MonGOOS 2025

Workshop

"Mediterranean Sea multiscale variability: knowledge, impacts and road ahead"

BOOK OF ABSTRACTS

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CoLAB +ATLANTIC, Lisbon (Portugal), 2-4 December 2025

https://mongoos.eurogoos.eu/

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Lisbon (Portugal)

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MonGOOS General Assembly

3-4 DECEMBER 2025

2025 MonGOOS Workshop

EDITO

MERCATOR OCEAN INTERNATIONAL

SOCIB Balearic Islands Coastal Observing and Forecasting System

cmcc

Consiglio Nazionale delle Ricerche

OGS National Institute of Oceanography and Applied Geophysics

CSIC

Objective of the Workshop

The state of the Mediterranean Sea evolves in time and space in response to both external surface and boundary forcings and internal dynamics. Processes and interactions occur across multiple scales, ranging from quasi-steady sea currents that span hundreds of kilometers to meso/submesoscale and small-scale turbulence with length scales of a few meters only. **Multi-scale hydrodynamics** influences biogeochemical processes that maintain the basin's productivity and are essential for the health of the Mediterranean Sea. **Climate change** impacts add an extra stress to Mediterranean ecosystems and vulnerable economies and societies, which are already threatened by unprecedented levels of human activity, including heavy ship traffic, overfishing, massive tourism, marine pollution with direct consequences on biodiversity loss and habitat degradation. In this context, understanding multiscale interdisciplinary interactions is essential to accurately predict the evolution of the Mediterranean basin and protect its biodiversity.

This workshop invites contributions related to multiscale observational networks in the Mediterranean, including in-situ and remote sensing measurements, instrument intercomparison, accuracy assessment, and data management strategies. We encourage submissions addressing the modelling of Mediterranean hydrodynamics and biogeochemistry, with particular interest in downscaling techniques, assimilation of in-situ and satellite observations, evaluation of model performance in capturing multi-scale processes and uncertainty quantification.

In addition, the workshop promotes the integration of data-driven methodologies, including Machine Learning (ML) and Artificial Intelligence (AI), for short- to medium-term forecasting, sub-seasonal to seasonal prediction, and long-term climate projections, across spatial scales ranging from local to basin-wide. Contributions addressing the representation of the ocean's various components within the framework of the Digital Twin of the Ocean (DTO) are particularly encouraged.

MonGOOS Mission

The Mediterranean Oceanographic Network for the Global Ocean Observing System (MonGOOS) seeks to develop and promote operational oceanography in the Mediterranean Sea. Its strategy is founded on four pillars: enhancing marine science, increasing the visibility and recognition of services, strengthening capacity building that facilitates knowledge transfer among partners, and encouraging downstream applications for social benefits.

Local Organisers

- Francisco Javier Campuzano (+ATLANTIC CoLAB, Portugal)
- Teresa Carmo Costa (+ATLANTIC CoLAB, Portugal)

Chairs

- Vanessa Cardin (OGS, Italy)
- Baptiste Mourre (IMEDEA CSIC-UIB, Spain)

Scientific Committee

- Svitlana Liubartseva (CMCC, Italy)
- Christian Ferrarin (CNR, Italy)
- Manuel Vargas-Yáñez (IEO CSIC, Spain)
- Emanuela Clementi (CMCC, Italy)
- Orens P. de Fommervault (IOC/UNESCO)
- Diego Alvarez (IEO-CSIC)

https://mongoos.eurogoos.eu/

About

The Mediterranean Oceanographic Network for the Global Ocean Observing System (MonGOOS) seeks to develop and promote operational oceanography in the Mediterranean Sea. Its strategy is founded on four pillars: enhancing marine science, increasing the visibility and recognition of services, strengthening capacity building that facilitates knowledge transfer among partners, and encouraging downstream applications for social benefits.

In 2012, MonGOOS established a series of international workshops aimed at providing a forum for experts, professionals, and early carrier scientists working on the latest developments in Mediterranean Sea operational oceanography systems. The last editions of the workshop took place in Málaga, Spain (2024); Tangier, Morocco (2023); Florence, Italy (2022); Virtual (2021); (2020); Trieste, Italy (2019).

Objectives of the workshop

The state of the Mediterranean Sea evolves in time and space in response to both external surface and boundary forcings and internal dynamics. Processes and interactions occur across multiple scales, ranging from quasi-steady sea currents that span hundreds of kilometers to meso/submesoscale and small-scale turbulence with length scales of a few meters only. Multi-scale hydrodynamics influences biogeochemical processes that maintain the basin's productivity and are essential for the health of the Mediterranean Sea. Climate change impacts add an extra stress to Mediterranean ecosystems and vulnerable economies and societies, which are already threatened by unprecedented levels of human activity, including heavy ship traffic, overfishing, massive tourism, marine pollution with direct consequences on biodiversity loss and habitat degradation. In this context, understanding multiscale interdisciplinary interactions is essential to accurately predict the evolution of the Mediterranean basin and protect its biodiversity.

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Local organization
Francisco Javier Campuzano (CoLAB +ATLANTIC, Portugal)
Teresa Costa (CoLAB +ATLANTIC, Portugal)
Soraia Romao (CoLAB +ATLANTIC, Portugal)
Cintia Bonanad (CoLAB +ATLANTIC, Portugal)

Communication support
Alicia Blanco (EuroGOOS)

General Assembly Agenda
Lisbon - Portugal
Hosted by CoLAB +ATLANTIC
R. do Instituto Industrial 16, 1200-225 Lisboa, Portugal

Tuesday 2 December 2025

9:00-9:15 Registration

09:15 - 10:45 Introductive session

09:15 – 09:25 **Welcome by the host institution** – *Nuno Lourenço (CoLAB +ATLANTIC)*

09:25 – 09:35 **Welcome by MonGOOS chairs** - *Vanessa Cardin* (OGS, Italy), *Baptiste Mourre* (IMEDEA CSIC-UIB, Spain)

09:35 – 10:05 *Invited lecture* **Strait of Gibraltar exchange processes and meso- to sub-basin-scale circulations on the Atlantic side** – *Álvaro Peliz (Universidade de Lisboa, Portugal)*

10:05 – 10:25 **EuroGOOS Updates and Ocean Policy** - *Dina Eparkhina, Alicia Blanco* (EuroGOOS, Belgium)

10:25 – 10:45 **MonGOOS objectives, activities and status** - *Vanessa Cardin* (OGS, Italy), *Baptiste Mourre* (IMEDEA CSIC-UIB, Spain)

10:45-11:15 Coffee break

11:15-12:30 Session on MonGOOS Working Group Activities

11:15 – 11:35 **Activities of the MonGOOS Observations WG** - *Manuel Vargas-Yañez* (IEO-CSIC, Spain), *Orens Pasqueron de Fommervault* (UNESCO)

11:35 – 11:55 **Activities of the MonGOOS Modeling WG** – *Emanuela Clementi* (CMCC, Italy), *Christian Ferrarin* (CNR, Italy)

11:55 – 12:15 **Activities of the MonGOOS Applications WG** – *Svitlana Liubartseva* (CMCC, Italy), *Diego Alvarez-Berastegui* (IEO-CSIC)

12:15 – 12:30 **Operational oceanography and fisheries** - *Diego Alvarez-Berastegui* (IEO-CSIC, Spain)

12:30 - 14:00 Lunch

14:00 - 15:20 Session on European projects

14:00 – 14:20 **FOCCUS on the Mediterranean: Integrating coastal observations, models, and applications for climate-resilient coasts** – *Emma Reyes* (SOCIB, Spain)

14:20 – 14:40 **ObsSea4Clim: Ocean observations and indicators for climate and assessments** – *Antonio Novellino* (ETT S.p.A., Italy)

14:40 – 15:00 **EDITO: European Digital Twin Ocean** – *Marina Tonani* (Mercator Ocean International, France)

15:00 – 15:20 **EDITO-Model Lab: underlying models for the European Digital Twin Ocean** – *Francisco Campuzano* (CoLAB +ATLANTIC, Portugal)

15:20-15:45 Coffee break

15:45 - 17:00 Discussion session

15:45 – 16:45 General discussion on MonGOOS activities and evolution

16:45 – 17:00 General Assembly Wrap – up

17:00 General Assembly closure

Mediterranean Sea multiscale variability: knowledge, impacts, and road ahead"

Workshop agenda
Lisbon – Portugal
Hosted by CoLAB +ATLANTIC
R. do Instituto Industrial 16, 1200-225 Lisboa, Portugal

Wednesday 3 December 2025

8:30 - 9:00 **Registration**

09:00 - 10:30 **Session 1:** ***Observing systems for monitoring the Mediterranean Sea multiscale variability***

09:00 – 09:15 **Sustained glider observations reveal multiscale physical-biogeochemical interactions in the Western Mediterranean Sea** – *Nikolaos D. Zarokanellos* (SOCIB, Spain)

09:15 – 09:30 **High-resolution air-sea CO_2 observations during the ATL2MED mission: data correction and process variability across the Eastern Atlantic Ocean and the Mediterranean Sea** – *Riccardo Martellucci* (OGS, Italy)

09:30 – 09:45 **Bathymetric and stratification effects on local dynamics from long-term deep-sea time series** – *Beatrice Giambenedetti (INGV, Italy)*

09:45 – 10:00 **Twenty-first century Mediterranean changes as seen by Argo data: from salinization at the surface towards deep water changes** – *Elena Terzić* (Institut Ruđer Bošković, Croatia)

10:00 – 10:15 **A multi-data approach for long term assessment of the Mediterranean outflow water** – *Marjahn Finlayson* (INGV, Italy)

10:15 – 10:30 **Subsurface ventilation processes in a wind-driven coastal system: insights from the Gulf of Oristano (Italy)** – *Andrea Cucco* (CNR-IAS, Italy)

10:30-11:00 Coffee break and posters

11:00-12:30 Session 1 (cont´d) : *Observing Systems for Monitoring the Mediterranean Sea Multiscale Variability*

11:00 – 11:15 **Long-term variability of eddy kinetic energy in the Mediterranean Sea: A multi-product altimetry perspective** – *Paul Hargous* (IMEDEA (CSIC-UIB), Spain)

11:15 – 11:30 **Revealing deep-sea warming in the Ionian Sea through novel smart cable technology observations** – *Nadia Lo Bue* (INGV, Italy)

11:30 – 11:45 **Climate change and sea level rise in the North Adriatic Sea** – *Sara Morucci* (ISPRA, Italy)

11:45 – 12:00 **Multi-scale interactions in Mediterranean health and biodiversity through innovative Biogeochemical-Argo floats and interdisciplinary cruises** – *Emanuele Organelli* (CNR-ISMAR, Italy)

