The Mediterranean observation systems: MonGOOS analysis of present capabilities, weaknesses and perspectives.

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Abstract. Ocean monitoring is a crucial component of Earth's observation systems. These systems have evolved to achieve a global scope and an exceptionally high level of complexity, encompassing not only observation programs but also data centres for collection and storage, as well as computational facilities where predictions and re-analyses of oceanic conditions are generated using coupled ocean-atmosphere circulation models. The products generated by the different components of the oceanic observation systems are of paramount importance for the knowledge of the environmental state of the oceans, their variability ranges, the impact of natural and anthropogenic stressors (such as climate change) and, in summary, the appropriate governance of the sea and the sustainable use of its resources.

Given the diverse nature of the data (collected through a wide range of technologies, instruments, and institutions across multiple countries), it can be challenging to maintain a comprehensive overview of existing observation programs and datasets. MonGOOS (Mediterranean Oceanographic Network for the Global Ocean Observing System) serves as a GOOS (Global Ocean Observing System) Regional Alliance (GRA). Through its Observations Working Group (OBSWG), MonGOOS has conducted an extensive consultation among Mediterranean institutions to compile information on ongoing observation programs and the institutions operating within this basin. The results of this consultation, obtained through the collaboration of a very large number of scientists and technicians from a wide range of institutions, are reflected in this community report. The objectives of this communication~~report~~ are:

i) To update our knowledge of existing observation capabilities in the Mediterranean Sea. ii) To identify contact persons for strengthening the current MonGOOS network in order to keep this information up to date in the future. iii) To describe the present strengths and weaknesses of the Mediterranean Sea's observation system. iv) To support European ocean observation programs such as the Copernicus Marine Service and the European Marine Observation and Data Network (EMODnet).

The consultation phase began in July 2023 and continued until December 2025. It included a survey addressed to 90 researchers from 59 institutions across 18 countries as well as contacts with several EuroGOOS task teams, IOC (Intergovernmental Oceanographic Commission) sea level monitoring, as well as OceanOPS, for the compilation of metadata. During this consultation phase, the list of researchers addressed increased to 128. Finally, metadata from observation activities were obtained from 74 institutions belonging to 16 countries, 4 companies and the European Joint Research Centre (JRC).

The description of all the observation capabilities in the Mediterranean Sea is not closed and should be considered as an ongoing effort to be reviewed periodically and more systematically in the future. However, we believe that this objective has been accomplished to a high degree of detail and inclusivity. The present compilation includes most of the currently active and operational observing systems, including 80 Argo floats and 16 surface drifters, 58 high-frequency radars (HFR), 220 tide gauges and 88 tsunami alerting devices, 9 periodic or sustained glider lines, 5 FerryBox lines, 11 wave buoys, 36 subsurface or deep moorings, 46 meteorological and oceanographic surface buoys, 5 seabed platforms or cabled observatories, 13 periodic transects or repeated cruises, and 17 oceanographic stations visited on a regular basis (time-series stations).

The present survey revealed a strong asymmetry in the distribution of these platforms, reflecting a clear discrepancy in the capabilities of different Mediterranean countries. It also shows the difficulty for maintaining long-term observations, the

fragility of some of these programs, and the need for national programs with structural and sustainable funds that are not only subject to competitive financial support

1 Introduction

It is impossible to overstate the importance of the oceans to our planet. They have~~It has~~ been (and continue~~s~~ to be) decisive for the emergence and evolution of life, as well as for regulating Earth's climate, to name just a few key aspects. Human societies also benefit from the different functions of marine ecosystems, described by the term 'ecosystem services'. These services are of paramount importance for human well-being and include multiple functions such as food production, nutrient recycling, primary production, and climate regulation (MEA, 2005; Cooley et al., 2022).

However, many anthropogenic pressures threaten these services and the overall health of the oceans. Among these~~,~~ are those associated with population growth driven by coastal migration (Neumann et al., 2015) and the intensification of maritime traffic. While, in principle, this increase could be considered as beneficial, as it is linked to economic development and the growth of countries' gross domestic product, it also poses significant environmental risks. These risks include a higher incidence of biological invasions (Sardain et al., 2019; Albano et al., 2021; Garrabou et al., 2022; Albano et al., 2024), an increased likelihood of accidental oil spills (Keramea et al., 2023; Liubartseva et al., 2025), eutrophication (Karydis and Kitsiou, 2012), plastic pollution (Liubartseva et al., 2018; Segur and Sonke, 2025), underwater noise (ACCOBAM, 2025), and the impact of maritime traffic on cetaceans (Cunha et al., 2017; Minton et al., 2021) and other marine organisms.

In addition to these threats, climate change already has a profound impact on the ocean, and further changes are anticipated in the coming decades (IPCC, 2021; Hassoun et al., 2025). Such climatic changes are projected to significantly affect marine ecosystems, for example, by inducing shifts in marine species populations caused by sea water warming. Simultaneously, coastal populations are increasingly vulnerable to direct consequences, including sea level rise and the escalating frequency and intensity of extreme events such as hurricanes and associated storm surges (Wolff et al., 2018; Miglietta and Rotunno, 2019), and marine heat waves (Juza et al., 2022; Dayan et al., 2023; Marullo et al., 2023; Pastor and Khodayar, 2023).

Ocean observing systems are currently organized under the umbrella of the Global Ocean Observing System (GOOS; see supplementary material for a glossary of acronyms), which is co-sponsored by the Intergovernmental Oceanographic Commission (IOC/UNESCO), the World Meteorological Organization (WMO), the United Nations Environment Program (UNEP) and the International Science Council (ISC). ~~However, r~~Regional ocean observing programs are highly diverse and monitor a wide range of variables, reflecting the specific objectives of each program as well as the priorities of their supporting funding agencies or institutions. According to GOOS, all of them should include ‘a minimum set of key variables that are critical to understanding ocean change and guiding policy’. These variables are considered as Essential Ocean Variables (EOVs; see for instance https://goosocean.org/what-we-do/framework/essential-ocean-variables/ and Martin Minguez et al., 2026 for a complete description and discussion about EOVs). Eventually, most of these variables (both EOVs and non-essential ones, for instance, those not included in the GOOS list; Martin Minguez et al., 2026) feed databases that describe the prevailing

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physical and biogeochemical state of marine ecosystems across different regions of the global ocean. These observations allow the detection of climatic long-term trends, extremes and anomalies. Additionally, the data collected are of high importance for the assimilation into numerical models that allow us to i) forecast short-term ocean conditions, ii) make projections about their future evolution based on the current climate change scenario, iii) perform long-term simulations backwards to generate consistent ocean reanalysis products, iv) support understanding of local land-sea interface dynamics for better environmental monitoring and preservation policies, v) provide sea surface currents in real time to support responsible entities during pollution mitigation and search and rescue activities.

In this way, global ocean observation systems integrate multiple aspects, including observation, numerical modelling, and the application of information for the proper management of the seas. ~~However, o~~Observations are the basis of this whole system since our capacity to describe the current state of the ocean depends on the available information. Besides this, the ability of our models to adequately describe and predict the potential dynamics and biogeochemistry of our seas also depends on the quality and quantity of the data assimilated into them (Virapongse et al., 2020).

These observation systems are also of paramount importance for the implementation of an efficient governance of the ocean, including Marine Protected Areas (MPAs), policies oriented to marine Carbon Dioxide Removal (CDR) and Zero Pollution Action Plan or the development of international treaties such as Biodiversity Beyond National Jurisdiction (BBNJ). They are essential for achieving a sustainable use of marine ecosystem services, preserving the good environmental status of regional seas, increasing maritime transport safety and mitigating climate change effects on coastal populations and beyond (Cappelletto et al., 2021). Therefore, it is crucial to determine the current state of these systems as accurately as possible, both globally and in regional seas. This task is particularly critical in the case of the Mediterranean Sea for several reasons (Tintoré et al., 2019; Mourre et al., 2022; Hassoun et al., 2025): First, this semi-enclosed sea's geographic context is highly complex, with riparian countries from three continents, which complicates coordination tasks. Second, sea warming in the Mediterranean Sea has been reported to be two or three times higher than that for the global average (Juza and Tintoré, 2021; Vargas-Yáñez et al., 2023). Last, but not least, the Mediterranean Sea is relatively small, accounting for less than 0.32% of the volume of the world's ocean and less than 1% of its surface. However, it hosts exceptionally high biodiversity, harbouring between 4% and 18% of all known macroscopic marine species, along with a high degree of endemism. These characteristics lead it to be considered a biodiversity hotspot (Bianchi and Morri, 2000; 2003).

The Mediterranean Sea is undergoing rapid and unprecedented changes driven by climate warming, marine heatwaves, biological invasions, overexploitation, pollution, and habitat degradation. These cumulative stressors are reshaping ecosystem structure and functioning, accelerating the tropicalization of Mediterranean biota, altering species distributions, and increasing the frequency and intensity of Mass Mortality Events (MMEs) affecting key habitat-forming species such as corals, gorgonians, and sponges. Such changes are contributing to biodiversity loss, population declines, and reduced ecosystem resilience, with cascading impacts on ecosystem services and regional socio-economic stability (Albano et al., 2021; Garrabou et al., 2022; Albano et al., 2024; Darmaraki et al., 2024; Hassoun et al., 2025; Vargas-Yáñez et al., 2025).

All the reasons outlined above make the monitoring of Mediterranean waters a task of paramount importance. Hence, this work tackles the aforementioned issue of describing and analysing the current state of the Mediterranean observation capabilities, which falls under the activities of MonGOOS (Mediterranean Oceanographic Network for the Global Observing System), a GOOS Regional Alliance (GRA), evaluating their strengths and weaknesses to outline a path for their future development.

Beyond this primary objective, this work also aims to serve as a guide or resource for those seeking information on marine observations in the Mediterranean Sea. It is important to recognize that ocean observation systems must, and indeed do, serve a broad community of users, extending beyond the oceanographic community involved in data collection and management. This community also includes policymakers, end-users, and the general public. Key stakeholders are the monitoring programs (e.g Copernicus Marine Service, European Marine Observation and Data network - EMODnet, etc), marine conventions (ACCOBAMS, Barcelona convention) and marine directives (e.g. Marine Strategy Framework Directive, Marine Spatial Planning, Water Framework Directive, etc). For this reason, an effort has been made to provide a clear and accessible description of the various observation systems, as well as the way in which the institutions involved in this field are structured.

2 Observation methods

Ocean observation methods are diverse and complex, with varying levels of spatial and temporal resolution and markedly different spatial coverage, often requiring the integration of multiple observational approaches. It is therefore more appropriate to refer to a *system of systems* for ocean observation. A full description of all these systems lies beyond the scope of this work and would require a far more extensive treatment. However, for the sake of completeness, below we provide a brief summary of the main observation components. This briefshort overview is intended to facilitate understandingthe reading of the following sections, which describe the current statuse of the different components of marine observations in the Mediterranean Sea (see Figure 1), and to provide guidanceserve as a guide for researchersa broader audience from related disciplines who are not directly involved in marine observation activities.

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The methods of ocean observation can be divided, in a somewhat simplistic way, as outlined in Fig. 1. A first division distinguishes between autonomous sensors and manually operated ones (see left column in Fig. 1). Autonomous sensors include those devices that work automatically without the need of an operator. In turn, among autonomous sensors, we distinguish those that operate remotely and those that do so *in situ* (see central column in Fig. 1). In the case of devices operated manually, they can only produce *in situ* measurements. Within autonomous devices that operate remotely, we can differentiate the first group of observations gathered by sensors installed on artificial satellites, airplanes or aerial drones (space-based remote sensing). These sensors collect observations from a great distance, without being in contact with the observed medium (the sea in this case). The most widely used sensors in ocean observation are radiometers, altimeters, scatterometers and radars. Radiometers are passive sensors which measure the electromagnetic radiation backscatter or emitted by the surface or the first

meters of the ocean at different frequency bands. This can be used to estimate sea surface temperature (from infrared radiation), conductivity or salinity (L-band microwave) or surface concentration of chlorophyll-*a* (through optical electromagnetic spectrum bands). Radars are active sensors that emit pulses of electromagnetic radiation and estimate a number of variables from the back-reflected signal. Among those variables, altimeters measure the elevation of the sea surface from the time elapsed between the emission of these pulses and the reception of the wave. Scatterometers allow for the reconstruction of the surface wind field from the roughness of the sea surface. Synthetic aperture radars (SARs) are imaging systems providing a very high-resolution two-dimensional reconstruction~~s~~ of the sea surface, including detection of oil spills (Zakzouk et al., 2025). Other autonomous and remote observation methods are gravimetric measurements, from which the water mass ~~contained~~ in a certain region of the ocean can be estimated. This is an essential component of the study of long-term sea level variations. The other group of autonomous and remote sensors are High Frequency Radars (HFRs). However, in this case, these active sensors are not operated from artificial satellites, but from shore-based stations. Thus, they can be defined as land-based remote sensing systems. HFRs are capable of measuring ocean surface currents (Capodici et al., 2019; Corgnati et al., 2021; Guérin et al., 2021; Lorente et al., 2022; Corgnati et al., 2024; Doronzo et al. 2025), sea state (Saviano et al., 2021; Lorente et al., 2022; Ursella et al., 2024; Morales-Marquez et al., 2025), and wind (Shen and Gurgel, 2018; Saviano, 2021), using the frequency difference between electromagnetic waves emitted and reflected by the sea surface. They monitor surface currents over wide areas (up to 80 km offshore for the most common systems installed in the Mediterranean Sea) in near-real time and with high spatiotemporal resolution (generally few kilometres and hourly frequency). These characteristics have made them an essential component of coastal ocean observing systems (Lorente et al., 2022), supporting a wide range of applications (Reyes et al., 2022), from maritime safety to monitoring of extreme hazards and environmental transport processes.

The other category, within autonomous devices, is made of those sensors which operate *in situ*, measuring different properties of the sea at the same measuring point where the sensor is located (either on the surface or at a certain depth of the sea). These devices include tide gauges, which measure sea-level rise from installations located in coastal infrastructures such as ports, either by a system of buoys or, more recently, using radar technology (IOC/UNESCO, 2016). Tide gauges provide accurate sea level data at all frequency ranges along the coastline since as far back as the nineteenth century in some harbours. Originally used for tides and hydrography in support of navigation and port operations, real time data are today integrated as an essential component of storm surge and tsunami/meteo tsunami warning systems. At the same time, long-term sea-level records from tide gauges remain fundamental for assessing coastal sea-level rise, especially when complemented with satellite altimetry data (Oppenheimer et al., 2019).

The group of in situ autonomous sensors also includes those installed in atmospheric and oceanographic buoys anchored to the sea bottom. These sensors may be accelerometers, which measure the frequency and height of waves, atmospheric sensors which measure temperature, humidity, atmospheric pressure as well as the direction and intensity of the wind or incident solar radiation, or oceanographic sensors, measuring sea temperature and conductivity (salinity), oxygen concentration, chlorophyll-*a* fluorescence, pH, turbidity and other variables. These buoys may also be equipped with Acoustic Doppler Current Profilers (ADCP) that measure the direction and intensity of marine currents at different depths using the Doppler effect. In other cases,

there are underwater stations located on the seabed (usually in shallow waters) that measure the above mentioned variables at the depth at which the underwater station is located. Finally, among the devices anchored to the sea floor, there are lines moored at greater depth and with a series of devices extending from the bottom of the sea to the surface or subsurface by means of a series of buoys that give buoyancy to the line. The sensors usually installed in these mooring lines are meant to measure pressure, temperature, conductivity (salinity), and direction and intensity of the current, but can also include turbidimeters and sediment traps to measure suspended particles and capture marine snow. There are different ways of transmitting data from the anchored devices. Tide gauges, weather and ocean buoys and wave buoys usually transmit data in real time via telephone or internet (cables), while deep anchorages work self-contained and data are registered and then downloaded during maintenance/retrieval operations carried out by oceanographic vessels.

