ARGO-ITALY ANNUAL REPORT 2022
CONTRIBUTION TO EURO-ARGO ERIC

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Approved for release by: ....

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1. Introduction

a. Why is the ocean important and why do we need to study it?

The ocean covers 71% of the Earth's surface, and its influence on our everyday lives cannot be understated. The ocean stores enormous amounts of carbon and heat and, as a consequence, regulates the climate of our planet. The ocean also regulates the water cycle and ocean surface properties have a huge impact on day-to-day weather. Finally, the ocean supplies food to billions of people around the world.

Monitoring and studying the current state and evolution of oceanic properties is crucial to better understand how life on Earth is affected by climate change, to improve predictions of weather forecasting, to improve early warning systems of hurricanes and tsunamis, and to understand how changes in biogeochemical cycles are affecting the ecosystem services provided by the ocean. Overall, ocean data are used to save human lives, to protect ocean ecosystems, and to support all human activities linked to the ocean.

b. The international Argo programme

The Argo programme is the most important in-situ component of the Global-Ocean Observing System. Argo is based on about 4000 floats distributed in the global ocean (figure 1).

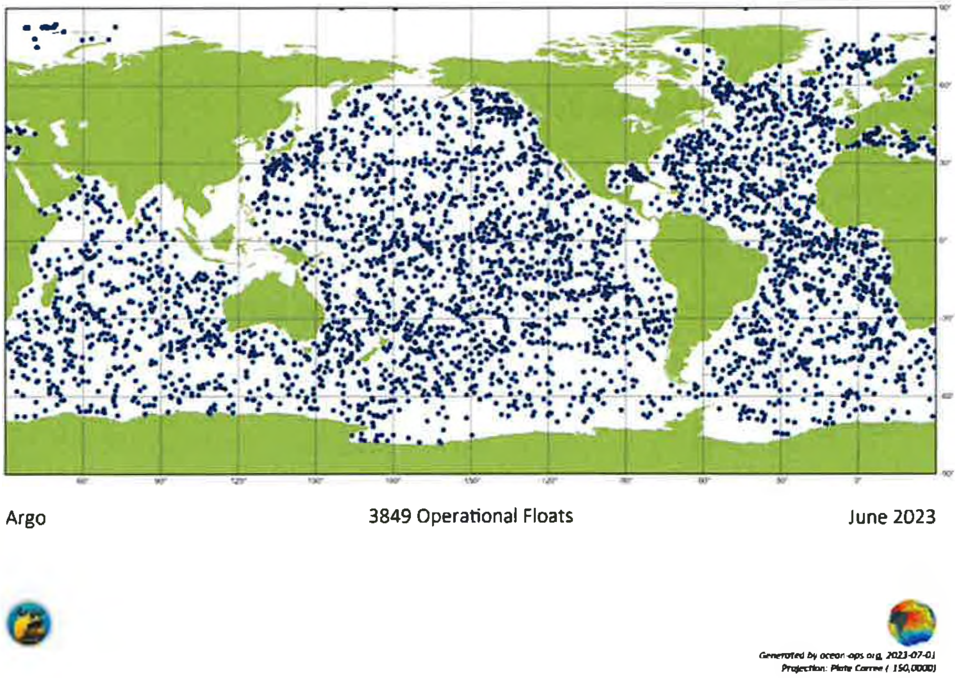


Figure 1. World wide distribution of active Argo floats as of June 2023.

A float is an autonomous platform capable of regulating its buoyancy that, after being deployed in the ocean, is parked at 1000 m (in the open ocean) where it drifts with currents. Every 10 days (or less in Marginal Seas), the float rises to the surface while collecting measurements that are transmitted to shore via a satellite link (figure 2). Argo data are then automatically processed and made freely available in near real time to scientific users and operational oceanographic centres. Argo is one of the most cost-effective ways to monitor the ocean interior on a long-term basis.

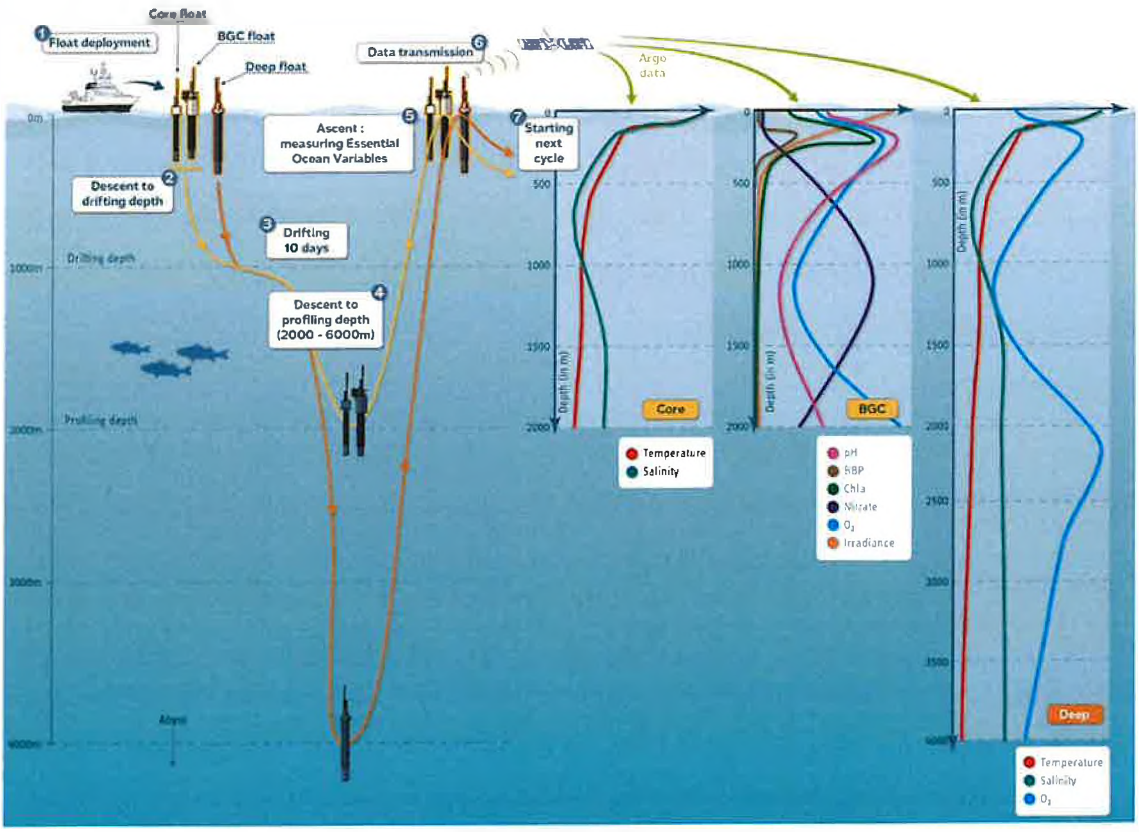


Figure 2. Typical cycle and measured parameters of the three Argo float types: core-Argo, BGC-Argo and Deep-Argo.

c. Objectives

The overall aim of Argo is to understand the ocean's role in Earth's climate to be able to make improved estimates of how it will change in the future.

