Recommendations to operate shallow coastal float in European Marginal Seas

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EXECUTIVE SUMMARY

Argo operations in targeted missions close to the coast were carried out in selected areas of the European marginal seas (Mediterranean, Black and Baltic Seas) under the European H2020 Euro-Argo Research Infrastructure Sustainability and Enhancement (Euro-Argo RISE) project. The Argo technology was pushed towards its limits to see the feasibility of these kinds of operations and to study the complementarity of Argo with the other existing coastal monitoring systems.

Argo deployments were performed in eleven sites, from the Baltic Sea (5) to the Mediterranean (4) and the north-western Black Sea (2); specific setting configurations were tested according to the missions' targets. The most critical configuration parameters are the park pressure, profile pressure and the cycle time: **park pressure and profile pressure were set deep enough (even at the sea bed) to try to limit the platform drift and cycle time between 1 and 5 (7) days in the Mediterranean and Black Seas (Baltic Sea)**. In addition, some national floats were also deployed to further study the best platforms' settings.

Areas are considered as shallow/coastal when the depth, and/or proximity of the coast are limiting factors for diving depths and choice of deployment.

Shallow/coastal operations with Argo floats have required the tailoring of the existing monitoring systems, the in-house development of warning procedures and the **need of real time data decoding**. The monitoring activity and the human-platform interaction can be high and linked up to the cycle length of the float.

Following the recommendations (as reported in this document and summarized in a cheat sheet in Annex I) during all the mission phases, floats can be kept in a relatively confined area or within the targeted area for a longer time. In particular, **1) pre-deployment operations should consider an analysis of the shipping and fishing activity, and of bathymetry and circulation systems in the area of interest; 2) during mission, operators should monitor that the float stays in the targeted area and if it is drifting too far, check for recovery options.** Baltic Sea experiences show that float recoveries in the area can be done routinely. Recovery and re-deployment, when possible, is recommended, both in ecological and economical viewpoints. In addition, sensor recalibrations of recovered floats give additional information for quality control purposes.

These test missions showed that Argo floats can be used for operations in shallow/coastal areas, especially in low dynamic areas that prevent the float from rapidly drifting away from the targeted area. If managed as recommended in this deliverable, floats can be kept in a relatively confined area and their life expectancy can reach approximately one year (or more, it depends on the region) before being inactive or drifting out of the targeted area. Hence, deployment strategies should consider this time window in order to obtain a continuous coverage of shallow/coastal areas with Argo floats.

The above proposed recommendations are similar for the three European marginal seas, despite the fact that each test area may require an additional tuning of the configurations, as reported in the methodology section of this deliverable.

Future work should be focused on further developing Argo operations in targeted shallow/coastal waters in terms of providing advanced strategies and to design new technology to limit the float drift, and to test new float models.

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1 Introduction – General framework

Although designed for the global oceans' monitoring, the Argo platform is increasingly covering the boundary areas between the open sea and the coastal zone. European H2020 Euro-Argo Research Infrastructure Sustainability and Enhancement (Euro-Argo RISE) project partners are working towards the strengthening of this process by proposing a future strategy plan for the monitoring of these areas under the project's Task 8.1 and especially under 8.3 Deliverable (under preparation at the time of writing). In this working document, the importance of such an expansion is described under the context of Argo's significant contribution to both oceanographic research and services. This contribution is already evident during the last years with the increasing utilisation of Argo data in regional climatic studies, input and data assimilation in high resolution regional models, research on ecosystem dynamics, and implementation of environmental policies. Moreover, the Argo expansion under Euro-Argo RISE makes a step forward in an attempt to investigate the Argo's contribution closer to the coast, in even shallower and more challenging areas. This process, discussed in the report, is inter-connected with the monitoring of the open ocean – coastal zone boundaries and is perceived as a complementary expansion of Argo not under a strict geographical point of view, but mainly under the concept of monitoring targeted coastal areas of significant importance.

The assessment of the on-going, and the enforcement of the future, coastal Argo missions, serve the bi-fold aim of filling the gaps with under-sampled areas in regional seas and also perform applied synergetic monitoring over the coastal zone. The description of short-scale events, the enhancement of coupled met-ocean and physical-biochemical models, the capture of extreme climatic events and the description of their possible impacts and, the monitoring of sensitive marine ecosystems, are among several fields in which Argo may contribute. Through such contributions, Argo will also strengthen its role in the major pan-European marine initiatives such as the European Ocean Observing System (EOOS) and the description of the Good Environmental Status (GES).

With relation to the latter, an extension of Argo to monitor the European coastal zone will raise its contribution to EU environmental policies, directives, and recommendations. The best example is Argo's emerging contribution to the Marine Strategy Framework Directive (MSFD), which is a priority for the EU Member States to protect and to preserve their marine environment. As extensively investigated in Euro-Argo RISE WP7 (Euro-Argo RISE D7.13 in Kassis et al., 2021c), Argo datasets can be proved extremely valuable for the assessment of several indicators describing the GES. Estimations of qualitative descriptors such as eutrophication, alternations of hydrography, and underwater noise, are some examples of how in-situ observations and particularly Argo data can contribute to MSFD. Furthermore, specially planned missions in targeted coastal areas may also contribute to the Water Framework Directive (WFD), which, in contrast with the MSFD, deals explicitly with coastal and transitional waters. In these cases, however, the Argo array could mainly act complementary with other in-situ observing components specially designed for the areas.

The extension of Argo in targeted coastal areas will also help in strengthening and expanding the Argo regional community by building collaboration and sharing activities. The Argo Regional Centres (MedArgo) and Systems (the Mediterranean Operational Network for the Global Ocean Observing System - MonGOOS and the Baltic Operational Oceanographic System - BOOS) can provide a strong support in such a context and can complement the activity planned in the Euro-Argo RISE project to foster collaboration and initiatives between countries working in the same region. Operations in coastal areas are especially important on the Baltic Sea, which is practically nothing but a coastal area, and as such all Argo operations there require a special approach. Finland and Poland have operated Argo in the Baltic Sea in selected areas, and Germany has started operations recently, but the areas to operate are still rather limited. Extending the possibilities and practices of operations could encourage more countries to participate in the area.

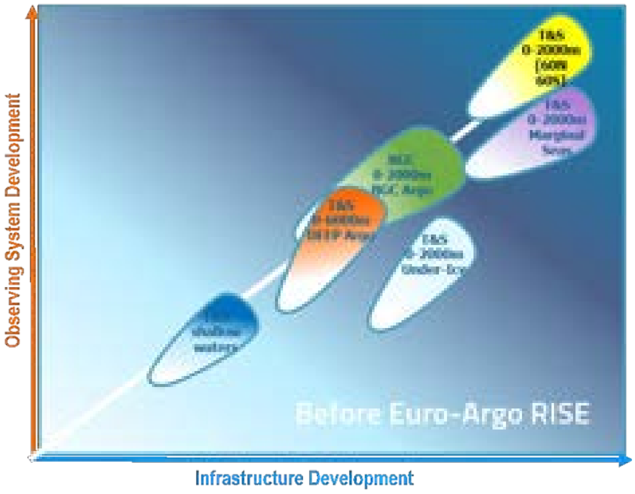


Figure 1. Status and evolution of the Argo infrastructure observing system (Source: Euro-Argo ERIC).

Coastal waters of European marginal Seas have important socio-economic impacts, and Argo floats were tested in targeted missions close to the coast. This extension of Argo towards such kind of areas is in its early stages (figure 1) and it has moved its first steps in the framework of the Euro-Argo RISE project (Notarstefano et al., 2021a). The use of Argo floats in shallow/coastal waters can be particularly advantageous since Argo is an autonomous platform that can perform a great number of profiles, it is programmable and potentially recoverable. The number of profiles acquired by Argo (figure 2) is extremely higher than profiles acquired with other platforms like CTD from R/V (figure 3) and the spatial and temporal coverage are more homogeneous.

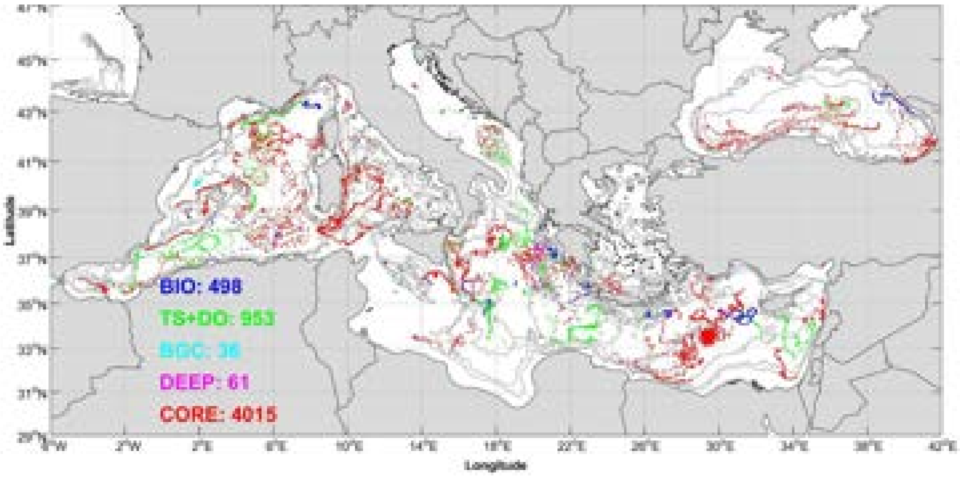


Figure 2. Number of CTD profiles (about 5000) from Argo floats in 10 months (Jan-Oct 2021) in the Mediterranean Sea. Profile locations are colour-coded per platform type (core-Argo carries CTD sensor; TS+DO carries CTD and dissolved oxygen sensors; BGC-Argo carries the full biogeochemical sensors' suite: oxygen, pH, nitrate, chlorophyll fluorescence, suspended particles, downwelling irradiance; Bio-Argo carries some of the BGC sensors; Deep-Argo is a deep float capable of reaching 4000 m).

Figure 3. Number of CTD profiles (about 8700) collected from R/V in the last 10 years in the Mediterranean Sea. Source: https://cdi.seadatanet.org/search#.

In Euro-Argo RISE we are pushing the existing Argo technology to move towards the coast for targeted missions with the aim of building complementarity with other networks to close spatial and temporal gaps in shallow/coastal waters (Euro-Argo ERIC, 2017). Argo's extension to coastal (and shallow) waters is essential for operational oceanography services and climate studies. Argo is also more cost-effective and less environmentally damaging than monitoring campaigns performed by R/V. Moreover, manufacturers and engineers are continuously working to reduce the environmental impact of Argo platforms. In particular, they aim at reducing rare metals in the electronics, using less polluting materials, reducing biocide, improving the recovery system of platforms, and optimising the energy consumption. This extension fosters the Euro-Argo ERIC objectives because it helps to engage with neighbouring countries and to develop regional partnership.

Monitoring tools are essential devices to check technical and mission details of the Argo missions in shallow/coastal areas. A set of common monitoring tools were used by WP6 partners for the experiments carried on in different areas of the three European marginal seas. In particular, the most popular tools, used by the majority of the partners, are the following:

1. The Euro-Argo monitoring tools set that includes: a) The fleet monitoring tool (https://fleetmonitoring.euro-argo.eu/dashboard) which provides a variety of parameters regarding the float's mission, like enhanced information regarding technical and functional parameters of the floats' performances, graphs and alerts (e.g, useful information such as the battery voltage, the float trajectory and behaviour at the park pressure, grounding events, pump actions, cycling characteristics, the GPS fix at each cycle, can be consulted), b) The data selection tool (https://dataselection.euro-argo.eu/), and c) The Euro-Argo online tool for Argo float recoveries (https://floatrecovery.euro-argo.eu)
2. The Ocean-OPS (https://www.ocean-ops.org/) tool that is a focal point for the metadata flow and a complete set of statistics on the Argo fleet.
3. The Marine Traffic website (https://www.marinetraffic.com/) that is a specific tool to discover vessels that are nearby floats (for recovery opportunity or hazards). Also, EMODnet maps (https://www.emodnet-humanactivities.eu/view-data.php) that help to identify the shipping density in Argo float targeted areas.

4. The available products on the Copernicus Marine website (https://resources.marine.copernicus.eu/) that provide useful information such as the estimate of the 3D current field at the float location.

2 Final results of Argo float operations in the Mediterranean Sea

2.1 Introduction

The Mediterranean Sea is a densely populated semi-enclosed European marginal sea with important socio-economic impacts. During the last decade, the systematic use of Argo floats in the basin has initiated a new era of oceanographic monitoring (Kassis and Korres, 2020). This evolution has been empowered by the joint efforts of the Euro-Argo European Research Infrastructure Consortium (Euro-Argo ERIC), which timely adopted a strategic monitoring plan for the European Sea (Euro-Argo ERIC, 2017), and the national Argo infrastructures in the Mediterranean. Regarding the monitoring of the Mediterranean’s coastal waters, Argo floats are being tested under targeted missions within the framework of the Euro-Argo RISE project (Notarstefano et al., 2021a). Preliminary results from these missions are promising and highlight the important role of Argo for the monitoring of coastal areas. More specifically, under special configuration settings, the floats have achieved an adequate number of profiles whilst remaining for a considerably long period in the targeted area. However, each case study revealed different constraints and priorities that have to be considered by the float operators. The first outcomes from 4 such missions in the Mediterranean are described in Euro-Argo RISE deliverable D6.2 (Kassis et al., 2021b). However, some of these missions are still on-going and new missions were launched, giving us the opportunity to further assess these operations and plan a future strategy regarding Argo contribution to Mediterranean coastal monitoring. This will include the monitoring of further parameters taking advantage of the Argo capacity to host biogeochemical sensors and, thus, contribute to the European environmental policies implementation.

In this section, we describe and discuss the outcomes from Argo operations during targeted missions in selected coastal areas of the Mediterranean Sea (Kassis et al., 2021a; 2021b), under the context of technical specifications, mission configurations, and the associated monitoring tools tailored for such operations. We further provide recommendations for the selection of the optimal configuration setup and the best practices for platform monitoring in similar future activities in the coastal areas of the sub-basins enclosed in the Mediterranean Sea.

2.1.1 Balearic experiment

The Western Mediterranean Sea 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). Also, it shows strong mesoscale activity and a general circulation pattern that is highly variable by year and seasonal temporal scales (Pinot et al. 1994, 1995, 2002). The principal currents are the Northern, Balearic and Algerian Currents (Figure 4). In the north-western Mediterranean, the Northern Current flows southward along the Spanish shelf-slope. Part of the Northern Current crosses the Balearic basin through the Ibiza Channel, while the other part is deflected eastward, forming the Balearic Current (La Violette et al. 1990, Salat 1995, García-Ladona et al. 1996). The north and south sub-basins of the Balearic Archipelago are connected by the Ibiza, Mallorca and Menorca Channels, with complex bathymetry around the islands. In the southwestern region, the average circulation is dominated by the Algerian Current 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).

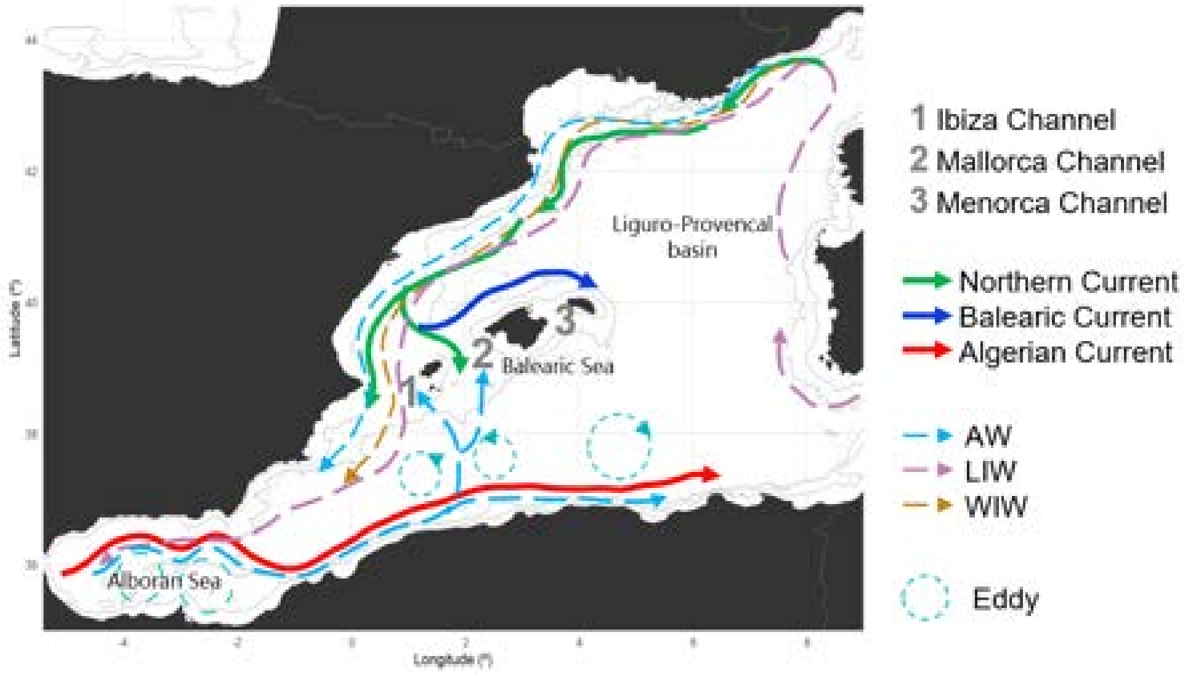


Figure 4. Western Mediterranean Sea: bathymetry, morphology and main surface circulation. AW: Atlantic Water; LIW: Levantine Intermediate Water; WIW: Western Intermediate Water. Modified figure from: Díaz-Barroso et al. (2022).

Given the importance and complex bathymetry of the Balearic archipelago and the comparatively low numbers of Argo profilers in the area, **we deployed a core Argo float (WMO 6901278, equipped with a CTD) in the Palma Bay (Mallorca Island) to investigate the potential of Argo in such coastal areas**. This float was purchased in the framework of the European H2020 Euro-Argo RISE project. **The configuration was chosen in order to keep the float in the area and collect many TS profiles**. However, strong currents until 200 m depth made the float drift further than intended. The float was drifting along the Balearic Current (over the Balearic continental shelf), and it sampled the Atlantic Water (AW), Resident AW and Levantine Intermediate Water (LIW), according to López-Jurado et al., 2008 and Juza et al., 2019. While the float was in shallow waters, some mission commands were changed four times. The changes were made in response to understanding the float behaviour according to mission commands and allowed us to achieve the objectives. All of this required a higher level of interactivity between the mission team and the float than would normally take place.

More recently, a national Spanish float (WMO 6904065), Core-Argo type, has approached the Balearic Archipelago (February 2022). The float was used to complement the Euro-Argo RISE experiment. This experiment supported the conclusion shown by the previous experiment: to keep the float in the targeted area, the best strategy is to park it at the sea bottom. However, slightly longer cycle times appeared more appropriate. This strategy offers a good Argo data coverage, both in space and time, in the coastal area.

2.1.2 North Adriatic experiment

The Adriatic Sea is a semi-enclosed continental shelf sea in the northernmost part of the Mediterranean, and it is characterised by a consistent input of freshwater from rivers. It can be divided in three parts: the very shallow (from 15 to 100 m) northern Adriatic; the Middle Adriatic characterised by the Pomo/Jabuka Pit (maximal depth 270 m); the South Adriatic with a deep depression reaching more than 1200 m (figure 5). The surface circulation scheme is mainly cyclonic, with re-circulations at the level of the Istria Peninsula and Palugruza Sill (southern part of the Pomo/Jabuka Pit). The Strait of Otranto connects the Adriatic Sea to the Ionian Sea and allows a consistent exchange of water between the two basins: the outflowing of the surface Adriatic water, the outflowing of the Adriatic Deep Water, and the inflowing of more saline and warmer waters at surface and intermediate layers (Cushman-Roisin et al., 2001). The Adriatic Sea represents the main source of dense waters for the Eastern Mediterranean basin and during winter, in the North Adriatic, an exceptionally dense water is formed that can reach density values larger than 30 Kg/m^3 (Bensi et at., 2013). This dense water flows southward filling first the Middle Adriatic Pit and then the South Adriatic Pit affecting the local deep stratification. Although the South Adriatic Sea is quite well sampled by Argo floats and other observing systems, the Central and North Adriatic are not covered by Argo in a systematic way. Given the importance of the North and Middle Adriatic as a formation and collection basins of dense water respectively, we tested the Argo technology in this shallow/coastal area.

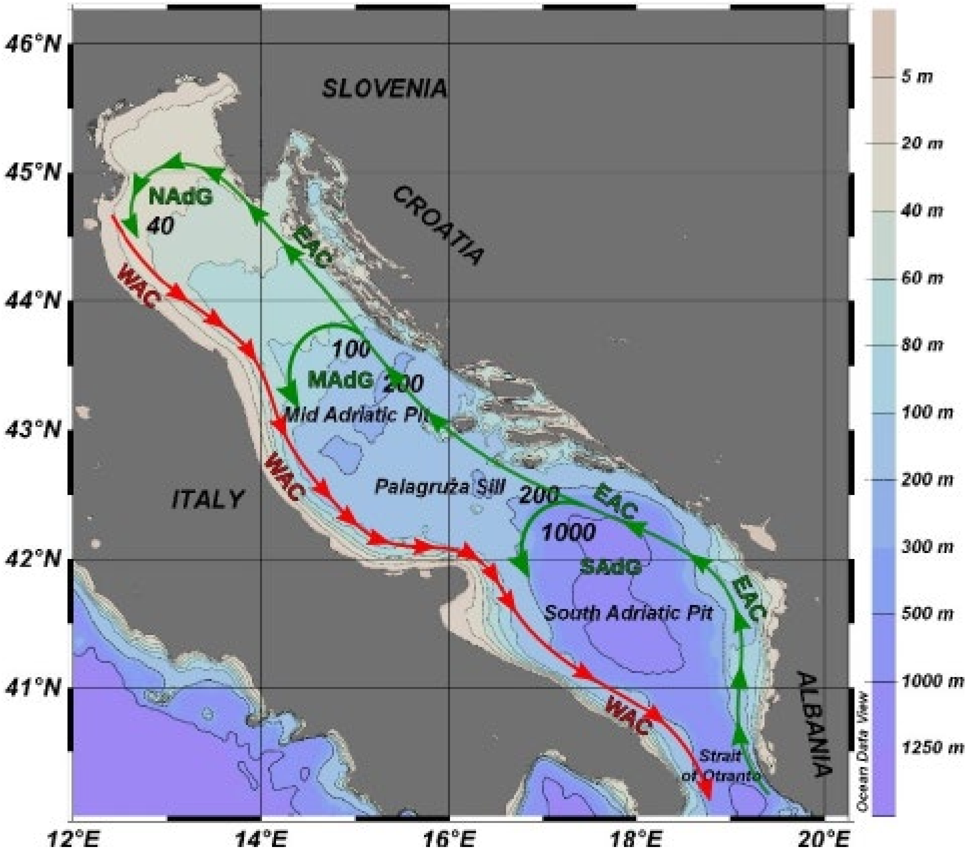


Figure 5. Adriatic Sea: bathymetry, morphology and main surface circulation (redrawn with modifications from Poulain and Cushman-Roisin, 2001). EAC: Eastern Adriatic Current; WAC: Western Adriatic Current; NAdG: North Adriatic Gyre; MAdG: Middle Adriatic Gyre; SAdG: South Adriatic Gyre. Source: Lipizer et al., 2014.

Three core-Argo floats (they are equipped with a CTD) have been deployed in the North Adriatic Sea. One platform was purchased in the framework of the European H2020 Euro-Argo RISE project and the other two belong to the Italian national program (Argo-Italy). **The target of all the missions in the Adriatic Sea is to keep the floats in a limited area in order they stay in shallow waters and relatively**

far from the coast. The first deployment (Argo float WMO 6903783, see Kassis et al., 2021b) gave us the opportunity to test Argo operations in a very shallow (70 metres) and narrow area. **A virtual mooring configuration was chosen in order to limit the platform displacement between consecutive profiles with the aim of collecting as many TS profiles as possible and strongly reducing the chance of stranding events**. The virtual mooring configuration consists of parking the float on the seafloor in order it remains inactive there for a predetermined time before starting the acquisition of another profile. The scope is to reduce the platform drift at least during the parking phase since the float is not anchored like a mooring system. The mission and technical parameters adopted worked well and allowed to achieve the requested targets. Anyway, good monitoring tools and warning systems were essential for being successful since this kind of Argo operations required a higher level of interactivity between the mission team and the platform. One Italian national float (WMO 6903800) was deployed in the same area in support of the test done with the Euro-Argo RISE float. Since both floats died prematurely in unknown conditions, it was decided to deploy a second Italian float (WMO 6903815) about 30 nm south-east of previous deployments, with a similar configuration. One Italian national Argo platform equipped with a CTD and the dissolved oxygen sensor was deployed in March 2019, before the Euro-Argo RISE project, with the aim of investigating the potential of the Argo technology in a confined area like in the Middle Adriatic Pit. The platform performed well and collected a great quantity of profiles on a regular basis within the depression area.

2.1.3 North Aegean experiment

The Aegean Archipelagos is a basin of increased oceanographic interest. However, especially its northern part is a challenging area for Argo float operations due to the complicated coastline, and the rapidly changing bathymetry, which includes shallow plateaus and deep trenches. Thus, specially designed missions are undertaken since 2020, within the Euro-Argo RISE H2020 project, focusing on better monitoring and increased float lifetime. These missions have been implemented by the Greek Argo Research Infrastructure (www.greekargo.gr) which is a component of the Hellenic Integrated Marine Inland water Observing, Forecasting and Offshore Technology System (HIMIOFoTS) (https://www.himiofots.gr/en) and member of the Euro-Argo ERIC.

The North Aegean's most important feature is that it communicates from the northeast with the Black Sea through the Dardanelles Straits. This results in the inflow of cold and fresh water, the Black Sea Water (BSW), which is a water mass characterised by a strong low salinity - temperature signal in the upper layers of the water column. Furthermore, from the southern Aegean, the high salinity Levantine Surface Water (LSW) (figure 6) and the Levantine Intermediate Water (LIW) inflow in the north Aegean forming a dominant high salinity core in the area's upper layers that create strong thermohaline fronts with BSW masses (Zervakis and Georgopoulos, 2002). The role of BSW inflow in the area is of particular importance since it can modulate the hydrography of the whole Aegean Sea (Kassis & Korres 2021). As shown in previous studies, weak BSW inflow in combination with increased winter atmospheric cooling and LSW intrusion, triggers Dense Water Formation (DWF) events which result in the formation of very dense water in the deep horizons of the sub-basin (Zervakis et al., 2000). Under this aspect, Argo floats were performed in the period 2020-2021 in targeted areas of the North Aegean in an attempt to assess floats' performance and highlight important hydrographic features revealed by the acquired profiles and trajectories. Two of the missions are still ongoing, and the current results have provided valuable information on both floats' capabilities and oceanographic processes of the coastal zone.

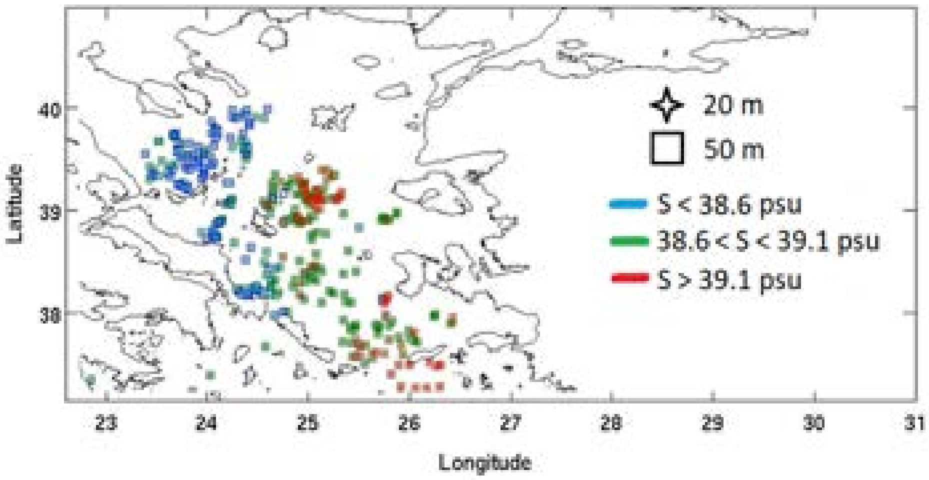


Figure 6. Surface salinity distribution from Argo floats in the North Aegean during 2014-2017 (modified from Kassis & Korres 2021).

2.1.4 Ligurian experiment

For more than a decade, the Ligurian Sea has been chosen as a relevant test bed for technological evolutions of profiling floats and their autonomous sensors, which significantly contributed to observational enhancements of the Argo program over the global ocean. The Ligurian Sea is a deep basin of the northwestern Mediterranean Sea, bordered by a steep continental shelf. It offers easy and quick access to open sea conditions under coastal influences in a temperate zone. The embedding large-scale circulation is dominated by a cyclonic system (figure 7). A geostrophic current enters from the north-west of Corsica, flows around the high densities of the central basin which form a dome, and exits towards the south-west along the Provençal coast. Exchanges between the coastal area and the central area are driven by well-characterised mechanisms that are associated with the dynamics of the geostrophic current (reviewed in, e.g., Prieur et al., 2020).

Thanks to these features, the Ligurian Sea can be also considered as relevant for the main objective of this Euro-Argo RISE work package: **investigate the potential of profiling floats to monitor marginal seas**.

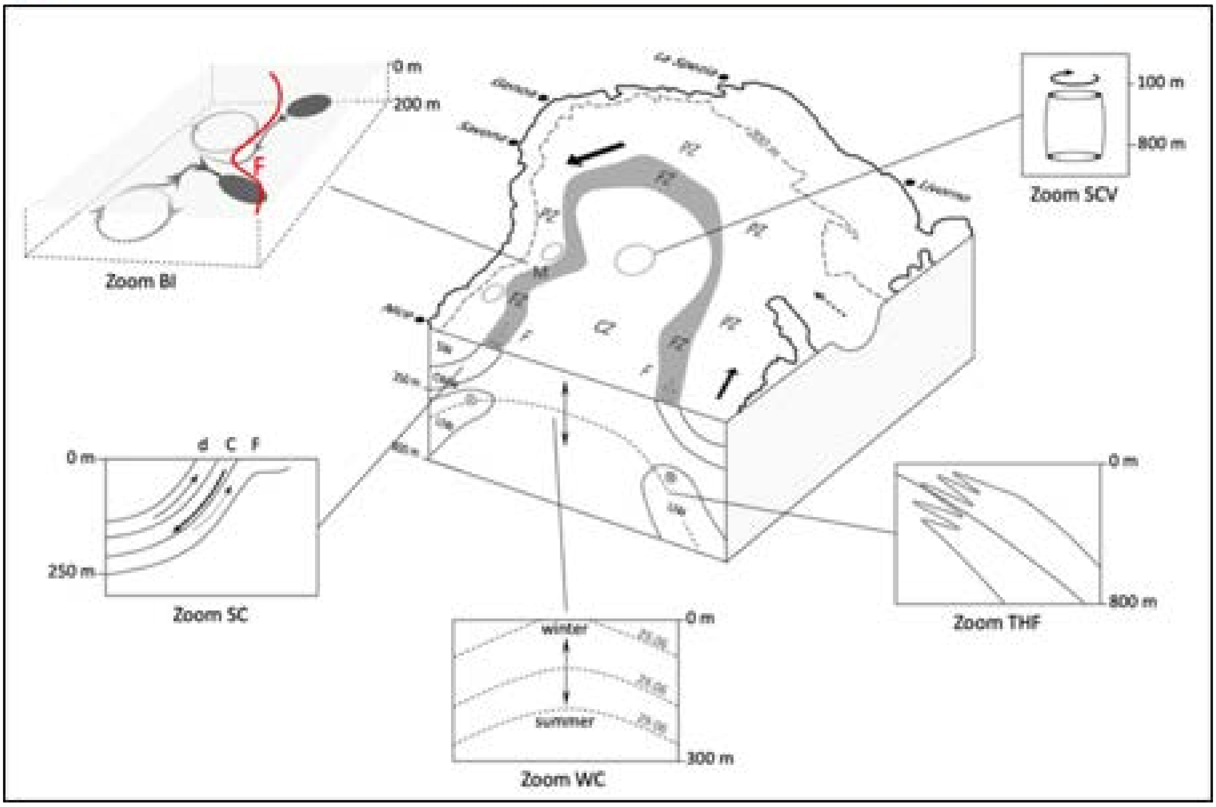


Figure 7. Schematic 3D representation of the Ligurian Sea circulation. CZ: central area; FZ: frontal zone; PZ: coastal area; BI : baroclinic instability ; SC : secondary instability ; F and THF : thermohaline front ; SCV : sub-coherent vortex; WC: winter convection. Source: Prieur et al. (2020).

2.2 Methodology

Four Euro-Argo RISE platforms and additional national floats have been deployed in the Mediterranean Sea since 2019 (table 1) in targeted areas for missions close to the coast (figure 8). Most of the locations were chosen to test floats in the unsampled or highly under-sampled areas according to the historical (prior to the Euro-Argo RISE project) Mediterranean Argo coverage (figure 9). Some deployments were done for the first time in shallow areas of sub-basins (see the north Adriatic in figure 10 in which Argo floats were never deployed). The potential of the Mediterranean for the shallow/coastal monitoring is well highlighted in figure 9 where it is evident that shallow areas (central-north Adriatic, the Sicily Channel), geographically complex areas (Aegean) and areas close to the coast with a depth less than 200 m (yellow line in figures 9 and 10) are under-sampled or not covered until now, but could be in the future with the outcome of the work done in the Euro-Argo RISE project. In general, shallow and/or coastal areas (depth less than 200 m) that are really under-sampled by Argo are clearly shown also by the distribution of the maximal depth of Argo float profiles (figure 11). Platforms' configurations were tested and the most useful monitoring tools were selected according to the characteristics of the area and the specificity of the mission. The final goal is to be able to operate Argo floats in shallow/coastal waters and to achieve a good life expectancy of platforms (Kassis et al., 2021a, b). The methodologies applied in the different experiments are described in sections from 2.2.1 to 2.2.4.

Figure 8. Euro-Argo RISE and national floats in the Mediterranean Sea. Last position is shown in yellow (grey) for active (inactive) floats as of time of writing. Floats' trajectories are shown as grey lines.

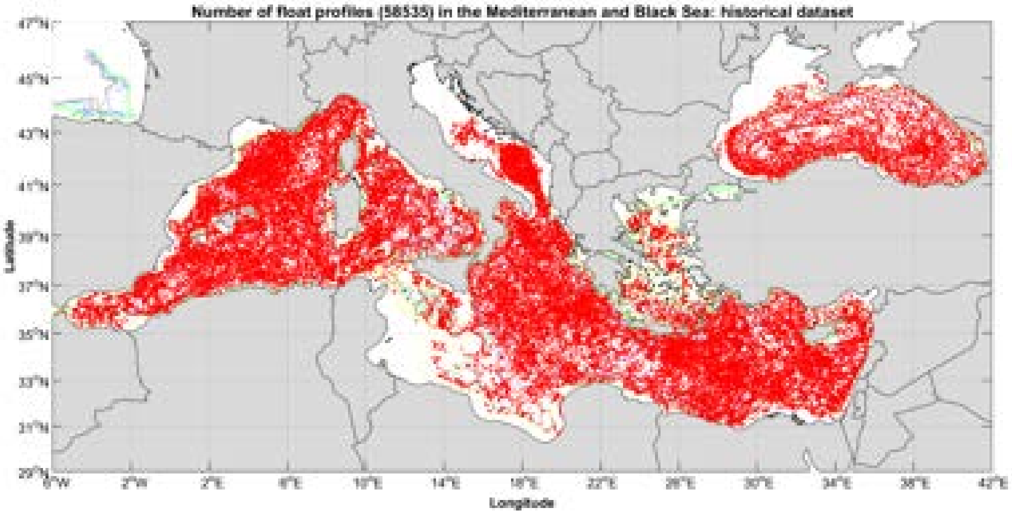


Figure 9. Argo float profiles locations (red dots) before the Euro-Argo RISE project (up to December 2018). The 200 (yellow line), 600 (green line), 1000 (cyan line), 2000 (blue line) and 3000 (black line) m isobaths are shown.

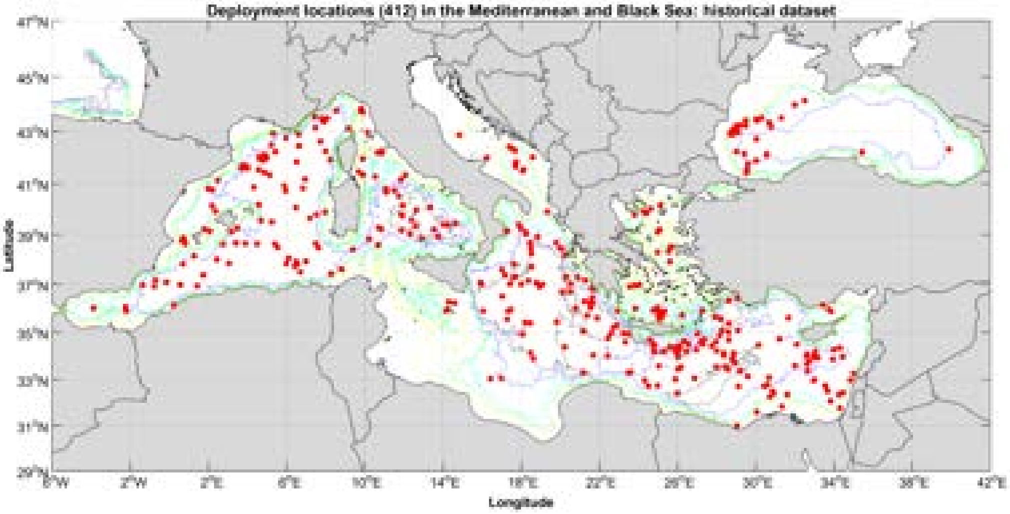


Figure 10. Argo float deployment locations (red dots) before the Euro-Argo RISE project (up to December 2018). The 200 (yellow line), 600 (green line), 1000 (cyan line), 2000 (blue line) and 3000 (black line) m isobaths are shown.

