CNR ISMAR ISTITUTO DI SCIENZE MARINE

CNR-ISMAR MARINE OBSERVING SYSTEM (SOM)
Consiglio Nazionale delle Ricerche – Istituto di Scienze Marine

authored by

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1 Introduction

The CNR-ISMAR Marine Observing System (SOM) is a set of tools and technologies that are used for the monitoring and study of marine processes, including the physical, chemical and biological aspects of the oceans.

SOM comprises a variety of facilities, including oceanographic vessels, fixed stations, buoys, moorings and elastic beacons, coastal monitoring stations, fixed sensors and mobile autonomous robotic platforms. This set of facilities enables the collection of real-time data on a range of environmental parameters, including water temperature, salinity, sea level and state, currents, nutrient and chlorophyll concentrations.

Additionally, it facilitates the planning and implementation of experimental activities and campaigns for the study of specific phenomena and processes of specific interest.

The data collected by the CNR-ISMAR SOM are employed in a variety of research endeavours, including the study and comprehension of oceanographic processes, the monitoring of marine pollution, the analysis of coastal area evolution, the evaluation of marine biodiversity, the analysis of the effects of climate change on marine ecosystems and to provide useful information for the sustainable management of marine resources. The measurements are also of particular importance for the validation of modelling tools, developed by the Institute and by the scientific community in general, as well as for the validation of satellite observation products.

Moreover, CNR-ISMAR engages in collaborative research with scientific institutions, universities, international organisations and government bodies with the objective of advancing marine research and achieving the goals of increasing knowledge in the context of international ocean monitoring and study projects.

In this context, the CNR-ISMAR SOM represents a valuable resource for research and understanding of marine environments, providing essential data for the monitoring and sustainable management of the oceans.

The full consistency of the CNR-ISMAR SOM is fully described in previous technical reports published in 2023 and 2025, respectively:

- DOI: 10.26383/CNR-ISMAR.2023.7: https://www.ismar.cnr.it/wp-content/uploads/2023/11/RT_Rete-Naz-Siti-Osservativi-Marini_ITA__ENG.pdf
- DOI: 10.26383/CNR-ISMAR.2025.01 https://www.ismar.cnr.it/web-content/wp-content/uploads/2025/02/TR-35.pdf.

SOM, which contributes to the IT-IOOS Italian Integrated Ocean Observing System, has been recently undergoing a profound transformation also enabled by targeted Italy's National Recovery and Resilience Plan (PNRR) investments, marking a transition from a predominantly ocean-focused network to an integrated **land–sea continuum observing framework** while introducing a major technological shift **towards autonomous, multi-platform, multi-sensor observing facilities.**

The recent upgrades significantly expand observational capability across rivers, lagoons, estuaries and deltas, coastal areas, and the open ocean. The network expansion, adding ten new observing sites across riverine, transition environments, and coastal ecosystems, substantially broadens both the disciplinary and spatial scope of marine and environmental observation. Combined with strengthened autonomous capabilities (ASVs, gliders, BGC-Argo, BGC-SVP drifters, smart imaging systems, wave buoys and HF-radar), SOM is increasingly aligned with **foresight priorities** for operational oceanography and observing systems of the future, enabling persistent, multi-sensor, multi-platform and intelligent high-frequency observation across tightly coupled land–sea domains.

These upgraded assets provide higher-resolution, more continuous observations across physical, biological, and biogeochemical domains, supporting enhanced modelling and forecasting capabilities. Future connections with strategic research initiatives and oceanographic campaigns will continue improving national and European capacity for deep-ocean studies, contributing to EuroGOOS priorities in **Innovation in Observations, Modelling, and Forecasting**. Cross-platform complementarities already foster new scientific pathways, improve data readiness, and strengthen the integrative potential of the observing system.

Aligned with **Digital Transformation, Integration, and Data Quality**, SOM has reinforced its data-sharing infrastructure, increased the proportion of sensor-based variables, improved data-return efficiency, and advanced interoperability and standardisation across multiple ESFRI Research Infrastructures (EMSO, EURO-ARGO, ACTRIS, ICOS, DANUBIUS, eLTER). These upgrades enhance FAIR/TRUST-aligned metadata standards and support development of Digital Twins and virtual research environments by supplying high-density, cross-domain, and machine-readable datasets. This foundation also paves the way to forthcoming AI-based quality-control workflows, anomaly detection, and predictive maintenance. Complementary analyses under development will document improvements in time-series stability, data return efficiency, and identify remaining gaps in spatial and variable coverage relevant for contributing to the Essential Variables frameworks.

The ongoing redesign of SOM governance and access policies strengthens alignment with **Co-Design, Engagement, and Inclusivity**. Enhanced procedures for transnational and national access and clearer documentation of available resources and collaborations support broader community engagement. Recognition of human-resource effort across technical, scientific, and data-management roles reinforces European capacity building and highlights the essential contribution of early-career and non-permanent personnel.

Over the past years, SOM has been developing a comprehensive governance and management framework that includes a network-wide upgrade roadmap, long-term sustainability strategies (beyond PNRR), maintenance, risk and obsolescence planning, cost and human-resource assessments, and platform-specific failure and recovery metrics. This governance foundation has addressed long-recognised structural gaps and enabled strategic design and prioritisation of PNRR investments, ensuring upgrades respond to operational needs, interoperability targets, and European observing priorities, aligning SOM with international best practices for sustained ocean observing systems.

Finally, SOM's multidisciplinary expansion enables integrated assessments of climate variability, biodiversity change, extreme events, pollution, and land–sea interactions. The upgraded network represents an open, advanced, interoperable, strategic national capability that supports scientific research, policy development, operational agencies, and society at large.

2 Impact of PNRR investments and upgrade

The PNRR investments have triggered a major structural and technological upgrade of the CNR-ISMAR SOM, enabling both a significant expansion of the observational network and a step change in its scientific and operational capabilities. The upgrade includes the deployment of new observing facilities, the integration of a large number of additional sensors on the existing infrastructures, and the expansion of the set of observed variables across physical, biogeochemical, biological and radiometric domains. The network expansion includes nearly ten new observing stations, accompanied by a substantial increase in deployed sensors and monitored variables, resulting in a marked growth in data streams and in the overall observational capacity of the network. These upgrades directly translate into improved calibration capability, higher data reliability, and strengthened continuity of long-term time series.

At the network scale, the scientific return is expected to arise from the integrated operation of multiple platforms rather than from single observing sites, enabling cross-platform analyses and new discoveries across environmental compartments. The SOM expansion extends ISMAR observational capacity into n riverine environments, coastal ecosystems, the Po River and delta system, and the enhanced Venice Lagoon observing network, while also strengthening radiometric observations and autonomous platform operations. This expansion marks a transition from a predominantly ocean-focused observing network towards a land–sea continuum observing system. The result is a strengthened multidisciplinary integration across the river–lagoon–coastal–open sea continuum, with major advances in biological, biogeochemical and radiometric observing capacity and in the monitoring of coastal ecosystem processes.

A key outcome of the PNRR upgrade, mainly driven by the ITINERIS project, is the **major technological shift toward an autonomous, multi-platform, multi-sensor observing system**, extending from coastal areas to the open sea, including the deep ocean. The increased deployment of autonomous platforms significantly enhances spatial and temporal resolution of observations, improves operational flexibility, and reduces dependency on ship-based operations. This shift enables persistent observations in offshore and deep-sea environments, supports adaptive sampling strategies, and allows rapid response to episodic or extreme events. The progressive transition toward autonomous observing also facilitates the integration of heterogeneous observing technologies within a single coordinated network, improving robustness and redundancy of data acquisition and increasing overall system resilience.

Within the PNRR ITINERIS framework, SOM has also strengthened its integration across Research Infrastructures, contributing to a more strategic positioning of the network at national and European levels. This process supports complementarity among RIs, reduces historical overlaps, and improves the efficiency of observational investments. In parallel, major progress has been achieved in interoperability, data sharing frameworks, and FAIR-aligned data management. The increase in the number of data streams, together with the higher proportion of sensor-based variables compared to sample-based measurements, represents a key step toward addressing gaps previously identified at the European level and reinforces CNR-ISMAR's role within multiple ESFRI Research Infrastructures as well as in the national and internal frameworks.

Within this framework, CNR-ISMAR contributes to the progressive harmonization of data formats, metadata standards, quality control procedures and data publication workflows, enabling improved integration of marine observing data into national and European data ecosystems. This process is aligned with FAIR data principles and supports seamless data exchange across heterogeneous observing facilities, strengthening the overall national research data infrastructure and improving accessibility and usability of environmental data streams.

At the national scale, the PNRR-ITINERIS analyses have highlighted that, despite major advances in data availability and interoperability, significant gaps persist in data quality, standardization consistency and completeness of quality control implementation across Research Infrastructures. In particular, the transition from sample-based measurements toward continuous sensor-based observations, while increasing data volume and temporal resolution, introduces new challenges related to calibration traceability, automated quality control, uncertainty quantification and long-term comparability of time series. These gaps, recognized also at the European level, represent a key priority for future development of the SOM and will guide upcoming investments and methodological developments, particularly in automated QC, harmonized calibration protocols, and advanced data validation workflows.

Within this national context, CNR-ISMAR is progressively positioning SOM as a reference node for marine environmental data interoperability, contributing to the integration of marine observing data within cross-domain infrastructures and supporting the development of shared services for data discovery, access and reuse. The increase in the number of data streams, observed variables and sensor-based measurements generated by SOM, combined with improved metadata completeness and machine-readable quality information, contributes to strengthening the Italian contribution to European research infrastructures and enhances national competitiveness in environmental monitoring and Earth system research. At the same time, the identification of remaining data-quality gaps provides a clear roadmap for future SOM activities, ensuring continuous improvement of data reliability, traceability, and long-term scientific usability.

PNRR investments have also strengthened access to observing sites and harmonized access procedures across the network, including transnational access within ESFRI frameworks. The definition of site-specific contact points and harmonized access guidelines, as further described in the following paragraph on "SOM Governance and Management Framework", will further improve transparency and usability of the infrastructure for the scientific community. Finally, the SOM upgrade reinforces ISMAR strategic capabilities in deep-ocean observation and strengthens links with major institutional initiatives, including deep-sea programmes and long-term Mediterranean observing strategies.

3 Network Governance and Management Framework

The evolution of SOM has been accompanied by the constant development of a structured governance and management framework designed to ensure long-term sustainability, operational reliability, and strategic alignment with the European observing priorities. The governance structure clearly defines responsibilities among CNR-ISMAR central coordination, individual observing sites and associated Research Infrastructures, ensuring efficient decision-making processes and harmonized operational standards across the network.

The SOM governance structure is based on a coordinated management model that has been operational since 2021, prior to the launch of PNRR activities. This early activation enabled the strategic design and technical planning of most of the ocean observing infrastructural upgrades that were subsequently implemented through PNRR investments, ensuring continuity between long-term institutional strategy and recent infrastructure strengthening actions, and alignment with national and international observing initiatives. The organization was formalized through official institutional acts defining responsibilities, coordination mechanisms and operational interfaces across CNR-ISMAR service units and observing site operators.

The governance framework is centered on two appointed coordinators responsible for the development, integration and management of the SOM. Their mandate includes the technical and scientific supervision of the SOM, which comprises the facilities and the instrumental systems forming the marine observational network of the Institute of Marine Sciences (ISMAR) of the National Research Council of Italy (CNR), and the overall management of services associated with the data generated by the network. The coordinators are also responsible for defining and implementing, in collaboration with the designed reference persons of each facility and European research infrastructure, a multi-year strategic development plan aimed at strengthening the SOM. This includes identifying and evaluating opportunities for infrastructure enhancement, technological upgrades, and ensuring the efficient allocation of resources to support SOM operations.

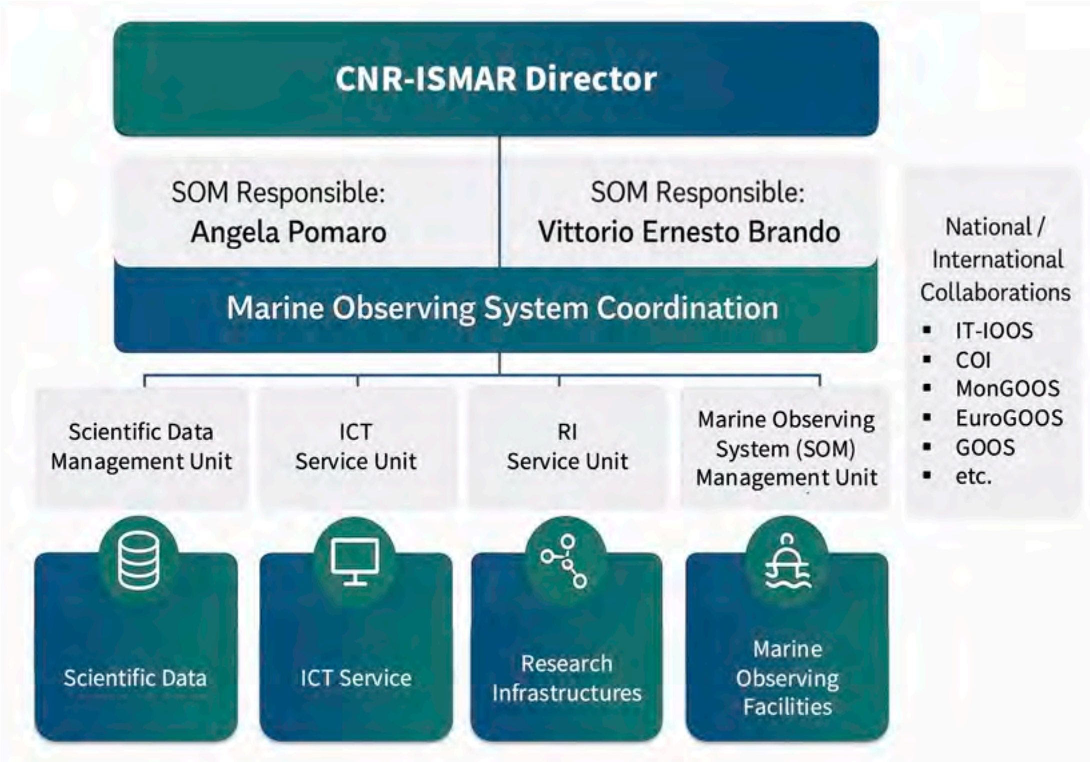

Figure 1 – CNR-ISMAR Marine Observing System (SOM) functional organization chart.

Core responsibilities include the coordination of facilities development activities, monitoring of operational status and performance of observing sites through periodic assessments, and supervision of data services and licensing policies associated with SOM data products, in accordance with the CNR-ISMAR Data Policy. The governance structure also ensures continuous monitoring of scientific exploitation of SOM data, evaluation of infrastructure upgrade opportunities, and promotion of efficient and coordinated management of observing sites, physical infrastructures and autonomous mobile platforms.

A key element of the governance model is the strong integration with CNR-ISMAR service units, including the Scientific Data Management Unit, the ICT Unit and the Research Infrastructures Unit. This integration guarantees consistency between observing operations, data management workflows and IT infrastructure, and supports the integration of SOM data within national and international data systems, including ESFRI Research Infrastructure, IT-IOOS and other national, European and global observing frameworks (e.g., COI, MonGOOS, EuroGOOS, GOOS).

The governance structure also promotes training activities related to observing system management and ensures internal communication through shared documentation and regular coordination meetings. Overall, this governance framework ensures that SOM operates as a coordinated, interoperable and strategically aligned national marine observing infrastructure.

The framework includes **standardised procedures for maintenance planning, calibration cycles, spare-parts availability and technical interventions**, supported by cost assessments at the level of individual facilities. Human-resource allocation is currently monitored, recognising the key role of technical, scientific, and data-management personnel in ensuring network performance. In the future, this activity could evolve toward a more structured and systematic monitoring framework for human resources, including the definition of dedicated indicators, competency mapping, workload distribution analysis and long-term staffing needs associated with infrastructure operation and development. Such an approach supports strategic workforce planning, improves operational resilience, ensures long-term sustainability of SOM activities, and complements the **risk management strategy addressing failures, obsolescence, and operational disruptions**, enabling rapid recovery strategies and minimizing data loss.

This integrated governance model aligns SOM with international best practices for sustained ocean observing systems and supports long-term strategic planning beyond the PNRR funding horizon.

The full list of observing facilities and Research Infrastructures (RIs) contributing to SOM activities is maintained within the operational framework of the SOM coordination structure and includes, for each station, the designated scientific and technical reference persons together with the typology of the observing platform. This distributed network of site coordinators ensures local operational continuity, supports maintenance and calibration activities, and guarantees the scientific quality and relevance of the acquired observations. In parallel, national and European Research Infrastructures participating in SOM contribute actively to the SOM working group. Their participation supports continuous monitoring of strategic development priorities and ensures alignment between SOM evolution and the scientific roadmaps and operational requirements of each RI. This mechanism strengthens complementarity between RIs, promotes shared technological development, and avoids duplication of observational efforts, while reinforcing SOM positioning within the broader national and European marine observing landscape.

Table 1 - Full list of observing facilities including the designated scientific and technical reference persons together with the facility typology

Station	Type	Reference person
AAOT	Fixed station	Mauro Bastianini, Alvise Benetazzo
Paloma	Elastic beacon	Carolina Cantoni
S1-GB	Elastic beacon	Caterina Bergami, Francesco Riminucci
Abate	Elastic beacon	Mauro Bastianini, Alvise Benetazzo
Lampedusa	Elastic beacon	Simone Colella, Gianluca Volpe
Portofino	Elastic beacon	Simone Marini
E1	Buoy	Caterina Bergami, Francesco Riminucci
Corsica	Mooring	Katrin Schroeder
Sicily C01 and C02 (substituted by Pantelleria P01)	Mooring	Katrin Schroeder

Pantelleria P01	Mooring	Katrin Schroeder
Sardegna	Mooring	Katrin Schroeder
Galatea	Mooring	Malek Belgacem, Stefania Sparnocchia, Florian V. M. Kokoszka
Canyon Levante	Mooring	Maristella Berta, Mireno Borghini
Rete radar-HF Mar Ligure e Golfo di Salerno	Radar-HF	Lorenzo Paolo Corgnati, Carlo Mantovani, Mauro Caccavale
Staz. Costiere Trieste (Molo Sartorio, Molo F.lli Bandiera)	Coastal station	Lorenzo Consorti
Staz. Costiera Golfo di Lerici (Lab Mare, Mitilicoltura)	Coastal station	Maristella Berta, Simone Marini
Staz. Costiere Golfo di Napoli (Posillipo, Porto, Bacoli, Lago Patria, Coroglio)	Coastal station	Fabio Matano
Staz. Costiere Golfo di Venezia (Riva 7M, Blue Moon)	Coastal station	Mauro Bastianini, Christian Ferrarin
Rete Laguna VE - CTD	Coastal station	Gian Marco Scarpa
Rete Laguna VE – Flussi	Coastal station	Gian Marco Scarpa
Rete torbidimetri	Coastal station	Gian Marco Scarpa
Radiometro Po	Coastal station	Gian Marco Scarpa
Staz. Fluviale Curriso	River station	Stefano Cozzi
Staz. Fluviale exCorrtag	River station	Stefano Cozzi
Staz. Fluviale Foce Volturno-Licola	River station	Fabio Matano
Gliders	Autonomous platforms	Jacopo Chiggiato, Marcello Gatimu Magaldi
Biogeochemical Argo Floats	Autonomous platforms	Emanuele Organelli, Giovanni La Forgia
Drifters and drift buoys (SVP, Lagrangian drifters)	Autonomous platforms	Marco Bellacicco, Maristella Berta

SWAMP-ASV	Autonomous platforms	Francesca De Pascalis
OpenSWAP	Autonomous platforms	Luca Gasperini, Giuseppe Stanghellini
LIDARs	Fixed station and new sensors	Davide Dionisi, Gian Luigi Liberti, Giovanni Giuliano

Table 2 - Full list of RIs and reference persons participating to the SOM activities

Research Infrastructure	Reference person
Danubius	Debora Bellafiore, Francesca De Pascalis
ICOS	Carolina Cantoni
Jerico	Marcello Magaldi
Euro-ARGO	Emanuele Organelli
eLTER	Caterina Bergami
Actris	Davide Dionisi, Giovanni Giuliano
EMSO	Katrin Schroeder
GO-SHIP (*)	Katrin Schroeder
OceanGliders (*)	Jacopo Chiggiato
OceanSITES (*)	Katrin Schroeder

(*) Not an RI, but included as a GOOS network

The **costs monitoring analysis** highlights the overall financial resources needed to ensure the operational continuity and technological development of the SOM network. The total monitored cost is approximately 726 k€ for 2025 (including the annual expense of around 300 k€ already allocated under the AAOT management contract) and rises to 1,270 k€ following PNRR investments. This figure encompasses expenditures related to infrastructure operation, maintenance activities, instrumentation lifecycle management, and data management services supporting the observing system.

The cost structure reflects the intrinsic complexity of maintaining a distributed, multi-platform observing network, where operational costs are not limited to hardware procurement but also include calibration procedures, spare parts availability, field operations, data transmission, data quality control and long-term data stewardship. The monitoring activity allows identification of cost drivers and supports optimisation strategies, particularly in the context of the transition toward increased use of autonomous platforms and multi-sensor systems.

From a strategic perspective, **systematic cost and risk monitoring** represents a key tool for ensuring long-term sustainability of SOM operations, especially in the context of post-PNRR funding scenarios. Consolidated cost metrics support evidence-based planning of future infrastructure upgrades, prioritisation of investments, evaluation of cost-benefit ratios associated with new technologies, and integration with risk management strategies. Furthermore, cost monitoring contributes to improving transparency and comparability with other national and

European Research Infrastructures, supporting SOM positioning within the broader research infrastructure landscape.

It is important to note that the presented cost estimates do not include Human Resources related costs (HR), which represent a significant component of the overall effort required to operate and maintain the SOM network. Personnel involved in field operations, sensor calibration, data quality control, data management, ICT support, and scientific coordination are essential to ensure data continuity, quality and operational reliability. The exclusion of HR costs means that the reported data should be interpreted as baseline operational and infrastructure costs, and not as the full cost of ownership of the observing system. Future developments may include a more structured cost accounting approach integrating infrastructure and personnel costs to support more comprehensive sustainability assessments and long-term financial planning, and mitigation of operational risks.

From an operational perspective, cost analysis also highlights the importance of evaluating cost versus platform typology. Fixed coastal stations, offshore moorings, autonomous mobile platforms and deep-sea observatories present very different cost profiles in terms of installation, maintenance frequency, logistics requirements, sensor payload complexity and expected data return. Autonomous platforms, while requiring higher initial investment and technological development costs, can provide improved spatial coverage, adaptive sampling capabilities and reduced long-term vessel dependency, potentially improving cost-efficiency over extended operational periods. Conversely, fixed stations ensure long-term time series continuity and stable reference observations but may require regular maintenance interventions. A platform-based cost analysis therefore represents a key tool for optimising future network design and for balancing scientific return against operational sustainability.

The following tables present a detailed breakdown of operational and maintenance costs for each observing station, showing both the 2025 baseline and the projected 2026 expenditures.

Table 3 - Operational and maintenance costs per observing station for 2025 (annual expense of around 300 k€ already allocated under the AAOT management contract is not included).

Station	Investment costs	Maintenance costs	Insurance costs	Taxes costs	Sub-total
AAOT	- €	22.700,00 €	- €	890 €	23.590,00 €
PALOMA	- €	29.960,00 €	- €	600,00 €	30.560,00 €
S1-GB	- €	24.350,00 €	12.650,00 €	- €	37.000,00 €
Abate	- €	5.000,00 €	- €	- €	5.000,00 €
Lampedusa	- €	35.000,00 €	- €	- €	35.000,00 €
E1	- €	24.000,00 €	6.000,00 €	- €	30.000,00 €
Corsica	- €	30.700,00 €	- €	- €	30.700,00 €
SiCO1 + SiCO2	- €	45.400,00 €	- €	- €	45.400,00 €
Rete radar HF (5 antennas)	- €	65.000,00 €	1.800,00 €	3.200,00 €	70.000,00 €
Coastal stations TS (Molo Sartorio, Molo F.lli Bandiera)	- €	1.500,00 €	- €	- €	1.500,00 €

Coastal stations NA + MOSYS (Posillipo, Porto, Bacoli, Lago Patria, Coroglio)	- €	3.500,00 €	- €	- €	3.500,00 €
Sist. Aut. Gliders (Teresa)	- €	49.000,00 €	- €	- €	49.000,00 €
Biogeochemical-ARGO (1 BGC-ARGO)	- €	8.000,00 €	- €	- €	8.000,00 €
Drifters: Biogeochemical-SVP (2 BGC-SVP)	- €	7.000,00 €	- €	- €	7.000,00 €
Drifters: Lagrangian	- €	1.750,00 €	- €	- €	1.750,00 €
OpenSWAP (ASV)	- €	8.000,00 €	- €	- €	8.000,00 €
Lidar	- €	35.000,00 €	- €	- €	35.000,00 €
Total 2025	*- €*	*395.860,00 €*	*20.450,00 €*	*4.690,00 €*	***421.000,00 €***

Table 4 - Operational and maintenance costs per observing station for 2026 (annual expense of around 300 k€ already allocated under the AAOT management contract is not included). Costs include new stations and sensors contributing to the SOM after PNRR investments.

Station	Investment costs	Maintenance costs	Insurance costs	Taxes costs	Sub-total
AAOT	85.000,00 €	55.000,00 €	10.000,00 €	- €	150.000,00 €
PALOMA	- €	41.960,00 €	- €	600,00 €	42.560,00 €
S1-GB	- €	26.850,00 €	12.650,00 €	- €	39.500,00 €
Abate	- €	10.000,00 €	- €	- €	10.000,00 €
Lampedusa	- €	35.000,00 €	- €	- €	35.000,00 €
E1	- €	25.000,00 €	6.000,00 €	- €	31.000,00 €
Corsica	- €	40.000,00 €	- €	- €	40.000,00 €
SiCO1 + SiCO2	- €	- €	- €	- €	- €
Rete radar HF (7+2 antennas)	- €	85.000,00 €	1.800,00 €	3.200,00 €	90.000,00 €
Coastal stations TS (Molo Sartorio, Molo F.lli Bandiera)	- €	4.000,00 €	- €	- €	4.000,00 €
Coastal stations NA + MOSYS (Posillipo, Porto, Bacoli, Lago Patria, Coroglio, Foce Volturno-Licola)	- €	3.997,00 €	- €	- €	3.997,00 €
Sist. Aut. Gliders (Teresa)	- €	35.000,00 €	- €	- €	35.000,00 €
Sist. Aut. Gliders (Esmeralda, Pandora, Morgana)	- €	94.000,00 €	- €	- €	94.000,00 €
Biogeochemical-ARGO (1+9 BGC ARGO)	- €	50.000,00 €	- €	- €	50.000,00 €
Drifters: Biogeochemical-SVP (2 BGC-SVP)	- €	7.000,00 €	- €	- €	7.000,00 €
Drifters: Lagrangian	- €	4.054,00 €	- €	- €	4.054,00 €
OpenSWAP (ASV)	- €	8.000,00 €	- €	- €	8.000,00 €
Lidar (RM + mobile)	- €	50.000,00 €	- €	- €	50.000,00 €
Portofino	- €	- €	- €	- €	- €
Pantelleria (ex SC01 and SC02)	- €	40.000,00 €	- €	- €	40.000,00 €
Sardegna	- €	- €	- €	- €	- €
Galatea	- €	20.000,00 €	- €	- €	20.000,00 €
Canyon Levante	- €	40.000,00 €	- €	- €	40.000,00 €
Coastal stations SP (Lab Mare, Mitilicoltura)	- €	500,00 €	- €	- €	500,00 €

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Coastal stations VE (Blue Moon, Riva 7M)	- €	1.500,00 €	- €	- €	1.500,00 €
Rete Laguna VE – CTD (7)	- €	32.000,00 €	- €	- €	32.000,00 €
Rete Laguna VE – Flussi (3)	- €	18.000,00 €	- €	- €	18.000,00 €
Rete torbidimetri (4)	- €	18.000,00 €	- €	- €	18.000,00 €
Radiometro Po	- €	11.000,00 €	- €	- €	11.000,00 €
River station TS (Curriso)	- €	21.450,00 €	- €	- €	21.450,00 €
River station TS (exCorrtag)	- €	21.450,00 €	- €	- €	21.450,00 €
Biogeochemical-SVP (8 BGC-SVP)	- €	43.000,00 €	- €	- €	43.000,00 €
SWAMP-ASV	- €	- €	- €	- €	- €
Contingencies	- €	8.989,00 €	- €	- €	8.989,00 €
Total 2025	*85.000,00 €*	*850.750,00 €*	*30.450,00 €*	*3.800,00 €*	***970.000,00 €***

4 SOM Performance and Data Management

While the current documentation provides a detailed description of facilities, observed variables, publications and scientific results, a comprehensive of SOM's operational performance requires the definition and implementation of **quantitative performance metrics**. These metrics, planned as a key activity for 2026, will include station-level stability indicators, data-return efficiency metrics linked to sensor functioning, calibration cycles, spare-parts availability, and recovery times following failures, as well as continuity indicators for long-term time series. Platform-specific failure rates and performance indicators reflecting compliance with Essential Ocean Variables (EOV), Essential Climate Variables (ECV), and Essential Biodiversity Variables (EBV) requirements will constitute central elements of this performance framework.

Additionally, the assessment will incorporate **an update on the number and coverage of observed EVs across the network**, tracking changes in spatial and temporal coverage, newly implemented sensors, and any gaps in data acquisition. This will allow for a quantitative evaluation of SOM's observational completeness and help prioritize future upgrades.

Another critical aspect concerns the role of SOM data in supporting modelling activities and emerging digital research ecosystems. Although SOM observations already contribute to satellite validation, data assimilation, and model calibration workflows, **a clear and systematic definition of how SOM data feed modelling chains and data assimilation pipelines is currently lacking**. Similarly, the contribution of SOM data to improvements in forecasting capabilities and scientific understanding—beyond what has been reported for the HF radar network or the Corsica mooring—is not yet fully documented.

Future developments will further strengthen SOM's role in supporting Digital Twins of the Ocean (DTO), Virtual Research Environments (VREs), and integrated modelling frameworks, enabling enhanced forecasting and understanding of ocean and coastal processes. Establishing **robust performance metrics**, including variable coverage updates, will be essential to quantify these contributions, guide operational improvements, and align multi-platform, high-frequency observations with the evolving requirements of operational oceanography and environmental prediction systems.

The table below summarises, for each observing station, the estimated percentage increment in EOV, ECV, and EBV variables that can be derived from the SOM network, providing a clear view of the improvements in observational coverage across the network. Percentages are calculated with reference to 35 selected reference EOV/ECV/EBV.

Table 5 – Variables coverage updates 2025.

Station	EOV/ECV/EBV percentage coverage	Variation vs 2023
AAOT	63%	- **(*)**
Paloma	51%	+9%
S1-GB	40%	- **(*)**
Abate	20%	-9%
Lampedusa	29%	+9%
Portofino	-	+3%
E1	31%	+6%
Corsica	17%	-3%
Sicily C01 and C02 (substituted by Pantelleria P01)	11% and 9%	-
Pantelleria P01	-	+9%
Sardegna	9%	-
Galatea	11%	-
Canyon Levante	-	+9%
Rete radar-HF Mar Ligure e Golfo di Salerno	6%	-
Staz. Costiere Trieste (Molo Sartorio, Molo F.lli Bandiera)	6% and 20%	-
Staz. Costiera Golfo di Lerici (Lab Mare, Mitilicoltura)	-	+9% and +3%
Staz. Costiere Golfo di Napoli (Posillipo, Porto, Bacoli, Lago Patria, Coroglio)	14%	+6%

Staz. Costiere Golfo di Venezia (Riva 7M, Blue Moon)	-	-
Rete Laguna VE - CTD	-	+20%
Rete Laguna VE – Flussi	-	+6%
Rete torbidimetri	-	+3%
Radiometro Po	-	+3%
Staz. Fluviale Curriso	-	+20%
Staz. Fluviale exCorrtag	-	+20%
Staz. Fluviale Foce Volturno-Licola	-	+17%
Gliders	-	+3%
Biogeochemical Argo Floats	-	+26%
Drifters and drift buoys (SVP, Lagrangian drifters)	-	+20% and +3%
SWAMP-ASV	-	+3%
OpenSWAP	-	-
LIDAR	11%	-

(*) The comparison includes a revision of the data for 2023, based on a more accurate assessment of the observed variables.

SOM facilties acquire observations in operational cycles (both in real-time and delayed mode) and forward them via the available telemetry paths (e.g., radio/satellite where present) or through periodic offloading in deferred mode. Alongside measurements, several instruments provide basic logs and housekeeping variables (e.g., status, battery, sampling interval) and station identifiers required to route packets downstream. Timestamps are synchronized to platform clocks and consolidated at the first reception point to ensure a consistent time base across platforms

Incoming packets are collected in SOM's intake endpoints (landing area), then parsed to extract observation values and ancillary data. Parsing normalizes field names, units, and timestamps and resolves station/platform codes against the authoritative SOM registries.

QC is implemented in multiple passes, as outlined in the "QC implementation" slides: a first automated screening on the normalized stream, followed by expert review for problematic segments and, where relevant, calibration adjustments. This produces quality flags and versions suitable for both operational and scientific use.

Metadata procedures are implemented to record platform types, locations, deployment periods, instrument models/serials, variable definitions, and links to QC/calibration notes and data policies. The metadata layer is essential for identifiers used by ingestion/QC and by publication and external exchanges, in compliance with FAIR principles and interoperability requirements.

The current status of data flow implementation, mostly referred to real-time data, is described in the following figure.

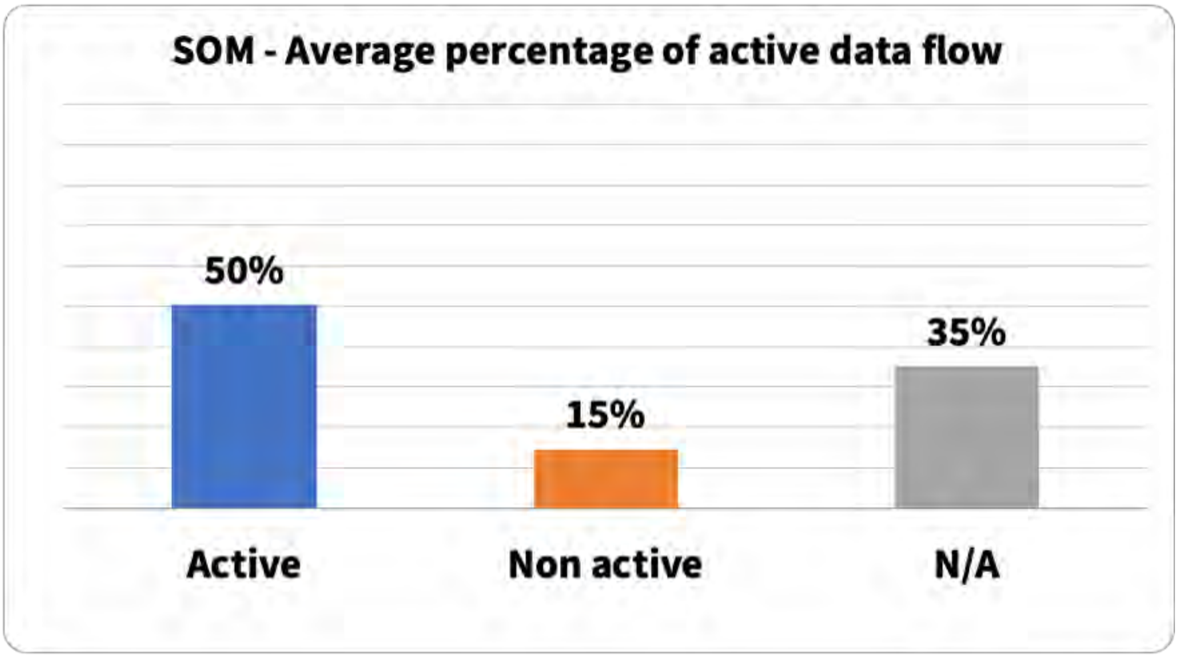

Figure 2 – SOM average percentage of active data flow. Average percentages of active data streams are shown in blue, inactive ones in orange, and those for which no information is currently available regarding the data stream are shown in grey.

To support the assessment of network operational reliability, the following figure provides an overview of the percentage of active data flow recorded for each observing station, highlighting the overall data availability and identifying potential critical points in data transmission continuity across the SOM network. A not negligible percentage of not available information on active data flow is still present mainly due to different interpretations of the concept of data flow and or because of the involvement of other institutions in data collections, which make it longer to establish how to define and handle data flow. Please note that S1-GB facility is currently out of service, hence no active data streams are currently available, following an incident that has necessitated the scheduling of emergency maintenance work, after which it will be returned to the sea.

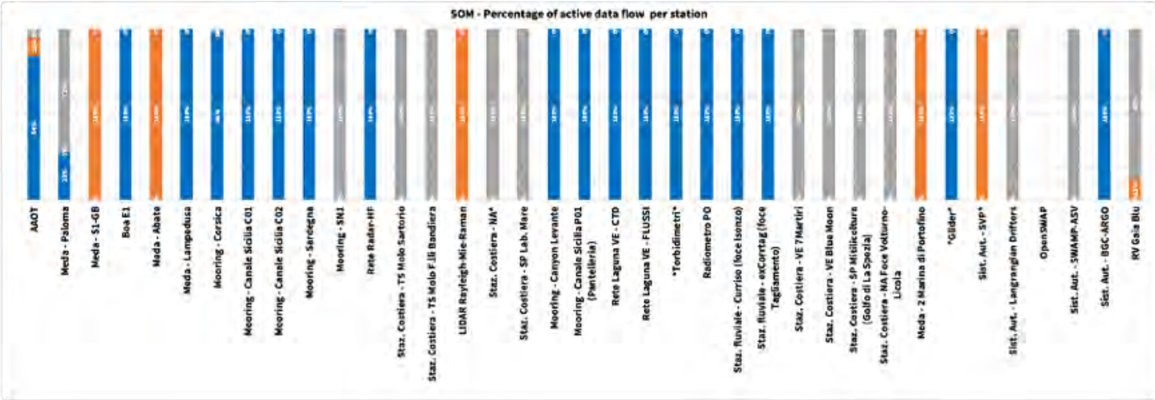

Figure 3 – Percentage of active data flow per observing station, providing an overview of the operational status of the network and highlighting stations with reduced or intermittent data transmission. Percentages of active data streams are shown in blue, inactive ones in orange, and those for which no information is currently available regarding the data stream are shown in grey.

The current status of metadata implementation is described in the following figure.

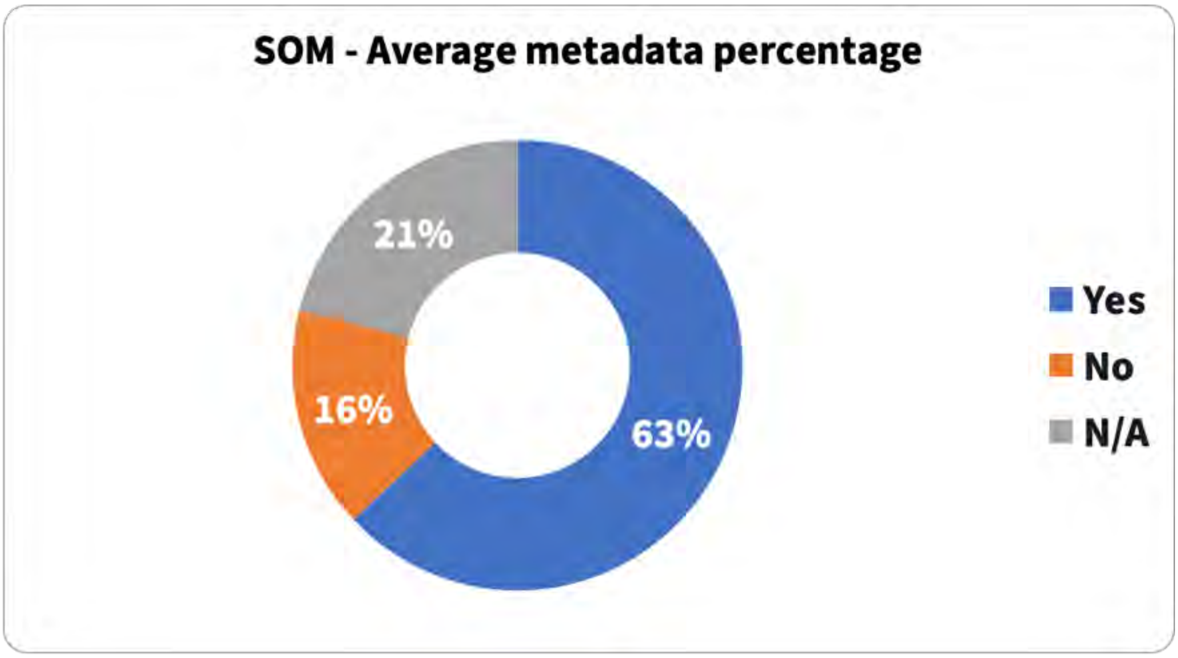

Figure 4 – SOM average percentage of metadata implementation. Average percentages of active metadata are shown in blue, inactive ones in orange, and those for which no information is currently available regarding metadata implementation are shown in grey.

A not negligible percentage of not available information on metadata implementation status is still present mainly due to different data management procedures and infrastructures. Metadata implementation status is also monitored per station.

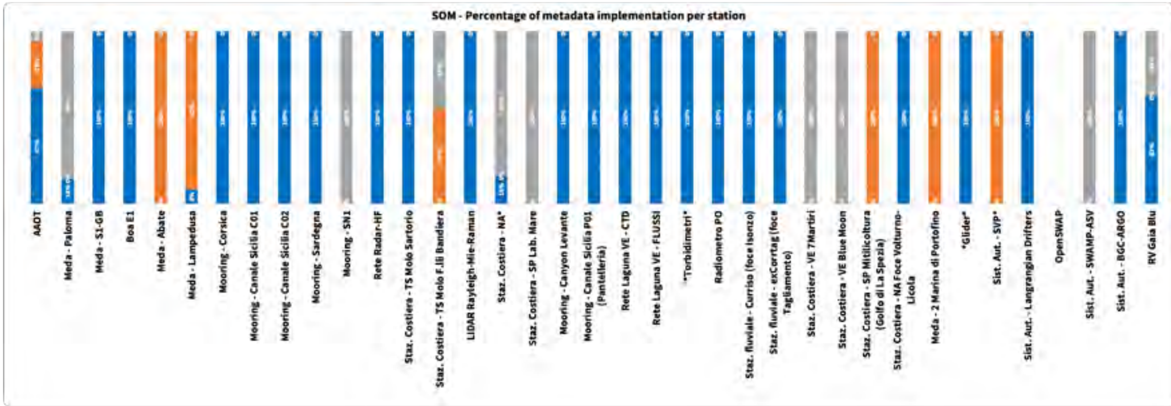

Figure 5 – Percentage of metadata implementation per observing station. Percentages of active metadata are shown in blue, inactive ones in orange, and those for which no information is currently available regarding metadata implementation are shown in grey.

Analogously, we provide current monitoring of QC implementation.

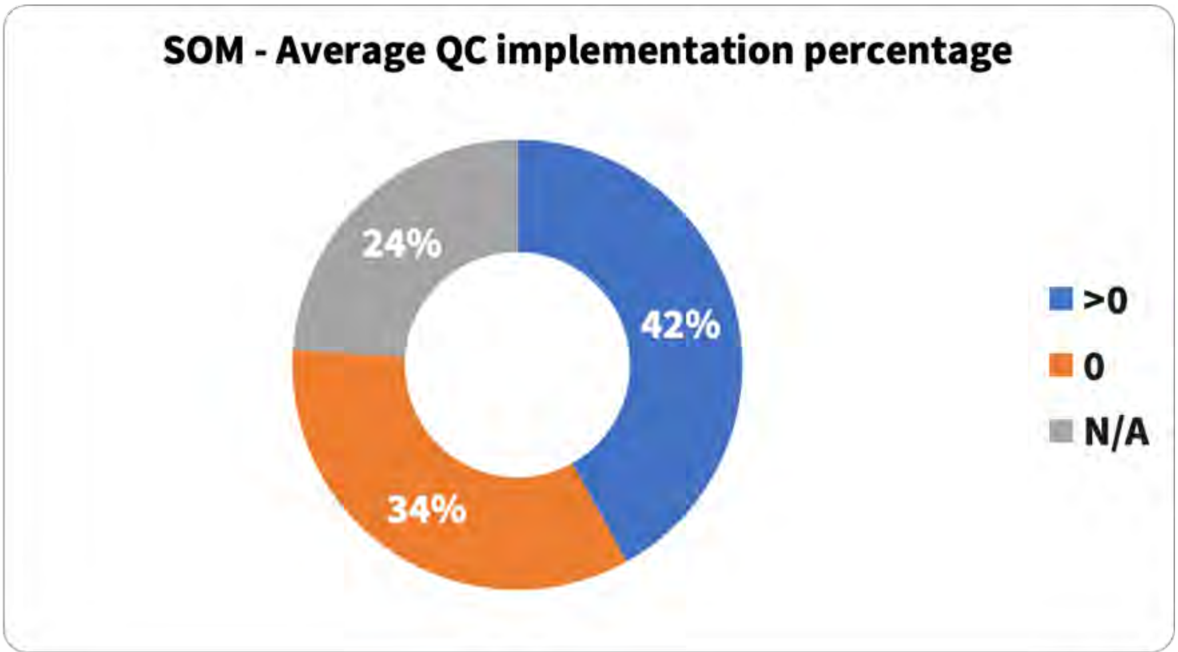

Figure 6 – SOM average percentage of QC implementation. Average percentages of active quality control implementation are shown in blue, inactive ones in orange, and those for which no information is currently available regarding quality control implementation are shown in grey.

