Report on strategy for shelf-open ocean boundaries monitoring in collaboration with other ERICs and research communities

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EXECUTIVE SUMMARY

Being the leading observational network of the world's oceans, Argo's geographical coverage is continually expanding towards the coast, providing high-quality data from the intermediate zone between the coast and the open ocean, to the shallow coastal areas of the marginal seas. The Argo float array is also one of the major contributors to the global *in-situ* oceanographic observation network.

Within the framework of the Euro-Argo RISE project, the major impacts of the Argo programme's expansion towards the coast are reported here, and a future Argo strategy for monitoring this coastal shelf-open ocean boundary in the European Seas is outlined. The shelf-open ocean boundary areas extend several hundred kilometres between the Atlantic Ocean and the European continental landmass, but are also found in the Mediterranean Sea separating its coastline with its deep oceanic plateaus.

Recent experience from floats' missions and the increasing technical developments in terms of floats' performance highlight the capacity of Argo to enhance ocean observations in these zones, in tandem with existing platforms. The complementary, and crucial, role of Argo in regional observing systems shows that such a strategy will strongly depend on the synergies and collaboration with other observational networks and Marine Research Infrastructures.

Several oceanographic communities, from satellites to ocean modelling, and from fixed-point observatories to gliders, are keen to benefit from Argo's expansion in these boundary zones. Moreover, the increasing capacity of floats for new sensor integration, raises the potential of Argo to contribute to the European marine environmental policy implementation for the open sea such as the Marine Strategy Framework Directive.

Nevertheless, the consolidation of a sufficient and sustainable Argo monitoring plan in the aforementioned areas requires additional activities and planning to overcome several constraints of the open-ocean Argo namely the modification of mission parameters, the operational monitoring of the floats' trajectory, and a float recovery plan.

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1 Introduction – General framework

In Europe, both oceanographic research and monitoring have been accentuated during the last 20 years via the introduction and rapid development of operational oceanography. The expansion of modern oceanographic *in-situ* monitoring tools and platforms, combined with the advancement of satellite technology and data processing algorithms, are nowadays providing unprecedented information regarding the physical and biochemical processes in the European Seas (Kassis 2017). The latter, however, is integrating a wide variety of marine environments that include open ocean basins, deep trenches, shallow plateaus, and coastal shelf areas with complex bathymetries. Furthermore, in these different areas, the various oceanographic processes evolve and interact under a strong dynamic nature.

The European monitoring arrays are roughly distinguished into two major networks related to the physical and topographic characteristics of the targeted areas, a) the open ocean, and b) the coastal shelf monitoring network. However, several basins in the European Seas comprise characteristics of both and can be defined as transitional areas, which extend over the boundaries of the coastal shelf and into the open ocean. These areas present a wide range of physical characteristics, from warm and hyperhaline sub-tropical waters in the eastern Levantine to cold waters in the Nordic Seas. Further to this diversity, important variability of the circulation systems at a sub-basin scale has been increasingly observed (Heslop et al., 2012; Kalimeris and Kassis 2020) along with variable hydrological and biogeochemical processes.

These facts underline the need for an especially designed pan-European monitoring strategy capable of resolving the different spatio-temporal scales that dominate in such processes and the utilisation of the optimal technology and platforms according to the needs of each area. Such a strategy will facilitate marine monitoring procedures but also address societal needs, such as the estimation of human pressures in the marine environment, the assessment of the environmental status, and the addressing of EU environmental policies.

For the open ocean environment, the Argo program is a major contributor to basic oceanographic research. Providing an unprecedented amount of cost-effective and highly spatio-temporally resolved data, the monitoring array of Argo floats is the main component of the global ocean observing system (Roemmich et al., 2019; Riser et al., 2016), essential for climate studies, and ocean state analysis and forecasting, whilst it has also become the major *in-situ* complement to the satellite ocean-observing system (Le Traon et al., 2019; Le Traon, 2013).

The Argo monitoring capacity towards coastal shelf seas has also increased in recent years (Figure 1) due to both the technical advancements of the floats and the specially designed missions of Argo operators. For the global Argo program, the extension into regions previously under-sampled, such as the ice-covered regions and the marginal seas, is ongoing (Jayne et al., 2017). Such efforts are specifically enforced by the Euro-Argo European Research Infrastructure Consortium (ERIC), which has described the extension of Argo float coverage to the European Marginal Seas (EMS) among its strategic targets (Euro-Argo ERIC 2017).

Results presented so far in such areas, from the Bothnian Sea (Haavisto et al., 2018) to the Black Sea (Palazov et al., 2014), and from the Baltic Sea (Siiriä et al., 2019), to the Adriatic (Vilibić and Mihanović 2013), Aegean (Kassis et al., 2016) and Ionian Seas (Kassis and Varlas 2020), show that Argo floats work well not only as a complementary monitoring tool but also as an independent monitoring system, especially for the physical properties of the marine environment. The fields where Argo data has proved especially useful include temperature and salinity variability, water masses dynamics, and hydrological changes, where both long and short-term phenomena are well captured.

Nevertheless, the level of Argo contribution to the monitoring of the shallow coastal shelf is still under investigation. In the Euro-Argo RISE H2020 project, several case studies were undertaken in targeted coastal shelf areas of the Mediterranean, Black, and Baltic Seas, showing that Argo is a useful complementary part of the monitoring system in such areas (Euro-Argo RISE D6.2, D6.3). However, for the transitional areas between the coastal shelf and the open ocean, implementing Argo monitoring is at a more mature stage. Because of advances in float technology and new operational controlling tools, enhanced monitoring in such transitional areas has been demonstrated, providing valuable information regarding hydrography and ecosystem functioning.

Under this framework, an updated Argo monitoring strategy plan focusing on the boundary areas between the coastal shelf and open ocean will be necessary for the strengthening of Argo's contribution to pan-European initiatives such as the European Ocean Observing System (EOOS) and the description of the Good Environmental Status (GES) under the Marine Strategy Framework Directive. Furthermore, with regards to climatic variability studies, enhanced Argo coverage into the sub-basins of marginal seas will help the investigation of extreme events over the coastal zone and the description of their possible impacts on the marine system (Kassis and Varlas, 2020). Particularly, this information can be used for the description of short-scale events enhancing coupled met-ocean forecasts, whilst it can also be potentially important for fisheries, aquaculture, and government agencies (e.g. national meteorological and oceanographic offices and the national oceanographic monitoring services) related to ecosystem preservation and tourism.

In this report, aspects of such a plan are investigated taking into account the monitoring needs of such areas and focusing on synergistic activities with other monitoring platforms. The planning and implementation of such a monitoring strategy are further discussed taking into account the recommendations provided by regional research communities and marine research infrastructures.

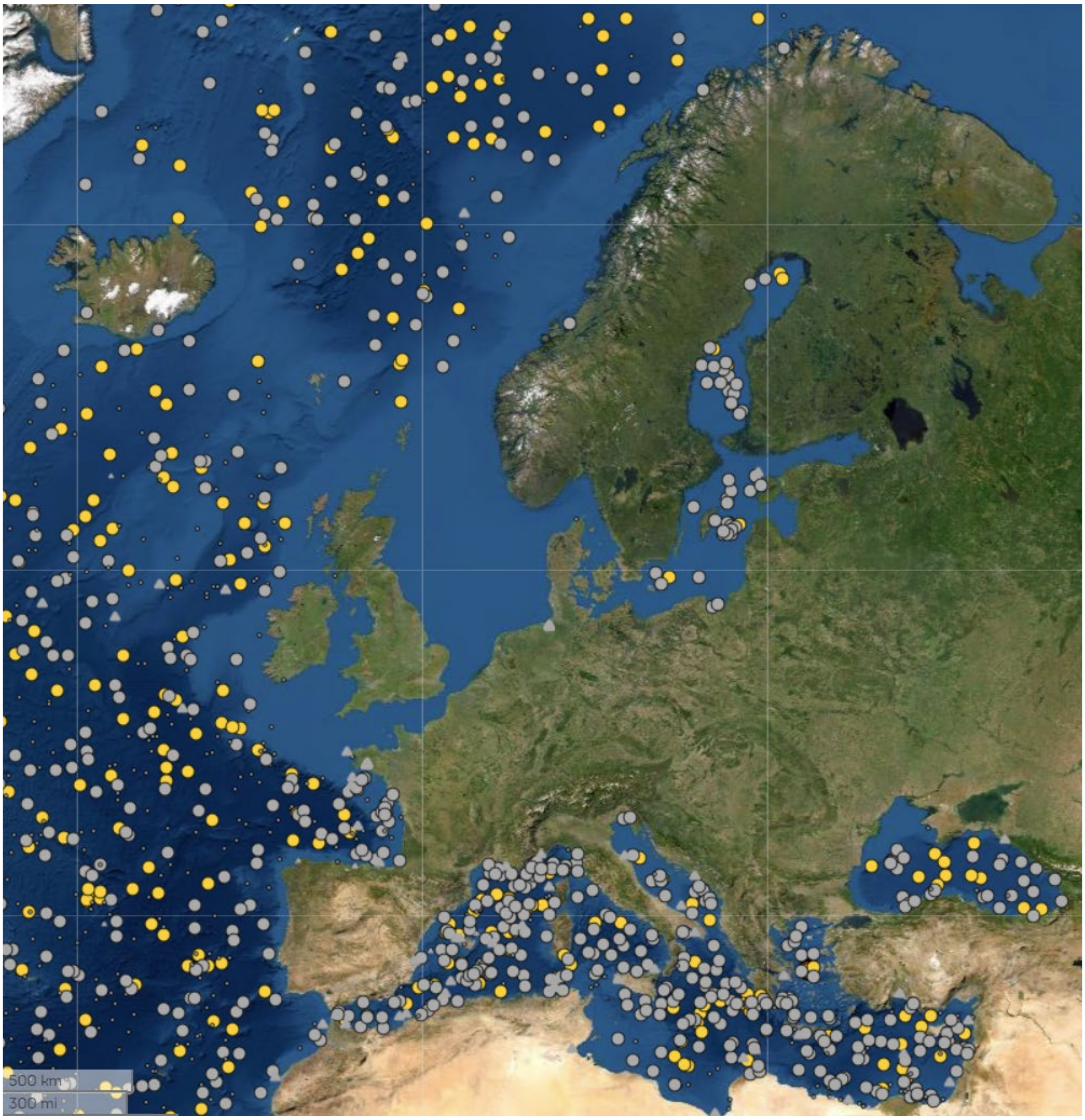

Figure 1. European Argo floats geographical distribution in the EMS since 2010. Yellow dots represent active floats (October 2022), grey dots represent inactive floats (https://fleetmonitoring.euro-argo.eu/dashboard).

2 Monitoring targets

2.1 Parameters measured

2.1.1 Physical parameters

The monitoring of the ocean's physical parameters is the baseline for all fields of oceanographic research. Parameters such as temperature, salinity, and ocean currents provide the basic information for the ocean state and are essential for the description of the hydrology and the hydrodynamic processes that dominate in the marine environment. Several mechanisms such as water masses' identification and distribution, circulation, mixing, air-sea fluxes, climatic variability, and ecosystem functioning, are linked with physical parameter distribution within the ocean's water column.

For temperature and salinity distribution, Argo is and has been the leading platform providing dense spatio-temporal data for over 20 years in the world's oceans. For the EMS (Figure 2), the increasing number of Argo temperature/salinity (T/S) profiles during the past decade has led to an increasing number of regional research studies, enhancement of high-resolution forecasting and re-analysis of numerical models, and new local-scaled user services. However, for the areas between the coastal shelf and the open ocean, mesoscale and sub-mesoscale variability dominate and thus an updated monitoring strategy is needed in order to capture such processes. The capability of the Argo platform to increase its spatio-temporal resolution mainly relies on the shortening of the profile cycling period and the vertical sampling resolution of the floats. Furthermore, the potential of Argo to sample up to the surface layer gives an additional asset, since it can provide useful datasets of Sea Surface Temperature and Salinity (SST, SSS) to complement satellite measurements. Moreover, such data is particularly important for the assessment of relevant satellite datasets, and research on ocean advection, mixing processes, air-sea fluxes and climatic variability (Josey et al. 2013; Durack 2015).

Another important aspect of a new Argo monitoring strategy in such areas is the enhanced estimation of the intermediate water layers' circulation where little information is currently available. However, the boundary currents that dominate in certain regions, especially in the zone outside of the coastal shelf are essential for understanding the general circulation of wider basins and the heat exchanges between local and global ocean currents that affect the regulation of local weather conditions and climate patterns (Kalimeris and Kassis 2020; von Schuckmann et al., 2016). For the global ocean, the commonly used 10-day cycles for Argo floats' missions only give a rough estimation of the deep-intermediate water layer circulation at 1000 m depth. However, for the EMS there are cases such as the Mediterranean where according to MedArgo specifications (Poulain et al., 2007) the cycle period is half this and the parking depth is reduced to 350 m. This results in a better estimation of the intermediate water layer circulation and can be further improved under this new monitoring strategy with shorter cycles and adjustable drifting depths for specific areas. This may lead to an important contribution for Argo on key issues with noticeable societal impacts such as sea level changes, carbon cycles and fisheries, marine search and rescue operations and pollutants' dispersal.

In general, an enhanced contribution for Argo on the monitoring of the shelf-open ocean boundaries will strongly rely on the synergies with other platforms that operate in these zones such as gliders and moorings. This will require the design of an integrated multi-platform observing system design for an efficient monitoring system operated jointly by regional research communities (MonGOOS, IBI-ROOS, BOOS) and research infrastructures (EMSO, GROOM-RI, JERICO-RI and others).

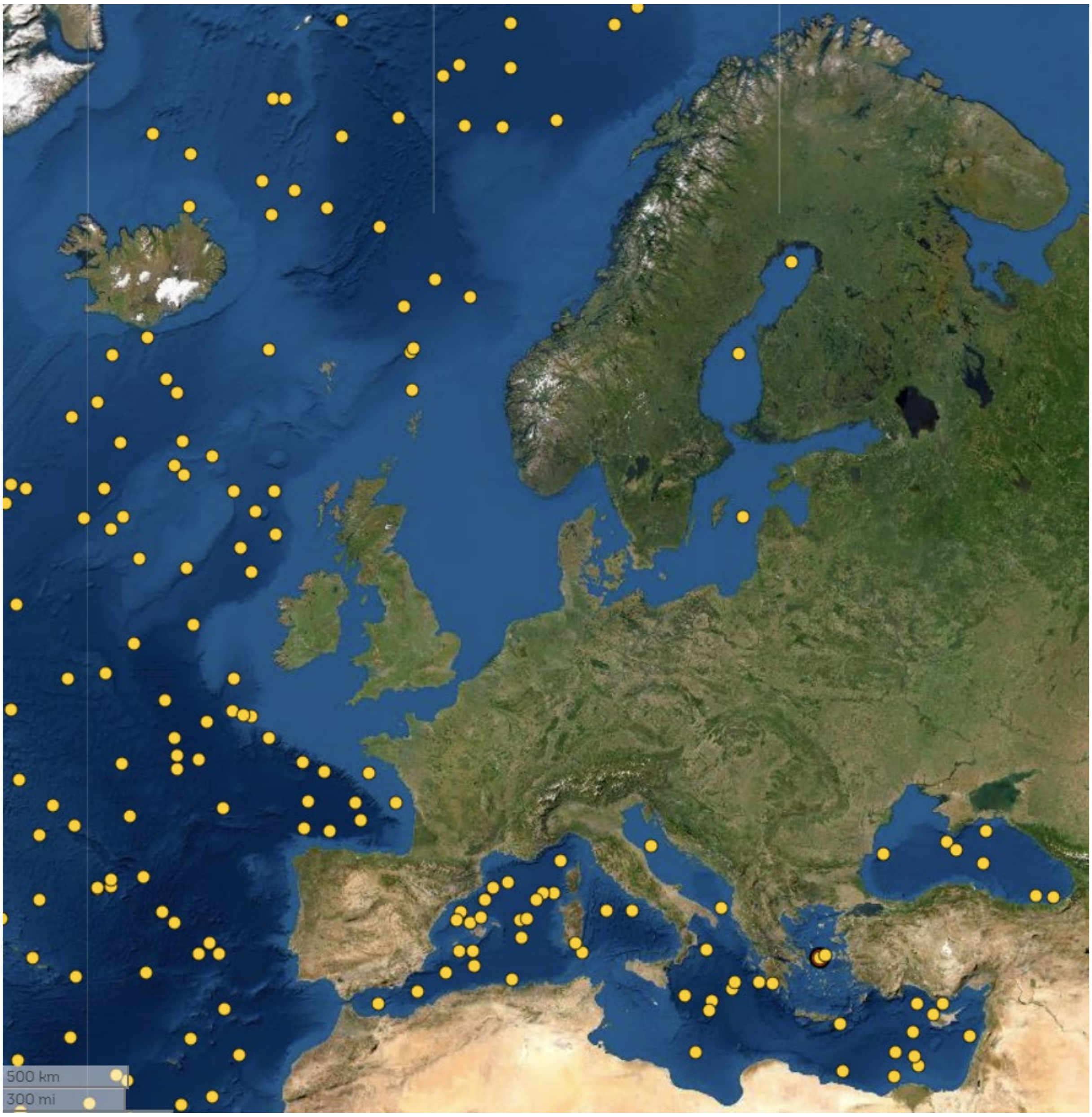

Figure 2. The active standard-CTD Argo float network in the EMS areas as of October 2022 (https://fleetmonitoring.euro-argo.eu/dashboard).