Specific objectives are:

- To measure the ocean heat content;
- To measure changes in sea level;
- To understand changes in global rainfall patterns by measuring changes in salinity;
- To better understand changes in the ocean carbon, oxygen and nutrient cycles;
- To investigate the dynamics of oxygen minimum zones, ocean acidification, phytoplankton communities and the biological carbon pump;
- To investigate and explore the ocean.

d. Argo missions

Argo is divided into three missions: Core Argo, Deep Argo and Biogeochemical Argo. Core and Deep Argo focus on collecting profiles of temperature and salinity between 2000 (Core) or 6000 m (Deep) to the surface. Biogeochemical Argo (BGC Argo), besides temperature and salinity, adds six biogeochemical variables: dissolved oxygen, nitrate, pH, chlorophyll fluorescence, suspended particles, and downwelling light.

e. Argo achievements

- Argo is uniquely suited to observe our changing climate and is a key player in addressing societal challenges linked to sea level rise, ocean heat content and warming, and circulation.
- Using Argo measurements, scientists have dramatically improved estimates of the ocean heat content and can now calculate how and where ocean heat content is changing. Since seawater expands as it warms, its contribution to sea level rise can also be estimated.
- In addition, Argo observes the ongoing intensification of the water cycle as the planet heats up. Warmer air stores and transports more water, so dry areas of the world have increased evaporation while wet places have higher precipitation. Argo observations of upper ocean salinity show that relatively salty (high evaporation, low precipitation) areas of the ocean are getting saltier while fresh (low evaporation, high precipitation) areas are getting fresher.
- Real-time Argo data are used by operational weather forecasting centres around the world to improve weather forecast and climate predictions. Profiling floats deployed in the tropical oceans during cyclone season, enable improved storm-intensity forecasts.

1.1 Argo Italy

Argo Italy is the Italian contribution to the international Argo programme and is an Italian Research Infrastructure that since 2014 also contributes to the Euro-Argo European Research Infrastructure Consortium (Euro-Argo ERIC).

Argo Italy focuses its activities in the Mediterranean Sea that is one of the main "hot-spots" of climate change and is known to respond to climatic changes with amplified signals. Additional regions of interest are the Black Sea and the Southern Ocean including the Ross Sea.

a. Objectives of Argo Italy

- To strengthen the Italian role in ocean observation at international level.
- To contribute to the international Argo programme by maintaining and strengthening the Core-Argo fleet.
- To contribute to the international Argo programme by implementing quality-control procedures and providing high-quality data to the Argo Global Data Assembly Centres.
- To study the deep Mediterranean waters, their properties and circulation, by deploying Deep-Argo floats in the Mediterranean Sea.
- To strengthen physical and biogeochemical observations by adding oxygen sensors to all Core-Argo floats.
- To monitor and investigate the health of marine ecosystems, and the dynamics of biogeochemical cycles by deploying BGC-Argo floats (ITINERIS project).
- To support the international BGC-Argo programme by testing alternative sensors (e.g., for nitrate, suspended particles) on Italian floats (ITINERIS project).
- To contribute to developing and testing new biogeochemical sensors and new sampling strategies (ITINERIS project).

b. Platforms

Argo Italy is an autonomous and integrated system of multidisciplinary marine observations mainly carried out by profiling buoys (Argo). Surface drifters, and glider activities are included to a much lesser extent to complement the monitoring activities. Italy has assumed the role of coordinator of drifter activities for the Mediterranean and the Black Sea and also in the tropical Atlantic, and has participated in international campaigns with gliders (integrated into EGO - Everyone's Gliding Observatories).

- **Argo floats**

  Platform description is provided in Introduction (point b and d).

- **Gliders**

  Gliders are an autonomous underwater vehicles (AUV) that uses changes of its buoyancy to move along the water column in the ocean in order to collect physical and biogeochemical ocean properties. Wings are used to convert vertical displacement into horizontal motion, resulting in a vertical sawtooth dive reaching 1000 m depth, and a horizontal speed of about 1 km/h. Compared to the traditional shipboard techniques, the glider provides a large amount of data on a finer temporal and spatial scale, with very low power consumption and management costs.

- **Drifters**

  Drifters are a lagrangian buoys that remains at surface following the local current and transmitting the surface temperature and GPS position. Measurements are generally taken every hour, and the batteries provide power for almost 2 years. Over the years, various types of drifters have been developed to meet oceanographic and scientific needs.

c. Impacts of Argo-Italy

- Argo Italy is contributing significantly to **monitoring and understanding the status and health of the Mediterranean Sea** (https://sdgs.un.org/goals/goal13, https://sdgs.un.org/goals/goal14).
- **Data produced by Argo Italy are widely used by the scientific community and by the operational oceanographic services and** this has a strong impact in climate-change studies, marine environmental protection, economic development and services to society (see an example at http://www.bio.isprambiente.it/cadeau/).
- Argo Italy provides the **data needed by operational ocean monitoring systems** to significantly improve atmosphere and ocean forecasts. Argo Italy is essential to producing the marine core products and downstream services of European Union **Copernicus Marine Environment Monitoring Service** - CMEMS (see product list for the Mediterranean Sea).

- Argo-Italy data are routinely **assimilated in the operational physical and biogeochemical models of the Mediterranean Sea**.
- Argo-Italy data are distributed in near real time on the **Global Telecommunication System** (GTS) that is a communication network critical for **forecasting and warnings of hydrometeorological hazards** (https://argo.ucsd.edu/organization/argo-data-system/).
- Argo Italy **contributes to other international oceanography programmes**, such as the Mediterranean Oceanography Network for the Global Ocean Observing System (**MONGOOS**) and the Global Earth Observation System of Systems (**GEOSS**)
- Argo-Italy data are also distributed through **other data networks** like: European Marine Observation and Data Network (EMODnet).
- Argo-Italy data are used to build **Ocean Monitoring Indicators** like the ocean heat content that is a key factor to measure global warming.
- Together with other observing networks, Argo-Italy data contribute to the **good environmental assessment** by quantifying several **MSFD indicators**, such as hydrographic changes and eutrophication.
- Argo-Italy **data are used by Italian regional users** (Agenzie ARPA regionali, Protezione Civile, Laboratorio di monitoraggio e modellistica ambientale in Tuscany) to improve regional forecasting models of marine currents, marine safety, coastal and marine environmental health, marine resources, climate, and daily and seasonal forecast.
- Argo-Italy data are used to **improve weather and ocean forecasts** to prevent catastrophic phenomena and extreme events.
- Argo Italy's focus on the Mediterranean Sea has provided a unique dataset to study **temperature and salinity trends of different water masses** and to monitor in real time extreme events such as **heat waves** and **medicanes** (Mediterranean tropical cyclones) that increasingly affect our seas. Papers on these topics have been published in prestigious scientific journals.
- Argo-Italy floats are also deployed in remote regions of the Earth like the **Ross Sea polynya** to study the water characteristics and formation and their modification in a rapidly changing environment as part of the Programma Nazionale di Ricerche in Antartide (PNRA).
- BGC-Argo data provided by Argo Italy contribute to studying key processes of the **carbon cycle** and to understand and quantify carbon sequestration.

1.2 Webpage of Argo-Italy data and activities

The operation of the instruments at sea and the collection of data started in February 2012, and a dedicated website was developed to support the activity and display in real-time data related to Argo-Italy operations, to post graphical and tabulated summaries, news and connected links, related to Argo-Italy. The website has been improved and updated to provide a better and more flexible overview of activities: http://argo.ogs.it/#/ (figure 3). Italian float distribution in the Mediterranean Sea is displayed together with the list of the WMO numbers in the Argo-Italy webpage. The WMO list contains a link to the Euro-Argo monitoring tool (https://fleetmonitoring.euro-argo.eu/dashboard), where the metadata and data collected are plotted for each specific float (figure 4).

