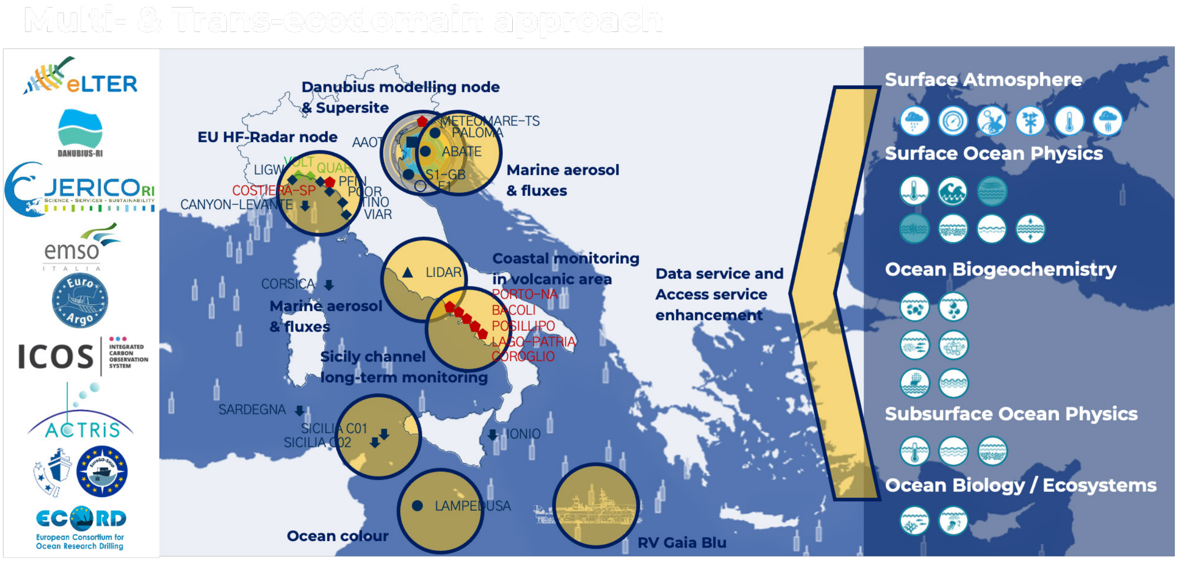
CNR
ISMAR
ISTITUTO
DI SCIENZE
MARINE

ITALIAN OCEAN OBSERVING NETWORK
Consiglio Nazionale delle Ricerche – Istituto di Scienze Marine



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1 Introduction

The Institute of Marine Sciences of the National Research Council of Italy (CNR–ISMAR) carries out multi–disciplinary scientific research activities within the following thematic areas:

- Physical oceanography and biogeochemistry for the study of climate processes and variability, from the open sea to coastal/transitional waters;
- Observational and operational services for the monitoring of Essential Ocean (physical and biogeochemical), Climate and Biodiversity variables (EOVs, ECVs, EBVs) and for risk assessment;
- Geological evolution of oceans, continental margins and transition areas for the evaluation of potential resources and the assessment of geological risks;
- Stratigraphy, paleoceanography and study of the mechanisms of change in the climate regime;
- Ecological research for the study of the structure, functioning and evolution of ecosystems;
- Interoperable management of marine data for maritime spatial planning and the development of an "ecosystem–based" maritime economy.

The marine observation system created and managed by CNR–ISMAR 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.

The system comprises a variety of platforms, including oceanographic vessels, fixed stations, buoys, moorings and elastic beacons, coastal monitoring stations, fixed sensors and mobile autonomous robotic platforms. This set of platforms 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 marine observation system 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 marine observation system represents a valuable resource for research and understanding of marine environments, providing essential data for the monitoring and sustainable management of the oceans.

2 The network of marine observation sites operated by CNR-ISMAR

Over the past three decades, the CNR has established an extensive observation network comprising fixed measurement systems, including a network of oceanographic platforms, buoys and long-term moorings located in coastal and open marine environments. These systems facilitate continuous monitoring of a range of meteorological, physical and biogeochemical parameters within the water column and at the air-water and land-sea interfaces (coast and seabed). The data collected from these systems is crucial for advancing our understanding of environmental quality and oceanographic processes, as well as for studying climate variability.

These systems are of great importance for the generation and continuation of climatological time series, which are also indispensable for the *early warning* of particularly critical environmental phenomena.

A number of fixed observation sites created and managed by the CNR-ISMAR are currently operational in the Italian seas. The Acqua Alta Oceanographic Tower in the northern Adriatic Sea, the E1 coastal buoy in the Adriatic, the elastic beacons S1-GB (Adriatic Sea) and PALOMA (Gulf of Trieste), and various multi-parameter submerged moorings (Corsica Channel, Sicily Channel and Sardinia Channel) are among the fixed observation systems currently operational in the Italian seas. Furthermore, a robust HF radar network has been stablished along the Ligurian coastline, complemented by coastal stations that monitor a range of meteorological, oceanographic and geophysical variables, including those pertinent to coastal dynamics (Gulf of Trieste, Gulf of Venice, Gulf of La Spezia, Gulf of Gaeta and Gulf of Naples). Further stations are instrumented and managed by the CNR-ISMAR in collaboration with relevant managing bodies. These include the spar buoys Abate (Adriatic Sea), owned by ARPAV, and Lampedusa, along the western coast of the island of the same name, owned by ENEA, in addition to the moorings, Levante Canyon, in the Ligurian Sea, and the GALATA mooring part of the EMSO-SN1 in the Western Ionian Sea operated jointly with INGV.

These stations are integrated by further stations managed by the CNR (ISP, IRBIM and IAS), including the moorings in the Bari canyon, the Tele-Senigallia beacon (Adriatic), the ODAS deep-sea buoy in the Ligurian Sea, the Kobold platform in the Strait of Messina and the coastal stations in the Gulf of Genoa.

Furthermore, the CNR-ISMAR observation network is enhanced by the autonomous and mobile robotic component, which comprises robotic platforms such as Biogeochemical-Argo profiling buoys, gliders and Lagrangian drifters. This component represents an extension of the ISMAR observation network towards more offshore regions, facilitating studies of the physical, biological and biogeochemical characteristics of the ocean dynamics at multiple spatial and temporal scales. These platforms provide essential observations for integrating satellite data, optimizing ocean models and reconstructing the three-dimensional structure of the ocean, which can be conceptualised as a digital twin of the ocean.

The observation infrastructures managed by CNR represent a significant contribution to the efforts of the Italian scientific community in understanding the processes that characterise the Mediterranean basin, as well as a range of other processes takin place in the ocean.

An integral part of this network is a series of measuring stations and transects located in areas of notable interest for which there are historical series of scientific relevance. These are included in national and international observation networks, such as for example the transects of Senigallia, the Fossa di Pomo, Mazara del Vallo-Capo Bon, Sardinia-Sicily, Capraia-Corsica and the system of hydro biochemical stations in the Venice lagoon.

The CNR-ISMAR marine observing system also has considerable potential for future development. The importance of research and monitoring of marine environments is widely recognized at the global level, both for the understanding of oceanographic processes and for the sustainable management of marine resources. Furthermore, there is an increasing interest in more effective and information-based marine observations, which will drive further evolution in this network.

Over the past four years, the Institute has also initiated an interdisciplinary and coordinated working group comprising representatives from the main observation sites and infrastructures. The group's objective is the development of oceanographic infrastructures and autonomous mobile systems, with particular attention paid to both a scientific coordination, to identify future development strategies for the network as a whole with a medium-long term time horizon, and a technical coordination, to facilitate the sharing of best practices and available funding for maintenance and further implementation.

Furthermore, the working group considers the constant monitoring of observed variables and catalogues, as well as costs and maintenance requirements, to be fundamental aspects of the process. In addition, the group prioritises the coordination of activities with the objective of achieving more efficient management, which encompasses both economic and technical considerations. This includes the integration of similar infrastructures and networks.

It is also of great importance to foster the identification of scientific questions that will enhance the interdisciplinary nature of the Institute and the observational heritage for breakthrough science.

The current investment in the network is estimated in approximately €3 million, with an annual management commitment of €698k, excluding the impact of personnel costs. Until 2023, the remaining costs for ordinary management was covered through participation in research projects, as well and other funding opportunities.

In 2024, we have received a dedicated funding from CNR-USRG for the annual management of the entire network. The total funding received was €398k. In addition, a dedicated funding of approximately €300k on an annual basis was already secured for the AAOT management. The confirmation for a consolidated annual funding for the CNR-ISMAR observational network maintenance, will enhance the organisation's capacity to cope with unforeseen expenses and facilitate more efficient and centralised expenditure management.

The dissemination activities undertaken thus far have included the presentation of the Working Group's activities to the CNR President and Supervisory Board during their visit in May 2024, as well as the presentation of a dedicated poster at the CNR-ISMAR Retreat 2024. Also, we provided a thorough revision of the infrastructure section of the new website with the aim of making the Institute's observational effort more visible.

The working group publishes the present technical reports on an annual basis, with the objective of disseminating information about the possibilities offered by the facilities network, together with the available data, within the Institute and also outside. This is intended to foster new cooperation and integration of novel scientific questions and research areas for the future development of the network, especially in the direction of unexplored interdisciplinary approaches.

3 Projects and networking

CNR has considerable experience in the management, maintenance and operation of a variety of multi-parametric fixed and mobile stations located in the Italian seas and in the Mediterranean in general. Some of these are integrated into regional, national and international networks and have contributed to, or continue to contribute to the implementation of national and international projects and programmes.

The CNR-ISMAR marine observation system plays a role in the advancement of research projects, the integration of research infrastructures and the formation of networks related to the study and monitoring of marine environments, including:

1. EuroGOOS: CNR-ISMAR is engaged with EuroGOOS (Global Ocean Observing System in Europe), a network that advocates for the integration of marine observation systems across Europe. EuroGOOS provides a framework for collaboration between member countries, facilitating improvements in the collection, storage and sharing of oceanographic data.
2. MonGOOS: CNR-ISMAR plays an active role within the regional alliance of GOOS for the Mediterranean. The alliance's primary objectives are: to advance the scientific understanding and technological development on which the observing system is based; to promote the visibility and recognition of the observing system at government agencies and private companies, encouraging their integration at

national, regional, European and global levels; and to promote the participation of non-EU Mediterranean countries in the observing system.

3. JERICO-RI: CNR-ISMAR is a participant in JERICO-RI (Joint European Research Infrastructure network for Coastal Observatory Research Infrastructure), a network of coastal observatories located across Europe. The JERICO-RI initiative facilitates the access and sharing of data collected by coastal monitoring stations in different European regions.
4. DANUBIUS-ESFRI: Italy is represented in DANUBIUS-RI by CNR-ISMAR, which coordinates one of the four thematic nodes, namely the modelling one, and is an integral part of one of the ten Supersites, that is, the Po delta and lagoons of the Northern Adriatic. DANUBIUS-RI is an ESFRI distributed research infrastructure that provides support for interdisciplinary research on large river-delta-sea systems (river-sea systems), based on existing European excellence.
5. eLTER-RI: CNR-ISMAR is responsible for the coordination of three of the Italian sites involved in eLTER-RI (the Lagoon of Venice, the Gulf of Venice and the Po Delta and Romagna Coast) and the Norther Adriatic Sea site. eLTER-RI is a distributed pan-European ESFRI research infrastructure, with the mission to studying long-term (multidecadal scale) ecological variations of structures, processes and functions in terrestrial, freshwater and coastal/transitional ecosystems through a holistic "whole system" approach.
6. ICOS: The Italian contribution to the ICOS programme, concerned with the study of the Earth's climate system, coordinated by CNR, encompasses three atmospheric, ten ecosystem and four marine stations, including the PALOMA elactic beacon, located in the Gulf of Trieste (North Adriatic). ICOS is a European Research Infrastructure (ERIC) that aims to provide accessible, high-quality data to improve our understanding of greenhouse gas emissions and removals. The infrastructure is structured around three thematic centres: namely atmospheric, ecosystemic and marine which are responsible for coordinating the three distinct types of stations, standardising data acquisition systems and validating and disseminating data.
7. EMBRC: The European Marine Biological Resource Centre is a European research infrastructure dedicated to marine biological resources. It provides access to marine resources, as well as participating research services and facilities that enable researchers, from both academia and industry, to study the ocean and develop innovative solutions to address societal problems.
8. EuroARGO: CNR-ISMAR is engaged in the EuroARGO initiative with the objective of developing effective quality control methodologies for radiometric measurements, advancing the scientific exploitation of the BGC-Argo network, facilitating the dissemination and promotion of research outcomes and training the next generation of researchers. Additionally, CNR-ISMAR plays an active role in strategic working groups, including the G7 FSOI and EuroGOOS. EuroARGO is a European Research Infrastructure (ERIC) that has been established with the objective of coordinating,

contributing to and strengthening the European contribution to the international Argo programme, which represents a principal component of the Global Ocean *Observing System* (GOOS) and the *Global Climate Observing System* (GCOS). It provides vertical profiles between 0–2000 m of hydrological and biogeochemical variables in near-real-time for operational oceanography services (e.g., Copernicus) as well as high-quality data for climate and oceanographic research activities. In particular, EuroARGO has the following objectives of (i) to guarantee the observation of the European seas, (ii) to implement the observational components of Argo linked to the study of biogeochemical processes, deep seas and polar seas, and (iii) to coordinate and provide access to high-quality data.

9. EuroFLEETS: CNR-ISMAR participates in this research infrastructure initiative, that aims to facilitate the coordination and integration of European research fleets, in two distinct capacities: as a user and as an infrastructure operator. Currently an H2020 project, EuroFLEETS aspires to become a European Research Infrastructure (RI) and which has been included in the Italian PNIR as a "category RI European". The EUROFLEETS+ project provides open and free access to an integrated and advanced fleet of research vessels, designed to meet the evolving needs of the user community. European and international researchers, from academia and industry, are able to apply for different entry programmes, through a single-entry system. EUROFLEETS+ prioritizes supporting research on sustainable, clean and healthy oceans by connecting to existing ocean observation infrastructures and supporting innovation through close collaboration with industry.
10. OceanSITES: CNR-ISMAR is a member of the OceanSITES network, which includes two moorings located in the Sicily Channel. OceanSITES is a global system of long-term offshore reference stations that measure a variety of variables and monitor the entire depth of the ocean, from air-sea interactions down to the sea floor. The network comprises a series of stations or observatories that facilitate the measurement of a number of oceanographic variables, including those pertaining to the ocean's surface and water column. The observations encompass meteorology, physical oceanography, water transport, biogeochemistry and parameters related to the carbon cycle, ocean acidification, marine ecosystems and geophysics.
11. EMSO: The European Multidisciplinary Seafloor and water column Observatory is a distributed infrastructure comprising observation facilities located in key sites across the European seas. Its mission is to support scientific and technological research aimed at understanding the complex interactions between the geosphere, biosphere and hydrosphere through the acquisition of long time series of data. By means of fixed platforms in a deep marine environment, relating to different disciplinary sectors (from oceanography to seismology and biology), data suitable for promoting a multidisciplinary approach to the study the evolution of climate and marine ecosystems, as well as the onset and evolution of extreme events of both natural and anthropogenic origin, can be obtained. CNR-ISMAR is a partner of the Western

Ionian Sea Regional Facility operating in collaboration with INGV the data collection in the water column (GALATEA mooring) and has also proposed the incorporation of the two moorings in the Sicily Channel into the infrastructure.

Furthermore, the institute engages in collaborative endeavours with national and international scientific organizations and institutions, with the objective of advancing research and comprehension of marine environments. These collaborations facilitate knowledge exchange, data integration and resource sharing, thereby enabling more comprehensive monitoring, a deeper understanding of marine environments and improved data quality. This is done with the intention of fostering interdisciplinary research. In this context CNR-ISMAR is also involved in the ACTRIS (the Aerosol, Cloud and Trace gases Research InfraStructure), which coordinates European-wide observations and research on aerosols, clouds and trace gases. The institute is a constituent part of the Joint Research Unit of ACTRIS-IT which represents the Italian component of the ACTRIS distributed research infrastructure.

Firthermore, CNR is engaged in various initiatives pertaining to the study of climate change, biodiversity and the sustainability of coastal areas, as well as risk analyses, monitoring and coastal forecasting.

It should be noted that some fixed stations are part of other international and Italian networks, including the Hydrochanges network (CIESM), the MARS Network (European Network of Marine Research Institutes and Stations), the Permanent Service for Mean Sea Level (PSMSL, Liverpool), the Global Sea Level Observing System (GLOSS) Network, the International Observation Network for Ocean Acidification, the Global Sea Surface Carbon Observing System, and the Rete Italiana per la Costa (RIC).

4 PNRR investment

The PNRR projects to which CNR-ISMAR contributes offer significant opportunities for the enhancement of observation sites and the integration of European research infrastructures, with a 10-year timeframe for infrastructure maintenance.

Of particular note is the PNRR-ITINERIS project, which provides support for the Italian hub of research infrastructures in the environmental scientific sector. This is with a view to facilitating observation and study of environmental processes in a number of key areas, including the atmosphere, the marine domain, the terrestrial biosphere and the geosphere. The project also makes it possible to access data and services, thereby supporting the country in addressing current and anticipated environmental challenges. In particular, the ITINERIS project coordinates a network of national nodes comprising 22 RIs (18 from the environmental sector, 2 from the agri-food sector with a strong link to the environment and 2 from the PSE sector, which supports services for the marine sector).

The principal objective of the project is to develop interdisciplinary research in environmental sciences through the use and repurposing of existing (or pre-operational) data and services, in conjunction with new observations, in order to address scientifically and socially relevant questions. These include the use sustainable use of natural resources, the implementation of so-called *nature-based solutions*, the *Green Economy* and the *Blue Economy*, the reduction of pollution, the management and restoration of critical areas and ecosystems, the carbon cycle, and the mitigation of climate and environmental changes. In collaboration with the European RI framework, ITINERIS will facilitate the involvement of Italian researchers in pan-European initiatives (ENVRIFAIR, EOSC) and in the domain of higher education (First Pillar, Missions, Partnerships, Clusters). This will have a substantial impact on national environmental research and provide scientific support for the development of effective environmental strategies. The ITINERIS project enables users to benefit from the integrated RI system and the knowledge produced by it, thereby designing a reference framework for the coming decades. produced by it, designing the reference framework for the coming decades.

Moreover, the ITINERIS project fosters the exchange of expertise across all subdomains of the environment, enabling the transfer of best practices from more established RIs to those that are newer and developing. This facilitates a complementary and synergistic development of expertise, services, and observations, thereby strengthening the national landscape of RI in the environmental sector.

In alignment with the overarching Earth System vision, ITINERIS deploys a comprehensive set of interdisciplinary actions (across the various environmental subdomains) that leverage the data, information, and knowledge generated by the diverse RIs across the four subdomains to construct a system of Virtual Research Environments (VRE), which will facilitate the delivery of novel services to address The project addresses a number of pertinent questions from both a scientific and a social perspective. These include the impacts of climate and land use changes and the related downstream environmental effects, the quantification of the carbon cycle in its multiple components, the adoption of monitoring programmes based on essential variables, the analysis of parasites in agroecosystems, the identification of critical zone processes and the creation of a national isotopic database.

In conclusion, the project will facilitate the establishment of the ITINERIS HUB, which will provide users with access to data and services. This will be achieved through the implementation of an appropriate access management system and the creation of a comprehensive catalogue of data and services, which will be derived from the harmonisation of existing data centres and catalogues.

5 Perspectives

The observation network has been developed as a result of sustained activity at the international, national and regional levels. This significant potential shall be harnessed for future advancement, as it will reinforce CNR's standing in scientific research pertaining to biodiversity, climate change, oceanography (operational and non-operational), and coastal studies. This will also contribute to confirm CNR's authority and visibility.

The considerable quantity of collected data is, in fact, irreplaceable and must be duly valued and supported. The maintenance and reinforcement of this invaluable network could enable CNR to assume a competitive role at the national and international levels. The observation network, given the extension and degree of complexity achieved, has the potential to serve as a reference for Europe and the nation, while also facilitating integration into regional technology parks and fostering collaboration with relevant ministries and stakeholders.

It will also be strategically beneficial to integrate the measurement and implementation activity of the fixed stations with a scientific communication initiative, with a renewed focus on media engagement, including the dissemination of information via online platforms. Additionally, training programmes tailored to a diverse range of individuals with varying scientific qualifications, all with an interest in environmental management, could prove invaluable.

Furthermore, the ISMAR marine observing system also has very promising prospects for the future. The importance of research and monitoring of marine environments is widely recognized at a global level., This is due to the fact that such research facilitates the understanding of oceanographic processes and enables the sustainable management of marine resources.

Over the past five years, the Institute has initiated an interdisciplinary and coordinated working group comprising representatives of all CNR-ISMAR observation facilities, comprising both oceanographic infrastructures and autonomous mobile systems, and European research infrastructure representatives. The group's main objective is to contribute to further develop the network, with specific attention to:

- Scientific coordination for the identification of future development strategies for the network as a whole with a medium-long term time horizon
- Scientific coordination to foster an expansion of the potential scientific questions that the network or its facilities can contribute to tackle, also facilitating external access and data sharing
- Technical coordination for sharing best practices
- Constant monitoring of observed variables
- Constant monitoring of costs and maintenance needs
- Coordination for the identification of resources for management (in both economic and technical terms), also in view of a more efficient use of the available resources
- Coordination of activities with the aim of achieving a more efficient management

Below are some of the prospects for the ISMAR observing system:

Interdisciplinary research: The CNR-ISMAR ocean observing system will serve as a critical platform for advancing interdisciplinary research by integrating cutting-edge technologies and comprehensive datasets across various scientific domains. By collecting high-resolution data on physical, chemical, and biological parameters in critical areas, this system provides unparalleled insights into marine ecosystems and their responses to environmental changes. Its capacity to link oceanographic data with climate science, ecology, and socio-economic studies fosters a holistic understanding of complex marine interactions. Additionally, the system's open-access approach encourages collaboration among researchers from diverse fields, including data science, robotics, and policy-making. The real-time monitoring capabilities enable swift responses to emerging challenges, such as marine pollution and biodiversity loss. Fostering new partnerships with academic institutions, industry stakeholders, and governmental agencies, CNR-ISMAR will promote the development of innovative methodologies and technologies for a thorough exploitation of the overall potential of its observing system, even far from the original purpose promoting the establishment of each specific site. Thus, the coordinate management ensured by the active working group will consider possible future expansions and implementation in a more effective way.

Technological advancement: with continuous advances in technology and innovation in the sector of monitoring instruments and sensors, the ISMAR observation system will be able to benefit from new devices and increasingly accurate and efficient detection methods, capable of collecting, processing and transmit ever greater quantities of measurements in near-real time. The possibilities offered by the introduction of AI and other innovative information tools will also contribute to a more efficient and information-based measurement acquisition. This will enable the collection of high-quality data and expand monitoring capabilities.

Data integration: The processing and integration of data collected from different sources and marine observation platforms will be key to obtaining a more complete view of marine environments. CNR-ISMAR will be able to play a key role in the management and analysis of large quantities of data from different sources, allowing a better understanding of ongoing processes and changes.

collaborations and partnerships: CNR-ISMAR will be able to continue to establish collaborations and partnerships with other research institutions, universities, government bodies and international organizations. These collaborations will allow the exchange of knowledge, access to additional resources and the possibility of participating in international research projects, thus helping to promote marine research globally.

Applications and social impact: the research activities conducted through the CNR-ISMAR observation system have the potential to significantly impact the management of marine resources, the assessment of the impacts of climate change on marine ecosystems, the prevention of marine pollution and the conservation of biodiversity. The CNR-ISMAR observing system will be able to continue to develop and apply its knowledge and results to support the planning and sustainable management of marine and coastal areas.

Science education and communication: CNR-ISMAR aims to promote science education and communication, raise public awareness of the importance of marine environments and the need to preserve them. This could be achieved through educational programmes, public events, accessible scientific publications and promoting greater awareness about the functioning and protection of the oceans.

6 The CNR–ISMAR ocean observing system in numbers

The CNR–ISMAR ocean observing system includes at least one fixed station with the capacity to acquire the majority relevant EOVs and ECVs. This is the Acqua Alta Oceanographic Tower, which is installed in the northern Adriatic Sea and is equipped with the necessary infrastructures to plan and undertake experiments and inter-calibration activities in the open sea. Also at the main instrumented beacons, such as PALOMA and S1-GB, the data acquisition activity process is oriented towards multidisciplinary criteria, with the objective of covering more than 50% of the essential variables.