2.1.2 Biogeochemical parameters

The extension of Argo to biogeochemical parameters is one of the best examples of the increased capability of the Argo platform. This extension began over a decade ago with the wide use of sensors measuring dissolved oxygen concentration. Nowadays, oxygen sensors on Argo floats are common and represent a large part of the international Argo fleet. In the last decade, additional biochemical sensors have been introduced to form new instrumentation suites on Argo floats. Although relatively new, the international Biogeochemical-Argo (BGC-Argo) programme has already produced numerous results and key information on both physical processes and ecosystem functioning (Claustre et al., 2020). For the boundary areas between the coastal shelf and open-ocean. *In-situ* datasets of biogeochemical parameters are particularly important for the investigation and monitoring of marine biogeochemical processes and ecosystem dynamics. The strategic expansion of BGC-Argo into EMS (Figure 3) according to the Euro-Argo ERIC's strategy plan (Euro-Argo ERIC, 2017) covers a part of this need. It is important to note that the combined information provided by an Argo float which may include physical and BGC data, opens new research fields for Argo itself such as biogeochemical cycles, plankton and fish transport, oxygen, CO_2, chlorophyll-a variability, and optical oceanography. Satellite observations along with other autonomous oceanographic platforms, such as moorings, seabed platforms, gliders and autonomous surface vehicles also contribute through the incorporation of similar sensors. Thus, as with the physical parameters, strong synergies are required between Lagrangian (mobile), Eulerian (fixed), and remote (satellite) sensors for the provision of the required spatio-temporal information to describe ecosystem functioning and improve model simulations and forecasts of ocean conditions and ecosystem health. Such synergistic activities should be taken into account for the building of a multidisciplinary coastal shelf to open ocean observing network of Argo floats equipped with an extensive range of biogeochemical sensors.

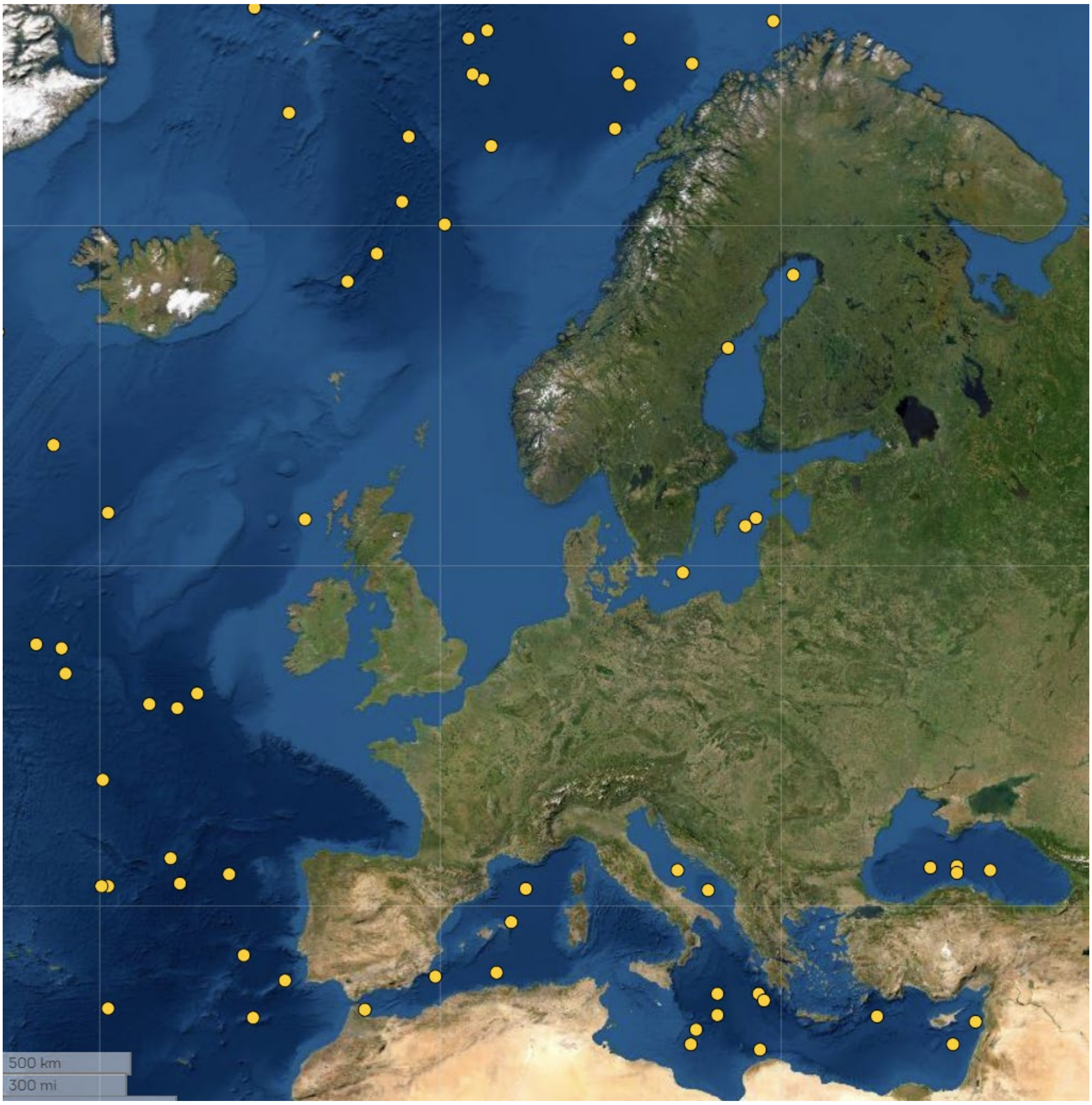

Figure 3. The active BGC Argo float network in the European Seas as of October 2022 (https://fleetmonitoring.euro-argo.eu/dashboard)

2.2 Areas of interest

2.2.1 Mediterranean Sea

The Mediterranean Sea is a regional sea that combines many oceanographic features from both the coastal shelf and the open ocean. It has been described as an ideal natural laboratory for oceanographic studies and research on climatic changes and ecosystem pressures. In this respect, Argo floats are particularly significant for monitoring the area and have contributed significantly to recent studies. During the past 15 years, Argo floats have been systematically used in the Mediterranean Sea to provide an unprecedented quantity of data from its coastal shelfs to its deep plateaus across its sub-basins (Figure 4). Thus, an updated monitoring strategy for the under-sampled shelf - open ocean boundary is critical for the provision of enhanced oceanographic monitoring across the Mediterranean. Additionally, the expansion of Argo in these zones will further contribute to the characterization of the mesoscale circulation activity in the Mediterranean Sea which is dominated by many permanent or recurrent structures that interact with and modify the flow at the basin scale (Menna et al., 2019; Kalimeris and Kassis 2020). The Mediterranean comprises two main sub-basins (Eastern & Western Mediterranean basins), each of them presenting special characteristics of specific oceanographic interest.

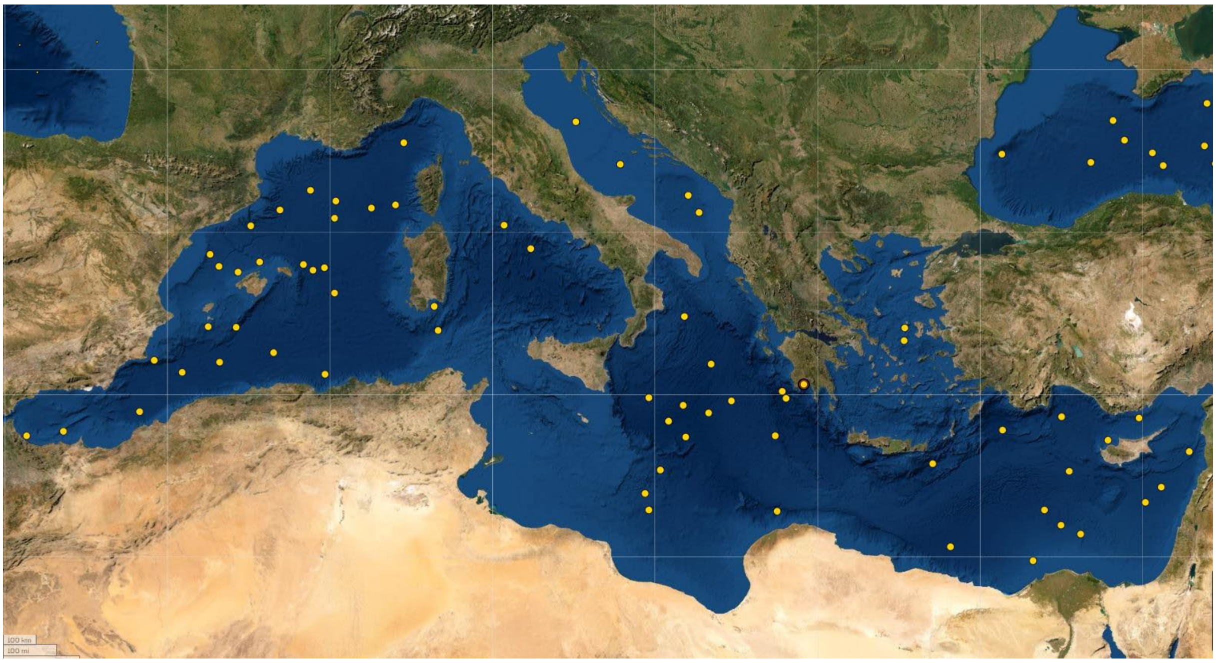

Figure 4. The active Argo float network in the Mediterranean Sea as of October 2022 (https://fleetmonitoring.euro-argo.eu/dashboard)

The Eastern Mediterranean basin presents many interesting features, such as complex circulation patterns that evolve in different spatio-temporal scales and Dense Water Formation (DWF) events, with the Eastern Mediterranean Transient (EMT) being the most important (Malanotte-Rizzoli et al., 1999). This area's main sub-basins (Adriatic, Ionian, Aegean and Levantine), dynamically interact with each other (Figure 5) and play a very important role in the general hydrology of both the Eastern and Western Mediterranean basins. Recent research in the Eastern Mediterranean basin has revealed positive temperature and salinity trends both in the upper and intermediate layers (Kress et al., 2014; Schroeder et al., 2017; Kassis and Korres 2020).

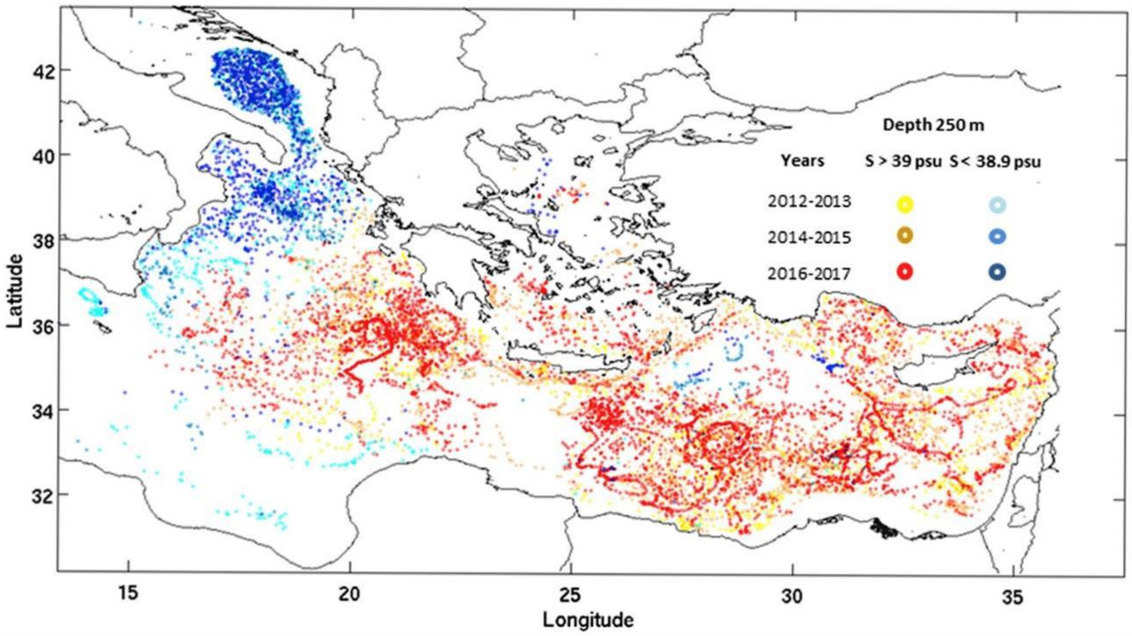

Figure 5. Spatiotemporal distribution of salinity values recorded from Argo profilers in the Eastern Mediterranean S < 38.9 and S > 39 at 250 m during 2012–2017 (From *Kassis and Korres* 2020).

On the other hand, the Western Mediterranean basin is characterised by cooler and more saline resident Mediterranean waters in the north, and warmer and fresher Atlantic waters in the south (Sayol et al. 2013). Specifically, the typical water masses present in this area are the recent and modified Atlantic Water (AW), the Western Intermediate Water (WIW), the Levantine Intermediate Water (LIW) and the Western Mediterranean Deep Water (WMDW). The scheme of water circulation patterns is: the North Current (NC) flows southward along the Spanish shelf-slope, with part of the NC crossing the Balearic basin through the Ibiza Channel while the other part is deflected eastward forming the Balearic Current (BC) (La Violette et al. 1990, García-Ladona et al. 1996). In the southwestern region, the average circulation is dominated by the Algerian Current (AC) and presents numerous front and eddy structures induced by the interaction of this boundary current with the steep coastal topographic slopes (Escudier et al. 2016, Capó et al. 2019). Finally, the Balearic Channels (Ibiza and Mallorca Channels) role needs to be emphasised as they control the meridional fluxes of the Western Mediterranean. The water mass exchanges between the northern and southern sub-basins occur through these channels (Heslop et al., 2012; Juza et al., 2013, 2019; Barceló-Llull et al., 2019). Also, in this area, recent research shows a positive trend in SST over the 39-year period around 0.032 +/- 0.002 ^{o}C/year (Juza and Tintoré, 2021).

The fact that these trends are stronger than those observed globally (Schroeder et al., 2017; Kassis and Korres 2020), highlights the important role of the Mediterranean's hydrography in investigating climatic changes and pressures.

2.2.2 Canary Current Upwelling System

The Canary Current Upwelling System (CCUS) is one of the four major Eastern Boundary Upwelling Systems (EBUS) of the world (Figure 6). EBUS are of critical importance because of their high productivity, intense fisheries activity and consequent economic and social implications. The strong dynamic link between the atmosphere and the ocean in these regions makes them highly sensitive to global changes. There is an almost agreed consensus that the global atmosphere/ocean system undergoes a generalised warming period, modifying the thermal structure of the ocean and its forcing factors (e.g. wind stress, surface heat fluxes), with consequences in the ecosystem functioning.