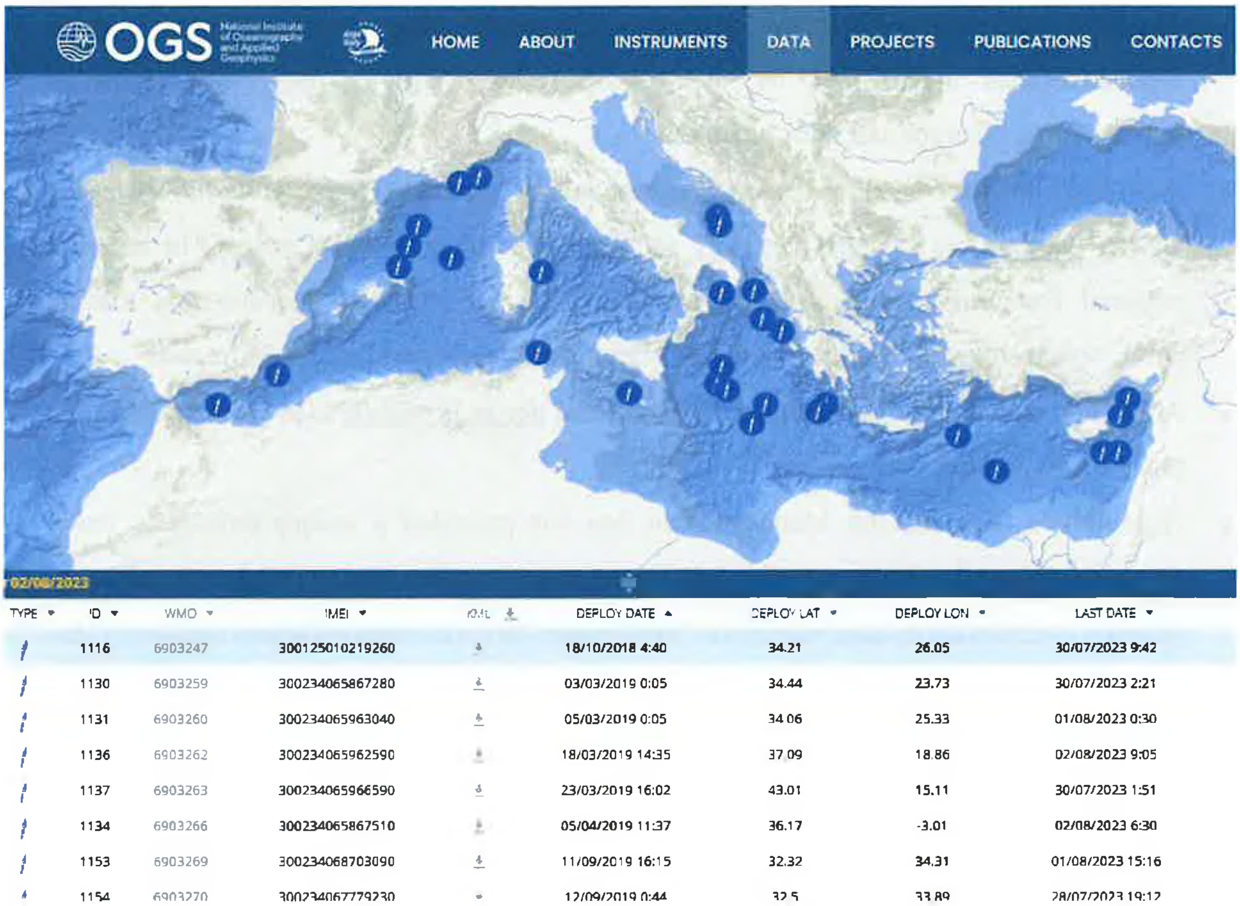


Figure 3. Italian float distribution in the Mediterranean Sea and the list of the related WMO numbers in the Argo-Italy webpage (https://argo.ogs.it/#/data).

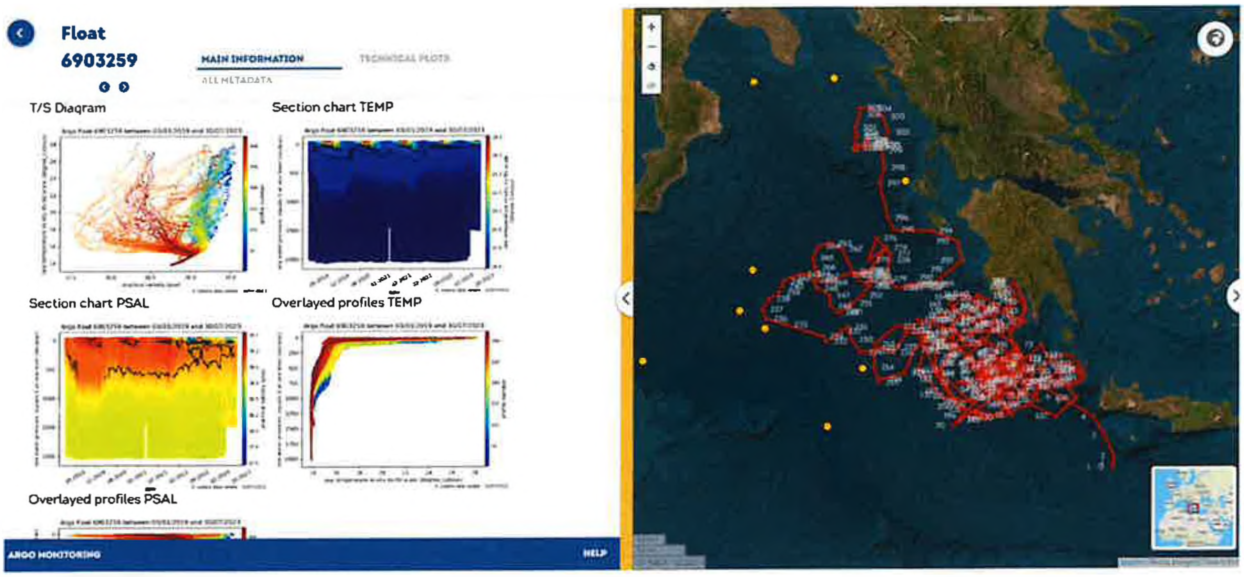


Figure 4. Selected Argo-Italy float displayed on the Euro-Argo monitoring tool (https://fleetmonitoring.euro-argo.eu/dashboard).

2. Argo float activities in 2022

This report summarizes the 2022 activities of Argo-Italy, funded by MUR, in terms of procurements of the instruments, their preparation and deployments. Information about data processing and archiving is also given. Plans for 2023 and beyond are included in the last section.

2.1 Float procurement

OGS purchased 16 floats in 2022 with funds provided by the Italian Ministry of Research, including 2 with dissolved oxygen sensors, 4 standard T/S floats, 7 standard T/S floats with implemented ice detection algorithm, 2 deep floats, and 1 BGC-float.

2.2 Float deployments

A total of 21 Italian floats were deployed in 2022 (see Tables 1 and 2 for details). These floats were Apex, Arvor-I, Arvor-Ice, Provor CTS4 and Deep-Arvor designs manufactured by Teledyne Marine (USA) and NKE (France). All floats transmit data via Iridium telemetry.

Mediterranean and Black Sea deployments

Fourteen units were released in the Mediterranean (Table 1). The Core-Argo floats have a park pressure at 350 dbar and maximal profiling depths alternating between 700 and 2000 dbar. Bio-Argo floats have a park pressure at 1000 dbar and the maximal profiling pressure was set to 1000 dbar for one platform and to 2000 dbar for two platforms. To measure high-frequency processes in the Sicily Channel, one Arvor-I float (WMO 6903821) was set to short cycles of 3 hours, while all other floats have cycles of 5 days during most of their initial operating life. Out of the fourteen, one Italian float was deployed in the shallow northern Adriatic (WMO 6903815) to complement the Euro-Argo RISE (EU H2020 project) fleet operating in a targeted shallow mission close to the coast. The cycle time was set to 5 days and the parking depth equal to the maximum bathymetry (less than 80 m).

Most floats were deployed from research vessels of opportunity (i.e., R/V Dallaporta, R/V Belgica II in figure 5, R/V Aegaeo, R/V Ammochostos, R/V Pourquoi Pas?, M/Y ROE in figure 6, Malta Guard Coast for the Mediterranean and R/V Agulhas II and Laura Bassi for South Atlantic, South Pacific and Southern Ocean) with the help of colleagues from Greece, Malta, Italy and Cyprus.