Again, a not negligible percentage of not available information on QC implementation status is still present mainly due to different interpretations of quality control levels and procedures. This survey contributes to highlighting this issue and paving the floor for a coordinated discussion.

QC implementation status is also monitored per station.

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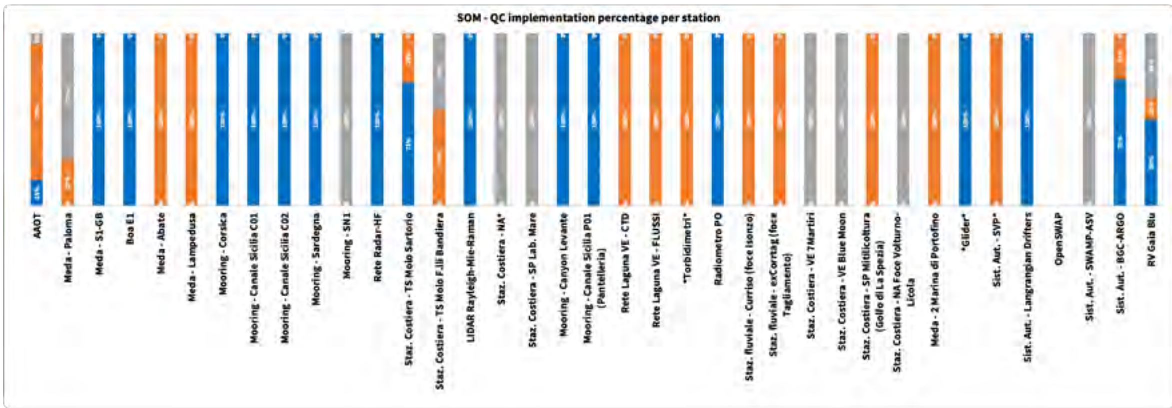

Figure 7 – Percentage of QC implementation per observing station. Percentages of active quality control implementation are shown in blue, inactive ones in orange, and those for which no information is currently available regarding quality control implementation are shown in grey.

Another key area of performance monitoring and strategic assessment concerns the quantitative evaluation of SOM contributions to national and European RIs. This assessment supports the identification and mitigation of potential observational overlaps while fostering technological, operational, and scientific co-location with synergies and complementarities. The analysis is conducted both at the network scale, considering overall variable coverage, spatial representativeness, and integration within RI observing strategies, and at the level of individual stations, where platform-specific contributions to EOV, ECV, and EBV requirements, data streams, and thematic RI priorities are evaluated. The current status of these contributions and integration levels is illustrated in the figures presented below.

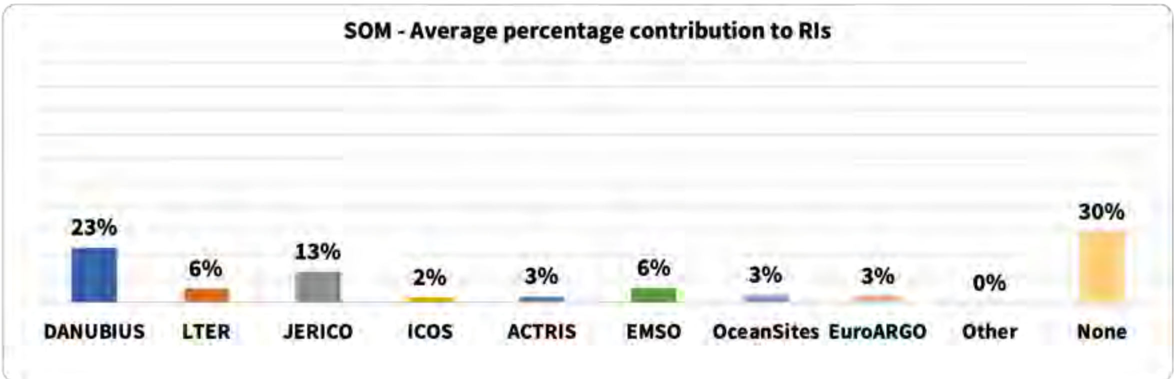

Figure 8 – SOM Percentage contribution to RIs.

RIs contribution is also monitored per station.

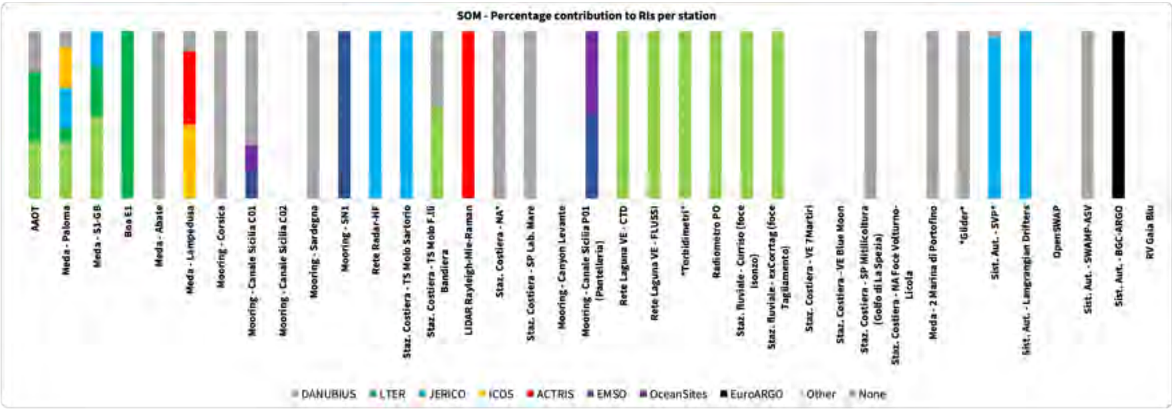

Figure 9 – SOM Percentage contribution to RIs per station. The results describe the RI contribution from both historical and present EVs and do not reflect the present status of RIs contribution from each station.

5 Gap analysis

A systematic gap analysis is required to evaluate the current SOM observational capacity in terms of spatial coverage and EVs monitoring. This includes identifying geographical blind spots, gaps in EOV/ECV/EBV coverage, missing observing assets, and integration gaps between observing sites and research infrastructures. Such analysis supports prioritization of future investments and optimization of network design.

In parallel, it is important to highlight the contribution of ISMAR oceanographic campaigns, including those conducted using R/V Gaia Blu of the National Research Council of Italy (CNR), which provide essential complementary observations and enable deployment and validation of new observing technologies. The integration of ship-based campaigns with fixed and autonomous observing systems strengthens the overall observational strategy and contributes to a more comprehensive assessment of marine environmental variability.

6 Perspectives

Future development of SOM will focus on the implementation of the 2026 upgrade plan and on the consolidation of a long-term technological roadmap. Planned developments include deployment of new sensor technologies, expansion of biological and biogeochemical observing capabilities, integration of artificial intelligence approaches for quality control and anomaly detection, and adoption of innovative observing strategies based on multi-platform coordination.

At the strategic level, SOM aims to strengthen its international positioning by reinforcing integration within the European Research Infrastructures and global observing programmes. Long-term sustainability beyond PNRR will rely on diversified funding strategies, optimisation of operational costs, and consolidation of partnerships at national and European levels.

Overall, SOM is evolving toward a fully integrated, interoperable and multidisciplinary observing system capable of supporting scientific research, operational services, climate monitoring and ecosystem management across the land–sea continuum, in line with future European and global observing priorities.

7 The stations of the network

The SOM facilities are strategically positioned to collect oceanographic, meteorological and environmental data in order to study marine ecosystems, monitor and understand environmental changes and provide information for the sustainable management of marine resources and for the study of marine-coastal hazards.

SOM is integrated with the opportunities offered by the availability of the R/V Gaia Blu and other naval support vessels for the implementation of oceanographic campaigns and research activities. A complete description of each facility, including historical context, legacy activities, and past developments, is available in the two previously published technical reports from 2023 and 2025:

- **DOI: 10.26383/CNR-ISMAR.2023.7**
  https://www.ismar.cnr.it/wp-content/uploads/2023/11/RT_Rete-Naz-Siti-Osservativi-Marini_ITA__ENG.pdf
- **DOI: 10.26383/CNR-ISMAR.2025.01**
  https://www.ismar.cnr.it/web-content/wp-content/uploads/2025/02/TR-35.pdf

The present document does **not** reproduce or summarise those previously documented activities. Instead, the following paragraphs focus **exclusively on the scientific contributions, upgrades, and recent advancements introduced at each station as part of the most recent developments and PNRR-driven expansions**.

7.1 Acqua Alta Oceanographic Tower

Figure 10 – Identification of the position of the Acqua Alta Oceanographic Tower in the northern Adriatic Sea. Images taken in March 1970 (installation) and in 2021, following the restoration of the instrumentation after the renovation completed in 2018. Photo credit: Luigi Cavaleri (1970) and Pomaro Angela (2021)

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The Acqua Alta Oceanographic Tower (AAOT), installed in March 1970 in response to the disastrous floods that hit Venice on 4 November 1966, is one of the main research infrastructures managed by the National Research Council of Italy.

Located about 15 km off the coast of Venice, in a stretch of sea with a depth of approximately 16 m (GPS position:45.3142467 N, 12.5082483 E), it consists of a laboratory module and accommodation, as well as sophisticated distribution systems for real-time data management and transmission of data from numerous measuring stations and sensors. It is also an important fixed point for the periodic sampling of the water column and the analysis of biological and chemical parameters.

The structure and the scientific equipment of the tower have been progressively developed and updated, in order to guarantee an ever greater and better use of the infrastructure also by the numerous external research and institutional bodies with which CNR collaborates. A thorough renovation was completed in 2018, with an overall investment of about 1M€.

The Acqua Alta Oceanographic Tower uses a heterogeneous system for data collection and quality control, managed by different organizations, each equipped with its own sensors and communication channels. The instruments installed by various entities (e.g., Municipality of Venice, ISPRA – Institute for Environmental Protection and Research, Public Works Authority of Veneto, NASA-JPL) operate independently, ensuring redundancy and reliability thanks to the simultaneous presence of multiple radio links and cellular network connections. These multiple and separate transmission channels guarantee that data reach management and storage systems in real time, even in the event of interruption or saturation of one of the links.

For each type of sensor, a data acquisition policy has been adopted according to the required measurement frequency and resolution. Meteorological parameters (such as temperature, wind, pressure, and precipitation) are generally recorded every five minutes. Directional wave and surface/subsurface current measurements are collected at intervals ranging between 15 and 30 minutes, depending on the profile considered. Some biological or chemical parameters—such as nutrients, zooplankton biomass, or dissolved oxygen—are measured on a monthly or seasonal basis, allowing more in-depth surveys with high-resolution analytical instruments. Optical sensors for turbidity, pH, chlorophyll, and sea color operate almost continuously, with sampling every five minutes or so, useful for the calibration and validation of satellite products.

In recent years, as part of the PNRR ITINERIS project, most real-time data collected by CNR–ISMAR instruments installed on the tower have been acquired, checked, and validated through a central ICT system compliant with Open Geospatial Consortium (OGC) standards (https://www.ogc.org/). This system also provides automated alerts to technical personnel in the event of transmission issues or data quality anomalies. All datasets, harmonized and structured according to the FAIR principles (Findable, Accessible, Interoperable, Reusable), are made available both internally within ISMAR and through the Marine Data Portal (https://it-ioos.eu) developed under the PNRR project ITINERIS (No. IR0000032) and FOE DANUBIUS.

The tower is currently the only national fixed-position infrastructure that enables the collection of complete, high-resolution time series in a stable marine environment with limited coastal interference. This provides highly reliable and consistent datasets over time, suitable for advanced modeling, weather forecasting, and climate-change studies.

Regarding connectivity, each data manager independently handles its own radio or mobile channel. Dedicated point-to-point radio links to the mainland ensure continuous data transmission even during heavy network traffic or adverse weather conditions. In parallel, 4G/5G cellular connections serve as a secondary channel, offering additional redundancy and backup for data flows. In the event of a radio link interruption, sensors automatically switch to the mobile network, preventing data loss.

Alongside scientific measurements, the tower hosts cameras both above and below the sea surface, streaming live images and videos via GARR.tv. These cameras provide HD or full-HD resolution for live streaming, and some experimental speed-dome cameras reach 4K resolution. The broadcasts are viewed daily by thousands of users, including fishermen, maritime operators, and enthusiasts, who can interactively choose among different views (open sea, underwater at 10 m, tower base). These images serve scientific, educational, and operational purposes, supporting daily field activities and enhancing public awareness and marine safety.

7.1.1 Scientific Outcomes and Contributions of recent activities

The AAOT is the only oceanographic research tower in the Mediterranean Sea and one of the few in the global oceans. It is a permanent station for observation of oceanographic and atmospheric variables used for process studies and as a reference for the calibration of forecast models and satellite-based products. Its strategic position in the northern Adriatic Sea makes it a valuable laboratory for the study of both open-sea and coastal processes.

A long series of publications has been produced relying on experiments carried out at the Acqua Alta Oceanographic Tower. Bulletins of the main research activities carried out from the tower in 2023, 2024 and 2025 were produced and are available through the CNR-ISMAR website in addition to all information reported in the technical reports mentioned at the premises of this chapter. These publications are planned to be made available also for the future, on a yearly basis.

7.1.2 National/International collaborations and ESFRI contribution

The Acqua Alta Oceanographic Tower contributes to the European research infrastructures DANUBIUS-RI, JERICO-RI, eLTER-RI, EMBRC ERIC, as well as to the NASA Aeronet monitoring network. The equipment at AAOT has recently been updated with funds from the PNRR ITINERIS project, described in detail the following paragraph. In the context of these infrastructures, AAOT represents a unique site, providing secure installations for both atmospheric and hydrological sensors. The possibility to control these sensors in real-time also helps in the planning of manned and unmanned experiments on board. It has hosted, and will continue to host, Trans-national Access (TNA) for the scientific communities planning experiments on board. The peculiarities of this infrastructure foster trans-disciplinary collaborations between networks with different objectives. The availability of long-term observations in different “spheres” gives the opportunity to provide unique datasets for climate change studies.

7.1.3 PNRR investments and expected outcome

Part of the funding from the PNRR ITINERIS project has been allocated to the acquisition of new instrumentation to replace existing sensors and ensure the continuity of high-quality data collection. Specifically, the new instruments include:

A profiling system equipped with a **SeaBird SBE37-SMP-ODO**, a high-accuracy microCAT sensor for measuring temperature, salinity, and dissolved oxygen replaces the former three level system increasing the vertical resolution (now up to 0.25 m) of the measurements and keeping the current time resolution. In early 2026, a **3D scanning atmospheric - marine LIDAR** system will be installed on the upper terrace (+14.5 m) to allow the acquisition of LIDAR signal from marine by moving the LIDAR head at positive zenith angles. This installation will pave the way for enhancing observational capabilities within the ACTRIS research infrastructure. In addition, this system will enable integration with other instruments associated with other research infrastructures already present on the platform.

During late 2025, AAOT will undergo the implementation of **a new renewable energy system based on solar panels and wind turbines** capable of generating the higher power required by the new assets of instruments data transmission systems and sampling devices.

7.1.4 Observed variables

The following table shows the summary of the essential oceanic and climatic variables acquired on an operational basis at the station.

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Atmosphere			
Surface			
Precipitation	2008	5 min	CNR-ISMAR / CPSM / ISPRA
Pressure	2008	5 min	CNR-ISMAR / CPSM / ISPRA
Radiation budget	2008	5 min	CNR-ISMAR / CPSM / ISPRA
Temperature	2008	5 min	CNR-ISMAR / CPSM / ISPRA

Water vapour	2008	5 min	CNR-ISMAR / CPSM / ISPRA
Wind speed and direction	1982	5 min	CNR-ISMAR / CPSM / ISPRA
Carbon Dioxide	2023	3 h	CNR-ISMAR
Ocean			
Physical			
Sea level	1983	5 min	CNR-ISMAR / CPSM
Sea state	1979	15 min	CNR-ISMAR / CPSM
Sea surface currents	2008	30 min	CNR-ISMAR
Sea surface salinity	2009	10 min	CNR-ISMAR
Sea surface temperature	2009	10 min	CNR-ISMAR
Subsurface currents	2008	30 min	CNR-ISMAR
Subsurface salinity	2009	10 min	CNR-ISMAR
Subsurface temperature	2009	10 min	CNR-ISMAR
Biogeochemical			
Nutrients	2009	monthly	CNR-ISMAR
Ocean colour	2002	5 min	JRC-EU / CNR-ISMAR
Oxygen	2009	monthly	CNR-ISMAR
Biological/ecosystems			
Phytoplankton biomass and diversity	2009	monthly	CNR-ISMAR
Zooplankton biomass and diversity	2012	monthly	CNR-ISMAR
Cross-Disciplinary			

Ocean Sound	2019	continuous	CNR-ISMAR

7.1.5 Publications (after 2023)

Cazzaniga, I., & Mélin, F. (2024). How Representative Are European AERONET-OC Sites of European Marine Waters? Remote Sensing, 16(10), 1793. https://doi.org/10.3390/rs16101793

Martellucci R., F. De Mendoza Paladini, M. Menna, A. Pirro, M. Reale, M. Gačić, P.M. Poulain, F. Riminucci, J. Le Meur, G. Patrizia, L. Langone, V. Cardin, C. Cantoni, C. Bergami, F. Grilli, M. Marini, A. Gallo, G. Notarstefano, S. Toller, M. Bastianini, M. Kralj, T. Diociaiuti, M. Pacciaroni, A. Bussani, E. Mauri, S. Miserocchi (2025). A multiobservation analysis of the 2017 dense water formation events: Climate change, bottom density currents, and Adriatic-Ionian sea circulation (Mediterranean Sea). Journal of Geophysical Research: Oceans, 130, e2024JC022306. DOI: 10.1029/2024JC022306

Mélin, F., Cazzaniga, I., & Sciuto, P. (2025). Compatibility Between OLCI Marine Remote-Sensing Reflectance from Sentinel-3A and -3B in European Waters. Remote Sensing, 17(7), 1132. https://doi.org/10.3390/rs17071132

Zibordi, G., D. D’Alimonte, B. Bulgarelli, T. Kajiyama, and I. Slutsker, 2025: On the Impact of Alternative Processing on AERONET-OC LWN. J. Atmos. Oceanic Technol., 42, 1661–1674, https://doi.org/10.1175/JTECH-D-25-0038.1.

Gavin H. Tilstone, Thomas M. Jordan, Dirk Aurin, Agnieszka Białek, Alexis Deru, Ashley Ramsay, Martin Hieronymi, Giorgio Dall’Olmo, Martin Ligi, Charles Kovach, Ilmar Ansko, Michael Ondrusek, Viktor Vabson, Giuseppe Zibordi, Juan Ignacio Gossn, Ewa Kwiatkowska, and Riho Vendt, "Radiometric field inter-comparison of fiducial reference measurements using an open source community processor," Opt. Express 33, 15756-15781 (2025)

Jaime Pitarch, Vittorio Ernesto Brando, Marco Talone, Constant Mazeran, Davide D'Alimonte, Tamito Kajiyama, Ewa Kwiatkowska, David Dessailly, Juan Ignacio Gos. Analytical modeling and correction of the ocean colour bidirectional reflectance across water types, Remote Sensing of Environment, Volume 329, 2025, 114920, ISSN 0034-4257.

Davide D'Alimonte, Tamito Kajiyama, Jaime Pitarch, Vittorio Ernesto Brando, Marco Talone, Constant Mazeran, Michael Twardowski, Srinivas Kolluru, Alberto Tonizzo, Ewa Kwiatkowska, David Dessailly, Juan Ignacio Go. Comparison of correction methods for bidirectional effects in ocean colour remote sensing, Remote Sensing of Environment, Volume 321, 2025, 114606, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2025.114606.

Giardino, C., Pahlevan, N., Fabbretto, A., Panizza, L., Pellegrino, A., Vandermeulen, R., … Gascon, F. (2025). ACIX-III Aqua: evaluation of atmospheric correction for hyperspectral PRISMA imagery over inland and coastal waters. International Journal of Remote Sensing, 46(23), 9066–9090. https://doi.org/10.1080/01431161.2025.2574517

Cavaleri, L., Pomaro, A., Bertotti, L. et al. 45 years of directional wave recorded data at the Acqua Alta oceanographic tower. Sci Data 12, 224 (2025). https://doi.org/10.1038/s41597-025-04541-8

Akaawase, B., Romero, L., Benetazzo, A., 2025. Observations of Wave-Breaking Direction and Energy Spread. Geophys. Res. Lett. 52. https://doi.org/10.1029/2025GL116452

Bernardi Aubry, F, Acri, F., Bastianini, M., Finotto, S., Pugnetti, A., 2025. Phytoplankton dynamics and responses to two extreme events in the Gulf of Venice, Northern Adriatic Sea, Italy. Estuar. Coast. Shelf Sci. 323, 109398. https://doi.org/10.1016/j.ecss.2025.109398

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7.2 PALOMA elastic beacon

Figure 11- Position of the PALOMA elastic beacon in the centre of the Gulf of Trieste, repositioning of the station, May 2022, after the renovation works and the station as it appears today.

The Advanced Oceanographic Laboratory Platform for the Adriatic Sea (PALOMA) is an elastic beacon located in the centre of the Gulf of Trieste, between the coastal towns of Piran (SIovenia) and Grado (Italy).

It is installed approximately 15 kilometres off the coast of Trieste, and it is anchored on a 25-metre depth seafloor (GPS 45.618283 N, 13.565217 E). It was first deployed in July 2002 by the Istituto Talassogafico of Trieste, which joined CNR-ISMAR in the following years. In November 2020, the station suffered serious damage and was subsequently brought ashore for major maintenance. After extensive refurbishment, it was installed again in May 2022.

Since 2002 it has provided near real-time meteorological data in collaboration with the Civil Protection - FVG and ARPA-OSMER.

Over the years, the station's instrumentation has been upgraded, with a particular focus on studying the air-sea exchanges of carbon dioxide (CO_2), a key driver of climate change.

As part of the PRO-ICOS_MED project, the platform has undergone further upgrades, including the installation of additional sensors and a new data transmission system. This has enabled near real-time monitoring of the parameters collected, which are now available on a dedicated website http://150.178.68.195/gc_apps/paloma_public/.

During 2025, near real time data transmission to the ICOS Carbon Portal was implemented, enabling Level-1 data visualization and distribution https://meta.icos-cp.eu/objects/Ewu7oIR5cyTMLJFdSGT15ifB.

Within the framework of the EU-funded LandSeaLot project (2024–2028), measurements of the chromophoric component of dissolved organic carbon (C-DOM) have been included among the monitored parameters since January 2025. This parameter complements the characterization of dissolved carbon, provides a link to automated F-DOM measurements, and supports the development of remotely sensed DOC data products.

7.2.1 Scientific Outcomes and Contributions of recent activities

Located in the central and deepest part of the Gulf of Trieste (GoT) under the direct influence of the Isonzo River, the PALOMA station is an ideal site to study several key processes in the Gulf. These include the formation of dense water in winter, the influence of riverine inputs, and the onset of hypoxia in summer and has been extensively used for these studies in the past years. Recently, data from the station contributed to the study at basin scale of 2017 dense water event (Martellucci et al., 2025b).

Research on **carbonate chemistry** conducted at the PALOMA station have contributed to the assessment of long-term trends in ocean acidification in the Adriatic Sea (Cantoni et al. 2024) and to basin scale multiplatform studies on air-sea CO_2 fluxes (Martellucci et al. 2024; Martellucci et al 2025). Station's quality-controlled data on sea surface carbon dioxide fugacity (fCO_2), measured as part of the ICOS-ERIC network (Steinhoff et al. 2019), contributed, also in 2024 and 2025 to the annual SOCAT compilation of global fCO_2 data (Bakker et al., 2025). These data are essential for Copernicus and other synthesis products and form a key step in the value chain of in situ measurements of inorganic carbon in the oceans. This information plays a crucial role in providing policy makers with insights into oceanic CO_2 uptake for climate negotiations.

7.2.2 National/International collaborations and ESFRI contribution

PALOMA contributes to the European Research Infrastructure ICOS-ERIC (Integrated Carbon Observations System). It was the first Italian marine station and the second European fixed site to be officially part of it, completing the data validation phase (labelling) in 2018. The station also contributes to the European Research Infrastructures DANUBIUS-ESFRI and JERICO-RI, which are currently being implemented. A proof-of-concept activity demonstrating the collaboration between these three RIs in the North Adriatic is underway as part of the EU-funded LandSeaLot project (2024-2028), where research and observations conducted at the PALOMA station are a central focus.

The station is also part of the Global Ocean Acidification Observing Network (GOA-ON) (https://www.goa-on.org/), a collaborative international network designed to improve the understanding of global ocean acidification conditions and impacts.

PALOMA hosts a meteorological station that is part of the Regional Civil Protection Network (Protezione Civile FVG) https://monitor.protezionecivile.fvg.it/#/misure/574/2 and provides data to the Meteorological Office of the Regional Environmental Protection Agency (OSMER ARPA FVG) https://www.osmer.fvg.it/monitor.php?ln=.

Monthly water column sampling is carried out in collaboration with ARPA FVG and the station since 2013, hosts instruments for ocean sound monitoring from ARPA FVG as part of specific projects (presently the UNDERSEA Interreg 2024-2026).

7.2.3 PNRR investments and expected outcome

The PNRR project ITINERIS enabled the addition of new measured parameters, expanded measurement levels, and improved data continuity, ensuring consistent coverage even during annual sensor calibrations and factory maintenance.

Specifically, in spring 2025, **measurements of salinity, pressure, and dissolved oxygen were added at both the –15 m depth and near the bottom at –25 m**, with a time resolution of 30 minutes and real-time data transmission. **Measurements of turbidity, chlorophyll, and fluorescent dissolved organic matter (F-DOM) were added at –3 m**. **Measurements of photosynthetically available radiation (PAR) were added both above the sea surface and at –3 m depth**.

In June 2025, a ***p*CO_2 sensor** was installed at –25 m; however, real-time data transmission for this instrument is still under development.

Overall, these developments will improve the characterization of short-term events such as river plumes and phytoplankton blooms, and their effects on sea-surface pCO_2 variability and air–sea CO_2 fluxes. The new high-frequency measurements of pCO_2 and oxygen near the bottom will allow the detection and study of short-term hypoxia events, as well as the role of near-bottom remineralization processes and wind-driven upwelling in air–sea CO_2 fluxes (Martellucci et al., 2025).

7.2.4 Observed variables

The following table shows the summary of the essential oceanic and climatic variables acquired on an operational basis at the station.

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Atmosphere			
Surface			
Pressure	2002	1 min	CNR-ISMAR / Prot. Civ. FVG
Radiation budget	2002	1 min	CNR-ISMAR / Prot. Civ. FVG
Temperature	2002	1 min	CNR-ISMAR / Prot. Civ. FVG
Water vapour	2002	1 min	CNR-ISMAR / Prot. Civ. FVG
Wind speed and direction	2017	15 min	CNR-ISMAR / Prot. Civ. FVG
Carbon Dioxide	2014-2018	2 h	CNR-ISMAR
Ocean			
Physical			
Subsurface salinity - 3m	2013	30 min	CNR-ISMAR
Subsurface salinity - 15 m	2025	30 min	CNR-ISMAR
Subsurface salinity - 25 m	2025	30 min	CNR-ISMAR
Subsurface temperature -3m	2013	30 min	CNR-ISMAR
Subsurface temperature -3m	2015	30 min	CNR-ISMAR

Subsurface temperature -3m	2015	30 min	CNR-ISMAR
Biogeochemical			
Inorganic carbon - pCO2 (-3m)	2013	6 h	CNR-ISMAR
Inorganic carbon - pCO2 (-25 m)	2025	24 h	CNR-ISMAR
Nutrients	2008	monthly	CNR-ISMAR
Oxygen (-3m)	2008	30 min	CNR-ISMAR
Oxygen (-15m)	2025	30 min	CNR-ISMAR
Oxygen (-25m)	2025	30 min	CNR-ISMAR
Dissolved organic carbon	2008	monthly	CNR-ISMAR
Dissolved organic carbon (f-DOM; ppm)	2024	30 min	CNR-ISMAR
Particulate Matter (Turbidity; NTU)	2024	30 min	CNR - ISMAR
Biological/ecosystems			
Phytoplankton biomass and diversity	2011	monthly	OGS/ CNR-ISMAR
Phytoplankton Biomass and Diversity (Chlorophyll; µg/L)	2024	30 min	CNR - ISMAR
Zooplankton biomass and diversity	2014	monthly	OGS / CNR-ISMAR
Cross-Disciplinary			
Ocean Sound	2013	continuous	ARPA FVG / CNR-ISMAR

7.2.5 Publications

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7.2.6 Open Data

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Tobias; Sullivan, Kevin F.; Sutton, Adrienne J.; Sweeney, Colm; Wada, Chisato; Wanninkhof, Rik; Akl, John; Arbilla, Lisandro A.; Azetsu-Scott, Kumiko; Battisti, Roman; Beatty, Cory M.; Becker, Meike; Benoit-Cattin, Alice; Berghoff, Carla F.; Bittig, Henry C.; Bonin, Jennifer A.; Bott, Randy; Bozzano, Roberto; Burger, Eugene F.; Brunetti, Fabio; Cantoni, Carolina; Castelli, Giuliano; Chambers, Don P.; Chierici, Melissa; Corbo, Andrea; Cronin, Margot; Cross, Jessica N.; Currie, Kim I.; Dentico, Carlotta; Emerson, Steven R.; Enochs, Ian C.; Enright, Matt P.; Enyo, Kazutaka; Ericson, Ylva; Evans, Wiley; Fay, Amanda R.; Feely, Richard A.; Fragiacomo, Elena; Fransson, Agneta; Gehrung, Martina; Giani, Michele; Glockzin, Michael; Hamnca, Siyabulela; Holodkov, Nikola; Hoppema, Mario; Ibánhez, J. Severino P.; Kadono, Koji; Kamb, Linus; Kralj, Martina; Kristensin, Tor O.; Laudicella, V. Alessandro; Lefèvre, Nathalie; Leseurre, Coraline; Lo Monaco, Claire; Maenner Jones, Stacy; Maenza, Reinaldo A.; McAuliffe, Anna M.; Mdokwana, Baxolele; Monacci, Natalie M.; Musielewicz, Sylvia; Neill, Craig; Newberger, Tim; Nojiri, Yukihiro; Ohman, Mark D.; Ólafsdóttir, Sólveig R.; Olivier, Léa; Omar, Abdirahman M.; Osborne, John; Pensieri, Sara; Petersen, Wilhelm; Plueddemann, Albert J.; Rehder, Gregor; Roden, Nicholas P.; Rutgersson, Anna; Sallée, Jean-Baptiste; Sanders, Richard; Sarpe, Dick; Schirnik, Carsten; Schlitzer, Reiner; Send, Uwe; Skjelvan, Ingunn; Sutherland, Stewart, C.; T'Jampens, Michiel; Tamsitt, Veronica; Telszewski, Maciej; Theetaert, Hannelore; Tilbrook, Bronte; Trull, Tom; Tsanwani, Mutshutshu; Van de Velde, Sebastiaan; Van Heuven, Steven M. A. C.; Veccia, Martín H.; Voynova, Yoana G.; Weller, Robert A.; Williams, Nancy L. (2025). Surface Ocean CO2 Atlas Database Version 2025 (SOCATv2025) (NCEI Accession 0304549). NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/648f-fv35.

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7.3 S1-GB elastic beacon

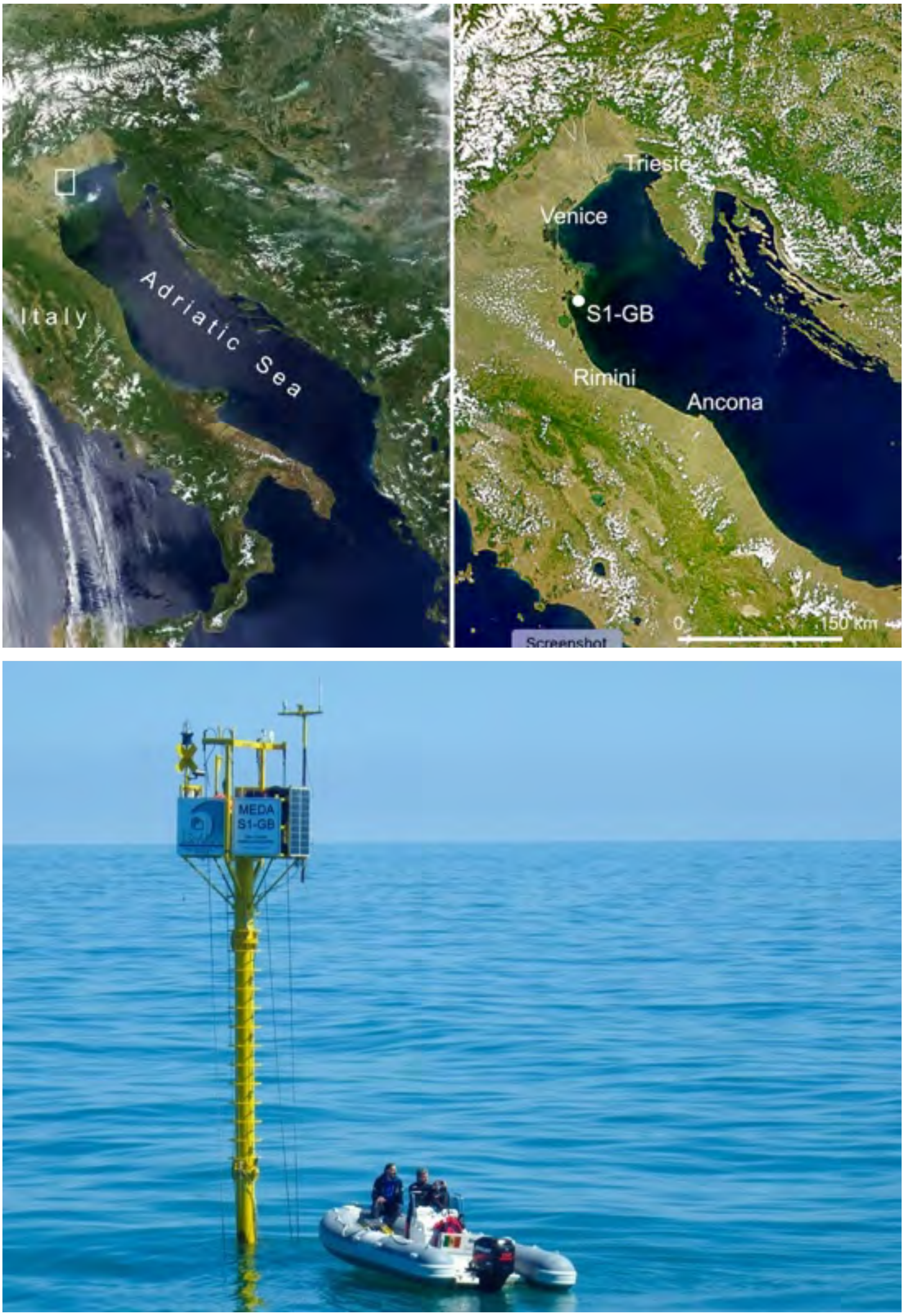

Figure 12 – Identification of the position of the Meda S1-GB south of the mouth of the Po di Goro (Po River delta - Northern Adriatic)

The S1-GB elastic beacon is one of the facilities managed by CNR-ISMAR along the Romagna coast, off the Po Delta.

The S1 meteo-oceanographic buoy was first installed by ISMAR in 2003 at a depth of about 21 m (44.7384 N - 12.4526 E) at the S1 study site, about 4 nautical miles south of the mouth of the Po di Goro (Po Delta - northern Adriatic Sea), on a seabed of 22.5 m. After a two-month test period in 2003, the S1 buoy was finally installed in March 2004.

In 2015, the S1 station was further updated: the semi-mobile floating buoy and instrumented chain system was replaced by an elastic beacon station. The station was renamed from buoy S1 to elastic beacon S1-GB.

The S1-GB beacon consisted of a meteorological station and a submerged mooring line housing oceanographic instruments at two depths (-2.5 m and -18.5 m).

The beacon was located a key area for the study of the interactions between the North Adriatic and the Po River, which experiences a wide range of oceanographic conditions and is considered representative of the continental shelf conditions of the North Adriatic Sea, in an area influenced by the solid and liquid discharges of the Po River. It recorded oceanographic, meteorological and biogeochemical parameters in NRT, also for the validation of physical and biological modelling of the northern Adriatic.

The system was equipped with NRT recording and transmission devices, 12 and 24V DC power supply systems, a meteorological station and a double winch (connected to the submerged mooring) housing the oceanographic instrumentation at two depth levels (including CTD probes, dissolved oxygen, chlorophyll, turbidity and CDOM, DCS sensors).

Following an extremely severe storm in December 2024, the S1-GB elastic beacon sank, resulting in the loss of the instruments installed on it, some of which had been acquired through the PNRR ITINERIS project (Riminucci et al. 2025a). The necessary instrumentation has since been reacquired, and the deployment of a provisional buoy at the same location is planned. The buoy is currently being assembled and is expected to be deployed in spring 2026. As soon as technically and financially feasible, a beacon structure, which is significantly more stable and capable of hosting more complex instrumentation, will be restored.

During summer 2025, a CTD probe was installed on the seabed of the S1-GB site. This activity was planned to ensure continuity—albeit partial—of the historical S1-GB time series dataset. Recovery of the mooring is scheduled for spring 2026, and the data will be downloaded and included in the Database.

Additional measurements are routinely collected at the site with periodic sampling covering biology, sedimentology, chemistry and oceanography.

The site contributes to the European research infrastructures eLTER-RI, within the Po Delta and Romagna Coast research site (https://deims.org/6869436a-80f4-4c6d-954b-a730b348d7ce), DANUBIUS-ERIC, and JERICO-RI.

7.3.1 Scientific Outcomes and Contributions of recent activities

Data from the E1 buoy and S1-GB elastic beacon are essential for advancing research on climate change, ecosystem health, and biogeochemical cycles in the northern Adriatic Sea. This data provides critical insights into the dynamic interactions between atmospheric, oceanographic, and ecological processes, enabling researchers to monitor long-term trends, assess the impact of human activities, and develop predictive models. The continuous and high-resolution measurements from these stations are essential for understanding the complex environmental changes occurring in this region, thereby supporting effective management and conservation strategies.

Recent research has significantly advanced the scientific value of the long-term observations collected at these sites. In particular, **turbidity measurements** have been crucial for the **validation of satellite-derived turbidity products**, improving our understanding of sediment dynamics in areas strongly influenced by the Po River (Pomaro et al., 2024). Continuous surface fluorescence time series from the **E1 buoy** have likewise supported new efforts to validate **satellite chlorophyll-a estimates**, strengthening the performance of ocean-colour algorithms used in remote sensing (Pomaro et al., 2024).

A series of 2024 studies has made extensive use of data from both E1 and S1-GB to investigate **nutrient dynamics, eutrophication processes, and broader biogeochemical patterns** in the northern Adriatic Sea, offering results that are directly relevant for ecosystem assessment and management (Pomaro et al., 2024). These platforms have also contributed to recent analyses of **extreme weather events and their effects on marine systems**, supporting a growing body of work dedicated to understanding the response of coastal environments to meteorological forcing (Pomaro et al., 2024; Martellucci et al., 2025; Riminucci et al., 2025b). In parallel, the systems have continued to provide essential information for **monitoring hypoxic and anoxic events** along the Emilia-Romagna coastline (Pomaro et al., 2024).

Other ongoing activities focus on the **sedimentary environment surrounding the observation sites**. Recent analyses have expanded our understanding of anthropogenic impacts and sedimentary processes using trace metals, major elements and radionuclides, shedding light on environmental changes over the last two centuries in the Po River prodelta (Pomaro et al., 2024). The sites also serve as observatories for **benthic microfauna**, supporting updated assessments of biodiversity patterns and ecological status in a heavily impacted region of the North Adriatic (Pomaro et al., 2024; D'Onofrio et al., 2025). All microfaunal datasets continue to be integrated into the **DiSSCo national digital repository**, following FAIR principles (D'Onofrio et al., 2024).

Most recently, investigations have applied long-term series of optical turbidity, salinity, hydrographic, wave, and meteorological data to explore the **drivers of turbidity variability on the north-western Adriatic shelf**, providing new insights into interactions among environmental forcing factors (Riminucci et al., 2025b). In addition, current research analysing **decadal chlorophyll-a optical records** aims to detect long-term trends in phytoplankton phenology and bloom dynamics across the northern Adriatic Sea (Toller et al., 2025).

7.3.2 National/International collaborations and ESFRI contribution

The S1-GB and E1 systems contribute to the activities of numerous European and national scientific research projects and several ESFRI Research Infrastructures (RIs). In particular, the Po

Delta and Romagna Coast site is part of the Italian Long-Term Ecological Research Network (LTER-Italy) and the eLTER-RI infrastructure. The S1-GB elastic beacon has been selected for Transnational Access within the JERICO-RI infrastructure, which provides access to researchers from other countries, and is also part of the DANUBIUS-ERIC infrastructure for the "Po Delta and North Adriatic Lagoons" supersite (De Pascalis et al., 2025).

The most recent (last 4-5 years) projects that have benefited from the activities of these observatories are:

- Horizon 2020 eLTER-PLUS: one of the projects supporting the implementation of eLTER-RI
- Horizon Europe Marco-Bolo (Marine Coastal Biodiversity Long-term Observations): Po Delta is one of the project's case studies
- Horizon Europe Biodiversity Meets Data (BMD) for automatic workflow of imaging and taxonomic recognition to VREs
- PETRI-MED call BIODIVERSA': S1-GB and E1 are two sampling sites (in-situ laboratories) for the calibrating of satellite observations
- Horizon 2020 Jerico-S3: S1-GB selected for transnational access.

The system received funding from the PNRR ITINERIS project for its implementation with new sensors increasing the number of observed variables and improving data transmission and management procedures.

Both systems provide biological data together with environmental data to the DISSCO Research Infrastructure (RI) for Natural Science Collections (NSC).

7.3.3 PNRR investments and expected outcome

The PNRR ITINERIS project has played a crucial role in the implementation of the S1-GB system. Following the severe storm of December 2024, which caused the sinking of the beacon and the loss of its instrumentation (including several sensors that had already been purchased and installed through the project), ITINERIS funded the **reacquisition of all sensors**, ensuring the continuity of the time series. A temporary buoy, currently under assembly, is planned to be deployed in spring 2026 at the same coordinates to guarantee the continuation of data collection. This provisional system will operate until a new beacon structure, which provides greater stability and allows the integration of more complex instrumentation, will be deployed.

ITINERIS also supported the **upgrade of data transmission system**, improving the reliability of near real-time data delivery and ensuring interoperability with the data repository managed by CNR-ISMAR. These upgrades align with the principles of open science and the FAIR data framework, facilitating data access and integration within European RIs and the IT-IOOS implemented in the project.

The renewal and integration of sensors at the S1-GB site will ensure a significant improvement in the quality, reliability, and continuity of oceanographic and atmospheric observations in the Northern Adriatic. The replacement of probes for subsurface temperature, salinity and oxygen will restore the site’s core capacity to monitor ECVs and EOVs related to physical and biogeochemical ocean processes.

The installation of new instruments, including a **turbidimeter**, **PAR sensors**, and the **wave measurement system** will expand the range of observed parameters, allowing for a more comprehensive characterization of water column properties, particulate dynamics, light availability, and sea state variability.

Overall, the upgraded system will strengthen the integration between physical, biogeochemical, and meteorological observations, supporting long-term assessments of climate variability and coastal dynamics in the Po Delta area.

Total amount of PNRR investments (sensors and ICT implementations): 170k€.

7.3.4 Observed variables

The following table shows the summary of the essential oceanic and climatic variables acquired on an operational basis at the station.