12:00 – 12:15 **Multiscale Wave Variability from High-Resolution Buoy Networks: Insights into Spectral Coherence and Observational Uncertainty** – *Stefano Taddei* (Consorzio LaMMA, Italy)

12:15 – 12:30 **High-Resolution Digital Twins for Crete: Powering Maritime Safety, optimal ship routing and AI-Driven oil spill response** – *Antonios Parasyris* (Foundation for Research and Technology-Hellas, Institute of Applied and Computational Mathematics, Greece)

12:30 - 14:00 Lunch and posters

14:00 - 15:15 Session 1 (cont´d): *Observing Systems for Monitoring the Mediterranean Sea Multiscale Variability*

14:00 – 14:15 **Impactful coastal marine heatwaves in the Mediterranean Sea: multiscale drivers, observation networks and future strategies** – *Nathaniel Bensoussan* (IFREMER-LOPS, France)

14:15 – 14:30 **Assessing SWOT-Derived Surface Currents against HFR Data in the Western Mediterranean** – *Guiomar López* (SOCIB, Spain)

14:30 – 14:45 **A multiplatform analysis of wind- and river-driven surface circulation in the Gulf of Trieste (northern Adriatic Sea)** – *Davide Lombardo* (OGS, Italy)

14:45 – 15:00 **Observed multiscale variability in the South Adriatic pit over the past two decades** – *Julien Le Meur* (OGS, Italy)

15:00 – 15:15 **Swarms of landers for sustained long-term ocean monitoring** – *César González-Pola* (CSIC, Spain)

15:15– 15:45 Session 2: *Advances in Mediterranean Sea Modelling Capabilities*

15:15 – 15:30 **The Black Sea oil pollution incident in December 2024** – *George Zodiatis* (ORION, Cyprus)

15:30 – 15:45 **OCEAMMUR project: Advancing High-Resolution modelling for sustainable management of the Region of Murcia coast (SE Spain)** – *Cintia Bonanad* (+ATLANTIC CoLAB, Portugal)

15:45 - 16:15 Coffee break and posters

16:15– 17:45 Session 2 (cont´d): *Advances in Mediterranean Sea Modelling Capabilities*

16:15 – 16:30 **The Copernicus Mediterranean Analysis and Forecasting Physical System: recent upgrades and validation** – *Emanuela Clementi* (CMCC, Italy)

16:30 – 16:45 **Improving the Mediterranean Forecasting System model via updated vertical and horizontal physics** – *Lucia Gualtieri* (CMCC, Italy)

16:45 – 17:00 **Validation of Mediterranean Sea biogeochemistry in an operational framework, from basin-wide to process oriented metrics** – *Anna Teruzzi* (OGS, Italy)

17:00 – 17:15 **Marine machine learning applications for sea level and wave forecasting and sparse satellite data reconstructions** – *Matjaz Licer* (Slovenian Environment Agency)

17:15 – 17:30 **Assessment of a high-resolution numerical model's ability to reproduce the dynamics shaped by the Pelops (Ionian Sea) anticyclonic eddy** – *Victor Quilfen* (SHOM, France)

17:30 – 17:45 **High-resolution numerical modeling of the Strait of Gibraltar: Exploring fine-scale dynamics** – *Jean-Baptiste Roustan* (SHOM, France)

20:00 Dinner in Lisbon (Zambeze restaurant, self-paid)

Thursday 4 December 2025

09:00 - 10:45 Session 3: *Advances in Mediterranean Sea Modelling Capabilities and Applications*

09:00 – 09:15 **A cloud-based multi-source approach to estimating ocean heat content** – *Enrico Baglione* (INGV, Italy)

09:15 – 09:30 **About the use of temperature climatologies for the study of the Spanish Mediterranean tropicalization** – *Manuel Vargas-Yáñez* (CSIC, Spain)

09:30 – 09:45 **What can we learn from the extraordinary mucilage event in the northern Adriatic in 2024?** – *Ivica Vilibić (*Institut Ruđer Bošković, Croatia)

09:45 – 10:00 **SHARE4MED - Shared Action Plan for the EU Ocean Mission in the Mediterranean basin.** – *Antonio Novellino* (ETT S.p.A., Italy)

10:00 – 10:15 **Citizen Science and Digital Twin Integration for Coastal Resilience: Lessons from Cala Iris (Morocco)** – *Houssine Nibani* (AGIR Al Hoceima Marine Observatory, Morocco)

10:15 – 10:30 **From saltwater Intrusion to freshwater plumes: Modeling the Adriatic coastal response to drought and flood extremes (2022–2023)** – *Alejandro Paladio-Hernandez* (CNR, Italy)

10:30 – 10:45 **Assimilation of SWOT satellite observations in high-resolution Western Mediterranean simulations** – *Baptiste Mourre* (IMEDEA (CSIC-UIB), Spain)

10:45 - 11:15 Coffee break and posters

11:15 - 12:45 Session 3 (cont´d): *Advances in Mediterranean Sea Modelling Capabilities and Applications*

11:15 – 11:30 **Assimilating nadir SLA at multiple resolutions in the Western Mediterranean Sea** – *Maximo Garcia-Jove* (SOCIB, Spain)

11:30 – 11:45 **December 2019 seiche episodes in the Adriatic Sea** – *Marco Bajo* (CNR-ISMAR, Italy)

11:45 – 12:00 **Oil hazard mapping of the Mediterranean Sea** –*Marco Seracini* (UNIBO, Italy)

12:00 – 12:15 **Integrating observations, models, and theory to characterize multi-scale ocean dynamics in the Northwestern Mediterranean** – *Jordi Isern-Fontanet* (FICM-CSIC/ICATMAR, Spain)

12:15 – 12:30 **Leveraging Objective Eulerian Coherent Structures to reduce drift-forecast errors for operational applications** – *Christian Mario Appendini* (Universidad Nacional Autonoma de Mexico, Mexico / Aarhus University, Denmark)

12:30 – 12:45 **Coastal Digital Twin: A science-based framework for sustainable resilience and adaptation** – *Jacopo Alessandri* (CMCC, Italy)

12:45 - 14:00 Lunch and posters

14:00 - 15:30 Session 4: EDITO TRAINING *(Joint with EuroGOOS Coastal Working Group)*

Introduction – *Gaëlle Henaff Sterbik* (Mercator Ocean International, France)

Training sessions:

Explore - Mathis Bertin (Mercator Ocean International, France)

Create - Lorinc Mesznaros (Deltares, Netherlands)

Contribute - Samuel Fooks (Flanders Marine Institute, Belgium)

15:30-16:00 Coffee break and posters

16:00 - 17:30 Session 4 (cont´d): EDITO TRAINING

Hands-on session: Validation toolbox - Camilo Melo Aguilar (SOCIB, Spain)

On-site support - Francisco Campuzano (CoLAB +ATLANTIC, Portugal), Camilo Melo Aguilar (SOCIB, Spain), Lorinc Mesznaros (Deltares, Netherlands)

Online support - Mathis Bertin (Mercator Ocean International, France), Samuel Fooks (Flanders Marine Institute, Belgium)

17:30 End of MonGOOS workshop

Posters (displayed on 3 and 4 December)

1. **Scaling multiscale coastal observing: Lessons from Global Networks for the Mediterranean** – *Tom Parry* (Sofar Ocean, Netherlands)

2. **Measurements and analysis of medicanes and meteotsunamis in the Strait of Sicily** – *Gabriele Nardone* (ISPRA, Italy)

3. **Enhancing marine monitoring through linked open data: innovations from the PNRR MER Project for Italian Coastal and Offshore Ocean Observation Networks** – *Marco Picone* (ISPRA, Italy)

4. **HPC-enabled oil-spill hazard mapping along shipping lanes in the Italian Seas** – *Juliana Ramos* (CMCC, Italy)

5. **Predicting short-term pollution in coastal zones: an integrated modelling approach** – *Alessandro Alabiso* (DHI, Italy)

6. **FLORETHA, a high-resolution operational system for bay-scale management: early validation in Alfacs Bay, Ebro Delta** – *Maria Liste* (UPC, Spain)

7. **Multi-year observations of the Adriatic Sea: hydrological pattern and variations in summer period** – *Simona Saviano* (Stazione Zoologica Anton Dohrn, Italy)

8. **A Year's Echo: Tracking MOW at 1000 m depth at the North Atlantic gateway** – *Carlos Sousa* (IPMA, CCMAR, Portugal)

9. **C-SWOT2023 field experiment. Mesoscale dynamics under SWOT swaths in the Mediterranean Sea** – Margot *Demol* (IFREMER-LOPS, France)

10. **LisOcean: An operational modelling system for coastal risk management and Blue Economy support in the Lisbon metropolitan area** – Soraia Romao (CoLAB +ATLANTIC, Portugal)

11. **Downscaling techniques for the service of the Spanish ports** – *Anna Matulka* (Puertos del Estado, Spain)

12. **Chasing Mediterranean outflow water with Argo floats** – *A. Miguel Piecho-Santos* (IPMA / CCMAR-Centre of Marine Sciences of the Univ. Algarve, Portugal)

List of abstracts

Subsurface ventilation processes in a wind-driven coastal system: insights from the Gulf of Oristano (Italy)

Andrea Cucco[1], Giovanni Quattrocchi[1], Matteo Sinerchia[1], Alberto Ribotti[1], Andrea Satta[1], et al.*

[1]National Research Council, CNR-IAS, Italy

High-resolution, year-long oceanographic observations were conducted in the Gulf of Oristano, a shallow, semi-enclosed coastal basin on the western coast of Sardinia, to address a critical gap in in-situ hydrodynamic data. Using a combination of synoptic CTD surveys and continuous current meter and temperature measurements (2023–2024), the study captured detailed spatial and temporal variability in thermohaline structure and circulation. Circulation was found to be predominantly wind-driven, with moderate to strong correlations between current velocities and local wind forcing. Beyond expected seasonal patterns, summer exhibited alternating periods of stratification and mixing. Spectral analysis revealed 20-day cycles in bottom temperature and current speeds, linked to pulsing moderate winds. These events advected cooler, stratified offshore waters into the Gulf, periodically ventilating the basin through horizontal advection rather than vertical mixing. This peculiar ventilation mechanism not only modified the thermal and density structure but also influenced biological processes. Satellite-derived chlorophyll-a concentrations showed episodic increases following wind-driven advection, suggesting enhanced primary productivity due to nutrient import. These findings underscore the sensitivity of semi-enclosed, wind-dominated systems to moderate wind events, with implications for their response to future climate-driven changes in wind patterns.