The CCUS extends from the northern Iberian Peninsula at 43° N to the south of Senegal at approximately 10° N. The CCUS is unique since it is divided by the discontinuity imposed by the Mediterranean entrance in the Gulf of Cadiz into a northern segment (Western Iberia) where the upwelling regime has a seasonal prevalence (approximately from April to October) and a southern segment (Northwest Africa) where upwelling is permanent with summer intensification in the northern part, and seasonal with winter predominance in the southern part (e.g. Senegal).

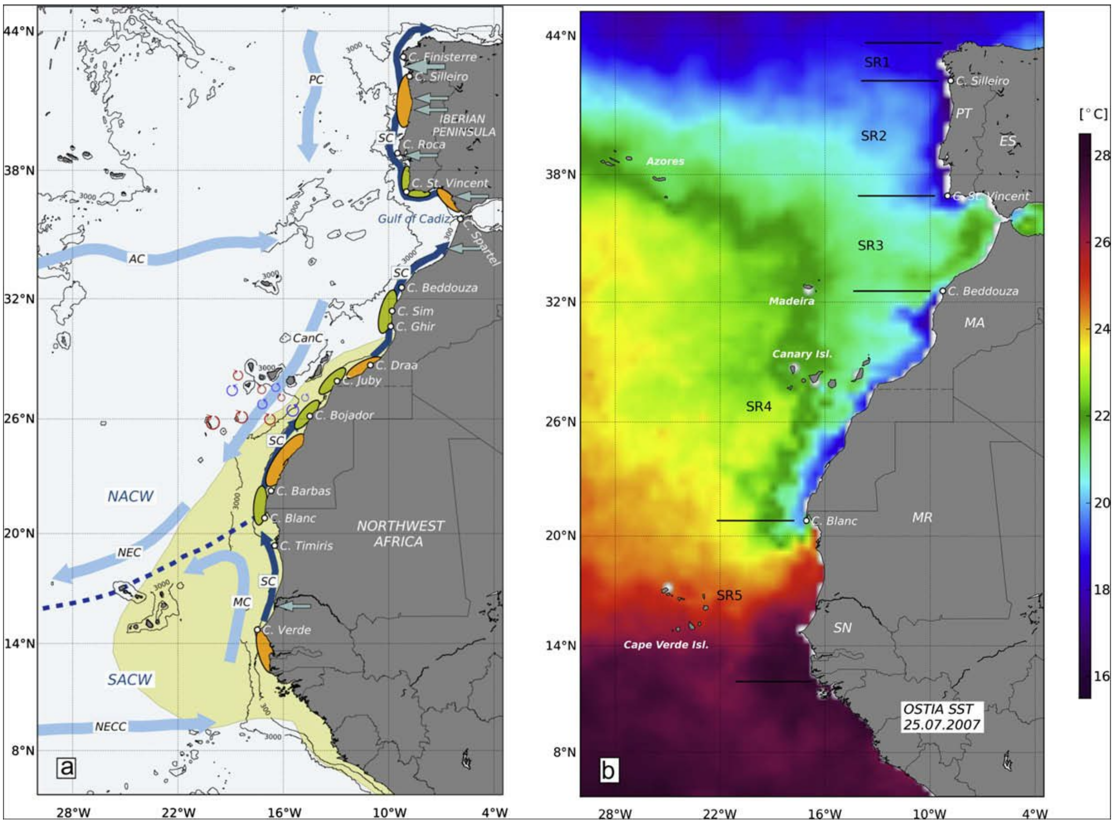

Figure 6. (a) Schematic map of the CCUS showing the main currents (light blue: surface currents; dark blue: slope current), major capes, freshwater (blue arrows) and dust inputs (yellow), retention (orange) and dispersion (green) zones on the shelf, frontal zone between water masses (dashed blue lines) and mesoscale eddies (blue: cyclones; red: anticyclones) south of the Canary Islands. NACW: North Atlantic Central Water; SACW: South Atlantic Central Water; AC: Azores Current; CanC: Canary Current; MC: Mauritanian Current; NEC: North equatorial Current; NECC: North equatorial Countercurrent; PC: Portuguese Current; SC: Slope Current. (b) Map of sea-surface temperature over the study area on 25 July 2007 from OSTIA (from Aristegui et al., 2009).

The CCUS is characterised off-shore by slow, broad, equator-ward gyre recirculation from a meridional alignment of coastlines, and a predominant equator-ward wind direction during a substantial part of the year (in some regions permanently) that forces an upwelling regime at the coast. This upwelling, transporting cold and nutrient rich water, is governed by the Ekman dynamics which predict cross-shelf transport proportional to the along-shelf wind stress and associated along-shore equatorward currents due to geostrophic adjustment. Pole-ward flows at sub-surface levels compensate for the along-coast mass transport (e.g., Aristegui et al., 2006, 2009). A conspicuous succession of mesoscale structures such as jets, meanders, ubiquitous eddies, upwelling filaments and counter currents, superimposed on the more stable variations at seasonal timescales, dominates the system (e.g., Peliz et al, 2002; Relvas & Barton, 2002; Relvas et al., 2007, 2009). The spatial and temporal scales of importance for the marine plankton communities are mainly related to these mesoscale features as reviewed by Santos et al., 2004, 2007).

Due to the strong link between biological activity and wind effects, upwelling areas constitute relevant places to study the impact of global warming on first trophic levels. Although long-term changes in the productivity of small pelagic fish (e.g., sardine) have been observed and explained (at least partially) by changes in upwelling conditions (e.g., Kifani, 1998; Santos et al., 2001, 2005; Borges et al., 2003), Santos et al (2004) showed that mesoscales features play an important role in the transport of larval stages and their retention in, or dispersal from, favourable nursery areas.

The Gulf of Cadiz (GoC) is a very dynamic system with inflow of Atlantic Water to the Mediterranean Sea and a Mediterranean Outflow (MO) into the North Atlantic Ocean (Figure 7) and along the western European coast. The MO spreads in the north-eastern part of the GoC as a bottom-gravity current but at the western part of the gulf the flow stabilises and continues flowing against the slope between the depths of 400 to 2000 m along the Atlantic coast of the Iberian Peninsula and reaching latitudes up to 55° N. The MO is characterised by temperature and salinity maxima at the depths of the main cores (400 m, 800 m and 1200 m), low-nutrient and oxygen contents, and relatively high abundance of particles. Along its path the current at times separates from the slope forming eddies (called meddies). The MO is an important source of salt and heat to the North Atlantic Ocean and its variability could have important consequences for the thermohaline circulation of the Atlantic Ocean.

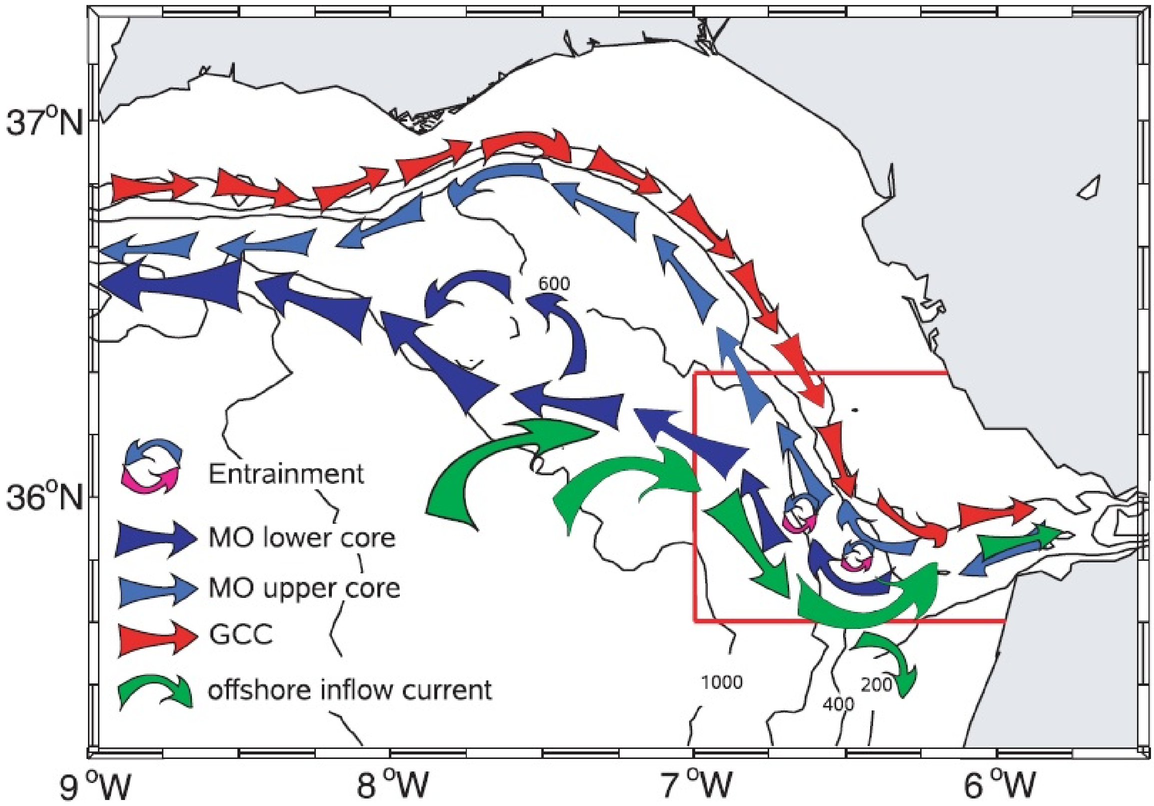

Figure 7. Schematic representation of the mean Gulf of Cadiz slope current system. The blue arrows represent the Mediterranean Outflow (MO) upper and lower cores. Bright red arrows represent the mean path of the inshore inflow (the Gulf of Cadiz slope current-GCC), and green arrows stand for the offshore Atlantic inflow (From Peliz et al., 2009).

2.2.3 Nordic Seas

The circulation in the Nordic Seas consists of two distinct components: a boundary current on the shelf circumnavigating the Nordic Seas (and the Arctic Ocean) (Rudels et al., 1999) and regional cyclonic circulation cells in the interior of the Nordic Seas. The boundary current (Figure 8) follows a cyclonic path around the sub-basins of the Nordic Seas (Latarius and Quadfasel, 2016) and its branches have been named West-Spitzbergen Current (WSC) on the eastern side of the Nordic Seas and East Greenland Current on the western side (EGC). The Fram Strait in-between both is the only deep connection between the Atlantic Ocean and Arctic Ocean, and the exchange of water through this gateway is of significant climatic importance. Changes in the Atlantic Water (AW) properties transported on the shelf influence the local climate (Walczowski et al., 2012) and also ice conditions north of Svalbard (Piechura, Walczowski, 2009). The stratified boundary current and the adjacent shelf areas make up about 20% of the area in the Nordic Seas. Mixing into the interior takes place by eddies and changes in water mass characteristics between the shelf and the interior. As the boundary current enters from the south across the Greenland-Iceland-Scotland Ridge the WSC current carries subtropical warm and saline Atlantic Water (AW) into the Nordic Seas where the AW is transformed through mixing with freshwater and negative buoyancy fluxes. Hydrographic fronts separate the AW from ambient waters in the WSC into two branches (west and east) which are both important for the lateral transport of AW into the interior (Walczowski, 2013). The East Greenland Current (EGC) consists of three distinct components (Havik et al., 2017); the well-known shelf-break branch, the inshore branch on the continental shelf, and a separate branch offshore of the shelf-break. The inshore branch contributes significantly to the overall freshwater transport of the rim current system, and the offshore branch recirculates a substantial amount of AW equator-ward in direct continuation of the western branch of the WSC.

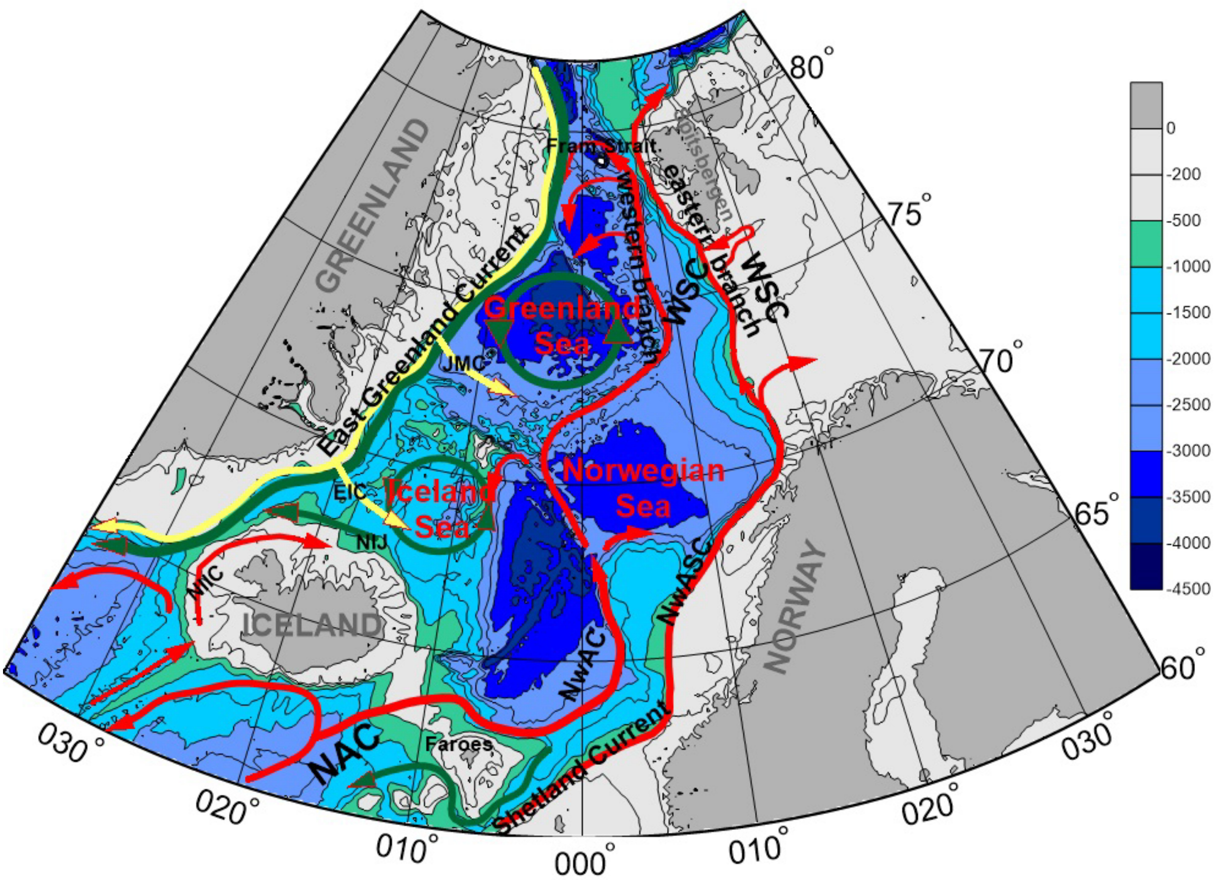

Figure 8. Circulation scheme of the Nordic Sea and the Arctic Ocean.

A strategy for monitoring the boundary regime between the shelf and the deeper interior ocean has been developed in WP2 of E-ARISE and has been detailed in deliverable D2.3 (A European strategy plan with regard to the Argo extension in WBC and other boundary regions).

In the same task, a simulation of floats trajectories (Figure 9) obtained using the CMEMS velocity fields from the Global Ocean Physical Multi Year CMEMS model product and the Virtual Fleet library were performed. This aimed at determining the best strategies for deployments.

The initial results showed:

- the necessity of integrating grounding behaviour in the Virtual Fleet tool when the simulations are done in shallow shelf-break regions (<1000m). In real life when a float hits the ground and cannot descend to the desired depth it performs a grounding management procedure. If a float hits the seabed during the descent to parking depth it will go up 50 dbar and try again to park at this depth. If the float hits the ground during the descent to profile depth, it starts the profile at the current position. The current version of the Virtual Fleet library includes this feature.