Essential Climate and Oceanic Variables (ECVs and EOVs) (*)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Atmosphere			
Surface			
Precipitation	2018	30 min	CNR-ISMAR
Pressure	2004	30 min	CNR-ISMAR
Temperature	2004	30 min	CNR-ISMAR
Water vapour	2004	30 min	CNR-ISMAR
Wind speed and direction	2004	5 min	CNR-ISMAR
Ocean			
Physical			
Subsurface currents	2004	30 min	CNR-ISMAR
Subsurface salinity	2004	30 min	CNR-ISMAR
Subsurface temperature	2004	30 min	CNR-ISMAR
Biogeochemical			

Nutrients	2006	every 6 months	CNR-ISMAR
Oxygen	2012	30 min	CNR-ISMAR
Transient tracers	2012	annual	CNR-ISMAR
Particulate matter	2012	30 min	CNR-ISMAR
Ocean colour	2012	30 min	CNR-ISMAR
Biological/ecosystems			
Phytoplankton biomass and diversity	2012	30 min	CNR-ISMAR

(*) The station is **currently out of service**, hence no active data streams are currently available, following an incident that has necessitated the scheduling of emergency maintenance work, after which it will be returned to the sea.

7.3.5 Publications

Martellucci R., Paladini de Mendoza F., Menna M., Pirro A., Reale, M., Gačić M., Poulain P.M., Riminucci F., Le Meur J., Giordano P., Langone L., Cardin V., Cantoni C., Bergami C., Grilli F., Marini M., Gallo A., Notarstefano G., Toller S., Bastianini M., Krali M., Diociaiuti T., Pacciaroni M., Bussani A., Miserocchi S., Mauri E. (2025). A Multiobservation Analysis of the 2017 Dense Water Formation Events: Climate Change, Bottom Density Currents, and Adriatic-Ionian Sea Circulation (Mediterranean Sea). Journal of Geophysical Research: Oceans, 130, e2024JC022306. https://doi.org/10.1029/2024JC022306

Toller S., Riminucci F., Böhm E., Capotondi L., Correggiari A., Lapucci C., Organelli E., Ravaioli M., Santoleri R., Stanghellini G., Bergami C. (2025). Decadal analysis of chlorophyll fluorescence, algal blooms and driving factors from a fixed-point observing system in the Northern Adriatic Sea. Estuarine, Coastal and Shelf Science, 323(109423), https://doi.org/10.1016/j.ecss.2025.109423

Riminucci F., Capotondi C., Correggiari A., Focaccia P., Gallerani A., Ravaioli M., Stanghellini G., Toller S., Bergami C. (2025a). Rapporto tecnico sull'incidente dell'8 dicembre 2024 al sistema meteo-oceanografico meda elastica S1-GB (Delta del Po – Adriatico Settentrionale). Technical Report N° 39, 2025, CNR-ISMAR, pp. 1-29, DOI: 10.26383/CNRISMAR.2025.04 (online http://www.ismar.cnr.it/prodotti/rapporti-tecnici).

Riminucci F., Bonaldo D., Capotondi L., Ravaioli M., Bergami C. (2025b). Variability and forcings of high turbidity events in the Northern Adriatic Sea from analysis of in-situ long-term data: a methodological approach. Progress in Oceanography 235 (103483). https://doi.org/10.1016/j.pocean.2025.103483

D'Onofrio R, Vitelletti ML, Riminucci F, Rossi V, Capotondi L. (2025). *Virgulinella fragilis* in the North Adriatic Coastal Sediments: A New Non-Indigenous Benthic Foraminiferal Taxon? Biology, 14(4):421. https://doi.org/10.3390/biology14040421

De Pascalis, F., Urbinati, E., Aalifar, A., Aveytua Alcazar, L., Arpaia, L., Bajo, M., et al., 2025. The DANUBIUS-RI supersite of Po delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea. Estuarine, Coastal and Shelf Science, 324, 109453. https://doi.org/10.1016/j.ecss.2025.109453

Pomaro A., Bastianini M., Bellacicco M., Bellafiore D., Bellati F., Benetazzo A., Bergami C., Berta M., Cantoni C., Chiggiato J., Colella S., Corgnati L., Davison S., De Pascalis F., Dionisi D., Gasperini L., Volmer Martin Kokoszka F., La Forgia G., Liberti G., Magaldi M., Mantovani C., Matano F., Organelli E., Raicich F., Schroeder K., Stanghellini G., Volpe G. (2024). ITALIAN OCEAN OBSERVING NETWORK. Technical Report N° 35, 2024, CNR-ISMAR, pp. 1-155, DOI: 10.26383/CNR-ISMAR.2025.01 (online http://www.ismar.cnr.it/prodotti/rapporti-tecnici).

D'Onofrio, R., Ferraro, L.; Giordano L., Riminucci F, Capotondi L. (2024). Foraminifera Natural Science Collection: a multiyear repository of biodiversity data from the Northern Adriatic Sea DOI:10.13140/RG.2.2.30835.34082

7.3.6 OpenData

Riminucci, F., Bergami, C., Bortoluzzi, G., Capotondi, L., Correggiari, A., Focaccia, P., Gallerani, A., Ravaioli M., Stanghellini, G., Toller, S. (2024). Salinity, Turbidity, Wind from the S1-GB pylon at the LTER site Delta del Po and Costa Romagnola (2012-2021) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.1098011

Acri, Bastianini, Bernardi Aubry, Camatti, Bergami, Boldrin, De Lazzari, Finotto, Minelli, Oggioni, Pansera, Sarretta, Socal, & Pugnetti. (2019). LTER Northern Adriatic Sea (Italy) marine data from 1965 to 2015 (Version 3) [Data set]. Zenodo.

7.4 Abate spar buoy

Figure 13 – Identification of the position of the Meda Abate in the Adriatic Sea.

The ABATE spar buoy was installed in March 2000, about 20 nautical miles from the coast, in a body of water at a depth of about 20 metres (GPS 45.25 N - 12.77666 E).

The station, owned by CNR ISMAR, houses the instrumentation of the Centro Previsioni e Segnalazioni Maree (CPSM) of the Municipality of Venice and it is a site of interest for the Institute of Marine Sciences for the **monitoring of long-term biogeochemical variables**. It's role within the SOM is currently under consideration, since this infrastructure needs significant refurbishment in order to continue to operate.

7.4.1 Scientific Outcomes and Contributions of recent activities

The spar buoy is located at a point of interest for the monitoring of meteorological conditions to **support the forecasting of the sea state and tidal conditions** in the northern Adriatic Sea and the Venice Lagoon.

7.4.2 National/International collaborations and ESFRI contribution

The spar buoy does not contribute to national or international research infrastructures (ESFRIs), nor is it currently integrated into formal collaboration frameworks. Its role remains focused on providing local, station-specific measurements that support operational monitoring and targeted scientific applications-.

7.4.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.4.4 Observed variables

The following table shows the summary of the essential oceanic and climatic variables acquired on an operational basis at the station.

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Atmosphere			
Surface			
Pressure	2016	10 min	CPSM
Temperatures	2016	10 min	CPSM
Wind speed and direction	2016	10 min	CPSM

Ocean			
Physical			
Sea level	2017	10 min	CNR-ISMAR

7.4.5 Publications

De Pascalis, F., Urbinati, E., Aalifar, A., Aveytua Alcazar, L., Arpaia, L., Bajo, M., et al., 2025. The DANUBIUS-RI supersite of Po delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea. Estuarine, Coastal and Shelf Science, 324, 109453. Available at: https://doi.org/10.1016/j.ecss.2025.109453

7.5 Lampedusa spar buoy

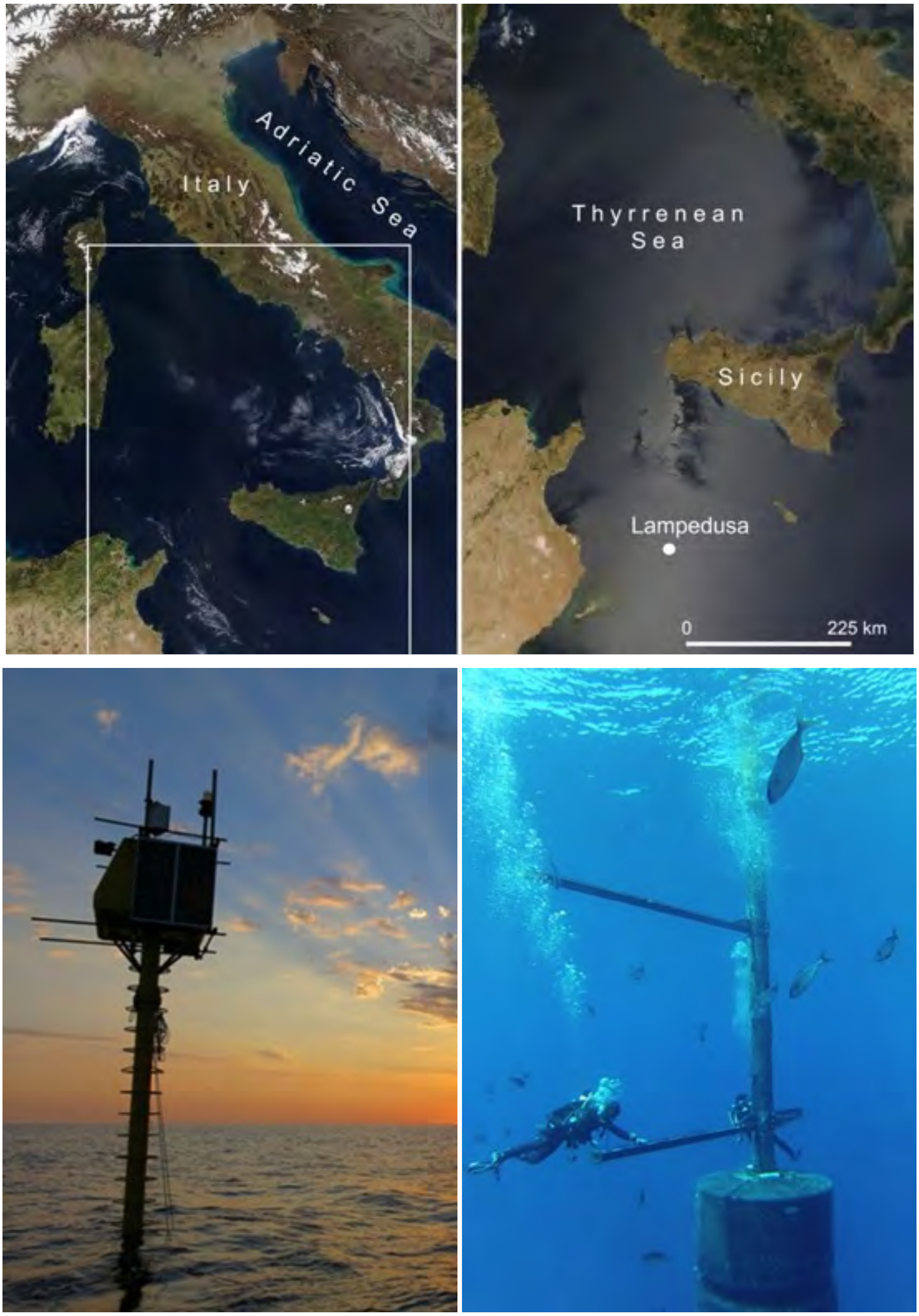

Figure 14 – Identification of the position of the Meda Lampedusa.

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The Lampedusa spar buoy is the oceanographic node of the integrated observatory dedicated to the measurement of parameters relevant for climate studies, owned by ENEA and located on the island of Lampedusa.

The spar buoy is installed in the Sicilian Channel, about 3.3 nautical miles from the south-western coast of the island of Lampedusa, in a body of water with a depth of about 74 m deep (GPS 35.49°N, 12.47°E). The spar buoy has been operational since August 2015, with sensors dedicated to the study of air-sea interactions and the validation of satellite observations.

The operational sensors installed on this site include, an atmospheric section with a weather station with a sonic anemometer, solar and infrared radiometers, a photosynthetically active radiation (PAR) sensor; and a marine section with sensors for temperature (at 1, 2, 5, 18 and 34 m depth), pressure, conductivity and oxygen (at 5 and 18 m depth), 2 Triplet WetLabs (ocean light scattering, chlorophyll fluorescence, dissolved organic matter, at 5 and 18 m depth), pH, partial pressure of CO2 and photosynthetic radiation (PAR) at sea, as well as 2 sets of hyperspectral radiometers at 2 different depths (supported by a radiometer in air), allowing operational measurements of radiometry below the sea surface (Remote Sensing Reflectance and/or Normalised Water Leaving Radiance).

The spar buoy is located at a particularly interesting point for monitoring the biogeochemical characteristics of the water, thanks to the conditions of high transparency, which are extremely relevant for the **validation of satellite observations**.

7.5.1 Scientific Outcomes and Contributions of recent activities

Over the past year, activities at the Lampedusa Oceanographic Observatory have focused on ensuring the continuity, maintenance, and enhancement of in-situ measurements, with targeted technical interventions to improve acquisition reliability, data quality, and the consistency of long-term time series. Radiometric measurements collected by the buoy have also been integrated into the Mediterranean bio-optical dataset used for the validation of ocean colour algorithms within the Copernicus Marine Environment Monitoring Service (CMEMS), strengthening the observatory’s contribution to regional satellite calibration and validation activities.

In addition, a recent study based on observatory measurements provided the first direct and continuous estimates of air–sea CO_2 fluxes in the central Mediterranean. Results show that the region acts as a net annual CO_2 sink, characterised by oceanic uptake during winter and release in summer. The analysis also highlighted the impact of the 2022–2023 marine heatwave, during which winter CO_2 absorption decreased by about 30% compared with the previous year. Sensitivity analyses indicate that this reduction was primarily driven by anomalously low wind speeds, which limited air–sea gas exchange, rather than by temperature alone, underscoring the role of extreme events and atmospheric forcing in modulating regional carbon fluxes (Pecci et al., 2026).

7.5.2 National/International collaborations and ESFRI contribution

The Lampedusa Oceanographic Observatory is a key component of the collaboration efforts between the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and the National Research Council of Italy (CNR). ENEA owns the infrastructure and has progressively equipped the buoy with various atmospheric instruments and in-water oceanographic sensors, including those for measuring temperature, oxygen, pCO2, and pH. CNR contributes by installing in-water radiometers and other bio-optical instruments along the water column.

Currently, the radiometric measurements made in Lampedusa are being used in the PRISCAV project, funded by the Italian Space Agency (ASI), which aims to **validate PRISMA hyperspectral satellite data over open ocean waters**.

At the international level, the observatory's data contributes to improving the accuracy of the Copernicus Marine Services, in particular for validating satellite products such as ocean colour, sea surface temperature and chlorophyll concentrations.

Lampedusa is also part of several European Research Infrastructures (RIs). Measurements of pCO2, pH, salinity, and temperature (at 5m depth) are included in the Integrated Carbon Observation System (ICOS).

In addition, part of the funding from the PNRR ITINERIS project will be used to acquire new instrumentation to replace the current sensors and ensure continued high quality data collection.

During the last year, within the framework of the European Multidisciplinary Seafloor and Water Column Observatory (EMSO), we have been working to assess the feasibility of establishing a multi-platform "super-site" in the Sicily Channel. The proposed infrastructure would integrate three observing components: the Capo Granitola Test Site (GRANSEA), the Pantelleria mooring system, and the Lampedusa Oceanographic Observatory, with the objective of strengthening coordinated, multidisciplinary observations in the region.

7.5.3 PNRR investments and expected outcome

Part of the funding from the PNRR ITINERIS project has been allocated to the acquisition of new instrumentation to replace existing sensors and ensure the continuity of high-quality data collection. Specifically, the new instruments include:

- **SeaBird SBE37-SMP-ODO** – a high-accuracy microCAT sensor for measuring temperature, salinity, and dissolved oxygen.
- **SeaBird ECO-PARs with bio-wiper** – an optical sensor designed to measure photosynthetically active radiation (PAR), equipped with an automatic wiper system to prevent biofouling.
- **ProOceanus CO2-PRO-CV** – a submersible sensor for the in-situ measurement of dissolved carbon dioxide (pCO_2) in seawater.

These sensors will guarantee the continuity of high-quality measurements during calibration and maintenance operations.

7.5.4 Observed variables

The following table shows the summary of the essential oceanic and climatic variables operationally acquired at the station.

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Atmosphere			
Surface			
Pressure	2016	1 min	ENEA
Temperature	2016	1 min	ENEA
Water vapour	2016	1 min	ENEA
Wind speed and direction	2016	1 min	ENEA
Surface Radiation Budget	2016	1 min	ENEA
Ocean			
Physical			
Sea state	2018	30 min	CNR-ISMAR
Subsurface salinity	2018	5 min	CNR-ISMAR/ENEA
Subsurface temperature	2018	1 min	CNR-ISMAR/ENEA
Sea surface temperature	2018	1 min	CNR-ISMAR/ENEA
Ocean surface heat flux	2021	30 min	CNR-ISMAR/ENEA
Biogeochemical			
Oxygen	2018	5 min	CNR-ISMAR/ENEA
Inorganic carbon	2021	30 min	CNR-ISMAR/ENEA

Phytoplankton biomass and diversity	2019	30 min	CNR-ISMAR/ENEA
Ocean colour	2019	30 min	CNR-ISMAR

7.5.5 Publications

Pecci M., Sferlazzo D., Anello F., Becagli S., Colella S., De Silvestri L., Di Iorio T., Iaccarino A., Meloni D., Monteleone F., Piacentino S., Principato E. and di Sarra A. G. (2026). First derivations of air-sea CO2 fluxes in the central Mediterranean and possible impact of the 2022–2023 marine heatwave. *Journal of Geophysical Research: Oceans*, 131, e2025JC023007. https://doi.org/10.1029/2025JC023007

Pecci, M., S. Colella, T. Di Iorio, D. Meloni, F. Monteleone, G. Pace, D. Sferlazzo, and A. G. di Sarra (2024). Validation of photosynthetically active radiation by OLCI on Sentinel-3 against ground-based measurements in the central Mediterranean and possible aerosol effects *European J. Remote Sens.*, **57**, 1, 2307617, 2024. doi:10.1080/22797254.2024.2307617

7.6 E1 buoy

Figure 15- Identification of the position of the E1 buoy in the Adriatic Sea, along the Romagna coast off the coast of Rimini.

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The E1 buoy is one of the two fixed point systems managed by ISMAR along the Romagna coast off the coast of Rimini.

The meteorological-oceanographic buoy E1 is located in the Northern Adriatic, approximately 4 nautical miles north of the city of Rimini, the system is anchored to the seabed by chain and dead weight on a seabed of 10.5 m (44.14325 N - 12.5701 E). The station was installed by ISMAR for the first time in August 2006 as an automatic station for monitoring anoxic and hypoxic events in the Romagna coastal area, in the framework of the LIFE+ Environment EMMA project; after the end of the project, the buoy was kept active and further implemented. The E1 buoy consists of a meteorological station and a submerged mooring line that hosts oceanographic instrumentation at two depths (-1.6 m and -8 m).

The buoy is located in a key monitoring area for studying the interactions between the Northern Adriatic and the Po River, experiencing a wide range of oceanographic conditions. It acquires in NRT oceanographic, meteorological and biogeochemical parameters also for the validation of physical and biological modeling. The station is considered representative of the coastal area conditions of the central-northern Adriatic.

The system is equipped with NRT logging and transmission devices, 12 and 24 V DC voltage power systems, meteorological station and oceanographic instrumentation at two depth levels (including CTD probes, dissolved oxygen, chlorophyll, turbidity and CDOM sensors, DCS sensors). Additional measurements are routinely collected at the site with periodic sampling covering biology, sedimentology, chemistry and oceanography.

The buoy contributes to the European research infrastructure eLTER-RI within the Po Delta and Romagna Coast research site (https://deims.org/6869436a-80f4-4c6d-954b-a730b348d7ce).

7.6.1 Scientific Outcomes and Contributions of recent activities

See paragraph 7.3.1, comprising also this station’s contribution.

7.6.2 National/International collaborations and ESFRI contribution

See paragraph 7.3.2, comprising also this station’s contribution.

7.6.3 PNRR investments and expected outcome

The PNRR ITINERIS project supported the implementation of the E1 system both for sensor acquisition and for the upgrading of data transmission systems, improving the reliability of near real-time data delivery and ensuring interoperability with the data repository managed by CNR-ISMAR. These upgrades align with the principles of open science and the FAIR data framework, facilitating data access and integration within European research infrastructures and the IT-IOOS implemented in the project.

The **renewal and integration of sensors** at the E1 buoy ensured a substantial enhancement in the accuracy, reliability, and temporal continuity of both oceanographic and meteorological observations in the Northern Adriatic. The replacement of key sensors, such as those **measuring subsurface temperature, salinity, and dissolved oxygen**, has strengthen the site's capacity to monitor core ECVs related to physical and biogeochemical ocean processes.

The installation of new **photosynthetically active radiation (PAR)** sensors, deployed both at the atmospheric interface and at the near-surface aquatic level (co-located with the chlorophyll fluorescence sensor), extended the range of observations toward the biogeochemical domain, enabling improved quantification of light availability and its influence on primary productivity and ocean colour dynamics.

Overall, the upgraded E1 system consolidated the long-term monitoring of coupled ocean–atmosphere processes in the Northern Adriatic, fostering integrated assessments of physical, biogeochemical, and climatic variability.

Total amount of PNRR investments (sensors and ICT implementations): 50k€.

7.6.4 Observed variables

The following table shows the summary of the essential oceanic and climatic variables acquired on an operational basis at the station.

Essential Climate and Oceanographic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Atmosphere			
Surface			
Pressure	2006	30 min	CNR-ISMAR
Temperatures	2006	30 min	CNR-ISMAR
Water vapor	2006	30 min	CNR-ISMAR
Wind speed and direction	2006	30 min	CNR-ISMAR
Precipitation	2012	30 min	CNR-ISMAR
Ocean colour	2024	30 min	CNR-ISMAR
Ocean			
Physical			
Sea state	2020	30 min	CNR-ISMAR

Subsurface currents	2006	30 min	CNR-ISMAR
Subsurface salinity	2006	30 min	CNR-ISMAR
Subsurface temperature	2006	30 min	CNR-ISMAR
Biogeochemical			
Nutrients	2006	every 6 months	CNR-ISMAR
Oxygen	2012	30 min	CNR-ISMAR
Transient tracers	2012-	annual	CNR-ISMAR
Particulate matter	2012	30 min	CNR-ISMAR
Ocean colour	2012	30 min	CNR-ISMAR
Biological/ecosystems			
Phytoplankton biomass and diversity	2006	30 min	CNR-ISMAR

7.6.5 Publications

See paragraph 7.3.4, comprising also this station's contribution.

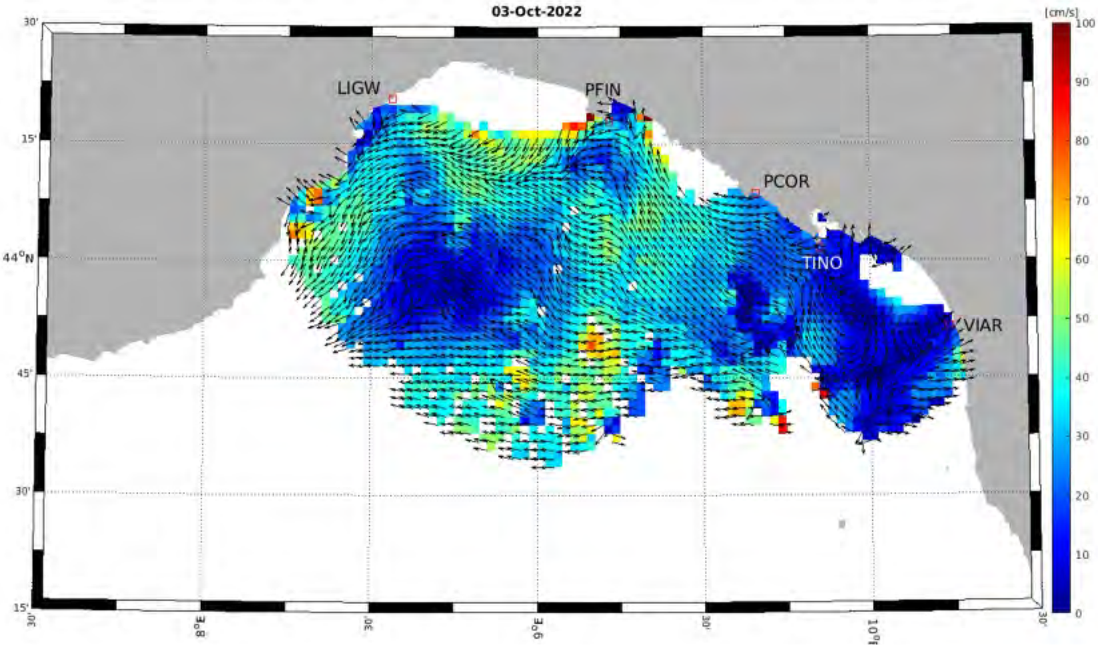
7.6.6 OpenData

Riminucci, F., Bergami, C., Bohm, E., Bortoluzzi, G., Capotondi, L., Correggiari, A., Focaccia, P., Gallerani, A., Ravaioli, M., Santoleri, R., Stanghellini, G., & Toller, S. (2025). Sea temperature, Dissolved oxygen, Chlorophyll-a from the E1 buoy at the LTER site Delta del Po and Costa Romagnola (2012-2022) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.14748898

Riminucci, F., Bergami, C., Böhm , E., Bortoluzzi, G., Capotondi, L., Correggiari, A., Focaccia, P., Gallerani, A., Ravaioli, M., Santoleri, R., Stanghellini, G., Toller, S. (2024). Salinity, Turbidity, Wind from the E1 buoy at the LTER site Delta del Po and Costa Romagnola (2012-2021) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.10980386

Acri, Bastianini, Bernardi Aubry, Camatti, Bergami, Boldrin, De Lazzari, Finotto, Minelli, Oggioni, Pansera, Sarretta, Socal, & Pugnetti. (2019). LTER Northern Adriatic Sea (Italy) marine data from 1965 to 2015 (Version 3) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.3516717

7.7 HF Radar Network



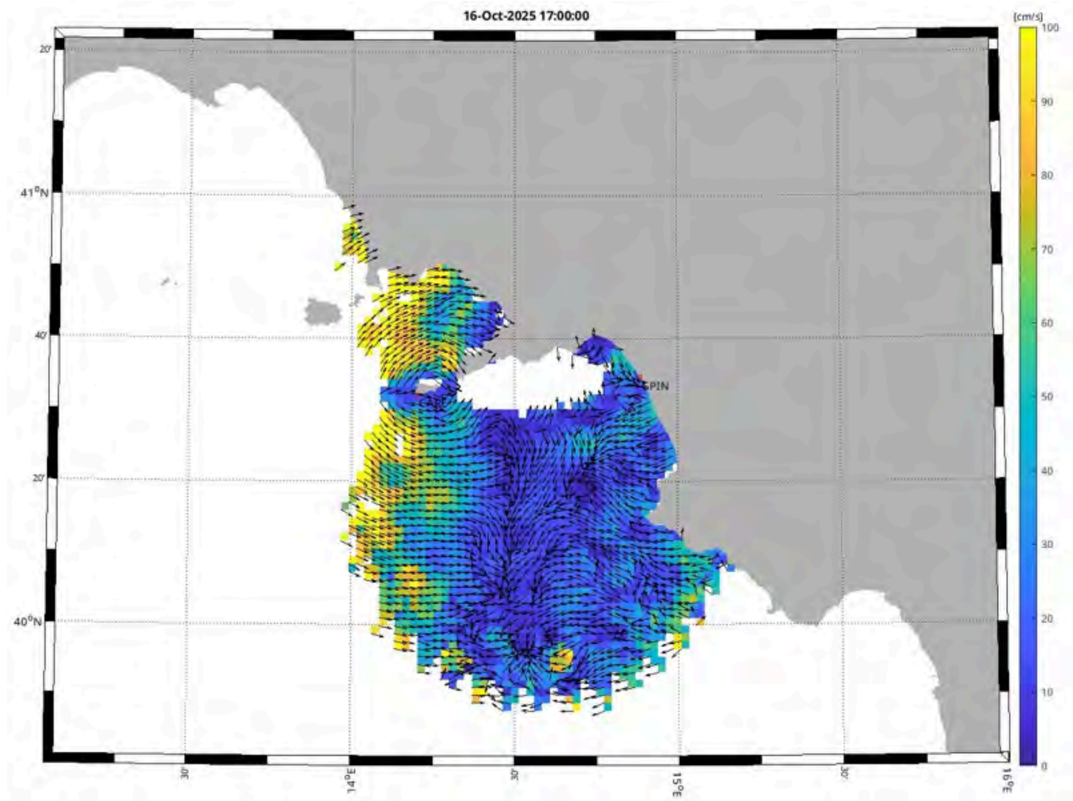


Figure 16 - Locations of the HF Radar systems that are part of the network of the Institute of Marine Sciences (top left), picture of the HF radar antenna installed at the Portofino lighthouse (GE), site code PFIN (top right), surface current field measured by the HFR-TirLig network on 03/10/2022 h. 00:00 (center), surface current field measured by the HFR-GoS network on 16/10/2025 h. 17:00 (bottom).

The HF radar network of the Institute of Marine Sciences is made up of 7 stations operating in the 13MHz and 25MHz frequency bands. 5 stations were put into operation at different times starting in 2016 along the coasts of the north-western Tyrrhenian and Ligurian Seas and 2 stations, since 2025, in the Gulf of Salerno, in the Tyrrhenian Sea (see Figure 16).

Operating stations:		
LIGW	Celle Ligure (SV)	44.29871 N, 9.21837 E
PCOR	Monterosso al Mare (SP)	44.14333 N, 9.65944 E
TINO	Tino Island (SP)	44.02638 N, 9.84916 E
PFIN	Portofino (GE)	44.29861 N, 9.21833 E
VIAR	Viareggio (LU)	43.85805 N, 10.23722 E
CARE	Punta Carena (NA)	40.53625 N, 14.19965 E
SPIN	Spineta (SA)	40.57645 N, 14.866167 E

Two other stations are awaiting installation permits and will be operational to monitor the port area of Genoa, while evaluations are underway to extend of the network to other important basins along the Italian coast. For these two stations, the executive project is underway in the framework of the PNRR RAISE project.

The 5 stations along the coasts of the north-western Tyrrhenian and Ligurian Seas (LIGW, PFIN, PCOR, TINO and VIAR) plus the 2 to be installed in the harbour of Genoa build the HFR-TirLig network, while the 2 stations in the Gulf of Salerno build the HFR-GoS network. For each network specific datasets are operationally produced.

HF radars provide maps of sea surface current velocities over large areas of the sea (the Institute's HF radar network covers 12,000 km^2, with a distance from the coast of up to 80 km) and at time intervals typically of one hour. They are suitable for the continuous monitoring of surface ocean currents. HF radar systems can also provide important statistical information on the wave field (e.g., significant wave height, mean period and mean direction) or even, in certain configurations, its full directional spectrum.

The Institute of Marine Sciences' HF radar network provides real-time access to hourly ocean current velocity fields (see paragraph 7.7.4).

7.7.1 Scientific Outcomes and Contributions of recent activities

The availability of HF radar–derived surface current data over the Ligurian Sea provided an opportunity to explore a new AI-based approach for predicting short-term ocean dynamics. By capturing fine-scale oceanographic features—such as rotating motions, areas of convergence and divergence, and deformation patterns—HF radar observations were used to train AI models, enabling them to reconstruct and predict complex patterns in ocean current behavior. Accurate forecasts up to six hours ahead were demonstrated using this novel methodology, significantly improving data-driven short-term predictability (Cavaiola et al., 2025).

Ongoing research is focusing on improving the accuracy of surface ocean current estimates for time-critical maritime operations such as Search and Rescue (SAR), with the aim to provide quantitative support tools for SAR operators and to define measurable, a priori indicators that can assess simulation reliability at the time an incident occurs, before the actual trajectory becomes known (Baudena et al, in preparation). Targeted experiments were conducted in collaboration with the Coast Guard in the Ligurian Sea area, investigating the performance of real-time Lagrangian simulations computed from HF radar–derived velocity fields, compared with the actual trajectories of drifting objects and with the forecasting tools currently used by the Coast Guard. A series of metrics were identified that allow us to determine, at the time of the incident, the degree of accuracy and robustness of the simulations. The two studies above can be combined to provide a novel operational tool for maritime stakeholders.

Data produced by the HF-radar network of the Institute of Marine Sciences are routinely used also for classical data assimilation procedures. The recent work of Bendoni et al. (2025) shows that HF radar data, together with in situ velocity data, are the observations that contribute most to the transport corrections in the Corsica Channel (see Figure 17). The assimilation reduces the root mean squared error of the model up to 60% and increases the correlation coefficient between model outputs and observations up to 0.4.

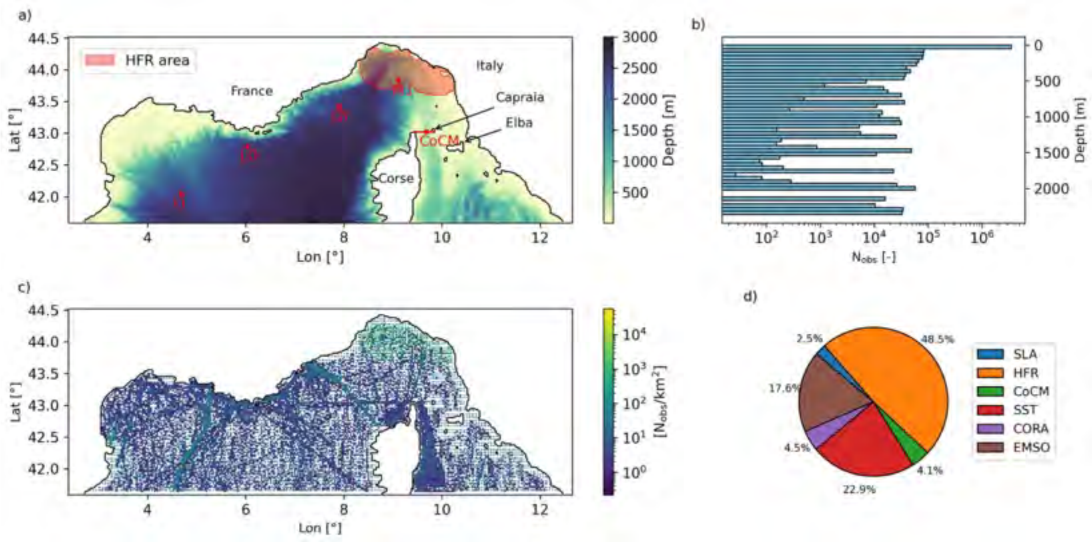


Figure 17 - (a) Domain and bathymetry for the assimilation experiments. Red dots represent the mooring stations from EMSO (LI: Lion, LO: Albatross, DY: Dyfamed, W1: W1M3A) and JERICO (CoCM: Corsica Channel Mooring). Red shaded area represents the extend of the ISMAR HF radar network. The dark red line indicates the Corsica Channel transect used to doublecheck the effects of the assimilation procedures. (b) Vertical distribution with depth of the assimilated observations. (c) Spatial horizontal density of the assimilated observations. (d) Proportion of the different sources of observations with respect to the total. Source: Bendoni et al. (2025).

A significant effort at the Institute of Marine Sciences is devoted to the continuous validation of HF radar data using drifters. Lagrangian metrics confirm that the network performs satisfactorily and aligns well with findings reported in previous studies (Corgnati et al. 2024, Doronzo et al. 2025a, 2025b).

7.7.2 National/International collaborations and ESFRI contribution

HF radars have been operated by CNR-ISMAR since 1996 (at the time “Istituto per lo Studio della Dinamica delle Grandi Masse”, based in Venice) and a first collaboration was established for several years with OGS, CO.RI.LA and, later, with Croatian research institutes.

Beginning in 2011, the management of all the CNR-ISMAR HF radar stations was transferred to the Institute’s branch in Lerici (SP). The HF radar network has gained increased visibility in recent years, facilitated by the Institute’s commitment to providing real-time data. This has enabled CNR-ISMAR to participate in national and international calls, and to establish long-term collaborations with research institutes across Europe and beyond. The following list details the most relevant collaborations:

- University of Toulon, University of Genoa, LaMMA Consortium, University of Napoli Parthenope, University of Aegean, and OGS, for interests on fundamental and applied research and for the establishment of a cross-border HFR network **supporting the safety of navigation** and the environmental monitoring and protection;

- AZTI, SOCIB and EuroGOOS, for the establishment and operation of the **European HF Radar Node** and the **distribution of quality-controlled surface current data to Copernicus In Situ TAC, Emodnet Physics and SeaDataNet**;
- The GOOS under the OceanOps action, US HF Radar Network (Rutger University, Old Dominion University, Scripps Institution of Oceanography), IEEE and Ocean Best Practice System, with interests in the framework of defining and promoting **best practices for HFR system management**, and the implementation of a global HFR network and data management.

Since the H2020-funded JERICO-Next project (2015), the CNR-ISMAR HFR network has been incorporated into the pan-European coastal observing system, which is expected to be included in the next ESFRI roadmap (2026) under the JERICO - Joint European Research infrastructure of Coastal Observatories. The HFR network has received funding from the PNRR ITINERIS and PNRR RAISE projects for its expansion in southern Italy and for its consolidation.

7.7.3 PNRR investments and expected outcome

ITINERIS project contributed to the expansion of the HFR network in southern Italy through the purchase and installation of two new Codar SeaSonde-type HF Radar stations at Capri and Battipaglia. These additions now ensure coverage of the Gulf of Salerno and the outer area of the Gulf of Naples. The radial velocity vectors produced by the Capri station can be combined with measurements from the Battipaglia site, managed by CNR-ISMAR, as well as with radials retrieved by stations located in the Gulf of Naples and on Ventotene Island. These last ones were purchased or renewed by ISPRA within the PNRR MER project and are operated by University of Napoli Parthenope and ISPRA, respectively.

ITINERIS also enhanced real-time data transmission and remote management across all stations through the purchase or replacement of several devices, including UPS units and high-performance 4G/5G M2M cellular modems/firewalls. While the 5G modems have already been installed, the firewalls are still undergoing testing due to certain restrictions imposed by cellular network providers.

Finally, ITINERIS provided an upgraded IT infrastructure, both as a decentralized node at ISMAR La Spezia and as central marine data repository at ISMAR Napoli, which is now being used also to deliver new or improved services for HFR data processing and access.

RAISE project focused on updating the proprietary software associated with the Codar SeaSonde systems, which handles instrument management, data acquisition, and processing. Thanks to RAISE, four out of five licenses were upgraded to the most recent versions, closing an almost 10-year gap that had accumulated at the CNR-ISMAR HFR stations. Furthermore, a new license for offline processing—intended for historical reprocessing of raw data from all sites at the CNR-ISMAR headquarters—was acquired.

Currently, among the seven operational SeaSonde systems, only one remains with an outdated license. Software updates are released annually and include compatibility improvements with new operating systems, bug fixes, and recent developments in data processing, visualization, and archiving. These updates are not mandatory (licenses do not expire) but are strongly recommended, as their costs accumulate yearly.

In addition, RAISE is set to fund the site preparation for two long-awaited phased-array HFR systems (WERA model) in the coastal area of Genoa, whose installations permits have been delayed over the past two years. These installations are part of the RAISE demonstrator “Laboratorio ibrido” for the port of Genoa, in collaboration with the Department of Civil, Chemical and Environmental Engineering of the University of Genova. The laboratory consists of a combination of observational instruments, deterministic modelling tools, and machine learning–based algorithms for describing and forecasting local metocean conditions (wind, waves, and currents).

Total amount of PNRR investments:

Physical infrastructure (new stations and accessories, planning and execution of works): 575k€

IT (servers and licenses): 185k€

A certain number of person-months has been devoted within the ITINERIS and RAISE projects to the following topics:

- FAIRification of HFR data
- Automatic near real-time quality control of surface velocity currents based on machine learning methods
- Assessment of methods for exploiting HFR surface velocity data in support of Search and Rescue (SAR) operations
- HFR data assimilation into numerical circulation models for the northwestern Mediterranean

Expected Outcomes:

- Improved stability in HFR data retrieval in near real-time
- More efficient maintenance through remote access
- Improved reliability of near real-time data streams for the operational use of HFR-derived surface velocity currents
- Improved services for HFR data processing and access, facilitating cross-platform and interdisciplinary studies
- Harmonization of best practices for HF radar management at the national level
- Scientific investigation of circulation in the new geographical area (Gulf of Salerno)
- Elaborate a circulation model for the Gulf of Salerno, based on HFR data, in support of Search and Rescue (SAR) operations and to the public administration
- Large-scale monitoring and scientific investigation of coastal circulation in the Tyrrhenian Sea

Next Objectives for the HFR Network:

- Keep software licenses up to date
- Keep HFR Network operational

- Replace obsolete HFR antennas and internal components
- Provide additional HFR spare parts
- Implement AI-powered quality control in near real-time
- Implement gap-filling methods of surface velocity maps
- Cross-validate HFR-derived wave measurements with wave buoys and wave models
- Maintain the centralized data processing and distribution node

7.7.4 Observed Variables

The following table shows the essential oceanic and climatic variables measured by the HF Radar network as part of the JERICO European Research Infrastructure.

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Surface current	2016	1h	CNR-ISMAR
Sea state	2016	10 min	CNR-ISMAR

7.7.5 Publications

Bendoni M., Moore A. M., Sciascia R., Brandini C., Schroeder K., Borghini M., and Magaldi M. G., 2025. Impact of assimilated observations on the Corsica Channel transport in a 4D-Var system for the northwestern Mediterranean Sea. Ocean Sci., 22, 281-303, https://doi.org/10.5194/os-22-281-2026

Cavaiola M., Marini S., Magaldi M. G., Mazzino A., 2025. AI-driven 6-hour ahead nowcasting of sea-surface currents using HF Radar. Appl. Ocean Res., 158, 104542, http://doi.org/10.1016/j.apor.2025.104542

Corgnati, L.; Berta, M.; Kokkini, Z.; Mantovani, C.; Magaldi, M.G.; Molcard, A.; Griffa, A. Assessment of OMA Gap-Filling Performances for Multiple and Single Coastal HF Radar Systems: Validation with Drifter Data in the Ligurian Sea. Remote Sens. 2024, 16, 2458. https://doi.org/10.3390/rs16132458

Doronzo, B.; Bendoni, M.; Taddei, S.; Boccacci, A.; Brandini, C. Validating HF Radar Current Accuracy via Lagrangian Measurements and Radar-to-Radar Comparisons in Highly Variable Surface Currents. Remote Sens. 2025a, 17, 1243. https://doi.org/10.3390/rs17071243

Doronzo, B.; Bendoni, M.; Taddei, S.; Boccacci, A.; Brandini, C. A Combined HF Radar and Drifter Dataset for Analysis of Highly Variable Surface Currents. Data 2025b, 10, 115. https://doi.org/10.3390/data10070115

7.7.6 OpenData

The data measured by the HF Radar network of the Institute of Marine Sciences are processed within the workflow of the EuroGOOS European HFR Node (https://www.hfrnode.eu/), which automatically combines the hourly radial velocity fields into total velocity hourly fields, applies Quality Control procedures to the radial and total data and converts the radial and total fields to netCDF format. The Quality Control procedures applied on the current data and the netCDF data-model in which the data are exported are those of the official European standard for the interoperability and distribution of HFR data (Corgnati et al., 2018).

The processed data is distributed in real time and in delayed-mode with free access (Creative Commons CC-BY 4.0 license) on the following data portals:

- EU HFR NODE THREDDS Data Server
  HFR-TirLig: https://thredds.hfrnode.eu:8443/thredds/NRTcurrent/HFR-TirLig/HFR-TirLig_catalog.html
  HFR-GoS: https://thredds.hfrnode.eu:8443/thredds/NRTcurrent/HFR-GoS/HFR-GoS_catalog.html
- Copernicus Marine Service in Situ TAC (http://www.marineinsitu.eu/), in the following products:
  INSITU_GLO_PHY_UV_DISCRETE_NRT_013_048
  INSITU_GLO_PHY_UV_DISCRETE_MY_013_044
  INSITU_GLO_PHYBGCWAV_DISCRETE_MYNRT_013_030
- EMODnet Physics
  https://emodnet.ec.europa.eu/en/physics
- EU HFR NODE ERDDAP Data Server
  HFR-TirLig:
  https://erddap.hfrnode.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=HFR-TirLig
  HFR-GoS:
  https://erddap.hfrnode.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=HFR-GoS
- IT-IOOS: https://it-ioos.eu/

7.8 Moorings

Figure 18 – Identification of the position of the moorings that contribute to the CNR-ISMAR observation system. (Bottom) Example of mooring deployment.