From an economic point of view, the set of fixed oceanographic infrastructures managed by CNR–ISMAR represents an investment of approximately €3 million and requires an annual financial commitment of €700.000 for their management, excluding the impact of personnel costs. Furthermore, the financial implications of the necessary ship days for maintenance operations on the moorings must be considered. These are estimated to be about 10 days of vessel operation every 6 months. Approximately €300.000 is covered by an annual contribution arranged by CNR–USRG for the Acqua Alta Oceanographic Tower site and dedicated vessels. The remaining costs associated with routine management are met through the scientific network's participation in research projects and EU research infrastructures and the use of other funding opportunities. These opportunities also contribute to broadening the scientific interest in terms of interdisciplinary and novel approaches to address emerging scientific questions.

From 2024 onwards, the assessment of management costs for mobile autonomous systems has been added and will be monitored in the future. The main associated costs include satellite telemetry, insurance and calibration costs, and in many cases the need for oceanographic vessels to be available for launch and recovery. The costs are highly diversified by type of vehicle, with costs for vehicles used for limited measurement campaigns differing significantly from those for Lagrangian instrumentation used for continuous tracking of environmental parameters until recovery or stranding. This latter category accounts for approximately 18% of the total costs. These types of tools are increasingly growing within the Institute, a rend mirrored internationally.

The mean annual expenditure incurred for the routine administration of each fixed observation site and mobile autonomous system is monitored, excluding the cost of technical and scientific personnel assigned to the management of instrumentation and infrastructure, as well as any cost associated with the access of oceanographic vessels.

In terms of data accessibility, the potential for establishing an Institute Data Policy and developing a comprehensive and consistent data catalogue, at least at the Institute level, in alignment with the prevailing international standards, is emphasised. The PNRR ITINERIS project is providing adequate resources for the implementation of this process.

At present, approximately 40% of the data acquired by the CNR–ISMAR observation system are available upon request to the data manager, while 15% are accessible by querying a CNR–ISMAR database.

In addition, a further 40% of the data is available in open format on an international database.

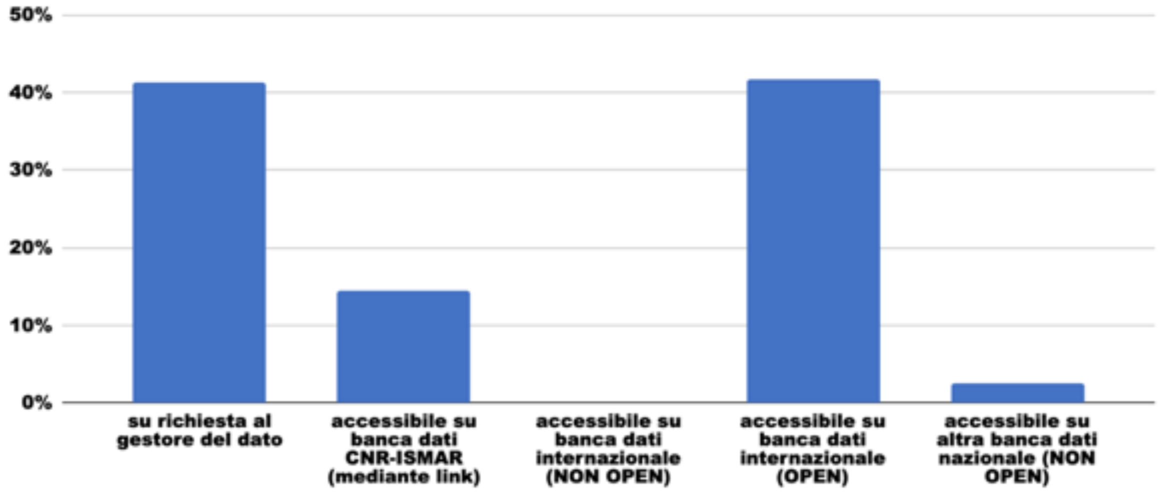

Table 1 – Summary histogram of data access methods and maturity.

The average availability of metadata for the CNR–ISMAR observation system measurements achieved the 69.5%, while the mean quality control (QC) level of 76.6% (Figure 1). Current work is oriented to increase this percentages, as well as the available real–time data transmission and dissemination by the end of 2025.

These figures are presented in the graphs below.

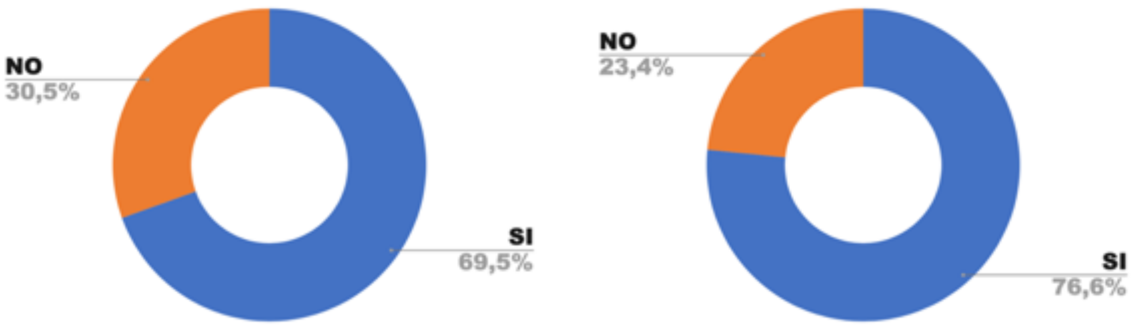

Figure 1 – Summary graphs of the percentage of metadating and quality control applied to the data acquired from the CNR–ISMAR observation system.

In the context of the dissemination activities pertaining to the marine observing system overseen by the Institute of Marine Sciences of the National Research Council of

Italy (CNR-ISMAR), we wish to acknowledge the smartphone application ISMARData, which has been conceived and developed for both iOS and Android systems.

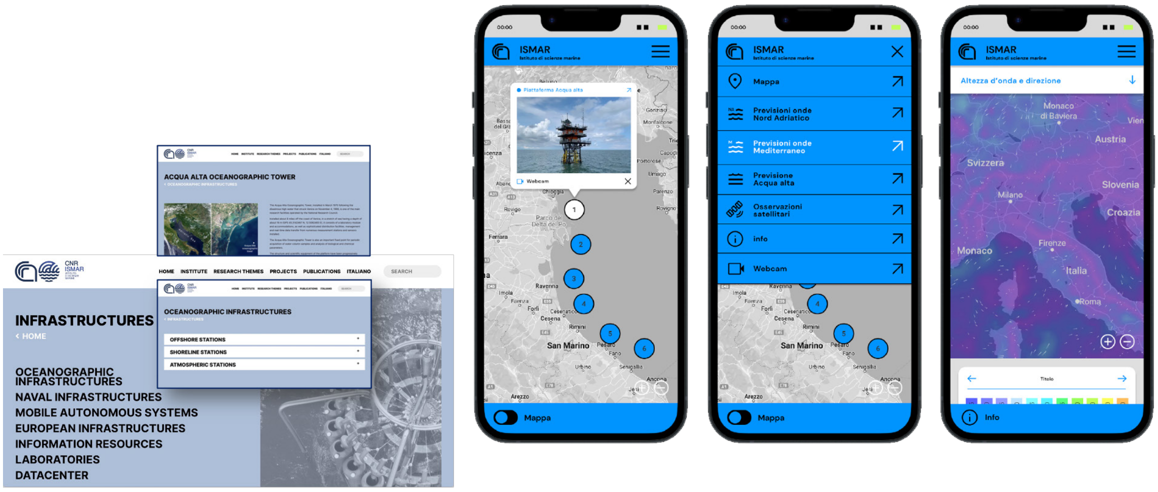

Figure 2 – Preview of the APP ISMAR Data and of the updated website pages presenting the CNR-ISMAR ocean observing system.

The application was developed by CNR-ISMAR in 2020 and a significant update is currently being developed.

The forthcoming update will facilitate the incorporation of data from a multitude of sources, as a result of the ongoing integration with the ITINERIS data server platform, which is currently in development. The integration will facilitate the real-time publication of all measurements from the principal observatories situated in the Adriatic Sea, including the Acqua Alta Oceanographic Tower, the Paloma elastic beacon, the E1 and the S1-GB buoys. The data server is being developed with an expandable structure, thereby enabling the prospective incorporation of supplementary sensors and observing stations.

The most significant data obtained from sensors deployed in these facilities will be disseminated via the updated application.

Moreover, the updated version of the application will feature measurements from the HF-radar system developed by the Institute for the Tyrrhenian Sea, thereby expanding the knowledge on the marine observational activities performed by the Institute.

Furthermore, the updated application will provide additional operational services. Additionally, data from the Nettuno wave forecast system for the Mediterranean Sea, the Henetus wave forecast for the northern Adriatic Sea, and the Issos tide forecast system will be disseminated with a novel and georeferenced graphical output. Furthermore, the updated version of the APP will disseminate information on the operational satellite products developed by CNR-ISMAR for the Mediterranean, specifically ocean colour and sea surface temperature.

The activities are still ongoing, driven by the necessity to implement the creation of a new data-server for real-time data transmission and management. The final product is scheduled for release by the end of May 2025.

7 The stations of the network

The Institute of Marine Sciences manages a marine observation network made up of different types of fixed stations distributed along the Italian coast and in marine areas of scientific interest. The observation network is enriched by autonomous robotic platforms (BGC-Argo floats, drifters, gliders and prototype autonomous vehicles) which allow the observation capacity to be expanded on multiple spatial and temporal scales. The monitoring stations 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.

The network of marine observation sites integrates with the opportunities offered by the availability of the new oceanographic vessel "R/V Gaia Blu" of the National Research Council of Italy and other naval support vessels for the implementation of oceanographic campaigns and research activities.

The marine observing system includes various platforms, such as oceanographic vessels, instrumented chains (or moorings), beacons/buoys, coastal monitoring stations and fixed sites, as well as repeated sea transects, BGC-Argo profiling floats, Lagrangian drifters and autonomous vehicles. These platforms allow to collect (and in most cases to transmit in real time) measurements of environmental parameters, with reference to the main variables of interest in the oceanographic and climate research fields.

Oceanographic infrastructure includes:

- Acqua Alta Oceanographic Tower
- Elastic beacons (Paloma, S1-GB, Abate, Lampedusa)
- E1 buoy
- HF Radar Network (5 stations, with 2 additional sites under configuration)
- Moorings (C01, C02, Corsica, Sardinia, Levante Canyon and EMSO-SN1/GALATEA)
- Repeated transects
- Coastal stations (in the areas of: Golf of Trieste, Golf of Venice, Golf of Naples, Golf of Gaeta and Golf of Lerici)
- Glider "Teresa"
- BGC-Argo floats
- Drifters and drifting wave buoys

Furthermore, the system is enhanced by the inclusion of an atmospheric LIDAR station, in addition to a network of interdisciplinary laboratories which are equipped with the most advanced technologies. The knowledge gained from the LIDAR measurements is currently leading to the configuration of 2 additional LIDAR stations for the simultaneous acquisition of atmospheric and oceanographic data, to be installed on the RV Gaia Blu and on the Acqua Alta Oceanographic Tower.

7.1 Acqua Alta Oceanographic Tower

Figure 3 – 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)

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.

The AAOT 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.

Equipped with the most advanced technologies, it is one of the few fixed structures in the world operating for scientific research in the open sea, allowing researchers and technicians to remain on board for long periods during measurement campaigns and in all weather and sea conditions.

After almost 40 years of activity, in June 2016 the National Research Council of Italy launched an important restructuring project to allow the maintenance of this important infrastructure, a reference point for research in marine sciences and oceanography, monitoring the ecosystem's health and meteorology.

The complex operation has allowed the complete renovation of the upper part of the structure and the reinforcement of the supporting substructures, as well as the rationalisation and strengthening of the technological systems supporting the scientific activity, offering further opportunities to all the subjects already interested in the acquisition of data and measurements carried out at the tower, confirming the commitment of scientific research to the protection of Venice and the marine environment in general.

The opportunity to renew this important infrastructure at sea has allowed the restoration of the instruments and sensors necessary first of all for the maintenance of the long historical series of data (e.g., Pomaro et al., 2018) and the collaboration with institutions such as the "Centro Previsioni e Segnalazioni Maree" of the Municipality of Venice and the Joint Research Centre of the European Commission, as well as the planning of a future increase in instrumental equipment.

For some years now, webcams have also been installed on the tower, accessible thrugh the website of the Institute of Marine Sciences (www.ismar.cnr.it) and through the ISMAR Data smartphone application.

The latter, in particular, in addition to providing access to real-time data, allowing the user to see the evolution of the measurements of the main meteorological, oceanographic and hydrological variables, uses the "analyse" function to display the archive history of the measurement data collected for each of the available stations, defining the time interval and the variables of interest, thus allowing in-depth analysis of aspects such as characteristic values, daily and stationary cycles and interdependences.

7.1.1 Scientific Impact

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. Recent studies have highlighted advances in the understanding and modelling of marine and coastal processes, and their importance for managing and mitigating environmental risks. Key topics studied at AAOT include wave dynamics, coastal vulnerability, sediment transport, and the impact of climate change on marine systems.

Considering **wave and sea-level dynamics**, data collected at this site has been used to study the interplay between waves, currents and atmospheric forces in coastal and semi-enclosed basins, such as the Adriatic Sea. Benetazzo et al. (2013, 2014, 2015) and Cavaleri et al. (2019, 2021) detail the prediction and characterisation of extreme sea states and wave-induced transport, while Banner et al. (2014) provide insights into wave group behaviour and breaking phenomena.

In addition, **numerical modelling innovation** plays a central role in these studies. As reported in Barbariol et al. (2017), wave energy assessments in the Adriatic Sea are shown to be improved by the use of coupled models, and Bajo et al. (2023) refine barotropic sea level predictions using data assimilation techniques. In addition, Barbariol et al. (2022) and Benetazzo et al. (2022) address wind-wave forecasting and regional climate projection corrections, highlighting tools for future climate scenarios.

Regarding **coastal and environmental vulnerability**, various studies assess coastal hazards and vulnerability due to storm events and sea level rise (Archetti et al. 2016; Bonaldo et al. 2019). The integration of multidisciplinary tools, as demonstrated by Bonaldo et al. (2020), highlights the importance of comprehensive approaches for coastal management.

Dedicated studies have investigated **rogue waves and extremes**, like Benetazzo et al. (2017) and Barbariol et al. (2016), focusing on the space-time dynamics of extreme waves, providing a framework for predicting and understanding their occurrence, critical for navigation and coastal safety.

Furthermore, **sediment transport and river plume dynamics** are documented, as reported in works by Brando et al. (2015) and Braga et al. (2017) using satellite and hyperspectral data acquired at the AAOT to map sediment transport and turbidity in dynamic regions, including river deltas such as the Po River. These results are crucial for monitoring environmental changes.

Among **technological and methodological advances**, innovations in data acquisition and analysis have been introduced, such as the use of stereo imagery for wave measurements (Benetazzo et al. 2012, 2018) and the development of open-source tools such as WASS for 3D wave reconstruction (Bergamasco et al. 2017).

Finally, the area is particularly interesting for **climate change studies**: publications address climate change scenarios, with emphasis on changes in wave climate and implications for coastal systems under severe climate change (Benetazzo et al. 2012; Bonaldo et al. 2020). Nonetheless, the series of wave directional measurements, uninterrupted since 1979, represents one of the longest historical series available worldwide (Pomaro et al., 2018) and provides key elements for understanding the evolution of the atmospheric pattern in the whole Mediterranean region (Pomaro et al., 2017).

In addition, **marine ecosystem responses** have been investigated, with works such as Braga et al. (2022) investigating human impacts, including those during the COVID-19 lockdown, revealing reduced human impacts on water transparency and coastal systems.

Finally, **underwater soundscapes** have been monitored at the AAOT between March 2020 and June 2021, as part of a network of nine monitoring stations, characterized by different natural conditions and anthropogenic pressures, in the Adriatic Sea (Petrizzo et al., 2023). Novel studies in the field of **underwater acoustics** are also being explored through dedicated experiments carried out at the tower under the PRIN SEAmPhonia, with the aim of studying the physical processes that can be characterised through the acoustic field, rather than the individual effects of noise on the marine ecosystem (Moretti et al., 2024).

As a permanent and manned station at sea, AAOT provides sea truth for the **calibration of instruments installed on satellites**, such as the ERS-1 altimeter and the optical properties of the sea detected by SeaWiFS and OLTS (Brando et al., 2015; Manzo et al., 2018). Wave measurement campaigns with personnel on board and sophisticated instrumentation have made it possible to elucidate unknown aspects of the dynamics of wind-driven wave generation by the wind, including extreme waves formation. In 2018 and the AAOT hosted the Fiducial Reference Measurements Inter-Comparison Exercise FRM4SOC. Fiducial Reference Measurements are independent sea surface measurements that provide confidence in satellite data products, through independent validation of satellite measurement uncertainty during the satellite mission. Inter-comparison of these measurements between laboratories, who work on the accuracy of Copernicus Sentinel

Ocean Colour and Sea Surface Temperature products, are an important component of quality checks of data collected in the field. During July 2018, a field inter-comparison exercise was carried out at the AAOT between Plymouth Marine Laboratory (PML), The Royal Belgian Institute of Natural Sciences (RBINS) and Tartu Observatory, Estonia (TO) on the UK research ship, RRS Discovery. In addition, in 2024, the AAOT hosted the FICE-2024 International training on remote sensing of waterbodies, with the objective to implement new sensors, the number of observed variables and data transmission and management procedures.

The permanent instrumentation includes meteorological and oceanographic sensors whose data are recorded on board and transmitted in real-time to CNR-ISMAR headquarters in Venice. Sea level, wind, and wave data collected offshore provide essential information for the operational forecasting of high tides in Venice and for the management of the MOSE barriers used to protect Venice from high tides.

The availability of fixed infrastructure in the open sea is not only relevant for the acquisition of measurements on an operational basis but also for the planning of experimental measurement campaigns for the study of meteo-oceanographic processes (physical, biogeochemical, etc.) by the international scientific community. This facility has allowed the detailed study of events such as the cold air outbreak of February 2012, the Vaia storm of 29 October 2018, and the exceptional flooding of Venice on 12 November 2019 (Ferrarin et al., 2020; Ferrarin et al., 2021; Cavaleri et al., 2019; Benetazzo et al., 2014).

In 2023 a bulletin of the main research activities carried out from the tower, which was produced and is available through the CNR-ISMAR website at the following link: https://www.ismar.cnr.it/wp-content/uploads/2024/02/rapporto-tecnico-25-CNR-ISMAR.pdf. This publication will be made available on an annual basis.

The main results of the most recent activities (2023-ongoing) are the following:

- **Air temperature anomalies**: 2023's record-breaking global temperatures, which reached unprecedented levels, particularly affecting regions such as the northern Adriatic Sea have been analysed. The year started with air temperature anomalies of up to +2°C above the historical average (2003-2020), which continued throughout the year, especially in autumn. This increase contributed to three distinct marine heatwave events in January, August, and October. These anomalies were tracked by monthly and daily sea temperature records at the AAOT, highlighting the impact of global climate change on local marine environments.
- **Sea level observations and extreme tides**: the 2023 records show a higher-than-average trend in sea level observations in the Adriatic Sea, reaching 38.6 cm above the baseline—the third highest recorded since 1974. However, February witnessed unusually low tides, the lowest on record, with levels falling below -50 cm at certain points in Venice's canals, making navigation difficult. In contrast, in late October and early November, a series of high tide events, driven by Sirocco winds and high sea levels in the Mediterranean, resulted in several peaks exceeding 110 cm and one

reaching 144 cm. These extreme variations highlight the complex interactions between atmospheric and oceanographic processes in the Adriatic.

- **Wave monitoring and real-time forecast validation**: technological advances have been achieved through the installation of a compact wave measuring buoy, the "SPOTTER". This innovative device, about the size of a basketball, provides efficient and cost-effective wave data collection with high accuracy. It provides real-time data essential for validating forecasts and understanding wave dynamics, especially during storm events. From October to December 2023, SPOTTER recorded significant wave heights approaching 3 metres, particularly during storm surges, which can exacerbate coastal flooding and erosion. The buoy's data have been integrated into the PELMO forecasting system, developed by CNR-ISMAR and Municipality of Venice, helping to improve forecasting models and enable a better response to extreme sea conditions.
- **Testing of wave buoys and 3D wave field mapping**: in collaboration with ISPRA and SIAP+MICROS, CNR-ISMAR carried out performance tests on wave buoys from the Italian National Wave Network using a stereo camera system. This innovative tracking method accurately captures buoy motion in three dimensions – heave, surge, and sway – by triangulating the buoy position based on camera images. By combining data from the buoy's internal sensors with measurements of the surrounding 3D wave field, the researchers gained insight into the relationship between the buoy's motion and the complex dynamics of the incoming wave field. This information is crucial for advancing wave measurement techniques and understanding wave-buoy interactions.
- **High-frequency internal waves**: measurements of high-frequency internal gravity waves have been recorded for the first time in May 2023, thanks to an ADCP (Acoustic Doppler Current Profiler) placed near the seafloor. These waves, which occur along density interfaces within the water column, play an important role in nutrient mixing and vertical transport. During the observed event, wave amplitudes of about 2 metres and wave periods of 5 to 10 minutes were recorded. The study highlights the ecological importance of internal waves for nutrient transport and heat exchange, with important implications for both coastal ecosystem health and climate processes.
- **Detection of breaking waves via digital imaging**: a collaborative project between CNR-ISMAR, Imperial College London and the University of Venice aims to better understand breaking wave dynamics through advanced digital image processing. Breaking waves contribute significantly to air-sea exchanges, forming whitecaps that can be tracked through images. A new algorithm has been developed to track individual whitecaps in sequential images, calculating movement with optical flow vectors, allowing a more accurate understanding of whitecap characteristics and distribution. This technology provides new insights into wave-breaking dynamics,

improving our knowledge of energy and gas exchange processes at the ocean surface.

- **Conservation of the endangered species Pinna nobilis**: the fan mussel, Pinna nobilis, is threatened by disease outbreaks that have devastated populations across the Mediterranean. A research team has deployed collectors at the AAOT to monitor larval recruitment to assess population health and dynamics. Twenty collectors were deployed at various depths in July 2023 and retrieved in January 2024 to search for juvenile fan mussels, some of which were successfully found. This effort, part of the INTERREG IT-SI TRECap project, aims to support conservation strategies for the species by studying larval dispersal and survival rates, particularly in the transitional coastal ecosystem of the Venice Lagoon, where survival rates may be higher.
- **Marine wood durability studies**: The tower is also part of an experimental study on the durability of various types of wood and their resistance to marine degradation, within the DuraSoft project. Wood samples from five species (including fir, spruce, pine, and oak) have been subjected to different treatments to assess resistance to xylophages such as isopods and shipworms, which are particularly destructive in marine environments. The location of the AAOT provides a unique opportunity to observe the effects of both environmental factors and specific marine organisms on wood materials over time, contributing to the development of durable and environmentally friendly treatment methods for wood used in marine applications. This project will continue until 2026, providing long-term insights into wood degradation processes.
- **CO_2 concentration**: a recent series of measurements started at the AAOT. Over a period of one year (2023), a seasonal cycle of pCO_2 is observed, where surface waters are undersaturated with respect to the atmosphere during the winter months and thus act as a strong sink for CO_2, with enhanced air-sea fluxes (up to 50 mmol m-2 d-1) during strong north-easterly wind events (Bora). Conversely, during summer, the temperature-driven increase in pCO_2, partly dampened by the increased biological activity and consequent CO_2 uptake, shows a slight oversaturation of surface waters, which become a moderate source of CO_2 as also recorded by the PALOMA station. In addition to pCO_2 and wind speed measurements, given the key role of wave breaking in the exchange of gases between the atmosphere and the ocean, measurements of surface waves and the penetration depth of entrained air bubbles were also collected with an upward-looking ADCP echosounder positioned on the seafloor (16 m depth) near the tower. The combined dataset allows estimation of air-sea CO_2 exchange, also using gas transfer velocity parametrizations that account for bubble-mediated effects due to wave breaking:

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 is currently being updated with funds from the PNRR ITINERIS project. 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 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
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
Ocean			

Physical			
Ocean surface heat flux	–		–
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 stress	–		–
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			
Inorganic carbon	–		–
Nitrous oxide	–		–
Nutrients	2009	monthly	CNR–ISMAR
Ocean colour	2002	5 min	JRC–EU / CNR–ISMAR
Oxygen	2009	monthly	CNR–ISMAR
Transient tracers	–		–

Particulate matter	–		–
Stable carbon isotopes	–		–
Dissolved organic carbon	–		–
Biological/ecosystems			
Marine habitats	–		–
Phytoplankton biomass and diversity	2009	monthly	CNR–ISMAR
Zooplankton biomass and diversity	2012	monthly	CNR–ISMAR
Fish abundance and distribution	–		–
Marine turtles, birds, mammals abundance and distribution	–		–
Microbe biomass and diversity (*emerging)	–		–
Invertebrate abundance and distribution (*emerging)	–		–
Cross–Disciplinary			
Ocean Sound	2019	continuous	CNR–ISMAR

7.1.4 Publications (after 2010)

Acri F, Bastianini M, Bernardi Aubry F, Camatti E, Boldrin A, Bergami C, Cassin D, Lazzari A De, Finotto S, Minelli A, others (2020) A long-term (1965--2015) ecological marine database from the LTER-Italy Northern Adriatic Sea site: plankton and oceanographic observations. Earth Syst Sci Data 12:215–230

Archetti, Renata, Agnese Paci, Sandro Carniel, and Davide Bonaldo. 2016. "Optimal Index Related to the Shoreline Dynamics during a Storm: The Case of Jesolo Beach." Natural Hazards and Earth System Sciences 16 (5): 1107–22. https://doi.org/10.5194/nhess-16-1107-2016.