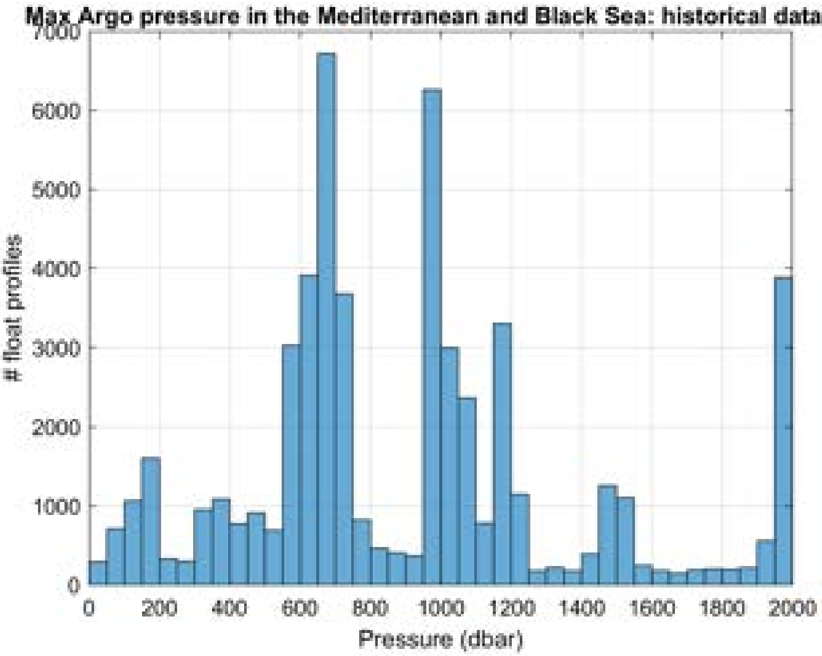


Figure 11. Distribution of the maximal depth of Argo float profiles before the Euro-Argo RISE project (up to December 2018). The 700 dbar peak is due to a predefined maximal depth level used in the Mediterranean Sea; the 1000 dbar peak is due to the standard Bio-Argo maximal depth; the 2000 dbar peak is due to the maximal depth reached by the Core-Argo floats.

Table 1. Summary of Argo missions in targeted areas close to the coast in the Mediterranean Sea.

WMO	Deployment Date/Time	Deployment location	Sub-basin	Total Cycles	Date of Last Cycle	Status
6903783	31/07/2020	44.05 N 13.70 E	North Adriatic	40	06/02/2021	Inactive
6903800	04/05/2021	44.05 N 13.62 E	North Adriatic	34	17/10/2021	Inactive
6903815	12/05/2022	43.68 N 14.27 E	North Adriatic	14	22/05/2022	Active
6903263	23/03/2019	43.01 N 15.11 E	Middle Adriatic	232	22/05/2022	Active
6903288	09/02/2020	40.42 N 25.42 E	North Aegean	120	05/10/2020	Inactive
6903297	17/10/2021	39.83 N 24.42 E	North Aegean	47	12/05/2022	Active
6903298	13/11/2021	38.87 N 26.42 E	North Aegean	42	08/06/2022	Active
6904065	14/08/2020	39.28 N 1.98 E	Balearic	202	13/06/2022	Active
6901278	12/03/2020	39.37 N 2.52 E	Balearic	215	09/06/2022	Active
6902899	11/12/2019	43.41 N 7.86 E	Ligurian	194	27/06/2021	Recovered

2.2.1 Balearic experiment

The Euro-Argo RISE float (WMO 6901278) was deployed in the Palma Bay on 12th of March 2020, on board RV SOCIB. This area extends around 32 km from the coast to a bathymetric line of 200 m depth. The local dependence on marine activities (maritime traffic, fishing, tourism, etc.) is very strong in this area. Also, marine reserves and other vulnerable marine ecosystems are particularly important. The launching point (figure 12, way point 1) was located in coastal shallow waters, of 94 m bottom depth. The region is an important transition area between the Atlantic and Mediterranean waters, due to the topographic controls on the exchanges between the sub-basins of Algeria and the Balearic Islands (Pinot et al., 2002). To the north of the launching point, the Balearic current recirculates cyclonically around the northern coastal shelf edge of Mallorca (Pascual et al., 2002), where the float was drifting (figure 13) when it left the Palma Bay.

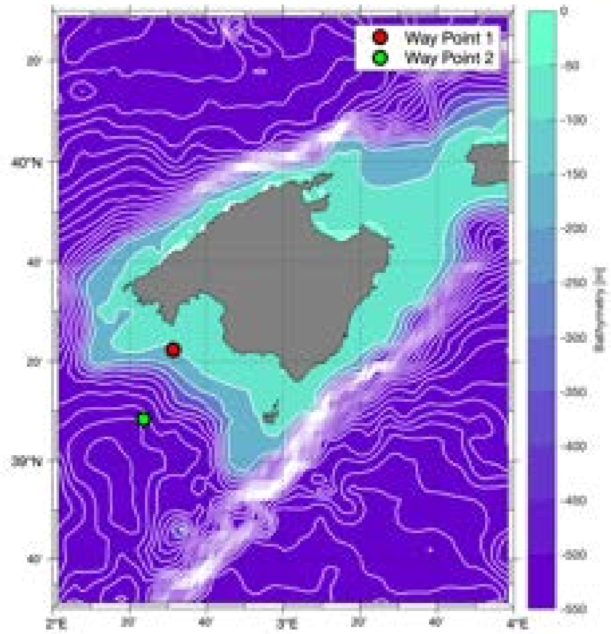


Figure 12. Bathymetry and WMO 6901278 launching point (Way Point 1).

The initial configuration for the float was park pressure 100 dbar, profile pressure 100 dbar and cycle time of 24 h. This configuration changed several times during the experiment, and these changes are given in table 2. A CTD reference profile was carried out at the deployment location: the first cycle (downcast) and the 2nd cycle (up-cast) of the float were compared with the downcast data from this reference ship CTD profile.

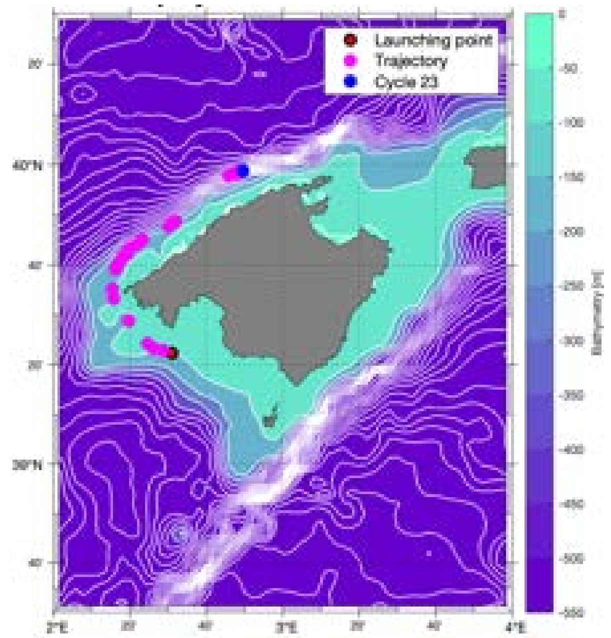


Figure 13. Bathymetry and WMO 6901278 GPS position since the launching day until the cycle 23.

Table 2. Summary of mission commands changed during the shallow waters mission of float 6901278 (Arvor model).

	19/03/2020	31/03/2020	22/04/2020	09/05/2020
MISSION COMMANDS	CONFIG_CycleTime_hours (hours) 48	CONFIG_CycleTime_hours (hours) 96	CONFIG_CycleTime_hours (hours) 24	CONFIG_CycleTime_hours (hours) 48
	CONFIG_ParkPressure_dbar (dbar) 300		CONFIG_ParkPressure_dbar (dbar) 1000	
	CONFIG_ProfilePressure_dbar (dbar) 300		CONFIG_ProfilePressure_dbar (dbar) 1000	
INTENTIONS	check the float behaviour and park the float close to the sea bottom	check the float behaviour	check the float behaviour and park the float close to the sea bottom	check the float behaviour
OUTCOMES	float moves a short distance (grounded), but it starts to drift with the Balearic Current	float moves a long distance (approx. 45 km), it arrives in a bathymetry between 500-1000 m	float moves a short distance (grounded)	float moves a short distance (grounded) and drift over a bathymetry of 200 - 500 m

The target of the mission was the regional expansion of Argo into shallow coastal areas of specific oceanographic interest, and also the implementation of the existing monitoring in the Marginal Sea context. To that end, **a number of different tools and approaches were used in order to facilitate the changing of the platform's configuration settings (e.g. cycle time, park pressure, profile depth, etc.) to keep it in shallow waters**.

To make decisions as soon as possible and know the GPS position, routinely, the SOCIB team decoded the float raw data before the Coriolis decoding chain had been initiated. In addition, several tools were used. SOCIB used an in-house developed tool called Euro-ARGO RISE experiment (figure 14a), which shows the Western Mediterranean OPerational forecasting system (WMOP) currents at different depths in the study area. This tool helped to forecast the float drift by the currents. The Euro-Argo monitoring tool (figure 14b) was used to compare the forecast. In this case, SOCIB used the sea surface currents provided by the AVISO satellite derived data to try to predict the float displacement. SOCIB Deployment Application (Dapp) (figure 14c) is a web based client application, developed by the SOCIB, intended to display and download deployments data. Using this app, the float trajectory was checked overlapping the EMODnet bathymetry contour and isobath maps and the WMOP currents to support the float park pressure planning decisions. **In general, the human-platform interactivity was higher than with the standard Mediterranean Argo configuration**. This was expected in order to understand how these tools help to make planning decisions, implement and test configuration changes and, use a shorter than standard cycle time to monitor the float position and change parameters where necessary.

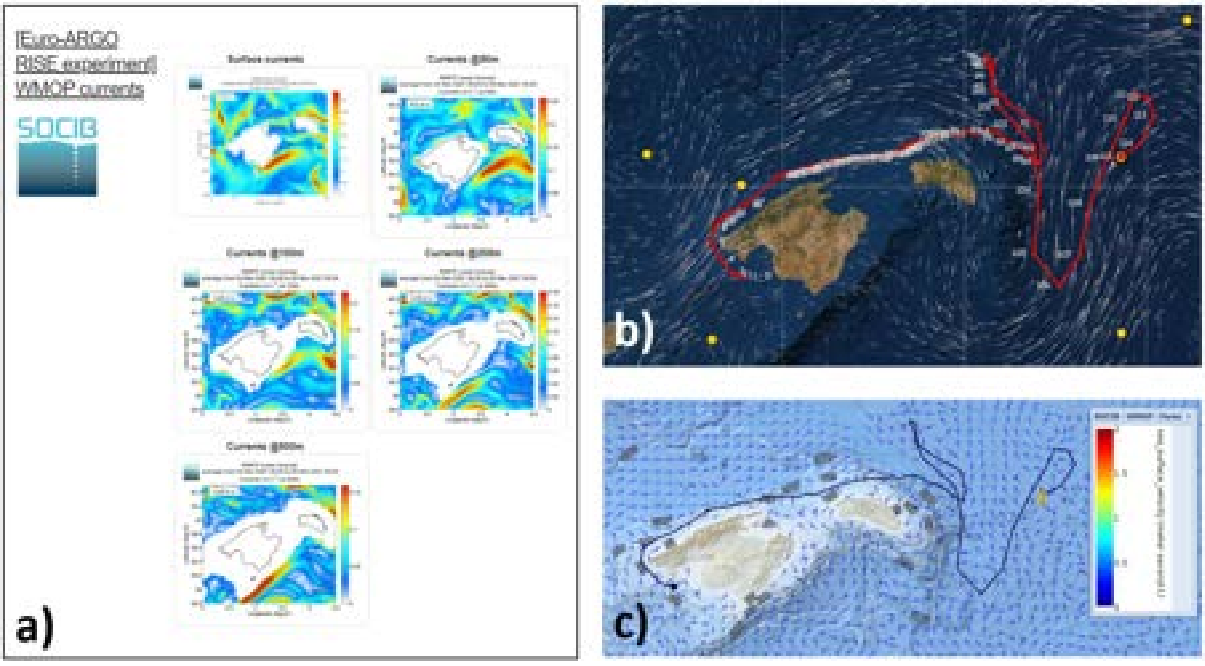


Figure 14. Tools used by SOCIB to monitor WMO 6901278 float; a) Euro-ARGO RISE experiment, b) Fleet monitoring tool, c) SOCIB Dapp.

2.2.2 North Adriatic experiment

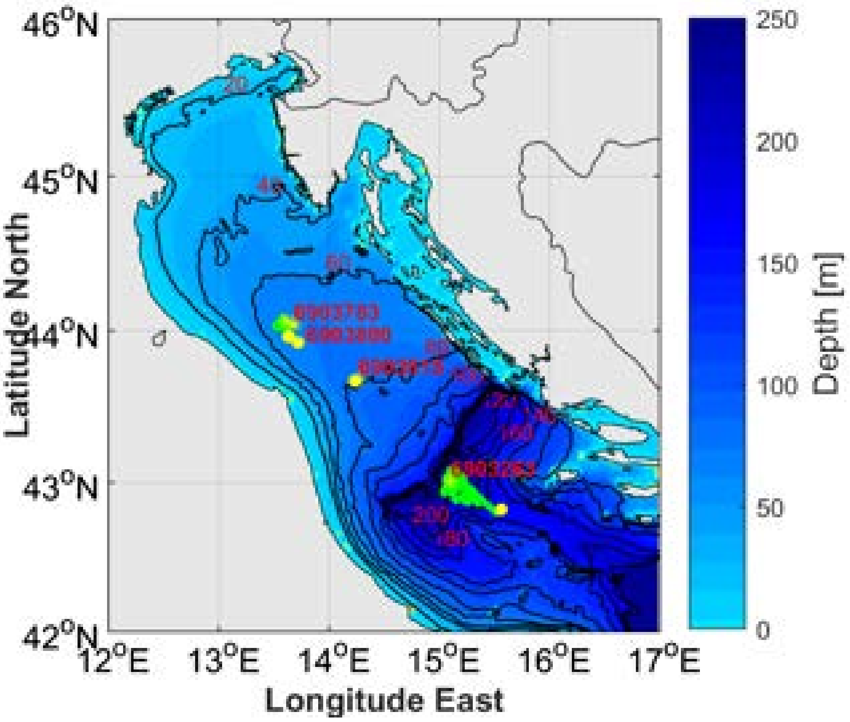


Figure 15. Bathymetry and GPS positions of floats deployed in the North and Middle Adriatic Sea.

The four floats deployed in the middle-north Adriatic Sea are shown in figure 15. The first test-case was done in March 2019, when the Italian float WMO 6903263 was deployed in the Middle Adriatic Pit with the help of the Italian colleagues of CNR by R/V Dallaporta (figure 16). The area was chosen because it is in the middle of the sub-basin and quite deep and hence more secure in terms of maritime traffic and stranding events. Moreover, it is a limited area that offers a good opportunity to test the configuration settings of the float in order it stays within the region and performs deep (relative to the area) measurements over a long time frame. The float was set up in a "virtual mooring" like configuration (see section 2.1.2 for virtual mooring definition) and the main mission and technical parameters are listed in table 3.

In particular, after the first cycles of the float, some parameters were tuned and the cycle time was set at 5 days (120 hours), the park and profile pressure at the sea bottom, the grounding modality was set up in "shift upward" mode in order the float re-bounces for 10 metres (GroundingModePresAdjustment) once it touches the sea bottom. The grounding activation level (CONFIG_GroundingModeMinPresThreshold_dbar) was set at 200 dbar, according to the expected bottom depth. The pressure target tolerance for stabilisation was left set at 30 dbar and the descending speed at 25 mm/s.

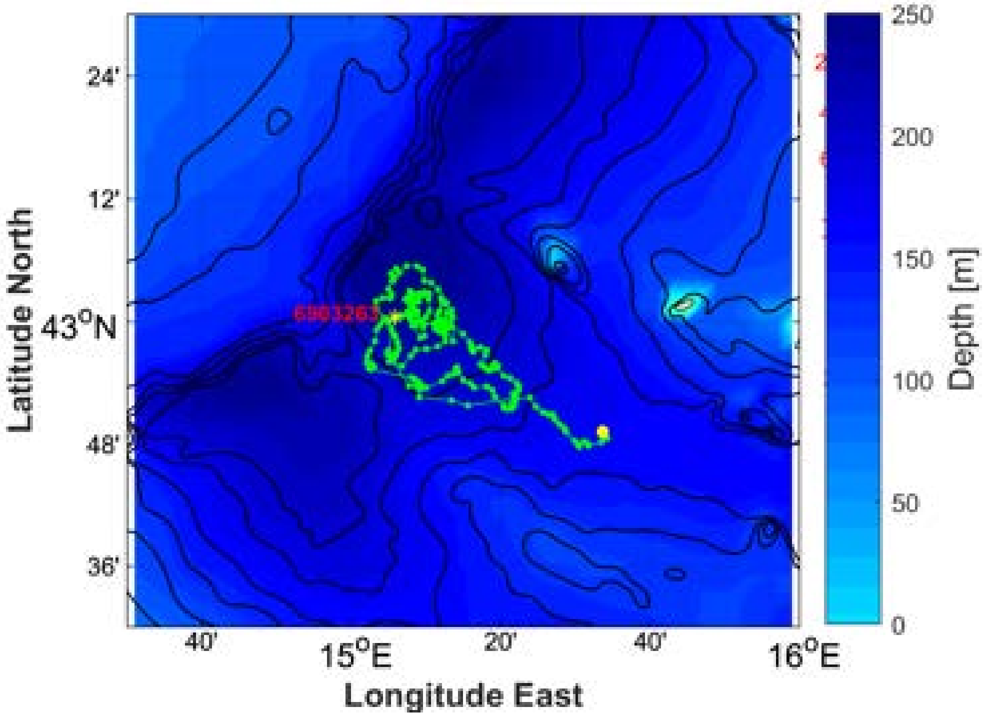


Figure 16. Trajectory of float WMO 6903263 deployed in the Middle Adriatic Sea.

Table 3. Summary of mission commands changed during the shallow waters mission of float 6903263 (Arvor model).

Platform	initial specific parameters	27/03/2019	29/04/2022
MISSION COMMANDS FOR WMO 6903263	CONFIG_CycleTime_hours (hours) 120		
	CONFIG_ParkPressure_dbar (dbar) 350	CONFIG_ParkPressure_dbar (dbar) 300	
	CONFIG_ProfilePressure_dbar (dbar) 350	CONFIG_ProfilePressure_dbar (dbar) 300	
	CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 0		
	CONFIG_GroundingModePresAdjustment_dbar (dbar) 100	CONFIG_GroundingModePresAdjustment_dbar (dbar) 10	
	CONFIG_PressureTargetToleranceForStabilisation_dbar (dbar) 30		
	CONFIG_GroundingModeMinPresThreshold_dbar (dbar) 200		CONFIG_GroundingModeMinPresThreshold_dbar (dbar) 100
	descending speed (mm/s) 25		
INTENTIONS	check the float behaviour	park the float close to the sea bottom	tuning the configuration since area is shallower
OUTCOMES	float worked as intended	the float re-bounces for 10 metres once it touches the sea bottom	float worked as intended

On the basis of the experience gained with float 6903263, one Euro-Argo RISE float (WMO 6903783, figure 17) was deployed in the North Adriatic Sea, in an area closer to the coast (25 nm off the italian coast) and quite shallow (maximal depth is about 70 m). The deployment was done in July 2020 by R/V Dallaporta.

A potential collaboration with Croatia was about to be established but difficulties were encountered at maritime laws level in particular for deployments and operations of autonomous marine platforms within EEZ and close to territorial waters. Further work is needed at policy makers and governmental offices level to move forward. Nevertheless, Croatia is willing to support and to be part of Argo activities and a more constructive collaboration with Euro-Argo will be put in place in near future.

The target of the mission is to keep the float in a limited area and to use it as a virtual mooring. To that purpose, the main configuration parameters adjusted during the mission are the cycle time and the park and profile pressure (table 4). The cycle time was set quite short (2 days) for the first float's cycles in order to check the float behaviour and the magnitude of its drift. Then, the cycle time was extended to 5 days. The park and profile pressure were set deep enough to reach the sea bottom (about 70 m). The grounding mode was set to the "stay grounded" modality and the pressure target tolerance for stabilisation was reduced to 10 dbar since the area is quite shallow.

No reference CTD data were collected at the deployment. CTD profiles were gathered nearby in February 2020, few months before the float deployment.

Table 4. Summary of mission commands changed during the shallow waters mission of float 6903783 (Arvor model).

Platform	**initial specific parameters**	**04/08/2020**
MISSION COMMANDS FOR WMO 6903783	CONFIG_CycleTime_hours (hours) 48	CONFIG_CycleTime_hours (hours) 120
	CONFIG_ParkPressure_dbar (dbar) 200	
	CONFIG_ProfilePressure_dbar (dbar) 200	
	CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 1	
	CONFIG_GroundingModePresAdjustment_dbar (dbar) 5	
	CONFIG_PressureTargetToleranceForStabilisation_dbar (dbar) 10	
	descending speed (mm/s) 25	
INTENTIONS	check the float behaviour	reduce the float displacement
OUTCOMES	float worked as intended, small displacement, virtual mooring configuration OK	float worked as intended

An Italian national float (WMO 6903800, figure 17) was deployed about 25 nm off the Italian city of Senigallia, in the north Adriatic Sea, where the maximal depth does not exceed about 70 metres. This is about the same location of float 6903783 when the Euro-Argo RISE platform stopped transmitting after 6 months of operativity. **The target of the mission was to try to continue the mission on the shallow shelf area of the north Adriatic Sea and hence to keep the float in a limited area. Therefore, its setting was almost the same as float 6903783 and a virtual mooring-like configuration was**

chosen. Small configuration adjustments were chosen and in particular the grounding activation level (CONFIG_GroundingModeMinPresThreshold_dbar) that was set at 50 dbar and the descending speed that was set up at 20 mm/s in agreement with what is currently done in the framework of MedArgo (table 5). Reference CTD data were collected at the deployment location.

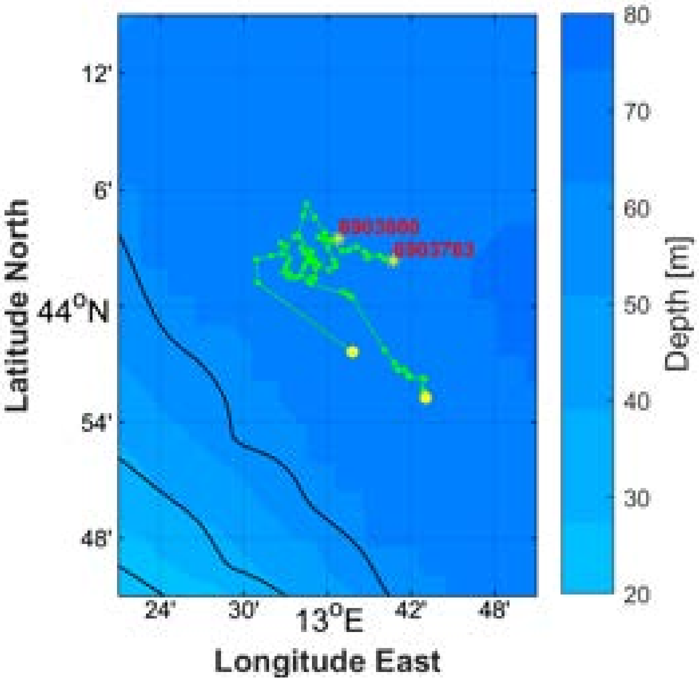


Figure 17. Trajectory of floats WMO 6903783 and 6903800 deployed in the Middle Adriatic Sea.

Table 5. Summary of mission commands changed during the shallow waters mission of float 6903800 (Arvor model).

Platform	initial specific parameters
MISSION COMMANDS FOR WMO 6903800	CONFIG_CycleTime_hours (hours) 120
	CONFIG_ParkPressure_dbar (dbar) 200
	CONFIG_ProfilePressure_dbar (dbar) 200
	CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 1
	CONFIG_GroundingModePresAdjustment_dbar (dbar) 5
	CONFIG_PressureTargetToleranceForStabilisation_dbar (dbar) 10
	CONFIG_GroundingModeMinPresThreshold_dbar (dbar) 50
	descending speed (mm/s) 20

In March 2022 another Italian float was deployed in the north Adriatic Sea. This time the deployment location was chosen south-east of the previous two floats, a bit further from the coast to reduce the chance of getting in touch with maritime traffic and fishermen. The configuration (table 6) is similar to float WMO 6903800 but the pressure target tolerance for stabilisation was increased to 20 dbar since the area is a bit deeper (80 m).

Table 6. Summary of mission commands changed during the shallow waters mission of float 6903815 (Arvor model).

Platform	initial specific parameters
MISSION COMMANDS FOR WMO 6903815	CONFIG_CycleTime_hours (hours) 120
	CONFIG_ParkPressure_dbar (dbar) 200
	CONFIG_ProfilePressure_dbar (dbar) 200
	CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 1
	CONFIG_GroundingModePresAdjustment_dbar (dbar) 5
	CONFIG_PressureTargetToleranceForStabilisation_dbar (dbar) 20
	CONFIG_GroundingModeMinPresThreshold_dbar (dbar) 50
	descending speed (mm/s) 20

Since the target of all the missions in the Adriatic Sea is to keep the floats in a limited area in order they stay in shallow waters and relatively far from the coast, the Euro-Argo monitoring tool was used in conjunction with in-house developed tools were used to perform a faster Argo SBD data decoding. Basically, the last GPS position is decoded from the relative SBD file and this information is used to estimate the local bathymetry (through a function) and the distance from the deployment point. An automatic email sender program was implemented. In particular, the notification system comes as an email (see example in figure 18) that is sent few hours after the float transmitted its data. The operator can see the float location, the bathymetry and the distance from the deployment point (available in Google Maps and as a kml file for visualisation in Google Earth, in figure 19).

CMEMS model of the daily mean sea water velocity near the float's park pressure (figure 20) was used to try to predict the direction of the float displacement. CMEMS information are now available also as an additional layer in the Euro-Argo fleet monitoring tool. The latter is obtained as a joint collaboration between WP6 and WP2 activity. In the example in figure 21, the daily mean horizontal velocity at about the park pressure of float 6093815 is shown. The velocity is in the order of a few cm/s and the direction is indicated by arrows. This tool is crucial to find the optimal park pressure in case of virtual mooring operation when we want to limit the float displacement from the deployment location.

Float 6903815 last position

On date (UTC) 27-04-2022 06:30:03 http://maps.google.com/maps?q=loc:43.6701+14.2311

Last estimated bathymetry (m):-79.5

Distance from the deployment point (km):3.2

Figure 18. Email notification system for float WMO 6903815.

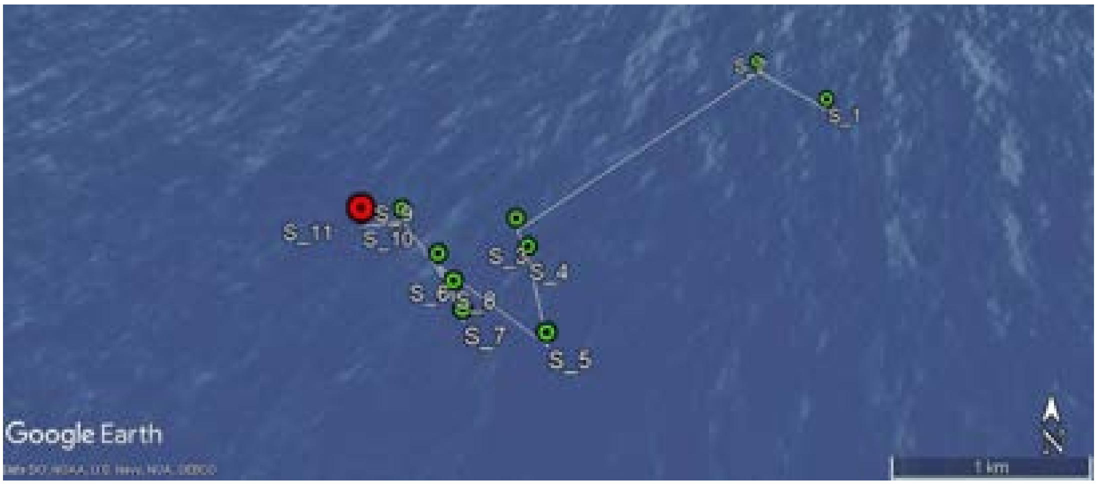


Figure 19. KML file of WMO 6903815 generated by the automatic notification system for Google Earth visualisation.

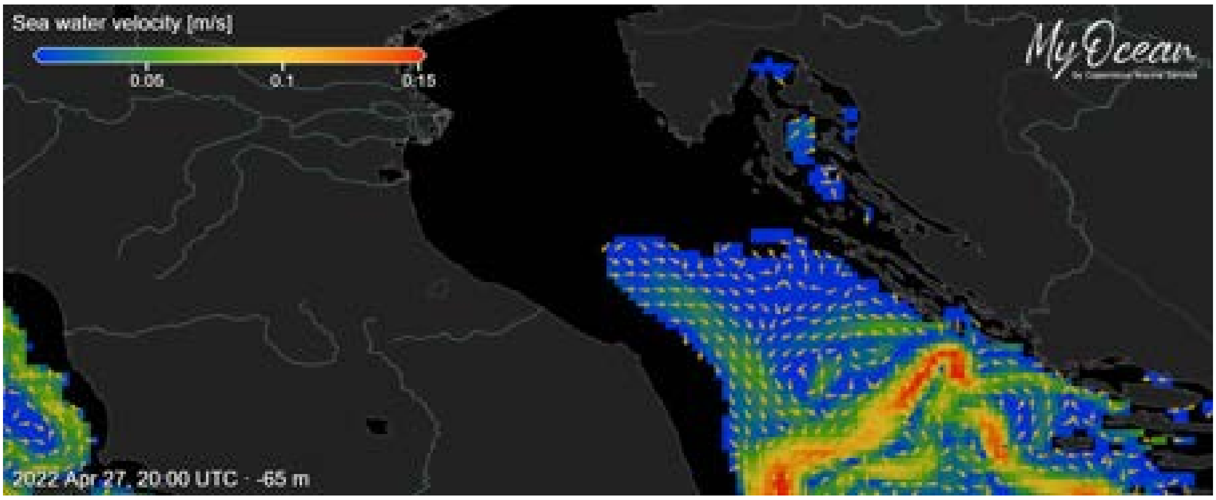


Figure 20. CMEMS model of the daily mean sea water velocity at about 65 meters depth. Source: https://resources.marine.copernicus.eu/product-detail/MEDSEA_ANALYSISFORECAST_PHY_006_013/INFORMATION

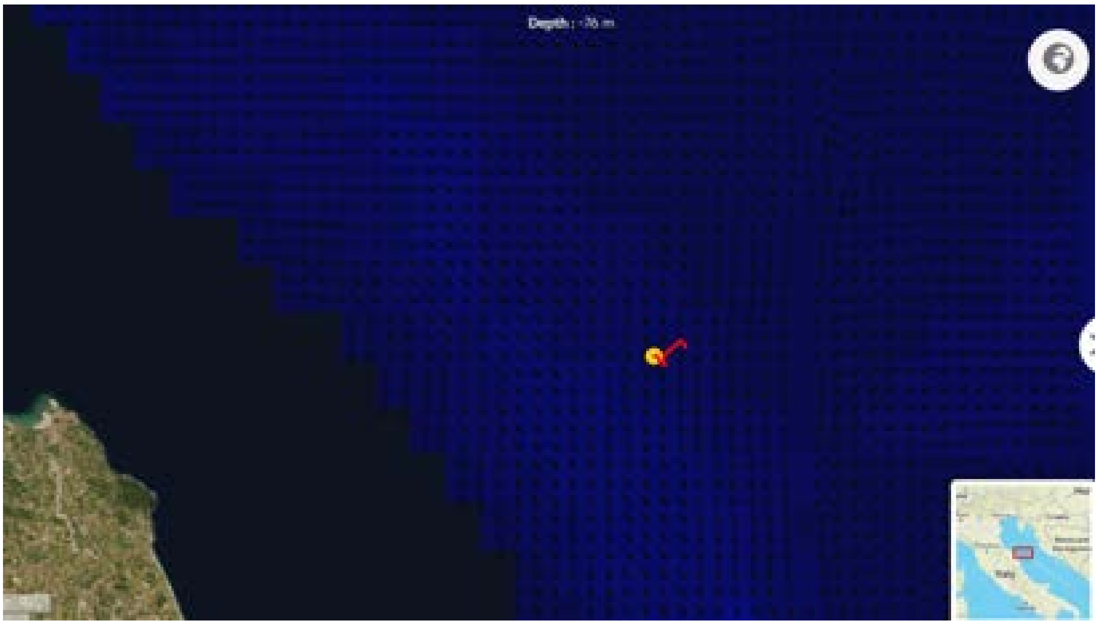


Figure 21. Float WMO 6903815 with daily mean horizontal velocity at about 70 m (close to park pressure). Few cm/s. Source: https://fleetmonitoring.euro-argo.eu/

2.2.3 North Aegean experiment

We used three standard CTD floats for the coastal experiments in the North Aegean. All floats were tested in terms of functioning and communication, and configured in the HCMR laboratory before the deployments. Different configuration settings were used in each case according to the mission requirements and monitoring needs. For the 6903288 case, **2-days mission cycles were chosen whilst the drifting and profiling depth of the float were both set to 800 m. This configuration was tested in order for the float to remain near the deployment location within the deep trench** north of Limnos Island shelf break (figure 22). More specifically, the scope of such configuration is to make the float drift at the depth horizon near the seabed and prevent it from exiting the trench whilst, and at the same time acquire a large number of profiles in relatively short time periods. Similar settings were chosen for the 6903298 float that was deployed in a relatively deep but narrow plateau south of Lesvos Island (figure 22). In this case, **a 5-days cycle was set in order to avoid frequent float surfaces and reduce the possibility of collisions with vessels** since this area presents intense shipping activity. On the contrary, for the 6903297 that was deployed in the deep plateau of the central part (figure 22), a setting similar to what is proposed in MedArgo (Poulain et al., 2007) was adopted. Details on the deployments and the basic configuration settings used for this mission are summarised in Table 7.

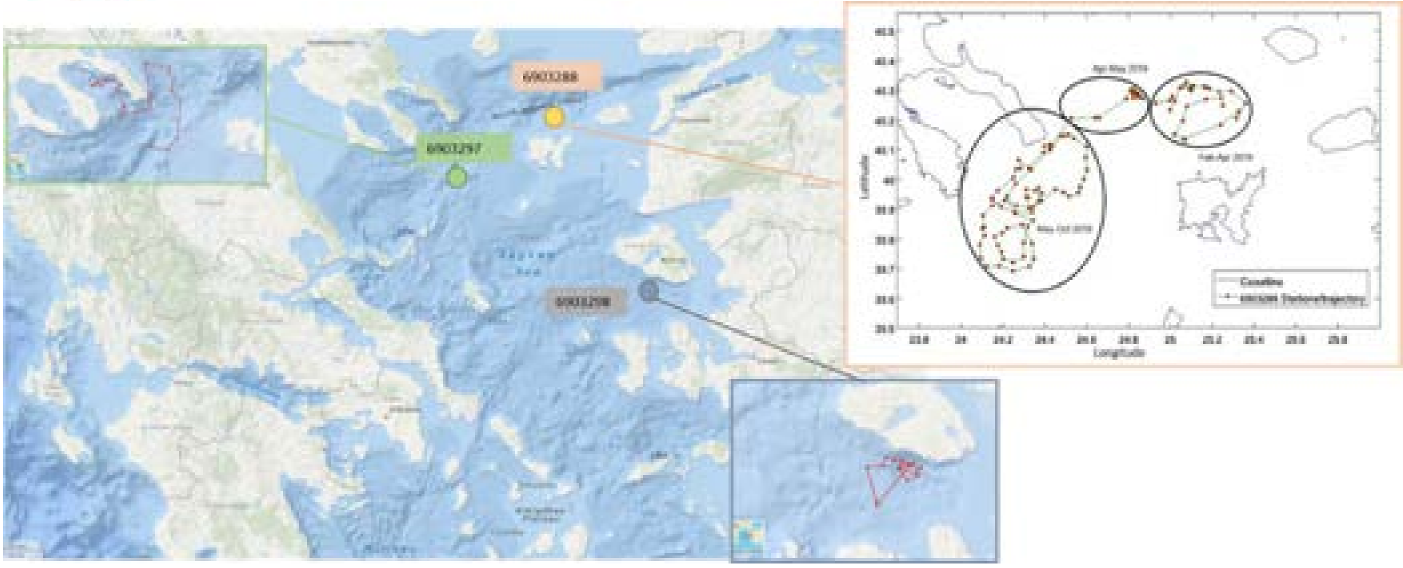
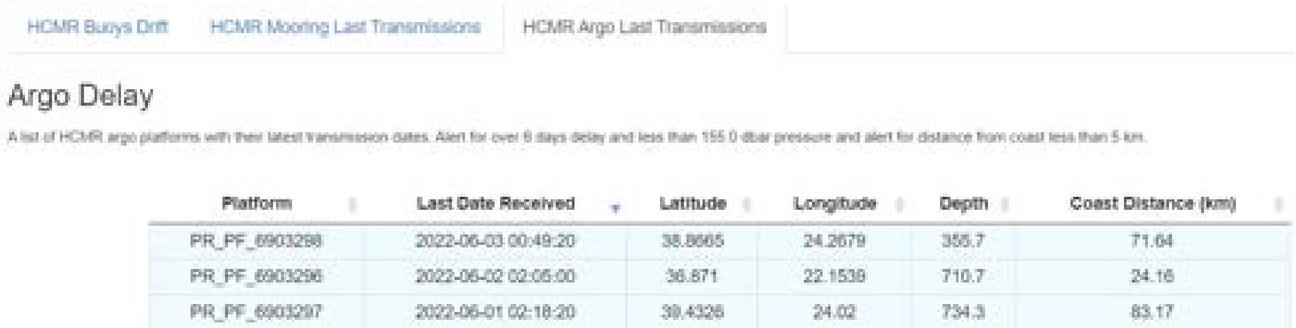


Figure 22. Trajectories of floats WMO 6903288, 6902397 and 6903298 deployed in the North Aegean Sea.