Within this category of autonomous devices that operate *in situ*, we also have Argo floats (since the beginning of the 21st century) and surface drifters (since the 1970s). Unlike stations anchored to the sea floor, these devices drift freely with the current and therefore, they have a Lagrangian character, in contrast to the Eulerian nature of fixed platforms

Argo floats periodically descend to a predetermined depth and then, during the ascent, they record pressure, temperature, conductivity, and sometimes biochemical variables, depending on the float type: (i) Core-Argo floats provide temperature and salinity (T/S) profiles down to 2,000 dbar. (ii) BioGeoChemical Argo (BGC-Argo) floats are equipped with sensors for dissolved oxygen, pH, nitrate, chlorophyll-a, suspended particles (via optical backscattering), and irradiance. (iii) Deep-Argo floats are capable of sampling to depths of 4,000–6,000 dbar. These data are finally transmitted via satellite by the Iridium and ARGOS systems. At present, the international Argo program constitutes a global network of about 4200 autonomous profiling floats covering the world ocean (https://www.ocean-ops.org/) and has become a major component of GOOS, providing fully FAIR (Findable, Accessible, Interoperable, and Reusable) and open and free data (Tanhua et al., 2019), supporting climate research, ocean forecasting, and marine services (Roemmich et al., 2019).

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Surface drifters are deployed at the sea surface and include a drogue or holey sock designed to follow near-surface currents. While standard Surface Velocity Program (SVP) drifters usually have drogues centred at around 15 m depth, different configurations exist, with drogues positioned at various depths depending on the targeted layer of the upper ocean and the specific application (e.g. circulation studies, HFR validation, or Lagrangian transport analysis). Their tracked positions allow the estimation of near-surface current velocities, and they are typically equipped with sensors measuring sea surface temperature, salinity and atmospheric pressure, among other variables. Data sets are transmitted via the Iridium system. Surface drifters are coordinated globally within the framework of the Data Buoy Cooperation Panel (DBCP), a joint initiative of WMO and IOC/UNESCO, which oversees the deployment and operation of drifting buoys worldwide.

The autonomous instruments mentioned above are all either fixed or passively transported by currents. The use of a new class of autonomous *in situ*-measuring devices is spreading rapidly (Rudnick et al., 2004). For instance, underwater gliders are buoyancy-driven autonomous platforms that operate without a propeller or traditional thruster, and move horizontally and vertically according to a predetermined mission plan. They can cover long distances over weeks or months and measure a range of variables, depending on their payload (*e.g.*, temperature, salinity, currents, oxygen, fluorescence, pH, turbidity,

turbulence). The collected data are transmitted via satellite each time the glider resurfaces. Finally, new technologies are incorporating to this set of autonomous devices. Among such, we should mention the surface autonomous vehicles (ASVs, Benatti et al., 2025).

Manual observation methods include all measurements taken from oceanographic or commercial vessels that must be moved to the location where the measurement is performed (oceanographic station). When observations are carried out from oceanographic vessels, they usually include measurements of pressure, temperature, conductivity (salinity), fluorescence, dissolved oxygen and turbidity performed by means of electronic probes such as CTDs (Conductivity-Temperature-Depth). These instruments are lowered from the vessel to the seabed using a winch and an electromechanical cable. Current profiling can also be carried out using Doppler current profilers, which are similarly lowered from the vessel. *In situ* sampling also enables water collection, typically using oceanographic bottles installed on a rosette or carousel. These samples, once analysed in the laboratory or aboard the vessel, allow the determination (among others) of nutrient concentrations, chlorophyll-*a*, dissolved oxygen, pH, total alkalinity, dissolved inorganic carbon, as well as the abundance and taxonomic composition of phytoplankton, heterotrophic prokaryotes, viruses, or zooplankton communities. Sampling at oceanographic stations can be divided into single station monitoring programs and multi-station surveys, in which stations are distributed along one or more transects. The visit of these stations is carried out in oceanographic campaigns. Usually, single station monitoring programs have a higher sampling frequency (weekly, fortnightly or monthly) than transects or larger-scale surveys, which, are often repeated on a quarterly, semi-annual or annual basis.

Commercial vessels on regular routes can be used for ongoing oceanographic monitoring. They routinely deploy XBTs (Expendable Bathythermographs) to measure temperature and salinity, or use thermosalinographs and/or FerryBoxes for continuous measurements of temperature, salinity, pH, pCO_2, surface fluorescence, etc. utilizing the ships' seawater supply. These thermosalinographs are also commonly installed on research vessels, collecting data while in transit between dedicated oceanographic stations. Recent developments include automatic flow cytometers which determine phytoplankton or prokaryotic abundances while in route (Pernice and Gasol, 2023).

The schematic description outlined above is summarised in Figure 1. However, it should be kept in mind that new technologies are continually emerging. Accordingly, this summary considers the technological tools that are most widely used at present, while the final section, devoted to future perspectives, will address some of the emerging technologies. In addition, the red rectangles in Fig. 1 highlight the observation platforms on which we will focus throughout this work when describing some of the current observational capabilities in the Mediterranean Sea.

Both this schematic and the analyses presented in the following sections require that the terminology employed be clearly defined. The EuroGOOS (https://eurogoos.eu/) regional alliance is structured in 6 task teams that correspond to 6 different types of oceanographic instruments or platforms: Argo (floats), FerryBox, Fixed Platforms, Gliders, HFRs and Tide Gauges. MonGOOS (https://mongoos.eurogoos.eu/) includes the following operational platforms: HFR, Open Ocean Fixed Oceanographic Stations, Profilers and drifters Med Argo, Gliders, and Repeated Cruises. The platforms and networks listed on OceanOPS (https://www.ocean-ops.org/) include: Argo, HFRs, DBCP, mainly for surface drifters, OceanSITES for

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moorings sampling the full water column, SOT (Ship Observations Team) which includes Voluntary Observing Ships (VOS) and Ships of Opportunity (SOOP), GO-SHIP for repeated cruises from research vessels, GLOSS for the Global Sea Level Observing System, and Ocean Gliders.

~~Therefore, d~~Different organisations show slight differences in how they group and name observation platforms and networks. In any case, such terminology, like any other, has a certain degree of arbitrariness, and any classification is acceptable as long as it is used consistently and clearly defined in advance. This would ensure that those consulting the dataset are properly informed about the type of platform included in each category and they can easily locate the needed information.

Hence, the categories adopted after considering those included in the organizations mentioned above are: HFR, Argo floats, surface drifters, and Gliders, adopted by both EuroGOOS and MonGOOS. We also include Tide Gauges, included in the EuroGOOS task teams and we have added Tsunami Alerting Devices (TADs). Then, we also include FerryBox from EuroGOOS. Both entities recognize a category which makes reference to anchored or moored platforms. This is Open Ocean Fixed Oceanographic Stations in the case of MonGOOS, Fixed Platforms in the case of EuroGOOS, and Open OceanSITES in OceanOPS. The first and third of these terms seem to be more restrictive because they allude to the open sea character of these instruments and apparently exclude coastal ones. Fixed Platforms is more general but is not descriptive. Finally, we have adopted the term “surface or subsurface moored buoys and submarine platforms”. In this way, these terms include and allude to those buoys (meteorological or oceanographic, coastal or open sea) that float at the sea surface while anchored to the sea bottom as well as those mooring lines equipped with oceanographic instrumentation along the water column and submarine modules or platforms deployed at the sea bottom. One of the MonGOOS platforms is Repeated Cruises (not included in the EuroGOOS task teams) which refers to *in situ* observations made from research or opportunity vessels. As will be shown in the following sections, some of these observations are made at a single location (oceanographic station), visited on a regular basis, whereas in other cases the periodic observations include several stations distributed along a transect, or larger geographical areas. These two cases have been divided into Time-Series Stations and Repeated cruises. Time-Series Stations are stations that are visited periodically with a research vessel, and Repeated cruises are transects or large sets of oceanographic stations that are visited with a research vessel on a periodic basis. In both cases, these observations have an Eulerian character, as measurements are carried out at fixed locations, but differ from the previous item (surface or subsurface moored buoys and submarine platforms) because they are not based on instruments anchored to the sea bottom.

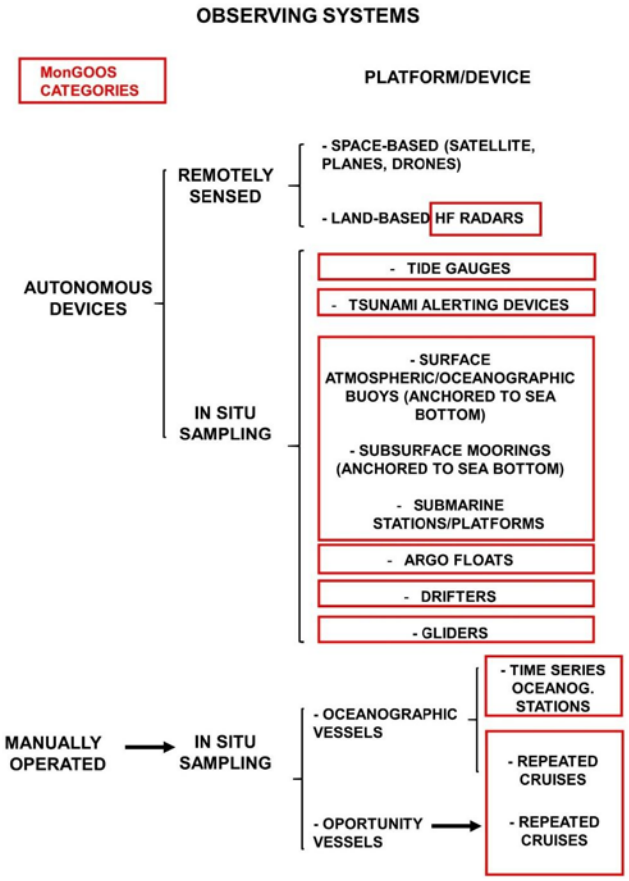


Figure 1. Scheme of the different sensors and devices used in ocean observation systems. The left column distinguishes~~shows a division~~ between autonomous and manually operated sensors. For each of these two categories, a further division is established, depending on the remote or in situ character of observations (central columns). The right column ~~shows~~ lists~~different~~ the sampling strategies and devices corresponding to the categories defined in central and left columns. The terminology used has been adapted from MonGOOS (https://mongoos.eurogoos.eu/), EuroGOOS (https://eurogoos.eu/), and OceanOPS. The red boxes highlight the categories adopted in the present work.

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3 The MonGOOS consultation phase

In the previous section, we have described the different categories established by the MonGOOS chair and its Observations Working Group (OBSWG) for grouping the different marine observation activities in the Mediterranean Sea. This classification was based on those already existing in EuroGOOS, MonGOOS and OceanOPS. Satellite observations were not considered in the present compilation, as this is a field that, because of its complexity, merits its own work. Here, the final categories considered were:

-High Frequency Radars (HFRs).

-Tide Gauges and Tsunami Alerting Devices.

- Surface or subsurface moored buoys. Submarine platforms.

- Argo floats.

- Surface Drifters.

- FerryBox Lines.

- Repeated Cruises.

- Time-series stations.

-Glider Lines.

For each observational category, a standardized metadata framework was developed to systematically compile and harmonize key technical and operational information related to the different sampling methods, including platform characteristics, measured variables, temporal resolution, spatial coverage and operational status. This structured approach ensured comparability across platforms and institutions and facilitated subsequent synthesis and gap analysis. An initial inventory of institutions and individual experts potentially engaged in Mediterranean observation activities was then compiled. This preliminary list comprised 62 persons representing 45 institutions across 17 countries. It is acknowledged that this initial mapping was necessarily influenced by the degree of engagement of Mediterranean oceanographers within MonGOOS and by the professional networks of the OBSWG team, potentially introducing representational bias. To mitigate this and enhance inclusivity and geographic representativeness, on 13 July 2023 the MonGOOS chair formally requested that individuals included in the initial list proposed additional relevant contacts. This snowball-style expansion aimed to broaden participation beyond the core MonGOOS community and reduce network-driven biases.

Following this enlargement phase, the contact list increased to 90 individuals, to whom the MonGOOS chair distributed standardized Excel templates designed to collect detailed and structured metadata on existing observation capabilities within their respective institutions. As the consultation process evolved, the list was further expanded. Ultimately, the templates were sent to 59 institutions from 18 countries, 4 companies, and researchers affiliated with OceanOPS and several EuroGOOS task teams (black bars in Fig. 2A). The geographical coverage of the survey is illustrated in Fig. 2B.

After the initial distribution, an iterative consultation and validation phase was implemented, involving sustained exchanges between the OBSWG and the broader Mediterranean ocean observing community (including some non-Meiterranean countries

such as Germany and Portugal). This process included clarification requests, cross-checking of metadata, and verification of operational status. The consultation and data validation phase extended until December 2025, during which the number of researchers contacted for consultation or clarification increased to 128.

Responses of varying levels of completeness were obtained from 48 institutions across 16 countries (white bars in Fig. 2A). Some institutions indicated interest in the initiative but reported operational constraints, funding limitations, or temporary inactivity of monitoring programs. Finally, additional information about institutions involved in observation activities was also obtained from OceanOPS and EuroGOOS task teams. Such information, together with our own survey, is presented by grey bars in Fig. 2A. It corresponds to 74 institutions from 18 countries that ultimately provided structured and usable metadata describing current operational observation capabilities within the predefined categories.

In addition to institutionally provided information, we also used published literature, technical reports, and publicly accessible documentation to enhance data completeness and consistency. This multi-source integration strengthened the robustness of the compiled inventory while maintaining transparency regarding data provenance. However, we have to acknowledge that, in some cases, the information compiled was not complete and we still observe some gaps in our knowledge that need to be addressed in the future.

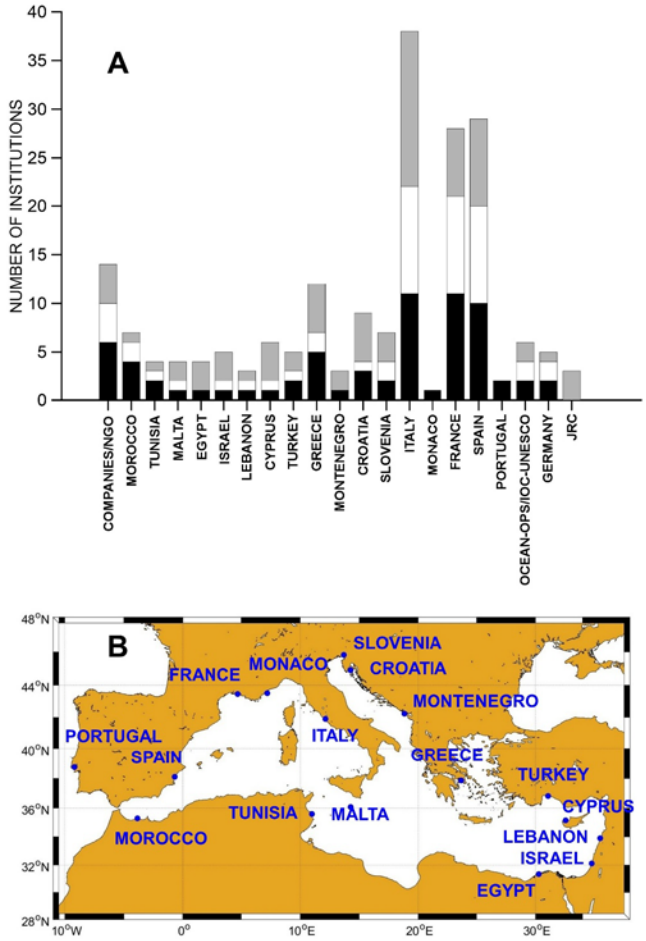


**Figure 2. ~~Figure 2~~(A)~~. Black bars show the n~~Number of institutions directly reached out for each country during the consultation phase (black bars). We also consulted 4 private enterprises and worked in collaboration with OceanOPS and EuroGOOS task teams. ~~White bars show the n~~Number of countries or companies that sent some kind of answer (white bars). ~~Grey bars show those I~~institutions from which some information was finally obtained (grey bars). Notice that, in this latter case, the information could

also be obtained indirectly from OceanOPS or EuroGOOS. ~~Figure 2~~(B) ~~shows the c~~Countries included in the survey. One institution from Germany was also consulted, although not shown in this figure.

