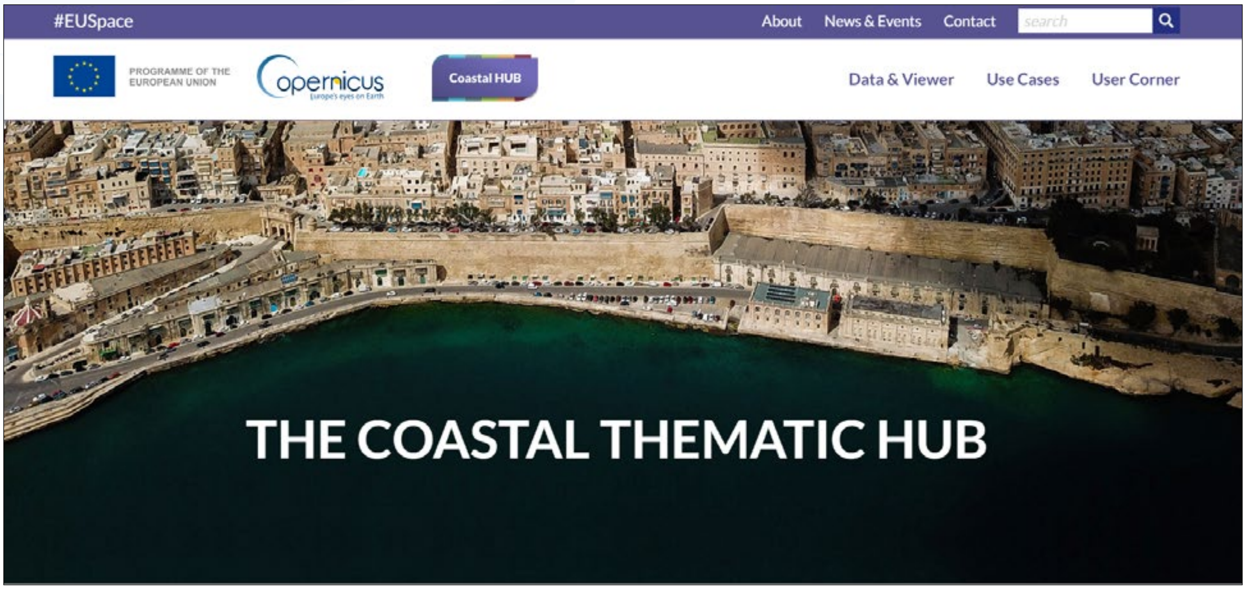

Figure 1. Image of the Coastal Hub' website home page.

ii) Marine Forum

The main aim of Marine Forum as initiative is to foster interactions between Member States (hereafter MS) and MOi and to ensure that the Copernicus Marine Service is closely aligned with user expectations and requirements. The Marine Forum functions as a consultative group and so far, encompasses representatives from 16 countries (Fig. 2). This open dialogue' platform will enhance collaboration between stakeholders and encourage MS to actively participate in the co-design and implementation of Copernicus Marine Service.

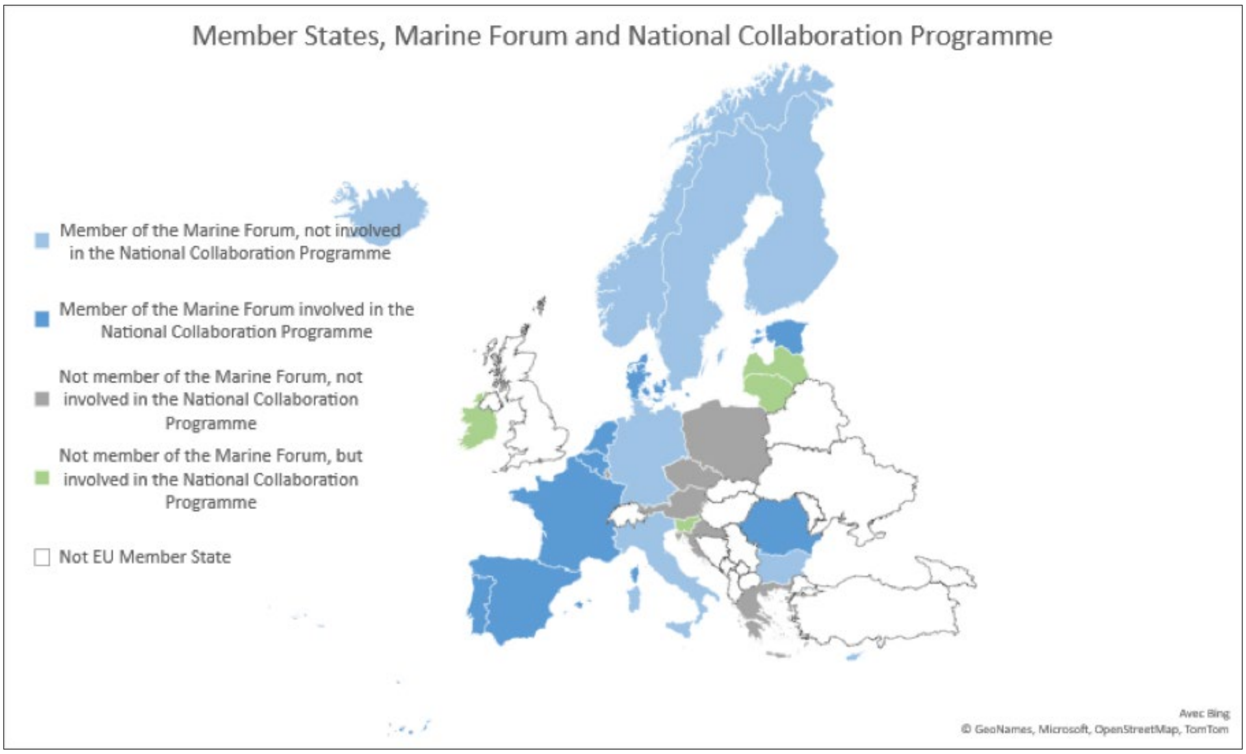

Figure 2. Members of Marine Forum and National Collaboration Programme.

iii) National Collaboration Programme

Additionally, the National Collaboration Programme will facilitate collaboration at the national and local scales to develop a seamless marine monitoring service which supports national implementation of EU Directives and with special emphasis on the crucial coastal zones due to their multifaceted significance. The start of this programme was recently marked by its recent User Engagement call for Tender, with the main aim to build demonstrators showcasing future seamless Copernicus coastal marine monitoring service extending from the open ocean to the coast.

The target tenders for this initiative were those that have developed a marine coastal (pre)operational service effectively showcasing their alignment with the implementation of EU Policies and Directives. The primary aim of this call was to foster collaboration and the seamless provision of ocean solutions between national marine coastal services and the Copernicus Marine basin-scale service. Integral to this is the demonstration of the incorporation of new, high-resolution marine coastal products from EU Member and Contributing States into the Copernicus Marine service portfolio, all within the framework of the open and free Copernicus data policy. Within this first call, 15 projects have been selected for an 18-month period encompassing representatives from 13 Member States countries.

User Engagement call for tenders are the backbone part of User Engagement strategy and these calls have been taking place since 2015 during which period, six User Engagement calls for tenders were launched, with a total of 122 bids received and 40 contracts signed.

The recent User Engagement call for tender concluded with 26 submissions, with representatives from 16 EU countries, among which 12 Portuguese organisations, 7 Spanish, 3 French, 2 Romanian, 2 Norwegian, while other countries (i.e.) were represented by 1 organisation. Based on the assessment scores, 15 proposals were chosen for implementation, from which 2 are lead by Spanish organisations, 2 by Portuguese, 2 by Romanian, and other countries had 1 winning bid (Table 1). The contracts for these 15 selected projects commenced on July 5th, 2023.

With this new User Engagement phase running until 2028, Copernicus Marine aims to enhance its interactions and collaboration with Core users at the national level within EU. Specifically, this pertains to marine policy and governance stakeholders in EU Member States and Contributing States. Given the immense societal, economic, and ecological significance of coastal zones, the focus of this phase will center around the coastal area. The Copernicus Marine Service's long-term objective is to augment its offerings with a broader range of marine coastal zone monitoring information, achieved through collaborative design with Member States and forging partnerships with national marine coastal operational monitoring solutions. Ultimately, the aim is to evolve the Copernicus Marine service by seamlessly integrating local and national coastal monitoring systems whenever feasible.

Together, these initiatives create an environment that fosters collaboration and synergies among different stakeholders, ranging from scientific communities to private sectors and international organizations. By encouraging dialogue, co-design, and knowledge sharing, these initiatives enable the ocean observation community to work collectively towards addressing global challenges and promoting the sustainable use of marine resources.

Table I. Winning contracts of User Engagement Call for Tender.

Leading Organisation	Name of the service	Country
SC JAILOO SRL	SYstem of Romanian COastal Monitoring	Romania
NIMRD	SAFEBLESS: Safe navigation in the Western Black Sea basins	Romania
SIA	New services of HywasPort system – seabed indicators in coastal zone and seamless transition between port and sea models	Latvia
Taltech	Estonian Coastal Monitoring and Forecast Service	Estonia
Klapeida University	Development of the Operational hydrodynamic model for the Curonian Lagoon and coastal area of the southeastern Baltic Sea (Lithuania)	Lithuania
Nologin	Enhancing Hydrodynamic, Heat and Haline exchanges in an OPErational coastal model downstream service in support of environmental protection, fisheries and aquaculture at enclosed bays	Spain
Quiet Oceans	Pilot Demonstration of Coastal Ocean Noise Operational Service to support the EU Marine Strategy Framework Directive in the Mediterranean	France
National Institute for Biology	Developing High-Resolution Models for Forecasting Sea Surface Currents and Marine Effluent Dispersion	Slovenia
Marine Institute	Technical proposal for the development of a pilot demonstrator in support of biodiversity restoration and oyster aquaculture in Galway Bay, Ireland, based on an operational coastal modelling service	Ireland
LNEC	CONNECT - local COastal moNitoriNg sErviCe for PorTugal	Portugal
DMI	DIO:Disko Bay forecast of Ice and Ocean	Denmark
AZTI	EUSkadi Coastal Operational Model validation & user-engagement	Spain
Deltares	Coastal marine (pre) operational services around the European Atlantic Ocean including the North Sea and the Arctic Ocean	The Netherlands
RBINS	Seamless downscaling of CMEMS NWS forecast products to the Belgian coastal zone	Belgium
IPMA	Pilot PortuguEse coastaL operatioNal modEl for the DIgital Twin of the Ocean	Portugal

2. CONCLUSION

2.1. Towards seamless Marine Monitoring: supporting EU Policies and Directives

In essence, MOi's user-centric approach aims to serve as a bridge between oceanographic data producers, intermediate users, and end-users, closing the gap between them. By comprehending and addressing user needs, preferences, and challenges, MOi tailors Copernicus Marine Data to fulfil real-world requirements. In tandem with (scientific and technical) evolvement of Copernicus Marine Service, MOi continually enhances the oceanography data value chain, fostering collaboration to meet evolving user demands and tackle scientific challenges. These efforts position MOi to play a pivotal role in enhancing the oceanography data value chain, promoting the utilization and significance of oceanographic data, and contributing to the sustainable management and conservation of our marine environment. Additionally, stakeholder engagement' initiatives are establishing a framework that nurtures collaboration and synergy among stakeholders. In particular, the Copernicus Thematic Hubs serve as central platforms for accessing Copernicus thematic information.

Marine Forum encourages MS' active involvement in shaping the Copernicus Marine Service's direction, and User Engagement calls seek to elevate its interactions with core users at the national level within the EU with special emphasis on the crucial coastal zones due to their multifaceted significance.

By embracing all these initiatives, MOi facilitates more informed decision-making and the effective development of policies for our marine environment. Moreover, fostering dialogue and co-design, these initiatives empower the ocean observation community to collectively address global challenges and promote the sustainable utilization of marine resources.

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MARine Biodiversity and Ecosystem Functioning leading to Ecosystem Services (MARBEFES): Stakeholder Engagement in Heraklion Gulf, Crete, Greece

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Keywords

Marine biodiversity, ecosystem services, stakeholders, societal needs, European seas

Abstract

MARBEFES is a Horizon Europe research project working on the links between marine biodiversity and the goods and services provided by the marine ecosystem. To bridge the gap between research, policy and practice, the project focuses on stakeholders of whom experience and interests can be considered and represented in the decision-making tools and instruments. To this end, representatives from a range of different sectors (public audience, public authorities, industry/private sector, academia/research) and across Europe (12 research areas named Broad Belt Transects, BBTs) have been invited to become involved in MARBEFES and share their point of view. Between 3rd and 7th April 2023, interviews and surveys were conducted with 18 different stakeholders (30 individuals) from the four above-mentioned stakeholder domains (e.g., museums, aquaria, research centres, Region of Crete, Ministry of Environment, NGOs, municipalities, cruise sector, commerce, tour guides, divers, teachers, hotel owners) related to the marine research area of Heraklion Gulf (BBT of Greece). Most of the stakeholders were very enthusiastic expressing their valuable insights concerning balance between nature, society and economy. The first results will be presented to them during a second visit to Crete which is to be organized within next year for a round of feedback.

1. INTRODUCTION

MARBEFES is a Horizon Europe research project working on the links between marine biodiversity and, the goods and services provided by the marine ecosystem (https://marbefes.eu/). It is an international and interdisciplinary project, involving 23 international partners from 11 European countries. The aim of the project is to develop tools and instruments with and for users to allow for better informed decision-making and management of marine and coastal areas, considering human and ecosystem needs.

To bridge the gap between research, policy and practice, the project focuses on stakeholders – the users and custodians of the sea. The project investigates how people working and living in coastal communities perceive the relationship between the sea, society and economy, and the pressures acting on this relationship. In this way stakeholder experience and interests can be considered and represented in the decision-making tools and instruments. To this end, representatives from a range of different sectors have been invited to become involved in MARBEFES project and share their point of view.

HuFoSS is a research foundation from the Netherlands (https://hufoss.nl/language/en/) that conducts socio-ecological research and coordinates stakeholder engagement for MARBEFES project (https://marbefes.eu/artykul/wp1-stakeholder-involvement-and-governance-rules). From February to September 2023 the first round of stakeholder interviews and surveys took place across Europe (12 research areas named Broad Belt Transects, BBTs, Fig. 1). In each research area, HuFoSS team met representatives from four stakeholder domains: public audience, public authorities, industry and private sector, and academia and research.

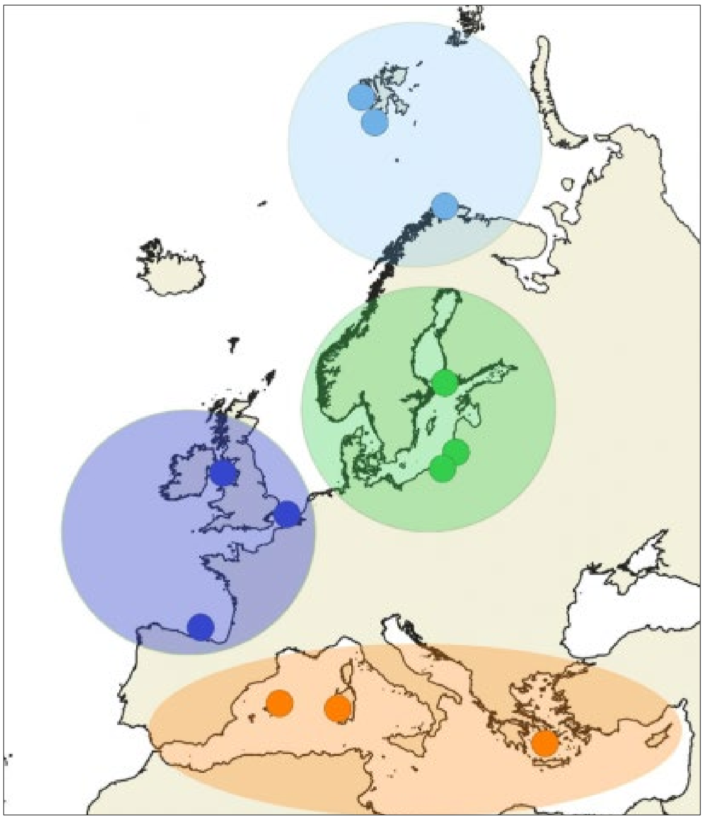

Figure 1. The MARBEFES broad belt transects (BBTs) in the Arctic, Baltic, Atlantic and Mediterranean.

2. METHODOLOGY

Interview and survey were designed to uncover how stakeholders see the relationship between nature, economy and society in their area, as well as the most important pressures. Fuzzy Cognitive Mapping (FCM) was central to the research method (Kosko, 1986; Özesmi & Özesmi, 2004). In order to prevent stakeholder fatigue and to make participation as pleasant as possible for stakeholders as well as researchers, interview and survey were game-like, invoking an informal atmosphere. More specifically:

2.1. Between September 2022 and February 2023, Hufoss team dedicated efforts to preparing for the upcoming stakeholder consultation visits in the various research areas, also known as Demonstration Areas. This primarily involved designing a stakeholder survey to assess stakeholders' perceptions, as well as devising an interview protocol that would meet the requirements of specific research purposes. This collaborative effort, due to the input from all partner institutes within MARBEFES project, successfully completed all the essential materials for the interviews and survey well ahead of research visits.

2.2. After a successful preparation, the primary focus in the subsequent phase revolved around actually visiting the various Demonstration Areas. These visits turned out to be immensely successful, as all the partner institutes at each location found and motivated local stakeholders, provided translation assistance and guidance during Hufoss team visits, and, above all, for the experiences shared..

2.3. Throughout Hufoss team visits, diverse stakeholders were engaged in conversations, each bringing their own unique perspective. From the local hotel-owner and recreational fisher, to industrial port authorities and national policy-makers, all research participants were invited to join in and express their views and opinions. Upon arrival, Hufoss team offered the stakeholders a presentation that provided additional context, outlining the purpose and significance of the MARBEFES project in detail, and explaining the value of their opinions and perspectives to the project..

2.4. Typically, Hufoss team conducted individual interviews with each stakeholder, followed by a survey. In certain research areas Hufoss team opted for group-surveys in which various stakeholders gathered together to participate in the survey simultaneously..

2.5. The interviews themselves were a mix between quantitative and qualitative research techniques. Methodology used a method known as 'fuzzy cognitive modelling', allowing to 'map' stakeholders' perspectives regarding the relationships between 'nature', 'economy', and 'society' within their (marine coastal) environment, the degree of 'balance' or 'disbalance' between these domains, and, importantly, so-called 'pressures' that might affect or disrupt this balance. During the sessions, stakeholders' accounts were distilled into keywords and placed on a magnetic sheet, after which the interviewees used markers and colours to establish connections between these keywords. The outcome was a collection of highly distinctive mind maps, which will be later processed digitally.

3. RESULTS

Between 3rd and 7th April 2023, HuFoSS team undertook the research trip to Heraklion, capital of Crete. Interviews and surveys were conducted -by HuFoSS team in collaboration with HCMR team- with 18 different stakeholders (30 individuals) from the four above-mentioned stakeholder domains (representatives of e.g., museums, aquaria, research centres, Region of Crete, Ministry of Environment, NGOs, municipalities, cruise sector, commerce, tour guides, divers, teachers, hotel owners) related to the marine research area of Heraklion Gulf (BBT of Greece). A record number of stakeholders expressed a great enthusiasm and interest in the research. They talked through the most important issues at hand, such as tourism, the status of the marine environment and the role of coastal development in this context. A tour was followed at the Cretaquarium offering a unique spectacle of the diversity of Mediterranean fish species and habitats by visualising the Mediterranean Sea life using modern ways and equipment. Finally, a visit was undertaken to the Archaeological Museum of Heraklion, where Minoan frescoes and artefacts depicting maritime scenes were encountered, demonstrating the extent to which already the prehistoric island inhabitants were bound to the sea.

Eighteen interviews were conducted with twelve to thirty keywords mentioned by the stakeholders. On average stakeholders mentioned 16.7 keywords. In the second phase of the interview the stakeholders made between sixteen and seventy connections between the keywords they had mentioned. On average the stakeholders made 32 connections. The most important variables mentioned during interviews with Stakeholders in Crete are shown in Table I. The most important variables: a) were very often mentioned during interviews with Stakeholders in Crete; b) were connected to many other variables, and are thus influencing, or influenced themselves by, many other variables; c) had very strong connections with other variables (per connection the strength could be from 1 to 5).

The most important variables mentioned during surveys with Stakeholders in Crete are shown in Table II. Indicated are the variables that got on an average a score of 4 or higher (for the categories the average over all variables is given). Scores ranged from 0 (not at all important / not present) to 5 (very important).

Table I. The most important variables mentioned during interviews with Stakeholders in Crete.

Variable	Percentage of times mentioned by Stakeholders	Average number connections to variable	Average sum of the strength of all connections together to/from a variable
Large scale tourism	89	4.9	10.7
Nature	61	2.4	7.4
Pollution	61	2.0	5.9
Economy	56	2.8	7.4
Biodiversity	56	2.7	7.8
Urbanisation & Coastal.development	56	1.8	4.4
Infrastructure & Transport	50	1.4	4.2
Awareness / Knowledge	50	1.3	3.3
Overexploitation	39	1.8	5.8
Education	28	2.2	7.9
Beach waters	8	3	1

Table 2. The most important variables mentioned during surveys with Stakeholders in Crete.

Structure and functions of coastal ecosystems	**3.7**
Biodiversity	4.4
Element/nutrient cycle	4.2
Habitats	4.1
Ecosystem Services	**3.0**
Biodiversity conservation	4.3
Water regulation	4.1
Socio-economic	**3.0**
Foreign tourism	4.8
Transport and infrastructure	4.5
Economic welfare	4.1
Domestic tourism	4.0
Socio-cultural	**3.5**
Relaxation	4.4
Amusement	4.1
Pressures	**3.1**
Tourism	4.4
Urbanization	4.2

Depending on the type of Stakeholders, different levels of importance was given (Fig. 2): a) Ecological structures and functions, Ecosystem Services, Socio-cultural issues were valued most by the Public at large and the Industry; b) the highest level for Socio-economic issues was given by the Industry; c) Pressures were judged equally important by all categories of Stakeholders.

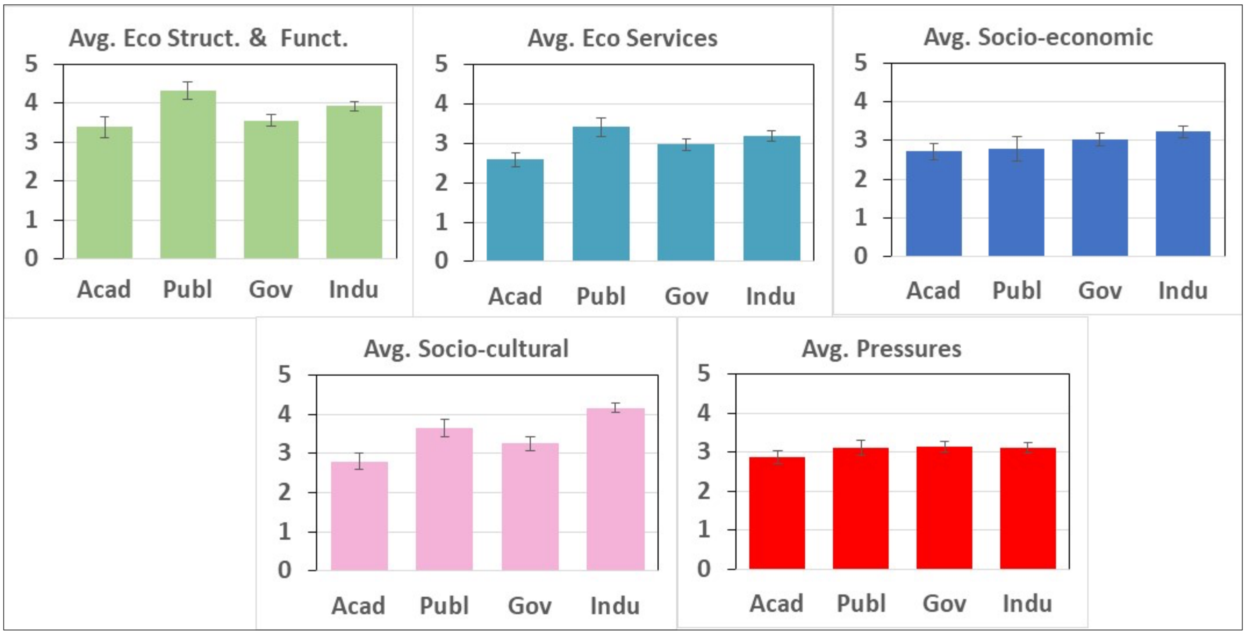

Figure 2. Averaged level of importance of different variables mentioned during surveys with different groups of Stakeholders in Crete (Ang: Average; Eco Struct. & Funct.: Ecological structures and functions; Eco Services: Ecosystem Services.

4. DISCUSSION-CONCLUSIONS

Most of the stakeholders were very enthusiastic expressing their valuable insights concerning balance between nature, society and economy. During the stakeholder engagement on Crete it was noticed that some specific issues were mentioned often by stakeholders. The coastal development on the northern shoreline is very high and is considered a pressure on the system. The control of the coastal development should be much more improved to control the risks and pressures stemming from the development. There is thus a need for a stronger governance to ensure the development of the economic sectors without rising risks. Mass-tourism is very strongly present across the northern shore, and often negative connotations are present about the pressures given by this mass tourism. Moreover, there is a lack of awareness and knowledge of the ecosystem on Crete. This could be improved by educating the residents. A second and third round of visits to the research areas will take place later in the project. During these visits HuFoSS team in collaboration with MARBEFES partners will again engage in dialogue with stakeholders. Feedback on the research results will be provided and demos of the tools and instruments that have been developed will be presented. Stakeholders will experiment with the demos, providing feedback and evaluating them according to their usefulness, user-friendliness and accuracy.

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Oral Presentaions – Session J

Operational oceanography in the coastal zone

Synthesis of JERICO-RI coastal Pilot Supersite implementation: towards integrated pan-European multiplatform coastal observations

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Keywords

Research Infrastructure, coastal seas, multiplatform observations, European integration

Abstract

The Joint European Research Infrastructure for Coastal Observatories, JERICO-RI, is developing pan-European multidisciplinary and multiplatform observing capacity delivering data and products for various key scientific challenges and meeting the needs of several user groups. To facilitate this process, JERICO-RI Pilot Supersites (PSS) have been implemented in 2021-22, as a proof of concept for coastal Supersites, to study how the coastal observations are best integrated, for provision of sustained multidisciplinary observations. PSS studies were realised at five regions (Baltic Sea, English Channel and North Sea, North-West Mediterranean Sea and Cretan Sea) to test how transnational and trans-institutional integration and sharing are best achieved. This study provides a synthesis of JERICO-RI PSS implementation, highlighting the lessons-learned for regional and pan-

European integration of coastal observations and identifying gaps and challenges in transnational operations. Study underlines the need for a pan-European strategy for coastal observations, to advance impactful scientific research in complex coastal waters and to yield common and consistent pan-European data and products, but at the same time to be inclusive for regional specificities. JERICO-RI with its regional observation structures and coastal Supersites are seen as a key component in such developments.

1. INTRODUCTION

JERICO-RI, Joint European Research Infrastructure of Coastal Observatories, is an integrated pan-European multidisciplinary and multi-platform research infrastructure dedicated to a holistic appraisal of coastal marine system changes (Puillat *et al.*, 2016; Farcy *et al.*, 2019). It aims to provide structured European RI to observe and monitor the marine coastal domain in a sustained way. JERICO-RI projects, JERICO (2011-15), JERICO-NEXT (2015-19), JERICO-S3 (2020-24) and JERICO-DS (2020-23), have been funded by EU FP-7 and H2020 INFRA programs. In the first phases, JERICO-RI improved networking of coastal observations, mainly for physical data, while JERICO-NEXT project improved harmonization of biological observations and interoperability generally. In the current phases JERICO-RI is structuring regional observations and builds scientific strategy and a long-term vision for European coastal observing RI.

JERICO-RI includes physical infrastructure-platforms for coastal sea observations, like FerryBox, cabled stations, moorings, fixed platforms, gliders, AUVs, HF radars and include also some research vessel -based observations (Puillat *et al.*, 2016; Farcy *et al.*, 2019). Especially JERICO-RI has been harmonizing the use of various sensors for physical, biological, and biogeochemical observations done at these platforms. It includes technological developments and data services, as well as transnational access to platforms and virtual access to data and information products. JERICO-RI products are used primarily for scientific research and operational services, but also for education, environmental management, and crises responses, to name some of the key uses. JERICO-RI aims to be a versatile RI, providing data, products and solutions for a full array of scientific challenges of the complex coastal ecosystems.

2. SUPERSITES FOR COASTAL OBSERVATIONS

Environmental Research Infrastructures (RIs) provide sustained long-term observations and data products to the scientific and other user communities. This helps them to understand and manage major environmental challenges such as climate change, biodiversity loss or food and water security. For dynamic and complex natural environments, like coastal seas, the observations must be made in multiple locations to adequately cover the diverse conditions of the ecosystems. The optimal design of the RI network should reflect the heterogeneity of the areas and the complexity of the studied systems, as well as the entire size of the studied areas (Hari *et al.*, 2016).

Hari *et al.*, (2016) introduced a conceptual design that included three connected hierarchical levels of observatories, called Stations (mostly referring to a specific platform or permanent site). In their concept, the Standard Stations provide measurements for basic characteristics of the system, while the Advanced Stations also provide flux measurements. Both types are vital for RI to expand the spatio-temporal coverage of observations. The most advanced layer, the Flagship Stations in Hari *et al.*, (2016) concept, operate as multidisciplinary sites with high diversity of observations, good capacity for ancillary mission-type operations, and connectivity with other RIs.

There is no overall agreement on the nomenclature of the study sites or stations for Research Infrastructures. Term Supersite is used widely (based on Google Scholar search) in atmospheric, terrestrial, geological and satellite observatory networks. Typically, Supersite refers to highly instrumented and permanent observatory with harmonized and standardized measurements and a high capacity (quality and quantity) for observations and is analogue to Flagship Stations presented by Hari *et al.*, (2016).

In JERICO-RI we developed a model of hierarchical coastal observations, including three levels of observatories (Figure 1). The task of Standard observatories is to provide continuous measurements of some key parameters, often for local or regional needs. Among them, list of variables measured is typically low and they may be logistical constrains not allowing new observation types. Advanced observatories provide comprehensive and top-level measurements in specific scientific areas or services. Supersites aim to integrate top-level high-frequency measurements in all required scientific areas, using integrated multiplatform strategy for long-term observations. They are, when needed, transnational, and key platforms to connect with other RIs.

In our concept, JERICO-RI coastal Supersites provide multiple *in situ* observations at appropriate and spatiotemporal resolution, have restricted geographical region, are maintained over long timescales, are designed to address interdisciplinary objectives, are driven by science and society needs and have well-established data flows. Network of coastal Supersites should allow integrated and coordinated studies across various coastal systems. The need to cover measurements of essential ocean variables and essential biodiversity variables using comparable and state-of-art technologies, as required for cross-regional studies. Supersites must have capacity to adopt new technologies and approaches. Finally, there need to be a centralised steering of observations.

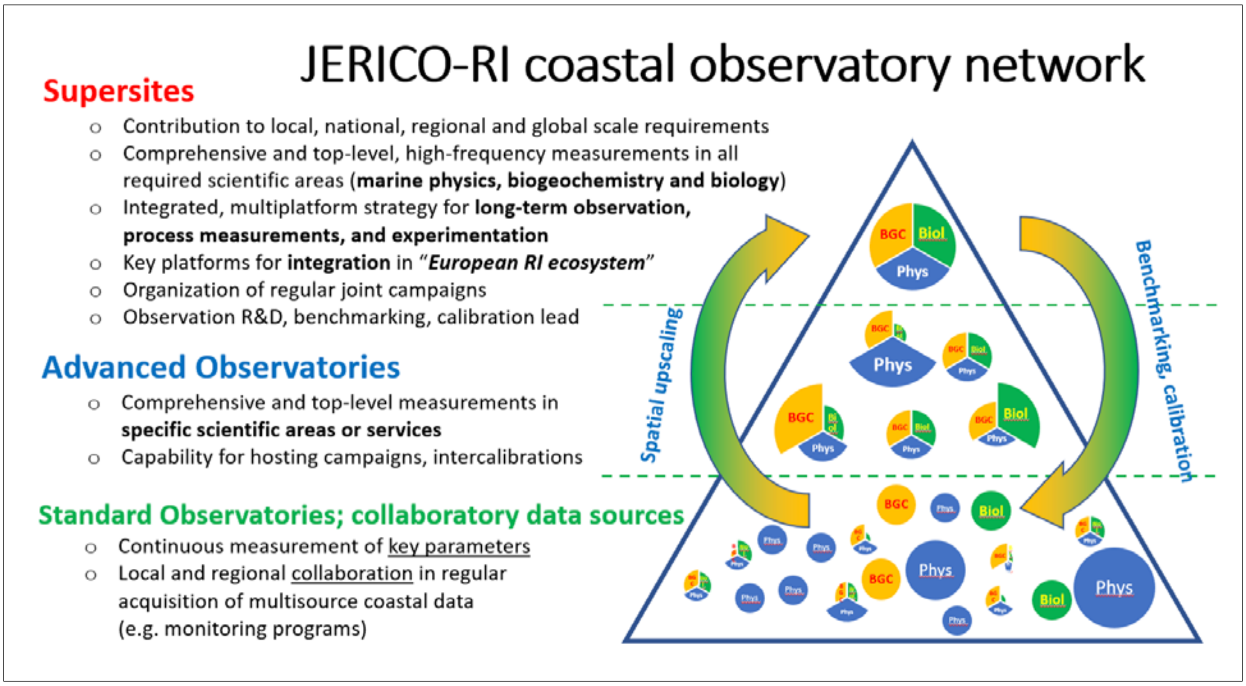

Figure 1. Illustration of JERICO-RI coastal observing facilities. Supersites enable integrated pan-European observations of complex multidisciplinary research questions. Advanced observatories provide high level integrated observations for specific questions. Standard observatories target more the regional and national questions for some key parameters.

3. JERICO-RI PILOT SUPERSITES

During 2021-22 JERICO-RI tested the Supersite concept at four regions, the Gulf of Finland (GoF PSS), the North-Western Mediterranean (NW-MED PSS), the North Sea and English Channel (forming a twin-PSS; NSEA and CHANNEL PSS), and the Cretan Sea (CRETAN PSS) (Figure 2). The Pilot Supersites (PSS) were different in their size and number of partners, including altogether twenty JERICO-RI partner institutes from 11 countries (Finland, Estonia, Germany, France, Italy, Spain, The Netherlands, Norway, Belgium, United Kingdom, and Greece).

Figure 2. JERICO-S3 regions for Pilot Supersites.

Diverse, practical, and well-defined transnational Actions (n=31) included studies related to data collection for specific key scientific challenges (e.g., carbonate system, phytoplankton), sharing the knowledge (e.g., best practices, research methods), linking to other communities (e.g., modelling, ocean color, other RIs) or connecting to end-users (e.g., regional conventions) (Table I). Use of emerging technologies and multiplatform sampling strategies were part of some Actions, while some others concentrated in harmonizing existing observation protocols and data flows (for details, see Seppälä and Frangoulis, 2021).

Overall, the main high-level questions studied during PSS implementation were:

- Which observations are needed to tackle grand environment challenges and requests for sustained and consistent data;
- How the hierarchy of pan-European coastal observation systems should be organized;
- How different EU Member States see the benefits of building and maintaining such structures.

Table Ia. List of JERICO-RI Pilot Supersite Actions studied in 2021-22.

	JERICO-RI Pilot Supersite Actions
GoF PSS #1	Harmonized observations
GoF PSS #2	The performance of operational forecast models
GoF PSS #3	Optical data for Ocean Color product validation
GoF PSS #4	Detection of cyanobacterial blooms
GoF PSS #5	Mapping the deep-water oxygen conditions
GoF PSS #6	Biological interplay with the carbonate system
GoF PSS #7	Forecast models for cyanobacterial blooms
GoF PSS #8	Extreme events affecting phytoplankton - AQUACOSM collaboration I
GoF PSS #9	Promotion of the use of PSS data and products
GoF PSS #10	Connecting the other RIs in the region
NW-MED PSS #1	Reconstruction of the 3D coastal dynamics
NW-MED PSS #2	Impacts of river discharge to coastal ecosystems
NW-MED PSS #3	Extreme events affecting phytoplankton - AQUACOSM collaboration II
NW-MED PSS #4	Biogeochemical data and ocean colour products
NW-MED PSS #5	RI interactions
NW-MED PSS #6	Transnational integration

Table Ib. List of JERICO-RI Pilot Supersite Actions studied in 2021-22.

	JERICO-RI Pilot Supersite Actions *(continuation)*
NSEA PSS #1	Harmonized observations of regional C fluxes
NSEA and CHANNEL PSS #2	Riverine input to the North Sea
CHANNEL PSS #3	Harmonized observations of plankton biomass, diversity and productivity dynamics
CHANNEL PSS #4	Products for Eutrophication Status Assessment
NSEA and CHANNEL PSS #5	Intercomparison of phytoplankton distribution using data integration
NSEA and CHANNEL PSS #6	Identification of Observational Gaps
NSEA and CHANNEL PSS #7	Cross-regional communication between PSSs (North Sea and Channel)
NSEA and CHANNEL PSS #8	Support to EU directives and ecosystem management
NSEA and CHANNEL PSS #9	Interaction with other RIs on ecosystem studies, eutrophication, coastal management and carbon
CRETAN PSS #1	Solubility and biological pumps
CRETAN PSS #2	Improved approximations of Primary Production
CRETAN PSS #3	Extreme events affecting phytoplankton - AQUACOSM collaboration III
CRETAN PSS #4	Upscale of Regional Data to a wider area
CRETAN PSS #5	New sampling strategies, new technologies, best practices
CRETAN PSS #6	Partnership building

The analysis of the key messages from various PSS Actions will guide us how the strategic planning of JERICO-RI regional observations, especially their interlinkages and coordination, will continue. The results will be streamlined with other JERICO-RI studies from other regions (so-called Integrated Regional Sites, IRSs). After analyzing the observed gaps and challenges, observed during PSSs and IRSs, the definition and fit-for-purpose of coastal Supersites will be revisited.

Though the analysis of PSS results is still under scrutiny, the following outcomes can be stated already for regional integration of observations:

- PSSs have provided a framework for thematic and interdisciplinary regional collaboration, joint use of resources, and planning and executing common activities;
- PSSs have created new connections, transfer of technologies and knowledge, and scientific results within regions;
- With PSSs, some observations/challenges are becoming more a regional issue, instead of being national ones;

- Improvements have been obtained in operationalising transnational multiplatform observations;

- Obstacles in integrating and manoeuvring transnational & multiplatform observations have been identified, and especially the need of clearly set goals and incentives has been noted and for pan-European integration;

- Pan-European cooperation needs more time and resources, but it needs to be done at the same time as regional integration;

- Some PSS actions have acted as seeding links to boost pan-European integration, e.g . for carbonate and phytoplankton observations, use of emerging technologies, between-RI work, research topics connecting land-to-sea;

- Management structures to steer pan-European integration are needed from start.

For thematic integration, to tackle regional, European and global aspects of key environmental challenges, the PSS work underlines the need to find balance between regional and pan-European integration, as sampling strategies may be different for each. In this work, Supersites should support also national and regional strategic monitoring plans, not only pan-European one. This requires formulation of common objectives, sampling strategies, and communications.

There were several region-specific examples of good collaborations with other RIs - from practical work to high impact science (e.g. land-sea continuum, multiplatform observations and connecting experimental observational approaches) – using a bottom up approach, which need to be aligned with strategic top-down approach.

PSSs came up with improvements in dataflows, data compilation, method harmonization and sharing of best practices. Especially, PSSs have improved practical harmonization of observations between nations and institutes and various bottlenecks preventing future improvements have been observed.

4. CONCLUSIONS

Overall, though our study of JERICO-RI Pilot Supersites lasted only two years, we obtained a lot of confidence that integrated, and jointly steered transnational multiplatform observations are the future of European coastal observing systems. We also found regional complementarities and differences in transnational collaboration structures to be studied further, and to extract best practices for transnational observing. Collaboration with other RIs and research initiatives – including EuroGOOS and EOOS, as well as national and regional actors is vital, and the regional structuration of coastal observing systems need to be co-created with them.

ACKNOWLEDGEMENTS

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Oral presentations – Session K

Evolution of ocean modelling

Evolution of the Copernicus Marine Service global ocean analysis and forecasting high-resolution system: potential benefit for a wide range of users

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Keywords

Ocean forecasting, global ocean modelling, high-resolution, data assimilation

Abstract

Since October 2016, and in the framework of Copernicus Marine Service, Mercator Ocean International delivers in real-time daily services (weekly analyses and daily 10-day forecasts) with a global 1/12° high-resolution system. Oceanic observations are assimilated in a numerical model using a reduced-order Kalman filter method. Along track altimeter Sea Level Anomaly, satellite sea surface temperature and sea ice concentration, and *in situ* temperature and salinity vertical profiles are assimilated to estimate the initial conditions for numerical ocean forecasting. A 3D-VAR scheme is also used to better control the slowly evolving large-scale biases in temperature and salinity.

A major release of this analysis and forecasting system is available since November 2022 with changes and updates concerning the three components of the system (ocean and sea-ice models, observations, data assimilation method). Some identified weaknesses present

in the previous system have been improved highlighting the new system's performance in terms of analysis and forecast capacities, in the representation of mesoscale activity and water masses, and in the representation of the dynamics. Improvements also include the accuracy of polar sea ice coverage, thickness, and concentration.

1. INTRODUCTION

A major release of the global 1/12° high-resolution (eddy-rich) Mercator Ocean PSY4 analysis and forecasting system (Lellouche *et al.,* 2018) is available since November 2022. The new system, called GLO12, has been substantially revisited. Some highlights of the updates are:

- A new version of NEMO ocean and sea-ice model codes, which feature new numerical schemes (time-splitting scheme allowing rapid phenomena, 2nd order vertical scheme, 3rd order horizontal advection scheme for dynamics), a coherent bulk formulation with the atmospheric forcing one, and the possibility to represent the ice in different categories. The previous sea-ice model was mono-category and only included one type of sea-ice. Now, the new version includes different classes of sea-ice, which helps to represent better the characteristics and behavior of ice under different conditions.

- Higher spatial and temporal resolution (1/15° - 1 hour) atmospheric forcing from IFS-ECMWF analyses and forecasts. This is a significant improvement from the previous system, for which the atmospheric forcing fields had a coarser resolution (1/8° - 3 hours).

- Assimilation of the L3 ODYSSEA high-resolution Sea Surface Temperature (SST) observation instead of the L4 OSTIA gridded product. The L3 dataset provides more raw SST data and uses its own native interpolation system, reducing errors and providing a more accurate representation of the SST. Additionally, the new system assimilates these SST observations daily, instead of once a week in the previous system. This provides a more up-to-date and accurate representation of SST, which is an essential factor in monitoring and forecasting ocean conditions.

- Use of a new Mean Sea Surface Height (MSSH), necessary for Sea Level Anomalies (SLA - altimetric observations) assimilation. The improved MSSH significantly impacts on the accuracy of the mean ocean circulation, particularly in the equatorial region. This also helps to represent important ocean processes more accurately, such as upwelling, which is critical for transporting nutrients and supporting marine life.

- Use of satellite-based monthly estimates of the Global Mean Sea Level to better constrain the model ocean mass.

- An improved parametrization of the model and observations errors used in the data assimilation method. Moreover, the concept of "super-observations" (Hoffman, 2018) has been introduced in the computation of the model equivalent to filtering out noisy data and scales that the model does not resolve. The analysis, which provides temperature, salinity, sea surface height, currents, and sea-ice corrections to be applied to the model, has also been improved with a better balance between the different corrections. This balance is crucial for providing a realistic depiction of the ocean, which relies on models as well as a variety of observations, such as moorings, buoys, floating devices, satellites, and Argo profiles.

- A 4D extension of the data assimilation scheme. This new approach will result in better spatiotemporal continuity of mesoscale structures such as eddies or fronts, providing a clearer picture of the complex dynamics of the ocean. This helps to provide a more accurate representation of the daily fluctuations of several ocean quantities and can support better decision-making in areas such as marine management and environmental monitoring.

2. EVALUATION OF THE SYSTEM COMPARED TO THE PREVIOUS ONE

2.1. Sea Surface Temperature

Figure 1 shows time series of the mean bias and the root-mean-squared (RMS) of the misfit (SST observation minus model analysis). The GLO12 sea-surface-temperature analysis is very close to *in situ* observations and displays a weak global average bias with respect to OSTIA (warm bias of 0.05 °C) and a comparable bias with ODYSSEA in terms of amplitude but of opposite sign (cold bias of 0.05 °C). The RMS error is around 0.45 °C for OSTIA and 0.6 °C for ODYSSEA, which is in the range of satellite observations' uncertainty. In any case, even if OSTIA is no longer assimilated into GLO12, we improve the system's performance with respect to this satellite, compared to the PSY4 system.

2.2. Temperature and salinity vertical profiles

For the temperature and salinity vertical profiles, Figure 2 shows time series of the mean bias and RMS of the misfits (difference between the observations and the model analyses). The time evolutions of temperature and salinity assimilation statistics are shown for the previous system PSY4 and for the new system GLO12, allowing inter-comparisons. On global average, the description of the ocean water masses in GLO12 is improved compared to PSY4. It is very accurate with very weak systematic warm biases. Departure from *in situ* temperature and salinity observations are generally below 0.3°C and 0.05 PSU respectively.