The Institute of Marine Sciences of the National Research Council of Italy is responsible for the management of four moorings in the Mediterranean Sea, which are operated on a regular basis. These moorings are located in the **Sicily Channel** and the **Corsica Channel**. Furthermore, the Institute collaborates in the management of two additional moorings, located in the **Ionian Sea** and the **Ligurian Sea**, respectively in collaboration with the Italian National Geophysical

Institute (INGV) and the Italian National Agency for New Technologies, Energy and the Environment (ENEA).

7.8.1 Sicily Channel Observatory (transition from SiCO1–SiCO2 to P1 Pantelleria)

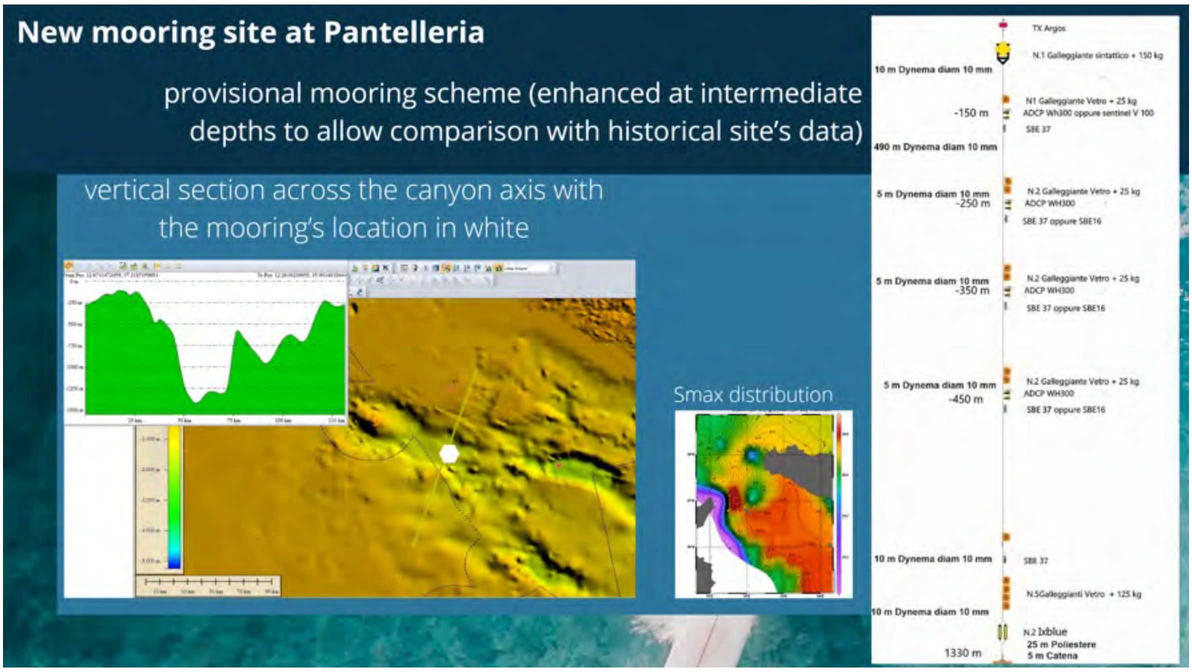


Figure 19 – Position and diagram of the P1 mooring. Distribution of the salinity maximum in its surroundings.

The historical Sicily Channel Observatory, composed of the twin moorings SiCO1 and SiCO2, has provided unique long-term observations of the intermediate circulation between the eastern and western Mediterranean basins since the early 1990s. Due to increasing operational constraints linked to their location within Tunisian territorial waters, the two moorings were progressively decommissioned (SiCO2 in March 2024; SiCO1 in August 2025).

To guarantee the continuity of this strategic time series, in February 2024 ISMAR deployed a new deep-water mooring, P1, located 24 nautical miles south-east of Pantelleria, in Italian waters but still aligned with the main pathway of intermediate water flowing westward through the Sicily Channel. The P1 site, at ~1300 m depth, was selected to ensure long-term operability and to maximise comparability with past observations.

7.8.1.1 Scientific Outcomes and Contributions of recent activities

The Sicily Channel is the second most critical Mediterranean choke point after Gibraltar. It intercepts the full exchange of Atlantic Water and Levantine Intermediate Water between the two sub-basins and represents a fundamental control point for:

- long-term heat and salt budgets of the Eastern Mediterranean;
- variability in intermediate circulation;

- the impact of ongoing climatic trends (warming, salinification, hydrological cycle changes);
- downstream implications for dense water formation in the western basin.

The historical SiCO series (1993–2024) constitutes the longest Mediterranean open-ocean sub-surface T/S time series, and is internationally recognised through its contributions to EMSO Italia, OceanSITES and the CIESM Hydrochanges programme.

The P1 Pantelleria mooring is designed to maintain scientific continuity with SiCO1/SiCO2 while providing enhanced intermediate-depth sampling to support cross-comparison during the transition phase.

A provisional mooring scheme, with additional sensors at intermediate depths, was implemented specifically to enable overlap comparisons.

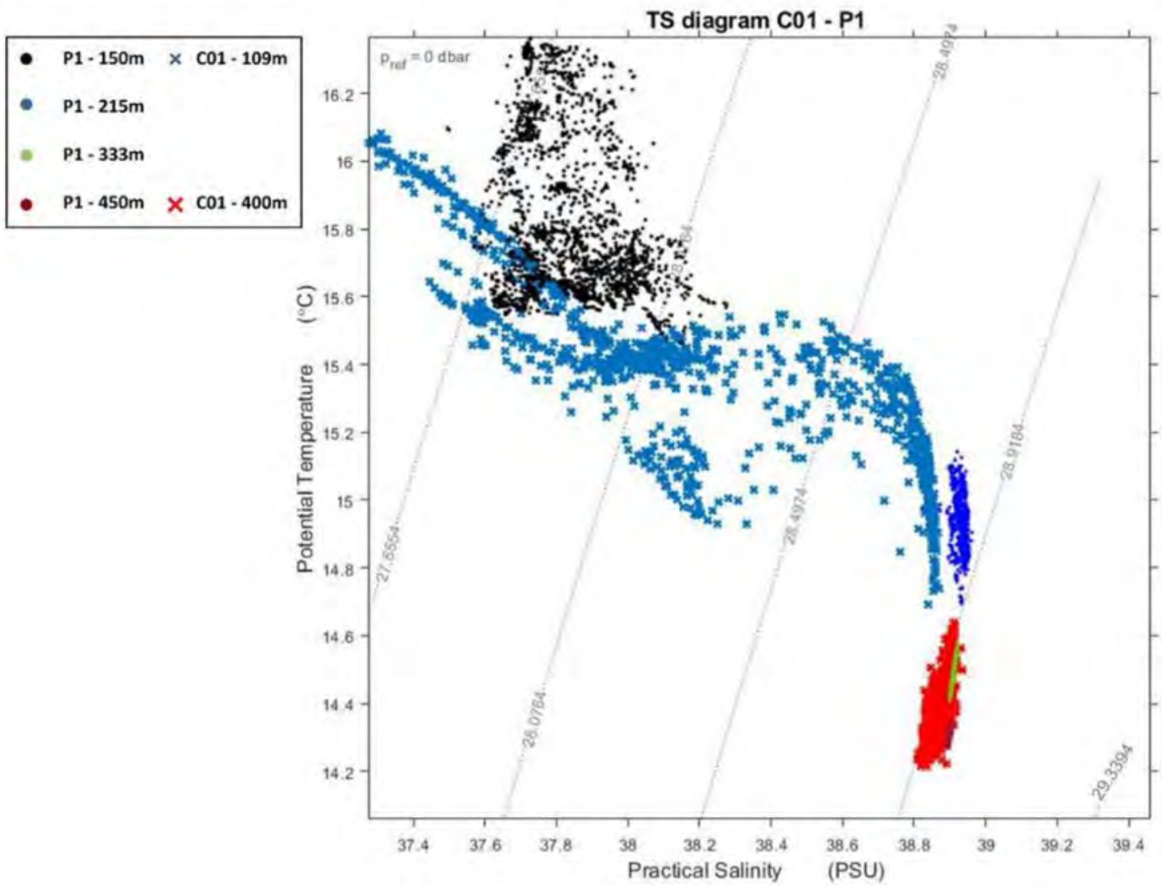


Figure 20 – First comparison with the historical mooring site in the TS diagram, showing a good comparability of the collected data.

The first Temperature–Salinity (TS) analyses between P1 and the historical SiCO data reveal:

- good consistency of the observed water masses;
- coherent variability in the Levantine Intermediate Water layer;
- matching signatures in both seasonal and mesoscale fluctuations.

By March 2025, a full 12-month overlap of CTD and ADCP measurements was available, enabling a robust assessment of the equivalence between the historical and new time series. This evaluation will guide the finalisation of the long-term configuration of the P1 facility.

7.8.1.2 National/International collaborations and ESFRI contribution

https://goosocean.org/

The P1 Pantelleria observatory is embedded in a broad network of national and international collaborations that strengthen its scientific relevance and ensure full integration into the European research landscape. At the national level, the observatory is a core component of **EMSO Italia**, supporting coordinated efforts across CNR, INGV and national universities to maintain a sustained, multidisciplinary infrastructure for deep-sea observations. Its data and operational routines are harmonised with the national guidelines for long-term ocean observing systems, ensuring interoperability and contributing to Italy's consolidated leadership in the Mediterranean.

Internationally, P1 contributes to several global frameworks for sustained ocean observations. Through its alignment with **OceanSITES**, it provides high-quality, long time series essential for assessing climate variability and change in one of the most sensitive choke points of the Mediterranean circulation. The observatory will be candidate to become a facility of the EMSO ERIC Research Infrastructure. By replacing the historical SiCO1 and SiCO2 sites with the more sustainable and operationally secure P1 location, Italy ensures the continuity of a strategic time series that underpins the EMSO scientific mission on climate processes, marine ecosystems and geohazards. P1 will function as a stable node within the EMSO distributed infrastructure, supporting long-term data flows, providing opportunities for technological testing, and reinforcing Europe's capacity to observe and understand the evolving Mediterranean deep sea. Through these coordinated contributions, the observatory enhances both national capacity and Europe's collective ability to address the grand challenges of marine science and climate change.

7.8.1.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.8.1.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Vertical current profiles (speed and direction)	2024	2 h	CNR-ISMAR

Venezia
Tesa 104 - Arsenale,
Castello 2737/F
30122 - Venezia, IT
+39 041 2407911
protocollo.ismar@pec.cnr.it
www.ismar.cnr.it

Bologna
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di Bologna –
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40129 - Bologna, IT
+39 051 639 8891

Lerici
Forte Santa Teresa,
Pozzuolo di Lerici
19032 - La Spezia, IT
+39 0187 1788900

Napoli
Calata Porta Di Massa
Porto Di Napoli snc
80133 - Napoli, IT
+39 081 5423802

Roma
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di Roma 2 - Tor Vergata
Via del Fosso del Cavaliere 100
00133 - Roma, IT
+39 06 45488634

Trieste
Area Science Park
Basovizza - Edificio Q2
Strada Statale 14, km 163.5 34149
- Trieste, IT
+39 040 3756872

Subsurface Temperature	2024	10 min	CNR-ISMAR
Subsurface Salinity	2024	10 min	CNR-ISMAR
Subsurface Pressure	2024	10 min	CNR-ISMAR

7.8.1.5 Publications

Schroeder K. and Borghini M. (2024). An example of a field service plan for oceanographic submerged moorings. Front. Mar. Sci. 11:1380914. doi: 10.3389/fmars.2024.1380914.

7.8.2 Corsica Channel Observatory

This mooring, located in the Corsica Channel (identified by WMO code 6101020), is dedicated to the long-term monitoring of surface and intermediate circulation, as well as and water exchanges between two adjacent basins (the Tyrrhenian and Ligurian Sea). The underwater installation is moored at a depth of approximately 450 metres depth between Corsica and the island of Capraia, at GPS position 43.025 N, 9.6833 E. Since 2010, the mooring has been equipped with traditional current measurement sensors and an ADCP, and it has been in operation since 1985. At depth, the installation is equipped with high-precision CTD probes for the continuous measurement of hydrological parameters.

A repeated transect between Corsica and the Italian mainland, which passes through the location of the moorings, is carried out twice a year by means of a research vessel.

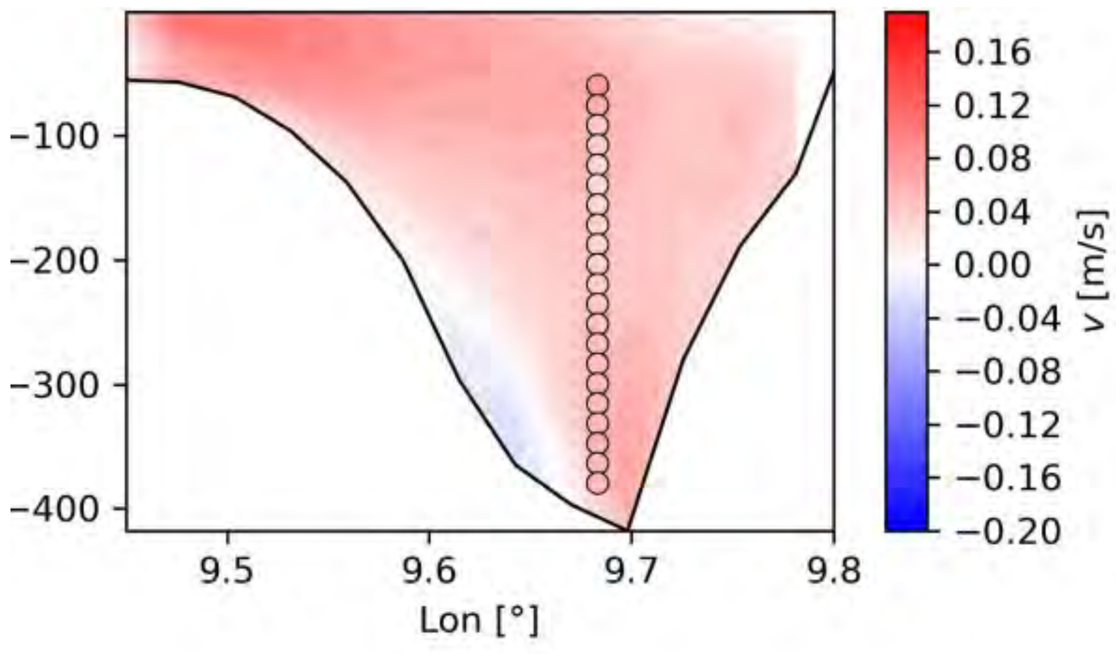

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Figure 21 – Yearly averaged value of the v-component of the modelled velocity at the transect in correspondence of the Corsica Channel mooring, together with yearly averaged observed values (colored dots). From Bendoni et al., (2025).

7.8.2.1 Scientific Outcomes and Contributions of recent activities

The site's primary strengths lie in its strategic location within a pivotal region that governs the influx of heat and salt into the region of formation of the dense waters of the western Mediterranean, a process primarily facilitated by the transportation of intermediate waters from the Tyrrhenian Sea to the Ligurian Sea. This influx is of paramount importance to the **formation of dense water** and the **characteristics of newly formed deep water**.

The time series, with a duration of 30 years, is a valuable resource for the evaluation of the impacts of climate change on Mediterranean waters. Consequently, there are numerous scientific inquiries that its monitoring has facilitated, is currently facilitating and will continue to facilitate, potentially with the incorporation of additional sensors.

7.8.2.2 National/International collaborations and ESFRI contribution

The facility is part of the CIESM Hydrochanges programme and has participated in a series of transnational access activities since 2013, under the umbrella of JERICO. https://goosocean.org/

7.8.2.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.8.2.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Vertical current profiles (speed and direction)	2010	2 hours	CNR-ISMAR
Subsurface Temperature	1993	10 min	CNR-ISMAR

Subsurface Salinity	1993	10 min	CNR-ISMAR
Subsurface Pressure	1993	10 min	CNR-ISMAR

7.8.2.5 Publications

Bendoni, M., Moore, A. M., Sciascia, R., Brandini, C., Schroeder, K., Borghini, M., and Magaldi, M. G.: Impact of assimilated observations on the Corsica Channel transport in a 4D-Var system for the northwestern Mediterranean Sea, Ocean Sci., 22, 281–303, https://doi.org/10.5194/os-22-281-2026, 2026.

7.8.2.6 OpenData

ftp://nrt.cmems-du.eu/Core/INSITU_MED_PHYBGCWAV_DISCRETE_MYNRT_013_035/cmems_obs-ins_med_phybgcwav_mynrt_na_irr/history/MO/MO_PR_MO_6101020.nc

7.8.3 EMSO SN1 Observatory/GALATEA mooring

Figure 22 – EMSO-Western Ionian Sea: Galatea Mooring line position.

The SN1 seafloor observatory is a cabled deep-sea observatory that has been operating in real-time since 2005, managed by the Italian National Geophysical Institute (INGV). It is located in the Ionian Sea, at 2100 m water depth at 25 km off the coastline of Catania. In 2016, it was rebranded as the Western Ionian Sea node and became part of the “European Multidisciplinary

Seafloor and water column Observatory” (EMSO) [http://www.emso-eu.org], a research infrastructure of the ESFRI Environment Sector.

Figure 23 – Galatea Mooring line recovery scheme, October 2025.

In 2014, as part of the Italian EMSO MedIT project, the Western Ionian Sea facility was enhanced by CNR-ISMAR by installing a multiparameter mooring, named GALATEA. Positioned at coordinates 37.5400433 N, 15.3973133 E, at a depth of approximately 2010 metres the mooring was designed to extend the monitoring along the water column with its payload of multiparametric probes (pressure, temperature, salinity, dissolved oxygen, turbidity) and Acoustic

Doppler current profilers (ADCP), installed at multiple levels of depth. After two years of operation, from 18 March 2015 to 26 March 2017, it was removed and later reinstalled on 17 July 2021 as part of a scientific collaboration between CNR-ISMAR and INGV.

A profiling yo-yo system was installed at the head of the mooring on 16 March 2016 with the purpose of measuring the properties of the water column from a depth of 150 m (approximately) to the surface but was removed earlier than expected on 9 August 2016 after the profiling unit was eradicated by fishermen. Following this accident, the yo-yo system was no longer used in this area considered to be at high risk for surface fishing.

Since 2021 a sediment trap has been installed on the mooring to collect particulate matter and study the contribution of volcanic ash to the marine ecosystem (Figure 23).

7.8.3.1 Scientific Outcomes and Contributions of recent activities

The Western Ionian Sea facility, which includes the SN1-GALATEA mooring, is located in an area highly suitable for multidisciplinary studies. It is one of the most seismically active areas of the Mediterranean: some of the strongest earthquakes occurred in 1169, 1693 and 1908, also causing very intense tsunami waves. It is close to Mount Etna, one of the largest and most active volcanoes in Europe, whose ashes are expected to have fertilizing potential in ocean water providing an external nutrient source for primary production that may stimulate biological drawdown of $CO2$. The site is also key for monitoring deep-water dynamics in the Ionian Sea, connecting the Levantine basin to the southern Adriatic basin where intermediate and deep waters are formed, and finally to the western Mediterranean Sea via the Strait of Sicily.

In Figure 24, one of the Seabird sensors SBE16-IM (SN 50097) deployed at 400 m depth from March to October 2025, providing continuous measurements of temperature, salinity, and pressure. The record shows relatively stable thermohaline conditions throughout the deployment, with low-amplitude variability typical of intermediate waters. Temperature and salinity fluctuations are generally coherent and suggest variability driven primarily by isopycnal heaving. Pressure remains stable, indicating minimal mooring motion.

The instrument was recovered and redeployed in October 2025. The data presented here correspond to ongoing preliminary processing and have undergone initial quality control checks; final calibrated datasets will be released following full post-recovery validation and sensor drift assessment.

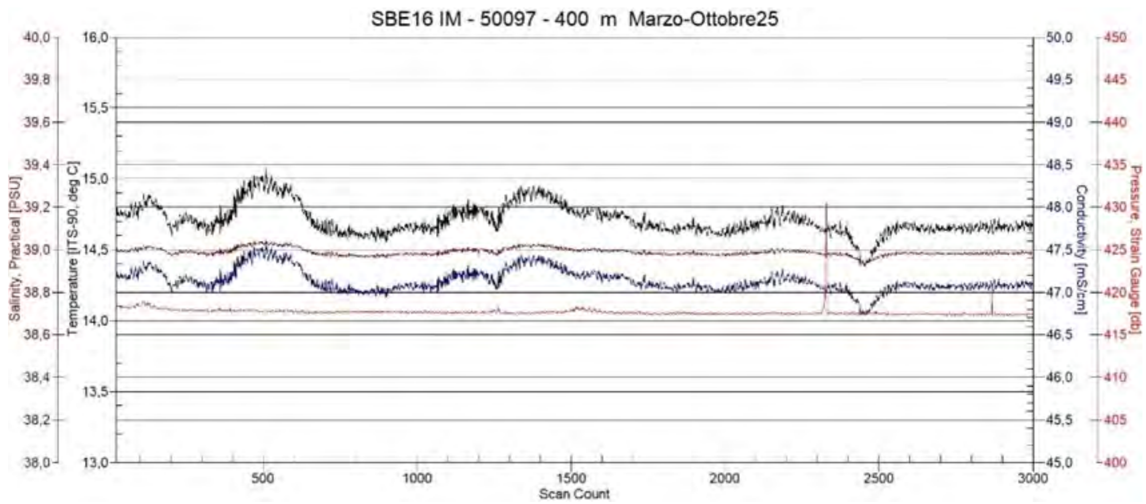

Figure 24 – Time series of temperature and salinity at 400 m depth recorded by the SBE16-IM (SN 50097), March–October 2025.

7.8.3.2 National/International collaborations and ESFRI contribution

The GALATEA mooring is part of the EMSO Western Ionian Sea facility operated by INGV, INFN, and CNR-ISMAR (https://emso.eu/observatories-node/western-ionian-sea/). Implemented as part of the EMSO MedIT project (PAC01_00044, funded under the “Research and Innovation” Line of the “Structural enhancement” Action of the “Action and Cohesion Plan for the Convergence” (PAC) programme, MIUR DD notice n. 274 of 02/15/2013), it is currently operated by INGV and ISMAR within the framework of an operational agreement within the JRU EMSO Italia (prot. 184247/2024 del 31/05/2024).

7.8.3.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.8.3.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Subsurface currents	2015[1]	1 or 2 hours[2]	CNR-ISMAR, INGV

Subsurface Temperature	2015[1]	1 hour	CNR-ISMAR, INGV
Subsurface Salinity	2015[1]	1 hour	CNR-ISMAR, INGV
Subsurface Pressure	2015[1]	1 hour	CNR-ISMAR, INGV
Biogeochemical			
Oxygen	2015[1]	1 hour	CNR-ISMAR
Particulate matter (sediment trap)	October 2022	10 or 15 days[3]	INGV
Particulate matter (turbidity sensor)	2021	1 hour	CNR-ISMAR

NOTES: [1] with interruption from March 2017 to July 2021; [2]sampling time depending on the ADCP model; [3]sampling time depending on deployment.

7.8.4 Levante Canyon Observatory

The Levante Canyon Observatory mooring was installed in September 2019 at a depth of 600 metres, at GPS position 44.0907167 N, 9.498333 E, and it is subject to regular maintenance and data download every six months.

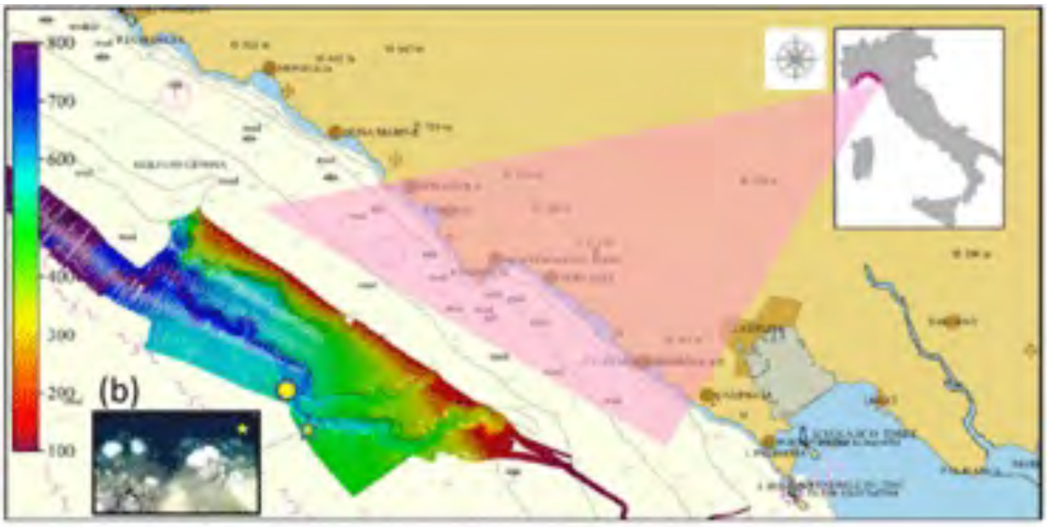

Figure 25 – Geographic map indicating the position of the mooring.

The station is equipped with a range of instruments designed for the monitoring of fundamental marine physical parameters. These include current measuring sensors, as well as sensors for measuring temperature and salinity at three different depths along the water column. In addition, the station is equipped with traps for the purpose of sediment sampling.

During 2023 the site has been equipped with dedicated cages designed for the study of the degradation of plastic material in a deep environment (600m depth for a period of 8 months). In the following figure the updated configuration of the mooring after the maintenance in October 2025.

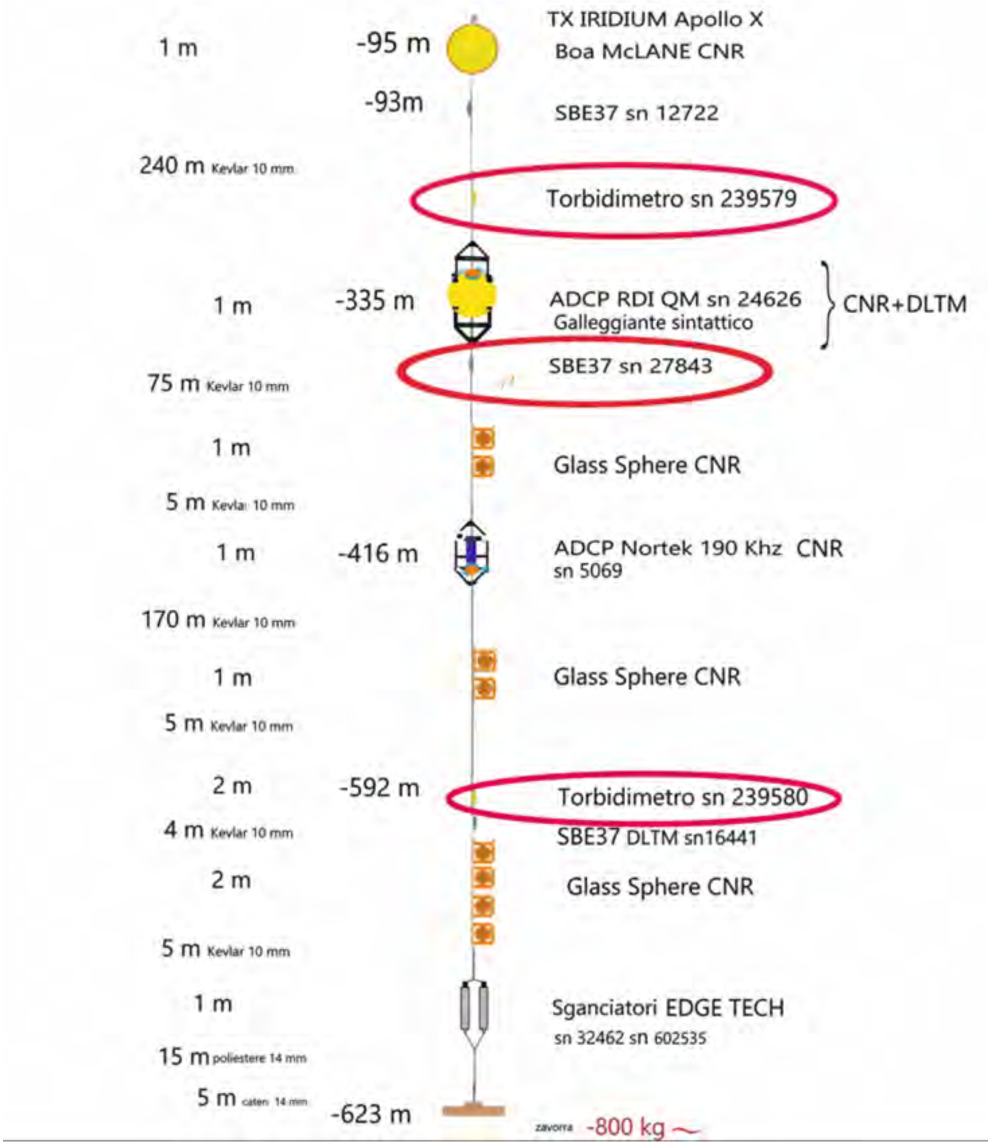

Figure 26 – Updated mooring's structure.

7.8.4.1 Scientific Outcomes and Contributions of recent activities

This mooring has been configured, and it is maintained for the purpose of continuous long-term monitoring being in a particular deep-sea area (about 600 m water depth) that has been identified as a biodiversity hotspot. This area is home to valuable and vulnerable ecosystems, including the deep-living cold-water corals. The mooring is located close to the Cinque Terre Marine Protected Area and the Pelagos Sanctuary for cetaceans.

The mooring has already yielded significant and unique observations in the context of climate and global change, which motivates the collection of new data and the advancement of the instrumented chain in the coming years. During 2025 the mooring has been visited twice for maintenance, the analysis of the downloaded data will follow.

7.8.4.2 National/International collaborations and ESFRI contribution

This observatory in the eastern Ligurian Sea is an infrastructure financed, initially, by the Liguria Region (PAR-FSC resources 2007-2013 "Fund for development and cohesion") and shared between various national bodies and Italian research institutes. These include the Ligurian District of Marine Technologies (DLTM), the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), the National Institute of Geophysics and Volcanology (INGV), the Hydrographic Institute of the Navy (IIM) and the Institute of Marine Sciences of the National Research Council of Italy (CNR-ISMAR), under the LABMARE framework. As a relatively recent development, the mooring is not yet included in an ESFRI, but as the continuity of observations and the data sharing plan continue to evolve and improve, the bodies involved will explore networking opportunities at European level.

7.8.4.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.8.4.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Sub-surface Temperature	2020-today	1h	LABMARE
Sub-surface Salinity	2020-today	1h	LABMARE

Sub-surface Pressure	2020-today	1h	LABMARE
Vertical current profiles (speed and direction)	2020-today	2h	LABMARE

7.8.4.5 Publications

No recent publications have been released.

7.8.4.6 OpenData

https://www.seanoe.org/data/00810/92236/

7.9 Repeated transects

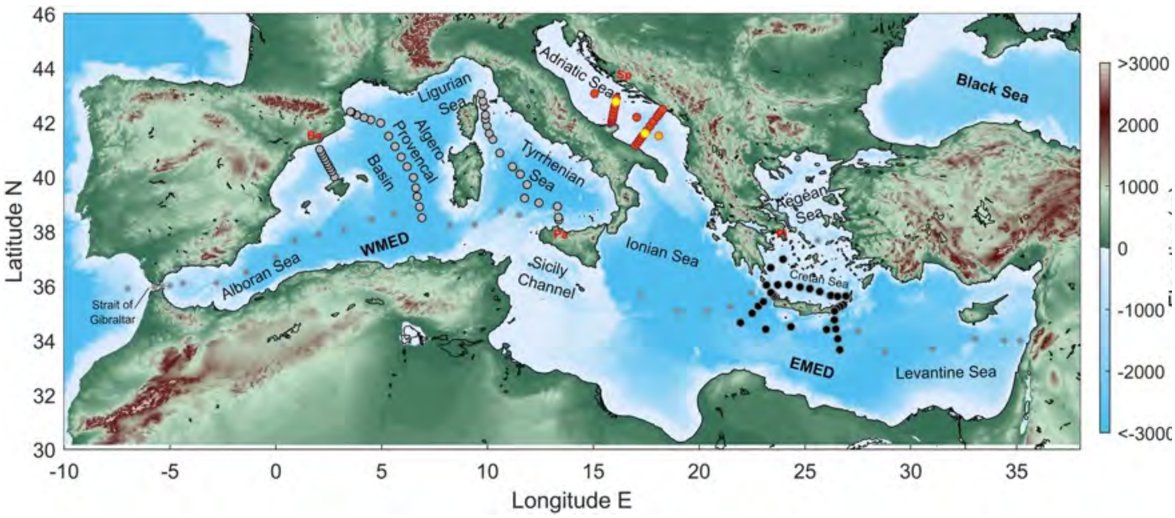

Figure 27 – Station map of the Med-SHIP cruises: TAlPro2016 (grey circles), CRELEV2016 (black circles), ESAW2015+ESAW2016 common stations in red (ESAW2015 only in orange and ESAW2016 only in yellow). The ports of these cruises are indicated in red letters (Pa=Palermo, Ba=Barcelona, Pi=Piraeus, Sp=Split). For completeness, MED01 GO-SHIP stations (repeated in 2011 and 2018, not presented in this paper) are shown by light grey stars. All cruises are ideally performed coast-to-coast, however permissions to work in southern and easternmost shore waters are rarely given. From Schroeder et al., 2024.

CNR-ISMAR routinely conducts a series of repeated hydrographic transects to monitor key oceanographic variables across the Mediterranean Sea.

Despite numerous technological advances, ship-based hydrography remains the only method capable of providing high-quality, high-spatial- and vertical-resolution measurements of physical, chemical, and biological parameters throughout the full water column. This approach is essential to document changes in the deep ocean, which represents 52% of the global ocean volume and 20% of the Mediterranean, and is largely inaccessible to Argo floats. Over the years, CNR-ISMAR has implemented repeated occupations of strategically selected transects, providing critical time series for understanding ocean variability and change.

The oceanographic vessel also serves as an integrated multidisciplinary platform, offering climate-quality observations for the calibration and validation of autonomous systems, including temperature and salinity for Deep Argo, salinity for Core Argo, and biogeochemical parameters for the emerging BGC-Argo network

These repeated transects have addressed a wide range of scientific questions, including heat and freshwater changes, circulation and mixing, deep-water formation and ventilation, transient tracers, anthropogenic carbon and ocean acidification, oxygen and deoxygenation, and macronutrient biogeochemical cycles. Biological studies have explored plankton taxonomic and functional diversity, the influence of physical processes on community composition, plankton-driven modulation of biogeochemical cycles (C, N, P), variability in carbon export fluxes, and plankton size spectra across sub-basins and biogeographical regions.

7.9.1 Scientific Outcomes and Contributions of recent activities

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7.9.2 National/International collaborations and ESFRI contribution

https://goosocean.org/https://goosocean.org/who-we-are/observations-coordination-group/global-ocean-observing-networks/global-ocean-ship-based-hydrographic-investigations-programme-go-ship/

CNR-ISMAR actively contributes to international ocean observing initiatives. The EuroGO-SHIP project aims to coordinate ship-based oceanography at the European level, while GOOS provides a global framework for Essential Ocean Variables. Within these networks, GO-SHIP focuses on sustained hydrographic sections to monitor climate variability and marine biogeochemistry. In the Mediterranean, Med-SHIP - the regional component of GO-SHIP and an Ocean Decade Project led by CNR ISMAR - provides high-quality, long-term observations through repeated hydrographic surveys.

CNR-ISMAR plays a leading role in these activities: it is represented on the GO-SHIP Science Committee and leads or co-leads recent repeat transects, including TALPro16, TALPro22, and the MED01 occupation in 2026. These efforts directly support the CNR-ISMAR Goal Oriented Unit "Climate Variability and Ocean Circulation" and leverage national research infrastructures coordinated by the CNR Infrastructure Office.

7.9.3 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Sea Surface Currents	2004	N/A	CNR
Sea Surface Salinity	2004	N/A	CNR

Sea Surface Temperature	2004	N/A	CNR
Subsurface Currents	2004	N/A	CNR
Subsurface Salinity	2004	N/A	CNR
Subsurface Temperature	2004	N/A	CNR
Biogeochemical			
Inorganic Carbon	2004	N/A	CNR
Nutrients	2004	N/A	CNR
Oxygen	2004	N/A	CNR
Transient Tracers	2004	N/A	CNR
Dissolved Organic Carbon	2004	N/A	CNR

7.9.4 Publications

Álvarez, M., García-Ibáñez, M. I., Lange, N., Kozyr, A., Velo, A., Tanhua, T., Civitarese, G., Cantoni, C., Belgacem, M., Schroeder, K., Acerbi, R., Coppola, L., Wagener, T., Fajar, N. M., Flecha, S., Giani, M., Giannoudi, L., Guallart, E. F., Hassoun, A. E. R., Huertas, E. I., Ibello, V., Keraghel, M. A., Louanchi, F., Luchetta, A., Pérez, F. F., Schirnick, C., Souvermezoglou, E., Urbini, L., Vidal, M., and Ziveri, P.: CARIMED (CARbon, tracers, and ancillary data In the MEDiterranean Sea): A ship-based data synthesis product – overview and quality control procedures, Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2025-759, in review, 2025.

Schroeder, K., Kovačević, V., Civitarese, G., Velaoras, D., Álvarez, M., Tanhua, T., Jullion, L., Coppola, L., Bensi, M., Ursella, L., Santinelli, C., Giani, M., Chiggiato, J., Aly-Eldeen, M., Assimakopoulou, G., Bachi, G., Bogner, B., Borghini, M., Cardin, V., Cornec, M., Giannakourou, A., Giannoudi, L., Gogou, A., Golbol, M., Hazan, O., Karthäuser, C., Kralj, M., Krasakopoulou, E., Matić, F., Mihanović, H., Muslim, S., Papadopoulos, V. P., Parinos, C., Paulitschke, A., Pavlidou, A., Pitta, E., Protopapa, M., Rahav, E., Raveh, O., Renieris, P., Reyes-Suarez, N. C., Rousselaki, E., Silverman, J., Souvermezoglou, E., Urbini, L., Zeri, C., & Zervoudaki, S. (2024). Seawater physics and chemistry along the Med-SHIP transects in the Mediterranean Sea in 2016. Sci Data, 11, 52. https://doi.org/10.1038/s41597-023-02835-3.

Leimbacher M, Raimondi L, Castrillejo M, Vockenhuber C, Pérez-Tribouillier H, Schroeder K, Tanhua T, Casacuberta N. Spatial Distribution and Decadal Variability of 129I and 236U in the

Western Mediterranean Sea. Journal of Marine Science and Engineering. 2024; 12(11):2039. https://doi.org/10.3390/jmse12112039

Belgacem, M., Schroeder, K., Álvarez, M., Lauvset, S. K., Chiggiato, J., Borghini, M., Cantoni, C., Ciuffardi, T., and Sparnocchia, S.: A consistent regional dataset of dissolved oxygen in the western Mediterranean Sea (2004–2023): CTD-O2WMED, Earth Syst. Sci. Data, 17, 5315–5336, https://doi.org/10.5194/essd-17-5315-2025, 2025.

Placenti, F., Torri, M., Schroeder, K., Borghini, M., Cerrati, G., Cuttitta, A., Tancredi, V., Buscaino, C., and Patti, B.: A 12-year-long (2010–2021) hydrological and biogeochemical dataset in the Sicily Channel (Mediterranean Sea), Earth Syst. Sci. Data, 16, 743–752, https://doi.org/10.5194/essd-16-743-2024, 2024.

7.9.5 OpenData

Álvarez, Marta; García-Ibáñez, Maribel I.; Lange, Nico; Kozyr, Alex; Velo, Antón; Tanhua, Toste; Civitarese, Giuseppe; Cantoni, Carolina; Belgacem, Malek; Schroeder, Katrin; Acerbi, Rubén; Coppola, Laurent; Wagener, Thibaut; Fajar, Noelia M.; Flecha, Susana; Giani, Michele; Giannoudi, Louisa; Guallart, Elisa F.; Hassoun, Abed El Rahman; Huertas, Emma; Ibello, Valeria; Keraghel, Mehdia Asma; Louanchi, Férial; Luchetta, Anna; Pérez, Fiz F.; Schirnick, Carsten; Souvermezoglou, Ekaterini; Urbini, Lidia; Vidal, Montserrat; Ziveri, Patrizia (2025). CARbon, tracers, and ancillary data In the MEDiterranean Sea (CARIMED) (NCEI Accession 0309255). [indicate subset used]. NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/cp5b-zq67. Accessed [date].

García-Ibáñez, M. I., Álvarez, M., Lange, N., Kozyr, A., Velo, A., Tanhua, T., … Ziveri, P. (2025). CARIMED (CARbon, tracers, and ancillary data In the MEDiterranean Sea) aggregated original cruise data product [Data set]. DIGITAL.CSIC. http://doi.org/10.20350/DIGITALCSIC/17785

Belgacem, Malek; Schroeder, Katrin; Lauvset, Siv K; Álvarez, Marta; Chiggiato, Jacopo; Borghini, Mireno; Cantoni, Carolina; Ciuffardi, Tiziana; Sparnocchia, Stefania (2025): CTD-O2WMED: Quality controlled dataset of CTD dissolved oxygen profiles in the Western Mediterranean Sea (2004-2023) from R/V oceanographic cruises [dataset]. PANGAEA, https://doi.org/10.1594/PANGAEA.982858

7.10 Coastal stations

The network is completed with coastal stations located along the coasts of the peninsula for monitoring the main meteorological and tidal variables of interest for coastal applications.

The main coastal stations are located in the following areas:

- Gulf of Trieste
- Gulf of Venice
- Gulf of Lerici (SP)
- Gulf of Gaeta
- Gulf of Naples

The activities of the coastal stations are integrated with the activities carried out at the open sea sites and at the laboratories of the Institute's headquarters and branches.

Though grouped under geographical labels such as "Gulf of…", this classification reflects primarily the stations' spatial distribution rather than a specific scientific or operational grouping. The detailed descriptions provided in the following paragraphs clearly outline the individual objectives, measurement strategies, and instrumental configurations that characterise each of the coastal systems included in each category.

7.10.1 Gulf of Trieste

Venezia
Tesa 104 - Arsenale,
Castello 2737/F
30122 - Venezia, IT
+39 041 2407911
protocollo.ismar@pec.cnr.it
www.ismar.cnr.it

Bologna
Area della Ricerca
di Bologna –
Via P. Gobetti 101
40129 - Bologna, IT
+39 051 639 8891

Lerici
Forte Santa Teresa,
Pozzuolo di Lerici
19032 - La Spezia, IT
+39 0187 1788900

Napoli
Calata Porta Di Massa
Porto Di Napoli snc
80133 - Napoli, IT
+39 081 5423802

Roma
Area della Ricerca
di Roma 2 - Tor Vergata
Via del Fosso del Cavaliere 100
00133 - Roma, IT
+39 06 45488634

Trieste
Area Science Park
Basovizza - Edificio Q2
Strada Statale 14, km 163.5 34149
- Trieste, IT
+39 040 3756872

Figure 28 – Trieste coastal meteorological network.

The Trieste meteo-marine network comprises two stations: the "Trieste - Molo Sartorio" (TSS) tide gauge station (Figure 28, bottom left) and the "Trieste - Molo Bandiera" (TSB) marine meteorological station (Figure 28, bottom right). Both stations are located within the harbour area of Trieste (Figure 28, top).

The history of the tide gauge station on Molo Sartorio dates back to 1859, with the initial installation being dismantled in 1925. The subsequent reconstruction of the tide gauge occurred in 1926, with the new structure being installed approximately 30 metres from its original position on the same pier. The current station is the outcome of a renovation project undertaken in 1961 which involved the refurbishment of the 1926 structure. The station is located within the state-owned area of Trieste harbour, equipped with a stilling well and four tide gauges. Three instruments, two of which are digital and one analogue, are provided with float sensors and are owned by CNR. A radar tide gauge is owned by the Civil Protection of the Friuli Venezia Giulia Autonomous Region, with which a collaboration exists. Atmospheric pressure is also measured at the station using an analogue barograph and a digital barometer. The reference plane inside the station (Contact Point) is quoted with respect to the Zero of the IGM (Istituto Geografico Militare) altimetric network. Sea level data are transmitted daily to the CNR-ISMAR branch in Trieste. Since 2009, the TSS has been part of the GLOSS (Global Sea Level Observing System) Core Network, identified with number 340.