4 Current observation capabilities

4.1 High Frequency Radars (HFRs)

At the time of writing (2026), the Mediterranean HFR network comprises 58 individual antennas, known as radial stations. These are organized into 16 networks, each consisting of a minimum of two radial stations whose respective data are combined to calculate total surface current vectors. Assimilation of HFRs data within oceanographic models and their combination with Lagrangian particle tracking, notably improve our representation of circulation patterns and the modelling of oil spills and floating debris, search and rescue, and navigation safety (Bellomo et al., 2015; Capodici et al., 2024; Bendoni et al., 2023; Hernández-Lasheras et al., 2025). However, it should be acknowledged that its application to operational oceanography remains relatively limited and most investigations have been confined to academic research contexts (e.g. Saviano et al., 2019; 2020; 2021; Wyatt, 2021, Morales-Márquez et al., 2025), with only a few examples addressing harbour environments (Lorente et al., 2022).

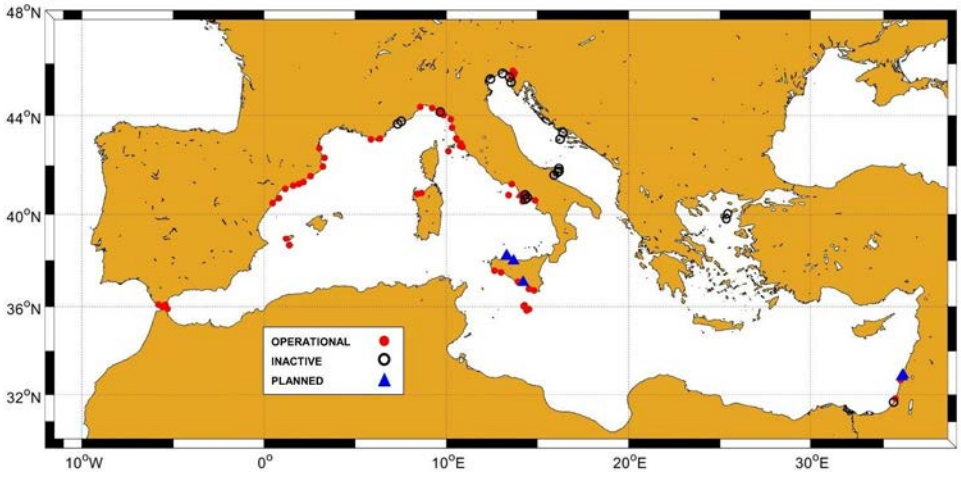


Figure 3. Location of operational (red dots), inactive (black open circles) and planned (blue triangles) HFR stations in the Mediterranean Sea (www.hfrnode.eu/map).

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The status of the known HFR stations in the Mediterranean is detailed in HFR_supplementary.xlsx in supplementary material. This file includes information about the countries, institutions, networks of each of the stations, as well as their position, start and end dates and contact persons. In the case that the HFR is active, the end date is specified as "ONGOING". For the sake of completeness, Table 1 summarizes the contributions of each of the countries and institutions throughout the Mediterranean Sea. This information is also presented in Fig. 3~~, distinguishing between operational (red dots), inactive (black open circles), and planned installations (blue triangles)~~. The information provided describes an updated Mediterranean HFR network that has incorporated three major developments since the reviews of Tintoré et al. (2019), Lorente et al. (2022) and Reyes et al. (2022), which already documented a substantial part of the existing network, developed over time through a combination of national efforts and European funding frameworks (e.g. ERDF programmes).

Among these developments was the deployment of an HFR network by ICATMAR (Catalan Institute of Research for the Governance of the Sea), which is a component of a multi-platform observing system, jointly managed by the Directorate-General for Maritime Policy and Sustainable Fisheries of the Government of Catalonia and the Institute of Marine Sciences (ICM/CSIC Spanish National Research Council). In 2026, the network became transnational through funding provided by the POCTEFA programme, with the installation of an additional radar in Canet-en-Roussillon operated by CEFREM, providing coverage to the whole Eastern Coastal Functional Area (AFLE) of the Euro-region Pyrenees Mediterranean.

Similar efforts to expand and strengthen coastal observing capacities have also taken place in Italy. The Institute for Environmental Protection and Research (ISPRA), in collaboration with Parthenope University of Napoli, Sapienza University, University of Palermo, and Consorzio LaMMA, implemented a major investment through the PNRR MER Project, funded by Next Generation EU. The aim of the project is to promote and enhance the integration of HFRs into a multi-instrumental system for observing the physical state of the sea along the Italian coasts. Also funded through Next Generation EU PNRR but coordinated by CNR (Consiglio Nazionale delle Ricerche), the Italian Integrated Environmental Research Infrastructures System (ITINERIS) was set to finish the deployment of a new network in the Gulf of Salerno before summer 2025. Within the same project, two more systems will be deployed by OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale) enhancing the Italian contribution to the Gulf of Trieste and north Adriatic network.

Besides the present compilation, up-to-date information and metadata regarding the HFR network are also accessible via tools developed under the JERICO-S3 (grant no. 871153) and EuroSea (grant no. 862626) projects. Specifically, the EU HFR Node API (Eur_HFR_Node API, https://api.hfrnode.eu/), developed by SOCIB, enables standardized machine-to-machine (M2M) discovery and access to critical metadata from European HFR stations, networks, and associated users (Mantovani et al., 2024). Additionally, the HFR Online Outage Reporting Tool (HOORT, https://hoort.hfrnode.eu/) provides a dynamic overview of the HFR inventory's operational health and performance.

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COUNTRY	INSTITUTION	OPERATIONAL	INACTIVE	PLANNED
SPAIN	PE	7		
SPAIN	ICATMAR	7		
SPAIN	SOCIB	2		
FRANCE	CEFREM	1		
FRANCE	UNIV. TOULON	2	2	
ITALY	ARPAS	2		
ITALY	UNIV. PALERMO	1		
ITALY	CNR-IAS	1		
ITALY	ARPA-SICILY	1		
ITALY	CNR-ISMAR	7	5	
ITALY	OGS	4		
ITALY	LaMMA	5		
ITALY	ARPA-FVG	1		
ITALY	ISPRA	8		3
ITALY	UNIV. NAPLES		3	
CROATIA	IOF		6	
SLOVENIA	NIB	1		
SLOVENIA	ARSO	1		
GREECE	UNIV. AEGEAN/HCMR		2	
ISRAEL	UNIV. TEL AVIV	2	1	
ISRAEL	HIES			2
MALTA	UNIV. MALTA	4		

Table 1. Summary of existing HFRs in the Mediterranean Sea, broken down by countries and institutions. Operational, inactive and planned stations are included.

4.2 Tide Gauges and tsunami alerting devices

The broad interest in these platforms across diverse applications has resulted in their operation by various types of institutions, which complicates efforts to comprehensively review existing observing capacity. In the Mediterranean and Black Seas, the most up-to-date and detailed overview of the tide gauges networks was performed in 2022 (Pérez Gómez et al., 2022). Here we include the information related to the Mediterranean Sea compiled by Pérez-Gómez et al. (2022) and completed with our own survey. This information includes 220 operational (active) stations (Fig. 4). Detailed information is provided in the file Tide_Gauges_supplementary.xlsx in the supplementary material. This file includes a sheet for each country. In each file, the information is broken down by institution, including the position, starting and end dates of the tide gauges, information about ancillary sensors and contact persons. Table 2 shows a summary of the number of operational, inactive (or closed) and planned tide gauges in the Mediterranean Sea.

Besides tide gauges, 88 tsunami alerting devices (TADs) have operated in the Mediterranean Sea. Table 3 shows the number of devices operated by each country and detailed information is provided in Tsunami_Alerting_Devices_supplementary.xlsx. Additional information about existing tide gauges and data availability can be obtained through two on-line tools developed within the EuroSea project (grant no. 862626), and coordinated by the EuroGOOS Tide Gauge Task Team (https://eurogoos.eu/tide-gauge-task-team). The first one is the Tide Gauge Metadata Inventory (EuroSea, 2023; eutgn.marine.ie), created by the Irish Marine Institute to resolve gaps and inconsistencies in metadata found across European tide gauge data portals (EuroSea, 2023). The second one was developed by La Rochelle University to display the sea level data content in different data portals worldwide (TGCAT: https://www.sonel.org/tgcat/; Testut et al, 2026). This tool is a community-oriented tool designed to simplify sea level data and metadata discovery, to support researchers, data providers and aggregators by helping to visualize available data, identify gaps or redundancies, verify data integration in standard web portals and assist in locating historical datasets. Future plans include expanding access to national portals coverage (only a limited number now) and promoting its use by the Global Sea Level Observing System (GLOSS) Data Assembly Centres (DACs). A comprehensive list of Mediterranean Tide Gauges and Meteo-tsunami devices is also offered by EMODnet Physics (Martín Míguez et al., 2019).

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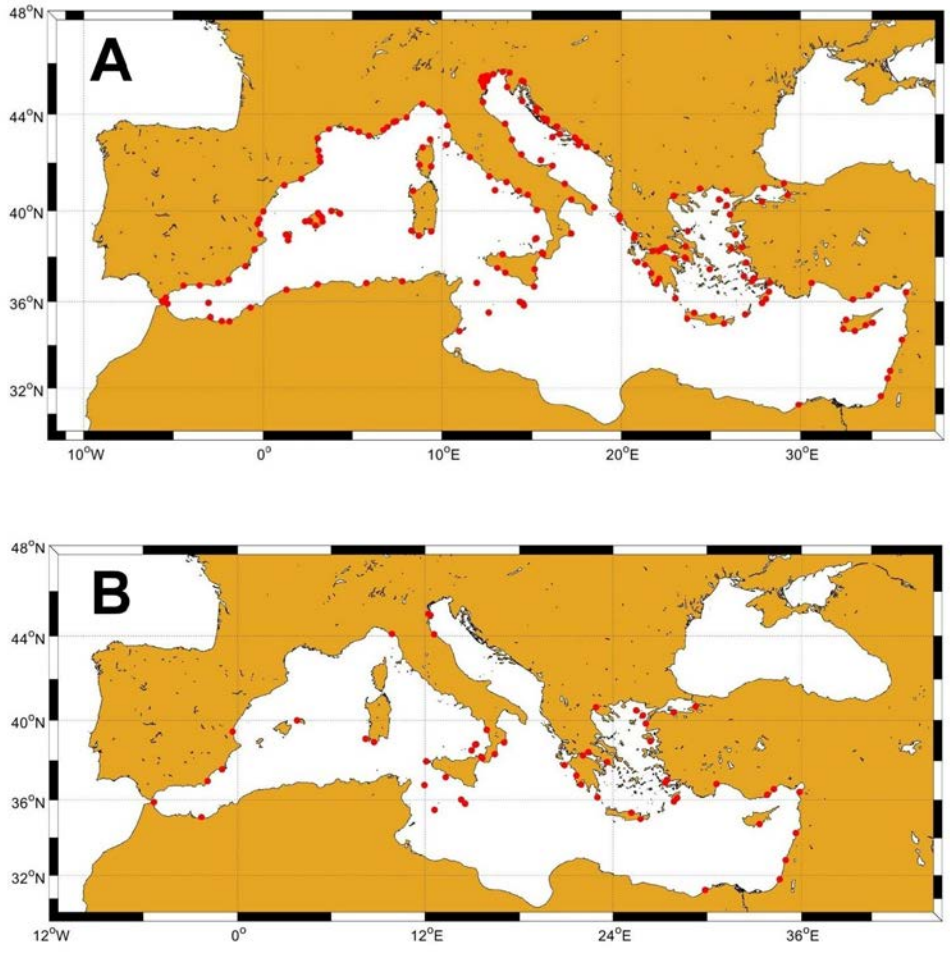
COUNTRY	INSTITUTION	OPERATIONAL	INACTIVE	PLANNED
SPAIN	PE	18	5	
	ICATMAR	1		
	SOCIB	6		
	IEO	4		
	IGN	9		
	ICM	1		
FRANCE	SHOM	14	2	
ITALY	IIM	7		
	ISMAR	4		
	ISPRA	11		
	JRC	2		
	UNKNOWN	39	5	
CROATIA	HHI	7		
	IOF	5	1	
	RBI	1		
	UNKNOWN	5		
SLOVENIA	ARSO	1		
MONTENEGRO	HMZCG	1		
	ZHMS	1		
ALBANIA	UNKNOWN	4		
GREECE	HNHS	22		
	UNKNOWN	19		
	HCMR	2		
	NTUA	7		
TURKEY	HGM	13		
	UNKOWN	2		
CYPRUS	DLS	4	1	
	CUT	1		
	DFMR		1	
	OC-UCY		1	
	JRC		1	
LEBANON	UNKNOWN	1		

ISRAEL	IOLR	1	1	
	RES. DEPT.	2	1	
EGYPT	CORI	1		
	ENODC		1	
	UNKNOWN		5	
ALGERIA	UNKNOWN	6		
TUNIS	UNKNOWN	1		
MOROCCO	UNKNOWN	1		
MALTA	MMA	1		
	UNKNOWN	4	1	

Table 2. Summary of existing tide gauges in the Mediterranean Sea, broken down by countries and institutions. Operational, inactive and planned stations are included.

COUNTRY		COUNTRY	
SPAIN	7	LEBANON	1
FRANCE	5	ISRAEL	2
ITALY	25	EGYPT	1
GREECE	15	MALTA	4
TURKEY	12	MOROCCO	2
CYPRUS	1	UNKNOWN	13

Table 3. Summary of Tsunami Alerting Devices by country.



492

493 **Figure 4.** ~~**Figure 4**~~**(A)** ~~**shows the p**~~**Position of Operational tide gauge stations in the Mediterranean Sea.** ~~**Figure 4**~~**(B)** ~~**shows the**~~
494 ~~**p**~~**Position of tsunami alerting devices.**

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4.3 Surface or subsurface moored buoys and. sSubmarine platforms

This category was already described in section 2 (Observation methods) with the rest of observation platforms. However, because of the different nomenclatures used by different organizations (Fixed Platforms, Open ocean Fixed Oceanographic Stations, Open OceanSITES), we include here a further description to avoid misunderstandings and to clarify the types of devices considered. This comprises all anchored devices deployed in coastal or open-ocean environments. ~~These platforms are moored to the seafloor and are designed to measure atmospheric and/or oceanographic variables.~~ Data collection can occur at the sea surface, throughout the water column, and at the seabed itself, depending on the specific platform. Fig. S1 in supplementary material shows a schematic of these different platforms and illustrates the terminology used in this section and also in the Excel files of supplementary material.