Bajo, Marco, Christian Ferrarin, Georg Umgiesser, Andrea Bonometto, and Elisa Coraci. 2023. "Modelling the Barotropic Sea Level in the Mediterranean Sea Using Data Assimilation." Ocean Science 19 (3): 559–79. https://doi.org/10.5194/os-19-559-2023.

Banner, M.L. L., X. Barthelemy, F. Fedele, M. Allis, A. Benetazzo, F. Dias, and W.L. L. Peirson. 2014. "Linking Reduced Breaking Crest Speeds to Unsteady Nonlinear Water Wave Group Behavior." Physical Review Letters 112 (11): 114502, 1–5. https://doi.org/10.1103/PhysRevLett.112.114502.

Barbariol, Francesco, J.H.G.M Alves, Alvise Benetazzo, Filippo Bergamasco, L. Bertotti, Sandro Carniel, Luigi Cavaleri, et al. 2017. "Numerical Modeling of Space-Time Wave Extremes Using WAVEWATCH III." Ocean Dynamics 67 (3–4): 535–49. https://doi.org/10.1007/s10236-016-1025-0.

Barbariol, Francesco, Alvise Benetazzo, Sandro Carniel, and Mauro Sclavo. 2013. "Improving the Assessment of Wave Energy Resources by Means of Coupled Wave-Ocean Numerical Modeling." Renewable Energy 60 (December): 462–71. https://doi.org/10.1016/j.renene.2013.05.043.

Barbariol, Francesco, Francesco Marcello Falcieri, Carlotta Scotton, Alvise Benetazzo, Sandro Carniel, and Mauro Sclavo. 2016. "Wave Extreme Characterization Using Self-Organizing Maps." Ocean Science 12 (2): 403–15. https://doi.org/10.5194/os-12-403-2016.

Barbariol, Francesco, Paolo Pezzutto, Silvio Davison, Luciana Bertotti, Luigi Cavaleri, Alvise Papa, Marco Favaro, Enrico Sambo, and Alvise Benetazzo. 2022. "Wind-Wave Forecasting in Enclosed Basins Using Statistically Downscaled Global Wind Forcing." Frontiers in Marine Science 9 (September). https://doi.org/10.3389/fmars.2022.1002786.

Bassani, C., C. Manzo, F. Braga, M. Bresciani, C. Giardino, and L. Alberotanza. 2015. "The Impact of the Microphysical Properties of Aerosol on the Atmospheric Correction of Hyperspectral Data in Coastal Waters." Atmospheric Measurement Techniques 8 (3): 1593–1604. https://doi.org/10.5194/amt-8-1593-2015.

Bastianini, M., L. Cavaleri, and T. La Rocca. 2012. "Brief Communication &Quot;An Extreme Meteorological Event at the ISMAR Oceanographic Tower&Quot;" Natural Hazards and Earth System Sciences 12 (2): 281–85. https://doi.org/10.5194/nhess-12-281-2012.

Bellafiore, Debora, Christian Ferrarin, Federica Braga, Luca Zaggia, Francesco Maicu, Giuliano Lorenzetti, Giorgia Manfè, Vittorio Brando, and Francesca De Pascalis. 2019. "Coastal Mixing in Multiple-Mouth Deltas: A Case Study in the Po Delta, Italy." Estuarine, Coastal and Shelf Science 226 (October): 106254. https://doi.org/10.1016/j.ecss.2019.106254.

Benetazzo, A., Halsne, T., Breivik, Ø., Strand, K. O., Callaghan, A. H., Barbariol, F., Davison, S., Bergamasco, F., Molina, C., and Bastianini, M.: On the short-term response of entrained air bubbles in the upper ocean: a case study in the north Adriatic Sea, Ocean Sci., 20, 639–660, https://doi.org/10.5194/os-20-639-2024, 2024

Benetazzo, A.; Davison, S.; Barbariol, F.; Mercogliano, P.; Favaretto, C.; Sclavo, M. Correction of ERA5 Wind for Regional Climate Projections of Sea Waves. Water 2022, 14, 1590. https://doi.org/10.3390/w14101590.

Benetazzo, A., A. Bergamasco, D. Bonaldo, F.M. Falcieri, M. Sclavo, L. Langone, and S. Carniel. 2014. "Response of the Adriatic Sea to an Intense Cold Air Outbreak: Dense Water Dynamics and Wave-Induced Transport." Progress in Oceanography 128. https://doi.org/10.1016/j.pocean.2014.08.015.

Benetazzo, A., S. Carniel, M. Sclavo, and Andrea Bergamasco. 2013. "Wave-Current Interaction: Effect on the Wave Field in a Semi-Enclosed Basin." Ocean Modelling 70 (October): 152–65. https://doi.org/10.1016/j.ocemod.2012.12.009.

Benetazzo, A., F. Fedele, S. Carniel, A. Ricchi, E. Bucchignani, and M. Sclavo. 2012. "Wave Climate of the Adriatic Sea: A Future Scenario Simulation." Natural Hazards and Earth System Science 12 (6): 2065–76. https://doi.org/10.5194/nhess-12-2065-2012.

Benetazzo, A., F. Fedele, G. Gallego, P.-C. Shih, and A. Yezzi. 2012. "Offshore Stereo Measurements of Gravity Waves." Coastal Engineering 64 (June): 127–38. https://doi.org/10.1016/j.coastaleng.2012.01.007.

Benetazzo, Alvise, Fabrice Ardhuin, Filippo Bergamasco, Luigi Cavaleri, Pedro Veras, Michael Schwendeman, Mauro Sclavo, et al. 2017. "On the Shape and Likelihood of Oceanic Rogue Waves." Scientific Reports 7: 8276 (1): 1–11. https://doi.org/10.1038/s41598-017-07704-9.

Benetazzo, Alvise, Francesco Barbariol, Filippo Bergamasco, Carniel Sandro, Mauro Sclavo, Jeseon Yoo, Luigi Cavaleri, et al. 2017. "Space-Time Extreme Wind Waves: Analysis and Prediction of Shape and Height." Ocean Modelling113: 201–16. https://doi.org/10.1016/j.ocemod.2017.03.010.

Benetazzo, Alvise, Francesco Barbariol, Filippo Bergamasco, Andrea Torsello, Sandro Carniel, and Mauro Sclavo. 2015. "Observation of Extreme Sea Waves in a Space-Time Ensemble." Journal of Physical Oceanography 45 (9): 2261–75. https://doi.org/10.1175/JPO-D-15-0017.1.

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7.1.5 OpenData

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7.2 PALOMA elastic beacon

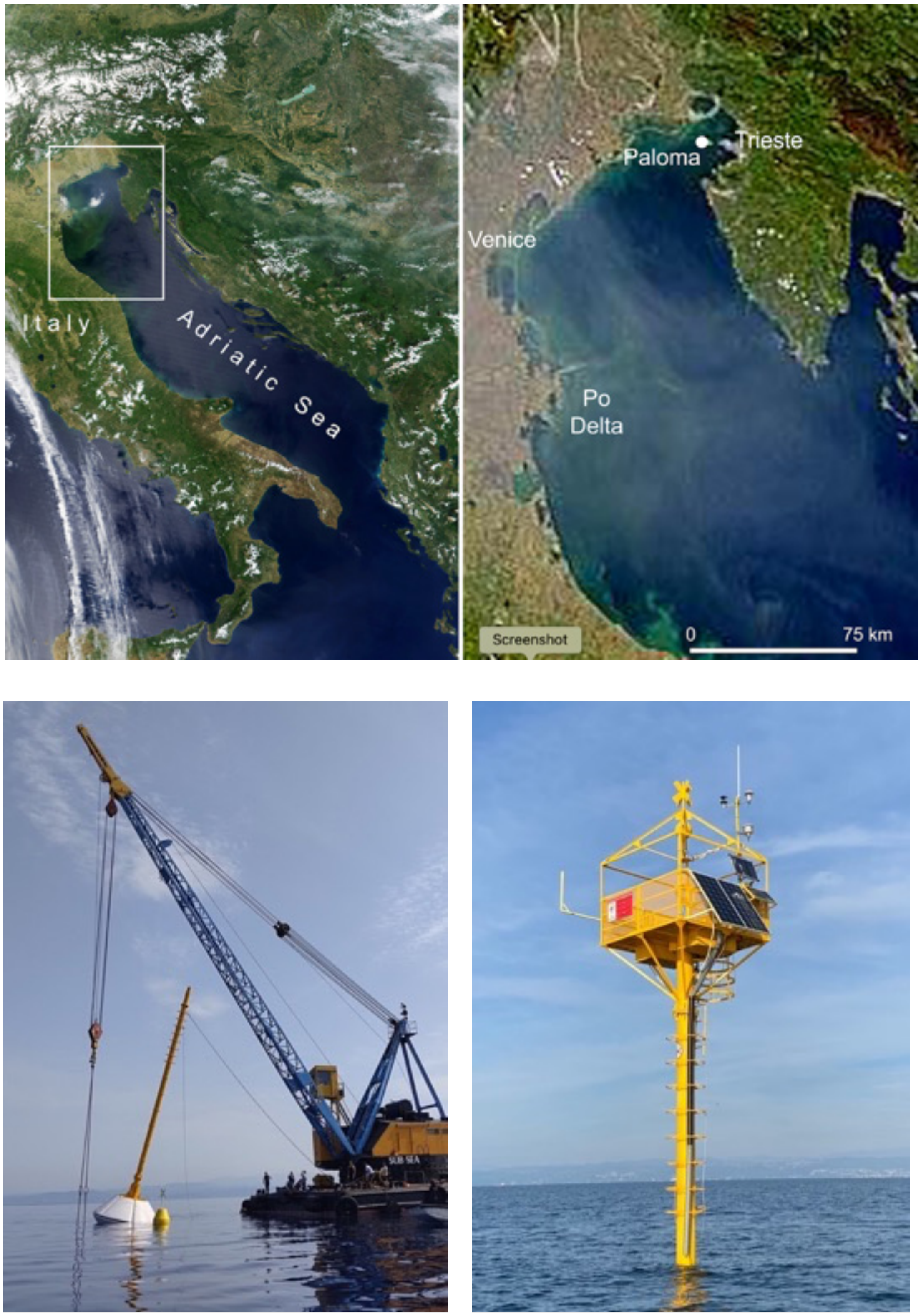

Figure 4– Position of the PALOMA elastic beacon in the centre of the Gulf of Trieste, repositioning of the station, May 2022, after the renovation works and the station as it appears today.

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 (Slovenia) 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/.

Since 2008, monthly monitoring of the water column has been carried out in collaboration with ARPA-FVG. Complete profiles of physical parameters are collected using a multi-parameter probe and discrete measurements of dissolved oxygen, nutrients, dissolved organic carbon (DOC), pH (accuracy ± 0.003) and total alkalinity are taken at four depths. These measurements allow a detailed characterisation of the carbonate system and represent the longest continuous time series of these variables in the Adriatic Sea.

7.2.1 Scientific Impact

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. The meteorological station provides high quality offshore meteorological data, which have been widely used by the research community since observations began (Bogunović & Malačič, 2008; Jeromel et al., 2009; Kotnik et al., 2022).

With the addition of seawater temperature measurements, the station has enabled the study of extreme winter cooling and **dense water formation** events, such as the extreme event that occurred in February 2012 (Raicich et al., 2013; Ravaioli et al., 2016; Cantoni et al., 2016) and contributed to biological (Reyes Suárez et al., 2022) and **biogeochemical studies of nutrient sources** in the GoT (Cozzi et al., 2004; Cozzi et al., 2008).

Research on **carbonate chemistry** conducted at the PALOMA station was among the first in the Adriatic to identify the main drivers of its variability (Cantoni et al., 2012) and the role of dense water formation on CO_2 sequestration (Cantoni et al., 2016). More recently these data have contributed to the assessment of long-term trends in ocean acidification in the Adriatic Sea (Cantoni et al. 2024).

The 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), are used for basin-scale studies (Skjelvan te al., 2021; Martellucci et al., 2024) and contribute to the annual SOCAT compilation of global fCO_2 data (Bakker et al., 2020). 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 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 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	2 h	CNR–ISMAR
Ocean			
Physical			
Subsurface salinity	2013	30 min	CNR–ISMAR
Subsurface temperature	2013	30 min	CNR–ISMAR
Biogeochemical			
Inorganic carbon	2013	6 h	CNR–ISMAR–
Nutrients	2008	monthly	CNR–ISMAR
Oxygen	2008	30 min	CNR–ISMAR
Dissolved organic carbon	2008	monthly	CNR–ISMAR
Transient tracers	–		–

Biological/ecosystems			
Marine habitats	–		–
Phytoplankton biomass and diversity	2011	monthly	OGS/ CNR-ISMAR
Zooplankton biomass and diversity	2014	monthly	OGS / CNR-ISMAR
Cross-Disciplinary			
Ocean Sound	2013	continuous	ARPA FVG / CNR-ISMAR

7.2.4 Publications

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M. Ravaioli, C. Bergami, F. Riminucci, L. Langone, V. Cardin, A. Di Sarra, S. Aracri, M. Bastianini, M. Bensi, A. Bergamasco, C. Bommarito, M. Borghini, G, Bortoluzzi, R Bozzano, C Cantoni, J Chiggiato, E Crisafi, D'Adamo R, Durante, C Fanara, Grilli F, Lipizer, Marini, Miserocchi, Paschini, P. Penna, S. Pensieri, A. Pugnetti, F. Raicich, K. Schroeder, G. Siena, A. Specchiulli, G. Stanghellini, A. Vetrano, A. Crise . The RITMARE Italian Fixed-point Observatory Network (IFON) for marine environmental monitoring: a case study. 2016 Journal of Operational Oceanography, Vol. 9, Iss. sup1 https://doi.org/10.1080/1755876X.2015.1114806

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7.2.5 Open Data

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Surface Ocean CO2 Atlas Database Version 2020 (SOCATv2020)(NCEI accession 0210711) DCE Bakker, SR Alin, N Bates, M Becker, R Castaño-Primo, CE Cosca, M Cronin, K Kadono, A Kozyr, SK Lauvset, N Metzl, DR Munro, S Nakaoka, KM O'Brien, J Ólafsson, A Olsen, B Pfeil, D Pierrot, K Smith, AJ Sutton, T Takahashi, B Tilbrook, R Wanninkhof, A Andersson, D Atamanchuk, A Benoit-Cattin, R Bott, EF Burger, WJ Cai, C Cantoni, A Collins, JE Corredor, MF Cronin, JN Cross, KI Currie, EH De Carlo, MD DeGrandpre, C Dietrich, S Emerson, MP Enright, W Evans, RA Feely, MI García-Ibáñez, T Gkritzalis, M Glockzin, B Hales, SE Hartman, G Hashida, J Herndon, SD Howden, MP Humphreys, CW Hunt, SD Jones, S Kim, V Kitidis, CS Landa, P Landschützer, GT Lebon, N Lefèvre, C Lo Monaco, A Luchetta, S Maenner Jones, AB Manke, D Manzello, P Mears, J Mickett, NM Monacci, JM Morell, S Musielewicz, T Newberger, J Newton, S Noakes, JH Noh, Y Nojiri, M Ohman, S Ólafsdóttir, AM Omar, T Ono, J Osborne, AJ Plueddemann, G Rehder, CL Sabine, JE Salisbury, R Schlitzer, U Send, I Skjelvan, S Sparnocchia, T Steinhoff, KF Sullivan, SC Sutherland, C Sweeney, K Tadokoro, T Tanhua, M Telszewski, M Tomlinson, A Tribollet, T Trull, D Vandemark, C Wada, DWR Wallace

7.3 S1-GB elastic beacon

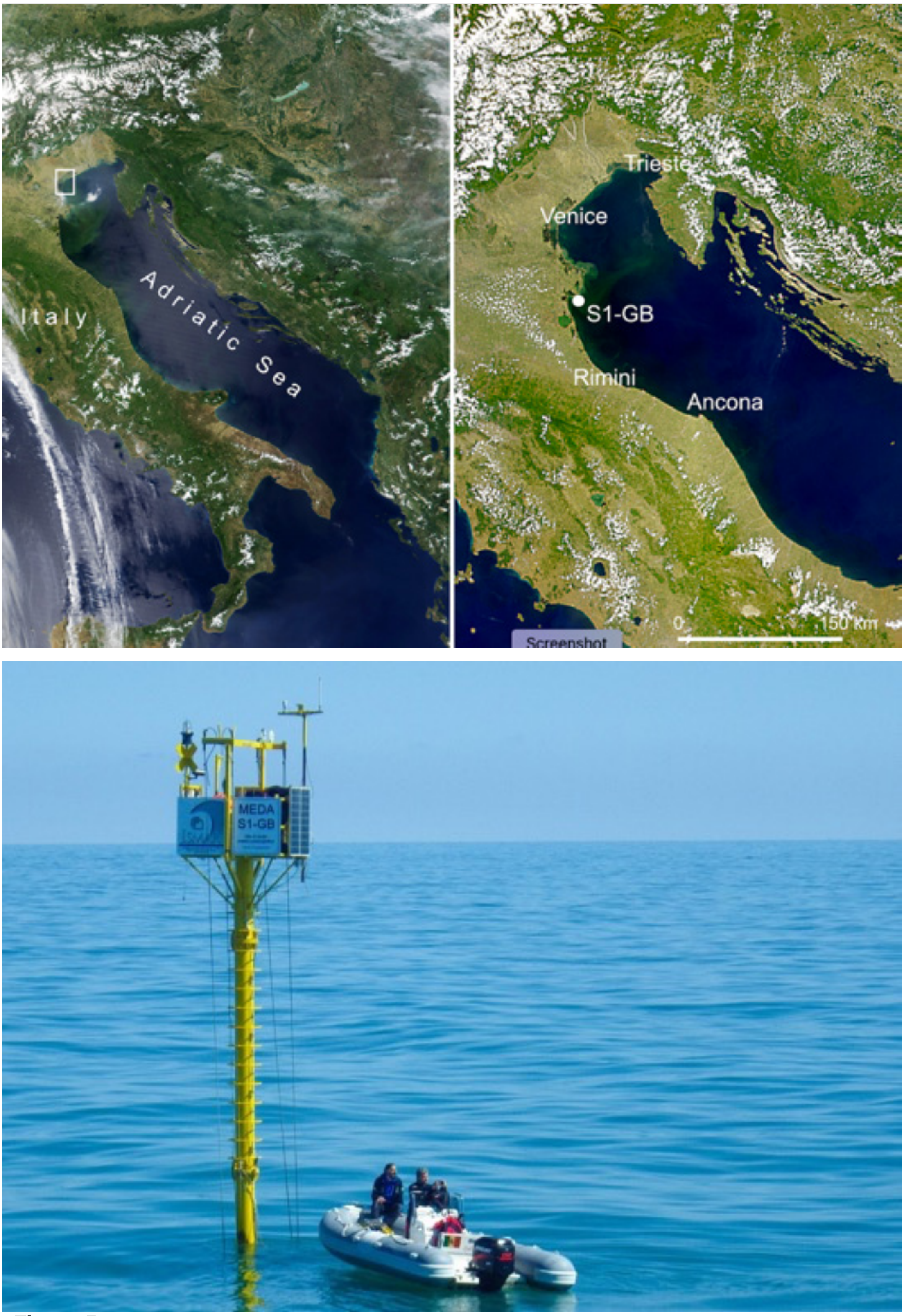

Figure 5 – Identification of the position of the Meda S1-GB south of the mouth of the Po di Goro (Po River delta – Northern Adriatic)

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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 (GPS 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 consists of a meteorological station and a submerged mooring line housing oceanographic instruments at two depths (-2.5 m and -18.5 m).

The beacon il 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 records oceanographic, meteorological and biogeochemical parameters in NRT, also for the validation of physical and biological modelling of the northern Adriatic.

The system is equipped with NRT recording and transmission devices, 12 and 24V DC 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, ADCP sensors). Additional measurements are routinely collected at the site with periodic sampling covering biology, chemistry and oceanography.

The site contributes to the European research infrastructures eLTER-RI, within the North Adriatic parent site, DANUBIUS-RI and JERICO-RI.

7.3.1 Scientific Impact

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 invaluable for understanding the complex environmental changes occurring in this region, thereby supporting effective management and conservation strategies.

Among the various applications, the turbidity data collected from these sites are particularly valuable for the **validation of satellite-derived turbidity measurements**, which are essential for accurately understanding sedimentary processes, especially in areas heavily influenced by the Po River (Braga et al., 2016). For example, continuous surface fluorescence measurements from the E1 buoy have played a key role in a study aimed at validating satellite-derived chlorophyll data, significantly improving the accuracy of ocean colour algorithms used in remote sensing (Böhm et al., 2016). In addition, research has used data from both the E1 and S1-GB stations to analyse biogeochemical cycles and assess water quality. One notable study focused on **nutrient dynamics and eutrophication impacts** in the northern Adriatic (Grilli et al., 2020), providing critical insights that could inform ecosystem management and policy. Other research efforts have leveraged these data to gain a deeper **understanding of extreme weather events** and their impacts on marine systems (Ravaioli et al., 2016; Davolio et al., 2015).

In addition, the data acquired by the systems have been used to **monitor hypoxic and anoxic events** along the Emilia-Romagna coastal area (Russo et al., 2009; Guarnieri et al., 2013).

Other activities are more focused on studying the characteristics of the sediments in the area where the observation systems are located. More specifically, trace metals, major elements and radionuclides on a sediment core provide new information on the sedimentary regime and anthropogenic impacts during the last 175 years in the Po River prodelta area (Riminucci et al., 2022). **Geochemical and trace element distribution** analyses have been carried out on marine sediments from these two sites, allowing to discriminate between the anthropogenic and natural sources of trace elements and pollutants (Barra et al., 2020). The two sites also represent an in-situ observatory for the **living benthic microfauna**, allowing to monitor the biodiversity pattern (Capotondi et al., 2019) and the ecological quality status in the North Adriatic Sea strongly affected by anthropogenic pressures. All the data and metadata on microfauna are part of the national repository for digital collections shared with FAIR principles within the DiSSCo Research Infrastructure (D'Onofrio et al., 2024).

More recently, long-term data series combining optical surface turbidity and salinity measurements, together with meteorological, hydrographic and wave data, have been analysed to investigate the **variability of surface turbidity** on the north-western Adriatic shelf (Riminucci et al., submitted). This work will provide valuable information on how different environmental factors interact to influence turbidity, thereby contributing to a more comprehensive understanding of coastal processes in this region. In addition, ongoing research focuses on decadal optical chlorophyll-a data to identify long-term trends in **phytoplankton phenology and bloom events** in the NAS.

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-RI infrastructure for the "Po Delta and North Adriatic Lagoons" supersite.

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

- 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 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

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Trieste
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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
Biological/ecosystems			
Phytoplankton biomass and diversity	2012	every 6 months	CNR–ISMAR
Zooplankton biomass and diversity	2012	every 6 months	CNR–ISMAR

7.3.4 Publications

Riminucci F., Bonaldo D., Capotondi L., Ravaioli M., Bergami C. Variability and forcingsof high turbidity events in the Northern Adriatic Sea from analysis of in-situ long-termdata: a methodological approach. Submitted (Progress in Oceanography.

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7.3.5 OpenData

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

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7.4 Abate spar buoy

Figure 6 – 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 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**.

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.

Meteorological and hydrological data, horizontal and vertical currents measurements are recorded with a temporal resolution of 10 minutes. Additional hydrological (CTD) and biogeochemical parameters (dissolved oxygen, inorganic nutrients, pHT, phytoplankton and zooplankton, chlorophyll) are sampled monthly.

This spar buoy contributes to the European LTER research infrastructure in the North Adriatic site.