Table 7. Summary of mission commands changed during the shallow waters mission in the North Aegean Sea.

Float type	WMO	Deployment date	Deployment location	Depth (m)	CONFIG_Cycle Time_hours (hours)	CONFIG_Park Pressure_dbar (dbar)	CONFIG_Profile Pressure_dbar (dbar)	Mission scope
APEX 11	6903288	9/2/2020	40.42 N, 25.42 E	820	48	800	800	virtual mooring
ARVOR I	6903297	17/10/2021	39.84 N, 24.42 E	1250	120	350	1000	std. Med
ARVOR I	6903298	13/11/2021	38.91 N, 26.30 E	690	120	450	600	virtual mooring avoid frequent surface

The floats have been operationally monitored through the combination of the updated Euro-Argo monitoring tool and the automatic alerting system (http://poseidonsystem.gr/alerts/?m=2) developed at HCMR. The latter addresses additional specific information, such as the platforms' data transmission activity, the bathymetry, and the distance from the coastline (figure 23). The alerting system is based on predefined thresholds and triggers an alert message if the thresholds are violated. Additional parameters and control criteria can be added to the alerting transmission messages such as the distance from the deployment point, weather information, sea currents estimation, etc. Such information could be particularly useful for the operator to monitor the float's mission and design potential recovery missions in case of emergency.



Argo Delay

A list of HCMR argo platforms with their latest transmission dates. Alert for over 6 days delay and less than 155.0 dbar pressure and alert for distance from coast less than 5 km.

Platform	Last Date Received	Latitude	Longitude	Depth	Coast Distance (km)
PR_PF_6903298	2022-06-03 00:49:20	38.8665	24.2679	355.7	71.64
PR_PF_6903296	2022-06-02 02:05:00	36.871	22.1539	710.7	24.16
PR_PF_6903297	2022-06-01 02:18:20	39.4326	24.02	734.3	83.17

Figure 23. Capture from the Argo real-time alerting system showing the latest data received, transmission delays, bathymetry, and distance from the coast (https://poseidonsystem.gr/alerts/?m=2).

Especially for the case of 6903288 Apex float, which was lost in October 2020, a recovery mission was planned after a notification received from a scuba diving school in the first half of 2021. According to the provided photographs (figure 24), an Apex float similar to 6903288 had been located on the seabed of Kissamos Bay, Crete, at a depth of 38 metres. The Greek Argo team performed a diving operation and retrieved the float which unfortunately was not the 6903288 (figure 24).

Figure 24. The recovery mission of the APEX float found at the west Cretan coastline stranded at 38 m depth.

2.2.4 Ligurian experiment

The mission strategy has been set up in the view of previous deployments of profiling floats in the Ligurian Sea. An assessment of this historical dataset was conducted over a set of 20 trajectories, in terms of (i) most probable pathway, and (ii) cycling characteristics.

1. In most cases, floats remained in the marginal zone, drifting within the current, until the entrance of the Gulf of Lions shelf where they finally joined the central area. In consequence, **a multi-mission strategy has been proposed, with deployments at the Dyfamed observation site (marginal zone) in Autumn and recovery in the Gulf of Lions (central area) the next summer**.

2. The park pressure and the cycle time were thought to be the two sensitive parameters that control the residence time of the floats inside the marginal zone. **The choice of a park pressure of**

1000m and cycle time of 3 days was confirmed to be a fair compromise to enhance the sampling duration of the marginal zone (about six months) with a mesoscale resolution.

The deployment of the Euro-Argo RISE float (WMO 6902899) occurred at the Dyfamed site (43°21’N, 7°54’E) on December 11th 2019 (figure 25). This observation site, visited monthly since 1993 (MOOSE network, https://www.moose-network.fr) has provided field logistics and reference measurements of essential variables (temperature and salinity profiles) to this deployment.

About Float

WMO: 6902899
Platform maker: NKE
Inst reference: OIN13-S4-D6
Platform type: PROVOR_III
Transmission system: IRIDIUM
PTT: lovbioOddw
Owner: EA-RISE
Data Centre: CORIOLIS

Deployment

Launched 2 years ago: 11/12/2019 14:52:47
Deployment Latitude: 43.412
Deployment Longitude: 7.8589
Ship: TETHYS II
Cruise: Boussole
Project: Euro-Argo RISE
Principal Investigator: Fabrizio D'ORTENZIO

Cycle activity

Status: Inactive
Age: 1.54 years old
Last station date: 27/06/2021 05:53:13
Cycle: 194
Last Surface Data: 2.2 dbar 23.516°C 37.898 PSU
Last Bottom Data: 992.4 dbar 13.243°C 38.532 PSU

Figure 25. Left: deployment of the Euro-Argo RISE float onboard R/V Tethys 2. Right: general information of the float and its mission.

The Euro-Argo fleet monitoring tool (figure 26) successfully helped to follow the progress of the mission. In the progress of the mission, the frequently looked visualisations were the following:

- First, the trajectory plot provided the pathway of the float and its position between the central area and the marginal zone.
- Second, the technical plots provided real time information about the health of the float (cycling characteristics, battery voltage, pump actions) and documented possible groundings and repositioning in the water column.
- Third, the profile plots provided a quick quality check of the collected measurements in order to identify possible metrological gaps that may happen during the mission.

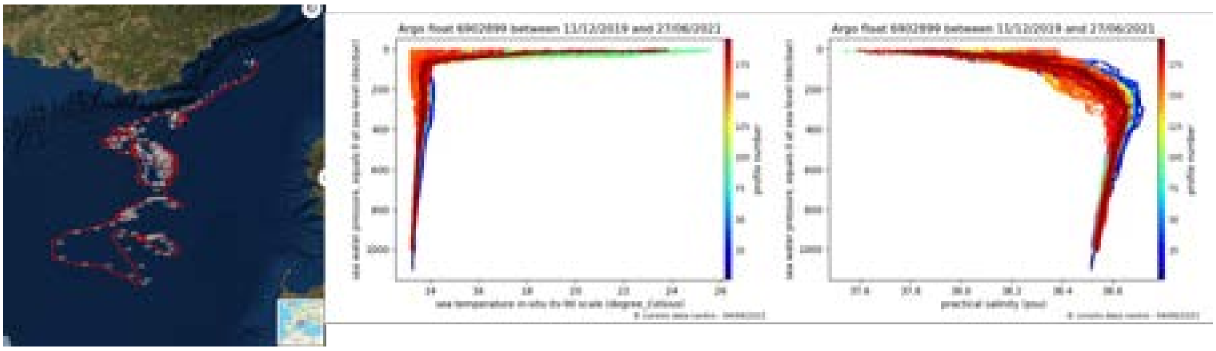


Figure 26. Left: trajectory plot during the whole mission. Middle: overlayed temperature profiles. Right: overlayed salinity profiles. Source: fleetmonitoring.euro-argo.eu

The initial plan was to recover the float during the cruise MOOSE-GE that was programmed in June 2020, but due to the sanitary crisis the cruise has been cancelled and the recovery operation needed to be postponed for one year. For the same reason, the float has not been redeployed yet.

The recovery of the Euro-Argo RISE float was achieved during the annual cruise MOOSE-GE in June 2021 after 194 cycles (figure 27). Our experience in this delicate operation has been formalised and shared in the framework of Euro-Argo RISE. The procedure applied for this recovery is available at the link https://github.com/euroargodev/recovery/files/5338781/SustainabilityNAOS_30_Jun-2.docx, this document has been gathered with other contributions of the project for capacity building of best practices and enhanced sustainability of the Argo program. (https://github.com/euroargodev/recovery/issues/3).

Figure 27. Recovery of the Euro-Argo RISE float on 27th June 2021, onboard the R/V Thalassa.

2.3 Results

2.3.1 Balearic experiment

Float WMO 6901278 was deployed in March 2020, and it is still active in April 2022. The configuration was changed a number of times (see table 2) in response to the objective to keep the float in shallow waters. Finally, it was drifting in shallow waters (Balearic continental shelf) for around 5 months and 73 cycles (figure 28). **Strong surface currents made the float drift on the surface further than intended (figure 29). The optimum sampling strategy eventually settled on a park and profile pressure "deeper than bathymetry" (float stays at bottom). It was useful to limit the time spent in the surface layer. These parameters appear more important than the cycle time**. Currently, this float is out of the continental shelf and has the Mediterranean standard configuration.

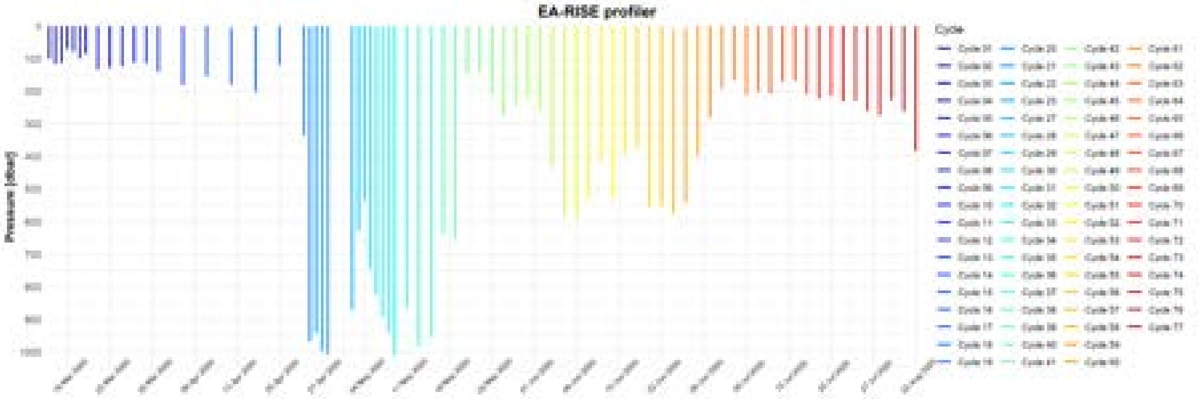


Figure 8. WMO 6901278: max. pressure during the mission.

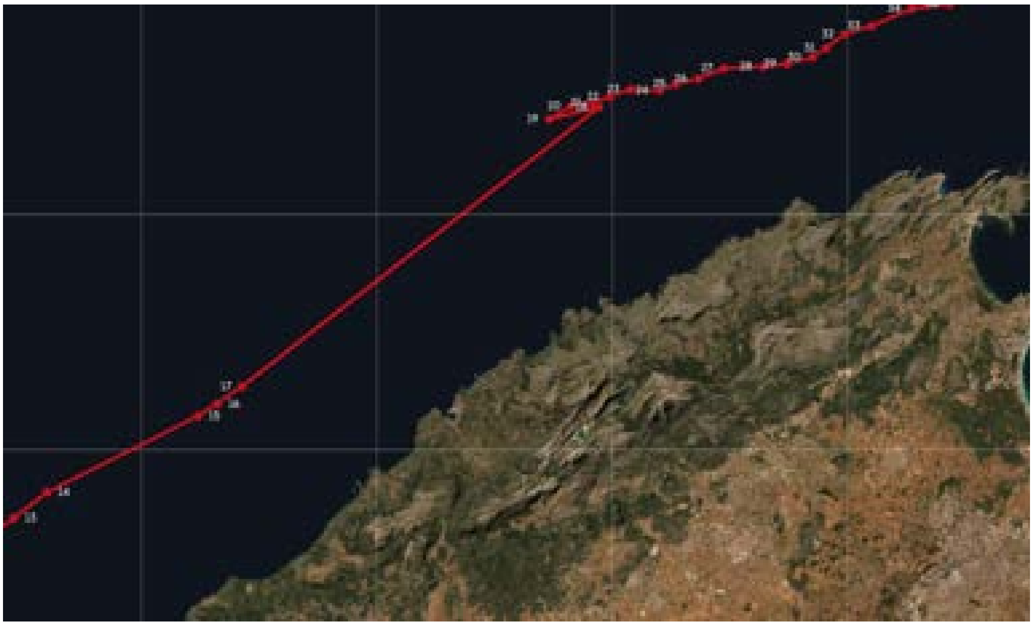


Figure 29. The float drifted around 15 miles in 4 days (4 miles per day) between cycles 17 and 18 (source: [Fleet monitoring](#)).

The support experiment carried out with the national Spanish float (WMO 6904065) re-confirmed that the deep (grounding) park and profile pressure is the best strategy to maintain the float for a longer time in the area of interest (figure 30). This float was drifting over the 200 m isobath with a standard float configuration (park pressure 1000 dbar, profile pressure 2000 dbar and cycle time 120 hours). This configuration was the best one to keep the float in coastal waters. The different tests showed that cycles of 48 or 120 h appeared more appropriate than 24 h to keep the float in the area. But the most important thing was to park the float at the sea bottom. A short test for a near bottom counter current, by setting a 180 m park pressure, did not reveal any sign of the existence of such a current. Currently, this float is also out of the continental shelf.

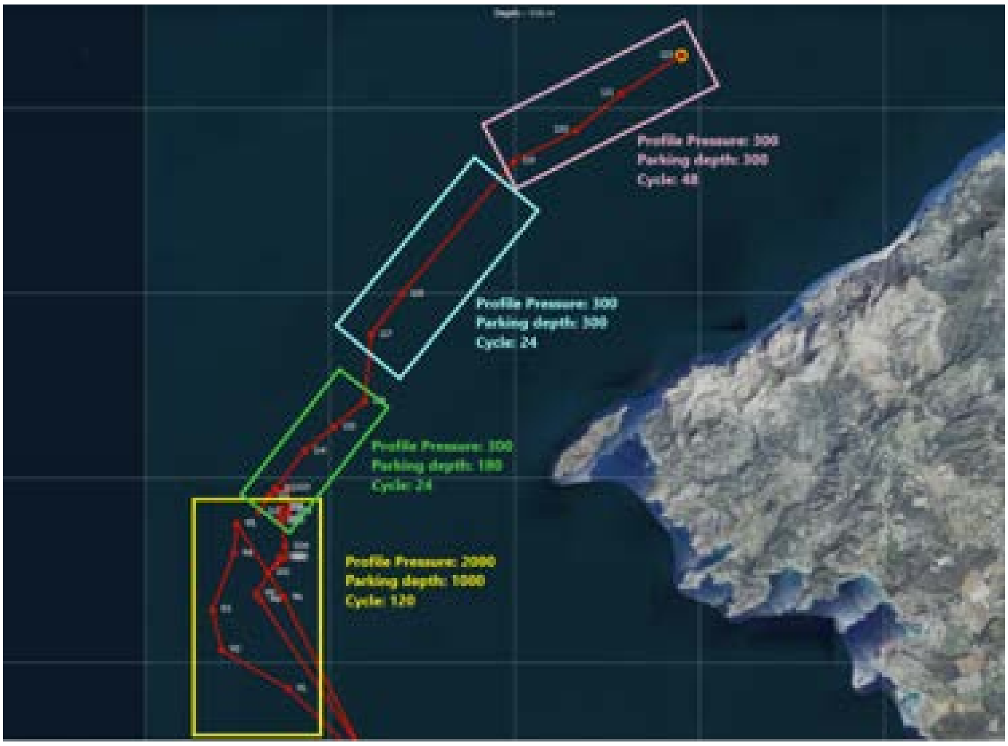


Figure 30. Float (WMO 6904065) trajectory depending on the mission parameters (source: Fleet monitoring).

Results appear satisfactory for the Euro-Argo RISE float (WMO 6901278) deployed in the Palma Bay. Using the standard configuration (cycle period 5 days), the average number of cycles in the 5 months period that the float was drifting in shallow waters would be approximately 30. However, the performance of this float increased at the same time as the human-float activity. Using a shorter cycle duration (1, 2 and 4 days), the float completed 73 cycles in the area of interest, the sampling capacity was therefore increased 143%.

The first cycle (downcast) of the float (WMO 6901278) was compared with the downcast data from ship observations at the same location and the 2nd cycle (up-cast). Significant deviations between the instruments, in particular in the upper 40 m for both T and S, were detected (figure 74 in Annex IV). A significant small scale variability is expected in shallow shelf waters. In fact, as is cited in the D2.7 (Klein et al., 2022), the mixed layer and shallow profiles are therefore not used to do the DMQC due to their high natural variability and seasonal signals in the water properties.

2.3.2 North Adriatic experiment

The float WMO 6903263 was deployed in March 2019 and it is still active in May 2022. The adopted configuration at the beginning of the mission was slightly tuned after the first cycles in order to be able to maintain the float within the targeted area (Middle Adriatic Pit) and to collect more than 225 profiles (dissolved oxygen, temperature and salinity) in about 3 years. In particular, the grounding mode parameter was configured to park the float at the sea bottom. **The float displacement was limited to much less than 30 km from for the greatest part of the float's life and after 2.5 years the platform was at approximately the same location of the deployment point** (figure 31). The entire water column of the central part of the Middle Adriatic Pit was sampled and a grounding event (between about 190 and 270 metres) occurred at every float's dive (figure 32). This seems to not have caused any technical problem till now. At the time of writing, the float WMO 6903263 is slightly drifting south-eastward in a less deep area of the Pit.

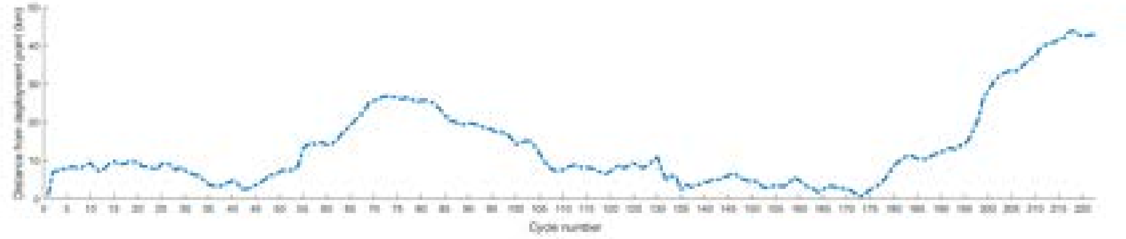


Figure 31. Distance from the deployment location of float WMO 6903263 (per cycle number).

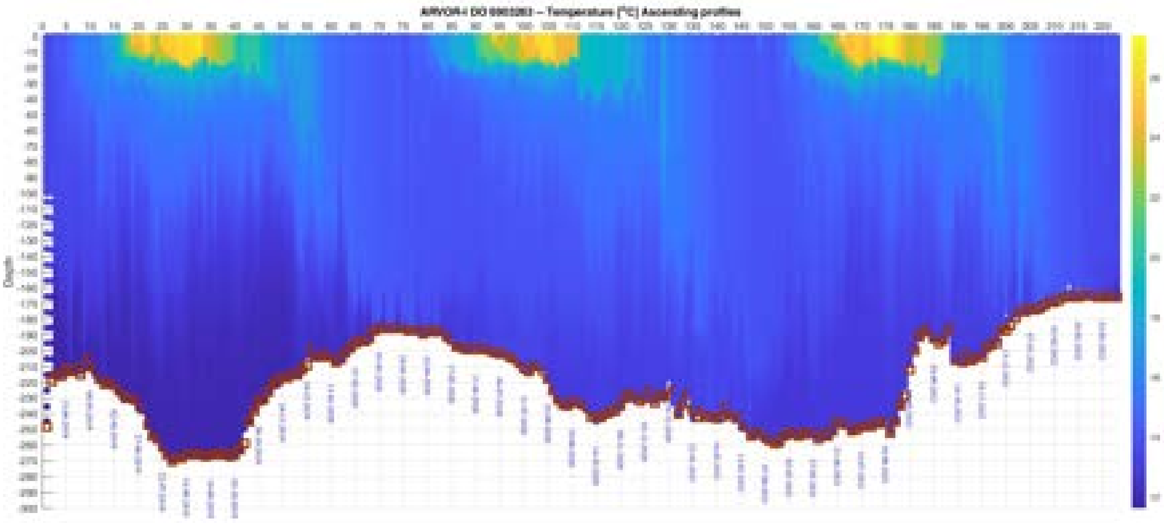


Figure 32. Hovmoller diagram of temperature for float WMO 6903263. Grounding events are highlighted in red boxes.

The float WMO 6903783 was deployed in July 2020 and performed 40 cycles before dying prematurely in February 2021 for reasons that are still unknown. Anyway, **we were able to limit the distance from the deployment location below 15 km** (figure 33), in agreement with the mission target. The float first moved north-westward up to cycle 13 and then south-eastward, at about a constant distance from the coast.

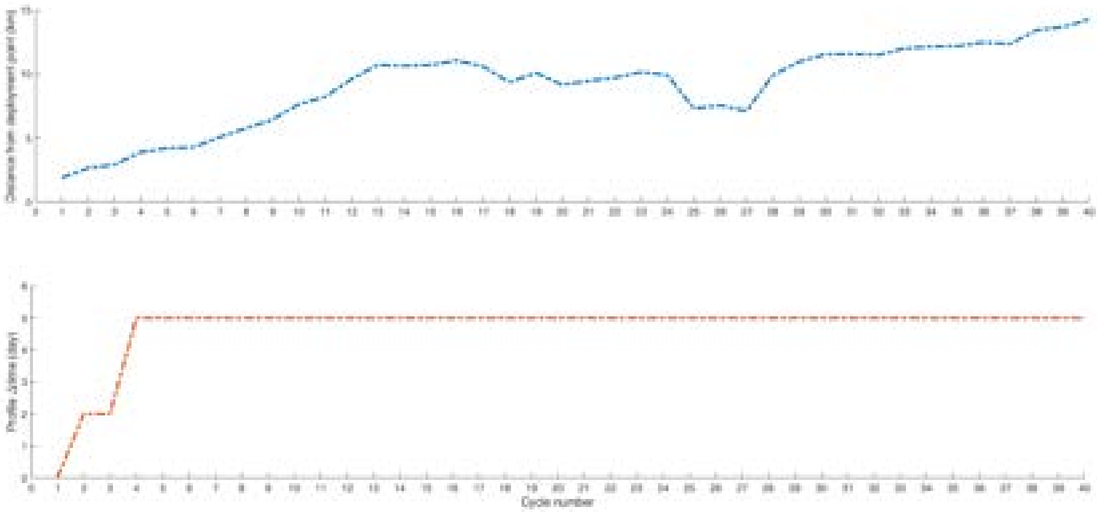


Figure 33. Distance from the deployment location (upper panel) and cycle time (bottom panel) of float WMO 6903263 (per cycle number).

The float WMO 6903800 was launched in May 2021 at approximately the same location as the float WMO 6903783. It performed 33 cycles and then suddenly stopped transmitting (October 2021). The adopted configuration was similar to float 6903783 with the exception of one technical parameter that was better tuned for shallow depth operations (grounding activation level, see table 5). The float performed very well and it collected T/S profiles in a very limited area.

Float WMO 6903815 was deployed in mid March 2022 and it is still too young to provide a description of its mission.

Despite it’s early to define the life expectancy of Argo floats in shallow/coastal areas of the Central-North Adriatic Sea, results are quite satisfactory in particular for the Central Adriatic where the float performance (WMO 6903263) is better than the mean half life of Argo platforms for standard operations in the Mediterranean Sea that is about 700 days and 150 cycles (figure 34). The performances of the two floats deployed in the North Adriatic are well below these numbers and further work is needed to understand if the life expectancy can be improved in this area.

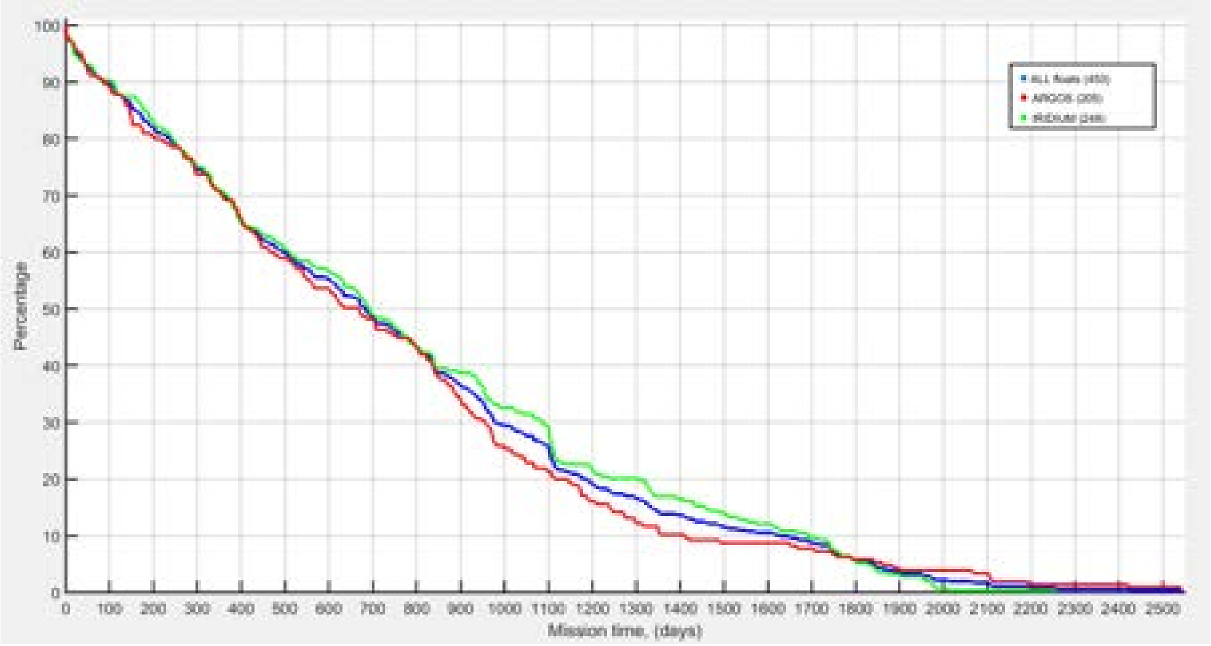


Figure 34. Survival rate diagram of the MedArgo fleet per telemetry system.

The quality control of profiling floats' data in shallow coastal waters as the North Adriatic Sea is complicated due to the high variability of the surface layers (more details in Annex IV). Moreover, the reference dataset which is mandatory to obtain useful statistics, is scarce both in spatial and temporal coverage. For this reason, **it is highly recommended to perform at least a reference CTD cast at the float deployment location and time because, when a CTD cast is available, float salinity can be checked with a higher degree of accuracy.**

The profiles of float WMO 6903783 covered the period between summer 2020 and winter 2021, capturing the seasonal variability typical of temperate climates. Density profile (figure 35, left panel) highlights a clear stratification of the water column during the summer months, and the deepening of the mixed layer during autumn and winter; also temperature profiles (figure 35, central panel) evidence this behaviour. Instead salinity profiles (figure 35, right panel) show different water masses typical of the investigated area characterised by the advection of LIW, NAdDW and fresh water (Cushman-Roisin, 2001).

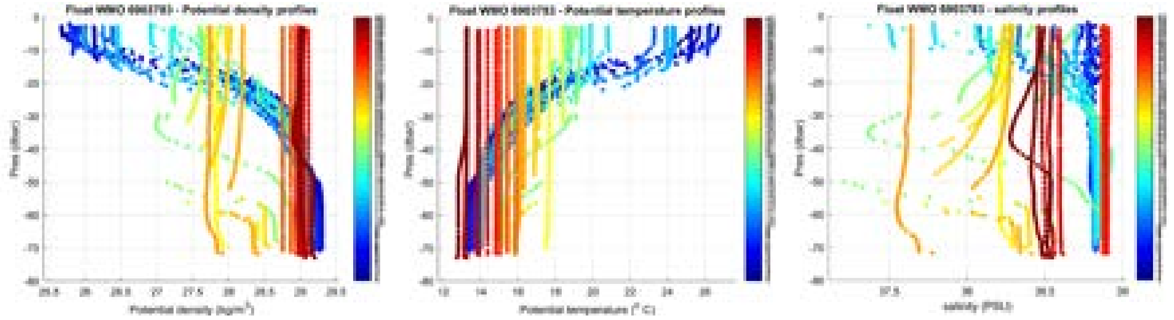


Figure 35. Potential density (left panel), potential temperature (central panel) and salinity (right panel) profiles colour-coded per cycle number for Argo float WMO 6903783.

2.3.3 North Aegean experiment

The 3 floats have acquired in total more than 195 profiles. The float 6903288 (Apex-11) performed 120 profiles in its lifetime between the period 9/2/2020 - 5/10/2020. The other two floats (6903297 and 69032988 Arvor -I) are still operational and have performed 65 and 59 profiles accordingly until June 2022. During their missions, all floats performed profiles that in their vast majority extended down to the sea bottom covering in such a way the whole water column of the monitored areas (figures 36, 2.3.3B). The grounding events recorded exceeded 75% of the total cycles for the cases of 6903297 and 6903298 floats (Figures 36, 37). For the 6903288 float, which had been configured to park and profile from the same depth (800 m), only 20% of grounding events were recorded due to the large depths of the monitored area (Figure 38). Nevertheless, **in all cases the grounding did not seem to have considerably affected the floats' performance**.

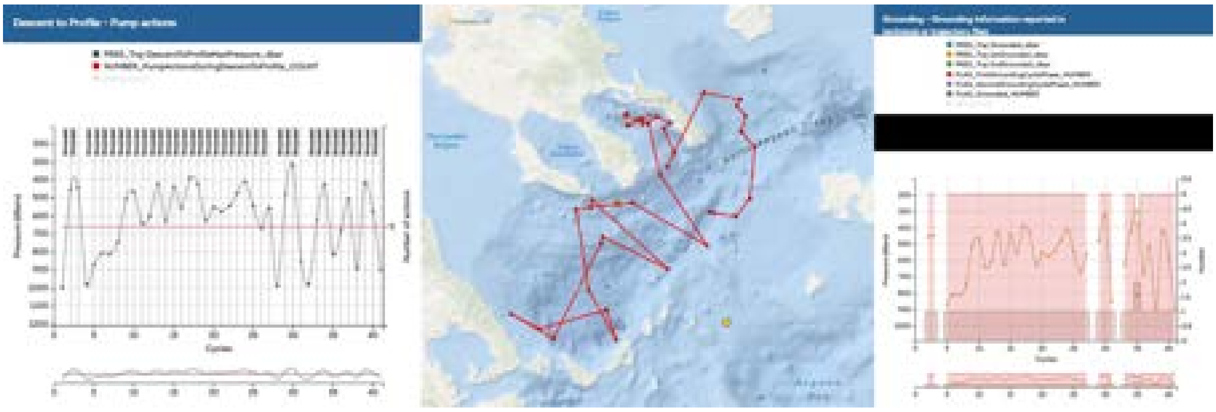


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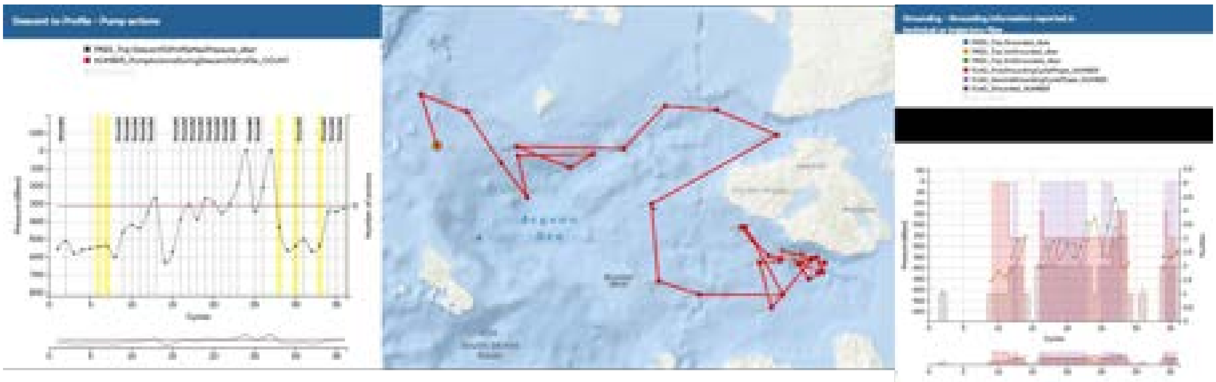
Figure 36. Information regarding pump actions, trajectory, and grounding events of the 6903297 float during the first 6 months of its operation. (https://fleetmonitoring.euro-argo.eu/float/6903297).



[redacted]

Figure 37. Information regarding pump actions, trajectory, and grounding events of the 6903298 float during the first 6 months of its operation. (https://fleetmonitoring.euro-argo.eu/float/6903298).

Figure 38. Information regarding pump actions, trajectory, and grounding events of the 6903288 float for the whole lifetime of its operation. (https://fleetmonitoring.euro-argo.eu/float/6903288).

An overall preliminary assessment of the coastal missions in the North Aegean shows that under alternative configurations, floats can survive for considerable long periods and provide a larger number of profiles in comparison to standard missions. More specifically, taking into account all missions in the North Aegean from January 2014 until May 2022, we observe that coastal missions have already provided almost 50% more profiles than the standard missions in the area (table 8).

Table 8. Statistical metrics regarding the standard vs the coastal missions in the North Aegean for the period January 2014 - May 2022.

Float group	Float Ids	Total cycles	Missing cycles	Valid cycles	Missing cycles (%)	Valid cycles (%)	Average missing cycles per float	Average valid cycles per float
Standard mission	6901884 6901888 6901890 6903275 6903279 6903283 6903285	494	178	306	38.48	61.94	25.4	43.7
Coastal mission	6903288 6903297 6903298	188	1	186	0.53	98.93	0.3	62

With regard to the data quality, the profile datasets have passed the automatic quality control procedure and this first data assessment process has shown that the vast percentage of recorded values (> 98 %) have successfully passed the automatic pre-defined tests and were flagged as “good”. Furthermore, missing cycles associated with several factors such as transmission failures, malfunction of communication systems, etc., have been significantly reduced. This fact is probably related to the different float models used for the coastal missions.

The North Aegean missions, although still in the preliminary phase, have also revealed several interesting oceanographic features. Such are the strong variable spatial distribution of thermohaline properties across the coastline and the association of LSW presence with DWF events. A depicted inhomogeneous salinity distribution of the upper-layers seems to determine the observed thermohaline differences in the bottom layers of the different coastal sub-basins of the North Aegean. On the contrary, BSW seems to be restricted with the exception of the central part of the basin. However, this was the only case of available profiles in the spring-summer period when the BSW presence is intensified (Kassis & Korres 2021). The absence of BSW signals north of Limnos Isl. during February-March 2020 is another interesting feature in relation to previous studies that describe a strong BSW-LSW front across the northeast of the island in winter that is transferred southeast of the island in the summer due to the Etesian winds (Zervakis & Georgopoulos, 2002). According to the data analyses in this work, in the two areas where LSW dominates, deep waters masses seem to have been recently produced from convention events (north of Limnos trench, figure 39), or DWF will be most probably triggered due to the preconditioning status and the intense winter surface cooling (south of Lesvos plateau). The latter has been identified as an area where convention events were favoured due to the deep homogenization observed during 2015-2017 (Kassis & Korres 2021). Regarding circulation, the existence of mainly cyclonic mesoscale systems at the bottom layers of the targeted areas can be noted (figure 39).

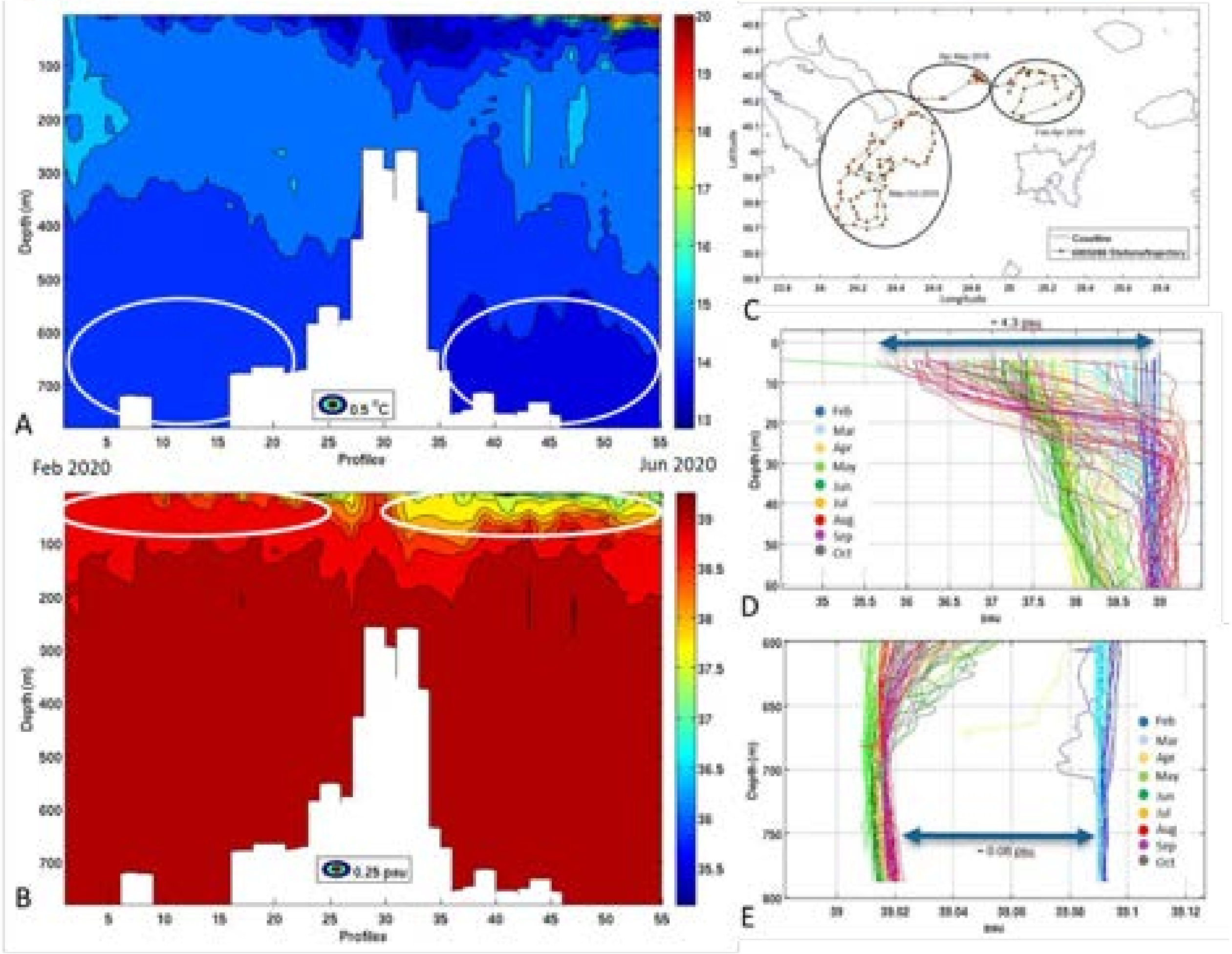


Figure 39. Hovmöller diagrams of Temperature (A) and Salinity (B) profiles, recorded by the 6903288 float during the first 6 months of its operation. In panel C the 6903288 float's trajectory is presented. Salinity variability in upper (D) and deep (E) layers as shown by the 6903288 total profile dataset.