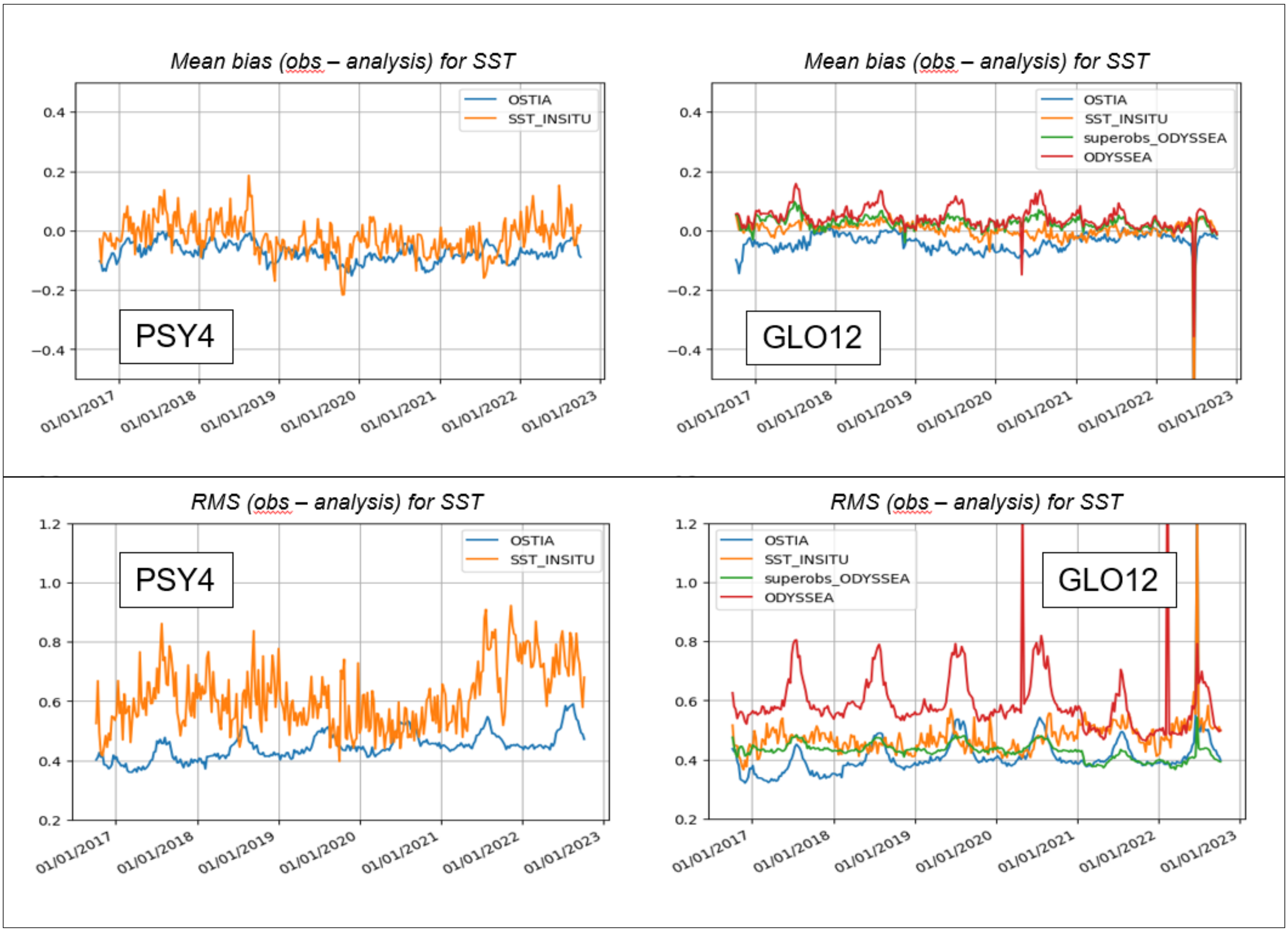


Figure 1. Sea Surface Temperature (°C) global misfit average (top) and RMS (bottom) for OSTIA observations (blue line), ODYSSEA observations (red line), "super-obs" ODYSSEA observations (green line) and *in situ* observations (orange line), for the (October 2016 - October 2022) hindcast period. Previous system PSY4 is on the left and GLO12 on the right.

2.3. Sea Level Anomaly

Figure 3 represents the time series of SLA bias and the RMS of the SLA misfit, comparing the PSY4 system (on the left) and the GLO12 system (on the right). GLO12 is closer to altimetric observations than PSY4 with a RMS difference around 4 cm for GLO12 and 5.5 cm for PSY4. The SLA mean bias and the RMS misfits are considerably reduced in GLO12 compared to PSY4, in nearly all regions of the ocean. observations are generally below 0.3°C and 0.05 PSU respectively.

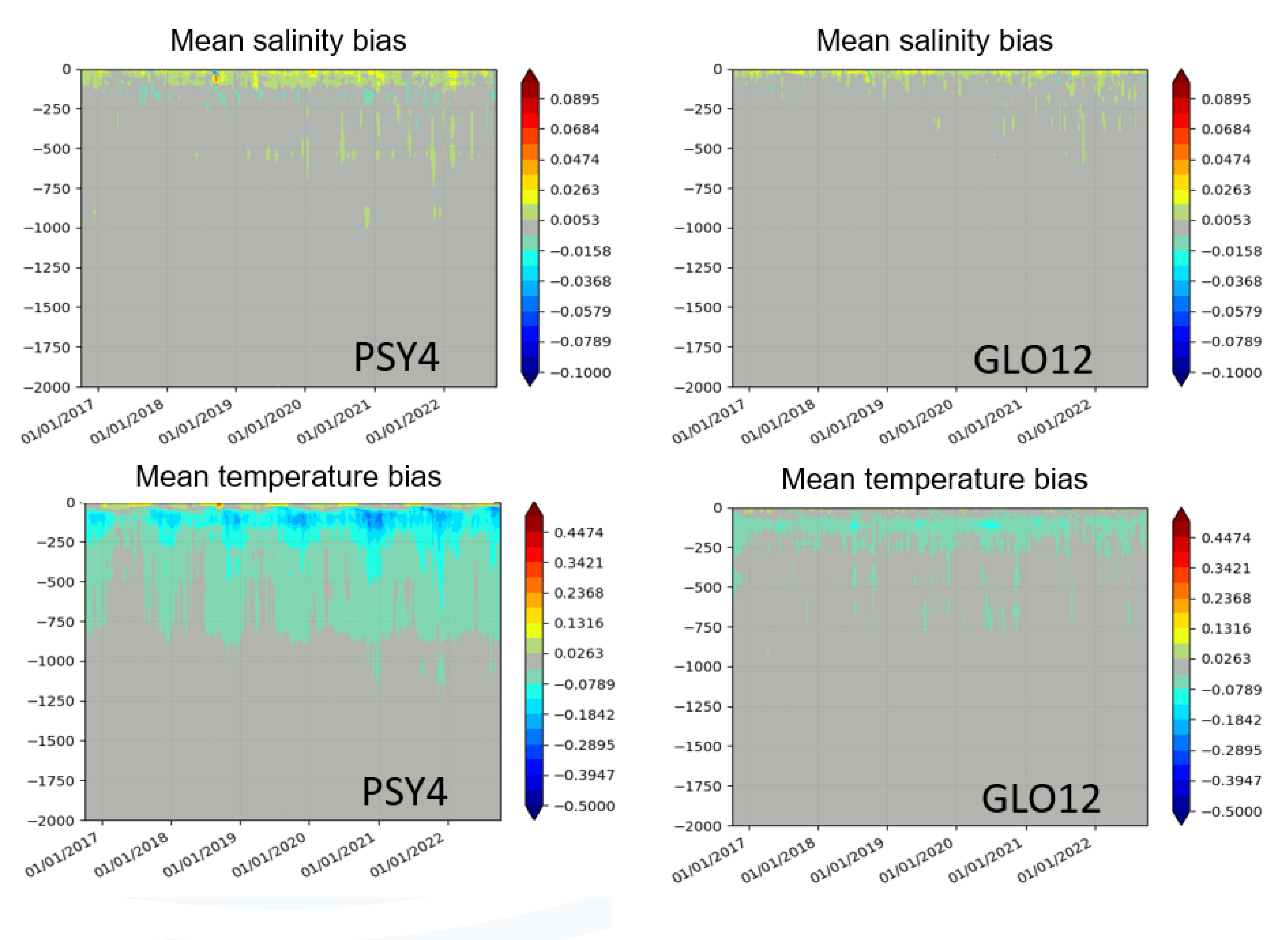
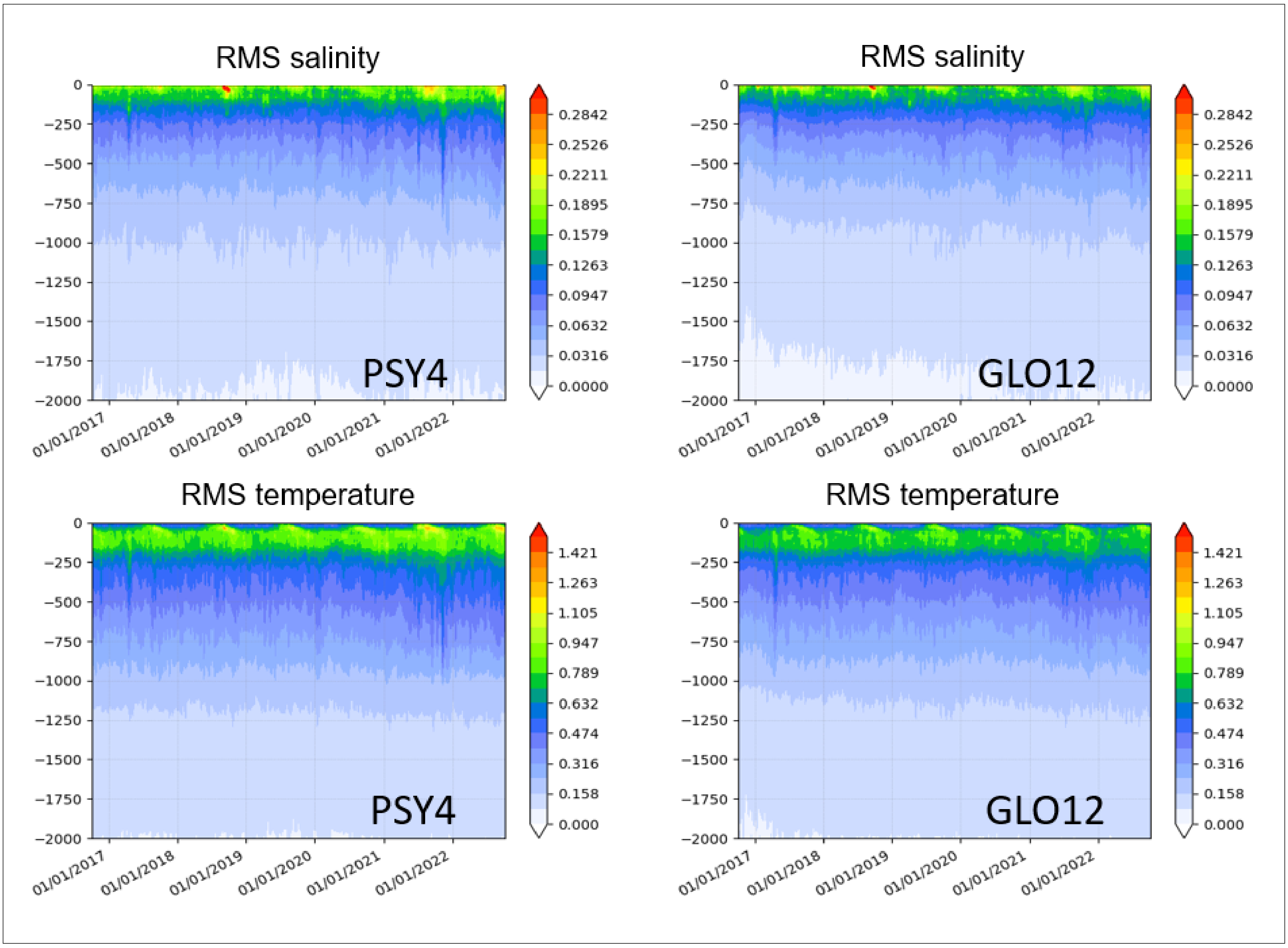


Figure 2. Assimilation diagnostics with respect to the assimilated vertical temperature and salinity profiles over the October 2016 – October 2022 period: mean misfits (observation minus model analysis) and RMS misfits for temperature and for salinity. Left panels (respectively right panels) concern PSY4 (respectively GLO12). These scores are averaged overall seven days of the data assimilation window, with a mean lead time equal to 3.5 days. Units are °C for temperature and PSU for salinity.


RMS salinity
PSY4
GLO12
RMS temperature
PSY4
GLO12
01/01/2017
01/01/2018
01/01/2019
01/01/2020
01/01/2021
01/01/2022
0.2842
0.2526
0.2211
0.1895
0.1579
0.1263
0.0947
0.0632
0.0316
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1.421
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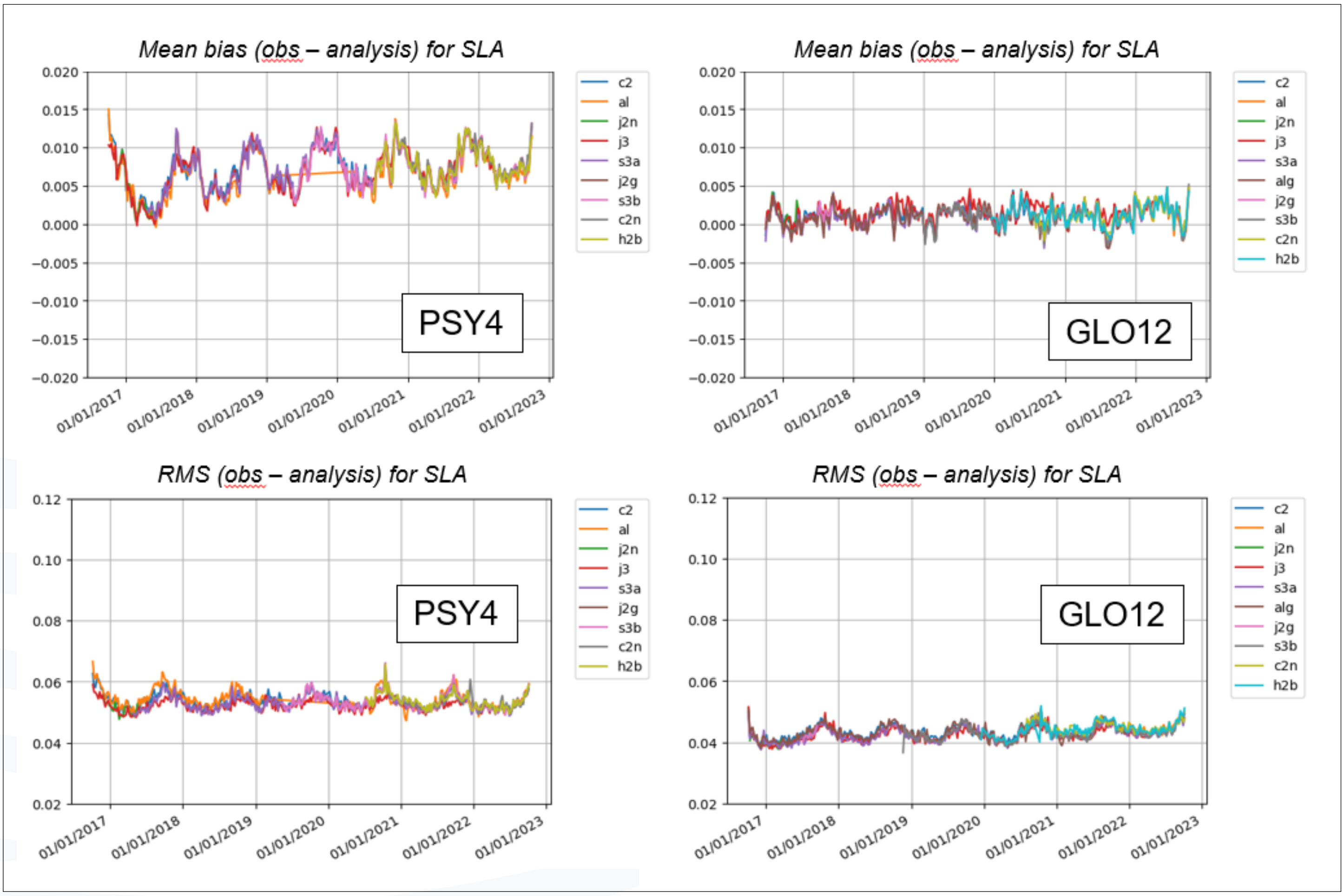

Figure 3. Time evolution of SLA data assimilation statistics averaged over the whole domain.

The repartition mass/steric distribution has been improved in GLO12 (loss of mass and too much steric diagnosed in PSY4), resulting in better trends for the different components of the Global Mean Sea Level (GMSL). Figure 4 represents the GMSL evolution over the GLO12 simulation period where we checked the model by comparing the results with AVISO estimates. The AVISO GMSL (black, 4.8 mm/yr) compares very well with the GLO12 GMSL (green, 4.7 mm/yr). Most of the trend is brought by the mass (cyan, 3.7 mm/yr). Steric (orange, 0.95 mm/yr) plays a smaller role.

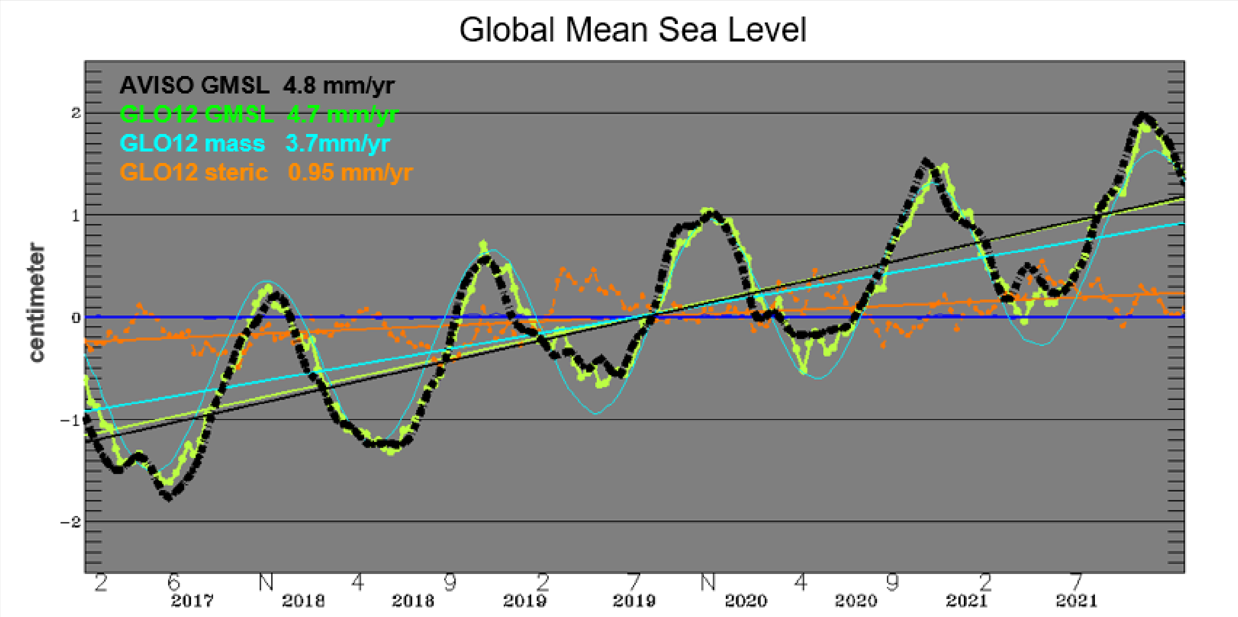

Figure 4. Time evolution of the Global Mean Sea Level for GLO12 and AVISO.

2.4. Sea-ice concentration

For sea-ice concentration (SIC), Figure 5 shows that GLO12 is closer to the observations than PSY4 (RMS around 8% for GLO12 and around 11% for PSY4). The large-scale features of the sea-ice cover are well captured both in the Arctic and the Antarctic oceans. The sea-ice concentrations are underestimated in the Arctic (respectively in the Antarctic) mainly during summer (respectively during austral summer), probably due to atmospheric forcing uncertainties.observations are generally below 0.3°C and 0.05 PSU respectively.

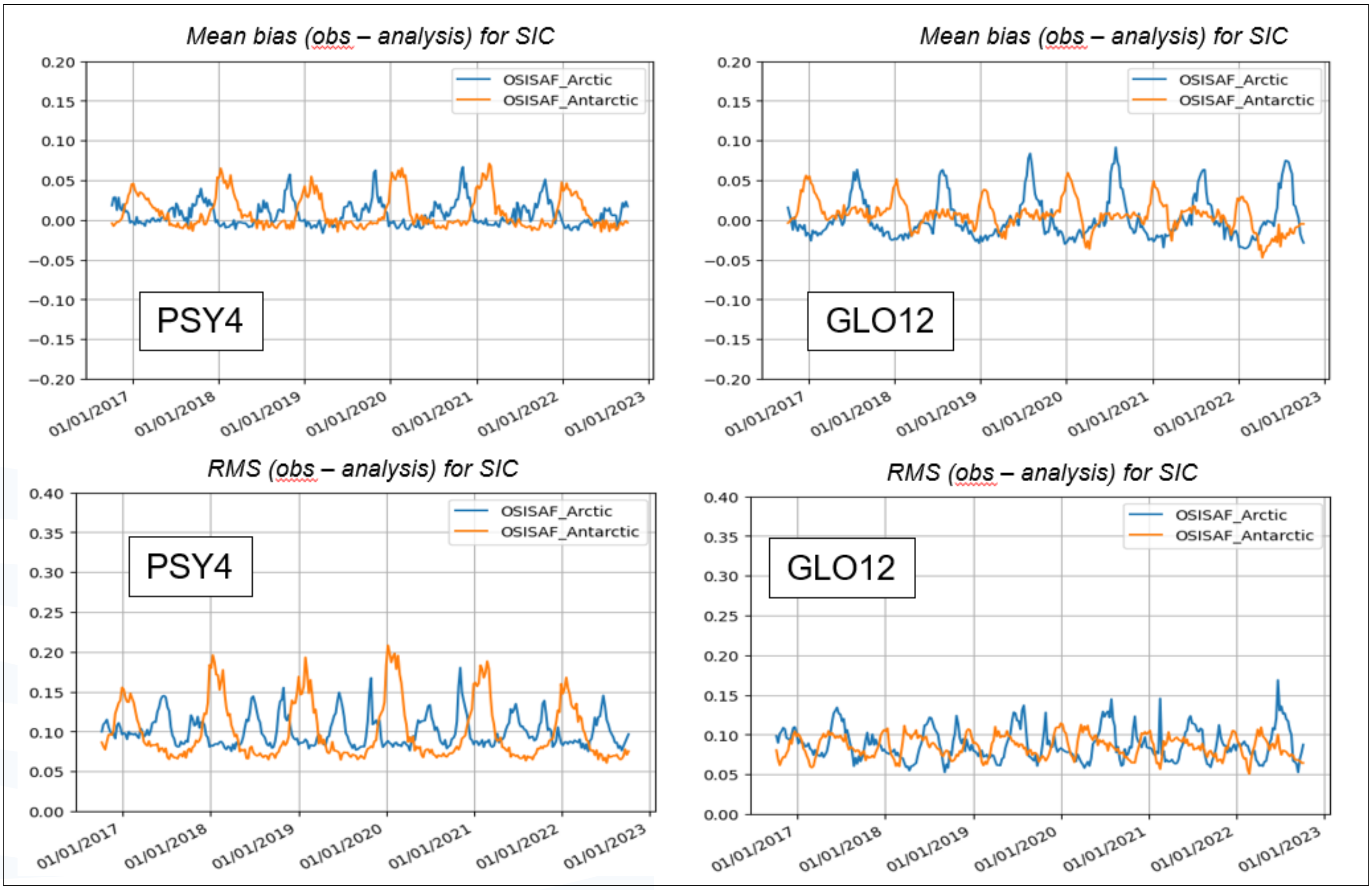

Figure 5. Time evolution of SIC data assimilation statistics averaged over the whole domain.

3. CONCLUSION

The new release of the global monitoring and forecasting physical system GLO12 is a major advancement in terms of representing high-frequency behavior in the ocean. The GLO12 system performs statistically very well, with an accurate representation of water masses, surface fields and mesoscale activity. Most of the components of the new system are improved compared to the previous system: global mass balance, 3D T/S, Sea Surface Height, sea-ice, currents. The improvements made to this release will potentially benefit a wide range of users, including several marine sectors as:

- Ocean health: better tracking of pollution (e.g., litter, oil) thanks to better representation of the mesoscale activity and equatorial current dynamics.
- Trade and marine navigation: better ship routing thanks to better representation of the mesoscale activity and equatorial current dynamics.
- Polar environment monitoring: more accurate provision of polar sea-ice conditions.

- Natural resources and energy: better characterization of oceanic resources for renewable energy prototypes thanks to better representation of sea-surface-temperature and water masses.

- Extremes, hazard and safety: better characterization of oceanic extremes thanks to better representation sea-surface-temperature, mesoscale activity and water masses.

- Climate and adaptation: better characterization of Marine Heat Waves thanks to better representation sea-surface-temperature and water masses.

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The Syrian oil spill predictions in the Eastern Mediterranean using SAR images, CMEMS and CYCOFOS forecasts

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Keywords

Mediterranean, oil spill modeling, SAR images, CMEMS, CYCOFOS

Abstract

Following the 12,000-ton crude oil spill from the fuel tanks of Syria's Baniyas power plant in the summer of 2021, MEDSLIK and MEDSLIK-II models conducted daily operational oil spill predictions of the spill's transport and fate in the Eastern Mediterranean Levantine basin, assisting REMPEC and national response organizations. The Syrian pollution incident lasted from August 23 to September 12, 2021, and was of the same magnitude in terms of spilled oil and similar source type as the one caused by the Jieh power plant during the Lebanon oil pollution in July 2006. The sea currents and sea surface temperature forecasting data from the CYCOFOS (Cyprus Coastal Ocean Forecasting and Observing System) and CMEMS Med MFC products were used together with ECMWF and the high-frequency SKIRON winds to initiate the predictions of the Syrian oil spills traced from satellite SAR images provided by EMSA-CSN (European Maritime Safety Agency, CleanSeaNet). The operational response during the Syrian oil pollution crisis, which also threatened neighboring countries in the NE Levantine, demonstrated a best practice within the broader context of the operational oceanography developments in the Mediterranean and the usefulness of the downstream

applications to the local and regional response agencies to support their decisions during major oil pollution incidents. To assess the Syrian oil spill predictions produced by MEDSLIK, inter-comparisons were carried out at a post-operational stage with the OpenDrift model under various met-ocean forcings and configurations and evaluated the two models' ability to adequately reproduce the oil spill spreading by comparing the SAR observed oil spillages against the model results using four statistical indicators.

1. INTRODUCTION

In the last two decades, it has been documented that the Levantine is vulnerable to major oil spill incidents due to the increase in shipping traffic following the enlargement of the Suez Canal and the numerous coastal infrastructures, particularly the fuel tanks of the power plants and refineries located close to the shorelines of the riparian countries. The first well-documented major oil pollution in the Levantine was caused in mid-July 2006, following the oil leakage of around 15,000 tons of heavy crude oil from the fuel tanks of the Jieh power plant, which is located south of Beirut in Lebanon (Lardner In the last two decades, it has been documented that the Levantine is vulnerable to major oil spill incidents due to the increase in shipping traffic following the enlargement of the Suez Canal and the numerous coastal infrastructures, particularly the fuel tanks of the power plants and refineries located close to the shorelines of the riparian countries. The first well-documented major oil pollution in the Levantine was caused in mid-July 2006, following the oil leakage of around 15,000 tons of heavy crude oil from the fuel tanks of the Jieh power plant, which is located south of Beirut in Lebanon (Lardner *et al.,* 2006; Zodiatis In the last two decades, it has been documented that the Levantine is vulnerable to major oil spill incidents due to the increase in shipping traffic following the enlargement of the Suez Canal and the numerous coastal infrastructures, particularly the fuel tanks of the power plants and refineries located close to the shorelines of the riparian countries. The first well-documented major oil pollution in the Levantine was caused in mid-July 2006, following the oil leakage of around 15,000 tons of heavy crude oil from the fuel tanks of the Jieh power plant, which is located south of Beirut in Lebanon (Lardner *et al.,* 2006; Zodiatis *et al.,*2007; Coppini *et al.,* 2011). Following a relevant request from REMPEC, daily oil spill predictions were carried out operationally using the well-established MEDSLIK oil spill model (Lardner *et al.,* 1998; De Dominicis *et al.,* 2013; Zodiatis *et al.,* 2021) with SKIRON and CYCOFOS met-ocean forecasting data. The CYCOFOS sea current forecast for mid-July 2006 showed a northerly flow, parallel to and close to the coasts of Lebanon and Syria, with flow velocities between 20 and 30 cm/s, while the SKIRON wind forecast showed winds varying in direction between South-West and south, with wind speeds generally varying between 2 and 7 m/s. Therefore, during the Lebanon oil pollution crisis, the oil spill extended close to the coastal area and heavily polluted the shoreline of Lebanon, northern than the Jieh power plant, and partially the southern coast of Syria up to Tartus, Jablah, and the south shoreline of Latakkia (Lardner *et al.,* 2006; Zodiatis *et al.,*2007; Coppini *et al.,*2011).

It is worth mentioning that during the Lebanon oil pollution crisis, limited satellite remote sensing SAR images were available by the JRC, which were used to validate the oil spill predictions regarding the extent of the oil pollution. A year later, the EMSA-European Maritime Safety Agency launched the CleanSeaNet portal, which provides Member States with oil spill warnings based on remote sensing satellite SAR data.

The systematic use of remote sensing SAR data from EMSA-CSN and ESA (European Space Agency) for a period of 5 years, from 2007 to 2011, made it possible not only to reveal more than a thousand possible oil slicks along the main shipping routes in the Levantine basin, but also to couple the satellite remote sensing SAR data with the MEDSLIK oil spill model and to provide in operational mode 24 hour forecasts and 24 hour backtracking of the satellite observed possible oil slicks using the SKIRON and CYCOFOS met-ocean forecasting data (Zodiatis *et al.,* 2012).

In mid-February 2021, an oil pollution incident landed a large amount of tar balls on the beaches of Israel, Lebanon, and the Gaza Strip following an offshore oil spill. The offshore spill was not detected by remote sensing satellite SAR images at the early stages of its development. Following REMPEC's request, MEDSLIK and MEDSLIK II were implemented using different met ocean forcings, such as SKIRON winds, CYCOFOS sea currents, CMEMS Med MFC sea currents, and ECMWF winds, respectively (Liubartseva *et al.,* 2022). The oil spill modeling results were compared with the on-shore coastline distribution of the accumulated oil to assist the investigation carried out by the Israeli authorities to identify the source of the oil spillage, which impacted an extended coastline of up to 160 km of the country.

As it was reported by REMPEC on the 25th of August 2021, following an official notification from the Syrian Ministry of Environment, a total of 12,000 tons of crude oil were spilled in the sea at around 10:00 UTC on the 23rd of August 2021 from the fuel tanks of the Baniyas power plant, which is located south of Latakia (Fig. 1). It is worth mentioning that the Syrian oil pollution is of the same order of magnitude in terms of the amount of oil spilled at sea from a similar source type as the one caused by the Jieh power plant during the Lebanon oil pollution crisis in mid-July 2006 (Lardner *et al.,* 2006; Zodiatis *et al.,* 2007; Coppini *et al.,* 2011).

In the frame of the MONGOOS-REMPEC agreement aiming to provide operational oil spill predictions in major pollution incidents in the Mediterranean Sea, members of MONGOOS, CMCC (Italy), ORION (Cyprus), and Orbital EOS (Spain) provided daily oil spill predictions using satellite remote sensing SAR data from August 25 to September 12, 2021.

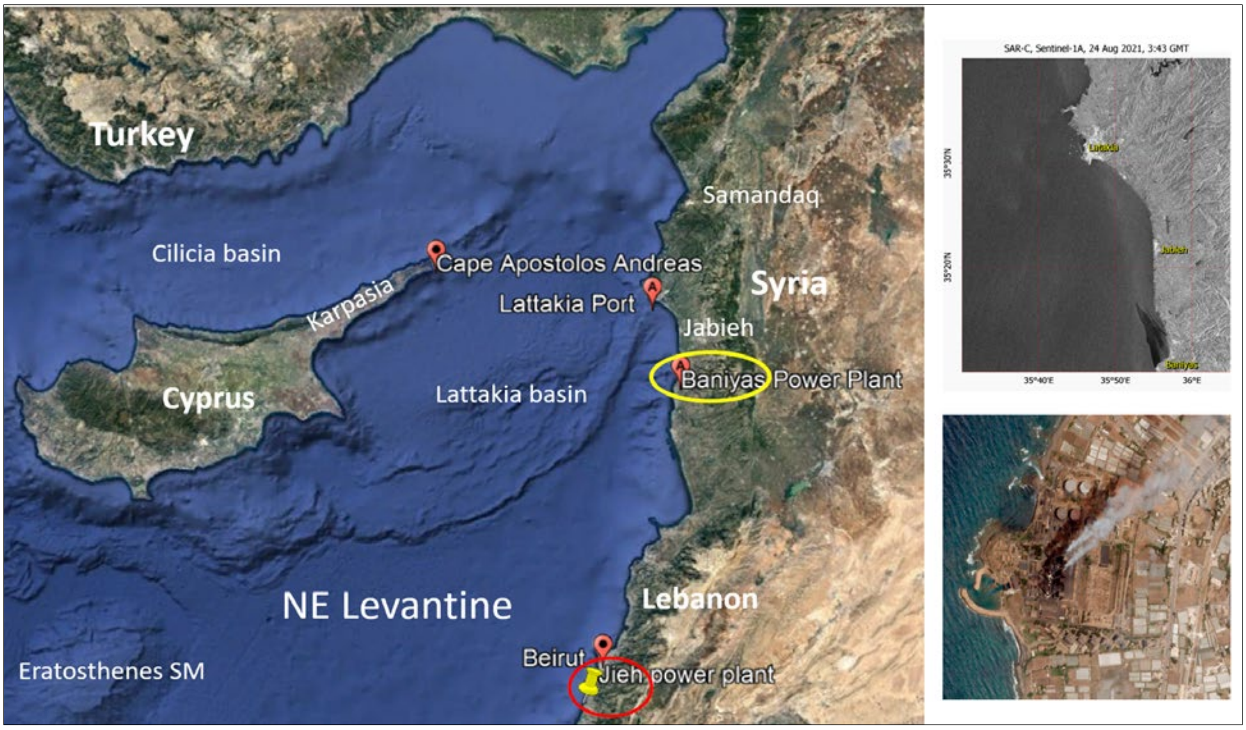
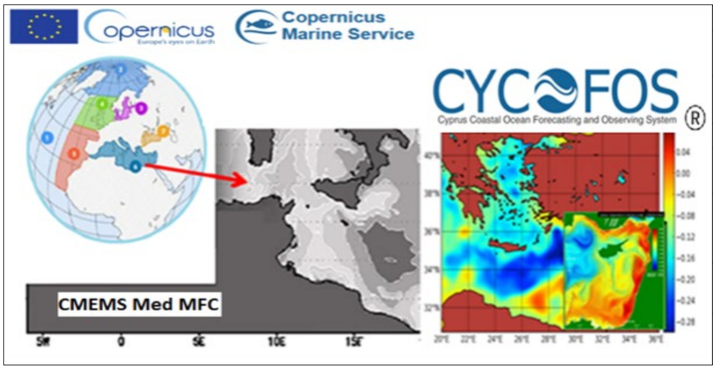


Figure 1. Left: NE Levantine with the locations of the Baniyas power plant in Syria (yellow circle) and of Jieh power plant in Lebanon (red circle). Left bottom: The Baniyas power plant June 20, 2021 (Planet Labs Inc.). Left top: The spillage from the Baniyas power plant on the 24 August 2021 as first detected by SAR image.

The current paper presents the operational oil spill predictions of the Syrian oil spillages using MEDSLIK and MEDSLIK II to assist REMPEC and regional response agencies. To assess the oil spill predictions produced by MEDSLIK, inter-comparisons were carried out at a post-operational stage with the OpenDrift model under various met-ocean forcings and configurations and evaluated the two models' ability to adequately reproduce the Syrian oil spill spreading by comparing the SAR observed oil spillages against the model results using four statistical indicators.

2. METHODOLOGY AND DATA USED

The MEDESS4MS multi-oil spill modeling approach (Zodiatis *et al.*, 2016) was applied operationally using different resolution met-ocean forecasting data from CMEMS Med MFC, ECMWF, CYCOFOS, and SKIRON systems (Fig. 2) and the well-established MEDSLIK (Zodiatis *et al.*, 2021) and MEDSLIK II (De Dominicis *et al.*, 2013) oil spill models. Moreover, 27 satellite-derived SAR and optical images provided by the seven surveillance satellites were processed in order to initiate the operational oil spill modeling predictions.



Parameter	Values
Location of spillages:	Polygons derived from SAR and optical images from ESA and EMSA CSN and MODIS
Oil type :	Heavy oil
Spill duration:	Instantaneous
Simulation length:	72 -96 hours ahead for every available SAR image from EMSA CSN and ESA
Hydrodynamic fields:	CMEMS Med MFC: hourly, 4 km CYCOFOS Aegean Levantine: 6 hourly, 2 km
Wind fields:	ECMWF: 6-hourly, ~11 km SKIRON: hourly, 10 km
Number of parcels used:	50,000 and 20,000

Figure 2. Left: The domains of CMEMS Med MFC and of the nested CYCOFOS models, the data of which were used in MEDSLIK and MEDSLIK-II operational simulations, while the CYCOFOS data were used also by the OpenDrift model. **Right:** The oil spill models simulation setup.

The offshore sea surface circulation pattern between Cyprus and Syria during the examined period (24 August to 12 September 2021) was dominated by two anticyclonic and one cyclonic eddy and a meandering northward current flowing between the eddy boundaries, while near the Syrian coast of the Baniya power plant, the sea surface currents were generally in the northward direction (Fig. 3).

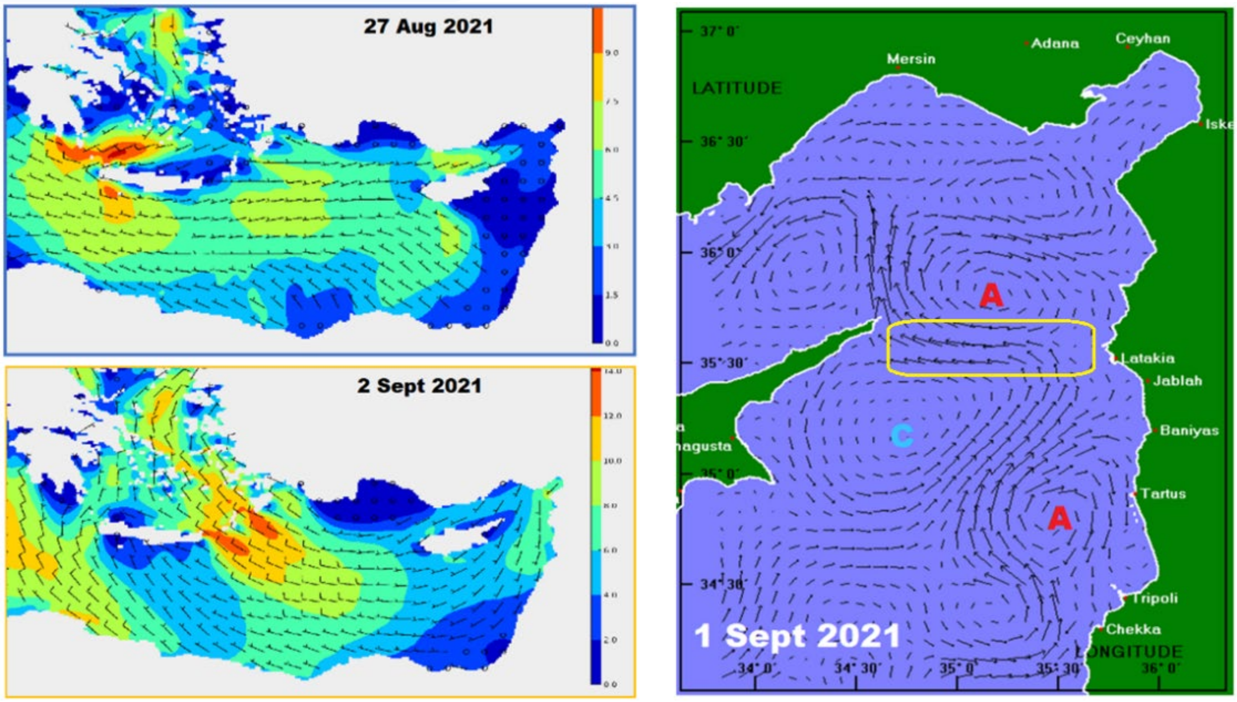


Figure 3. Left: SKIRON forecasted winds: weak winds between 25 to 28 August 2021 and moderate winds in early September 2021, in the area between Syria and Cyprus, NE Levantine. **Right:** The CYCOFOS sea surface currents in the area between Cyprus and Syria dominated throughout the Syrian oil pollution crisis by two anticyclonic and one cyclonic Eddy.

The SKIRON winds in the NE Levantine, between Cyprus and Syria, were shown to prevail in calm wind conditions from August 23 until August 28, 2021, while later southerly light breeze to gentle breeze winds prevailed (Fig. 3).

At the post-operational stage, to evaluate the ability of the oil spill models to adequately reproduce the oil spill spreading, a number of quantitative metrics were used by comparing the SAR-observed oil spillages against the model results. MEDSLIK and MEDSLIK II use the same advection and fate algorithms; therefore, the evaluation of the oil spill predictions was carried out using MEDSLIK (Zodiatis *et al.*, 2021) against the OpenDrift oil spill model (Dagestad et al., 2018). The model's intercomparison results were statistically evaluated using the same ocean data as the evolution of the oil spill trajectory.

3. RESULTS AND DISCUSSION

The oil spillage from the *Baniyas PP* on August 23, 2021, initially washed up at higher concentrations along the southern coast of Latakia. Later, after August 27, part of the emulsified oil was transferred offshore westward and widely spread in the NE Levantine between Syria, Cyprus, and Turkey, threatening the cape of Apostle Andreas at the eastern tip of Cyprus (Fig. 4). The fast westward spread of the oil spill was caused by the strong westward sea current generated along the southern and northern periphery of the anticyclone and cyclone eddies (Fig. 3), respectively, which dominated the local circulation. The oil spill was mostly re-circulated by the anticyclone eddy, where part of the oil was re-landed at the Syrian coast in the broader coastal area of Latakia and part of it was washed on the Turkish coast near Samandaq, under the increased southerly wind force. After September 6, the emulsified, thin-sheen oil spill was progressively dispersed under the increased wind-wave action.

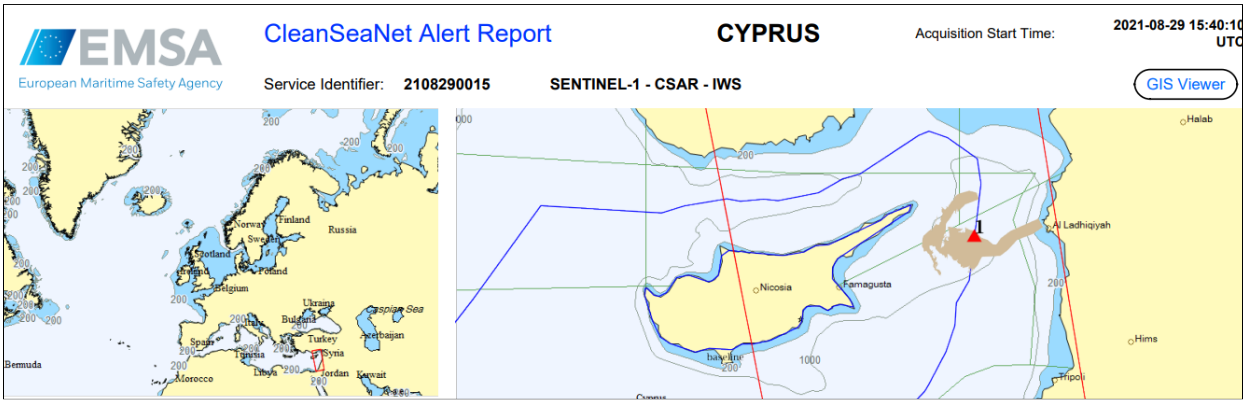


Figure 4a. EMSA CSN alert report showing the offshore spread of the Syrian oil spill based on SAR image derived at 15:41 29 Aug.2021.