Twenty-first century Mediterranean changes as seen by Argo data: from salinization at the surface towards deep water changes

Elena Terzić[1], Ivica Vilibić[1], Vanessa Cardin[2], Julien Le Meur[2], Martin Vodopivec[3], et al.*

[1]Institut Ruđer Bošković, Croatia
[2]OGS–National Institute of Oceanography and Applied Geophysics, Italy
[3]National Institute of Biology, Slovenia

The Mediterranean Sea exhibits pronounced climate-driven transformations across multiple scales, as revealed by Argo observations. In the deep Southern Adriatic Pit (dSAP), a mid-2000s transition has led to unprecedented warming (0.8ºC) and salinization (0.2) over the past decade, accelerating beyond historical trends and reversing previous density patterns. These changes, sustained by increasingly saline-driven dense water formation in the northern Adriatic and reinforced by inflows from the Eastern Mediterranean, propagate into the deep Ionian Sea, reflecting the coupled influence of regional and basin-wide processes. Concurrently, surface layers across Mediterranean basins show increasingly frequent–surface saline lakes–(SSLs), characterized by strong near-surface salinity gradients during summer. SSL prevalence peaks between August and October, affecting up to 70% of profiles in the Levantine basin and spreading into northern basins. Depths and intensity of SSLs exhibit significant positive trends, linking atmospheric heat and water fluxes to thermohaline modifications at intermediate and deep levels. Together, these findings highlight the rapid amplification of Mediterranean warming and salinification, from surface SSLs to deep Adriatic and Ionian waters, emphasizing the critical role of Argo data in detecting, quantifying, and contextualizing ongoing climate-driven ocean changes.

Marine machine learning applications for sea level and wave forecasting and sparse satellite data reconstructions

Matjaz Licer[1], et al.*

[1]Slovenian Environment Agency, Slovenia

This presentation discusses the role of deep learning in environmental research, forecasting, and applications, with a focus on work done at the Slovenian Environment Agency. It introduces the HIDRA model, which is used for storm surge predictions in Slovenia, Denmark, and Estonia, and addresses key forecasting problems related to the phase lag between tides and seiches. The DELWAVE model is presented as a tool for emulating surface ocean gravity waves, capable of simulating future climate scenarios. The CRITER and DIRECT algorithms are used for reconstructing sea surface temperature (SST) fields and other sparse satellite data. The SIREN model is in development for hydrological flood predictions.

Measurements and analysis of medicanes and meteotsunamis in the Strait of Sicily

Gabriele Nardone[1], Carlo Lo Re[1], Marco Picone[1]*

[1]ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale (Italy)

We explore the influence of climate change on the occurrence of extreme marine events in the central Mediterranean and aims to deepen our understanding of medicanes and meteotsunamis by integrating long-term observations from marine monitoring systems with the analysis of recent events in the Strait of Sicily. Data were collected through the ISPRA monitoring network. The medicane under study displayed the structural characteristics typically associated with tropical cyclones in the Mediterranean basin. Its development and trajectory revealed anomalous atmospheric and oceanic conditions that align with signals of broader climate change. In contrast, the meteotsunami event, although clearly recorded by the monitoring system, exhibited more complex dynamics. The available data do not conclusively establish a direct relationship between meteotsunami occurrence and climate variability, highlighting the need for targeted research. These findings highlight two key points:(1) medicanes appear increasingly relevant as indicators of climate anomalies in the Mediterranean region, reinforcing concerns about the basin's vulnerability to extreme weather events; (2) meteotsunamis in this context are still insufficiently defined, suggesting that future studies should prioritize the connection between their generation and climate-related forcing factors. In conclusion, this research demonstrates the importance of expanding and integrating observations including through the MONGOOS network.

The Black Sea oil pollution incident in December 2024

George Zodiatis[1], Panayiota Keramea[2], Georgios Sylaios[2], Giovanni Coppini[3], Svitlana Liubartseva[3], Hari Radhakrishnan[1], Andreas Nikolaidis[1], Kyriakos Prokopi[1], Dmitry Soloviev[4]*

[1]ORION, Cyprus
[2]DUTH, Greece
[3]CMCC Foundation – Euro-Mediterranean Center on Climate Change, Italy
[4]MHI-RAS, Russia

The Black Sea is vulnerable to major oil spill incidents due to maritime accidents, following the sinks of tankers under severe met-ocean conditions. One of the first well documented oil pollution in the Black Sea was caused between November 10-12, 2007 in the Kerch Strait, following the oil leakage of around 6,500 tons from several vessels that were sunk and damaged due to extreme met-ocean conditions (Korshenko et al. 2011), impacted about 180 km of nearby shoreline. A similar oil pollution in the Black Sea was caused on December 15, 2024, where about 4,000 tons of mazut fuel leaked, when the hull of the tanker “Volgoneft 212” broke at the southern entrance of the Kerch Strait. The weather at that time was very rough, with winds of up to 18 m/s and significant wave heights of up to 3 m and max. wave heights of up to 5.5 m. To address the challenge of this oil pollution incident, the well-established MEDSLIK oil spill model was used along with the CMEMS Black Sea currents, the CYCOFOS waves and the SKIRON winds. It was predicted (Zodiatis et al. 2025) and reported from on-site observations that the oil spill during the first 3 days impacted an extended part of the nearby southeastern coast, up to 60 km long from Veselovka to Anapa beaches, along the northeastern shorelines of the Black Sea, while later due to the change of the met-ocean conditions the oils spill entered the Kerch Strait, and affected the western shoreline of the strait.

LisOcean: An operational modelling system for coastal risk management and Blue Economy support in the Lisbon metropolitan area

Soraia Romao [1], Teresa Costa[1], Cintia Bonanad[1], Francisco Campuzano[1], Pedro Almeida[1] et al.*

[1]CoLAB +ATLANTIC, Portugal

The Lisbon Metropolitan Area (AML), with 2.8 million inhabitants, concentrates key economic activities along its coast and estuaries, including ports, marinas, bivalve aquaculture, tourism, industrial hubs, and protected areas. However, the region faces pressures such as flooding, erosion, heat waves, and risks associated with maritime traffic. To support the sustainable development of the blue economy, the LisOcean hydrodynamic operational model was implemented, fully covering the water continuum from the Tagus and Sado estuaries to the ocean. The MOHID-based model, with a 280 m resolution, integrates AROME-model, Copernicus Marine and EMODnet data, and is coupled with SWAN to forecast the coastal risk due to the total water level. Complementarily, a seasonal forecast for LisOcean with a 6-month horizon simulates hydrodynamics and water quality in the estuaries and adjacent coastal zone, supporting key sectors in adapting to seasonal variability. These forecasts are distributed using international standards and tailored to the requirements of the target end-users such as ports, environmental agencies, and oyster producers, aiding risk management and blue economy activities. Cost-effective technologies and citizen science are integrated to enhance monitoring capacity and validate modelling results in under-sampled areas. An online visualization portal aggregates observations and simulations, serving as a one-stop-shop for coastal data in the AML.

Downscaling techniques for the service of the Spanish ports

Anna Matulka[1], et al.*

[1]Puertos del Estado, Spain

Ports suffer from extreme events related to essential physical variables, especially wind, waves and sea level. These affects port installations during all phases of the harbor life, from design to operation. To respond to these complex needs at Puertos del Estado the SAMOA initiative (System of Meteorological and Oceanographic Support for Port Authorities) was born to enhance the delivery of user-customised operational met-ocean information to aid Spanish Port Authorities making harbour safety, environmental management and operational decisions. This initiative provides high-resolution coastal operational prediction systems in domains such as harbours and nearby coastal waters. The SAMOA systems are based on high-resolution ROMS model applications. The CMEMS downstream services are being used for the coastal models nested into the regional IBI forecast solution and at the surface, SAMOA systems use as forcing daily updated hourly winds and heat and water fluxes from the Spanish Meteorological Agency forecast services.

Linking *in-situ* observations and marine heatwaves: insights from the ObsSea4Clim Project

Antonio Novellino[1], Beatrice Maddalena Scotto[2], Steffen Olsen[3], Chiara Bearzotti[3], Ronan McAdam[4] et al.*

[1]ETT S.p.A., Italy
[2]University of Genoa, ETT S.p.A., Italy
[3]DMI, Denmark
[3]CMCC Foundation – Euro-Mediterranean Center on Climate Change, Italy

ObsSea4Clim(Ocean observations and indicators for climate and assessments) is a HE project that aims to advance the European ocean observation framework by strengthening the definition and application of EOVs and ECVs. Building on the GOOS Rolling Review of Requirements (RRR) process, the project develops methodologies and tools to improve the reliability, accessibility, and interoperability of ocean data in support of climate assessments, ESM, and sustainable development indicators. Within this context, a Density Map tool has been created to evaluate the spatial and temporal coverage of in-situ observations made available through EMODnet Physics. This tool provides an interactive way to identify observational gaps, quantify data availability, and assess the adequacy of monitoring systems. Beyond coverage assessment, it also enables the extraction of correlations between in-situ temperature records and marine heatwave events, thus supporting the validation of extreme climate indicators and improving the reconstruction of past events. Marine heatwaves represent one of the project's core application areas, as they are increasingly frequent under climate change and have strong impacts on ecosystems, fisheries, and socio-economic activities. By linking in-situ data density with the detection of extreme events, ObsSea4Clim contributes to reducing uncertainties in EOV/ECV-based indicators and enhances Europe's capacity to monitor, understand, and predict ocean-climate interactions.

Long-term variability of eddy kinetic energy in the Mediterranean Sea: A multi-product altimetry perspective

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Mesoscale activity influences ocean variability by modulating the mixing of biogeophysical tracers, such as heat and carbon. Eddy Kinetic Energy (EKE), a metric used for studying the intensity of mesoscale processes, has been shown to increase globally in energetic regions such as the principal western boundary currents. Here, we assess whether the Mediterranean Sea, a hotspot for climate change impacts, exhibits such intensification. Using daily geostrophic currents from satellite altimetry, we estimate EKE trends over the last three decades. We compare EKE trends computed from three different gridded altimetry products: a global product derived from a stable two-satellite constellation (two-sat) and two other products (global and European) incorporating all available satellites (all-sat). While all products reveal a general EKE increase Mediterranean Sea-wide, the trend from the two-sat product is not statistically significant. This discrepancy is strongly correlated to the increasing number of satellites over time used to construct the all-sat data sets, which enhances both spatial and temporal coverage. To evaluate the fidelity of these trends, we compare gridded and along-track data in contrasting high-energy regions of the Mediterranean Sea: the Alboran Sea and the Ierapetra area. Our findings highlight the importance of using altimetry products with a stable number of satellites constructed for climate applications when addressing long-term ocean variability analysis.