- A parking depth around 350 m was more effective to keep the floats inside the WSC than a parking depth of 500 m. Deeper parking depths were not tested due to the initial lack of grounding management in the Virtual Fleet library.

- A score was developed to evaluate the simulated float trajectories according to the objective to maximise sampling of the boundary current. The score consisted of three parts: trajectory length, residence time and covered latitude range. The parts are standardised on a scale between 0 and 100 and are combined by taking the weighted sum of:
    - Length of the trajectory: Length trajectory / maximum length x 100
    - Time spent inside the boundary current: Number of timestamps in the polygon / total amount of timestamps x 100
    - Difference in latitude: (Maximum latitude - minimum latitude) / maximum difference x 100

- The deployment locations used were selected from the AREX cruises station grid from IOPAN. Both Poland and Germany use these cruises every summer for float deployments. The stations located in the southern part of the WSC proved to be better for keeping floats in the WSC and thus had higher scores. Only floats deployed near the Fram Strait entered the ECG.

- The optimization tool developed at IFREMER (private repository https://github.com/euroargodev/VirtualFleet_Optimization) was used at BSH to find the float mission configurations that maximised the trajectory scores resulting in the following optimum configurations:
    - WSC:
        - Parking depth: 389 m
        - Cycle duration: 10 days
        - Score: 45.4
    - ECG:
        - Parking depth: 311 m
        - Cycle duration: 7 days
        - Score: 65.14
- Work is ongoing to perform more simulations to test the configurations with grounding and with a larger number of floats and a wider range of deployment years to cover internal variability.

In addition to the regular deployments by Germany, France, Norway and Poland in the Nordic Seas, Denmark will soon contribute to the Argo Program in the region as a new Euro-Argo member. Their initial focus is to observe the ECG in shallower regions using BGC floats. Operating floats as a virtual mooring is one of the possibilities being discussed. In such a case, the use of the Virtual Fleet library could be useful to find optimum mission configurations.

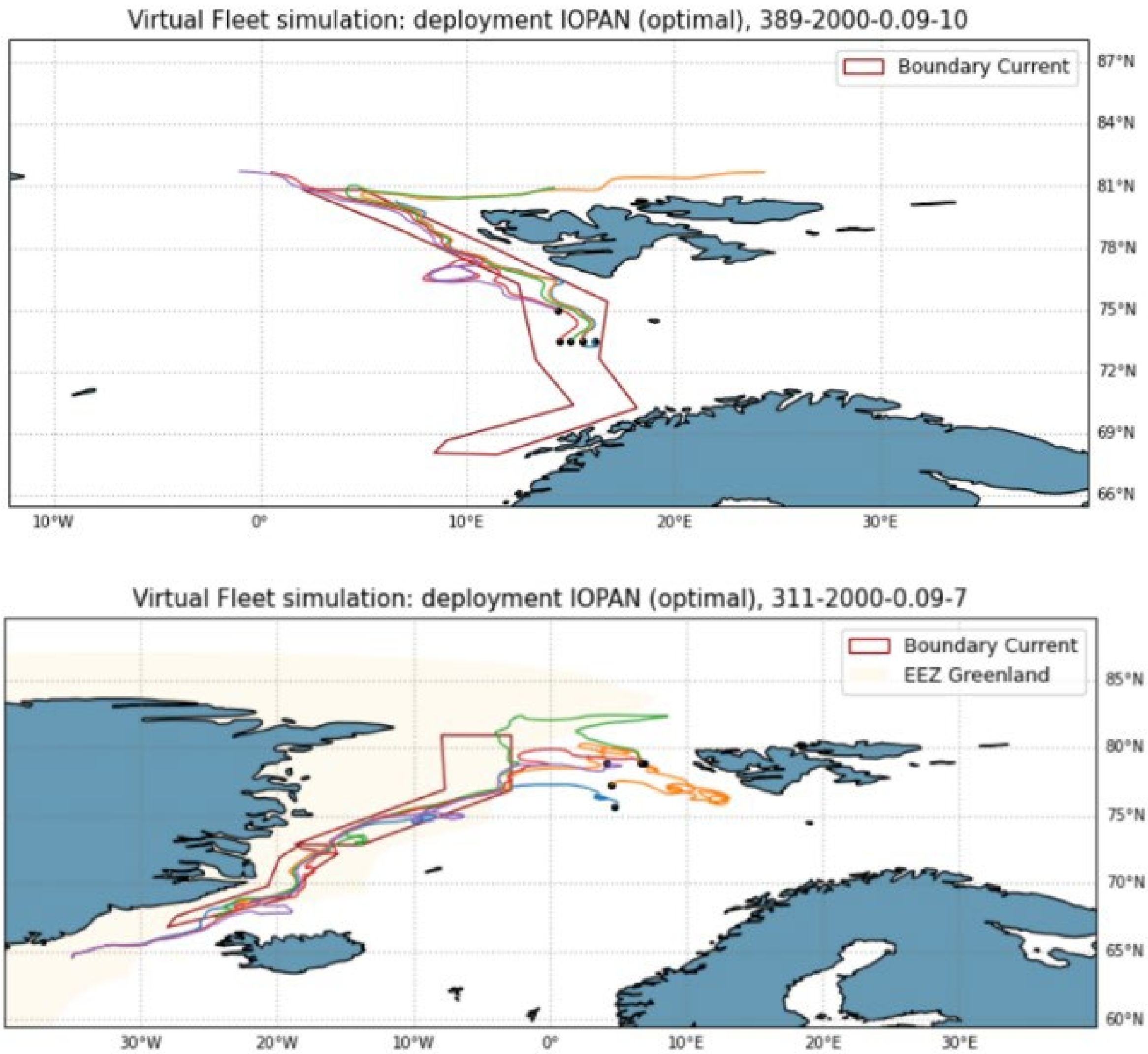

Figure 9. Simulations of the best trajectories using the optimum deployment positions from the AREX cruises and the optimum mission configurations in the WSC (top) and ECG (bottom)

3 Collaboration framework

3.1 Argo collaboration with Marine RIs

The upgrade and expansion of the European marine observing network is the main priority of several major operational oceanography initiatives, aiming to meet both scientific and societal needs. Until recently, such activities have relied on national observational networks or EU projects with restricted timescales, and thus limited sustainability. The formation of the European Research Infrastructure Consortia (ERICs) (European Strategy Forum on Research Infrastructures [ESFRI], 2018) has significantly increased the capability of long-term planning and implementation of the monitoring component of the European Seas (Figure 10). Such benefits can be amplified by combined activities and joint efforts of the different Marine Research Infrastructures (RIs).

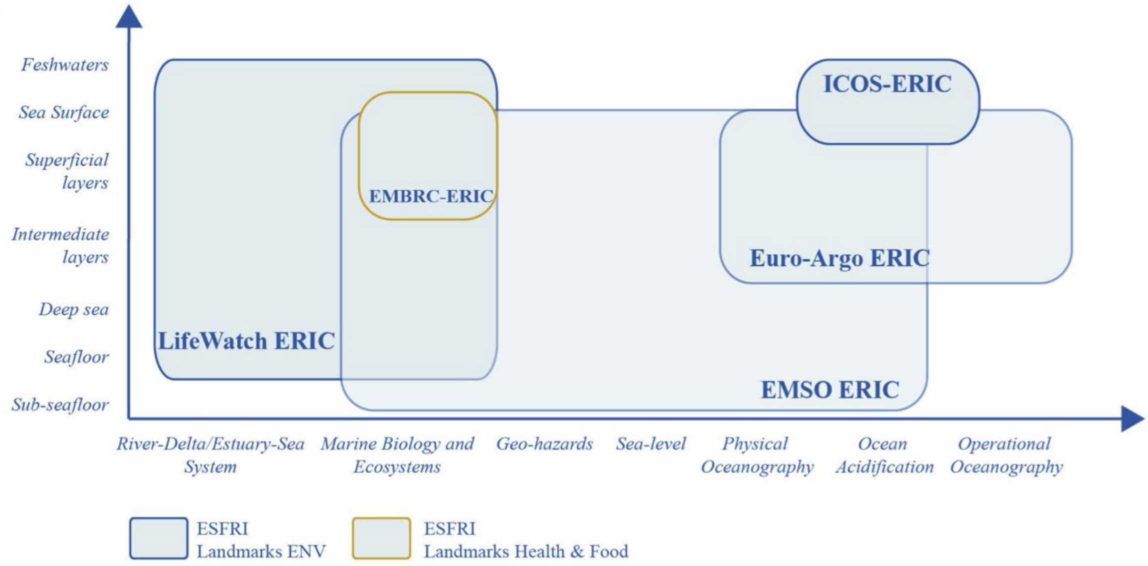

Figure 10. Schematic representation of the observing capacities of five ERICs with respect to their hydrosphere components and environmental processes (from Dañobeitia et al., 2020).

In the context of the European Ocean Observing System (EOOS) initiative, joint collaborative activities between Marine RIs, especially in field monitoring under a synergistic monitoring strategy, are a key tool for the monitoring and understanding of the oceanic system through a multi-disciplinary approach. This may address several issues related to sea safety, mitigation of climate change risks, anthropogenic pressures, and loss of biodiversity among other stressors for the benefit of society (Dañobeitia et al., 2020).

The strengthening of links between the European Marine RIs is amongst the scope of the Euro-Argo RISE project and especially of T8.1 targets. Building on the past 5-years of efforts of the Euro-Argo ERIC, when several initiatives have been undertaken towards this scope, T8.1 partners have formed a collaboration framework between existing and aspiring marine ERICs such as EMSO ERIC, LifeWatch ERIC, ICOS ERIC, EMBRC ERIC, DANUBIUS-RI, JERICO-RI, , EuroFleets, and GROOM-RI. This framework facilitated discussion between the research consortiums and resulted in an open online event that was organised by T8.1 partners and the Euro-Argo Office during the EuroGOOS 2021 conference (Berry et al., 2022).

The event took place on 5th May 2021, it was entitled "*Cooperation Framework Between Marine Research Infrastructures*" and was attended by more than 80 marine scientists, researchers, and officers, including representatives from 11 marine RIs from Europe. The main thematic fields of the event were defined jointly with the 11 RIs: a) Implementation of the Observing system b) Joint actions and RIs sustainability, and c) User engagement. Of these topics, the first two were either directly or indirectly linked with the monitoring strategies of each infrastructure where a big part of the strategies concerned the shelf-open ocean boundaries. Regarding monitoring strategies, the vast majority of Marine RIs share a common interest in the monitoring of such regions. During the meeting, it was agreed to prioritise the list of suggested collaborative and synergistic activities to develop a more integrated multi-RI monitoring strategy, and set of actions.

Therefore, the Argo strategy, under development within Euro-Argo RISE, should also account for a multi-RI approach to fill existing gaps and reduce overlaps of these areas, but also jointly address scientific questions, better coordination of operations at sea, share expertise on new sensors and technological advancements, develop a FAIR integrated multi-RI data management, and provide interoperable access to homogenised observing data and products that will emerge.

3.2 Argo collaboration with other Research Communities

3.2.1 Regional observing systems

The European regional observing systems play an important role in the operational oceanographic monitoring of the areas between the open ocean and the coastal shelf. Since the beginning of the 21st century, and in close collaboration with regional research communities and research infrastructures that focus on such areas (ie. MONGOOS, IBI-ROOS, GROOM-RI, JERICO-RI, etc.), several national initiatives have been developed in the European marginal seas providing marine *in-situ* data through multi-arrays of different oceanographic platforms. Several examples of such European observing components which have integrated Argo floats are described hereafter.

Since 1998 the POSEIDON system (https://poseidon.hcmr.gr) has been the leading operational oceanographic monitoring infrastructure of the Eastern Mediterranean basin. Funded by the Greek State and EU, it focuses on both the provision of marine observations of physical and biogeochemical parameters, and validated forecasts of the marine environment. Following the general EU marine policy frameworks, the system has been developed in accordance with the suggestions of IOC/GOOS, EuroGOOS, MonGOOS and GEO. The Greek Argo infrastructure initiated its activities in 2010, and since then Argo floats have been integrated into the POSEIDON's monitoring network with more than 30 Argo float deployments in the Eastern Mediterranean. Argo missions under the POSEIDON network are undertaken under a multi-platform approach that has also allowed synergies between its different components such as moored buoys, underwater gliders, ferryboxes, cabled observatories, HF radars, and repeated shipborne monitoring. Lately, POSEIDON activities have been integrated into the larger HIMIOFoTS (Hellenic Integrated Marine Observing and Forecasting system) (https://www.himiofots.gr/en) under which the operational support of the whole marine infrastructure is coordinated, the monitoring and forecasting components of the system is upgraded, and coastal zone management activities are linked. The HIMIOFoTS marine component consists of five research and academic institutions and it is coordinated by the Institute of Oceanography-HCMR.

The OBSERVA.PT programme is the main ocean observation program at IPMA in which the main objective is the development of methodologies for automatic observations, especially using Argo floats and national vessels of opportunity (e.g., cargo, fishing and cruise vessels). The programme aims to obtain information necessary to support the management of marine ecosystems and maritime meteorology (mainly) in this vast area of the north-eastern Atlantic Ocean. The program is divided into four main activities: (i) surface marine observations based on "ferrybox"-type equipment and meteorological stations (the latter under EUMETNET E-SURFMAR); (ii) sub-surface observations based on measurement instruments installed on fishing gears; (iii) biogeochemical indices from data obtained from surface water collected in the ferrybox water circulation system for nutrient measurement, identification of planktonic communities (including non-indigenous species), and cetacean observations obtained by trained observers; and (iv) sub-surface observations using Argo floats. These data serve to create base indicators of biodiversity, exotic species, trophic chains and eutrophication, to contribute to the evaluation of the Marine Strategy Framework Directive (MSFD) descriptors (e.g., D1, D2, D4 and D5). Specifically for Argo, it is envisaged the deployment of four core Argo floats at the end of 2022 (or beginning 2023) in the Gulf of Cadiz, one complete BGC float, and another float with only DO during 2023 in the Azores region. This ocean observing system is complemented by the European Multidisciplinary Seafloor and water column Observatory (EMSO) under EMSO.PT, who maintain the Iberian Margin Observatory in the Gulf of Cadiz[1].

The Balearic Islands Coastal Observation and Forecasting System (SOCIB) operates an observation and forecasting system that continuously monitors the western Mediterranean, collecting data through multiple platforms including high-frequency coastal radars, integral beach monitoring systems, autonomous underwater gliders, Lagrangian observation platforms (Argo floats and surface drifters), oceanographic buoys, meteorological and sea level stations, and the Research Vessel (R/V SOCIB). The ocean data collected can be consulted in real time and in open access. In particular, through the Spanish Institute of Oceanography (IEO) and SOCIB, Spain participates as a full member of Euro-Argo ERIC (European Research Infrastructure Consortium) ensuring a minimum deployment of 3 Argo profilers per year since 2015. This has resulted in the deployment of more than 25 floats since the beginning of their participation in Euro-Argo ERIC, which means more than 3500 T-S profiles in the Western Mediterranean Sea. The free drifting nature of Argo float profiles allows SOCIB to examine the wider area context of their monitoring programmes by other platforms.

The MOOSE network (supported by CNRS and the French infrastructure ILICO) is an integrated and multidisciplinary network based on the north-western Mediterranean region (Coppola et al., 2019). It consists of Eulerian observations ranging from high frequency (moorings, Meteo France buoys) to monthly (sea campaigns) and Lagrangian monitoring through regular deployments of ocean gliders on two endurance lines (Nice-Calvi, Marseille-Minorca) and annual sea campaigns that allows a mesoscale coverage of the basin (MOOSE-GE campaigns) (Coppola et al., 2019; Tintoré et al., 2019). The Argo float array complements the MOOSE array since 2012 (NAOS French program, D'Ortenzio et al., 2020) by increasing the spatial and temporal resolution of physical and biogeochemical measurements. In particular, the Argo float array allows near-real-time observation of the depth of the mixed layer, which characterises the intensity of convection in winter and changes in heat, salt and O2 ventilation (Coppola et al., 2017; Fourrier et al., 2022). It also allows estimation of the impact of mixing on nitrate upwelling and primary production with indicators such as Chl-a concentration and chlorophyll maximum depth (DCM) (Mayot et al. 2017). The network of Argo floats is now an integral part of the operational set-up of the MOOSE network and allows synergy between the different marine EU infrastructures operating in the NW Mediterranean Sea (EURO-ARGO, EMSO, JERICO-RI).