7.4.1 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	CNR-ISMAR
Temperatures	2016	10 min	CNR-ISMAR
Wind speed and direction	2016	10 min	CNR-ISMAR
Ocean			
Physical			
Sea level	2017	10 min	CNR-ISMAR

7.5 Lampedusa spar buoy

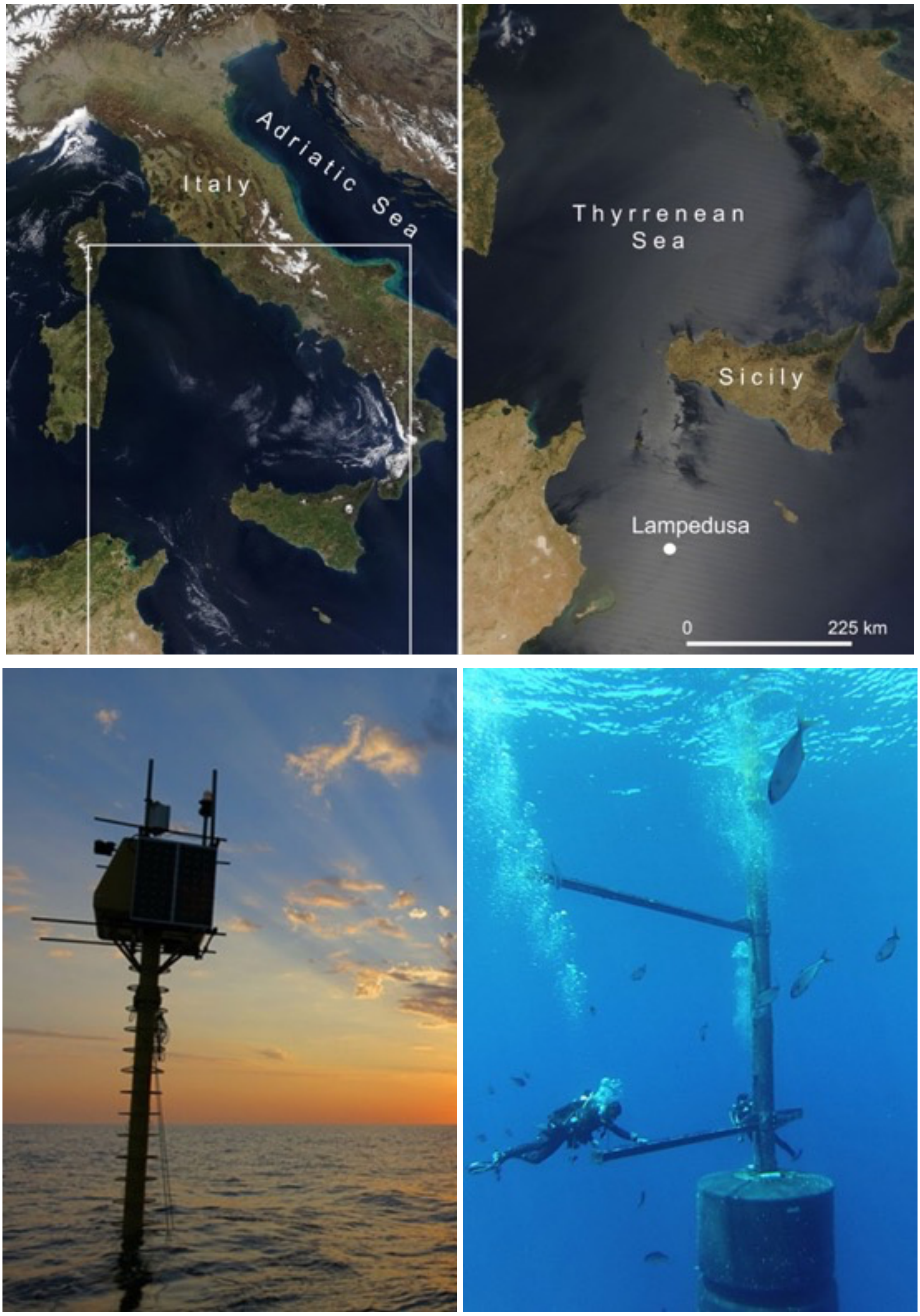

Figure 7 – Identification of the position of the Meda Lampedusa.

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 Impact

This site, also called Lampedusa Oceanographic Observatory, is dedicated to the **study of air-sea interactions**, with particular interest on how these dynamics affect climate change, and it also plays a critical role in satellite calibration and validation (cal/val) activities. The buoy is part of a wider network of oceanographic and atmospheric observing systems designed to gather essential environmental data.

Strategically located in the open sea, Lampedusa serves as a boundary between the western and eastern Mediterranean. This region is recognised as a climate change hotspot, making it highly vulnerable to the effects of global warming impacts. The Oceanographic Observatory complements the Atmospheric Observatory established on the island of Lampedusa in 1997, which focuses on climate-related studies such as meteorology, greenhouse gases, aerosols, radiation, and cloud dynamics.

The buoy's location is ideal for scientific observations due to its distance from major pollution sources and its frequent cloud-free conditions—with over 60% clear skies in summer and peaks of 80% from June to August. During the winter months, cloud-free conditions fall below 20%. The region also experiences low aerosol concentrations, except during occasional Saharan dust events. The marine environment is typically oligotrophic, characterised by low nutrient levels and low primary productivity, as evidenced by the clear blue waters. However, seasonal changes due to water mass intrusion, such as the Atlantic inflow through the Strait of Gibraltar, can cause brief increases in nutrient levels hence chlorophyll concentrations, through localised upwelling events.

These conditions make Lampedusa an ideal location for satellite cal/val activities and environmental research.

Recently, the observatory was involved in a study by Marullo et al. (2023), which analysed an unprecedented marine heatwave in the Mediterranean Sea from May 2022 to spring 2023. The study combined in-situ data from the Oceanographic Observatory, satellite observations and ocean reanalysis, highlighting the increasing frequency of **extreme heat events due to climate change and their impact on marine ecosystems and air-sea interactions.**

For satellite cal/val activities, the Lampedusa buoy provides critical in-situ measurements that are compared with satellite data to ensure accuracy and improve reliability. Following the decommissioning of the Boussole buoy, Lampedusa has assumed a more prominent role in the **validation of satellite data, particularly for sea surface temperature (SST), atmospheric fields, solar radiation, and radiometric measurements** in the southern Mediterranean. Although it does not fully replace the optical measurement capabilities of Boussole, it remains essential for **ocean colour validation, particularly in the context of the Copernicus Marine Services**.

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), while other in-water acquisitions contribute to the European Multidisciplinary Seafloor and Water Column Observatory (EMSO).

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.

7.5.3 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

7.5.4 Publications

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7.6 E1 buoy

Figure 8– Identification of the position of the E1 buoy in the Adriatic Sea, along the Romagna coast off the coast of Rimini.

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 body on a seabed of 10.5 m (GPS 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 VDC DC voltage power systems, meteorological station and oceanographic instrumentation at two depth levels (including CTD probes, dissolved oxygen, chlorophyll, turbidity and CDOM sensors, ADCP). Additional measurements are routinely collected at the site with periodic sampling covering biology, chemistry and oceanography.

The buoy contributes to the European research infrastructure eLTER-RI, as part of the Northern Adriatic parent site.

7.6.1 Scientific Impact

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 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
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
Biological/ecosystems			
Phytoplankton biomass and diversity	2006	every 6 months	CNR–ISMAR

7.6.4 Publications

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Ravaioli M., C. Bergami, F. Riminucci, L. Langone, V. Cardin, A. Di Sarra, A. Aracri, M. Bastianini, M. Bensi, A. Bergamasco, C. Bommarito, M. Borghini, G, Bortoluzzi, R Bozzano, C Cantoni, J Chiggiato, E Crisafi, D'Adamo R, Durante, C Fanara, Grilli F, Lipizer, Marini, Miserocchi, Paschini, P. Penna, SA Crisis (2016). The RITMARE Italian Fixed-point Observatory Network (IFON) for marine environmental monitoring: a case study. Journal of Operational Oceanography, 9:sup1, pp202-p214, DOI:10.1080/1755876X.2015.1114806

S. Davolio, P. Stocchi, A. Benetazzo, E. Böhm, F. Riminucci, M. Ravaioli, X.-M. Li, S. Carniel (2015). Exceptional Bora outbreak in winter (2015). Validation and analysis of high-resolution atmospheric model simulations in the northern Adriatic area, Dynamics of Atmospheres and Oceans, 71, pp. 1-20, DOI: 10.1016/j.dynathmoce.2015.05.002

Russo, A., Coluccelli, A., Carniel, S., Benetazzo, A., Valentini, A., Paccagnella, T., Ravaioli, M., Bortoluzzi, G. (2013). Hierarchy of operational models for short term marine predictions: The Adriatic Sea example, in 2013 MTSIEEE OCEANS, Bergen, https://doi.org/10.1109/oceans-bergen.2013.6608139.

Guarnieri, A., Pinardi, N., Oddo, P., Bortoluzzi, G., Ravaioli, M. (2013). Impact of tides in a baroclinic circulation model of the Adriatic Sea. J. Geophys. Res. 118, 166-183. http://dx.doi.org/10.1029/2012JC007921.

Russo, A., Colucelli, A., Iermano, I., Falcieri, F., Ravaioli, M., Bortoluzzi, G., Focaccia, P., Stanghellini, G., Ferrari, C.R., Chiggiato, J., Deserti, M., (2009). An operational system for forecasting hypoxic events in the northern Adriatic Sea. Geofizika, 26(2), 191-212.

7.6.5 OpenData

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

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.10980111

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7.7 HF Radar Network

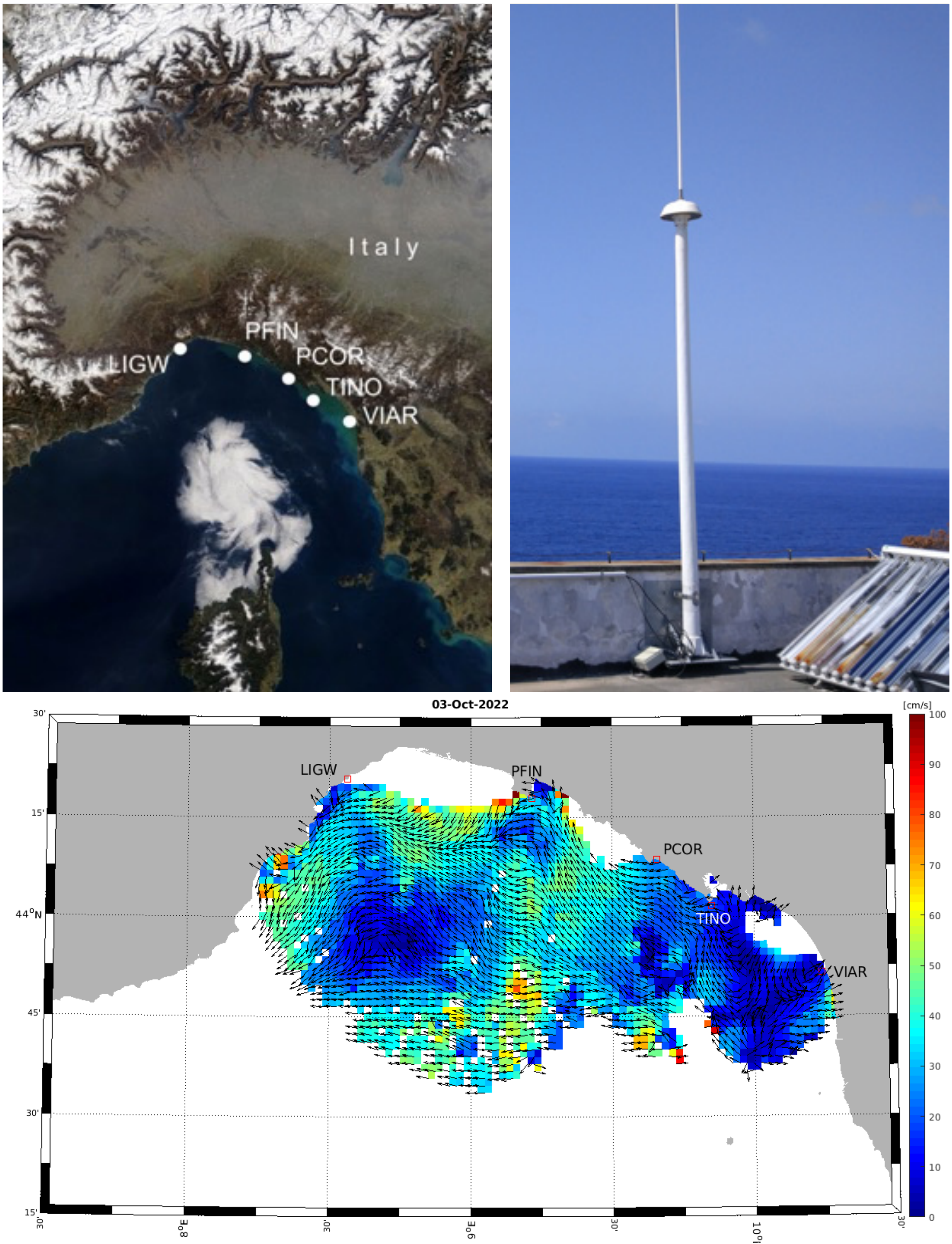

Figure 9 – Locations of the HF Radar systems that are part of the network of the Institute of Marine Sciences (top left), picture of the HF radar antenna installed at the Portofino lighthouse (GE), site code PFIN (top right), surface current field measured by the network on 03/10/2022 h. 00:00 (bottom).

The HF radar network of the Institute of Marine Sciences is made up of 5 stations operating in the 13MHz and 25MHz frequency bands, which have been active since 2016 along the coasts of the north-western Tyrrhenian and Ligurian Seas (see Figure 9).

Venezia
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Pozzuolo di Lerici
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Napoli
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Porto Di Napoli snc
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Roma
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+39 06 45488634

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

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

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.

HF radars provide maps of sea surface current velocities over large areas of the sea (the Institute's HF radar network covers 10,000 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 7.7.3).

7.7.1 Scientific Impact

High-frequency (HF) radar technology is based on the principle of Bragg scattering of electromagnetic radiation from the rough conductive sea surface (as described by Crombie in 1955). The radial current component is deducted through analysis of the Doppler shift of radio waves scattered by surface gravity waves with half their electromagnetic wavelength. Each radar site is configured to estimate radial currents moving towards or away from the receiving antenna. Deriving the wave speed from linear wave theory enables the computation of the velocity of the underlying ocean surface currents through subtraction. The distance to the backscattered signal is determined by range-gating the returns. In regions of overlapping coverage from two or more sites, radial current estimations are geometrically combined to estimate total current vectors on a predefined Cartesian regular grid.

In the context of the study of environmental transport processes, HF radars have demonstrated a capacity to provide very valuable measurements to continuously **monitor the mesoscale structures and frontal dynamics** that organise the coastal surface flow and associated transport through the understanding of the Lagrangian dynamics of the smallest scale (Rubio et al., 2020). The data collected by the HF radar network of the Institute of Marine Sciences has contributed significantly to the analysis of the role of surface ocean transport in supplying recruits of European sardine (Sardina pilchardus) to the Gulf of Manfredonia, a known nursery area in the Adriatic Sea (Sciascia et al, 2018).

HF radars also measure the variability of surface currents that transport substances in the sea. The application of dispersion models, utilising these data, facilitates the **calculation of probable trajectories and travel times of specific pollutants and floating objects** as they disperse from a source in the sea. In this context, data collected by this HF radar network was used to **evaluate the connectivity between Marine Protected Areas (MPAs)** and to **predict potential interactions between port activities and adjacent MPAs**, evaluating their potential impact and the most favourable conditions for their implementation. In addition to the significant scientific contributions of these studies, a notable outcome was the publication of a book that provides detailed guidelines and strategies for the governance of MPAs, with a particular focus on cross-border areas (Magaldi et al., 2021).

Currently, the HF radar network is contributing to the **development of an early warning and decision support system for coastal marine areas** that are heavily impacted by tourism. This system will leverage artificial intelligence techniques and adaptive monitoring strategies to automatically detect and classify gelatinous zooplankton (e.g., jellyfish and ctenophores) using video data. Additionally, Lagrangian surface dispersion models based on HF radar data are integrated in the system.

An important Institute effort is dedicated to the continuous **validation of surface current data** with ADCP and drifter data (Corgnati et al., 2019, 2024). Eulerian and Lagrangian metrics demonstrate that the network performs at a satisfactory level and compares favourably with the previous literature results (Corgnati et al., 2024).

Data produced by the HF radar network of the Institute of Marine Sciences is already used for classical **data assimilation** procedures with error reduction ranging from 10% to 50%, and an increase in correlations from 5% to more than doubled (Bendoni et al., 2023). In addition, they are currently being integrated into numerical oceanic models in a simulation experiment. The objective of this experiment is to assess whether the utilisation of machine learning (ML) to mitigate model error bias in a data assimilation (DA) system enhances the accuracy of forecasts.

The HF radar network is playing a key role in the multi-platform analysis aimed at the **4D reconstruction of the ocean circulation**, considering both mesoscale and sub-mesoscale features in the North-Western Mediterranean Sea (Berta et al 2020). The group approach, which has been successfully implemented in the area of Toulon (Berta et al., 2018), will be adopted in this study. This approach involves the integration of multiple data sources, including HF radar data, glider data, vessel surveys, weather stations, and atmospheric models. The combination of these data sources will provide valuable insights into **wind-induced variability and surface currents in the Northern Current**.

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 (2025) under the JERICO – Joint European Research infrastructure of Coastal Observatories. The HFR network has received funding from the PNRR ITINERIS project for its expansion in southern Italy and for its consolidation.

7.7.3 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

7.7.4 Publications

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

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Lorente, P., Aguiar, E., Bendoni, M., Berta, M., Brandini, C., Caceres-Euse, A., Capodici, F., Cianelli, D., Ciraolo, G., Corgnati, L. et al ., Dadic, V., Doronzo, B., Drago, A., Dumas, D., Falco, P., Fattorini, M., Gauci, A., Gomez, R., Griffa, A., Guerin, C. .-A., Hernandez-Carrasco, I., Hernandez-Lasheras, J., Licer, M., Magaldi, MG, Mantovani, C., Mihanovic, H., Molcard, A., Mourre, B., Orfila, A., Revelard, A., Reyes, E., Sanchez, J., Saviano, S., Sciascia, R., Taddei, S., Tintore, J., Toledo, Y., Ursella, L., Uttieri, M., Vilibic, I., Zambianchi, E., Cardin, V., 2022. Coastal high-frequency radars in the Mediterranean -- Part 1: Status of operations and a framework for future development. Ocean Science, 18, 3, 761—795. https://en.copernicus.org/articles/18/761/2 doi: 10.5194/os-18-761-2022.

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Bellomo L., Griffa A., Cosoli S., Falco P., Gerin R., Iermano I., Kalampokis A., Kokkini Z., Lana A., Magaldi MG., Potiris E., Sayol JM, Barbin Y., Berta M., Borghini M., Bussani A., Corgnati L., Dagneaux Q., Gaggelli J., Guterman P., Mallarino D., Mazzoldi A., Molcard A. ., Orfila A., Poulain P. -M., Quentin C., Tintoré J., Uttieri M., Vetrano A.,Zambianchi, E.,Zervakis, V., 2015. Toward an integrated HF radar network in the Mediterranean Sea to improve search and rescue and oil spill response: the TOSCA project experience. Journal of Operational Oceanography, pp. 10–11. 1.13, doi: 10.1080/1755876X. 2015. 1087184.

7.7.5 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:
  https://thredds.hfrnode.eu:8443/thredds/NRTcurrent/HFR-TirLig/HFR-TirLig_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 (by the end of 2024)

7.8 Moorings

Figure 10 – 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, of which three are operated on a regular basis. These moorings are located in the **Sicily Channel**, the **Corsica Channel** and the **Sardinia Channel**. Furthermore, the Institute collaborates in the management of two additional moorings, located in the **Ionian Sea** and the **Tyrrhenian**

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 (SiCO1 and SiCO2)

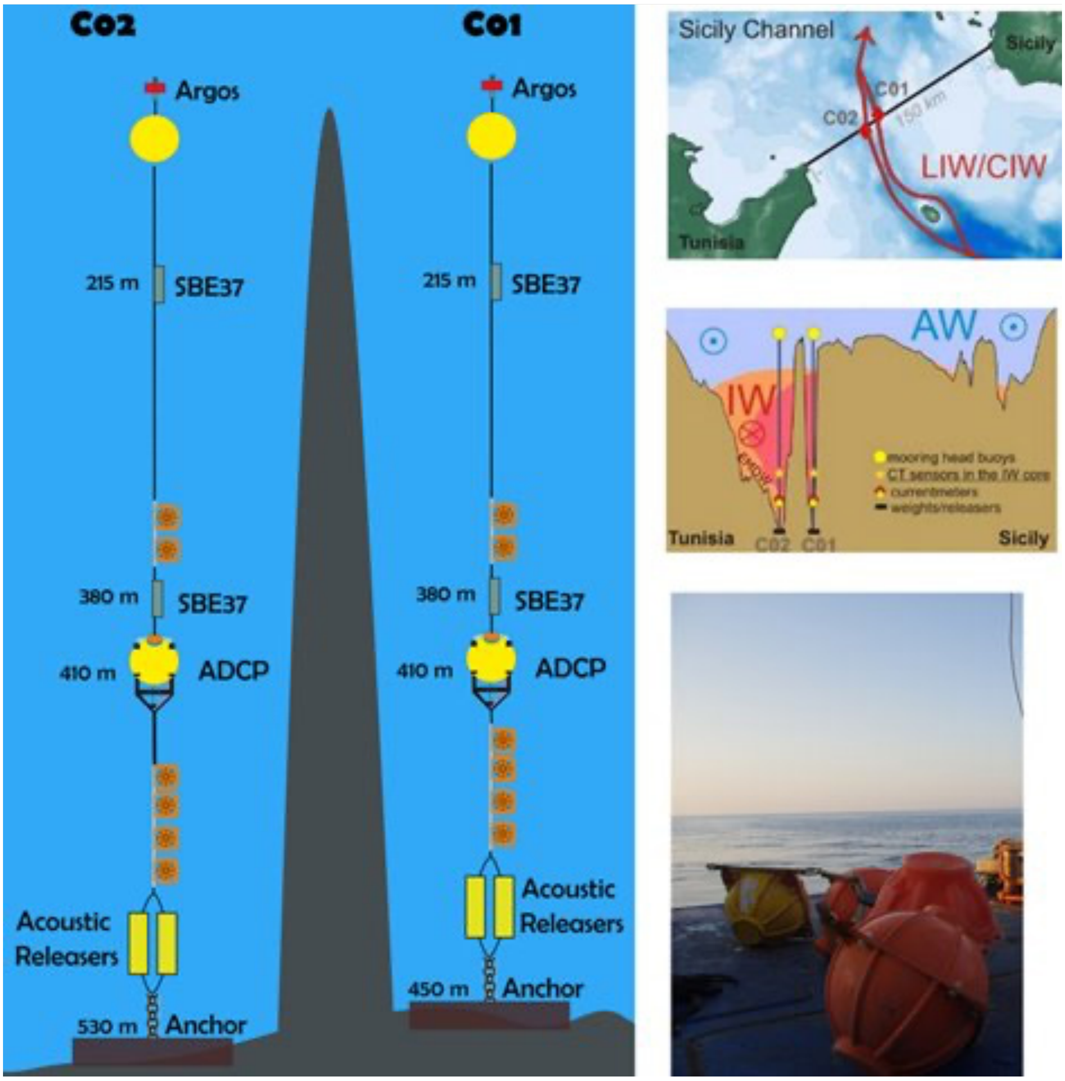

Figure 11 – Diagram of the two moorings (left), in two parallel pits that convey water from east to west, (top right) diagram of the vertical section between Sicily and Tunisia, with indication of the bathymetry and water masses present (AW=Atlantic Water, IW=Intermediate Water), (bottom right) mooring buoys ready to be launched into the sea.

The Sicilian Channel is the location of a twin mooring system (SiCO1 and SiCO2 stations, identified by WMO codes 6101021 and 6101022, respectively) dedicated to the long-term monitoring of surface and intermediate circulation and mass exchanges between the eastern and western Mediterranean basins. The underwater installations, moored at a depth of approximately 500 metres, are strategically positioned between Sicily and Tunisia, extending beyond the continental shelf of Sicily and along the western threshold of the Sicilian Channel at GPS location 37.38°N 11.591°E for the SiCO1 station and 37.285°N 11.5°E for the SiCO2 station.

These installations are designed to facilitate continuous monitoring of the exchange of surface and intermediate water masses between the eastern and western basins of the Mediterranean Sea. Since 2010, the system has been equipped with traditional current measurement sensors and ADCPs, and it has been operational since 1993. At depth, they are equipped with high precision CTD probes for the continuous measurement of hydrological parameters. The structure is part of EMSO Italia and OceanSITES, as well as the CIESM Hydrochanges program. Since 2013, it has also participated in a series of transnational access activities, under the umbrella of JERICO. A repeated transect between Sicily and Tunisia, passing through the location of the moorings, is carried out twice a year by means of a research vessel.