The TSB station is a cabin, built in 1956 on Molo Fratelli Bandiera (Porto Lido) in the state-owned area of the Trieste harbor. It has been operating since 1986. The station is equipped with probes that measure meteorological variables at 10 m height, including air temperature, wind speed and direction, and relative humidity, as well as sea temperature at 0.4, 2 and 6 m depths. Instruments belonging to the Civil Protection of Friuli Venezia Giulia Autonomous Region, with which a collaboration exists, are also installed alongside those of CNR. At the TSB, due to malfunction, the datalogger that includes reading of sea water temperature probes is going to be replaced, expected in 2026. TSB will be further improved with a new ultrasonic anemometer (wind speed gauge), which installation is expected in the near future.

7.10.1.1 Scientific Outcomes and Contributions of recent activities

The tide gauge station on Molo Sartorio has facilitated the collection of relative sea level elevations for over a century, with the datum continuity ensuring a homogeneous time series that has been used in studies concerning **long-term sea level changes** since at least the 1930's. Depending on the time scale, the sea level behaviour at Molo Sartorio is indicative of both the Adriatic Sea and the Mediterranean Sea. The temporal coverage of the dataset encompasses hourly readings since the beginning of the 20th century, complemented by 1-minute data since 2001, thus ensuring a comprehensive and continuous record. This makes the station suitable for **studies on extreme events magnitude and frequency**. The data set provides a comprehensive coverage of all temporal scales, ranging from hourly to multidecadal, thereby facilitating detailed **climate studies**.

The Molo Bandiera data time series is comparatively short; therefore, its use is limited to studies on the sea temperature evolution during the last few decades, and sea temperature extreme events. A non-exhaustive list of works using the data recorded from these stations can be found in the literature.

7.10.1.2 National/International collaborations and ESFRI contribution

The hourly sea-level data are periodically transmitted to the GLOSS Fast-Delivery Center (University of Hawaii, Honolulu, US), and the monthly and annual sea-level means are sent to the PSMSL (Permanent Service for Mean Sea Level, Liverpool, UK).

Both "Molo Bandiera" and "Molo Sartorio" stations contribute to the DANUBIUS ERIC Research Infrastructure. Data synthesis given by these stations are also periodically published in ARPA FVG bulletins entitled "Segnali dal clima" and in the semestral issued "Metereorologica" from the SMAA Society.

7.10.1.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.10.1.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			

Sea Level	2001	1 min	CNR-ISMAR
Subsurface Temperature	2009	10 min	CNR-ISMAR
Subsurface Temperature	1993	5 min	Prot. Civile RAFVG
Atmosphere			
Surface			
Surface Sea Level Pressure	2019	10 min	CNR-ISMAR
Surface Air Temperature	2009	10 min	CNR-ISMAR
Surface Wind Speed and Direction	2009	10 min	CNR-ISMAR
Surface Air Temperature	1993	5 min	Prot. Civile RAFVG
Surface Sea Level Pressure	1993	5 min	Prot. Civile RAFVG
Surface Precipitation	1993	5 min	Prot. Civile RAFVG
Surface Wind Speed and Direction	1993	5 min	Prot. Civile RAFVG
Surface Radiation Budget	1993	5 min	Prot. Civile RAFVG

7.10.1.5 Publications

De Pascalis, F., Urbinati, E., Aalifar, A., Aveytua Alcazar, L., Arpaia, L., Bajo, M., et al., 2025. The DANUBIUS-RI supersite of Po delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea. Estuarine, Coastal and Shelf Science, 324, 109453. Available at: https://doi.org/10.1016/j.ecss.2025.109453

Raicich, F., 2025. A semi-empirical approach to estimate the future frequency of extreme sea level events: The case study of Trieste (North Adriatic). Natural Hazards, accepted. Preprint at https://doi.org/10.21203/rs.3.rs-6860208/v1.

Raicich, F., 2025. High-frequency sea level oscillations from over 100 years of observations at Trieste (north Adriatic). Natural Hazards. https://doi.org/10.1007/s11069-025-07468-w.

Raicich, F., 2023. The sea level time series of Trieste, Molo Sartorio, Italy (1869-2021). Earth System Science Data, 15, 1749-1763. https://doi.org/10.5194/essd-15-1749-2023.

7.10.1.6 OpenData

Raicich, F., 2025. Sea level observations at Trieste, Molo Sartorio, Italy. SEANOE. https://doi.org/10.17882/62758.

7.10.2 Gulf of Venice (VE)

The Venice monitoring network comprises two stations: the coastline monitoring system in the Lido of Venice and the meteorological station at Riva 7 Martiri.

A) Lido of Venice coastline monitoring system

During January 2025, a camera system was installed to monitor the coastline along the Lido di Venezia at the Blue Moon beach. This system consists of three optical cameras positioned in a fan-shaped manner, with the aim of covering as much of the beach area as possible (Figure 29).

Figure 29 – Blue Moon coastal webcam monitoring system.

A thermal camera was also installed to enhance the information gathered by the optical cameras during night and in low-visibility conditions such as storms or fog. The cameras have been installed on an existing 25m high pile. The cameras record every 15 minutes at 2 Hz, and a TIMEX image is generated every 30 minutes. To track shoreline changes, panoramic images are first constructed using a stitching method. The coastline is then identified via segmentation using the watershed algorithm. The resulting shoreline positions, along with oceanographic (e.g., tides) and atmospheric data (e.g., wind and pressure), are analysed to describe coastal evolution under varying weather conditions. The images also reveal features such as beach width, orientation, and, during extreme events, submerged sandbars.

7.10.2.1 Scientific Outcomes and Contributions of recent activities

The deployment of this high-frequency monitoring network marks a significant step forward in the continuous observation and characterization of water quality dynamics in the Venice Lagoon. Real-time data enable the investigation of hydrodynamic and biogeochemical processes that control lagoon functioning, including the effects of river discharge, tidal forcing, meteorological events, and seasonal variability. These observations provide a solid basis for understanding spatial and temporal trends in water quality, supporting research on ecosystem responses, land–sea connectivity, and biogeochemical cycles. They also serve as essential reference data for the validation of satellite-derived water quality products and as inputs for data assimilation into numerical models, improving simulations of circulation, mixing, sediment transport, and biogeochemical dynamics. The integration of in situ, satellite, and modelling approaches enhances the overall capacity to monitor, predict, and manage lagoonal and coastal systems.

7.10.2.2 National/International collaborations and ESFRI contribution

The network was designed and deployed in close collaboration with regional and national authorities and integrated with existing observational infrastructure to ensure a coordinated, multi-platform monitoring system. These activities directly contribute to the objectives of the DANUBIUS-RI Strategic Research and Innovation Agenda (SRIA), which identifies water sufficiency, sediment management, and ecosystem health as key research priorities. Within the Italian Supersite, Po River Delta and North Adriatic Lagoons, (De Pascalis et al. 2025) these priorities are addressed by improving the quantification of lateral inputs (water, sediment, nutrients), extending coverage to the Region of Freshwater Influence (ROFI), and monitoring changes in the land–sea interface. In situ measurements are integrated with Earth Observation and numerical modelling, supporting EO product validation, algorithm development, and data assimilation to advance understanding of river–sea system dynamics.

7.10.2.3 PNRR investments and expected outcome

The implementation of this monitoring station is part of the broader PNRR ITINERIS investment aimed at expanding national observational capabilities and integrating them into the DANUBIUS-RI European research framework.

The main expected outcomes include:

- Deployment of a permanent, **real-time monitoring network** across key transition zones.

- Generation of continuous, high-quality datasets for model validation and coastal monitoring.
- Improved understanding of spatial and temporal variability in coastal flooding under natural and anthropogenic drivers.
- Enhanced capacity to detect and analyse extreme events such as sea storms and storm tide.
- Support for ecosystem-based management strategies, coastal planning, and climate adaptation strategies.

7.10.2.4 Observed variables

Measured variables			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Coastline position	2025-04-01	30 min	CNR-ISMAR

7.10.2.5 Publications

De Pascalis, F., Urbinati, E., Aalifar, A., Aveytua Alcazar, L., Arpaia, L., Bajo, M., et al., 2025. The DANUBIUS-RI supersite of Po delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea. Estuarine, Coastal and Shelf Science, 324, 109453. Available at: https://doi.org/10.1016/j.ecss.2025.109453

B) Riva 7 Martiri monitoring system

This monitoring component of the network, located in Riva 7 Martiri, in Venice, comprises of meteorological station and components supporting the Acqua Alta Oceanographic Tower radio connection infrastructure. The equipment is installed in the premises of the historical headquarters of CNR-ISMAR, located here.

Figure 30 – View of Riva 7 Martiri historical headquarters of the Institute of Marine Sciences, where the equipment is installed.

7.10.2.6 Scientific Outcomes and Contributions of recent activities

The equipment is mostly instrumental and supports the network management.

7.10.2.7 National/International collaborations and ESFRI contribution

The station does not contribute to national or international research infrastructures (ESFRIs), nor is it currently integrated into formal collaboration frameworks. Its role remains focused on providing local, station-specific measurements that support operational monitoring and targeted applications.

7.10.2.8 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.10.2.9 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**

Atmosphere			
Surface			
Pressure	2016	10 min	CPSM
Temperatures	2016	10 min	CPSM
Wind speed and direction	2016	10 min	CPSM

7.10.2.10 Publications

No recent publications have been released.

7.10.3 Gulf of Lerici (SP)

The coastal station in Lerici (SP), located at GPS position: 44°4'54,96” N 09°52'50,12” E. It is a cabled and coastal site installed since March 2020 at a depth of 10 m in the bottom of the Bay of S. Teresa in the Gulf of La Spezia. It is equipped with sensors for measuring water temperature and salinity, as well as special cages specifically designed to contain different types of plastic materials, in order to study their degradation as well as their role in the adsorption of dissolved contaminants. The station is equipped with a "junction-box" which allows the connection of innovative and prototype devices to test them in a controlled and protected environment.

Figure 31 – Gulf of Lerici coastal station (SP).

7.10.3.1 Scientific Outcomes and Contributions of recent activities

The observatory's primary function is the **study of coastal ecosystems and hydrodynamic processes, with a long-term focus on the impact of climate change**. It also serves as a testing site for novel instruments and sensors. The coastal station has been recovered in 2025 for maintenance, planning for future activities is in progress.

7.10.3.2 National/International collaborations and ESFRI contribution

The coastal station has been developed within the framework of the LABMARE initiative, a collaborative effort involving CNR, ENEA, DLTM, INGV and IIM. https://smartbaysteresa.com/ stakeholders within the Gulf of La Spezia, including the municipality of Lerici (SP), mussel farmers and a sailing school benefit of the observations provided by the coastal station.

7.10.3.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.10.3.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Subsurface Temperature	2020-2025	10 min	LABMARE
Subsurface Salinity	2020-2025	10 min	LABMARE

7.10.3.5 Publications

No recent publications have been released.

7.10.3.6 OpenData

https://www.seanoe.org/data/00764/87643/

7.10.4 Gulf of Gaeta

Figure 32 – Coastal weather station located on the north side of Lago Patria (left) and view of the south side of the coastal lake (right).

There are two integrated meteorological coastal stations located in the Gulf of Gaeta including the "Lago Patria" station, that has been operational since 2020, and the "Foce Volturno-Licola" station, that was installed on December 2024. The first station is located on the lakeshore of Lago Patria, the largest coastal lake in Campania with an approximate surface area of 2 km^2, while the second one is located within the territory of the regional nature reserve of Foce Volturno - Costa di Licola.

7.10.4.1 Scientific Outcomes and Contributions of recent activities

The two stations enable the continuous **monitoring of key meteorological and climatic parameters**, including temperature, rainfall, wind (direction and intensity), relative humidity, atmospheric pressure and solar radiation. The measurement frequency is 10 minutes. The Lago Patria control unit is also equipped with a web camera that captures images of the surface of the coastal lake.

Since 2020, the lacustrine site has been subject of periodic water sampling to evaluate the trophic state (CTD, nutrients, CHLa) of the coastal lake. This study is carried out with the ongoing investigation into the **geological and environmental evolution of the region**, which has spanned a decade. The uninterrupted data acquisition ensures a consistent meteorological time series, which is used in studies regarding the **ecology of Lago Patria and in water balance analysis**.

The Foce Volturno-Licola station is working within the activity of the SAL.WE. Project (2024-2026) aimed at exploring the SALine WEdge intrusion processes in the Volturno coastal plain. The project has been promoted by Southern Apennines River Basin District Authority funded by Italy's Development and Cohesion Fund - FSC 2014-2020 – PED ACQUE.

7.10.4.2 National/International collaborations and ESFRI contribution

The "Lago Patria" coastal station has been nominated to participate in the European research infrastructure DANUBIUS-RI, and its meteorological datasets have been used in the interdisciplinary research project for the environmental health assessment of Lake Patria and surrounding ecosystems since 2020, as well as in the national project SAL.WE., which is funded by the River District Authority Appennino Meridionale and focuses on the study of the saline wedge intrusion in the Volturno plain.

7.10.4.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.10.4.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Atmosphere			
Surface			
Rain (rate and total intensity)	Dec. 2020/Dec. 2024	10 min	CNR-ISMAR
Air Temperature	Dec. 2020/Dec. 2024	10 min	CNR-ISMAR
Air Humidity	Dec. 2020/Dec. 2024	10 min	CNR-ISMAR
Atmospheric Pressure	Dec. 2020/Dec. 2024	10 min	CNR-ISMAR

Wind Speed and Direction	Dec. 2020/Dec. 2024	10 min	CNR-ISMAR
Long and short wave solar irradiance	Dec. 2020/Dec. 2024	10 min	CNR-ISMAR

7.10.4.5 Publications

Alberico I., Matano F. (2024) Subsidence and recent landscape evolution at Volturno Coastal Plain (Italy). Quaternary International, 712, 109584.

Pacifico L.R., Alberico I., Angelino A., Capasso G., Casaburi A., Cesarano M., D'Adamo R., De Chiara G., Di Fiore V., Fortelli A., Di Gregorio C., Fabbrocini A., Ferraro L., Giordano L., Iavarone M., Luongo D., Mercadante A., Molisso F., Pisciotta G., Punzo M., Tarallo D., Matano F. & Corbelli V. : Preliminary assessment of saltwater intrusion in the Volturno coastal plain (Southern Italy): a multidisciplinary case study. Abstract. Congresso SGI-SIMP, Le Geoscienze e le sfide del XXI secolo. Padova, 16-18 september 2025

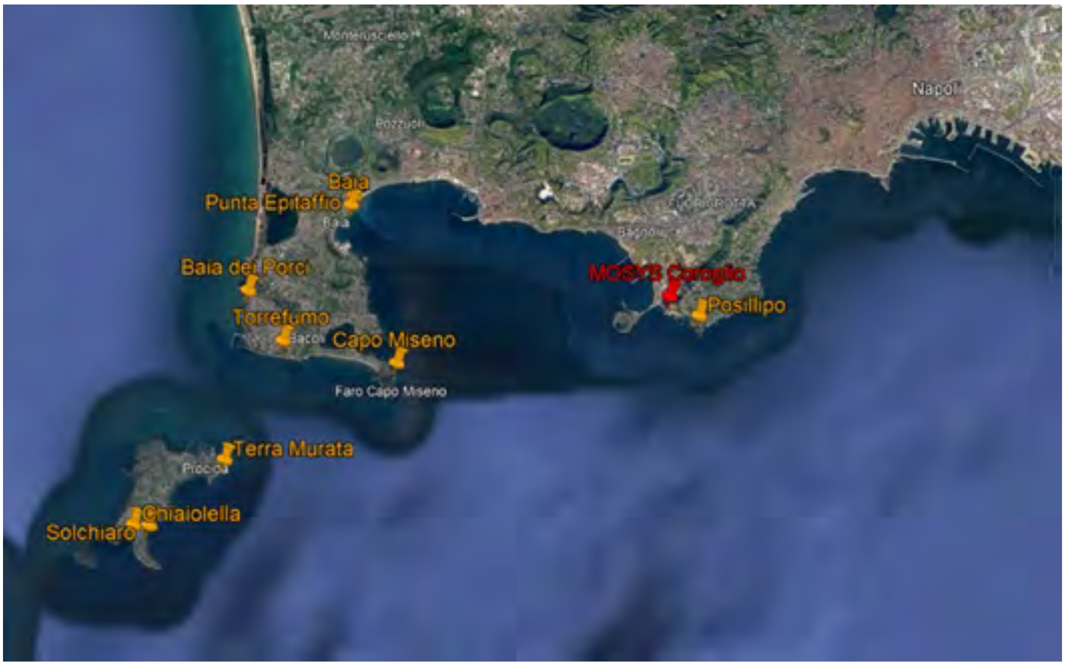
Pacifico, L.R., Alberico, I., Angelino, A., Casaburi, A., Cesarano, M., D'Adamo, R., Di Fiore, V., Fortelli, A., Di Gregorio, C., Fabbroncini, A., Ferraro, L., Giordano, L., Iavarone, M., Luongo, D., Mercadante, A., Molisso, F., Punzo, M., Tarallo, D., Matano, F. – Preliminary assessment of saltwater intrusion in the Volturno coastal plain (Southern Italy): a multidisciplinary case study. BeGeo 2025 Conference, Napoli 17-18 november 2025.http://eprints.bice.rm.cnr.it/id/eprint/20963

7.10.5 Gulf of Naples

Figure 33 – Coastal stations of the Gulf of Naples (starting from the left: Naples Capo Posillipo, Naples Port, Bacoli tourist port).

The coastal stations of the Gulf of Naples comprise meteorological stations and monitoring systems for numerous coastal cliffs present in the Phlegraean and Neapolitan areas, where various natural risks (volcanic, seismic, geo-hydrological, and coastal) and anthropogenic risks persist in a densely populated area.

Meteorological monitoring is carried out using three integrated control units, which have been operational since 2013 in Capo Posillipo (Naples) and at the tourist port of Bacoli (NA) and since 2020 in the Port of Naples, at the institute's headquarters. These instruments facilitate continuous monitoring of the primary meteorological and climatic parameters, including temperature, rain, wind (direction and intensity), relative humidity and atmospheric pressure. The measurement frequency is 10 minutes.



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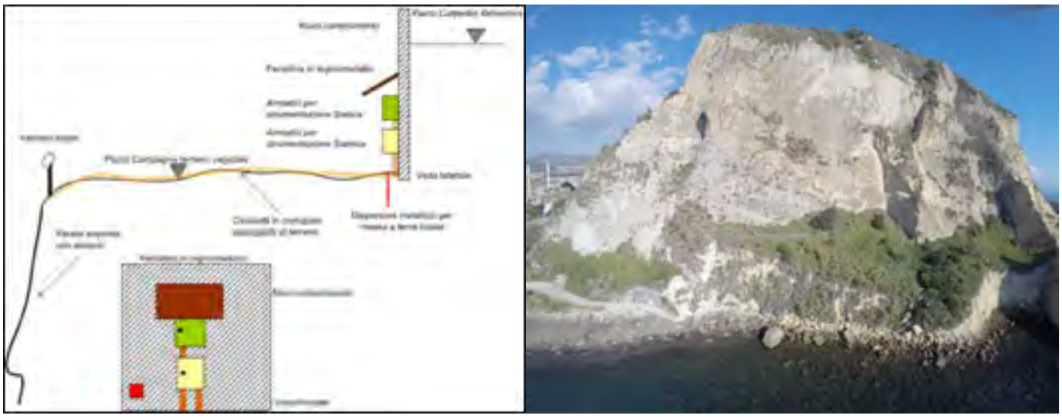


Figure 34 – MOSYS monitoring system of the Coroglio cliff (Naples).

The morphological evolution of several coastal cliffs composed of tuffaceous and volcanoclastic rocks in the Phlegraean area is monitored through periodic high-precision surveys using terrestrial laser scanning, digital photogrammetry, and dedicated monitoring systems.

The **MOSYS** system, an experimental multi-instrumental network, monitors the Coroglio tuff cliff in Naples (40°47'53.96" N, 14°10'34.17" E). Active since 2014, it remotely acquires and archives data from crack meters, tilt meters, velocity meters, thermometers, and fibre-optic sensors to detect geo-hydrological instability. The system records parameters every 30 minutes and transmits them to a remote server at the Institute's Naples branch. Data refer to the physical and geotechnical behaviour of the tuff rock mass and are divided into **static** data (fracture opening, block rotation, surface temperature) and **dynamic** data (continuous seismic noise and seismic events above a set threshold).

7.10.5.1 Scientific Outcomes and Contributions of recent activities

The Gulf of Naples monitoring coastal network consists of three complete meteorological stations, operational since 2013, and a cliff monitoring system, operational since 2014 to 2020. The weather station acquisition continuity guarantees homogeneous meteorological time series that are used in studies about **coastal erosion, coastal landsides and sea-storms hazard**.

7.10.5.2 National/International collaborations and ESFRI contribution

The coastal weather stations have been identified as potential contributors to the European research infrastructure DANUBIUS-RI, with the meteorological datasets currently being used for interdisciplinary research projects focusing on coastal erosion and landslides.

Additionally, these datasets are used for the national project PRO.DAM., which is dedicated to landslide hazard analysis and it is funded by the River District Authority Appennino Meridionale.

7.10.5.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.10.5.4 Observed variables

The meteorological stations provide the following EOVs and ECVs:

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Atmosphere			
Surface			
Rain (rate and total intensity)	Dec. 2013 and Dec. 2020	10 min	CNR-ISMAR
Air Temperature	Dec. 2013 and Dec. 2020	10 min	CNR-ISMAR
Air Humidity	Dec. 2013 and Dec. 2020	10 min	CNR-ISMAR
Atmospheric Pressure	Dec. 2013 and Dec. 2020	10 min	CNR-ISMAR
Wind Speed and Direction	Dec. 2013 and Dec. 2020	10 min	CNR-ISMAR
Long and short wave solar irradiance	Dec. 2020	10 min	CNR-ISMAR

The MOSYS coastal cliff monitoring system provides the following EOVs and ECVs:

Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Air Temperature	Dec. 2014	30 min	CNR-ISMAR
Air Temperature near rock surface	Dec. 2014	30 min	CNR-ISMAR
Tuff fracture opening	Dec. 2014	30 min	CNR-ISMAR
Tuff block rotation	Dec. 2014	30 min	CNR-ISMAR

7.10.5.5 Publications

Tursi M.F., Matano F., Casaburi A., Fortelli A., Sacchi M., Aucelli P.P.C., 2024. Coastal hazard in tuffaceous cliff under the influence of climate change: The case of Capo Miseno (Gulf of Naples). Proceedings of the 22nd International Symposium on Geo-disaster Reduction, Salerno (Italy 22-25 July 2024, 109-114.

Tursi M.F., Matano F., Sacchi M., Aucelli P.P.C., 2024. Rockfall/Rockslide hazard analysis in tuffaceous coastal cliffs: The case of Miseno cliff, Phlegraean Fields, Italy. EGU General Assembly Conference Abstracts, 18607.

7.10.5.6 OpenData

Fortelli A., Matano F., Sacchi M. (2025) Continuous solar radiation observations at the Naples's harbor weather station (Naples, Italy) during the period Feb. 2023-Dec. 2023. ZENODO, doi: 10.5281/zenodo.14647305.

https://doi.pangaea.de/10.1594/PANGAEA.958730

https://doi.pangaea.de/10.1594/PANGAEA.946032

https://doi.org/10.1594/PANGAEA.933342

https://doi.org/10.1594/PANGAEA.933332

7.11 Atmospheric LIDAR

Figure 35 – Identification of the position of the CNR-ISMAR atmospheric LIDAR and view of the Tor Vergata research area and the experimental field.

A multi-channel Rayleigh–Mie–Raman (RMR) lidar system, designed at CNR in the late 1990s, is operational at the CNR-ISMAR headquarters in Rome Tor Vergata and currently installed at the CNR-ISAC Rome Atmospheric Supersite (CIRAS), about 15 km southeast of Rome. The site, managed by CNR-ISAC with contributions from CNR-ISMAR, hosts the RMR lidar and other instruments for atmospheric monitoring, with a focus on air-quality and planetary boundary-layer observations.

The system is housed in two stacked containers and can operate both routinely on-site and during field campaigns. It includes:

- **a transmitter** with an Nd:YAG laser emitting vertically at 355 nm and 532 nm (with potential extension to 1064 nm);
- **a reception unit** with 9+1+1 telescopes covering 0.15–60 km altitude, wavelength-separation optics, and photomultipliers. The system, originally equipped

with 8 channels (355, 387, 407, 532 nm), has been upgraded to increase spectral coverage and add depolarization capability.

Auxiliary control systems (alignment, temperature regulation, automated roof, etc.) ensure stable operation. The system and its data-processing chain have also supported numerous advanced-training activities, including internships and PhD research in collaboration with several universities.

The processed data are archived in the databases of the international networks to which the system refers, while the raw data are accessible via the lidar website http://lidar.artov.ismar.cnr.it/.

The raw data and processed preliminary products are also available at the following link, accessible via password:

https://file.sic.rm.cnr.it/index.php/apps/files/?dir=/RAMAN&fileid=6654558

In mid-September 2025 the first 3D scanning atmospheric - marine LIDAR system was installed on a dedicated platform built on the starboard of RV Gaia Blu, for allowing the acquisition of LIDAR signal from marine by moving the LIDAR head at positive zenith angles. The installation of the second system on the AAOT is planned for March 2026, as the Platform is still undergoing maintenance for the upgrade of the electrical system.

7.11.1 Scientific Outcomes and Contributions of recent activities

The Italian Atmospheric Rome joinT supersitE (ARTE) National Facilities comprises two experimental ground-based fixed sites located within the metropolitan area of Rome:

- BAQUNIN (Boundary-layer Air Quality Using Network of Instruments, https://www.baqunin.eu/) urban site located at “Sapienza” University, in the city centre. This site is operated by La Sapienza University of Rome.
- The RMR lidar described herewith.

The RMR lidar is located in an environment that is of particular relevance for atmospheric pollution monitoring and characterization. In addition, the city of Rome is located in close proximity to the Tyrrhenian coasts and it is exposed to sea-breeze circulation and to extreme aerosol events, as Saharan dust is frequently transported through the Mediterranean Sea. Rome is also subject to energetic meteorological events, especially during the autumn and winter periods. Consequently, together with the other atmospheric instrumentation hosted at the CIRAS supersite, the adopted observational methodologies are directed towards the **study of atmospheric composition, boundary layer dynamics, meteorology and the study of precipitation**.

The RMR lidar, thanks to its characteristic multi-channel configuration, allows estimating the profiles of the following atmospheric variables:

- Temperature
- Water vapor mixing ratio
- Properties of atmospheric aerosols
- Properties of clouds

The scientific fields of application of the products generated by data processing are as follows:

- **Studies of atmospheric processes particularly in the middle and upper atmosphere**
- **Monitoring of climatic variables**
- **Air quality monitoring**
- **Meteorology**

Furthermore, the system designed within CNR facilitated the acquisition of knowledge for the development of instrumentation, which has been applied to define the changes necessary for the ongoing system update, as well as in other sectors of interest for the Institute (e.g., the **definition of the instrumental requirements for lidars dedicated to the study of marine properties**).

7.11.2 National/International collaborations and ESFRI contribution

The system is currently part of two international monitoring networks:

- Network for the Detection of Atmospheric Composition Change (NDACC) (since 2008), https://lidar.jpl.nasa.gov/ndacc/
- European AeRosol LIdar NETwork (EARLINET) (since 2016), www.earlinet.org

Furthermore, the RMR lidar is part of The Italian Atmospheric Rome joinT supersitE (ARTE) National Facilities within ACTRIS (Aerosol, Cloud and TRace gases InfraStructure, https://www.actris.eu/) research infrastructure.

The overarching aim of ACTRIS is to coordinate European observations and scientific research on aerosols, clouds and gases, with a view to providing high quality services to a large community of public and private users. The system is currently undergoing the process of being labelled as an Aerosol Remote Sensing component for the Rome National Facility, as part of ACTRIS.

Finally, Lidar RMR data have contributed and continue to contribute to the validation of satellite data (e.g., EarthCARE).

7.11.3 PNRR investments and expected outcome

The system upgrade was carried out in the context of the ITINERIS project within the Work Package 4 for strengthening the observational capacity to characterize atmospheric aerosols. The implementation of new LIDAR acquisition channels required the purchase of selected state-of-the-art equipment which had to compatible for the integration with the optical elements already present in the RMR LIDAR system. Specifically:

- Analysis and detection system composed by 3 transient recorders to reconstruct the vertical profile of the atmospheric signal, a spectrometer with a focal length of 750 mm with 3 diffraction gratings connected with a fibre-optic assembly compatible with the optical elements of the RMR lidar system and a 32-channel multi-anode photomultiplier (PMT) integrated in the spectrometer.

- Integration of 4 optical units for spectral selection of elastic scattering signal at 355 and 532 nm, with the information on the polarization state of the signal at 355 nm, and through Raman scattering at 387, 407 and 607 nm respectively.
- Replacement of 10 PMT specific for photon counting measurement and with maximum responsivity at the wavelengths of interest listed above.
- Installation of 1 multi-axis electronic control system to operate the stepping motors required for the alignment and focusing of each telescope.

A summary of the 11 separate Newtonian f/3 telescopes (two single with diameters of 150 mm and 300 mm and nine 500 mm telescopes) mounted at different positions relative to the laser beams installed in the RMR LIDAR is given in the following figure.

Telescope	**#1**	**#2**	**#3**
Type	Array of nine	Single	Single
Diameter (mm)	500 (each)	300	150
Focal length (mm)	1500	900	450
FOV (mrad)	0.5	0.9	1.8
Full overlap (m)	From 4000 to 8000	< 1000	< 300

Figure 36 – Upgraded telescope characteristics.

The reported figure provides an overview of the new configuration with the upgraded design of the optical system for the 150- and 300-mm telescopes results in an increased number of detection channels, from five to twelve and with the inclusion of polarization channels to achieve the minimum configuration 1β + 1α + 1δ at 355 nm detailed in the ACTRIS Aerosol Remote Sensing Observational Platform ACTRIS guidelines. The significant upgrade from 1 to 32 channels for a single 500 mm telescope, with a focus on the study of fluorescence from atmospheric aerosols, atmospheric water vapor and CO2 mixing ratio is also reported.

Group	Previous CH#	New CH#	Tele ø (mm)	λ (nm)	Type	Acq. mode (LICEL)	IF FWHM (nm)	PMT model
ACTRIS	N/A	1	150	354,7	Elastic transmitted	A	0,5	H10721P-110-01
	N/A	2		354,7	Elastic reflected	PC	0,5	H10721P-210-01
	N/A	3		386,7	N_2 Raman	A	0,3	H10721P-210-01
	N/A	4		407,5	H_2O Raman	PC	0,3	H10721P-210-01
	1	5		532,1	Elastic	A	1,0	H10721P-113-01
	N/A	6		607,6	N_2 Raman	A	1,0	H10721P-210-01
	8	7	300	354,7	Elastic transmitted	A + PC	0,5	H10721P-110-01
	N/A	8		354,7	Elastic reflected	PC	0,5	H10721P-210-01
	4	9		386,7	N_2 Raman	A + PC	0,3	H10721P-210-01
	5	10		407,5	H_2O Raman	PC	0,3	H10721P-210-01
	2	11		532,1	Elastic	A + PC	1,0	H10721P-113-01
	N/A	12		607,6	N2 Raman	A + PC	1,0	H10721P-210-01
Medium-high atmosphere	3	13	8 x 500	532,1	Elastic			
	6	14		386,7	N_2 Raman			
	7	15		407,5	H_2O Raman			
Troposphere (32-channel PMT with a 750 mm spectrograph)	N/A	16 - 47	1 x 500	350 - 650	Aerosol fluorescence, atmospheric water vapor and CO2 mixing ratio			

Figure 37 – Overview of the upgraded acquisition channels at RMR LIDAR.

The schematic of the optical path for the 150 and 300 mm telescopes is shown in Figure 38.

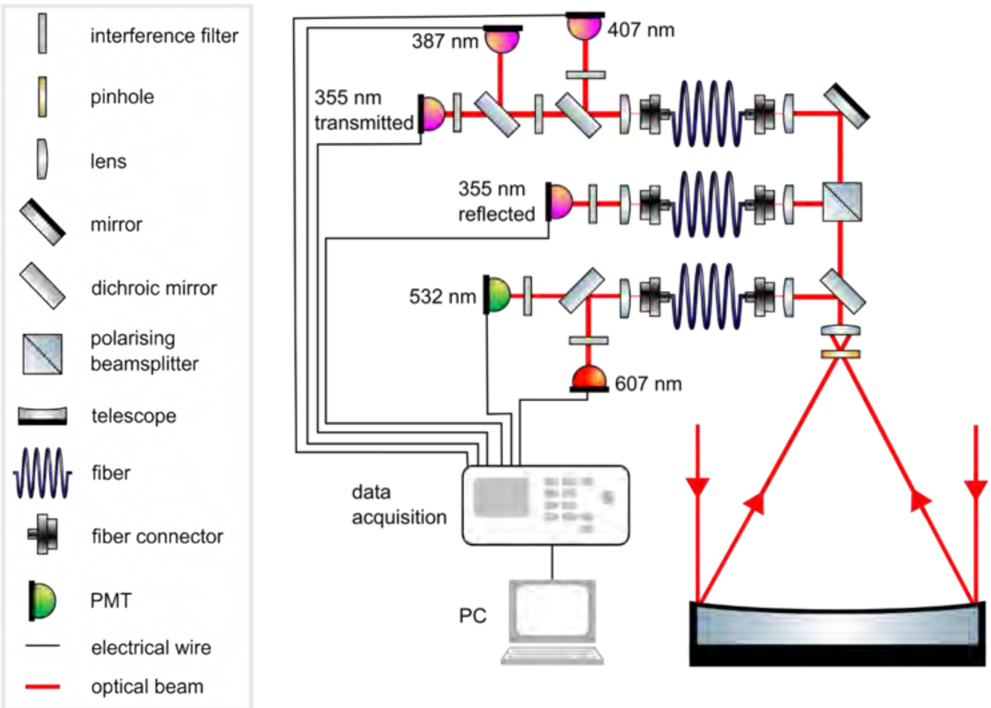


Figure 38 – Schematic of the upgraded channels configuration for the ACTRIS telescopes.

7.11.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start***	**Measurement interval**	**Institution**

Atmosphere			
Aerosol-extinction coefficient	2003	30 minutes	CNR - ISMAR
Aerosol-layer height	2003	30 minutes	CNR - ISMAR
Water Vapour Mixing Ratio	2003	60 minutes	CNR - ISMAR
* Note that regular LIDAR RMR measurements are acquired following the pre-defined ACTRIS Aerosol Remote Sensing high-power aerosol LIDARs schedule for with 5 observations per week, each with a duration of minimum 3 hours, times a week when weather conditions are suitable.			

7.11.5 Publications

Riviste peer-reviewed

D. Nicolae, C. Talianu, J. Vasilescu, V. Nicolae, L. Belegante, A. Nemuc, A. Dandocsi, I. S. Stachlewska, D. M. Szczepanik, L. Janicka, A. Hafiz, A. Papayannis, V. Amiridis, E. Marinou, D. Bortoli, V. Salgueiro, L. Mona, N. Papagiannopoulos, A. Amodeo, G. D'Amico, M. Mitilinaios, B. De Rosa, C. Dema, H. Baars, A. A. Floutsi, R. Engelmann, B. Heese, J. Hofer, A. Skupin, D. Althausen, M. Haarig, D. Balis, K. A. Voudouri, K. Michailidis, J. L. Baray, R. E. Mamouri, A. Nisantzi, N. Ajtai, H. I. Stefănie, X. Shang, M. Filioglou, M. Komppula, M. Iarlori, V. Rizi, Q. Hu, P. Goloub, A. Sannino, M. Di Paolantonio, G. Giuliano, A. Szkop, A. Pietruczuk, A. Boselli, S. Romano, L. Calcagnile, T. Trickl, H. Vogelmann, M. Posyniak, D. Wang, "Aerosol properties in Europe: quality assured EARLINET–ACTRIS lidar observations during 2015–2023", in preparation.

C. A. Papanikolaou, A. Papayannis, M. Gidarakou, S. F. Abdullaev, N. Ajtai, H. Baars, D. Balis, D. Bortoli, J. A. Bravo–Aranda, M. Collaud-Coen, B. De Rosa, D. Dionisi, K. Eleftheratos, R. Engelmann, A. A. Floutsi, J. Abril–Gago, P. Goloub, G. Giuliano, P. Gumà–Claramunt, J. Hofer, Q. Hu, M. Komppula, E. Marinou, G. Martucci, I. Mattis, K. Michailidis, C. Muñoz–Porcar, M. Mylonaki, M. Mytilinaios, D. Nicolae, A. Rodríguez–Gómez, V. Salgueiro, X. Shang, I. S.Stachlewska, H. I. S, tefănie, D. M. Szczepanik, T. Trickl, H. Vogelmann, K. A. Voudouri, "Large-Scale Network-Based Observations of a Saharan Dust Event across the European Continent in Spring 2022", Remote Sensing 2024, 16, 3350, DOI: 10.3390/rs16173350

D. Dionisi, S. Bucci, C. Cesarini, S. Colella, D. D'Alimonte, L. Di Ciolo, P. Di Girolamo, M. Di Paolantonio, N. Franco, G. Gostinicchi, G. Giuliano, T. Kajiyama, E. Organelli, R. Santoleri, G. L. Liberti, "Exploring the potential of Aeolus lidar mission for ocean color applications", Remote Sensing of Environment 313, 114341, 2024, 10.1016/j.rse.2024.114341

https://gcos.wmo.int/en/essential-climate-variables/n2o

https://fleetmonitoring.euro-argo.eu/float/6903816

https://doi.org/10.3389/fmars.2020.00210

https://doi.org/10.1594/PANGAEA.917506

https://doi.org/10.1016/j.atmosenv.2015.05.017

https://www.atmos-meas-tech.net/6/457/2013/

https://www.atmos-chem-phys.net/13/11853/2013/acp-13-11853-2013.html

https://gcos.wmo.int/en/essential-climate-variables/surface-temperature

https://gcos.wmo.int/en/essential-climate-variables/surface-wind?via%3Dihub

https://gcos.wmo.int/en/essential-climate-variables/sea-state

https://gcos.wmo.int/en/essential-climate-variables/sea-state

7.11.6 OpenData

NDACC session integrated water vapour mixing ratio profiles: https://www-air.larc.nasa.gov/missions/ndacc/data.html?station=rome/ames/lidar/

ACTRIS Aerosol Remote Sensing Data Center Unit (ARES): ACTRIS Aerosol Remote Sensing Data during the COVID-19 pandemic, https://doi.org/10.21336/gen.w3w1-j222, 2020.

ACTRIS Aerosol Remote Sensing Data Center Unit (ARES): Data of the ACTRIS Aerosol Remote Sensing COVID-19 campaign held in May 2020, https://doi.org/10.21336/gen.xmbc-tj86, 2020.

7.12 Mobile autonomous systems

7.12.1 Autonomous Surface Vehicles (ASV) – OpenSWAP

Figure 39 – OpenSWAP

OpenSWAP is a lightweight, fully autonomous and remotely controlled surface vehicle designed for custom tasks, geophysical surveys, and video inspections. It is economical, highly customizable, and compatible with standard GPS systems and sensors.

The vehicle uses open-source platforms (Arduino, Raspberry Pi) and features dual-GPS autonomous navigation with integrated inertial sensors. It is a small PELLD plastic catamaran with four brushless motors, a modular structure, and simple water entry. Its aluminium frame allows easy integration of instruments such as side-scan sonars, multiparameter probes, sub-bottom profilers, and multibeam echo sounders, supporting payloads over 40 kg and both commercial and custom sensors.

OpenSWAP marks the beginning of CNR-ISMAR initiatives to develop prototype autonomous vehicles capable of carrying instruments in hard-to-reach areas at significantly lower cost than traditional survey platforms.

7.12.1.1 Scientific Outcomes and Contributions of recent activities

Despite their capacity to accommodate diverse sensor types, these vehicles were meticulously engineered for geophysical surveys, specifically for the procurement of bathymetric and stratigraphic data through single- and multibeam echosounders, side-scan sonars, and seismic-reflection systems.

The principal attribute of the OpenSWAP vehicles is their capacity to traverse pre-defined routes with a high degree of accuracy under favourable weather and sea conditions. This capacity facilitates the execution of 4D (repeated) surveys, which serve as a potent instrument for the **analysis of morphological and stratigraphic alterations at the sediment/water interface and**

the shallow substratum, consequent to sediment dynamics (erosion vs. deposition), slumps and gravitative failures, earthquakes (slip along seismogenic faults and secondary effects of shaking), tsunamis, and so forth.

The affordability and the open hardware/software architectures of these systems, which can be modified by the end users, facilitate the planning and execution of cooperative and adaptive surveys with different instruments not yet implemented or tested.

7.12.1.2 National/International collaborations and ESFRI contribution

OpenSwap has been used in the context of data acquisition in a variety of national and international projects, encompassing diverse environmental settings. These include coastal lagoons, shallow marine coastal waters, lakes, and a range of environments across multiple countries. Notably, OpenSwap has been used in extreme condition, such as the polar seas, specifically the Ross Sea in Antarctica.

7.12.1.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.12.1.4 Observed variables

OpenSwap is completely modular and can host different sensors. To date, it has been used to acquire morpho-bathymetric data (multibeam and single beam echosounders, side scan sonars.) as well as sub-bottom profilers, to penetrate the first tens of meter in the stratigraphic sequence.

7.12.1.5 Publications

No recent publications have been released.

7.12.2 Autonomous Surface Vehicles (ASV) – SWAMP

Figure 40 – SWAMP - Shallow Water Autonomous Multipurpose Platform; up left panel) equipped with ROX and SUNA V2; down left panel) equipped with MBES R2- Sonic; right panel) in action in Svalbard Islands

The Shallow Water Autonomous Multipurpose Platform (SWAMP) is an autonomous surface vehicle developed by CNR for monitoring extremely shallow waters using portable, modular, and highly maneuverable robotic systems. Within the INTERREG IT-HR projects **InnovaMare** (2020–2023) and **DIH INNOVAMARE** (2024–2025), SWAMP was equipped with a multifrequency R2-Sonic MBES, an automated field-spectroscopy system (RoX), a SUNA V2 nitrate sensor, and a high-resolution AI-based underwater camera (Guard1).

Designed and built by the CNR-INM research group, SWAMP is a modular catamaran-type USV powered by four pump-jet azimuth thrusters integrated within its lightweight soft-foam hulls. Each hull houses an independent MINION unit for propulsion, control, navigation, communication, and power.

The vehicle's physical modularity is complemented by a flexible software architecture and an onboard Wi-Fi network enabling communication among system components. SWAMP can be fully disassembled, transported, and reconfigured to suit different mission needs.

Thanks to its compact design and shallow-draft propulsion, SWAMP can operate in extremely shallow environments, providing high-resolution data in areas otherwise inaccessible to conventional survey platforms.

SWAMP allows for navigation in extremely shallow water, disclosing unprecedented data in a hostile navigation environment.

7.12.2.1 Scientific Outcomes and Contributions of recent activities

The Shallow Water Autonomous Multipurpose Platform (SWAMP) is a groundbreaking development in the field of autonomous surface vehicles (ASVs), specifically designed for operations in extremely shallow waters. This innovative platform has several significant scientific impacts:

1. **Enhanced Environmental Monitoring:** SWAMP enables detailed and precise environmental monitoring in wetlands, which are crucial ecosystems that require continuous protection and assessment. Traditional methods often struggle with accessibility and data resolution in these areas. SWAMP's ability to navigate shallow waters allows for high-quality data collection, improving our understanding of these environments.
2. **Modular and Reconfigurable Design:** The platform's modularity and reconfigurability make it highly adaptable for various scientific missions. Researchers can customize the vehicle with different sensors and equipment to suit specific needs, from water quality monitoring to bathymetric surveys. This flexibility enhances the scope and efficiency of scientific investigations.
3. **Innovative Propulsion System:** SWAMP features a unique propulsion system integrated within the hull, designed to operate efficiently in shallow waters. This system minimizes the risk of damage and ensures smooth navigation, even in challenging conditions. The use of soft materials and innovative design principles further enhances the vehicle's durability and performance.
4. **Multi-Agent Distributed Control**: The platform employs a sophisticated guidance, navigation, and control (GNC) system that supports multi-agent operations. This allows multiple SWAMP units to work together, covering larger areas more effectively and providing comprehensive data sets. Such capabilities are essential for large-scale environmental monitoring and research projects.
5. **Support for Regulatory Compliance:** By facilitating detailed and frequent monitoring, SWAMP can help regional administrations comply with national and international environmental directives. For instance, the European Water Framework Directive mandates systematic monitoring of coastal ecosystems, which SWAMP can efficiently support.
6. **Cost-Effective and Safe Operations**: The portability and ease of deployment of SWAMP reduce the costs and risks associated with traditional manned surveys. Researchers can conduct extensive fieldwork without the need for large crews or expensive equipment, making scientific exploration more accessible and safer.