2.3.4 Ligurian experiment

The deployment of the Euro-Argo RISE float occurred at the outer edge of the marginal zone, however influenced by the regional circulation. Following its deployment, the float crossed about 140 km in the sector south-south west at an average speed of 3km/day. It drifted in the cyclonic edge of the geostrophic current until the 19th January 2020. At the entrance of the Gulf of Lions shelf, the float was stopped and detained from the current until 10 March 2020, recirculating there under the retention of meandering activity at this point. Then the float went on sampling the cyclonic circulation along the shelf break until 22 March 2020. It definitely escaped from the current at the meridian 5°30'E, and remained offshore in the central area of the northwestern Mediterranean basin (figure 40). Fortunately, the float has not drifted away from the MOOSE spatial extension (that covers the basin north 40°N), so the collected dataset in the central area still deserves this marine observatory with a full annual cycle.

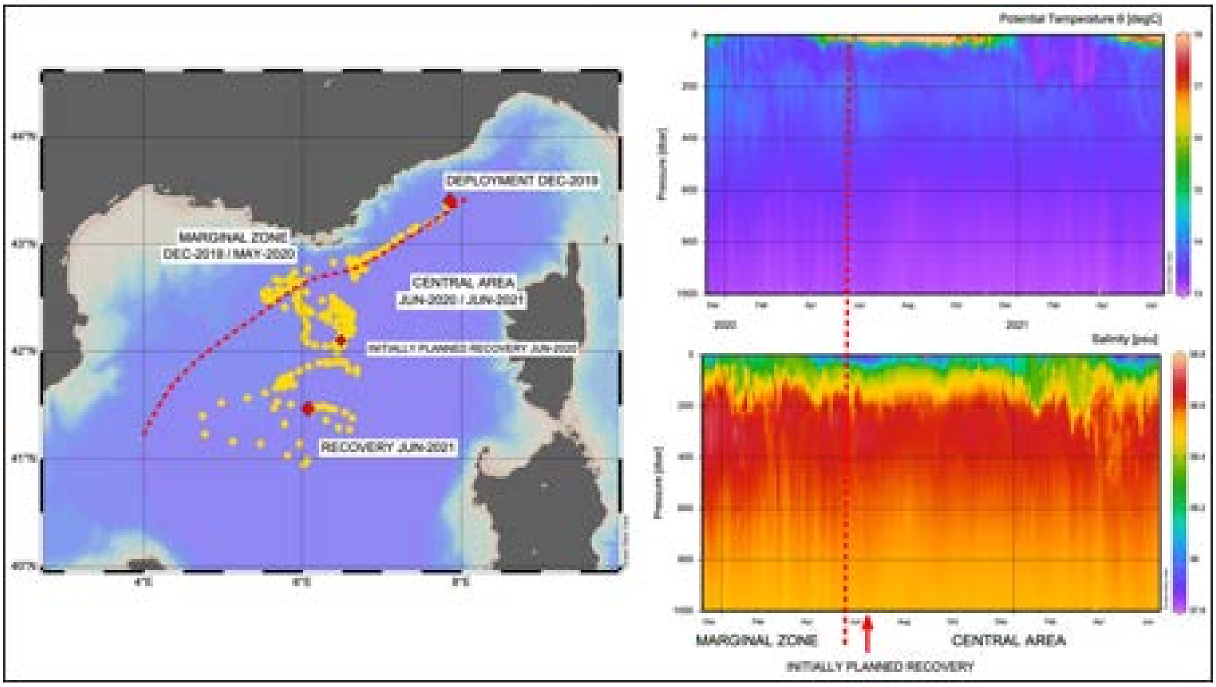


Figure 40. Left: spatial distribution of the collected profiles. Right: time series of temperature and salinity during the mission. The interface between the marginal zone and the central area is indicated in red dotted lines. The initially planned recovery is also indicated in the figures.

The float has worked correctly all along its mission; the collected data monitored regularly with the Euro-Argo fleet monitoring tool did not exhibit any anomalous gap or any sensor's dysfunction. A more accurate examination of the metrological state of the autonomous CTD sensor (SBE41) could be achieved thanks to reference profiles collected some hours/some km from their deployment and their recovery (194 cycles 2.5 years after). Its initial calibration appeared accurate with reference to intermediate water properties and transition to deep water properties. Calibration drift could be estimated lower than 0.01 in salinity, which is the nominal accuracy of such sensor (figure 80 in Annex IV).

2.4 Discussion – Conclusions

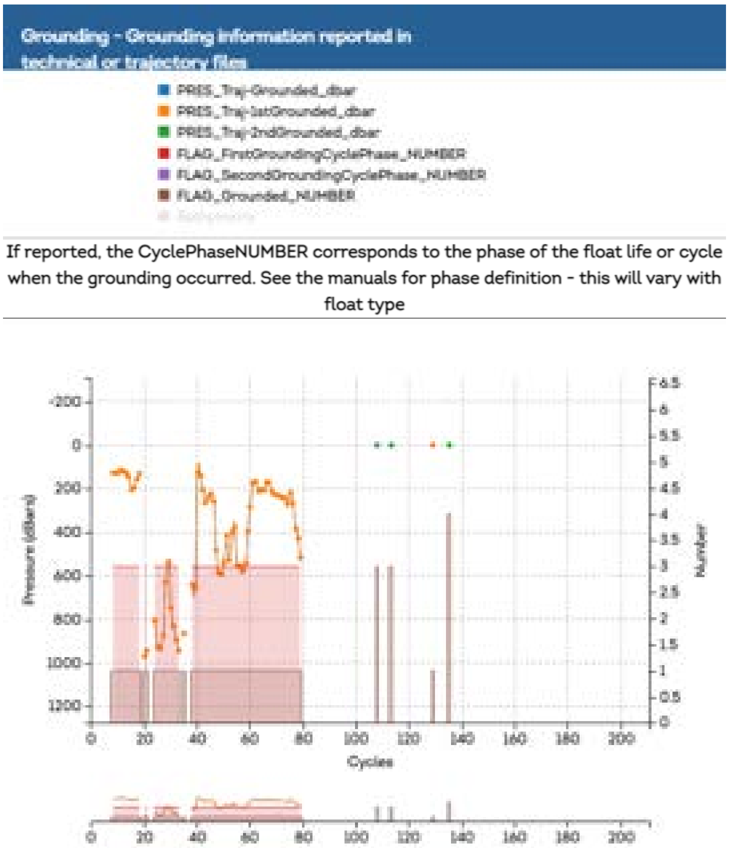
2.4.1 Balearic experiment

Experimental (WMO 6901278) and operational (WMO 6904065) results were promising to go further and keep on exploring shallow coastal waters with Argo floats. There was the risk that the floats would beach on the coast, but in both cases, the floats (WMO 6901278 and WMO 6904065) drifted with the Balearic Current over the Balearic continental shelf. However, in this area, keeping the float close to the deployment area is complicated due to the Balearic Current. Maybe a more southerly deployment would perhaps have ensured that the float stayed in the slope current for longer.

Apparently, a good strategy to keep the float in a more restricted area, could be to deploy the float in the Balearic continental shelf, south of the previous launch point or in the Menorca Channel. These areas are shallow waters, and they are further away from the Balearic Current, at the north of the islands.

To choose the best platform configuration, at the first mission cycles, it is suggested a short cycle time of about 24-48 hours to check the float drift. However, the Balearic Sea is a high vessel route density area, and this increases the risk of collisions between floats and vessels. For this reason, in the rest of the mission, it is suggested to use a longer cycle time to avoid too frequent surfacing times. Also, the experiments in the Balearic continental shelf, showed that **to obtain truly the longest duration in a shallow water region a long cycle time (perhaps even 96-120 hours) and a park and profile pressure on the bottom is preferable.**

Oceanographic forecasts, identifying the currents at different depths in order to predict the drift of the float, are essential to predict and test mission parameters to keep the float in the area. In addition, good bathymetric maps are fundamental to know the bottom geomorphology in order to select the parameters. **Virtual mooring configurations were a good technical solution to avoid long drifts**, even in an area with a Boundary Current. For this, it is chosen a park pressure and a profile pressure at the sea bottom or at a dynamically low level, to ground the float at depth (figure 41) and to limit the time spent drifting when currents are strong.



Grounding - Grounding information reported in technical or trajectory files

If reported, the CyclePhaseNUMBER corresponds to the phase of the float life or cycle when the grounding occurred. See the manuals for phase definition - this will vary with float type

Figure 41. Grounding periods (red) while the WMO 6901278 float was drifting over shallow waters.

The catching of the floats by ships/nets sometimes happened. For this issue, it will be interesting to use EMODnet maps to identify heavy marine traffic areas (figure 42). In addition, there is a strong case for developing alert systems to take into consideration the distance from the shore (possible stranding) and to identify when floats go far away from the targeted bathymetry.

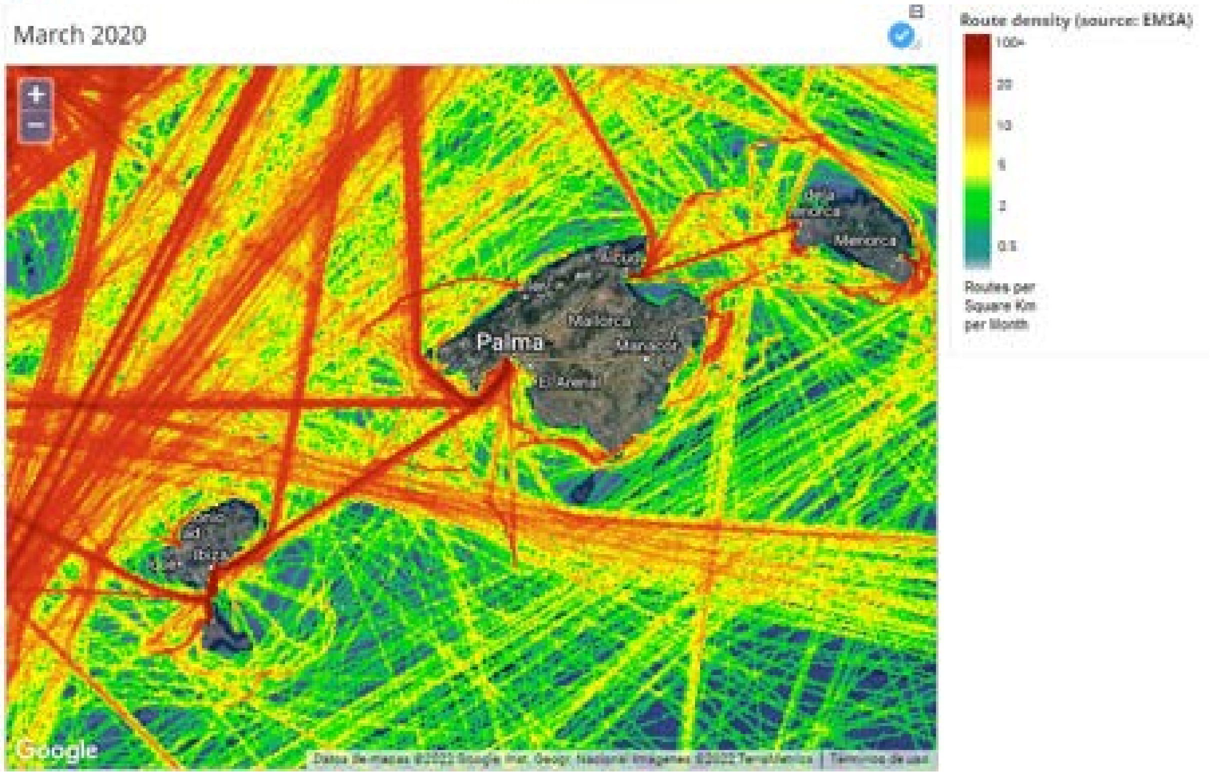


Figure 42. Maritime route density during the WMO 6901278 float deployment (source: https://www.emodnet-humanactivities.eu/view-data.php).

2.4.2 North Adriatic experiment

Floats' missions in the Central and North Adriatic went quite well from the technical and management point of view. Operations gave promising results to go further and keep on exploring this shallow coastal area with Argo floats. **Repeating groundings seemed to have no impact on the float performance and to not cause any particular problem to the Argo platform** (more on this in Euro-Argo RISE deliverable 2.6 of Arduini Plaisant et al., 2021). As originally planned, **displacements from the deployment locations were strongly limited thanks to the adopted configurations**. This allowed us to keep the platforms within the targeted area, on the shallow shelf of the north Adriatic Sea (and within the depression of the Middle Adriatic Sea) and at a quite constant distance from the coastline. Unfortunately, the floats WMO 6903783 and 6903800 stopped transmitting prematurely and the cause is still unknown.

The best strategy for a successful mission in the Central and North Adriatic Sea should be to perform the deployments relatively far from the coast (35 nm) in order to reduce the potential risk of being picked up by fisherman. Moreover, legal aspects linked to territorial water and EEZ have to be taken into account in case bi-lateral or joint missions (mainly between Italy and Croatia) are not considered. **Float operations should be conducted far away from the main circulation patterns of the region in order the float can stay in the targeted area** for the duration of the mission (or as long as possible) and the odds of strandings are limited. Float operators can rely on circulation tools available on the Euro-Argo monitoring tool and https://resources.marine.copernicus.eu/product-detail/MEDSEA_ANALYSISFORECAST_PHY_006_013/INFORMATION to have an estimate of the 3D current field at the float location. **It should be also considered doing the deployments in concert with**

other monitoring activities to enhance synergies with other observational networks and to cross check sensors at field.

In terms of platform configuration, it is suggested that **a short cycle time of about 24-48 hours is used at the beginning of the mission** to check the float displacement and the general behaviour of the platform. **Then, the cycle time can be extended to 120 hours (5 days)**. **Virtual mooring configurations seem to be a good technical solution to keep the float in the targeted area** and hence the park pressure is chosen at the sea bottom or at a dynamically low level. The grounding mode is set accordingly, and it can be a "stay grounded" or a "shift upward" (GroundingModePresAdjustment) configuration. The maximal profiling depth is usually chosen as deep as possible. A specific technical parameter for the grounding activation level (CONFIG_GroundingModeMinPresThreshold_dbar) has to be tuned according to the bathymetry. Another technical parameter that needs to be adjusted is the pressure target tolerance for stabilisation that in case of 70 metres depth was set to 20 dbar.

A large set of monitoring tools provided by Euro-Argo and Ocean-OPS is used in addition to other in-house developed tools and systems. In-house developed tools to quickly decode Argo data of a specific float and have notifications in near real time were generated. This is needed to have important information such as platform location, bathymetry and distance from the deployment location. Moreover, model current data from CMEMS to estimate float trajectory are fundamental tools to achieve the best mission performance.

A preliminary quality control of the float salinity data was performed. Despite the reference dataset used is scarce, the analysis reveals that there is quite a good agreement with the Argo data in the deepest layers of the water column. However, the at field calibration is difficult to achieve due to the high natural variability and the expected accuracy for the Argo salinity could be in the range of 0.05-0.1. It is important to collect a CTD reference profile at the float's deployment location/time to check at least the first float profile is good.

2.4.3 North Aegean experiment

The coastal Argo missions in the North Aegean have been so far successful in terms of floats' performance. It is shown that, under specially designed configuration settings, Argo floats can sample in targeted coastal sub-basins of regional seas like the Aegean for considerably long periods. However, these promising results are still preliminary and more case studies should be undertaken in order to conclude in the best strategy for an effective and sustainable coastal operational monitoring.

The future strategy float operators should follow includes several aspects such as the choice of the deployment location, the float's configuration settings, and the tools to monitor floats' performance. With regard to the former, as shown from the North Aegean experience, **the targeted areas should preferably be distinct, in terms of bathymetry, sub-basins in which floats may remain "trapped" for several weeks or months**. Such areas could be either deeper than the surrounding area, plateaus, or extended trenches, which are common in the North Aegean. **It is important nevertheless for the float operator to take into account, apart from the scientific interest certain areas have, other factors such as the upper and intermediate circulation, the shipping and fishing activity, and the feasibility of recovery missions when needed**.

The choice of the best configuration set is closely interconnected with the targeted area. The missions in the North Aegean have shown so far that **deep park pressures (close to the bottom) act favourably**

for the missions, since the floats do not easily drift away or beach. Additionally, **short cycles serve an increased sampling density which is important for two main reasons: a) capability to capture higher frequency features that evolve in shorter, than the open ocean, spatio-temporal scales, and b) capacity for the operator to monitor the mission more frequently, timely diagnose possible risks for the mission, and act with corrective actions**.

For the floats' monitoring, the central tool developed by Euro-Argo has been proven very efficient and helpful. However, custom tools should also be encouraged to be developed and tested by local operators. Such tools could focus on the special characteristics of each mission and add further useful information for the operator which could be: a) forecasts of the local circulation and wave fields, b) shipping and fishing activity, c) high resolution bathymetry, d) float's distance from the coast. Specific recommendations on the monitoring tools have been highlighted under the Euro-Argo RISE project through the joint work of WP6 and WP2 partners. The outcomes are assessed, presented, and summarised in the two associated Euro-Argo RISE deliverables (Euro-Argo RISE deliverables D2.1 and D6.1 in Cancouët et al., 2021 and Notarstefano et al., 2021b, respectively).

For future missions in areas like the North Aegean the operators should investigate the possibilities of performing synergetic deployments both in terms of synergies with other platforms, but also of joint deployments with other institutes, and/or countries. The former results in better monitoring and, thus, better assessment and exploitation of Argo data. The latter increases the cooperation, and the capability of float recoveries whilst, enhances the Argo network and gives an added value to Argo contribution in regional scale.

2.4.4 Ligurian experiment

To address the objective of the Euro-Argo RISE project work package, the Ligurian Sea offered an interesting test bed of a narrow and dynamic marginal zone adjacent to the open sea. The actual design of the Argo program intrinsically covers this kind of area, however, with a strong focus in open sea sampling rather than in marginal zones. This is mostly due to coarser cycling frequency (usually 5-10 days) and reduced residence times (drifting depth of 350m in the Med Sea), which are not adapted for the characterization of underlying mechanisms in the marginal zone. The proposed cycling characteristics of the Euro-Argo RISE float (higher cycle time, higher park pressure) enhanced the sampling strategy of the marginal zone, with about half year time series at mesoscale resolution collected in the Ligurian Current. So a yearly-based multi-mission strategy was proposed in order to reproduce such observational coverage, which requires float recovery to be sustainable. Unfortunately, the sanitary crisis limited this effort to a single mission, and stressed how demanding can be in-situ observation even with autonomous platforms.

As a matter of fact, such a sampling configuration requires recurrent sea operations, which increases allocated efforts in terms of time and infrastructure. The MOOSE observation network played a crucial role to make this experimentation feasible and possible. Endorsed with such a regional observing system, operations benefited for recurrent field surveys, with observation sites monthly visited for float deployment and large-scale oceanographic cruises annually achieved for float recovery. The quality of the collected data also benefited from MOOSE, with metrological verifications of the float's autonomous sensors at deployment (pre-mission calibrations) and at recovery (post-mission calibrations).

The fleet monitoring tool developed by Euro-Argo has been efficient to follow the progress of the mission, with user-friendly visualisations of (i) the float pathway overlayed to maps, SST images, flow simulations, (ii) the float health and behaviour in the water column, (iii) the dataset collected by the float autonomous sensors. As a suggestion to improve this tool, feedback to users (in the form of alerts) could be set up in terms of predefined criteria in order to get cycling characteristics more adaptive, e.g. changing frequency when the float enters or exits the marginal zone.

3 Final results of Argo float operations in the Black Sea

3.1 Introduction

The Black Sea is one of the biggest semi enclosed sea basins on the Earth and has several specific features. It receives drainage from almost one-third of the continental Europe which includes 17 countries with about 160 million inhabitants. It is relatively isolated from the world ocean and has a limited exchange with the Mediterranean Sea through the Bosporus-Dardanelles Straits System. The fresh Black Sea water and salty water of Mediterranean origin inputs generate extremely strong vertical stratification, which prevents ventilation of the deepest part of the basin causing anoxia in the deep Black Sea (Palazov et al, 2019). The Black Sea surface circulation is mainly cyclonic and is controlled by the wind forcing, bottom topography and baroclinicity of the waters (Tuzhilkin, 2007), with a persistent coastal circuit, defined as the Rim Current. Its main bathymetric feature is the presence of a narrow shelf (generally less than 20 km) and steep topographic slope (generally less than 30 km) around 2,000 m deep interior basin (Oguz, 2017). The shelf occupies a large area (25% of the total) in the north-western part of the Black Sea where it is over 200 km wide, and has a depth ranging from 0 to 160 m (Shapiro, 2009). The width of the western shelf gradually reduces toward south and finally terminates to the east of the Bosphorus Strait region. Although the deep Black Sea is well sampled by Argo floats, the north-western shelf part of the Black Sea is not visited by the Argo floats because of its shallow depth and the specifics of sea currents (figure 43).

For this reason, the activities in the Black Sea were aimed at assessing the possibilities for using Argo floats in the north-western part of the basin and at shallow depths of 100-200 m. This layer is also of the greatest scientific interest, as the vertical circulation of water in the Black Sea is a relatively slow process due to stratification in the basin, the inflow of fresh water from many flowing rivers and the inflow of saltier Mediterranean waters through the Bosphorus strait. In addition, the Black Sea is highly eutrophicated and the main biogeochemical processes take place in the surface layer and below about 200 m there is an oxygen-free zone with a high concentration of hydrogen sulphide and lack of life except for anaerobic bacteria.

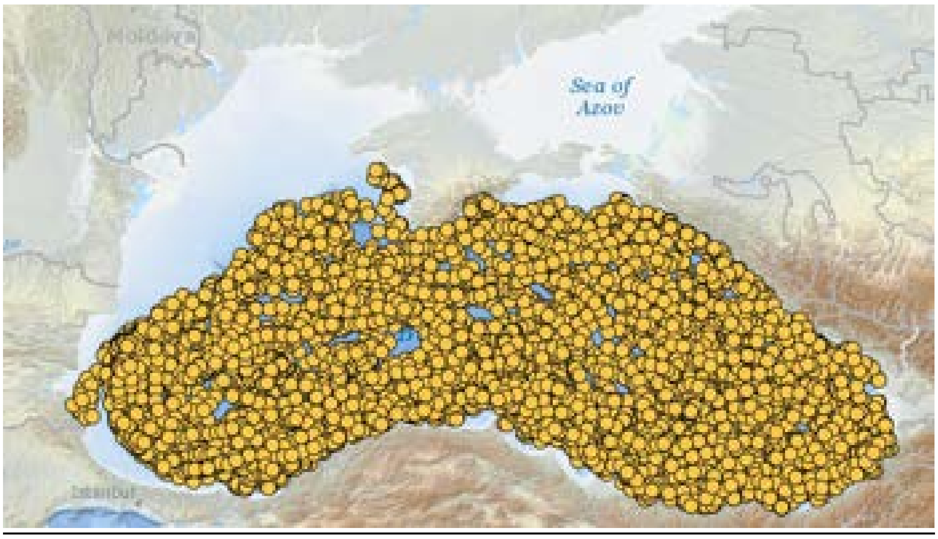


Figure 43. *Locations of all Argo profiles collected in Black Sea (source: https://dataselection.euro-argo.eu/).* Few/no profiles in the shallow north-western shelf (light blue area in the figure).

3.2 Methodology

Two types of experiments were conducted in the north-western shelf of the Black Sea (table 9 and figures 44 and 46) and this was the first time of Argo deployments in this shallow area. Both the floats were used with a virtual mooring configuration but the technical approach was completely different: one float (WMO 6903271) was deployed near the shelf break off the Danube River delta and a park pressure configuration at the sea bottom was adopted; the other float (WMO 6903865) was anchored and attached to a fishing rope on the western shelf off the Bulgarian coast at 50 m depth.

Float 6903271 has been providing excellent temperature and salinity profiles for about 15 months along the north and western shelf before moving to the open sea. Specific technical and mission parameters were used (see section 3.2.1) and tuned (see table 21 in Annex III) to achieve the target of maintaining the float over the Black Sea shelf (see description in section 3.3.1). Moreover, an intense interaction with the platform was needed to adjust the configuration according to the mission's objective. The Euro-Argo and Ocean-OPS monitoring tools together with some in-house developed tools were intensely used to have real time information of the platform behaviour and to plan any adjustment of the configuration.

The float WMO 6903865 was moored (fixed) in the Bulgarian Black Sea shelf at 50 m depth using fishing cord attached to the anchor from one side and to the float from the other side to prevent its movement to the offshore areas. Numerical simulations were applied in order to design the Argo float mooring systems. 3 types of mooring line and sea current profiles were considered (see Euro-Argo RISE deliverable D6.3 in Palazov et al., 2021). Before deployment the float was tested and configured in the IO-BAS laboratory. After the deployment, the float uncounted difficulty to dive and ascend in the water column compared to normal. For some cycles the float was not able to ascend and reach the surface which affected its regular transmissions. Most of the CTD profiles were with low quality. No valid GPS position could be determined which caused a serious problem for monitoring of the float and its recovery.

Table 9. Summary of Argo missions in targeted areas close to the coast in the Black Sea.

WMO	Deployment Date/Time	Deployment location	Area	Total Cycles	Date of Last Cycle	Status
6903271	1/10/2019	44.54 N 30.97 E	northwestern shelf	335	6 May 2022	Active
6903865	24/07/2020	42.98 N 28.23 E	western shelf	94	15 Nov 2020	Inactive

3.2.1 North-western experiment

Float WMO 6903271 was deployed the 1st of October 2019 (figure 44) in the northwestern shelf of the Black Sea, about 60 nm off the Danube River delta, by the Romanian R/V Mare Nigrum thanks to a joint collaboration between Italy, Bulgaria and Romania. A virtual mooring configuration was used to limit the drift from the deployment location. A CTD cast was performed at the deployment location. The float was deployed towards the shelf break and quite far from the coast to avoid the high marine traffic present in the area. The mission objective was to perform Argo profiles in shallow water of the north-western shelf. To that purpose, the platform was initially configured with a park pressure at the sea bottom and a "stay grounded" modality. **Several mission and technical parameters were used and adjusted (see table 21 in Annex III) to achieve the target of this Argo operation**. In particular, **mission parameters like the cycle time, park pressure, grounding modality and technical parameters like the electrovalve action duration on surface, pressure target tolerance for stabilisation, second threshold buoyancy reduction, ascent end pressure were carefully tuned** and adjusted many times, in agreement with the strategy plan.

As described in Palazov et al. (2021) deliverable D6.3, Black Sea operations required an intense monitoring activity that can be linked up to the cycle time when the float is in proximity of costalines shelf breaks, high dynamic areas and out of targets. In particular, the Euro-Argo fleet monitoring tool used in conjunction with the Black Sea horizontal velocity information (available on CMEMS and as additional option on the Euro-Argo tool, see example in figure 3.2.1B) were used routinely to check the float status, its technical information and to have a picture of the currents' speed and direction in the area of the float location. The in-house developed tool to perform a quick SBD Argo data decoding was a precious and fundamental source of information since we had to interact with the platform on a short time frame, in particular during the first 6-7 months of the mission. Indeed, the float WMO 6903271 configuration was adjusted many times to keep the float on the Black Sea shelf, that is quite a dynamic area and hence difficulties arise while performing this kind of mission with autonomous platforms like Argo floats. The cycle time values used in this mission and distance from the deployment location are reported in figure 45.

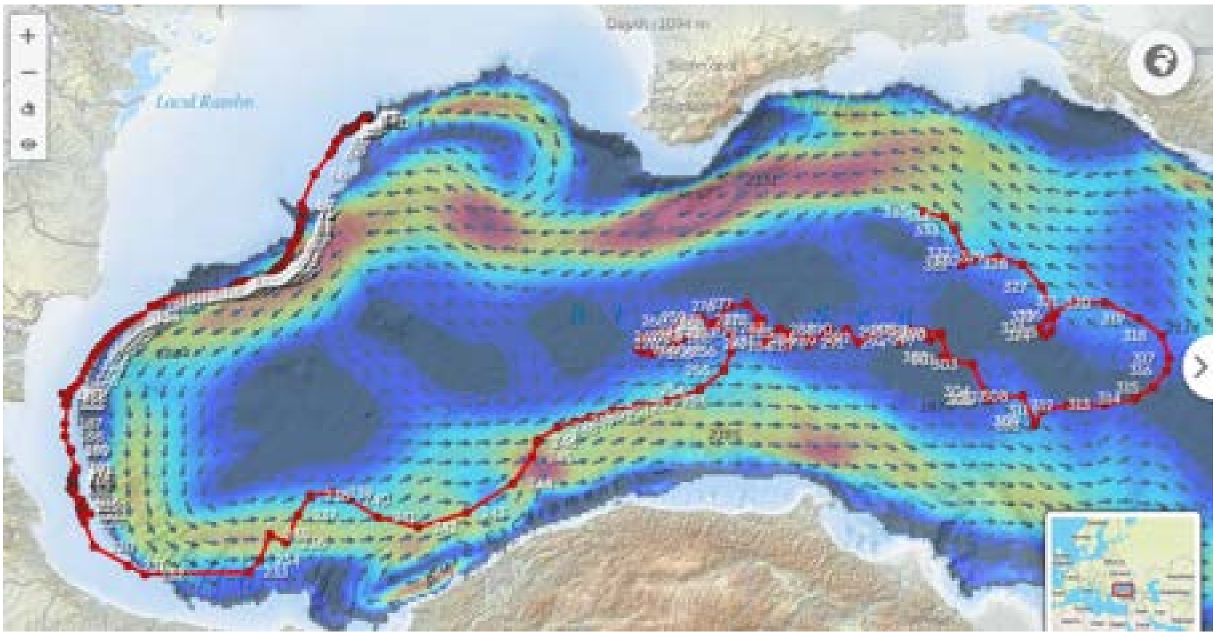


Figure 44. Black Sea horizontal velocity at selected depth: additional CMEMS layer available on https://fleetmonitoring.euro-argo.eu/. Trajectory (and cycles' locations) of float WMO 6903271 are superimposed.

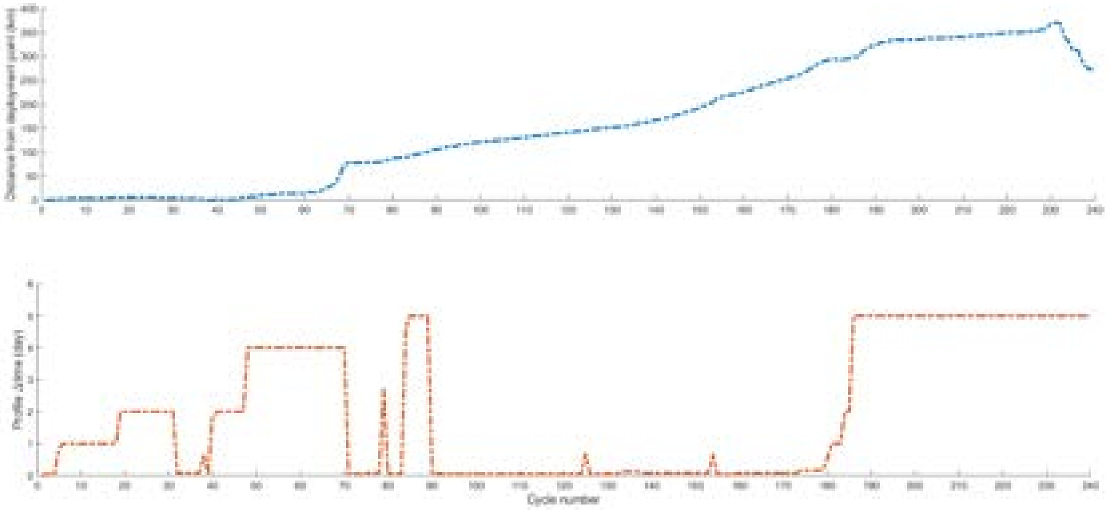


Figure 45. Distance from the deployment location (upper panel) and cycle time(lower panel) for float WMO 6903271.

A CTD cast was done at the Argo float deployment location to check the behaviour of float sensors.

3.2.2 Western experiment

Float WMO 6903865 was deployed on 24th of July 2020 off the Bulgarian Black Sea shelf at 50 m depth in front of the mouth of the largest Bulgarian river Kamchia (figure 46). The mission objective was to fix the float using a fishing line attached to the anchor to allow collection of CTD profiles in shallow waters never visited before by Argo floats. The length and the diameter of the fishing line attached to the float and anchor were 100 m and 2 mm, respectively. Its density was 1150 kg/m3 and the calculated weight of the water is 42,4 gr. The platform was configured to drift at 40 metres depth and to profile to 50 m. The mission cycle was set up to 24 hours. The adopted configuration at the beginning of the mission was slightly tuned after a few cycles in order to better correspond to the mooring depth (see table 10).

Table 10. Summary of mission commands changed during the shallow waters mission for float WMO 6903865 (Arvor model).

Platform	**initial specific parameters**	**06/08/2020**
MISSION COMMANDS FOR WMO6903865	CONFIG_CycleTime_hours (hours) 24	
	Drift Sampling Period (hours) 19	Drift Sampling Period (hours) 1
	CONFIG_ParkPressure_dbar (dbar) 40	
	CONFIG_ProfilePressure_dbar (dbar) 50	
	surface slice thickness (dbar) 1	
	Intermediate slice thickness (dbar) 10	Intermediate slice thickness (dbar) 1
	CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 0	CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 1
	bottom slice thickness (dbar) 25	bottom slice thickness (dbar) 1
	CTD Sensor Cut-Off pressure (dbar) 5	CTD Sensor Cut-Off pressure (dbar) 2.5
INTENTIONS	Initial setup	tuning the configuration for shallow water mooring
OUTCOMES	float worked as intended	ok

Figure 46. Locations of float WMO 6903865. Last position is depicted as a red dot. Profiles' numbers are indicated.

The Euro-Argo tool was used to monitor the transmission delayed (see example in figure 47 and deliverable D6.3 in Palazov et al., 2021 for details).

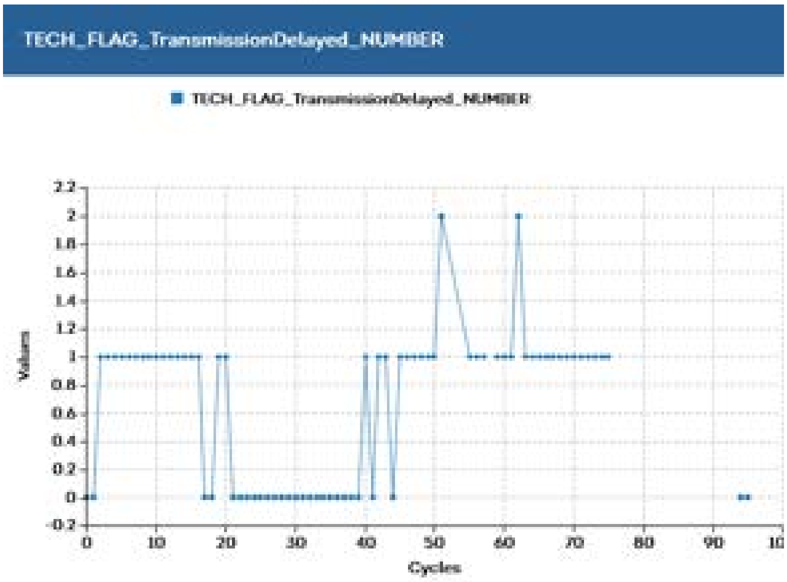


Figure 47. Transmission delayed of Euro-Argo RISE Argo float WMO 6903865 (source https://fleetmonitoring.euro-argo.eu/float/6903865).

In Deliverable 6.3 we considered several possible reasons for the float's abnormal behaviour. Since the float was not recovered, possible technical problems in communication and mooring could not be checked, and we decided to check whether the float has sufficient buoyancy to overcome the hydrodynamic forces occurring during the mooring.

According to the ARVOR-I float user manual (ARVOR-I user manual), the maximum positive displacement of the float is 900 ml. To verify this, we conducted a field experiment by activating an ARVOR-I float and deploying it in seawater in the harbour area (figure 48). We gradually added lead weights to a net attached to the lower end of the float, starting with 50g. and watched the float sink until the float sank to the top of the antenna (figure 49). The float sank to the top of the antenna with 300 g. extra load.

Figure 48. Test deployment.

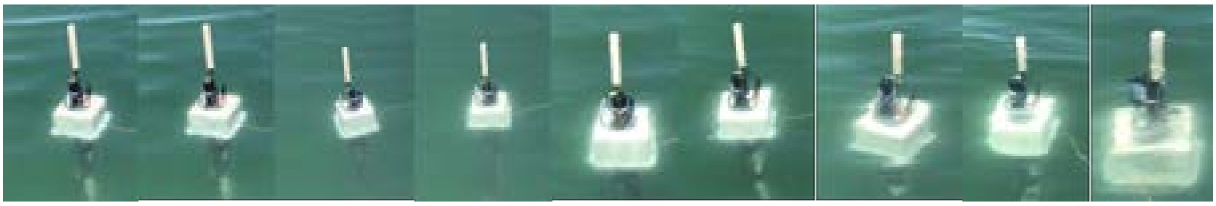


Figure 49. Sinking of the float at different load.

Additional calculations were done to evaluate the needed float buoyancy for selected mooring conditions. The float system was simulated under current conditions with low frequency regular waves instead of still water. Hydrodynamic analysis application AQWA-Line was applied for float performance estimation. In order to reflect the influence of buoyancy force on the float dynamics three different values are adopted in the analysis. Buoyancy forces were 0.0, 0.3, 0.6 and 1 Kg. (called case 1 case 2 case3 and case 4 respectively) while environment conditions were kept similar. Velocity profile was described according to table 11. Time domain simulations of about 30 minutes each for all cases were performed. The following load effects: current load and wave drift damping, were applied to predict float response. The environmental load effects included current and long regular waves.