SHARE4MED - Shared Action Plan for the EU Ocean Mission in the Mediterranean basin

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SHARE4MED (SHAREd transition agenda FOR the MEDiterranean) is a governance project under Interreg NEXT MED Programme that supports Mediterranean cities in achieving the EU's Restore our Oceans and Waters goals. The project recognizes that small municipalities often lack the scale, resources, and collective influence for effective sustainability and climate action initiatives. This fragmentation limits regional capacity to protect the crucial Mediterranean ecosystem. SHARE4MED addresses this by providing methodologies and tools enabling municipalities to coordinate actions and monitor local and collective progress. The project builds on the Coalition of Mayors for the Ocean Mission and acts as a key instrument for its geographical expansion and operationalization to non-EU countries like Algeria and Tunisia (project partners), ensuring a truly transnational approach. The main outputs are the Shared Action Plan and the SHARE4MED Governance Dashboard. The Shared Action Plan harmonizes municipal actions across borders while, the Dashboard is an IT platform integrated with data sources, such as EMODnet and Copernicus, that provides municipalities with a clear, data-driven overview of their impact, helping them to adjust policies and make informed decisions. The project aligns local efforts with the EU Mission Ocean, enhancing regional governance and awareness to drive sustainable development.

Improving the Mediterranean Forecasting System model via updated vertical and horizontal physics

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The interplay of vertical mixing and horizontal transport operates across scales and is critical in the Mediterranean Sea, where stratification and basin-scale gradients enhance sensitivity to multi-scale dynamics. Vertical mixing drives mass, heat, and nutrient transport vertically, but must be parameterized due to unresolved small-scale turbulence, while horizontal advection and diffusion spread them laterally. Optimizing these processes together is challenging, as mismatches can lead to biases in stratification, unrealistic water mass pathways, and degraded model skill.
Our model builds on the Mediterranean Forecasting System (Med-FS) of the Copernicus Marine Service, using the NEMO general circulation model coupled with WaveWatch III, including an Atlantic box to resolve exchanges at the Strat of Gibraltar. Sensitivity tests on vertical mixing (including different mixing schemes) and horizontal dynamics were performed and evaluated against ARGO floats and satellite observations. These tests identify an optimal configuration that significantly improves the Med-FS representation of temperature and salinity for 2015–2023 across temporal and spatial scales. This new configuration also substancially improves the representation of mesoscale SST patterns and removes a spurious warming trend at the depth range of the Levantine Intermediate Water. At the Strait of Gibraltar, we also show that local mixing at Camarinal Sill modulates basin-scale circulation.

High-resolution numerical modeling of the Strait of Gibraltar: Exploring fine-scale dynamics

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For several years, LAERO and SHOM have developed a high-resolution ocean circulation model based on the non-hydrostatic, non-Boussinesq core of the Coastal and Regional Ocean Community model (CROCO). The simulation uses three two-way nested grids, increasing the resolution from 900 m in the surrounding basins to 60 m over Camarinal Sill, the main topographic feature of the Strait of Gibraltar.
This configuration has been extensively validated using data from a field campaign conducted by SHOM aboard R/V L'Atalante in October 2020, dedicated to sampling fine-scale dynamics. The resulting dataset provides valuable insights into small-scale processes (Roustan et al., 2023; 2024a; 2024b).
Building on these results, we first assess the model's ability to reproduce the complex fine-scale structure of the flow and associated mixing. Then, the impact of the nested grid, which enable to simulate the largest turbulent eddies, is further investigated. Finally, preliminary indications of small-scale feedback on the large-scale circulation are discussed.

Predicting short-term pollution in coastal zones: an integrated modelling approach

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Within the framework of the Italian PNRR MER – Marine Ecosystem Restoration project, funded by the European Union under NextGenerationEU, MISSION 2 – Green Revolution and Ecological Transition – COMPONENT 4 – Protection of Land and Water Resources –, and INVESTMENT 3.5 – Restoration and Protection of Marine Seabed Habitats, an integrated modelling system is being developed to predict short-term pollution events in coastal and marine areas characterized by the presence of aquaculture and tourist–recreational activities. The system is implemented at three pilot Italian sites – Sacca di Goro (Adriatic Sea), Follonica (Tyrrhenian Sea), and Lavagna (Ligurian Sea) – using SHYFEM–WW3 based modelling systems, and, for Lavagna, an additional MIKE by DHI based modelling system (dual operational configuration). The system enables 72-hour forecasts of wave and hydrodynamic conditions, and the dispersion of pollutants (E. coli and particulate organic matter) originating from discharges, river inputs, and aquaculture sites. Beyond the marine–coastal component, the system integrates the characterization of contamination sources and processes, supported by dedicated ongoing monitoring activities, a hydrological–hydraulic module for estimating river flows and concentrations, and the engineering and automation of the modelling framework under a comprehensive platform. Together, these components will provide operational support for coastal zone management during short-term pollution events.

Observed multiscale variability in the South Adriatic pit over the past two decades

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Multiscale variability and climate-induced changes in the South Adriatic Pit (SAP) were analyzed using high-frequency time series of thermohaline data from the EMSO-E2M3A Regional Facility (spanning 2006 to present), complemented by Argo floats and reanalysis data. The study examines how physical processes, from the basin scale to the microscale, modulate thermohaline variability and deep ventilation.
On the basin scale, over the past two decades, the SAP has undergone increased warming and salinization, with rates up to four times higher than in the Mediterranean. Winter 2017 marked a turning point in the SAP dynamics, as the water column shifted to a two-layer structure due to the intrusion of high-salinity Levantine Intermediate Water.
At the submesoscale, intermittent gravity currents were observed in the deepest layer of the SAP in 2012, 2017, 2018, and 2022. These events showed increased importance of salinity, variability in the gravity current path, and timescales of around two months from the North Adriatic to the SAP.
At the microscale, salt fingering was identified as the main double-diffusive regime, leading to enhanced vertical mixing. After the 2017 event, the subsurface layer (350-550 dbar) showed an increase in salt fingering observations from 27% to 72%.
The results indicate that 2017 was a pivotal year for the SAP thermohaline variability, and that multiscale process analysis is essential for investigating climate-induced changes across the Mediterranean.

Assessment of a high-resolution numerical model's ability to reproduce the dynamics shaped by the Pelops (Ionian Sea) anticyclonic eddy

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During the past few years, the SHOM has developed a global ocean circulation model for the Mediterranean Sea which resolution (~1.8 km and 80 vertical levels) is commensurable everywhere with the first internal Rossby radius; it is thus able to capture a wide part of the dynamical scales across the spectra. Its numerical solutions have been extensively validated against in situ observations (moorings, Argo floats, and oceanographic cruises) and remote sensed observations (SST and SSH from radiometer and altimeter) with a series of targeted and original diagnostics. After a general overview of these simulations and diagnostic, a focus on the PROTEION experiment period (March 21st to April 17th 2024 – Ionian Sea) will be presented. The targets of this experiment at sea are two equilibrated anticyclonic eddies: Pelops and a past-Pelops which has drifted westward from its generation area. PROTEION data exhibits some particular features that should be accounted for in numerical model (especially the deep roots of these long-lived eddies). These two eddies are likely to play a significant role in the fate of the warm and salty waters out from the Cretan Sea and the fate of the Levantine Intermediate Waters from the eastern to the entrance of the western basin. Particular attention is paid to the way the dynamics shaped by these persistent and recurrent eddies is captured from large mesoscale to the surrounding submesoscale.

A cloud-based multi-source approach to estimating ocean heat content

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The Mediterranean Sea is warming at an accelerated rate, exceeding the global ocean average and exhibiting marked changes in its thermohaline structure. Due to its semi-enclosed nature and complex circulation, this region is particularly sensitive to the impacts of climate change: this highlights the urgency of improved monitoring tools.
This study presents an enhanced cloud-based workflow for estimating the Ocean Heat Content (OHC) across user-defined sub-regions and depth layers of the Mediterranean basin. Developed within the framework of the EU Blue Cloud 26 project, the workflow aims to integrate machine-to-machine access through Beacon data lake to major marine data infrastructures (SeaDataNet, Copernicus Marine Service, EuroArgo, and the World Ocean Database) for a multi-data assessment approach.
The Beacon output in parquet format is vertically interpolated on standard vertical levels for further horizontal gridding through the DIVAnd tool. The results are validated against ocean reanalysis products from INGV and the Copernicus Marine Service.
Preliminary results highlight the spatial and vertical variability of OHC trends, shedding light on the dynamic interplay between circulation patterns and regional warming. This refined workflow enables continuous updates of essential ocean variables indicators, ensuring alignment with the latest community standards and supporting data-driven decision-making for climate adaptation in the Mediterranean region.

Multi-scale interactions in Mediterranean health and biodiversity through innovative Biogeochemical-Argo floats and interdisciplinary cruises

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Marine ecosystems are profoundly threatened by climate stress and anthropogenic pressures that disrupt circulation patterns, increasing the vulnerability of biodiversity and trophic webs. Planktonic communities are particularly affected, with cascading impacts on carbon fluxes to the seafloor. Understanding interactions between physical and biological processes across scales remains challenging, especially in oligotrophic open-ocean regions where meso- to submesoscale dynamics generate transient productivity and diversity hotspots.

Within the Italian ITINERIS project, new observational efforts have targeted to address multi-scale interactions that characterize the health and biodiversity of planktonic ecosystems in Mediterranean open waters. An array of nine BioGeoChemical-Argo floats, equipped with innovative sensors to measure phytoplankton and zooplankton abundance and diversity, provides the core observations for investigating multi-scale ecosystem properties in the upper 2 km. During the ITINERIS–EYES cruise (July 2025), these floats were strategically deployed in dedicated multi-platform experiments, combining drifters, gliders, ship, and ferrybox acquisitions. This coordinated approach allowed investigation of biodiversity–circulation interactions by exploiting the complementary observing capabilities of the different platforms.

Here, we present achievements and integration strategies pursued to enhance marine interdisciplinary and multi-scale observations.

Revealing deep-sea warming in the Ionian Sea through novel smart cable technology observations

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Through the first European implementation of wet smart cable technology, we present compelling evidence of deep-sea warming in the Ionian Sea. Real-time temperature data collected from three points, spaced six kilometers apart along a 20-km cable, reveal a clear warming trend in deep Ionian waters, enhancing knowledge of an area monitored since 2001.
The Smart Cable initiative represents a major advance in real-time, continuous deep-ocean observation, offering a pathway to bridge knowledge gaps in remote and poorly accessible regions. Ensuring the long-term reliability of such time series requires systematic validation and the development of dedicated methodologies. However, cross-correlation analyses with data from other autonomous observatories in the Western Ionian Sea confirm the robustness of the results, providing an unprecedented view of deep-ocean thermal variability over the past two decades.
These findings raise new scientific questions on deep-sea heat transport, water-mass transformation, and broader climate feedbacks. Our work highlights the transformative potential of smart cable systems for continuous, high-resolution monitoring of ocean change, and underscores the urgent need to expand deep-sea observational networks capable of capturing long-term trends in a rapidly evolving climate system.