Overall, the SWAMP ASV platform represents a significant advancement in environmental science and robotics, providing a versatile and efficient tool for studying and protecting vital aquatic ecosystems. In 2026, within DIH Innovamare project, a field campaign in the Venice Lagoon was carried out. SWAMP was equipped with a single-beam echosounder (SBES) and a georeferenced underwater optical camera. Although single-beam systems do not provide the spatial swath coverage of multibeam echosounders, they are particularly well suited for ultra-shallow environments, where MBES efficiency is constrained by limited swath geometry and navigation restrictions. The SBES survey was therefore essential to provide reliable depth measurements and seabed acoustic information in the shallow subtidal zone, effectively bridging the elevation data derived from UAV-LiDAR and the bathymetric surfaces produced from MBES surveys. In addition, SBES observations were used as an independent validation dataset to assess the interpolation between the UAV-derived 3D model and MBES bathymetry.

7.12.2.2 National/International collaborations and ESFRI contribution

National collaborations: The initial prototype of the SWAMP platform was developed by the Institute of Marine Engineering of the Italian National Research Council (CNR-INM) in collaboration with the University of Genoa. Subsequent developments were carried out by CNR-INM in partnership with CNR-ISMAR and OGS to integrate various payloads.

International Collaborations: The enhancement of the SWAMP ASV was a key focus in two INTERREG IT-HR projects: InnovaMare (2020-2023) and DIH INNOVAMARE (2024-2025). Additionally, in July 2023, SWAMP was utilized during a collaboration with the Institute of Oceanology of the Polish Academy of Sciences at the Svalbard Islands.

ESFRI Contribution: The platform is part of the ESFRI Infrastructure DANUBIUS-RI and has collaborated with the ESFRI RI SIOS. This collaboration included work with the Institute of Oceanology of the Polish Academy of Sciences at the Svalbard Islands.

7.12.2.3 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.12.2.4 Observed variables

SWAMP is a platform that can carry different payloads, with the actual payload it can acquire the following variables.

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
ECV - Ocean, Biogeochemical: Ocean Colour	1st and 2nd February 2023 and 28th and 29th of June 2023	-	CNR-ISMAR
EOV - Cross-Disciplinary: Marine Debris *emerging	2023	-	CNR-ISMAR
EOV Ocean, Biogeochemical: Nutrients sub-variable Nitrate	1st and 2nd February 2023	-	OGS

EOVs supporting variable or ancillary data: Bathymetry	12-16 January 2026	-	CNR-ISMAR

7.12.2.5 Publications

No recent publications have been released.

7.12.3 Gliders

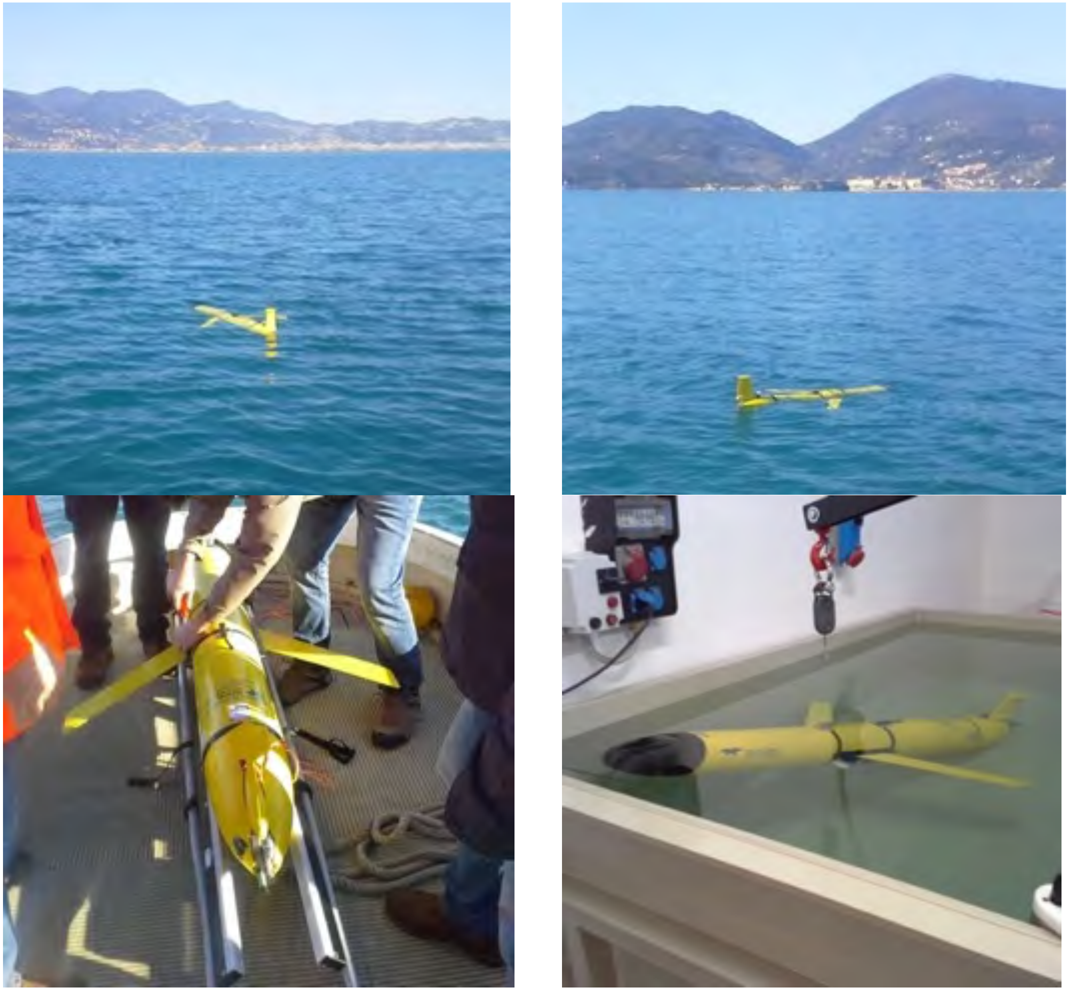


Figure 41 – Glider "Teresa"

The "Teresa" glider is an autonomous underwater vehicle without propulsion, which is capable of monitoring the water column down to a depth of 1000 metres using vertical sections and descent and ascent measurement cycles termed yo-yo. Its vertical and horizontal movements occur exclusively thanks to variations in density (i.e., the vehicle floats and sinks) and displacements of the centre of mass (i.e., the vehicle tilts).

The glider is equipped with a CTD probe, a dissolved oxygen sensor and a microstructure sensor, which facilitate the acquisition of measurements of seawater temperature and salinity, dissolved oxygen and turbulence. Propulsion is achieved through the gliders's buoyancy which is made alternately negative (descent) and positive (ascent) during the yos. This is achieved by inflating an external chamber to an appropriate extent, thereby altering its volume for a constant mass.

The glider's movement incorporates a horizontal component, which is achieved by manipulating the position of its centre of mass. This horizontal component is a result of the glider's ability to adjust its centre of mass, enabling it to move in a horizontal direction even when its trajectory would otherwise be vertical. Consequently, the glider's trajectory makes a zigzagging motion along the water column, akin to gliding. The absence of propulsion, and therefore of vibrations, allows for the high-precision measurement of turbulence, facilitated by the use of shear sensors and high-frequency thermistors.

During the mission, part of the acquired data can be transmitted via satellite during surfacing, a process necessary for the positioning and navigation control of the vehicle.

The "Teresa" glider, in common with the majority of gliders, is characterised by its modular design, which facilitates rapid reconfiguration of the sensors, thereby enabling adaptation to diverse research requirements or emergency scenarios.

The GLIDER was procured by the CNR in 2014 through CNR-DCSPI funds as part of the EUROFLEEETS Project (FP7-2009 / 2013, Coordination: IFREMER).

The SLOCUM DEEP GLIDER G2 GLIDER “Teresa” is characterized by the following technical specifications:

- Maximum Depth: 1000 m
- Global Positioning System: GPS
- Satellite: Iridium and Argos
- Batteries: Alkaline and Lithium
- Digital Tail Fin: digi-fin
- Year of purchase: 2014
- The sensors currently installed are:
- CTD: Seabird Electronic SGP (Slocum Glider Payload)
- Dissolved Oxygen Sensor: Optode mod.430 from Anderaa
- Microstructure Sensor: Microrider (MR) from Rockland Scientific, equipped with the following technical specifications:
  - Velocity shear – turbulence probes: SPM-38-1
  - Fast response thermistors: FP07-38-1
  - High resolution pressure sensor
  - High resolution acceleration sensor

7.12.3.1 Scientific Outcomes and Contributions of recent activities

CNR has been collected microstructure data obtained using a MicroRider (MR) from Rockland Scientific mounted on the Slocum glider called “Teresa,” a Slocum Deep Glider G2, deployed along a longitudinal transect between Sardinia and the Balearic Islands (SMART missions, i.e. Sardinia-Mallorca Repeat Transect) during the period 2015-2024. In addition to the MR observations, the glider measured temperature, salinity, depth-average velocity, and oxygen up to 1000m. Several water masses are present in the study area which allowed us to characterize their temporal and spatial variability. On the upper layer, we have the presence of the Atlantic Water (AW) that interplays with the Mediterranean surface waters, at intermediate layers we have the presence of the Levantine intermediate water (LIW). The operation depth of the glider allowed us to capture partially the upper part Western Mediterranean Deep Water (WMDW). The repeatable missions allow us to characterize water mass properties and mixing/turbulence levels during different seasons (spring, summer, and autumn). In particular, high-precision turbulence measurements can be obtained due to shear sensors and high-frequency thermistors installed on the MR. The MR observations can be correlated with hydrological (conductivity, temperature, and depth) and chemical (dissolved oxygen) measurements from the glider, allowing us a finer and more comprehensive description of water mass mixing properties.

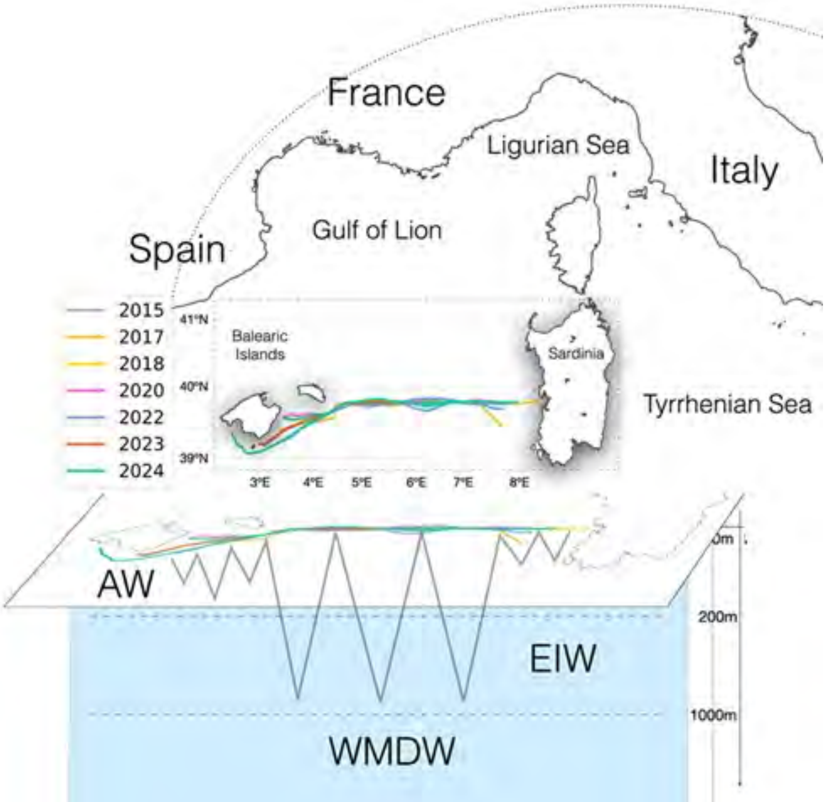


Figure 42 – Glider Teresa mission along its longitudinal transect, by years (in colors). The scheme indicates the deployment between Sardinia and Balearic Islands in the Western Mediterranean Sea. Sawing black lines indicate a schematic trajectory from surface up to 1000m-depth, encountering layers of the Atlantic Water (AW) in surface, the Eastern Intermediate Water (EIW) and the Western Mediterranean Deep Water (WMDW).

The three (3) SEAEXPLORER gliders acquired through the ITINERIS project are working on enhancing the scientific capacity of the JERICO research infrastructure by expanding autonomous observations in the northwestern Mediterranean, with particular benefit to the sustained monitoring of the Ligurian Sea. Equipped with physical and biogeochemical sensors—including measurements of chlorophyll fluorescence, turbidity/backscatter, and CDOM—these platforms are main to provide high-resolution Essential Ocean Variable (EOV) data that are critical for assessing phytoplankton dynamics, particle loads, and dissolved organic matter variability. Their long-endurance capability supports the planning and maintenance of repeat transects, enabling continuous sampling from coastal to offshore areas and can offer a robust baseline for long-term environmental assessment. In addition, two of them equipped with ADCP and microrider sensors thus, can supply vertical profiles of turbulence and currents that complement the horizontally resolved surface currents provided by the existing HF radar network, contributing to a more complete three-dimensional characterization of regional dynamics. Overall, the integration of these platforms can deliver persistent and multidisciplinary observations that improve the understanding of physical–biogeochemical interactions and strengthen operational ocean monitoring - for now - in the Ligurian Sea.

To date, for deployments on three coordinated glider campaigns (AMBO25, EYES ON GLIDERS, and TrialCap) were carried out in the Ligurian Sea in April, July–August, and November–December 2025 using the three glider platforms acquired through the PNRR - ITINERIS project to reinforce JERICO research infrastructure activities. Together, these early-stage missions demonstrated the capability of the new gliders to collect high-resolution EOV data across coastal and offshore environments while capturing the complex physical and biogeochemical dynamics characteristic of the region.
During AMBO25, the glider Morgana, equipped with a CTD, dissolved oxygen, and a biogeochemical triplet sensor for chlorophyll fluorescence, turbidity and CDOM measurements, repeatedly surveyed a 10 km transect off Deiva Marina over 17 days.

The second campaign, conducted in synergy with the Gaia Blue R/V operation (ITINERIS EYES experiment). Pandora and Morgana were deployed along reciprocal L-shaped transects connecting coastal areas, the EMSO-W1M3A buoy, and the Janua seamount. Morgana monitored the region for nearly 20 days, while Pandora—equipped with the same sensors plus an ADCP for current measurements and MR1000G microturbulence sensor—completed a shorter 4-day mission.

The third campaign was carried out by the glider *Esmeralda* for over 17 days along transects offshore of Monterosso, extending toward the EMSO-W1M3A buoy and primarily over the Janua Seamount. In addition to the standard sensor suite, the glider was equipped with an ADCP and an MR1000G microturbulence sensor. It performed focused transects over the seamount to acquire high-resolution current and microturbulence measurements, while also characterizing key biogeochemical variables that likely play an important role in this ecologically significant area, known for its relevance to cetacean populations.

Overall, these campaigns highlight the suitability of the ITINERIS gliders for resolving multiscale oceanographic processes and for strengthening long-term observational capacity in the Ligurian Sea, a region of key importance for understanding shelf–open sea exchanges and physical–biogeochemical interactions in the western Mediterranean.

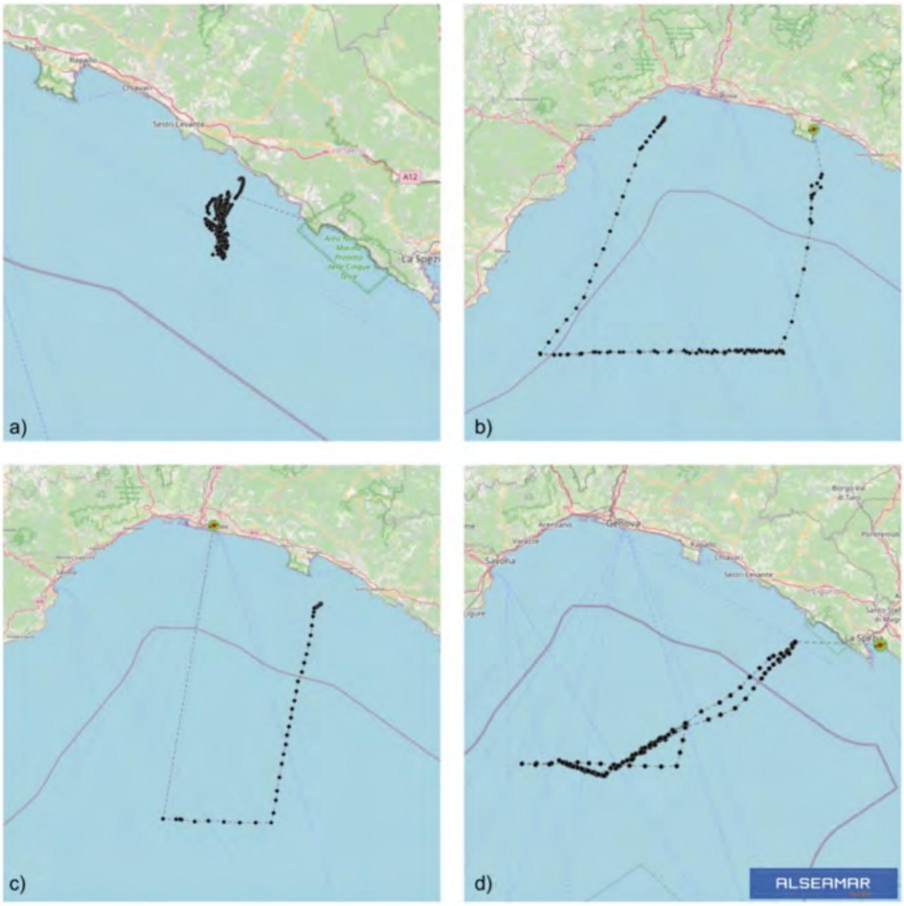


Figure 43 – The up to now CNR-JERICO glider deployments in the Ligurian Sea. a) AMBO25 mission during April 2025 with glider Morgana, b) EYES ON GLIDERS mission in July 2025 with glider Morgana and c) and glider Pandora.,d) TrialCap mission in November with glider Esmeralda.

7.12.3.2 National/International collaborations and ESFRI contribution

The SLOCUM DEEP GLIDER G2 GLIDER “Teresa” is contributing to OceanGliders, one of the GOOS networks.

The CNR-JERICO gliders, Esmeralda, Pandora and Morgana are contributing to JERICO-RI, the integrated pan-European multidisciplinary and multi-platform research infrastructure.

7.12.3.3 PNRR investments and expected outcome

The CNR – JERICO glider fleet is composed of three (3) SeaExplorer gliders, Esmeralda (SEA111), Pandora (SEA112) and Morgana (SEA113). SeaExplorer gliders are autonomous underwater vehicles designed to collect high-resolution oceanographic data by repeatedly profiling the water column. They operate using a buoyancy-driven propulsion system: an internal pump adjusts the vehicle’s volume, causing it to alternately sink and rise. Small wings and internal battery package convert this vertical motion into forward gliding, allowing the platform to follow a saw-tooth trajectory through the water. Data are periodically transmitted to shore (when the gliders is surfacing) via Iridium, enabling near-real-time monitoring and mission adjustment. This low-energy propulsion strategy supports long-duration deployments, and the rechargeable batteries making SeaExplorer gliders effective tools for persistent ocean observations.

The gliders Esmeralda, Pandora and Morgana were procured by the CNR in the end of 2024 (December 2024) through the ITINERIS -Italian Integrated Environmental Research Infrastructures System project, a project funded by EU – Next Generation EU PNRR- Mission 4 “Education and Research” – Component 2: “From research to business” – Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”.

Figure 44 – CNR-JERICO gliders in the field.

	ESMERALDA	PANDORA	MORGANA
GENERAL INFORMATION			
WMO Number	8901150	8901151	8901152
GENERAL PLATFORM INFORMATION			
Purchase Year	12/2024	12/2024	12/2024
Max Depth	1000m	1000m	1000m
Position System	GPS	GPS	GPS
Com. System	IRIDIUM	IRIDIUM	IRIDIUM
Redundant System	ARGOS (wildlife)	ARGOS (wildlife)	ARGOS (wildlife)
Batteries	Rechargeable Li-ion	Rechargeable Li-ion	Rechargeable Li-ion
Payload	ADCP compatible (2 conns)	ADCP compatible (2 conns)	ADCP compatible (2 conns)
SENSORS			
Unpumped CTD	RBRlegato puck-port version	RBRlegato puck-port version	RBRlegato puck-port version
Oxygen Sensor	JFE Advantech Rinko AROD-FT	JFE Advantech Rinko AROD-FT	JFE Advantech Rinko AROD-FT
Triple-channel optical biogeochemical sensor	WetLabs FLBBCD (chlorophyll-a @470/695 + Turbidity @ 700 + CDOM @ 370/460nm)	WetLabs FLBBCD (chlorophyll-a @470/695 + Turbidity @ 700 + CDOM @ 370/460nm)	WetLabs FLBBCD (chlorophyll-a @470/695 + Turbidity @ 700 + CDOM @ 370/460nm)
ADCP	NORTEK AD2CP	NORTEK AD2CP	-
Turbulence Sensor	Rockland MR1000G	Rockland MR1000G	-

Figure 45 – Gliders' technical specifications.

7.12.3.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**

Ocean			
Physical			
EOV-Turbulence (emerging)	2017		CNR-ISMAR
EOV-SubSurfaceTemperature	2017		CNR-ISMAR
EOV-SubSurfaceSalinity	2017		CNR-ISMAR
EOV-Subsurface Current	2024		CNR-ISMAR
Biogeochemistry			
EOV-Oxygen	2017		CNR-ISMAR
EOV-Ocean Colour	2024		CNR-ISMAR

7.12.3.5 Publications

F. V. M. Kokoszka, M. Borghini, K. Schroeder, J. Chiggiato, J. Tintoré, N. Zarokanellos[4], A. Miralles, P. Rivera Rodríguez, M. Rubio, M. Charcos, B. Casas and A. Doeschate, 2025. Advancing Turbulence Essential Ocean Variable: A Reference Glider-Based Microstructure Dataset from the Western Mediterranean. Earth System Science Data Discussion, https://doi.org/10.5194/essd-2025-451

Organelli E. et al. (2025). R/V Gaia Blu Cruise Report - ITINERIS' EYES INTEGRATING, INNOVATING, EVOLVING RESEARCH INFRASTRUCTURES FOR HEALTHY AND PREDICTED MARINE ECOSYSTEMS. IT-IOOS. https://doi.org/10.82175/it-ioos/vq4g-0t11.

Z. Kokkini, M. Berta, A. Boccacci, A. Di Macco, D. Lagomarsino-Oneto, R. Sciascia, R. Tagliavini, N. Zarokanellos, and M. G. Magaldi, From project to ocean: First ITINERIS glider-based insights in the Ligurian sea. In: Book of Abstracts – ITINERIS 3rd Project Meeting, 25–26 September 2025, Rome, Italy, *p. 32*. https://hdl.handle.net/20.500.14243/556548

Z. Kokkini, M. Berta, A. Boccacci, A. Di Macco, D. Lagomarsino-Oneto, R. Sciascia, R. Tagliavini, N. Zarokanellos, and M. G. Magaldi, “Shelf–Open Sea Exchange Processes and Their Impact on the Eastern Ligurian Sea: Insights from Glider Observations,” OSM 2026, Glasgow (to be presented).

7.12.3.6 Open Data

Kokoszka Florian Volmer Martin, Borghini Mireno, Schroeder Katrin, Chiggiato Jacopo, Tintoré Joaquín, Zarokanellos Nikolaos, Miralles Albert, Rivera Rodríguez Patricia, Rubio Manuel,

Charcos Miguel, Casas Benjamin, Ten Doeschate Anneke (2025). Turbulence microstructure dataset from Slocum Glider Teresa (Western Mediterranean, 2015–2024). SEANOE. https://doi.org/10.17882/107995

Glider mission data can be downloaded from the SOCIB data centre:
http://thredds.socib.es/thredds/catalog/auv/glider/teresa-cnr_teresa/catalog.html

Three types of data are available, all in NetCDF format:

- L0, raw data;
- L1 data with quality control along mission profiles;
- L2 data quality checked and remapped to a regular grid.

CNR-JERICO glider data are expected to be available via ERDDAP on: https://erddap.cnrgliders.eu/erddap/index.html

7.12.4 BioGeoChemical-Argo Profiling Floats

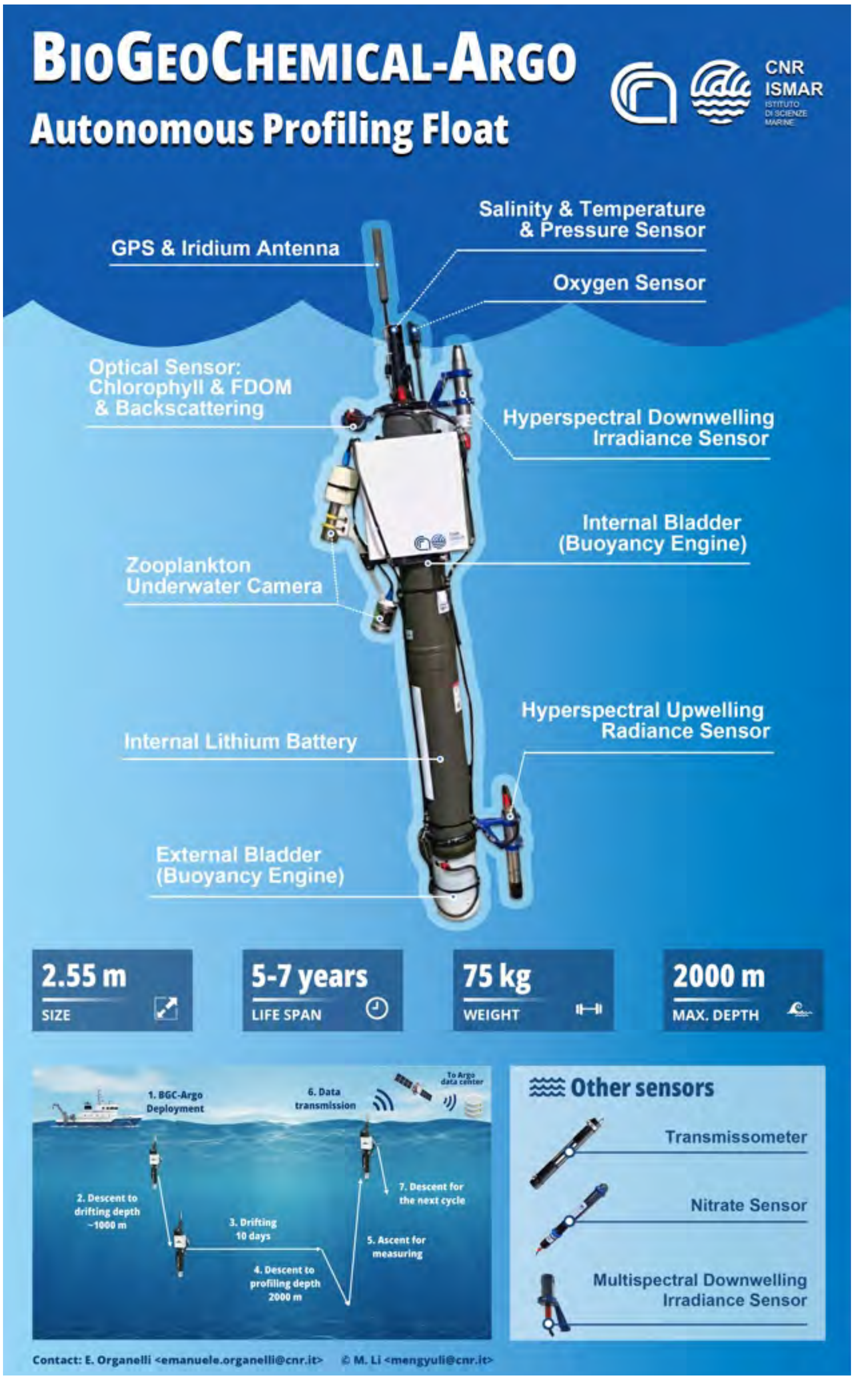


Figure 46 – BioGeoChemical (BGC) - Argo autonomous profiling platform.

Biogeochemical (BGC) Argo floats are autonomous profiling platforms that measure key physical, chemical, biological, and optical properties of the ocean to support research on climate, ecosystem health, and biodiversity. These floats drift at ~1000 m depth and profile from 2000 m to the surface roughly every 10 days. Each unit includes GPS for positioning and an Iridium antenna for satellite data transmission, after which automated quality control is applied within 24 hours.

BGC-Argo floats carry miniaturized sensors measuring temperature, salinity, pH, dissolved oxygen, nitrates, chlorophyll, suspended particles (via optical backscattering), fluorescent dissolved organic matter, and 4-band downward solar irradiance (visible–UV). Recent technological developments now allow integration of hyperspectral radiometers (>100 bands), transmissometers, and video systems for zooplankton studies. A new "Jumbo" version with a 66% larger battery extends float lifetime to 5–7 years and enables better planning of recovery and redeployment. In Figure 46, an example of a Jumbo float equipped with new sensors, standard float mission and operations is shown.

The first CNR-ISMAR Jumbo float (WMO 2903797), deployed in November 2023, is an NKE PROVOR CTS5 Jumbo model measuring temperature, salinity, dissolved oxygen, chlorophyll, suspended particles, fluorescent DOM, 4-band irradiance (380, 412, 490 nm and PAR), and zooplankton community composition. In 2025, thanks to the PNRR investments, CNR-ISMAR enriched its array with 9 new NKE PROVOR CTS5 Jumbo floats equipped with innovative sensors (for details see Section 7.12.4.3).

7.12.4.1 Scientific Outcomes and Contributions of recent activities

The CNR-ISMAR array of BGC-Argo floats, deployed in the Mediterranean Sea, addresses a wide range of scientific questions while improving the quality and management of acquired data. Sensor payloads and deployment strategies have been carefully designed to maximize the number of marine ecosystem processes that can be observed and investigated. This strategic framework aims to evaluate the relations between ocean circulation (from mesoscale to large patterns), plankton biodiversity, the ocean carbon cycle, and climate change (including extreme events) from the surface to the deep ocean. For example, the float deployed in the Ionian Sea in 2023 provided novel insights on the functioning of open sea nutrient-poor environments by demonstrating the influence of coastal ocean dynamics on offshore biogeochemical plankton- and organic particle-related processes (La Forgia et al., 2024, 2025).

A major effort has also been devoted to equipping part of our float array with underwater vision profilers (Hydroptic UVP6), designed to simultaneously image and quantify large particles (>100 µm) and zooplankton from 1000 m depth up to the surface. This relatively recent technology enables the taxonomic classification of zooplankton groups throughout the entire water column, significantly enhancing our capacity to investigate ecosystem structure, trophic interactions, and carbon export processes in the Mediterranean Sea.

Leveraging the expertise of CNR-ISMAR in BGC-Argo radiometry, two major advancements in international Argo data management and quality control have been achieved in 2025. Pitarch et al. (2025) have developed a new algorithm – based on machine learning approaches – to derive accurate measurements of the Photosynthetically Available Radiation (PAR) along the water column from 4-band radiometric profiles. La Forgia and Organelli (2025) have developed a new quality control for real-time radiometric measurements that has been selected by the Argo Data Management Team for implementation at the international level. Thanks to methodology by La Forgia and Organelli, a critical reassessment of the definitions of the euphotic and mesopelagic layers is also under review.

The investment of floats with hyperspectral radiometers is already delivering new insights on phytoplankton diversity and seascape definition at the Mediterranean scale, while providing a fundamental resource of data to validate observations of the NASA's satellite PACE mission recently launched. A first intercomparison between hyperspectral Argo and radiometric observations acquired by independent sensors on board the R/V Gaia Blu is also underway to assess the interoperability among various research infrastructures and facilities.

The scientific studies carried out by CNR-ISMAR also rely on the FAIRness of the international Argo program by accessing other floats both for regional and global studies. For example, the study by Li et al. (2024) has shown how the occurrence of extreme episodic high temperatures (i.e., marine heatwaves) limits the growth of annual blooms of phytoplankton and biomass production in the Mediterranean Sea. This generates a reduction of the carbon fraction exported to the deep sea and a cascade effect towards the higher trophic levels starting from zooplankton. Furthermore, a new study shows how the various components of the marine carbon pumps (biological, physical, and microbial) are tightly connected and enhance carbon sequestration in the subtropical gyre of the North Atlantic Ocean.

7.12.4.2 National/International collaborations and ESFRI contribution

The CNR-ISMAR BGC-Argo floats are a component of the European contribution to the International OneArgo programme, which aspires to have 1000 BGC-Argo floats operational in all the world's oceans. This endeavor is facilitated by the EURO-ARGO ERIC research infrastructure (https: //www.euro-argo.eu). The OneArgo programme is an initiative of the G7 Future of the Seas and Oceans Initiative (https://www.g7fsoi.org/), and part of the EUROGOOS programme with the Argo Task Team (https://eurogoos.eu/eurogoos-argo-task-team/) which is also co-chaired by CNR-ISMAR. The CNR-ISMAR floats also contribute to Argo-Italy, the Italian node of Argo.

The CNR-ISMAR BGC-Argo network has been upgraded with funds from the PNRR ITINERIS project (see section 7.12.4.3 below). The procurement of nine new BGC-Argo floats, equipped with hyperspectral radiometers and underwater cameras for zooplankton, has been pursued to facilitate the monitoring of marine biodiversity in offshore waters and deep environments across the Mediterranean Sea. Such investment puts CNR-ISMAR at the forefront of an innovative network of biological and biogeochemical observations in line with European and international deals and strategies.

The CNR-ISMAR BGC-Argo floats play a pivotal role in strengthening European and international collaborations. This is achieved through active participation in Argo technological and data quality groups/activities (e.g., Argo Data Management Team) and science projects funded by Horizon Europe and the European Space Agency (ESA). In 2025, the Horizon Europe EuroArgo One project started. In this project, CNR-ISMAR leads fundamental research to improve the feedback along the value chain from Argo operators to user communities, including Copernicus and space agencies, and supports the alignment of the European Argo strategy to the international OneArgo programme.

7.12.4.3 PNRR investments and expected outcome

In the framework of the PNRR ITINERIS project, the CNR-ISMAR's network of BGC-Argo has grown up with additional nine Jumbo floats (NKE Instrumentation) for a total investment of about 1.2 M€. This PNRR ITINERIS action aimed to consolidate and empower observational needs in area of the Mediterranean Sea where Essential Variables, and especially the biological ones, are under-sampled. Indeed, besides state-of-the-art sensors to acquire temperature and salinity, dissolved oxygen, nitrate, chlorophyll, optical backscattering and fluorescent dissolved organic matter, the sensor payload of the majority of ITINERIS floats have been enhanced with imaging cameras to better observe marine zooplankton (Hydroptic UVP6, France) together with hyperspectral radiometers for measuring both downwelling irradiance and upward radiance (Trios Ramses, Germany) to infer diversity and abundance of phytoplankton. These floats have also been equipped with a NKE IMU (3D gyroscope, accelerometer, and magnetometer) sensor. One ITINERIS float has been equipped with a beam attenuation meter (SeaBird, USA) and capability to drift at multiple parking depths to improve current understanding of organic carbon fluxes along the water column. The full description of the payload for each of the nine BGC-Argo floats is reported in Table 5.

The nine floats have been deployed from May to October 2025 in the Italian seas. One float was deployed in the South Adriatic Sea, two floats in the Ionian Sea, two floats in the Tyrrhenian Sea, two floats in the Algero-Provençal basin and two floats in the Ligurian Sea (Figure 47). Such distribution was planned to maximize observations by encompassing the optical and trophic variability that characterizes Mediterranean open waters. This plan has been mainly achieved thanks to the ITINERIS' EYES cruise (Organelli et al., 2025) carried out in July 2025 on board the CNR's R/V Gaia Blu, during which a total of six out of nine BGC-floats has been deployed across the Western Mediterranean.

Several scientific and technological outcomes are expected from this new array of BGC-Argo floats, that have been strategically deployed also in combination with other facilities and Research Infrastructures (not exhaustive list):

- Interplay between ocean circulation, biodiversity and climate (including extreme events) from the sea surface to the bottom, over multiple spatial and temporal scales;
- Improved understanding of the ocean carbon cycle and the role of biological processes across the Mediterranean Sea;
- Enhanced 4-dimensional reconstruction of open waters and predictability over time and in the deep sea;
- Strengthened synergies with satellite observations of Ocean Colour, from validation to upscaled understanding of current ocean and ecosystem health across the basin;
- Addressed the technological interoperability of the diversity of sensors across observational facilities within the European RI environment.

Figure 47 – Successive surface positions (green lines) and last position (light green markers) of the 9 BGC-Argo floats acquired in the framework of the PNRR ITINERIS project (reference period: from deployment to 07/11/25). Each float is identified by its WMO number, as listed in Table 5. Float trajectories and data are available on https://fleetmonitoring.euro-argo.eu/. Map source: https://biogeochemical-argo.org/.

Table 6 - PNRR ITINERIS Argo autonomous profilers (NKE Instrumentation, France) listed in chronological order of deployment at sea. The last column lists the sensors on board each float: CTD – Sea-Bird SBE41CP (Conductivity-Temperature-Depth), DOXY – Aanderaa Optode 4330 (dissolved oxygen concentration), ECO – Sea-Bird WETLabs ECO FLBBCD (fluorescent dissolved organic matter – FDOM, chlorophyll concentration and optical particle backscattering), OCR – Satlantic OCR504 (multispectral downwelling irradiance), H_Ed/H_Lu – TriOS Ramses (hyperspectral downwelling irradiance / upwelling radiance), UVP6 – Hydroptic UVP6LP (Underwater Vision Profiler), SUNA – Seabird SUNA V2 (nitrate concentration), NKE IMU (3D gyroscope, accelerometer, and magnetometer) and CP – Seabird C-Rover (beam transmission).

WMO	Date of deployment	Latitude first profile	Longitude first profile	Specific sensors
7902260	18/05/2025	38.5342	17.4948	CTD, DOXY, ECO, UVP6, H_Ed, H_Lu, IMU
3902641	20/05/2025	41.4463	17.4152	CTD, DOXY, ECO, OCR, CP
4903847	11/07/2025	40.6693	10.8198	CTD, DOXY, ECO, UVP6, H_Ed, H_Lu, IMU
6990684	12/07/2025	39.534	12.9097	CTD, DOXY, ECO, UVP6, H_Ed, H_Lu, IMU
6990685	19/07/2025	39.5539	6.6324	CTD, DOXY, ECO, UVP6, H_Ed, H_Lu, IMU

5907147	20/07/2025	40.9977	7.1828	CTD, DOXY, ECO, UVP6, H_Ed
5907146	21/07/2025	42.615	7.3722	CTD, DOXY, ECO, UVP6, H_Ed, H_Lu, IMU
6990686	25/07/2025	43.7408	8.4932	CTD, DOXY, ECO, OCR, SUNA
4903848	02/10/2025	37.303	16.0772	CTD, DOXY, ECO, UVP6, H_Ed, H_Lu, IMU

7.12.4.4 Observed variables

Essential Climate, Ocean and Biodiversity Variables (ECVs, EOVs and EBVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Sea Surface Temperature	2023	1, 5, 10 days	CNR-ISMAR
Subsurface Temperature	2023	1, 5, 10 days	CNR-ISMAR
Sea Surface Salinity	2023	1, 5, 10 days	CNR-ISMAR
Subsurface Salinity	2023	1, 5, 10 days	CNR-ISMAR
Biogeochemical			
Oxygen	2023	1, 5, 10 days	CNR-ISMAR
Particulate Organic Matter	2023	1, 5, 10 days	CNR-ISMAR
Dissolved Organic Matter	2023	1, 5, 10 days	CNR-ISMAR
Nutrients	2025	1, 5 days	CNR-ISMAR
Biological/Ecosystem			
Plankton	2023	1, 5, 10 days	CNR-ISMAR

Phytoplankton Biomass and Diversity	2023	1, 5, 10 days	CNR-ISMAR
Phenology of marine spring phytoplankton bloom	2023	1, 5, 10 days	CNR-ISMAR
Marine primary productivity	2023	1, 5, 10 days	CNR-ISMAR
Zooplankton Biomass and Diversity	2023	1, 5, 10 days	CNR-ISMAR
Functional composition of marine plankton (based on trait	2023	1, 5, 10 days	CNR-ISMAR
Cross-disciplinary			
Ocean Colour	2023	1, 5, 10 days	CNR-ISMAR

7.12.4.5 Publications

Organelli E. et al. (2025). R/V Gaia Blu cruise report - ITINERIS' EYES INTEGRATING, INNOVATING, EVOLVING RESEARCH INFRASTRUCTURES FOR HEALTHY AND PREDICTED MARINE ECOSYSTEMS. IT-IOOS. https://doi.org/10.82175/it-ioos/vq4g-0t11.

La Forgia G., Santoleri, R., Organelli E. (2025). BGC-Argo Observations reveal particle transport and retention in oligotrophic waters. 8th Euro-Argo Science Meeting, Heraklion, Crete, Greece.

La Forgia G., Organelli E. (2025). Real-time quality assessment for Biogeochemical Argo radiometric profiles. Limnology and Oceanography: Methods, 23, 526-542. https://doi.org/10.1002/lom3.10701

Pitarch J., Leymarie E., Vellucci V., Massi L., Claustre H., Poteau A., Antoine D., Organelli E. (2025). Accurate estimation of photosynthetic available radiation from multispectral downwelling irradiance profiles. Limnology and Oceanography: Methods, 23, 261-272. https://doi.org/10.1002/lom3.10673

Li M., Organelli E., Serva F., Bellacicco M., Landolfi A., Pisano A., Marullo S., Shen F., Mignot A., van Gennip S., Santoleri R. (2024). Phytoplankton spring bloom inhibited by marine heatwaves in the North-Western Mediterranean Sea. Geophysical Research Letters, 51, e2024GL109141. https://doi.org/10.1029/2024GL109141.

Dionisi D., Bucci S., Cesarini C., Colella S., D'Alimonte D., Di Ciolo L., Di Girolamo P., Di Paolantonio M., Franco N., Gostinicchi G., Giuliano G., Kajiyama T., Organelli E., Santoleri R., Liberti

G. (2024). Exploring the potential of Aeolus lidar mission for ocean color applications. Remote Sensing of Environment, 313: 114341. https://doi.org/10.1016/j.rse.2024.114341.

La Forgia G., Santoleri, R., Organelli E. (2024). Life advected in oligotrophic waters: results of the PIONEER cruise. 43rd CIESM Congress, 14-18 October 2024, Palermo (Italy).

7.12.4.6 OpenData

The data acquired by the BioGeoChemical – Argo profiling floats can be freely accessed through the following portals:

- https://fleetmonitoring.euro-argo.eu/
- ftp://ftp.ifremer.fr/ifremer/argo/dac/coriolis

7.12.5 Drifting buoys (drifters)

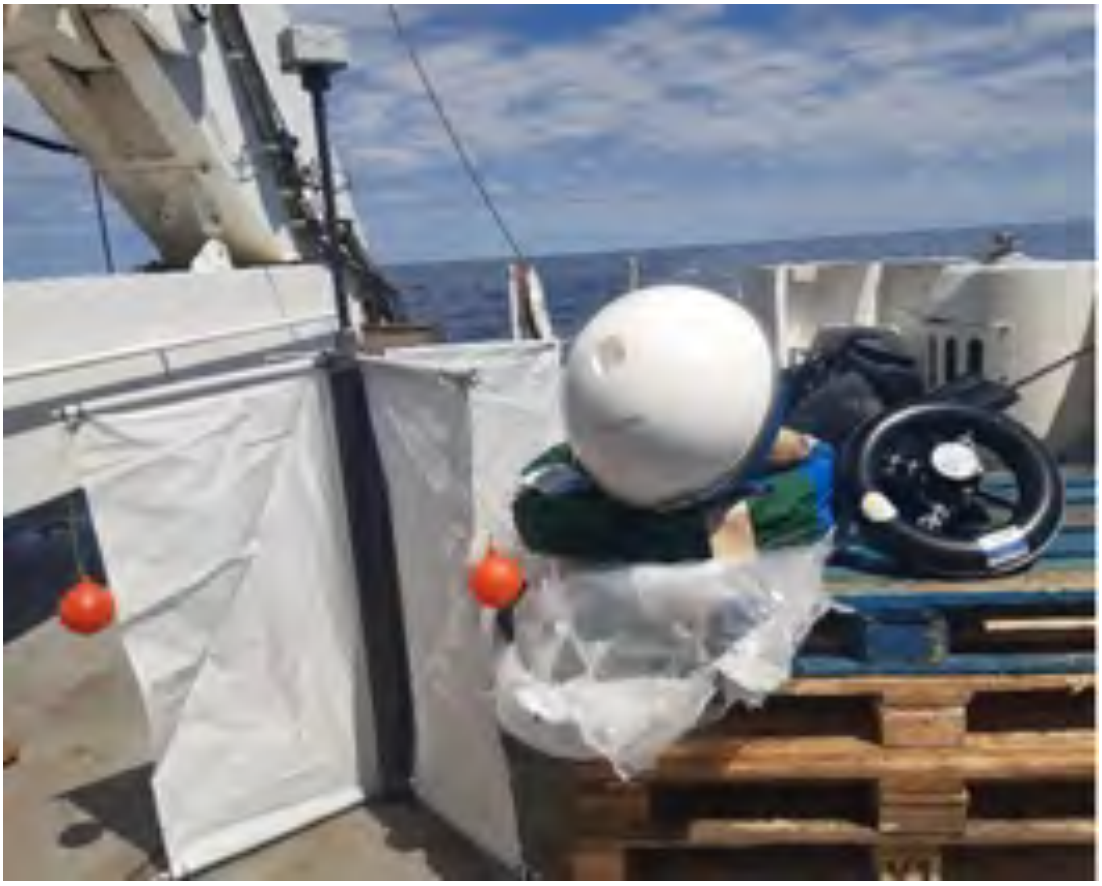


Figure 48 – Several examples of Lagrangian drifters (CARTHE, CODE, SVP)

Drifting buoys, also known as "drifters", are oceanographic instruments designed to follow ocean currents, thereby providing information on their GPS position at regular fixed time intervals, via satellite communication (e.g., Iridium system) or Global System for Mobile Communications (GSM). These instruments can measure a variety of parameters that characterize water masses, including temperature, salinity, and other physical quantities. Additionally, they can also measure biogeochemical variables derived from measurements of phytoplankton chlorophyll-fluorescence or suspended particulate concentration.