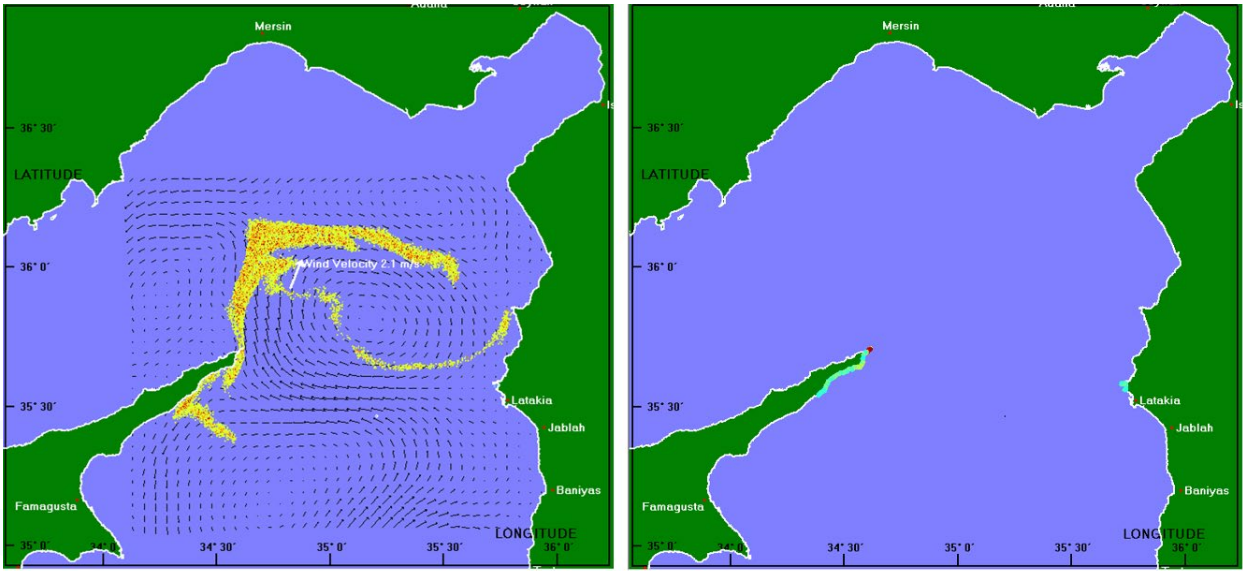


Figure 4b. Left: MEDSLIK simulations of the surface oil spill initiated with the same SAR image. **Right:** MEDSLIK simulation of the oil landed on coast after 96 hours (1 Sept. 2021) initiated with the same SAR image.

To assess the two models' predictability of the oil spill compared to the satellite observations, the models were intercompared with the SAR image obtained on August 30, 2021, at 03:41 UTC, i.e., after 12 hours from the initialization of the two models using the SAR image obtained on August 29, 2021, at 15:41 UTC. To get a closer estimate of the predicted spill area, the MEDSLIK model introduced a different horizontal diffusion compared to the one used by OpenDrift. The implemented statistical indices showed an overall good agreement between the models regarding the predictions shown in Fig. 5 (left), which illustrates that both models' predictions are very close to each other, and at certain areas, their oil spill extends were overlaid on each other. In addition, it is observed that their oil spill extent is very well convergent with the SAR satellite image (Fig. 5 right). This is indicated by the corresponding statistical indicator of Success Rate SR = 0.70, revealing that the convergence rate (SR and FR indicators) of both MEDSLIK and OpenDrift with the satellite SAR image is around 33%. On the other hand, the Centroid Skill Score index (CSS) is very high for both models (CSS = 0.89 for MEDSLIK and CSS = 0.81 for OpenDrift) when compared to the SAR image collected on August 30, 2021, at 15:41.

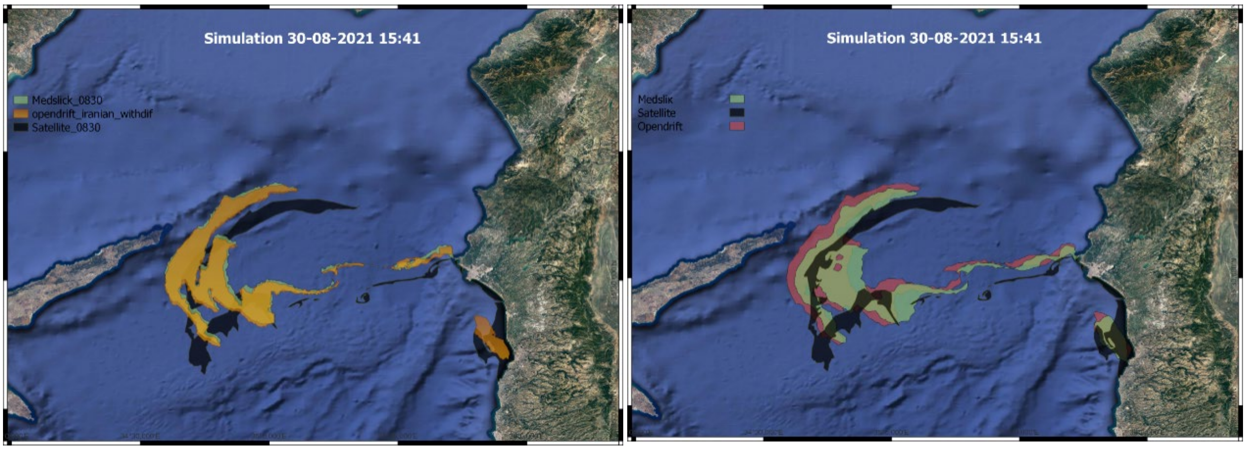


Figure 5. Left: Left: MEDSLIK and OpenDrift models shown a very good agreement between them, comparing the predicted extend of the slick areas when both models used the same forcing data and same main model parameters. Orange color expresses the results of OpenDrift model, green color indicates the results of MEDSLIK model and black color the satellite SAR data. Right: Comparative Analysis of the results of MEDSLIK and OpenOil models (predicted extend area) vs SAR data at 30/08/2021 03:41, after 12 hours of simulation initiated with the SAR image of the 29/08/2021 15:41. Red color expresses the results of OpenDrift model, green color indicates the results of MEDSLIK model and black color the SAR data.

4. CONCLUSIONS

The MONGOOS members, ORION (Cyprus), CMCC (Italy), and Orbital EOS (Spain), following a request from REMPEC, provided operational oil spill predictions of the Syrian oil spill on a daily basis using the MEDSLIK and MEDSLIK II models from August 25th to September 9th, 2021, initiated with the CMEMS Med MFC, CYCOFOS, ECMWF, and SKIRON met-ocean forecasts and SAR data provided from EMSA CSN and ESA. After the first leak, the Syrian oil spill was transferred from the Baniyas Power Plant northward, south of Latakia. From there, the emulsified oil was quickly spread offshore because of the strong westward currents between the local anticyclonic and cyclonic eddies. The spread of the offshore spill was generally driven by the anticyclonic eddy and resulted in the re-landing of the spill in the broad coastal area of Latakia. The coastal region of Samadaq in Turkey and the point of Apostol Andreas at the most eastern tip of Cyprus received some minor emulsified oil. The remaining emulsified spill was dispersed gradually with the increase in wind after September 6. At a post-operational stage, the MEDSLIK predictions were compared with the OpenDrift model using the same met-ocean forcing and, in addition, against the extent of the oil spill traced from SAR images. The statistical indicators showed good agreement between the two intercompared models and between the models and the SAR images obtained after 12 hours from the models initialization.

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Oral presentations – Session L

Ocean observing meeting societal challenges

OLAMUR: offshore low-trophic aquaculture in multi-use scenario realisation

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Keywords

Seaweed and mussels, Wind farm, Fish farm, Data-based service system, Baltic Sea and North Sea

Abstract

Globally, food security, and human well-being are threatened as aquatic ecosystems and natural fisheries can no longer sustain the production of living aquatic resources. Agricultural expansion alone cannot meet future food needs without significant impacts on ecosystems. OLAMUR is a Horizon Europe project that promotes sustainable Multi-Use Low-Trophic Aquaculture (MU-LTA) in offshore waters, specifically in wind or fish farms. It aims to develop a commercially viable solution for MU-LTA, including seaweed and mussel farming, in both low and high salinity, high eutrophic, and high energy offshore waters. Through a holistic approach, OLAMUR demonstrates the co-use of marine space and how low-trophic aquaculture can contribute to resilient and sustainable food production with minimal impacts and emissions. MU-LTA offers environmental, social, and economic benefits, aligning with various Sustainable Development Goals. It has low climate and environmental stress, preserves ecosystem integrity, and reduces import dependency, food insecurity, and malnutrition. OLAMUR actively involves producers and stakeholders in the decision-making process. Encouraged by the European Community, OLAMUR contributes to improving marine data standardisation and accessibility through programs like Copernicus and EMODnet. It aims to enhance access to observational data throughout their life cycle, supporting knowledge-based smart decisions by policymakers. The project develops governance arrangements, policy levers, and an integrated service system to achieve effective and sustainable governance of multiple uses. This system assists producers in all stages of the production chain and provides information on the potential of low-impact aquaculture.

1. INTRODUCTION

The population growth, the resulting increase in demand for fish products, the overfishing and the stagnation of traditional activities, is leading globally to an increase in the production of farmed fish, shellfish, crustaceans, seaweed and other aquatic species. Aquaculture now provides more than 50% of the seafood for human consumption globally. However, at present, Europe is unable to feed itself in the case of seafood and is heavily dependent on imported seafood, with major food security and safety implications, which can also be viewed as an ethical challenge (Costa-Pierce, 2016). The EU has highlighted the need for a new strategy for aquaculture to become sustainable and to enable future growth in this sector (COM/2021/236) and the new approach for a sustainable blue economy (COM/2021/240).

To significantly increase seafood production beyond current levels, a promising approach involves a synergistic combination of harvesting seafood at lower trophic levels, along with advancements in mariculture for macroalgae, herbivores, and carnivores (SAPEA, 2017). Broad evidence supports the potential of low trophic aquatic food to reduce food and nutrition insecurity and tackle malnutrition (Golden *et al.*, 2021; FAO, 2022), while at the same time posing the lowest stressors on climate and environment (Gephart *et al.*, 2021), delivering essential ecosystem services and enabling achieving UN Sustainable Development Goals (SDGs) (Duarte *et al.*, 2021).

The coupling of the breeding of low-trophic organisms (seaweeds and mussels) with other activities can bring mutual advantages, meeting several essential demands for a more secure and sustainable Europe. For example, multi-use of marine space by co-existence of low trophic aquaculture and wind farms has been suggested as an efficient way of providing renewable energy and healthy seafood with a high yield of productivity and a low-carbon emission (Golden *et al.*, 2021; Gephart *et al.*, 2021). Instead, the combination with fish farming would reduce nutrient overloading caused by fish farming, as well as eutrophication caused by agriculture in surrounding land areas, as is the case in the Baltic Sea (Chopin *et al.*, 2012), reducing environmental problems and improving ecosystem services.

This paper presents the four-year Horizon Europe OLAMUR (Offshore Low-trophic Aquaculture in Multi-Use scenario Realisation) project (https://olamur.eu/), started in January 2023, that fits into this context. OLAMUR aims to develop and demonstrate a sustainable solution for commercial Multi-Use Low Trophic Aquaculture (MU-LTA) (e.g., seaweed and mussel farming) in both low and high salinity, high eutrophic and high energy offshore waters (i.e., wind farms and fish farms).

OLAMUR research and activities are organised in work packages (WPs) each of which corresponds to a specific objective of the project.

Firstly, the project establishes three pilot demonstration sites in the North Sea (A = Germany) and Baltic Seas (B = Denmark, C = Estonia). These sites are geographically and ecologically diverse, allowing for comprehensive testing and showcasing of the proposed multi-use low-trophic aquaculture concept. The pilot studies are designed to demonstrate the practicality and replicability of this approach (Fig. 1). In the pilot sites, Case study A and B are conducted within large-scale offshore wind parks. On the other hand, Case study C is strategically placed adjacent to an existing rainbow trout farm, creating a unique setup that combines both high trophic and low trophic species. The selected low trophic organisms for aquaculture include sugar kelp (*Saccharina latissima*) and sea lettuce (*Ulva sp.*) as seaweeds, along with blue mussels (*Mytilus edulis*).

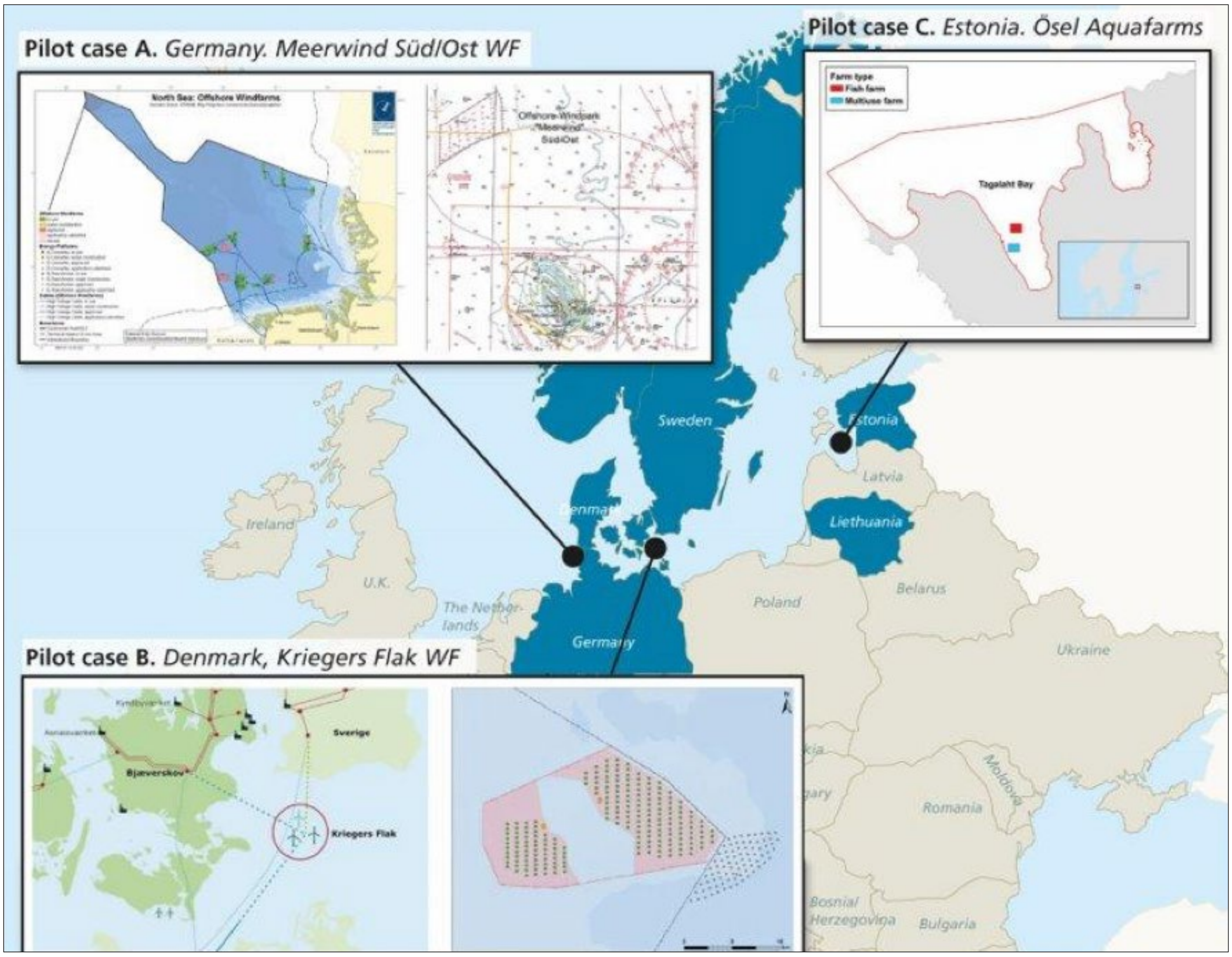

Figure 1. OLAMUR Pilot cases.

The next important step of the project is the identification of suitable locations for multi-purpose uses of the marine space. These locations are carefully chosen to support future developments of low-impact and low-carbon activities in the North Sea and Baltic Sea regions. The project assesses the suitability of these multi-purpose use locations specifically for the industrial production of low trophic species with economic interest in these areas.

To enable efficient monitoring and assessment of aquafarms and facilitate informed decision-making, the project focuses on developing a robotics and model-based monitoring, forecasting, and assessment capacity.

Moreover, a data-based management support system is being realized for aquaculture monitoring and data analysis. This system is designed to provide essential services to farmers, helping them adopt sustainable monitoring practices, optimize production, and enhance sales strategies.

In line with sustainability goals, the project conducts a Cradle-to-Cradle System level Life Cycle Assessment (LCA) and multi-actor Total Economic Assessment (TEA). These assessments ensure economic viability for all actors along the value chains, and they also document the broader system value of circular resource management systems, which extend beyond financial profits and contribute to growth in positive ways.

Recognizing the importance of effective governance, the project aims to co-create holistic multi-level governance solutions for innovations in offshore seaweed and shellfish farming within windmill farms. This involves a comprehensive assessment of the governance structures at all relevant levels, from local to global, within the three pilot sites. The engagement of all relevant stakeholders, including those from science, policy, industry, and society, is an integral part of this process.

Finally, the project emphasizes the importance of fostering communication and interaction with the sector. By actively listening to the needs of the stakeholders, the project team can provide valuable recommendations and ensure that the project outputs are effectively transferred to both private and public stakeholders.

2. MATERIALS AND METHODS

A specific objective of OLAMUR is to develop and implement a decision support system that enhance the user experience (UX) in the field of aquaculture and multi-use management. The system will enable a market-wide monitoring and data analysis for aquaculture, offering modules both for general indicator service and in the different pathways for the pilot cases, which will be available to partners, and eventually to other users. The modules tools tailored to meet the specific decision support needs of the users.

The UX will be provided through a web-based system that will incorporate features for searching, interacting, downloading, and visualising pre-processed data derived from the project work. The development process involves the use of protocols and algorithms created by other WPs within the project. The algorithms are crucial to the development of decision support methodologies and the generation of customised information that adds value to the stakeholders involved. These modules consume data and data products available within the infrastructure and employ both online and offline algorithms to generate decision support information tailored to specific requirements. All of these products will be implemented in the portal to be interrogated by users.

3. RESULTS

The technical infrastructure for data sharing and distribution within and outside the consortium, including further distribution to European marine data aggregators, is built in order to facilitate the data harmonization and operate as integrator and data translator for facilitating the data use and interoperability. To effectively manage the diverse requests within a unified system, data and flow management are harmonised using an architecture that incorporates ERDDAP (Environmental Research Division's Data Access Program) and GeoServer, common open tools to query for and view data collections and data products.

ERDDAP and GeoServer facilitate data interoperability between and within the various observing networks and provide a robust architecture for the project. The data used in the study comprises publicly distributed datasets, such as Copernicus or EMODnet, as well as internally generated data for project-specific purposes.

The developed data management infrastructure is the basis for the development of targeted data services that consumes data and data-products made available on infrastructure and run algorithms created by other WPs:

- Event Warning Service: warning module tool that identifies high impact events for early warning based on forecast, satellite and local monitoring data (e.g., storms, high seas, severe ice conditions, algal blooms.

- Offshore Operation Planner: optimised local forecasting tool based on multiple large-scale forecasts and local observations in order to determine the working window in daily operations by combining user-defined criteria for offshore operations. The tool will be based on a multi-model ensemble developed in CMEMS and machine learning.

- Alien Species Risk: tool to assess the risk of alien species dispersal, adopting and adapting AquaNIS - the aquatic non-native and cryptogenic species information system serving HELCOM and OSPAR areas and other world regions.

- Disease Propagation Risk: spatial risk assessment tool for selected parasites to enable favourable site-layout and evaluation of alternative disease control options in relation to dynamic ocean conditions.

- Farm Performance Control: tool to assess farm health conditions (e.g., growth, health, bacterial and environmental risks) by aggregating data from regular farm areas and their maintenance.

These data services are integrated into the web-based UX, offering various modules designed to enhance the user experience:

- Local Farm Design and Planning: implementation of products and protocols (sustainability, legal, administrative, and policy outcomes) to offer data and tools to help optimise farm design and planning processes

- Farm Deployment and Operation: provision recommended standards for farms and environment monitoring, integrating inputs from different WPs, including information on shared responsibility for monitoring and field operations

- Product, Marketing, and Capacity Building: provision of data and information on potential food products, marketing strategies, capacity building, and other associated issues. It includes detailed product descriptions, food safety and quality considerations, information on low-trophic aquaculture technologies and capacity building, knowledge groups, and training resources

- Large-Scale MSP and Impact Assessment: provision of data and information on potential impacts of aquaculture and MSP-related issues. It supports stakeholders and decision-makers by offering assessments of large-scale feasibility, environmental footprints, and other relevant aspects of aqua-farming.

4. CONCLUSIONS

Effective data management and sharing are critical for the success of the OLAMUR project. The establishment of an integrated data management infrastructure, including the OLAMUR backend, facilitates data flow within the consortium and ensures data interoperability. By utilising common open tools like ERDDAP and GeoServer, OLAMUR promotes harmonisation, accessibility, and sharing of data. These efforts contribute to the project's overall objective of achieving multi-use management and enhancing the sustainability of low-trophic aquaculture practices.

In this project, decision support system modules are being developed to significantly enhance the user experience in the field of aquaculture. Leveraging algorithms created by OLAMUR WPs the valuable products such as the Event Warning Service, Offshore Operation Planner, Alien Species Risk, Disease Propagation Risk, and Farm Performance Control. These modules are integrated into a web-based system that improves data management and sharing capabilities.

The incorporation of these modules and specific products within the system addresses the decision support needs of various stakeholders, including policymakers, farmers, operators, and others involved in aquaculture. These modules consider sustainability, legal frameworks, administrative aspects, and policy-related outcomes, providing effective tools for farm design, deployment, operation, marketing, and policy formulation. The use of algorithms and a robust data management infrastructure ensures the accessibility, interoperability, and usability of data according to FAIR principles, thereby enabling informed decision-making processes.

Overall, this project contributes to the advancement of sustainable and multi-use management practices in low-trophic aquaculture, facilitating the achievement of different SDGs. The development and implementation of decision support systems that enhance the user experience not only improve data management and sharing capabilities but also support stakeholders in making informed decisions related to aquaculture.

- Product, Marketing, and Capacity Building: provision of data and information on potential food products, marketing strategies, capacity building, and other associated issues. It includes detailed product descriptions, food safety and quality considerations, information on low-trophic aquaculture technologies and capacity building, knowledge groups, and training resources

- Large-Scale MSP and Impact Assessment: provision of data and information on potential impacts of aquaculture and MSP-related issues. It supports stakeholders and decision-makers by offering assessments of large-scale feasibility, environmental footprints, and other relevant aspects of aqua-farming.

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Oral presentations – Session M

Oceanographic services for ocean health

Improving ocean ecosystem predictions by coupled data assimilation of physical and biogeochemical observations

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Keywords

Data Assimilation, Ensemble, Kalman filter, Biogeochemistry, Satellite Observations

1. OVERVIEW

The CMEMS Monitoring and Forecasting Center for the Baltic Sea (BAL-MFC) computes reanalysis and forecasts for the Baltic Sea utilizing the NEMO ocean model coupled to the ERGOM, which simulates biogeochemistry and the carbonate system. Operationally, observations are assimilated using the open-source software PDAF (Parallel Data Assimilation Framework, https://pdaf.awi.de) using a fixed ensemble read from model snapshots. In the EU-funded project SEAMLESS, the operational model setup builds the basis for enhancements by a fully dynamical ensemble data assimilation (DA) approach. For this, the coupled NEMO-ERGOM model system is augmented by the DA functionality of PDAF and NEMO-ERGOM is run in ensemble mode. The system allows to assimilate a variety of observations. Here satellite sea surface temperature (SST) and chlorophyll-a (CHL) observations are assimilated daily using an ensemble of 30 members. We assess the impact of the assimilation on the forecast skill with a focus on the biogeochemical variables. In addition, ecosystem indicators, like tropic efficiency, pH, and phytoplankton community structure are analyzed. The developments on the DA system are in wide parts generic and can also be applied with other model configurations or components. The open-source character of the developments will help to enhance co-design and inter-operability including the initialization for digital twins and inclusion of possible developments in machine learning.

2. METHODOLOGY

The model used here is the ocean circulation model NEMO (Madec, 2012). NEMO is a widely used model for research but it is also used operationally at CMEMS. The particular variant of NEMO used here is NEMO-NORDIC (Hordoir *et al.*, 2019) in an upgraded version, which is based on NEMO 4.0 and uses a resolution of one nautical mile and 56 model layers. A time step of 90 seconds is used. In addition, the model setup utilizes the IO-Server XIOS to allow for efficient parallel IO. The complete model setup including the model grid specifications, boundary and forcing files were provided by the BAL-MFC. The configuration covers the full North Sea and Baltic Sea. While the model includes the North Sea, we focus the analysis on the Baltic Sea because this is the focus region of the BAL-MFC.

The biogeochemistry model ERGOM (see, e.g., Neumann, 2000; Maar *et al.*, 2011, http://www.ergom.net) was recently coupled to NEMO within the BAL-MFC with the aim of operational biogeochemical forecasting. ERGOM simulates biogeochemical processes and includes bacteria, two phytoplankton groups as well as nutrients, zooplankton and detritus. In addition, a carbonate cycle allows to simulate the partial pressure of CO_2, pH, alkalinity, and particulate carbon.

For the DA, the parallel data assimilation framework PDAF (Nerger *et al.*, 2005, Nerger and Hiller 2013, https://pdaf.awi.de) is used. The BAL-MFC already operates NEMO-ERGOM with PDAF. However, their code version couples the model and PDAF through disk files and does not use dynamic ensemble integrations. We have coupled PDAF directly into NEMO using the approach discussed by Nerger and Hiller (2013). Subroutine calls have been inserted to NEMO that modify the model to become an ensemble model with DA functionality. This approach allows for high scalability and a smaller amount of disk output compared to file-based coupling. In particular, by keeping the ensemble information in memory, the complete ensemble only needs to be written into files for model restarts. The dynamic ensemble integrations will be important for accurate error variance and covariance estimations for the DA. The Error Subspace Transform Kalman Filter (ESTKF, Nerger and Hiller, 2013) is applied.

Satellite observations of sea surface temperature (SST) and chlorophyll-a (CHL) are assimilated. Used are satellite products provided by CMEMS through their website (https://marine.copernicus.eu). Daily level-3 data products for SST and CHL were obtained from the CMEMS data store. For the CHL, there are separate data products for the North Sea and the Baltic Sea. The resolution of the SST product is 0.02 degrees and hence slightly coarser than the model grid. In contrast, the CHL observations are provided at a resolution of 1km, which is finer than the model grid. In the DA process, the data files from CMES are directly read and an observation operator is applied to interpolate from the model grid to the observation locations. The observation error used for the DA are 0.8oC for the SST and a relative error of 0.3 for CHL.

A free ensemble run without DA was started on January 1, 2015. The initial ensemble was generated around the initial state estimate from the operational model. The DA was performed daily using an ensemble of 30 members for the spring bloom period from February 1 to May 31, 2015, initialized from the ensemble of the free run. A horizontal localization radius of 30 km is applied for SST and 15km for CHL in the analysis step. Within this radius, the observation errors are inflated with increasing distance to obtain a smooth assimilation effect. Applied is weakly coupled DA. Thus, the SST observations only influence the model physics directly, while the chlorophyll observations only influence the ERGOM variables. For the model physics, the DA updates only the temperature field. This is because including more physical variables resulted in model instabilities. For the biogeochemistry, the full set of variables is updated with the exception of alkalinity, dissolved organic carbon (DIC), and dissolved organic matter represented as nitrogen (LDON). In addition to the daily DA cycling, we performed two longer forecasts over 14 days without DA. These have been initialized from the DA state estimate on March 1, 2015 and May 1, 2015 and allow to analyze the forecast skill over longer lead time.

3. RESULTS

For a first assessment of the impact of the DA of SST and CHL observations we analyze the root-mean square difference (RMSD) between the model state and the assimilated satellite observations. The observations are only independent for the forecast state, which has not yet assimilated the data. Figure 1 shows the RMSD for the SST and logarithmic CHL concentrations. For the SST, the RMSD is significantly reduced from 0.73oC in the free run to 0.28oC in the DA analysis and 0.34oC in the 24h forecast. Here, the reductions are particularly large in February with up to 0.7oC. The RMSD for CHL shows more fluctuations than that of SST, which is caused by a large influence of clouds. The log-RMSD is here reduced from 0.39 in the free run, to 0.22 in the DA analysis and 0.28 in the DA forecast. The growth rate of the RMSD from the analysis to the forecast is larger for the CHL than the SST.The green lines in Fig. 1 show the RMSD for the ensemble forecasts over 14 days.

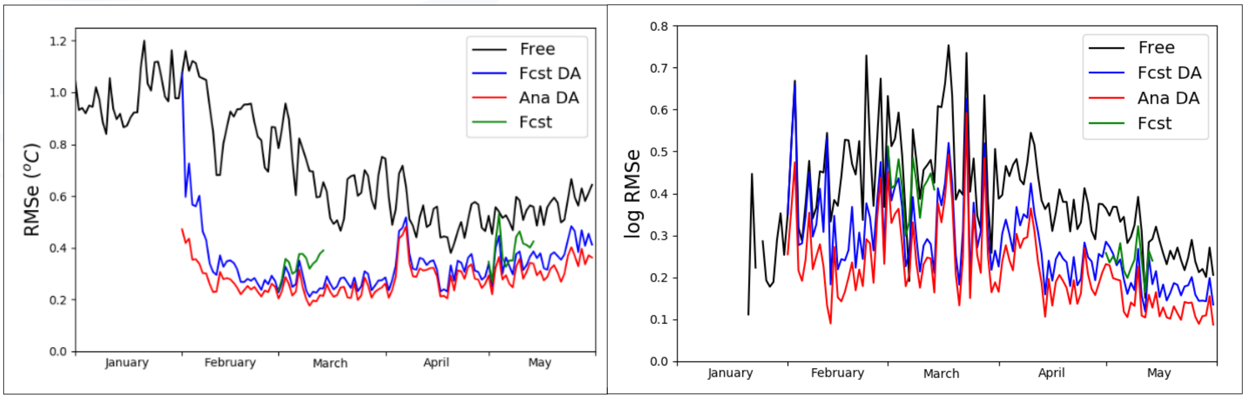

Figure 1. Root mean square difference (RMSD) between the model and the satellite observations. Shown are (left) the RMSD for the SST and (right) the RMSD for logarithmic chlorophyll concentrations. The lines are (black) free run, (blue) 24h DA forecast, (red) DA analysis. The green lines show the 14-day free forecasts. Data gaps are visible for chlorophyll in particular during January for days without any observations in the Baltic Sea.

The forecasts were initialized from the DA analysis on March 1, 2015 and May 1, 2015, respectively, and then run without further DA. For the SST a small increase of the RMSD is visible. For the forecast in March, the reduction of the error in the 24h forecast compared to the free run was 48%. This reduction of the error was only slightly reduced to 43% after 8 days and 35% after 14 days free ensemble forecast. Thus, the effect of the DA remains in the state for a longer period. For the CHL, the effect of the DA on the forecast is less well visible in Fig. 1 due to the high variability of the RMSD. The reduction of the RMSD was less persistent for CHL. In March, the reduction of the RMSD compared to the free run was 33% after 24h forecasting. The reduction then further decreased to 20% after 8 days and 5% after 14 days. Thus, an improvement of the forecast skill is achieved at least over 8 days. Figure 2 shows the difference between the model and observations for the free run and forecasts of different lead times for chlorophyll on March 9 and SST on March 15. Again, the better forecast skill in the SST is visible. The effects are similar in May (not shown).

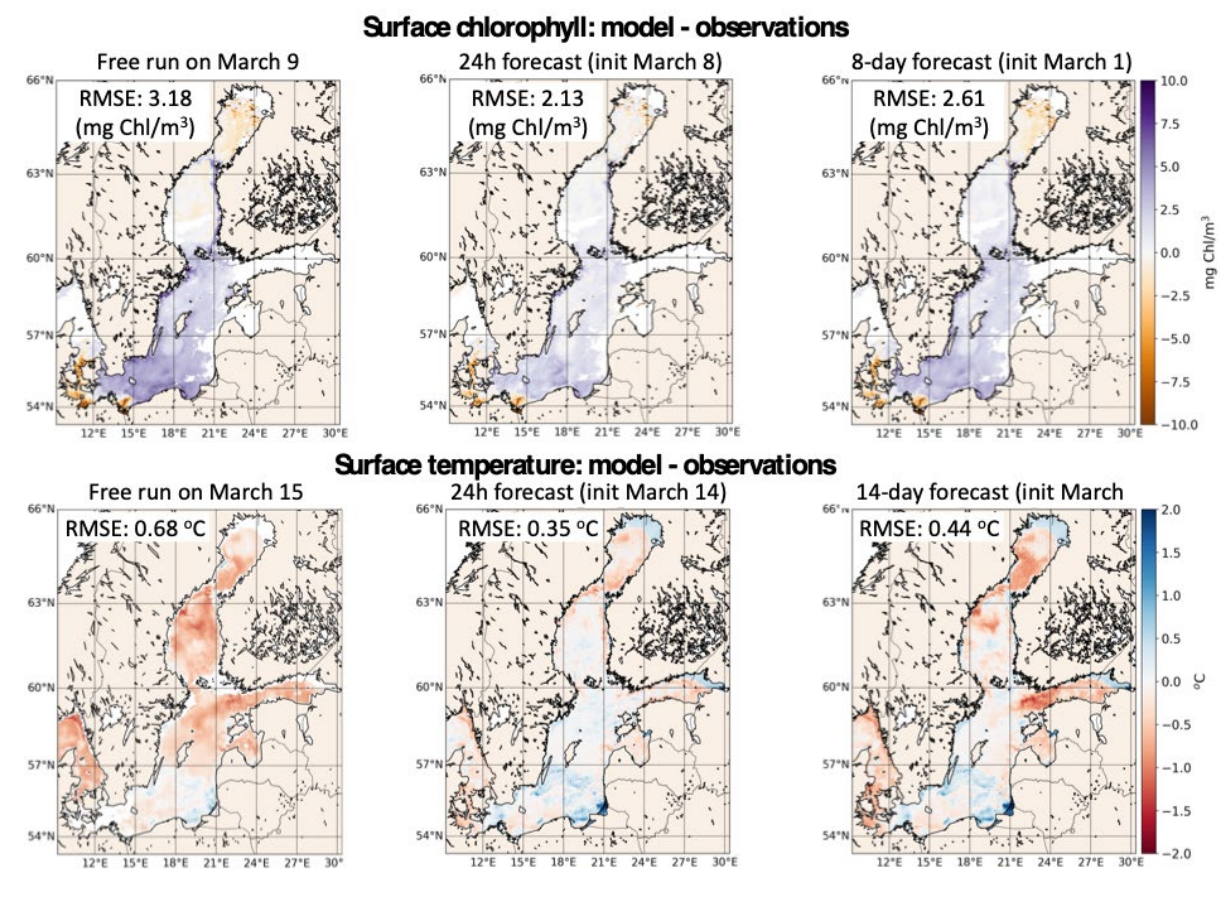

Figure 2. Difference between the model field and the observations on March 9 for chlorophyll and March 15 for SST at model midnight. The upper row shows the surface chlorophyll while the lower row shows the SST. The columns show the (left) free run, (middle) 24h forecast, and (right) 8-day forecast of chlorophyll and 14-day forecast of SST. Next to the fields the corresponding RMS errors are shown. They show that an improvement of the model skill due to the DA exists also after 8 days of free forecast.

To further assess the effect of the DA on the ecosystem, we consider different indicators. These have been selected within the SEAMLESS project to, e.g., provide information on the group composition of the phytoplankton. Here, we consider three indicators:

- **Relative diatom abundance (RDA):** This is the fraction of diatoms in the total phytoplankton, which consists in ERGOM of three phytoplankton groups (diatoms, cyanobacteria, flagellates);
- **Trophic efficiency (TE):** This is the ratio of total zooplankton concentration to total phytoplankton concentration, i.e. the ratio of the high tropic level to the lower trophic level. Zooplankton is represented in ERGOM by two groups representing different size classes;
- **pH:** This indicator is modeled by the carbonate system in ERGOM. Hence, it provides an indication for changes related to the carbonate system that are induced by the assimilation of temperature and chlorophyll.

Figure 3 shows the spatial distribution of the three indicators on May 1, 2015. We compare the free run with the DA forecast estimate. In the free run the RDA is very close to one in most of the Baltic Sea, except the Gulf of Finland, Gulf of Riga and the transition region to the North Sea. Thus, the diatoms strongly dominate the phytoplankton at this date. The DA mainly reduces the RDA. The largest effect is visible in the Baltic proper. Thus, a more balanced composition of the phytoplankton community is induced by the DA.

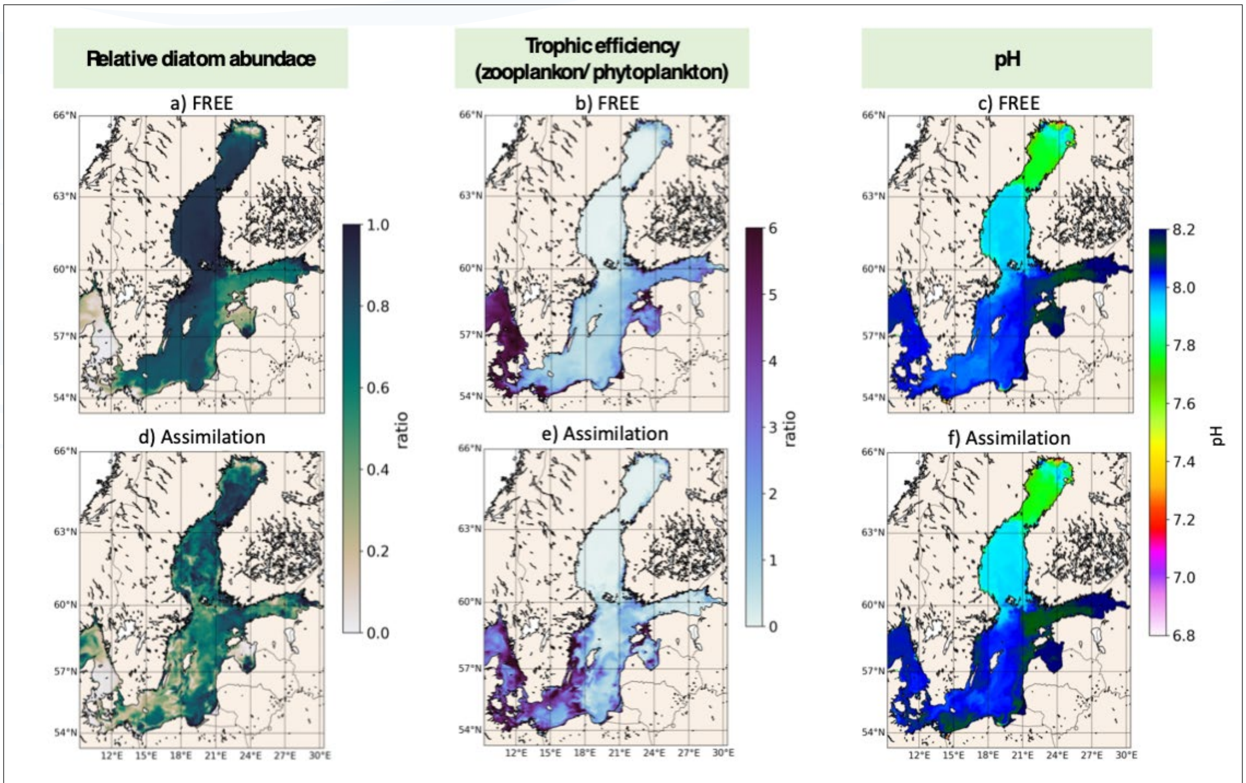

Figure 3. Effect of the data assimilation on ecosystem indicators on May 1, 2015. Shown are the (left) relative abundance of diatoms in the total phytoplankton biomass, (center) trophic efficiency computed as ratio of zooplankton concentration to phytoplankton concentration, and (right) value of pH. The upper row shows the indicators for the free run, while the lower row shows the 24h forecast from the assimilation.

The TE (Fig. 3 middle column) in the free run is high only in the transition region to the North Sea and reaches values of 6 here. Slightly increased values are also visible in the Gulf of Finland and the Gulf of Riga. In the Bothnian Sea, the ratio is particularly low. Here, the phytoplankton dominates over the zooplankton. This might be due to the spring conditions. With further warning of the waters during the summer, the TE increases here. The DA results in lower TE in the regions where it was elevated in the free run. In contrast, the TE is increased in the Baltic proper and the southern Baltic Sea. Thus, the DA causes a higher ratio of the zooplankton to phytoplankton. This is mainly caused by a reduction of the phytoplankton concentration (not shown), which increases the relative fraction of zooplankton. For pH, a significant variation is visible over the Baltic Sea. It is around 7.8 and lower in the Bothnian Bay and around 8.0 in the Baltic proper. The pH is particularly high in the Gulf of Finland, where it reaches a value of 8.2. The DA leads to regional changes. In the far southern Baltic close to the coasts of Germany and Poland, the pH is increased. In addition, the pH is increased at the western end of the Gulf of Finland. In contrast, the pH is decreased in the Gulf of Riga and in the Bothnian Sea.

4. DISCUSSION AND CONCLUSION

We assimilated satellite observations of SST and chlorophyll into the coupled ocean-biogeochemical model NEMO-ERGOM. The assimilation was performed using the ensemble Kalman filter variant LESTKF. The filter uses a dynamic ensemble, which results in dynamic estimates of uncertainty and covariances at the time of each analysis update.

The DA directly influences the temperature field and the ecosystem variables of ERGOM. We found significant improvements of the surface temperature field. The improvements of the chlorophyll, and hence the phytoplankton, concentration was relatively lower. This is consistent with the rather high observation errors for chlorophyll. The generation of accurate chlorophyll from satellite data is a known issue in the complex brackish water of the Baltic Sea. The forecast skill for the SST and CHL was tested for up to 14 days. The improvements in the temperature induced by the DA were still significant after 14 days of free forecasting. For the CHL, the model system shows lower forecast skill, which is consistent with the smaller effect of the DA. Given that the chlorophyll concentration was overestimated by the model in the Baltic proper, the ecosystem dynamics are biased. This is likely due to the parameterization of ERGOM. While the DA process reduces the CHL concentration, this dynamic bias is not resolved and the model tends to evolve to the unconstrained model solution of higher concentration. Nonetheless, an improvement of the forecast skill of chlorophyll by the DA was visible at 8 days lead time.

The DA also results in changes of the phytoplankton community structure as well as the trophic efficiency. As was exemplified for May 1, 2015, the widespread dominance of diatoms was reduced; mainly reducing the overall phytoplankton concentration. This also led to an increased ratio of the zooplankton to the phytoplankton, thus effects on the trophic efficiency of the model. Changes in the value of the pH indicated that also the carbonate system was influenced by the DA process. Regional increases of the pH by up to 0.2 units were obtained, e.g. in the Gulf of Finland and the far southern part of the Baltic Sea. These changes mainly happened in the regions of high pH (8.0 or higher). The pH was increased in the Baltic proper, albeit to a lower amount. While these changes indicate effects to the carbonate system, their extent has to be further analyzed.

Both, the DA framework PDAF (https://pdaf.awi.de, Nerger, 2023) and the DA code developed for NEMO (https://github.com/PDAF/NEMO-PDAF) are available as free open-source developments. PDAF itself is model agnostic and was already applied with a wide variety of models. Also, the developments for the assimilation in NEMO-ERGOM are in wide parts generic and can be adapted to other components and models. Here, the open-source availability of the codes enables co-development as well as inter-operability by using the same code base for different applications. This allows other scientists to benefit from the existing developments and experiences. The similarity of machine learning methods with the statistical methods applied in DA can further lead to mutual benefits, e.g. for the development of nonlinear data assimilation methods (e.g. Hu and van Leeuwen, 2021). Such developments can be integrated into PDAF and hence made available to the operational and research users.

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MARBEFES – comprehensive approach to understanding reasons and sharing knowledge on biodiversity changes in European seas

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Keywords

Biodiversity, climate change, European seas, Ocean Literacy, bioblitz

Abstract

The MARBEFES (MARine Biodiversity and Ecosystem Functioning leading to Ecosystem Services) project is one of those initiatives which tackles the above challenges, since its overall aim is to determine links between biodiversity, ecosystem functioning and the resulting ecosystem services and societal goods and benefits and to achieve ecological and socio-economic valuation through a validated set of innovative tools in a distributed toolbox to enhance policy and governance for the marine environment to secure its benefits for current and future generations. The goal is to progress substantially beyond the current state-of-the-art regarding causes and consequences of biodiversity decline, and the loss and gain of ecological and economic value and the consequences for marine management and governance across European seas.

In order to link these aspects of natural capital to the ecosystem services provided by the natural system from which society then obtains societal goods and benefits after investing human capital. MARBEFES works on an integrated system of concepts that span natural to

socio-economic perspectives and aims to provide data and new knowledge by quantifying these aspects to directly measure ecosystem services and ecological and economic connectivity in complex socio-ecological systems. For these purposes, 12 Broad Belt Transects (BBTs), spanning from the Arctic to the Mediterranean Sea, have been selected.

1. INTRODUCTION

European Member States (MSs) need to value coastal and marine biodiversity and their ecosystem services and societal goods and benefits, as a basis for cost-effective environmental management. Above all, this requires ecological and monetary and non-monetary valuation (Carmen *et al.,* 2018, Martínez-López *et al.,* 2019).

Europe requires and is aiming for a coherent marine policy, with special focus on the sustainable use of living resources, climate change mitigation, and conservation of nature. The widely acknowledged holistic Ecosystem Approach (EA) is the main concept to address these problems which can be summarised as the need to protect and maintain the natural biodiversity, structure and functioning while at the same time ensure the seas provide ecosystem services from which society gathers goods and benefits (Carmen *et al.,* 2018). However, the main practical difficulty in achieving this is to include and quantify these aspects due to the extreme diversity of marine ecosystems, their habitats and species in Europe - from the rapidly warming European Arctic, to the cold brackish Baltic, through the full marine Atlantic and North Sea coasts to the subtropical areas of Mediterranean. All these regions are important for their value in supporting numerous ecosystem services and delivering, in monetary and non-monetary terms, a range of societal goods and benefits (https://sustainabledevelopment.un.org/sdgs, 2017). MARBEFES needs to cover the breadth of European marine biodiversity given the large variability in dynamics and response to global change.