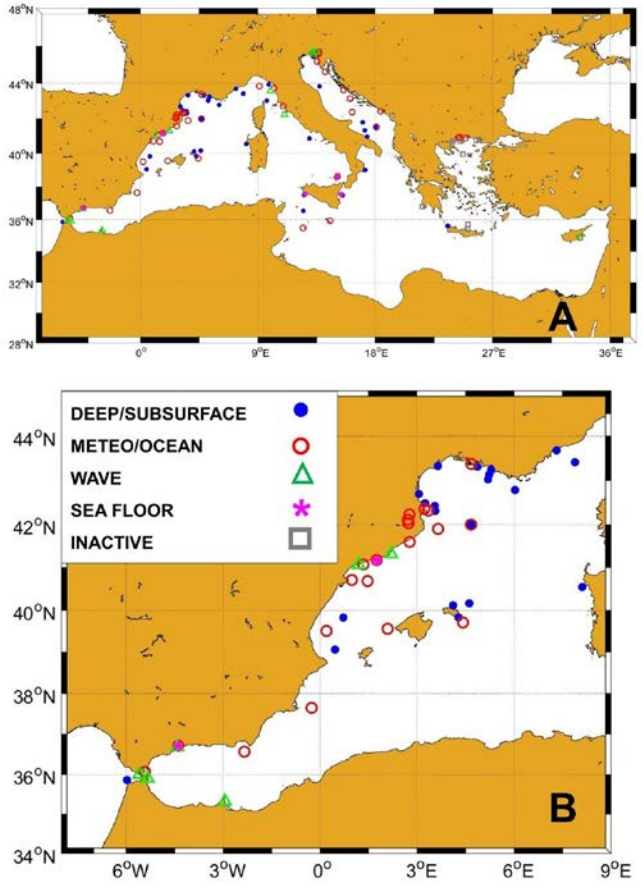
Surface buoys, anchored to the seabed by a deadweight anchor, can be equipped with sensors devoted to the measurement of oceanographic variables at the sea surface and/or atmospheric variables. Some of them are equipped with accelerometers devoted to the measurement of the height and frequency of waves. In this latter case, we will name them as wave buoys (Fig. S1A). Atmospheric buoys are usually equipped with sensors for measuring air temperature and pressure, wind direction and intensity, air humidity and solar radiation. Oceanographic buoys are equipped with sensors measuring sea surface temperature and salinity and the direction and speed of surface currents. Very frequently, currents are measured by means of Doppler profilers and hence these platforms do not only provide information about currents at the sea surface, but also along the water column below the surface. These platforms can also include pH, chlorophyll and dissolved oxygen sensors. When surface buoys include sensors for measuring both atmospheric and oceanographic variables, they are named as atmospheric/oceanographic buoys.

In some cases, a submarine node or module is installed at the seabed, including oceanographic sensors and even submarine cameras and hydrophones. These platforms are connected to the surface buoy from which data are transmitted in real time by telephone or satellite technology. In these cases, these platforms might be located in shallow coastal waters (Del Río et al., 2020; Fig. S1A).

Finally, subsurface moored buoys are made of a set of instruments deployed along the water column, from the seabed to which they are fixed by means of a deadweight anchor, to subsurface waters. Subsurface buoys along or at the end of the line provide buoyancy to the instruments maintaining them in a, more or less, upright position. These moorings usually extend to 30-50 meters below the surface, but other designs are also possible. The instruments measure variables such as temperature, salinity and current direction and speed (Fig. S1B).

Fig. 5A shows the position of buoys existing in the Mediterranean Sea and belonging to the different types described above. This information was gathered from our own survey. ~~Figure 5B is a zoom for the westernmost sector or the Mediterranean Sea whereas Figures 5C and 5D are zooms for the central and eastern Mediterranean.~~ Table 4 summarizes the number of platforms

existing in the Mediterranean Sea~~. This information is broken down by countries and institutions. However,~~ and a more detailed information is provided in Moored_Buoys_supplementary.xlsx in the supplementary material. As in the case of tide gauges, this file contains a sheet for each country where information is organized by institutions, including the platform type, the position, the included sensors, the start and end dates and a contact person. These platforms and their data can also be obtained from EMODnet Physics.



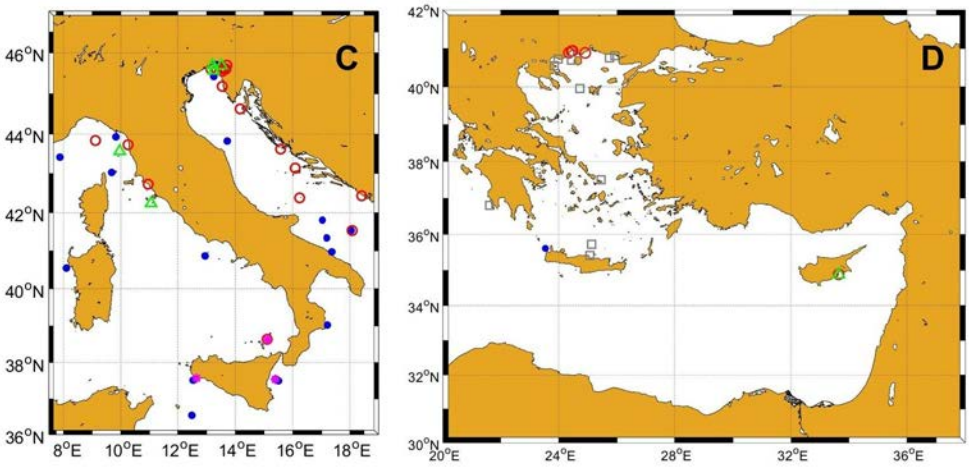


Figure 5. ~~Figure 5~~**(A)** ~~shows a g~~**General illustration of all the surface (meteo/oceanographic), subsurface and submarine platforms existing in the Mediterranean Sea. Blue dots are used for deep or subsurface moorings. Red open circles are for surface buoys equipped with meteorological and/or oceanographic sensors. Green triangles correspond to wave buoys, submarine platforms are shown by means of magenta asterisks, and grey squares are used to show the positions of platforms that are not active at present.** ~~Figure 5~~**(B)** ~~shows a z~~**Zoom for the westernmost sector of the Mediterranean Sea**~~., Figure 5~~**(C) Zoom for** ~~corresponds to~~ **the Tyrrhenian and Adriatic Seas**~~. and Figure 5~~**(D)** ~~shows the p~~**Platforms existing in the Aegean Sea and Levantine Basin.**

COUNTRY	INSTITUTION	TYPE	OPERATIONAL	INACTIVE	PLANNED
SPAIN	IEO	SEAFLOOR PLAT.	1		
		METEO/OCEAN	1		
		DEEP/SUBSURFACE	6		
	PE	METEO/OCEAN	8		
		WAVE	6		
	UPC	SEAFLOOR PLAT.	1		
		METEO/OCEAN	1		

	UNIV. MÁLAGA	DEEP/SUBSURFACE	1		
	UB	DEEP/SUBSURFACE	1		
	ICATMAR	METEO/OCEAN	8		
	CNRS	DEEP/SUBSURFACE	10		
	CNRS- UNIV.MONTPELLIER	DEEP/SUBSURFACE	1		
	CNRS-AMU	DEEP/SUBSURFACE	1		
	MÉTEO FRANCE	METEO/OCEAN	2		
ITALY	ISPRA	DEEP/SUBSURFACE	16		
	CNR-ISP	DEEP/SUBSURFACE	2		
	CNR-IAS	SEAFLOOR PLAT.	1		
		DEEP/SUBSURFACE	1		
	CNR-ISMAR	DEEP/SUBSURFACE	3		
		METEO/OCEAN	1		
	ING	SEAFLOOR PLAT.	2		
		METEO/OCEAN	1		
		DEEP/SUBSURFACE	1		
	CFR-TOSCANA	METEO/OCEAN	2		
		WAVE	2		
	OGS	METEO/OCEAN	8		
		DEEP/SUBSURFACE	1		
		WAVE	3		
	ENEA	METEO/OCEAN	1		
GREECE	HCMR	METEO/OCEAN		3	

		DEEP/SUBSURFACE		3	
		SEAFLOOR PLAT.		1	
	UNIV. DEMOCRITUS	METEO/OCEAN	4		
		SEAFLOOR PLAT.		1	
CROATIA	DHMZ	METEO/OCEAN	5		
SLOVENIA	ARSO	METEO/OCEAN	2		
	NIB	METEO/OCEAN	1		
CYPRUS	ORION	WAVE	1		
	ORION	METEO/OCEAN	1		
MALTA	UNIV. MALTA	METEO/OCEAN	1		

Table 4. Summary of the number of existing meteo/oceanographic buoys, deep or subsurface moorings, wave buoys and submarine platforms existing in the Mediterranean Sea (operational, inactive and planned). The information is broken down by countries and institutions. More detailed information is provided in the file Moored_buoys_supplementary.xlsx.

4.4 Argo Floats

Core and BGC-Argo floats deployed in the Mediterranean Sea follow configuration settings adapted to the characteristics of the Mediterranean Sea. Traditionally, Core floats park at a target pressure of ~350 dbar, with the main aim of following the pathway of the Levantine Intermediate Water (LIW) across the whole basin. Floats drift with the current for approximately five days, and then descend to a profiling depth of up to 2000 dbar, where bathymetry allows, before ascending to the surface while collecting data (Poulain et al., 2007; Roemmich et al., 2019). Similar cycle characteristics with 5-days profiling frequency and descents down to 2000 dbar are also implemented for BGC-Argo floats. However, the implementation plans and results achieved by the NAOS project (Novel Argo Observing System; D'Ortenzio et al., 2020) have indicated that a parking depth of 1000 dbar may be optimal, where bathymetry allows. This parking depth guarantees a good coverage over long time periods of the distinct phytoplankton phenology-based bioregions (D'Ortenzio and Ribera d'Alcalá, 2009; Mayot et al., 2016) which underlay different ecosystem structures and functions.

The Mediterranean component of the Argo program develops under the framework of the European contribution to the Argo international program, coordinated by the EuroArgo ERIC (European Research Infrastructure Consortium, www.euro-

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argo.eu). Float deployments began in the early 2000s (Fig. 6A shows the evolution of Argo deployments). Historically, the deployment of Argo floats in the Mediterranean Sea has involved different contributing countries over time. Today, however, the effort relies almost entirely on a small number of nations from the European Union, primarily Italy (48 floats), France (14), Spain (11), Greece (6) and European Union (1) (see Fig. 6B). For BGC-Argo, France carried out the first deployments in the Mediterranean Sea in 2012 of about 30 floats thanks to the national investments represented by the NAOS project (D'Ortenzio et al., 2020). Since then, Italy has become the main contributor, now responsible for nearly 70% of the BGC-Argo floats currently operating in this region.

Fig. 7A shows the position of all Core, BGC, Deep and Coastal Argo floats deployed since 2000 and Fig. 7B shows those that are currently operational. Detailed information is provided in Argo_supplementary.xlsx in the supplementary material. At the time of writing, 80 Argo floats are active in the Mediterranean Sea, including 29 Core-Argo and 51 BGC-Argo. 8 of the BGC-Argo are also Deep-Argo floats and one of the Core-Argo is a coastal one. Based on the targets defined by the international Argo program for marginal seas, there is a notable deficit in Core-Argo floats (target = 55), whereas the targets are exceeded for Deep-Argo (target = 1) and largely surpassed for BGC-Argo (target = 8). However, pH is not measured at all at the basin scale, while both BGC and Deep-Argo floats also acquire core measurements of temperature and salinity.

It is also worth noting that efforts are being made to increase the recovery rate of floats at the end of their lifetime, which represents a real opportunity in terms of cost savings, sensor recalibration, and reduction of environmental impact. Although still in its early stages, this initiative is beginning to take shape. This growing interest is reflected in recent initiatives such as the Euro-Argo ONE project ~~(grant no. 101188133)~~. Euro-Argo, in collaboration with Ifremer, launched in 2021 a web portal designed to assist in the localisation and recovery of Argo floats (https://floatrecovery.euro-argo.eu/), allowing users to visualise float positions in near real time and supporting recovery operations during research cruises. At the scale of the Mediterranean Sea, approximately 15% of floats are recovered, which is above the global average (4%), but still well below the recovery rates achieved in some other marginal seas, such as the Baltic Sea, where nearly 70% of floats are retrieved (Cancouët et al., 2020). EMODnet Physics is federated with the ARGO Global Data Assembly Centre and offers access to all Mediterranean Core, BGC and Deep-ARGO. All Argo missions, metadata and acquired data are showcased by the EuroArgo ERIC (https://fleetmonitoring.euro-argo.eu/).

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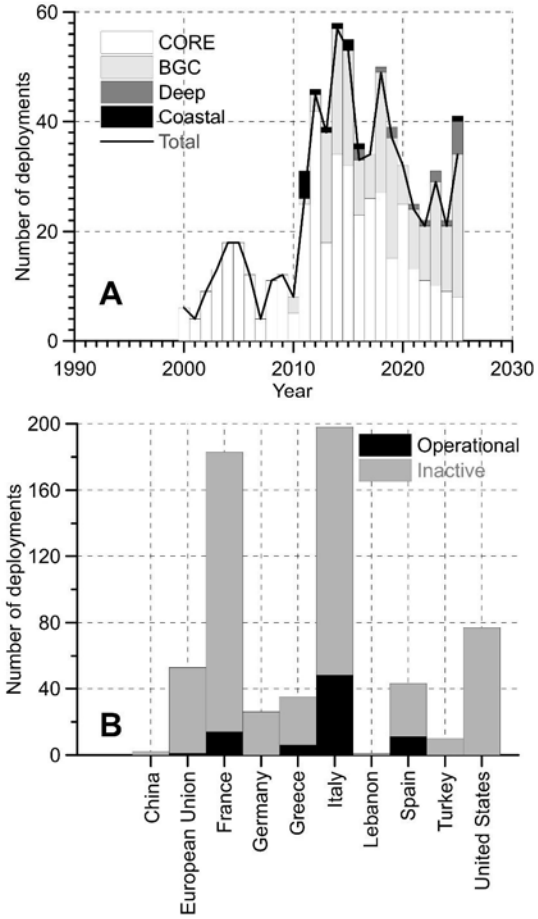


Figure 6. ~~Figure 6~~(A) ~~shows the n~~Number of Argo floats deployed in the Mediterranean Sea during each year since 2000. These deployments were split in: Core (white bars), Biogeochemical (BGC, light grey bars), deep Argo (dark grey bars) and coastal Argo (black bars). ~~Figure 6~~(B) ~~shows the n~~Number of Argo floats (all types) deployed by each country, distinguishing those inactive (grey bars) and active (black bars) at present.