Issues encountered in the Mediterranean Sea in 2022

The BGC-Argo 6903805 equipped with sensors to measure the 6 EOVs was deployed in the Southern Adriatic Pit in November 2021. The float stopped transmitting data after 33 cycles (end of January 2022) and the cause is unknown.

The Deep-Argo 6903827 was deployed in the eastern Ionian Sea in mid December 2022 and it failed at launch (it did not surface after the deployment). According to NKE a possible cause of failure could be the fact that the float was stored in the crate too long before the deployment. In such a case, a battery failure can happen and they suggested next time running an autotest to check the float. Unfortunately, due to logistical problems (the ship's time and project planning), this float was not deployed within a few months of its manufacture.

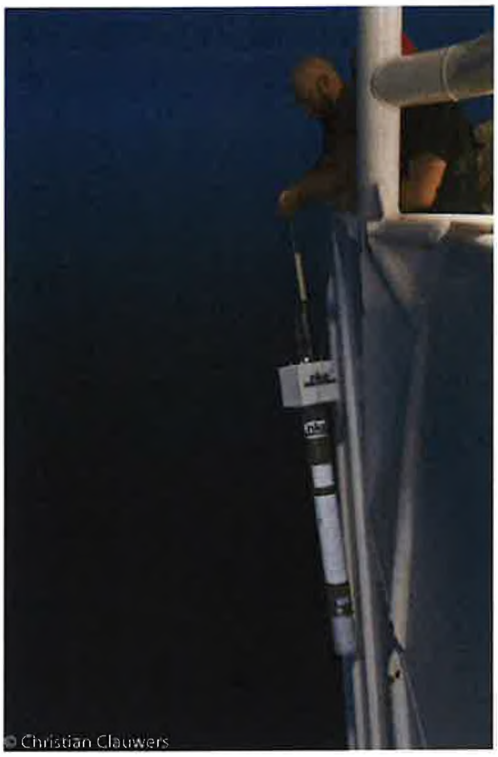


Figure 5. Arvor-I WMO 6903820 deployed from R/V Belgica II in the Tyrrhenian Sea, May 2022.

Figure 6. Arvor-I DO WMO 6903822 in the Ionian Sea from M/Y ROE (Seakeepers).

Model	WMO	Depl. Date	Lat	Lon	Cycles	Last Date	Lat	Lon	Status*	Cyc.**
Apex APF9	6903816	23-Feb-2022 16:20	40.56	2.62	107	26-Mar-2022 23:17	38.92	-0.05	D	-
Arvor - T/S Diss. Oxy	6903818	03-Mar-2022 13:53	40.73	2.67	220	21-Feb-2023 16:52	38.81	3.78	A	5
Arvor - T/S Core	6903817	04-Mar-2022 09:33	40.89	2.78	214	21-Feb-2023 09:58	40.61	2.63	A	5
Arvor - T S Core	6903815	17-Mar-2022 10:17	43.68	14.27	69	22-Feb-2023 04:29	43.89	14.07	A	5
Arvor - T/S Core	6903819	19-May-2022 21:02	40.51	11.00	56	20-Feb-2023 07:54	41.09	11.33	A	5
Arvor - T/S Core	6903820	21-May-2022 18:49	38.89	13.29	56	22-Feb-2023 05:51	40.52	12.68	A	5
Arvor- T/S Core	6903821	25-May-2022 07:57	35.90	14.10	388	18-Feb-2023 12:58	36.13	15.63	A	5
Arvor - T/S Diss. Oxy	6903822	01-Jun-2022 11:41	36.26	20.52	53	17-Feb-2023 03:54	35.33	21.34	A	5
PROVOR CTS4	6903823	21-Nov-2022 08:42	34.31	33.08	25	18-Feb-2023 11:23	33.43	33.59	A	5
Arvor - T/S Diss. Oxy	6903824	25-Nov-2022 17:18	33.94	28.11	18	20-Feb-2023 14:22	33.26	28.56	A	5
PROVOR CTS4	6903825	14-Dec-2022 08:13	41.50	18.12	18	22-Feb-2023 11:46	42.02	18.08	A	5
Arvor - T/S Diss. Oxy	6903826	15-Dec-2022 13:20	34.90	23.50	15	19-Feb-2023 05:44	35.50	20.80	A	5
Arvor – I DEEP	6903827	16-Dec-2022 21:10	35.60	22.47	-	-	-	-	D	-
PROVOR CTS4	6903828	18-Dec-2022 05:18	35.77	22.30	15	19-Feb-2023 11:28	35.43	21.35	A	5

**Status in early February 2023: A = active, D = dead;*
***Cycle: Length of cycle in days.*

Table 1. Status information for the 14 Italian floats deployed in the Mediterranean Sea during 2022.

South Atlantic, South Pacific and Southern Ocean

With the help of Italian colleagues onboard the R/V Laura Bassi: a total of 7 Arvor-I equipped with ice-detection software were deployed (Table 2): two of them, while crossing the circumpolar current (6903808, 6903809), two along the Ross Ice Shelf polynya (6903810, 6903811), one at Terra Nova Bay (6903812, this float was recovered and re-deployed) and two (6903813, 6903814) in the Somov sea. The adopted configuration in the Ross Ice Shelf Polynya consisted of a 7-day cycle with parking depth at 1000 dbar (i.e. at the seafloor).

Model	WMO	Depl. Date	Lat	Lon	Cycles	Last Date	Lat	Lon	Status*	Cyc.**
Arvor-T/S ICE	6903808	11-Jan-2022 16:42	-61.01	175.36	41	16-Feb-2023 15:12	-59.85	-162.59	A	10
Arvor-T/S ICE	6903809	12-Jan-2022 06:47	-63.03	176.69	41	17-Feb-2023 05:33	-59.12	-163.93	A	10
Arvor-T/S ICE	6903810	27-Jan-2022 11:53	-77.16	168.93	66	26-Jan-2023 08:51	-77.31	168.42	recovered	7
Arvor-T/S ICE	6903811	27-Jan-2022 21:41	-77.42	174.34	71	18-Feb-2023 05:37	-76.74	173.26	A	7
Arvor-T/S ICE	6903812	01-Feb-2022 08:56	-75.28	164.12	52	25-Jan-2023 06:45	-75.18	164.05	A	7
Arvor-T/S ICE	6903813	08-Mar-2022 12:28	-66.00	148.05	67	18-Feb-2023 01:29	-64.52	130.64	A	10
Arvor-T/S ICE	6903814	11-Mar-2022 08:46	-65.53	146.90	67	23-Feb-2023 01:25	-64.68	160.37	A	10

**Status in early February 2023: A = active, D = dead.*
***Cycle: Length of cycle in days.*

Table 2. Status information for the 7 Italian floats deployed in the Southern Ocean, South Atlantic and South Pacific during 2022.

In summary, at the end of 2022, the Argo-Italy program consists of a total of 85 active floats, including 35 in the Mediterranean Sea, 1 in the Atlantic Ocean (it left the Mediterranean Sea through the Strait of Gibraltar), 2 in the Black Sea (figure 7), and 47 in the South Pacific, South Atlantic, and Southern Oceans (south of 60°S, see figure 8).