Figure 50 shows numerical predicted results of Case 4. It can be seen that the buoyancy force is big enough to keep the body floating at the free surface.

Table 11. Current velocity characteristics used by simulated cases.

Water depth [m]	**0**	**12**	**27**	**50**
Case 1 Velocity[m/s]	0.3	0.15	0.1	0
Case 2 Velocity[m/s]	0.5	0.25	0.15	0
Case 3 Velocity[m/s]	0.7	0.3	0.2	0

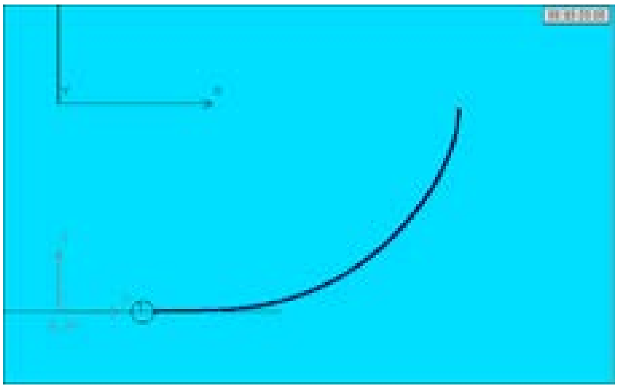


Figure 50. Quasi-steady state of moored buoy by Case 4.

Numerical time domain coupled prediction method for the motion response of moored float with variable buoyancy force was constructed. In the time domain analysis, using a float and mooring line dynamics the effect of buoyancy force of the float quasi-steady position has been conducted. Based on the simulations results are presented in figure 51.

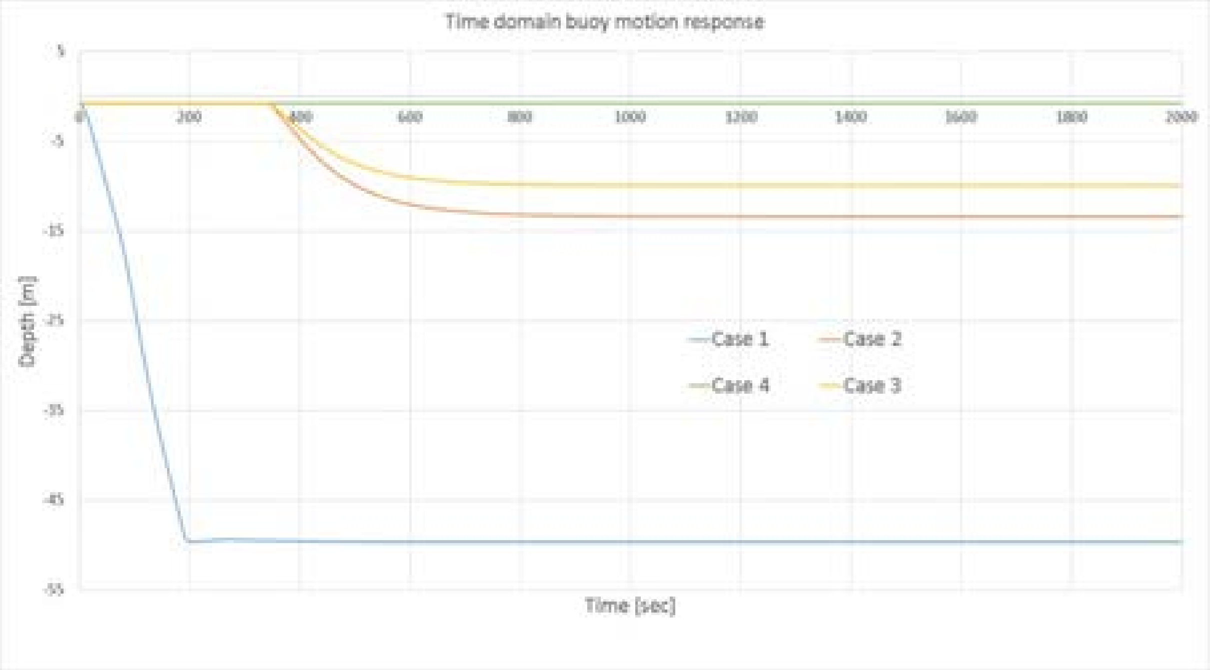


Figure 51. Float vertical position time series for 4 cases.

According to figure 51 it can be drawn that the buoyancy force below 1 kg is not big enough to keep the device floating. The reason for this tendency is that drag force generated by interaction - mooring line – water flow is bigger than buoyancy.

The buoyancy force appreciably impacts vertical position and respectively the possibility of the float to emerge for data transmissions. When the buoyancy force is smaller than 1 kg the buoy stays fully submerged at different depths because drag forces exceed it.

3.3 Results

3.3.1 North-western experiment

The initial platform configuration was set in order to have the cycle time at 24 hours to check the float behaviour, and it was then extended to 48 hours the 15th of October 2019 (cycle 17). Float started to drift southward in November 2019, hence cycle time and park pressure were shortened with the result that the platform drifted westward thanks to a different current field. After the float reached approximately the deployment location (cycle 46, in figure 52), the cycle time was set to 96 hours and the park pressure at the sea bottom. The repeated contacts with the sea bed are highlighted in figure 55, where it is also shown the maximal profiling depth.

Figure 52. Trajectory of float WMO 6903271 from cycle 1 to about 70.

The float reached the shelf break and crossed a canyon at the end of February 2020 (cycle 70). We tried to let the float be captured by the surface current and moved to the west (cycle time was set to 1 hour) but this did not happen. Hence, we gradually extended the cycle time to 120 hours and parked the float at the bottom of this shelf break area (beginning of March 2020). At the beginning of April 2020 (cycle 89), the analysis of the sea water currents near the surface revealed that we could have done an attempt to "drive" the float westward towards the shelf (target area of this mission). The aim was to perform very short cycles (1 or 2 hours) near the surface layer with a park pressure of 10 dbar. The float is not designed for such kind of missions, nevertheless, a discussion with the NKE manufacturer allowed us to tune specific technical parameters and to push the Argo technology towards its limits. In particular, each electrovalve action duration at surface was reduce (500 csec); we informed the float earlier about the descending phase (4 dbar); we reduce the tolerance for stabilisation (4 dbar) and modified the end pressure to favour the ascent phase (2 dbar). The last two commands were not received or used by the float but it worked as it was planned and the platform eventually reached the western shelf in mid April 2020 when the settings were re-adjusted to standard values (cycle 185). The float passage from the shelf to the open sea and its return to the shelf is well depicted in figure 53.

Figure 53. Trajectory of float WMO 6903271 from about cycle 70 to 150.

We managed to keep the float of the shelf until mid December 2020 when it eventually reached the open sea (figure 54, 55 and 56). The configuration was then changed (cycle 234) according to the typical Black Sea settings (main parameters' values are reported in table 21 in Annex III). The float WMO 6903271 is still active at the moment of writing and it performed 335 cycles as of May 2022.

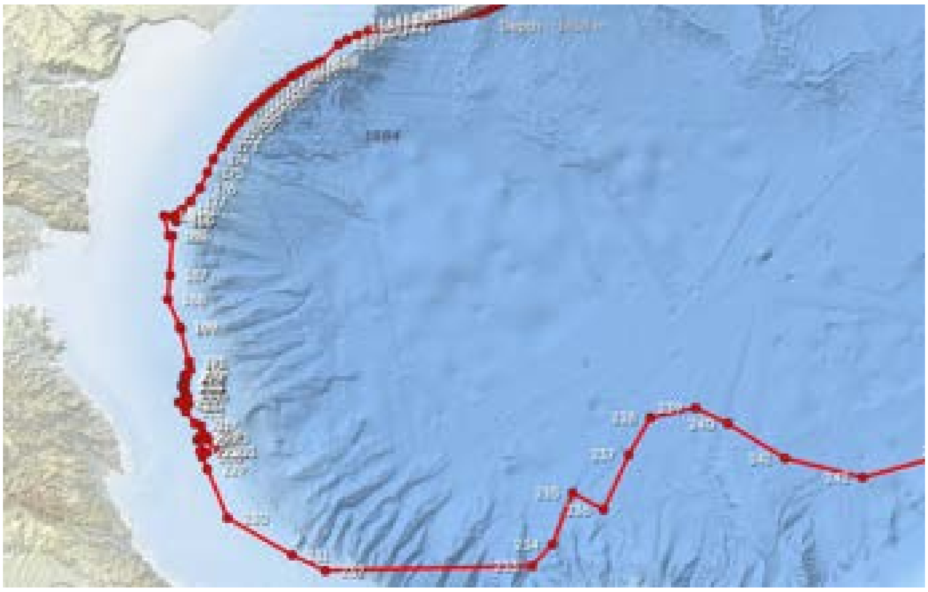


Figure 54. Trajectory of float WMO 6903271 from cycle 150 to about 240.

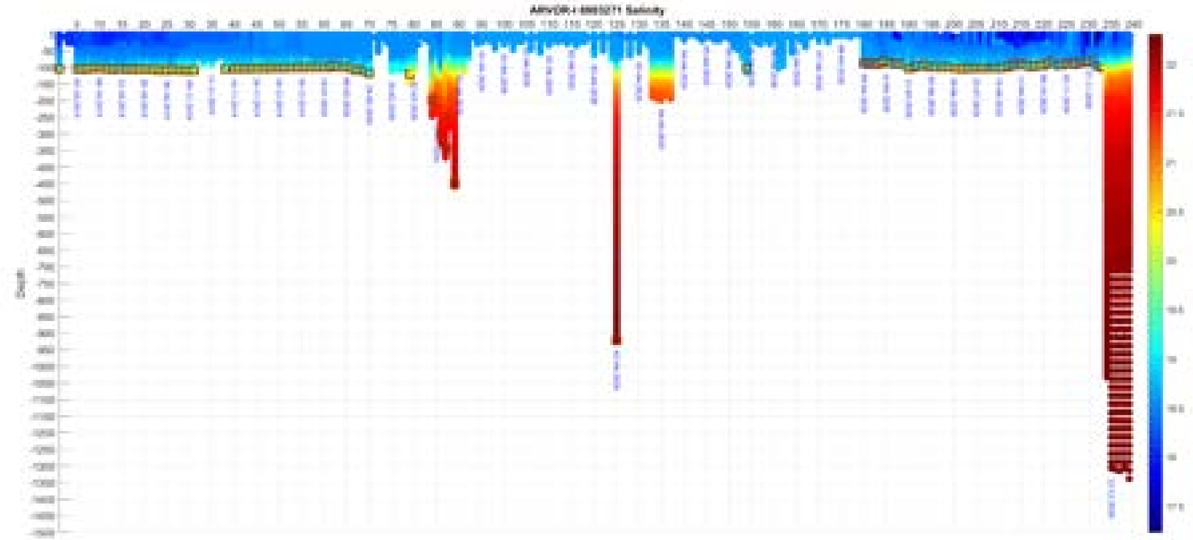


Figure 55. Hovmoller diagram of salinity for float WMO 6903271. Grounding events are shown as red boxes.

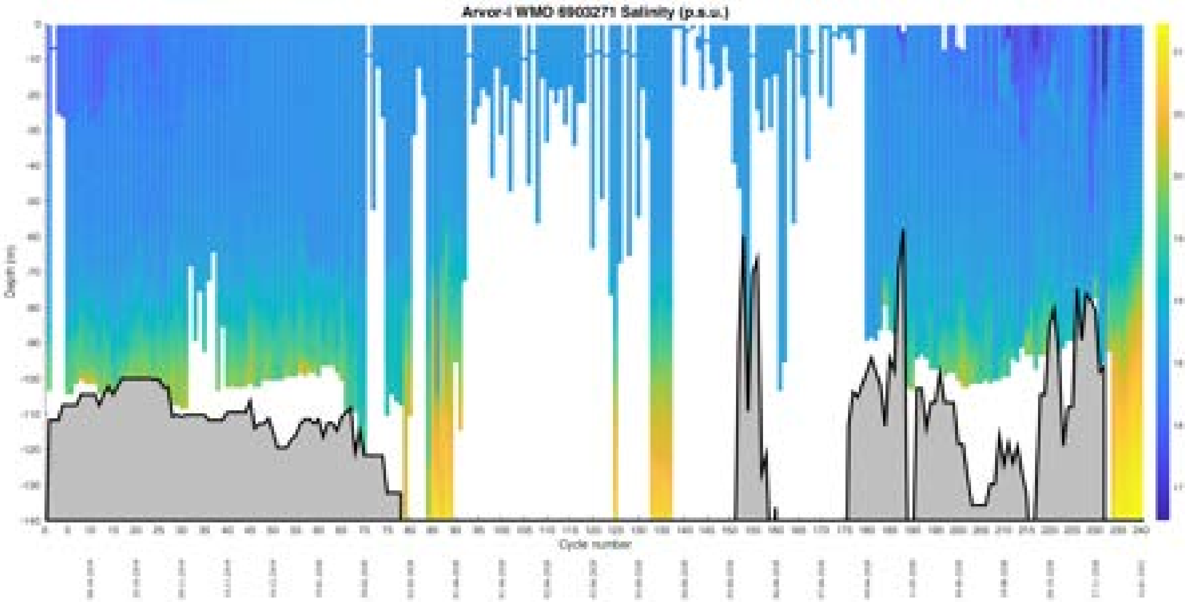


Figure 56. Hovmoller diagram of salinity for float WMO 6903271 in the first 140 metres. Sea bottom is shown in grey.

Despite the mission was difficult and the human-interaction intensive from the technical point of view, we managed to perform the Argo mission for about 15 months on the northwestern shelf of the Black Sea and to collect 230 profiles. **This should be the first time that an Argo float monitored this shelf area in its entire dimension**.

A comparison between the Argo float and the reference data shows a good agreement and no potential salinity offset/drift was observed. Hence, the salinity data of float WMO 6903271 is accurate (more in Annex IV).

3.3.2 Western experiment

After the deployment, the float uncounted difficulty to dive and ascend in the water column compared to normal. For some cycles the float was not able to ascend and reach the surface (Figure 57) which affected its regular transmissions. Most of the CTD profiles consist of only a few measurements (Fig. 58). The pressure offset correction of the float was 12 dbar for some cycles between cycles 3 and 20 (Figure 59). No valid GPS position could be determined which caused a serious problem for monitoring of the float.

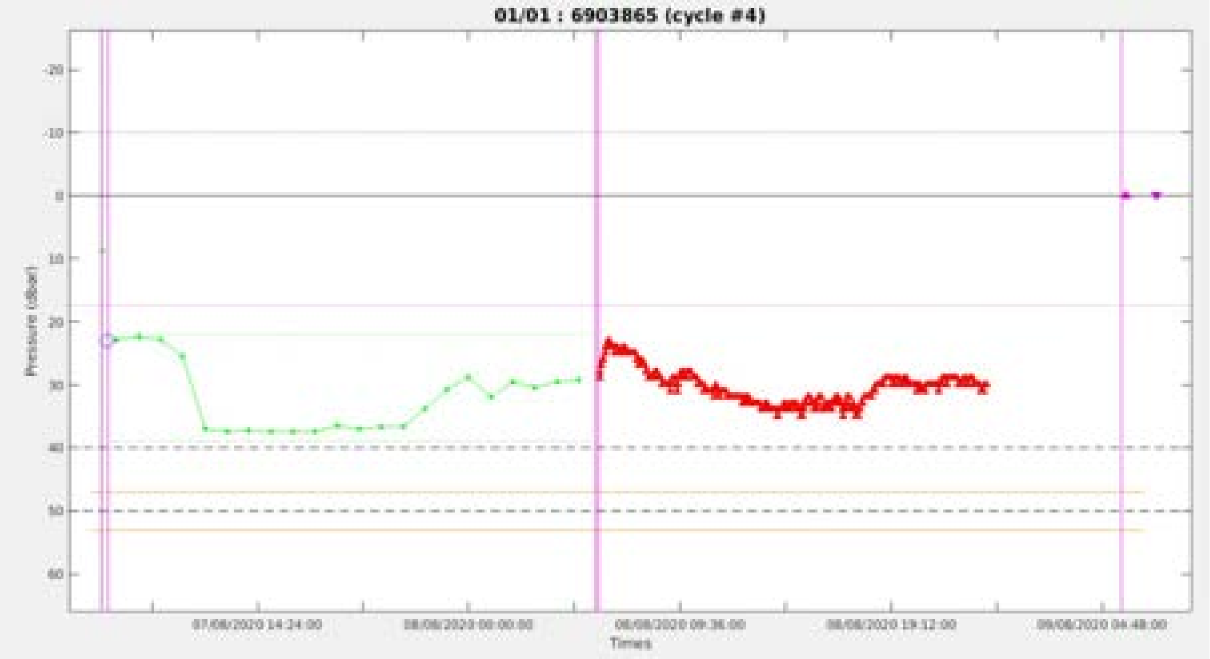


Figure 57. Underwater trajectory (time versus pressure figure) of the float WMO 6903865 for cycle 4. Coriolis DAC (Argo decoder nc_cycle_trace_times) Pump actions are depicted in red, suggesting the float had difficulties to ascend since its pressure did not decrease much.

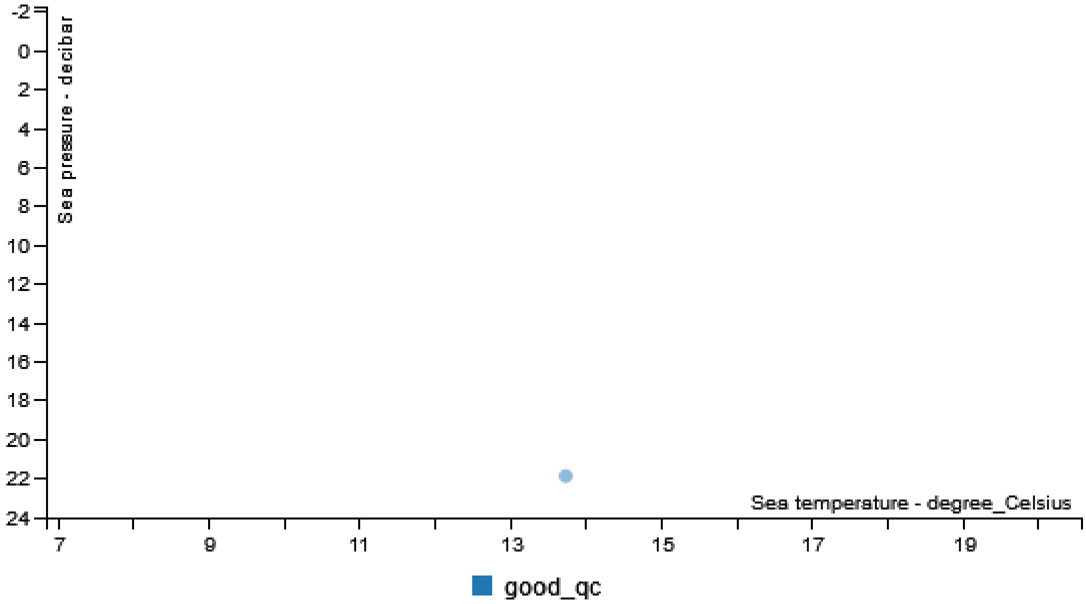


Figure 58. Temperature profile of the float WMO 6903865 for cycle 5 (https://fleetmonitoring.euro-argo.eu/float/6903865).

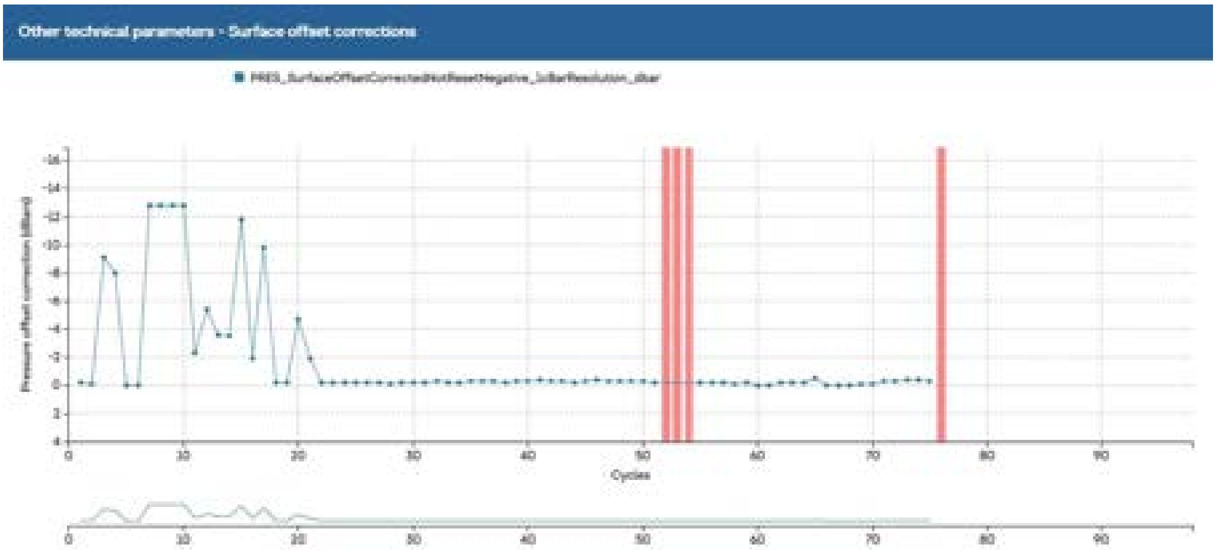


Figure 59. Pressure offset correction (https://fleetmonitoring.euro-argo.eu/float/6903865).

Calculated float position shows that after the 20th profile (24/08/2020) the float starts to drift and leave mooring position (figure 60).

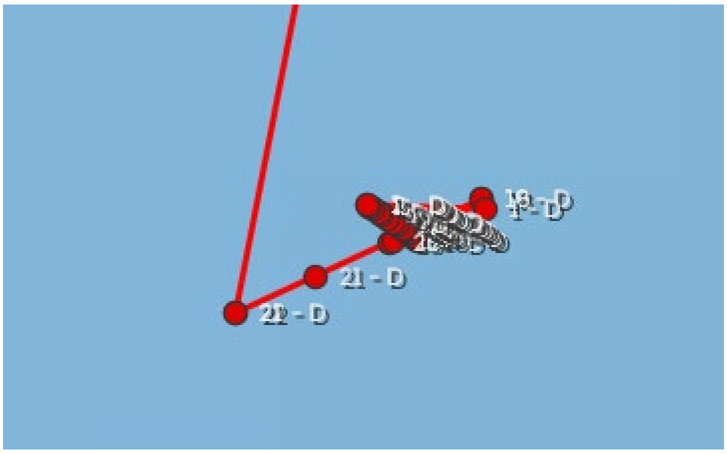


Figure 60. Float position around the mooring point location.

The last received message from the float WMO 6903865 was on 15th November. Its last IRIDIUM position was in the area close to Bağırkanlı Limanı port in Turkey. Regardless of the IO-BAS team's efforts to recover the float we couldn't discover it. Unreliable GPS data of the position of the float did not allow us to attempt to recover it.

The data collected by the float WMO 6903865 shows typical for the western part of the Black Sea waters temperature profiles. Profiles within 20-30 metres depth are from the mooring point and the deeper profiles up to 70 metres are from the drifting period of the float (figure 61).

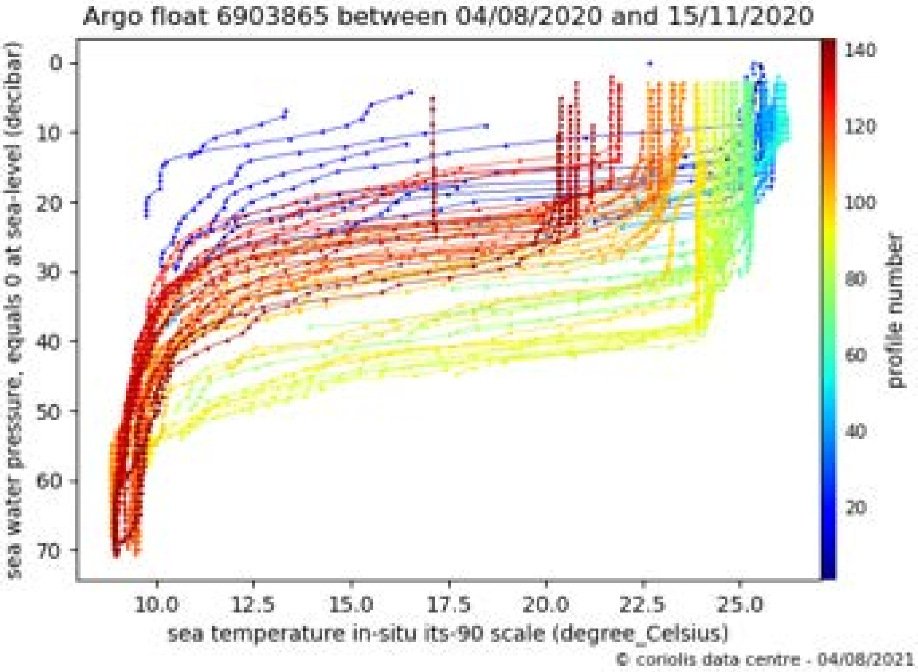


Figure 61. Float profiles between 04.08.2020 and 15.11.2020.

3.4 Discussion – Conclusions

3.4.1 North-western experiment

Operations in the north-western shelf of the Black Sea were challenging but successful. We demonstrated that, despite the high dynamic of the area, it is possible to keep the float on the shelf. **Repeated groundings, platform settings pushed at the edge of what is technically feasible with an Argo float, a large use of monitoring tools and a strong interactivity with the platform were the crucial ingredients to achieve the targets**. According to our experience, it is difficult to limit the float displacement. Nevertheless, the float can be slightly driven to stay in the targeted area, if properly set up.

The choice of the deployment location is a compromise between coast and shelf break. **Deployments should be done not too close to the shelf break in order to avoid the maximal strength of the Rim current but also not too close to the coast since floats could easily beached, been captured by fishermans or been damaged by vessels and boats**. Given the relatively high dynamic of the area, a monitoring activity at cycle time period is suggested with the help of automatic warning systems.

A virtual mooring configuration (with a park pressure at the sea bottom) is preferred to limit the float displacement with a stay grounded modality or a small shift upward (GroundingModePresAdjustment). The cycle time can span between 24-48 hours (mostly to check the float behaviour) and 120 hours. Specific mission and technical parameters might be tuned according to the needs as described in the document.

The monitoring tools provided by Euro-Argo and OceanOPS are highly recommended. Additional tools to have notifications in near real time for platform location, bathymetry and distance from the deployment location are needed. Model current data from CMEMS or other sources are also useful to estimate the float trajectory.

Bulgaria is the only country of the region that deploys floats in the Black Sea but Romania and Turkey are active and keen on collaborating in Argo activities. Hopefully, eastern Black Sea countries (who attended the workshop organised in the framework of the Euro-Argo RISE project) will join Argo in the near future and this will impact on the development and strengthening of the infrastructure with a stronger at field activity and a better float coverage.

3.4.2 Western experiment

From a scientific point of view, the use of Argo floats in a fixed position would give a long series of profiles for the needs of process analysis and improvement of forecasts for the state of the Black Sea. This kind of use of Argo floats is also important for the other specific regions of the world ocean. Kobi Alberto Mosquera Vasquez is planning to use a moored float on the shelf of Peru. Antonio Lourenco is doing a similar experiment in the austral ocean but the results are not published yet.

The experiment with anchoring an Argo float with the help of a fishing line did not give the expected result, but it showed that it is possible. Additional experiments showed that ARVOR-I float do not use its maximum buoyancy during deployment and it is not clear when and how it can be used. **Calculations showed that about one kilo buoyancy will be needed to ensure proper functioning of Argo moored with fishing line in western Black Sea.**

Additional experiments are needed to clarify the mooring technical details or to test different kinds of anchoring and the limits of its applicability. **Consultations with Argo manufacturers concerning**

increasing or maximum use of the float buoyancy will help to evaluate the applicability of this technology.

4 Final results of Argo float operations in the Baltic Sea

4.1 Introduction

The Baltic Sea (figure 62) is a very specific body of water because its contact with the world ocean is very limited. The only inflow of salty oceanic water comes from the North Sea through the narrow and shallow Danish Straits. In addition, the large ratio of the catchment (1 721 000 km^2) to the sea area (393 000 km^2) and the small depth (on average 52 m) make the Baltic Sea one of the largest brackish water reservoirs.

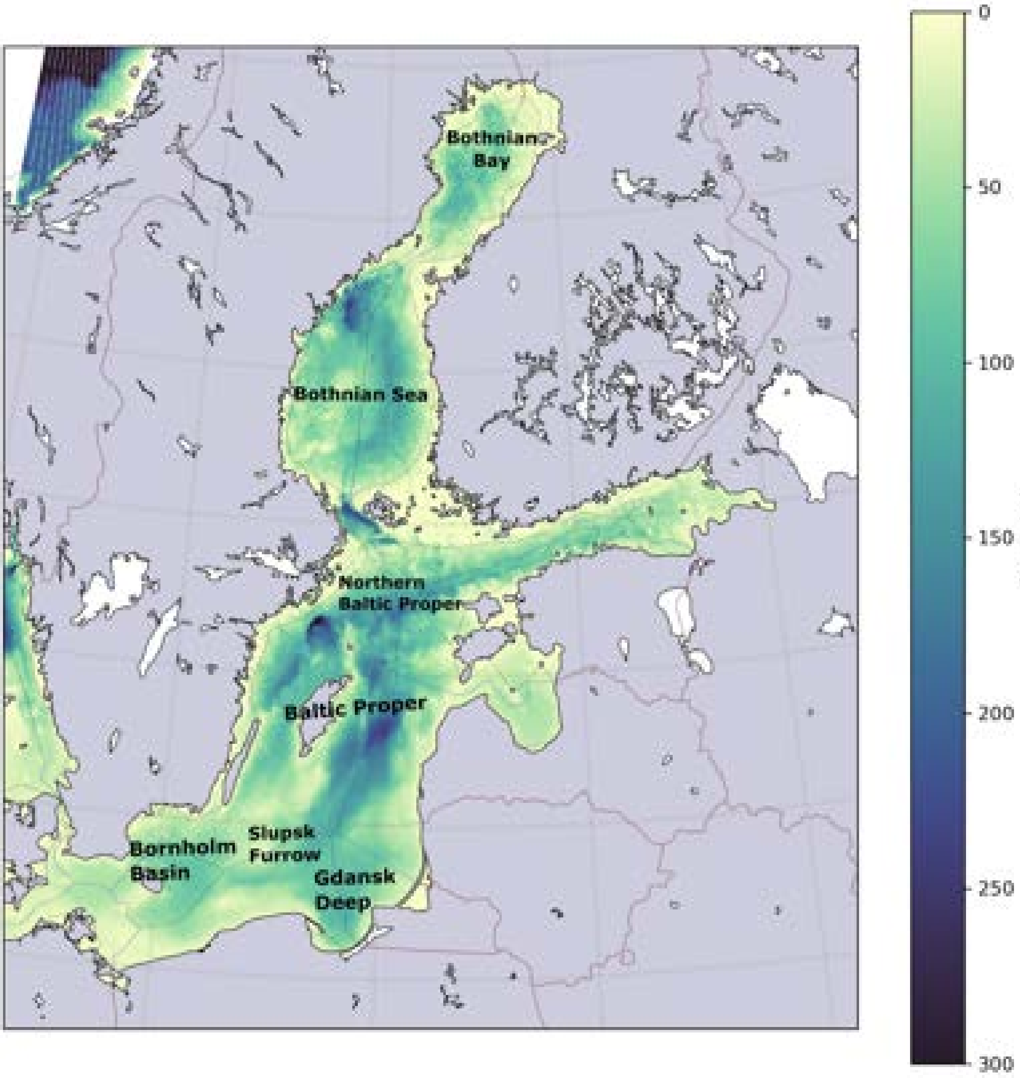


Figure 62. Areas of Argo operations, Exclusive Economic Zone (EEZ) limits and depths of the area.

The inflow of saline water from the North Sea through Danish Straits and the voluminous freshwater input to the Baltic Sea results in strong gradients – both in the horizontal and vertical properties of Baltic water and the high regional variation. For this reason, different regions of the Baltic Sea are distinguished and also the rules of application of Argo differ depending on the body of water in which it is launched.

The whole Baltic Sea is divided in the EEZs of it's neighbouring countries: Bothnian Sea and Bothnian Bay between Sweden and Finland, Gulf of Finland between Finland, Estonia and Russia, and Baltic Proper with Finland, Sweden, Estonia, Latvia, Lithuania, Russia, Poland, Germany and Denmark.

The Polish Exclusive Economic Zone (EEZ) is located in the southern Baltic Sea and includes part of the Bornholm Basin, the Słupsk Furrow, part of the Eastern Gotland Basin and the Gdańsk Basin. Floats launched by the Institute of Oceanology Polish Academy of Sciences (IO PAN) operate in the Baltic Proper region. This region is characterised by a very strong vertical gradient of salinity. This phenomenon causes a strong vertical density gradient not found in the open ocean. This places additional demands on Argo floats. They must have a large volume of the bladder and a specific ballasting to be able to overcome a strong pycnocline. The first APEX floats used by the Institute of Oceanology in 2016 did not meet this condition. They only reached the depth of the pycnocline and were not able to dive deeper. Only the use of NKE Arvor floats solved this problem. These floats were able to overcome the difference in density caused by surface water salinity 7 and deep water salinity 18. To achieve this effect, it was necessary to change the float settings in cooperation with specialists from NKE and Euro Argo ERIC. In the northern part of the Baltic Sea, where the vertical salinity gradient is lower, it is possible to use floats with a smaller bladder volume.

In the northern parts of the Baltic Sea Argo floats have been successfully operated in Bothnian Bay, Bothnian Sea and Baltic Proper, on Gotland Deep area. As a new region, the northern Baltic Proper has been experimented during the Euro-Argo Rise project. In all of these areas, **the challenges come in constraining the floats on the desired area**. In the northern regions, especially in Bothnian Sea and Bothnian Bay the ice avoidance algorithms are a necessity. This is further described in the Euro-Argo RISE deliverable D5.1 by Angel-Benavides et al., 2022. Both APEX and Arvor type floats have been tested, and found functional in these areas, although the balancing of the floats must be set up for each area, as well as the mission parameters. In addition to these, NKE's Provor type of floats have been tested in the Euro-Argo Rise project. Provor floats as well as Apex floats have been also used by Germany, as they started their Argo operations in Baltic Proper, Gotland Deep with total of 7 floats. 2 PROVOR, 4 APEXes were deployed in Feb/March 2021, and one more PROVOR late march 2022.

Early experience with the use of Argo floats in the Baltic Sea has shown that they can be a useful tool for monitoring (Haavisto et al. 2018, Siiriä et al., 2019, Siiriä et al., 2020). It has been estimated that **in order to sufficiently monitor the basic Baltic properties, one float must be placed in each of the deep basins**. However, the specific dynamics of the Baltic Sea, the flows between basins make it difficult to keep the floats in a limited area. This resulted in the floats quickly leaving the Bornholm Basin and flowing through the Slupsk Furrow to the Gdańsk Deep and further north, to the Gotland Basin. In order to maintain floats in the Bornholm Basin and the Gdańsk Deep, it was necessary to recover them out in the Gotland Basin, transport and redeployment in the Bornholm Basin. Therefore, **the Euro-Argo RISE program decided to carry out attempts to reduce the mobility of floats by using the 'bottom mooring' method**.

4.2 Methodology

49 Argo floats in total have been deployed in the Baltic Sea by FMI, IO PAN, and IOW from 2013 to spring 2022 (figure 63). With the Euro-Argo RISE, MOCCA EU project (grant no.

EASME/EMFF/2015/1.2.1.1/SI2.709624) and national contributions, some of these have been dedicated for extending and improving the possibilities of the Argo missions in the area.

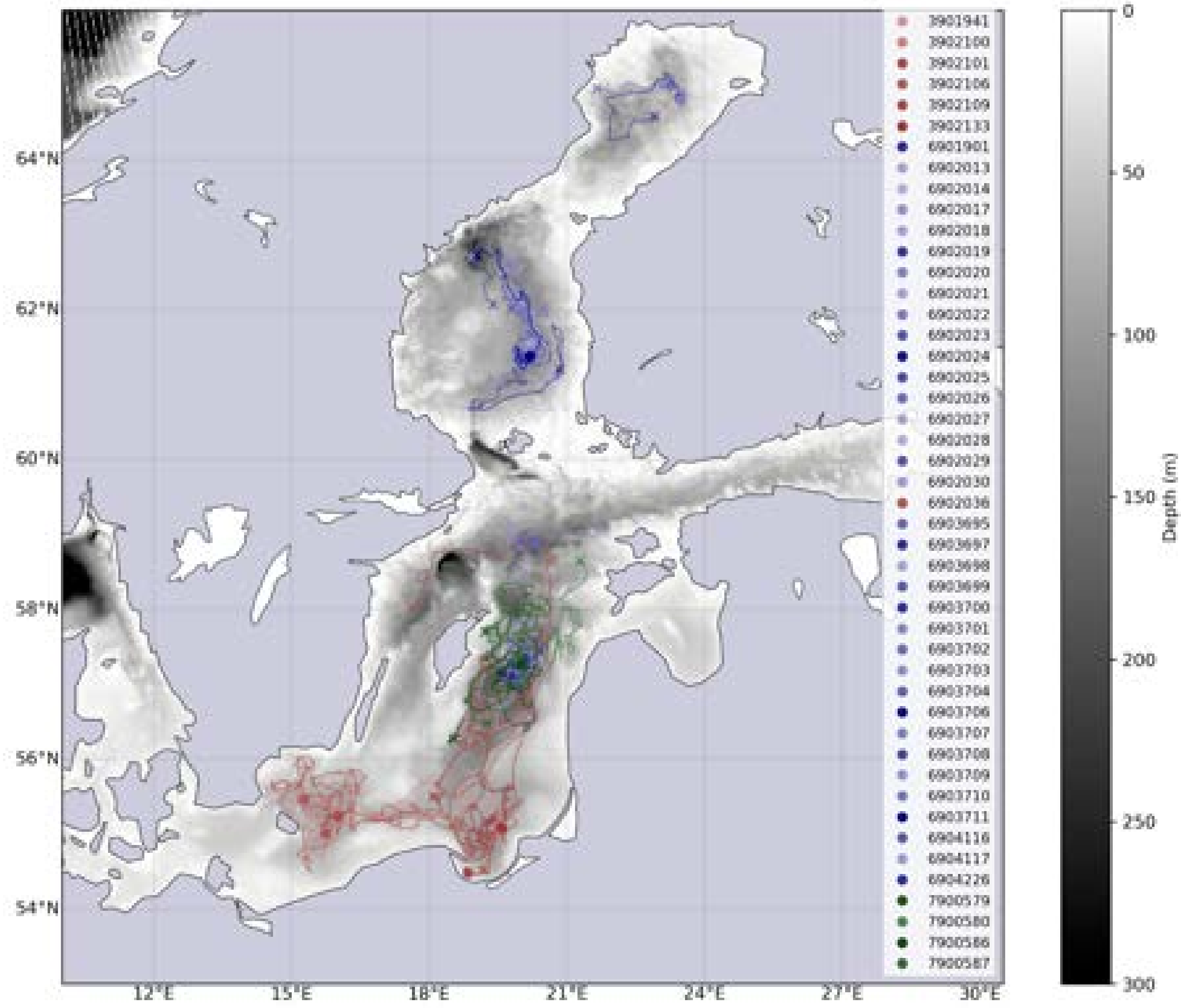


Figure 63. Trajectories and WMO's of Finnish (blue), Polish (red) and German (green) Argo missions. Dots show deployment points and x the location of the last profile.