To maintain an active Argo array, every 2 years the MOOSE program deploys approximately 3 ARVOR-TS, 3 ARVOR-DO and 2 PROVOR-BGC during annual cruise. The cruises also assist to validate and adjust the Argo floats' data through deep CTD casts and seawater sampling (DO, nutrients, pigments). The deployment of Argo floats in this region will continue to provide predictions for nutrient and CO2 variables using the CANYON-MED neural network and qualified TSO2 data (Fourrier et al., 2022). Along with the data provided by the BGC floats, these predictions will also be used to feed the CMEMS SOCA3D product that provides gridded fields of particulate organic carbon (POC), backscatter coefficient (bbp), and chlorophyll-a (Chl-a) concentration at depth (Guinehut et al., 2021).

[1] http://emso.eu/observatories-node/iberian-margin/, last accessed 2022/09/02.

3.2.2 Models, reanalysis and forecasts

The existing European regional operational ocean forecasting systems have been significantly enhanced during the last decade. This evolution largely relies on the expansion of the *in-situ* monitoring system and especially of the Argo expansion in marginal seas. This has played a crucial role on the development of central services such as the Mediterranean Forecasting System (MFS; Tonani et al. 2014) which operates under the framework of the Copernicus Marine Environment Monitoring Service (CMEMS), (http://marine.copernicus.eu). The Argo floats are increasingly covering zones between shallow coastal and open coean areas, providing datasets assimilated in higher resolution regional models. Some examples are the Aegean Forecast System (Korres et al., 2010), the Sicily Channel and the Adriatic Forecasting Regional Models (Olita et al., 2012), the Tyrrhenian Sea Forecasting System (Vetrano et al., 2010), and SOCIB (Tintoré et al., 2013).

Argo data provides similar contribution to other European regional models such as the North West Shelf (NWS) Monitoring Forecasting Centre (MFC) (Figure 11), the Iberian-Biscay-Ireland (IBI) MFC, and the Black Sea (BS) MFC, all contributing to the CMEMS forecasting services (Le Traon et al. 2019). In these cases, but also in several other cases of the emerging biochemical models, new Argo data in previously under-sampled areas such as the shelf- open ocean zone are assimilated and significantly improve regional systems such as the Mediterranean Forecasting System. Another example is the improvement in biogeochemical model predictions of oxygen, nutrients, carbon and chlorophyll through the water column by assimilating BGC-Argo data complementary to surface ocean colour data (Wood et al., 2018). In general, the combination of information from satellite and *in-situ* data (Argo floats), and new high-resolution observations (gliders and HF radar) will help towards an enhanced quantitative and long-term assessment of the models' performance and will lead to an increased understanding of their abilities and limitations. Furthermore, the important process of near real time validation, which is performed daily, is based on the comparison of model outputs with temperature and salinity profiles from Argo floats along with gridded satellite products and physical parameters from fixed moorings (Juza et al. 2016).

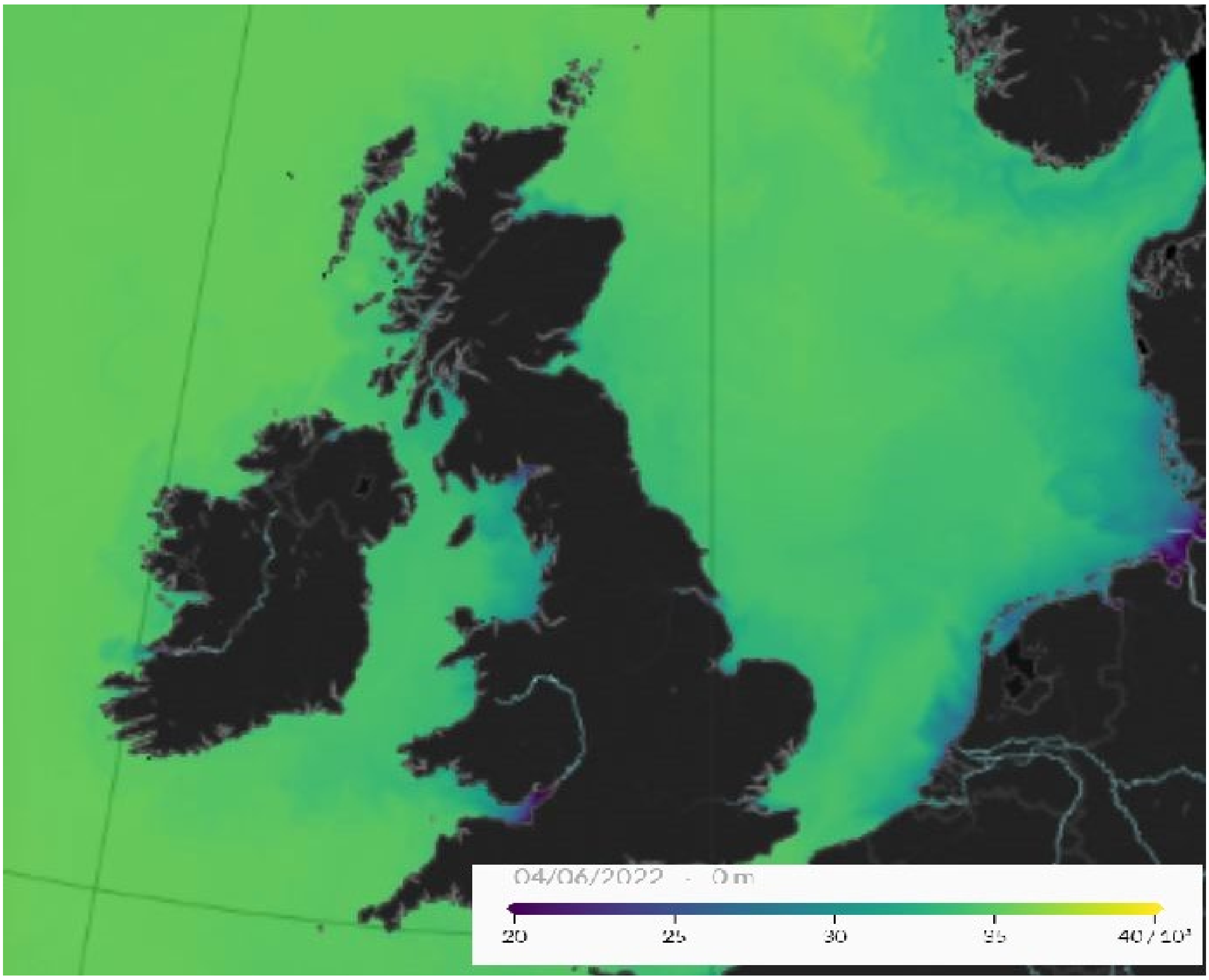

Figure 11. Salinity field based on the CMEMS Ocean Physics Analysis and Forecast product of the Atlantic - European North West Shelf region. For the production of the model's output Argo profiles have been utilised (https://doi.org/10.48670/moi-00054)

The feedback of observations to models is not solely a one-way interaction. It can also act vice versa as the regional monitoring-forecasting systems depict. In *de Mey-Frémaux* et al. (2019) it was shown that integration of the coastal ocean observations with models, substantially increased the value of the observations themselves and provide several new applications.

3.2.3 Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) emerged as a primary driver for the EU Member States to protect and to preserve the marine environment, which is adversely affected by human activities, and ensure that the anthropogenic impacts on the marine biodiversity and marine ecosystems are insignificant (https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive). In contrast with the Water Framework Directive (WFD), which deals explicitly with coastal waters, MSFD deals with open sea environments. However, it is still restricted within national territorial waters and thus refers directly to the coastal shelf- open ocean zones. In this respect, the expansion of Argo in these zones is closely related to the contribution of Argo to the MSFD. Through the provision of newly introduced datasets in these regions, parameters for several indicators for the description of Good Environmental Status (GES) will require significant contribution from the *in-situ* observing components in order to be addressed. The estimation of qualitative descriptors such as eutrophication, alternations of hydrography, and noise, are some examples of how *in-situ* observations and particularly Argo data can contribute to MSFD. Several projects in the past such as PERSEUS FP7 project focused on these issues and highlighted the need for planning and implementation of new platform deployments including new biochemical sensors on Argo floats to complement the existing open ocean multi-parametric moorings and coastal stations, which are located within key zones of the Southern European Seas (Kassis et al., 2013).

The capability of Argo network to provide high-quality datasets for the description of the hydrographical conditions of seawater, is particularly important for the description of the dynamics of marine ecosystems. This capability can be significantly increased under a renewed Argo monitoring strategy which will integrate the boundary areas between the coastal shelf and the open ocean. An additional asset towards this process is the emerging BGC Argo component which already provides large datasets of parameters such as nitrates, phosphate, O_2, and bio-optics which together with the core Argo's standard monitoring of the background physical conditions provides particularly valuable information for the existence, survival, and reproduction of threatened marine organisms. Under Euro-Argo RISE, an investigation to identify existing and potential links with the MSFD has been implemented under WP7 and summarised in the project's deliverable D7.13 (Euro-Argo RISE D7.13). As shown in the aforementioned report, the extension of Argo coverage towards the coastal zone (Figure 12) will be crucial in Argo becoming a systematic source of data for the GES assessment.

However, apart from the MSFD implementation, an updated Argo monitoring strategy for the shelf-open ocean boundary zone will have to design the future Argo network's capacity on delivering data relevant to marine environmental monitoring, and assessing gaps in our knowledge on the ecosystem dynamics. This means that several EU requirements related to environmental policies, directives, and recommendations should be integrated, such as the priorities of the Green Deal regarding the protection of ecosystems and biodiversity, and the sustainability of the blue economy.

Table 1: Level of Argo contribution (Low, Medium, and High) to basic parameters required by MSFD (Euro-Argo RISE D7.13)

MSFD important parameters	MSFD important Geographical areas and other aspects	Potential Argo contribution
Temperature, Salinity	Coastal shelf	High
	Open sea	High
Currents	Coastal shelf	Medium
	Open sea	Medium
Dissolved Oxygen	Coastal shelf	Medium
	Open sea	High
pCO2, pH	Coastal shelf	Low

	Open sea	Medium
Light, Noise	Coastal shelf	Medium
	Open sea	Low
chl-a, other pigments	Coastal shelf	Medium
	Open sea	Medium
Nutrients	Coastal shelf	Low
	Open sea	Medium
Pollutants, Litter	Coastal shelf	Low
	Open sea	Low
Physical Parameters	Coastal shelf/Data from several layers of the water-column	High
	Open Sea/Data from several layers of the water-column	High
	Coastal shelf /Cost-effectiveness	Medium
	Open Sea/Cost-effectiveness	High
Biogeochemical parameters	Coastal shelf/Data from several layers of the water-column	High
	Open Sea/Data from several layers of the water-column	High
	Coastal shelf/Cost-effectiveness	Low
	Open Sea/Cost-effectiveness	Medium

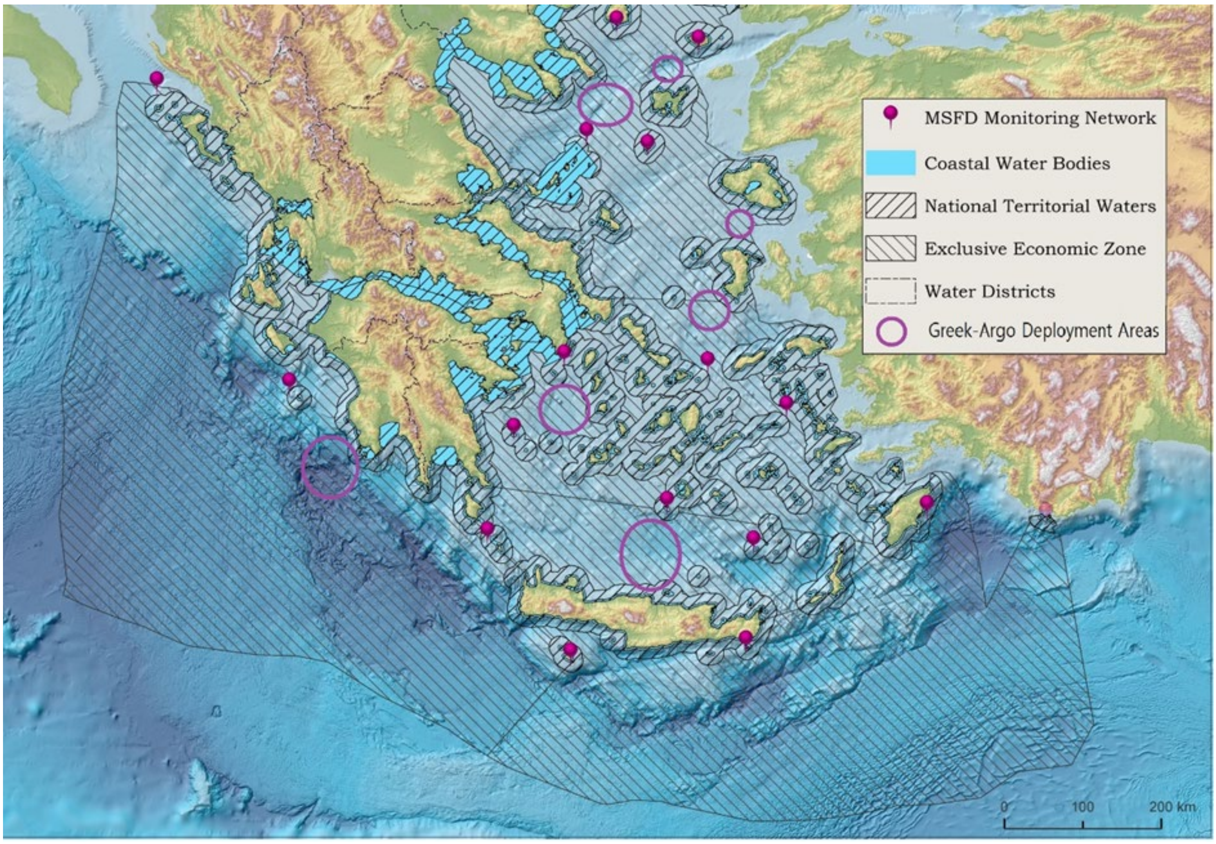

Figure 12. Map of the geographical extent of the Greek MSFD programme including the Greek Argo floats deployment areas (Euro-Argo RISE D7.13).

3.2.4 Ocean glider community

Argo profiling floats use their buoyancy engine simply to go up and down in the water column; typically spending a few days at a parking depth before making a profile cycle up and down through the water column and communicating their data when at the ocean surface. Whilst at the surface, the Argo floats can be re-programmed remotely for parameters such as parking depth, profiling depth and cycle frequency. As such, they are not considered navigable although knowledge of water column velocity structure and careful selection of parking depth and cycle frequency have the potential to offer some limited control over their long-term drift through the ocean.

Ocean gliders are small autonomous underwater vehicles (AUV) that can migrate vertically by changing their buoyancy and steer horizontally by gliding on wings (Stommel 1989; Eriksen et al. 2001; Sherman et al. 2001). Ocean gliders usually achieve this by moving their internal battery pack. Gliders use buoyancy to ascend or descend through the water column from the ocean surface to 1000 m deep in the same way as the profiling floats. Whereas profilers can only move vertically up and down, gliders fitted with wings that allow them to glide forward with a horizontal velocity of 0.27 m s^{-1} and vertical of 0.09 m s^{-1} as they ascend or descend (Rudnick 2016).

The result of this manoeuvrability is that ocean gliders are generally used for continuous long monitoring and process studies without the necessity to park at a depth or needed to stay for long periods. Therefore, we tend to think of a mission duration (battery charge life) of 1-3 months for the ocean gliders, whereas Argo profilers are expected to carry out mission periods of up to 3-5 years or more. Interestingly but perhaps unsurprisingly, bearing in mind the similarity of their buoyancy engines, the battery lifetimes in terms of data profiles recorded is much more closely comparable as they gliders perform in average 4-6 profiles per day depending on the operation depth and the Argos perform commonly 1 profile every 5-10 days.