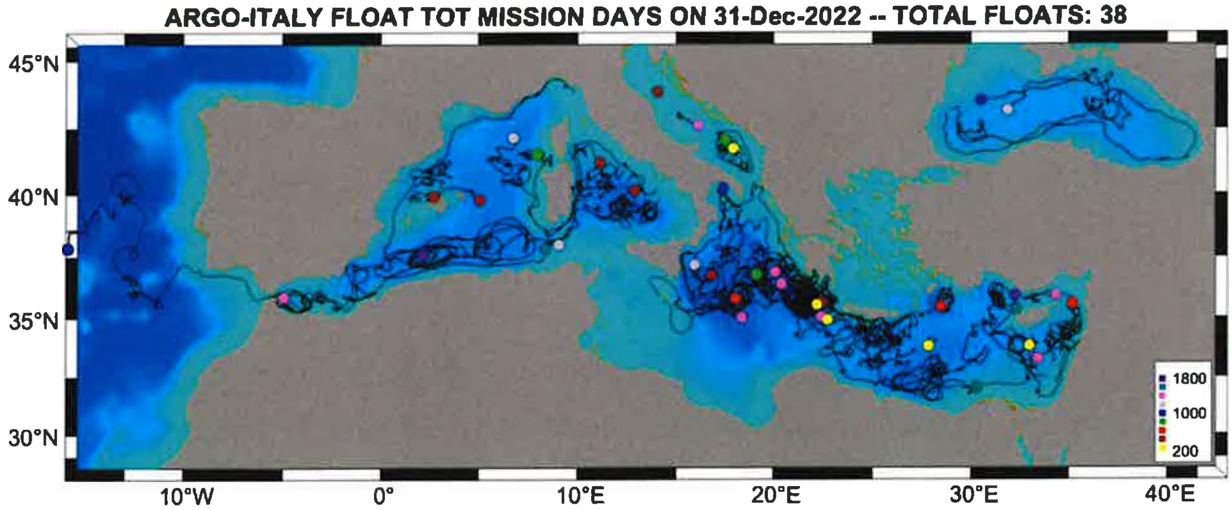


Figure 7. Trajectories and positions (circle symbols) on 31 December 2022 of the 38 Argo-Italy floats active in the Mediterranean and Black Sea. Circles are color-coded as a function of float age in days.

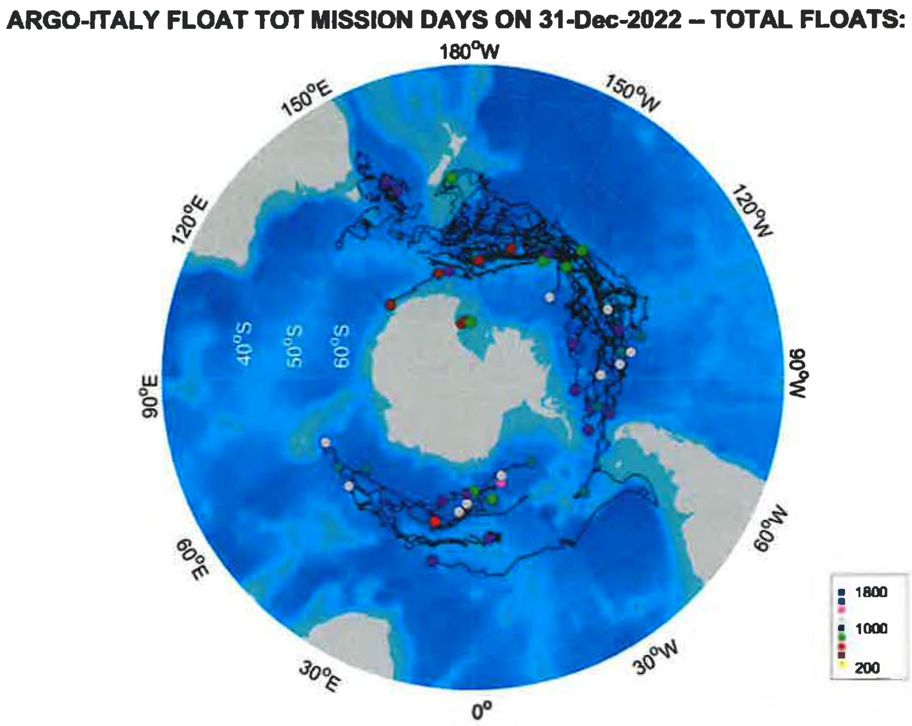


Figure 8. Trajectories and positions (circle symbols) on 31 December 2022 of the 47 Argo-Italy floats in the South Pacific, South Atlantic and Southern Oceans. Circles are color-coded as a function of float age in days.

2.3 Near real-time data processing

The data of drifters, floats and gliders were processed and archived in near real-time on OGS servers. Processing includes editing and creating graphics and tables which are posted on the Argo-Italy's websites.

In parallel, raw data from drifters, floats, and gliders were sent to the Global Data Assembly Centers (drifter data: AOML/NOAA, Miami, Florida; Float data: Coriolis, Ifremer, Brest, France; glider data: EGO (Everyone's Glider Observatories)). Drifter, float and glider data were distributed in near real time on the Global Telecommunication System (GTS) and assigned a WMO number.

The data of biogeochemical (BGC) floats were processed by Coriolis and made available in near-real time on its DAC server.

2.4 Delayed Mode quality control of Argo physical data

The delayed mode quality control (DMQC) of the physical data (pressure, temperature, and salinity) provided by the Italian floats in the Mediterranean and Black seas was done on floats deployed between 2009 and 2021 in the Mediterranean and Black Seas, and Southern Ocean (all information and statistics to create the D-files have been sent to Coriolis). The QC was performed for approximately 74% of eligible floats (169 out of 227 eligible floats, figures 9 and 10). The remaining floats will be checked as soon as a more robust reference dataset will be built up. Physical data were quality controlled in delayed-mode following the standard Argo procedure. In particular, the OWC method in conjunction with other procedures is adopted to check and adjust the salinity data. The OWC is a statistical method based on the comparison between float salinity profiles and an accurate historical reference dataset. The high-quality ship-based CTD reference data from the near-surface to depths more than 2000 m, for QC purposes of Core and Deep-Argo float data in the Mediterranean and Black seas, was reviewed and improved. OGS collected CTD data from several research institutes at regional level and from the main European Marine Services in order to complement the official reference dataset.

The reference dataset was quality controlled to obtain a good spatial distribution with more recent/contemporaneous data to reduce the effects of both the inter-annual and the seasonal variability of the Mediterranean Sea, mostly in the upper and intermediate layers of the water column. In order to obtain an even more accurate reference dataset, the procedure developed at BSH is being adapted to marginal seas to find errors, suspicious data, large time gaps, etc. Due to the high natural variability in the water column of the Mediterranean Sea, additional qualitative checks (i.e., a comparison between nearby floats and analysis of the deepest portion of the temperature-salinity diagram) are used in conjunction with the OWC method to better interpret results and hence provide an improved quality control analysis. OGS continuously implements these procedures to solve some problems (i.e. when different vertical sampling is used) and to better adapt them to marginal seas in order to obtain data of increasingly high quality. The DMQC analysis has been conducted also on the deep floats deployed in the Mediterranean Sea. This analysis requires a different approach with respect to Core-Argo floats, due to the pressure-dependent salinity bias. Hence, the correction for pressure effects on conductivity, called CPcor correction, is necessary before applying the OWC procedure for checking any sensor drift and offset in salinity. The DMQC was applied to 5 out of 7 eligible floats. Of these, only two D-files were sent to Coriolis because the floats only have between 1 and 10 cycles and need no correction.

For the other three that show potential drift and need correction, the procedure is under development.

Some of the BGC variables (BBP and Radiometry) acquired by the Italian fleet will be also processed in Delayed-mode by OGS and CNR operators.