2. METHODOLOGY, OBJECTIVES AND EXPECTED RESULTS

The overall aim of MARBEFES is to determine the links between biodiversity, ecosystem functioning and the resulting ecosystem services as well as societal goods and benefits in order to achieve ecological and socio-economic valuation through a validated set of innovative tools in a distributed toolbox to enhance policy and governance for the marine environment to secure its benefits for current and future generations (Carmen *et al.,* 2018, Martínez-López *et al.,* 2019). We will progress substantially beyond the current state-of-the-art understanding of the causes and consequences of biodiversity decline, and the loss and gain of ecological and economic value and the repercussions for marine management and governance across European seas (Willcock *et al.,* 2018).

Our underlying premise is that while marine conservation has focussed on ecological structure, as in the EU Habitats Directive, i.e. 'how much' of a habitat and 'how many' in a population, less attention is given to the functioning of a system, hence valuing ecosystem services and societal goods and benefits. There is a need, therefore, to develop new and better tools at high TRLs (Technological Readiness Levels) to quantify and explore marine biodiversity and functioning at all levels of biological organisation from cells and genes, through individuals and populations, to communities and ecosystems. In order to link these aspects of natural capital to the ecosystem services provided by the natural system from which society then obtains societal goods and benefits after investing human capital, MARBEFES works on an integrated system of concepts that span natural to socio-economic perspectives and aims to provide comprehensive data and new knowledge by quantifying these aspects to directly measure ecosystem service production and ecological and economic connectivity in complex socio-ecological systems.

The objectives of MARBEFES are to:

i. Characterise marine biodiversity in selected areas in Europe and understand the links between ecological structure and functioning across biological organisation levels from the molecule, through the individual and population, to the community and ecosystem;

ii. Establish biodiversity-ecosystem functioning-ecosystem service links for focal habitats and selected important or iconic species in a range of ecological and socio-economic contexts;

iii. Capture ecological value related to the fragility, connectivity, uniqueness, irreplaceability and vulnerability of selected genes, species, habitats and ecosystems;

iv. Demonstrate how different European coastal ecosystems provide services, and societal goods and benefits, including cultural value, and clarify how this provision is dependent on healthy biodiversity;

v. Use natural capital accounting to determine the value of ecosystem services, societal goods and benefits;

vi. Recommend how management interventions should be directed and addressed to maximise the ecological value and optimise the economic value of the marine system;

vii. Inform action to meet the major global and European societal and marine management and governance demands;

viii. Foster biodiversity and human well-being by creating a toolbox for biodiversity and ecosystem valuation to support international and EU-level policy and decision making.

These objectives and the project results will be communicated and disseminated over the course of the MARBEFES life-time and they will overlap with other project activities to provide their full coverage. The activities are spread over 48 months of project duration.

In order to promote the project results as well as using the outstanding potential of the project research and dissemination teams we have developed a multitude of modern mechanisms for the support of the outreach actions dedicated to a variety of stakeholders as well as to general public. These include the use of social media, non-formal education techniques, including, science fairs and open days, bioblitz type of activities, as well as events focused on stakeholders and decision makers.

3. CONCLUSIONS

The MARBEFES team brings six innovative concepts, methods and products, which have been applied in certain areas but never combined and implemented at wider scales. The project combines achievements from many disciplines and domains, the outputs of which will break the current barriers between them.

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Resolving the bloom dynamics and ecological role of *Noctiluca scintillans* in the southern North Sea

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Keywords

Noctiluca, North Sea, Underwater cameras, FlowCam, nutrients

Abstract

Recently, we found that dinoflagellate Noctiluca scintillans proliferates more frequently and intensively in many regions around the globe, including the North Sea. This organism tolerates rapidly changing conditions, thrives under eutrophication, and exhibits multiple reproductive strategies, leading to intense and rapid blooms, which can affect community composition and productivity. To further investigate the bloom dynamics of this species, and its effects on phytoplankton diversity, we studied Noctiluca and collected data during three cruises in summer 2022 in the southern North Sea with traditional techniques, underwater cameras and remote sensing. We measured unusually high ammonium and phosphate concentrations within dense surface patches, suggesting that Noctiluca acts an essential nutrient recycler during blooms. CPICS (Continuous Plankton Imaging and Classification Sensor) and FlowCam images were analysed with applied machine learning techniques, and revealed phytoplankton community composition, prey types, and intraspecific interactions. Noctiluca's frequently observed ingestion of diatoms followed by a shift to phosphate-affine dinoflagellates suggests a potentially important role within plankton communities. Through satellite images, the bloom extent was visualized, and associated impacts on local coastal communities could be better estimated. Considering its recent development and great adaptability to changing conditions, *Noctiluca* might play an increasingly important part within plankton communities.

1. INTRODUCTION

The blooms of dinoflagellate Noctiluca scintillans have increased in frequency and duration over the past decades in many areas (Hallegraeff *et al.*, 2019; Qi *et al.*, 2019), including the North Sea (Ollevier *et al.*, 2021; Kordubel *et al.*, in prep). Noctiluca proliferations are non-toxic but negatively impact water quality, since this heterotrophic organism can deplete waters of oxygen and increase ammonium (NH4+) concentrations (Hallegraeff *et al.*, 2019). This has led to reduced fishing and aquacultural yields (Guo *et al.*, 2014). Furthermore, as non-selective feeder, Noctiluca ingests prey across a wide size-range and simultaneously competes with phytoplankton and zooplankton for resources (Kiørboe, 2003). It also acts as food chain disruptor, outcompetes and replaces more selective organisms such as diatoms, and indirectly fuels "jellification" (Oguz and Velikova, 2010).

Noctiluca forms ephemeral blooms along temperate, subtropical, and tropical coasts (Elbrächter and Qi, 1998). These blooms can cover areas of more than hundreds of hectares (Zevenboom*et al.*, 1991) with complex horizontal and vertical patterns. Since most studies use traditional sampling methods (e.g. plankton-nets, bottles, buckets), *in situ* observational data at appropriate spatiotemporal scales are lacking. Hence, factors driving temporal, horizontal, and vertical distribution of *Noctiluca* throughout a bloom are still not fully understood. This significantly complicates the assessment of current and future dynamics of this potentially important species. Therefore, there is a need to apply integrated sampling techniques for studying Noctiluca in its natural environment. With the recent development of autonomous measurement devices such as high-resolution underwater camera systems and remote sensing, *in situ* data can be collected continuously, allowing near real time observations of plankton dynamics. Considering the observed increase in sightings of this species in multiple coastal regions over the last decades, its great adaptability to changing conditions, and its potentially strong direct and indirect effects on food web dynamics (Kordubel *et al.*, in prep), *Noctiluca* might play a major role within plankton communities. This role needs to be better understood, and therefore in this study we present results from a set of cruises in the North Sea, where we sampled *Noctiluca* using combined novel and traditional techniques aiming to resolve its role within the coastal plankton community of the North Sea.

2. METHODOLOGY

Data was collected during three cruises with *RV Ludwig Prandtl*, in June (#1: 8-12; #2: 21-28) and August 2022 (#3: 1-12). On a daily basis, samples were collected around Helgoland (Fig. 1a) at two stations: one in the north of the island (Station 1) and one in the south (Station 2). When bloom structures were visible, additional sampling was carried out within the bloom (Station 3-6). Vertical profiles of temperature, salinity, dissolved oxygen, fluorescence and turbidity were measured using a calibrated conductivity, temperature and depth profiler (CTD). Surface conditions were continuously measured with an on-board flow-through membrane pump or FerryBox. At each station, seawater was collected with the CTD below and above the thermocline, and within the Chlorophyll-a maximum (reference depths). From each depth, water was filtered and processed with the FlowCam. Images were analysed using the VisualSpreadsheet software. Water samples were also analyzed for nitrate, nitrite, ammonium and phosphate using an automated continuous flow system and standard colorimetric techniques. At each station, an automated underwater camera system (CPICS) was deployed at the reference depths for high-resolution plankton imaging. The images were analyzed with semi-supervised machine learning techniques. To improve classification accuracy, an unsupervised step using unlabeled images was employed as pre-training to initialize supervised training. For the supervised step, a random subset (~10,000) of the >700000 images were manually labeled for type, class or species (Fig. 2). These labeled images were used to train a convolutional neural network (CNN) in the supervised training step.

3. RESULTS AND DISCUSSION

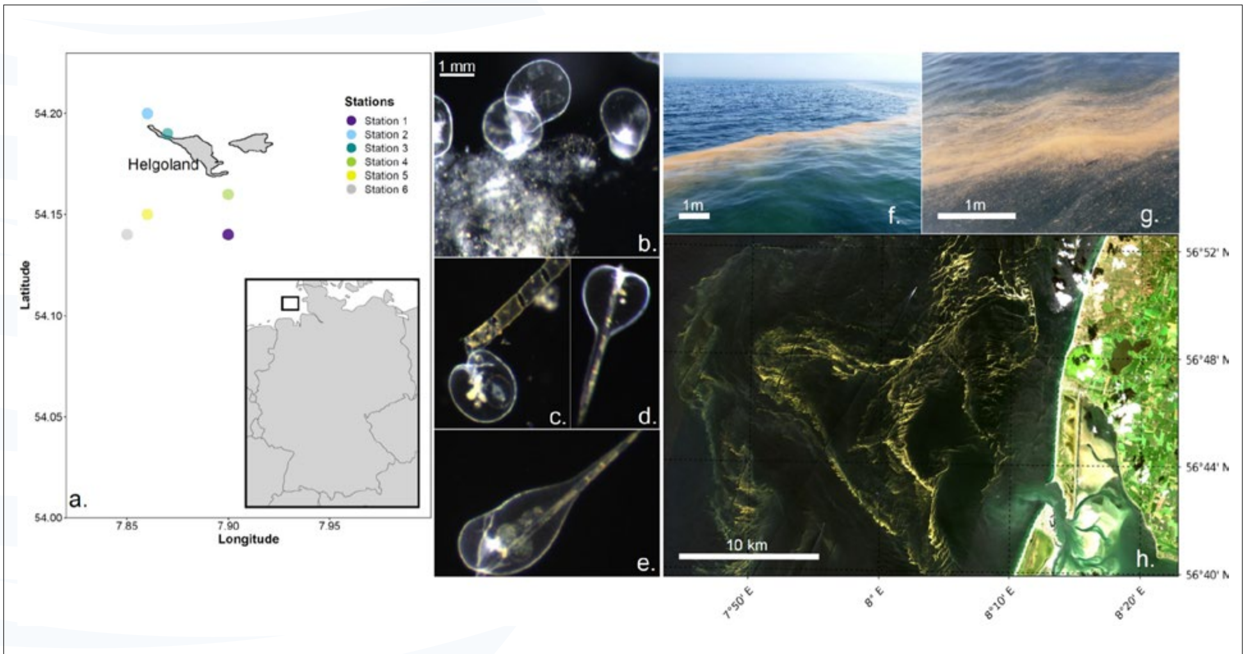

Figure 1. Study site (a.). Recorded with the CPICS during #2, images (b.-e.) represent: agglomerated cells feeding on marine snow (b.) and single cells ingesting diatom chains (c.-e.). Pictures taken from RV Ludwig Prandtl during #2 (f.-g.); and satellite image from the Sentinel-2 satellite in June 2022, Northeastern German Bight (h.).

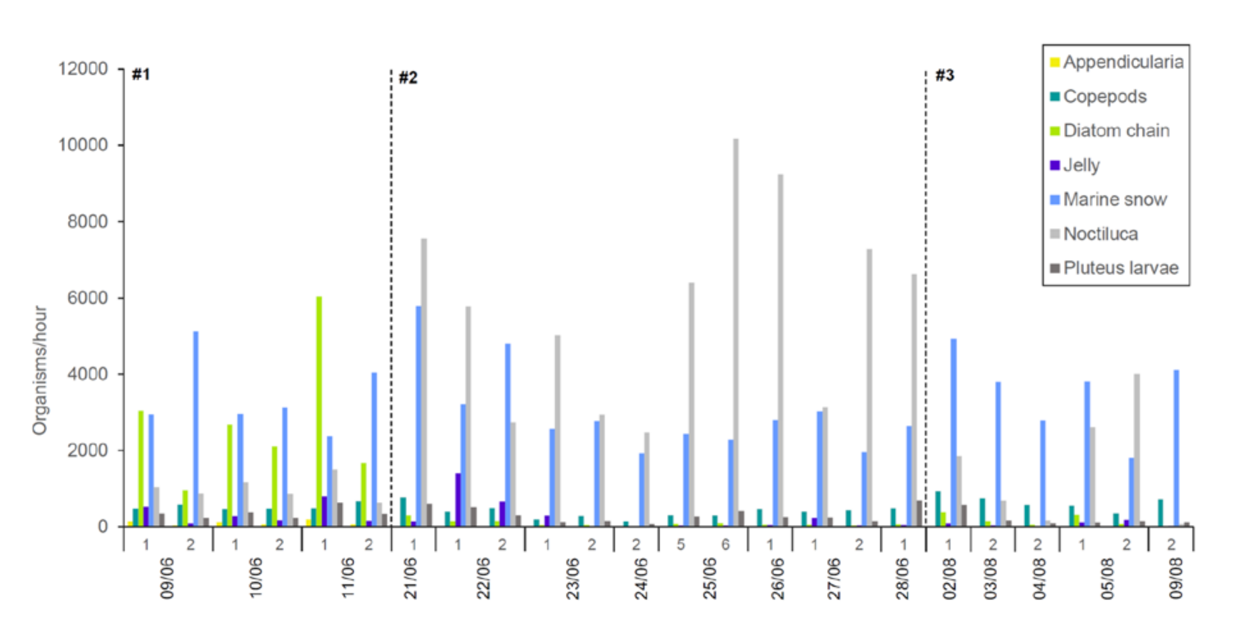

Figure 2. Preliminary results for the temporal variation in abundance of plankton recorded with the CPICS in June and August 2022 at the different stations (1-2, 5-6) in the study area.

Throughout the study, plankton community composition shifted from waters dominated by diatoms at the beginning of June (#1) to Noctiluca-dominated waters at the end of June (#2), to higher marine snow concentrations in August (#3) (Fig. 2). Diatoms are considered Noctiluca's most common prey type (Kiørboe, 2003) and populations are commonly down-grazed by Noctiluca (Dela-Cruz *et al.*, 2002). We observed numerous Noctiluca cells ingesting diatom chains during #1 and #2 with the CPICS (Fig. 1c-e), support the possibility that Noctiluca successfully contributed to the end of the diatom bloom. A similar pattern can be observed in Fig. 3, with a clear separation between cruises #2 and #3. Additionally, diatoms (chains, other) were negatively correlated with temperature. Diatoms were more abundant in June when temperatures were lower than in August, when dinoflagellates (Ceratium, Prorocentrum) were more abundant. Indeed, dinoflagellates were positively correlated with temperature. Furthermore, diatoms were positively correlated to NO_3^-, suggesting a high demand for nutrients (Bender *et al.*, 2014), which were still available in early June (Fig. 4). Our results showed a positive correlation between dinoflagellates and PO_4^{3-}, reflecting their high demand in phosphorus (Rizzo, 2003). *Noctiluca* released high concentrations of NH_4^+ and PO_4^{3-} upon bloom decay (Fig. 4). This might fuel the development of the dinoflagellate bloom recorded during #3 and indicate a potentially important role of *Noctiluca* in the shift from diatom- to dinoflagellate-dominated waters.

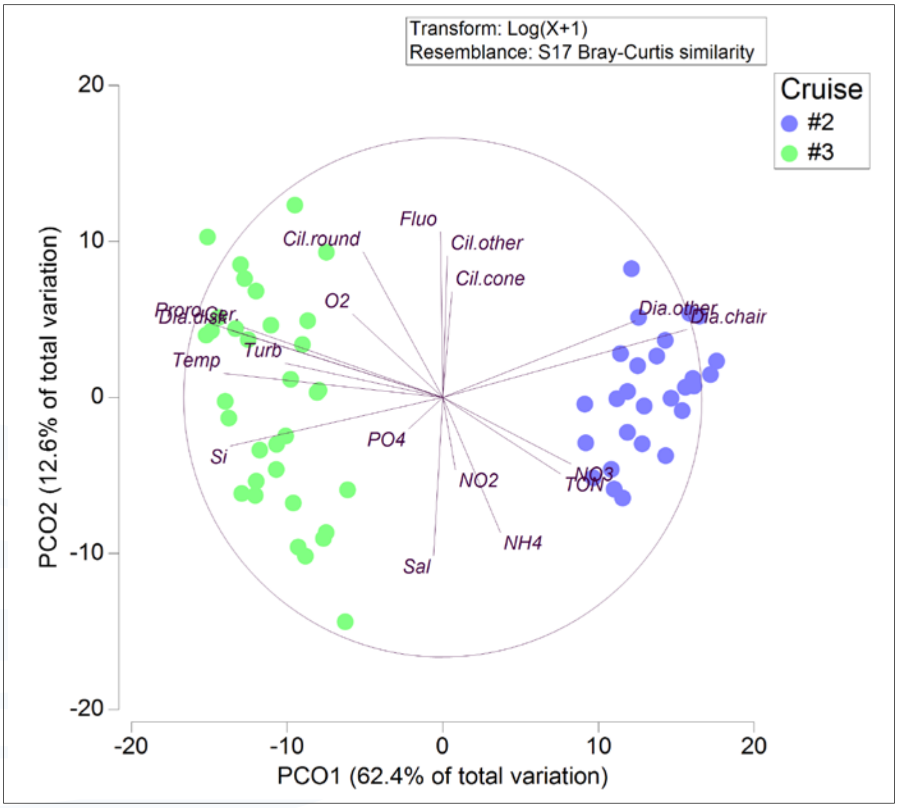

Figure 3. Principal coordinates analysis (PCO) of environmental parameters and phytoplankton community during June and August in the study area. The percentage of variability explained by each axis is indicated. Samples (circles) and variables (lines) are plotted against the first two axes.

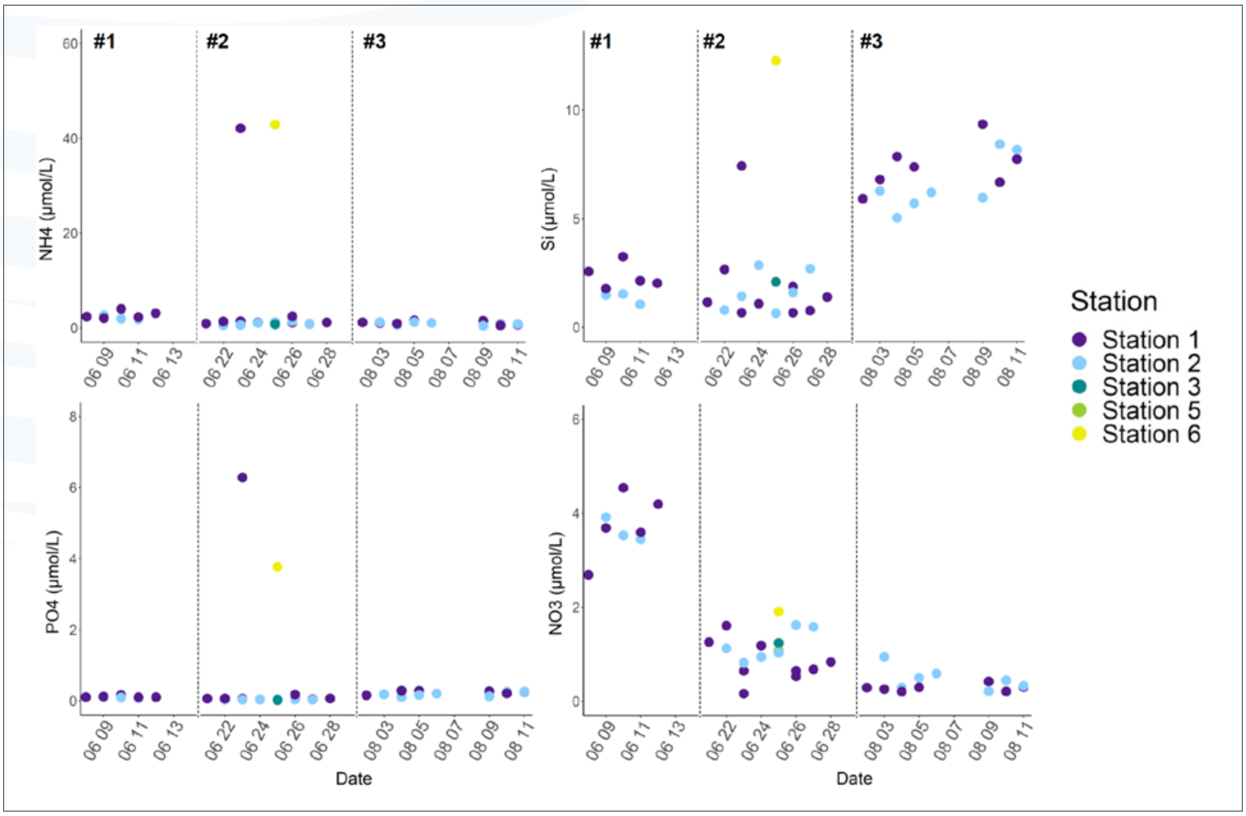

Figure 4. emporal variation of nutrient concentration in June and August 2022 at the different stations (1-3, 5-6) in the study area. Extreme values measured during #2 correspond to dense Noctiluca surface slick measurements.

Our findings indicate that *Noctiluca* might importantly influence the phytoplankton community composition in the southern North Sea (Fig. 5). Under suitable conditions including temperatures ~12°C (Kordubel *et al.*, in prep) and food availability, *Noctiluca* can rapidly develop. The high feeding pressure of *Noctiluca* on diatoms, nutrient depletion and increasing temperatures are likely to induce the end of the diatom bloom, causing Noctiluca to accumulate at the surface. Upon cell lysis, nutrients are released, which might contribute to the development of a dinoflagellate bloom.

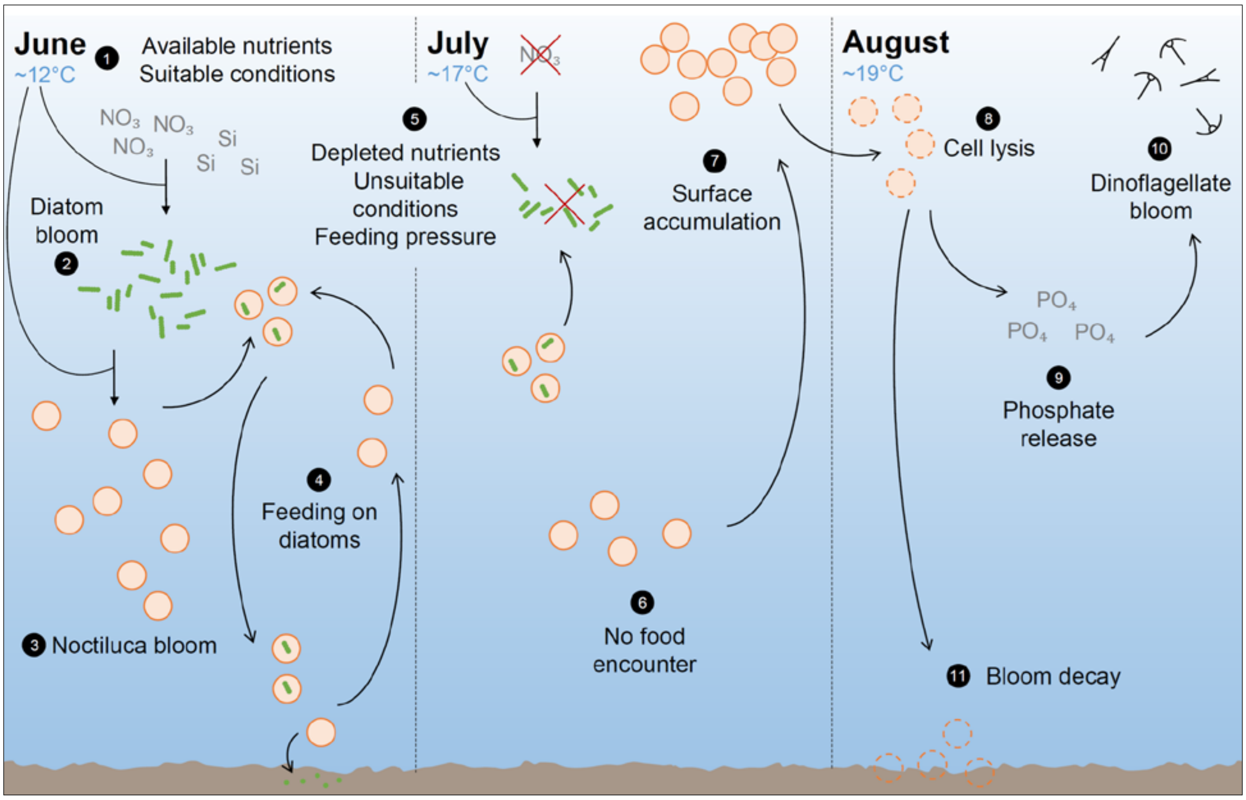

Figure 5. Schematic summary of the potential role of Noctiluca within the coastal phytoplankton community of the southern North Sea.

3. CONCLUSION

Our results suggest that *Noctiluca* potentially plays a central role within the coastal phytoplankton community composition of the southern North Sea. When considering the recent evolution of *Noctiluca* bloom dynamics in this region (Ollevier *et al.*, 2021; Kordubel *et al.*, in prep), it can be expected that an intensification could further alter phytoplankton populations. However, to achieve a better understanding about bloom dynamics and effects, additional analysis including class-specific traits such as interspecific interactions, feeding, and reproduction are needed. Furthermore, in order to draw definite conclusions on *Noctiluca*' role within coastal food webs, there is a need for holistic observations such as continuous imaging of the plankton community throughout the bloom period.

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Multiscale harmonised automated observations of phytoplankton biomass, diversity and productivity dynamics in the English Channel and North Sea as part of the coastal Pilot Super Site approach (JERICO S3)

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Multiscale automated observations. Phytoplankton biomass and diversity. Productivity dynamics. North Sea and the English Channel. Coastal Pilot Super Site.

Abstract
Multiscale harmonised automated observations of phytoplankton are essential for accurately monitoring the state and functioning of marine coastal ecosystems. Novel approaches are implemented for almost a decade in fixed autonomous stations, moorings, dedicated cruises and ships of opportunity (FerryBox) within the English Channel and North Sea Pilot Super Site of the Joint European Research Infrastructure for Coastal Observatories (JERICO-S3). These marginal seas are characterized by significant connectivity to adjacent seas, strong hydrodynamics and high riverine inputs, influencing biogeochemical and biological processes as recurring phytoplankton blooms of relevant impact on marine food webs, human health and economy. Automated measurements provide a more precise information on the dynamics of functional (flow cytometry and multispectral fluorometry) and taxonomical (imaging) diversity, photosynthesis and productivity (variable fluorometry) at high spatial and temporal resolution, assigning community changes to different bloom situations and pelagic habitats state, complementing physical, biogeochemical and biological variables. The models used to compute photosynthetic parameters and production using FRRf measurements show different seasonal patterns, which were synchronous or delayed with that of chlorophyll biomass and diversity. Automation in data analysis, common data vocabulary and operational practices, should allow addressing scientific, societal and economic challenges through a new perspective, facing global and local changes.

1. INTRODUCTION
Multiscale harmonised automated integrated observations of phytoplankton are essential for accurately monitoring the state and functioning of marine coastal ecosystems. Novel approaches are implemented in fixed autonomous stations, moorings, dedicated cruises, and ships of opportunity (FerryBox) within the English Channel and North Sea coastal Pilot Super Site of the Joint European Research Infrastructure for Coastal Observatories – Science, Services, Sustainability (JERICO-S3) for provision of sustained multidisciplinary observations, characterized by significant connectivity to adjacent seas, strong hydrodynamics, and high riverine inputs, influencing biogeochemical and biological processes as recurring phytoplankton blooms of relevant impact on marine food webs, human health and economy. Functional and taxonomical diversity as well as photosynthetic parameters were addressed by combining reference methods (pigments, microscopic counts) and innovative automated imaging inflow and *in situ* devices, pulse shape-recording flow cytometers as well as in vivo fluorometers. These approaches were implemented in different platforms (fixed autonomous stations, moorings, dedicated cruises, and measurements of opportunity -FerryBox), at high spatial and temporal resolution, in the frame of different monitoring networks carried out by four partners in four different systems from the Celtic Seas, through the English Channel to the southern bight of the

North Sea and the German Bight. Selected models were used to compute high-resolution-resolved photosynthetic parameters and primary production using variable fluorescence measurements. Moreover, harmonised data pipelines and synthesis were carried out, applying conventional statistics, Artificial intelligence and Machine Learning.

2. RESULTS

2.1. High spatial resolution measurements of opportunity and dedicated cruises

Autonomous measurements combining phytoplankton and pCO2 underwater recording were carried out in fisheries cruises (Endeavour R/V) in English waters of the Western English Channel (WEC) and Celtic Seas (CS) in summer 2020-2021 by CEFAS.

Harmonised flow cytometry data (following the common vocabulary stated un a collaborative SeaDataNet work, Thyssen *et al.*, 2022) confirmed that nanophytoplankton and microphytoplankton were responsible for the blooms at the edge of the Celtic Seas. Maps of diversity were implemented through a shiny app soon available for external queries.

The spatial distribution of phytoplankton communities was addressed at high resolution in the English Channel and North Sea during different fisheries cruises (Thalassa R/V): IBTS in winter 2020 and 2022 as well as CGFS in fall 2022, by coupling an automated flow cytometer (CytoSense) and a multispectral fluorometer and/or a FastAct2 (Chelsea) Fast Repetition Rate Fluorometer (FRRf). Moreover, a French-Finnish collaboration allowed a doctoral student from the SYKE laboratory in Helsinki (Kaisa Kraft) to participate in IBTS 2020 to connect an ImagingFlowCytobot (IFCB, McLane, USA). The inter-comparison of the two techniques is underway which made it possible to prepare its acquisition and deployments in IBTS in winter 2023. Flow cytometry data were pre-analyzed by applying a real-time data processing and visualization software (EasyClus) developed by Thomas Rutten (TRP, NL). This tool provides a quick and real-time graphic visualization (https://www.fytoplankton.nl/).

Spatial and temporal variability of phytoplankton photosynthetic production was addressed during seasonal cruises to compare the two types of variability. When considering two photosynthetic parameters, that the temporal and spatial variability over a year are not equivalent for the Eastern English Channel and the Southern North Sea ecosystems. Temporal and spatial observations complement each other for estimating primary production in ecosystems characterized by a high hydrodynamic regime.

The joint Spring Plankton Cruises organized by VLIZ in the North Sea and English Channel PSS since 2016 involved different partners. Transfer of knowledge and the harmonization of competencies between key persons and institutes were effective so that best practices for plankton imagery and fluorometry observations were further developed in the PSS. Also, through collaborations between institutes and joint research efforts, the large-scale observations allowed for regional spatial variability to be investigated using a complementary set of molecular, chemical, and imaging tools (Aubert *et al.,* 2021). In May 2022, VLIZ and CNRS-LOG joined for the Spring Plankton Cruise on board the RV Simon Stevin. The primary objective of the cruise was to compare the protocols of two instruments, namely the FlowCAM and the automated flow Cytometer, used routinely by the respective institutes. Also, other relevant observations of temperature, salinity, PH, and pCO2 were recorded during the survey. Metadata of the cruise, registered through the Marine Information Data Acquisition System (MIDAS), can be found on the IMIS platform of VLIZ: https://www.vliz.be/nl/imis?module=dataset&dasid=8069#. The biological data will become available through the following links via the Marine Data Archive (MDA - Marine Data Archive (vliz.be)) and LifeWatch Data Explorer (Lifewatch data explorer). Moreover, photosynthetic parameters obtained by VF gathered from the *in situ* profiler in the natural gradient of light were compared to those recorded on board, that is under artificial light, with the FRRf Act2, as part of the spatial characterization of water bodies at synoptic scale during the Life-Watch VLIZ joint sampling campaign of 2019.

During the summer of 2022, three cruises were undertaken by HEREON in the southern North Sea (PhytoDive project aiming to generate new knowledge about the role of phytoplankton diversity and productivity in the coastal carbon cycle and food web dynamics using combined techniques such as remote sensing, underwater cameras, and automated measurement systems). Our observations suggest a potentially important role of the dinoflagellate Noctiluca scintillans in the shift from diatoms towards dinoflagellate-dominated waters. The images recorded with the CPICS (Continuous Plankton Imaging and Classification System, Coastal Ocean Vision, 2021) were analyzed with applied machine learning techniques. Undergoing several rounds of general and specific labeling using the interface Label Studio, the images were then fed into a neural network. The image analysis revealed *in situ* feeding strategies of N. scintillans, their prey types, and interactions with other organisms at high resolution. This information is extremely valuable to expand the understanding of the functional role and the dynamics under future climate conditions of this dinoflagellate in the German Bight.

In 2022, Macovei *et al.,* (2022) demonstrated that continuous high-frequency observations can be used to assess the impact of small-scale (mesoscale) phytoplankton blooms on carbon sequestration. We used flow-through measurements from chlorophyll fluorescence measurements from different instruments (AlgaeOnlineAnalyser (AOA), TriOS microFlu fluorometer), pCO_2 and pH measurements, and salinity and temperature from the FerryBox to capture these mesoscale dynamics. We were able to capture a very late phytoplankton bloom

(October-November, 2021), which would not have been seen via satellite imagery at this time of year, but which we found had a significant impact on the amount of carbon sequestered, compared to the trend observed over the past 5 years. This was an example to also show the importance of surface water measurements available from ships of opportunity in coastal regions, where carbon gradients and primary production rates are high.

2.2 Ongoing long-term observations at high spatial and temporal resolution

Automated sensors (CytoSense/Sub, Fluoroprobe) continued to be deployed in French waters from the Bay of Somme (E. Channel) to Dunkerque (North Sea) as a complement to local (SRN Ifremer) and national (REPHY, PhytOBS, SOMLIT) observing networks of the French Research Infrastructure for Coastal and Littoral Observation (ILICO). In addition, a coastal-offshore transect (Radiale Baie Saint Jean-DYPHYRAD), supported by different projects, was sampled at higher temporal (weekly to daily frequence) and high spatial (~1km) resolution. Combining reference methods (pigments, microscopic counts) and innovative automated imaging inflow and benchtop devices, pulse shape-recording flow cytometers, imaging systems as well in vivo fluorometers made it possible to investigate drivers of phytoplankton outbursts and community occurrence and changes addressed at different scales about changes in marine ecosystem state.

The interannual trend as well as the phenology of blooms (including those of Phaeocystis globosa) are being explored by combining reference and automated approaches, in the frame of Zéline Hubert's Master Thesis (2021) and ongoing PhD for which a publication is in progress. Moreover, photosynthetic production (by variable fluorescence (VF) was also addressed using Fast Repetition Rate fluorometry (FRRf) along the inshore-offshore coastal gradient. The VF time series were studied in terms of seasonality through the comparison of two of the main algorithms used to estimate photosynthetic production of microalgae. It was possible to follow the different successions of five main functional phytoplankton groups along the coastal-offshore gradient and to explore interannual trends. The models used to compute photosynthetic parameters and production in absolute units using FRRf measurements show different seasonal patterns, which were respectively synchronous or delayed with that of chlorophyll biomass and diversity.

2.3 High Frequency fixed autonomous stations and moorings

The smart multisensor marine observation platform, Costof2, was installed in the MAREL Carnot instrumented platform located at the end of the Carnot dyke in Boulogne-sur-Mer (http://www.seanoe.org/data/00286/39754/), representing the core of the EMSO Generic Instrumentation Module (EGIM). Experiments were conducted in spring 2021 and 2022 to complement this set of measurements with a spectral fluorometer as well as with an automated flow cytometer. Fine dynamics of the spring bloom in the Eastern Channel were addressed by deploying a CytoSub device in spring 2021 and in spring and summer 2022, making it possible to identify variability at different scales, as part of the M.Sc. thesis of Kévin Robache (publication in progress). These deployments on the MAREL Carnot station are strongly linked to the implementation of the cEGIM station in the bay of Seine with an onboard intelligent system controlling data acquisition depending on the environmental context.

The Helgoland Underwater Observatory (HUWO), a long-term monitoring station at Margate near the island of Helgoland in the North Sea (54.193°N, 7.878°E), has been running with only a few temporal gaps for technical reasons since 2020. It is also affiliated with the COSYNA (Coastal Observation System for Northern and Arctic Seas) coastal monitoring network and is currently being operated in a collaboration between Hereon and AWI. The HUWO comprises a central node with several permanently submerged landers, to which environmental measuring equipment, such as CTD, turbidity, chlorophyll, oxygen, and current flow (ADCP) sensors are attached. The HUWO's profiling platform contains a CPICS imaging system alongside a CTD. Plankton and particle imaging data were collected continuously in real-time, at a high temporal resolution, at this location from June 2021 until August 2022.

2.4 Automation in data treatment and analysis

To extract relevant information from complex data sets (combining Low Frequency and high Frequency data), IFREMER's and ULCO/LISIC's teams improved the management of large data matrices. Data validation and qualification tools were proposed, as well as adaptations to analytical methods for completion, regularisation, clustering, and learning of these series to optimally extract information and thus predict future events. A combination of multivariate, multi-source, and multi-scale approaches were set to account for the complexity of interactions among environmental parameters and pressure/impact effects. Moreover, as part of the observation of plankton diversity and abundance, IFREMER's developed an automated analysis tool for plankton image recognition that can be deployed during cruises in near real-time, combining image processing techniques and deep learning algorithms. This tool tested on FlowCam data but could be implemented on other acquisition devices (i.e. other imagery systems such as ZooScan, and FlowCytometer). A graphical user interface was developed to update the graphical outputs (maps, bar plots, etc.) to obtain/visualize the results in near real-time (Wacquet & Lefebvre, 2022). Moreover, the first-year survey was analysed in the frame of Florine Verhaeghe's engineering thesis through a collaboration between CNRS LOG and IFREMER.

In addition to strengthening the collaboration between the partners involved in action#3, the activities carried out contributed to reinforcing the dynamics of data

FAIRisation, improving data flows, and the associated development of data pre-processing and processing tools. New collaborations or new projects were carried out related to observation in wind farm areas and/or monitoring and prediction of HABs by Artificial Intelligence and Machine Learning.

3. CONCLUSIONS

The high-frequency measurements provided more precise information on the distribution and dynamics of phytoplankton functional types (flow cytometry) and main taxa (imaging) and consequently improved the discrimination between temporal and spatial changes in communities defining the different bloom situations and pelagic habitats, as a complement of physical, biogeochemical and biological variables. These measurements provide more precise information on the dynamics of phytoplankton functional and taxonomical diversity, photosynthesis, and productivity at high spatial and temporal resolution, assigning community changes to different bloom situations and pelagic habitat states, complementing physical, biogeochemical, and biological variables. Finally, harmonised data pipelines and synthesis applying conventional statistics, Artificial Intelligence, and Machine Learning, make it possible to address scientific, societal, and economic challenges through a new perspective, facing global and local changes.

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Plenary presentations

The future of operational oceanography

Blue-Cloud-2026, a Federated European Ecosystem to deliver FAIR & Open data and analytical services, instrumental for the Digital Twins of the Oceans

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Keywords
Open science, EOSC, data discovery, data access, EOVs, data lakes, subsetting API, VRE, VLabs, WorkBenches

Abstract
The pilot Blue-Cloud H2020 project combined interests of developing a thematic marine EOSC cloud and serving the Blue Economy, Marine Environment and Marine Knowledge agendas. It deployed a versatile cyber platform with smart federation of multidisciplinary data repositories, analytical tools, and computing facilities in support of exploring and demonstrating the potential of cloud based open science for ocean sustainability, UN Decade of the Oceans, and G7 Future of the Oceans. The pilot Blue-Cloud delivered: 1) Blue-Cloud Data Discovery & Access service (DD&AS), 2) Blue-Cloud Virtual Research Environment infrastructure (VRE) and 3) Five multi-disciplinary Blue-Cloud Virtual Labs (VLabs). Since early 2023, Blue-Cloud 2026 aims at a further evolution into a Federated European Ecosystem to deliver FAIR & Open data and analytical services, instrumental for deepening research of oceans, EU seas, coastal & inland waters, and building a major data ground segment for the Digital Twins of the Oceans (DTO's).

The EMODnet Data Ingestion portal plays a role in the pathways towards the EMODnet data portal. Specifically, the services it provides to data holders include: (a) data submission, with integrated services such as the online submission form, user management service, tracking service, (b) discovery and access, operating on the ingested and completed data submissions, and (c) operational data integration.

1. INTRODUCTION

1.1. Blue-Cloud 2026 Project

Over the past decades, Europe developed an impressive capability for aquatic environmental observation, data-handling and sharing, modelling and forecasting, second to none in the world. This builds upon national environmental observation and monitoring networks and programs, complemented with EU infrastructures such as the Copernicus satellite observation programme and related thematic services, the European Marine Observation and Data Network (EMODnet), as well as a range of environmental European Research Infrastructures and major R&D projects.

Within this framework, since October 2019, the pilot Blue-Cloud project (https://blue-cloud.org/about-h2020-blue-cloud) combined both the interests of the European Open Science Cloud (EOSC), aiming to provide a virtual environment with open and seamless access to services for storage, management, analysis and re-use of research data, across borders and disciplines, and the blue research communities by developing a collaborative web-based environment providing simplified access to an unprecedented wealth of o multi-disciplinary datasets from observations, analytical services, and computing facilities essential for blue science.

The successor Blue-Cloud 2026 project (https://blue-cloud.org) aims at a further evolution of this pilot ecosystem into a Federated European Ecosystem to deliver FAIR & Open data and analytical services, instrumental for deepening research of oceans, EU seas, coastal & inland waters. It develops a thematic marine extension to EOSC for open web-based science, serving the needs of the EU Blue Economy, Marine Environment and Marine Knowledge agendas.

Blue-Cloud 2026's overall Objective is to expand the federated approach of Blue-Cloud, involving more aquatic data stakeholders, and interacting with EOSC developments, in support of the EU Green Deal, UN SDG, EU Destination Earth, and the EU Mission Starfish on healthy oceans, seas, coastal and inland waters, ultimately to provide a core data service for the Digital Twins of the Ocean.

1.2. Blue-Cloud Tools and Services

The pilot Blue-Cloud project delivered:

- **Blue-Cloud Data Discovery & Access service (DD&AS)**, federating key European data management infrastructures, to facilitate users in finding and retrieving multi-disciplinary datasets from multiple repositories);

- **Blue-Cloud Virtual Research Environment infrastructure (VRE)** providing a range of services and facilitating orchestration of computing and analytical services for constructing, hosting and operating Virtual Labs for specific applications;

- **Five multi-disciplinary Blue-Cloud Virtual Labs (VLabs)**, configured with specific analytical workflows, targeting major scientific challenges, and serving as real-life **Demonstrators,** which can be adopted and adapted for other inputs and analyses.

Over the course of 42 months starting in January 2023, Blue-Cloud 2026 will evolve these core services, integrating more blue analytical services, configuring more Virtual Labs, improving services for uptake of new data sets from a multitude of data originators (such as SeaDataNet, EurOBIS, Euro-Argo, ELIXIR-ENA, SOCAT, EcoTaxa, and ICOS-Ocean), and major e-infrastructures, namely EUDAT, D4Science, EGI, and WEkEO (CMEMS DIAS) and for discovery and access to their structured data collections.

Moreover, it will develop:

- **Three Workbenches for Essential Ocean Variables (EOVs)**, implementing efficient operational workflows that allow ocean and data scientists to harmonise, validate and qualify large and various *in situ* data sources into high quality EOV data collections, which are key input for many applications, including the Digital Twins of the Ocean.

2. BLUE-CLOUD DATA DISCOVERY & ACCESS SERVICE

The federated Data Discovery & Access Service (DD&AS) provides users with an easy and FAIR service for discovery and access to multi-disciplinary data sets and data products managed and provided by leading Blue Data Infrastructures (BDIs). The federation facilitates sharing of datasets as input for analytical and visualisation services and applications, that are hosted and further developed as VLabs and WorkBenches in the Blue-Cloud VRE. The DD&AS has been developed, is operated, and is being upgraded and expanded by MARIS together with CNR (IIA) and CINECA (EUDAT), interacting with each of the BDIs. The figure below gives an overview of the currently federated BDIs and their data resources.

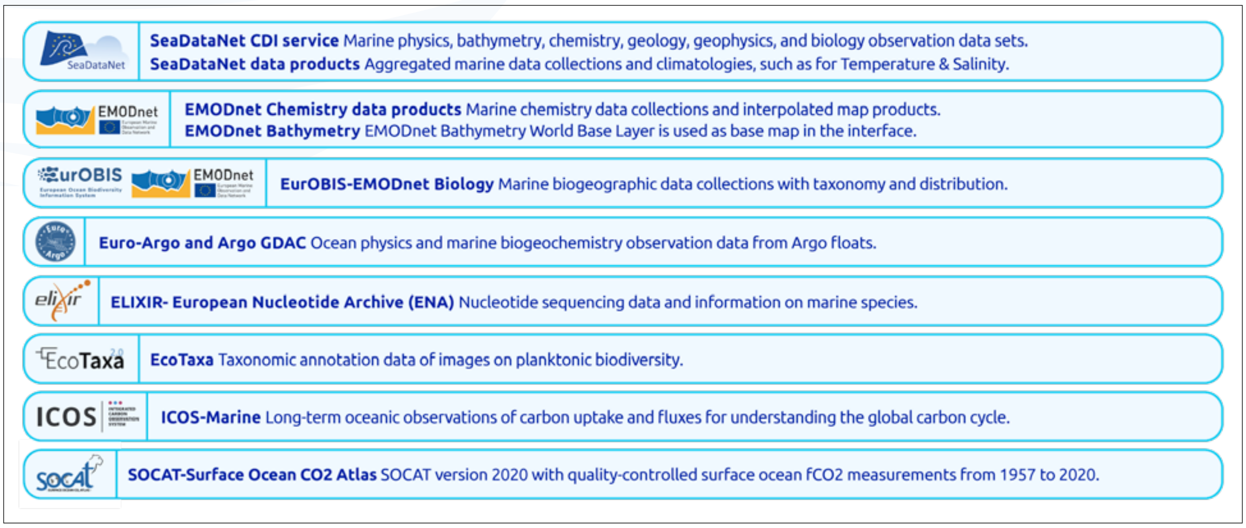

Figure 1. Current Blue Data Infrastructures (BDIs) federated in the DD&AS.