7.8.1.1 Scientific Impact

The site is of particular importance for the Mediterranean being located at a critical choke point in the region, second only to Gibraltar, where it is possible to intercept all the masses of water that flow between the eastern basin and the western basin. The location also allows attempts to close the mass and heat balance of the eastern Mediterranean. The time series already has a duration of 30 years, meaning it is useful for assessing the impacts of climate change on Mediterranean waters.

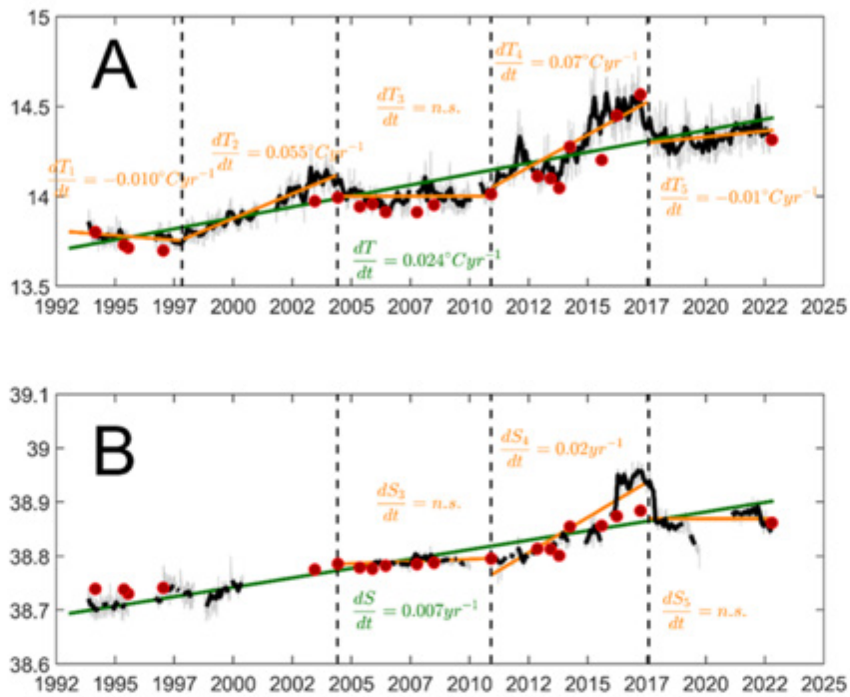

Figure 12 – Temperature and Salinity time series collected at 400 m depth in the SiCO2 site from 1993 to today (update from Schroeder et al., 2017).

The monitoring of this time series has yielded numerous scientific insights and has the potential to provide further answers to scientific questions, possibly with the incorporation of additional sensors. Among the most relevant studies we acknowledge the **investigation of changes in the bulk properties of water**, which has been possible because this is the longest time series of sub-surface temperature and salinity data recorded in the Mediterranean Sea. This data has been significant also for the study the effect of increased salt and heat import on **dense water formation processes** in the western Mediterranean.

The availability of a very long time series has contributed to investigating the causes of the observed trends, **understanding the impact of climate change in the eastern Mediterranean** area (warming, changes in the hydrological cycle).

Another relevant contribution is represented by the **evaluation of transport and its variability across the straits** (budget closure for the Eastern Mediterranean). Furthermore, the calculation of biogeochemical flows between eastern and western basins is a vital component of the research, with implications for **productivity and the carbon pump studies.**

Finally, the investigation of **biological and sedimentological research**, considering diurnal vertical migration of zooplankton which can be observed by acoustic backscattering force in ADCP data, as well as sediment resuspension), revealed essential properties for understanding the dynamics of the system.

The facilitation of multidisciplinary and interdisciplinary research is enabled by the capacity to incorporate permanent or temporary sensors for ad hoc experiments (e.g., degradation of plastic, determination of the dissolved and bioavailable concentration of chemical pollutants, sediment traps to study the flow of particles and the C pump, comparison of various dissolved oxygen sensors, etc.).

7.8.1.2 National/International collaborations and ESFRI contribution

Marine research infrastructures are essential for understanding oceanographic processes and addressing global environmental challenges. Over the past two decades, significant investments by European nations and the European Commission have supported these infrastructures, which are crucial for monitoring the marine environment, supporting research, and informing policy decisions. Several European projects have integrated existing infrastructures, supported by the European Strategy Forum on Research Infrastructures (ESFRI). Notable marine infrastructures include EURO ARGO, EMSO, and EMBRC, which have established legal structures for coordination and management. Italy, through the CNR, manages key infrastructures like the moorings in the Corsica and Sicily Channels (Borghini et al., 2021), part of programs such as CIESM Hydrochanges (Schroeder et al., 2013) JRU EMSO-Italia, and OceanSITES. These infrastructures provide valuable long-term data on water mass dynamics, biogeochemical processes, and climate change impacts (Schroeder et al., 2017; Borghini et al., 2014). The

Global Ocean Observing System (GOOS) coordinates global ocean observations, providing critical information on essential ocean variables. GOOS's networks, such as OceanSITES, are integral to this effort. GO-SHIP focuses on sustained hydrographic sections to monitor climate variability and marine biogeochemistry, while OceanSITES provides long-term time series data from fixed-point observatories.

The site is part of the Joint Research Unit EMSO Italia, and it has been nominated by Italy to become an EMSO ERIC facility.

It is contributing to OceanSITES, one of the GOOS networks.

7.8.1.3 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 h	CNR-ISMAR
Subsurface Temperature	1993	10 min	CNR-ISMAR
Subsurface Salinity	1993	10 min	CNR-ISMAR
Subsurface Pressure	1993	10 min	CNR-ISMAR

7.8.1.4 Publications

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Ben Ismail S., Schroeder K., Chiggiato J., Sparnocchia S., Borghini M. (2021). Long term changes monitored in two Mediterranean Channels. In: Copernicus Marine Service Ocean State Report, Issue 5, Journal of Operational Oceanography, 14:sup1, 1–185, DOI: 10.1080/1755876X.2021.1946240.

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7.8.1.5 OpenData

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7.8.2 **Corsica Channel Observatory**

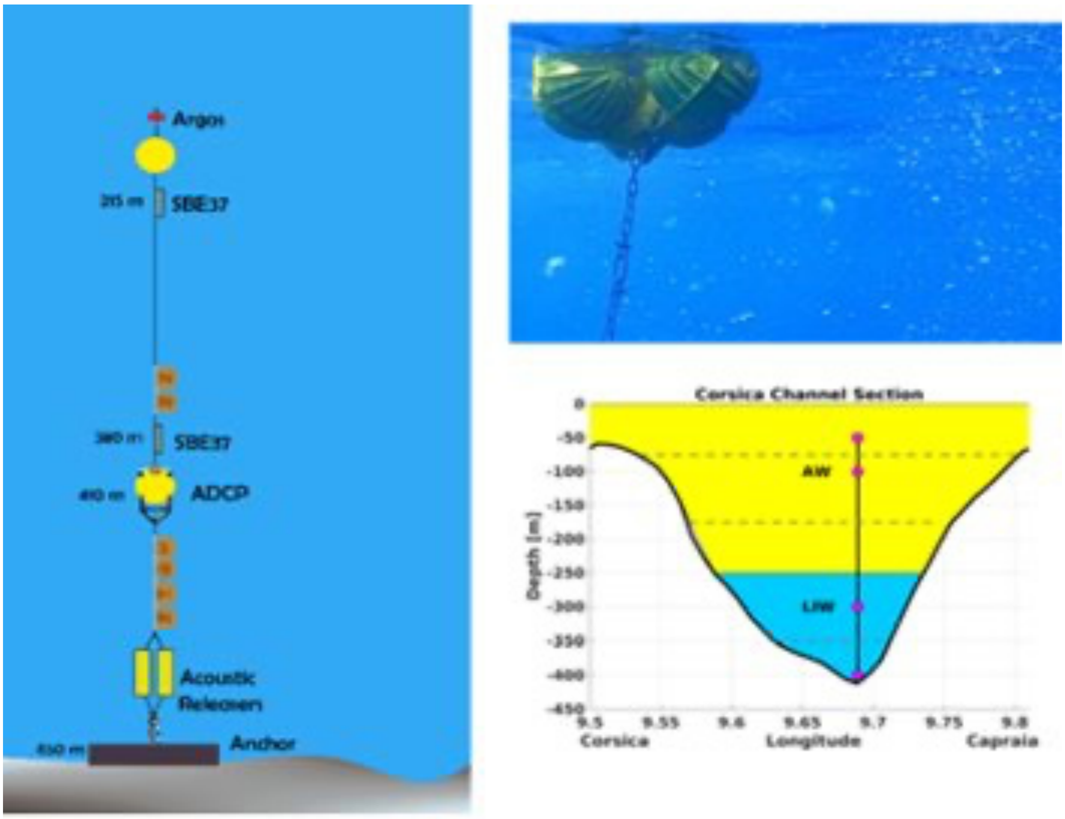

Figure 13 – Diagram of the mooring (left) and of the cross section between the Island of Capraia and Corsica, with an indication of the water masses present (right).

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.

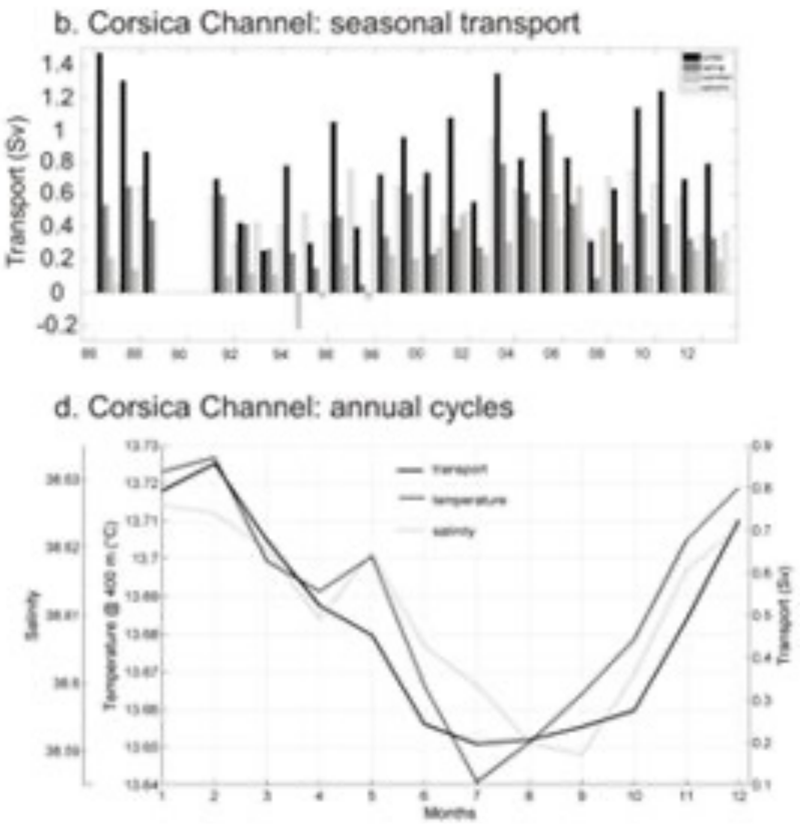

Figure 14 – Some of the results derived from the measured quantities (currents, transport, temperature and salinity) are represented in the center and at the bottom.

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. 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.

7.8.2.1 Scientific Impact

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.

For the most relevant studies, refer to paragraph 0.

7.8.2.2 National/International collaborations and ESFRI contribution

Marine research infrastructures are essential for understanding oceanographic processes and addressing global environmental challenges. Over the past two decades, significant investments by European nations and the European Commission have supported these infrastructures, which are crucial for monitoring the marine environment, supporting research, and informing policy decisions. Several European projects have integrated existing infrastructures, supported by the European Strategy Forum on Research Infrastructures (ESFRI). Notable marine infrastructures include EURO ARGO, EMSO, and EMBRC, which have established legal structures for coordination and management. Italy, through the CNR, manages key infrastructures like the moorings in the Corsica and Sicily Channels (Borghini et al., 2021), part of programs such as CIESM Hydrochanges (Schroeder et al., 2013) JRU EMSO-Italia, and OceanSITES. These infrastructures provide valuable long-term data on water mass dynamics, biogeochemical processes, and climate change impacts (Schroeder et al., 2017; Borghini et al., 2014). The Global Ocean Observing System (GOOS) coordinates global ocean observations, providing critical information on essential ocean variables. GOOS's networks, such as OceanSITES, are integral to this effort. GO-SHIP focuses on sustained hydrographic sections to monitor climate variability and marine biogeochemistry, while OceanSITES provides long-term time series data from fixed-point observatories

The site is part of the Joint Research Unit EMSO Italia, and it has been candidated by Italy to become an EMSO ERIC facility.

It is contributing to OceanSITES, one of the GOOS networks.

7.8.2.3 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

7.8.2.4 Publications

Poulain, P.-M., E. Mauri, R. Gerin, J. Chiggiato, K. Schroeder, A. Griffa, M. Borghini, E. Zambianchi, P. Falco, P. Testor, L. Mortier, 2020. On the dynamics in the southeastern Ligurian Sea in summer 2010. Continental Shelf Research, 196, 104083, doi: 10.1016/j.csr.2020.104083.

Guerra, D., Schroeder, K., Borghini, M., Camatti, E., Pansera, M., Schroeder, A., Sparnocchia, S., and Chiggiato, J.: Vertical migration of diel zooplankton in the Corsica Channel (1999). Ocean Sci., 15, 631–649, https://doi.org/10.5194/os-15-631-2019,

Testor, P., Bosse, A., Houpert, L., ... Schroeder, K., ... (2018). Multiscale observations of deep convection in the northwestern Mediterranean Sea during winter 2012-2013 using multiple platforms. Journal of Geophysical Research: Oceans, 123, 1745-1776. https://doi.org/10.1002/2016JC012671.

Aracri S, Borghini M, Canesso D, Chiggiato J, Durante S, Schroeder K, Sparnocchia S, Vetrano A, Honda T, Kitawaza Y, Kawahara H, Nakamura T. Trials of an autonomous profiling buoy system. Journal of Operational Oceanography Vol. 9, Iss. sup1,2016.

Ravaioli M., C. Bergami, F. Riminucci, L. Langone, V. Cardin, A. Di Sarra, A. Aracri, M. Bastianini, M. Bensi, A. Bergamasco, C. Bommarito, M. Borghini, G, Bortoluzzi, R Bozzano, C Cantoni, J Chiggiato, E Crisafi, D'Adamo R, Durante, C Fanara, Grilli F, Lipizer, Marini, Miserocchi, Paschini, P. Penna, SA Crisis (2016). The RITMARE Italian Fixed-point Observatory Network (IFON) for marine environmental monitoring: a case study. Journal of Operational Oceanography, 9:sup1, pp202-p214, DOI:10.1080/1755876X.2015.1114806

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Schroeder K., C. Millot, L. Bengara, S. Ben Ismail, M. Bensi, M. Borghini, G. Budillon, V. Cardin, L. Coppola, C. Curtil, A. Drago, B. El Moumni, Font J, Fuda JL, Garcia-Lafuente J, Gasparini GP, Kontoyiannis H, Lefevre D, Puig P, Raimbault P, Rougier G, Salat J, Sammari C, Sanchez Garrido JC, A.M. Sanchez-Roman, S. Sparnocchia, C. Tamburini, I. Taupier-Letage, A. Theocharis, M. Vargas-Yanez, and A. Vetrano first overview of the HYDROCHANGES network. Ocean Sci., 9, 1-24, doi:10.5194/os-9-1-2013.

[PMC free article] [PubMed] Grignon L., Smeed D., Bryden HL, Schroeder K., 2010. Importance of the variability of hydrographic preconditioning for deep convection in the Gulf of Lion, NW Mediterranean. Ocean Sci., 6, 573–586, doi:10.5194/os-6-573-2010.

Gasparini, G.P., Schroeder, K. and Sparnocchia, S.: Straits and Channels as key regions of an integrated marine observatory of the Mediterranean: our experience on their long-term monitoring. In Towards an integrated system of Mediterranean marine observatories, F. Briand (Ed.), CIESM Workshop Monographs, No 34, 75-79, 2008.

Vignudelli, S., Cipollini, P., Astraldi, M., Gasparini, G.P. and Manzella, G.: Integrated use of altimeter and in situ data for understanding the water exchanges between the Tyrrhenian and Ligurian Seas, J. Geophys. Res., 105(C8), 19649-19663, 2000.

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EURO MODEL Group: Progress from 1989 to 1992 in understanding the circulation of the Western Mediterranean Sea. Oceanologica Acta, 18(2), 255-271, 1995.

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Astraldi, M., Gasparini, G. P., Manzella, G. M. R. and Hopkins, T.: Temporal variability of currents in the eastern Ligurian Sea, J. Geophys. Res., 95(C2), 1515-1522, 1990.

Astraldi, M. and Manzella, GMR: Some observations on current measurements on the Eastern Ligurian Shelf, Mediterranean Sea, Cont. Shelf Res., 2, 183-193, 1983.

7.8.2.5 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

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.

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.

7.8.3.1 Scientific Impact

The Western Ionian Sea facility, which includes the 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 CO_2. 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.

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 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.

7.8.3.4 Publications

S. Sparnocchia, M. Borghini, S. Durante, V. Meccia, A. Giordano and G. Biasini, "From the seafloor to the sea surface: A technical solution for the cabled EMSO-SN1 observatory in the Western Ionian Sea," OCEANS 2015 - Genova, Genova, Italy, 2015, pp. 1-5, doi: 10.1109/OCEANS-Genova.2015.7271527.

7.8.4 **Sardinia Channel Observatory**

The Sardinia Channel, located in the Western Mediterranean, represents a wide opening between Tunisia and Sardinia. This region features a threshold at about 1900 m, characterised by a narrow and deep trench that facilitates the exchange of the upper segment of the deep water between the Algerian sub-basin (depth > 2500 m) and the Tyrrhenian sub-basin (depth > 3000 m).

Since 2002, a mooring (currently under maintenance) has been deployed in the channel, at GPS position 38.3341 N, 9.33265 E, equipped with an SB37 probe and a current measuring sensors positioned near the seafloor.

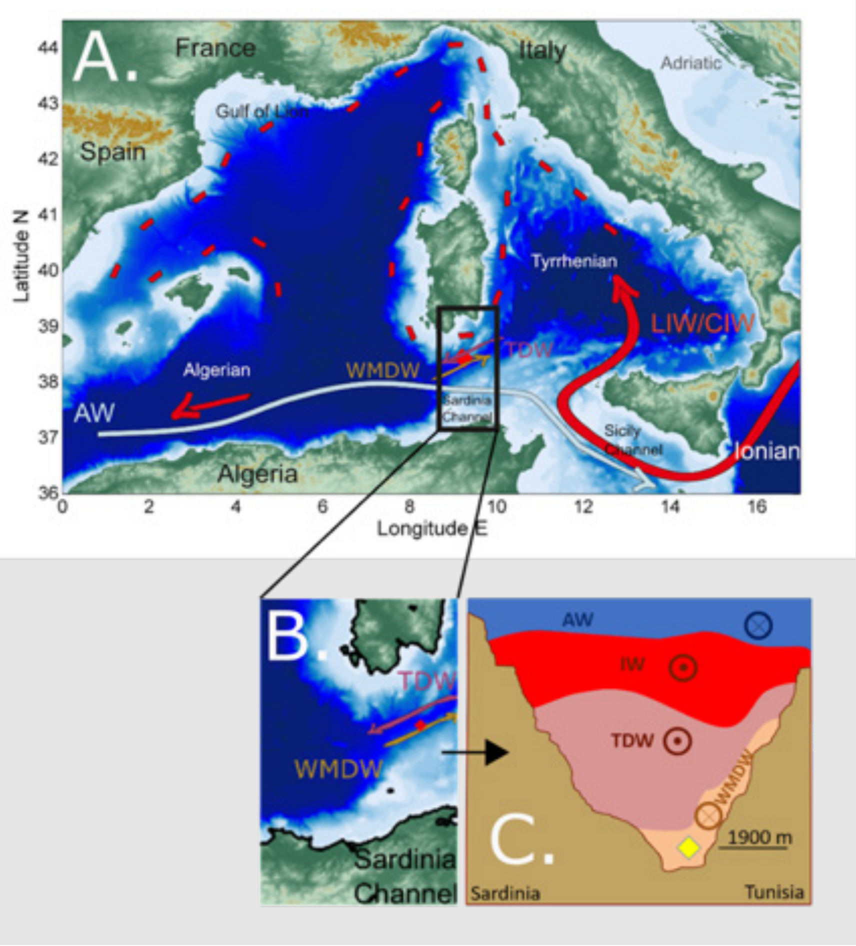

Figure 15 - (A) Geographical map indicating the position of the mooring, with detailed zoom of the area (B) and (C) diagram of the vertical section between Sardinia and Tunisia with the

indication of the masses of water in transit (AW=Water Atlantic, IW=Intermediate Water, TDW=Tyrrhenian Deep Water, WMDW=Western Mediterranean Deep Water).

7.8.4.1 Scientific Impact

The site enables the observation of the evolution of warming and salinification, which are affecting all Mediterranean water masses as a consequence of climate change.

The sites's primary strength lies in its depth, ensuring the thermohaline properties and the signals of interest are highly precise and subject to minimal variability at high frequencies. This feature enables the study of climate signals, enhancing its accuracy.

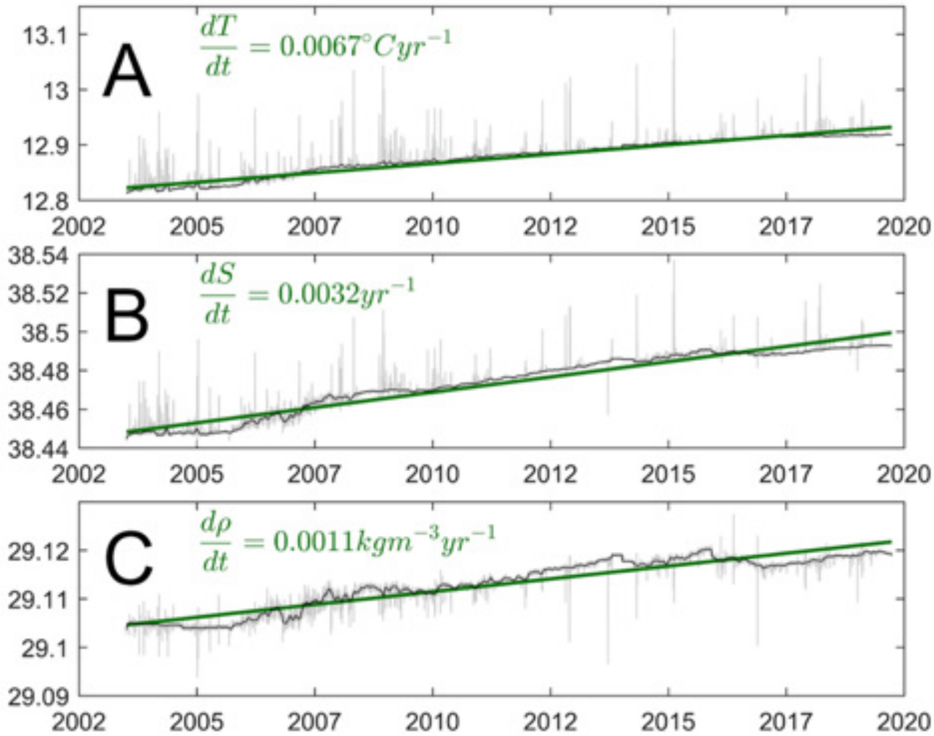

Figure 16 – Time series of Temperature, Salinity and density, collected at 1900 m depth at the site from 2003 to 2019 (Ben Ismail et al., 2021).

7.8.4.2 National/International collaborations and ESFRI contribution

Marine research infrastructures are essential for understanding oceanographic processes and addressing global environmental challenges. Over the past two decades, significant investments by European nations and the European Commission have supported these infrastructures, which are crucial for monitoring the marine environment, supporting research, and informing policy decisions. Several European projects have integrated existing infrastructures, supported by the European Strategy Forum on Research Infrastructures (ESFRI). Notable marine infrastructures include EURO ARGO, EMSO, and EMBRC, which have established legal structures for coordination and management. Italy, through the CNR, manages key infrastructures like the Sardinina Channel mooring (Borghini et al., 2021), part of programs such as CIESM Hydrochanges (Schroeder et al., 2013).

The site is currently not contributing in the ESFRI context.

7.8.4.3 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Current speed and direction	2002–2019	2 hours	CNR–ISMAR
Subsurface Temperature	2002–2019	10 min	CNR–ISMAR
Subsurface Salinity	2002–2019	10 min	CNR–ISMAR
Subsurface Pressure	2002–2019	10 min	CNR–ISMAR

7.8.4.4 Publications

Schroeder K. and Chiggiato J., eds. (2022). Oceanography of the Mediterranean Sea. An Introductory Guide. Elsevier, ISBN: 9780128236925.