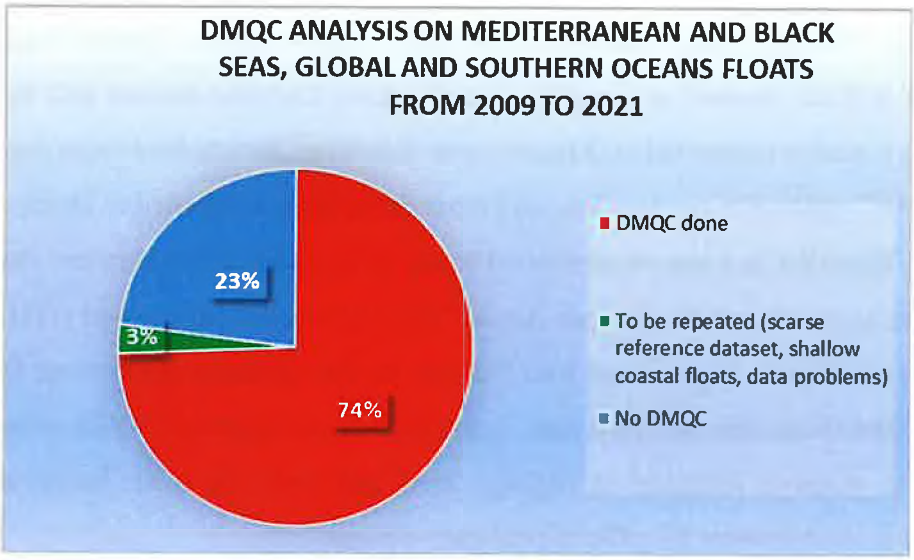


Figure 9: Status of the DMQC.

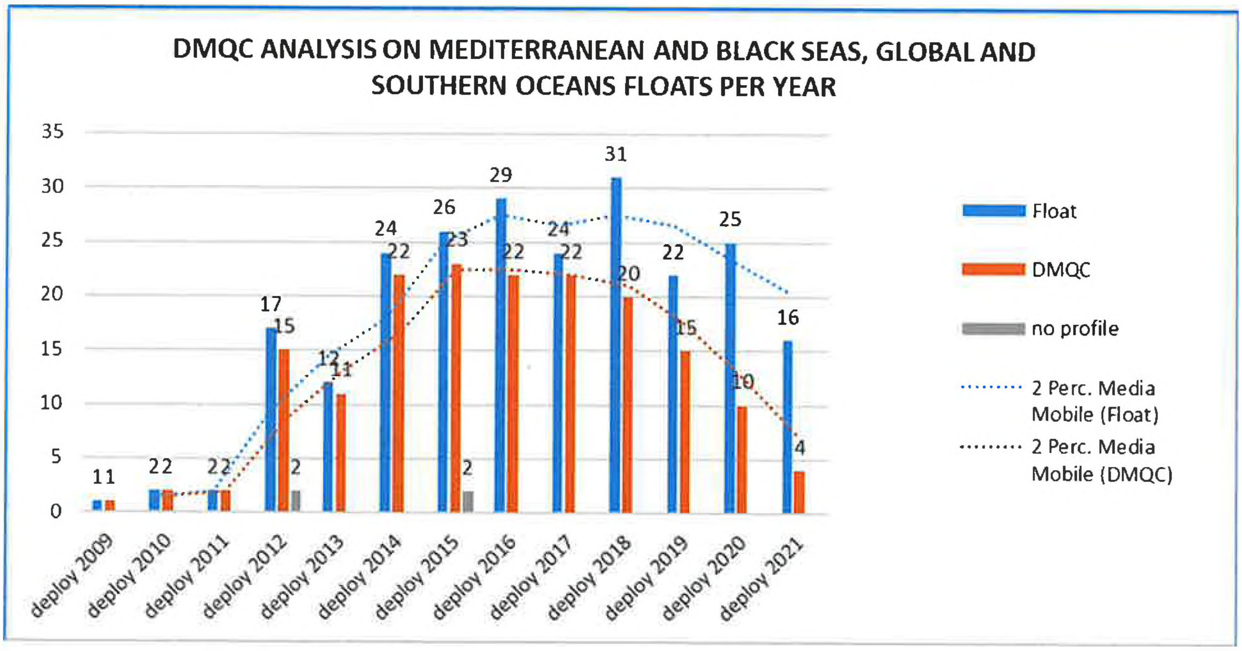


Figure 10: Status of the DMQC per year (from 2009 to 2021).

2.5 Long term Argo float statistics

The temporal evolution for the period 2012-2022 of the active float number is shown in figure 11, along with the annual numbers of float deployments and float deaths. The float population in 2022 is quite stable with about 85 active instruments. In 2022, the number of deployments exceeded the number of dead floats to compensate for the year before when the number of dead floats overcame that of new deployments.

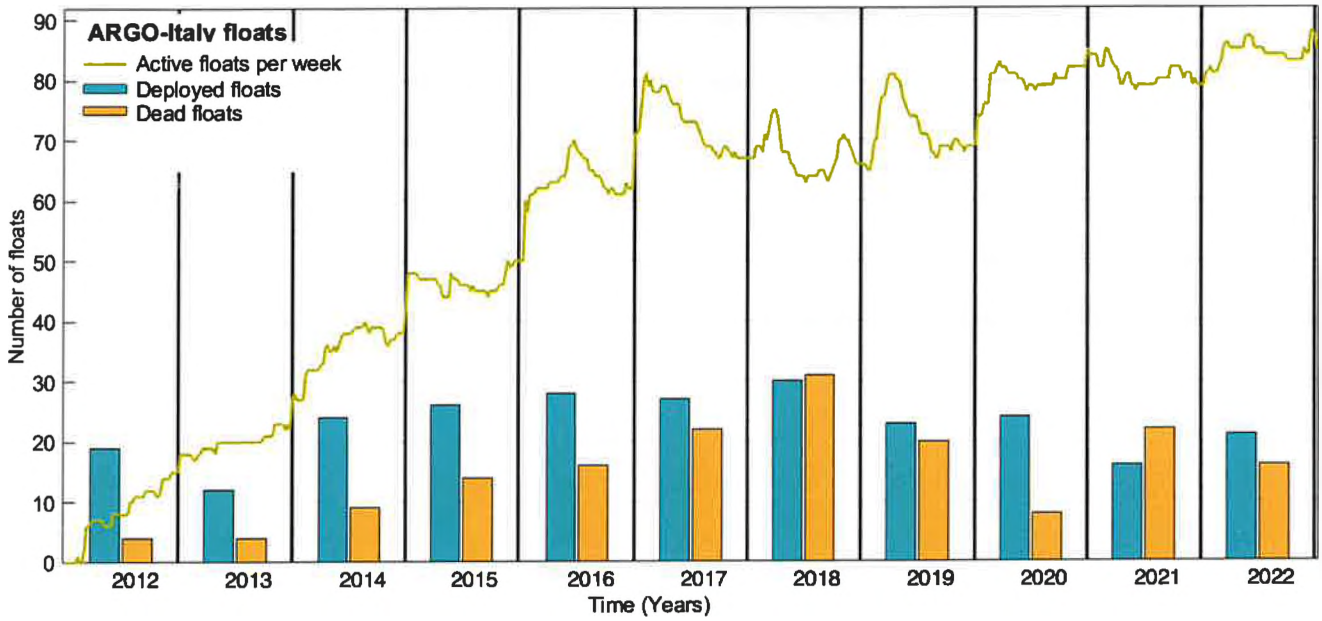


Figure 11. Temporal evolution of the number of Argo-Italy active floats with weekly resolution and histogram of the annual float deployments and losses.

Since 18 February 2012, a total of 250 Argo-Italy floats have been deployed, 147 in the Mediterranean and Black Seas and 103 in the Southern Hemisphere oceans. Over a 10 year period, they have provided about 38.000 CTD profiles. The histogram of the number of CTD profiles per float is shown in figure 12. One hundred and seven floats, about 43% of the total deployments, have collected more than 180 profiles. Overall (during the period 2012-2022), ~6% of floats failed shortly after deployment.