Nearshore Mediterranean Sea Level Variability from SWOT KaRIn

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We appraise the capability of SWOT–KaRIn observations to resolve coastal sea-level variability and extremes across the Mediterranean, in comparison with gridded L4 products (NRT, MY, MIOST v.2.0.1). Coastal series are constructed by collocating wide-swath KaRIn segments with CMEMS tide gauges within coastal buffers and applying a uniform protocol. Performance is quantified with correlation, RMSE, bias, and variance ratio; extreme-event skill is examined using a peak-over-threshold framework.

Beyond the standard 2-km L3 product, we also examine the 250-m coastal KaRIn fields. After strict coastal/land-contamination screening, the 250-m product yields systematically closer agreement with tide gauges in the very nearshore and sharper reproduction of storm-forced set-ups than 2-km L3, particularly on narrow shelves, in semi-enclosed gulfs, and through island straits. Tide gauges act as the ground truth throughout. To complement their point coverage, SCHISM hydrodynamic simulations provide spatially continuous context to characterize event footprints, phase propagation, and consistency along uninstrumented coasts.

Regional contrasts between Western and Eastern sub-basins reveal where KaRIn information is effectively propagated into L4 reconstructions and where sampling gaps or complex bathymetry still constrain skill, offering guidance for integrating SWOT into Mediterranean coastal monitoring (nowcasting and alerts) and for refining L4 interpolation schemes nearshore.

A multi-data approach for long term assessment of the Mediterranean outflow water

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The Mediterranean Outflow Water (MOW) is a North Atlantic intermediate water mass exiting the Mediterranean Sea through the Strait of Gibraltar, which has demonstrated increased temperature and shifting salinity in most recent decades. MOW thermohaline characteristics depend on the long term changes in the Mediterranean Sea and its relationship with the North Atlantic. Using a multi-data approach, we cross-validate the best available in-situ and model data products to maximize the data availability in our analysis and reduce the resulting uncertainty. We analyze the long-term changes in MOW from the Strait of Gibraltar to the Bay of Biscay, and recompute and extend the Copernicus Marine Service MOW indicator using the best available data outputs. The analysis considers in-situ observations from the Espartel Sill mooring, the World Ocean Atlas 2023, global and regional reanalyses. The MOW index has been estimated exploiting the Blue Cloud Virtual Research Environment to subset in-situ data from the Beacon Data Lake instances of SeaDataNet, CORA, World Ocean Database and ARGO and the European Digital Twin of the Ocean platform to extract the reanalysis and hindcast products. Due to the resolution differences and modeling system implementations in the multiple datasets, meticulous result interpretation is imperative. Generally, results show consistency between models and observations, allowing the derivation of long term tendencies even if historical observations are sparse.

Coastal Digital Twin: A science-based framework for sustainable resilience and adaptation

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A Coastal Digital Twin of the Ocean (C-DTO) provides an integrated and dynamic framework that merges near-real-time observations with predictive modelling to advance science-based coastal resilience and sustainable management. The system features six interlinked cores–waves, circulation, sediment transport, vegetation, flooding, and biogeochemistry–capturing critical feedbacks such as wave-current, wave-sediment, current-vegetation, and hydrodynamic–biogeochemical interactions. Built on deterministic foundations and enhanced by machine learning, the C-DTO assimilates diverse datasets including bathymetry, vegetation, and ocean state variables to improve calibration and forecasting. The coupling of biogeochemical and physical dynamics enables the assessment of ecosystem functioning, carbon cycling, and water quality under changing conditions. Designed for flexibility and accessibility, the framework supports forecasting, scenario testing, and evaluation of both gray and nature-based adaptation strategies. Case studies, including the Ianos Medicane, seagrass-based protection, breakwater impacts, Posidonia restoration, and Venice Lagoon barrier operations, highlight its capacity to simulate complex processes and inform adaptive, sustainable coastal management.

FLORETHA, a high-resolution operational system for bay-scale management: early validation in Alfacs Bay, Ebro Delta

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The Ebro Delta, a low-lying, heavily managed system in the NW Mediterranean, faces growing pressures from climate variability and resource use while hosting ecosystems of high conservation value (Natural Park, Natura 2000, UNESCO Biosphere Reserve). Within this setting, Alfacs Bay supports productive aquaculture alongside sensitive habitats. To support bay-scale decisions, NOW Systems, IRTA and UPC are developing FLORETHA, an operational service linking Copernicus Marine products to local high-resolution needs.

FLORETHA builds on a COAWST wave-current coupled system nested in the Copernicus Marine regional solution, extending the existing Ebro Delta downscaling (e3HOPE) with a new ~70 m domain for Alfacs Bay and delivering seamless regional-to-bay forecasts. The service is integrated into the NAUI platform, a configurable web layer that merges in situ observations and model outputs at stakeholder-selected sites.

We present the first-stage implementation of the Alfacs system and its pre-operational qualification based on a one-year hindcast. Validation against CTD profiles demonstrates skill for temperature and salinity, reproducing the seasonal stratification cycle and river-driven low-salinity pulses that shape flushing and exposure in the bay. These early results provide a robust baseline for FLORETHA and define the roadmap toward impact-oriented indicators and early-warning products, Coastal Flooding & Erosion and Harmful Algal Bloom risk, within the NAUI platform.

Climate change and sea level rise in the North Adriatic Sea

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Tide gauges provide long-term relative sea level changes, that are inherently influenced by Vertical Land Movements (VLM), which can obscure the true signal of Absolute Sea Level Rise (ASLR).
The integration of GNSS with tide gauges has significantly enhanced the accuracy and reliability of Absolute Sea Level measurements.
Before the use of GNSS, it was challenging to distinguish oceanographic trends from local geological processes. This is the case of Punta della Salute (Venice), which holds one of the longest time series in the Mediterranean basin. For decades, subsidence in Venice was estimated using a mareographic approach: the nearby Molo Sartorio station (Trieste) located in the same North Adriatic sector and considered geologically stable was assumed to be a fixed reference point. By comparing the mean sea level time series of the two locations, the difference was entirely attributed to the VLM, i.e. the subsidence affecting Venice city centre.
The integration of GNSS data made it possible to directly measure the VLM, allowing for the distinction between absolute sea level rise (eustatism) and vertical land motion (subsidence). Using this integrated approach, an ASLR of about 3 mm/yr has been evaluated in 2000-2024, in agreement with Copernicus satellite estimates for the North Adriatic basin.
In such vulnerable coastal area, the combined use of these monitoring systems provides essential information for evidence-based decision-making and climate adaptation strategies.

A multiplatform analysis of wind- and river-driven surface circulation in the Gulf of Trieste (northern Adriatic Sea)

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This study examines the dynamics of the Gulf of Trieste (GoT) under varying environmental conditions. The analysis focuses on the hydrodynamic response of the GoT in autumn 2023 by integrating river discharge, meteorological data, and HF radar measurements, supported by numerical simulations using the MITgcm model. Between October and November 2023, significant Isonzo/Soča floods coincided with sea level rise and a severe coastal storm, resulting in flooding and damage to coastal infrastructures. The event showed that strong river outflow can locally influence circulation patterns, generating anticyclonic circulation in the central GoT and cyclonic circulation in the northern area. The study also highlights the impact of wind in the absence of river input. Bora winds reinforce the typical cyclonic circulation and offshore flow, while southerly winds induce anticyclonic circulation, enhancing onshore flow, and raising the sea level. Southerly winds were observed to accelerate surface currents more effectively than Bora due to their larger fetch. Based on the 2023 results, CODE drifters were deployed in 2024–2025 under different wind and river discharge conditions to validate HFR data and characterise currents. Qualitative drifter analyses confirmed agreement with HFR measurements. Overall, the combined dataset provides a comprehensive overview of the interaction between freshwater input, meteorological forcing, and surface currents in influencing GoT dynamics.

Validation of Mediterranean Sea biogeochemistry in an operational framework, from basin-wide to process oriented metrics

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The Med-BGC system provides forecasting and reanalysis products for Mediterranean Sea biogeochemistry as part of MED MFC within the operational EU Copernicus Marine Service. Over the past fifteen years, Med-BGC has evolved in scientific and technological aspects including methods for product quality validation, an essential task in Copernicus Marine. Since the beginning, the validation has relied on satellite chlorophyll observations, which ensure relatively uniform spatial and temporal coverage at the sea surface. In addition, in-situ observation datasets have been continuously incorporated, enabling validation in the ocean interior and for a wider range of variables. The availability of real-time BGC-Argo measurements since 2013 has further supported the validation of Med-BGC products. Depending on the availability of satellite and in-situ observations, the skill performance metrics adopted in Med-BGC address different spatial and temporal scales of biogeochemical dynamics, allowing different levels of accuracy estimation to be communicated. For instance, basin-wide spatial gradients and mean annual values (level 1) are validated for primary production, while daily and mesoscale dynamics (level 2) are validated for oxygen and chlorophyll, with specific key biogeochemical processes (level 3) also assessed. In this context, qualified and accessible observation datasets play a crucial role in maintaining and further developing the operational Med-BGC system and its accuracy.

Scaling multiscale coastal observing: Lessons from Global Networks for the Mediterranean

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Understanding and managing the multiscale variability of the Mediterranean Sea requires observing networks that capture the full spectrum of interacting physical, chemical, and biological processes. Coastal regions, where these dynamics converge, remain data-poor due to the high cost and complexity of traditional ocean observing systems.

New approaches that combine in-situ, remote, and model-based observations are reshaping what is possible. Through its global network of over 2,500 multi-parameter Spotter systems, Sofar Ocean has shown how affordable, distributed platforms can generate over 1.5 million near real-time observations daily, supporting both fine-scale and basin-scale analysis. Similar public–private partnerships, such as Aqualink (reef monitoring across 50+ sites) and IMOS (Australia's national observing system), show how shared infrastructure and open data frameworks enhance coverage, interoperability, and research capacity.

These experiences illustrate how hybrid, multi-scale networks could strengthen Mediterranean observing capacity, integrating in-situ sensors, satellite data, and AI-enabled modelling to improve understanding of mesoscale-to-submesoscale dynamics, ecosystem shifts, and human impacts.

By aligning affordable technology, open data governance, and regional collaboration, Mediterranean partners can build a multidisciplinary observing framework that bridges physical and ecological processes to better predict and protect the basin's future.