Ben Ismail S., Schroeder K., Chiggiato J., Sparnocchia S., Borghini M. (2021). Long term changes monitored in two Mediterranean Channels. In: Copernicus Marine Service Ocean State Report, Issue 5, Journal of Operational Oceanography, 14:sup1, 1–185, DOI: 10.1080/1755876X.2021.1946240.

Cherif S, et al. (2020) Drivers of change. In: Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report [Cramer W, Guiot J, Marini K (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 59–180, doi:10.5281/zenodo.7100601.

7.8.4.5 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_TS_MO_SardiniaChannel.nc

7.8.5 **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.

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.

Since October 2022 the site has been equipped with dedicated cages designed for the study of the degradation of plastic material in a deep environment.

Figure 17 – Mooring's structure.

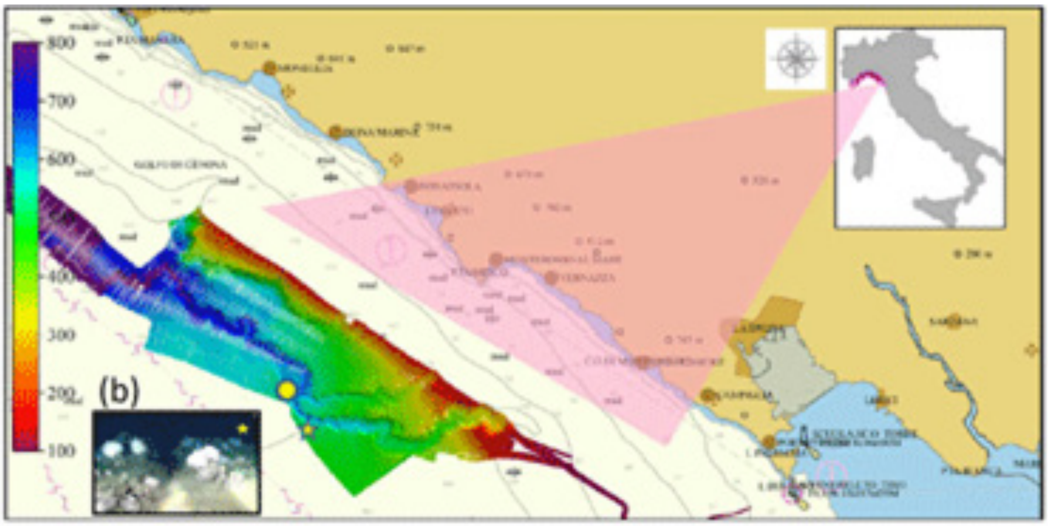

Figure 18 – Geographic map indicating the position of the mooring.

7.8.5.1 Scientific Impact

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.

Its strategic position for biological and ecological studies, coupled with its component dedicated to plastic degradation in deep environments, makes it a valuable asset.

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.

7.8.5.2 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

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plan continue to evolve and improve, the bodies involved will explore networking opportunities at European level.

7.8.5.3 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

7.8.5.4 Publications

Ciuffardi, T., Kokkini, Z., Berta, M., Locritani, M., Bordone, A., Delbono, I., Borghini, M., Demarte, M., Ivaldi, R., Pannacciulli, F., Vetrano, A., Marini, D., and Caprino, G.: Deep-water hydrodynamic observations around a cold-water coral habitat in a submarine canyon in the eastern Ligurian Sea (Mediterranean Sea), Earth Syst. Sci. Data, 15, 1933-1946, https://doi.org/10.5194/essd-15-1933-2023, 2023.

7.8.5.5 OpenData

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

7.9 Repeated transects

A series of hydrological transects are regularly repeated to monitor variables of oceanographic interest.

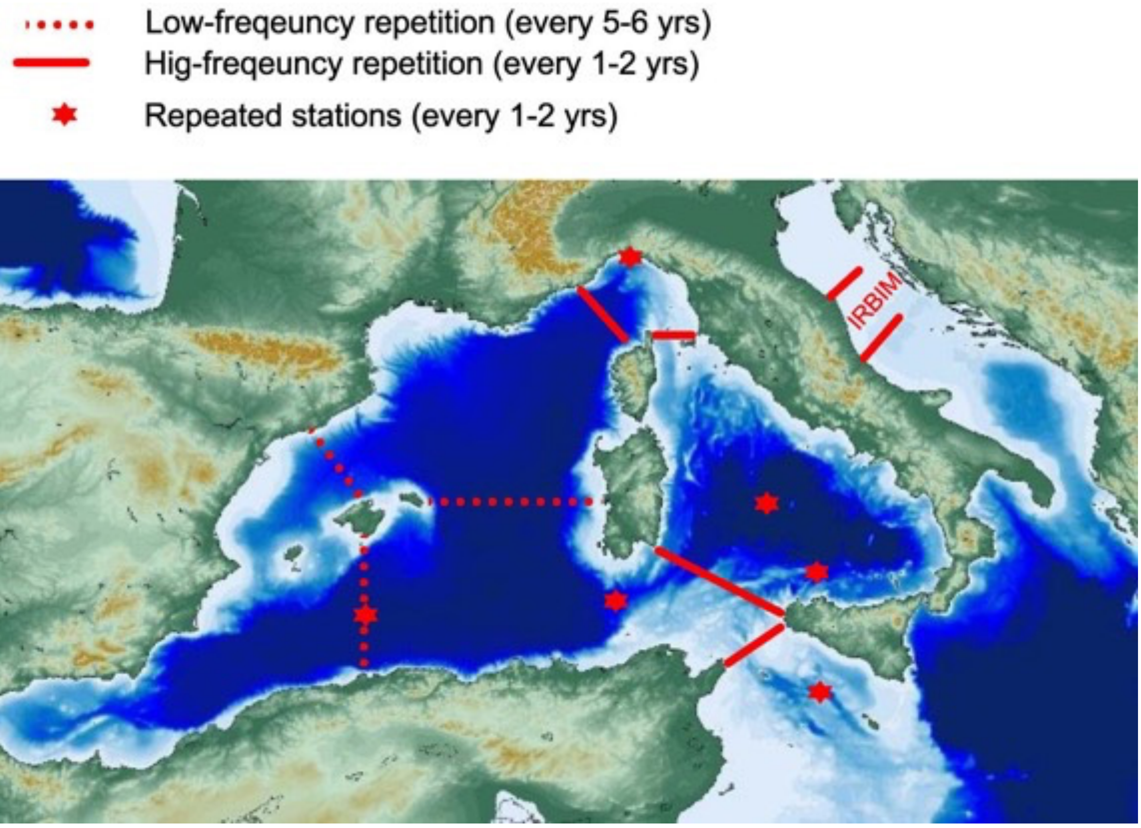

Figure 19 – Identification of the position of the repeated transects.

Despite the numerous technological advances in recent decades, ship-based hydrography remains the only method for obtaining high-quality, high-spatial- and vertical-resolution measurements of a range of physical, chemical, and biological parameters over the entire water column. Ship-based hydrography is essential for the documentation of oceanic changes throughout the water column, particularly in the deep ocean (which constitutes 52% of the global ocean volume and 20% of the Mediterranean, and is therefore not sampled by the ARGO floats). Over the years, CNR-ISMAR has implemented a series of repetitions of transects considered to be of particular significance.

Furthermore, the oceanographic vessel also represents an integrated multidisciplinary marine science platform, providing climate-quality observations for continuous calibration of measurements from existing and new autonomous platforms. This includes biogeochemical observations for the nascent Biogeochemical Floating Array (BGC)-Argo; temperature and salinity for Deep Argo and salinity for Central Argo array.

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7.9.1 Scientific Impact

The scientific questions that this observational facility helped to answer are related to the study of changes in heat and freshwater, circulation and mixing, ventilation and transient tracers, anthropogenic carbon and ocean acidification, oxygen and deoxygenation, and biogeochemical cycles of macronutrients.

With regard to biological implications, also models of plankton taxonomic and functional diversity, impact of physical processes on the composition and diversity of plankton communities, plankton-driven modulation of ocean biogeochemical cycles (C, N, P), variability of carbon export fluxes in different sub-basins and biogeographical regions, and patterns in the plankton size spectrum are also relevant.

7.9.2 National/International collaborations and ESFRI contribution

The EuroGO-SHIP project aims to become a Research Infrastructure that coordinate ship-based oceanography at the European level. The Global Ocean Observing System (GOOS) coordinates global ocean observations, providing critical information on essential ocean variables. GOOS's networks, such as GO-SHIP are integral to this effort. GO-SHIP focuses on sustained hydrographic sections to monitor climate variability and marine biogeochemistry. The Mediterranean Ship-based Hydrographic Investigations Program (Med-SHIP) is the Mediterranean component of the global GO-SHIP initiative, which aims to provide high-quality, long-term observations of the world's oceans. Med-SHIP focuses on the Mediterranean Sea, conducting repeat hydrographic surveys to monitor changes in water mass properties and biogeochemical cycles. Med-SHIP is an Ocean Decade Project lead by CNR.

The activities are related to the ISMAR Goal Oriented Unit (GOU) "Climate Variability and Ocean Circulation" and the servicing involves Research Infrastructures supported by the CNR Infrastructure Office.

The site is currently not contributing in the ESFRI context.

It is contributing to Med-SHIP, the Mediterranean component of GO-SHIP, one of the GOOS networks.

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

Belgacem, M., Schroeder, K., Lauvset, S. K., Álvarez, M., 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): O2WMED, Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2024-365, in review, 2024.

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Vladoiu A., P. Bouruet-Aubertot, Y. Cuypers, B. Ferron, K. Schroeder, M. Borghini, S. Leizour, 2021. Contrasted mixing efficiency in energetic versus quiescent regions:

insights from microstructure measurements in the Western Mediterranean Sea, Progress in Oceanography, 102594.

Schroeder K, Cozzi S, Belgacem M, Borghini M, Cantoni C, Durante S, Petrizzo A, Poiana A and Chiggiato J, 2020. Along-Path Evolution of Biogeochemical and Carbonate System Properties in the Intermediate Water of the Western Mediterranean. Front. Mar. Sci. 7:375. doi: 10.3389/fmars.2020.00375

Ferron B., P. Bouruet-Aubertot, K. Schroeder, H. Bryden, M. Borghini, Y. Cuypers (2021). Contribution of thermohaline staircases to deep water mass modifications in the Western Mediterranean Sea from microstructure observation. Frontiers in Marine Science 8, 544.

K. Schroeder, S. Cozzi, M. Belgacem, M. Borghini, C. Cantoni, S. Durante, A. Petrizzo, A. Poiana & J. Chiggiato, 2020 Along-Path Evolution of Biogeochemical and Carbonate System Properties in the Intermediate Water of the Western Mediterranean. Frontiers in Marine Science 7:375.https://doi.org/10.3389/fmars.2020.00375

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Durante, S., Schroeder, K., Mazzei, L., Pierini, S., Borghini, M., Sparnocchia, S. (2019). Permanent Thermohaline Staircases in the Tyrrhenian Sea. Geophysical Research Letters, 46. https://doi.org/10.1029/2018GL081747.

Testor, P., Bosse, A., Houpert, L., … Schroeder, K., … (2018). Multiscale observations of deep convection in the northwestern Mediterranean Sea During winter 2012-2013 using multiple platforms. Journal of Geophysical Research: Oceans, 123, 1745-1776. https://doi.org/10.1002/2016JC012671.

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7.9.5 OpenData

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Schroeder, K. (2021): LADCP current profiles collected during MedSHIP cruise TAIPro2016. PANGAEA, https://doi.org/10.1594/PANGAEA.932316

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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.

7.10.1 Gulf of Trieste

Figure 20 – Trieste coastal meteorological network.

The Trieste Meteomarine Network comprises two stations: the "Trieste – Molo Sartorio" (TSS) tide gauge station (Figure 20, bottom left) and the "Trieste – Molo Bandiera" (TSB) marine meteorological station (Figure 20, bottom right). Both stations are located within the harbour area of Trieste (Figure 20, 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 1961m 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 harbour. It has been in operation 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.

7.10.1.1 Scientific Impact

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. Table 7.10.1.1 only accounts for the present installation.

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 Research Infrastructure.

7.10.1.3 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

7.10.1.4 Publications

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.

Raicich, F., R.R. Colucci, 2021. A mean-sea-level pressure time series for Trieste, Italy (1841-2018). Earth System Science Data, 13, 3363-3377. https://doi.org/10.5194/essd-13-3363-2021.

Zerbini, S., Bruni, S., and Raicich, F., 2021. Tide gauge data archaeology provide natural subsidence rates along the coasts of the Po Plain and of the Veneto-Friuli Plain, Italy". Geophysical Journal International, 225, 253-260. https://doi.org/10.1093/gji/ggaa602.

Raicich, F., R.R. Colucci, 2019. A near-surface sea temperature time series from Trieste, northern Adriatic Sea (1899-2015). Earth System Science Data, 11, 761-768. https://doi.org/10.5194/essd-11-761-2019.

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Raicich, F., V. Malačič, M. Celio, D. Giaiotti, C. Cantoni, R.R. Colucci, B. Čermelj, A. Pucillo, 2013. Extreme air-sea interactions in the Gulf of Trieste (North Adriatic) during the strong Bora event in winter 2012. Journal of Geophysical Research - Oceans, 118, 5238-5250. https://doi.org/10.1002/jgrc.28398.

Raicich, F., 2007. A study of early Trieste sea level data (1875-1914). Journal of Coastal Research, 23, 1067-1073. https://doi.org/10.2112/04-0325.1.

Beretta, A., H.E. Roman, F. Raicich, F. Crisciani, 2005. Long-time correlations of sea-level and local atmospheric pressure fluctuations at Trieste. Physica A, 347, 695-703. https://doi.org/10.1016/j.physa.2004.08.027.

Raicich, F., 2003. Recent evolution of sea-level extremes in the North Adriatic. Continental Shelf Research, 23, 225-235. https://doi.org/10.1016/S0278-4343(02)00224-8.

7.10.1.5 OpenData

Raicich, F., 2023. Sea level observations at Trieste, Molo Sartorio, Italy. SEANOE. https://doi.org/10.17882/62758.

Raicich, F., R.R. Colucci, 2021. Mean-sea-level atmospheric pressure from 1841 to 2018 at Trieste, Italy. PANGAEA. https://doi.org/10.1594/PANGAEA.926896.

Raicich, F., RR Colucci, 2019. Trieste 1899-2015 near-surface sea temperature. SEANOE. https://doi.org/10.17882/58728.

7.10.2 **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. 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.

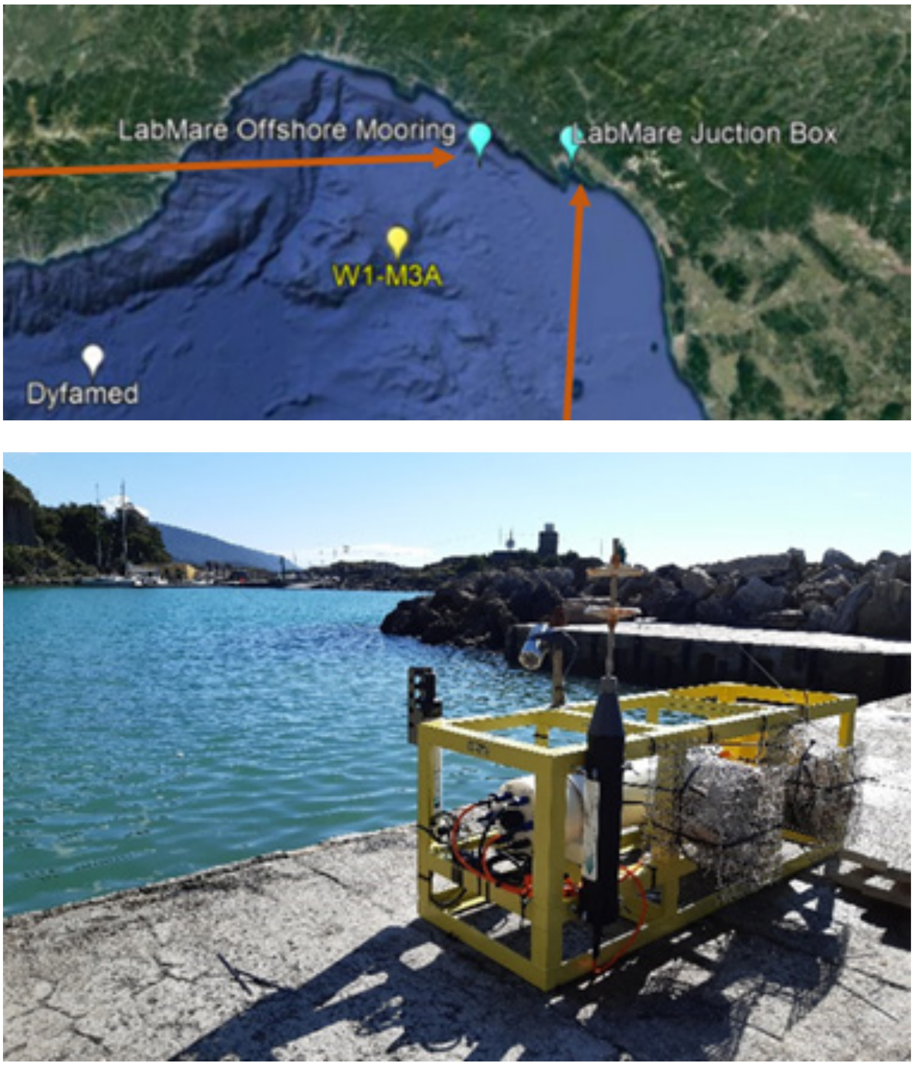

Figure 21 – Gulf of Lerici coastal station (SP).

7.10.2.1 Scientific Impact

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.

7.10.2.2 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. This station is integrated into the SmartBay collaboration network (https://smartbaysteresa.com/), a partnership among local research institutions (CNR, ENEA, INGV) and stakeholders within the Gulf of La Spezia, including the municipality of Lerici (SP), mussel farmers and a sailing school.

Within the PNRR ITINERIS project framework, several monitoring investments are envisaged in the sea area facing La Spezia, and the coastal station will benefit from the expanding constellation of observing systems in the surrounding area.

7.10.2.3 Observed variables

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

7.10.2.4 Publications

De Monte, C.; Locritani, M.; Merlino, S.; Ricci, L.; Pistolesi, A.; Bronco, S. An In Situ Experiment to Evaluate the Aging and Degradation Phenomena Induced by Marine Environment Conditions on Commercial Plastic Granules. Polymers 2022, 14, 1111. https://doi.org/10.3390/polym14061111

7.10.2.5 OpenData

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

7.10.3 **Gulf of Gaeta**

Figure 22 – Coastal weather station located on the north side of Lago Patria (left) and view of the south side of the coastal lake (right).

The coastal station located in the Gulf of Gaeta comprises an integrated meteorological station that has been operational since 2020. This station is located at "Lago Patria", the largest coastal lake in Campania with an approximate surface area of 2 km^2, which is part of the Foce Volturno nature reserve – Coast of Licola.

7.10.3.1 Scientific Impact

This station enables 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 control unit is also equipped with a web camera that captures images of the surface of the coastal lake.

Since 2020, the same 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.**

7.10.3.2 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 Autority Appennino Meridionale and focuses on the study of the saline wedge intrusion in the Volturno plain.

7.10.3.3 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	10 min	CNR-ISMAR
Air Temperature	Dec. 2020	10 min	CNR-ISMAR
Air Humidity	Dec. 2020	10 min	CNR-ISMAR
Atmospheric Pressure	Dec. 2020	10 min	CNR-ISMAR
Wind Speed and Direction	Dec. 2020	10 min	CNR-ISMAR

7.10.3.4 Publications

Aiello G., Allocca V., Arienzo M., Barra D., Bravi S., New Year M., Carraturo F., Castello N., Colantuono P., Coda S., Crovato P., Cusano D., D' Adamo R., Donadio C., Fabbrocini A., Ferrara L., Gherardi S., Guarino FM, Guida M., Libralato G., Maio N., Mezzasalma M., Molisso F., Parisi R., Petraccioli A., Risso V., Sacchi M., Siciliano A., Tonielli R., Toscanesi M., Trifuoggi M. (2020) – Assessment of the environmental health status of Lake Patria and neighboring ecosystems – Preliminary data and indications on the first feasible interventions. Project Report, ISMAR-CNR. http://eprints.bice.rm.cnr.it/id/eprint/20963 (Unpublished).

Di Rita F., Molisso F., Sacchi M. (2018) – Late Holocene environmental dynamics, vegetation history, human impact, and climate change in the ancient Literna Palus (Lago Patria; Campania, Italy). Review of Palaeobotany and Palynology, 258, 48-61.

Sacchi M., Molisso F., Pacifico A., Vigliotti M., Sabbarese C., Ruberti D. (2014) – Late-Holocene to recent evolution of Lake Patria, South Italy: An example of a coastal lagoon within a Mediterranean delta system. Global and Planetary Change, 117, 9 - 27.

7.10.3.5 OpenData

Fortelli, Alberto; Matano, Fabio; Sacchi, Marco (2022): Continuous meteorological observations at Lago Patria weather station (Campania Plain - Giugliano in Campania - NA - Italy) during the period Jan. 2021-Dec. 2021. PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.946028

7.10.4 **Gulf of Naples**

Figure 23 – 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.

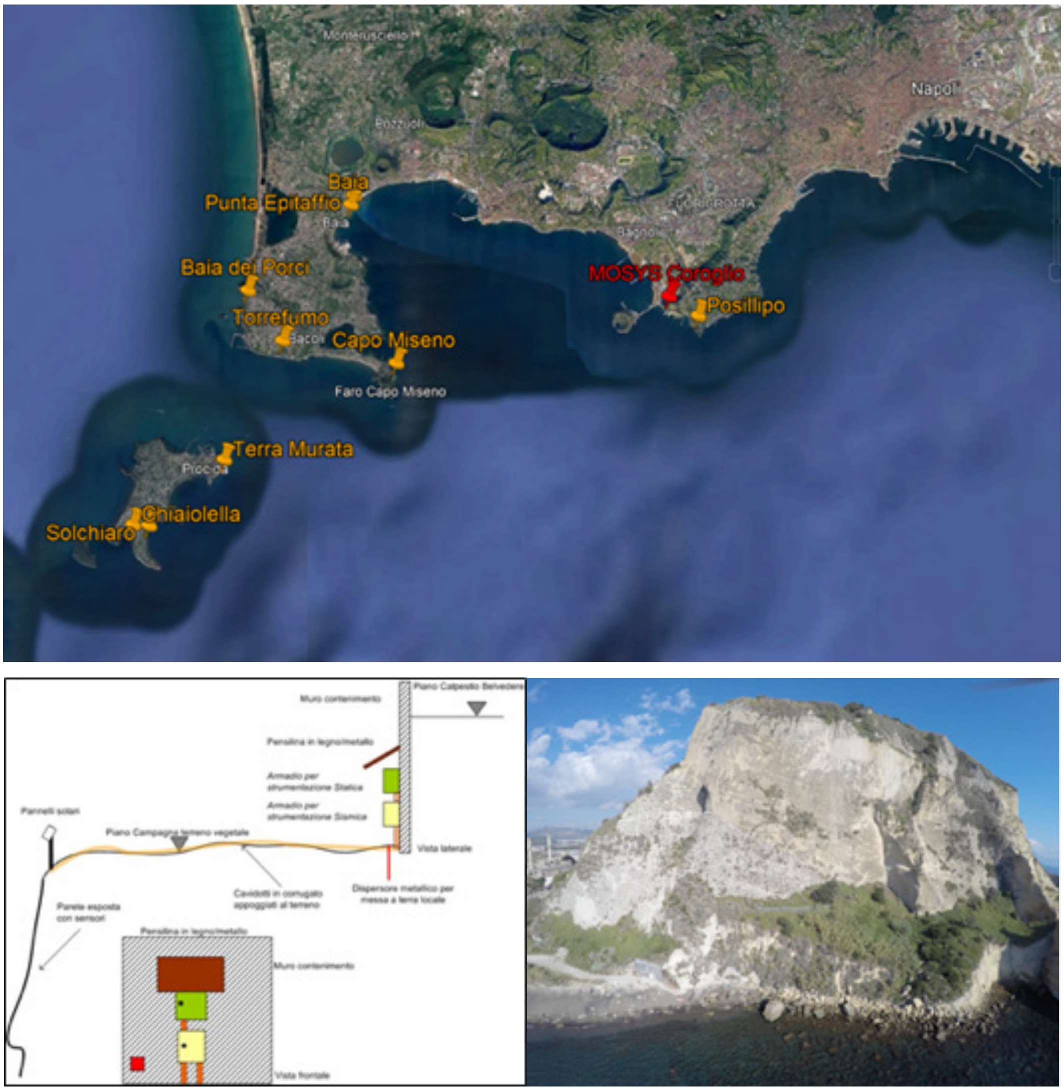

Figure 24 – MOSYS monitoring system of the Coroglio cliff (Naples).