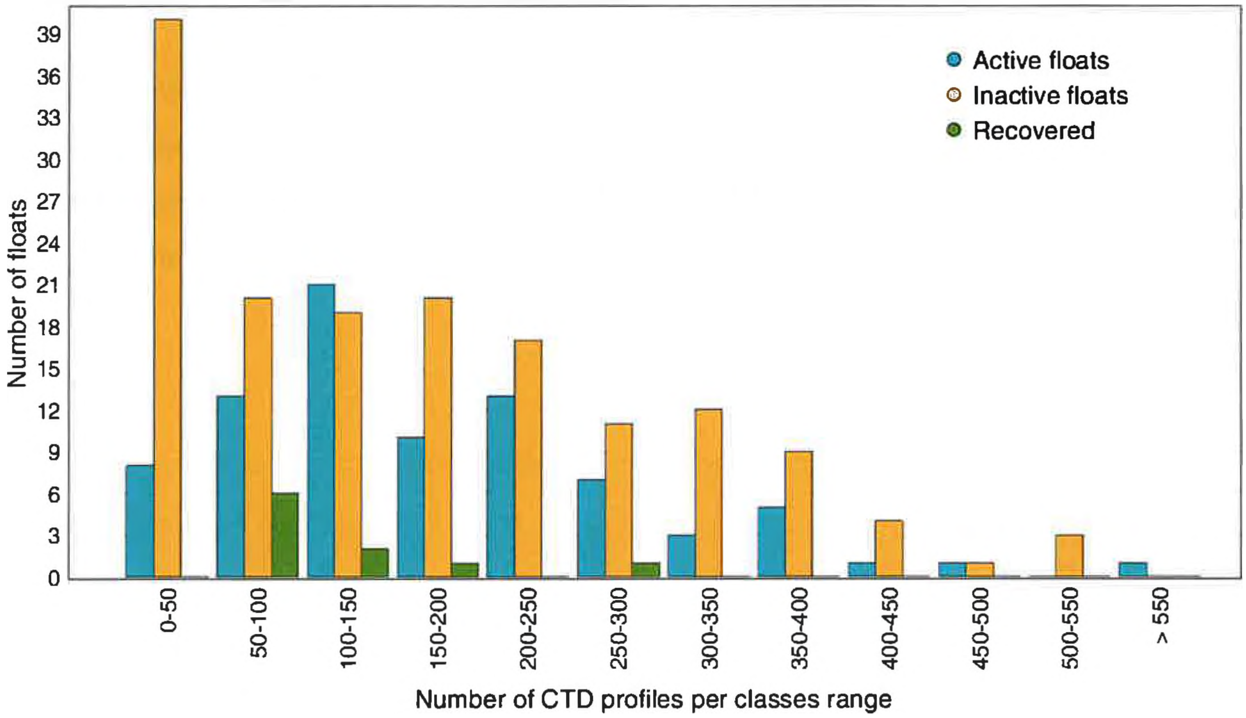
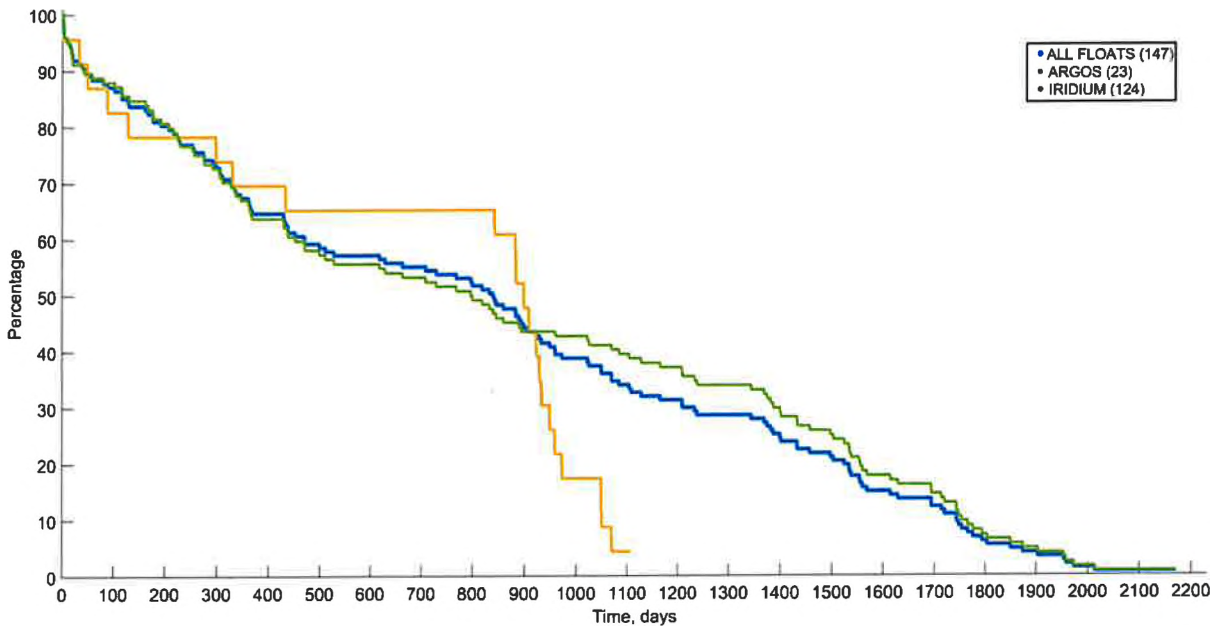


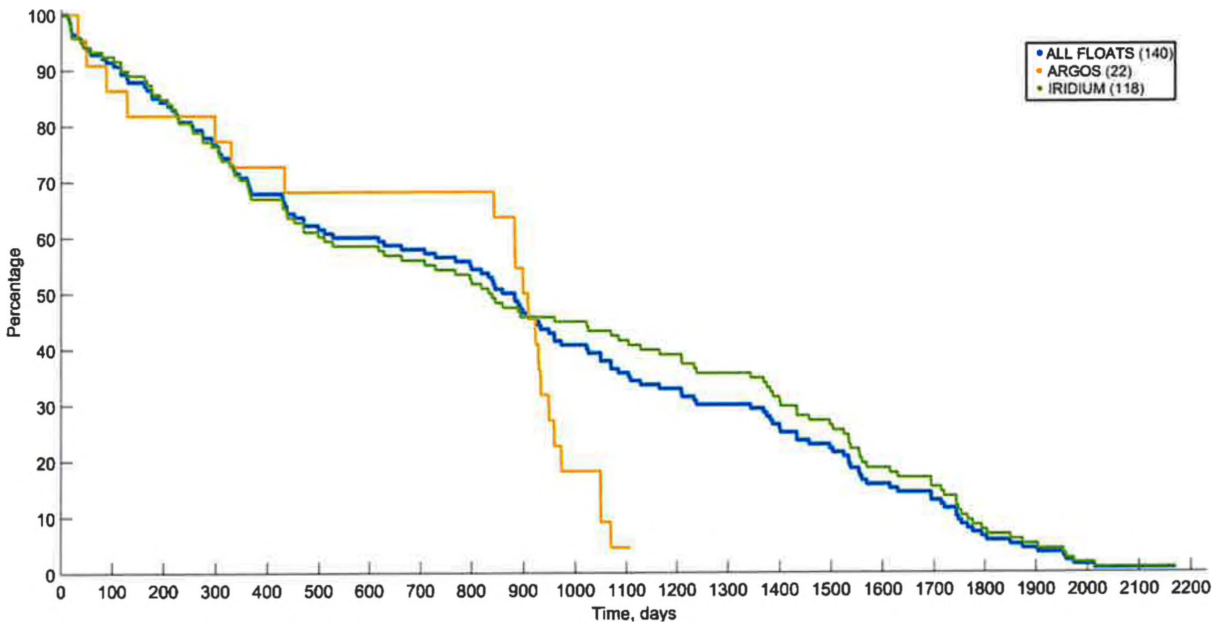
Figure 12. Histogram of the number of floats in selected CTD profile classes at the end of 2022.

After about 10 years of activities in the Mediterranean and Black seas, the maximum operating life of the Argo-Italy floats is about 5.5 years (~2010 days, see figure 13). If we consider all the floats (dead + alive) the mean half-life (life-time of 50% of the fleet) is about 850 days for all floats in the Mediterranean and Black seas (figure 13, top). If we exclude the floats still alive (with a life <= 850 days), we get a better estimate of the mean half-life which is about 900 days (figure 13, middle). Arvor's floats show the longest performance, exceeding the threshold of 2000 mission days threshold (figure 13, bottom).