The DD&AS this way facilitates common discovery and access to more than 10 million marine datasets for physics, chemistry, geology, bathymetry, biology, biodiversity, and genomics. It is fully based on machine-to-machine brokering interactions with web services as provided and operated by the BDIs. As part of Blue-Cloud 2026 it will expand by federating more leading European Aquatic Data Infrastructures, as illustrated in the next figure:

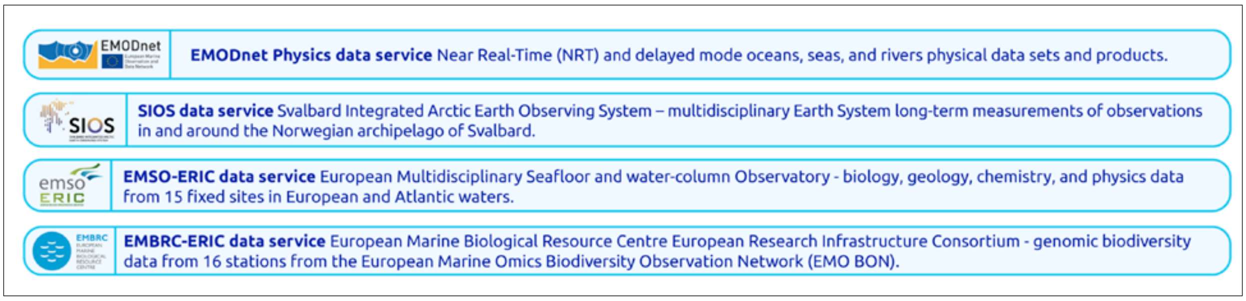

Figure 2. Blue Data Infrastructures (BDIs) to be added to the DD&AS federation.

The DD&AS works with brokerage services both at metadata and data level. Discovery and selection are done in a two-step approach - from data collections using a common metadata profile, to detailed records using extended metadata profiles- and fully based on web services (such as OGC-CSW, OAI-PMH, ERDDAP, DCAT, and dedicated APIs), as published and maintained by connected BDIs. For the first step - collection level - the DAB Metadata Brokerage mechanism (developed by CNR (IIA)) is used, harmonising individual outputs of BDI discovery web services to a common syntactic metadata model (ISO19115 – 19139). The second step drills down within identified collections to get more specific data, using free search, geographic and temporal criteria, but this time at granular level, and including additional BDI-specific search criteria. Users are able to download and store the retrieved data collections on their own machines or in a Data Pool in the Blue-Cloud VRE. The two-step approach is effective to go from coarse to fine and to determine at an early stage which of the BDIs might have interesting datasets.

The shopping mechanism is based on the shared experience and services of MARIS, IFREMER, and EUDAT from developing and managing the SeaDataNet CDI service, from which selected services were adapted. The DD&AS is available by means of a GUI, while level 1 – the collections catalogue – is also published as OGC CSW service, which is e.g. used for sharing the Blue-Cloud collection records with the EUDAT B2FIND data catalogue service at the EOSC Marketplace. This way, EOSC users can find relevant Blue-Cloud data collections and are then directed to the Blue-Cloud DD&AS for further down drilling and actual download of datasets at granule level.

As part of Blue-Cloud 2026, the DD&AS is being elaborated in a number of ways:

- Optimising and refining current web services at BDIs and DD&AS federation principles for increasing the FAIRness of the integrated services and the provided output;

- Achieving semantic interoperability for common metadata tags, such as parameters, instruments, platforms, sea regions, etc: Each BDI is using own vocabularies for several metadata tags. A semantic brokerage service component will be developed and integrated into the DD&AS;

- Adding sub-setting and extracting services to the DD&AS by means of APIs at BDIs: Currently, the DD&AS supports discovery and download of predefined data objects, while several applications might require specific extracts and slices of data. Also, repositories like WEkEO (CMEMS DIAS) are managing big datasets for which sub-setting and slicing is more appropriate as otherwise very large files are downloaded, which might be updated and increased regularly as results of model runs. New APIs will be developed or existing APIs will be adapted, where required to facilitate the compilation of Blue-Cloud 'Data Lakes' for specific data types;

- Defining, developing, and operating Blue-Cloud Data Lakes: Data Lakes will function as 'harmonised buffers' of observation data as combined from multiple BDIs and also from major international repositories like the NOAA World Ocean Database (WOD) and others. Data Lakes will improve data access both in terms of data harmonisation and of technical efficiency of data access. The data lakes will be very relevant for organising input for the Vlabs and Work Benches, while they also will be relevant for providing high quality output to other initiatives such as the Digital Twins of the Ocean (DTO).

3. BLUE-CLOUD DATA VIRTUAL RESEARCH ENVIRONMENT

The Blue Cloud Virtual Research Environment (VRE) provides an Open Science platform for collaborative marine research, using a wide variety of datasets and analytical tools, complemented by generic services such as sub-setting, pre-processing, harmonising, publishing and visualisation. For each Virtual Lab and each Workbench, accounts of researchers will be configured at the VRE. Each will enact a family of analytical workflows which consist of a series of applications and make use of selected datasets as input. The multi-disciplinary datasets can be retrieved from the BDIs using the Blue Cloud DD&AS and its Data Lakes, and external resources. Outputs, such as data products, data collections, maps, notebooks, software applications, and services can be documented with DOIs for citation, provenance for reproducibility, and published in the Blue-Cloud Catalogue. All methods and services in this Catalogue are exchanged with the EOSC Portal Catalogue & Marketplace.

The Blue-Cloud VRE is organised as a multi-site digital infrastructure with a central hub and peripheral sites. The central hub is located at the D4Science data centre, operated by CNR. It is responsible for four common services: 1) Identity and Access Management (IAM) Service, 2) the Information System (IS), 3) the Resource Manager (RM), and 4) the persistent, fault-tolerant and replicated Storage Manager (SM). The peripheral sites host most of the computing resources and the tailored storage devices that offer low-latency and efficient storage solutions for supporting large and complex data analytics processes. Overall, it offers an aggregated shared capacity of 3,650 CPU cores with 13.7 TB RAM and 0.6 PB persistent storage and will power the Blue-Cloud 2026 VRE at the beginning of the project. This initial capacity will be then expanded with additional sites, each with a minimum capacity of 256 CPU cores with 512 GB RAM and 10 TB persistent storage to enlarge the overall computing capacities and enable distribution of the load, fault tolerance, advanced resilience and exclusive assignment of resources to the data and computing intensive WorkBenches for EOVs. By exploiting those digital resources, services will be able to join and leave the VRE according to the provisioning policies specified at the service integration time. This "system of systems" will give a good grade of autonomy at the site level (independence and evolution), openness (join and leave; dynamic reconfiguration); distribution (interdependence and interoperability) which makes it easier to define policies for the addition of new site providers to the VRE. All physical resources of the infrastructure will be manageable through a single platform for both hardware and software layers, which will simplify the RI management, enhance scaling of the VRE deployment, and reduce the total cost of ownership.

Most of this physical architecture is invisible to the final users, which will see and access the resources from a single and unified access point (i.e., the Blue-Cloud Gateway). The Analytics Computing Framework - i.e., the Kubernetes clusters, used to deliver Jupyter Notebooks via the JupyterLab web-based interactive development environment, RShiny and RStudio applications, the Docker Swarm clusters used to operate containerised applications, the computing clusters used to support high-throughput computing (HTC) tasks, and the worker clusters used to support map-reduce jobs - will be located in several sites to ensure scalability, reliability and fault-tolerance.

As part of Blue-Cloud 2026 project, the VRE will be elaborated in a number of ways:

- Further evolution of the 4 VRE common services and operation: IAM, IS, RM, and SM components will be evolved to better serve the needs of the enlarged community and to deliver them a high-quality operation. IAM will join Identity Federation of the EGI Check-in service in support of Single Sign On (SSO) for the users at the integrated VRE platform. IS and RM will manage new resources, computing and services, joining the Blue-Cloud VRE for enlarging its overall capacities and capabilities. SM will offer more tailored configurations for analytical services;

- Enhancing the computing facilities: The Analytics Computing Framework will support HTC on (Docker and Linux) containerised applications. This will improve the portability of the application and its reproducibility in other infrastructures, isolation of application packages, increased security, and reduced operational costs. The JupyterHub component will be enhanced for deployment over multiple Kubernetes clusters to ensure high scalability;

- Expanding the VRE by federating multiple e-infrastructures: the VRE powered by D4Science, will federate resources and services, namely provided by EGI, WEkEO, EUDAT, and JERICO-CORE. It will provide a return on investment for each provider joining the Blue-Cloud VRE since compliance with the EU Regulation (as for GDPR), security, monitoring, accounting, user management, fault management, and alerting management will be granted by the VRE with no cost for the provider of the digital resources. In turn, the provider will be acknowledged by the users in all products and services generated by exploiting the provider's resources. This seamless expansion will support orchestrating workflows, with algorithms and computing resources, divided over and running at the different e-infrastructures. This way, it will also open the connectivity to applications in new EU projects such as iMAGINE (AI applications for marine domain), and EGI-ACE (applications for ocean use cases);

- Expanding the monitoring of availability and usage of the integrated VRE platform: the initial Blue-Cloud VRE monitoring system, empowering central dashboards of uptime and users and uses of all services will be expanded towards the newly developed services and the additional e-infrastructures.

Finally, **an EOSC Blue Task Force for Blue-Cloud integration with EOSC core services** will be established to ensure the compliance of the Blue-Cloud technical framework with the EOSC principles for service management, including Service Level Agreement (SLA), Operation Level Agreement (OLA), incident and service request management, service availability and continuity management.

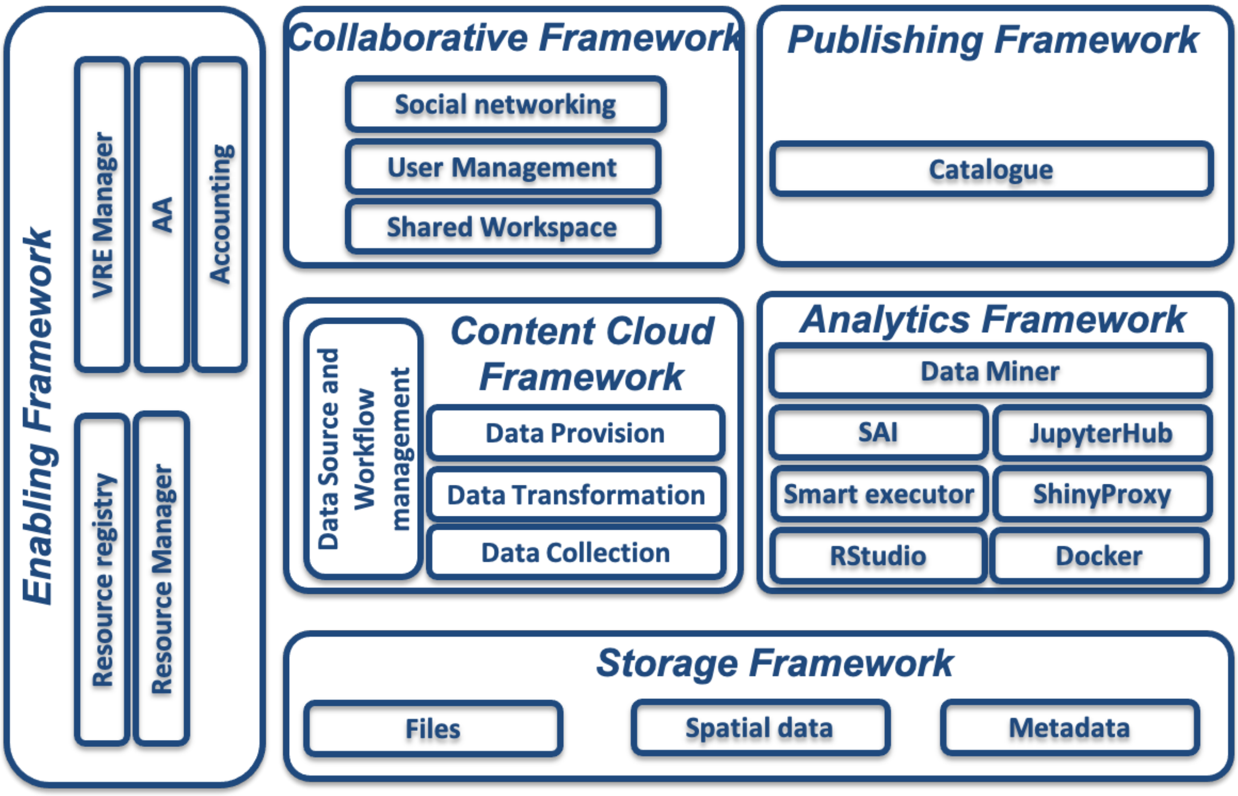

Figure 3. High-level architecture of the D4Science infrastructure.

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European contribution to the OneArgo array

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Keywords

OneArgo, ocean observing, design, BGC-Argo, Deep-Argo, dissolved oxygen

Abstract

The Argo Programme is a major component of both the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS). Originally designed to provide temperature and salinity profiles in the upper 2 km of the ice-free ocean, the array has been expanded into seasonal ice zones, marginal Seas, deeper waters (Deep-Argo) and biogeochemical parameters (BGC-Argo), forming the new "global, full-depth and multidisciplinary" OneArgo programme. Euro-Argo aims at maintaining ¼ of the new OneArgo array, with a regional perspective and focusing on European marginal seas and the European part of the Arctic Sea.

The Euro-Argo strategy focuses on providing sustained high quality oceanic data to the science community to better understand the role of the ocean in the Earth climate, to address issues of climate change, health of the oceanic ecosystems and their impacts on society. Euro-Argo is a major source of information for operational centres in Europe (e.g. Copernicus Marine Service), and supports the enhancement of monitoring and observing systems for model-assimilation and model-validation purposes. Namely, thanks to the near-real-time transmission on the GTS (Global Telecommunication System), Euro-Argo data contribute to weather and ocean forecast.

Within this context, Euro-Argo is currently revising its deployment strategy for the next decade, taking into consideration specific European needs in terms of *in situ* ocean observations, while contributing to the global OneArgo new ambitious design.

1. INTRODUCTION

The Euro-Argo programme, coordinated by Euro-Argo ERIC, represents the European contribution to the Argo international programme, a major component of both the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS). Originally designed to provide temperature and salinity profiles in the upper 2 km of the ice-free ocean, the Argo array has progressively been expanded into seasonal ice zones and marginal or enclosed seas. Furthermore, regional pilot programmes, where Euro-Argo partners played an important role, have allowed to develop and test Argo floats able to measure biogeochemical (BGC) parameters (BGC-Argo), and floats able to make measurements throughout the water column to 6000 m depth (Deep-Argo). The BGC-Argo and Deep-Argo missions are now being implemented by Euro-Argo and internationally to complement the initial Core-Argo mission. Together they form the new global, full-depth and multidisciplinary OneArgo programme (Fig. 1, Roemmich *et al.,* 2019).

This document provides rationale for the OneArgo network implementation strategy in Europe, focusing on the new Deep-Argo and BGC-Argo missions. Euro-Argo's long-term objective is to maintain one fourth of the international OneArgo array, which corresponds to about 1200 active floats, including 300 Deep and 250 BGC floats. This target, to be achieved by 2030, is very ambitious and will require significant increase in Euro-Argo financial and human resources.

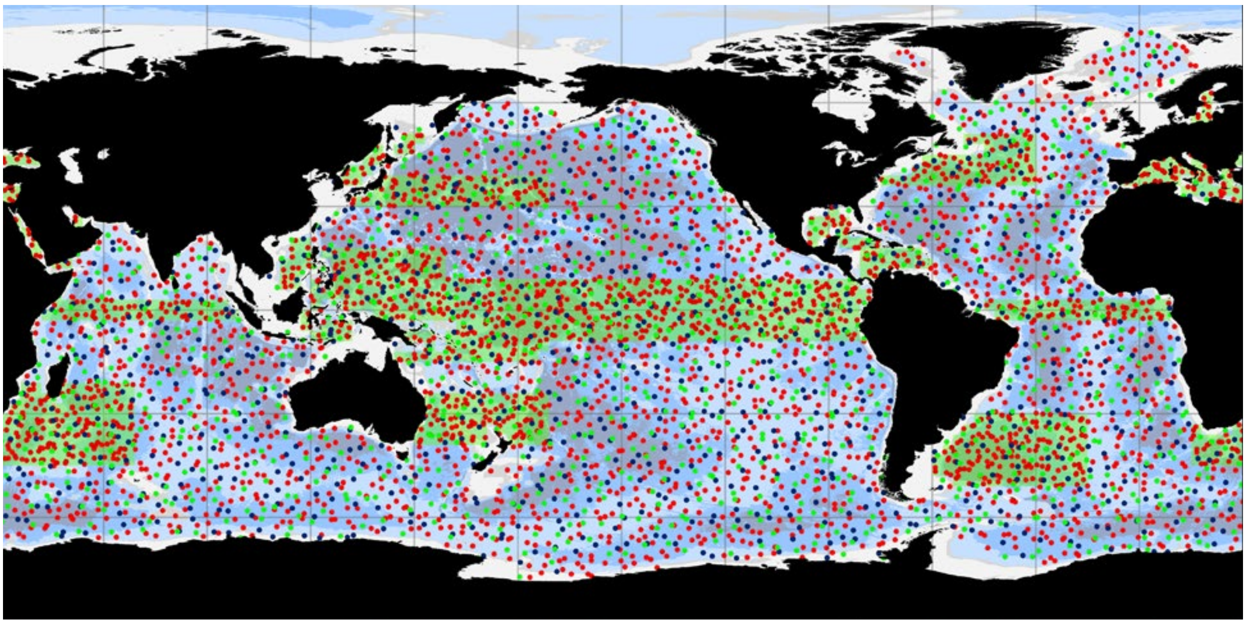

Figure 1. OneArgo design - adapted from Roemmich *et al.,* 2019.

2. EUROPEAN CONTRIBUTION TO BGC-ARGO

Euro-Argo partners are ready to take up the challenge to increase their BGC floats deployments in the coming decade, to contribute to the full BGC-Argo design of 1000 active floats able to measure the 6 core BGC-Argo variables (Biogeochemical-Argo Planning Group, 2016), enabling the exploration and understanding of key biogeochemical processes (e.g. ocean uptake of carbon dioxide, ocean acidification, deoxygenation, and variability in biological productivity). The European contribution to BGC-Argo is driven by scientific interest in the European scientific community, while considering the needs of both the operational and satellite-based ocean colour communities, and ensuring a global implementation of the OneArgo design. Bio-optical sensors installed on BGC-Argo floats provide a clear link with satellite-based remote sensing of ocean colour. Together, BGC-Argo and remote sensing can complement their observations over multiple horizontal, vertical, and temporal scales in order to achieve a 4-Dimensional view of ocean biogeochemistry and carbon cycle. In addition, BGC-Argo provides Space Agencies with the fundamental information required to maximise the quality of observations of satellite sensors at the top of the atmosphere and across the global ocean (e.g., European Copernicus Sentinel 3 missions). BGC-Argo also contributes significantly to reducing uncertainties in marine biogeochemical simulations through data assimilation, as recently shown in data assimilation applications in the operational Marine Copernicus model system for the Mediterranean Sea. The monitoring of European marginal Seas, namely the Baltic, the Black and the Mediterranean Seas, is one of Euro-Argo priorities for BGC-Argo. Maintaining a network of BGC-Argo floats in these regions will contribute to the monitoring and assessment of the marine environment status and functioning in relation to climate change as part of the European Union Green Deal. In complement, Euro-Argo aims to contribute to the implementation of BGC-Argo at global scale, in coordination with international programmes, with a specific interest in maintaining an appropriate array of BGC floats in the Nordic Seas and the South West Indian, and taking advantage of deployment opportunities around the global ocean.

Euro-Argo has been a key player in driving the evolution of Argo and its new missions. A new type of float able to carry additional BGC sensors, while enabling the float to fulfil its BGC-Argo mission (10 days cycles, for 4 years) has recently been developed in Europe. A number of these jumbo floats have been deployed with two additional types of sensors: (i) particle size imagers, with the aim to characterise the temporal dynamic of particles contributing to the gravitational export of carbon within the mesopelagic zone, and (ii) hyperspectral radiometers, able to recognize hundreds of colours, putting the way forward to develop new proxies to study phytoplankton communities, particulate and dissolved carbon dynamics, and ecosystem health along the water column. The results are encouraging, and when the data distribution pipelines for these new variables - which are being established - will be ready, these types of measurement will be ready to be evaluated by the international Argo Steering Team as potential sensors that could deliver additional ecosystem measurements to the already 6 recognized variables. On the longer term, new developments are planned within the GEORGE HE EU project to integrate novel sensors ultimately enabling for the first time systematic autonomous, *in situ* seawater CO_2 system characterisation, and CO_2 fluxes, on Argo and other ocean observing platforms.

3. EUROPEAN CONTRIBUTION TO DEEP-ARGO

Euro-Argo has been involved in Deep-Argo since the beginning, in particular through the deployment of a pilot array in the North Atlantic. Currently, Euro-Argo is following international recommendations for the Deep-Argo mission to both maintain the current pilot experiments and initiate new regional foci in regions of substantial seasonal-to-decadal variability, while pursuing efforts towards technological refinements (e.g. long-term stability) and a coordinated data-management strategy (e.g. quality control). Because of their predominant roles in the ventilation and long-term sequestration of climatic signals into the deep (via convective mixing and downslope cascading), the North Atlantic, the Nordic Seas and the Southern Ocean stand out as the most natural targets and will be European scientific priorities (Desbruyères *et al.*, 2016). Efforts will also be made to maintain an appropriate number of Deep active floats in the Mediterranean Sea, and to contribute to the global Deep-Argo network implementation in collaboration with other international programmes.

European objectives will be built upon a cost-effective strategy, striking a balance between the Deep-Argo floats with 6000 dbar capability in relatively deeper areas and the twice-cheaper Deep-Argo floats with 4000 dbar capability in shallower areas. Besides, Euro-Argo teams will continue their strong involvement in the development of data quality control procedures and in the monitoring and assessment of sensors accuracy, in collaboration with manufacturers, to improve data reliability. Pilot projects are planned for the coming years to integrate commercially available optical scattering sensors, that have been tested to 6000 m, onto Deep-Argo floats. The first successful tests open up the lead to new applications of Deep-Argo, e.g. the quantification of sediment resuspension and transport near the ocean bottom.

4. DISSOLVED OXYGEN

The distribution of dissolved oxygen (DO) concentration at global scale is driven by physical, biogeochemical and biological processes and has been used to gain insights on those processes since the early age of oceanography. DO data is in a key position of many biogeochemical processes. It also can be used to interpolate (e.g., through neural network techniques) nutrient concentrations and carbonate system parameters, and ultimately estimate anthropogenic carbon storage and export (Sauzède *et al.*, 2017). The optode DO sensor is of proven maturity and can provide very accurate measurements, after appropriate corrections have been applied (e.g. sensor drift, time response). It is currently carried by a large proportion of Euro-Argo floats, including most of European Deep-Argo float, and in the long-term, Euro-Argo plans to equip at least 3/4 of its fleet (all missions) with a DO sensor. This step could lead, for instance, to a major advance in biogeochemical monitoring of the marine ecosystem and operational services in the European Seas.

5. NETWORK IMPLEMENTATION AND ASSOCIATED COST

The OneArgo design is ambitious and its implementation will require strong efforts and additional resources. An assessment of the resources needed for Euro-Argo to achieve 25% of the OneArgo design, including the contribution to BGC-Argo and Deep-Argo has been carried out, based on a constant rough estimate of retail price for each type of float, which is obviously unrealistic. This assessment considers both float procurement and operations costs on one hand (i.e. testing, shipping, satellite communications) and personal costs on the other hand (i.e. personal cost for data processing, operations, etc.). In total, the estimated cost of Euro-Argo contribution to OneArgo is 25M€ per year: among the 15.4M€ needed for float procurement and operation (i.e. excluding personal costs), 7.8M€ are for BGC-Argo and 4.7M€ for Deep-Argo. To achieve its target of maintaining 25% of the OneArgo design in the next decade, Euro-Argo will have to find, at least, an additional 10M€ per year, to complement the current fundings.

6. ONEARGO AS A CONTRIBUTION TO A MULTIPLATFORM OCEAN OBSERVING SYSTEM

An integrated ocean observing system is the crux of a holistic scientific understanding of the Earth system. As autonomous platforms, post-calibration of Argo data is impossible. The Argo programme thus strongly relies on high accuracy CTD casts and reference samples such as calibrated CTD-O2 cast; bottle NO3, etc. collected from ships (GO-SHIP) to achieve the data quality needed for climate studies. This is more particularly true for BGC-Argo and Deep-Argo, whose sensor technology is less mature than for core-Argo floats. Networks coordination is needed for a better Ocean integration (Tanhua *et al.*, 2019, Révelard *et al.*, 2022). An efficient coordination at all levels of the ocean observations value chain leads for instance to increased cost effectiveness of the global observing system and better data uptake by users thanks to improved interoperability. Collaboration has proven its worth in various domains such as technology or data. One example is the involvement of Argo data experts in the development of Ocean Gliders Best Practices and Standard Operation Procedures, within the EuroSea project.

In terms of network implementation and ocean observing system design, although the OneArgo design does not take into account other platforms in its global definition, the design implementation at regional level will require strong coordination to be efficient and to properly answer user needs. The Euro-Argo strategy for ocean monitoring in the European marginal seas will address this complementarity with other networks.

7. CONCLUSION

The implementation of the new OneArgo design, and more specifically the BGC and the Deep-Argo missions, comes with new challenges for Euro-Argo, including the cost, but also the need for growing capacity both at manufacturer level and in the teams involved with operations, data management, data quality and sensor accuracy assessment and monitoring. As one piece of a multiplatform ocean observing system, Argo and Euro-Argo will also have to improve synergies with other ocean observing networks in the future, to efficiently progress in ocean knowledge and management. The European strategy for Deep-Argo and BGC-Argo presented here will be part of a wider effort initiated by Euro-Argo to define the general "Euro-Argo scientific strategy for the OneArgo array implementation"

ACKNOWLEDGEMENTS

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ANERIS: Towards a network of Operational Marine Biology

Authors

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Keywords

Operational Marine Biology, Life Sensing Technologies, Marine Infrastructures, Observational Networks

Abstract

Biological observations need to improve radically to serve our understanding of marine ecosystems and biodiversity under long-term global change and multiple stressors. However, this is not trivial as biological properties are more difficult to measure and integrate compared to physical or chemical parameters. In the ANERIS project (operAtional seNsing lifE technologies for maRIne ecosystemS), we address these observational challenges by developing the next generation of scientific instrumentation tools and methods for sensing marine-life. ANERIS will improve and integrate different acquisition technologies based on genomics, imaging and participatory systems to cover the wide range of body sizes of the different organisms that lives in the ocean. The project proposes the concept of Operational Marine Biology, understood (in analogy with the Operational Oceanography) as a systematic and long-term routine measurements of the ocean and coastal life, and their rapid interpretation and dissemination. The achievement of the Operational Marine Biology network is a key goal for the next decade and will enable a base line of biological information related to Essential Biodiversity Variables (EBVs) and Essential Ocean Variables (EOVs). It will also deliver critical data for descriptors for Marine Policies, in particular the Marine Strategy Framework Directive (MSFD)).

1. INTRODUCTION

The ongoing biodiversity crisis may result in much of the ocean's biodiversity being lost or deeply modified without even being known. As the climate and anthropogenic-related impacts on marine systems accelerate, biodiversity knowledge integration is urgently required to evaluate and monitor marine ecosystems and to support suitable responses to underpin a sustainable future. Biological observations need to improve radically to enhance our understanding of marine ecosystems and biodiversity under long-term global change and multiple stressors. However, this is not trivial as biological properties are more difficult to measure and integrate, compared to physical or chemical parameters. The EU funded project ANERIS proposes to implement the concept of Operational Marine Biology (OMB), understood as a biodiversity information system for systematic and long-term routine measurements of the ocean and coastal life, and their rapid interpretation and dissemination. The OMB information flow is summarized in Fig. 1.

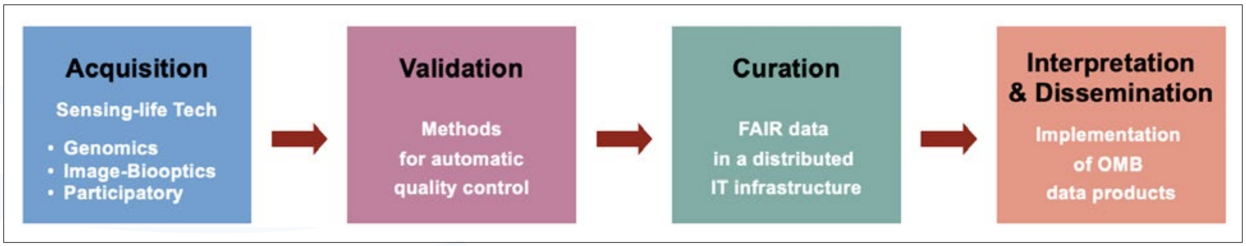

Figure 1. The Operational Marine Biology (OMB) information flow will be based on an automatic pipeline of information production, from acquisition to interpretation and dissemination.

The achievement of the new Operational Marine Biology system is a key goal for the next decade and will enable a baseline of biological information related to Essential Biodiversity Variables (EBVs) and Essential Ocean Variables (EOVs). It will also deliver critical data for Marine Policies descriptors, in particular the Marine Strategy Framework Directive (MSFD).

The design of the new instruments and methods will integrate different types of marine life-sensing technologies: genomics, imaging-biooptics and participatory sciences. The technologies will be implemented in a co-design framework, involving all the interested stakeholders: academia, industry, civil society and government.

The production of FAIR Operational Marine Biology data will be carried out in a distributed IT infrastructure built from edge and cloud compute nodes, to be connected with the European Open Science Cloud (EOSC). The technologies will be tested and validated in different case studies, involving the ANERIS innovations, commercial instruments to be improved in different European research infrastructures: LifeWatch-ERIC (Arvanitidis *et al.*, 2019), EMSO-ERIC (Dañobeitia *et al.*, 2018), EMBRC (Piña *et al.*, 2018, Santi *et al.*, 2022), Euro-BioImaging (Pfander *et al.*, 2022) and the European Grid Initiative (Kranzlmüller *et al.*, 2010). The project will develop a training program for the operation and use of these new solutions for all the involved stakeholders and particularly the research infrastructures staff. Overall, the project proposes to benefit all the actors involved in the quintuple helix framework of innovation, promoting innovation and knowledge sharing among them: (1) the academy with new life-sensing technologies to use in research; (2) the industry with new technologies and methods to exploit; (3) the governments, with improved observational systems and data products to be used in environmental management directives; (4) the civil society, empowered through the proposed participative technologies and large collaborative networks and (5) the involved Marine Research Infrastructures in ANERIS, integrating new generation of sensing instruments and methods, and their staff being trained on those new technologies.

2. THE INTEGRATION OF ANERIS TECHNOLOGIES TO GENERATE OMB PRODUCTS

The vision of ANERIS life-sensing technologies is represented in Figure 2-A showing how the combination of the different proposed technologies may overcome the different data gap challenges. The objective is to generate OMB data products by combining the different information layers Figure 2-B. As a first example, Figure 2-C, shows how ANERIS data could complement the existing European Marine Omics Biodiversity Observation Network (EMO BON), coordinated by EMBRC-ERIC: with a large number of complementary observation points, based on the idea of "Participatory Genomics" proposed in the project, the complementary approach would ensure filling marine genomics spatial gaps, improving the global information provided by the EMO BON network.

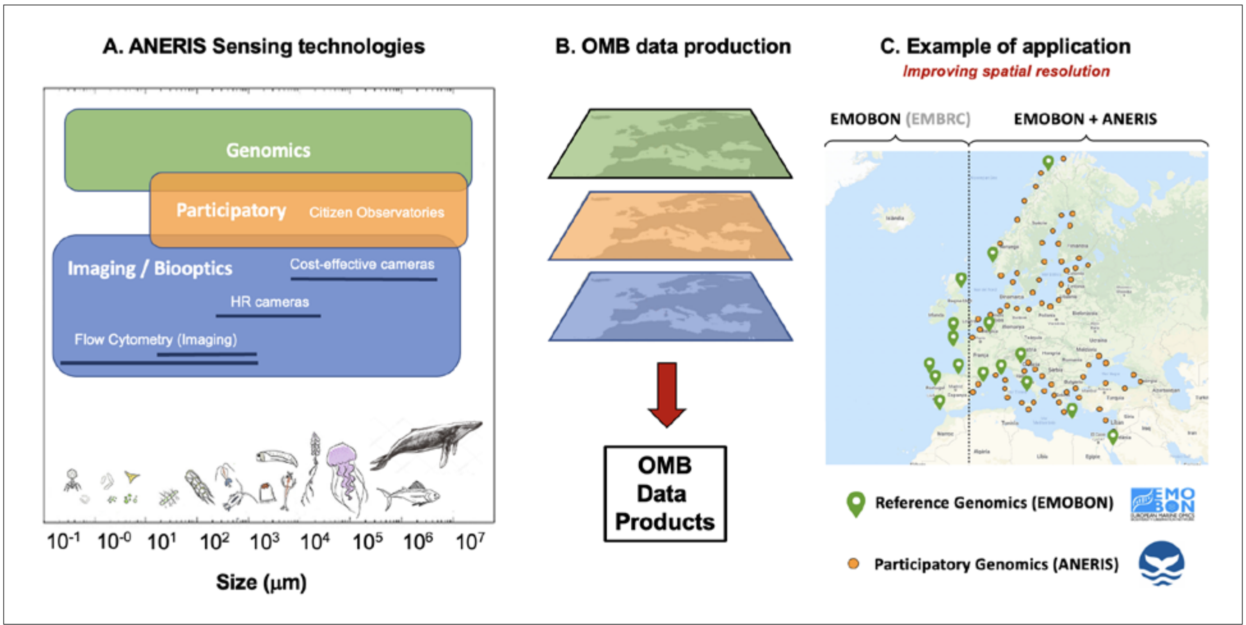

Figure 2. (A): Overall approach of the involved technologies for sensing life that will ensure that we will cover all the taxonomic groups. (B): The idea is to create the different Operational Marine Biology (OMB) Data products by integrating information from the different information layers generated by the proposed technologies. (C): An example of how this approach may improve the services linked to different RI. In this case, the information generated in EMO BON (by the EMBRC-ERIC) could be improved significantly with the participatory genomic information provided in the future by the ANERIS network

Figure 3 shows another example of the combination of different technologies proposed in ANERIS. Different advanced imaging technologies for automatic denoising and colour correction, combined with method of identifying Regions of Interest (ROI) could provide the final images for each organism identified in one image. This could facilitate and significantly improve the process to report and validate observations in citizen observatories, which will promote a substantial increase of participation from the volunteers.

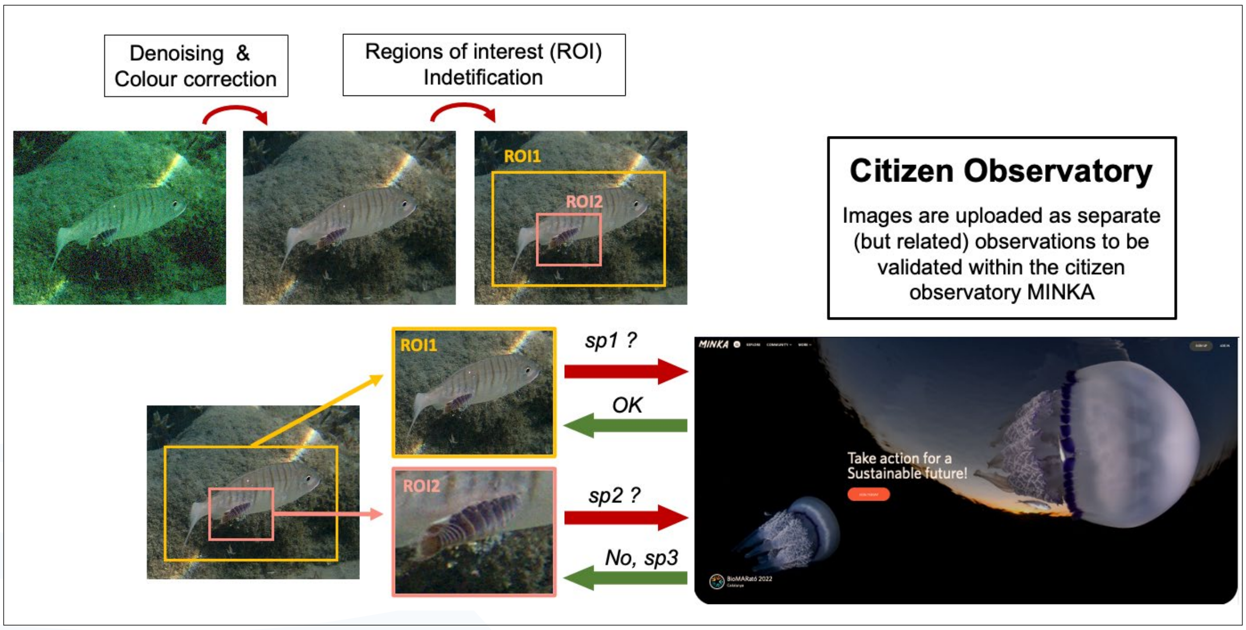

Figure 3. Example of a Pipeline of AENRIS technologies to facilitate the reporting of marine species.

3. THE ANERIS NETWORKS

ANERIS will take advantage of the existing networks, shown in Fig. 4, in which different partners coordinate or collaborate:

Figure 4. Observational networks linked to the ANERIS project.

- EMO BON: European Marine Omics Biodiversity Observation Network (https://www.embrc.eu/emo-bon), coordinated by EMBRC. It will provide the reference measurements for genomic based observations;

- MedCities (https://medcities.org/) 67 local authorities from all shores of the Mediterranean basin will be connected to ANERIS outcomes;

- Ocean Cities (https://ocean-cities.org/) will connect ANERIS with a worldwide network supported by the UN Decade of Ocean Science for Sustainable Development;

- The Atlantic Network of Intertidal Monitoring will provide all the sites to validate the proposed ANERIS technologies in a completely different habitats that the ones explored in the Mediterranean sites.

Complementing these networks, the *Catalan Federation of Underwater Activities* (FECDAS) is promoting, as ANERIS partner, the participation in different project activities and events. The Federation is acting as a bridge between different SMS linked to the Blue Economy (diving clubs, snorkel guides, …) and the volunteers interested in being involved in the ANERIS participatory technologies. FECDAS is be involved in training activities to explain the different technologies and engaging both SMEs and volunteers to strength the networking activities and the engagement events planned in the project.

4. ANERIS FIRST RESULTS

One of the first outcomes form ANERIS has been the consolidation of a community of practice for volunteer reporting in the first pilot study around the Catalan Coast. As a result, the achieved data set of marine biodiversity contains more than 100,000 validated observations, as reported in the news from the Institute of Marine Sciences (Fig. 5).

This massive number of observations has been achieved as a combination of the Participatory technologies, in particular the MINKA observatory platform (https://minka-sdg.org/, mentioned in Fig. 3) that provides dedicated services for collaborative reporting and validation, and the engagement strategies described in Liñan *et al.*, 2022. The proposed engagement strategies consider citizen science projects as a collaboration between multiple stakeholders to ensure long-term volunteer engagement. These stakeholders include the volunteers, but also new roles such as enabling communities that act as a bridge between different communities (volunteers, academia, SMEs). In this pilot study the role of enabling community has been taken by the Catalan Federation of Underwater Activities (FECDAS), connecting diving clubs, and different SMEs linked to scientific tourism and sea-watching activities with the volunteers.

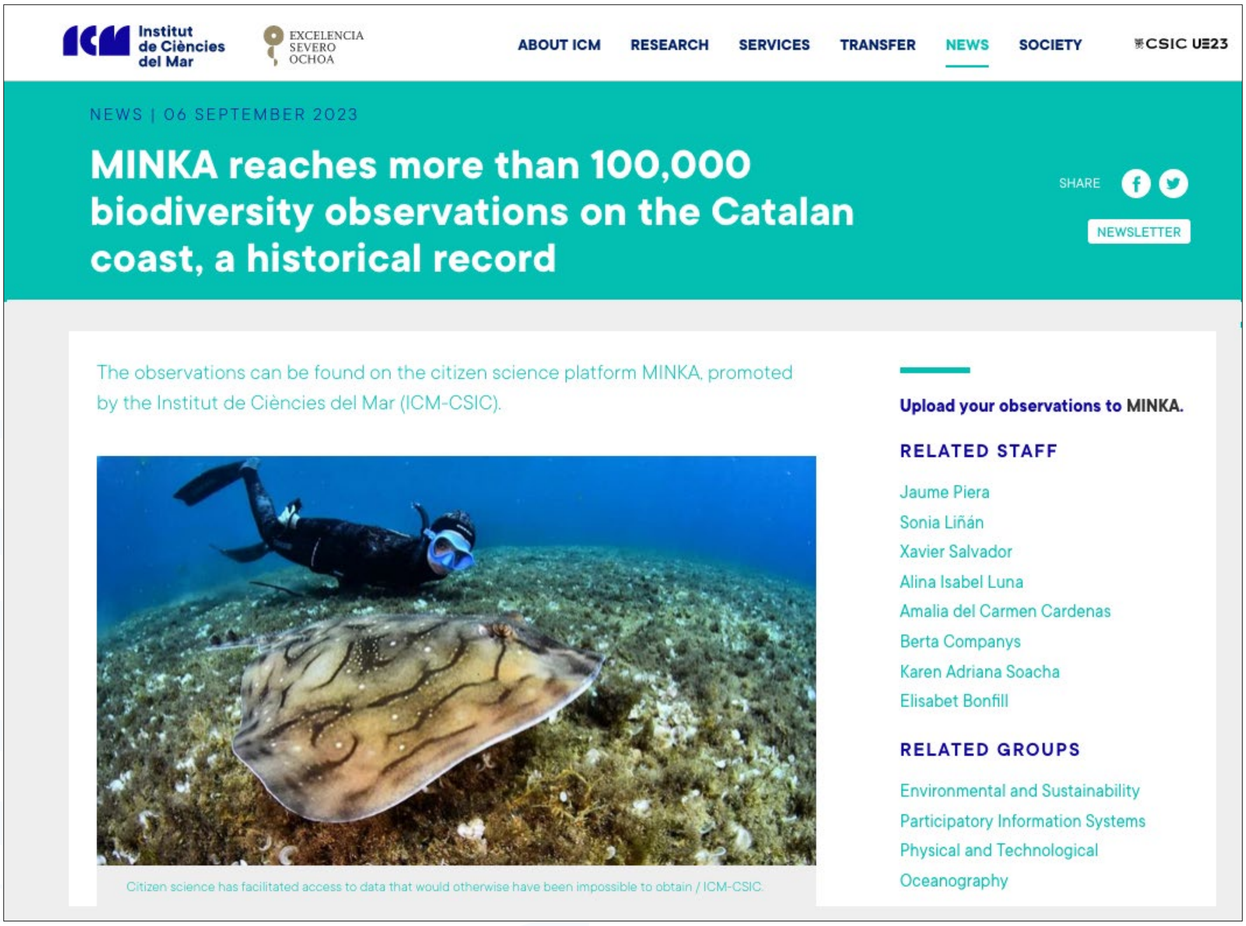

Figure 5. News from the Institute of Marine Sciences (6/9/2023): https://www.icm.csic.es/en/news/minka-reaches-more-100000-biodiversity-observations-catalan-coast-historical-record

The success of this pilot study may provide high resolution maps, both in space and time, of the species distribution from the reported volunteer observations. The pilot study will be used as the reference to scale up this approach to larger regional areas (the whole Mediterranean and other European Seas). The final goal is to produce one of the first Operational Marine Biology Data Products based on volunteer participation.

ACKNOWLEDGEMENTS

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Poster presentations

A bathymetric digital twin to design the bathymetric product of tomorrow

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Keywords

Digital Twin, Bathymetric data, Quality analysis, Data fusion and management, S-102

Abstract

Shom collects hydrographic information on the physical marine environment, particularly bathymetric measurements, allowing the elaboration of nautical products (including nautical charts). Presently, each cartographic operator must currently go through laborious process of selection of bathymetric information from the SBDB. Shom's aim is to provide all its cartographers with a digital bathymetric twin to facilitate the production of new digital products.

1. INTRODUCTION

The French Hydrographic Service, Shom, provides hydrographic services, compliant with regulation 9 of chapter V of the SOLAS convention (IMO, 1974) by collecting, compiling and disseminating up-to-date hydrographic information on nautical publications, hence ensuring safe navigation.

Currently, Shom's bathymetric data are archived in a dedicated Bathymetric Database (SBDB), managed as a stack of overlapping or intersecting surveys. Data from these surveys are derived from different types of sensors and periods. Therefore, data held in the SBDB is of varying quality as acquisition procedures have evolved over time.