The Copernicus Mediterranean Analysis and Forecasting Physical System: recent upgrades and validation

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The Mediterranean Analysis and Forecasting System, developed in the framework of the Copernicus Marine Service, operationally produces analyses and 10-day forecasts of the main physical parameters for the entire Mediterranean Sea at 4km resolution.
The system is based on the NEMO hydrodynamic model, including the explicit representation of tides, which is coupled with the WaveWatchIII wave model and forced by high-resolution atmospheric fields from ECMWF. The OceanVar system produces forecast initial conditions by assimilating Sea Level Anomaly and vertical profiles of temperature and salinity; moreover, satellite Sea Surface Temperature gridded data is used to correct heat fluxes. An updated system will become operational in December 2025 which includes: updated lateral boundary conditions at the Dardanelles Strait to better represent the fluxes at the strait and the dynamics in the Aegean Sea; updated data assimilation code, OceanVar2, which includes a barotropic model operator and diffusive filter to better assimilate available observations; an updated operational chain for the production of the daily forecast which will be initialized every day with analysis fields.
Validation results show that the system evolutions have provided an improved skill with respect to the previous one in terms of reduction of tracers and sea level anomaly errors when compared to in-situ and satellite data.
An overview of the future evolutions planned for the next year will also be presented.

High-Resolution Digital Twins for Crete: Powering Maritime Safety, optimal ship routing and AI-Driven oil spill response

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The complex and high-traffic coastal environment of Crete demands a move from traditional metocean forecasts to fully integrated, actionable services. This presentation introduces the Coastal Crete Digital Twin of the Ocean (DTO), an operational framework designed to provide advanced, on-demand applications for maritime stakeholders. The DTO is built upon the COASTAL CRETE 2.0 data assimilated forecasting system, an operational, high-resolution (1 km) coupled model (NEMO-Wavewatch 3) forced by a 3 km WRF dynamically downscaled model, that provides the core metocean data backbone for the region. This high-fidelity forecast data fuels two distinct, high-impact Digital Twin applications: Firstly, the Ship routing/Harbor safety DTO where it provides dynamic, optimized ship routing to reduce emissions and enhances harbor safety. By integrating the COASTAL CRETE 2.0 forecasts with a refined, high-resolution 50-meter wave model (SWAN) for critical areas like the Port of Heraklion mitigating risks during navigation and port operations. Additionally, the service uses the Djikstra optimisation algorithm and VISIR-2 software (Mannarini et al., 2024, Parasyris et al., 2025) to recommend the most efficient routes for vessels, depending on real time weather routing forecasts. Secondly, AI-Driven Oil Spill Response service represents a significant leap toward automated environmental monitoring. It integrates a Deep Learning (U-Net) model that continuously analyzes Near-Real-Time (NRT) Sentinel-1 satellite (SAR) data to automatically detect and delineate oil spills. Upon detection, the system automatically triggers the MEDSLIK-II (De Dominicis et al., 2013) trajectory and weathering model, which is forced by the high-resolution metocean forecasts if the spill falls within the Cretan region. This "detection-to-forecast" pipeline delivers rapid, actionable intelligence on a spill's potential trajectory and fate, enabling a swift and effective response. By linking a high-resolution operational forecast system with specific, AI-enhanced applications, the Coastal Crete DTO framework provides a complete "forecast-to-action" solution. It demonstrates a scalable model for evidence-based decision-making in coastal management, maritime safety, and environmental protection.

Integrating observations, models, and theory to characterize multi-scale ocean dynamics in the Northwestern Mediterranean

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A major challenge in ocean observation, modeling, and understanding arises from the scale dependence of flow properties, a fundamental characteristic of turbulence. Accurately characterizing ocean dynamics therefore necessitates multi-scale observational approaches. At ICATMAR— a joint initiative between the Government of Catalonia and the ICM-CSIC— we have developed an observing network along the Catalan coast designed to complement existing regional systems. This network comprises seven CODAR SeaSonde HF radars (13.5 MHz), five coastal moored observatories measuring wind, waves, and currents, and the regular deployment of surface and ARGO drifters. In parallel, two high-resolution (800 m) numerical models of the northwestern Mediterranean Sea have been implemented using the CROCO and MITgcm frameworks. The CROCO model is coupled to the WaveWatch III wave model, while the MITgcm is coupled to the Biogeochemical Flux Model (BFM). Advancing the understanding of ocean dynamics further requires robust theoretical frameworks for the analysis of both observations and simulations. One such framework is the Multifractal Theory of Turbulence, which posits that dissipation and velocity increments in turbulent flows follow local power-law relationships characterized by singularity exponents. Here, we employ this framework to develop new methodologies for model-observation intercomparison and to enhance our understanding of ocean functioning.

Enhancing marine monitoring through linked open data: innovations from the PNRR MER Project for Italian Coastal and Offshore Ocean Observation Networks

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The PNRR MER (Marine Ecosystem Restoration) project represents a major step forward in the modernization and integration of Italy's marine monitoring networks, with particular focus on the National Wave Measurement Network, the Offshore Wave Network, and the National Tide Gauge Network managed by ISPRA. The initiative enhances the acquisition, management, and dissemination of oceanographic data through upgraded platforms equipped with high-precision sensors, real-time data transmission, and harmonized acquisition protocols.
A central innovation lies in the development of an open, interoperable digital ecosystem for marine observations. All data collected and harmonized within MER are published as Linked Open Data through ISPRA's digital infrastructures, ensuring full adherence to FAIR principles supported by the PNRR ITINERIS project, which strengthens metadata standardization and interoperability across research domains. This approach promotes transparency, facilitates cross-domain integration, supports advanced applications in research, policy-making, and operational oceanography, enables connections across heterogeneous datasets, fostering the creation of knowledge graphs for marine and coastal systems. The proposed architecture supports the integration of data-driven approaches aimed at improving forecasting and long-term climate projections, with its core innovation residing in the ability to transform marine data into interconnected, reusable, and open knowledge.

Multi-year observations of the Adriatic Sea: hydrological pattern and variations in summer period

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The Adriatic Sea is an area of particular interest in the eastern Mediterranean Sea, due to its morphological characteristics, presence of the Po River, and ocean hydrodynamics sensitive to atmospheric conditions. These characteristics make it a climate hotspot in the context of global warming, as it is exposed to marine heat waves (MHW) more frequently than other Mediterranean basins. Hydrographic data collected during oceanographic cruises in the summer period from 2019 to 2025 in 16 sites distributed in the northern-central part of the Adriatic basin was investigated using an integrated approach with in situ measurement of physical parameters, current data from acoustic doppler current profiler (ADCP) measurements and satellite data of Sea Surface Temperature (SST) and turbidity. The Copernicus Reprocessed Mediterranean dataset of SST was used to investigate the MHW in the sampling area using three sites as references for the south, central, and north part of the sampling area. Changes in atmospheric forcing and river runoff lead to observable alterations, as recognized in recent years, and observed during the sampling period, with high variability in salinity values compared to the average value for the basin. In this work, an analysis of the characteristics and variations of the basin's water masses was carried out, considering both factors (atmospheric forcing and river runoff) to understand the contribution of both and the trend of this sub-basin.

About the use of temperature climatologies for the study of the Spanish Mediterranean tropicalization

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Studying this process requires precise knowledge of temperature ranges and their natural variability. This work shows how the use of climatologies in the Spanish Mediterranean, derived from databases compiling observations made within the framework of various projects and observation systems over many decades, allows for the establishment of clear differences between the temperatures preferred by species recently found in the Mediterranean and those native to this sea. A multidisciplinary analysis that combines temperature observations along the water column with knowledge of Mediterranean fish communities allows for a rigorous approach to the problem of the tropicalization of the Spanish Mediterranean, refining previous studies. It shows the arrival of species of tropical origin in the Mediterranean, but highlights that a significant part of these changes is due to other anthropogenic factors, aside from global warming.

HPC-enabled oil-spill hazard mapping along shipping lanes in the Italian Seas

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Oil pollution hazard mapping is critical to anticipate and mitigate spill impacts along heavily navigated coasts. We present a large-scale experiment for the Italian seas that delivers a new generation of hazard maps with stronger multiscale representation and enhanced forecasting capacity. Release scenarios are derived from ship-traffic density maps, with seeding points stratified by vessel category (Pleasure and Passenger ships, Cargo and Service ships, Fishing Fleet, Tankers, and Remaining ships) and fuel type assigned accordingly (Diesel Oil, Crude Oil, or Heavy Bunker Fuel). We apply Monte Carlo ensembles to capture uncertainty in timing, location, and environmental variability and evaluate 10-day trajectories on a 1-km grid. To meet the demand of about 55,000 simulations per month, scalable to higher throughput, Medslik-II is executed in parallel on high-performance infrastructure. Early experiments indicate that large ensembles recover fine-scale spatial heterogeneity and increase the temporal robustness of hazard estimates. Parallel execution runs thousands of simulations concurrently in about the time of a single run, while preserving local detail. By combining data-driven scenarios, ensemble modeling, and scalable computation, this work advances hazard mapping in the Italian seas and has the potential to inform emergency planning, support stakeholders, and contribute to marine digital-twin initiatives.

Chasing Mediterranean outflow water with Argo floats

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The Mediterranean Outflow Water (MOW) plays a key role in shaping the thermohaline structure of the North Atlantic, influencing intermediate water masses and contributing to large-scale circulation. Formed by dense water exiting the Strait of Gibraltar, MOW spreads along the Iberian slope before cascading westward into the Atlantic and mixing with surrounding waters. Despite its importance for water mass transformation and climate dynamics, monitoring MOW is challenging due to complex topography and mesoscale variability.
This study explores the use of Argo profiling floats, especially those with oxygen sensors, to track MOW in the eastern North Atlantic. By analysing temperature, salinity, and oxygen, we identify the hydrographic signature of MOW along float trajectories west of the Iberian margin and south of the Azores Front. Results show that Argo floats can detect key pathways and recirculation zones of MOW, including interactions with the Mediterranean Water Undercurrent and mesoscale eddies ("meddies") that transport its signal over long distances.
The study highlights the value of autonomous observing systems for understanding intermediate-depth water dynamics. Integrating Argo data with models and historical hydrography will improve knowledge of MOW's role in stratification, oxygen distribution, and the Atlantic Meridional Overturning Circulation. Sustained observations are essential to track future changes linked to climate-driven variations in the Mediterranean.