The morphological evolution of numerous coastal cliffs in tuffaceous and volcanoclastic rocks present in the continental and insular Phlegraean area is monitored through periodic precision topographic surveys using terrestrial laser scanners and digital photogrammetry and monitoring systems.

The MOSYS system, an experimental monitoring system, is used for the surveillance of the tuffaceous cliff of Coroglio, Naples (at GPS position 40° 47′ 53.96” N, 14° 10′ 34.17 E). Since 2014, it has been capable of acquiring, managing and archiving data remotely from a network multi-instrumental (crack meters, tilt meters, velocity meters, thermometers, and fibre optic sensors) for monitoring geo-hydrological instability phenomena. The system is configured to record parameters at 30-minute intervals and to transmit this data to a remote server located at the Institute's branch offices of Naples. The parameters relate to the physical and geotechnical characteristics of the tuff rock mass. The data is divided into two categories: "static" data, which includes variations in the opening of the fractures in the rock mass, measurement of the angular rotations of rock blocks, and surface temperature); and "dynamic" data, which includes continuous seismic noise and seismic events above a pre-established threshold.

The historical measurement series provide detailed knowledge of the behaviour of the tuff rock mass in response to meteorological and climatic forcing, with the possibility of developing and calibrating alert thresholds linked to the extent of the movements measured in relation to variations in rainfall and temperature and to seismic inputs for rockfall prediction. A network of fibre optic sensors coupled to crackmeters was tested in the first years of the system's operation. Instrumental monitoring is integrated by numerous multi-temporal acquisitions with RIEGL VZ1000 terrestrial laser scanner (TLS) and digital photogrammetry from drone (UAV).

7.10.4.1 Scientific Impact

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**.

7.10.4.2 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.

7.10.4.3 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:

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

7.10.4.4 Publications

Somma R., Matano F., Marino E., Caputo T., Esposito G., Caccavale M., Carlino S., Iuliano S., Mazzola S., Molisso F., Sacchi M., Troise C., De Natale G., 2014. Application of Laser Scanning for Monitoring Coastal Cliff Instability in The Pozzuoli Bay, Coroglio Site, Posillipo Hill, Naples. In: G. Lollino et al. (eds.), Engineering Geology for Society and Territory – Volume 5, Ch. 133. DOI: 10.1007/978-3-319-09048-1_133, © Springer International Publishing Switzerland.

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7.11 Atmospheric LIDAR

Figure 25 – 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 was designed within the CNR in the late 1990s, and is currently operational, at the Rome Tor Vergata headquarters of the Institute of Marine Sciences of the National Research Council of Italy. This system is currently installed in the CNR-ISAC Rome Atmospheric Supersite (CIRAS, https://www.isac.cnr.it/it/infrastrutture/ciras), located approximately 15 km south-east of Rome in a semi-urban environment. This site is operated by the Institute of Atmospheric Sciences and Climate with the participation of the Institute of Marine Sciences.

The site hosts, in addition to the RMR lidar system, a set of instruments for atmospheric monitoring of the ISAC-CNR or other bodies on the basis of collaboration agreements/projects. Among the main objectives of all the instrumentation present on the site is the monitoring of air quality and, more generally, of the planetary boundary layer.

The system is assembled in two stacked containers and can be used for routine in situ observations or transported for measurement campaigns in remote sites. The system is composed of:

- a transmitter that emits the pulses generated by the laser source (NdYAG) vertically into the atmosphere. The current configuration includes emission at 355 nm and 532 nm with the possibility of implementing emission also at 1064 nm.
- a reception system based on a set of 9+1+1 telescopes of various sizes and characteristics to guarantee coverage of a vast range of altitudes in the atmosphere (0.15–60 km); an optical system for the separation of the acquired wavelengths; a set of sensors (photomultipliers) and associated electronics for signal acquisition. The current configuration allows the acquisition of 8 channels for the wavelengths of 355, 387, 407, 532 nm. The system is being updated with the extension of the number of channels acquired both by increasing the spectral coverage and by implementing depolarization measures.

The control systems (e.g., alignment control, air conditioning, roof opening/closing, etc.) are an integral part of the infrastructure and are fundamental for the correct functioning and monitoring of the instrumentation.

Finally, the system, the processing of the products and their analysis have been the subject of numerous advanced training activities from curricular internships and doctorates in collaboration with different 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

7.11.1 Scientific Impact

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 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 LIDAR RMR measurements are taken two or three times a week when weather conditions are suitable.			

7.11.4 Publications

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7.11.5 OpenData

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7.12 Mobile autonomous systems

7.12.1 Autonomous Surface Vehicles (ASV) – OpenSWAP

Figure 26 – OpenSWAP

OpenSWAP is a fully autonomous, remotely controlled surface vehicle designed for a variety of applications, including custom projects, geophysical surveys, and video inspections. It is lightweight, economical, fully customisable and compatible with the most common GPS and sensors.

The vehicle features open–source platforms (Arduino, Raspberry Pi) with dual GPS autonomous navigation system and integrated inertial sensors.

It is a small plastic catamaran (PELLD) with four brushless motors, a modular design and a straightforward water–entry process. The aluminium frame is versatile, allowing for easy interfacing with instruments such as side scan sonars, multiparametric probes, sub–bottom profilers and multi–beam echo sounders. It is compatible with both commercial and non–commercial sensorsfacilitating the expansion of the load capacity to over 40 kg.

OpenSWAP represents the genesis of a series of initiatives underway at CNR–ISMAR for the creation of prototype autonomous vehicles capable of supporting instrumentation and sensors that can acquire measurements in areas that are difficult to access with other means and at much lower costs than a traditional vehicle.

7.12.1.1 Scientific Impact

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 Observed variables

OpenSwap id 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.

7.12.1.4 Publications

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7.12.2 Autonomous Surface Vehicles (ASV) – SWAMP

Figure *27*– 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 that has been developed by CNR for access and monitoring extremely shallow water by means of portable, modular, reconfigurable and highly maneuverable robotic vehicles. Within the INTERREG IT-HR projects InnovaMare (2020-2023) and DIH INNOVAMARE (2024-2025), SWAMP was equipped with a multifrequency multibeam echosounder (MBES) R2-Sonic (CNR-ISMAR), an automated field spectroscopy device (RoX) (CNR-ISMAR), a SUNA V2 nitrate sensor (OGS), a high resolution and high sensitivity AI underwater camera, Guard1 (CNR-ISMAR).

SWAMP is a portable, modular Unmanned Surface Vehicle (USV), designed and built by the CNR-INM research group. The vehicle is of the catamaran type and it is equipped with four azimuth pump-jet thrusters, all contained within the hulls, and designed specifically for SWAMP. The hulls are constructed from of a soft-foam lightweight material, with each hull accommodating a propelling and control unit (MINION).

The SWAMP vehicle has been designed to ensure high levels of modularity and flotation, thus allowing it to adapt to the requirements of the mission and its users. This physical modularity is also reflected in the software architecture. Furthermore, the hulls are fully independent, each comprising its own control, guidance, power, propulsion, navigation and communication systems. An onboard Wi-Fi communication network is in place, enabling communication among all elements, with the exception of the two hulls. This design makes SWAMP a completely modular vehicle that can be dismounted and transported and then remounted in various possible configurations.

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

7.12.2.1 Scientific Impact

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.

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 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

7.12.2.4 Publications

Odetti, Angelo; Braga, Federica; Brunetti, Fabio; Caccia, Massimo; Marini, Simone; Madricardo, Fantina; Rovere, Marzia; De Pascàlis, Francesca; Development of innovative monitoring technologies in the framework of InnovaMare Project, EGU General Assembly Conference Abstracts, , , EGU21-10131, 2021.

Ferreira, Fausto; Babić, Anja; Oreč, Martin; Mišković, Nikola; Motta, Corrado; Ferretti, Roberta; Odetti, Angelo; Aracri, Simona; Bruzzone, Gabriele; Caccia, Massimo; , Heterogeneous marine robotic system for environmental monitoring missions, 2023 IEEE Underwater Technology (UT), 1-5, 2023, IEEE.

Babić, Anja; Ferreira, Fausto; Kapetanović, Nadir; Mišković, Nikola; Bibuli, Marco; Bruzzone, Gabriele; Motta, Corrado; Ferretti, Roberta; Odetti, Angelo; Caccia, Massimo; , Cooperative marine litter detection and environmental monitoring using heterogeneous robotic agents, OCEANS 2023-Limerick, 1-6, 2023, IEEE.

Ferretti, Roberta; Bibuli, Marco; Bruzzone, Gabriele; Odetti, Angelo; Aracri, Simona; Motta, Corrado; Caccia, Massimo; Rovere, Marzia; Mercorella, Alessandra; Madricardo, Fantina; , Acoustic seafloor mapping using non-standard ASV: Technical challenges and innovative solutions, OCEANS 2023-Limerick, 1-6, 2023, IEEE.

Motta, Corrado; Aracri, Simona; Ferretti, Roberta; Bibuli, Marco; Bruzzone, Gabriele; Caccia, Massimo; Odetti, Angelo; Ferreira, Fausto; de Pascalis, Francesca; A framework for FAIR robotic datasets, Scientific data, 10, 1, 620, 2023, Nature Publishing Group UK London.

7.12.3 **Gliders**

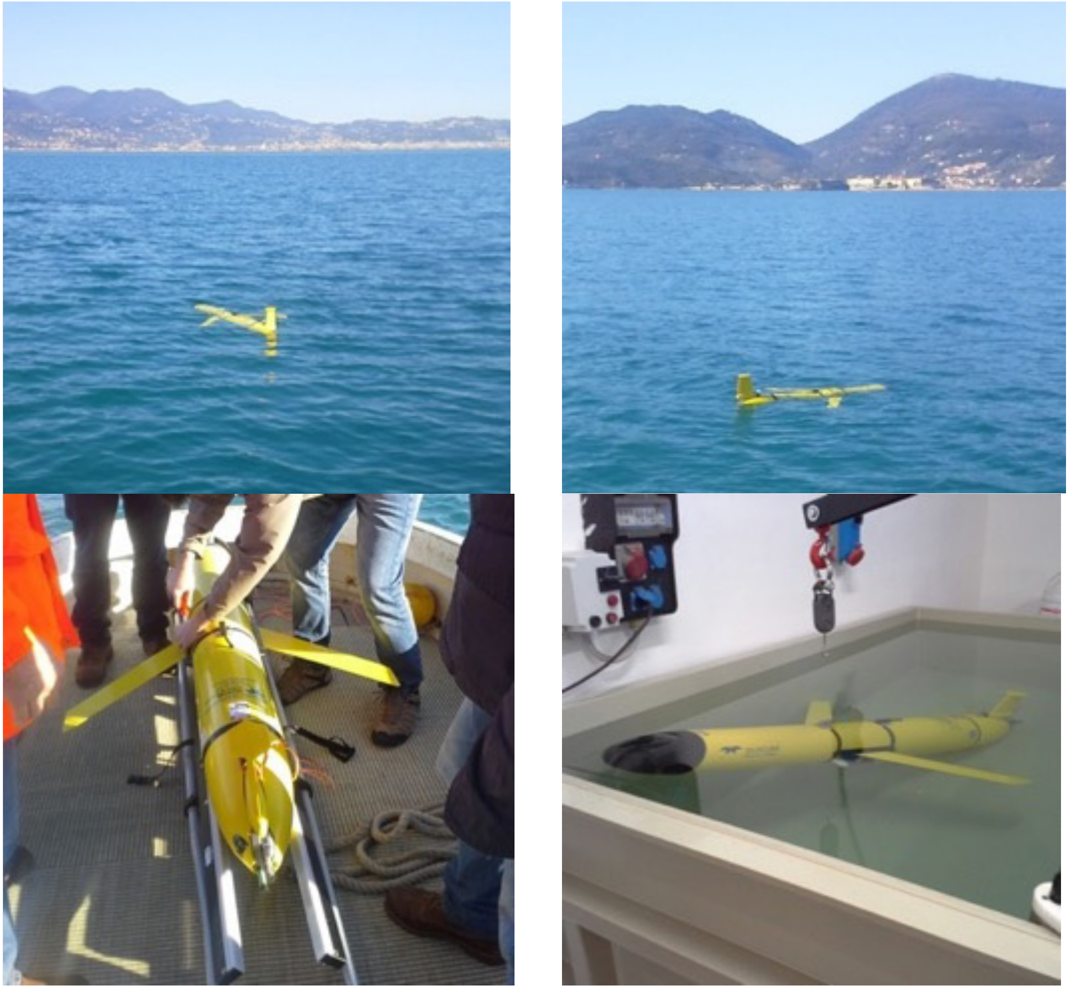

Figure 28 – Glider "Teresa"

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 Impact

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 2015-2023. 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.

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.

7.12.3.3 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
EOV-SubSurfaceTemperature	2017		CNR-ISMAR
EOV-SubSurfaceSalinity	2017		CNR-ISMAR
Biogeochemistry			
EOV-Oxygen	2017		CNR-ISMAR

7.12.3.4 Publications

Testor, P., DeYoung, B., Rudnick, DL, Glenn, S., Hayes, D., Lee, C., Pattiaratchi, CB, Hill, KL, Heslop, E., Turpin, V., Alenius, . P., Barrera, C., Barth, J., Beaird, N., Becu, G., Bosse, A., Bourrin, F., Brearley, A., Chao, Y., Chen, S., Chiggiato, J., Coppola, L., Crout, R., Cummings, J., Curry, B., Curry, R., Davis, R., Desai, K., DiMarco, S., Edwards, C., Fielding, S., Fer, I., Frajka-Williams, E., Gildor, H., Goni, G., Gutierrez, D., Hanson, S., Haugan, P., Hebert, D., Heiderich, J., . Heywood, KJ, Hogan, P., Houpert, L., Huh, S., Inall, ME, Ishii, M., Ito, S., Itoh, S., Jan, S., Kaiser, J., Karstensen, . J., Kirkpatrick, B., Klymak, J., Kohut, J., Krahmann, G., Krug, M., McClatchie, S., Marin, F., Mauri, E., Mehra, A., Meredith, MP, Miles, T, Morell, J, Mortier, L, Nicholson, S, O'Callaghan, J, O'Conchubhair, D, Oke, PR, Sanz, EP, Palmer, M, Park, J., Perivoliotis, L., Poulain, P.-M., Perry, R., Queste, B., Rainville, L., Rehm, E., Roughan, M., Rome, N., Ross, T., ., Ruiz, S., Saba, G., Schaeffer, A., Schonau, M., Schroeder, K., Shimizu, Y., Sloyan, BM, Smeed, D., Snowden, DP, Song, Y., . Swart, S., Tenr eiro, M., Thompson, AF, Tintore, J., Todd, RE, Bull, C., Venables, H., Waterman, S., Watlington, R., Wilson, D. OceanGliders: GOOS (2019) Frontiers in Marine Science, 6 (JUL), art. when. 422, DOI: 10.3389/fmar.2019.00422 ISSN: 22967745

7.12.3.5 Open Data

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.

7.12.4 **BioGeoChemical-Argo Profiling Floats**

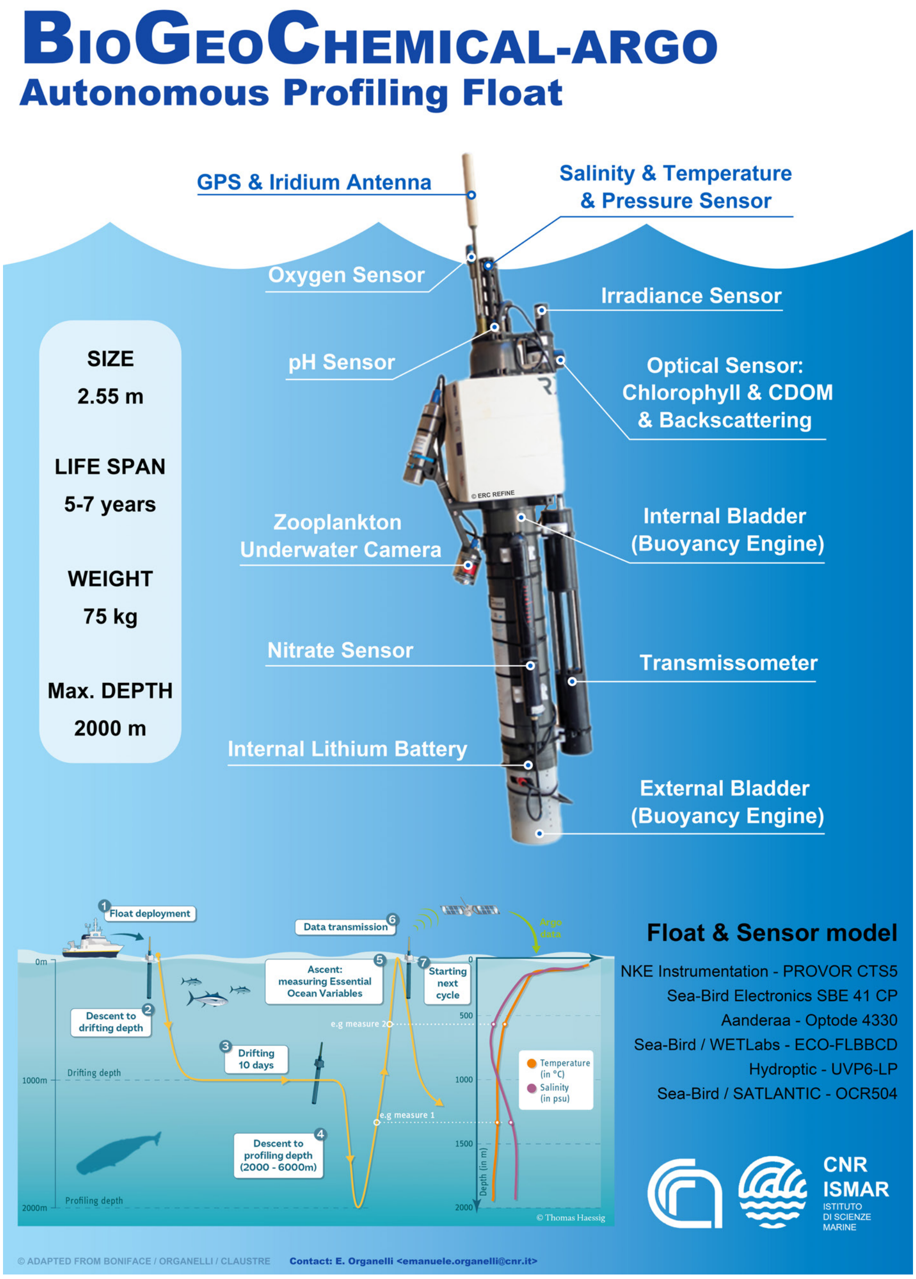

Figure 29 – BioGeoChemical (BGC) – Argo autonomous profiling platform.

Biogeochemical (BGC) – Argo floats are profiling platforms that autonomously measure physical, chemical, biological and optical properties of the oceans to answer key scientific questions on ocean health, climate and biodiversity (https:// biogeochemical – argo.org/).

These floats drift passively following the currents at a depth of 1000 metres, and are programmed to profile between 2000 metres and the surface at least once every 10 days. All floats are equipped with a GPS to ascertain their position and an Iridium antenna to transfer the data acquired to the ground via satellite. Once the data has been received, a quality control procedure is started within 24 hours from the sampling event. The BGC-Argo floats are equipped with miniaturized sensors that acquire measurements of temperature, salinity, pH, dissolved oxygen, nitrates, phytoplankton chlorophyll, suspended particulate matter (via optical backscattering), coloured dissolved organic matter and 4-band descending solar irradiance in the spectrum of visible and ultraviolet radiation. Recent technological developments have enabled the integration of hyperspectral radiometers (> 100 bands) to measure descending irradiance and ascending radiance, transmissometers, and underwater video systems that facilitate the study of zooplankton diversity.

The profiling float currently used by CNR-ISMAR (international identifier: WMO 2903797) acquires profiles of temperature, salinity, dissolved oxygen, phytoplankton chlorophyll, suspended particulate matter (via optical backscattering), coloured dissolved organic matter, 4-band descending solar irradiance (380, 412, 490 nm and PAR - Photosynthetically Available Radiation), and zooplankton community composition.

The profiling float used by CNR-ISMAR is produced by NKE Instrumentation - model PROVOR CTS-5 Jumbo version (developed in collaboration with H. Claustre CNRS France - ERC REFINE project). A brief description of the platform and the sampling mode is provided in Figure 29.

The Jumbo version is equipped with a 66% larger battery with a nominal duration of activity ranging from 5 to 7 years. The state of the battery can be monitored to plan recovery, maintenance and renewal actions, and new launches at sea.

7.12.4.1 Scientific Impact

The CNR-ISMAR BGC-Argo float (WMO 2903797) was deployed on 20 November 2023, in the oligotrophic waters of the Ionian Sea (17.73° E, 35.92° N, Mediterranean Sea) during the PIONEER Cruise aboard the CNR's R/V "Gaia Blu". To date, the acquisition of over 60 vertical profiles within the upper 2000 m has yielded novel insights, providing a comprehensive **understanding of the influence of coastal ocean dynamics on biogeochemical processes that sustain life in offshore nutrient-poor environments**.

Three-dimensional velocity and chlorophyll concentration fields from the Mediterranean Copernicus Marine Service highlight the **role of coastal upwelling along the southern coast of Sicily**, driven by the Atlantic-Ionian Stream (AIS). This upwelling transports cold, nutrient-rich waters eastward, facilitating long-range particle transport and forming chlorophyll-rich filaments in the central Ionian Sea (Figure 30, panel a).

The CNR-ISMAR float was carried by the AIS and encountered one such chlorophyll-rich filament (Figure 30, panel b) before becoming entrapped at the edge of an anticyclonic eddy. The interaction with the filament led to sharp biogeochemical changes along the water column, with significant increases in chlorophyll and backscattering data collected down to 150 meters (Figure 30, panel c). The cold, nutrient-rich filament, funnelled between eddies with opposite vorticity, was further intensified by secondary baroclinic instabilities, which drove nutrients downward, away from the euphotic zone. Biogeochemical profiles acquired by the float confirmed that anticyclonic eddies can trap biomass from the filament at their peripheries, enhancing nutrient retention in the productive layer.

These findings underscore the scientific value of BGC-Argo floats in capturing fine-scale processes within such oligotrophic systems, providing critical insights into how life persists in nutrient-depleted regions across the global ocean.

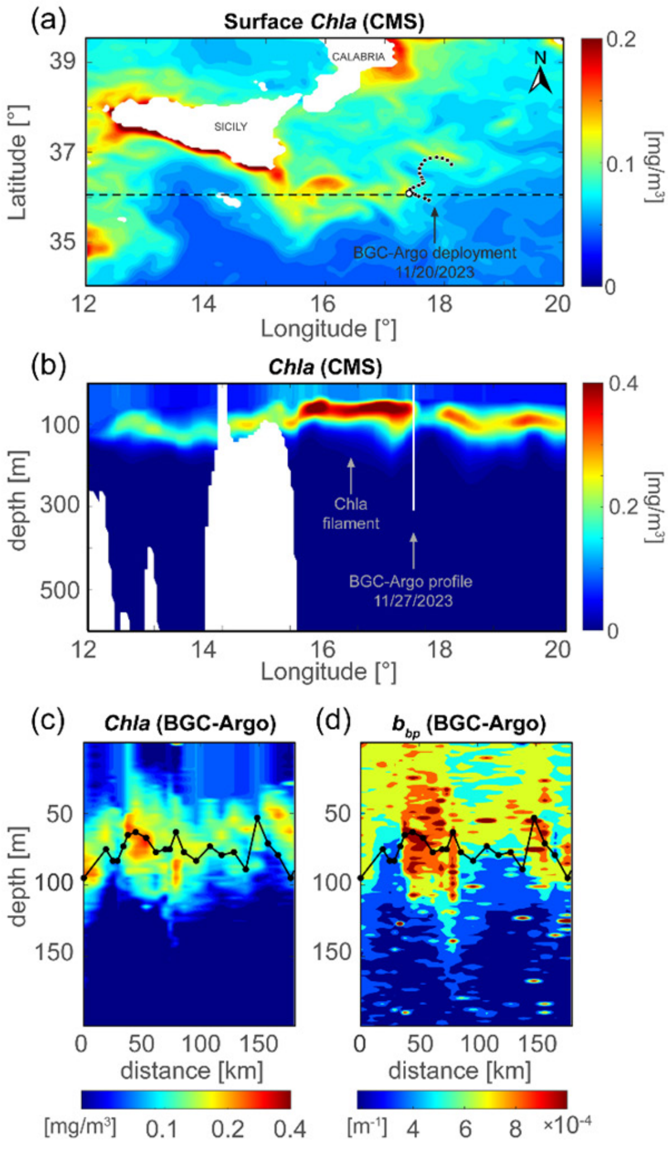

Figure 30 – Horizontal (a) and vertical (b) sections of daily averaged mass concentration of chlorophyll from CMS on Nov. 27th, 2023. The dashed line indicates the transect shown in (b), black dots depict the trajectory of the BGC-Float, while the white dot in (a) and the solid white line in (b) denote the float's position on Nov. 27th, 2023. Interpolated spatial evolution of (c) mass concentration of chlorophyll and (d) optical backscatter collected by the BGC-Argo Float (WMO 2903797) from Nov. 21th to Dec. 20th, 2023. Black lines in (c)

and (d) indicate the interpolated euphotic depth derived from simultaneous PAR measurements along BGC-Float profiles (black dots).