2. BATHYMETRIC DATA FUSION AND TETHYS PROJECT

Following a recent effort to digitalize all the bathymetric information collected by Shom through the last 300 years, the Téthys project aims at constituting the best current bathymetric knowledge as a bathymetric reference surface and a bathymetric digital twin, in which a selection of the best quality soundings is being done. Bathymetric data fusion is a vast research topic which has been largely discussed in the literature (Elmore *et al.*, 2008;

Calder, 2006; Stateczny e Bodus-Olkowska, 2015; Gomes e Oliveira, 2008). Globally speaking, the process deals with the aggregation of depth soundings for dedicated products.

Generating this bathymetric reference surface, see Figure 1, will then allow Shom to speed up the generation of nautical charting and bathymetric modelling process by capitalizing on the selection efforts, along with strengthening the management and the valorisation of the source information.

From this compiled, homogeneous and machine-readable data source, it becomes very simple to produce new bathymetric products useful for sea users. This article (Le Deunf *et al.*, 2023) describes in detail the workflow implemented as part of the Téthys project. Using the Téthys tiles already produced (see Figure 2 left), we can generate new high-resolution bathymetric products. This new S-102 bathymetric products (standards still under development) of the International Hydrographic Organisation and which will allow in the future a strong interoperability with the new digital cartographic products (S-1XX), see Figure 2 right.

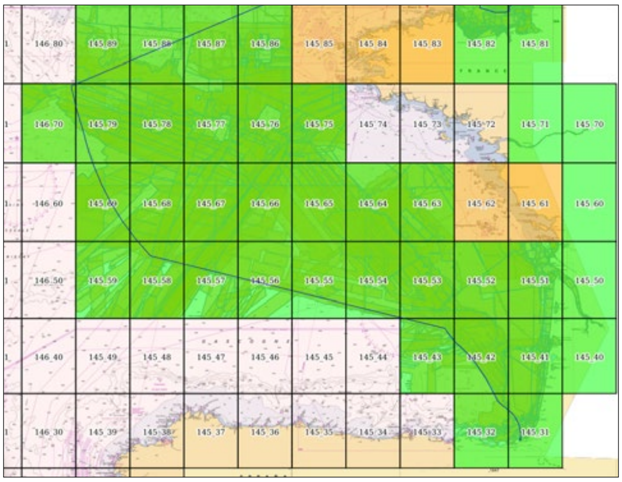

Figure 1. First tile of the Téthys project on Saint-Malo area.

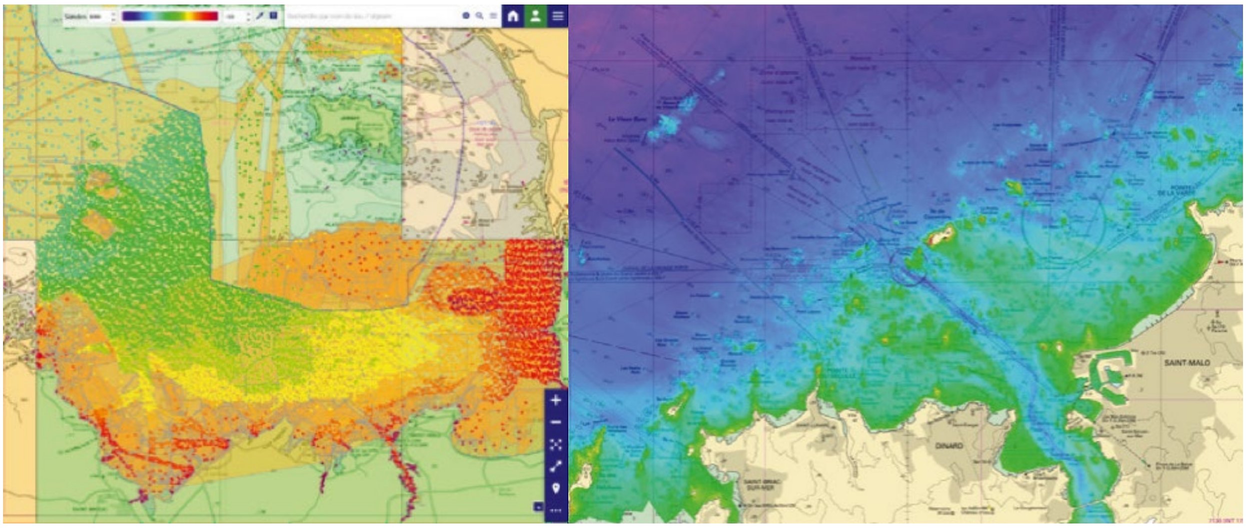

Figure 2. Left: progress of the Téthys project on the French Atlantic coast, the green tiles correspond to the digital bathymetric twin already completed. **Right:** S-102 bathymetric data, Saint-Malo harbour.

3. DISCUSSION

The current concept of use of the Téthys is oriented towards cartographic use applied for the safety of navigation, which translates into the implementation of more than 300 expert rules to ensure the control and deconfliction of bathymetric surveys. However, different concepts of use might require different rules or preferences to be implemented on the deconfliction process. For example, some users, with less constraints on the selection of shoals might welcome relaxed deconfliction rules with potential weighting of the prioritized sources of overlapping surveys.

Moreover, with an increasing effort brought to the automation of the overall workflow, the transformation of the hydrographic profession is questionable. While an effort to generate the first iteration of the reference tiles is currently needed, it is also believed that, through subsequent updates, the hydrographers will have to focus on more and more specific technical issues related to their training without being distracted from minor processing tasks, hence generating a virtuous cycle.

The Téthys workflow systematically implements automation techniques and methodological developments that allow to take advantage of the intelligence of the data.

ACKNOWLEDGEMENTS

We would like to extend our gratitude to the to the bathymetry department for all their efforts to complete this project and to the company Geofit for the the web portal development. This project financed by the Fonds de Transformation de l'Action Publique is a structuring project for the Shom.

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Physical/biogeochemical modelling of the global coast with ICON – the impact of continental runoff

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Keywords
Biogeochemical modeling, riverine eutrophication, ICON, unstructured grid, primary production

Abstract
ICON-coast-E2E is the coastal version of the newly developed global ocean model ICON-O, which is itself part of the ICON (Icosahedral Non-hydrostatic) earth system modelling framework, developed by the Deutscher Wetterdienst and the Max-Planck-Institute for Meteorology. ICON-coast-E2E uses an unstructured, triangular computational mesh with a regular bisection-type mesh refinement technique to increase the horizontal resolution along the global coast. The global tides are included by adding gradients of the full tidal potential to the equations of motion. Furthermore, an interface to the FABM 1.0 framework was implemented, which enables a coupling with the biogeochemical model ECOSMO-E2E. First numerical experiments indicate that about 5 % of the global oceanic primary production are caused by riverine eutrophication.

1. INTRODUCTION

Photosynthesis is a key component of the global carbon cycle. Therefore, oceanic biogeochemical modules, i.e., the calculation of plankton growth and associated changes in nutrient concentrations and other chemical properties (e.g., oxygen or carbon concentration), became important components of Earth system models. In this context, the nearshore ocean is of particular importance: here, nutrients brought into the ocean by rivers cause increased biological production. Other sources of nutrients are the resuspension of sedimented nutrients in the region of shallow water at maximum tidal amplitude and coastal upwelling, which can transport nutrients from the deep ocean to the surface.

However, the width of these biologically active coastal strips is often only a few kilometers, so that they are usually not resolved by global ocean models. The unstructured grids used by ICON-O, on the other hand, offer the possibility of increasing resolution specifically along the coast, giving us the ability to simulate small-scale coastal processes in the global system.

1.1. Coupling ICON-O and ECOSMO-E2E

ICON-O (Korn 2017) is a new ocean model developed at the Max Planck Institute for Meteorology in Hamburg and part of the Earth System Model in the ICON Framework (ICON-ESM). The coastal ecosystem model ECOSMO E2E (Daewel & Schrum 2013) is coupled and adapted to global scales. Further components of our ICON-O development are an ICON grid generator, which creates grids with higher resolution along the coastline and consideration of tides, which are often the dominant hydrodynamic structure in coastal waters (Logemann *et al.,* 2021). Furthermore, we have added iron dynamics to ECOSMO E2E. We name this development ICON-coast-E2E.

1.2. The experiment

In a first basic experiment, the dependence of the global primary production (phytoplankton growth) on riverine nutrient input, based on the GEMS-GLORI world river discharge database (Meybeck & Ragu 2012), will be calculated. For this purpose, the nutrient concentrations (NO_3, NH_4, PO4, SiO_2, Fe) of the river water are set to zero and the differences to a realistic reference run are calculated.

2. RESULTS

In order to get a very first impression of the model performance the vertically integrated annual mean net primary production is computed after a spin-up of 1,5 years using a regular grid of 150 km resolution. The resulting field shows essentially realistic structures: minima in the sub-tropical gyres, maxima along the equator and other upwelling areas, and in the subpolar gyres. If now also horizontally and temporally integrated over one year, we get a global primary production of 33.0 Gt/yr. This value is slightly below the range of the observation based estimates, which are between 39 and 58 Gt/yr (Buitenhuis *et al.,*, 2013; Richardson & Bendtsen, 2019; Kulk *et al.,* 2020). If the nutrients are now removed from the river water, the global primary production drops to 31.3 Gt/yr. Thus, in this first rough estimate riverine eutrophication is responsible for around 5 % of global primary production. Further experiments will comprise longer spin-up periods and irregular computational meshes with higher coastal resolution.

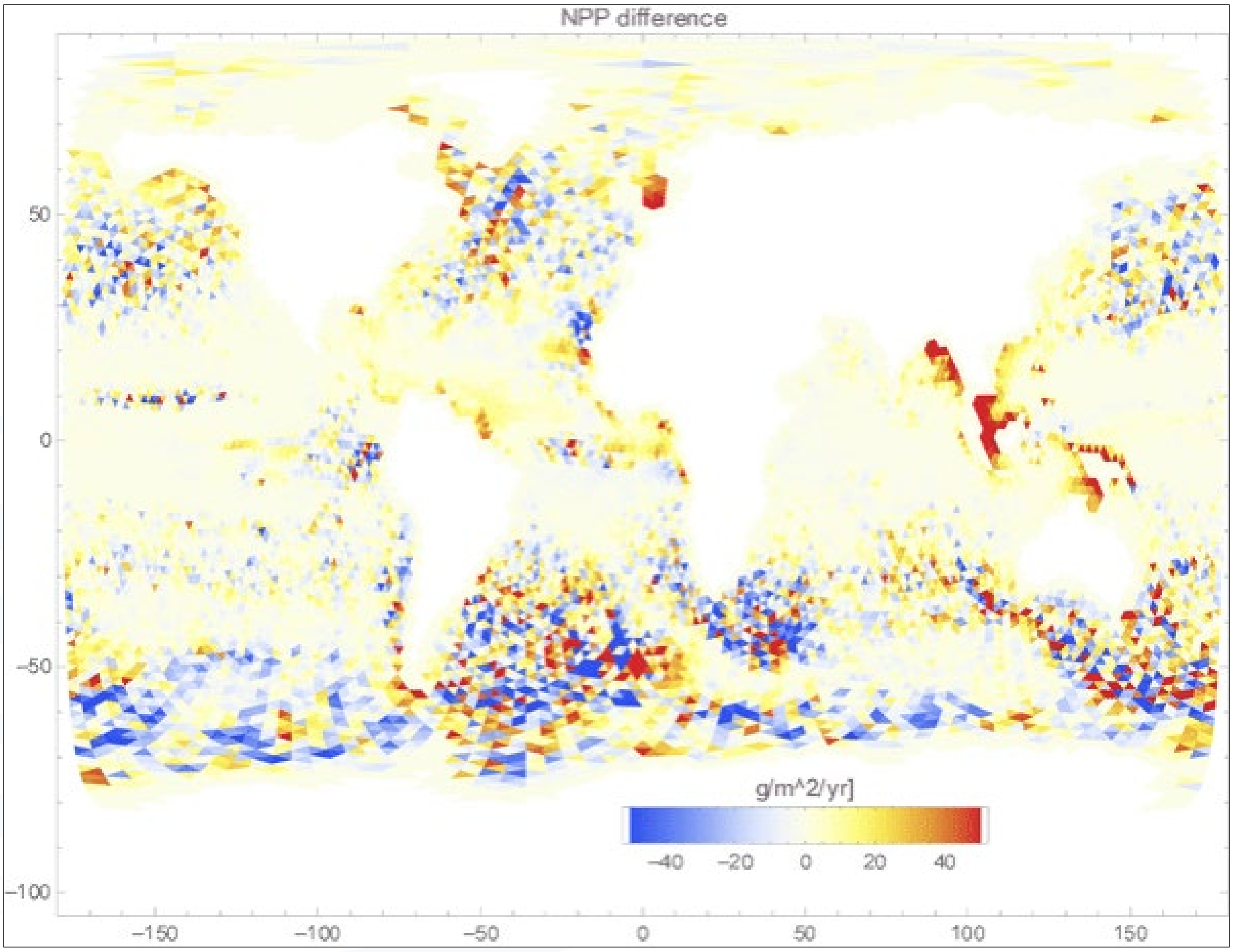

Figure 1. Influence of riverine eutrophication on vertically integrated primary production. Shown is the difference in annual means between the run with riverine eutrophication and the run without.

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Joint venture to maintain a permanent glider observation line between Nazaré Submarine Canyon (W Portugal) and Canary Islands

Authors

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Keywords

Permanent glider line; Capacity sharing, Jerico S3, iFado, real time observation

Abstract

Since 2019, Plataforma Oceánica de Canárias (PLOCAN) and Instituto Hidrográfico (IH) have been collaborating to maintain a sustainable glider observation line between the Nazaré Submarine Canyon (off the west coast of Portugal mainland) and Canary Islands. PLOCAN provides the glider and the expertise about the technology, while IH contributes with ship time and infrastructure to test and deploy the glider, as well as retrieval in case of mission abortion. In addition, IH performs the calibration of the glider's CTD, which increases confidence in the collected data and reduces the costs of manufacturer calibration. In 2019 the PLOCAN Seaglider sailed 780 nm from Nazaré to Madeira Island, from April 2nd to June 12th, 2019, and in the following year, from February 7th to May 5th of 2020, the glider cruised 968nm. The most recent mission off Setúbal Canyon contributed for iFado project, together with the PAAnoramic mission while a new mission is planned to be conducted in October 2023, contributing to the European project JERICO. This joint venture has been very productive in leveraging the resources of the several institutions towards the increase of observations available along the eastern boundary layer of the North Atlantic and the exchange knowledge and services that strengthen ties between the institutions and countries.

1. INTRODUCTION

Instituto Hidrográfico (IH) has been collaborating with Plataforma Oceánica de Canárias (PLOCAN) in the last recent years, to establish sustained glider observations across the Eastern North Atlantic. PLOCAN detains the glider equipment and the know how regarding the maintenance and piloting and IH contributes with the Calibration Lab, calibrating the CTD sensors, and provides the ship time and logistic facilities to storage, deploy and recover the glider on Portuguese Waters. The ocean glider observation line extends from the middle of the Nazaré Submarine Canyon, where IH maintains since 2010 the Nazaré Canyon real time Monitoring System (MONICAN) (Martins *et al.*, 2010), to the Canary platform (Fig. 1a) and 1b)), crossing some important structures such as Cape St. Vincent, the Gorringe Bank, and the Tagus Abyssal Plain (Lamas *et al.*, 2021). Also in the last year, IH has been collaborating with iFado project in the transnational glider mission *PAAnoramic* (Fig. 1c) and 1d)).

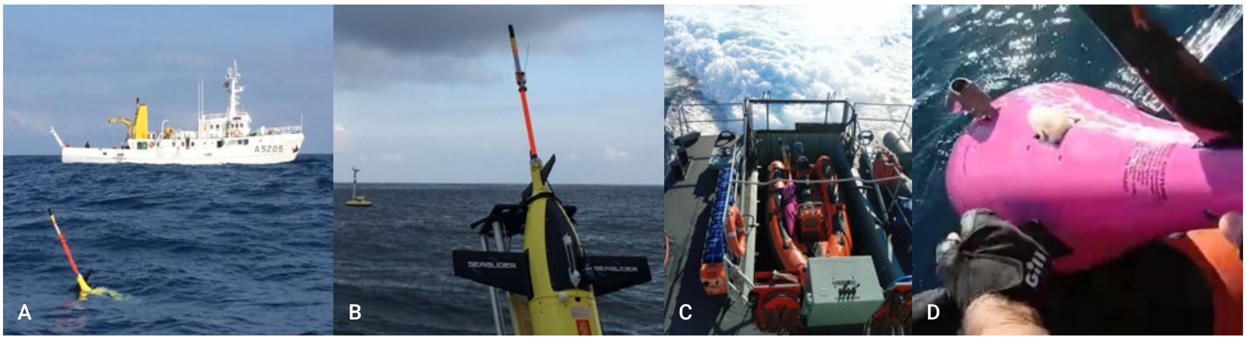

Figure 1. a) and **b)**: Pictures of "Lisboa" 2019 and 2020 glider missions with PLOCAN glider, and the IH MONIZEE offshore Nazaré buoy. **c)** and **d)**: the National Oceanographic Centre (NOC) and Cyprus Subsea glider being recovered in Portuguese EEZ waters on the Leg 2 of *PAAnoramic* mission.

2. GLIDER MISSIONS

Buitenhuis, E. T., Hashioka, T., and Quéré, C.L. (2013). Combined constraints on global ocean In 2019 the PLOCAN Seaglider sailed 780 nm from Nazaré to Madeira Island, from April 2^{nd} to June 12^{th}, 2019, and in the following year, from February 7^{th} to May 5^{th} of 2020, the glider cruised 968nm, from MONIZEE Nazaré offshore Buoy to Canary Islands. In the mission conducted in 2021, the glider only sailed 212nm, from August to September, due to technical problems on the glider. The mission had to be aborted and the glider needed to be rescued from 60nm off Portugal coast with the PT navy *Search and Rescue* (SAR) ship.

The *PAAnoramic* mission covered part of the European Atlantic Ocean using autonomous underwater vehicles combined with *in situ* monitoring cruises and supported by satellite imagery and operational numerical modelling. The *PAAnoramic* glider mission was divided into several sections: Leg-1: Marine Institute covered a return transect from the initial release point and the Porcupine Abyssal Plain Sustained Observatory (PAP-SO); Leg-2: National Oceanographic Centre (NOC) covered the section from the Irish coast to Portugal; Leg-3: IPMA designed a mission in Western Iberia from the open ocean to the coastal area *Eshed-iFADO* (Eddy Shedding monitoring off Setúbal Bay), using the PLOCAN glider wit support of IH logistics to prepare the glider deploy and recover it. In this last leg the equipment was autonomously collecting data from the water column between the surface and 1000m depth for 28 days in the Setúbal submarine canyon, travelling in total about 260 nautical miles.

A new mission is planned to be conducted in October 2023 with PLOCAN glider, contributing both to the European projects iFADO and JERICO S3 (in this case, profiting from Transnational Access funding).

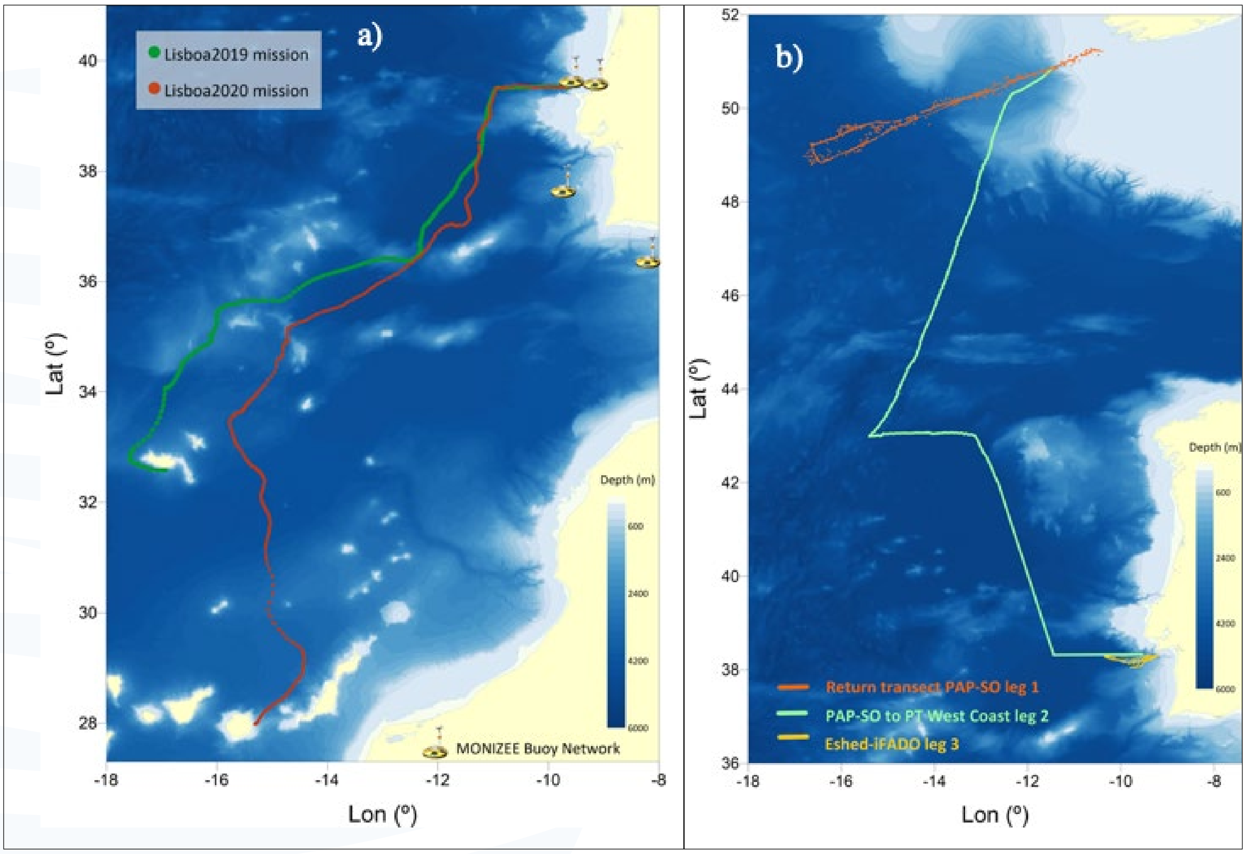

Figure 2. a): Both "Lisboa" 2019 and 2020 PLOCAN glider missions and the IH MONIZEE buoy network. **b):** Legs from PAAnoramic iFado Project glider mission: Leg1: Return transect PAP-SO (The Porcupine Abyssal Plain Sustained Observatory); Leg 2: PAP-SO to Portuguese continental west coast; Leg3: Eshed-iFADO (Eddy Shedding monitoring off Setúbal Bay). Both left and right figures were plotted over the General Bathymetric Chart of the Oceans (GEBCO, 2023) bathymetry.

3. CONCLUSIONS

This joint venture increased availability of observations and led to valuable insights into the dominant processes that occur in the eastern boundary layer of the North Atlantic area. The missions also demonstrated how gliders can reduce logistics, costs, and risks of ocean monitoring and covering remote areas during harsh weather conditions. Moreover demonstrated how international collaboration can be the key for monitoring the ocean, expanding knowledge and addressing complex challenges in several fields.

ACKNOWLEDGEMENTS

We acknowledge to General Bathymetric Chart of the Oceans (GEBCO) Compilation Group (2023) GEBCO 2023 Grid (doi:10.5285/f98b053b-0cbc-6c23-e053-6c86abc0af7b) and the crew of NRP Andromeda and NRP Hydra, who contributed to the deployment and successful recovery of glider. “Lisboa 2019”, “Lisboa 2020”, PAAnoramic and Eshed-iFADO missions were funded by iFADO project – Innovation in the Framework of the Atlantic Deep Ocean (Interreg Atlantic - EAPA 165/2016).

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Achieving Accurate Return Period Estimation of Significant Wave Height Using FAIR-Compliant Data

Authors

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Keywords

FAIR principle, return period, block maxima, peak over threshold, point process approach

Abstract

This paper presents the calculation of the return period for the significant wave height using three different methods: Block Maxima (BM), Peak Over Threshold (POT) and Point Process (PP). The data used for the calculation is in accordance with the FAIR (Findable, Accessible, Interoperable and Reusable) principle, with an example provided for the case study of Marina di Massa, Italy, for an hourly dataset of 40 years (1979-2018). The BM method is based on evaluating the maximum waves over a given period, while the POT method focuses on the peak values of the waves. The POT method is a widely used technique which can be used to estimate the return period of extreme waves. This method can determine the threshold values of the wave heights that represent extreme events. With this method, one can choose between graphical approach or an automatic threshold estimation approach to determine the threshold values of the wave heights representing extreme events. This study further includes the main characteristics of the POT method, provides insight into the two threshold estimation methods, while the Point Process approach is based on the identification of extreme wave events. All three methods are compared in terms of accuracy, and goodness-of-fit score (i.e negative log-likehood, AIC and BIC) and the results are then used to calculate the return period of the significant wave height for 25, 50 and 100 years. This analysis shows that POT is the most accurate and reliable method for calculating the return period of the significant wave height. The BM and the PP approaches show marginally lower accuracies.

1. INTRODUCTION

Extreme Value Analysis (EVA) is an essential tool in various fields, including hydrology, meteorology, finance, and environmental science, where the study of rare, extreme events is paramount. The traditional way of analyzing extreme values is based on extreme values distributions. Originally introduced by Fisher and Tippett, 1928, these distributions account for maxima distributions in samples of identically distributed random and independent variables. Extreme value analysis (EVA) or Extreme Value Theory (EVT) aim to develop mathematical models and methods able to predict the occurrence of rare phenomena i.e., to estimate the likelihood of the occurrence of extreme values based on a few basic assumptions and observed/measured data (Benstock and Cegla, 2017). Although the extreme values are not frequent, the impact of these values on humans is huge. Studying such extreme values provides an overview of the parameter, for instance the rareness of such extreme data. The paper aims to assess return period calculation methods for significant wave height, specifically Block Maxima (BM), Peak Over Threshold (POT), and Point Process (PP). It adheres to the FAIR data principle and employs a 40-year hourly dataset from Marina di Massa, Italy. In fact, in this framework, the application of FAIR rationale is a necessary precondition for a good data management and analysis.

2. METHODS

Data used in this work have been retrieved by available climate services in Europe, mainly relying on Climate Data Store (CDS) of the Copernicus Climate Change Service (C3S) and on CORDEX data. As such, these data comply with the FAIR approach. Specifically, climate data in this work follow Climate and Forecast (CF) convention for metadata formalisation and are provided using the Network Common Data Format (NetCDF) model. Typical approaches are applied to annual maxima or occasionally over a different time period (e.g., monthly) i.e., the Block Maxima (BM). The classical reference on this method is Gumbel (1958) though there are a range of other methods to fit the distributions. Other alternative approaches have been introduced more recently. One is to look at exceedances over a defined threshold rather than maxima over a fixed period i.e., the Peak Over Threshold (POT) method (Pickands, 1975). There is a third approach as well, which uses r-largest order statistics that considers values based on the comparison of BM and POT.

In this paper, we will focus on evaluating the results of significant wave height return levels using the Block Maxima, Peak over Threshold and Point approach methods. Due to space limitations, we cannot describe the methodology in detail, however, a full description can be found in Anton *et al.*, 2023.

3. RESULTS

Threshold selection constitutes a fundamental step in the Extremal Value Analysis (EVA), particularly when employing the Peak Over Threshold (POT) methodology. The objective of this threshold is to help reduce the number of observations and reduce the variance by avoiding too low values as thresholds that induce bias (Acero *et al.*, 2018). There are many ways to select a threshold value for a set of observations, but in this paper, we will focus only on two methods: graphical approach and an automatic threshold selection. The easiest method to estimate the residuals is to fit the Generalised Pareto Distribution (GPD) for a range of thresholds (Coles, 2001; Smith, 2002). This can be done in the graphical method which implies choosing the threshold from multiple plots like: mean residual life (Coles, 2001), parameter stability plot or Pickand plot. For the present study, the statistical modelling of extreme events from R-packages “ismev” (Janet E. Heffernan, 2022) and “extRemes” (Gilleland & Katz, *et al.*, 2016) are used for choosing the optimal threshold. The threshold should be chosen at the value where the shape and scale parameters remain constant. The threshold value selected from these graphics is equal to 2. However, this method of selection of the threshold conducts to a high bias as it depends on the expertise of the reader to choose the suitable value. To avoid this bias, an automated threshold selection method available in the “EVA” R package (Bader, Yan and Zhang, 2018) was applied. Using the Anderson Darling test, we obtained a threshold value of 1.629. For this threshold, the p-value is 0.224, test number is 77 and we have 15664 values above the selected threshold.

Using historical time series (1979-2018) of significant wave heights (Hs (m)) in Marina di Massa, the EVA for the POT method is presented in Table I. The accuracy of each method is assessed in terms of AIC and BIC based on location-scale and shape parameters. A return level and confidence interval for the POT method are presented in Table I. GPD shows a higher goodness-of-fit value (lower prediction error) than PP for POT methods. In BM, the GEV shows a lower AIC and BIC value than Gumbel. Return levels increase across growing return periods for POT methods. BM method show a more irregular behaviour. GPD and PP return levels are very similar, despite PP’s higher goodness of fit scores (AIC and BIC).

4. CONCLUSION

In this work, we applied and compared different EVA methods to analyse historical time series of significant wave heights. Using a standardized approach, suitable distributions and return periods are identified and assessed in terms of accuracy metrics. The best results have been achieved using the POT method and specifically the GPD model, since it has proven to be the most accurate for significant wave height return levels computation across different return periods.

Table I. Results for POT and BM methods.

Method	Sample size	Location	Scale	Shape	Neg Log likehood	AIC	BIC	Hs_{25} (m)	Hs_{50} (m)	Hs_{100} (m)
BM – GEV	40	3.21	0.32	-0.32	10.772	27.55	32.61	3.86 (3.73; 4.00)	3.94 (3.78;4.09)	4.00 (3.81;4.18)
BM – Gumbel	40	3.153	0.31	NA	13.86	31.72	35.094	4.37 (3.86; 4.58)	4.143 (4.03;4.79)	4.36 (4.20;4.42)
POT - GPD	350616	NA	0.88	-0.34	309.35	622.70	631.40	3.197 (3.00; 3.39)	3.417 (3.17;3.66)	3.591 (3.29;3.90)
BM – GEV	350616	1.13	1.05	-0.34	1178.01	2362.01	2375.07	3.19 (3.11; 3.28)	3.414 (3.32;3.51)	3.59 (3.49;3.69)

Note: POT method includes a threshold = 1.63 and uses hourly data; the BM uses annual maxima data with the block of one year. Hsn represents the return levels for n return period, together with their confidence interval in brackets.

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The GROOM 2 data roadmap: Shaping the open science collaborative future of glider data operations

Authors

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Keywords

OceanGliders, Global Ocean Observing System (GOOS), Operational Oceanography, Co-design

Abstract

This paper presents the executive summary and abridged results from the development of a stakeholder driven development roadmap for the Glider for Research and Operational Ocean Monitoring (GROOM) 2 project that is scoping the development of a research infrastructure (RI) for Marine Autonomous Systems (MAS) in Europe. The roadmap outlined recommendations for next 1-2 years, 5 years and 10 years with key themes in the recommendations including; the move toward open source community governed software environments, the need to address key gaps in capability such as quality control, the need for tools and service to be readily adopted by new nodes as the MAS networks grow, and that training of the research community so ensure a sustainable future. The GROOM 2 data roadmap is currently being integrated into the wider GROOM 2 RI scoping. This paper aims to present the results of the data roadmap to the EuroGOOS community to solicit feedback on the results that will be incorporated into the GROOM roadmaps for the formation of a MAS RI in Europe.

1. EXECUTIVE SUMMARY

The Glider for Research and Operational Ocean Monitoring (GROOM) 2 project aims to scope a research infrastructure (RI) for Marine Autonomous Systems (MAS) in Europe. **With the vision:**

> *"Be the European Research Infrastructure harnessing the advantages of Marine Autonomous Systems (MAS) to provide high-quality ocean observation data and services for the benefit of society, enabling scientific excellence and moving towards net-zero activities."*

And the mission:

> *"This European Research Infrastructure integrates national infrastructures for Marine Autonomous Systems (MAS) to provide access to platforms and services to the broadest range of scientific and industrial users, as well as other ocean observing RIs. It maintains a unique centralized provision of cyber-infrastructure, data and knowledge for the optimized use of MAS to study climate and marine environments, and to support operational services and the blue economy."*

The evolution of a stakeholder-focused data system, software and infrastructure is a crucial element of a future MAS RI to meet the needs of the growing number and diversity of platforms.

The GROOM II project has developed a roadmap to scope and shape the data ecosystem to be included in any potential MAS RI. The roadmap involved extensive stakeholder engagement, starting from the EuroSea glider data management workshops in the summer of 2022, followed by project-level workshops to distil the results into a roadmap presented here.

The roadmap is summarised in this conference paper in Table I. The roadmap outlined recommendations for the next 1-2 years, five years and ten years, with key themes in the recommendations including; the move toward open source community-governed software environments, the need to address key gaps in capability such as quality control, the need for tools and service to be readily adopted by new nodes as the MAS networks grow, and that training of the research community so ensure a sustainable future.

The roadmap also has broader implications for the wider Global Ocean Observing System (GOOS) with the need for interaction between networks on aspects such as common infrastructure (e.g. for data assembly centers to enable rapid addition of new nodes) and quality control where common sensor types are used across GOOS networks with the essential alignment of data quality to enable data across networks to be readily utilized.

The GROOM II data roadmap is currently being integrated into the wider GROOM II RI scoping. This paper aims to present the results of the data roadmap to the EuroGOOS community to solicit feedback on the results that will be incorporated into the GROOM design of a future European MAS RI.

Table 1. Summary of the GROOM RI data management road map.

Roadmap — GROOM II — CHECK OUR DETAILED ROADMAP HERE

Research Infrastructure data management	1-2 years	5 years	10 years
Infrastructure	• Proposed structure for future developement (cloud-native services & open-source community development) • International agreement • Define the data portal's scope	• Operational exemplars of DAC & GDAC managed whith open-source community & deployed in EOSC • Tools and services aligned with international policies • Operational data portal	• Open source solutions for DAC & GDAC management (OceanGliders community) • Unambiguous and seamless data flows
Tools and services	• Scoping of FAIR data • Meeting with OceanGliders 1.0 format • Data visualisation requirements • WIS 2.0 - BUFR implementation • RTQC consensus on standard tests • Integration data methodologies into OBS framework	• FAIR data alignment with IOC data policy • Data visualisation and user interface for priority • WIS 2.0 - BUFR implemented • RTQC - standard tools • DMQC - 1-2 EOVs + cloud native tools • Alignment and publication of data methodologies whit OBS framework	• Data visualisation and user interface to meet the diverse range of users • RTQC- Operational BGC RTQC • DMQC - 90% of observed EOVs allowing for new ones to come through + cloud native tools • Sustainable & efficient route for new EOVs
Network management	• Agreement of the scope of MAS • Scope tools to harmonize metadata management & planning tools for EOOS observations	• Sensor and platform metadata integrated into the EOOS • Complete vocabulary collections • Agreement of the scope of MAS • Tools to harmonize metada management & planning tools for observations accross marine RI	• Planning and network management integrated in the EOOS • Globally recognised processes to entrain new sensors and platforms
Network evolution	• New networking groups on emerging sensors and platforms • Scope processes to entrain new sensors and capabilities	• Process to entrain new sensors and capabilities as part of wider OG activity	• Globally recognised processes to entrain new sensors and platforms
Skills and training	• Data skills audit	• Training courses on the gaps in data skills	• Training network and activities
The GROOM RI user community	• Define the user community	• Establish coordination groups and committees	• Sustainable data user community

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Bridging Communities for the Ocean we Want

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Keywords

Ocean literacy, community engagement, sustainable ocean

Abstract

The international ocean science community has made enormous efforts to prove and communicate the vital role the ocean plays on the planet - by regulating the Earth's climate and contributing to human wellbeing. Their efforts are finally bearing fruit: in the recent years the ocean has reached top positions in the international agenda, and its importance is more and more emphasised in the media. At the heart of the Ocean Decade, it is now more than ever crucial to keep this momentum and generate, explain and disseminate targeted, science-based ocean information and knowledge. Why? To keep raising awareness, bridging communities and inspire future generations. Mercator Ocean International (MOi) is committed to supporting action paving the way towards the ocean we want. Through the Copernicus Marine Service, MOi provides reliable ocean data and information, and shares knowledge on the state of the ocean and its role on Earth's ecosystems. By working towards ocean literacy, MOi reaches policymakers and governments, the ocean science community and citizens at large. The Ocean State Report, an annual report providing the latest evidence on the state of the ocean, is available in different formats adapted to the general public and decision-makers. Through training activities, we target not only ocean science students and researchers but also government bodies and lately also journalists and science communicators. The Ocean Explainers provide the citizens at large with accessible information on operational oceanography and ocean phenomena and threats, through structured texts, tables and infographics. They also explain the existing policies scenario, as well as the international goals to protect the ocean. The objective is to bridge the gap between these communities in terms of ocean knowledge and to help find solutions to the immense challenges facing the marine environment, while advocating for a sustainable ocean.

1. INTRODUCTION

The importance of the Ocean in the functioning of the planet is undeniable. Yet, the ocean is under severe pressure, mainly caused by human activities. Intense resource exploitation, pollution and habitat and biodiversity loss are some of the major problems we are currently facing (IOC-UNESCO. 2022). It is, therefore, of critical importance that we all understand the need to preserve marine life and the balance of its complex marine ecosystems.

In recent years, the Ocean has finally become a priority in national and international agendas. Measures are being taken at governance level to ensure the protection of marine species and the restoration of impacted ecosystems (Scholaert and Jacobs 2022). The United Nations has announced 2021-2030 as the decade for Ocean Science for Sustainable Development, underlining the current need for more sustainable ways of living and using marine resources.

As a scientific organisation producing knowledge and information in oceanography, Mercator Ocean International (MOi) operates in parallel, since 2014, the European Commission's Earth Observation Copernicus Marine Environment Monitoring Service (CMEMS). A service delivering free of charge and accessible data and information on the physical and chemical and biological parameters of the ocean. The widened responsibility in delivering more than just knowledge, but also ensuring European level distribution and support on the use of marine data, has been an important focus in MOi's work.

Through the Copernicus Marine Service MOi develops targeted training on the use of marine products and creates scientific-based and accessible information on the state of the ocean, as well as on the functioning of the marine environment. These activities intend to reduce the gap between scientific and non-scientific communities - knowledge and action sectors respectively. To face current pressures on the marine species and environment, global awareness and science-informed actions are needed more than ever.

In this paper we present the activities and publications Mercator Ocean International has been developing towards ocean literacy, in the framework of the Copernicus Marine Service.

2. INSTRUMENTS FOR OCEAN LITERACY

2.1. The Ocean State Report Summary

The Ocean State Report is produced every year and it is meant to be used by European Union's policy makers and environmental agencies in Europe (EEA, EMSA etc.). As it is nevertheless a scientific report, a summary of the report with digestible language is also provided, targeting mainly policy officers and governmental bodies.

2.2. **Ocean Explainers**

The Ocean Explainers provide concise explanations and visuals to convey key aspects of oceanography. They target the general public and aim at increasing literacy about the Ocean.

They cover topics within three main areas:

- Phenomena and Threats, explaining how human-induced climate change, including ocean warming and acidification, affects the Ocean;
- Policies, summarizing strategies and measures implemented to protect the Ocean;
- Operational Oceanography, showcasing scientific aspects of oceanography.

2.3. **The Ocean Climate Portal**

Ocean Monitoring Indicators are key variables which help us understand the state of the marine environment. The Ocean Climate Portal offers an alternative view of the Copernicus Marine Ocean Monitoring Indicators (OMIs) through interactive graphs, infographics and deep explanations on the information they provide and their importance.

The target of the Ocean Climate Portal is the general public.

2.4. **Training Activities**

Every year, a series of 5 to 6 workshops targeting a broad community of users and non-users of the Copernicus Marine Service is delivered freely online. Workshops focus on the different European Seas and Regions covered by CMEMS (the Northwest Shelf Sea, Iberia-Biscay-Irish Sea, Mediterranean, Baltic, Black, and the Arctic) More recently, these workshops have been focusing on specific communities of users (researchers, governmental bodies, marine science institutes, blue economy sector and more recently journalists). The courses offer guidance through the available datasets, and showcase uses for the open-source Copernicus Marine Data.

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EMODnet Physics: Setting Up and Operating the European River Data Operational Node

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Keywords

EMODnet, data accessibility, interoperability practices, standardization, river inputs

Abstract

River runoffs exert substantial influence on adjacent coastal areas, impacting water stratification, circulation patterns, and upwelling effects. However, the decline of hydrometric networks raises uncertainties regarding river runoff reaching the coast and water properties such as temperature and salinity. Variable river flows due to heavy rainfall disrupt plant and animal life, affecting reproduction. This information is vital for coastal management and forecasting. The European Marine Observation and Data network, particularly EMODnet Physics and EMODnet Ingestion, established a single-stop-shopping river-runoff data service. This service offers standardized operational river data from national and regional water administrations, gathering information from hydrologic stations to the coastal areas which are unaffected by tides. Currently, it incorporates data from over 700 stations from 35 providers across 17 countries and 3 continents (Europe, North America, and South America). EMODnet Physics River runoff operational product is operated in collaboration with CoLabAtlantic+. The research quality river data database is operated by the Global Runoff Data Center. EMODnet Physics includes a subset of the GRDC: with a focus on coastal areas, EMODnet includes only the stations that are close to the river's mouth. The paper outlines EMODnet Physics' ongoing development of an open, FAIR operational product, providing near real-time river outflow data at mouth stations. These data are essential for enhancing coastal services, and the paper proposes recommendations to encourage more providers to contribute to this significant achievement.

1. INTRODUCTION

EMODnet Physics is one of the seven domain-specific projects of the European Marine Observation and Data network that has successfully designed, organised and run operational services providing ocean physical data and data products. The available parameters cover temperature, salinity and currents profiles, sea level trends, wave height and period, wind speed and direction, water turbidity (light attenuation), underwater noise, river flow, and sea-ice coverage. EMODnet Physics products range from *in situ* data collections (time-series, profiles and datasets) as recorded by platforms (tide gauge, river stations, CTDs, etc.), to reanalysis, trends, and climatology. EMODnet Ingestion and safe-keeping of marine data is a trans-thematic platform that seeks to identify and reach out to organisations from research, public, and private sectors who are holding marine datasets and who are not yet connected and contributing to the existing marine data management infrastructures which are driving EMODnet. A core service is the Data Submission service which facilitates data providers to submit their data sets. A low threshold is offered by splitting the completion of the submission form in 2 parts, whereby a data submitter only completes a part of the metadata together with the uploading of a data package. Each data submission is then assigned to a competent data centre for completing the metadata of the submission. EMODnet Physics and EMODnet Data Ingestion are sharing effort facilitate the access to operational data streams. In this framework, to accomplish to stakeholders need and include crucial information on river runoff data, EMODnet Physics and Ingestion had to design a new and dedicated river-data management workflow. While river climatology and research quality data are linked in from the Global Runoff Data Center (EMODnet Physics includes a subset of the GRDC, focusing on coastal areas and including only stations located near the river mouths), the operational River runoff product is operated in collaboration with CoLabAtlantic+.

2. RIVERS OUTFLOW DATA MANAGEMENT

The following scheme presents a simplified schema of the operational river runoff data publishing pipeline. Sources (river basins administrative authorities) are contacted to establish an operational data flow from their services towards EMODnet river data node. River outflow may be a direct outflow measurement or a derived value from river level (according a conversion law based on the river section). Quality check/quality flag is applied by checking data with MOHID, and data are combined with harmonized metadata that use controlled vocabularies (Table 1, Table 2).

[1] MOHID– Modelo Hidrodinâmico is a comprehensive water modeling system that aims to simulate and predict the behavior of water bodies such as oceans, rivers, lakes, and estuaries. https://github.com/Mohid-Water-Modelling-System/Mohid/releases

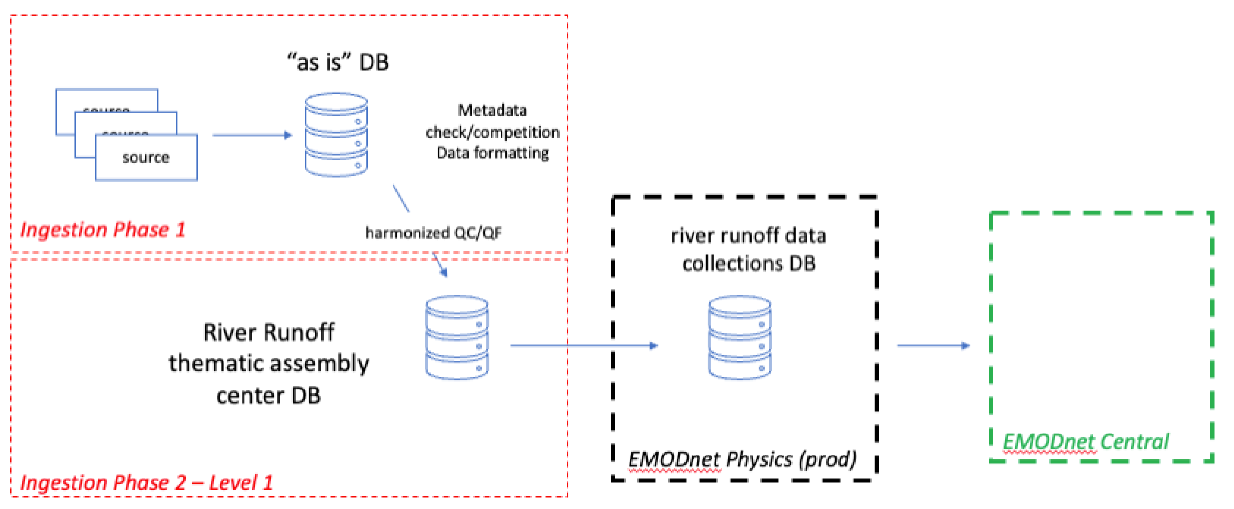

Figure 1. Simplified workflow for river runoff data ingestion.