SOCIB has established scientific links between Glider and Argo communities. This was a natural result of its participation in different complementary European projects (JERICO NEXT, JERICO S3 and Euro-Argo RISE projects specifically but not exclusively) and SOCIB's multidisciplinary, multi-platform approach.

This link has been useful to investigate the larger scale importance of variability and trends in oceanographic characteristics on monitoring lines maintained by ocean gliders. In particular, it has been possible to research the similarities and contrasts over larger spatial areas that may be observed in the free roaming nature of the Argo float. For example, increasing salinity in intermediate to deep water mixing lines in the Ibiza Channel, Western Mediterranean, from seasonal cruise campaigns and continuous glider monitoring, may be seen reflected across the western end of the W. Mediterranean basin in Argo float profiles (Figure 13).

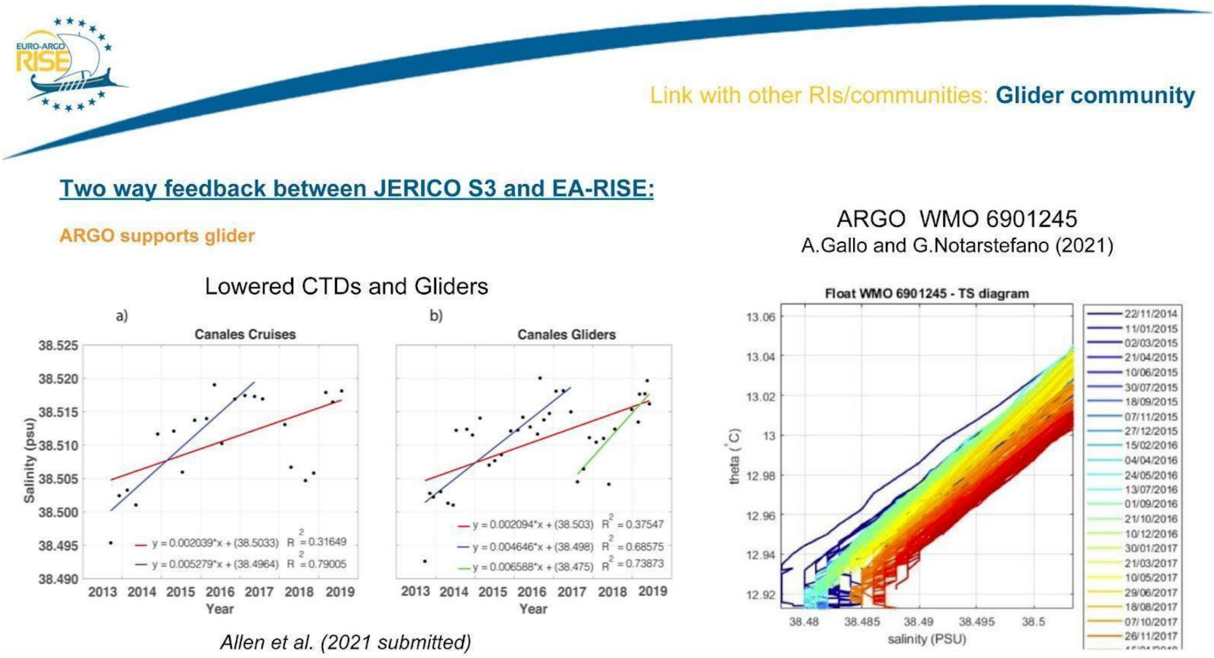

Figure 13. Increasing salinity in intermediate to deep water mixing lines in the Ibiza Channel, Western Mediterranean, from seasonal cruise campaigns (left), Glider continuous monitoring lines (centre) and reflected across the western end of the W. Mediterranean basin in Argo float profiles (right). Slide from the presentation of Allen et al. (2021) at the Mediterranean and Black Seas Workshop organised by WP6.

4 Recommendations for monitoring strategies

4.1 Deployment strategy

Argo operators have to take into account several parameters before and after performing deployments in the boundaries of the coastal shelf-open ocean zone. A pre-deployment mission design is essential for successful operations and is strongly related to a) the area's characteristics, and b) the monitoring needs in conjunction with other monitoring tools available. Regarding the first, and in contrast with strictly coastal deployments, the mesoscale and general circulation systems should be carefully investigated since strong currents usually prevail in these boundary zones both in the upper and in deeper layers (Figure 14). This fact may result in extended trajectories during which the float drifts from one area to another with completely different characteristics, and this should be projected beforehand by the Argo operators. Furthermore, other characteristics such as the topography of the areas should be studied, since challenging bathymetries and intricate coastlines may introduce additional risks for the floats and therefore reduce their life expectancy.

Argo floats can be used in both the open sea and in proximity to the coast either as stand-alone platforms, or in synergies with other monitoring components, For the intermediate zone the sea currents can be particularly strong and make the float drift away rapidly from the deployment area. Thus, careful mission planning is needed so as to take into account the possibility of extended drift in relation to the proximity to the coast to prevent stranding. Additionally, planning on a possible recovery mission and the estimated time that such a case may occur would be useful.

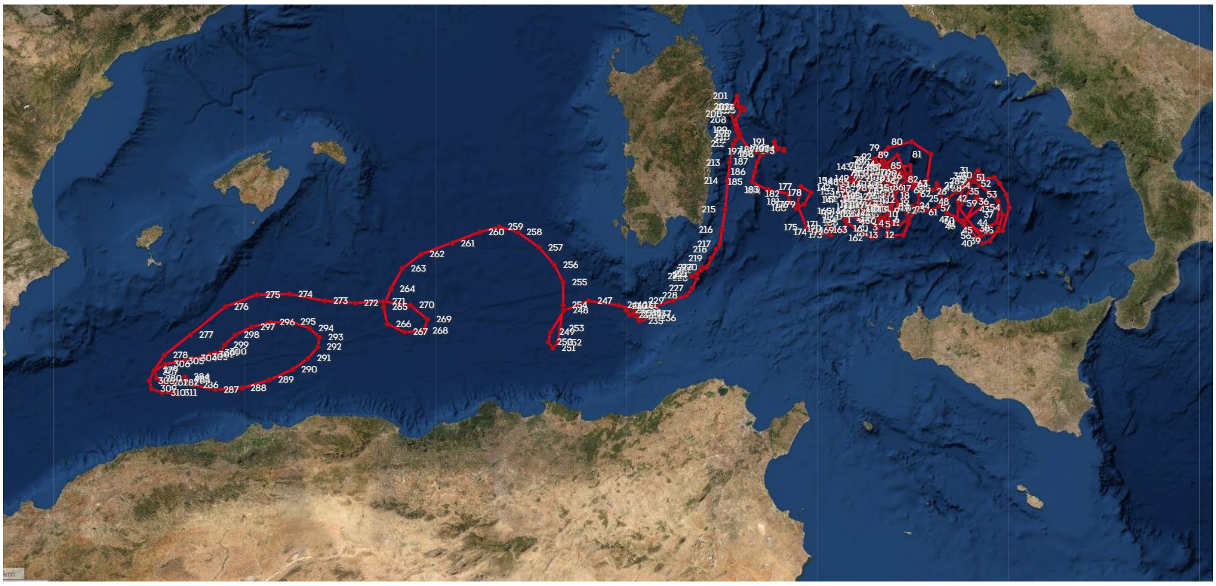

Figure 14. The trajectory of the Italian float 6903239 that was deployed in March 2018. The float is still active and has performed 311 cycles; its trajectory reveals features of the circulation system of the central-western Mediterranean Sea.

In an update to the status report in Euro-Argo RISE D2.3, studies were performed with the virtual fleet software to obtain an optimum sampling of the boundary currents in the Nordic seas and specific mission configurations were obtained. The suggested mission parameters were successfully tested in the field with national floats and created long trajectories on the shelf. Eddy interaction between the boundary current and the shelf and the internal gyres will eventually move the floats offshore into the basin circulations.

4.2 Technical parameters and floats' configuration

As described in Euro-Argo RISE deliverable D6.8 entitled "Recommendations to operate shallow coastal float in European Marginal Seas", the main configuration parameters that are important for coastal Argo float missions are a) the maximum profile depth, b) the parking depth, and c) the duration of the float's cycle. In targeted missions performed during Euro-Argo RISE, it has been shown that through the modification of these parameters, it is possible to carry out successful missions in coastal areas with different and more appropriate profiling frequencies. Furthermore, in areas where the bathymetry is shallow, higher operator-float interactions are needed to avoid grounding that may potentially damage the float either physically (problems with scratches, bladder, etc.) or electronically (pressure sensor, pump activity, etc.).

Table 2 shows the most important recommendations for float operators in coastal shelf areas of the Mediterranean Sea, derived from the Euro-Argo RISE WP6 experiences. It should be noted that these settings should be modified according to the special topographic characteristics of the case study areas. Nevertheless, for areas that are directly connected to the open ocean and therefore where floats are expected to perform trajectories within both environments, the recommendations for mission configuration should be adjusted accordingly. This means that the float operator may need to modify the mission parameters while the float is active and drifting from one area to the other. Under this interactive process, the operator should monitor the float's drift and performance in real-time and intervene on the platform's settings when needed.

Table 2. Suggested float configuration of specific mission (5) and technical (3) parameters for targeted coastal operations in the Mediterranean Sea (Euro-Argo RISE D6.8)

mission parameters	technical parameters
cycling period (hours) 24/48 - 120	pressure target tolerance for stabilisation (dbar) 10/30
parking depth (dbar) relatively deep or bottom or close to bottom (it depends on the area and type of mission)	grounding activation level (dbar) (it depends on the type of mission)
max profile depth (dbar) at least as deep as the parking depth and preferably slightly deeper than the bathymetry of the area	descending speed (mm/s) 20
grounding mode (Shift, Stay grounded →virtual mooring)	

shift upward (dbar) it depends on the type of mission (few dbar)	

4.3 Monitoring of floats' performance

The experience from coastal deployments in targeted areas of the European marginal seas that were undertaken in Euro-Argo RISE WP6 has shown that a continuous monitoring of floats' performance is needed. The updated Euro-Argo monitoring tool (https://fleetmonitoring.euro-argo.eu/dashboard) has proven particularly valuable for the operational monitoring of several technical parameters of the floats' missions (Figure 15). A constant upgrade of this tool is ongoing however, hence at this stage the combination of this service with custom developed monitoring systems is recommended. This will cover both the needs for a generic tool that provides enhanced information regarding technical and functional parameters of the floats' performance, and address additional specific information useful for operators such as the platforms' data transmission activity, the bathymetry, and the distance from the coastline. Furthermore, several alerting systems that are usually based on predefined thresholds may be utilised in order for the operator to receive alert messages when these thresholds are violated. Additional parameters and control criteria can be added to the monitoring systems such as weather information, sea currents, etc. This information could be particularly useful for the operator to monitor the float's mission and design potential recovery missions in case of emergency. All the above requirements could be integrated in the fleet monitoring tool after being tested through the in-house developed alerting systems and proved to be useful for the operators.

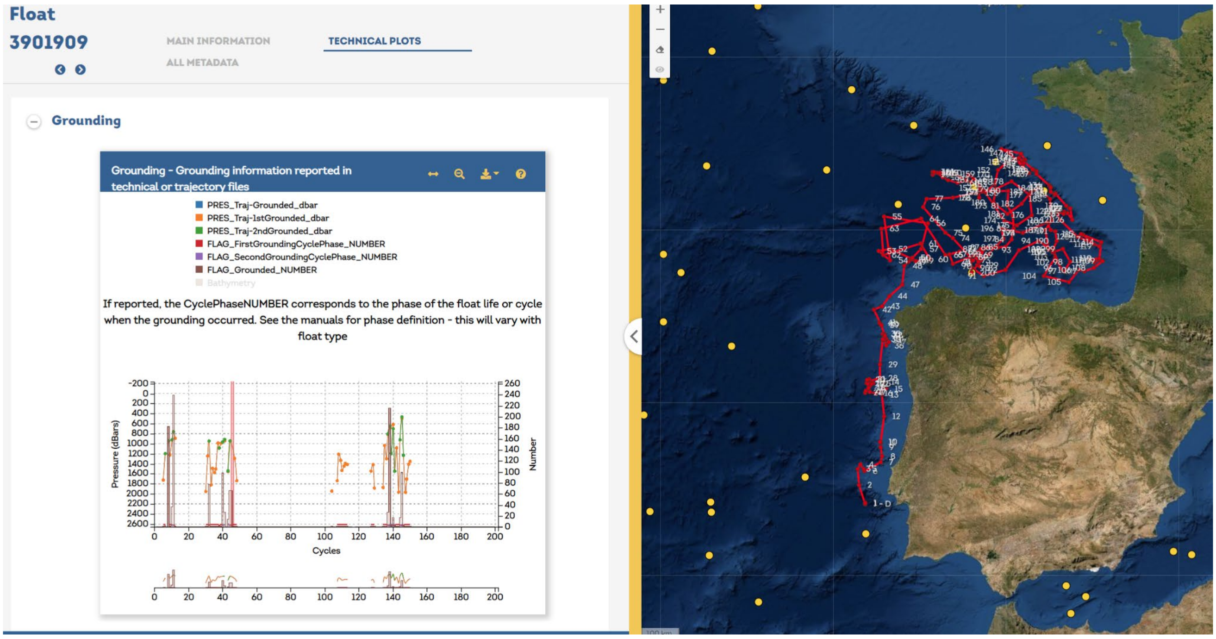

Figure 15. Information panel showing the grounding events along with the trajectory of the Euro-Argo float 3901909 (MOCCA-EU project) provided by the Euro-Argo Argo fleet monitoring tool (https://fleetmonitoring.euro-argo.eu/float/3901909).

4.4 Recovery strategy and floats' reusability

A strategy for floats' recoveries is an increasingly emerging need for Argo infrastructure and is amongst the ongoing activities of Euro-Argo ERIC that seeks to: a) reduce the environmental footprint of European floats, and b) reduce the costs of float operations by reusing recovered floats. For floats operating in coastal areas, recovering the floats also allows assessing the accuracy of the sensor at recovery and eventually correcting the data in delayed mode if the sensor drifted. This is a critical issue for Argo in coastal areas as the normal delayed mode QC methods can't be applied as the floats never reach stable water masses during their life. Currently, float recoveries are undertaken through national initiatives in a rather opportunistic way within territorial waters or EEZs of the European marginal seas (Figure 16). A centralised operational plan for floats' recoveries is a particularly demanding process that requires a lot of coordination between different countries, infrastructures, and agencies.

Recently, efforts from the Euro-Argo ERIC have been initiated in order to coordinate such activities and enforce float recoveries especially in the European marginal seas. For this scope, a tool (Figure 17) has been released which provides information on floats that are listed for potential recovery missions.

Floats are included on the list for potential recovery on Principal Investigator's request following criteria such as malfunctioning sensor(s) or battery reaching depletion. The recovery operation then usually takes place into two steps: First, the float's position is made available and updated on a daily basis so that the operation at sea can be planned, making sure optimal conditions are reached (according to weather forecast, ship schedule, etc) and that it can be carried out in the most safe and efficient manner. Secondly the float's positioning is switched to real-time decoding as soon as the planned vessel starts its approach for the float's actual recovery. All float recoveries are logged and archived by Euro-Argo ERIC in order to ensure traceability of both operations and instruments.