7.12.4.2 National/International collaborations and ESFRI contribution

The CNR-ISMAR BGC-Argo float (WMO 2903797) is 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 endeavour 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 (https://eurogoos.eu/eurogoos-argo-task-team/), in which CNR-ISMAR is also involved. The CNR- ISMAR float also contributes to Argo-Italy, the Italian node of Argo. .

The CNR-ISMAR BGC-Argo network is to be upgraded with funds from the PNRR ITINERIS project. The procurement of nine new BGC-Argo floats, equipped with hyperspectral radiometers and underwater cameras, will facilitate the monitoring of marine biodiversity in offshore waters across the Mediterranean Sea.

The CNR-ISMAR BGC-Argo float plays 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 addition, CNR-ISMAR has recently published two peer-reviewed articles as a leading institute, using the fairness of the Argo data system to validate the latest generation of satellite Lidar missions (Dionisi et al., 2024) and to evaluate the impact of extreme climate events, such as marine heatwaves on the structure and functioning of phytoplankton and zooplankton communities in the offshore pelagic realm of the Mediterranean Sea (Li et al., 2024).

7.12.4.3 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Sea Surface Temperature	2023	1, 5, 10 days	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
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
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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	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
Biological/Ecosystem			
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
Cross–disciplinary			
Ocean Colour	2023	1, 5, 10 days	CNR–ISMAR

7.12.4.4 Publications

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.

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Stoer A.C., Takeshita Y., Maurer T.L., Begouen Demeaux C., Bittig H.C., Boss E., Claustre H., Dall'Olmo G., Gordon C., Greenan B.J.W., Johnson K.S., Organelli E., Sauzède R., Schmechtig C.M., Fennel K. (2023). A census of quality-controlled Biogeochemical-Argo float measurements. Frontiers in Marine Sciences 10: 1233289. doi: 10.3389/fmars.2023.1233289.

Uitz J., Roesler C., Organelli E., Claustre H., Penkerc'h C., Drapeau S., et al. (2023). Characterization of bio-optical anomalies in the Kerguelen region, Southern Indian Ocean: A study based on shipborne sampling and BioGeoChemical-Argo profiling floats. Journal of Geophysical Research: Oceans, 128: e2023JC019671. https://doi. Org/10.1029/2023JC019671.

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Terzić E., Miró A., Organelli E., Kowalczuk P., D'Ortenzio F., Lazzari P. (2021). Radiative Transfer modeling with Biogeochemical-Argo float data in the Mediterranean Sea. Journal of Geophysical Research Oceans 126: e2021JC017690, https://doi.org/10.1029/2021JC017690.

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Lazzari P., Salon S., Terzić E., Gregg W., D'Ortenzio F., Vellucci V., Organelli E., Antoine D. (2021). Assessment of the spectral downward irradiance at the surface of the Mediterranean Sea using the radiative Ocean-Atmosphere Spectral Irradiance Model (OASIM). Ocean Science 17: 675-697, https://doi.org/10.5194/os-17-675-2021.

Organelli E., Claustre H. (2019). Small phytoplankton shapes colored dissolved organic matter dynamics in the North Atlantic subtropical gyre. Geophysical Research Letters 46: 12183-12191, https://doi.org/10.1029/2019GL084699.

Bittig H.C., Maurer T.L., Plant J.N., Wong A.P.S., Schmechtig C., Claustre H., Trull T.W., Bhaskar T.V.S.U., Boss E., Dall'Olmo G., Organelli E., Poteau A., Johnson K.S., Hanstein C., Leymarie E., Le Reste S., Riser S.C., Rupan A.R., Taillandier V., Thierry V., Xing

X. (2019). A BGC-Argo guide: Planning, deployment, data handling and usage. Frontiers in Marine Science 6: 502, https://doi.org/10.3389/fmars.2019.00502.

Bellacicco M., Cornec M., Organelli E., Brewin R.J.W., Neukermans G., Volpe G., Barbieux M., Poteau A., Schemchtig C., D'Ortenzio F., Marullo S., Claustre H., Pitarch J (2019). Global variability of optical backscattering by non-algal particles from a Biogeochemical-Argo dataset. Geophysical Research Letters 46: 9767-9776, https://doi.org/10.1029/2019GL084078.

Terzić E., Lazzari P., Organelli E., Solidoro C., Salon S., D'Ortenzio F., Conan P. (2019). Merging bio-optical data from Biogeochemical-Argo floats and models in marine biogeochemistry. Biogeosciences 16: 2527-2542, https://doi.org/10.5194/bg-16-2527-2019.

Barbieux M., Uitz J., Bricaud A., Organelli E., Poteau A., Schmechtig C., Gentili B., Obolensky G., Leymarie E., Penkerc'h C., D'Ortenzio F., Claustre H. (2018). Assessing the variability in the relationship between the particulate backscattering coefficient and the chlorophyll a concentration from a global Biogeochemical-Argo database. Journal of Geophysical Research Oceans 123: 1229-1250, https://doi.org/10.1002/2017JC013030.

Organelli E., Barbieux M., Claustre H., Schmechtig C., Poteau A., Bricaud A., Boss E., Briggs N., Dall'Olmo G., D'Ortenzio F., Leymarie E., Mangin A., Obolensky G., Penkerc'h C., Prieur L., Roesler C., Serra R., Uitz J., Xing X. (2017). Two databases derived from BGC-Argo float measurements for marine biogeochemical and bio-optical applications. Earth System Science Data 9: 861-880, https://doi.org/10.5194/essd-9-861-2017.

Organelli E., Claustre H., Bricaud A., Barbieux M., Uitz J., D'Ortenzio F., Dall'Olmo G. (2017). Bio-optical anomalies in the World's oceans: An investigation on the diffuse attenuation coefficients for downward irradiance derived from Biogeochemical Argo float measurements. Journal of Geophysical Research Oceans 122: 3543-3564, https://doi.org/10.1002/2016JC012629. Selected as research spotlight by EOS - the Earth and Space Observation US magazine (https://doi.org/10.1029/2017EO073123).

Roesler C., Uitz J., Claustre H., Boss E., Xing X., Organelli E., Briggs N., Bricaud A., Schmechtig C., Poteau A., D'Ortenzio F., Ras J., Drapeau S., Haëntjens N., Barbieux M. (2017). Recommendations for obtaining unbiased chlorophyll estimates from in situ chlorophyll fluorometers: A global analysis of WET Labs ECO sensors. Limnology and Oceanography Methods 15: 572-585, https://doi.org/10.1002/lom3.10185. Top downloaded article 2017-2018.

Xing X., Claustre H., Boss E., Roesler C., Organelli E., Poteau A., Barbieux M., D'Ortenzio F. (2017). Correction of profiles of in-situ chlorophyll fluorometry for the contribution of fluorescence originating from non-algal matter. Limnology and Oceanography Methods 15: 80-93, https://doi.org/10.1002/lom3.10144.

Organelli E., Claustre H., Bricaud A., Schmechtig C., Poteau A., Xing X., Prieur L., D'Ortenzio F., Dall'Olmo G., Vellucci V. (2016). A novel near-real-time quality-control procedure for radiometric profiles measured by Bio-Argo floats: Protocols and performances. Journal of Atmospheric and Oceanic Technology 33: 937-951, https://doi.org/10.1175/JTECH-D-15-0193.1.

7.12.4.5 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)**

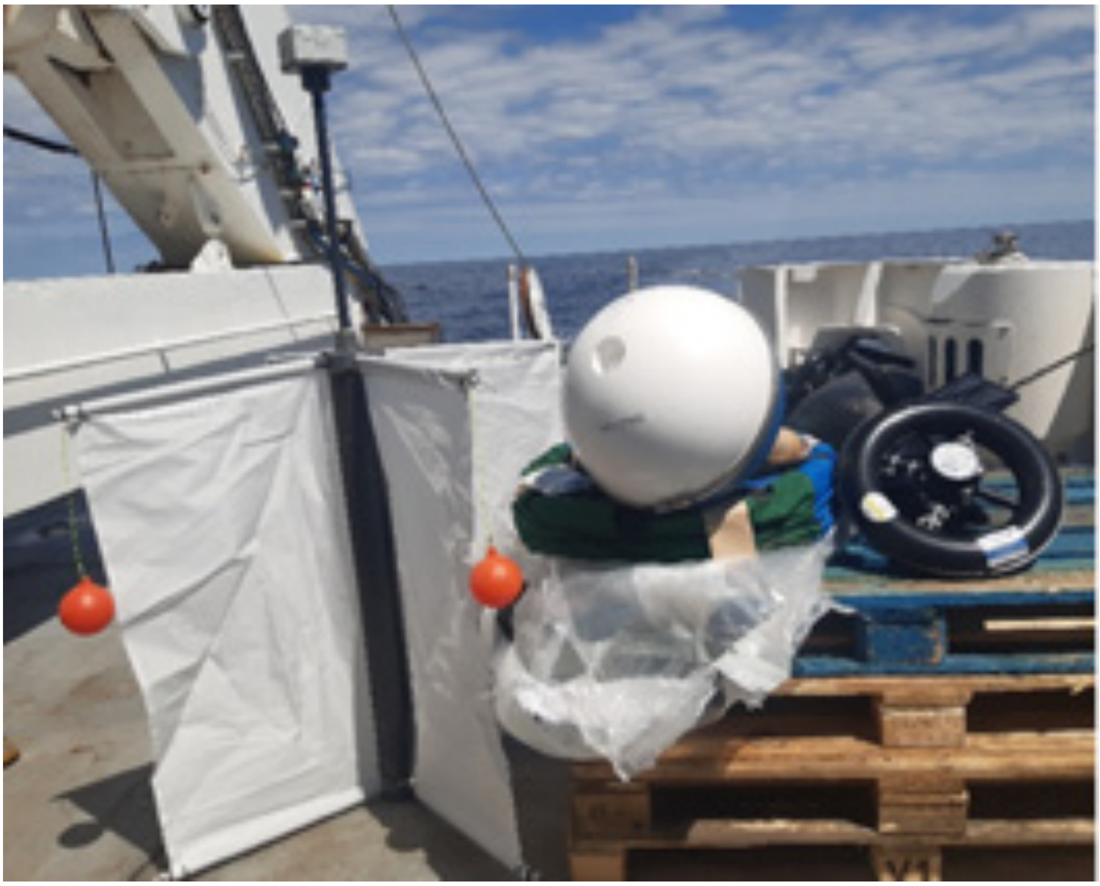

Figure 31 – Several examples of Lagrangian drifters (CARTHE, CODE, SVP)

Drifting buoys, also known as "drifters", are oceanographic instruments designed to follow ocean currents, thereby proving information on their GPS position at regular fixed time intervals, via satellite communication (e.g., Iridium system) or GSM. These instruments are capable of measuring a variety of parameters that characterize the water masses, including temperature, salinity and other physical quantities. Additionally, they can also measure biogeochemical variables derived from measurements of phytoplankton chlorophyll 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 depths (CARTHE and CODE) or even a few centimetres from the surface (SPOTTER), depending on the applications of interest.

7.12.5.1 Scientific Impact

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 levels. 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 (BioGeoChemical SVP drifter, BGC-SVP; Bellacicco et al., 2024; Figure 32). The integration of these observations enables to unravel the mechanisms underlying bio-physical dynamics in the ocean, which are fundamental to ocean ecosystem productivity (e.g., the **study the biological responses of phytoplankton to ocean dynamics and physical structures**).

Furthermore, drifters find applications in more operational scenarios, such as the **tracking of 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.

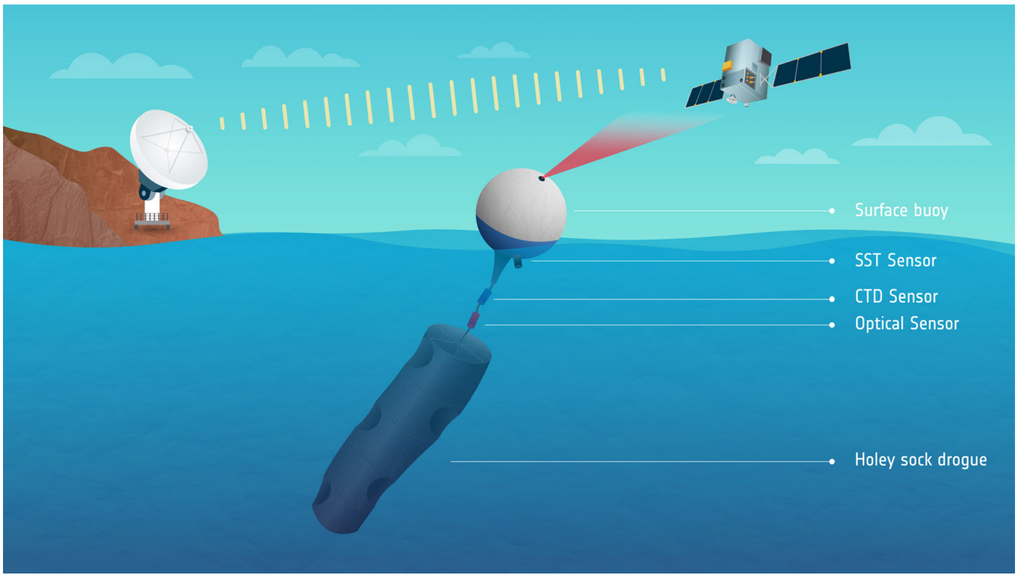

Figure 32 – Infographic picture showing a deployed BGC-SVP drifter with indicated the depths of the SST, CT, and optical sensors. Oxygen integration is an ongoing activity, from Bellacicco et al., (2024).

7.12.5.2 National/International collaborations and ESFRI contribution

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

Over the past 15 years, CNR-ISMAR has participated 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 33 and Figure 34).

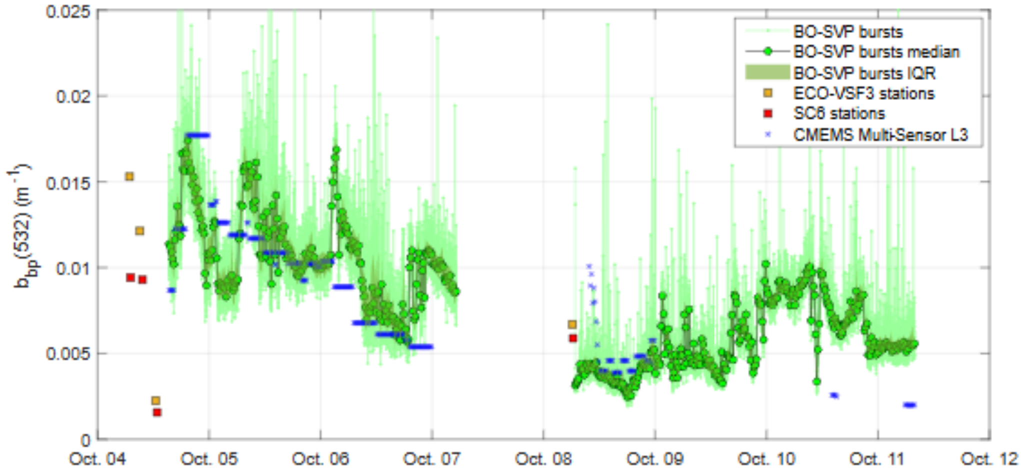

Figure 33 – Original (bursts) and 15-min median bbp (532) time series collected by the BGC-SVP drifter in the Tyrrhenian Sea with overlaid corresponding independent in situ cruise data and the median satellite value of a 3x3 box for each drifter position obtained from daily ocean color product. Figure from Bellacicco et al., (2024).

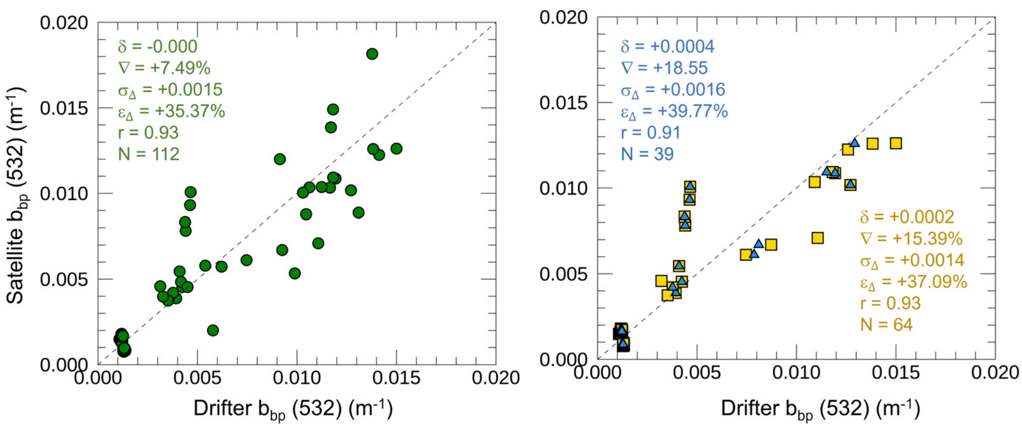

Figure 34 – Matchups between space-borne bbp observations and all in situ bbp collected by BGC-SVP drifter during the COSIMO22 oceanographic cruise held during November 2022 in the Tyrrhenian Sea and BIOSWOT-Med cruise held in May 2023 (left panel). In the right panel, gold squares are matchups obtained 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 as well the deployment 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 2025–2026 it is envisaged the participation in the following national/international cruises:

- PATASWOT (https://www.swot-adac.org), NASA-CNES Program: CARTHE drifters will be deployed in the Malvinas Current in 2025-2026 for the validation of SWOT satellite altimetry and for the investigation of local transport pathways, including vertical velocities.
- ITINERIS (PNRR Program): by the conclusion of the project (summer 2025), a cruise in the Mediterranean Sea (ITINERIS EYES), is likely to be organized in subsequent lags, that will involve the majority of the new infrastructures for an extended multiplatform experiment including CARTHE, BGC-SVP drifters, BGC-Argos, gliders and HF radars.

7.12.5.3 Observed variables

Essential Climate and Oceanic Variables (ECVs and EOVs)			
Variable	**Operational Measurements Start**	**Measurement interval**	**Institution**
Ocean			
Physical			
Surface currents	Targeted deployments. Data 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

7.12.5.4 Publications

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M. Berta, A. Griffa, M.G. Magaldi, T.M. Ozgokmen, A.C. Poje, A.C. Haza, M. J. Olascoaga (2015). Improved surface velocity and trajectory estimates in the Gulf of Mexico from blended satellite altimetry and drifter data. Journal of Atmospheric and Oceanic Technology vol.32, 18801901. Doi: 10.1175/JTECH-D-14-00226.1.

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M. Berta, L. Ursella, F. Nencioli, A.M. Doglioli, A.A. Petrenko, S. Cosoli (2014). Surface transport in the Northeastern Adriatic Sea from FSLE analysis of HF radar measurements. Continental Shelf Research vol.77, pp.14-23. Doi: 10.1016/j.csr.2014.01.016

7.12.5.5 Open Data

Drifters' data are available in open format through a variety of platforms, as listed below:

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

As outlined in Paragraph 7.12.5, there are numerous types of drifter buoys. Among these, drifting wave buoys are frequently used as instruments for measuring the free surface elevation in the ocean. This is due to the fact that they can be installed with relative ease, thus obviating the need for a supporting structure. Traditionally, the volume of such measurements has been limited by the high cost of commercially available instruments. However, an increasingly attractive solution that overcomes this issue is to use instruments produced in–house from open–source hardware and firmware, such as the OpenMetBuoys (OMB) developed at the Norwegian Meteorological Institute (Rabault et al., 2022).

These drifters have lateral dimensions of 16 x 16 cm and a height of 9 cm with an overwater structure measuring approximately 3 cm. Powered by alkaline batteries, they have an operational period of approximately 2 months, which could be extended with higher-capacity batteries. Each drifter is equipped with an inertial measurement unit (IMU) with six degrees of freedom, enabling precise high-frequency measurements of acceleration and angular rates in the three spatial dimensions. Wave spectra, covering a frequency range between 0.040 and 0.307 Hz, are acquired at fixed intervals with measurements taken for 20 minutes every 3 hours. Additionally, a GPS module is integrated for tracking the drifters' positions at 30–minute intervals. The impact of direct windage effects is minimized due to the small size and immersion-to-windage ratio of the drifters, which is especially advantageous in strong current regions where surface drift is primarily driven by geostrophic currents.

7.12.6.1 Scientific Impact

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).

Furthermore, the trajectory of these instruments can be used in a more conventional manner, to examine the **dispersion of particles drifting near the surface**, which may include fish eggs, macro plastics or ship debris, under the influence of a combination of Eulerian currents and the Stokes drift associated with the wind-generated surface wave field.

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 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 36). 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.

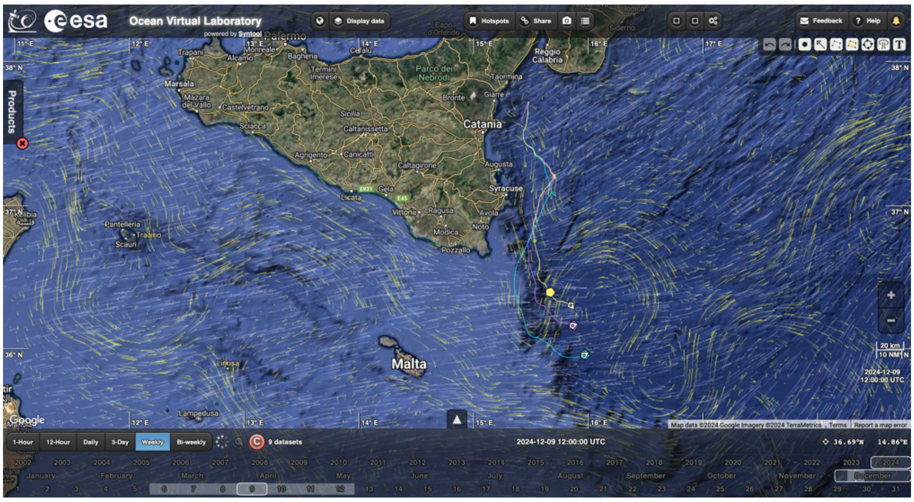

Figure 36 – Screenshot of the Ocean Virtual Lab portal (https://ovl.oceandatalab.com/) showing the tracks (blue-, magenta- and yellow-coloured lines) of the three wave drifters deployed in the Ionian Sea during the MARSiCo-2024 cruise.

7.12.6.2 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

7.12.6.3 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

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Rabault, J.; Nose, T.; Hope, G.; Muller, M.; Breivik, O.; Voermans, J.; Hole, L.R.; Bohlinger, P.; Waseda, T.; Kodaira, T.; et al. OpenMetBuoy-v2021: An Easy to-Build, Affordable, Customizable, Open-Source Instrument for Oceanographic Measurements of Drift and Waves in Sea Ice and the Open Ocean. Geosciences 2022, 12, 110. https://doi.org/10.3390/geosciences12030110

7.12.6.4 Open Data

Drifting wave buoys data are available through the following platform:

https://ovl.oceandatalab.com/

8 Conclusions

Italy, due to the extension of its coasts, its geographical position and cultural tradition, has the possibility of playing a central leadership role in the Mediterranean Sea on the topic of observation and multidisciplinary oceanographic modelling activity, in capable of integrating aspects and knowledge relating to physical oceanography, with the implications and study of the interaction processes with the seabed and the atmosphere, with those relating to biogeochemistry, up to the monitoring and forecasting of the sustainable exploitation of resources.

To this end, technical-scientific coordination is essential, supported by adequate planning of economic investments in existing structures, which guarantees continuity, operation and access to data for the purposes of knowledge, prediction and support for political and management decision makers.

To do this it therefore appears necessary that the research infrastructures linked to marine observatories are progressively interconnected and structured.

Existing sites and networks must be consolidated, maintained and updated with advanced and innovative sensors, and it is desirable that they be integrated with new measurement points in critical areas.

Finally, access to data must be rationalized and structured, where not already present, to guarantee international distribution in an open manner.

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