FOCCUS on the Mediterranean: Integrating coastal observations, models, and applications for climate-resilient coasts

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The Mediterranean coast is among the most densely populated and socio-economically active marine regions worldwide. Climate change, coastal urbanization, and intensive human activities increasingly threaten its ecosystems, driving erosion, flooding, and habitat loss. These stresses highlight the need for multi-platform integrated observing systems and advanced modeling to monitor, understand, and predict coastal impacts for adaptive management.
The Horizon Europe FOCCUS (Forecasting and Observing the Open-to-Coastal Ocean for Copernicus Users) project strengthens the coastal dimension of the Copernicus Environment Monitoring Service (CMEMS) by integrating novel observations, models, and applications.
In the Mediterranean, FOCCUS delivers high-resolution products, including: Sentinel-6A sea level, SST and biogeochemical anomalies, seagrass maps, beach monitoring products, surface currents, riverine optical properties. Modelling advances improve CMEMS and regional forecast and reanalysis systems, wave–circulations–sediment coupling for erosion risk, multi-model SST and wave forecasts, S6A data assimilation, and physics-informed emulators for major river estuaries. By combining multi-platform observations, multidisciplinary models and AI-approaches, FOCCUS enhances Digital Twin capabilities for a climate-ready Mediterranean Sea, supporting erosion risk assessment, marine heatwave monitoring, and ecosystem restoration. Funded by the EU project FOCCUS (GA. No. 101133911).

Assimilating nadir SLA at multiple resolutions in the Western Mediterranean Sea

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Recent advancements in the Western Mediterranean OPerational forecasting system (WMOP) focus on enhancing Data Assimilation (DA) by integrating high-resolution Sentinel-6A Sea Level Anomaly (S6A SLA) data. S6A provides along-track measurements at 20 Hz, resolving with unprecedented accuracy coastal and (sub)mesoscale features. We evaluate how assimilating these high-frequency (HF) SLA data improves (sub)mesoscale forecasting and ocean dynamics representation. Using an Ensemble Optimal Interpolation scheme, Nadir S6A SLA at 1 Hz, 5 Hz, and 20 Hz were assimilated into the 2-km WMOP model. The DA system also incorporates satellite sea surface temperature (SST), HF radar currents, and T/S profiles from Argo floats and moorings. Three SLA assimilation experiments (Apr–Mar 2023) tested: (i) 1 Hz; (ii) 5 Hz and (iii) 20 Hz. Model skill was assessed using independent observations from the Surface Water and Ocean Topography mission and glider data. Results show that assimilating 5 Hz and 20 Hz S6A data improves reconstruction of (sub)mesoscale features, with higher correlations and lower errors. These configurations better capture the amplitude and structure of observed eddies, enhancing short-term forecast skill.

Sustained glider observations reveal multiscale physical-biogeochemical interactions in the Western Mediterranean Sea

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The Ibiza Channel is a biodiversity hotspot where three-dimensional water mass exchanges modulate the circulation, stratification, and ecosystem variability. The SOCIB Glider Endurance program across the Mallorca and Ibiza Channels has completed more than 70 missions and 90,000 physical and biogeochemical profiles since 2011. By examining the temporal and spatial variability, we captured distinct seasonal transport regimes that showed southward flow in winter–spring and northward flow in late summer. Furthermore, observations reveal (sub)mesoscale variability, water-mass transformation, and the ecosystem's response to these changes. Recent Atlantic Water (AWr) intrusions, Western Intermediate Water advection, and the modulation of the Northern Current (NC) are associated with rapid circulation changes. The NC transport increased during winter–spring 2014 and 2017, advecting Modified Atlantic Water (AWm) and Levantine Intermediate Water (LIW) southward, strengthening vertical shear, and redistributing nutrients across density surfaces. Episodes of NC intensification and AWr intrusions promoted frontal instability, eddy generation, and enhanced nutrient availability, driving patchy chlorophyll distributions at the Atlantic–Mediterranean interface. Warming and salinification were also observed, indicating changes in water-mass characteristics. Results show that sustained glider observations are needed to resolve physical & biogeochemical variability from small to large scales.

Leveraging Objective Eulerian Coherent Structures to reduce drift-forecast errors for operational applications

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Accurate short-term drift forecasts are critical for search and rescue, pollution response, and ichthyoplankton transport, where multiscale circulation and hyperbolic flow regions challenge standard particle tracking. We present an operational correction that augments any Lagrangian trajectory model using Objective Eulerian Coherent Structures (OECS). The method derives the instantaneous rate-of-strain tensor from gridded surface currents, identifies attracting and repelling OECS, and applies a local, radius-limited adjustment to particle velocity direction and speed consistent with the diagnosed deformation field. This correction preferentially mitigates divergence and path-deflection errors near stagnation lines and saddle-type features, improving trajectory skill over 1 to 5 day horizons. Implementation relies on routinely available inputs, such as Copernicus Marine Service currents and HF-radar velocity fields, including those provided by the Mediterranean HF-radar network, and it integrates as a post-processing layer without modifying the hydrodynamic model. The OECS-guided approach is physics-informed and lightweight, reducing trajectory uncertainty and supporting rapid decision making.

A Year's Echo: Tracking MOW at 1000 m depth at the North Atlantic gateway

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The Southwest Iberian Margin is a dynamic transition zone where Eastern North Atlantic Central Water (ENACW), dominant in the Canary Current System and occupying the upper thermocline (~0–700 m), meets the Mediterranean Outflow Water (MOW), a warm, saline plume descending from the Strait of Gibraltar to depths of 800–1200 m. This water flows westward across the Gulf of Cádiz, creating strong currents, mesoscale eddies (meddies), and turbulent mixing. These processes generate a distinct mid-depth salty plume that extends far into the North Atlantic, influencing large-scale circulation, including the Atlantic Meridional Overturning Circulation (AMOC).

This work presents the Eulerian observatory deployed in the São Vicente Canyon (off Cape São Vicente, SW Portugal) at ~1000 m depth, monitoring the MOW over a year. The system will measure temperature, salinity, dissolved oxygen, turbidity, bottom pressure, currents, and underwater sound, as part of the EMSO ERIC Iberian Margin Regional Facility. Preliminary results are expected in late 2026, and will provide insights into MOW variability, including meddy-related thermohaline and oxygen anomalies.

These observations will help distinguish long-term trends from natural variability and assess how MOW evolution connects Mediterranean changes to North Atlantic processes. The data will also serve as benchmarks for circulation models and future observing programs, advancing our understanding of deep-water variability and climate impacts.

From saltwater Intrusion to freshwater plumes: Modeling the Adriatic coastal response to drought and flood extremes (2022–2023)

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The northern Adriatic Sea represents one of the most dynamic coastal systems of the Mediterranean, where river discharge, wind forcing, and topography interact across multiple spatial and temporal scales. In recent years, this region has experienced unprecedented hydroclimatic variability, offering a unique opportunity to assess how large-scale atmospheric anomalies translate into local hydrodynamic responses.

We focused on the Po River Delta and the Emilia Romagna coastal zone by comparing two contrasting years: the drought of 2022 and the flood of 2023. This study reviews the mechanisms controlling saltwater intrusion and freshwater plumes.

A 3D SHYFEM model (https://github.com/georgu/shyfemcm-ismar) was applied to simulate hydrodynamics, salinity, and temperature. The model was forced with CMEMS and CERRA reanalysis. River discharge data were measured when available; when not (e.g., during extreme floods disrupting gauges), values were derived from a PROGEA hydrological model used by ARPAE.

Results reveal a nonlinear and spatially heterogeneous response to freshwater forcing. During 2022, low discharge allowed saline water to penetrate >40 km upstream, nearly doubling earlier projections. Conversely, the 2023 floods generated high-discharge plumes extending up to 8 km offshore. Surface salinity variability highlighted a low-salinity corridor along the ER coast connecting with the Po plume, underscoring cross-scale coupling between local runoff and basin-scale circulation.

Oil hazard mapping of the Mediterranean Sea

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The Mediterranean Sea is a region of large maritime traffic, thus small operational oil spills, ranging from one to ten tons, occur almost daily.
To support marine environmental protection, hazard mapping is an important tool to identify zones exposed to hazard from oil pollution (Liubartseva et al., 2025). This contribution documents a new oil hazard mapping platform developed as part of the HEU Project EDITO-Model-Lab.
The platform maps two hundred potential release points in a coastal belt between ten and fifty kilometers, covering the entire Mediterranean Sea. Following the work of Sepp-Neves et al. (Sepp-Neves, 2020), the hazard index for the whole coastline has been calculated, employing a numerical approach based on the results of more than 77.000 simulations, performed with a new version of Medslik-II (Atake et al., 2025) and spanning a five-year time period (from 2018-2022).
For each point, a different ten days simulation, initiated every five days, computed the concentration in open sea and the beached oil volumes. Considering the amount of oil arriving to the coast, the hazard index has been calculated and shown in a normalized 0-to-1 scale. The achieved results are available on the EDITO web platform (https://edito-modellab.eu/) which offers three different products: the time average oil surface concentration, the time average beached oil and the hazard index, all relative to the selected release point among the available ones.

Swarms of landers for sustained long-term ocean monitoring

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An oceanographic lander is a modular structure equipped with miscellaneous sensors/equipment which is positioned directly on the seabed to operate autonomously for a defined timeframe. A drawback of landers is the high cost of recovery systems, typically depending on buoyancy modules plus expendable ballast. LanderPick concept consists of a specific towed vehicle to deploy and recover oceanographic landers not provided with recovery elements, but having a capture mesh that facilitates their hitching (LanderPick-suited landers).
LanderPick-suited landers are simple structures that offer a cost-effective solution for deploying swarms of observation spots across vast areas of the ocean floor. The first LanderPick came into service in 2021 and other 3 vehicles followed, operating in Spain, Ireland and Portugal. A fleet over 40 landers is currently active, providing Essential Ocean Variables at key locations from Ireland to the Canaries under the formal network 'Atlantic arc Lander Monitoring' (ALaMo) and in the Western Mediterranean. Over 25,000 data-days has been gathered so far from ~100 deployments. First landers were built as stainless-steel structures, while current developments are focusing of GRP (Glass-fiber Reinforced Plastics), lowering the unitary cost by an order of magnitude. Also, flying saucer-shaped landers adapted to resist trawling gears are under testing. The system can potentially be expanded across the Mediterranean to support sustained monitoring.

Citizen Science and Digital Twin Integration for Coastal Resilience: Lessons from Cala Iris (Morocco)

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The Cala Iris pilot, developed by the Al Hoceima Marine Observatory in northern Morocco, demonstrates how citizen participation and digital innovation can reinforce marine observation and governance across the Mediterranean. Integrating Citizen Science (CS) with Digital Twin Ocean (DTO) technologies, the initiative engages fishers, students, and local actors in monitoring water quality and biodiversity within a Smart Marine Protected Area.
Using the I SEE SEA mobile app and real-time Develogic sensors, data on temperature, salinity, turbidity, and microbial contamination are collected and harmonized through Darwin Core and PPSR Core standards for interoperability with European infrastructures such as ILIAD, ODYSSEA, and EDITO.
This hybrid approach strengthens adaptive management, supports aquaculture sustainability, and enhances community ocean literacy. The Cala Iris case highlights the role of citizen-driven observations in improving data granularity and fostering co-responsibility for coastal resilience. It contributes to MonGOOS's shared objective of building an inclusive Mediterranean Digital Twin Ocean connecting people, technology, and nature.