Figure 16. A float recovered by an Estonian vessel on December 2020, (WMO3902106). The float launched by IOPAN in 2018 within the Bornholm Basin was recovered by the Estonian vessel R/V Salme, North of the island of Hiiumma (https://mailchi.mp/937b91149a9f/euro-argo-newsbrief-7845469)

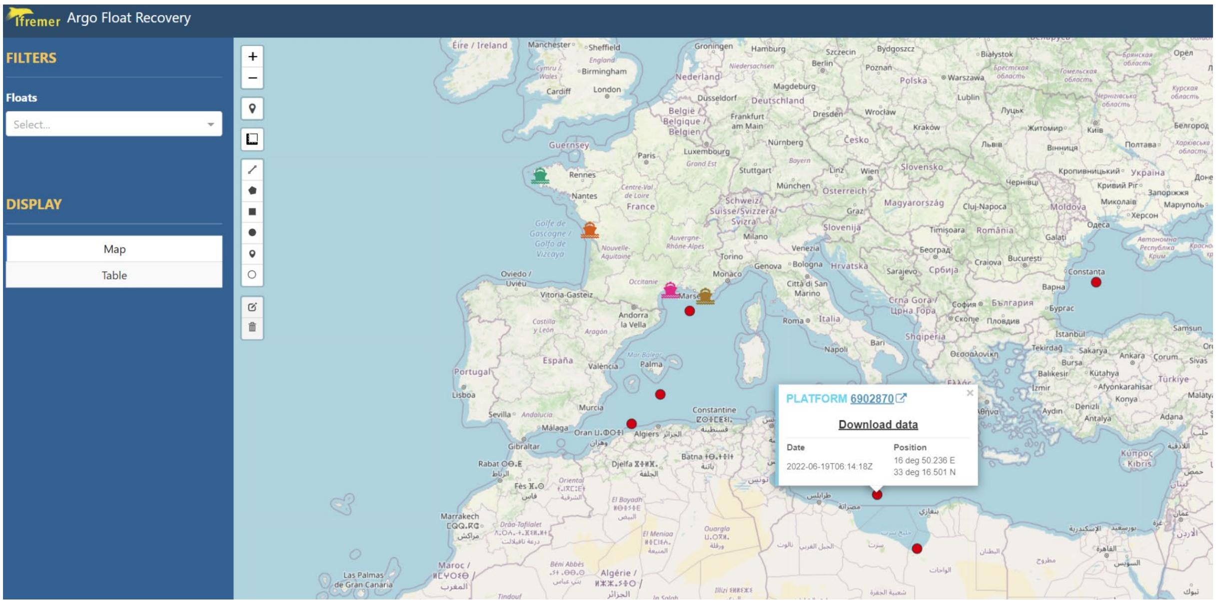

Figure 17. The Euro-Argo online tool for Argo float recoveries (https://floatrecovery.euro-argo.eu)

5 Discussion and concluding remarks

5.1 Argo expansion in the shelf-open ocean boundaries

Being a key *in-situ* network for operational oceanography, Argo nowadays provides thousands of daily measurements of ocean physics and, inceasingly becoming the major source of BGC observations in the open seas. The expansion of the European Argo array in the boundaries between the coastal shelf and open ocean has been an ongoing process for several years already. A further specific expansion to shallow waters has also been achieved lately in the Baltic. However, in order for the Argo expansion at the boundaries between the coastal self and the open ocean to become a sustainable monitoring component of the European seas, the Euro-Argo community needs to propose a strategy and proceed towards a monitoring implementation plan taking into consideration recommendations from pan-European initiatives and policies. For example, the CMEMS recommendations for the *in-situ* observing system focus on both the critical sustainability gaps and the sampling gaps, especially with regard to biogeochemical parameters (e.g., carbon, oxygen, nutrients, chl-a). In terms of platforms, a strong priority for CMEMS is the consolidation of the Argo core mission including the sampling of polar and marginal seas, and developing its two major extensions (BGC Argo and Deep Argo) (Roemmich et al., 2019). In addition, the remote sensing community seeks for higher spatiotemporal resolution and suggests that maintaining and enhancing the *in-situ* observing system are critical for validating and complementing future high-resolution satellite observations.

In general, the Argo monitoring component needs to be complemented by reference measurements from long time series at fixed points from moorings and ship-based hydrographic surveys to the best quality (GO-SHIP) standards. The improvement of the ROOSes' key observing systems such as FerryBoxes, gliders, tide gauges and HF radars is among the strong priorities for regional CMEMS products. For example, with regards to the Arctic region, a specific effort is needed due to severe limitations of measurements within the seasonal ice zone, which is growing broader, and none of the platforms available today can collect data in these areas. Also, the development of a dedicated network, capable of collecting a wide range of in-situ ocean variables that are also estimated by the Copernicus Satellite component, is also important for CMEMS. (Le Traon et al., 2019).

On the other side, the expansion of Argo towards the coast serves the European environmental policy agenda. Especially for the shelf-open ocean boundaries, the MSFD community expects a large contribution from the Argo network. Amongst others, the recommendations from MSFD include the need for ocean monitoring to be consistently maintained over the long-term. It is also required to integrate a variety of freely available data. This is absolutely essential if key questions regarding climate change, coastal ocean processes, and ecosystem variability are to be answered, and to improve the estimates of present ocean states and to constrain model predictions, thus contributing to the proper implementation of GES as required by the MSFD.

5.2 Synergies with other platforms

As previously shown, Argo platform is a major contributor in areas close to the coastline but it should not stand alone. Synergies are required and many already exist between the Argo and other ocean observation initiatives. Implemented through the OceanOPS office, six monitoring programmes have been brought together including; 1) moored and drifting buoys coordinated by the Data Buoy Cooperation Panel, 2) glider surveys coordinated by OceanGliders, 3) Argo floats coordinated by International Argo, 4) seabed moorings and arrays coordinated by OceanSites, 5) sea level observing stations coordinated by GLOSS and 6) shipboard surveys coordinated by GO-SHIP.

Additionally, through the cooperation framework between the European Research Infrastructures, the synergistic monitoring activity is expected to expand. The fixed observation stations in the open ocean and shelf seas operated by EMSO ERIC are such an example as EMSO provides data in real-time, paralleling the Argo programme. In general, the common framework under which all of these operational initiatives supply ocean data is undergoing a profound transformation (Riser et al., 2016), and this is amongst Euro-Argo interests.

Another important contribution of the Argo platform is its complementarity to satellite observations such as the Jason satellite mission which provides global sea surface height observations for climate monitoring and ocean and seasonal forecasts. The long term increase in sea surface height results from the thermal expansion of the warming ocean water column, which the profiling Argo floats are constantly monitoring and reporting. As the Argo programme captures the underlying temperature, salinity, and density structure with global coverage and sufficient resolution, the Argo data is used to constrain the steric component of the altimetric signal and enable interpretation of altimetric sea surface height variation. In return, the satellite altimetry provides useful spatial/temporal contextual data to each Argo float, such mesoscale variability.

Even though the Argo/altimetry complementarity is remarkable, it is only one part of the synergy between Argo and many others *in situ* and satellite observing system elements (Roemmich and The Argo Steering Team, 2009; Freeland et al., 2010; Riser et al., 2016; Wuldera et al., 2016), such as the SMOS and Aquarius satellite programs which monitor global sea-surface salinity, another parameter monitored globally by the Argo programme. Furthermore, the recent development of low-consumption and miniature neutrally buoyant optical sensors, sometimes measuring the same properties as derived from space, makes them good candidates for being mounted on floats and gliders.

A synergy of the Argo floats and gliders allowed us to have a 3D/4D view of the physical and biogeochemical processes in the global ocean in real-time. As the primary target of Argo is the open ocean, it is highly complementary to glider observations conducted over the shelf-open ocean interface. BGC-Argo and OceanGliders share biogeochemical sensors used with a similar mode of operation.

5.3 Recommendations for the future.

The building of an operational monitoring network in the areas that separate the coastal shelf from the open ocean is a procedure that involves several factors related to both the monitoring tools and the oceanographic infrastructures and services. It therefore requires a multidisciplinary approach that will take into account the existing coastal shelf and open ocean monitoring networks, and the oceanographic features of these boundary areas. Strengthening synergies between different monitoring platforms will form the foundation of an effective and sustainable monitoring system in these regions.

Amongst the infrastructures to lead such efforts is the Euro-Argo community, which successfully manages to expand the Argo network from the open ocean towards the coast. However, closer cooperation with the existing infrastructures and scientific communities will be required in the near future. The JERICO, GROOM, and EMSO ERIC infrastructures are some examples amongst others.

Furthermore, Argo activities should sustain and enhance the already existing strong links with the remote sensing and modelling community. Links that are set for the core Argo mission need to be enhanced and updated for the boundary zones' monitoring. Beyond the Euro-Argo RISE project, the priority, also identified by CMEMS, should be the maintenance and improvement of the Argo network. To carry on this task, a close collaboration between Euro-Argo members is needed in order to deploy more Deep and BGC floats and further work towards targeted deployments in the European marine seas, especially where sampling gaps have been identified. Regarding the BGC Argo network specifically, its expansion will play a catalytic role in Argo's contribution to European environmental monitoring policies such as the MSFD.

Nevertheless, extending Argo activities from the open ocean to the coastal shelf seas will not be a straightforward procedure. Several aspects should be reconsidered such as the deployments and recoveries strategy, the floats' configuration and the monitoring of their missions, the cost and benefits analysis in relation to existing and potential funding schemes.

6 References

Arístegui, J., Álvarez-Salgado, X.A., Barton, E.D., Figueiras, F.G., Hernández-León, S., Roy, C., Santos, A.M.P., 2006. Oceanography and Fisheries of the Canary Current/Iberian Region of the Eastern North Atlantic (18a.E), Chapter 23 In: The Sea. The Global Coastal Ocean: Interdisciplinary Regional Studies and Syntheses, Vol. 14 (Part B), A. R. Robinson and K. H. Brink, eds, Harvard University Press, Cambridge, MS, USA., pp. 879-933

Aristegui, J., Barton, E.D., Álvarez-Salgado, X.A., Santos, A.M.P., Figueiras, F., Kifani, S., Hernández-León, S., Mason, E., Machu, E., Demarcq, H., 2009. Sub-regional ecosystem variability in the Canary Current upwelling. Progress in Oceanography, 83: 33-48, doi: 10.1016/j.pocean.2009.07.031

Barceló-Llull, B., Pascual, A., Ruiz, S., Escudier, R., Torner, M., Tintoré, J., 2019. Temporal and spatial hydrodynamic variability in the Mallorca channel (western Mediterranean Sea) from 8 years of underwater glider data. J. Geophys. Res 124, 2769–2786. doi: 10.1029/2018JC014636

Berry, A., Kassis, D., Gourcuff, C., Pouliquen, S., 2022. Cooperation Framework between Marine RI - Meeting Report. Zenodo. https://doi.org/10.5281/zenodo.6810214

Borges, M.F., Santos, A.M.P., Crato, N., Mendes, H., Mota,B., 2003. Sardine regime shifts off Portugal: a time series analysis of catches and wind conditions. Scientia Marina, 67(Suppl.1): 235-244.

Capó, E., Orfila, A., Mason. E., Ruiz, S., 2019. Energy conversion routes in the Western Mediterranean Sea estimated from eddy–mean flow interactions. J Phys Oceanogr 49: 247–267

Claustre, H., Kenneth, S. J., Takeshita, Y., 2020. Observing the Global Ocean with Biogeochemical-Argo, Annual Review of Marine Science, 12:1, 23-48

Coppola, L., Prieur, L., Taupier-Letage, I., Estournel, C., Testor, P., et al., 2017. Observation of oxygen ventilation into deep waters through targeted deployment of multiple Argo-O2 floats in the north-western Mediterranean Sea in 2013, Journal of Geophysical Research: Oceans, 122(8), 6325-6341, doi:10.1002/2016jc012594.

Coppola, L., P. Raimbault, L. Mortier, Testor, P., 2019. Monitoring the environment in the northwestern Mediterranean Sea, Eos, 100, https://doi.org/10.1029/2019EO125951. Published on 25 July 2019.

Dañobeitia, J. J., Pouliquen, S., Johannessen, T., Basset, A., Cannat, M., Pfeil, B. G., et al., 2020. Toward a comprehensive and integrated strategy of the European marine research infrastructures for ocean observations. *Frontiers in Marine Science*, *7*, 180.

de Mey-Frémaux, P., Ayoub, N., Barth, A., Brewin, R., Charria, G., Campuzano, F., ... & Zhu, X., 2019. Model-observations synergy in the coastal ocean. Frontiers in Marine Science, 6, 436.

D'Ortenzio, F., Taillandier, V., Claustre, H., Prieur, L. M., Leymarie, E., Mignot, A., et al., 2020. Biogeochemical Argo: The Test Case of the NAOS Mediterranean Array. Frontiers in Marine Science 7, 120. http://dx.doi.org/10.3389/fmars.2020.00120.

Durack, P. J., 2015. Ocean salinity and the global water cycle. Oceanography. 28:20–31. doi:10.5670/oceanog.2015.03.

Eriksen, C. C., Osse, T. J., Light, R. D., Wen, T., Lehman, T., W., Sabinet, P. L., et al., 2001. Seaglider: A long-range autonomous underwater vehicle for oceanographic research. IEEE J Ocean Eng 26:424–436. https://doi.org/10.1109/48.972073

European Strategy Forum on Research Infrastructures [ESFRI], (2018). Strategy Report on Research Infrastructures in Europe, Roadmap 2018. Available at: http://roadmap2018.esfri.eu (accessed May 19, 2019).

Euro-Argo RISE H2020 project Deliverable 6.2 https://www.euro-argo.eu/EU-Projects/Euro-Argo-RISE-2019-2022/Deliverables

Euro-Argo RISE H2020 project Deliverable 6.3 https://www.euro-argo.eu/EU-Projects/Euro-Argo-RISE-2019-2022/Deliverables

Euro-Argo RISE H2020 project Deliverable 7.13 https://www.euro-argo.eu/EU-Projects/Euro-Argo-RISE-2019-2022/Deliverables

Euro-Argo ERIC, 2017: Strategy for evolution of Argo in Europe. EA-2016-ERIC STRAT. https://doi.org/10.13155/48526

Escudier, R., Mourre, B., Juza, M., Tintoré, J., 2016. Subsurface circulation and mesoscale variability in the Algerian subbasin from altimeter-derived eddy trajectories. J Geophys Res Oceans 121: 6310–6322

Freeland H. J., Roemmich, D., Garzoli, S. L., Le Traon, P. Y., Ravichandran, M., Riser, S., et al., 2010. ARGO - a decade of progress. OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2), Venice, Italy, 21-25 September 2009.

Fourrier, M., Coppola, L., D'Ortenzio, F., Migon, C., Gattuso, J.-P., 2022. Impact of intermittent Convection in the northwestern Mediterranean Sea on Oxygen content, Nutrients and the Carbonate system. Journal of Geophysical Research: Oceans, 127, e2022JC018615. https://doi.org/10.1029/2022JC018615. 2022

García-Ladona, E., Castellón, A., Font, J., Tintoré, J., 1996. The Balearic current and volume transports in the Balearic basin. Oceanol Acta 19: 489–497

Grayek, S., Stanev, E. V., Schulz-Stellenfleth, J., 2015. Assessment of the Black Sea observing system. A focus on 2005-2012 Argo campaigns. Ocean Dynamics 65, 1665–1684 (2015). https://doi.org/10.1007/s10236-015-0889-8

Guinehut S., B Buongiorno Nardelli, T Chau, F Chevallier, D Ciani, et al.. THE MULTI OBSERVATIONS THEMATIC ASSEMBLY CENTRE OF THE COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE. 9th EuroGOOS International conference, Shom; Ifremer; EuroGOOS AISBL, May 2021, Brest, France

Haavisto, N., Tuomi, L., Roiha, P., Siiriä, S. M., Alenius, P., Purokoski, T., 2018. Argo floats as a novel part of the monitoring the hydrography of the Bothnian Sea. *Frontiers in Marine Science*, *5*, 324. https://doi.org/10.3389/fmars.2018.00324

Håvik, L., Pickart, R. S., Våge, K., Torres, D., Thurnherr, A. M., Beszczynska-Möller, A., ... & von Appen, W. J., 2017. Evolution of the East Greenland Current from Fram Strait to Denmark Strait: Synoptic measurements from summer 2012. Journal of Geophysical Research: Oceans, 122(3), 1974-1994.

Heslop, E. E., Ruiz, S., Allen, J., López-Jurado, J. L., Renault, L., Tintoré, J., 2012. Autonomous underwater gliders monitoring variability at "choke points" in our ocean system: A case study in the Western Mediterranean Sea, *Geophys. Res. Lett.*, 39, L20604, doi:10.1029/2012GL053717.