These instruments are also referred to as "Lagrangian" instruments, named after the mathematician Lagrange, due to their capacity to characterize and observe the surrounding environment by following the particles of the moving fluid.

There are various types of drifting buoys which differ in their design and the depth at which they follow ocean currents. Depending on their structure and the ballast used, they can follow the flow at 15 m (SVP) or at 1 m of depth (CARTHE and CODE) or even a few centimeters from the surface (SPOTTER), depending on the application of interest.

7.12.5.1 Scientific Outcomes and Contributions of recent activities

The use of drifter data collection is instrumental in the identification of transport pathways across sea basins, thereby facilitating the comprehension of **water masses exchange from the coast to the open ocean**.

Furthermore, the trajectories of these drifters can be used to infer additional characteristics of the flow such as **dispersion processes and kinematic properties** (e.g., divergence, vorticity and strain, as demonstrated in Berta et al. (2016) and in Esposito et al. (2021) and to estimate vertical velocity in the upper layer sampled by the drifters (Tarry et al., 2022; Esposito et al., 2023).

The integration of bio-optical and physical sensors on drifters has enabled the collection of data on parameters such as local temperature (surface and subsurface), salinity (subsurface), and oxygen concentration. Recent advancements have also facilitated the collection of data on particulate matter, including phytoplankton biomass and dynamics from chlorophyll from fluorescence and optical backscattering measurements at two bands (BioGeoChemical SVP drifter, BGC-SVP; Bellacicco et al. (2024); Figure 49 and Table below). The integration of these observations enables to unravel the mechanisms underlying bio-physical dynamics in the ocean, which are fundamental to ocean ecosystem productivity and functioning (e.g., the **study the biological responses of phytoplankton to ocean dynamics and physical structures**).

Figure 49 – BGC-SVP drifters on ship deck of R/CV Gaia Blu during the ITINERIS'S EYES cruise.

In addition, drifters find applications in more operational scenarios, such as **tracking lost objects, people at sea, or pollutant spreading**.

The involvement of drifters in numerous European networks (e.g., JERICO-RI) and global monitoring programs (e.g., Global Drifter Program, GDP) is indicative of their significance in contemporary oceanography.

The drifter data collected in the last three years (see paragraph 7.12.5.2) yield to different publications, and further analysis is in progress.

Table 7 - Physical, bio-optical and biogeochemical parameters collected by each BGC-SVP drifter.

Parameter	Resolution	Range	Accuracy or Sensitivity
Sea Surface Temperature (SST, °C)	0.01	-5 to 35.95	0.05
Atmospheric Pressure (mBar)	0.1	850 to 1054.7	0.55
Geolocation (GPS receiver, °N and °E)	0.0000001 m	-90 to 90 and 0 to 360	2.5 (horizontal position accuracy rms, in m)
Horizontal wind speed* (m s^{-1})	0.01	0 to 60	± 3% to 40, ± 5% to 60
Horizontal wind direction* (°)	1	0 to 360	± 3° to 40 m s^{-1} ± 5° to 60 m s^{-1}
Backscattering (b_b, m^{-1})	10^{-4} at 470 nm; 10^{-5} at 532 nm	0 to 5	0.003 (given as sensitivity)
Chlorophyll-Fluorescence (Chl-Fluo, mg l^{-1})	0.001	0 to 50	0.025 (given as sensitivity)
Conductivity (C, S m^{-1})	0.00001	0 to 7	0.0003
Subsurface temperature (T, °C)	0.0001	-5 to 45	0.002
Dissolved Oxygen (DO, µM/l)	0.1	0 to 400	≤10%

7.12.5.2 National/International collaborations and ESFRI contribution

CNR–ISMAR has gained considerable expertise in the domain of Lagrangian instrumentation, deployment, and data analysis. The versatility of this type of platform has enabled participation in numerous experiments at both regional and international levels, with a variety of scientific objectives.

Over the past 15 years, CNR-ISMAR has been involved in several projects and cruises as the responsible party for the deployment of drifters (e.g., CARTHE, CODE, SVP, and BGC-SVP). Among these, the following relevant initiatives can be listed:

- **TOSCA** (http://tosca.ismar.cnr.it/index.html), EU Med Program: in which clusters of CODE surface drifters were deployed (2011,2012) to study **dispersion processes for environmental, pollution and safety (SAR) applications** in the Ligurian-Tyrrhenian Sea.
- CARTHE (http://carthe.org,), Gulf of Mexico Research Initiative (GOMRI) Program: CARTHE drifters have been deployed in multiple experiments (2012,2016, 2017) to study **dispersion processes for environmental, pollution applications related to oil spills** (after the Deep-Water Horizon accident) in the Gulf of Mexico.
- IMPACT (http://impact-maritime.eu), IT-FR Interreg Program: the CARTHE drifter was deployed in 2019 to study dispersion processes for environmental, pollution, biological and safety applications in areas where Marine Protected Areas and ports coexist (Ligurian-Provençal basin).
- JERICO-NEXT, JERICO-S3 (https://www.jerico-ri.eu), H2020 Program: CARTHE and CODE drifters were deployed in 2011 and 2022, respectively, for the **validation of remote observation instruments** (such as sea surface currents from HF radar) and for the development of coastal monitoring supersites in the Mediterranean Sea and across Europe. Both CARTHE, SVP, and SVP-BGC are components of the JERICO-RI, which is included in the roadmap for ESFRI.
- CALYPSO (http://calypsodri.whoi.edu), Office of Naval Research (ONR) Program: CARTHE drifters have been deployed in multiple experiments (2019, 2022) to **study the upper ocean dynamics, including vertical velocities**, in the Western Mediterranean Sea.
- BIOSWOT-Med (https://www.swot-adac.org), NASA-CNES Program: CARTHE drifters were deployed in the Western Mediterranean Sea in 2022. The primary objective of this experiment was to **validate remote observation instruments, specifically SWOT satellite altimetry and ocean colour sensors**. BGC-SVP and several SVP instruments were also deployed. These were used to integrate surface front detection with biogeochemical patterns, offering a multifaceted approach to data collection.
- AstrAL/EKEMSAT project: the deployment of BGC-SVP drifter, coupled with other SVP drifters, was conducted in a manner that facilitated its retrieval after a brief period. The primary objective of these drifting operations was to **observe and understand the impact of the monsoon on the biogeochemical characteristics of the marine ecosystem**. This activity was in synergy with the US (e.g., Lagrangian Drifter Laboratory of Scripps) and Indian Research Institutes.
- NORSE project: the BGC-SVP drifter was deployed **to prove the reliability of an optical sensor in an oligotrophic regime** in the Norwegian Sea. This deployment was conducted in synergy with the support of NATO/CMRE and the Lagrangian Drifter Laboratory (LDL) of Scripps (SIO).
- JPI-OCEAN S4GES cruise: the deployment of the BGC-SVP drifter in the North Sea was oriented to evaluate the technology in a coastal environment and to acquire new insights into the **tidal effects on bio-optical properties**.

- COSIMO22 cruise: the deployment of the BGC-SVP drifter along the coast of the Tyrrhenian Sea, from coastal to open ocean waters, has facilitated the acquisition of measurements to **assess the robustness of optical backscatter estimates** and subsequently to **validate ocean colour data** (see Figure 50 and Figure 51).

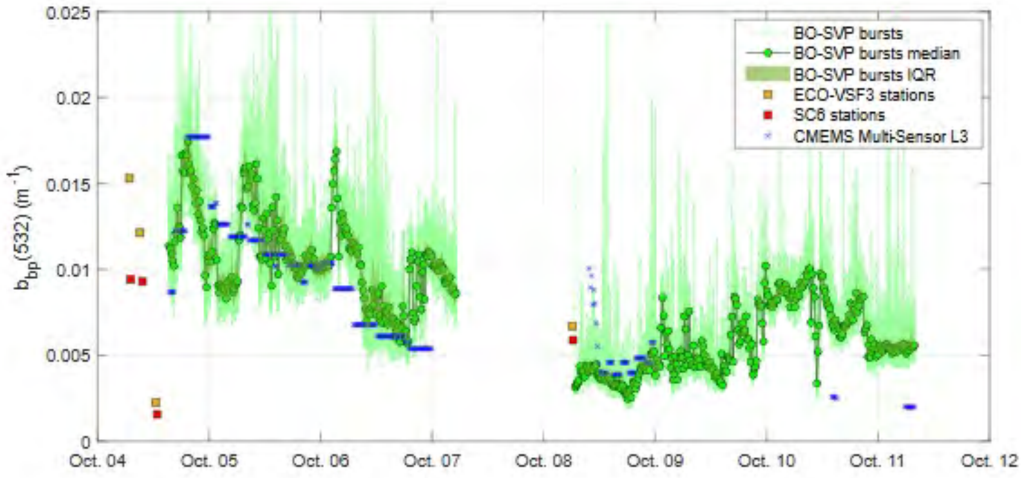


Figure 50 – Original (bursts) and 15-min median bbp (532) time series collected by the BGC-SVP drifter in the Tyrrhenian Sea with overlaid corresponding independent in situ cruise data and the median satellite value of a 3x3 box for each drifter position obtained from daily ocean color product. Figure from Bellacicco et al., (2024).

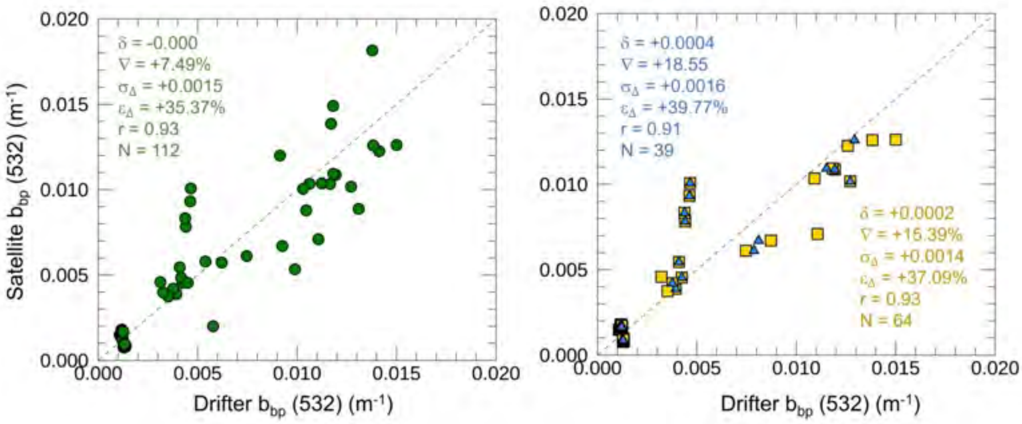


Figure 51 – Matchups between space-borne bbp observations and all in situ bbp collected by BGC-SVP drifter during the COSIMO22 oceanographic cruise held during November 2022 in the Tyrrhenian Sea and BIOSWOT-Med cruise held in May 2023 (left panel). In the right panel, gold squares are matchups obtained by using all daytime drifter observations; blue triangles are matchups using observations across satellite passage. Figure from Bellacicco et al., 2024).

During 2024, CNR-ISMAR participated to two polar marine experiments that involved the deployment as well of surface CARTHE drifters:

- MARGOCEAN (https://margo.obs-banyuls.fr/index.php/en/): CARTHE drifters were deployed off Kerguelen Island to **study the fate of fresh water melted from Antarctic glaciers and its impact on water fertilization**, considering future scenarios of global warming.
- BALTARCTIC (https://barc.ug.edu.pl/): CARTHE and CODE drifters have been deployed following the Norwegian shelf break to **investigate transport pathways of water masses to high latitudes**.

In 2025 drifter deployments were involved in the following national/international cruises:

- PATASWOT (https://www.swot-adac.org), NASA-CNES Program: CARTHE drifters were deployed in the Malvinas Current in October 2025 for the validation of SWOT satellite altimetry and for the investigation of local transport pathways at the shelf break, including vertical velocities.
- ITINERIS' EYES (PNRR Program): in July 2025 the cruise in the Western and Central Mediterranean Sea involved the majority of the new PNRR infrastructures for an extended multiplatform experiment including CARTHE, BGC-SVP drifters, BGC-Argo, gliders and HF radars (see details in the next paragraph).
- At the beginning of September, one BGC-SVP drifter was deployed from R/V Laura Bassi in the South Adriatic gyre during an oceanographic cruise led by OGS. The BGC-SVP drifter has been launched in synergy with Argo floats.

7.12.5.3 PNRR investments and expected outcome

During the ITINERIS' EYES cruise, a total of 69 autonomous lagrangian drifters, funded by the ITINERIS project, were deployed at sea. These drifters belonged to four different types: (i) 40 CARTHE; (ii) 6 CODE; (iii) 16 SVP (Surface Velocity Program); and (iv) 7 BioGeoChemical (BGC)-SVP. Each type of drifter has specific geometry and design that influence how it interacts with the surrounding flow (as mentioned in 7.12.5).

CODE and SVP drifters were provided by OGS, which collaborated to the cruise effort.

A mesoscale process study was conducted in the Ligurian Sea (Figure x) to investigate the response of biology to circulation structures through a multiplatform experiment involving drifter deployments (Figure xx), CTD casts on R/V Gaia Blu, two SeaExplorer gliders (funded by the ITINERIS project) continuously monitoring bio-physical parameters along the water column, an aerial drone (provided by the Coast Guard in the framework of the SEASTEMAR Project) patrolling the area to identify sea surface fronts and the concurrent presence of marine mammals.

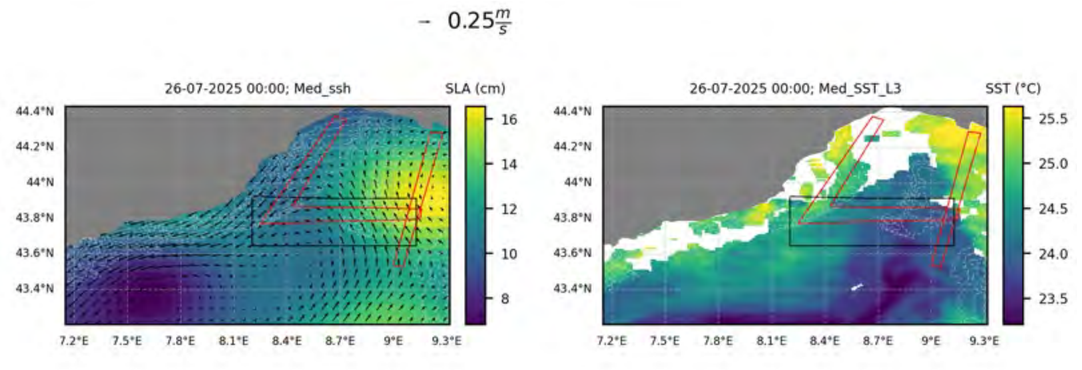


Figure 52 – Area of the Ligurian Sea where the mesoscale process study took place on July 26th, 2025. The black rectangle identifies the drone area. Red transects identify areas covered by gliders. A) Seal Level Anomaly (SLA) and surface geostrophic currents in the Ligurian Sea on July 26th, 2025; B) Sea Surface Temperature (SST) in the Ligurian Sea on July 26th, 2025. After Organelli et al., 2025.

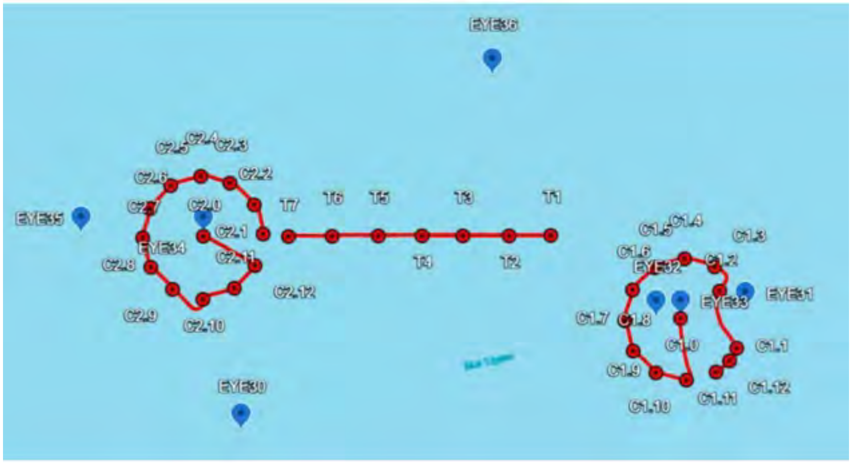
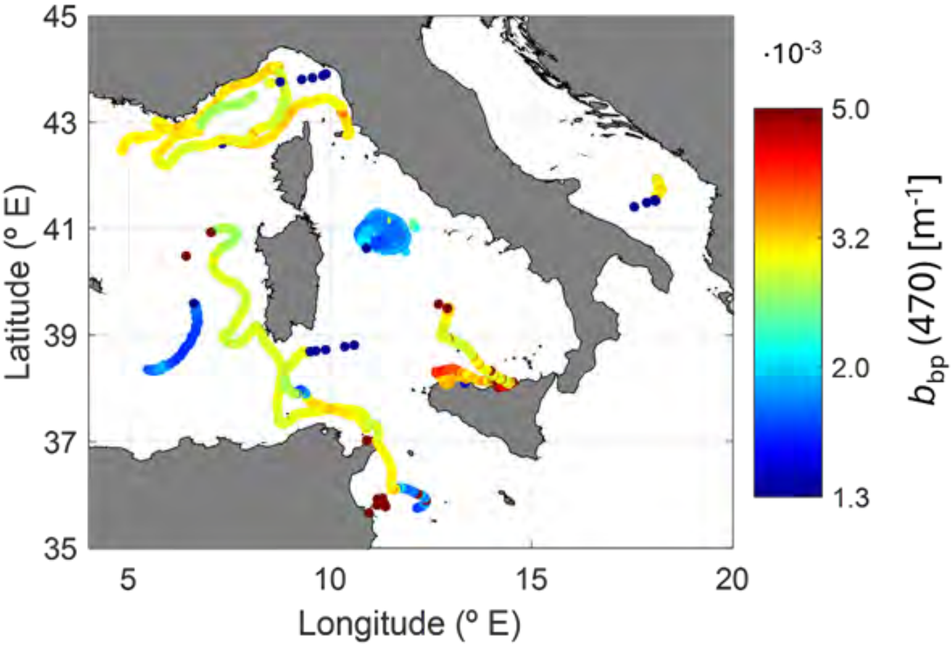


Figure 53 – Drifter deployment strategy in the Ligurian Sea, details of the activity in the area indicated by the black square in Figure 49, after Organelli et al. (2025).

During the cruise, most of the BGC-SVP drifters were deployed in synergy with the BGC-Argo floats to collect simultaneous information about the 4D dimension of ocean ecosystems targeting well known mesoscale eddies in the Western Mediterranean Sea. In addition, to better understand the dynamic nature of the ocean in terms of kinematical properties of seawater (e.g., strain, vorticity), the BGC-SVP drifters were deployed coupled with an array of SVP drifters, CODE and CARTHE drifters.



IDs of BGC-SVP	Name of BGC-SVP	Status
300534065377600	Susan Abulhawa	Recovered
300534065377620	José Saramago	Recovered
300534065378310	Francisco Coloane	Partially transmitting
300534065378600	Luis Sepulveda	Beached in Tunisia
300534065379120	Marcela Serrano	Beached in Tunisia
300534065379230	Bjorn Larsson	Transmitting
300534065370010	Wu Ming	Partially transmitting
300534065370010	Don Durito	Transmitting

Figure 54 – Status of BGC-SVP drifters in the Central Mediterranean Sea deployed from R/V Gaia Blu at the 23th Sept. 2025. The colobar indicates the particle backscattering coefficient at the 470nm.

7.12.5.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Surface currents	Targeted deployments. Data avialable since 2019	10min-1h	CNR-ISMAR
Subsurface currents	Data available for 2022 and 2023 deployments	Variable/Flexible	CNR-ISMAR
Surface temperature	Data available for 2022 and 2023 deployments	Variable/Flexible	CNR-ISMAR
Subsurface temperature	Data available for 2022 and 2023 deployments	Variable/Flexible	CNR-ISMAR
Subsurface salinity	Data available for 2022 and 2023 deployments	Variable/Flexible	CNR-ISMAR
Biogeochemical			
Particulate Matter	Data available for 2022 and 2023 deployments	Variable/Flexible	CNR-ISMAR
Biological/Ecosystem			
Phytoplankton Biomass and Diversity	Data available for 2022 and 2023 deployments	Variable/Flexible	CNR-ISMAR
Cross disciplinary			
Ocean Color	Data available for 2022 and 2023 deployment	Daily	CNR-ISMAR

7.12.5.5 Publications

Laurina Oms, Andrea Doglioli, Monique Messié et al. “Living on the edge” Fine-scale observations reveal distinct frontal phytoplankton communities, 22 May 2025, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-6412120/v1]

Nalivaev, A., d'Ovidio, F., Bopp, L., Berta, M., Rousselet, L., Azarian, C., and Blain, S.: Glaciogenic iron transport pathways to the Kerguelen offshore phytoplankton bloom, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-2145, 2025.

Donnet, S., Huntley, H. S., Berta, M., Centurioni, L., Middleton, L., Özgökmen, T., Poulain, P.-M., Kinsella, A., and Griffa, A.: Surface evolution and wind effects during a cyclonic eddy splitting event in the Balearic Sea, Ocean Sci., 21, 3221–3240, https://doi.org/10.5194/os-21-3221-2025, 2025.

Organelli et al. 2025, R/V GAIA BLU CRUISE REPORT ITINERIS' EYES INTEGRATING, INNOVATING, EVOLVING RESEARCH INFRASTRUCTURES FOR HEALTHY AND PREDICTED MARINE ECOSYSTEMS. https://doi.org/10.82175/it-ioos/vq4g-0t11

Bellacicco, M., Pitarch, J., Organelli, E., Zoffoli, M. L., Concha, J. A., Falcini, F., ... & Centurioni, L. R. (2024). Near-surface particulate backscattering observations with bio-optical Lagrangian drifters. Journal of Atmospheric and Oceanic Technology.

M. Saraceno, N. Bodnariuk, L.A. Ruiz-Etcheverry, M. Berta, C.G. Simionato, F.J. Beron-Vera, M.J. Olascoaga, Lagrangian characterization of the southwestern Atlantic from a dense surface drifter deployment, Deep Sea Research Part I: Oceanographic Research Papers, Volume 208, 2024, 104319, https://doi.org/10.1016/j.dsr.2024.104319.

PM Poulain, L Centurioni, C Brandini, S Taddei, M Berta, M Menna (2023). Relative dispersion and kinematic properties of the coastal submesoscale circulation in the southeastern Ligurian Sea. Ocean Science 19 (6), 1617-1631

7.12.5.6 Open Data

Drifters’ data are available in open format through a variety of platforms, as listed below:
https://www.seanoe.org/data/00896/100828/
https://www.seanoe.org/data/00924/103561/
https://www.seanoe.org/data/00740/85161/
https://www.seanoe.org/data/00612/72369/
https://doi.org/10.6084/m9.figshare.21432558.v1
https://fleetmonitoring.euro-argo.eu/float/6903816
https://data.gulfresearchinitiative.org/data/R1.x134.115:0004
https://data.gulfresearchinitiative.org/data/R1.x134.115:0003
https://data.gulfresearchinitiative.org/data/R4.x265.237:0004
https://data.gulfresearchinitiative.org/data/R4.x265.237:0006

7.12.6 Drifting wave buoys

Figure 55 – Example of drifting wave buoys produced by the Norwegian Meteorological Institute (OpenMetBuoys)

As outlined in Paragraph 7.12.5, several types of drifter buoys exist. Among them, drifting wave buoys are widely used to measure ocean surface elevation because they are easy to deploy and do not require fixed infrastructure. While commercial instruments are often expensive, low-cost open-source solutions such as the OpenMetBuoys (OMB) developed by the Norwegian Meteorological Institute (Rabault et al., 2022) now offer an attractive alternative.

These compact drifters (16 × 16 cm, 9 cm height, with a small 3 cm overwater profile) operate for about two months on alkaline batteries, with longer endurance possible using higher-capacity cells. Each unit includes a six-degree-of-freedom inertial measurement unit (IMU) that records high-frequency accelerations and angular rates. Wave spectra (0.040–0.307 Hz) are sampled every three hours over 20-minute bursts, and an integrated GPS module provides positions at 30-minute intervals. Thanks to their small size and favourable immersion-to-windage ratio, windage effects are minimal—an advantage in strong-current regions where drift primarily reflects geostrophic flow.

7.12.6.1 Scientific Outcomes and Contributions of recent activities

The scientific impact of wave buoy data collection lies primarily in the use of summary statistics derived from the measured directional wave spectrum, such as significant wave height (Hs) and peak period (Tp), for the calibration and validation of phase-averaged operational ocean forecast and hindcast models (Janssen et al., 1997; Bidlot et al., 2002), as well as satellite observations, especially in regions with sharp current gradients and strong wave-current interactions.

Another key contribution of these drifters is the ability to evaluate the wave-induced Stokes drift along their tracks and compare it with model outputs. This is possible since the knowledge of both the measured wave spectrum and trajectory of the buoy is required (Altiparmaki et al., 2024).

Six OMB drifting wave buoys were deployed during the oceanographic cruise MARSiCo-2024 (Management and Retrieval of Submerged Infrastructures in the Sicily and Corsica Channel-2024) in the Mediterranean Sea onboard CNR’s RV Gaia Blu. Specifically, three wave buoys were

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Lerici
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+39 0187 1788900

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+39 081 5423802

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deployed in the Ionian Sea (37.72698611 °N, 15.47956639 °E) on 1 December 2024 and another three in the Thyrrenian Sea (41.98847222 °N, 11.63941667 °E) on 4 December 2024 (Figure 56). The deployment of these buoys was intended to facilitate the capture of the distinct wind-wave and surface current dynamics exhibited by the two basins.

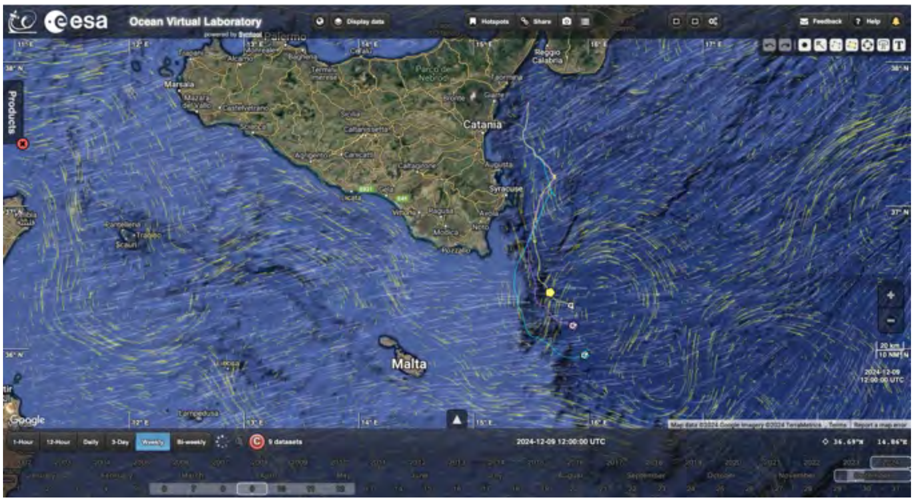

Figure 56 – Screenshot of the Ocean Virtual Lab portal (https://ovl.oceandatalab.com/) showing the tracks (blue-, magenta- and yellow-coloured lines) of the three wave drifters deployed in the Ionian Sea during the MARSiCo-2024 cruise.

7.12.6.2 PNRR investments and expected outcome

No investments have made in the framework of the PNRR.

7.12.6.3 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Surface currents	Targeted deployments. Data available from 2024	1h	CNR-ISMAR
Sea state	Targeted deployments. Data available from 2024	3h	CNR-ISMAR

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7.12.6.4 Publications

Altiparmaki, O.; Breivik, O.; Aouf, L.; Bohlinger, P.; Johannessen, J. A.; Collard, F.; et al. (2024): Influence of Ocean Currents on Wave Modelling and Satellite Observations: Insights From the One Ocean Expedition. Journal of Geophysical Research: Oceans, 129, e2024JC021581. https://doi.org/10.1029/2024JC021581

7.12.6.5 Open Data

Drifting wave buoys data are available through the following platform:

https://ovl.oceandatalab.com/

7.13 Stazione costiera SP Mitilicoltura

Figure 57 – The imaging device deployed in the mussel farm in the Gulf of La Spezia

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The Station implements a system for the observation of nectonic biomass flows in a coastal marine area with strong mussel farming activity. The system consists of one or more autonomous intelligent imaging devices GUARD1, implemented according to the technology described in the European patent EP 2863257 B1 – "Underwater images acquisition and processing system".

One or more GUARD-1 imaging devices are deployed in the mussel farm in the Gulf of La Spezia, programmed to acquire images continuously throughout day and night. Each device executes on board specifically designed image processing algorithms for the detection and classification of fishes and it is equipped with data communication facilities to transfer the relevant content extracted from the acquired images, as for example, images containing fish specimens and/or abundance time series of the detected species.

The current configuration of the observing system consists of a GUARD-1 device equipped with an AI-based tool for the automated detection of fishes from underwater images and a 4G modem positioned on a buoy surface for data transfer. Currently the imaging device acquires an image every 20 minutes, processing it on board and transfers both the acquired images and a text file containing the list of bounding box vertices of the detected organisms. New devices will be positioned in the next months in different locations inside the mussel farm.

7.13.1 Scientific Outcomes and Contributions of recent activities

The aim of the station is the investigation of the biodiversity in the mussel farm and in its proximity, together with the analysis of the fauna assemblage and its temporal dynamic.

Moreover, the mussel farm in the gulf of La Spezia is affected by the presence of harmful fish species (i.e., Sparus aurata) predating the mussels and, for this reason, it is important to track their abundance along the seasons and to understand the environmental conditions they are more active.

Figure 58 – Images acquired by the device deployed in the mussel farm in the Gulf of La Spezia

In the top image several fishes are grazing the mussels without producing any damage, while in the bottom image a specimen of Sparus aurata is eating the mussels.

Besides the Sparus aurata, many other species are present in the mussel farm, depending on the season and the environmental conditions. The following are some examples of automated detection of fishes and gelatinous macro zooplankton:

Figure 59 – The imaging device deployed in the mussel farm in the Gulf of La Spezia

Finally, this observing system contributes to the research on AI-based analysis approaches for the underwater fauna and the design and development of autonomous intelligent devices for complex observing tasks.

7.13.2 National/International collaborations and ESFRI contribution

This research activity is part of the PNRR ecosystem of innovation RAISE - Robotics and AI for Socio-economic Empowerment - (https://www.raiseliguria.it/), it is developed within the project "Advances technological platforms for sea monitoring and forecasting". This research activity is also part of the JERICO research infrastructure (https://www.jerico-ri.eu/).

7.13.3 PNRR investments and expected outcome

The GUARD-1 has been conceived as low-cost device, thus PNRR RAISE invested about 5000€, AI software for specimen detection and communication facility included. The device has no costs for the power supply, as it is based on two rechargeable batteries used alternatively. Also, the maintenance has no costs as it is operated with the boats of the mussel farm operators.

The outcome of this research activity consists in the study and understanding of the temporal dynamics of the fauna present in the mussel farm and the monitoring of the corresponding biodiversity. Another outcome regards the study and development of autonomous intelligent underwater observing systems.

7.13.4 Observed variables

Observed Variables			
Variable	**Operational Measurements Start***	**Measurement interval**	**Institution**
images	27 June 2025	20 minutes	CNR - ISMAR

7.13.5 Publications

Ferrari M., D'Agostino D., Aguzzi J., Marini S. Underwater Mediterranean image analysis based on the compute continuum paradigm (2025) Future Generation Computer Systems, 162, art. no. 107481. DOI: 10.1016/j.future.2024.107481

Ortenzi L., Aguzzi J., Costa C., Marini S., D'Agostino D., Thomsen L., De Leo F.C., Correa P.V., Chatzievangelou D. Automated species classification and counting by deep-sea mobile crawler platforms using YOLO (2024) Ecological Informatics, 82, art. no. 102788. DOI: 10.1016/j.ecoinf.2024.102788

Spoto M., Lagomarsino-Oneto D., Gristina M., Marini S., Pierri C., Rinaldi A., Cavaiola M.Taxonomic Identification of European Seahorse H. Guttulatus and H. Hippocampus Based on Machine Learning Techniques (2024) 2024 IEEE International Workshop on Metrology for the Sea, MetroSea 2024 - Proceedings, pp. 438 - 443. DOI: 10.1109/MetroSea62823.2024.10765623

Francescangeli M., Marini S., Martínez E., Del Río J., Toma D.M., Nogueras M., Aguzzi J. Image dataset for benchmarking automated fish detection and classification algorithms (2023) Scientific Data, 10 (1), art. no. 5. DOI: 10.1038/s41597-022-01906-1

Ottaviani E., Francescangeli M., Gjeci N., del Rio Fernandez J., Aguzzi J., Marini S. Assessing the Image Concept Drift at the OBSEA Coastal Underwater Cabled Observatory (2022) Frontiers in Marine Science, 9, art. no. 840088. DOI: 10.3389/fmars.2022.840088

Bonofiglio F., De Leo F.C., Yee C., Chatzievangelou D., Aguzzi J., Marini S. Machine learning applied to big data from marine cabled observatories: A case study of sablefish monitoring in the NE Pacific (2022) Frontiers in Marine Science, 9, art. no. 842946. DOI: 10.3389/fmars.2022.842946

Marini S., Bonofiglio F., Corgnati L.P., Bordone A., Schiaparelli S., Peirano A. Long-term High Resolution Image Dataset of Antarctic Coastal Benthic Fauna (2022) Scientific Data, 9 (1), art. no. 750. DOI: 10.1038/s41597-022-01865-7

Marini S., Bonofiglio F., Corgnati L.P., Bordone A., Schiaparelli S., Peirano A. Long-term automated visual monitoring of Antarctic benthic fauna (2022) Methods in Ecology and Evolution, 13 (8), pp. 1746 - 1764. DOI: 10.1111/2041-210X.13898

Aguzzi J., Chatzievangelou D., Company J.B., Thomsen L., Marini S., Bonofiglio F., Juanes F., Rountree R., Berry A., Chumbinho R., Lordan C., Doyle J., del Rio J., Navarro J., De Leo F.C., Bahamon N., Garcia J.A., Danovaro P.R., Francescangeli M., Lopez-Vazquez V., Gaughan P. The potential of video imagery from worldwide cabled observatory networks to provide information supporting fish-stock and biodiversity assessment (2020) ICES Journal of Marine Science, 77 (7), pp. 2396 - 2410. DOI: 10.1093/icesjms/fsaa169

Lopez-vazquez V., Lopez-guede J.M., Marini S., Fanelli E., Johnsen E., Aguzzi J. Video image enhancement and machine learning pipeline for underwater animal detection and classification at cabled observatories (2020) Sensors, 20 (3), art. no. 726. DOI: 10.3390/s20030726

Marini S., Corgnati L., Mantovani C., Bastianini M., Ottaviani E., Fanelli E., Aguzzi J., Griffa A., Poulain P.-M. Automated estimate of fish abundance through the autonomous imaging device GUARD1 (2018) Measurement: Journal of the International Measurement Confederation, 126, pp. 72 - 75. DOI: 10.1016/j.measurement.2018.05.035

Marini S., Corgnati L., Mantovani C., Bastianini M., Ottaviani E., Fanelli E., Aguzzi J., Griffa A., Poulain P.M. An autonomous imaging system for argo floats (2017) IMEKO TC19 Workshop on Metrology for the Sea, MetroSea 2017: Learning to Measure Sea Health Parameters, 2017-October, pp. 39 - 43.

Corgnati L., Marini S., Mazzei L., Ottaviani E., Aliani S., Conversi A., Griffa A. Looking inside the ocean: Toward an autonomous imaging system for monitoring gelatinous zooplankton (2016) Sensors (Switzerland), 16 (12), art. no. 2124. DOI: 10.3390/s16122124

Mazzei L., Corgnati L., Marini S., Ottaviani E., Isoppo B. Low-cost stereo system for imaging and 3D reconstruction of underwater organisms (2015) MTS/IEEE OCEANS 2015 - Genova: Discovering Sustainable Ocean Energy for a New World, art. no. 7271554. DOI: 10.1109/OCEANS-Genova.2015.7271554

Marini S., Corgnati L., Mazzei L., Ottaviano E., Isoppo B., Aliani S., Conversi A., Griffa A. GUARD1: An autonomous system for gelatinous zooplankton image-based recognition (2015) MTS/IEEE OCEANS 2015 - Genova: Discovering Sustainable Ocean Energy for a New World, art. no. 7271704. DOI: 10.1109/OCEANS-Genova.2015.7271704

7.13.6 Open Data

Image data are available through the PNRR RAISE portal at:

https://guard-one.s4raise.it/

7.14 Stazione fluviale CURRISO

Figure 60 *– Station CURRISO located in the Regional Nature Reserve of the Isonzo River Mouth. Automated remote station and the stilling pipe containing CTD instruments are also shown.* I

7.14.1 Scientific Outcomes and Contributions of recent activities

River discharges are the most important forcing that modulate hydrological and biogeochemical conditions in shallow continental shelves, like the Northern Adriatic Sea. River regime and the inputs of natural and anthropogenic compounds due to the runoff are also the major mechanism in which human pressures and climate changes affect the evolution of these coastal marine ecosystems. A large body of oceanographic studies and data series are available in the Northern Adriatic Sea, whereas information on river discharges is scarce and often limited to the river water flows only. For this reason, a more detailed characterization of biogeochemical parameters at the river mouths is a basic point to improve our understanding of estuarine processes and of the interactions between river and sea systems.

7.14.2 National/International collaborations and ESFRI contribution

The station CURRISO was implemented in collaboration with the Regional Civil Protection, which owns its support structure (Protezione Civile FVG; https://monitor.protezionecivile.fvg.it/) and with OGS - National Institute of Oceanography and Applied Geophysics (https://www.ogs.it/en), which manage in this site a instrumentation for the measurement of water temperature and river flow rate (https://nodc.ogs.it/geoportal/).

The station was installed by CNR – ISMAR in the framework of ITINERS project (Italian Integrated Environmental Research Infrastructures System, MUR - PNRR) and it currently contributes to the European Research Infrastructure DANUBIUS ERIC (International Centre for Advanced Studies on River-Sea Systems, HORIZON 2020 – INFRA DEV 2), as well as to EU-funded research project LandSeaLot (Land-Sea interface: Let's observe together!, HORIZON-CL6-2023-GOVERNANCE-01-11). Monthly water sampling of biogeochemical parameters is also conducted by personnel of CNR – ISMAR Trieste in this site to enlarge the set of environmental parameters available in this transition zone between river and coastal water systems.

7.14.3 PNRR investments and expected outcome

Near real time data series acquired in this station will be important for coastal oceanographic studies, for the monitoring of river water quality performed by the Regional Environmental Protection Agency (ARPA FVG, https://www.arpa.fvg.it/) and for ecological studies performed by the Biological Station of Cona Island (SBIC, https://riservafoceisonzo.it/gestione/stazione-biologica-isola-della-cona/), which manages the Regional Nature Reserve of the Isonzo River Mouth. The station is also located in a Nature 2000 area (26,68 km2), protected under both Birds (147/09) and Habitats (43/92) European Directives, and it will important for its preservation and management.

7.14.4 Observed variables

The following table shows the summary of the essential oceanic and climatic variables acquired on an operational basis at the station CURRISO.

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start***	**Measurement interval**	**Institution**
Water			

ECV - Ocean, Physical: Sea Level (m)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Physical: Sea Surface Temperature (°C)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Physical: Sea Surface Salinity (Conductivity; mS/cm)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Physical: Sea Surface Salinity (PSU)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Biogeochemical: Oxygen (Concentration; mg/L)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Biogeochemical: Oxygen (Saturation; %)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Biogeochemical: Inorganic Carbon (pH; unit)	31 January 2025	10 minutes	CNR - ISMAR
EOV - Biogeochemistry: Particulate Matter (Turbidity; NTU)	31 January 2025	10 minutes	CNR - ISMAR
EOV - Biology and Ecosystems: Phytoplankton Biomass and Diversity (Chlorophyll; µg/L)	31 January 2025	10 minutes	CNR - ISMAR

7.14.5 Publications

De Pascalis F., Urbinati E., Aalifar A., Aveytua Alcazar L., Arpaia L., Bajo M., Barbanti A., Barbariol F., Bastianini M., Bellafiore D., Bellati F., Benetazzo A., Bologna G., Bonaldo D., Bongiorni L., Braga F., Brando V.E., Brunetti F., Caccavale M., Camatti E., Campostrin P., Cantoni C., Canu D., Capotondi L., Cassin D., Castelli G., Celussi M., Correggiari A., Cozzi S., Dabalà C., Davison S., Fadini A., Falcieri F.M., Falcini F., Ferrarin C., Foglini F., Gissi E., Ghezzo M., Grande V., Guarneri I., Lanzoni A., Laurent C., Lorenzetti G., Madricardo F., Manfè G., Mc Kiver W., Menegon S., Moschino V., Nesto N., Petrizzo A., Pomaro A., Ravaioli M., Remia A., Riminucci F., Rosina A., Rosati G., Santoleri R., Scarpa G.M., Scroccaro I., Stanghellini G., Solidoro C., Umgiesser G. 2025. The DANUBIUS-RI Supersite of Po Delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea. Estuarine, Coastal and Shelf Science, 109453 Doi: 10.1016/j.ecss.2025.109453

7.14.6 Open Data

The data acquired by the station CURRISO are automatically uploaded to the data centre of the ITINERIS project. They will be made available to the public after the refinement of the procedure of filtration and quality control.

7.15 Stazione fluviale exCORRTAG

Figure 61 - Station exCORRTAG located at the mouth of Tagliamento River in the Pine Forest "Riviera Nord". Automated remote station and the stilling pipe containing CTD instruments are also shown***.***

7.15.1 Scientific Outcomes and Contributions of recent activities

River discharges are the most important forcing that modulate hydrological and biogeochemical conditions in shallow continental shelves, like the Northern Adriatic Sea. River regime and the inputs of natural and anthropogenic compounds due to the runoff are also the major mechanism in which human pressures and climate changes affect the evolution of these coastal marine ecosystems. A large body of oceanographic studies and data series are available in the Northern Adriatic Sea, whereas information on river discharges is scarce and often limited to the river water flows only. For this reason, a more detailed characterization of biogeochemical parameters at the river mouths is a basic point to improve our understanding of estuarine processes and of the interactions between river and sea systems.

7.15.2 National/International collaborations and ESFRI contribution

The station exCORRTAG was implemented in collaboration with the Regional Civil Protection, which owns its support structure (Protezione Civile FVG; https://monitor.protezionecivile.fvg.it/) and with OGS - National Institute of Oceanography and Applied Geophysics (https://www.ogs.it/en), which has managed in this site a instrumentation for the measurement of water temperature and level (https://nodc.ogs.it/geoportal/).