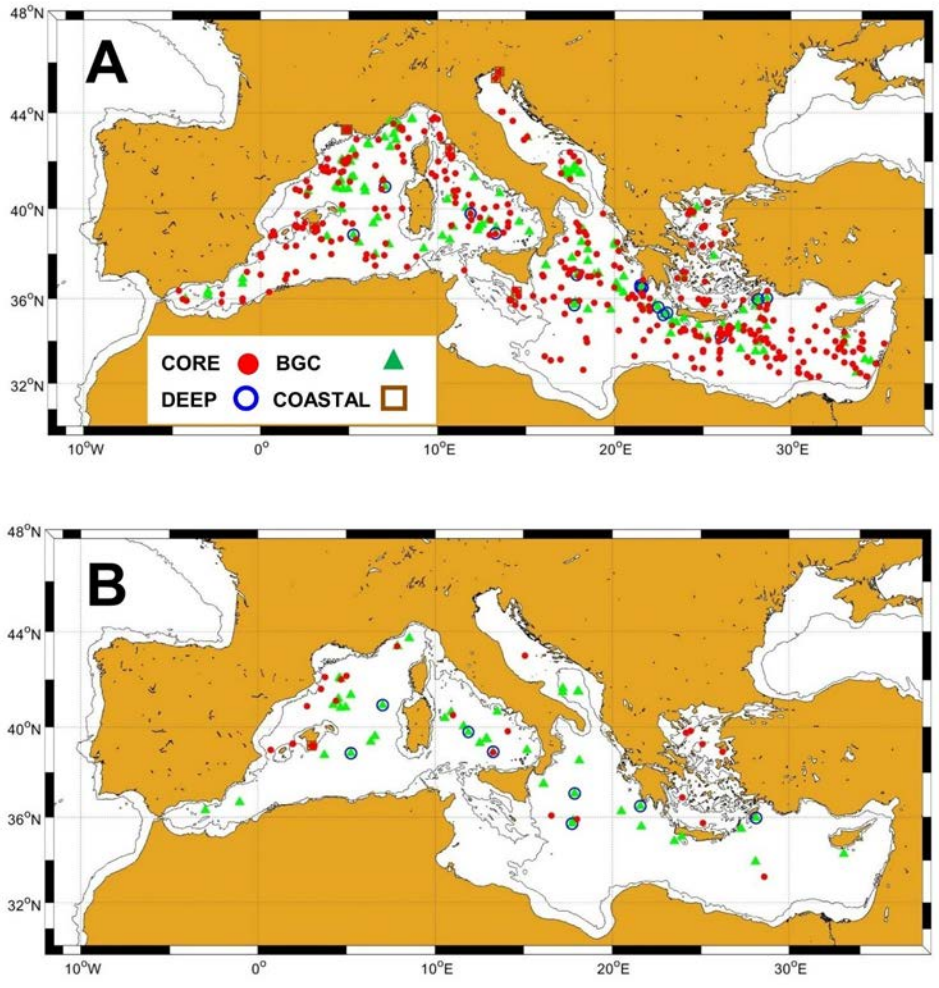

A
B
CORE
BGC
DEEP
COASTAL
48°N
44°N
40°N
36°N
32°N
10°W
0°
10°E
20°E
30°E

Figure 7. ~~Figure 7~~(A) ~~shows all the~~ Argo floats deployed in the Mediterranean Sea since 2000. Red dots correspond to core Argo floats, green triangles to biogeochemical Argo, open blue circles to Deep Argo and brown squares to coastal Argo. ~~Figure 7~~(B) ~~shows those f~~Floats that are active at present. The 500 meters isobaths has been included (black solid line).

4.5 Surface Drifters

Ocean surface drifters are an efficient tool for assessing surface currents at both global (Lee and Maximenko, 2025; Lumpkin and Pazos, 2007) and regional or local scales (Poulain, 2013). A large dataset of surface drifters has been compiled for the Mediterranean Sea (Ribotti et al., 2023), and these observations have been widely used to analyse both geostrophic and tidal currents (Poulain et al., 2012, 2018). These Lagrangian instruments typically consist of a surface buoy equipped with GPS and satellite telemetry, tethered to a drogue centred around 10–15 m depth to ensure that their motion closely follows water parcels rather than direct wind forcing (other designs are also possible). In the Mediterranean Sea, drifter observations have been instrumental in resolving the complex interplay between basin-scale thermohaline circulation, mesoscale eddies, boundary currents, and wind-driven processes, particularly in dynamically active regions such as the Algerian Current and the Levantine sub-basin. High-frequency position data enable the estimation of surface velocity fields, eddy kinetic energy, and dispersion coefficients, providing constraints for numerical circulation models and improving forecasts of pollutant transport, marine debris pathways, and biological connectivity (De Dominicis et al., 2016; Celentano et al., 2023).

Some surface drifter observations in the Mediterranean Sea also contribute to the Global Surface Drifting Buoy Array, a branch of GOOS. Through this framework, a subset of Mediterranean deployments contribute to ocean monitoring at the global scale and supporting weather forecasting, ocean state estimation and climate studies.

In addition, initiatives such as the Barometer Upgrade Program aim to enhance the capabilities of these platforms by incorporating improved atmospheric pressure sensors. The acquisition and deployment of these upgraded drifters are often carried out through collaborative efforts involving multiple research institutions and operational agencies.

EMODnet Physics lists more than 600 drifters used through years since 1997 in the Mediterranean Sea, while Figure 8 shows the position of the active ones.

At present, there are 16 operational surface drifters in the Mediterranean Sea, deployed by Italy (9), European Union (1) and United States (6). Detailed information about these platforms, including deployment day, last position (at the date of data compilation), network, etc. are presented in the file Drifters_supplementary.xlsx. It should be noted that this number reflects the operational status at the time of the survey, whereas drifter observations are more widely available through continuous and successive deployments across the basin, often associated with specific scientific studies and model calibration and validation activities, including applications related to HF radars.

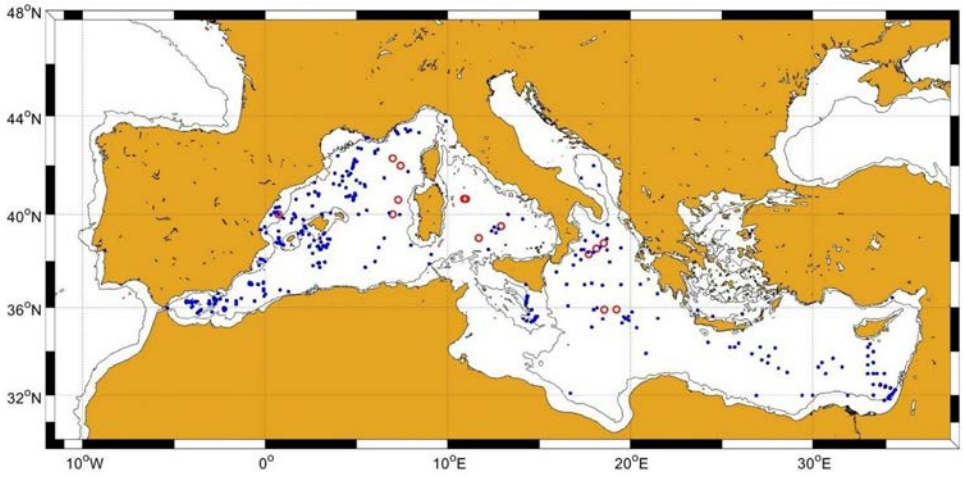


Figure 8. Positions of surface drifters deployed in the Mediterranean Sea since 2001 (blue dots) and those currently operational (open red circles). The 500 meters isobaths has been included (black solid line).

4.6 FerryBox Lines

FerryBox is an autonomous *in situ* system installed on ships of opportunity, such as cargo vessels, commercial liners, or research vessels. This through-flow system automatically measures physical, chemical, and biological variables from the surface seawater that circulates through it during the ship's voyage. Measured variables can include sea temperature, salinity, turbidity, chlorophyll and oxygen concentrations, pH, and pCO_2. Moreover, carousel samplers allow the collection of water samples at specified locations along the ship route. These are kept in cold conditions and, when at the port, they are collected and analysed in the laboratory for a number of variables.

FerryBox data are beneficial in assessing marine water quality and ecology. They can help us understand more about air-sea interactions, such as air-sea CO_2 exchange, modifications in the surface carbonate system, as well as ocean acidification trends. In addition, flow cytometry using surface-water flow-through systems has been applied on research vessels~~R/Vs~~ for getting biodiversity information about phytoplankton groups, demonstrating its applicability to FerryBox systems (Marrec et al., 2021). Moreover, Chl-a data can be used for satellite validation (Petersen, 2014) and calibration (Petersen et al., 2008; 2003),

while it has been proven as a helpful tool in the study of water circulation, in particular when SST is assimilated into prognostic numerical circulation models to improve their accuracy (Korres et al., 2014).

The first Mediterranean FerryBox system was installed and operated on the route Piraeus–Heraklion (Greece) in 2003 with a discontinued operation until today (2026). The initial system measuring temperature, salinity, oxygen, fluorescence and turbidity was upgraded in 2023 to include *p*CO2 and a sampler, and again in 2026 to include total alkalinity and pH. Daily SST data from this FerryBox route was successfully assimilated into the appropriate modelling module of the POSEIDON forecasting system. This FerryBox is the only Mediterranean line, up to our knowledge, that also contributed with *pCO2* data to SOCAT (Surface Ocean CO_2 Atlas; Bakker et al., 2016). In addition to the scientific importance, the FerryBox system has proven an excellent testing platform for new sensors and techniques, as it provides ample energy and a relatively friendly environment to work.

The metadata in the present work were sourced from Petersen and Colijn (2017) and the FerryBox task team website at EuroGOOS. Subsequently, direct consultations were held with relevant contacts to clarify the findings (https://www.ferrybox.org/routes_data/routes/, downloaded on 10 February 2025).

Código de campo cambiado

This information is presented in Figure 9 and Table 5. The colour code for the routes is as follows: red lines indicate routes that are currently active, grey lines represent routes that were operational in the past but are not active at present, and blue lines denote routes that are intermittently active. Detailed information about FerryBox lines is presented in FerryBox_lines_supplementary.xlsx.

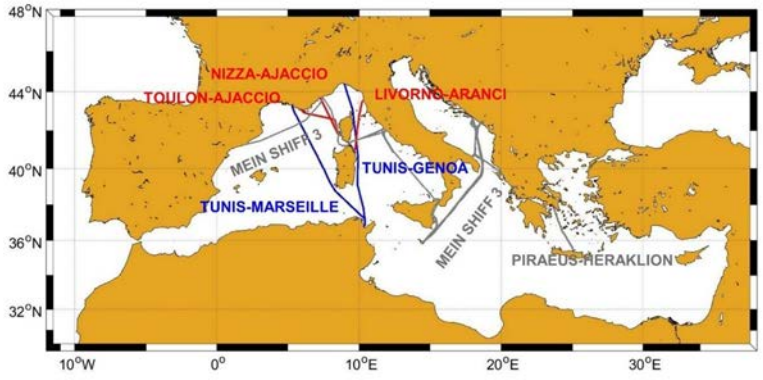


Figure 9. FerryBox lines obtained from EuroGOOS's FerryBox task team (https://www.ferrybox.org/routes_data/routes/mediterranean_sea/index.php.en). Red lines are those active at present, blue lines are intermittently active, and grey lines are not active. FerryBox data courtesy of EuroGOOS.

Código de campo cambiado

COUNTRY	INSTITUTION	START POINT	END POINT	START DATE	END DATE
ITALY	UNIV. CAGLIARI	TOULON	AJACCIO		ACTIVE
	UNIV. CAGLIARI	NIZZA	AJACCIO		ACTIVE
	UNIV. CAGLIARI	LIVORNO	ARANCI		ACTIVE
GREECE	HCMR	PIRAEUS	HERAKLION	2003	INTERMITTENT
TUNISIA	INSTM	TUNIS	MARSEILLE	2016	INTERMITTENT
	INSTM	TUNIS	GENOA	2016	INTERMITTENT
GERMANY	HZG	BARCELONA	CORFU		INACTIVE

Table 5. Information ~~that could be gathered~~ about FerryBox lines in the Mediterranean Sea from https://www.ferrybox.org and personal consultations.

Código de campo cambiado

4.6 Repeated cruises and time-series stations.

Here, we collect all the non-autonomous *in situ* observations made from oceanographic vessels or ships of opportunity. We include those observing programs that have a long duration with repeated observations. ~~However, w~~We distinguish two different categories: repeated cruises and time-series stations. In the first case we consider a large set of stations which can be distributed (although not necessarily) on one or several transects, whereas in the case of time series stations we only consider one or at most two periodic stations.

In the case of repeated cruises, we must distinguish between those that are periodic and those that are quasi-periodic or occasional. We have to admit that this distinction between repeated cruises and time-series stations is somehow arbitrary and all these observations could be included in one single category. However, we maintain this division because we believe it provides a clearer idea of the different observational capabilities existing in the Mediterranean Sea. It also illustrates some differences regarding spatial coverage and sampling frequency between these two types of monitoring activities. Additionally, we retain the current terminology adopted by MonGOOS (Repeated Cruises, https://mongoos.eurogoos.eu/), although we add a new term (time-series stations) in this work.

Código de campo cambiado

4.6.1 Repeated cruises

Repeated cruises are oceanographic campaigns conducted on a regular basis to provide time series of in situ observations over a relatively large geographical area. The sampling is frequently multidisciplinary, (varying among sampling programs), and is carried out at a set of oceanographic stations. These stations are typically distributed along transects extending off shore from the coast, across channels and passages of particular relevance for circulation, or over areas of special interest within the Mediterranean Sea. In other cases, the oceanographic stations are distributed over a wider region without a transect-based organization. Measurements are collected using CTDs and oceanographic carousels or XBTs and thermosalinographs, sometimes in combination with instruments designed to collect biological and chemical samples (i.e., Niskin bottles or plankton fishing tows).

Table 6 presents the repeated cruises currently operating in the Mediterranean Sea and their main characteristics. The positions of their oceanographic stations are also shown as coloured dots in Figure 10A. Note that this figure includes the XBT line Genoa-Palermo, maintained by INGV (Istituto Nazionale di Geofisica e Vulcanologia). According to the nomenclature used in OceanOPS, this line corresponds to a different platform type and falls under the Ship Observations Team (https://www.ocean-ops.org/sot/). The main distinction being the use of ships of opportunity. It has nonetheless been included here for completeness with respect to vessel-based *in situ* observations. ~~Figure 10B provides a zoom of the westernmost sector of the Mediterranean Sea, where the sampling effort is greatest and Figure 10C is a zoom for the eastern Mediterranean.~~ A more detailed description of these cruises is available in the supplementary file Repeated_Cruises_supplementary.xlsx. This file contains a different sheet for each country where information is organized by cruise.

Código de campo cambiado

REPEATED CRUISES					
COUNTRY	INSTITUTION	NAME	PERIODICITY	START DATE	END DATE
SPAIN	IEO	RADMED	3 MONTHS	07/2007	ONGOING
	SOCIB	CANALES	3 MONTHS	09/2013	ONGOING
FRANCE	CNRS	MOOSE	ANNUAL	2010	ONGOING
ITALY	CNR-ISMAR	CORSICA CHANNEL	6 MONTHS	1990	ONGOING
		SICILY CHANNEL	6 MONTHS	2003	ONGOING
		SARDINIA-SICILY	2 YEARS	2003	ONGOING
	INGV-ENEA	GENOVA-PALERMO	3 MONTHS	2021	ONGOING
CROATIA	RBI	ROVINJ-PO	1-3 MONTHS	1979	ONGOING

	IOF	SPLIT-GARGANO	1-3 MONTHS	1952	ONGOING
		COASTAL	3 MONTHS	2019	ONGOING
		DUBROVNIK	3 MONTHLY	1952	ONGOING
SLOVENIA	NIB	MONTHLY CRUISE	1 MONTH	1990	ONGOING
ISRAEL	IOLR	HAIFA SECTION	6 MONTHS	2010	ONGOING
MOROCCO	INRH	PERIODIC CRUISE	6 MONTHS	2011	ONGOING
TIME SERIES					
SPAIN	IEO	FUENGIROLA BEACH	DAILY	1985	ONGOING
		MALAGA BAY	1 MONTH	2023	ONGOING
	ICM	BBMO	1 MONTH	2001	ONGOING
		L'ESTARTIT	1 WEEK	1970	ONGOING
FRANCE	CNRS-IFREMER	MOOSE-ANTARES	1 MONTH	2009	ONGOING
	CNRS	DYFAMED	1 MONTH	1994	ONGOING
	CNRS-IFREMER	MOLA	1 MONTH	2003	ONGOING
	CNRS-IFREMER	POINT B	1 WEEK	1957	ONGOING
	CNRS-IFREMER	FRIOUL	2 WEEKS	1995	ONGOING
	CNRS-UNIV. MONT.	SETE	2 WEEKS	2018	ONGOING
	CNRS-IFREMER	SOLA	1 WEEK	1997	ONGOING
ITALY	CNR-ISMAR	STATION 51	6 MONTHS	2003	ONGOING
		GEOSTAR	6 MONTHS	2003	ONGOING
GREECE	HCMR	POSEIDON E1M3A	1 MONTH	2010	2024
		POSEIDON HCB	1 MONTH	2016	2024
LEBANON	CNRS-L	B1	1 MONTH	2009	ONGOING
		B2	1 MONTH	2009	ONGOING

Table 6. Repeated cruises and Time-series stations. Columns 1 to 6 show the country, institution, name of the program, sampling periodicity, start and end dates of the monitoring projects. Those programs currently active are indicated as "ongoing". The upper part of the table corresponds to Repeated cruises, whereas the power part is for Time-series stations.