Table I. Applied standards.

Method	Vocabulary exists	Link to vocabulary	Vocabulary governance
Platform id	*		EMODnet Physics
Station		https://www.bafg.de/SharedDocs/ExterneLinks/GRDC/grdc_reference_stations_zip.html?nn=201698	GRDC
Owner/provider Institution	Yes	https://edmo.seadatanet.org/	SeaDataNet
Variable names	Yes	http://vocab.nerc.ac.uk/collection/PXX/current/ where XX=02;01;07	BODC:NVS
Unit	Yes	https://vocab.nerc.ac.uk/collection/P06/current/	BODC:NVS
Quality Flag Scheme	Yes	http://www.oceansites.org/docs/oceansites_data_format_reference_manual.pdf	OceanSites
Time	Yes	ISO8601	ISO
Datum	Yes	WGS84	ISO
Country	Yes	ISO3166	CC
License	Yes	https://creativecommons.org/	OceanSites
INSPIRE	Yes	ISO 19115	ISO/INSPIRE

* Currently EMODnet Physics is assigning a unique id to river stations, anyhow this inventory will adopt a new convention based on river name and river station, and integrate the GRDC station number.

Table 2. Parameters.

Metadata field	Definition	Link to term
SDN::P09::RVFL	Volume of water passing a given point in the course of a river per unit time	http://vocab.nerc.ac.uk/collection/P09/current/RVFL/
SDN:P02::RVDS	Parameters related to the volume of water passing through a point in a river system per unit time, including the rates of freshwater, dissolved material and particulate load discharge from a river into the sea.	https://vocab.nerc.ac.uk/collection/P02/current/RVDS/
SDN:P01::RVDSCH02	Riverine discharge of water by direct reading current meter and calculation from flow	https://vocab.nerc.ac.uk/collection/P01/current/RFDSCH02/
SDN:P01::RVDSCH03	Riverine discharge of water by water level gauge and calculation from level	https://vocab.nerc.ac.uk/collection/P01/current/RFDSCH03/
SDN:P01::	Height of river water relative to ground surface	Under the validation/publishing process

EMODnet Physics data infrastructure is logically divided in three layers: 1) data layer (that includes all the machinery to collect and update *in situ* data from sources, as well as new thematic products), 2) application layer (that organizes data in consistent manner to make it consumable) and 3) service layer (that exposes the services towards the Central Portal and users). More specifically EMODnet Physics adopts ERDDAP, GeoServer, ncWMS and GeoNetwork such as data service and catalogue tools. Physics uses ncWMS to serve WMS from gridded data, hence it's not used for river data management.

Once river data is processed as described in Figure 1, the river outflow collection is update and made available for direct M2M use (ERDDAP) or to be explored under the Central Portal (GeoServer + GeoNetwork. To consume data operationally, the user may directly connect to the ERDDAP data collection, User can query timeseries data from the ERDDAP Dataset ID page:

https://prod-erddap.emodnet-physics.eu/erddap/tabledap/ERD_EP_RVFL_NRT.html

The Dataset ID page is a web tool to construct and refine queries, e.g. to list the operational platforms (and their positions) in the dataset the user has to select EP_PLATFORM_ID, LAT, LONG (and platform_code) and to save the results as a csv listing the platforms, the user can simply write:

https://prod-erddap.emodnet-physics.eu/erddap/tabledap/ERD_EP_RVFL_NRT.csv?EP_PLATFORM_ID%2CEP_PLATFORM_TYPE%2CEP_PLATFORM_CODE%2CEP_PLATFORM_LINK%2Ctime%2CTIME_QC%2Cdepth%2CDEPTH_QC%2Cpres%2CPRES_QC%2Clatitude%2Clongitude%2CPOSITION_QC%2CRVFL%2CRVFL_QC%2CRVFL_DM%2Csite_code%2Cplatform_code%2Cplatform_name%2Cpi_name%2Carea%2Cauthor%2Csource%2Ccontributor_name%2Ccontributor_url%2Cdata_assembly_center%2Cinstitution_edmo_code%2Cinstitution_references%2Cinstitution&time%3E=2023-07-05T13%3A40%3A18Z

If the user wants to see the platform page from the mapviewer (dev) he can use the following construct:

e.g. https://map.emodnet-physics.eu/platformpage/?platformid=1049774

While to download data for a given platform from erddap:

https://prod-erddap.emodnet-physics.eu/erddap/tabledap/ERD_EP_RVFL_NRT.htmlTable?EP_PLATFORM_ID%2Ctime%2Clatitude%2Clongitude%2CRVFL&EP_PLATFORM_ID=%2229697%22&time%3E=2023-07-05T14%3A04%3A39Z

The same can be used to connect the operational data flow to any further service.

3. CONCLUSION

The significance of accounting for river inputs in oceanographic analysis becomes evident, as rivers bridge the gap between land and ocean, influencing circulation patterns, biotic diversity, and essential processes such as eutrophication. EMODnet Physicsintegrates more than 700 stations from 35 providers of 17 countries from 3 continents (Europe, North America, and South America). The ongoing development of EMODnet Physics River Node, with its focus on near real-time outflow data from river mouth stations, reflects a crucial step towards comprehensive coastal management and effective support to EMODnet stakeholders.

OCEAN:ICE interactions and exchanges and their climate and Earth impacts

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Keywords

Antarctic Ocean, ice-sheet-ocean, climate change, prediction models

Abstract

Recent mass loss of the Antarctic Ice Sheet, resulting in freshwater discharge to the ocean, has accelerated, presumably due to increased ocean heat transport under the ice shelves and the retreat of their grounding lines. The processes controlling this transport, which are still poorly understood, need further investigation in order to provide information and predictions of the resulting impacts on sea-level rise and global ocean circulation. OCEAN:ICE is a Horizon Europe project that aims to explore unknown areas, significantly improve our understanding of the ice-ocean interactions and our ability to model and predict these processes and their impacts. This is possible by combining historical datasets with new observations, novel data processing techniques and numerical modelling. In this way, OCEAN:ICE aims to provide policy-relevant advice for secular planning.

1. INTRODUCTION

The mass loss of the Antarctic Ice Sheet (AIS) and the resulting increased freshwater discharge into the ocean have the potential for profound effects on the sea-level rise (SLR) and global ocean circulation (Meredith *et al.*, 2019; Schloesser *et al.*, 2019; Adusumilli *et al.*,2020; Fox-Kemper *et al.*, 2021). Key to this are the processes, increasingly accelerating, that deliver heat from the Southern Ocean to the AIS, govern ice sheet response, and control meltwater feedbacks on ocean circulation (Bronselaer *et al.*, 2018). These processes are subject to large uncertainties, due to the paucity or absence of relevant observations, and our limited understanding and ability to model them. The OCEAN:ICE (Ocean-Cryosphere Exchanges in ANtarctica: Impacts on Climate and the Earth System) project, funded by Horizon Europe and UK Research and Innovation, aims to overcome limitations in our understanding of the influence of the Antarctic Ice Sheet and the surrounding Southern Ocean on our global climate, deep water formation and ocean circulation. The project also aspires to reduce uncertainties in projections of freshwater fluxes and SLR from future melting. Spatial and knowledge gaps in ocean observations around Antarctica are expected to be reduced. OCEAN:ICE will improve the modelling and prediction of processes and their impacts. In addition, the project will provide free and open access to all data generated and contribute to international assessments, climate model development, multinational ocean observing initiatives and policy making and collaborate with several international organisations also connected to the Southern Ocean Observing System (SOOS).

2. MATERIALS AND METHODS

OCEAN:ICE uses an ambitious and innovative combination of remote sensing, ocean and ice sheet observations, novel data processing techniques and numerical modelling. This provides numerous new observations, including unexplored bottom water export pathways, which will be combined with historical datasets. This will support modelling efforts to constrain the ice sheet melt and to understand the impacts and feedbacks it will have on the global climate system over the coming centuries. OCEAN:ICE takes an integrated view of the problem following a transdisciplinary approach with a strong interaction between the oceanographic, cryospheric and climate domains, a prerequisite to reduce the current uncertainty in the role of the poles in global climate (IPCC AR6, 2021). The project is organised in work packages (WPs). Using observational and modelling techniques, OCEAN:ICE investigates the ocean circulation around the entire Antarctic and South Atlantic (WP1) and how it interacts with ice shelf melting, the subsequent ice sheet mass loss, enhanced iceberg formation and their melt behaviour (WP2). These feed into the development of the AIS model, which in turn will produce freshwater fluxes to the ocean for the present day and recent past (WP3). These models will be extended into the future to the year 2300 (WP4). Such freshwater flux scenarios, supported by first-of-their-kind observations of the Atlantic Bottom Water, will be used to constrain investigations of the Atlantic Meridional Overturning Circulation and to understand the relative importance of northern and southern deep water sources on centennial to millennial timescales (WP5). The global impacts and feedbacks of these scenarios will be explored using coupled ice-sheet climate models benefiting from OCEAN:ICE development (WP6). The results will be communicated to key data centres, scientific assessment and coordination bodies, regional and global policy makers and the public (WP7-9).

3. CONCLUSIONS

OCEAN:ICE aims to provide a better understanding of key ocean-ice processes and policy-relevant advice for planning horizons from decades to centuries. The project will interface with and directly contribute to European and international observing initiatives, centres and projects, as well as policy interface bodies to ensure efficient coordination, implementation and communication of the project results at the international climate assessment and policy level. OCEAN:ICE emphasises the importance of an integrated circumpolar approach to assessing the climate-scale impact of the changing Southern Ocean and AIS, and how the SOOS network can help support such observations and be of particular benefit to the development of coupled ice sheet-climate models.

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Shallow-coastal operations with Argo floats in the Mediterranean Sea

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Keywords

Shallow-coastal missions, Argo floats, Mediterranean Sea

Abstract

Tests of Argo floats in shallow/coastal waters of selected Mediterranean areas demonstrated that this kind of platform can be used in such kind of marine environments when properly configured. In particular, the most important settings to be adjusted are the cycle-time and the park pressure. Argo coastal data can complement measurements from other monitoring systems and used to enhance model data assimilations.

1. INTRODUCTION

Argo floats were tested in selected areas of the Mediterranean Sea in near-shore and shallow waters (continental shelf) as part of the European H2020 project Euro-Argo Research Infrastructure Sustainability and Enhancement (Euro-Argo RISE). In this work, we present the experiments conducted in the Adriatic and Aegean Sea, and the Balearic Islands (Figure 1) to demonstrate that Argo floats originally designed for open-ocean operations can also be adequately deployed in these shallow-coastal areas as part of a new extension of Argo.

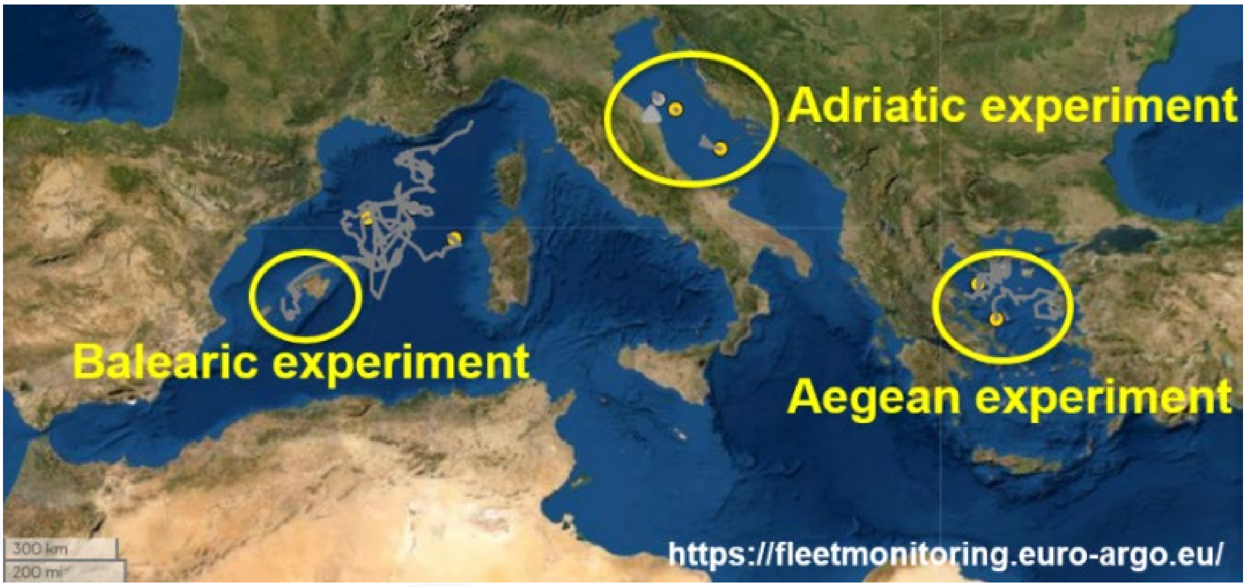

Figure 1. Euro-Argo RISE and national floats in the Mediterranean Sea. Last position is shown in yellow (grey) for active (inactive) floats as of time of writing. Floats' trajectories are shown as grey lines. Areas presented in this worked are circled in yellow.

2. METHODOLOGY

Park pressure and cycle time are critical parameters that must be accurately set and potentially adjusted during missions to achieve the best results. Park pressure was set at specific depths (typically quite deep and even on the seafloor) to limit platform drift from target areas. The cycle time was set between 1 and 5 days. The choice of cycle time is critical and is often a compromise to collect as many profiles as possible and greatly reduce the risk of drifting far away or becoming stranded (Notarstefano *et al.*, 2022).

3. RESULTS

In the central and northern Adriatic Sea, four Arvor I floats were deployed between 2019 and 2022. The Argo floats were parked very close to or on the seafloor using a virtual mooring configuration to try to keep them within a limited range of miles from the deployment sites. Results showed that displacements from deployment sites were limited Figure 2a) thanks to the configurations chosen, and it was demonstrated that these pl(atforms could be deployed in shallow and narrow sub-basins such as the Adriatic Sea.

In the northern part of the Aegean Sea, three Arvor I floats were deployed in 2021-2022. The floats were configured to drift at depths from 600 to 800 m to remain in the targeted area and sample at short intervals (less than 120 hours). Although the northern Aegean basin is not an ideal area for Argo float deployments due to its rapidly changing bathymetry (shallow plateaus and deep trenches, as shown in Figure 2b) and complicated coastline, missions have been successful to date.

An Arvor I float was deployed off the coast of Mallorca island in 2020. After testing several mission parameters, a virtual mooring configuration and cycles of 48-120 hours proved to be the optimal sampling strategy, which allowed limiting the float's time in the surface layer and keeping it in shallow waters (Figure 2c). However, the influence of the Balearic Current made it difficult to keep the float near the deployment site.

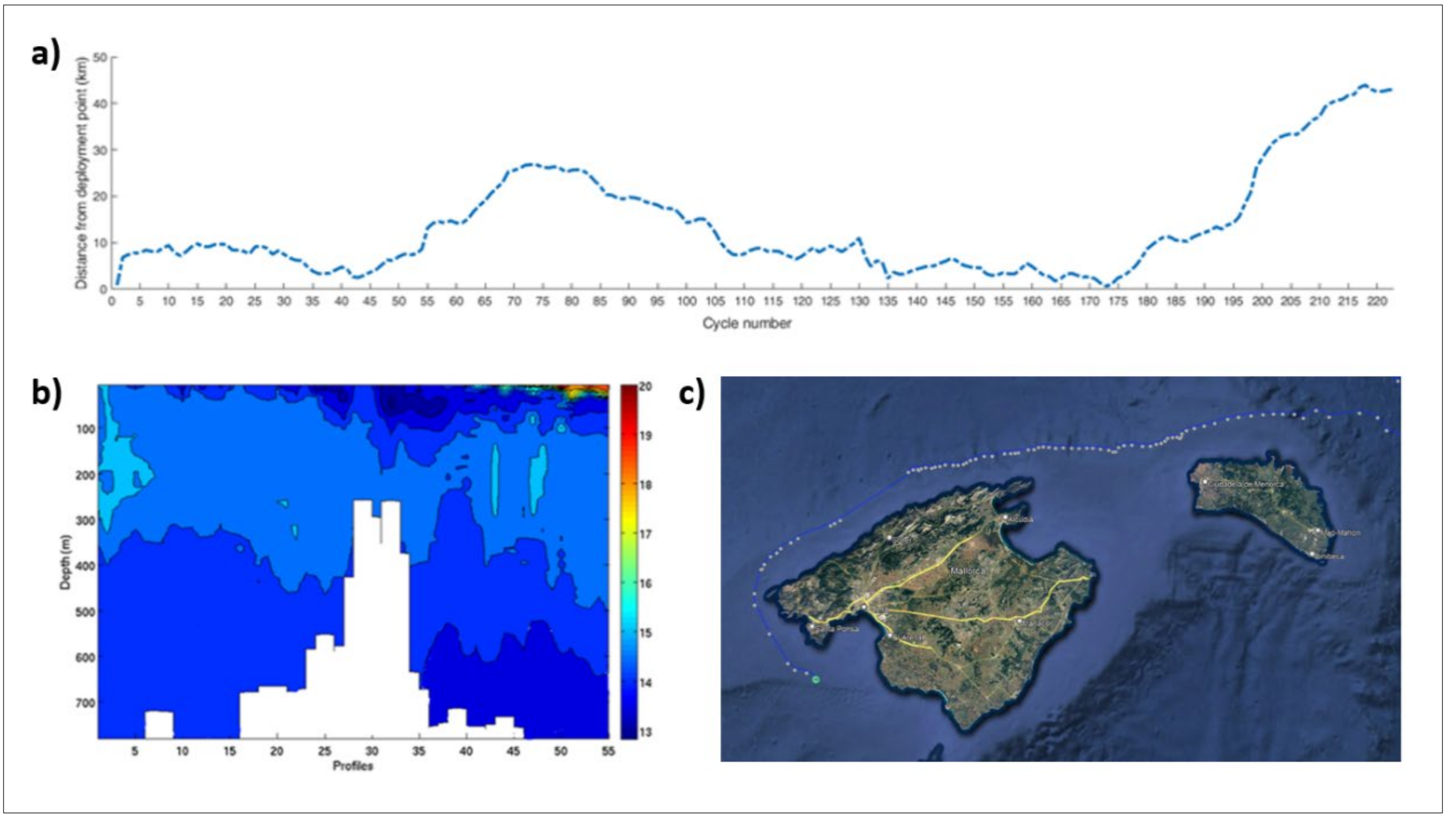

Figure 2. Distance from the deployment location of float WMO 6903263 (per cycle number), deployed in the Central Adriatic Sea (2a); Hovmöller diagrams of temperature profiles, recorded by the WMO 6903288 float during the first 6 months of its operation. Sea bottom is depicted in white (2b); Trajectory of float WMO 6901278 along the continental shelf of the Balearic Islands (2C).

4. CONCLUSION

The investigation of float profiles acquired in shallow coastal waters is complicated due to the complexity of the different areas and the high variability of the near-surface layers. Several qualitative analyses have been developed to try to obtain a reliable quality control and a robust reference dataset is required to obtain useful statistics. These shallow-coastal operations with Argo floats are essential to enhance the data assimilation and improve the predicting capabilities in the coastal ocean.

The work carried on in the Euro-Argo RISE project has shown that Argo floats can be used in proximity to coasts and in shallow waters where the sea currents are not strong enough to make the floats drift away rapidly from the targeted area. In addition, Argo floats can be used to complement measurements from other coastal observing systems.

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Linking science to society through case studies showing benefits of the ocean observing and forecasting

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Keywords

Earth observation value chain, societal benefits, marine environmental management, coastal

1. INTRODUCTION

As the effects of climate change worsen and human activity keeps taking its ever-growing toll on the marine world, never has our Ocean, and the precious resources it provides, felt so vital to our societies and our economies. In this context, understanding, monitoring and predicting what will happen in marine and coastal environments, plays a crucial role in protecting our planet's largest ecosystem – the Ocean, using its resources in a sustainable manner, and safeguarding communities by informing adaptation and mitigation measures in the face of a changing climate.

The role of Earth Observation (EO) and derived information products and services are more than ever needed to find effective and urgent solutions for ocean and coastal challenges. From satellite and *in situ* observation, to monitoring and forecasting services, to data access and cloud services, to marine and coastal derived applications and services, the EO value chain provides multiple benefits to different stakeholders and end-users. To demonstrate the socioeconomic and environmental benefits of the EO value chain, the EU4OceanObs project has produced a series of use cases focusing on ocean and coastal challenges. The themes selected include for monitoring and prediction of i) marine litter (trajectories, abundance, distribution) ii) Arctic Sea ice extent iii) Sargassum inundation events iv) eutrophication (harmful algae blooms, ecosystem degradation) and EO to support v) sustainable fisheries management (detection of Illegal, Unreported and Unregulated (IUU) fishing, ensuring food security, reducing ecosystem degradation).

1.1. How EO and derived services can help society

The use cases shed light on each component of the EO value chain, various type of measurements by satellites and *in situ* platforms (research vessels, buoys, Argo floats, etc.), the modelling and forecasting services to fill in data gaps with modelled data, facilitate predictions, and analyse trends, relationships and anomalies, data infrastructures to provide access to data and information, derived data products and applications to respond to various user needs for evidence-based information (e.g. early warning systems, mitigation and adaptation strategies, monitoring directives, biodiversity restoration actions, etc.). Each use case provides concrete examples highlighting EU-funded programmes, projects and services supporting the EO value chain specific to each theme. Identifying gaps in observation, monitoring and forecasting, and challenges with data access, the use cases also put forward recommendations to address some of these gaps.

From policy makers, national and local authorities, to blue economy actors and maritime security, to coastal communities, different end users will be able to see and understand the direct benefits of the Earth observation value chain and the need for enhanced ocean and coastal observing and forecasting.

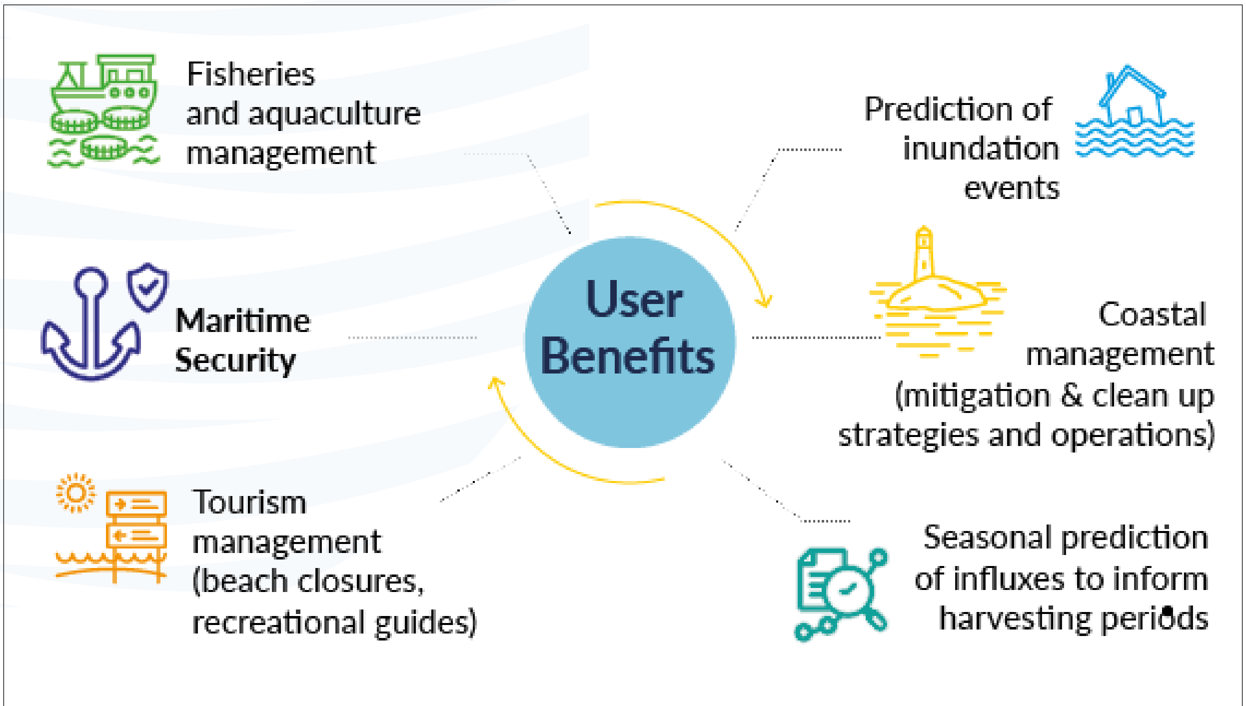

Figure 1. Examples of user benefits from access to Sargassum EO-based information, monitoring and forecasting tools, and data services. EU4OceanObs use case on EO to address challenges of Sargassum inundations in the tropical Atlantic.

1.2. EU4OceanObs supporting enhanced global ocean observation

EU4OceanObs is a European Commission Foreign Policy Instrument, funded by the European Union and implemented by Mercator Ocean International, with the aim to strengthen international ocean governance for the enhanced collection, sharing and use of ocean observation for societal benefit. Through its different components, upstream working with the G7 Future of the Seas and Oceans Initiative and downstream working with GEO's Blue Planet Initiative, the project catalyses essential partnerships between European and international infrastructures and programmes across the ocean observing value chain to foster international commitment and collaborative partnerships to increase data coverage, improve sharing of and access to ocean data, coordinate regional international efforts, and use data and knowledge for a comprehensive global ocean observing system. As part of its cross-cutting communication activities, EU4OceanObs works to raise public awareness on the importance of ocean observing and use of observations for society by disseminating use cases and other communication products among various stakeholders.

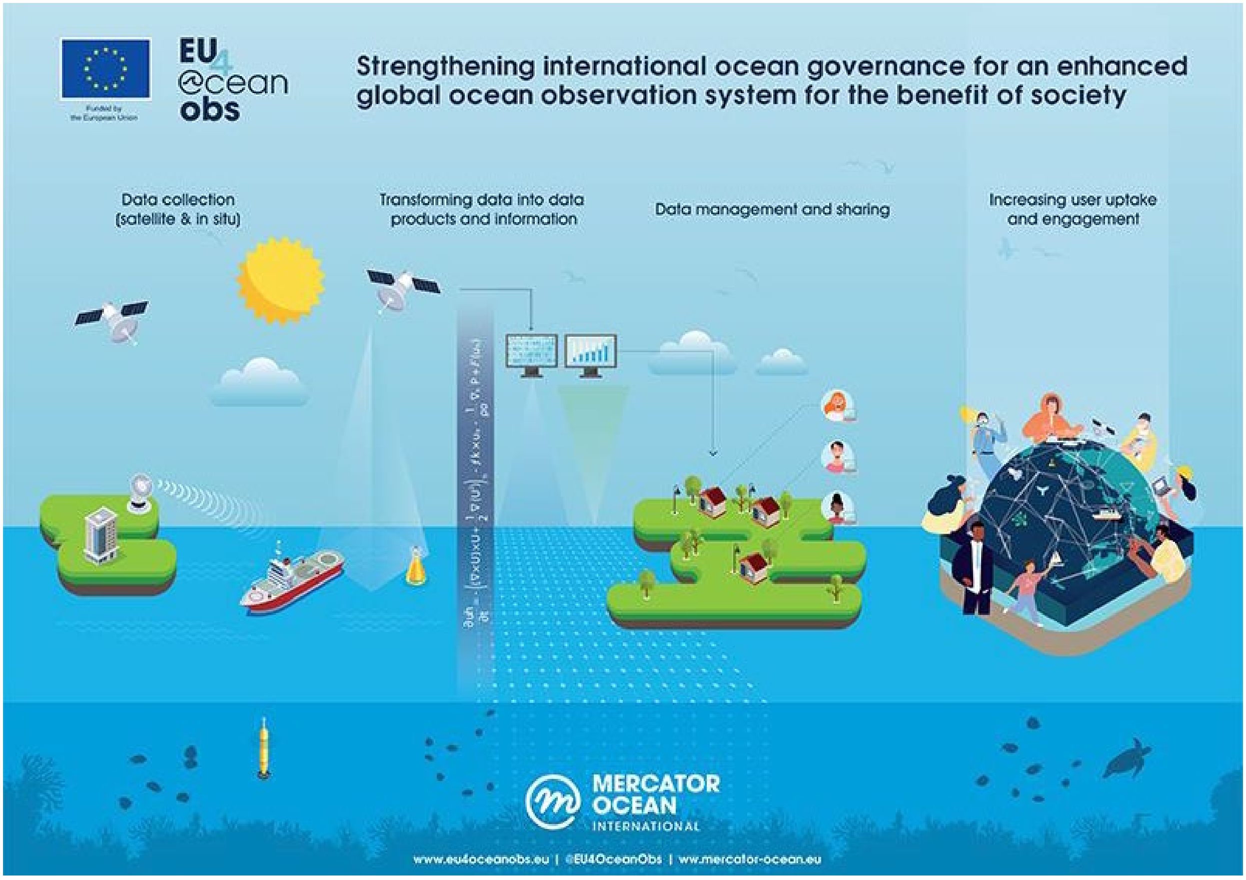

Figure 2. EU4OceanObs working to enhance the ocean observing value chain by catalysing essential partnerships between European and international infrastructures and programmes across the ocean observing value chain to deliver a coordinated fit-for-purpose system

Links

https://www.eu4oceanobs.eu/use-cases/

Technologies for ocean sensing (TechOceanS project)

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Keywords

Autonomous observations, sensors, samplers, imaging processing workflow, EOVs

Abstract

To address oceanographic community requirements for autonomous observations, new types of technology must be developed. New *in situ* sensors and samplers will have to measure new parameters, reduce in size and power consumption, increase measurement traceability, improve stability, reduce mechanical engineering requirements and improve communication and automatic data transfer to data centres. TechOceanS project will fill the existing gaps by delivering sensors, samplers and improved image processing workflows capable of remotely measuring essential ocean variables (EOVs) as well as regulatory targets such as the Marine Strategy Framework Directive and OSPAR. To test the technology, a set of experiments and integration on a suit of platforms have been organised. The final tests will be carried out in Gran Canaria in spring 2024 where at least 7 new technologies developed in this project will be combined and integrated in 4 different autonomous vehicles. This unique opportunity will be used to provide a multidisciplinary practical training with students directly involved in the preparation (i.e. calibration/validation of sensors, preparation of the platforms) and management of deployments and will include at least 4 students and technicians from ODA recipient states.

In alignment with the objective of the UN Ocean Decade to secure "a transparent and accessible ocean", TechOceanS has joined a growing partnership of initiatives and has a repository of methodological documents and candidate best practices in both the Ocean Best Practices System (OBPS) and Better Biomolecular Ocean Protocols (BeBOP). These protocols are followed during sensor tests and are available for a community review in these platforms alongside sensor development templates developed in the project.

1. INTRODUCTION

The oceans cover over 70% of our planet (Attachment 2 to Tsukuba Communiqué, G7, 2016), directly contribute $2.5trillion/yr in economic benefit, equivalent to the world's 7th largest economy and provide $25 trillion in ecosystem services (Hoegh-Guldberg *et al.,* 2015). Whilst 90% of their value depends on healthy ecosystems, 30-35% of critical marine habitats are overused or have been destroyed, ocean acidity is up 26%, and oxygen is depleting in key areas (Brunson *et al.,* 2018). The international community is coordinating its response to these urgent challenges through the UN Decade of Ocean Science for Sustainable Development, the Tsukuba Communiqué and the recommendations of the G7 expert workshop on future of the oceans and seas. Noting that 1) satellite observations provide unparalleled broad scale views of the ocean, but only see the surface, and 2) that research vessels are essential for process studies and benchmarking, but survey too infrequently and sparsely to address observation needs, the G7 expert workshop recommended sensor innovation particularly for biogeochemical and biological processes "from the range of available observing platforms and systems". Both scientists and other stakeholders (offshore engineering, fisheries and aquaculture industries) currently rely on carbon and cost intensive methods (e.g. manual sampling of decommissioned energy and aquaculture installations), while key variables to monitor ocean health remain critically under-sampled. Remote, *in situ* measurement systems can reduce the need, or potentially obviate these traditional methods, vastly improving data spatial and temporal resolution and filling capability gaps.

TechOceanS addresses these challenges through a balance of innovation and operations. Having selected the most promising technologies and leading researchers and engineers in the field, we proposed an ambitious yet deliverable programme of development and demonstration of measurement systems that can be deployed without the need for extensive logistics including research ships. TechOceanS targets variables with the greatest impact as prioritised through the Framework for Ocean Observing (FOO) / GOOS Essential Ocean Variable (EOV), Marine Strategy Framework Directive (MSFD) and direct stakeholder feedback.

2. THE PROJECT

The project will deliver 5 new sensor classes for biogeochemistry, biology and ecosystems addressing 10 of 19 EOVs, 31 of 73 subvariables, 6 of 9 MSFD targets together with microplastics and a range of biotoxins and contaminants. It will also develop a new image processing workflow for extracting EOVs (9) and MSFD (6) and litter measurements from images.

TechOceanS has 3 technology development themes and a cross-cutting theme:

- Theme 1 aims to introduce new processes and technologies which will allow eDNA to be collected and sequenced continuously and in highly challenging subaquatic environments;

- Theme 2 is dedicated to the development of a suite of novel optical and imaging technology, analytic software and communication methods that will directly support the ambitious goals of the project, namely low cost, continuous remote autonomous ocean monitoring and measurement;

- Theme 3 aims to provide the capability to measure macro-nutrients, pollutants, microplastics, toxins and to analyse phytoplankton by flow cytometry, by "shrinking" the laboratory processes currently used and making them capable of functioning aboard small, remote AUVs (autonomous underwater vehicles) and other platforms.

It is clear from the scope of Themes 1, 2 and 3 that TechOceanS has very ambitious targets to bring such a wide range of innovations together in a single platform. For this reason, the project's Theme 4 has been striving to ensure:

- All systems developed in lab settings are able to integrate with one another in the final design of the platform, which itself will function in challenging environments;

- The rigorous testing of all individual systems prior to integration to ensure they are each capable of achieving their targets in real-world operating environments;

- The processes, protocols and practices being developed over the course of the project are in line with the IOC-UNESCO Ocean Best Practices System and that these practices are assimilated into any designs or future revisions of TechOceanS technologies and methods.

Our future plans for testing and validation activities includes demonstration missions that will focus on aquaculture, built infrastructure (with relevance to offshore industries) and global ocean observing. Deployments are scheduled to take place between May and June 2024 in Stazione Zoologica Anton Dohrn (Naples, Italy) and in March 2024 in the Canary Region and PLOCAN's facilities and test site (Spain).

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Data Handling and Management in the Context of SO-CHIC Project (Southern Ocean Carbon and Heat Impact on Climate)

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Keywords

Antarctic Ocean, Climate models, Data management, Data visualization, Carbon and Heat exchange

Abstract

The Southern Ocean plays a critical role in regulating global climate by controlling the exchange of heat and carbon between the atmosphere and the ocean. However, a lack of understanding of the underlying processes has made it one of the major weaknesses

in climate simulation and projection. The SO-CHIC project aims to bridge this gap, addressing the exchange of heat and carbon between the atmosphere and the deep ocean by measuring their fluxes at the air-sea-ice interface and the estimation of their variability in time and space. It uses a combination of old and new observations, ranging from *in situ* and satellite data, to model output. To ensure that the collected data are accessible and effectively used, the project has adopted common standards and recommendations from the Southern Ocean Observing System (SOOS) and the major European marine data integrators (EMODnet, Copernicus Marine Service, SeaDataNet). The data collected by the project is organized by a backend system, which ensures consistency and accuracy before storage in the data repository, as well as immediate data interoperability towards marine data integrators. A WebGIS offers FAIR access to data and measurements, providing users with a comprehensive overview of the project's progress and areas of focus.

1. INTRODUCTION

The Southern Ocean, as a vital connector between major ocean basins, plays a pivotal role in facilitating the exchange of water and nutrients across different layers of ocean circulation (Ganachaud & Wunsch, 2000; Macdonald & Wunsch, 2000). Furthermore, it acts as carbon sink, absorbing a significant portion of anthropogenic carbon emissions from the atmosphere (Chris *et al.*, 2004, Sallée *et al.*, 2012). Recent observations indicating substantial changes in the Southern Ocean have raised concerns among various stakeholders, including researchers, policymakers, marine resource managers, and educators. They have a vested interest in monitoring these rapid regional changes and accessing Southern Ocean data and related products.

To address these concerns, the Southern Ocean Carbon and Heat Impact on Climate (SO-CHIC) project has outlined several key objectives that encompass monitoring heat and carbon budgets in the Southern Ocean. The project aims to improve our understanding of ocean mixed-layer dynamics and associated air-sea fluxes, sea ice distribution, and the reopening of the Weddell Polynya. Additionally, it seeks to enhance knowledge of bottom water formation and export, identifying crucial factors in the Southern Ocean climate system for accurate modelling and reducing uncertainties in projecting oceanic heat and carbon content. Acting as an integrating force, SO-CHIC brings together products and expertise from a wide range of European, national, and international initiatives, fostering collaboration and coordination. By providing valuable information for the development of Climate Services, annual Ocean State Reports, and Ocean Monitoring Indicators, SO-CHIC directly contribute to addressing the challenges posed by climate change.

2. MATERIALS AND METHODS

The project will deliver 5 new sensor classes for biogeochemistry, biology and ecosystems addressing 10 of 19 EOVs, 31 of 73 subvariables, 6 of 9 MSFD targets together with microplastics and a range of biotoxins and contaminants. It will also develop a new image processing workflow for extracting EOVs (9) and MSFD (6) and litter measurements from images.

3. RESULTS

3.1. Backend management infrastructure: Data Flow

The data collected within the project follow a specific data management flow. SO-CHIC is a delayed mode data producer, hence, once recovered, data undergo quality control and quality flagging process (applied by the SO-CHIC experts). Metadata are also checked and validated. The next step, data are assigned a Digital Object Identifier (DOI) to ensure their persistent identification and accessibility and harmonized to ensure consistency and compatibility across different datasets. Once, DOI is assigned, data are linked to the SO-CHIC infrastructure, which is based on ERDDAP and GeoServer, hence ready for interoperability and further uses. To facilitate internal reviews (QC/QF) before sharing high quality data, the backend is organized in two containers, one public and one private.

3.2. Frontend management infrastructure: Data portal

The primary objective of the data portal is to provide a centralized platform for accessing and utilizing all relevant SO-CHIC data. On top of the backend, the map viewer allows a FAIR access to data and measurements, providing users with a comprehensive overview of the project's progress and focus areas. The user experience prioritizes accessibility and ease of use in data visualization tools to benefit a wide range of users. Users can access raw observational data and search for processed or aggregated versions of the observations over time or space. The primary users of the SO-CHIC portal are the SO-CHIC partners, SO-CHIC research is not only based on SO-CHIC data, hence the tool integrates data from diverse sources employing a catalogue format, showcasing data packages/products along with thumbnail previews of their contents. A side panel enables users to visualize the parameters available for each platform and identify platforms measuring specific parameters: selecting a platform and/or a parameter and a time scale of interest, a pop-up window appears, displaying the available datasets as data product cards with summarized main features. By selecting a specific product, users can locate the corresponding measurement on the map. Furthermore, clicking on a platform in the map triggers the display of a dedicated page, showcasing the trends of each available parameter and providing detailed information about the platform. Additionally, web APIs are available for data downloads. SO-CHIC map viewer has been adopted and it is powering the SOOS map viewer.

2. CONCLUSION

One of the key achievements of the SO-CHIC project is the increase in confidence in climate change projections. Through extensive research, data collection, and analysis, the project has provided valuable insights into the complex interactions between the Southern Ocean and the global climate. Moreover, the SO-CHIC project's commitment to open access, interoperability, and data transparency is of paramount importance. Thanks the strong cooperation with SOOS, it not only advances scientific knowledge but also empowers stakeholders by providing them with the essential information needed to address climate change effectively. The project's open approach paves the way for collaboration, innovation, and evidence-based decision making, ultimately contributing to a more sustainable and climate-resilient future.

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Oxygen trend and variability from a biogeochemical reanalysis of the Mediterranean Sea

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Keywords

Oxygen, reanalysis, Mediterranean Sea, trend, monitoring

Abstract

A 1999-2021 biogeochemical reanalysis of the Mediterranean Sea at 1/24° horizontal resolution and its interim monthly extensions till present, implemented within the Copernicus Marine Service, are used to analyze trend and variability of the dissolved oxygen and to continuously monitor the marine ecosystem state. In particular, we estimated a small but statistically significant oxygen trend of -0.1 ÷ -0.05 $mmolO_2$ m-3 y^{-1} at surface, consistently with the decrease in oxygen solubility due to the increase in sea surface temperature. On the other hand, we did not detect clear trends in the subsurface layers, where we observed the influence of mesoscale spatial variability on the subsurface oxygen maximum, which

in summer displays values of 230 ÷ 250 $mmolO_2\ m^{-3}$ concentration and 30 ÷ 100 m depth. Focusing on a highly sensitive area of the basin (i.e., the southern Adriatic Sea), we ascribed the variability of the dissolved oxygen along the water column to multiple drivers and the transitional low concentrations in the intermediate layers observed after 2019 are under careful monitoring.

1. INTRODUCTION

Dissolved oxygen is one of the indicators of ocean health and monitoring its trend and variability is of crucial importance for life on Earth. The Copernicus Marine Service biogeochemical reanalysis produced by the Mediterranean Sea Monitoring and Forecasting Centre provides a valuable overview of oxygen variability in the Mediterranean Sea from 1999 till present, at a relatively high horizontal resolution (1/24°) and with daily output. The reanalysis, built on a coupled hydrodynamic-biogeochemical modeling system, includes data assimilation of ocean colour and shows good performances in reproducing the dissolved oxygen dynamics, especially in the epipelagic layers. Thus, it can constitute a benchmark for the computation of climatologies to be used as a reference for climate projections, operational forecasts and, in perspective, a Digital Twin of the Mediterranean Sea.

So far, the reanalysis allowed us to: (i) evaluate possible multi-decadal trends in the marine oxygen content; (ii) detect signals of oxygen variations at temporal scales ranging from inter-annual to sub-weekly in areas particularly sensitive to meteo-marine drivers; (iii) characterise different oxygen phenomenologies depending on local physical and biogeochemical processes. In fact, dissolved oxygen is affected by air–sea interactions, horizontal and vertical transport, mixing and stratification of the water column, and production and consumption by marine organisms. As a result, in the Mediterranean Sea oxygen dynamics include: (i) a summer subsurface oxygen maximum (SOM) at around 50 m depth; (ii) an oxygen minimum layer (OML) between 300 and 1000 m shallowing westwards; (iii) winter deep maxima in the areas characterized by deep water formation (e.g., Gulf of Lion, southern Adriatic Sea, Cretan Sea).

2. RESULTS

On the long-term scale, the reanalysis shows a small but statistically significant deoxygenation trend at surface in most of the basin (Cossarini *et al.*, 2021). The estimated value of the trend is in the range -0.1 ÷ -0.05 $mmolO_2\ m^{-3}\ y^{-1}$, which is consistent with the oxygen solubility decrease due to the observed increase in sea surface temperature in the Mediterranean Sea.

No clear signal of decreasing oxygen is simulated in the subsurface layers. In fact, the summer SOM shows a mesoscale spatial variability that depends on summer biological production and vertical motions and that is associated with concentration and depth in the range 230 ÷ 250 mmolO_2 m^{-3} and 30 ÷ 100 m, respectively (Fig. 1), but with negligible inter-annual variability and trends (Di Biagio *et al.*, 2022). Moreover, a study focusing on a winter deep convection area (i.e., the southern Adriatic Sea) highlighted how the oxygen long-term variability is affected by shorter-term signals (Di Biagio *et al.*, 2023). For instance, lower oxygen concentrations along the water column were detected in the area after 2019 and associated with modifications in water mass formation and transport. Possible consequences for marine organisms and the ventilation of the Ionian-Adriatic area will be carefully monitored in the future thanks to the interim production, which continuously updates the reanalysis time series. Interestingly, for this specific site, we proposed an innovative bias correction procedure taking advantage of a particularly favourable availability of BGC-Argo floats.

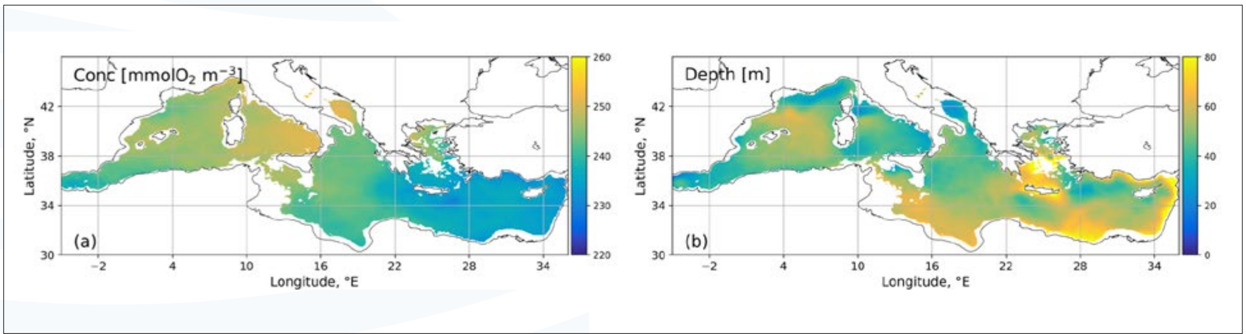

Figure 1. Mean concentration (a) and depth (b) of the summer subsurface oxygen maximum in the Mediterranean Sea, according to the Copernicus Marine Service biogeochemical reanalysis. Coastal areas (i.e., shallower than 200 m) are masked.