4.2.1 Central and Northern Baltic experiment

FMI has deployed Argo floats in four different areas in the Baltic Sea: Bothnian Bay, Bothnian Sea, Northern Baltic Proper and Gotland Deep, in Baltic Proper (figure 63). Of these, Bothnian Sea was the first area of operation, originally picked for its rather large deeper area and reasonable currents. Later on the operations were extended to the Gotland Deep, as its bathymetry allowed it to keep the float relatively stationary. Bothnian Bay was a further extension as a shallow, but confined area. **The Euro-Argo Rise project made it possible to further experiment with the deployments. The Northern Baltic Proper area was chosen, as it has a deeper area of roughly 170 metres, which can be used to confine the float**.

The initial setup for both floats is shown on table 12. The profiling and park pressures are set identical in Baltic missions, as the whole area is shallow, and **the park pressure is kept near the bottom. The deployment was made on short cycle time in order to react and adjust the parameters quickly**, and once the floats started to perform as preferred, the adjustments were minimal. All changes on parameters are listed in table 13 **The approach in initial changes was to first make sure the float won't hit the bottom, and the cycle time is short enough that the changes can be made. If the float stays on expected depth, the park pressure can be adjusted to closer match the depth of the desired area**.

Table 12. Key initial values of the Northern Baltic Proper floats. Note, that as Arvor and APEX have different software, the actual names of the parameters vary. Ice detection on APEX is initially turned off. For the Arvor floats the ice parameters were set to safe values, as at the time of setting the missions the option to turn them completely off was not available.

Configuration parameters	WMO 6903703 (Arvor-I)	WMO 6903704(APEX)
CONFIG_ProfilePressure_dbar(dbar)	120	100
CONFIG_ParkPressure_dbar (dbar)	120	100
CONFIG_CycleTime_hours (h)	6	8
Ice detect temperature (°C)	0.3	-
Ice detection layer min (dbar)	15	-
Ice detection layer max (dbar)	35	-

Table 13. Main changes (at specific float cycles) performed during the missions for each float. For APEX float cycle time is given in minutes, here converted to hours for comparison. For APEX there was an additional set of cycle time changes around 10/2020 as Aranda was nearby doing comparison profiles.

WMO 6903703 (Arvor-I)	**1(initial)**	**4**	**6**	**8**	**12**	**13**	**15**	**20**	**21**	**46**	**58**	**60**
CONFIG_ProfilePressure_dbar(dbar)	120	140	148	155						115	95	100
CONFIG_ParkPressure_dbar (dbar)	120	140	148	155						115	95	100
CONFIG_CycleTime_hours (h)	6				36	24	48	72	168			
INTENTIONS	Initial setup	closer to bottom, restrict movement			Gradually lengthen interval, while monitoring float					depth adjustment, due float movement		
OUTCOMES	success, no bottom contacts	ok, could go lower	ok, could go lower	good depth	ok	shorter due person availability	ok	ok	final interval	still risk of bottom contacts	too shallow	ok
WMO 6903704(APEX)	**1 (initial)**	**5**	**7**	**9**	**11**	**12**	**13**	**14**	**16**	**19**		
CONFIG_ProfilePressure_dbar(dbar)	100	140	145	150			155	156				
CONFIG_ParkPressure_dbar (dbar)	100	140	145	150			155	156				
CONFIG_CycleTime_hours (h)	8	13			17	30		43	57	172		
INTENTIONS	Initial setup	closer to bottom, restrict movement			lengthen cycle time, observe behaviour		Fine tune the diving depth for area, lengthen cycle time to target					
OUTCOMES	ok, can go lower	ok, can go lower	ok, can go lower	ok, observe	ok	ok	ok	fine tuned depth	ok	ok		

In the Bothnian Sea FMI tested a NKE's Arvor-C type float (WMO 6903702) which is designed to remain on bottom, instead of drifting between the profiles. It has feets on the bottom, and descends faster. On the other hand, the model has less possibilities for changing the operation during the mission than other NKE's floats, and is limited to 300 metres of depth. The option to remain steadily on the bottom proved out to be promising, given the right conditions. The float was deployed on 04/06/2020, and transmitted its last profile on 28/05/2021 after its batteries suddenly ran out. It provided in total 53 profiles, and due to its bottom contacting setup, it remained within 4 NM distance of the point of origin during the whole year, which is considerably more stationary than any other float on the area surviving that long (figure 64). Future missions should consider the deployment of standard Argo floats in the Bothnian Sea with a grounding configuration at each cycle, in order to provide a reliable technical comparison between the two platforms.

In addition, during the Euro-Argo Rise project, we have tested two floats with RBR-CTD sensors, one on Gotland Deep (WMO 6903709), and another in the Bothnian Sea (WMO 6903710). Initial results of these are promising, and further discussed on deliverable D2.9 (Siiriä et al, 2022). Key advantages with these are the possibility to measure the very surface, and being less likely to get clogged as the water flows freely through the RBR sensor, whereas Seabird sensor uses tube and pump.

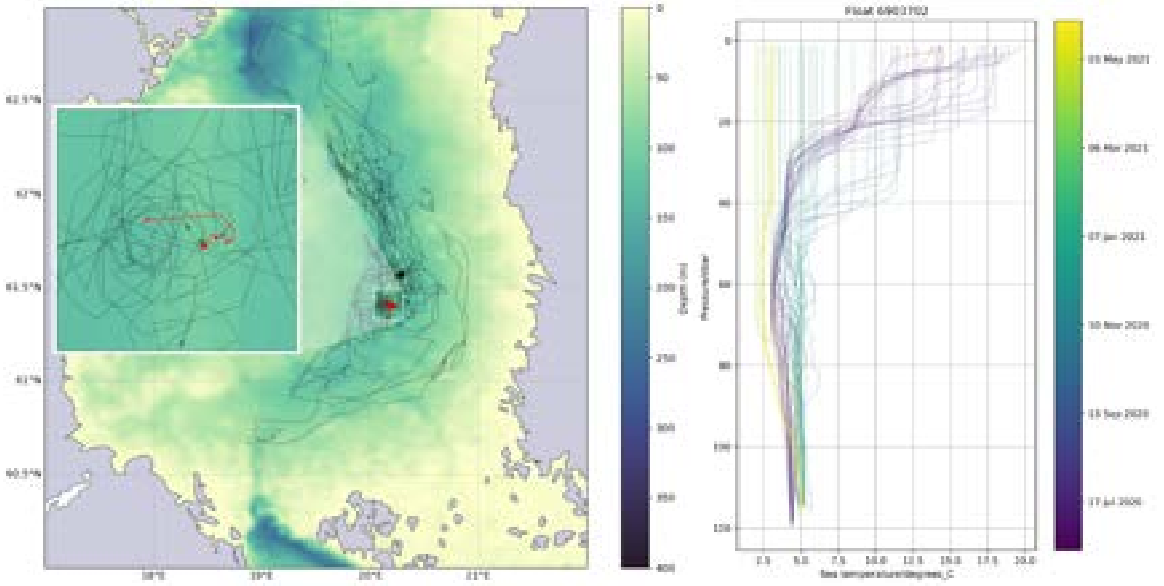


Figure 64. Left side shows the Arvor-C trajectory (red) during the mission, in comparison to typical Argo float trajectories in the area. Right side shows the temperature measurements of the float during the mission. With roughly once a week profiling cycle, such time series with such a little variation in location would be hard to acquire with other means.

The float monitoring process in FMI at the beginning of a mission on APEX floats is based mostly on monitoring the mission and log files transmitted into the FMI server, and for Arvor floats on decoding the e-mail-delivered messages from the float. At the beginning these are used, as they are the fastest, and most direct way of determining if the float operates as supposed. After usually several cycles of adjusting the diving depths and cycle times, if the float performs as expected, the cycle time is increased.

Earlier, after this point, most of the monitoring was done by checking the servers, and in-house python scripts, but as the tools provided by Euro-Argo (Fleet monitoring, Data selection) have improved, the standard monitoring has been shifted to mostly using these services.

Typically, for the fleet monitoring tool we can determine if every float has been transmitting as expected, and remains in the preferred area. The data selection tool is used to have a quick look at the data occasionally to see if there are deviations on the data.

Most typically human interaction is needed if it seems that the float is having technical troubles in diving or communication or is drifting too far. Diving and communication problems have typically been attempted to fix by either varying the piston movements, to get the float deeper or surface better, or by increasing the time on surface or connection attempts to give the float better chances to establish connections. For these operations only simple ssh connections to servers and text editors are needed.

FMI attempts to recover every float it deploys in the Baltic Sea. As the Baltic Sea is small, and there are research vessels around frequently enough, this is a reasonable approach both economically, as the floats can be re-used and ecologically, as the floats won't remain in the sea. **Typical reason for float recovery is, that it's estimated battery life is being reached, or in few cases, that the float has drifted too far from the intended area, and is at risk of drifting to shore.** As recovery timing must most often be synchronised with scientific campaigns, this does however limit the mission lengths, as the recovery options can be limited to a couple of times a year, depending on area.

Typically during float recovery, FMI has had one person monitoring the floats server during the recovery operation, first setting the float into shorter cycle time as the recovery approaches, then setting it to rescue mode, and frequently sending the location for the ship on site. The location is monitored both on the ship and on shore with in-house python scripts to estimate the drift direction and possible point of recovery.

The recovered missions from FMI controlled floats are listed on table FMI_recov. Most of the recoveries are operated with R/V Aranda. As the floats do not have any lights, and are relatively hard to spot from the sea, the rescue must be timed on day time.

In addition to this, we attempted with good results with float WMO 6903703 the Euro-Argo float recovery tool in cooperation with the Estonian R/V Salme.

FMI has successfully recovered over 20 floats (table 14) in Baltic Sea and lost as of writing 5 floats. Two of these were lost practically immediately, due to malfunctions. Both were first tests of their type, one Arvor-C, and another Provor from WP 4. One Apex floats were most likely lost in the Bothnian Sea for getting stuck on the bottom, or other malfunction. Another Arvor-C was lost for battery problems. For the Apex lost on Northern Baltic Proper, the reason is still unclear as of writing. All in all, the ratio of recovery on the Baltic Sea is relatively high.

For redeployment of the APEX floats, FMI has sent the recovered floats to Teledyne Webb Research for re-calibration and battery change, after which, they have been re-deployed similarly to a new float. For calibration experiences, see further details on deliverable D2.7 (Klein et. al., 2022). Similar process for Arvor floats with NKE for FMI is in development.

The refurbished floats have so far performed well, without showing any problems clearly related to their age. As such, based on current experiences, there is not yet information on the maximum times a float can be deployed. However, as the models change, the support for older models may not be available. Webb Research has for example informed that they will no longer maintain the older AFP9 type floats.

Table 14. FMI recovered floats since 2012.

WMO-number	Float serial. No	Float type	Country/ Programme	Deployment date	Date of last profile
6901901	5397	APEX	Argo Finland	17.05.2012	05.12.2012
6902013	5396	APEX	Argo Finland	13.06.2013	02.10.2013
6902014	6711	APEX	Argo Finland	14.08.2013	21.08.2014
6902017	5397	APEX	Argo Finland	31.05.2014	24.10.2015
6902018	6710	APEX	Argo Finland	31.05.2014	13.11.2014
6902019	7191	APEX	Argo Finland	21.08.2014	05.08.2015
6902020	6711	APEX	Argo Finland	05.08.2015	03.08.2016
6902021	6710	APEX	Argo Finland	22.09.2015	13.05.2016
6902022	5396	APEX	Argo Finland	13.05.2016	11.10.2016
6902023	5397	APEX	Argo Finland	13.07.2016	25.01.2018
6902024	7191	APEX	Argo Finland	03.08.2016	15.06.2017
6902036	7507	APEX	Argo Poland	29.11.2016	01.02.2017
6902025	7958	APEX	Argo Finland	09.05.2017	02.10.2018
6902026	7959	APEX	Argo Finland	06.06.2017	02.06.2019
6902027	6711	APEX	Argo Finland	15.06.2017	15.10.2018
6902028	6710	APEX	Argo Finland	06.08.2017	04.09.2018
6902029	5396	APEX	Argo Finland	06.08.2017	27.10.2017
6902030	5396	APEX	Argo Finland	10.07.2018	04.03.2019
6903697	7191	APEX	Argo Finland	15.10.2018	18.08.2019
6903703	AI2600-19FI001	Arvor	Euro Argo RISE	10.06.2020	5.02.2022
6903706	P53338-20FR001	Provor	Euro Argo RISE	19.05.2021	7.4.2022
3902109	AI2600-19PL001	Arvor	Euro-Argo RISE	03.06.2020	05.08.2021

4.2.2 Southern Baltic experiment

As the first to deploy the 'virtual mooring', the Gdansk Bay region was chosen – the shallow reservoir located closest to the IO PAN. Gdansk Bay borders Gdansk Deep, one of the important basins of the Baltic Sea. The greatest depth in this body of water is 113 m, cyclonic circulation prevails. From the west, Gdansk Deep has a connection with the Slupsk Furrow, the only route of advection of salty, deep waters from the Bornholm Basin, in the north-east it is open to the Gotland Basin. Most of the coast of the Gdansk Bay belongs to Poland, only its eastern part belongs to Russia.

Cooperation with Russian oceanographers before the outbreak of the war in Ukraine was going well. IOPAN even performed joint deployments and recoveries of Argo in the Baltic Sea (E-A RISE, WP 5). For political reasons cooperation was interrupted. Cooperation with the Russian authorities has always been more difficult. Argo-Poland has repeatedly received warnings from OceanOPSabout the approach of the Polish float to the coast of Russia. Repeated attempts to contact the Russian ‘focal point' failed. On the other hand, there were no diplomatic clashes due to floats approaching the Russian EEZ.

Float WMO 3902109 was deployed on 03.06.2020 in the inner part of the Gdansk Bay (figure 65) in very shallow water, about 20 metres deep. **The aim of the experiment was to use float as 'virtual mooring', to limit float drift**. **A 12-hour profiling period and a park pressure greater than the maximum depth of the adjacent sea were used. This ensures that the float will remain at the bottom after the profile has been made and it has gone into the parking phase**. After 30 days in shallow water, the float began to drift towards the centre of the Gdańsk Bay. Then the float moved several times along the southeast-northwest line, and at the end of the mission made a large cyclonic loop around the southern part and across the Gdańsk Deep. During the entire mission, the float covered a distance of 502 km with an average speed of 1.36 cm s^{-1}. This is much lower speed than for floats working in this region, which was about 8 cm s^{-1} (Walczowski at all, 2020). The float remained within an area with a maximum radius of 39 km. Both parameters show that the experiment was successful and that it makes sense to use floats as 'virtual moorings' in the deep regions of the Baltic Sea.

During the mission, four modifications to the operating parameters of the float were made (table 15). The biggest change was the shifting of the cycle time from 12 to 24 hours after 75 days of mission. This was to check the suitability of different float cycle times for the study of seasonal cycles of temperature and salinity in the studied area. Later, only the park pressure was changed, and at the end of the mission, an unsuccessful attempt was made to extend the mission time (maximum number of profiles). Change of the profiling period did not significantly affect the average speed of the float (1.42 cm s-1during the 12-hour cycle time, 1.38 cm s-1 during the entire mission). **On the other hand, several significant float shifts were observed between consecutive measurements**, with a speed of up to 12 cm s-1 (figure 66). This does not appear to be **related** to fishing vessel activity, but rather **to a weak 'anchorage' of the float to the bottom**. Also in the central part of the Gdańsk Deep, the float speed was much higher than the average. It is connected with the change of the park pressure from 150 to 70 m made on April 30. This was done while the float was getting too close to the shores of Russia, to allow the float to drift into deeper water. The operation was successful and after 38 days the settings allowing parking on the bottom were returned to. **This experiment clearly shows that it is possible (to a limited extent) to influence the trajectory and the operating region of the float**. The experiment lasted more than a year, until 01.08.2021. Float performed 500 profiles. Before the 500th cycle was performed, efforts were made to establish contact with the float in order to recover it. However, it did not work, probably because the command was sent too late. The float surfaced and stopped working. This was the result of a bug in the programming of the float. The standard CONFIG _ MaxCycles _ NUMBER = 500 used for ocean floats was left in the configuration file. Nobody expected a float to complete more than 500 cycles. Fortunately, the story ended well, the float was recovered (see the recovery section).

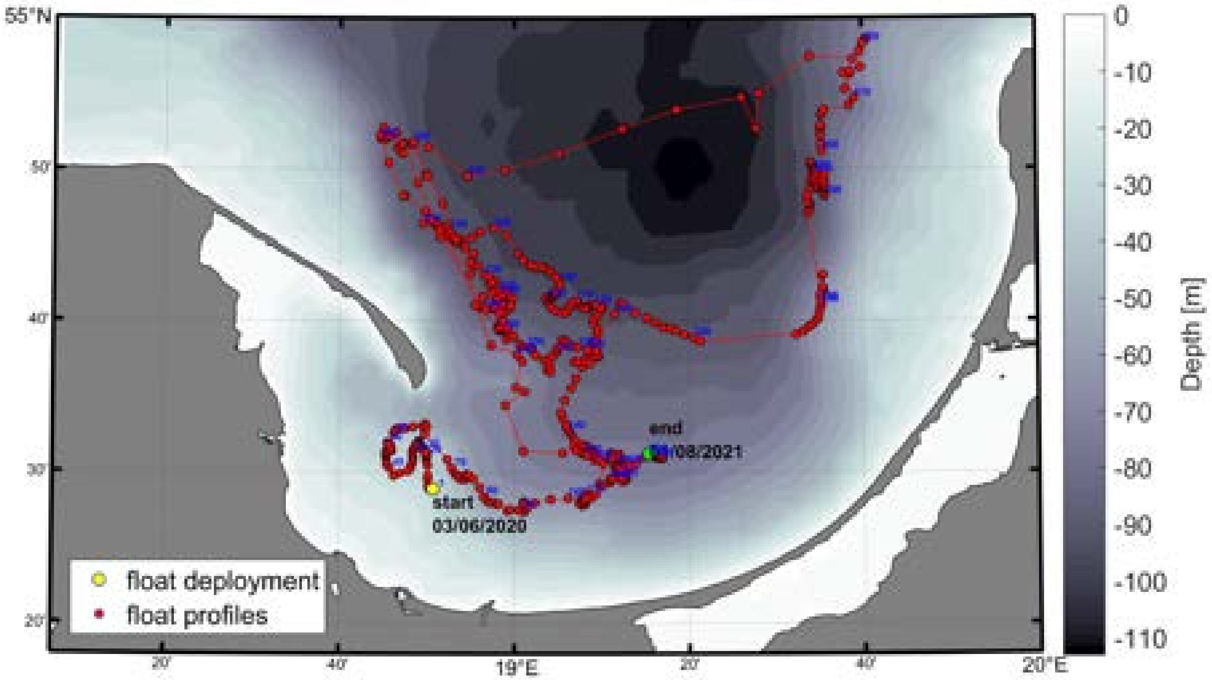


Figure 65. Trajectory of float 3902109.

Table 15. Main changes performed during the mission of float float WMO 3902109 (Arvor model).

WMO 3902109	Initial configuration 03.06.2020	Modification 18.08.2020	Modification 24.08.2020	Modification 30.04.2021	Modification 08.06.2021
CONFIG_ProfilePressure_dbar(dbar)	200	200	200	200	200
CONFIG_ParkPressure_dbar (dbar)	100	100	150	70	150
CONFIG_CycleTime_hours (h)	12	24	24	24	24
INTENTIONS	Getting two profiles per day in a restricted region	Changing the profiling frequency to check for variations in drift velocity and the suitability of the results for different profiling periods	Increasing park pressure to improve anchoring in the central part of the Gdańsk Deep	Anchoring to the bottom was interrupted to allow the float to move away from the Russian EEZ	Return to 'virtual mooring' (bottom mooring) settings
OUTCOMES	Successful experiment, low float drift velocity	Insignificant impact on drift speed, usefulness of the results for analyzes of seasonal variability	Anchoring has been improved, drift has been reduced	Successful action, the float moved away from the Russian EEZ	Reduction of drift, work in a limited water area

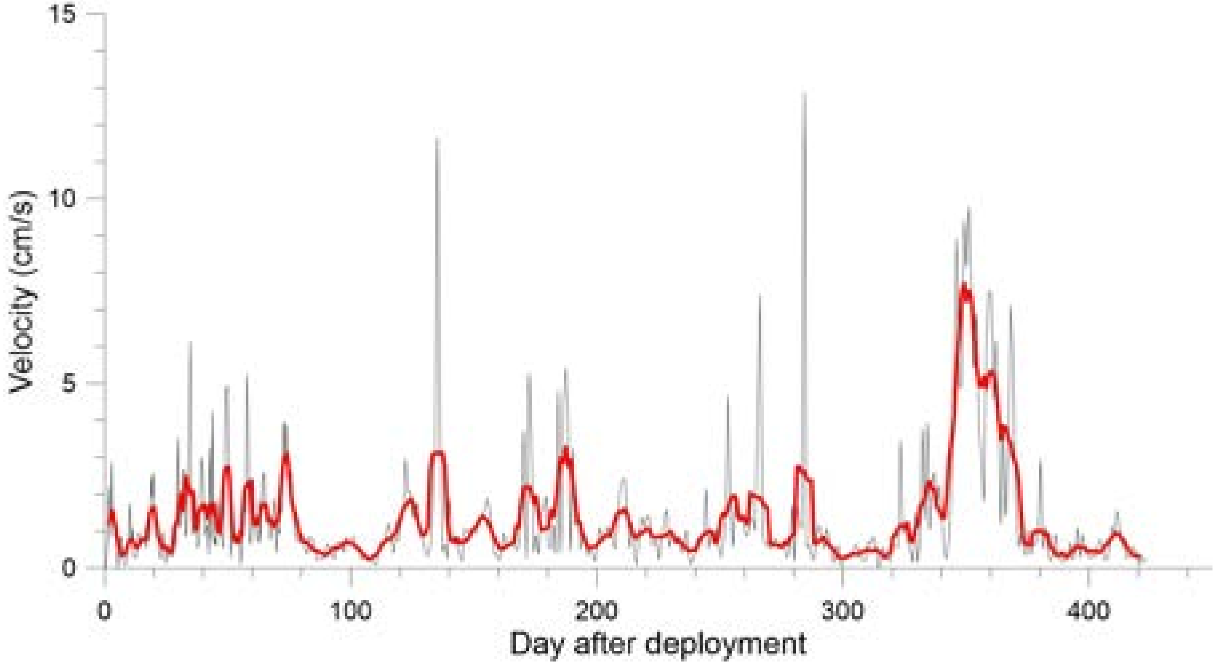


Figure 66. Velocity between profiles (black line) and velocity 7-days moving average (red line) of the 3902109 float.

After the success of the float in the Gulf of Gdansk, it was decided to continue experiments in another body of water. The second Polish float was launched in the Bornholm Basin. Float WMO 3902115 launched on 15. 06 2021 during r/v Oceania transit to the AREX Arctic cruise.

Platform settings at launch: CONFIG_ProfilePressure_dbar: 350; CONFIG_ParkPressure_dbar: 300; CONFIG_CycleTime_hours: 49. The settings remained unchanged. Since then, the float has been working continuously and has made 220 profiles. All measurements remain within the Bornholm Basin. Contrary to other, free-floating floats, it does not drift east, to the Gdańsk Deep.

At the time of Argo launching from r/v Oceania, a CTD profile is always made using the Seabird probe. Additionally, in the Argo work area (Bornholm Basin, Gdansk Deep), research cruises and CTD measurements are carried out 4 times a year.

In May 2022, IO PAN received a float from the manufacturer after battery replacement and sensors calibration. It was decided to use this device to conduct experiments in very shallow water. The first experiment consisted in anchoring the float to the bottom at a depth of 15 m. An acoustic release, a buoyancy buoy and a 25 m long line were attached to the 25 kg ballast. A float was attached to the end of the line. The length of the line (about 1.7 times the depth of the water body) allows for free emergence, and the line (with a slightly positive buoyancy) does not reach the surface when the float stays at the bottom. The float was launched on May 26 at 1 p.m. in the sheltered waters of the Gdansk Bay (figure 67). Profiling period was set for 2 hours, park pressure 100 m. Float did not send the data until the next day, but since May 26 it has been sending it continuously. On May 30, the frequency of profiling was changed to 7 hours. The test lasted until June 18, 2022. An acoustic release was used to disconnect the float from the dead anchor. The whole set - acoustic release, float and buoyancy buoy have been recovered. The experiment was carried out with the wind up to 6 B, with a wave height of up to 1 m.

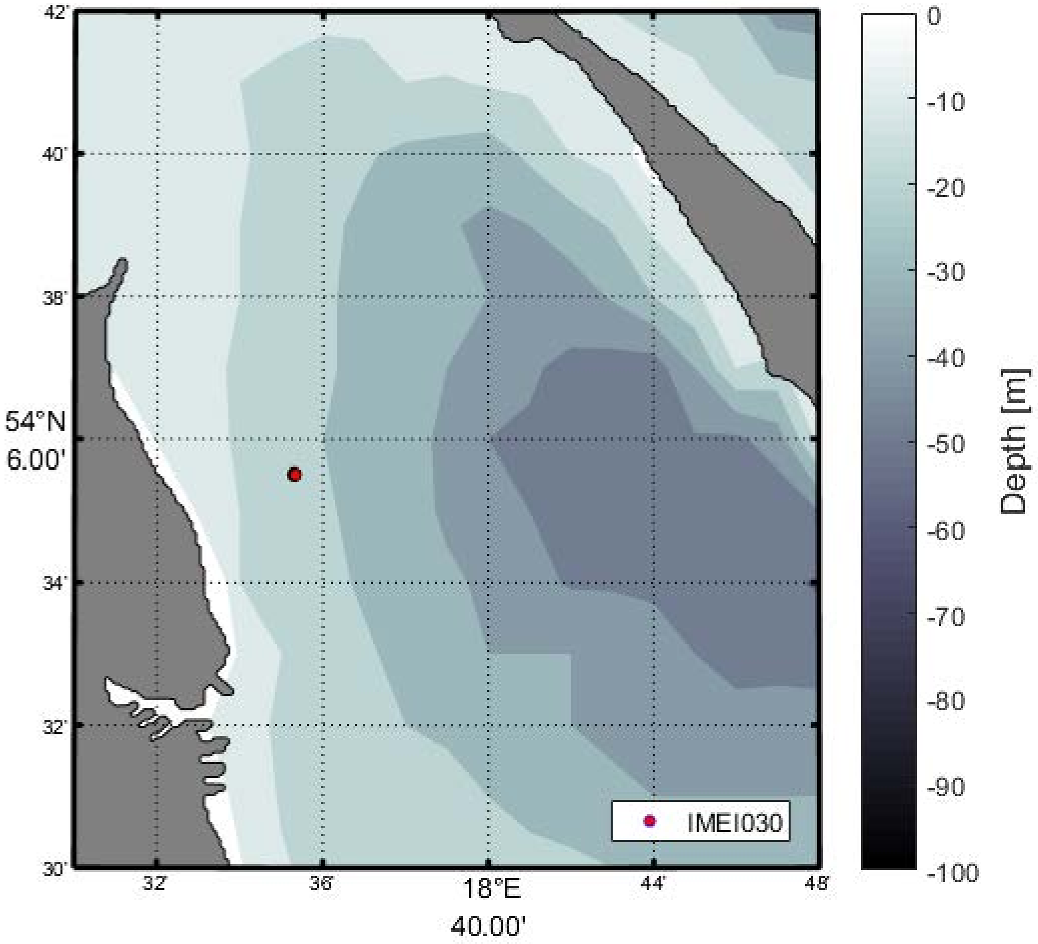


Figure 67. Location (red dot) of the first anchored Argo in the inner waters of the Gdansk Bay.

On August 29, 2022, the experiment was repeated. The float was anchored at a depth of 40 m, position 54.58° N, 18.65° E, in a sheltered area of the Gulf of Gdańsk. A 60 m long line, an acoustic release and a dead anchor were used. The experiment continues, the float is profiled at a frequency of 7 hours. Most of the temperature and salinity profiles are from the bottom to the surface (figure 68). Both experiments are promising. They show that it is possible to profile with Argo floats attached to the bottom with a line of a suitable length. The profiling period of 2 hours used at the beginning of the first experiment is too short. A period of 6 hours seems to be appropriate. An installation of this type can be very useful in the continuous monitoring of small, semi-enclosed bodies of water.

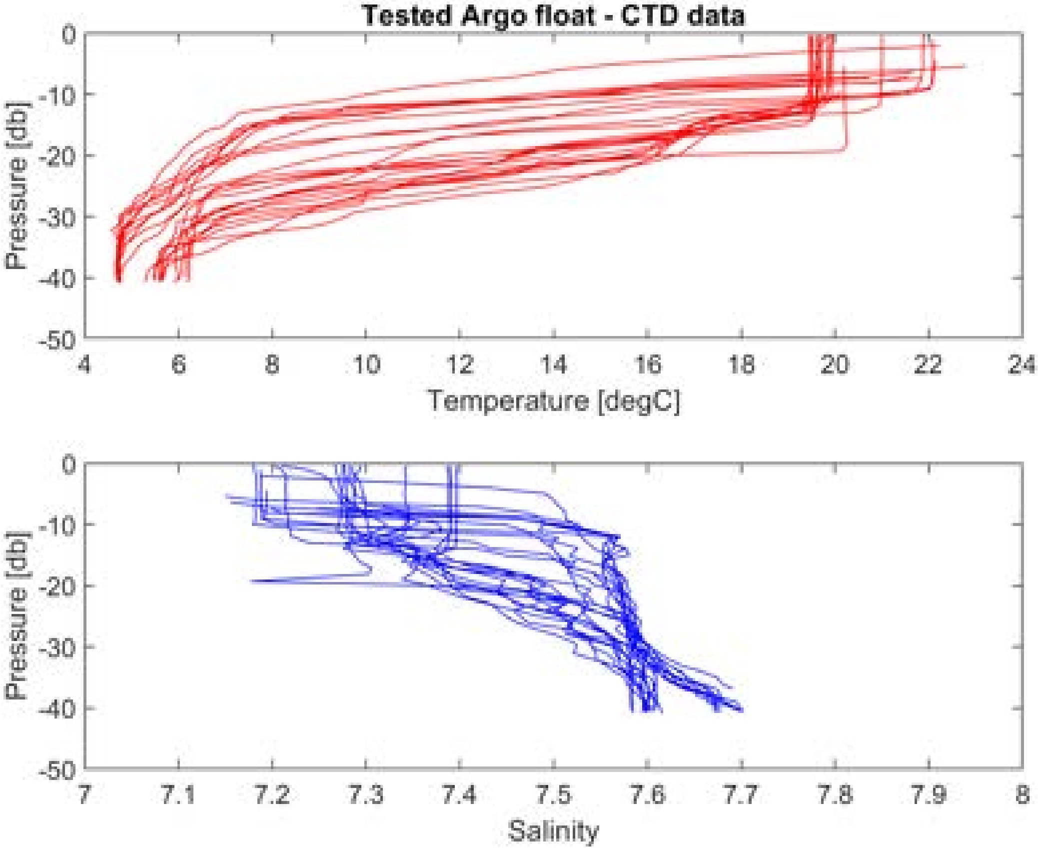


Figure 68. Temperature and salinity profiles obtained by float anchored at 400 m depth.

For the Baltic Sea monitoring, IOPAN uses standard tools provided by Euro-Argo. In specific operations, like float recovery, special procedures are applied. One of them consists of reading SBD files, decoding the data and sending exact positions to the vessel. This greatly improves the ability to find the float, especially during rough sea conditions. Meteorological conditions are usually checked in the marine zyGrib service: https://zygrib.org/. Good weather forecast helps in choosing the right time for recovery. The portal prepared by Euro-Argo ERIC, dedicated to float recovery is a new tool and has not yet been used by IOPAN. We intend to test it in the near future.

IO PAN also uses sea currents predictions to influence displacement of the float. During expected surface current from the shore (upwelling case) the float is forced to stay on the surface in order it drifts offshore. When wind induces downwelling events, the park pressure is set deeper, so that the float moves away from the shore. To proper select the float depth, the Polish Argo team collaborates with modellers and use a high-resolution model of the Baltic Sea (http://ebaltic.plgrid.pl/#). This method will be further developed and the virtual floats tracking in specific model layers will be introduced.

The tool used in Argo Fleet Monitoring - sea currents at particular levels is also useful. It may be suggested that for mission planning climatic data - monthly or quarterly mean currents at particular levels and at the bottom level may be useful. IO PAN also collaborates with the SatBaltic system (http://www.satbaltyk.pl/en/). Data from Argo floats are provided and assimilated in the model. Model results are used for checking the Argo data and predicting the drift.

Due to the size of the reservoir, recovery of the floats is possible in the Baltic Sea and can be profitable. This is especially true for expensive BGC floats. IO PAN has significant experience in float's recovery (table 16). These actions were taken for various reasons. These were:

- The float was too close to the shore;
- The float was too far from the assumed measurement region;
- Fear of battery depletion and needing maintenance

Recovery was usually carried out from the IO PAN r/v Oceania vessel, but in several cases the float was recovered out by another unit.

Table 16. Floats recovery activities carried out by IO PAN.

Float WMO	Type	Deployment	Recovery	Vessel	Number of profiles	Remarks
6902036	APEX CTD	21/11/ 2016 Bornholm Basin	01/02/ 2017 Bornholm Basin	r/v Oceania	56	redeployed as 3902100
3902100	APEX CTD	15/03/2017 Bornholm Basin	Summer 2019 Southern Baltic	Fisherman vessel	234	caught in fishing net after it stopped working
3901904	ARVOR CTD	31/05/2018 Bornholm Basin	02/06/2018 Bornholm Basin	r/v Oceania	51	Redeployed as 3902133
3901941	ARVOR CTD	21/09/2017 Bornholm Basin	19/10/2020 Bornholm Basin	r/v Oceania	382	After recovery sent for maintenance, sensor calibration and battery exchange.
3902101	ARVOR CTD+O_2	06/02/2018 Bornholm Basin	07/02/2020 Eastern Gotland Basin	s/y Magnus Zaremba	373	
3902104	ARVOR CTD+O_2	31/05/2018 Bornholm Basin	02/06/2018	r/v Oceania	51	Redeployed as 3902106
3902106	ARVOR CTD+O_2	31/05/2018 Bornholm Basin	01/12/2020 Estonian coast	Estonian vessel r/v Salme	418	After recovery sent for maintenance, sensor calibration and battery exchange.
3902109	ARVOR CTD	03/06/2020 Gulf of Gdansk	31/07/2021 Gulf of Gdansk	German Navy vessel "Oker"	500	Delivered to IOPAN, foreseen for refurbishment

Successful float recovery operations show that it is profitable in the conditions of a small sea like the Baltic. On the other hand, the small size of the sea raises other problems - the whole sea is divided into EEZs of coastal countries. This raises the need for close cooperation between countries and institutions in individual countries. IOPAN has started such cooperation - float WMO 3902106 was recovered by an Estonian research vessel R/V Salme. It was a coordinated operation of searching for and recovering a float that came too dangerously close to the shore.

Another example of international cooperation is the story of float 3902109. The float purchased from the EA RISE float stopped working after performing 500 profiles. The float drifted on the surface and was recovered by the German Navy wessel Oker. Float was brought to Poland from the German Eckernförde base by another German vessel visiting the port of Gdynia.

4.3 Results

4.3.1 Central and Northern Baltic experiment

FMI floats on Northern Baltic Proper WMO 6903703 (Arvor-I) and WMO 6903704 (APEX) were deployed on 10/06/2020. The Arvor-I (figure 71) recorded its last profile, number 113, on 01/02/2022. It was recovered after it had drifted away from the targeted area, and was at risk of getting stranded if drifting further (figure 69). APEX float (figure 70) transmitted its last successful profile, number 116, on 24/02/2022. After this, it transmitted partial data on 04/03/2022 and finally 11/03/2022. On the last attempt it had issues on ascending speed and connection. As of writing, it is still unknown what caused the float malfunction, but there has been a contact, that the float has been found in Saaremaa, Estonia. Most likely the float has failed to surface properly, and has since drifted eastward, out of the target area, perhaps similarly than the Arvor-I float. As seen in figure 69 the float stayed during its mission in a relatively small area.