Multiscale Wave Variability from High-Resolution Buoy Networks: Insights into Spectral Coherence and Observational Uncertainty

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Understanding the multiscale nature of wave dynamics is crucial to improving wave modelling, forecasting, and long-term projections in the Mediterranean Sea. In winter 2022–2023, a dense grid of Directional Wave Spectra Drifters (DWSD) was deployed offshore Livorno (Italy), generating a unique dataset of high-frequency, spatially distributed wave spectra at ~1–2 km resolution. This network served as a reference for validating spectral wave models (WAM, WW3, SWAN) and supporting AI-based reconstructions.
This contribution explores two key aspects:
(1) the spatial coherence of wave parameters at the kilometre scale, analysed through spectral metrics;
(2) the quantification of observational uncertainty, shown to vary with sea-state conditions.
Results highlight that wave fields can appear homogeneous under swell-dominated regimes, but exhibit greater variability during wind-sea event, challenging the reliability of pointwise model validation. Observational uncertainty is also affected by mooring configuration and local dynamics. Based on these findings, we outline a workflow to cluster sea-states using observed spectra. This pathway (from in-situ data to model validation and climate-oriented spectral classification) supports more robust trend analysis and data-driven reconstructions. The study offers insight into the multiscale structure of the Mediterranean wave climate and contributes to next-generation observational strategies with benefits for coastal hazard assessment.

Assessing SWOT-Derived Surface Currents against HFR Data in the Western Mediterranean

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The Surface Water and Ocean Topography (SWOT) mission's high-resolution Sea Surface Height (SSH) enables the observation of submesoscale features that are key to the ocean's global energy cascade. However, at these scales, the presence of unbalanced motions and departures from geostrophic balance can complicate the derivation of velocities from SSH. To evaluate the accuracy of SWOT-derived velocities, we compared them with independent High-Frequency Radar (HFR) surface current measurements in two contrasting Western Mediterranean regions: the Ibiza Channel and Delta Ebro. At the latter site, located under SWOT's 1-day repeat CalVal orbit, we compared HFR geostrophic velocities to those derived from SWOT, which were calculated using two methods: spatial derivatives and a 2D fitting kernel. The latter method proved superior, improving correlation with HFR-derived velocities by ~50% compared to conventional multi-mission altimetry. In the dynamically complex Ibiza Channel, SWOT captured a ~12 km radius cyclonic eddy, demonstrating its ability to resolve submesoscale dynamics. However, SSH-derived geostrophic velocities overestimated HFR's by up to 10 cm/s. Applying the cyclogeostrophic balance approximation significantly reduced this bias, achieving close agreement with HFR velocities. This empirical validation highlights the critical value of HFR measurements for verifying and refining the methodologies used to derive velocities from SWOT's high-resolution SSH.

The added value of very-high resolution modelling in coastal and marine operational forecasting systems

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Operational forecasting systems are fundamental to the development of effective Early Warning Systems. This applies to the modelling chain implemented by the Hydro-Meteo-Climate Service of Arpae. The chain's first hydrodynamic model is nested within the Copernicus Mediterranean Sea Physics Analysis and Forecast system and consists of a 3-D, 1 km resolution Adriatic implementation (AdriaC) of the COAWST suite (online-coupled hydrodynamics - ROMS - and wave - SWAN - models). AdriaC, however, does not fully capture the complexity of coastal dynamics (e.g., Po Delta and lagoons). Hence, the finite element model SHYFEM was implemented for the Emilia-Romagna coastline and the Po Delta area (shyfER). This approach allows for variable spatial resolution, with a finer resolution near the coast, lagoons, and river branches. The results of the operational suite for the coastal storm that impacted the Emilia-Romagna coast on 5 October 2025 are presented with statistical performance indicators (MAE, RMSE) being analyzed alongside spatial maps illustrating the distribution of high sea levels during the event. The sensitivity of the system to wind forcing is also examined, as variations in wind fields resulted in substantially different forecasts. Furthermore, the long-term performance of the model in areas not resolved by larger-scale (e.g. MFS and AdriaC) is assessed, demonstrating its capability to accurately represent regions that are challenging for finite-difference approaches.

OCEAMMUR project: Advancing High-Resolution modelling for sustainable management of the Region of Murcia coast (SE Spain)

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The OCEAMMUR project aims to develop a coastal operational modelling system for Spain's Murcia region, with a focus on the Mar Menor–Europe's largest coastal saltwater lagoon. Leveraging expertise in numerical modelling and environmental monitoring, the project will increase Copernicus Marine model resolution to deliver high-quality local hydrodynamic forecasts using the MOHID Water hydrodynamic model. These tools will support EU directives including the Water Framework Directive, Marine Strategy Framework Directive, Common Fisheries Policy, and the European Green Deal. Two use-cases will demonstrate the system's impact: promoting sustainable aquaculture and marine spatial planning on the eastern Murcia coast and supporting ecological restoration and management of the Mar Menor lagoon. The project, composed by public-private consortium, will incorporate low-cost temperature sensors, stakeholder co-design and tailored visualization tools to deliver robust, high-resolution coastal products. By bridging scientific innovation with policy implementation, OCEAMMUR will empower regional stakeholders with actionable data to drive sustainable coastal governance and long-term environmental resilience.

Assimilation of SWOT satellite observations in high-resolution Western Mediterranean simulations

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The SWOT (Surface Water and Ocean Topography) satellite mission has been mapping sea surface topography with unprecedented spatial resolution since 2023, providing new insights into small-scale ocean variability. Within the FaSt-SWOT project, a sea trial was conducted in the Balearic Sea in April-May 2023, monitoring the thermohaline and kinematic properties of a ~20-25 km radius intrathermocline anticyclonic eddy detected under the satellite swath. This experiment took place during the initial fast-sampling phase of the mission, which provided daily observations over two specific tracks in the Western Mediterranean. The collected measurements demonstrate that SWOT significantly improves the representation of this small-scale eddy compared to conventional altimetry, both in observed sea level and derived geostrophic currents. The accuracy of SWOT observations enables their assimilation into regional numerical models. We present initial results on the contribution of SWOT data to improving the representation of ocean variables in high-resolution regional simulations. Both SWOT and in situ observations from the FaSt-SWOT campaign were assimilated into the 2 km,Äìresolution Western Mediterranean Operational System (WMOP). In addition to generic along-track SSH, SST, and Argo profile data, the assimilation included SWOT, glider, and CTD observations. We evaluate the 3D eddy structure and associated sea-level signal in the assimilated simulations.

C-SWOT2023 field experiment. Mesoscale dynamics under SWOT swaths in the Mediterranean Sea.

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The twin field experiments C-SWOT-2023 and WEMSWOT were carried out in March-April 2023 and aimed to support the new-generation SWOT altimeter (NASA/CNES) calibration and validation. This satellite provides a measurement of sea surface elevation and rugosity with unequalled space-time coverage, particularly during its intensive observation phase from March to June 2023. The originality of this field experiments is the mobilisation of two research vessels (the R/V Thetys II for C-SWOT-2023 and the R/V Atalante for WEMSWOT) that sailed along together to explore statistics of the surface ocean dynamics (vorticity, strain, divergence) that are seldomly accessible in fine scale observations. Common transects recording at least velocities, temperature and salinity in the four hundred metres under the surface were performed in order to disentangle the geostrophic and the ageostrophic part of the circulation. To complete this approach, an intensive lagrangian experiment was also performed using Carthe or WOCE drifters and direct measurements of sea surface height using GNSS have been tried out. At the end of the cruise the potential of an unmanned surface vehicle for oceanography (the DRIX) was tested during 5 days to catch the North Current variability and related small scale variability.
The poster provides an overview of the work carried out during the cruises and the initial results.

High-resolution air-sea CO_2 observations during the ATL2MED mission: data correction and process variability across the Eastern Atlantic Ocean and the Mediterranean Sea

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The ATL2MED mission (October 2019-July 2020) investigated air-sea CO_2 exchange across the Eastern Atlantic Ocean and the Mediterranean Sea using high-resolution measurements from Saildrone autonomous surface vehicles (SDs), complemented by fixed stations, gliders, and research vessels. Operating under diverse environmental conditions, the SDs provided detailed observations of seawater CO^2 and hydrographic parameters, although sensor drift and biofouling affected data quality during the long deployment. Dedicated data correction and validation procedures were applied: salinity was corrected using model products and validated against independent observations. Dissolved oxygen was adjusted using the Argo oxygen correction. These efforts compensated for limited discrete sampling during COVID-19 restrictions. The corrected data revealed strong regional contrasts in CO_2 dynamics driven by physical and biogeochemical processes. Intense outgassing occurred in the upwelling regions off northwest Africa, while the western Mediterranean Sea acted as a CO_2 sink during the spring bloom. The Adriatic Sea showed recurrent outgassing episodes linked to stratification, river plumes, and coastal upwelling. The SDs captured sub-mesoscale and short-term variability often missed by traditional platforms and model simulations. The study highlights the importance of high-frequency, multi-platform measurements to resolve the highly variable air-sea CO_2 fluxes occurring at short temporal scales.

Impactful coastal marine heatwaves in the Mediterranean Sea: multiscale drivers, observation networks and future strategies

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Marine heatwaves (MHWs) are emerging as one of the most pervasive threats to global coastal marine biodiversity due to climate change (CC). The Mediterranean basin is a well-known hotspot for CC, experiencing accelerated warming and significant ecological shifts due to MHWs. These events endanger marine biodiversity in various habitats, including seagrass meadows, macroalgal forests, and coral assemblages. Documented impacts include changes in species distribution and phenology, physiological stress and mass mortality events, which have cascading effects on ecosystem structure and function.

To advance our understanding and forecasting capacity of coastal MHWs and mitigate their impacts on ecological systems, better knowledge of the three-dimensional structure of MHWs and their multiscale drivers is required. This study takes advantage of the T-MEDNet coastal observation network to explore the vertical structure and dynamics of MHWs associated with significant mass mortality events. I then present an enhanced multi-platform regional observatory framework, as envisaged for the European Coastal Research Infrastructure JERICO, which highlights the complementarity of HF coastal observatories together with satellite and model data to assess multiple and imbricated scales of variability.