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Implementing machine learning method based on profile classification approach in the quality control of Argo floats

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Keywords

Machine Learning, Delayed Mode Quality Control, Argo data, Profile Characterization Model

Abstract

We present the DMQC-PCM (SO_assesment) software based on a machine learning approach used to improve the quality control of measurements from Argo floats. This software improves the selection of Argo and hydrographic data (used for validation of Argo data), belonging to similar water mass regimes leading to reduction of the noise from other water masses and a decrease of the error bars of suggested corrections by the software during the analysis. DMQC-PCM software allows to improve the robustness and quality of science-ready Argo data.

1. INTRODUCTION

Argo is a collaborative international partnership launched in 2000 to measure the changing properties of the upper 2000 meters of the global ice-free oceans, expanded to reaching full ocean depth, down to 6000 m and measure BioGeoChemical oceanographic variables. It is the most important source of *in situ* ocean data, which have a remarkable impact on ocean and climate services, predictions on timescales from days to seasons, enabling better understanding ocean ecosystems, forecasting ocean productivity and constraining the global carbon and energy budgets. Argo data are crucial in the development of policies and legislation to protect vulnerable areas of our coasts and to better recognise patterns and trends in forecasting future changes.

2. RESULTS

2.1. DMQC analysis

To ensure the highest quality of core (pressure, temperature and salinity) data by Argo floats, one of the most significant data management activities is a delayed mode quality control (DMQC) analysis. DMQC processing of Argo floats is the set of analyses based on statistical methods and scientific expertise to estimate the quality of salinity data with the associated error (Cabanes *et al.*, 2016). DMQC OWC software package (Cabanes *et al.*, 2022) allows the estimation of drift and offset of conductivity measurement to produce salinity profiles that are consistent with climatological values, typically within a well-determined water mass. Any inconsistencies or incorrect data are appropriately adjusted (if possible) or flagged (Wong *et al.*, 2023).

Some ocean regions like the Southern Ocean (SO) are characterised by very strong ocean dynamics with a wide spectrum of ocean regimes, with relatively limited and sparse hydrographic data from climatology compared to many other ocean regions. These factors make the DMQC analysis of Argo floats often very challenging, which needs to be performed with a very high care.

2.2. Implementation of the PCM method

DMQC-PCM software is a new developed method and tool to support the DMQC analysis of Argo data, which output can be further used in the traditional well-defined DMQC procedures and software (Cabanes *et al.*, 2016). This method improves the selection of Argo and hydrographic data (used for validation of Argo data), belonging to similar water mass regimes. DMQC-PCM software is based on a machine learning approach and use the statistical classifier Profile Classification Model (PCM). PCM is a scientific analysis approach that allows the user to automatically assemble temperature and salinity profiles in clusters according to similarities in their vertical profile structure. It is based on the unsupervised and automatic classification of profiles with a Gaussian mixture model (Maze *et al.*, 2017). This method allows, for front detection, water mass identification, natural region contouring, and reference profile selection for validation (Maze *et al.*, 2017). The DMQC-PCM () has been initially developed within at Ifremer/LOPS (Euro-Argo RISE, 2022) and further automatized, tested and implemented in the larger scale quality assessment of Argo floats in the SO as a part of the Euro-Argo RISE Argo project (Euro-Argo RISE, 2022).

3. SUMMARY

The key achievement of this method tested for the SO and also in various global oceans shows an improvement in reduction of the noise from other water masses and a decrease of the error bars of suggested corrections by the software during the analysis. The DMQC-PCM allows the DMQC operators to improve their confidence in decision-making process. This method and tool may lead to a more robust quality control analysis of oceanographic data in delayed mode and thereby higher-quality of science-ready data. DMQC-PCM can be uses for every day operations as well as for Argo Regional Centres to quickly check a large number of floats. Moreover, this method might also fine use in improving the real-time checks of and help to improve the quality of other oceanographic parameters from various oceanographic platforms.

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Next generation multiplatform Ocean observing technologies for research infrastructures (GEORGE Project)

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Keywords

Research Infrastructures, carbon, autonomous observations

Abstract

Large improvements in oceanic observations are necessary to deliver a fit for purpose observing system capable of real time estimates of the uptake of carbon by all relevant parts of the ocean. This includes the deep ocean and coastal zone and will in turn support better decision making relevant to both climate (the scale and timing of mitigation and adaptation measures) and food production (the scale and location of aquaculture). The challenges include developing better technologies and improving network organisation and standardisation. Advances will provide more consistent data streams with greater accessibility to support and improve the related science and assessment associated with the state and variability of the oceans. The main aim of the GEORGE project is to develop and demonstrate a state-of-the-art biogeochemical, multi-platform observing system operated across ERICs that can carry out integrated biogeochemical observations for characterisation of the ocean carbon system. One of the principal aims of the project is to advance the technology readiness level of state-of-the-art sensors, enabling for the first time systematic autonomous, *in situ*, seawater CO_2 system characterisation and determination of CO_2 fluxes on moving and fixed platforms. Together with sensor manufacturers, GEORGE will optimise sensor technologies for measurements on platforms operated by ERICs and according to their operational requirements. Technology will be co-developed between industry and ERICs ensuring direct route to market and potential for scalability. The technologies will be validated according to a rigorous TRL progression engineering process and demonstrated at sea as an integrated multi-platform observing system during several field campaigns where ERICs are active.

1. INTRODUCTION

The ocean is a major component of the global carbon cycle, exchanging massive quantities of carbon with the atmosphere via natural cycles driven by ocean circulation and biogeochemistry. Since seawater has a high capacity for absorbing carbon, the ocean also is a significant modulator of the rate of accumulation of carbon in the atmosphere, and hence global warming. A quarter of anthropogenic CO_2 emissions is taken up by the ocean each year which, due to the chemistry of carbon in water, causes a decline in ocean pH, also known as ocean acidification. The potential ecological consequences of ocean acidification are now well known and therefore constraining carbon uptake by the ocean is critical for understanding how the carbon cycle and climate are evolving under the impact of human activities. Large improvements in oceanic observations are necessary to give us a fit for purpose observing system capable of estimating in near real time the uptake of carbon by all relevant parts of the ocean including the deep ocean and coastal zone in support of better decision making relevant to both climate (the scale and timing of mitigation and adaptation measures) and food production (the scale and location of aquaculture). The challenges comprise better technologies, improved network organisation and standardisation, more consistent data streams and accessibility to support and improve the related science and assessment related to the state and variability of the oceans. Therefore, sustained and constantly improved long-term *in situ* observations are crucial to better understand and predict the impact of climate change on Ocean ecosystems, increase resilience, develop sound mitigation and adaptation strategies, and better protect marine ecosystems. Furthermore, long-term sustained *in situ* Ocean observations are required to support environmental and climate policies such as the European Green Deal and related policies aiming to reach net zero, achieve sustainable blue economy, protect nature and reverse ecosystem degradation [EMB 2021].

The proposed project NEXT GENERATION MULTIPLATFORM OCEAN OBSERVING TECHNOLOGIES FOR RESEARCH INFRASTRUCTURES (GEORGE) is providing better technologies that are pivotal to improve the entire value chain of data on the ocean carbonate system.

2. THE PROJECT

Ocean observing research infrastructures (RIs) in Europe (i.e. ICOS, EMSO, Euro-Argo) have successfully implemented a world-leading system of standardised Ocean observations over the past 15 years building on more of a century of experiences by the involved marine institutes. This community has joined forces in the GEORGE project proposal to take them to the next level of technology: systematic long-term autonomous observations. GEORGE aims to develop and demonstrate a state-of-the-art biogeochemical, multi-platform observing system operated across ERICs that can carry out integrated biogeochemical observations for characterisation of the Ocean carbon system. This will be achieved by bringing observing technology development leaders from academia and industry together with the observing community (through EMSO, ICOS and Euro-Argo) to develop fit-for-purpose observing technologies. GEORGE will harmonise technologies, methods and standards for carbon observations across the three ERICs and according to recommendations and guidance from the international carbon observing community (International Ocean Carbon Coordination Project, IOCCP) and streamline data treatment and flow to data repositories. It will work towards making ocean observing more sustainable by establishing a framework of cooperation and identifying synergies with industry operating in the ocean domain. GEORGE will consider requirements for important end-users and stakeholders such as: governments and regulatory bodies (e.g. environmental agencies), operational ocean services (e.g. Copernicus Marine Service, EMODnet) and intergovernmental frameworks (e.g. SDG14, GOOS, IOCCP) and will optimise the observing system in a process of co-design and stakeholder engagement. This will guide the design of demonstration activities which will provide examples of integrated and coordinated autonomous ocean carbon observations. GEORGE will contribute to the implementation of the European Ocean Observing System (EOOS) strategy, towards an integrated European observing system, and working closely with the IOCCP.

GEORGE will enhance the observing capability of ERICs and their effectiveness in monitoring ocean biogeochemistry and carbon cycling by: a) advancing the technology readiness level of state-of-the-art sensors (WP2), b) enhancing the observing capability of autonomous platforms (WP3) equipping them with the latest sensor technology and developing communication from and between platforms and by incorporating novel autonomous vehicles to the ERIC observing fleet, c) harmonising technologies, methods and SOPs for biogeochemical observing and develop a framework for multi-platform, cross-ERIC biogeochemical observing from sensor to data repositories (WP4), d) building capacity in ERICs by providing training in the use of new technologies and SOPs on data handling and reporting to staff and member organisations (WP6), and e) facilitating cooperation between industry and ERICs ensuring direct route to market and potential for scalability (eg. WPs 2,3,7) of new technologies.

ACKNOWLEDGEMENTS

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Twenty Thousand Sounds Under the Seas

Authors

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Keywords

Engagement, board game, underwater soundscape, museum, marine science

Abstract

"20,000 Sounds Under the Sea" is an AR-enhanced card game for the dissemination of science and support ocean literacy. The game engages the players on the importance of the underwater soundscape in aquatic environmental ecology, raising awareness of the noise pollution problem, highlighting how anthropogenic sounds impact marine ecosystems. The players explore the ocean drawing cards from three decks (one for each depth level) and placing them on the table to form the game board. The wildcard "sound card" requests the player to listen to a sound that is triggered by the AR feature of the game. The virtual dashboard provides the player with tools to filter the sound from surrounding noise, to identify the sound-source, add the sound to their collection, and continue with the mission. The team who first collect one sound per depth level and return to shore before their tank is empty, wins. "20.000 Sounds Under the Sea" has followed a data-driven approach in its design and development and is one of the serious games developed under CulturGAME project.

1. INTRODUCTION

Culturgame.it is an Italian research project (Ministry of University and Research, PON Research and Innovation 2014-2020) that adopts an experimental approach to study applied games for the enhancement of cultural heritage and scientific dissemination and the development of cultural heritage and ocean literacy. On the use of games in museums, see, among others: Barekyan and Peter 2023; Ćosović and Ramić Brkić 2020; DaCosta and Kinsell 2023; Solima 2021, 2020, 1998. CulturGAME develops a series of serious games following a common *fil rouge*: water, as a critical factor in power dynamics throughout history, and a vital part of our ecosystems. While most of the games are designed for either on site use in the museum or for remote use, one game offers both modes of fruition. The project demonstration sites, namely National Archaeological Museum of Naples, Darwin Dohrn Museum of Naples, Museum of the University of Sassari. Each site links the other sites, each game explores different means of interaction and user experience (ranging from augmented reality to immersive virtual tours) to engage the users.

The paper introduces an AR-enhanced card game aimed at enriching the visiting experience at the Stazione Zoologica Anton Dohrn.

The underwater sounds originate from a research database complete with metadata such as location, depth, and more. The case study is a powerful example on how to use scientific data for dissemination purposes that applies the guidelines set by the United Nations in the Ocean Decade project (see Caruso *et al.*, 2022, especially Outcome 7).

2. 20,000 SOUNDS UNDER THE SEAS

The game "Twenty Thousand Sounds Under the Seas" aims to spark the players' interest on the broad spectrum of underwater sounds that can be heard at sea, raising awareness on the issue of noise pollution and the impact that anthropological sounds have on marine ecosystems.

Participants are divided into teams and each team drives a bathyscaphe, so players become members of the crew. They explore the depths of the sea by drawing unexpected cards from various decks (one for each depth level) and place the cards on the game board. When the team places the bathyscaphe on a sound card, they trigger the enhanced AR experience: by snapping the card they access to a virtual dashboard that has to be used to clean the sound from background noise, identify the sound-source, collect the source, and unlock the next level of the mission.

The current version of the game includes 12 different soundtracks from the database of the Anton Dohrn Zoological Station: anthropic, biological and geological sound-tracks for the 3 depth levels.

Table I. Sounds selected from the database of the Anton Dohrn Zoological Station

Level 1	Dolphin
	Weddel seal
	Iceberg
	Diver
Level 2	Airgun
	Humpback
	Killer whale
	Submarine earthquake
Level 3	Hydrothermal spring
	Large ship
	Sperm whale
	Torpedo

The alfa and pre-beta versions have been tested with high-school students and families (ca. 70 players), and confirmed the usefulness of this new approach to engage (younger) students on sea threating topics and as a tool for facilitating dissemination on culture heritage and ocean literacy. A new playtesting campaign of the beta version is planned at the end of September.

Indeed, the game is designed to stimulate curiosity about the wide variety of sounds present in the marine world, while alerting the audience on the harmful interference of unregulated human activities (on this topic see Duarte *et al.*, 2021, Popper and Hawkins 2019).

The structure of the game lends itself to include an ever-growing set of sounds, as well as personalized missions and expansions by adding new marine settings.

3. CONCLUSION

The game was devised to function as a tool for informal learning purposes in the Darwin Dohrn Museum in Naples. simplified version of the deck, together with introductory information on underwater soundscapes, provides schools and families an engaging activity in the museum laboratory. The complete version of the game, however, has all the components of a commercial high-tech board game, allowing the museum to tap into an audience that is usually under-reached by Italian museums.

ACKNOWLEDGEMENTS

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Designing and delivering user-driven services through Copernicus Marine Service

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The Copernicus Marine Service is one of the six pillar services of the Copernicus program. Mercator Ocean International (MOi) is entrusted by the European Union for implementing the Copernicus Marine Service over the 2021-2027 period. It follows a user-driven process by taking into consideration user feedback to consistently improve its portfolio of products and services. Copernicus Marine Service user database (>55 000 registered users) includes users from all communities, including private, public, and academic sectors.

User feedback is collected through diverse channels. The main process of collection is displayed in Figure 1. The User Support Team of Copernicus Marine Service provides individual assistance to all users of this service. Besides helping users to find the products and services that best fit their needs, this team also collects feedback on unresolved queries. Another source of feedback is through events organized by MOi. On many occasions during the year, events are organized to provide training to all users. These events can be in the form of webinars, workshops, conferences, and specific meetings with determined sectors and markets. Feedback regarding service and portfolio evolution is collected through these events but to a lesser extent. Surveys are one of the main sources to collect user needs. Annual surveys, known as Service Assessment Questionnaires, are delivered each year to all registered users to collect general information on products and services. Additional surveys are also delivered to collect feedback focusing on specific thematic and products. These questionnaires are often made in collaboration with producers and target specific users.

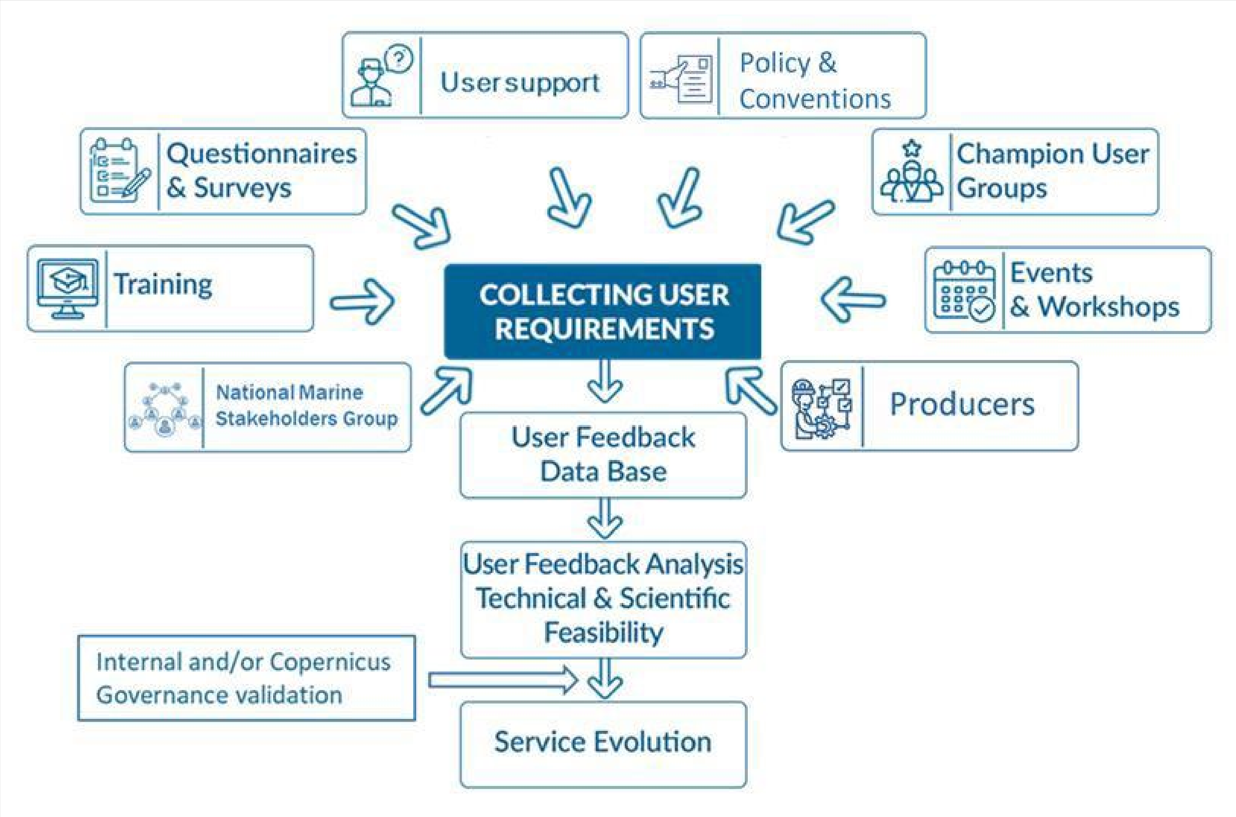
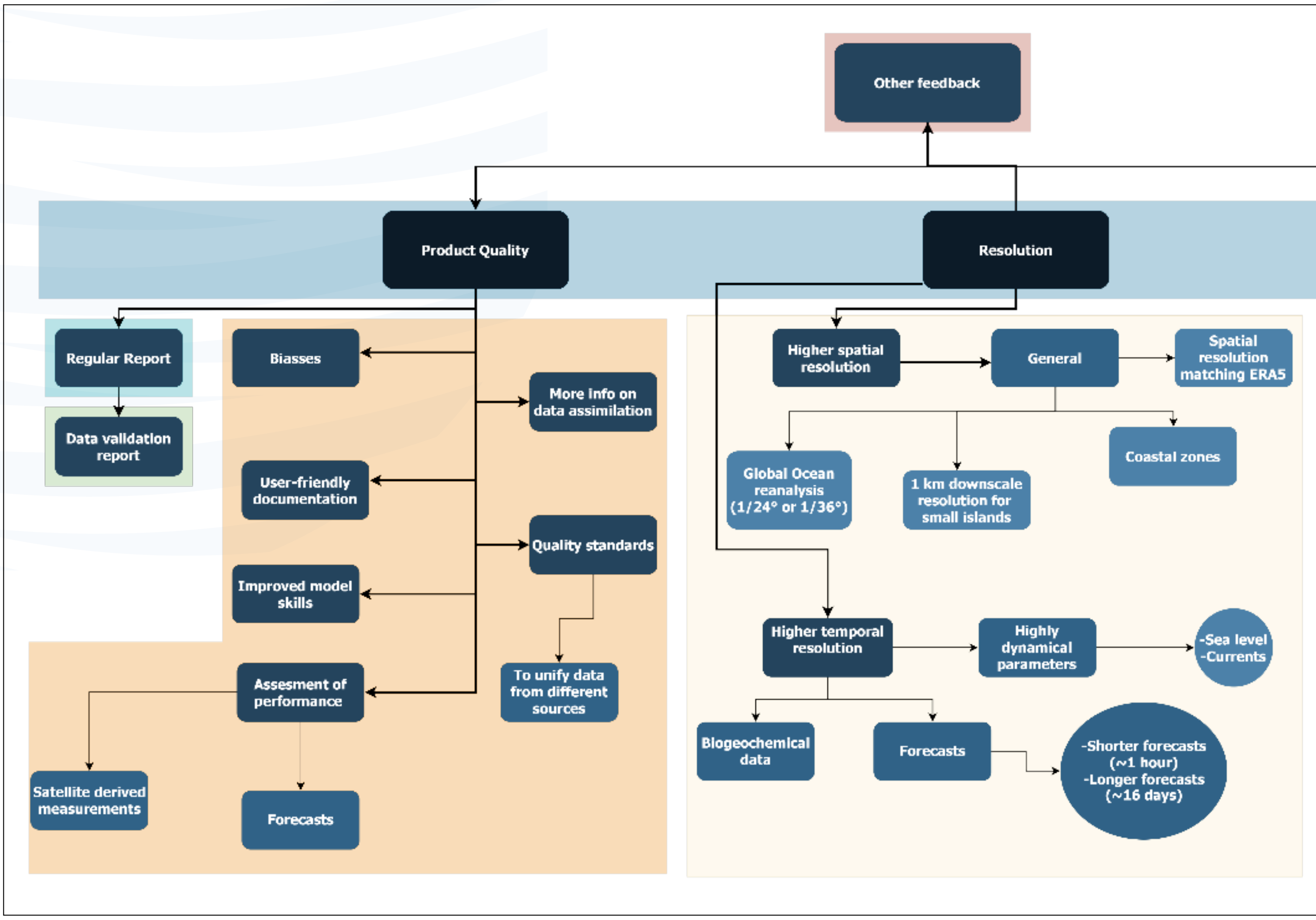


Figure 1. User-driven approach implemented in Copernicus Marine Service

Since Copernicus Marine Service aims to support the policy sector, several actions to have direct conversations with this community have been implemented. In October 20202, the National Marine Stakeholders Group (also known as Marine Forum) was kicked off by MOi to foster interactions with EU Member and Contributing States (MS) representatives and national entities in the marine domain. This will be of particular importance to co-design and implement actions with MS in the coastal marine areas. Moreover, the User Engagement Uptake Programme also plays a key role: through this call for tender, the Copernicus Marine Service aimed at developing National Collaboration with MS for the development of high-resolution marine coastal monitoring, which will serve as pilots for a future seamless Copernicus coastal marine monitoring service extending from the open ocean to the coast. On the other hand, several working meetings were held with representatives of the Regional Sea Conventions (OSPAR, HELCOM, UNEP-MAP, and Black Sea Commission) as well as experts from different entities involved in gathering data and compiling indicators for these Regional Conventions (IFREMER, OFB) to collect marine policy need and to provide training to stakeholders.

Finally, communication with specific users with advanced knowledge of the Copernicus Marine portfolio and with the producers of these products is maintained throughout the entire year. The Champion User Advisory Group (CUAG) was established with the aim of discussing the service evolution with experts from different sectors. This group consists of 18 independent expert users of Copernicus Marine Service. Its members were selected among active users from the twelve Copernicus Marine blue markets and according to their specific market and marine data expertise, representing a wider community of users. The aim of this group is to assess whether the current Copernicus Marine products and services are fit-for-purpose and relevant for their specific markets, research, and applications, and to advise on how to improve the current services and portfolios.

Following the process explained in Figure 1, after the collection of feedback through all these diverse sources, these requirements are saved in a database. An extract of some of these needs is shown in Figure 2. The analysis of this information is made by the Portfolio & Market Intelligence team at MOi, which translates those needs into achievable service/product evolution objectives. After studying the feedback in the database, those requirements are directly discussed with producers. Consequently, if it is decided that those changes are going to be implemented, they are validated internally and later injected and integrated into the service evolution. On the other hand, some feasibility studies to identify major gaps in user needs and the applicability of new products are performed as well. More discussion can take place during specific meetings with producers and experts, such as during the annual review and coordination meetings. In other words, the feedback provided by users drives the service evolution by generating user and policy-driven products in collaboration with data producers. Finally, these updated or new products are integrated into the product offer and announced in the roadmap to all users.



In addition to the user feedback process implemented for Copernicus Marine Service, MOi is also actively involved in several Horizon Europe projects such as CoCliCo (https://coclicoservices.eu/), ACCIBERG (https://acciberg.nersc.no/), and NECCTON (https://www.neccton.eu/), in the stakeholder engagement and exploitation and dissemination through Copernicus Marine Service. The stakeholder engagement involves identifying key stakeholders in each of the sectors (for example, coastal services, biodiversity, policy and decision makers) and having direct communication to collect their needs and to ensure that the outputs fit their needs. Moreover, the stakeholder engagement work package, implements a co-design strategy, where key stakeholders and scientists work together in the specification of new products and services that will enable the Copernicus Marine Service to better inform ocean policymakers, managers and publics.

As an example of how these needs help to shape the future evolution of the portfolio of Copernicus Marine Service, from the policy sector there is a need for more indicators linking the main physical variables (wind, wave, temperature) with possible consequences due to climate change, such as loss of biodiversity, coastal areas affected, and others. The creation of the Copernicus Thematic Hubs, such as the Coastal and Arctic will support the decision-making process for mitigation plans by gathering all available resources in one

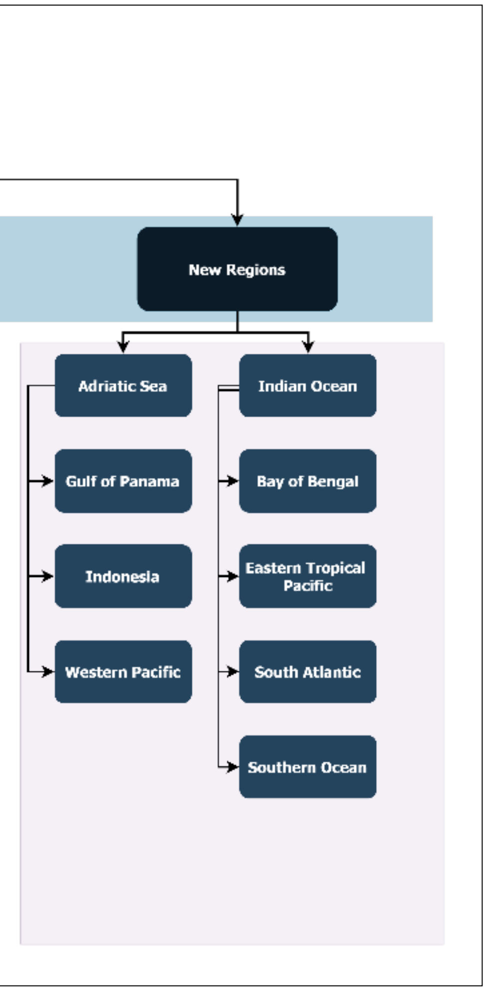


Figure 2. User needs on product quality, resolution, and regions collected in 2023.

single access point. Moreover, as also requested by this sector, a new dashboard is going to be developed in 2024 for policymakers. Regarding products, users requested higher spatial and temporal resolution, especially near the coast. This is currently being addressed by increasing the spatial resolution of many products, such as for the Arctic model products (from 3 km to 1.5 km), as well for the Black Sea and the Atlantic-Iberian Biscay Irish regions.

In conclusion, the user-driven approach has proved beneficial in driving service and product evolutions. The collection methods allow a wide representation of users, with different levels of expertise and knowledge on Copernicus Marine Service. Since the service is in constant development and improvement, gathering user feedback is essential to guide this evolution.

JERICO-RI: A Decade of Delivering Access to Strengthen Operational Oceanography in Europe

Authors

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Abstract

Throughout the decade of Transnational Access (TA) provided by JERICO-RI, numerous projects using the operational observation system have been facilitated. This paper explores the development of the JERICO-RI TA access and how this has facilitated a diverse and inclusive user group in the oceanographic community. Three case studies will highlight TA projects that have accessed JERICO-RI facilities to illustrate the varied uses and the benefits of the TA programmes in providing access to a wide variety of coastal observation infrastructure, as well as the strengthening of collaborative relationships between users and the JERICO-RI community.

1. INTRODUCTION

The Joint European Research Infrastructure of Coastal Observatories (JERICO-RI) is a network of European coastal observatories providing operational service for the delivery of high quality environmental data and information products related to the marine environment. A key service of JERICO-RI is the Transnational Access (TA) programme which offers scientists and researchers free of charge access to high-quality coastal infrastructures that are not available in their home country. This access enables capacity building through the formation of new collaborative relationships between users and the JERICO-RI partners; it also encourages knowledge transfer during users' on-site visits to the host facility.

2. DECADE OF TRANSNATIONAL ACCESS

Access to JERICO-RI facilities commenced with the JERICO-FP7 project in 2011 through to the most recent JERICO-S3 project running until 2024. Throughout three JERICO-RI projects (JERICO-FP7 (Sparnocchia & Meccia 2015), JERICO-NEXT (Sparnocchia & Ferluga, 2019), JERICO-S3 (Gaughan & Berry 2020; Loughlin & Gaughan 2021)) in over 10 years, there has been a significant increase in facilities participating in providing more access to a wider range of infrastructure which addresses the growing needs of the user base.

The development and growth of TA activity from JERICO-FP7 to JERICO-S3 is displayed in Table I. The increase in EU funding after JERICO-FP7 meant that JERICO-RI could offer more access to coastal observation infrastructures. The most successful infrastructure types were i) cabled observatories which provided the greatest number of access days, and ii) gliders which supported the greatest number of projects (Figure. 1). Figure 2 shows the legal status of the lead organisations for projects in each JERICO-RI TA programme, where a diverse user group is developed over the decade.

Table I. The decadal development of JERICO-RI TA programmes is outlined. **a)** Originally 19 facilities offered, however 5 were unavailable due to operational issues and therefore no longer available for offer. **b)** 47 projects were accepted and granted support, however due to project specific problems 4 were cancelled before operations started. **c)** includes associated countries (European Commission, 2019).

	JERICO-S3 (2020-2024)	JERICO-NEXT (2015-2019)	JERICO-FP7 (2011-2015)
Facilities on Offer	42	35	14[a]
Targeted facilities (% vs offered facilities)	23 (55%)	24 (69%)	13 (93%)
Submitted TA projects	49	40	24
Supported TA projects (% vs submitted projects)	43[b] (88%)	28 (70%)	19 (79%)
Days of Access Offered	4466	4128	1385
Number of users (Women, %)	131 (39, 30%)	102 (29, 28%)	55 (14, 34%)
Non-EU Users[c]	8	5	2

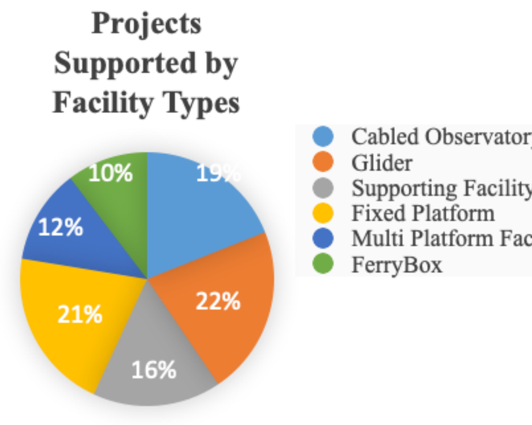

Figure 1. The percent of projects supported by each facility type in all three JERICO-RI TA programmes.

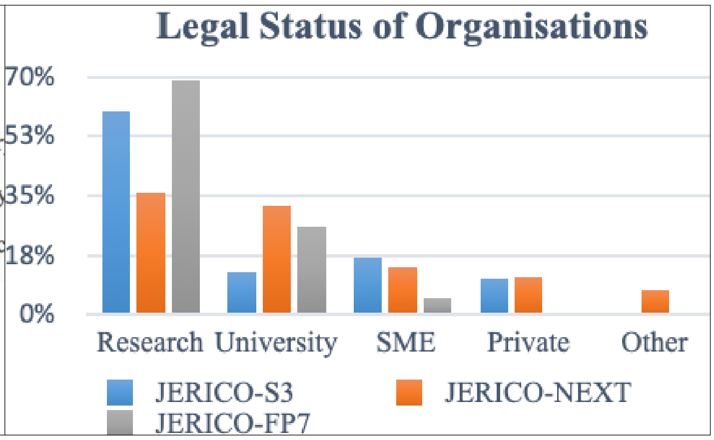

Figure 2. The breakdown of legal status of lead organisations for JERICO-RI projects. Legal status follows the classification of the European Commission.

3. CASE STUDIES

The three case studies below explore the different uses and benefits of the JERICO-RI TA programmes in using operational oceanographic infrastructure for monitoring or testing purposes, and the strengthening of collaborative relationships throughout the decade long access provided.

3.1. YUCO-CTD

Seaber, a French based SME, used the SmartBay coastal observatory (Ireland) to test and validate their micro-AUV YUCO-CTD (Lamson & Simon, 2021). After the JERICO-S3 trials in Galway Bay, the AUV underwent minor redesigns based on the results of the experiment to improve the CTD data collected. These trials provided necessary results for Seaber to provide the marine community with a unique operational oceanographic product (Simon, 2023).

3.2. ABACUS

The ABACUS team, led by Italian Università degli Studi di Napoli “Parthenope”, has realised 5 JERICO-RI TA projects, with multiple missions each, since 2014 using the CSIC & SOCIB gliders (Spain) (Cotroneo & Aulicino, 2023). ABACUS seeks to assess the importance of the monitoring line across the Algerian Basin between Palma de Mallorca and Algeria. This long term collaborative effort with the SOCIB glider technicians has provided consistent monitoring of the water column in the Algerian Basin).

3.3. ANB

ANB Sensors Ltd., a UK based SME, has completed projects in JERICO-NEXT and JERICO-S3 (Lawrence & McGuinness, 2022). JERICO-S3 supported three projects for trialling ANB’s coastal and ocean pH sensors which used the OBSEA coastal observatory (Spain), HCMR multi-platform facility (Greece), SYKE ferrybox (Finland), and the supporting facility of the associated calibration laboratories in Greece and Finland. To date, these trials have allowed ANB to highlight key issues in order to improve the system for long term oceanographic pH monitoring.

4. CONCLUSION

Over the last 10 years the JERICO-RI TA programmes have built upon and enhanced a strong demand from the coastal marine research community for efficient access to marine research infrastructures, enabling better research outcomes through well managed access practices. It is clear that the proposed continuation of this access in a sustainable Research Infrastructure such as JERICO-RI will only improve the efficiency and effectiveness of the Access Programmes. To continue to strengthen the TA programme, JERICO-RI would benefit from a centralised coordination office which would oversee management of facility availability and expertise, and streamline the access process for both users and JERICO-RI facilities. Through providing access to JERICO-RI facilities, the TA programmes have been instrumental in supporting operational oceanographic projects for innovative new technologies and long-term oceanographic monitoring.

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Argo floats as part of monitoring the state of the Baltic Sea

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Keywords

Argo floats, Baltic Sea, monitoring

Abstract

The Argo floats have been used in the Baltic Sea since 2012. The first deployment took place in the Bothnian Sea and since then the operations have expanded to include the Gotland deep, Bornholm Basin, Gdansk Basin, Bothnian Bay and northern Baltic Proper. Although the Argo missions do not cover all the Baltic Sea basins, the increased number of temperature and salinity profiles as well as wider temporal coverage of measurements have significantly increased the possibilities to monitor changes in the state of the Baltic Sea. In addition, an increasing number of floats also measure biogeochemical parameters. The experiences and best practices to operate Argo floats in marginal seas and seasonally ice-covered areas compiled during the Euro-Argo RISE project (2019-2022) further enhanced the availability of Argo data in the Baltic Sea. Measurements throughout the year are now possible in the seasonally ice-covered northern Baltic Sea. Also, methods to perform delayed mode quality control for the Argo data in the shallow Baltic Sea were developed and are now being put to practice by the Baltic Argo community.

1. BALTIC SEA ARGO FLOATS

The use of Argo floats has become a natural part of marine observations in the Baltic Sea. The technologies and methods for using Argo floats have been developed and tested in the Baltic Sea since 2012 (Siiriä, 2018), when Finnish Meteorological Institute started regular Argo measurements in the Bothnian Sea. Since then, the Baltic Sea Argo Program has expanded to also cover several of the Baltic Sea sub-basins (e.g., Walczowski *et al.*, 2020) and is currently performed by three countries with some contributions from EU projects (Fig. 1).

Operating Argo floats in the Baltic Sea poses unique challenges. In the northern part of the Baltic Sea, seasonal ice cover needs to be considered. Sea ice prevents the float from rising to the surface and causes risk of damaging the float. Methods for operating floats in seasonally ice-covered regions have successfully been developed and tested. The Baltic Sea provides an excellent place for this, thanks to its ice winters. Argo floats in the Bothnian Sea and the Bothnian Bay have already been successfully measuring under ice for a few winters, providing valuable data and information on the performance of the methods. There are, however, still challenges in geolocating the profiles under the ice.

While drifting is a desired feature in large oceans for monitoring currents, in the Baltic Sea, it's crucial to limit this due to risks of stranding and deviating from the area of interest. For instance, deployments in the Bornholm Basin can drift into the northern part of the Gotland Basin within months. One strategy to remedy this is choosing mission locations deeper than their surroundings, (e.g., Gotland Deep), and adjusting the diving depth close to the area's maximum depth. An alternate method to restrict free drift is "parking at the bottom." Post-profiling, the float is lowered to the seabed and remains there until the next cycle, typically 1-2 days. This method has markedly minimized float drift, ensuring they stay within a specific basin.

As the operating areas are relatively small, and close to shores, the Argo floats can be frequently recovered from the Baltic Sea, unlike from Oceans. While this requires shortening the missions to ensure the availability of suitable recovery option before batteries run out, the practice makes it possible to reuse the floats multiple times, as well as recalibrating and examining them to detect possible drifts in sensors.

The Baltic Sea, in contrast to the oceans, introduces unique challenges for Delayed Mode Quality Control (DMQC). One of the most prominent differences is the rapid salinity variations across short geographical spans, which means the profiles can look quite different even if taken close from each other. Furthermore, heavy stratification, combined with complex bathymetry results in strong changes even within the same profile. These strong variations would mark many profiles typical for the Baltic Sea as faulty, if common Argo DMQC tools would be applied directly. Both general changes in requirements as well as local tunings for specific areas are required for successful handling of data quality. Figure 2. presents example of the variability of profiles in two locations.

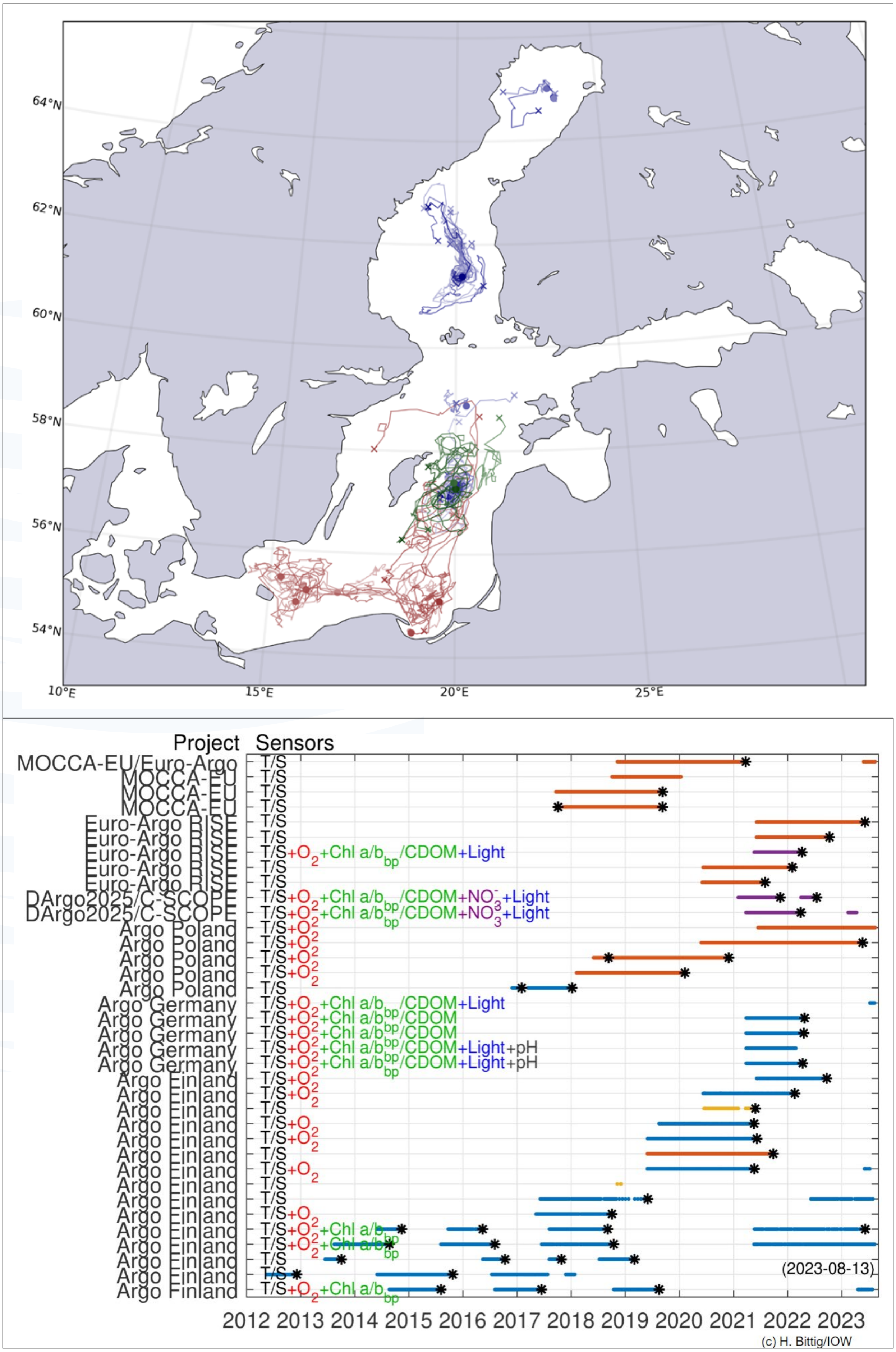

Figure 1. Top: trajectories of the Baltic Sea Argo floats. **Below** temporal coverage of the measurements and sensors used.

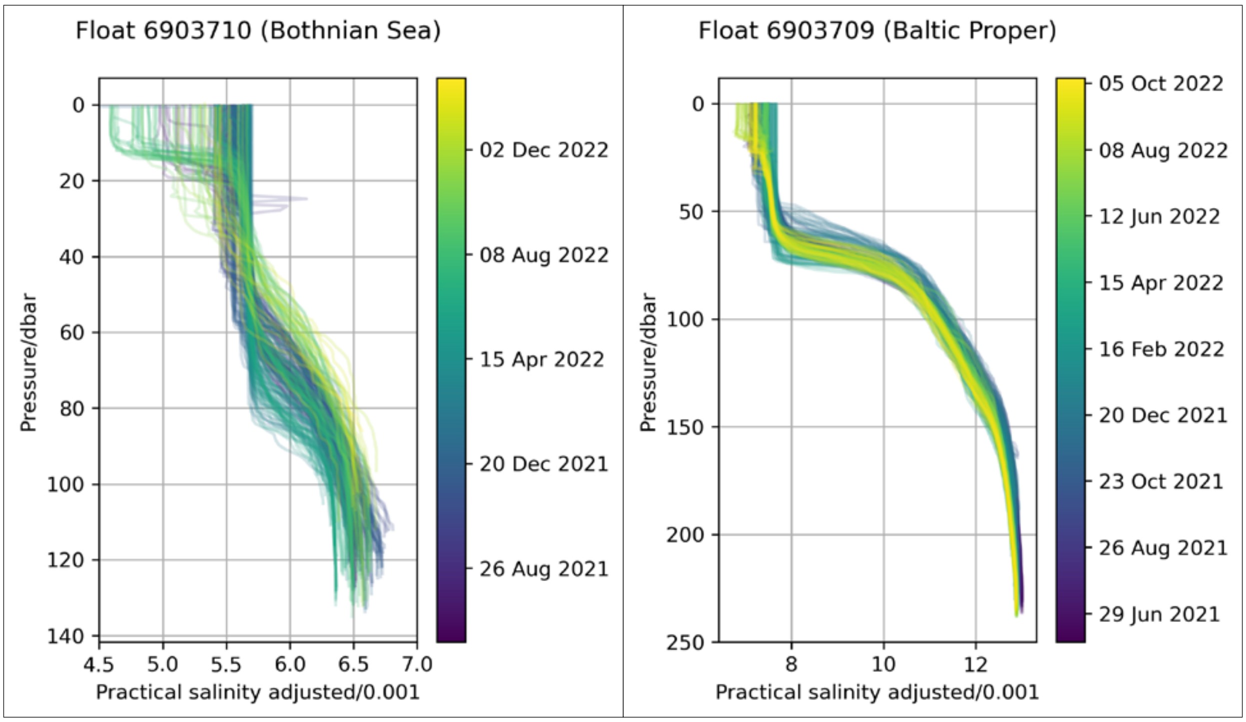

Figure 2. Left: example of salinity profiles from one Bothnian Sea mission. **Right:** a Baltic Proper Mission.

The Argo floats are welcome additions to the Baltic Sea monitoring providing substantial number of measurements. This allows observing of changes on shorter timescales and the analysis of seasonal variations in temperature and salinity, which is not as feasible with traditional methods like shipborne measurements (e.g., Haavisto *et al.*, 2018).

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