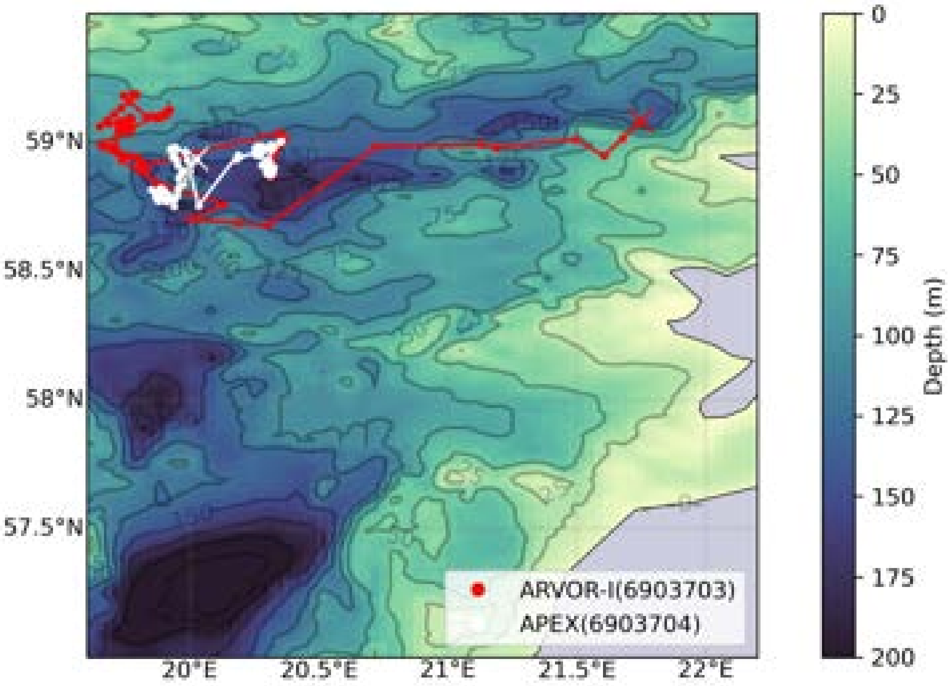


Figure 69. The final routes of both Northern Baltic Proper floats. The Arvor-I (in red) escaped the area after staying relatively well in the area for over a year. Apex float stayed in the area at the end of its mission, due to most likely being stuck on bottom.

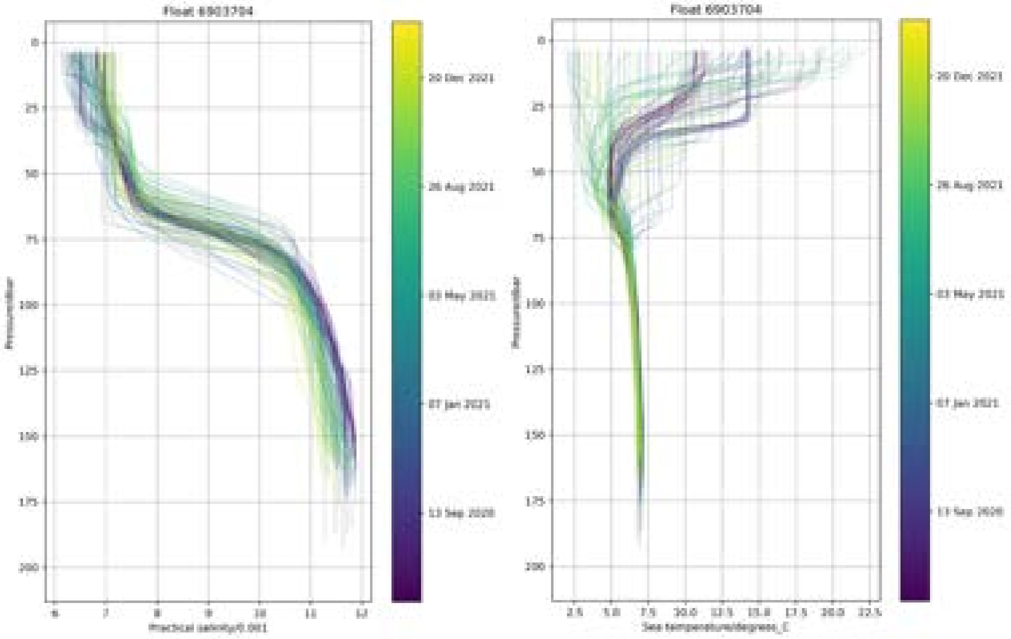


Figure 70. Salinity (left) and temperature(right) profiles for the whole mission for the Northern Baltic Proper APEX float (WMO 6903704).

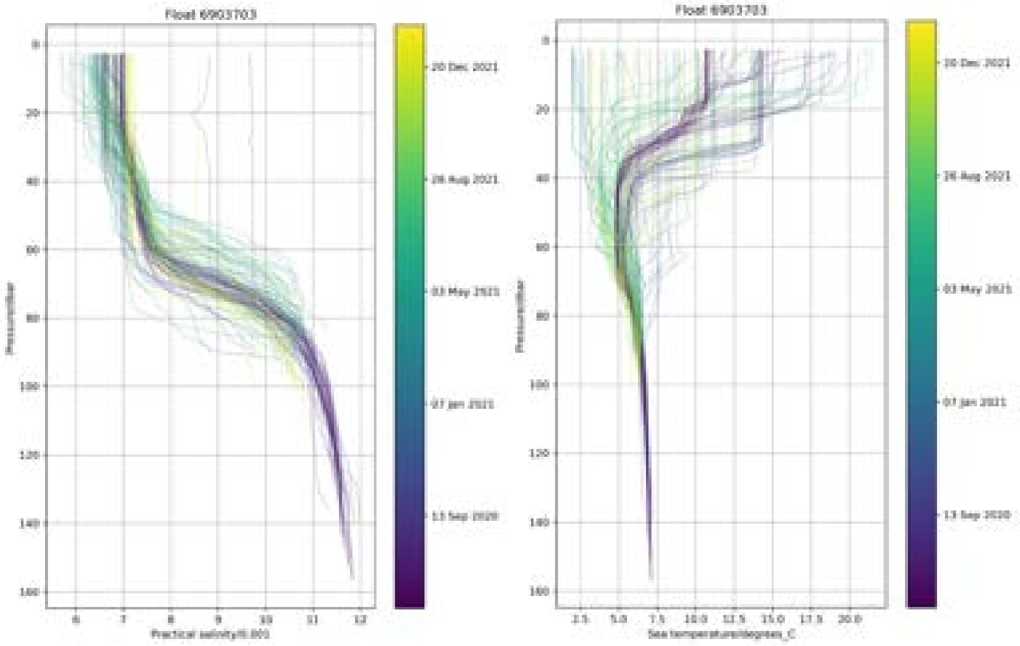


Figure 71. Salinity (left) and temperature(right) profiles for the whole mission for the Northern Baltic Proper Arvor-I float (WMO 6903703).

Float data (WMO 6903702, 6903703, 6903704) were compared to measurements acquired by the R/V Aranda (see Annex IV for details). The depths near the thermocline have largest differences, which is to be expected, as the changes are sharp and easily change in a short time or distance. For the rest of the area, floats are in good agreement with the ship CTD, and most of the differences can be explained with the small difference in location and time.

As Arvor-C always descends to the bottom, and has ‘feet’ to hold it steady, it moves considerably less than other models (figure 64). Based on this, such a construction is, at least in this part of the Baltic Sea, a promising option to complement the typical, freely drifting missions, even if this specific mission was abruptly ended by battery problems. Further experiments would be needed to determine how much the promising performance is due to the feet, and how well a typical float would perform in a similar mission, as it would have higher risk of getting stuck on the bottom and/or still drift with the currents.

4.3.2 Southern Baltic experiment

In both experiments (Bornholm Basin, Gdansk Deep), the float remained in the region with a radius of less than 30 km for over a year. During this time, the float did not come too close to the shore, as it did not drift into the area shallower than 60 m. The distances between the successive profiles are generally less than 1 nautical mile. However, in a few cases they are much larger, even over 5 miles. In these cases, the bottom parking probably wasn't working. These cases will be analysed.

Threats such as getting stuck to the bottom, entanglement in fishing nets or stranding are lower than anticipated in the initial phase of use of floats in the South Baltic Sea. Most of the deployed floats were recovered. The maximum number of profiles obtained by one float so far is 500 (EA RISE float WMO 3902109) and it is certainly not the final number. At that time, the battery level was 10.1V. Due to the setting error described above, the experiment was not carried out further. It was also not possible to check the float batteries in the laboratory, because after the recovery of the float it was not turned off and the batteries were discharged.

In the Gdańsk Bay, a time series of temperature and salinity data (figure 72) for a period longer than a year was obtained for data in a circle with a radius less than 30 km. In the Baltic conditions, they can be considered representative of the studied area. This allowed for the study of the seasonal variability of temperature and salinity at individual levels as well as the heat content in the entire water column (figure 73). The latter figure is very useful as it allows the heat transfer between the sea and the atmosphere to be calculated.

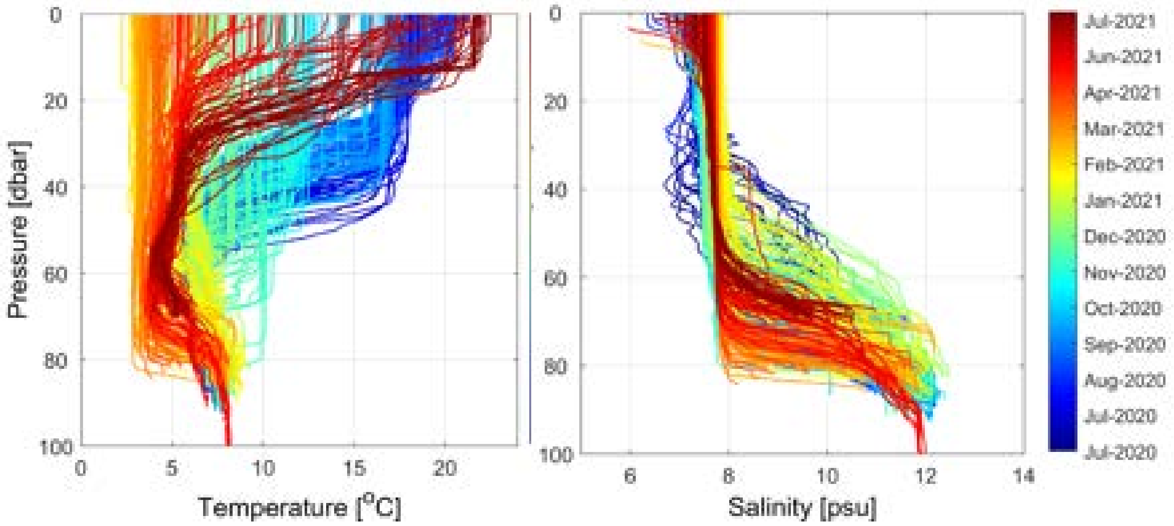


Figure 72. Yearly time series of temperature and salinity profiles from the Gdansk Bay obtained by EA RISE float WMO 3902109 working as 'virtual mooring'.

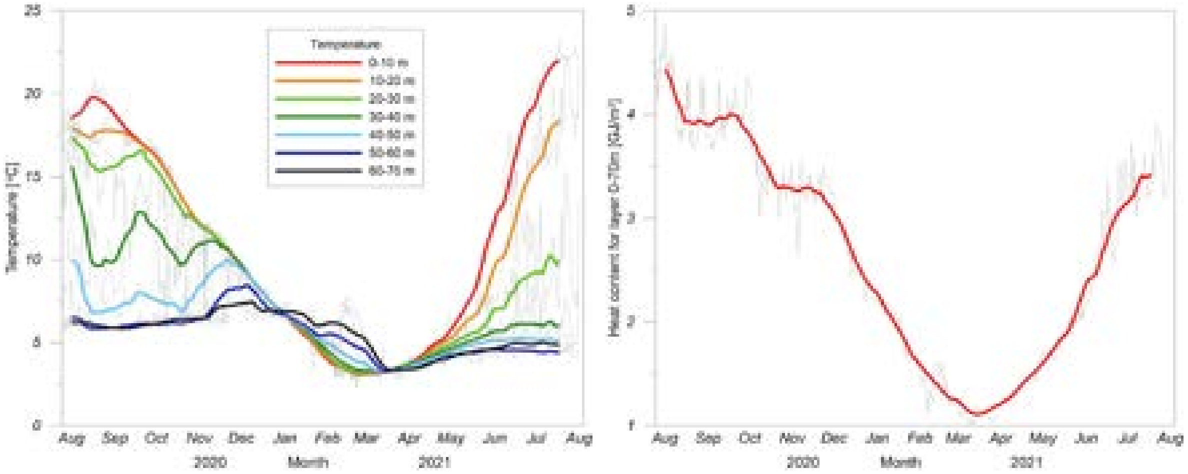


Figure 73. Temperature at various levels (left) and heat content in the 0-70 m water layer in the period August 2020- August 2021.

Preliminary results on the use of one moored Argo float show that the such kind of platform can be used for tethered profiling in a shallow, sheltered body of water.

4.4 Discussion – Conclusions

4.4.1 Central and Northern Baltic experiment

The first Finnish experiments with Argo in the Gulf of Bothnia, and then the Polish ones in the South Baltic Sea showed that despite many physical properties of the basin, which seem to be unfavourable for the use of Argo, **the Baltic Sea is suitable for exploration with these devices. Argo floats may be used as part of a comprehensive Baltic monitoring system**. Various sources of data, such as floats, cruises and moorings, can provide extensive, complementary data for the better monitoring of the Baltic Sea, the improvement of numerical models and validation of satellite observations (Walczowski et al., 2017).

Despite its small size, the Baltic Sea is a body of water very diverse in terms of its physical properties. Therefore, it is difficult to establish one recommendation for the entire body of water. The most important seems to be the cycle time and the float park pressure. Cycle time in typical cases is set to 7-10 days, but initially 6-10 hours, to allow adjustments and monitoring of performance at the beginning. Optimal park pressure depends on the area, but should target on staying at least 10 metres from the depth of the area to restrict the movement, and avoiding unnecessary adjustments or getting stuck by bottom contacts. Suggested depths are listed on table 5.3 for given areas. For first dives it is recommended to aim 10-20 % shallower, in case the float balance is off.

Argo operations in the Baltic Sea are well feasible, and **the ratio of recoveries is high, roughly 4-5 floats recovered for each lost so far**. The exact setup of the mission however must be adjusted to the specific area of operation. Suggestions of the initial setup for tested areas are given in table 5.3. Here it must be observed though, that specific values can be float dependent. In FMI's experience every deployed float will initially need some adjustments. For this reason, the diving depths and cycle times are listed as initial and target value.

The initial values are how the mission should start. **The idea is to have a short cycle time to observe the behaviour, and slightly more shallow diving depth than intended, to avoid fast contact with the bottom. After it has been established that the float operates as intended, the cycle time is lengthened to the target, as well as the diving depth established to close to the deepest values of the target area. This is to ensure that the float cannot drift too far from the set area**.

In earlier experiments FMI used to adjust the depth more frequently, trying to match the bottom of the specific area, while avoiding direct contacts with the bottom. The later experiences, partially made possible with the Euro-Argo RISE extensions, have indicated that the bottom contact is not as high a risk for the float than originally anticipated, and as such, frequent change of the depth is more likely to allow the float to escape. Based on the practises of monitoring the float trajectory, and estimating the probable location on the next surface it was initially thought that a more complex learning-algorithm could be used on the float operation and fine-tuning the diving depths. In the light of the current operations, especially as avoiding the bottom contact is less important than initially thought, it seems that for the moment a simpler and more passive approach to the operation is recommended.

Based on the Euro-Argo RISE experiences, the Northern Baltic Proper seems a promising new area for the Argo operations, both test floats performed well over a year. As at least one of them finally escaped from the area, although staying relatively confined until that. To avoid such situations in future, the standard diving depth could be increased for the next missions.

The Arvor-C, bottom contacting float in the Bothnian Sea managed to stay exceptionally stationary compared to any other missions in the area. Although this specific float stopped functioning after a year due to battery problems, it seems that the bottom contact strategy should be further studied.

Any Argo deployments in the Baltic Sea are in an EEZ of one country or another, so the permissions for deployments need to be requested, and missions planned well in advance. Depending on a country's practices, this often means several months in advance.

4.4.2 Southern Baltic experiment

IO PAN uses various platform settings. This applies to both the cycle time, the park pressure, and the behaviour of floats in the bottom zone. Settings depend on mission objectives, weather conditions, proximity to the shore, batteries status. During float recovery specific settings and operations are needed.

For modern core floats working in the open ocean, profiling is recommended every 10 days. This guarantees the float's operation of 4-5 years and obtains up to 180 of 0-2000 m profiles with a total length of 360 km. To obtain 360 km of profiles at shallow water, 4500 profiles 0-80 m should be performed. At a frequency of 10 days, the float would have to work for 123 years. It indicates that in a sea as shallow as the Baltic Sea, the profiling period should be changed. Of course, in the conditions of shallow profiling, floats cannot perform 360 km of profiles due to the different regime of pomp work (need for more frequent 'pump actions') and other conditions (such as grounding) causing higher energy consumption. However, even these simple calculations show that the time regime of floats working in shallow water must be changed.

For the ‘Baltic core mission’ IO PAN applies a profiling period of two days. This is a sufficient period for basic monitoring of changes in physical conditions occurring in the water column. This applies to both the surface layer (seasonal changes in temperature and oxygenation of water), the thermocline and halocline layer (the depth of both regions of strong property gradients) and the bottom layer (changes in water properties associated with barotropic and baroclinic inflows from the North Sea. The two-day period allows making 550 profiles in three years. **The park pressure is usually 45-50 m**. This allows the float to drift through the Słupsk Furrow and at the same time prevents the float from getting too close to the shore.

The experiments performed (and ongoing) clearly show that the use of Argo as virtual moorings with the option of parking on the bottom is sensible and beneficial. This method significantly reduces float drift and causes them to be trapped in one region. In the case of the Baltic Sea, this has several kinds of benefits:

- **Easier planning of floats arrangement;**
- **Easier deployment and recovery;**
- **Prevention of drift to too shallow water;**
- **Easier DMQC (different DMQC criteria must be used for each region).**

For floats used as virtual mooring, the cycle time of one or two days is also sufficient. **The park pressure is set to twice the maximum water depth**. In addition, the parameter responsible for the behaviour of the float in contact with the bottom is set so that the float does not immediately rise up after the contact, but stays at the bottom until the next cycle.

In accordance with the procedures set out in Resolution IOC EOC XLI, some coastal countries have requested to be informed reasonably in advance of the Argo floats that might drift into their EEZs. In the Baltic Sea, this procedure only applies to Russia. For floats approaching close to the Russian border, the warning system used by OceanOPS is in operation. In the email warning that our float is approaching the Russian EEZ, contacts are given to the Russian Argo focal points from State Research Institute for Navigation-and Hydrography Ministry of Defence and Far-Eastern Hydrometeorological Research Institute, Russian Federal Service for Hydrometeorology & Environmental Monitoring. Unfortunately, it was never possible to contact by mail any of the focal points. This is a great inconvenience and a loss for the scientific community, because in such a small body of water as the Baltic Sea, which is completely divided into EEZs, international cooperation is especially needed. We experienced this because one Polish float was recovered by an Estonian science vessel, another by a German navy vessel. Collaboration is needed both in handling floats as well as in data processing and data delivery to DMQC. Contrary to appearances, the Baltic databases are quite poor in publicly available CTD data suitable for the validation of float results. Therefore, **for DMQC purposes, it is recommended to perform CTD profiles during floats deployment and recovery and cooperation between operators of various measurement systems is highly suggested**. Another task in Euro-Argo RISE is addressing DMQC's problems, but there are several aspects to this.

The Baltic Sea is a sea of very high variability, both temporally and spatially, and a single measurement is not always representative of the area under study. That is why the Argo float is a valuable device, and the Argo system is an extremely valuable tool for research and monitoring of the Baltic Sea. It enables frequent sampling and appropriate data processing. The variability of the fields is clearly visible in the figure 73 showing the temperatures at various levels. The grey thin lines show the measurement results, the bold colored lines give the results averaged over 7 days. Only averaging a lot of data gives a consistent picture. Both the high variability of properties and their range (e.g. salinity varies in the range from 3 to 28 PSU) means that the accuracy of the Baltic data does not have to be as high as oceanic data. The results obtained from Argo fully meet the requirements for oceanographic data. By contrast, this variety of conditions causes difficulties with DMQC and procedures are yet to be developed (Euro-Argo RISE deliverable D2.7 in Klein et al., 2022). Initial IOPAN analyses show that when validating salinity for the 10-30 m surface layer in the southern Baltic, the distance between the reference profile and obtained from Argo should not be greater than 30 km, and the difference in time should be less than 30 days.

5 Summary and recommendations

5.1 Floats' configuration

The tests done in different targeted Argo operations close to coastal areas of the European marginal seas demonstrate that the platforms' configurations used (listed in tables 18 and 19) are, in most of the cases, adequate to achieve the objectives of the missions (listed in table 17).

Table 17. Objectives of the Argo mission in shallow/coastal areas of European marginal seas.

Marginal sea	Region	Specific objective
Mediterranean Sea	Balearic Archipelago (Palma Bay, Mallorca Island)	Keep the float in shallow/coastal waters. Park and profile pressure at the sea bottom (grounded).
Mediterranean Sea	North Adriatic Sea	Keep the float in shallow waters and relatively far from the coast, and limit its drift. Use a virtual mooring configuration (park and profile pressure at the sea bottom with grounding modality on, cycle time 5 days).
Mediterranean Sea	North Aegean Sea	Keep the float in the targeted area. Use a deep park pressure (also close to the sea bottom).
Mediterranean Sea	Ligurian Sea	Investigate the potential of profiling floats to monitor marginal sea areas close to the coast in the Ligurian Sea. (park pressure at 1000 dbar, cycle time 3 days).
Black Sea	North-western shelf	Monitoring of the north-western shelf. Use a virtual mooring configuration (park pressure and profile at the sea bottom, cycle time 4-5 days).
Black Sea	Western shelf	Keep the float moored and collect time series of high resolution data in shallow waters
Baltic Sea	Northern Baltic Proper	Keep the float in the targeted area, which is very dynamic. Park pressure close to the sea bottom
Baltic Sea	Bothnian Sea, Bothnian Bay	Keep the float in the targeted area. Park pressure near the bottom with typical floats. For Arvor-C or other float designed for bottom contacts at the sea floor.
Baltic Sea	Gdansk Bay	Keep the float in the targeted area.

Three main configuration parameters seem to be crucial: the profile pressure, park pressure and cycle time. **The coastal test missions revealed that a relatively deep profile pressure and park pressure and in some cases a park pressure at the sea bottom is probably the best setting to keep the float for a longer period in the targeted area**. Then, the float should be **recovered**, refurbished, calibrated and re-deployed, as usually done mainly in the Baltic Sea's strategy. Otherwise, the float should be left at sea and re-configured for standard operations in marginal seas. These two options impact on the data quality control since Argo profiles collected mainly in shallow waters are hardly quality checked in-situ: quality control methods exist (see deliverable D2.7 in Klein et al., 2022) but such kind of procedures require the availability of a reference dataset very close in space and time that is usually difficult to have.

Regarding the cycle time, tests show that setting the sampling frequency in the range 1 to 5 (7) days in the Mediterranean and Black Seas (Baltic Sea) appears to allow a balance between the results obtained using short and long cycles: to acquire a great number of profiles near the coast and to check more frequently the platform location and to limit the platform displacement between consecutive profiles, respectively. Other specific mission and technical parameters, mainly linked to grounding management, platform's descending speed and stabilisation have been identified as important and, if properly set, can help in achieving better results.

In table 18 and 19, a guideline is presented to help the float operator to properly set the most important mission and technical parameters for operations in targeted areas close to the coast. The suggested configuration has to be considered as a starting point and then has to be adjusted according to the aim of missions and the characteristics of the area. The main mission and technical parameters' names and codes for Arvor and Apex models are described in table 20 in Annex II.

Table 18. Suggested float configuration of specific parameters for targeted coastal operations in the Mediterranean and Black Sea.

mission parameters	configuration parameters
CONFIG_CycleTime_hours (hours) 24/48 - 120	**CONFIG_PressureTargetToleranceForStabilisation_dbar (dbar)** 10/30
CONFIG_ParkPressure_dbar (dbar) relatively deep or bottom or close to bottom (it depends on the area and type of mission)	**CONFIG_GroundingModeMinPresThreshold_dbar (dbar)** (it depends on the type of mission)
CONFIG_ProfilePressure_dbar (dbar) at least as deep as the park pressure and preferably largely deeper than the bathymetry of the area	**CONFIG_DescentSpeed_mm/s (mm/s)** 20
CONFIG_GroundingMode_LOGICAL (Shift, Stay grounded →virtual mooring**)**	
CONFIG_GroundingModePresAdjustment_dbar (dbar) it depends on the type of mission (few dbar)	

Table 19. Suggested float configuration of specific parameters for targeted coastal operations in the Baltic Sea.

mission parameters	parameter code (APEX)	parameter code (Arvor)
CONFIG_ProfilePressure_dbar and **CONFIG_PistonProfile_COUNT** [Initial/target (Area)]] (db) 50/70 (Bothnian Bay) 50/108 (Bothnian Sea) 120/150 (Northern Baltic Proper) 190/228 (Baltic Proper)	DeepDescentPressure = the target depth in decibars DeepDescentCount = smaller is deeper. Actual value depends on balancing and float type, must be checked with the manufacturer.	MC 12
CONFIG_ParkPressure_dbar (db) Same as max profiling depth. and **CONFIG_PistonPark_COUNT** Same as CONFIG_PistonProfile_COUNT	ParkPressure = the target depth in decibars ParkDescentCount = smaller is deeper. Actual value depends on balancing and float type, must be checked with the manufacturer.	MC 11
CONFIG_CycleTime_hours 6 hours at start, once performance established, gradually to 7 days	DownTime = drift time in minutes, 3600=6h, 100800=7 days UpTime (280) [min], determines how long the float can stay up, transmitting.	MC 2
CONFIG_IceDetection_degC +0.2°C (Bothnian Bay, Bothnian Sea) +0.3°C (Northern Baltic Proper) +0.4°C (Baltic Proper)	IceCriticalT = target temperature in °C	IC5 integer 1/1000 °C e.g. +0.2°C = 200
CONFIG_IceDetectionMixedLayerPMin_dbar (db) 35	IceDetectionP = Ice detection pressure, in db, ice avoidance calculation starts here	IC3, start pressure detection
CONFIG_IceEvasionStopPressure_dbar (db) (18)	IceEvasionP = Ice evasion pressure in db. The depth, when floats stop ascending, if ice is detected.	IC4, stop pressure detection
Ice months (no standard CONFIG variable name available) In Bothnian Bay, Bothnian Sea from Jan to May. Southern areas, needed only on harsh winters. Needs monitoring.	IceMonths (0x000) Hexadecimal number, each bit denotes one month (bit 1 Jan, bit 2 Feb, etc) value 0x000 means ice avoiding is off, each raised bit means ice avoidance is on for the month indicated.	N/A

5.2 Operational monitoring

The set of monitoring tools used and tailored for operations in targeted areas close to the coasts, and additionally tuned for the specificity of the experiments, are indeed the key to succeed in coastal Argo missions. In particular, the Euro-Argo and OceanOPS monitoring tools combined with sea state information, detailed bathymetry maps, near-real time notification systems and a fast data decoding system are fundamental to reach the best float performance. In addition, the in-house developed tools by the partners were useful to respond to the specific needs of each study area.

5.3 Floats' performance

Despite it's early to define the life expectancy of Argo floats in shallow/coastal areas, results are quite satisfactory. The mean half life of Argo platforms for standard operations in the Mediterranean Sea is about 700 days and 150 cycles. Shallow/coastal missions exhibit a slightly lower performance on average, both in terms of time and cycles performed, but there are examples that show a similar behaviour. It has to take into consideration that a comparison between the two statistics is perhaps not fully pertinent, since targeted missions close to the coast are different and in general riskier in terms of survival rate. Nevertheless, we can conclude that most of the coastal Argo operations reached the planned targets.

Rough estimates for the Black Sea are difficult to present, since we can rely on one out of two successful missions only. Nevertheless, the float deployed in the north-western shelf area provided 230 profiles in about 15 months on the north-western shelf of the Black Sea, and it is still alive (in open sea) as of May 2022, well in line with the average life-time of floats in this regional sea.

In the Baltic Sea, floats can typically perform for one to two years, before recovering them becomes reasonable. During their mission, they typically measure 100 - 200 profiles. The deployment locations must be selected in such a way that the floats do not drift on shore or otherwise out of the area, thus ending the mission prematurely. Northern Baltic Proper seems as a viable new location based on the test performed on the Euro-Argo RISE, however further experimentation with the mission parameters should be done to avoid floats drifting from the target area. When estimating float lifetimes in the Baltic Sea it must be noted that most of the missions end in recovery, rather than end of battery life, making it possible to re-deploy the same float, and makes the comparison to other areas more difficult.

5.4 Final recommendations on future Argo operations in shallow/coastal areas

The experiments conducted in the framework of the Euro-Argo RISE project show that targeted shallow/coastal float operations are possible, but they require a **high level of interactivity between the operator and the float**, much higher than what is usually needed for standard operations where interactivity is usually reduced to the minimum and float setting is rarely modified. Hence, an **intense monitoring activity is also required to track the floats and change their configurations when needed**. The latter can be linked up to the cycle time of the float or even to a shorter time scale and at least one operator is needed for this work.

Thinking from an integrated observing system perspective, autonomous and semi-autonomous platforms like Argo floats and Gliders can complement each other but it is important to consider the efficiency and cost-effectiveness of platforms before planning missions. Deep Gliders (1000m) are able to perform dives in a yo-yo shape without any issue from the first 30 to 1000m. As they have a slow pump, their response is not quick enough for shallow waters and their flight characteristics are not great from 0-30m. For shallow waters, a shallow Glider is ideal since it carries a quick pump, and it can perform and respond faster. Glider missions duration is totally dependent on batteries that can last approximately between 1 and 4 months depending on the Glider model, battery type and sensor configuration. Core-Argo floats can perform longer missions in shallow waters (more than one year) with a high frequency cycle time (24 hours or less). The standard cost for refurbishment of a float (general check, battery replacement, sensors' calibration) is around 3.000 €, whilst the battery pack replacement for Gliders is in the range 3.000-15.000 €. Gliders generally require a higher human-machine interaction since a 24-7 piloting is usually requested mostly during night-time and can be reduced during daylight hours. Interaction with Argo floats can be estimated on the order of the cycle time as a maximum for operation in shallow/coastal areas. A team of people is hence requested for glider operations, whilst 1-2 operators can manage a small fleet of Argo floats. The advantage of using Gliders in proximity of coasts is that they are piloted, and hence the risk of running ashore or out of the targeted area is limited when compared to Argo. Anyway, both the platforms can be damaged by collisions when they are at the surface. Bureaucracy is also an important factor to take into consideration, and it seems this is more related to Gliders. **Most of the time bilateral agreements are needed in small basins that have EEZs and territorial waters, and permits have to be released by the Maritime Authority: hence, it is highly recommended to ask for permits several months in advance of the deployment date (Euro-Argo RISE D8.2 in Belbeoch et al. (2022))**.

The work carried on in WP6 with Argo floats have shown that:

1. **It is sometimes possible to reduce the float drift from the targeted area**
2. **A great number of profiles can be acquired close to the coast**
3. **Repeated grounding events are manageable**
4. **Argo is a powerful monitoring platform that can complement coastal measurements acquired by other systems.**

Hence, **Argo floats can be used (alone or in synergy with other observing systems) in proximity to the coast and in shallow waters, especially where the sea currents are not strong enough to make the float drift away rapidly from the targeted area**. If properly managed, missions' length of Argo platforms can be estimated approximately at one year (or more, it depends on the region), then the **float should be recovered (especially in the Baltic Sea where an international effort for floats recovery in EEZs has started**) since there are chances that: 1) it drifts out of the targeted area; 2) it beaches; 3) it gets stuck at the sea bottom. About one year is hence the estimated time after that a re-deployment or a replacement of the platform is requested.

Argo operations in targeted shallow/coastal waters are in early stages. Nevertheless, the work done in the framework of this WP is promising and provides robust strategies to operate Argo floats in coastal areas. Experiments have been conducted with the present technology adapted to achieve the mission targets (virtual mooring configuration, anchored float, specific settings) and tests have been done with some float models/types. Future work should be focused on testing other float models, new technology and methodology. The output of this work has highlighted the need to strongly limit the float drift both during the park phase at the seabed and at predefined depths. *Ad hoc* mechanisms should be designed and tested, since at the moment we can rely only on technology onboard the Arvor C model (spikes at the bottom of the float). Moreover, other improvements could be oriented towards the real time estimation of the 3D current field directly by the float, in order it can automatically find the best park pressure. The anchored float methodology should also be further investigated through the testing of new designs and the optimization of the float buoyancy when the platform is attached to a rope or a fishing line.

The expansion and development of this extension of Argo is particularly useful for operations in the Mediterranean and Black Sea, where targeted missions close to the coast were done for the first time. In the Baltic Sea the Argo operations have been ongoing since 2013, and currently Finland and Poland are actively operating in the area, and Germany has recently started their Argo operations on the Baltic Proper. Further development of the operations are still needed, to encourage more operators for the area, and expand the coverage. Experiences done with Euro-Argo RISE demonstrate one new operating area (the Northern Baltic Proper). Typically, the drift of the float is limited by careful selection of the deployment area and diving depth. Experiments with bottom landing Arvor-C, and Polish experiments with virtual mooring show promising possibilities with other methods of float control on the area. Experiments with a float attached to the bottom with a fishing line show that it is possible to monitor shallow, sheltered waters using Argo floats. The advantages of the Argo system - real-time data, surface-to-bottom profiling, are particularly important in this case.

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7 Annex I: Cheat sheet for Argo float operations in the European marginal seas

Float requirements

Provor, Arvor, Arvor-C (NKE manufacturer) and Apex (Teledyne Webb Research manufacturer) tested, but also another models can be considered in future experiments

Two-way Iridium communication system

Ice Avoiding Algorithm, if deploying to areas with seasonal ice

Check possible salinity values, make sure the float is balanced to cope with them

Pre-deployment operations

Make sure float is in pressure activation mode, and ready to start mission before moved to ship

Make sure an operator is available to check floats first performances

Get information on shipping and fishing activity in the area of interest

Analyse previous missions in the area (if available)

Check earlier deployments in the area to determine appropriate diving depths

Setup float communication, use short cycle time initially (6-12; 24-48 hours)

Get information on bathymetry and circulation system in the area of interest

Check and eventually adjust the expected hour at surface for the first profile and the following ones

Save a log file after float testing (battery voltage, internal vacuum, sensors communication, electrovalve and pump action) and configuration

Deployment should be timed on ice-free time on the deployment area, and initially ice avoidance turned off to confirm float works otherways, before activating it, if possible

Deployment operations

Check all covers from sensors are off

Ensure float doesn't hit anything on its way

Perform at least a CTD cast at the deployment location

Check the first technical message transmission

Take note on weather, sea state and bathymetry

During mission

Operators should check the floats first profiles, adjust park pressure and other parameters to final targets based on the area. Once float performance is ensured, cycle time can be increased to target

Monitor that the float stays in the targeted area: setting park pressure based on current area, even allowing constant bottom contacts, can prevent drifting

If seeing beforehand a rough weather, can time the surfacing to avoid drifting

If drifting too far, check for recovery options or shift to standard mission for marginal sea

Crucial technical and mission parameters

Start with the suggested configuration and on the basis of previous experiences (if available) and then tune the setting according to the needs. Main parameters are:

CONFIG_CycleTime_hours

CONFIG_ParkPressure_dbar

CONFIG_ProfilePressure_dbar

CONFIG_GroundingMode_LOGICAL

CONFIG_PressureTargetToleranceForStabilisation_dbar

CONFIG_GroundingModeMinPresThreshold_dbar, descending speed

Ice-avoidance: critical Temperature, min-max pressures when measuring

Useful monitoring tools

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

https://dataselection.euro-argo.eu/

https://floatrecovery.euro-argo.eu/

https://www.ocean-ops.org/board?t=argo

https://argovis.colorado.edu/

https://www.marinetraffic.com/

https://resources.marine.copernicus.eu/products

https://www.emodnet-humanactivities.eu/view-data.php

https://sportulo.socib.es/~modelling/WMOP/EuroARGO-RISE_MallorcaChannel/latest.html

http://apps.socib.es/dapp/

https://ggmb.org/

Legend (Black → European marginal seas, Orange → Mediterranean Sea, Green→ Mediterranean & Black Sea, Red → Baltic Sea)

8 Annex II: Main mission and technical parameters names

Table 20. Main mission and technical parameters' names and codes for Arvor and Apex models.

parameter name	parameter code (Arvor model)	parameter code (Apex model)
CONFIG_ParkPressure_dbar (dbar)	**MC 11**	ParkPressure (dbar) ParkDescentCount
CONFIG_ProfilePressure_dbar (dbar)	**MC 12**	DeepDescentPressure DeepDescentCount
CONFIG_CycleTime_hours (hours)	**MC 2**	DownTime
CONFIG_GroundingMode_LOGICAL	**MC 24 (0=Shift, 1=Stay grounded)**	N/A
CONFIG_GroundingModePresAdjustment_dbar (dbar)	**MC 25**	BuoyancyNudge (Piston position steps, not dbar)
CONFIG_PressureTargetToleranceForStabilisation_dbar (dbar)	**TC 5**	ParkDeadBand (default 10.0 dbar, present in APF11 or newer models)
CONFIG_GroundingModeMinPresThreshold_dbar (dbar)	**TC 11**	N/A
CONFIG_DescentSpeed_mm/s (mm/s)	**TC 13**	N/A, PistonPosition and FullExtension determine the speed.
CONFIG_IceDetection_degC (°C)	**IC5**	IceCriticalT
CONFIG_IceDetectionMixedLayerPMin_dbar (db)	**IC3**	IceDetectionP
ICONFIG_IceEvasionStopPressure_dbar (db)	**IC4**	IceEvasionP
Ice months (no standard CONFIG variable name available)	**N/A**	IceMonths, determines in which months the ISA is active

9 Annex III: Main mission and technical parameters configurations used for float 6903271

Table 21. Summary of mission commands changed during the shallow waters mission of float WMO 6903271 (Arvor model).