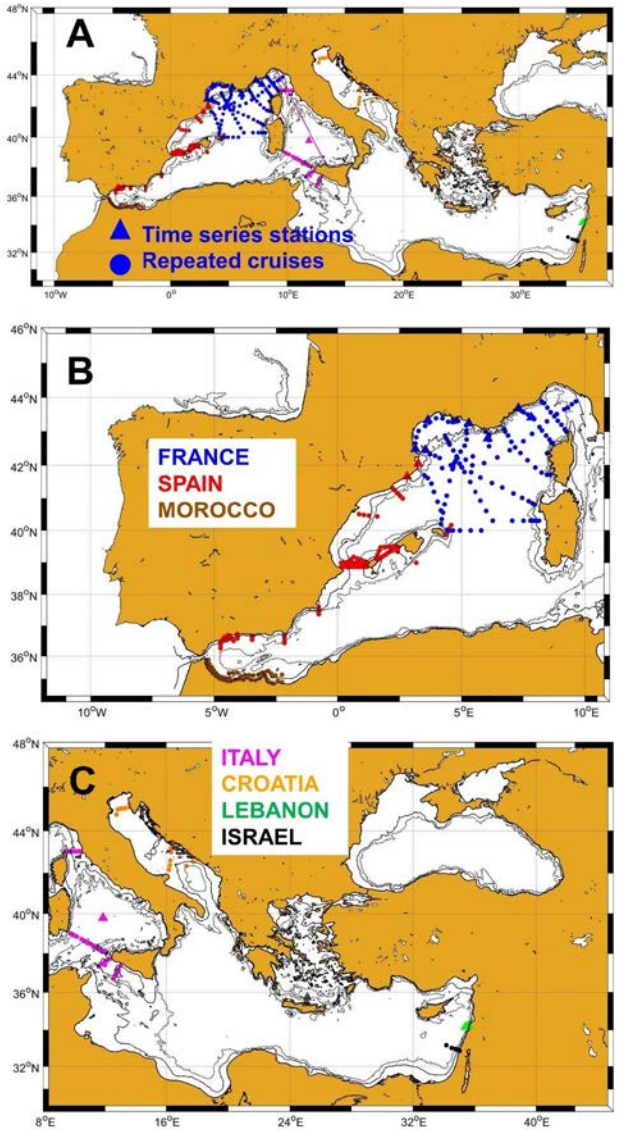

A
Time series stations
Repeated cruises
B
FRANCE
SPAIN
MOROCCO
C
ITALY
CROATIA
LEBANON
ISRAEL

Figure 10. ~~Figure 10~~(A) ~~shows the~~ ~~p~~Position of oceanographic stations sampled in repeated oceanographic cruises (dots) and also in time series stations (triangles). The colour code indicates the country: Red for Spain, blue for France, magenta for Italy, orange for Croatia, green for Lebanon, black for Israel and brown for Morocco. The magenta continuous line ~~is~~shows the Genoa-Palermo transect sampled with XBTS by Italy (INGV) using opportunity ships. Triangles ~~are show~~ the position~~s~~ of time series stations. The colour code is the same. ~~Figure 10~~(B) ~~shows a z~~Zoom for the WMED. ~~and Figure 10~~(C) ~~is a z~~Zoom for the eastern Mediterranean. Grey triangles along the Cretan coast are currently inactive due to a lack of funding, but have been included to illustrate the capabilities of the former Greek observing system, Poseidon. 200 m (solid black line) and 1000 m (dotted black line) isobaths have been included in the three figures for showing the relative position of coastal and deep stations.

The Med-SHIP program (Schroeder et al., 2015 and 2024) is a basin-scale initiative inspired by the GO-SHIP program (http://www.go-ship.org/), aiming to provide high-quality repeated hydrographic observations across the Mediterranean Sea. While GO-SHIP is a global coordinated effort with established funding sources from national and international programs (*e.g.*, NSF in the USA, European funding schemes), Med-SHIP operates as a more flexible framework in which individual cruises are supported through different funding mechanisms. It relies on collaborative efforts among several Mediterranean research institutions and communities, including CIESM (Mediterranean Science Commission). However, it does not receive structural funding from this organization and depends on national and European research projects, institutional resources, and occasional access to research vessels provided by programs such as Eurofleets.

~~Med-SHIP is not formally part of GO-SHIP, with the exception of its east–west transect (MED01, shown as black dots in Figure 11). However, it follows GO-SHIP methodology and best practices to ensure consistency in data collection, and since 2025 its sections have been recognised as so-called 'Associated Sections'.~~

~~Unlike GO-SHIP, which operates under a structured international governance, Med-SHIP relies on collaborative efforts among several Mediterranean research institutions and communities, including CIESM (Mediterranean Science Commission), although it does not receive structural funding from this organization. Instead, cruises conducted under the Med-SHIP framework are supported through national and European research projects, institutional resources, and occasional access to research vessels provided by programs such as Eurofleets.~~

Several key cruises have taken place within the Med-SHIP framework:

- **MED01** (2011, 2018, and 2026): A basin-wide survey covering the entire Mediterranean Sea, providing critical reference data for physical and biogeochemical variables (black dots in Figure 11).
- **TALPro** (2016, 2022, with future repetitions planned): Focused on meridional transects in the Provençal and Tyrrhenian basins (grey open circles in Figure 11).

Código de campo cambiado

- **ESAW** (2015, 2016, magenta squares in Figure 11) and **CRELEV** (2016, red triangles in Figure 11): Conducted in specific regions of the Mediterranean, with potential for repetition subject to future funding (see Schroeder et al., 2024 and Velaoras et al., 2019 for further details).

Although Med-SHIP cruises aim to follow approximate sampling periodicity around 7-9 years for the MED01 transect and 5-7 years for the other transects, their scheduling is not fixed, as it depends strongly on the availability of funding and ship time. Detailed information about these cruises is included in the file Repeated_cruises_supplementary.xlsx as a separate sheet.

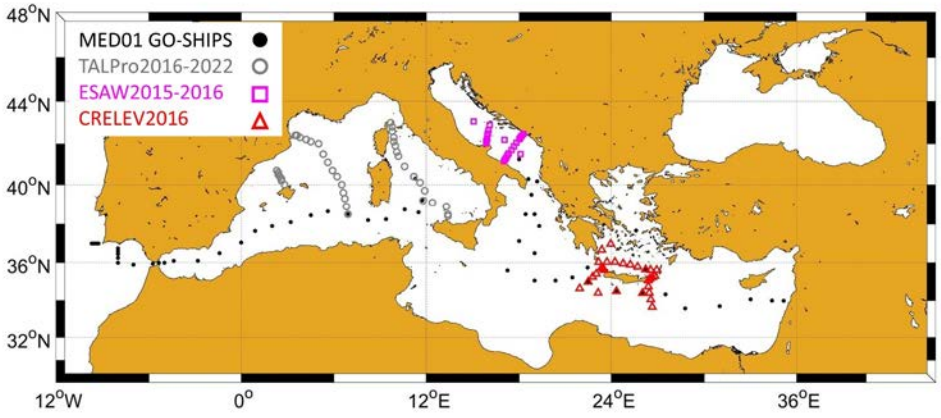


Figure 11. MED-SHIP cruises. Black dots correspond to MED01 cruise, repeated in 2011, 2018 and planned for 2025 or 2026, grey dots to TALPro2016 cruise, repeated in 2016 and 2022, magenta dots are for ESAW2015 and 2016 cruises and finally red dots correspond to CRELEV cruise, carried out in 2016. TALPro, ESAW and CRELEV will be repeated within the framework of MED-SHIP activities when possible.

A notable feature of the repeated cruises landscape is their relative scarcity in the Eastern Mediterranean (see also the discussion section). Two observation systems in this region are noteworthy: the POSEIDON observation system in Greece and DEKOSIM in Turkey. With regard to POSEIDON, contact with scientists involved in the program confirmed that it is not currently active due to the lack of funding. However, information about inactive time-series stations in the POSEIDON system is available in table 6 and Time_series_stations_supplementary.xlsx. For DEKOSIM, partial information was available through reports describing the cruise program conducted by Turkish Naval Forces during 2024

(https://www.shodb.gov.tr/shodb_esas/index.php/en/coordination/scientific-marine-research-cruise-plans/mcrp-2023). Figure 12 shows the geographical areas sampled in selected 2024 cruises that appear to have a periodic character.

Código de campo cambiado

Continuous observations were carried out between Cyprus and Egypt from 1995 to 2015 by means of repeated cruises and XBT lines carried out from research and opportunity vessels. These cruises and XBT lines were supported by projects funded by the European Union and therefore they are not active anymore. However, they provide a valuable information about the long-term properties of water masses and circulation in the Levantine Basin (Zodiatis et al., 2023).

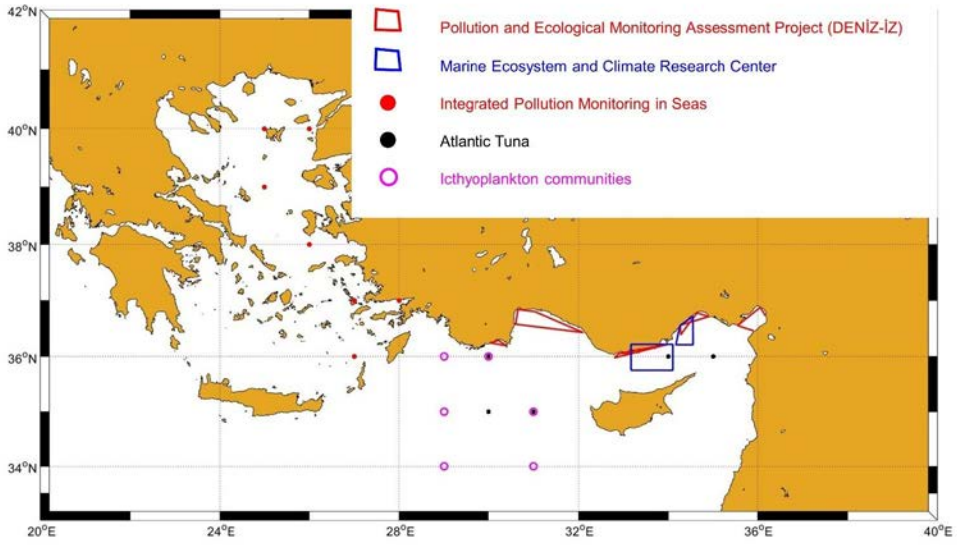


Figure 12. Some geographical areas sampled in the DEKOSIM's cruises developed in 2024.

Finally, it is worth mentioning that there are some programs in the Mediterranean Sea, oriented to the study of the ecology of certain species or the biodiversity of Mediterranean ecosystems. These programmes are intended to address the assessment needs of regional fisheries management organisations, such as the International Commission for the Conservation of Atlantic Tunas (ICCAT). They carry out annual surveys aimed at the collection and study of the early life stages of tuna species (e.g. Atlantic bluefin tuna, *Thunnus thynnus*) and other species in key ecological areas of the Mediterranean Sea. These campaigns also serve to characterise the pelagic habitat, through CTD casts, Niskin bottle sampling for biogeochemical analyses, and bongo net tows targeting micro and mesozooplankton communities. The datasets provided by these sampling programs

represent valuable information, providing time series of oceanographic information for these key ecological areas (i.e, Balbín et al., 2025). The sampling stations have not been included in the Repeated_cruises_supplemenary.xlsx file, as the stations do not have fixed positions and the sampling can be extended to hundreds of stations (they can be consulted in SeaDataNEt https://csr.seadatanet.org/report/21036538). As an example, Figure 13 shows the positions of the stations carried out in three of these surveys: TUNIBAL, TUNSIC and TunEMED. Other Mediterranean coordinated programs also exist to monitor small pelagics with acoustic surveys in which CTD casts are also collected (Giannoulaki et al., 2021; Placenti et al., 2024).

Another sampling network is TMEDnet (https://t-mednet.org/). This is a network devoted to tracking the evolution of the Mediterranean Sea surface and sub-surface waters to study the impact of sea warming and extreme events on mass mortality events and loss of biodiversity. This goal is pursued by means of a network of thermometers deployed at different depths of the upper 50 meters of coastal waters.

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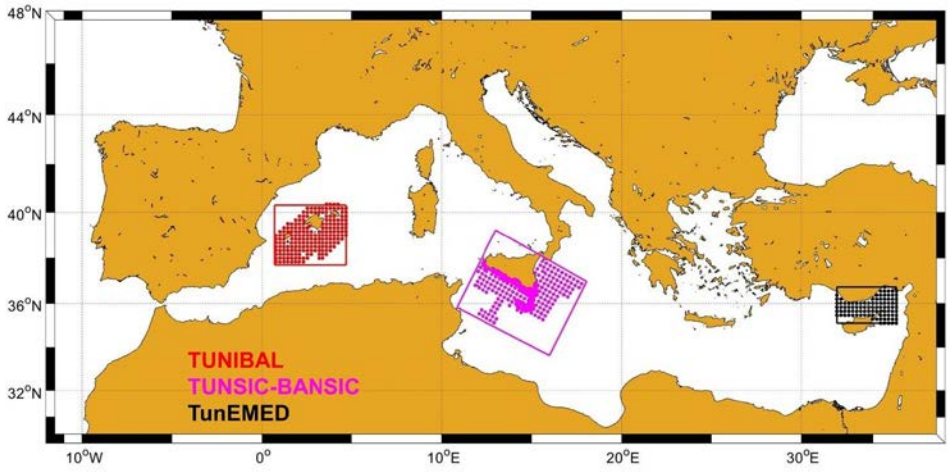


Figure 13. Stations sampled during the surveys TUNIBAL, TUNSIC and TunEMED within the frame of the "early life ecology" programs for monitoring tunas and other pelagic species. These surveys are carried out on an annual basis. The polygons show the sampling area, though the specific position of stations can vary for each survey.

4.6.2 Time-series stations

A time-series station is an oceanographic station, defined by its geographic coordinates, that is visited periodically by a research vessel. During each visit, measurements are taken and samples are collected for a range of variables. Sampling is therefore

often (though not always) multidisciplinary. These stations are commonly located in coastal areas in proximity to an oceanographic laboratory. The repeated sampling of these stations generates time series of Essential Ocean Variables (EOVs, see definition in the introduction).

The positions of time-series stations in the Mediterranean Sea for which information has been collected by OBSWG are shown as triangles in Figure 10. Figure 10B provides a zoom of the westernmost sector of the basin, where the sampling effort is greatest. A summary of the existing stations is presented in Table 6 and a more detailed description is provided in supplementary file Time_series_stations_supplementary.xlsx.