Jayne, S., Roemmich, D., Zilberman, N., Riser, S., Johnson, K., Johnson, G., Piotrowicz, S., 2017. The Argo Program: Present and Future. *Oceanography, 30*(2), 18-28. Retrieved November 29, 2020, from http://www.jstor.org/stable/26201840

Josey, S. A., Gulev, S., Yu, L., 2013. Exchanges through the ocean surface. In: Ocean circulation and climate: a 21st century perspective. International Geophysics, Vol. 103. Oxford (UK): Academic Press, Elsevier; p. 115–140. doi:10.1016/B978-0-12-391851-2.00005-2.

Juza, M., Renault, L., Ruiz, S., Tintoré, J., 2013. Origin and pathway of winter intermediate water in the Northwestern Mediterranean Sea using observations and numerical simulation. J. Geophys. Res 118, 1–13. doi: 10.1002/2013JC009231

Juza, M., Mourre, B., Renault, L., Gómara, S., Sebastián, K., Lora, S., et al., 2016. SOCIB operational ocean forecasting system and multi-platform validation in the Western Mediterranean Sea. Journal of Operational Oceanography, 9:sup1, s155-s166, DOI: 10.1080/1755876X.2015.1117764

Juza, M., Escudier, R., Vargas-Yáñez, M., Mourre, B., Heslop, E., Allen, J., Tintoré, J., 2019. Characterization of changes in Western Intermediate Water properties enabled by an innovative geometry-based detection approach. Journal of Marine Systems, 191, 1-12, https://doi.org/10.1016/j.jmarsys.2018.11.003

Juza, M., Tintoré, J., 2021. Multivariate Sub-Regional Ocean Indicators in the Mediterranean Sea: From Event Detection to Climate Change Estimations. Frontiers in Marine Science 8:610589, doi: 10.3389/fmars.2021.610589

Kalimeris, A., Kassis, D., 2020. Sea surface circulation variability in the Ionian-Adriatic Seas, Progress in Oceanography, 189, 2020, 102454, ISSN 0079-6611, https://doi.org/10.1016/j.pocean.2020.102454.

Kassis, D., Varlas, G., 2020. Hydrographic effects of an intense "medicane" over the central-eastern Mediterranean Sea in 2018. Dynamics of Atmospheres and Oceans, 2020, 101185, ISSN 0377-0265, https://doi.org/10.1016/j.dynatmoce.2020.101185

Kassis, D., Korres, G., 2020. Hydrography of the Eastern Mediterranean basin derived from argo floats profile data. *Deep Sea Research Part II: Topical Studies in Oceanography*, *171*, 104712, https://doi.org/10.1016/j.dsr2.2019.104712

Kassis, D., 2017: Operational in - situ monitoring of the Greek seas as a tool to describe hydrodynamic variability and its effect on the biochemical distribution. PhD thesis, National Technical University of Athens (NTUA) https://www.didaktorika.gr/eadd/handle/10442/40700

Kassis, D., Krasakopoulou, E., Korres, G., Petihakis, G., Triantafyllou, G. S., 2016. Hydrodynamic features of the South Aegean Sea as derived from Argo T/S and dissolved oxygen profiles in the area. Ocean Dynamics, 66(11), 1449-1466.

Kassis, D., Schroeder, K., Bozzano, R., Pensieri, S., Coppola, L., Pairaud, I., et al., 2013. Multi parametric moorings upgrade with new sensors and expansion. PERSEUS Project. ISBN no: 978- 960-9798-15-0

Kifani, S., 1998. Climate dependant fluctuations of the Moroccan sardine and their impact on fisheries. In: Durand, M.H., Cury, P., Mendelssohn, R., Roy, C., Bakun, A., Pauly, D. (Eds.), Global Versus Local Changes in Upwelling Systems. ORSTOM, Paris, pp. 235–248.

Korres, G., Nittis, K., Perivoliotis, L., Tsiaras, K., Papadopoulos, A., Triantafyllou, G., et al., 2010. Forecasting the Aegean Sea hydrodynamics within the POSEIDON-II operational system. Journal of Operational Oceanography, 3:1, 37-49, DOI: 10.1080/1755876X.2010.11020112

Kress, N., Gertman, I., Herut, B., 2014. Temporal evolution of physical and chemical characteristics of the water column in the Easternmost Levantine basin (Eastern Mediterranean Sea) from 2002 to 2010. Journal of Marine Systems, 135, 6-13.

La Violette, P. E., Tintoré, J., Font, J., 1990. The surface circulation of the Balearic Sea. J Geophys Res 95: 1559−1568

Latarius, K., Quadfasel, D., 2016. Water mass transformation in the deep basins of the Nordic Seas: Analyses of heat and freshwater budgets. Deep Sea Research Part I: Oceanographic Research Papers, 114, 23-42.

Le Traon, P. Y., 2013. From satellite altimetry to Argo and operational oceanography: three revolutions in oceanography. *Ocean Science*, *9*(5), 901-915.

Le Traon, P. Y., Reppucci, A., Alvarez Fanjul, E., Aouf, L., Behrens, A., Belmonte, M., et al., 2019. From observation to information and users: the Copernicus Marine Service perspective. *Frontiers in Marine Science*, *6*, 234.

López-Jurado, J. L., Marcos, M., Monserrat, S., 2008. Hydrographic conditions affecting two fishing grounds of Mallorca island (Western Mediterranean): during the IDEA Project (2003–2004). Journal of Marine Systems, 71(3-4), 303-315, https://doi.org/10.1016/j.jmarsys.2007.03.007

Malanotte-Rizzoli, P., Manca, B. B., d'Alcala, M. R., Theocharis, A., Brenner, S., Budillon, G., Ozsoy, E., 1999. The Eastern Mediterranean in the 80s and in the 90s: the big transition in the intermediate and deep circulations. Dyn. Atmospheres Oceans 29, 365–395. doi:10.1016/S0377-0265(99)00011-1

Mayot, N., F. D'Ortenzio, V. Taillandier, L. Prieur, O. P. de Fommervault, H. Claustre, A. Bosse, P. Testor, and P. Conan (2017), Physical and Biogeochemical Controls of the Phytoplankton Blooms in North Western Mediterranean Sea: A Multiplatform Approach Over a Complete Annual Cycle (2012–2013 DEWEX Experiment), J. Geophys. Res. Oceans, 122, 9999–10,019, doi:10.1002/2016JC012052

Menna, M., Suarez Reyes, N.G., Civitarese, G., Gačić, M., Rubino, A., Poulain, P. M., 2019. Decadal variations of circulation in the Central Mediterranean and its interactions with mesoscale gyres. Deep-Sea Research Part II, 164 (2019), pp. 14-24

Olita, A., Dobricic, S., Ribotti, A., Fazioli, L., Cucco, A., Dufau, C., Sorgente, R., 2012. Impact of SLA assimilation in the Sicily Channel Regional Model: model skills and mesoscale features. Ocean Science, 8(4), 485-496.

Palazov, A., Slabakova, V., Peneva, E., Stanev, E., 2014. BIO ARGO floats: tools for operational monitoring of the Black Sea. EGU General Assembly Conference Abstracts, 2014EGUGA..16.8158P

Pascual, A., Buongiorno Nardelli, B., Larnicol, G., Emelianov, M., Gomis, D., 2002. A case of an intense anticyclonic eddy in the Balearic Sea (western Mediterranean), Journal of Geophysical Research, 107(C11), 3183, https://doi.org/10.1029/2001JC000913

Peliz, Á., Marchesiello, P., Santos, A.M.P., Dubert, J., Teles-Machado, A., Marta-Almeida, M., Le Cann, B., 2009. Surface circulation in the Gulf of Cadiz: 2. Inflow-outflow coupling and the Gulf of Cadiz slope current. J Geophys Res 114, CO3011, doi: 10. 1029/ 2008JC004771

Peliz, A., Rosa, T., Santos, A.M.P., Pissarra, J. L., 2002. Fronts, jets, and counter-flows in the Western Iberian upwelling system. Journal of Marine Systems, 35(1-2): 61-77.

Piechura, J., Walczowski, W., 2009. Warming of the West Spitsbergen Current and sea ice north of Svalbard. Oceanologia, 51(2), 147-164.

Pinardi, N., Cessi, P., Borile, F., Wolfe, C. L., 2019. The Mediterranean Sea Overturning Circulation J Phys Oceanogr, 49 (2019), pp. 1699-1721

Pinot, J. M., López-Jurado, J. L., Riera, M., 2002. The CANALES experiment (1996-1998). Interannual, seasonal, and mesoscale variability of the circulation in the Balearic Channels. Progress in Oceanography, 55, 335-370, https://doi.org/10.1016/S0079-6611(02)00139-8

Poulain, P. M., Barbanti, R., Font, J., Cruzado, A., Millot, C., et al, 2007: MedArgo: a drifting profiler program in the Mediterranean Sea. *Ocean Science*, 3 (3), 379–395.

Poulain, P. M., Kourafalou, V. H., Chushman-Roisin, B., 2001. Northern Adriatic Sea. In: Cushman-Roisin, B., Gacic, M., Poulain, P.-M. (Eds.), Physical Oceanography of the Adriatic Sea. Past, Present and Future. Kluwer Academic Publishers, pp. 143e166.

Relvas, P., Barton, E.D., 2002. Mesoscale patterns in the Cape São Vicente (Iberian Peninsula) upwelling region. Journal of Geophysical Research 107 (C10), 3164. doi:10.1029/2000JC000456

Relvas, P., Barton, E.D., Dubert, J., Oliveira, P.B., Peliz, A., da Silva, J.C.B., Santos, A.M.P., 2007. Physical Oceanography of the Western Iberia Ecosystem: latest views and challenges. Progress in Oceanography, 74(2-3): 149-173, doi:10.1016/j.pocean.2007.04.021

Relvas, P., Luis, J., Santos, A.M.P., 2009. The importance of the mesoscale in the decadal changes observed in the Northern Canary upwelling system. Geophysical Research Letters, 36, L22601, doi:10.1029/2009GL040504

Riser, S. C., Freeland, H. J., Roemmich, D., Wijffels, S., Troisi, A., et al, 2016: Fifteen years of ocean observations with the global Argo array. *Nature Climate Change*, *6*(2), 145-153.

Roemmich, D., and the Argo Steering Team. 2009. Argo: The challenge of continuing 10 years of progress. Oceanography 22(3):46–55, doi:10.5670/oceanog.2009.65

Roemmich, D., Alford, M. H., Claustre, H., Johnson, K., King, B., Moum, J., et al, 2019. On the future of Argo: A global, full-depth, multi-disciplinary array. Frontiers in Marine Science, 6, 439.

Rudels, B., Friedrich, H. J., Quadfasel, D., 1999. The Arctic circumpolar boundary current. Deep Sea Research Part II: Topical Studies in Oceanography, 46(6-7), 1023-1062.

Rudnick, D. L., 2016. Ocean Research Enabled by Underwater Gliders. Ann Rev Mar Sci 8:519–541. https://doi.org/10.1146/annurev-marine-122414-033913Salat, J., 1995. The interaction between the Catalan and Bale a ric currents in the southern Catalan Sea. Oceanol Acta 18: 227−234

Santos, A.M.P., Borges, M.F., Groom, S., 2001. Sardine and horse mackerel recruitment and upwelling off Portugal. ICES Journal of Marine Science 58, 589–596.

Santos, A.M.P., Chícharo, A., Dos Santos, A., Moita, T., Oliveira, P.B., Peliz, A., Ré, P., 2007. Physical-biological interactions in the life history of small pelagic fish in the Western Iberia Upwelling Ecosystem. Progress in Oceanography, 74(2-3): 192-209, doi:10.1016/j.pocean.2007.04.008.

Santos, A.M.P., Kazmin, A.S., Peliz, A., 2005. Decadal changes in the Canary upwelling system as revealed by satellite observations: their impact on productivity. Journal of Marine Research 63, 359–379.

Santos, A.M.P. , Peliz, A., Dubert, J., Oliveira, P.B., Angélico, M.M., Ré, P., 2004. Impact of a Winter Upwelling Event on the Distribution and Transport of Sardine Eggs and Larvae Off Western Iberia: A Retention Mechanism. Continental Shelf Research, 24: 149-165.

Sayol, J. M., Orfila, A., Simarro, G., Lopez, C., Renault, L., Galan, A., Conti, D., 2013. Sea surface transport in the Western Mediterranean Sea:a Lagrangian perspective. J Geophys Res Oceans 118: 6371−6384

Schroeder, K., Chiggiato, J., Josey, S. A., Borghini, M., Aracri, S., Sparnocchia, S., 2017. Rapid response to climate change in a marginal sea. Scientific Reports, 7(1), 1-7.

Sherman, J., Davis, R. E., Owens, W. B., Valdes, J., 2001. The autonomous underwater glider “Spray.” IEEE J Ocean Eng 26:437–446. https://doi.org/10.1109/48.972076

Siiriä, S., Roiha, P., Tuomi, L., Purokoski, T., Haavisto, N., Alenius, P., 2019. Applying area-locked, shallow water Argo floats in Baltic Sea monitoring, Journal of Operational Oceanography, 12:1, 58-72, DOI: 10.1080/1755876X.2018.1544783

Stommel, H., 1989. The Slocum Mission. Oceanography 2:22–25. https://doi.org/10.5670/oceanog.1989.26

Theocharis, A., Nittis, K., Kontoyiannis, H., Papageorgiou, E., Balopoulos, E., 1999. Climatic changes in the Aegean Sea influence the eastern Mediterranean thermohaline circulation (1986–1997). Geophys. Res. Lett. 26, 1617–1620. doi:10.1029/1999GL900320

Tintoré J., Pinardi, N., Álvarez-Fanjul, E., Aguiar, E., Álvarez-Berastegui, D., Bajo, M., et al.,, 2019. Challenges for Sustained Observing and Forecasting Systems in the Mediterranean Sea. Frontiers in Marine Science, 6:568, https://doi.org/10.3389/fmars.2019.00568

Tintoré, J., Vizoso, G., Casas, B., Ruiz, S., Heslop, E., Renault, L., et al., 2013. SOCIB; the Balearic Islands Observing and Forecasting System responding to science, technology and society needs. Marine Technology Society Journal, Vol 47, N. 1, 101-117, http://dx.doi.org/10.4031/MTSJ.47.1.10

Tonani, M., Oddo, P., Korres, G., Clementi, E., Dobricic, S., Drudi, M., ... & Pinardi, N., 2014. The Mediterranean Forecasting System: recent developments. In EGU General Assembly Conference Abstracts (p. 16899).

Vetrano, A., Napolitano, E., Iacono, R., Schroeder, K., Gasparini, G. P., 2010. Tyrrhenian Sea circulation and water mass fluxes in spring 2004: Observations and model results. Journal of Geophysical Research: Oceans, 115(C6).

Vilibić, I., Mihanović, H., 2013. Observing the bottom density current over a shelf using an Argo profiling float, *Geophys. Res. Lett.*, 40, 910–915, doi:10.1002/grl.50215.

Von Schuckmann, K. Le Traon, P. Y., Alvarez Fanjul, E., Axell, L., Balmaseda, M., Breivik, et al., 2016. The Copernicus Marine Environment Monitoring Service ocean state report. J. Oper. Oceanogr. 9(2):s235–s320.

Walczowski, W., 2013. Frontal structures in the West Spitsbergen Current margins. Ocean Science, 9(6), 957-975.

Walczowski, W., Piechura, J., Goszczko, I., Wieczorek, P., 2012. Changes in Atlantic water properties: an important factor in the European Arctic marine climate. ICES Journal of Marine Science, 69(5), 864-869.

Wood, R., Ford, D., Gasprin, F., Palmer, M., Rémy, E., le Traon, P. Y., et al., 2018. *Synthesis of OSSE Results*. Atlantos H2020 deliverable D1.5 Available online at: https://www.atlantos-h2020.eu/project-information/work-packages/deliverables

Wuldera, M. A., et al. "The Global Observing System for Climate: Implementation Needs. GCOS Implementation Plan 2016, GCOS-200 (GOOS-214)." (2016).