Platform	**initial specific parameters**	**15/10/2019**	**10/11/2019**	**11/11/2019**	**26/11/2019**	**27/02/2020**
MISSION COMMANDS FOR WMO 6903271	CONFIG_CycleTime_hours (hours) 24	CONFIG_CycleTime_hours (hours) 48	CONFIG_CycleTime_hours (hours) 2	CONFIG_CycleTime_hours (hours) 15	CONFIG_CycleTime_hours (hours) 96	CONFIG_CycleTime_hours (hours) 1
	CONFIG_ParkPressure_dbar (dbar) 150			CONFIG_ParkPressure_dbar (dbar) 50	CONFIG_ParkPressure_dbar (dbar) 150	
	CONFIG_ProfilePressure_dbar (dbar) 150					
	Threshold Intermediate/Bottom pressure (dbar) 500					
	Surface slice thickness (dbar) 1					
	Intermediate slice thickness (dbar)					
	MC 21 5 Bottom slice thickness (dbar) 5					
	CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 1					

	CONFIG_GroundingModePresAdjustment_dbar (dbar) 5					
	electrovalve action duration on surface (cseconds) 800					
	CONFIG_PressureTargetToleranceForStabilisation_dbar (dbar) 30					
	second threshold buoyancy reduction (dbar) 7					
	CONFIG_GroundingModeMinPresThreshold_dbar (dbar) 200					
	descending speed (mm/s) 25					
	ascent end pressure (dbar) 10					

28/02/2020	**02/03/2020**	**01/04/2020**	**02/04/2020**	**06/04/2020**	**08/04/2020**	**15/04/2020**	**16/12/2020**	**25/01/2021**
CONFIG_CycleTime_hours (hours) 65	CONFIG_CycleTime_hours (hours) 120	CONFIG_CycleTime_hours (hours) 1		CONFIG_CycleTime_hours (hours) 2	CONFIG_CycleTime_hours (hours) 24	CONFIG_CycleTime_hours (hours) 120		
CONFIG_ParkPressure_dbar		CONFIG_ParkPressure_dbar (dbar) 10			CONFIG_ParkPressure_dbar		CONFIG_ParkPressure_dbar	

(dbar) 1000					(dbar) 1000		(dbar) 200	
CONFIG_ProfilePressure_dbar (dbar) 1000		CONFIG_ProfilePressure_dbar (dbar) 10			CONFIG_ProfilePressure_dbar (dbar) 1000		CONFIG_ProfilePressure_dbar (dbar) 1500	
				electrovalve action duration on surface (cseconds) 500	electrovalve action duration on surface (cseconds) 800			
				second threshold buoyancy reduction (dbar) 4	second threshold buoyancy reduction (dbar) 7			
			CONFIG_PressureTargetToleranceForStabilisation_dbar (dbar) 10					
			CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 0				CONFIG_GroundingMode_LOGICAL (0=Shift, 1=Stay grounded) 0	
							CONFIG_GroundingModePresAdjustment_dbar (dbar) 100	
								descending speed (mm/s) 20
							Threshold Intermedi	

							ate/Bottom pressure (dbar) 700	
							Surface slice thickness (dbar) 2	
							Intermediate slice thickness (dbar) 10	
							Bottom slice thickness (dbar) 25	

10 Annex IV: Quality checks

Mediterranean Sea: Balearic experiment

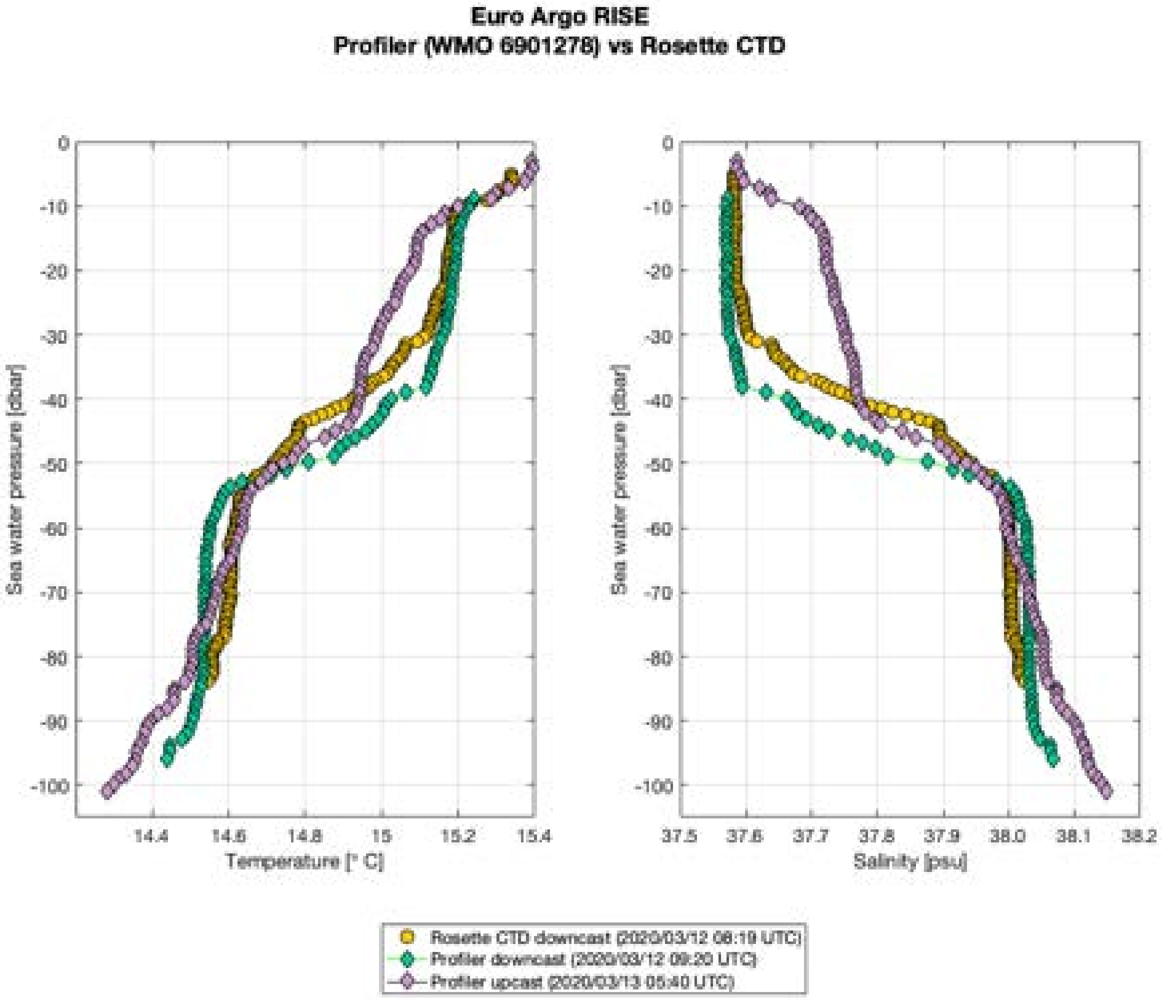


Figure 74. Temperature (a) and salinity (b) comparison from ship rosette CTD and profiling float WMO 6901278.

Mediterranean Sea: North Adriatic experiment

When float profiles are compared with the most recent reference CTD data that are very close in space to the float locations, it is evident that the natural variability is very high. In figure 75, the salinity of the first profile of float 6903783 is depicted in black while other colours represent the salinity reference profiles. The red colour means that the historical data are more recent with respect to the float ones, while magenta means that the float data are more recent than the historical ones (the maximal difference is 1 year). Reference salinity ranges approximately between 38.8 and 38.9 in the deepest part of the water column and hence it is extremely important to have a CTD cast at the deployment time of the float in order to perform a reliable comparison and check the conductivity sensor behaviour on board the platform.

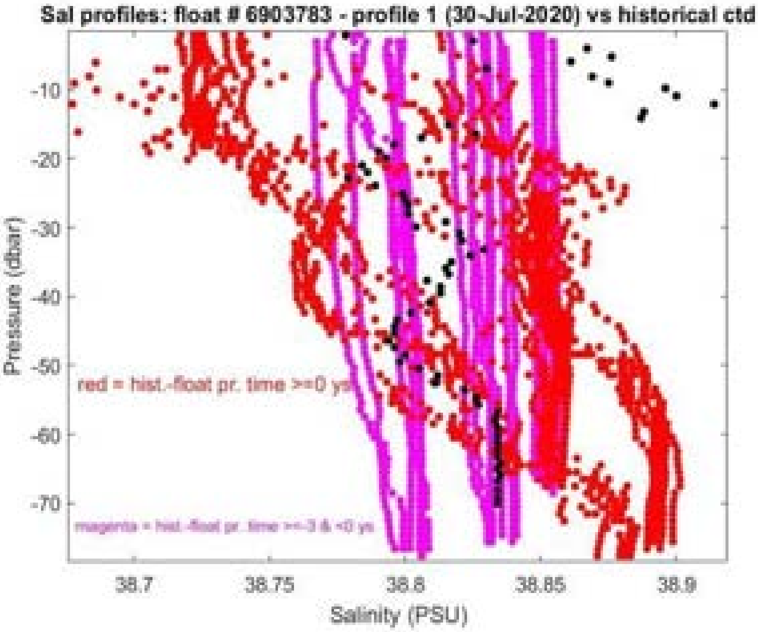


Figure 75. Salinity of first float WMO 6903783 profile (black dots) and reference CTD profiles (purple and red dots) colour-coded per time difference with respect to float profile.

In figure 76 it is shown the difference between the availability (for float WMO 6903800) and not availability (for float WMO 6903783) of a reference profile at the time of the float deployment. When a CTD cast is available, float salinity can be checked with a higher degree of accuracy. In the example, the difference between the float and the reference salinity is below 0.01 and we are confident that the float’s conductivity sensor is performing well.

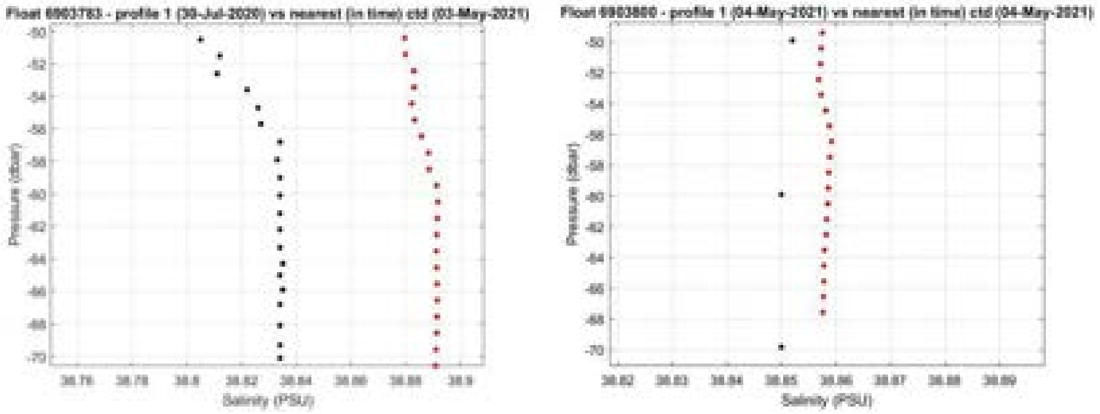


Figure 76. The salinity float profile number 1 (black dots) of float WMO 6903783 (left panel) and WMO 6903800 (right panel) compared to the nearest in time reference profile (red dots) at the maximal depth reached by the float.

The analysis of the θ-S diagram of Argo profiles and most recent historical data (float WMO 6903783 is shown in figure 77) shows a good agreement in the deepest layers of the water column.

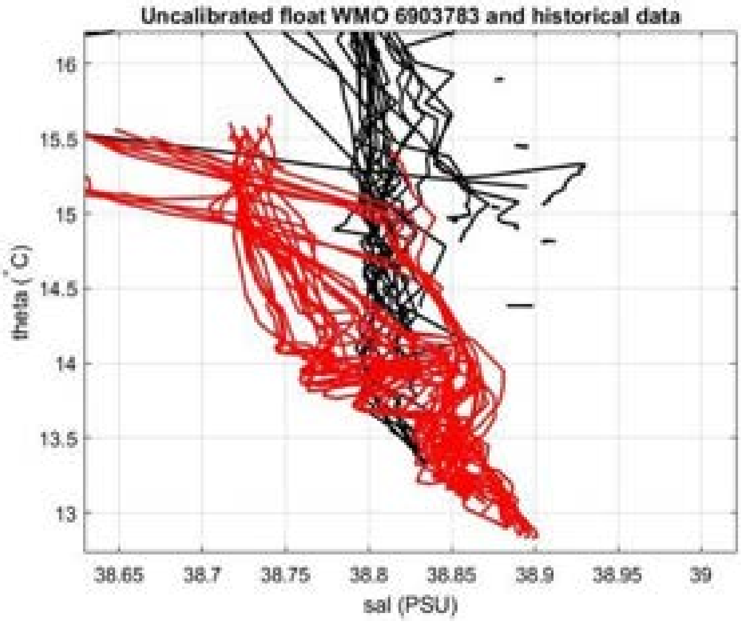


Figure 77. Float WMO 6903783 salinity profile (black lines) and historical data (red lines).

The float salinity and potential temperature data are compared with the historical variability taking into account CTD profiles within 50 km from float locations (figure 78 for float 6903800). The Argo profiles outside the standard deviation range are probably due to some particular events that have an important impact on the hydrography of the area. Taking in account only the float profiles inside the standard deviation range, the mean of float salinity data and the mean of the most recent reference salinity data (2019-2021) are compared (figure 78). The difference between the two salinity means is less than 0.05 below 50 metres.

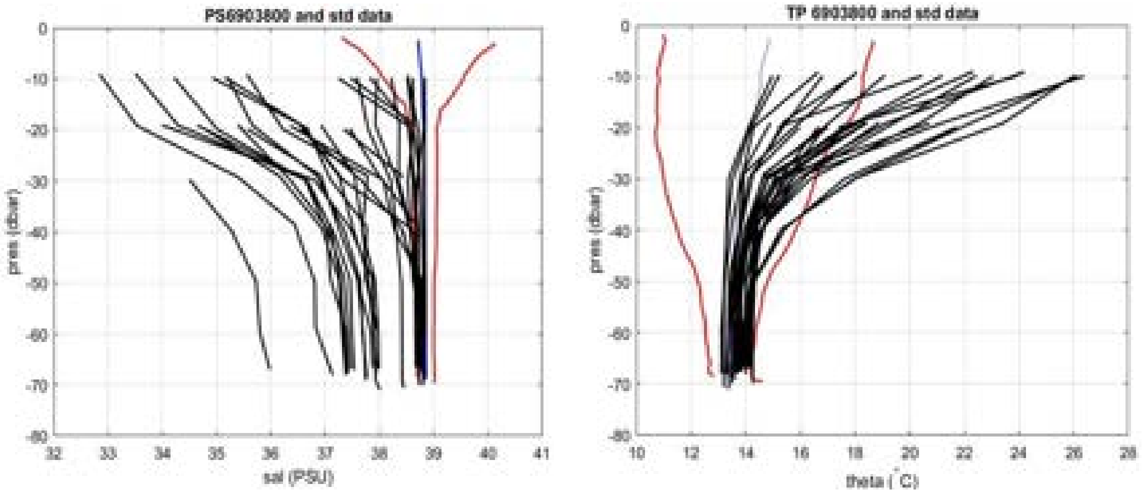


Figure 78. Float WMO 6903800 salinity profiles (black lines in left panel) and potential temperature profiles (black lines in right panel). The mean of the most recent CTD data is in blue and standard deviation is in red.

The variability of the area was investigated using model output data retrieved from the CMEMS catalogue, using the analysis products for the Mediterranean Sea physics (Clementi et al, 2021). Figure 79 shows the Hovmöller diagram of salinity averaged between 40 and 60 metres depth in days close to the first cycles of the float. The model clearly highlights a high zonal salinity gradient and natural variability.

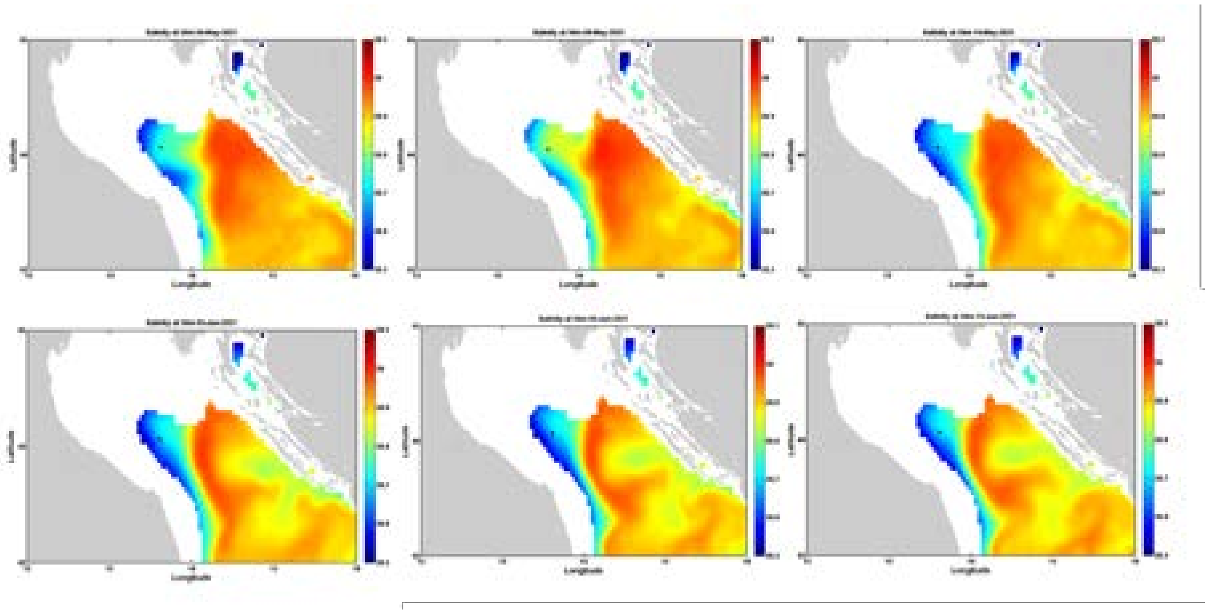
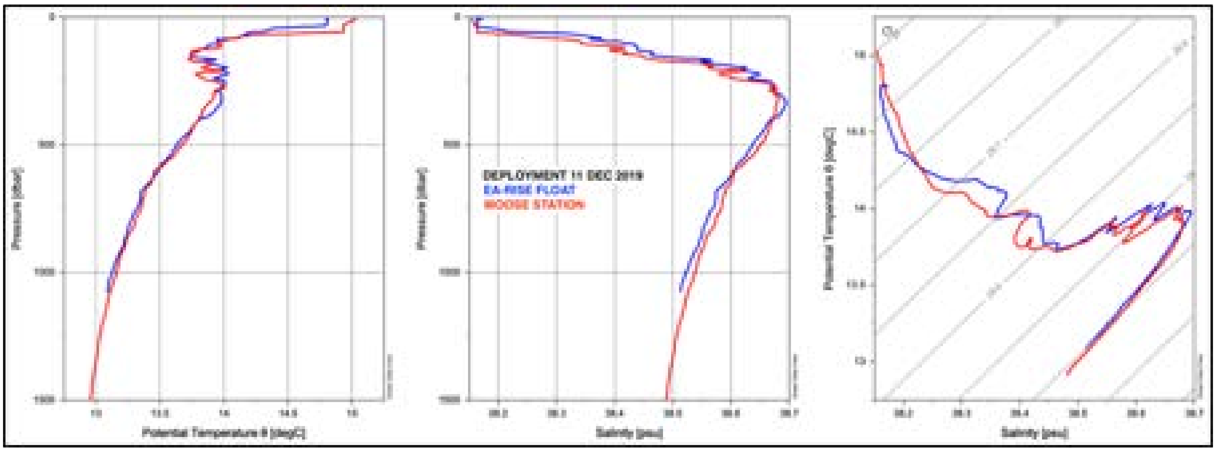


Figure 79. Hovmöller diagram (y-latitude/x-longitude) of salinity in days close to the first cycles of the float WMO 6903800. The black dot is the float's location.

Mediterranean Sea: Ligurian experiment



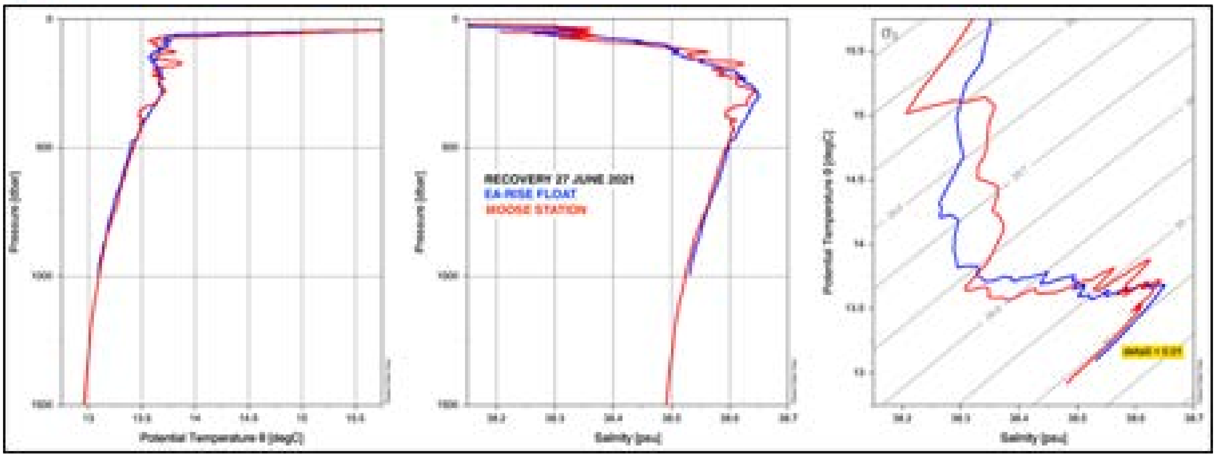


Figure 80. Comparison of CTD profiles between the float autonomous sensor (SBE41, blue lines) and reference shipborne casts (SBE911, red lines). Upper panels: temperature and salinity profiles at deployment. Lower panels: temperature and salinity profiles at recovery.

Black Sea: North-Western experiment

The comparison of these 3 selected salinity float profiles with the closest (in space and time) salinity reference profile in shown in figures from 81 to 83. The agreement between the selected float salinity profiles and the historical salinity profiles is good in the intermediate and deeper layers, where the water column is more stable.

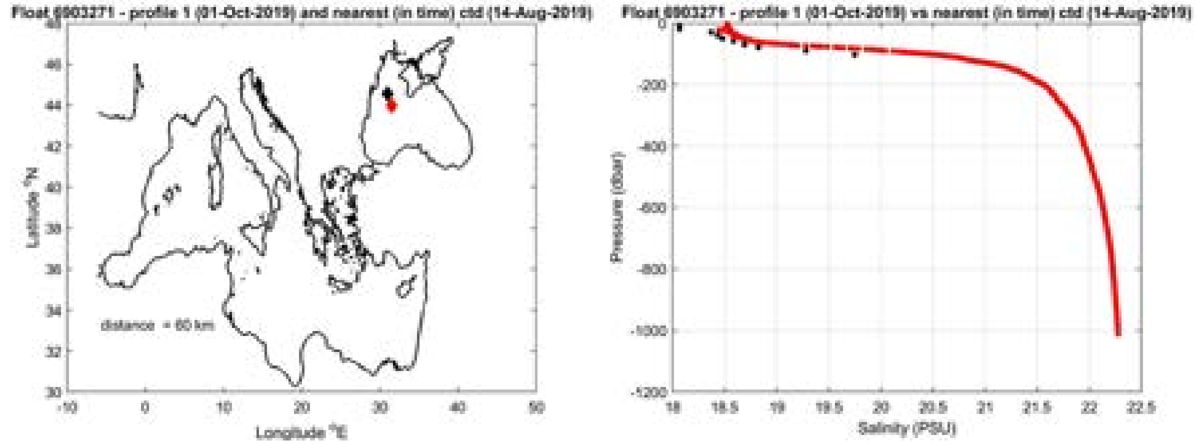


Figure 81. Float 6903271. The salinity float profile number 1 (black dots) are compared to the nearest in time reference profile (red dots). The locations of the two profiles and their distance is given in the left panel.

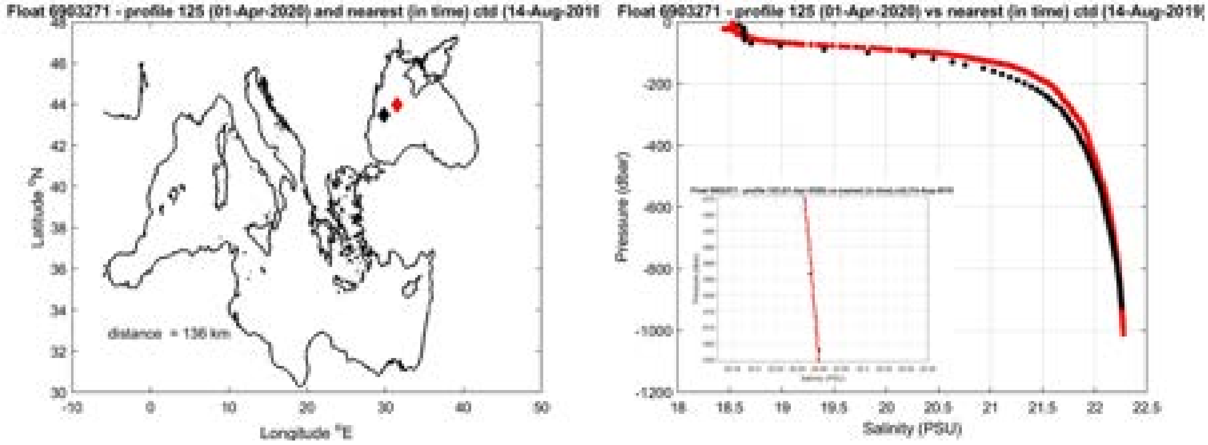


Figure 82. Float 6903271. The salinity float profile number 125 (black dots) are compared to the nearest in time reference profile (red dots). The locations of the two profiles and their distance is given in the left panel. The small plot shows the comparison in the deeper layers.

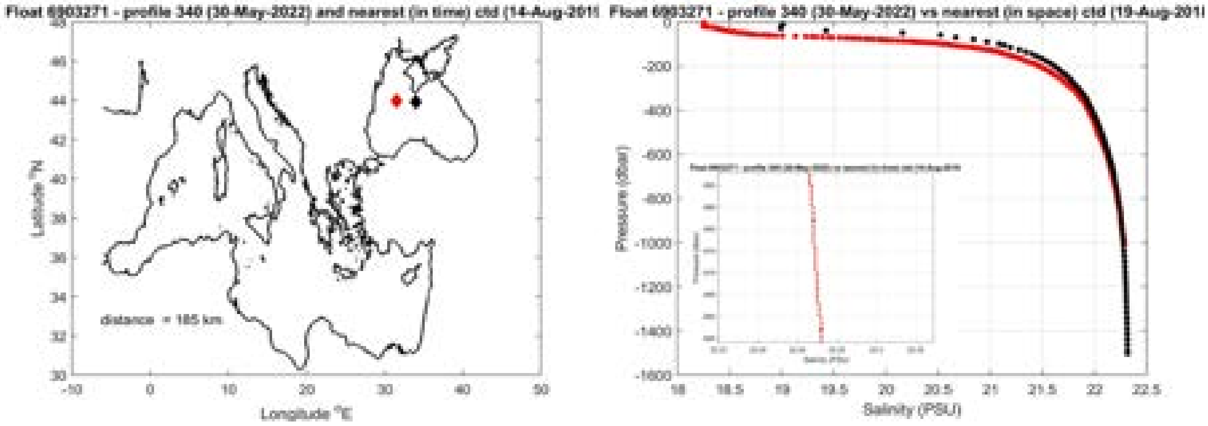


Figure 83. Float 6903271. The salinity float profile number 340 (black dots) are compared to the nearest in time reference profile (red dots). The locations of the two profiles and their distance is given in the left panel. The small plot shows the comparison in the deeper layers.

The analysis of the potential temperature (θ)-salinity (S) diagram of deeper profile segments of float and reference data (figure 84) shows a good agreement between the two datasets.

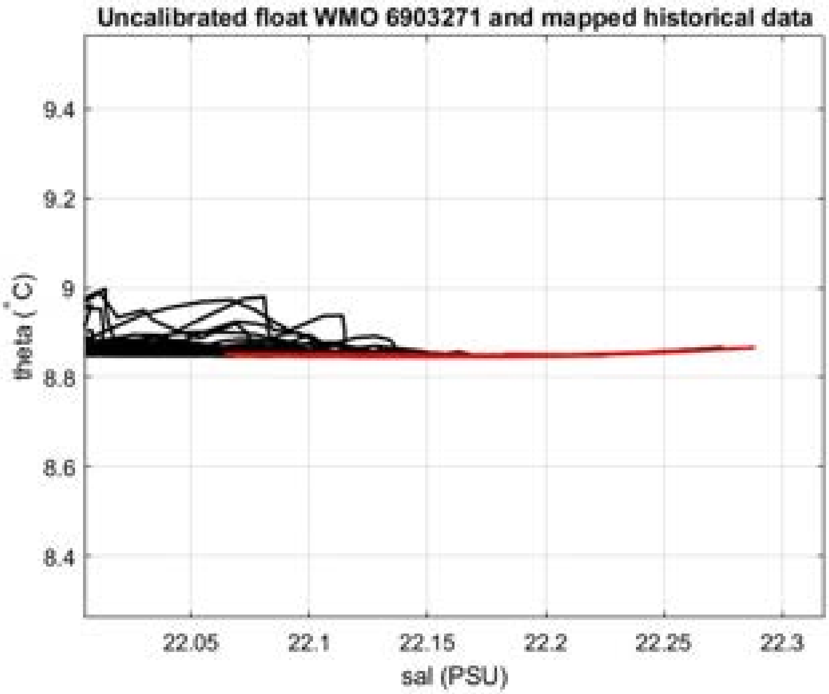


Figure 84. Float 6903271.Uncalibrated float salinity profile (black lines) and mapped historical data (red lines) in the most uniform part of the θ-S curve.

Baltic Sea: Central and Northern Baltic experiment

In a rare opportunity, 08/10/2020 R/V Aranda was near both Northern Baltic Ago floats, and was able to perform comparison measurements for both. For WMO 6903704 the comparison measurement was made 17:45 UTC at 58.963 °N 20.271 °E. This was compared to profile 43, 16:50 UTC at 58.957 °N 20.272 °E (figure 85). For further details of the quality control procedures on Baltic Sea, see Deliverable D2.7 in Klein et al 2022.

For WMO 6903703 the comparison measurement was made 21:33 UTC at 58.976 °N 19.693 °E. This was compared to profile 42, 20:49 UTC at 58.980 °N 19.683 °E (figure 86).

Both measurements had thus under one kilometre, and under one hour difference.

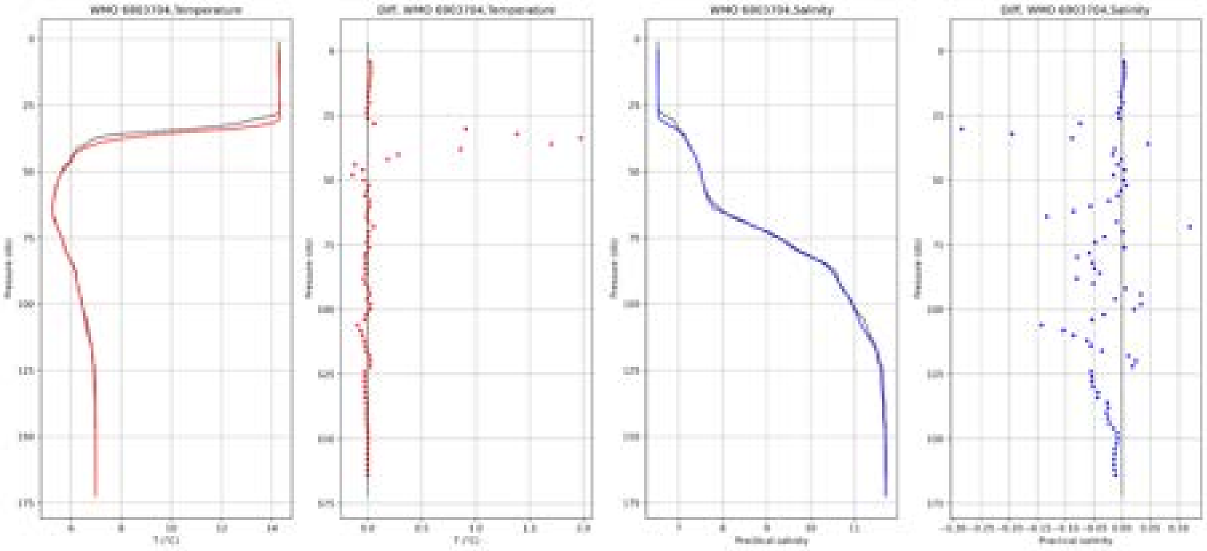


Figure 85. Comparison of Aranda CTD (grey) with float WMO 6903704 on 08/10/2020 with under one kilometre, and one hour differences. From left to right, Temperature profiles, temperature difference with Aranda CTD, float, Salinity profiles, difference with Aranda CTD and profile.

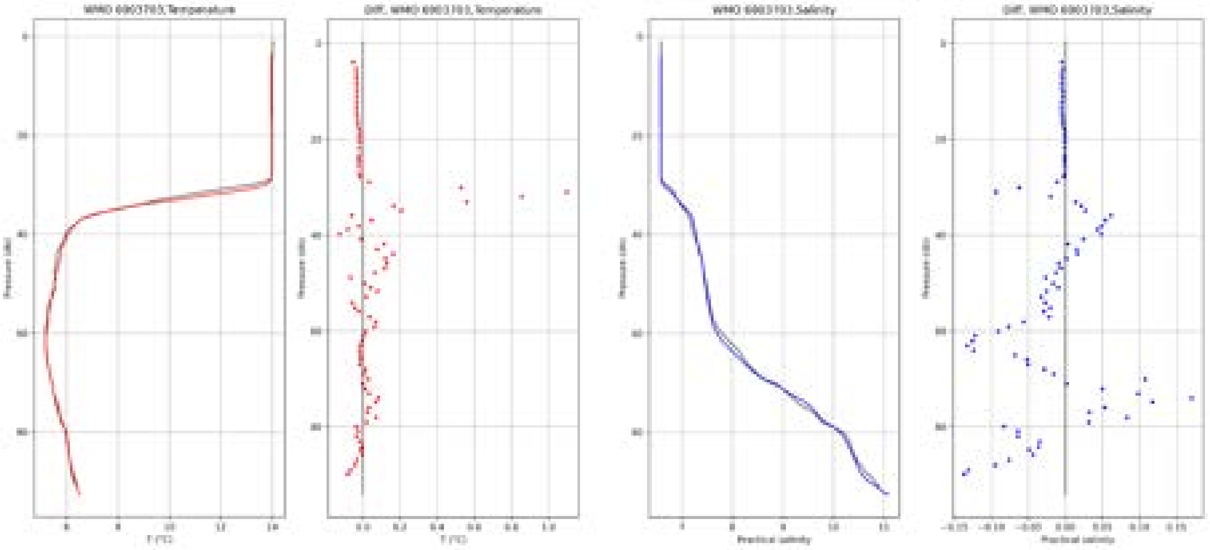


Figure 86. Comparison of Aranda CTD (grey) with float WMO 6903704 on 08/10/2020 with under one kilometre, and one hour differences. From left to right, Temperature profiles, temperature difference with Aranda CTD, float, Salinity profiles, difference with Aranda CTD and profile.

A comparison profiling was also made for Arvor-C (WMO 6903702) during the Aranda cruise. Even if the floats timing could not be changed during the mission the cruise timing was lucky enough to get a close match. Comparison measurement was done 13/10/2020 00:52 UTC, while closest float profile was at 13/10/2020 1:08 UTC. Ship CTD was at 61.406 °N 20.214 °E and the floats profile at 61.404 °N 20.216 °E. The comparison (figure 87) indicates similar quality of measurement than other established Argo models. As Arvor-C always descends to the bottom, and has 'feets' to hold it steady, it moves considerably less than other models (figure 64). Based on this, such a construction is, at least in this part of the Baltic Sea, a promising option to complement the typical, freely drifting missions, even if this specific mission was abruptly ended by battery problems.

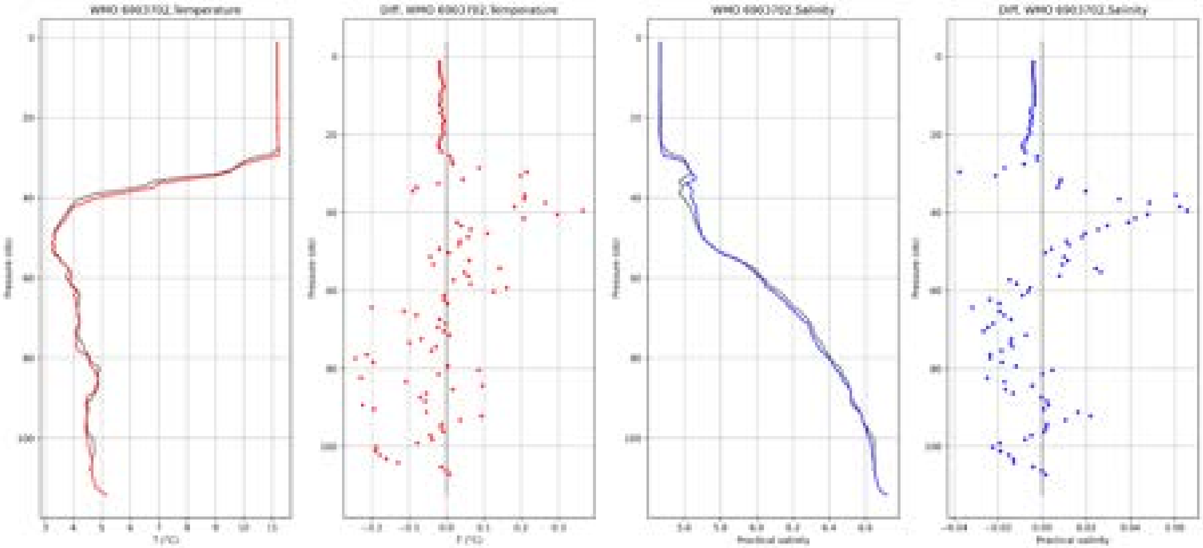


Figure 87. Comparison of Aranda CTD (grey) with float WMO 6903702 on 13/10/2020 with under one kilometre, and one hour differences. From left to right, Temperature profiles, temperature difference with Aranda CTD, float, Salinity profiles, difference with Aranda CTD and profile.