4.7 Glider Lines

Ocean Gliders form a mature observation network within GOOS, coordinated at the international level by its OceanGliders program (https://www.oceangliders.org/). These platforms are autonomous underwater vehicles that cover a pre-programmed route while sampling EOVs (Testor et al., 2019). These variables depend on the sensors installed in the glider but, besides pressure, temperature and conductivity, these vehicles are frequently equipped with fluorescence, CDOM (Colored Dissolved Organic Matter), optical backscattering and dissolved oxygen sensors. Some gliders are also equipped with turbulence sensors (Kokoszka et al., 2026).

Código de campo cambiado

The first deployments in the Mediterranean Sea took place in 2004, initially by Germany and then by France. Since then, over 350 missions have been carried out, and today eight countries are equipped with this technology: France, Spain, Italy, Greece, Germany, Cyprus, UK and Israel.

Some institutions have carried out glider missions over limited periods of time, including CEFREM in France (Gentil et al., 2022), the Democritus University of Thrace in Greece, and AGIR in Morocco as part of the ODYSSEA EU project (Damghi et al., 2025). These missions were primarily intended to test the technology and to investigate water masses and ecosystem functioning within the framework of specific research projects. However, here we focus on lines that are maintained repetitively (endurance lines) for a long period of time and therefore are suitable for operational purposes such as assimilation into numerical models, analysis of prevailing conditions, detection of regime shifts or the study of long-term trends (Zarokanellos et al., 2023). These glider endurance lines in the Mediterranean Sea are shown in Figure 14, whereas Table 7 presents summarized information about the existing endurance lines. A more detailed description of these lines can be consulted in Glider_lines_supplementary.xlsx in supplementary material.

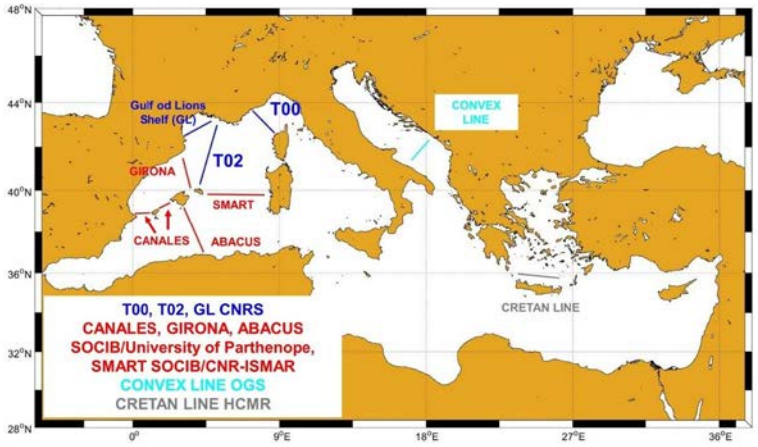


Figure 14. Endurance glider lines in the Mediterranean Sea and institutions responsible for the missions. As in other cases, lines which are not active at present, but have had a long duration have been included with grey colour for the sake of completeness.

COUNTRY	INSTITUTION	NAME	PERIODICITY	START	END
SPAIN	SOCIB	CANALES	300 DAYS/ YEAR	2011	ONGOING
	SOCIB	CANALES	300 DAYS/ YEAR	2011	ONGOING
	SOCIB	GIRONA			ONGOING
SPAIN/ITALY	SOCIB/UNIV. PARTHENOP	ABACUS	1 OR TWICE/YEAR	2014	ONGOING
	CNR-SOCIB	SMART	1 OR TWICE/YEAR	2017	ONGOING
FRANCE	CNRS, IFREMER	T00	4.5 MONTH/YEAR	2009	ONGOING
		T02	4.5 MONTH/YEAR	2010	ONGOING
		G. OF LIONS	1 MONTH/YEAR	2011	ONGOING
ITALY	OGS	CONVEC LINE	2 OR 4/YEAR	2013	ONGOING
GREECE	HCMR	CRETAN LINE	3 MONTHLY	31-10-2017	15-12-2023

Table 7. Long-lasting glider lines in the Mediterranean Sea including the country, institution, name of the line, periodicity or number of days per year, and start and end dates of the line.

5 Organizations involved in the governance of observing systems

As explained above, MonGOOS is the Mediterranean oceanographic network for the Global Ocean Observing System. It does not have a legal status, but is a partnership of institutions devoted to oceanographic research. According to its Memorandum of Agreement (MoA), MonGOOS was established in 2012 through the merger of two previously existing organizations: MedGOOS (Mediterranean Global Ocean Observing System) and MOON (Mediterranean Operational Oceanography Network). MedGOOS originated as an initiative launched during the IOC Workshop on GOOS Capacity Building for the Mediterranean Region, held in Malta in 1997. It was formally established through the signing of a Memorandum of Understanding (MoU) in 1999. MOON evolved from the EuroGOOS Mediterranean Task Team and was formally established through a Memorandum of Understanding (MoU) in 2005. After several years of close collaboration, MedGOOS and MOON were integrated into MonGOOS, which was created in 2012 to provide a unified framework for operational oceanography in the Mediterranean region. MonGOOS does not have a budget, and members do not pay a membership fee, therefore, it does not give financial support to observing or modelling activities. Its main goal is the promotion and coordination of such activities, favouring the connection and cooperation between different research groups, producing synergies and giving visibility to the activities and capabilities of the Mediterranean oceanographic community. It is not the aim of the present study to conduct a comprehensive bibliometric analysis of MonGOOS's impact on the Mediterranean scientific community. Nevertheless, a preliminary search in Google Scholar highlights the relevance of MonGOOS, with 439 documents (including scientific articles, reports, and other publications) mentioning or referring to the organization between 2012 and 2025 (see Figure S2 in Supplementary Material for the annual distribution of publications.

In order to achieve these goals, MonGOOS is structured in three Working Groups (WGs) coordinated by two co-chairs: Observations, Modelling, Applications and relation with the industry. The objectives of MonGOOS partially overlap those of other two organizations: EuroGOOS, which is the regional Alliance of GOOS for Europe, and EOOS, the European Ocean Observing System.

EOOS is an alliance of voluntary partnerships involving public and private stakeholders and has no legal status. Its role is to coordinate the observing platforms and infrastructures operating in European seas. Together, these coordinated assets constitute the European ocean observing system, which contributes to GOOS and GEOSS. Therefore, MonGOOS platforms located in European Mediterranean waters are part of EOOS, whereas those operating in the southern Mediterranean countries are not. ~~EOOS is defined as "an alliance of voluntary partnerships including public and private sector" (https://www.eoos-ocean.eu) and has no legal status. The EOOS is considered as the set of platforms and means for the observation of European waters. This set, once coordinated, constitutes itself an observation system, being a component of GOOS and GEOSS (Global Earth Observation System of Systems). Therefore, it includes those platforms from MonGOOS located in the European waters of the Mediterranean Sea, but not those in the southern riparian countries~~. As in the case of MonGOOS, it does not have a budget and is funded through the in-kind contributions of its members. EOOS is structured by a steering group and advisory and operations committees, aimed at fostering coordination and development of existing capabilities.

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EuroGOOS, as a GOOS regional alliance, shares the same objectives as the aforementioned organizations (MonGOOS, EOOS and GOOS), that is, to foster the observation of the oceans, promote the development and maintenance of observing systems, provide guidance and good practices for such systems, and favour the connection and cooperation between different institutions and countries. It is at the same level as MonGOOS, which is also a GRA, being the main difference that EuroGOOS is restricted to European Countries, whereas MonGOOS integrates all riparian countries of the Mediterranean Sea, also from Africa and Asia, and consequently pays special attention to north-south relationships. Another difference is that EuroGOOS has a legal status as a non-profit organization and is funded by membership fees as well as European projects, and maintains a permanent secretariat in Brussels. EuroGOOS is directed and coordinated by a chair and vice-chair, a board and a secretariat. Finally, both MonGOOS and EuroGOOS, as well as other GRAs, are under the umbrella of GOOS. GOOS has no legal status and is a program of the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO). It is funded by IOC-UNESCO, the World Meteorological Organization (WMO) and the International Science Council (ISC) and maintains an office in the UNESCO headquarters in Paris.

CIESM (Mediterranean Science Commission) is a scientific organisation exclusively focused on marine research in the Mediterranean Sea. It is an international organisation with legal status, whose member countries pay an annual membership fee. As in the case of MonGOOS or EuroGOOS, CIESM does not fund observation programmes, but supports and coordinates some of them, such as the aforementioned MED-SHIP or Hydrochanges, a network of deep moorings aimed at studying climate change and regime shifts affecting the deep waters of the Mediterranean Sea (Schroeder et al., 2013). It should be noted that some of the platforms listed in the present compilation also form part of this latter network.

Another institution involved in marine science with an European scope (and therefore also a Mediterranean one) is EurOCEAN. In contrast to other organisations mentioned above and throughout this work, this non-profit organisation is not directly involved in the definition of technical or scientific strategies, nor in the promotion of observation networks. However, it is mentioned here for the sake of completeness and to provide context for the reader. EurOCEAN focuses on disseminating knowledge and providing information on marine science across European countries. These activities are also partially shared by MonGOOS.

Concerning the coordination of different observation platforms and observation networks, which is directly related to the scope of the present work, EuroGOOS is structured in several task teams: Argo, FerryBox, HFR, Tide Gauges, and Fixed Platforms. These task teams gather information about the existing capabilities for each of these categories in European waters, and hence also cover the Mediterranean ones. This implies the need for coordination between EuroGOOS task teams and MonGOOS WGs. Certainly, some of the MonGOOS members are active actors in EuroGOOS task teams and many of the metadata compiled in the frame of the present work were obtained thanks to this cooperation. However, as we intend to provide guidance for end users searching for information about observing platforms, some minor points should be clarified. MonGOOS offers a dashboard at present. Some of the categories or platforms included are: HFR, MedArgo and Drifters, and Gliders. These three categories are also included in the EuroGOOS task teams. However, Tide Gauges and FerryBox were not represented and so, part of the results obtained in this work will help to update the MonGOOS dashboard, including the information concerning

these categories. EuroGOOS task teams contain a category named ‘Fixed Platforms’ which only include platforms fixed to the bottom. In this case, “fixed” is interpreted as anchored, whereas MonGOOS includes “Open Ocean fixed Oceanographic Stations” which includes platforms moored or anchored to the bottom, but also some oceanographic stations visited with a research vessel, but always at the same position. In this latter case, ‘fixed’ was understood as an indication of the Eulerian character of the observations. Besides this, the MonGOOS dashboard includes the ‘Repeated cruises’ category for oceanographic surveys with a larger geographical scope. In practice, the information available up to the moment is that corresponding to MED-SHIP, which is the Mediterranean contribution to the global program GO-SHIP, devoted to the sampling of physical and bio-geo-chemical variables worldwide with certain periodicity. ~~In order to complete this review of the contribution of different organizations to the monitoring of observation activities, i~~It should be noticed that GOOS carries out this task through its office OceanOPS. In the case of ship-based observations, OceanOPS distinguishes between two categories named as Ship Observations Team (SOT) and GO-SHIP. In the first case, observations from regular lines or periodic transects carried out by both opportunity ships and research vessels are included. In the second one, information from the already mentioned GO-SHIP program is gathered.

Because of the slight differences between the nomenclatures of MonGOOS, EuroGOOS task teams and OceanOPS, here we have proposed some definitions in section 2, which do not pretend to be better, nor worse than others, but simply to define clearly the names of each platform in such a way that it is fully informative for potential users. This nomenclature will be implemented in the near future in the MonGOOS web site and all the Excel files in the supplementary material of the present work will also be made available at such web site. Besides this, it should be desirable to increase the coordination between different organizations and their web sites for easing the search to end users. However, this is a point on which we will come back in the discussion and future perspectives section.

Finally, ~~and in order to complete this brief review of organizations involved in the observation of the Mediterranean and their governance,~~ we should mention the existing Research Infrastructures (RI). For instance, the French National Observatory System (SNO), which comprises moorings, repeated cruises and time-series stations, belongs to the RI ILICO (infrastructure de recherche littorale et côtière). In the case of Italy, ITINERIS (https://itineris.cnr.it Toller et al., 2026) is intended to coordinate and create a system of research infrastructures in the environmental domain, and hence, also in the marine one.

Some of these RI can obtain from the European Commission the legal status of consortium as “European Research Infrastructure Consortium” or ERIC. ERICs can be devoted to any research field. There are two ERICs exclusively related to oceanographic observation. The first one is EMSO-ERIC (European Multidisciplinary Seafloor and water Column Observatory), which is made of a set of moorings and platforms deployed at the sea bottom and along the water column. The second one is Argo-ERIC, which is the European contribution to the Argo program. Other ERICs are not exclusively dedicated to marine observations, but also do make a very important contribution to the observation of the seas, as is the case of ICOS-ERIC (Integrated Carbon Observation System). ERICs do not have a budget and, as in previous cases, they are funded by in-kind contributions of the partners. However, their legal entity allows them to apply for European funds or any other type of calls for projects, and then, can be financed by this means.

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6 Discussion: Strengths, weakness and future perspectives.

The present work has shown that a large number of institutions from both the northern and southern shores of the Mediterranean, as well as from its western and eastern basins, are involved in the observation and monitoring of its waters. These observations encompass many types of platforms for the observation of different Essential Ocean Variables which include temperature and salinity, ocean currents, dissolved oxygen and chlorophyll-*a* concentrations, inorganic nutrients, dissolved inorganic carbon, sea surface height, etc. Figures 3 to 14, Tables 1 to 7, and the more complete and detailed information compiled in the Excel files in the supplementary material, evidence the existence of an active community within the Mediterranean region which is of course one of the main strengths of the MonGOOS community. Such coordinated regional participation enhances data interoperability, improves temporal and spatial coverage, and strengthens the reliability of European marine data integrators and programs such as EMODnet, and in particular the EMODnet Physics products. It supports the implementation of marine conventions, such as the Barcelona convention and ACCOBAMS (2025) or the compliance of European marine directives such as the Marine Strategy Framework, the Marine Spatial Planning, or the Water Framework Directives.

The main aim of this work was to compile the metadata of all existing observation platforms in the Mediterranean Sea and make it easily accessible to users. We are aware that the information gathered and presented here does not represent the entirety of what exists. Furthermore, in many cases it is incomplete because we could not obtain the full information related to some platforms. However, it is sufficiently comprehensive to serve as a promising starting point. In this regard, the objectives of the work can be considered to have been achieved to a high degree. ~~As already stated, this was made possible thanks to the existence of a very active MonGOOS community, which meets annually to share information and activities such as the present one, at the initiative of the MonGOOS Chair and the Executive Board.~~ The process of compiling information on observation capabilities has itself contributed to connecting and expanding this community. The preparation of this manuscript required contact with 128 researchers, some of whom have now been identified as potential contact points for future enquiries and for updating and completing the information presented here. We directly obtained information (through our survey) from 52 institutions. Additional information from a total of 74 institutions was gathered thanks to the collaboration with EuroGOOS task teams and OceanOPS. Altogether, this constitutes one of the strengths of the Mediterranean observation system.

Nevertheless, the consultation phase also revealed certain weaknesses within the Mediterranean community engaged in ocean observation. The process of collecting metadata was highly uneven across the different countries and institutions consulted. The difficulties encountered in accessing this information often reflected the lack of well-resourced observation programs and personnel in some countries (we have already mentioned that the information compiled was incomplete in some cases). This, in turn, results in a clear asymmetry in the geographical coverage of available oceanographic data, with some regions insufficiently sampled. This is not anything new and is simply the result of the economical and political problems existing in some regions of the Mediterranean (which are out of the scope of MonGOOS). However, it also reflects the difficulty of sustaining observation systems indefinitely. It is specially outstanding the case of Greece where the POSEIDON observation

system has stopped all platforms after many years of successful functioning because of the funding cuts, or the risk for the continuity of L'Estartit coastal station, which is the longest *in situ* temperature time series in the whole Mediterranean Sea, or the scarcity of observations in most of the southern riparian countries, just to mention a few.