The instrumentation installed by CNR – ISMAR in the framework of ITINERS project (Italian Integrated Environmental Research Infrastructures System, MUR - PNRR) currently contributes to the European Research Infrastructure DANUBIUS ERIC (International Centre for Advanced Studies on River-Sea Systems, HORIZON 2020 – INFRA DEV 2), as well as to EU-funded research project LandSeaLot (Land-Sea interface: Let's observe together!, HORIZON-CL6-2023-GOVERNANCE-01-11). Water sampling of biogeochemical parameters is also conducted by personnel of CNR – ISMAR Trieste in this site, to enlarge the set of environmental parameters available in this transition zone between river and coastal water systems.

7.15.3 PNRR investments and expected outcome

Near real time data series acquired in this station will be important for coastal oceanographic studies and for the monitoring of river water quality performed by the Regional Environmental Protection Agency (ARPA FVG, https://www.arpa.fvg.it/). The station will be also useful for the monitoring of an estuarine system that is heavily affected by seaside tourism.

7.15.4 Observed variables

The following table shows the summary of the essential oceanic and climatic variables acquired on an operational basis at the station exCORRTAG.

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start***	**Measurement interval**	**Institution**
Water			
ECV - Ocean, Physical: Sea Level (m)	31 January 2025	10 minutes	CNR - ISMAR

ECV - Ocean, Physical: Sea Surface Temperature (°C)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Physical: Sea Surface Salinity (Conductivity; mS/cm)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Physical: Sea Surface Salinity (PSU)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Biogeochemical: Oxygen (Concentration; mg/L)	31 January 2025	10 minutes	CNR - ISMAR
ECV - Ocean, Biogeochemical: Inorganic Carbon (pH; unit)	31 January 2025	10 minutes	CNR - ISMAR
EOV - Biogeochemistry: Particulate Matter (Turbidity; NTU)	31 January 2025	10 minutes	CNR - ISMAR
EOV - Biology and Ecosystems: Phytoplankton Biomass and Diversity (Chlorophyll; µg/L)	31 January 2025	10 minutes	CNR - ISMAR

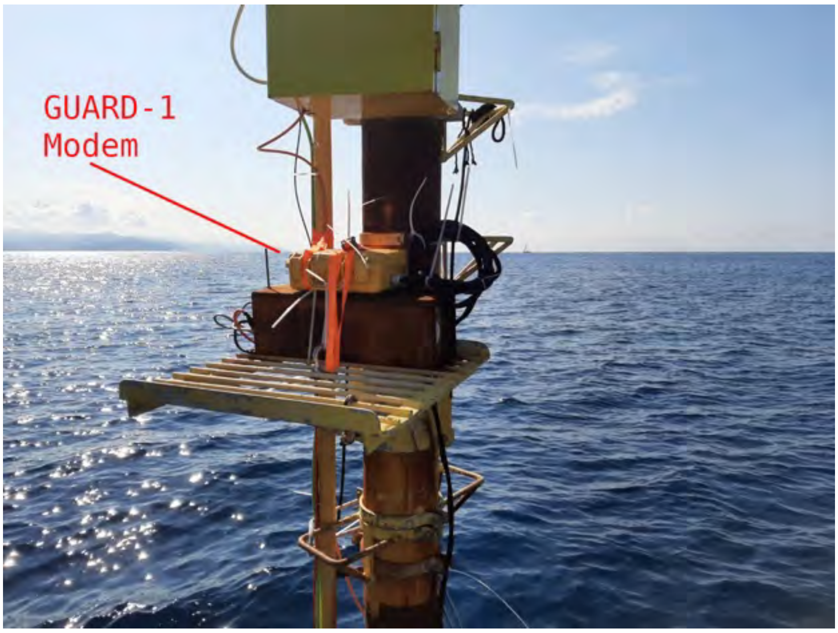
7.15.5 Publications

De Pascalis F., Urbinati E., Aalifar A., Aveytua Alcazar L., Arpaia L., Bajo M., Barbanti A., Barbariol F., Bastianini M., Bellafiore D., Bellati F., Benetazzo A., Bologna G., Bonaldo D., Bongiorni L., Braga F., Brando V.E., Brunetti F., Caccavale M., Camatti E., Campostrin P., Cantoni C., Canu D., Capotondi L., Cassin D., Castelli G., Celussi M., Correggiari A., Cozzi S., Dabalà C., Davison S., Fadini A., Falcieri F.M., Falcini F., Ferrarin C., Foglini F., Gissi E., Ghezzo M., Grande V., Guarneri I., Lanzoni A., Laurent C., Lorenzetti G., Madricardo F., Manfè G., Mc Kiver W., Menegon S., Moschino V., Nesto N., Petrizzo A., Pomaro A., Ravaioli M., Remia A., Riminucci F., Rosina A., Rosati G., Santoleri R., Scarpa G.M., Scroccaro I., Stanghellini G., Solidoro C., Umgiesser G. 2025. The DANUBIUS-RI Supersite of Po Delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea. Estuarine, Coastal and Shelf Science, 109453 Doi: 10.1016/j.ecss.2025.109453

7.15.6 Open Data

- The data acquired by the station exCORRTAG are automatically uploaded to the data centre of the ITINERIS project. They will be made available to the public after the refinement of the procedure of filtration and quality control.

7.16 Meda 2 Portofino



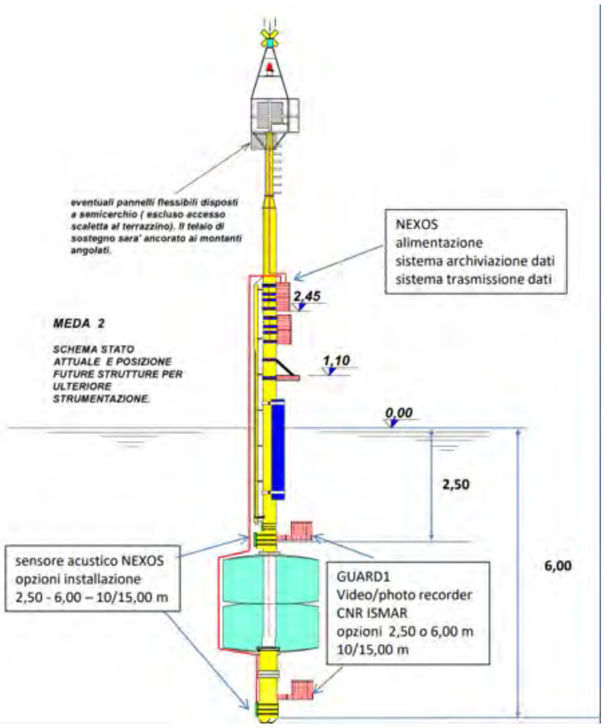


Figure 62 – The diagram representing the MEDA 2 buoy and the instruments installed on it.

The Station is analogous to the one in the mussel farm in the Gulf of La Spezia. It implements a system for the observation of biodiversity and specifically the nectonic and macro gelatinous zooplankton biomass in the Marine Protected Area (MPA) of Portofino (Ge). The system consists of one or more autonomous intelligent imaging devices GUARD1, implemented according to the technology described in the European patent EP 2863257 B1 – "Underwater images acquisition and processing system".

A GUARD-1 imaging device is installed on a moored Meda buoy, and it is programmed to acquire images continuously along day and night. The device executes on board specifically designed image processing algorithms for the detection and classification of fishes and macro gelatinous zooplankton and it is equipped with data communication facilities to transfer the relevant content extracted from the acquired images, as for example, images containing fish specimens and/or abundance time series of the detected species.

The current configuration of the observing system consists of a GUARD-1 device equipped with an AI-based tool for the automated detection of fishes from underwater images and a 4G modem positioned on the Meda buoy for data transfer. Currently the imaging device acquires an image every 20 minutes, process it on board and transfers both the acquired images and a text file containing the list of bounding box vertices of the detected organisms. New devices will be positioned in the next months in different locations inside the MPA.

7.16.1 Scientific Outcomes and Contributions of recent activities

Aim of the station is the investigation of the biodiversity in the MPA, together with the analysis of the fauna assemblage and its temporal dynamic.

Moreover, the station is included into a research activity defined in the PNRR ecosystem of innovation RAISE - Robotics and AI for Socio-economic Empowerment – (https://www.raiseliguria.it/). Such research activity deals with the definition of an early warning system for gelatinous zooplankton detection and classification in touristic coastal areas. Such a early warning system consists of one or more intelligent imaging devices GUARD-1 distributed throughout the area of interest; one or more smart buoys that collect physical, biochemical, and meteorological parameters of the water column and the air column near the buoy; an oceanographic model for tracking particles dispersed in the water (i.e., gelatinous plankton specimens); and a Decision Support System (DSS) that integrates data from the various system components.

Specifically, the imaging devices identify a bloom and communicate the information to the DSS; the DSS activates the oceanographic model by providing as input the geolocation of the bloom, the number of identified individuals, and the weather-marine conditions detected by the smart buoys; the oceanographic model outputs a forecast of the dispersion of the individuals forming the bloom; the DSS raises a warning if the dispersion of the gelatinous organisms is expected to impact a sensitive area, such as a crowded beach.

Beside the presence of gelatinous zooplankton, many nektonic species are present in the MPA, depending on the season and the environmental conditions. The following are some examples of automated detection of fishes:

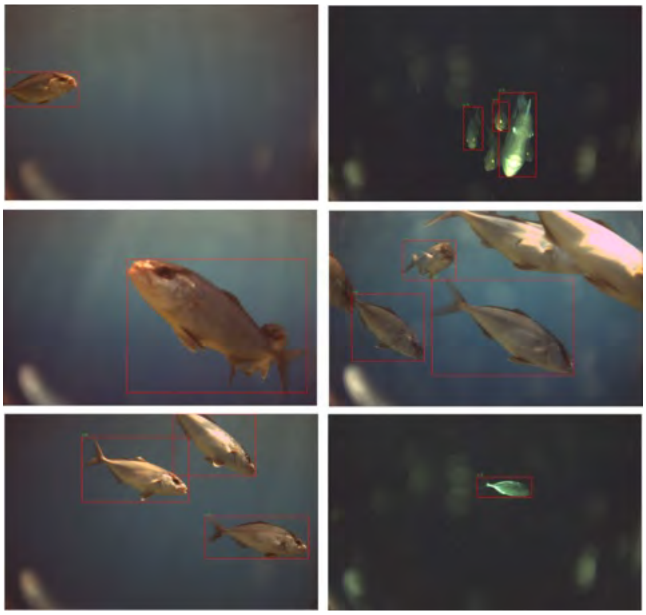


Figure 63 – Some examples of acquired images

Finally, this observing system contributes to the research on the AI-based analysis approaches for the underwater fauna and the design and development of autonomous intelligent devices for complex observing tasks.

7.16.2 National/International collaborations and ESFRI contribution

This research activity is part of the PNRR ecosystem of innovation RAISE - Robotics and AI for Socio-economic Empowerment - (https://www.raiseliguria.it/), it is developed within the project "Advances technological platforms for sea monitoring and forecasting". This research activity is also part of the JERICO research infrastructure (https://www.jerico-ri.eu/).

7.16.3 PNRR investments and expected outcome

The GUARD-1 has been conceived as low-cost device, thus PNRR RAISE invested about 5000€, AI software for specimen detection and communication facility included. The device has no costs for the power supply, as it is based on two rechargeable batteries used alternatively. Also, the maintenance has no costs as it is operated with the boats of the mussel farm operators.

The outcome of this research activity consists in the study and understanding of the temporal dynamics of the fauna present in the mussel farm and the monitoring of the corresponding biodiversity. Another outcome regards the study and development of autonomous intelligent underwater observing systems.

7.16.4 Observed variables

Observed Variables

Variable	Operational Measurements Start*	Measurement interval	Institution
Ocean			
Images	31 July 2025	20 minutes	CNR - ISMAR

7.16.5 Publications

Ferrari M., D'Agostino D., Aguzzi J., Marini S. Underwater Mediterranean image analysis based on the compute continuum paradigm

(2025) Future Generation Computer Systems, 162, art. no. 107481. DOI: 10.1016/j.future.2024.107481

Ortenzi L., Aguzzi J., Costa C., Marini S., D'Agostino D., Thomsen L., De Leo F.C., Correa P.V., Chatzievangelou D. Automated species classification and counting by deep-sea mobile crawler platforms using YOLO (2024) Ecological Informatics, 82, art. no. 102788. DOI: 10.1016/j.ecoinf.2024.102788

Spoto M., Lagomarsino-Oneto D., Gristina M., Marini S., Pierri C., Rinaldi A., Cavaiola M.Taxonomic Identification of European Seahorse H. Guttulatus and H. Hippocampus Based on Machine Learning Techniques (2024) 2024 IEEE International Workshop on Metrology for the Sea, MetroSea 2024 - Proceedings, pp. 438 - 443. DOI: 10.1109/MetroSea62823.2024.10765623

Francescangeli M., Marini S., Martínez E., Del Río J., Toma D.M., Nogueras M., Aguzzi J. Image dataset for benchmarking automated fish detection and classification algorithms (2023) Scientific Data, 10 (1), art. no. 5. DOI: 10.1038/s41597-022-01906-1

Ottaviani E., Francescangeli M., Gjeci N., del Rio Fernandez J., Aguzzi J., Marini S. Assessing the Image Concept Drift at the OBSEA Coastal Underwater Cabled Observatory (2022) Frontiers in Marine Science, 9, art. no. 840088. DOI: 10.3389/fmars.2022.840088

Bonofiglio F., De Leo F.C., Yee C., Chatzievangelou D., Aguzzi J., Marini S. Machine learning applied to big data from marine cabled observatories: A case study of sablefish monitoring in the NE Pacific (2022) Frontiers in Marine Science, 9, art. no. 842946. DOI: 10.3389/fmars.2022.842946

Marini S., Bonofiglio F., Corgnati L.P., Bordone A., Schiaparelli S., Peirano A. Long-term High Resolution Image Dataset of Antarctic Coastal Benthic Fauna (2022) Scientific Data, 9 (1), art. no. 750. DOI: 10.1038/s41597-022-01865-7

Marini S., Bonofiglio F., Corgnati L.P., Bordone A., Schiaparelli S., Peirano A. Long-term automated visual monitoring of Antarctic benthic fauna (2022) Methods in Ecology and Evolution, 13 (8), pp. 1746 - 1764. DOI: 10.1111/2041-210X.13898

Aguzzi J., Chatzievangelou D., Company J.B., Thomsen L., Marini S., Bonofiglio F., Juanes F., Rountree R., Berry A., Chumbinho R., Lordan C., Doyle J., del Rio J., Navarro J., De Leo F.C., Bahamon

N., Garcia J.A., Danovaro P.R., Francescangeli M., Lopez-Vazquez V., Gaughan P. The potential of video imagery from worldwide cabled observatory networks to provide information supporting fish-stock and biodiversity assessment (2020) ICES Journal of Marine Science, 77 (7), pp. 2396 - 2410. DOI: 10.1093/icesjms/fsaa169

Lopez-vazquez V., Lopez-guede J.M., Marini S., Fanelli E., Johnsen E., Aguzzi J. Video image enhancement and machine learning pipeline for underwater animal detection and classification at cabled observatories (2020) Sensors, 20 (3), art. no. 726. DOI: 10.3390/s20030726

Marini S., Corgnati L., Mantovani C., Bastianini M., Ottaviani E., Fanelli E., Aguzzi J., Griffa A., Poulain P.-M. Automated estimate of fish abundance through the autonomous imaging device GUARD1 (2018) Measurement: Journal of the International Measurement Confederation, 126, pp. 72 - 75. DOI: 10.1016/j.measurement.2018.05.035

Marini S., Corgnati L., Mantovani C., Bastianini M., Ottaviani E., Fanelli E., Aguzzi J., Griffa A., Poulain P.M. An autonomous imaging system for argo floats (2017) IMEKO TC19 Workshop on Metrology for the Sea, MetroSea 2017: Learning to Measure Sea Health Parameters, 2017-October, pp. 39 - 43.

Corgnati L., Marini S., Mazzei L., Ottaviani E., Aliani S., Conversi A., Griffa A. Looking inside the ocean: Toward an autonomous imaging system for monitoring gelatinous zooplankton (2016) Sensors (Switzerland), 16 (12), art. no. 2124. DOI: 10.3390/s16122124

Mazzei L., Corgnati L., Marini S., Ottaviani E., Isoppo B. Low cost stereo system for imaging and 3D reconstruction of underwater organisms (2015) MTS/IEEE OCEANS 2015 - Genova: Discovering Sustainable Ocean Energy for a New World, art. no. 7271554. DOI: 10.1109/OCEANS-Genova.2015.7271554

Marini S., Corgnati L., Mazzei L., Ottaviano E., Isoppo B., Aliani S., Conversi A., Griffa A. GUARD1: An autonomous system for gelatinous zooplankton image-based recognition (2015) MTS/IEEE OCEANS 2015 - Genova: Discovering Sustainable Ocean Energy for a New World, art. no. 7271704. DOI: 10.1109/OCEANS-Genova.2015.7271704

7.16.6 Open Data

Image data are available through the PNRR RAISE portal at:

https://guard-one.s4raise.it/

7.17 Stazione radiometro Po

As part of the PNRR ITINERIS project *(EU - Next Generation EU Mission 4, Component 2 - CUP B53C22002150006 - Project IR0000032 – ITINERIS - Italian Integrated Environmental Research Infrastructures System*) and specifically within the DANUBIUS ERIC research infrastructure, a WISPStation hyperspectral spectroradiometer has been installed by the Institute of Marine Sciences of the National Research Council (CNR-ISMAR) at the AIPO (Agenzia Interregionale per il fiume Po) floating platform located on the left bank of the Po River in Pontelagoscuro (Santa Maria Maddalena, 44°53'22.25"N, 11°36'38.82"E). The WISPStation, developed by Water Insight BV, is an autonomous, continuously operating system designed to derive water surface reflectance. Reflectance is calculated from the combination of three radiometric measurements: water-leaving radiance (Lw), sky radiance (Lsky), and downwelling irradiance (Ed). Through the application of specifically calibrated algorithms, these reflectance products allow for the estimation of key water quality parameters, including turbidity, total suspended solids (TSS), and chlorophyll concentration. The resulting high-frequency time series of water optical properties can be integrated with high-resolution satellite observations along the river course. This synergy enables the assessment of daily variability in relation to river discharge and tidal dynamics, as well as the detection and analysis of extreme events, such as floods, low-flow conditions, or salt intrusion, and their impacts on riverine and coastal ecosystems.

7.17.1 Scientific Outcomes and Contributions of recent activities

The installation of the WISPStation hyperspectral spectroradiometer represents a significant step forward in filling observational gaps in river–sea continuum research, providing continuous optical measurements in a system where satellite products alone are insufficient. While satellite observations are widely used to monitor floods and track sediment and biogeochemical transport, existing water quality products, such as those from the Copernicus Marine Service (CMEMS), do not cover river channels and deltaic transition zones, limiting our understanding of land–sea connectivity. To address this gap, CNR-ISMAR is developing and testing methodologies to generate and validate water turbidity, surface temperature (SST), total suspended solids (TSS), and chlorophyll concentration maps from multispectral (Copernicus Sentinel-2, NASA Landsat 8/9) and hyperspectral (ASI PRISMA) satellite missions for the terminal reach of the Po River. The continuous high-frequency in situ measurements from WISPStation — particularly the high-frequency reflectance-derived water quality parameters — will be integrated with these satellite products to assess temporal variability (daily, seasonal, interannual) and spatial heterogeneity (among river branches and deltaic lagoons). This integrated approach will also enable more accurate detection and characterization of extreme events and their impacts on deltaic and coastal ecosystems. Furthermore, the continuous reflectance measurements collected by WISPStation will directly support satellite calibration and validation (Cal/Val) activities for both multispectral and hyperspectral missions, contributing valuable reference data to European and national space agencies.

7.17.2 National/International collaborations and ESFRI contribution

The radiometric monitoring site at Pontelagoscuro directly contributes to the research priorities identified in the DANUBIUS-RI Strategic Research and Innovation Agenda (SRIA) — *water sufficiency, sediment management, and ecosystem health* — by providing continuous optical observations at the river–sea interface of the Po Delta. Within the Italian Supersite *Po River Delta and North Adriatic Lagoons*, (De Pascalis et al. 2025) these measurements are fundamental for characterizing water quality dynamics, sediment and nutrient fluxes, and biogeochemical exchanges across the land–sea continuum. The WISPStation continuously measures above-water radiometric properties (water-leaving reflectance, upwelling and downwelling irradiance) and derive parameters such as turbidity and chlorophyll concentration. These observations improve the quantification of lateral inputs of water, sediments, and nutrients, and extend the observational coverage of the Region of Freshwater Influence (ROFI), enabling the assessment of hydrodynamic and ecosystem responses to anthropogenic and climatic drivers. The Pontelagoscuro site was established in coordination with regional and national authorities and integrated with existing observational infrastructure to ensure a coherent, multi-platform monitoring system within the DANUBIUS-RI and Italian Supersite frameworks.

7.17.3 PNRR investments and expected outcome

The implementation of the Pontelagoscuro site is part of the broader PNRR ITINERIS investment, aimed at expanding national observational capabilities and integrating them into the DANUBIUS ERIC European research framework.

Key expected outcomes include:

- Establishment of a permanent, real-time observation site in a critical river–sea transition zones.
- Generation of continuous, high-quality datasets for satellite validation, model data assimilation, and ecosystem monitoring.
- Improved understanding of spatial and temporal variability in water quality under natural and anthropogenic drivers.
- Enhanced capacity to detect and analyse extreme events (e.g., floods, freshwater pulses, salt intrusion) and their ecological impacts.
- Support for ecosystem-based management strategies, coastal planning, and climate adaptation strategies

7.17.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start***	**Measurement interval**	**Institution**

Biogeochemical			
Ocean colour	2024	15	CNR - ISMAR

7.17.5 Publications

De Pascalis, F., Urbinati, E., Aalifar, A., Aveytua Alcazar, L., Arpaia, L., Bajo, M., et al., 2025. The DANUBIUS-RI supersite of Po delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea. Estuarine, Coastal and Shelf Science, 324, 109453. Available at: https://doi.org/10.1016/j.ecss.2025.109453

Scarpa, G.M., Ghirardi, N., Jiang, D., Braga, F., Bresciani, M., & Pinardi, M. (2025). Validation of Sentinel-2 Water Reflectance Using High-Frequency Radiometric Observations in a Dynamic River System. Poster presented at the 7th Sentinel-2 Validation Team (S2VT) Meeting, European Space Agency (ESA), 13–14 October 2025.

Scarpa, G.M., Ghirardi, N., Jiang, D., Bellafiore, D., De Pascalis, F., Fu, C., & Braga, F. (2025). Using Autonomous In-Situ Radiometry for Monitoring Suspended Sediments During Flood Events in the Po River, Italy. Poster presented at the ESA Living Planet Symposium 2025, Vienna, Austria, 23–27 June 2025.

Scarpa, G.M., Bellafiore, D., Brando, V., Bresciani, M., Falcini, F., Fu, C., Giardino, C., Manfè, G., Zaggia, L., & Braga, F. (2024). Exploring Water Quality Dynamics in the Po River Delta Through Multisource Optical Sensors. Poster presented at Ocean Optics XXVI, Gran Canaria, Spain, 6–11 October 2024.

7.18 Rete laguna VE CTD

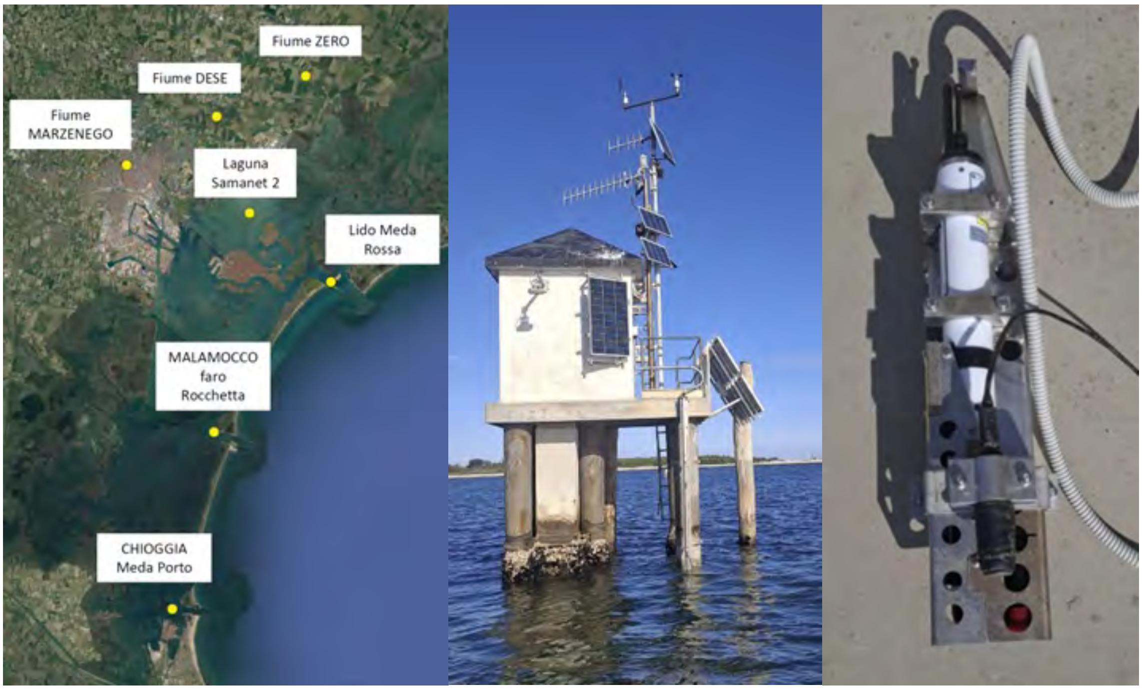


Figure 64 –Location and configuration of the CTD monitoring network. *(Left)* Spatial distribution of the CTD stations deployed across the main lagoon inlets and tributaries. *(Center)* A fixed station equipped with solar-powered telemetry for real-time acquisition. *(Right)* Detail of the multiparametric CTD probe used.

As part of the PNRR ITINERIS project *(EU - Next Generation EU Mission 4, Component 2 - CUP B53C22002150006 - Project IR0000032 – ITINERIS - Italian Integrated Environmental Research Infrastructures System*) and specifically within the DANUBIUS ERIC research infrastructure, the Institute of Marine Sciences of the National Research Council of Italy (CNR-ISMAR) has enhanced its capacity for long-term environmental observation in transitional land–sea systems through the deployment of a network of in situ monitoring stations in the Venice Lagoon. The network has been designed and implemented in collaboration with institutional stakeholders, provides continuous, real-time measurements of key water parameters. Each station is equipped with a Sea-Bird HydroCAT EP V2 multiparameter probe, measuring conductivity, temperature, pressure, dissolved oxygen, turbidity, and chlorophyll-a. Sites were selected to complement existing monitoring infrastructure and to capture key hydrological gradients. Stations are located at river–lagoon interfaces, where freshwater inflows affect water properties, and in proximity to tidal inlets, within lagoon–sea exchange areas. Monitoring stations and coordinates are:

Fiume Dese – 45°31’39.83” N, 12°18’17.02” E

Fiume Zero – 45°33’15.35” N, 12°22’42.77” E

Fiume Marzenego – 45°29’51.25” N, 12°13’44.27” E

Laguna Samanet 2 – 45°28’13.86” N, 12°20’05.16” E

Lido – 45°25’57.14” N, 12°24’36.22” E

Malamocco – 45°20’20.73” N, 12°18’39.56” E

Chioggia – 45°13'57.13" N, 12°16'51.13" E

7.18.1 Scientific Outcomes and Contributions of recent activities

The deployment of this high-frequency monitoring network marks a significant step forward in the continuous observation and characterization of water quality dynamics in the Venice Lagoon. Real-time data enable the investigation of hydrodynamic and biogeochemical processes that control lagoon functioning, including the effects of river discharge, tidal forcing, meteorological events, and seasonal variability. These observations provide a solid basis for understanding spatial and temporal trends in water quality, supporting research on ecosystem responses, land–sea connectivity, and biogeochemical cycles. They also serve as essential reference data for the validation of satellite-derived water quality products and as inputs for data assimilation into numerical models, improving simulations of circulation, mixing, sediment transport, and biogeochemical dynamics. The integration of in situ, satellite, and modelling approaches enhances the overall capacity to monitor, predict, and manage lagoonal and coastal systems.

7.18.2 National/International collaborations and ESFRI contribution

The network was designed and deployed in close collaboration with regional and national authorities and integrated with existing observational infrastructure to ensure a coordinated, multi-platform monitoring system. These activities directly contribute to the objectives of the DANUBIUS-RI Strategic Research and Innovation Agenda (SRIA), which identifies water sufficiency, sediment management, and ecosystem health as key research priorities. Within the Italian Supersite — *Po River Delta and North Adriatic Lagoons* —(De Pascalis et al. 2025) these priorities are addressed by improving the quantification of lateral inputs (water, sediment, nutrients), extending coverage to the Region of Freshwater Influence (ROFI), and monitoring changes in the land–sea interface. In situ measurements are integrated with Earth Observation and numerical modelling, supporting EO product validation, algorithm development, and data assimilation to advance understanding of river–sea system dynamics.

7.18.3 PNRR investments and expected outcome

The implementation of this monitoring network is part of the broader PNRR ITINERIS investment aimed at expanding national observational capabilities and integrating them into the DANUBIUS-ERIC European research framework. The main expected outcomes include:

- Deployment of a permanent, real-time monitoring network across key transition zones.
- Generation of continuous, high-quality datasets for satellite validation, model assimilation, and ecosystem monitoring.
- Improved understanding of spatial and temporal variability in water quality under natural and anthropogenic drivers.

- Enhanced capacity to detect and analyse extreme events such as freshwater pulses, hypoxia, and storm surges.
- Support for ecosystem-based management strategies, coastal planning, and climate adaptation strategies.

7.18.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start***	**Measurement interval**	**Institution**
Ocean			
Physical			
Sea level	2025	10 min	CNR - ISMAR
Subsurface salinity	2025	10 min	CNR - ISMAR
Subsurface temperature	2025	10 min	CNR - ISMAR
Biogeochemical			
Oxygen	2025	10 min	CNR - ISMAR
Particulate matter	2025	10 min	CNR - ISMAR
Phytoplankton biomass and diversity	2025	10 min	CNR - ISMAR

7.18.5 Publications

De Pascalis, F., Urbinati, E., Aalifar, A., Aveytua Alcazar, L., Arpaia, L., Bajo, M., et al., 2025. *The DANUBIUS-RI supersite of Po delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea*. Estuarine, Coastal and Shelf Science, 324, 109453. Available at: https://doi.org/10.1016/j.ecss.2025.109453

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7.19 Rete laguna VE Flussi

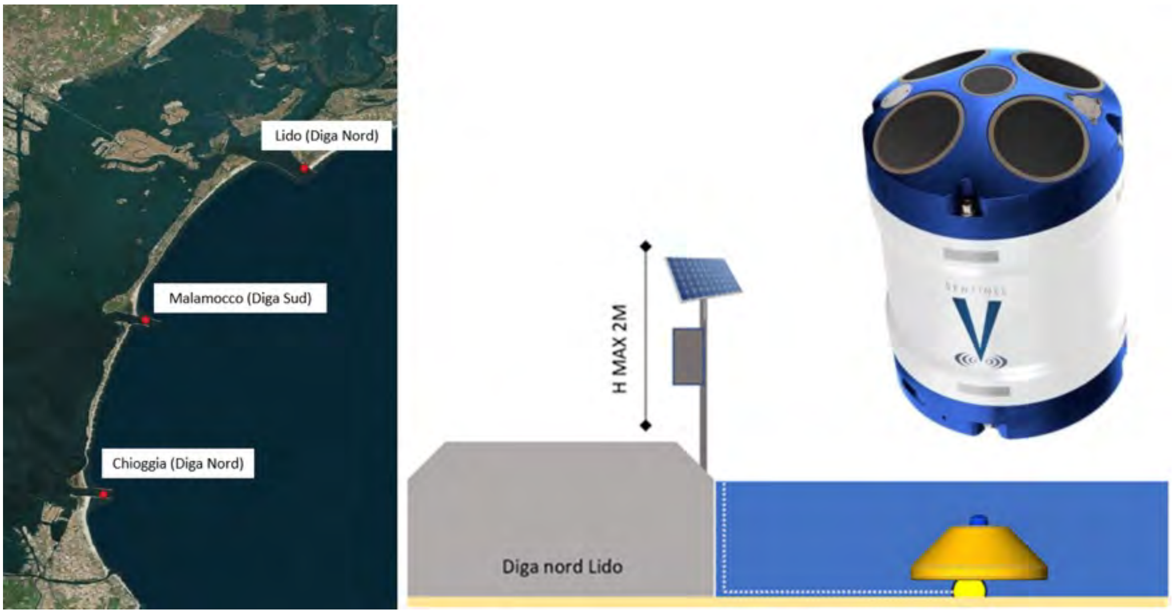

Figure 65 – Image. Overview of the measurement system: locations of the monitoring stations at the lagoon inlets (Lido, Malamocco, and Chioggia), schematic diagram of a typical installation, and the current profiling instrument employed (Teledyne Sentinel V ADCP).

As part of the PNRR ITINERIS project (EU – Next Generation EU, Mission 4, Component 2 – CUP B53C22002150006 – Project IR0000032 – ITINERIS – Italian Integrated Environmental Research Infrastructures System) and specifically within the DANUBIUS ERIC research infrastructure, the Institute of Marine Sciences of the National Research Council (CNR-ISMAR) has enhanced its long-term environmental observation capacity in land–sea transitional systems through the installation of a network of in situ monitoring stations providing continuous, real-time measurements of hydrodynamic and sediment transport parameters.

Each station is equipped with a Teledyne Sentinel V ADCP (Acoustic Doppler Current Profiler), which measures current velocity and direction throughout the water column, as well as acoustic backscatter. The monitoring sites were selected to complement existing observation infrastructures and to provide key information on flow exchanges between the lagoon and the sea.

Monitoring stations and coordinates:

- Lido inlet - Subaerial component 45°25'35.3"N 12°25'52.1"E, subaqueous component 45°25'30"N 12°25'44"E;
- Malamocco inlet - Subaerial component 45°19’54.3”N 12°20’03.3”E, 45°20'03"N 12°20'03"E;
- Chioggia inlet - Subaerial component 45°14’02.2”N 12°18’35.9”E, 45°13'54"N 12°18'33"E.

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7.19.1 Scientific Outcomes and Contributions of recent activities

The deployment of this high-frequency monitoring network represents a major advancement in the continuous observation and characterization of hydrodynamic processes in the Venice Lagoon. Real-time measurements of current velocity and direction along the water column provide a unique opportunity to investigate flow exchanges between the lagoon and the sea, sediment transport dynamics, and the response of the system to tidal forcing and meteorological events.

These observations form a robust basis for understanding spatial and temporal variability in water circulation and sediment fluxes, supporting research on lagoon–sea connectivity, morphological evolution, and ecosystem functioning. The high-resolution datasets acquired by the network are essential for the calibration and validation of numerical models of circulation, mixing, and sediment dynamics, as well as for the integration with remote-sensing products.

By combining in situ observations, modelling, and satellite data, this infrastructure significantly enhances the capacity to monitor, predict, and manage hydrodynamic and morphodynamic processes in transitional coastal systems such as the Venice Lagoon.

7.19.2 National/International collaborations and ESFRI contribution

The monitoring network was designed and deployed in close collaboration with local authorities, including the Port System Authority of the Northern Adriatic Sea and the Interregional Authority for Public Works in Veneto, Trentino-Alto Adige, and Friuli Venezia Giulia, and is integrated with existing observational infrastructures operating within the lagoon and at the inlets. This coordinated approach ensures a multi-platform system for the continuous observation of hydrodynamic and sediment transport processes.

The activity directly contributes to the objectives of the DANUBIUS-RI Strategic Research and Innovation Agenda (SRIA), which identifies sediment management, water exchanges, and ecosystem health as key research priorities. Within the framework of the Italian Supersite — Po River Delta and North Adriatic Lagoons, these priorities are addressed by improving the quantification of lateral fluxes of water and sediment, and by enhancing long-term monitoring of lagoon–sea interactions and hydromorphological dynamics.

The in-situ observations collected by the network are integrated with Earth Observation data and numerical modelling, supporting model calibration and validation, data assimilation, and the development of integrated monitoring strategies in alignment with the long-term objectives of ESFRI and DANUBIUS ERIC.

7.19.3 PNRR investments and expected outcome

The implementation of this hydrodynamic monitoring network is part of the broader PNRR ITINERIS investment aimed at strengthening national observation capabilities and integrating them into the DANUBIUS-RI European research framework.

The main expected outcomes include:

- Deployment of a permanent, real-time monitoring network at the lagoon inlets, designed to continuously measure current velocity, direction, and acoustic backscatter using bottom-mounted ADCP systems.
- Generation of high-resolution time series to support data assimilation, model calibration and validation, and the characterization of flow exchanges between the lagoon and the sea.
- Improved understanding of spatial and temporal variability in hydrodynamics and sediment transport under the combined influence of tides, river inputs, and meteorological forcing.
- Enhanced capacity to detect and analyse extreme events, such as storm surges, wind-driven circulation, and operational impacts of the Mo.S.E. barriers.
- Support for coastal and lagoon management, morphological evolution studies, and climate adaptation strategies based on ecosystem-scale observation and modelling.

7.19.4 Observed variables

Current velocity and direction	2025	15 min	CNR-ISMAR
Acoustic backscatter (proxy for suspended particulate matter)	2025	15 min	CNR-ISMAR
Wave parameters (significant height, period, direction)	2025	15 min	CNR-ISMAR

7.19.5 Publications

De Pascalis, F., Urbinati, E., Aalifar, A., Aveytua Alcazar, L., Arpaia, L., Bajo, M., et al., 2025. *The DANUBIUS-RI supersite of Po delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea*. Estuarine, Coastal and Shelf Science, 324, 109453. Available at: https://doi.org/10.1016/j.ecss.2025.109453

7.20 Rete laguna VE Torbidimetri

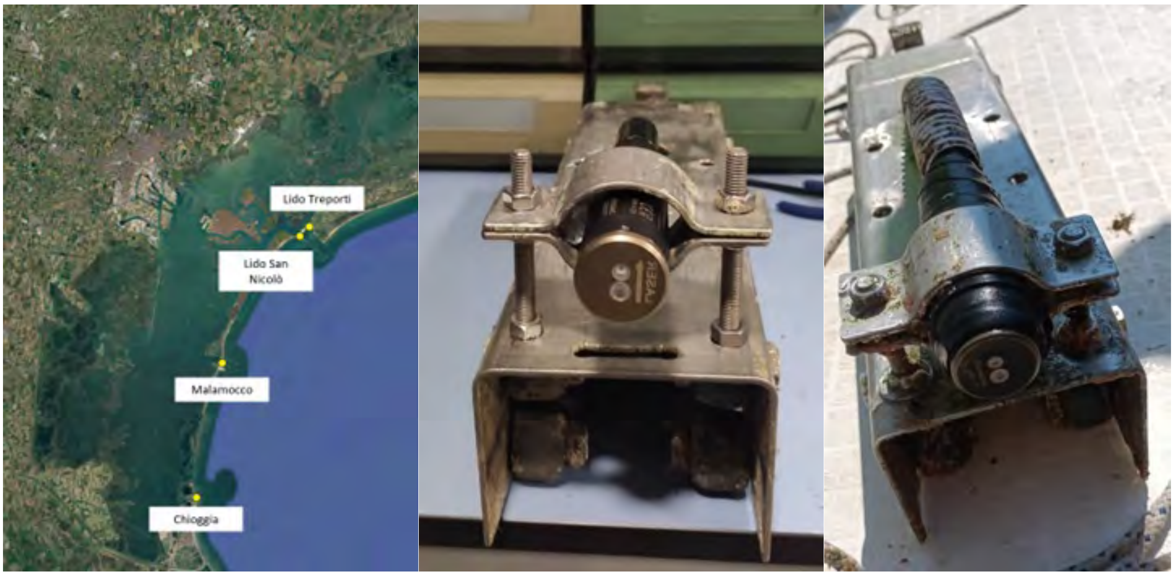

Figure 66 –Configuration of the turbidity monitoring network at the lagoon inlets. (Left) Spatial distribution of the four stations. (Center, Right) Optical backscatter sensors (turbidimeters) mounted on custom stainless-steel frames.

The turbidity monitoring network, operational since 2020, represents a key observational component for investigating suspended sediment dynamics and particle transport processes at the lagoon–sea interface. Since 2023, it has been formally integrated into the DANUBIUS-RI Supersite where it is managed and maintained as part of the long-term observational infrastructure. The network consists of four monitoring systems installed at the lagoon's main tidal inlets: Treporti (Lido inlet), San Nicolò (Lido inlet), Malamocco, and Chioggia, each equipped with optical turbidity sensors deployed at 2 m depth. The sensors are mounted on stainless-steel guide poles and connected to self-powered surface control units transmitting data in real time via GSM network. Measurements are collected every 10 minutes, providing high-frequency data essential for characterizing sediment transport and exchange processes between the lagoon and the adjacent coastal waters. Originally equipped with Campbell Scientific OBS501 sensors, the network has recently been upgraded with Clarivue 10 devices due to hardware obsolescence and damage to part of the submerged instrumentation. The OBS501 sensor remains in operation at the Chioggia station.

Monitoring stations and coordinates:

Treporti (Lido inlet) – 45°26'06.06" N 12°24'49.80" E

San Nicolò inlet – 45°25'57.13" N 12°24'36.16" E

Malamocco inlet – 45°20'01.52" N 12°19'38.99" E

Chioggia inlet – 45°14'02.04" N 12°17'44.99" E

7.20.1 Scientific Outcomes and Contributions of recent activities

Continuous turbidity observations at the lagoon inlets provide unique insight into sediment fluxes, resuspension events, and the hydrodynamic processes driving particles transport. These long-term data are essential for assessing tidal exchanges, storm surge impacts, and seasonal variability, as well as for quantifying sediment exchanges across the lagoon–sea interface. The dataset supports research on sediment budgets, erosion–deposition dynamics, and turbid plume formation, while contributing to the validation of satellite-derived suspended sediment products. The integration of in situ measurements with Earth Observation data and sediment transport models improves the understanding of plume dispersion, sediment pathways, and particle–flow interactions under both natural variability and anthropogenic pressures.

7.20.2 National/International collaborations and ESFRI contribution

The turbidity monitoring network directly contributes to the research priorities identified in the DANUBIUS-RI Strategic Research and Innovation Agenda (SRIA) — water sufficiency, sediment management, and ecosystem health — by providing continuous, high-frequency observations of suspended sediment dynamics at the main lagoon–sea exchange point. Within the Italian Supersite — *Po River Delta and North Adriatic Lagoons* —(De Pascalis et al. 2025) these measurements are fundamental for investigating sediment transport, lagoon morphodynamics, and ecosystem responses to climate variability and human pressures. Originally developed to study sediment dynamics in relation to the operation of the MOSE system, the network has evolved into a long-term observational service supporting the understanding of lagoon–coastal processes and sediment transport pathways. The stations enable the quantification of sediment fluxes, the detection of resuspension events, and the assessment of hydrodynamic controls on sediment transport and deposition. The network is integrated within the DANUBIUS-RI and Italian Supersite frameworks, ensuring coordination with regional and national authorities and complementarity with other observational infrastructures to support multi-platform environmental monitoring across the lagoon–coastal system.

7.20.3 PNRR investments and expected outcome

The upgrade and integration of the turbidity monitoring network within the DANUBIUS-RI Supersite *Po River Delta and North Adriatic Lagoons* have been supported by DANUBIUS-related activities, building upon the infrastructure originally established in 2020 with non-PNRR funding. These actions aim to ensure the long-term operation, interoperability, and scientific relevance of the network within the broader European research framework. Key expected outcomes include:

- Consolidation of a permanent, real-time monitoring service for sediment and turbidity dynamics at key lagoon–sea exchange points.
- Generation of continuous, high-quality datasets for the validation of satellite products, model data assimilation, and ecosystem monitoring.
- Improved quantification of sediment fluxes and resuspension dynamics under varying hydrodynamic and climatic conditions.

- Enhanced capacity to detect and analyse the effects of storm events, tidal forcing, and human interventions on sediment transport.

7.20.4 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start***	**Measurement interval**	**Institution**
Ocean			
Physical			
Subsurface temperature	2020	10 min	CNR - ISMAR
Biogeochemical			
Particulate matter	2020	10 min	CNR - ISMAR

7.20.5 Publications

De Pascalis, F., Urbinati, E., Aalifar, A., Aveytua Alcazar, L., Arpaia, L., Bajo, M., et al., 2025. *The DANUBIUS-RI supersite of Po delta and North Adriatic Lagoons: a living lab on transitional environments in the Adriatic Sea*. Estuarine, Coastal and Shelf Science, 324, 109453. Available at: https://doi.org/10.1016/j.ecss.2025.109453

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