This compilation process also revealed the difficulty, in some cases, of connecting the oceanographic community involved in biology and fisheries with those monitoring programs under the umbrella of MonGOOS, EuroGOOS and GOOS. We had access to some important initiatives such as the annual surveys carried out under the ICCAT programs devoted to the study of reproduction of *Thunnus Thynnus* in the Mediterranean Sea, the TMEDnet, or the BBMO (which is part of the Spain-LTER network; Long Term Ecological Research). However, we are aware of the existence of other observation platforms to which we had no access. Such observations are carried out by universities or local institutions and they could contribute to complete the description of the Mediterranean observation capabilities.

Observation programs are managed within each country by different institutions. There are some Mediterranean countries where these programs are coordinated under the umbrella of a national observation program, in a similar way to that used in meteorological national services. This is the case of the French Ocean Observation System (Fr-OOS) which coordinates the aforementioned National Observation Services (SNO) related to observation of the seas. In the case of Italy, the ITINERIS project (Toller et al., 2026) is intended to create IT-IOOS (Italian Integrated Ocean Observing System). However, to our knowledge, this is not the case for many other countries. This complicates, not only the knowledge about the current state of observation capabilities, but also the sustainability of the existing observation programs. Some examples of these problems are the aforementioned POSEIDON and L'Estartit difficulties, but it also affects others such as MED-SHIP or Argo. In the former case, the lack of a more structured and sustained funding strategy does not allow us to ensure the long-term continuity and periodicity of basin-wide hydrographic observations in the Mediterranean Sea. In the case of the Argo program, it should be emphasized that it supports the Mediterranean Ocean Forecasting System and is used for the validation of various Copernicus Marine models. Besides this, it serves as a testbed for technological innovation, particularly for the development and validation of new sensors (e.g., UVP for zooplankton measurements, hyperspectral radiometry). To ensure the continuity of these services and to address future climatic, management, and governance challenges in the Mediterranean, it is essential to maintain the Argo network as well as the rest of observing programs. However, current funding is short-term and primarily project-based, which makes the continuity of observing systems inherently fragile. It is therefore urgent to move towards more stable and sustained funding mechanisms, combining national and supranational frameworks, in order to ensure continuity, coherence and adequate coverage of observing systems beyond national boundaries. In this context, national observing programs should be recognized as critical infrastructures.

A clear weakness in the present observation system of the Mediterranean (and very likely in other regions of the world) is the uneven and asymmetrical distribution of platforms and capabilities. This issue is not as pronounced in the case of freely drifting platforms, (Argo floats and surface drifters; see Figures 7 and 8), but, it is evident for fixed platforms such as HFRs (Figure 3), tide gauges (Figure 4), and surface or subsurface moored buoys and submarine platforms (Figure 5A). These differences

are also apparent in ship-borne observations, including those obtained from repeated cruises and time-series stations (Figure 10A).

These gaps in our current observation capabilities are even larger when biochemical variables are considered. Besides the problem, already commented, of involving the biological and fishery community in the present compilation, there is a scarcity of this kind of data. BGC Argo does not cover coastal, shelf and upper continental slope waters, with the only exception of coastal-Argo, of which only one float is currently operational. Notice that the 500 m isobaths has been included in Figure 7 and there are almost no Argo floats in waters shallower than this depth (see Figure 7B). Moored buoys only provide in most of the cases dissolved oxygen concentrations, chlorophyll-*a* fluorescence and pH in very scarce positions. Hence, the sampling of biogeochemical variables, especially along the water column, still rely to a great extent on ship-borne observations which are also very biased to the northwest and westernmost regions of the Mediterranean Sea (Figure 10A). Glider missions can also sample some BGC variables along the water column and with a good time resolution, but once again, most of these regular lines are located in the northwestern basin (Fig. 14). MED-SHIP surveys carry out very comprehensive sampling including physical and biochemical variables such as pH, alkalinity and/or dissolved inorganic carbon (Figure 11). The repetition in time of these surveys (some years apart in some cases) provides an invaluable tool for assessing regime shifts in the functioning of the Mediterranean Sea or trends in those variables with a low natural variability, as those associated with deep waters. However, and despite their global coverage of the Mediterranean Sea, they are insufficient for other purposes, especially when high frequency processes are involved. Therefore, it can be concluded that some EOVs such as pH, inorganic carbon or phyto- and zooplankton (see Fig. 2 in Martin Minguez et al., 2026) are not currently monitored *in situ* on a basin scale.

The gaps mentioned above in the present Mediterranean observation systems limit our capacity for describing trends in those variables or depth ranges with a high variance, or even to establish climatologies and ranges of variability for many of the BGC variables, which are essential to describe the health state of marine ecosystems. Furthermore, it imposes important limitations for our modelling capabilities. *In situ* observational data play an essential role in numerical models validation and they are used to correct and constrain numerical models, reduce ~~by reducing~~ uncertainties in data-assimilation schemes and reduce initialization errors~~, by improving analyses of water-mass formations, resolving mesoscale features like fronts and eddies that are often poorly captured, especially in their spatial displacement, by models alone~~ (Zarokanellos et al., 2022; Aydogdu et al., 2025~~). By assimilating real-world *in situ* data, the modelling systems can reduce initialization errors and produce more skilful forecasts (Aydogdu et al., 2025).~~ Without these ground-truth observations, uncertainties in models would persist, reducing confidence in operational forecasts used for maritime navigation, pollution control, and ecosystem management. Besides this, *in situ* observations are not only important for short-term forecasts but also for long-term monitoring and reanalysis. Long-term data help to constrain and evaluate model long-term reconstructions, correct systematic biases, and inform parameterizations for better predictive skills.

~~These observations also play an essential role in numerical models validation, ensuring that model outputs remain reliable for the large variety of user's needs. Without these ground-truth observations, uncertainties in models would persist, reducing confidence in operational forecasts used for maritime navigation, pollution control, and ecosystem management. Besides this,~~

~~*in situ* observations are not only important for short-term forecasts but also for long-term monitoring and reanalysis. Long-term data help to constrain and evaluate model long-term reconstructions, correct systematic biases, and inform parameterizations for better predictive skills.~~

In summary, the spatial imbalance (mainly north-south) and limited BGC measurements commented above, constitute a weakness of the current Mediterranean observation system. This does not only affect our capacity for describing the current state and variability of water mass properties, their circulation and the present state of marine ecosystems, but also complicates forecast and reanalysis works.

We have stressed the importance of the existence of observing systems, the need for achieving a complete and geographically balanced network of observations, and the need for compiling the related information (metadata). However, these systems are of very limited utility if there is not an appropriate data flow (not only metadata) between observing platforms, data centres and end-users.

In this context, EMODnet plays a crucial role as one single shop system for accessing the Mediterranean data in the European Marine Observation and Data network (https://emodnet.ec.europa.eu/en) under its Physics section (Shepherd, 2018).

EMODnet Physics is the domain-specific project (Novellino et al., 2024; Martín Mínguez et al., 2019) that provides in situ ocean physics data, including temperature, salinity, current profiles, sea level trends, wave height and period, wind speed and direction, water turbidity (light attenuation), underwater noise, river flow, and sea-ice coverage. EMODnet Physics delivers access to these data by federating national, regional, and international data infrastructures and repositories. For platforms participating in international monitoring programs such as ARGO, GO-SHIP, and Ocean Gliders, data are directly federated from the Global Data Assembly Centres (e.g., Coriolis). Other international platform data are connected through European nodes for specific platforms (for example, INGV serves as the node for XBT and the MED01 line, while CNR-ISMAR acts as the European node for HFR data). Coastal data are typically aggregated at the regional level by the Copernicus Marine Service and by *in situ* Thematic Data Assembly Centres (INSTACs). Then, they are made available to both Copernicus Marine Service products and EMODnet Physics (e.g., the POSEIDON network). Sea level data follow multiple paths: the Joint Research Centre TAD provides EMODnet with near real-time meteo-tsunami data; the IOC supplies data from GLOSS core sea level stations; some national networks (Italy, Croatia, Malta) are directly connected to EMODnet, and others (France, Spain, Greece, Slovenia) are first processed by Copernicus Marine INSTACs before integration into EMODnet. EMSO ERIC stations expose APIs that enable integrators to connect and retrieve data seamlessly.

Importantly, once a data platform is integrated into EMODnet Physics, it becomes readily accessible to the Copernicus Marine Service *in situ* Thematic Assembly Centers, and conversely, data integrated into the INSTACs are made available to EMODnet Physics. This strong collaboration and interoperability ensure that any new *in situ* operational data are accessible to the modelling community, supporting improvements in met-ocean forecasts and other oceanographic applications. Furthermore, it contributes to the development of the European Digital Twin of the Ocean, and facilitates the implementation of the Ocean Pact (a European initiative aimed at enhancing sustainable ocean governance, fostering collaboration among stakeholders, and promoting open access to marine data for science, policy, and society).

For all the reasons presented above, it is of paramount importance to continue the effort to identify all the observation programs and platforms that do not yet contribute to EMODnet and guarantee the data flow from all the existing observation platforms. The present work can be considered as a work in progress. Now that most of the potential actors have been identified, MonGOOS is committed to maintaining regular contacts in order to keep the compiled information up to date. Another next step will be to update and maintain this information on the MonGOOS website dashboard, also ensuring that the files containing the metadata are accessible. This task necessarily requires stronger coordination among the various organizations dedicated to fostering, coordinating, and visualising observing systems in the Mediterranean Sea, in Europe, and worldwide. This coordination effort should also consider the unification of the terminology used by ~~We have identified several discrepancies in the terminology used by~~ different actors within the observing systems. ~~Furthermore, during certain phases of the present work, it has been challenging to contact some of them, to locate the required information, or to understand the functioning and interrelationships between these organisations.~~

We have also evidenced ~~in~~ (section 5) that there are many organizations and institutions devoted to fostering and coordinating observation systems in Europe and in the Mediterranean Sea. Sometimes their activities overlap and, in other cases, it is not easy to identify their roles for a non-specialist public. For these reasons, in future developments, we must increase coordination and take into account that information concerning organisations, observation programmes, and access to metadata should be designed not only for specialised researchers involved in such programmes, but also for a broader scientific and non-scientific community. This coordination and homogenization should also include web sites where information is publically available. To this concern, it is worth mentioning that this coordination would be aligned with the current GOOS reform process (https://goosocean.org/news/call-for-proposals-global-ocean-observing-system-reform-consultancy/).

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This international cooperation should not be limited to harmonizing the criteria, nomenclature, and activities of the different organizations involved (MonGOOS, EuroGOOS, EOOS, etc.). It should also include initiatives aimed at assessing the actual capabilities of existing observing systems to serve different purposes, such as improving forecasting systems, detecting long-term changes, or establishing a scientifically sound bio-regionalization of the Mediterranean Sea. Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs), conducted by a team composed of members of the Observations and Modelling Working Groups, could help optimize existing observing networks and support the planning of new ones. This would ensure that the integration of the national systems contributes effectively to the development of a single, well-coordinated Mediterranean observing system.

Another challenge of MonGOOS, in relation to the commitment of gathering and updating our description of current observation capabilities, is to include emergent technologies as they incorporate the Mediterranean observing system. The emergence of new technologies is profoundly transforming ocean observing approaches, offering unprecedented opportunities to enhance existing systems. Recently, three emerging observing networks have been incorporated into GOOS to complement traditional platforms and leverage existing infrastructure through industrial partnerships: the Fishing Vessel Observing Network (FVON), the Surface Ocean CO2 Observing Network (SOCONET), and the SMART (Science Monitoring And Reliable Telecommunications) Cables network (https://goosocean.org/news/three-emerging-observing-networks-join-the-

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global-ocean-observing- system/?utm_source=chatgpt.com). Although their deployment is still ongoing, specific initiatives and applications are already being implemented or prepared in the Mediterranean, highlighting their potential to enhance regional observation coverage (Dañobeitia et al., 2024; Penna et al., 2023).

In December 2023, the first European wet SMART cable was deployed by INGV in the deep Mediterranean Sea at ~2000 m depth, within the Western Ionian Sea EMSO facility. The installation consists of a 21-km cable equipped with environmental sensors designed to monitor temperature, bottom pressure, and seismic activity. This pioneering experiment, supported by the ITU–UNESCO/IOC–WMO Joint Task Force within the Ocean Decade framework, aims to advance deep-sea monitoring across both oceanographic and geophysical domains. More broadly, SMART cable technology represents a key step toward the development of a global deep-ocean observing system capable of delivering continuous, large-scale, real-time measurements.

In parallel, Un-crewed Surface Vehicles (USVs) are poised to become key observing platforms (Patterson et al., 2025). In the Mediterranean Sea, Sail-drone USVs have already demonstrated their potential during the ATL2MED mission (Martellucci et al., 2024), providing high-resolution, long-duration air–sea surface observations.

Micro-autonomous underwater vehicles (micro-AUVs) represent another promising emerging technology, combining compactness, autonomy, and the ability to acquire fine-scale data across challenging spatial and temporal scales. In the Mediterranean, YUCO micro-AUVs have been deployed to map river plumes and complex coastal structures (Pairaud et al., 2025). They also open new avenues for applications such as environmental DNA (eDNA) monitoring, underwater imaging, and seafloor mapping.

7. Conclusions

There is a very active oceanographic community in the Mediterranean region, including experts engaged in observations, modelling, and applications. The compilation of existing information regarding observational capabilities in the Mediterranean Sea, together with MonGOOS's commitment to updating this information and presenting it in an accessible manner for the oceanographic community, policy-makers, and stakeholders, will support the consolidation and improvement of this observation system, contributing to EuroGOOS, EOOS, EMODnet, Copernicus Marine Service, and, more in general to GOOS.

~~However, t~~The main obstacles to overcome are the uneven distribution of observations across the Mediterranean Sea. The origin of this issue is well known and relates to political and economic difficulties in certain regions, which lie beyond the scope and capabilities of MonGOOS. Other shortcomings concern coastal and shelf waters, and particularly biogeochemical variables. Despite the fact that the development of emerging technologies may help to address some of these gaps, the sampling of many of these variables still rely on ship-borne observations, which are also unevenly distributed.

It is also important to emphasize the need for stronger coordination among international organizations involved in the development, support, and promotion of ocean observing systems. This coordination is particularly critical in areas where their

mandates and commitments overlap, helping to avoid duplication of efforts and improve operational efficiency. It should also foster the harmonization of terminology, metadata standards, and data management practices.

This work and most of MonGOOS activities are based on the belief that increasing the visibility of existing programs, as well as evidencing the quality and quantity of current observations and their potential applications, could encourage national governments around the Mediterranean Sea to fund and expand, when necessary, observation programs on a long-term basis. Such programs within each country should be coordinated and, most of all, their funding should be structural and not subject to short-term projects.

Code and data availability

All the metadata compiled during this work are freely accessible through the Excel files in the supplementary material.

Supplement link

The link to the supplement will be included by Copernicus, if applicable.

Author contributions

Manuel Vargas-Yáñez, Orens Pasqueron de Fommervault and Vanessa Cardin: Conceptualization; investigation; methodology; data curation; writing.

All other co-authors: Data curation; conceptualization; writing.

Competing interests

The authors declare no conflicts of interest.

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