For floats deployed in the South Pacific, South Atlantic, and Southern Ocean, the maximum operational lifetime is about 6.5 years, and the mean half-life approaches two years (figure 14). The longest service is attributed to the Arvor floats with more than 2300 mission days (figure 14, bottom).

These statistical survival rate should be interpreted with caution because most of the floats are still alive (38 floats out of 147 units in the Mediterranean and Black Seas, 47 floats out of 103 in the Southern Hemisphere). In addition, these statistics include the floats with all types of "end of service" (low battery power, stranding, involuntary and voluntary recovery, etc.).





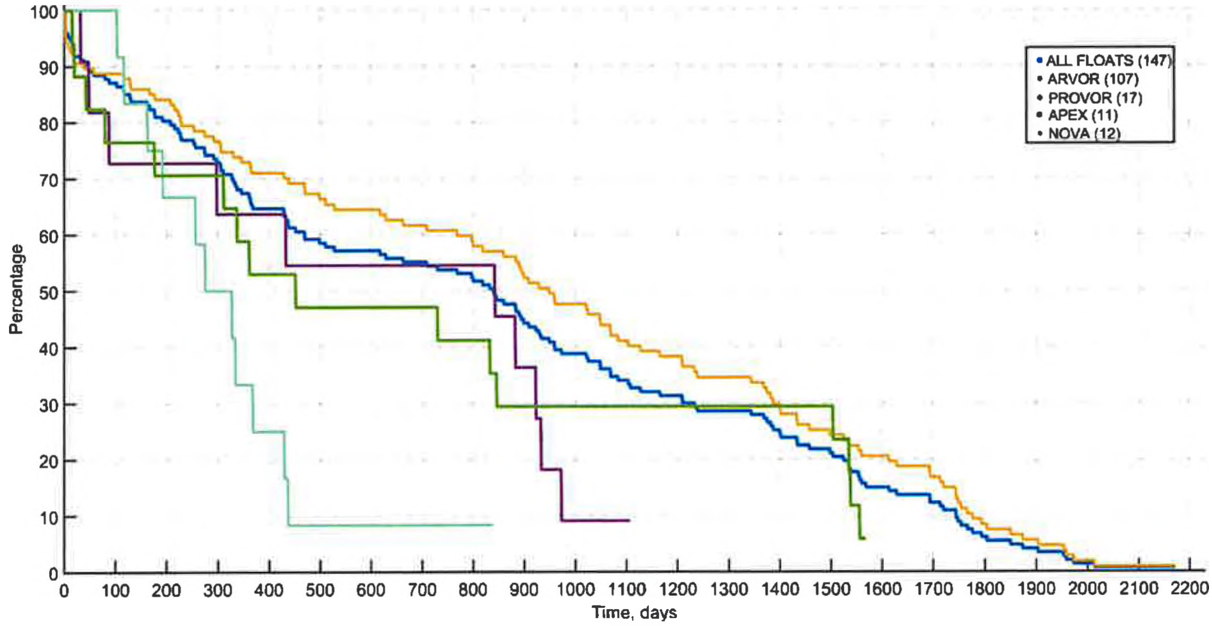


Figure 13. Survival rate diagrams for Argo-Italy floats in the Mediterranean and Black seas, by transmission mode (top and middle) and float type (bottom).

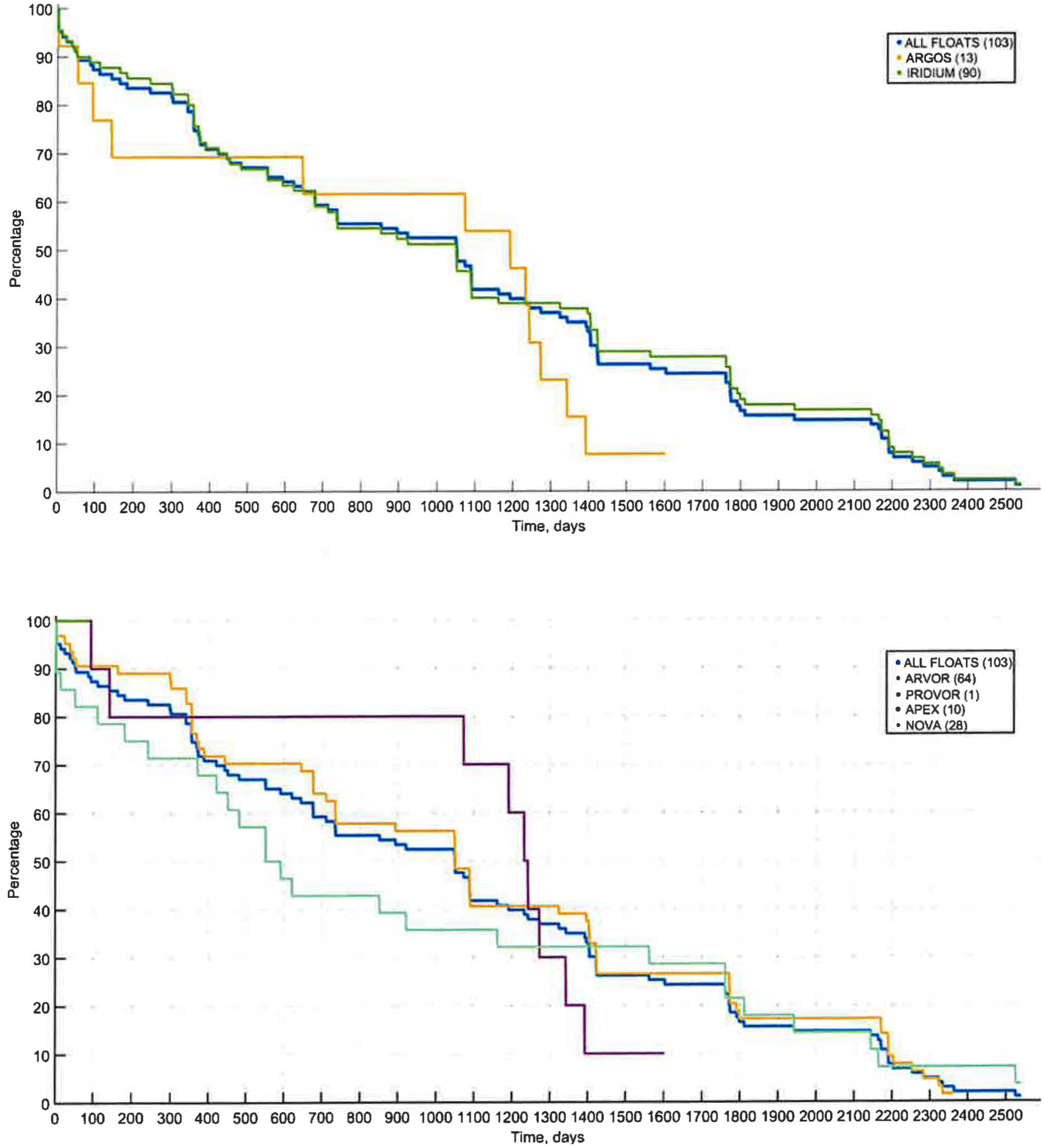


Figure 14. Survival rates for all Argo-Italy floats in the South Pacific, South Atlantic and Southern Ocean, by transmission mode (top) and float type (bottom).

The Mediterranean basin was divided in 2x2 degree boxes (Black Sea not included) and the percentage of CTD profiles in each box was computed with respect to the total amount (reported in the title of figure 15) considering three periods: Jan_2012-Dec_2022, Jan_2018-Dec_2022 and Jan_2022-Dec_2022, see figure 15.

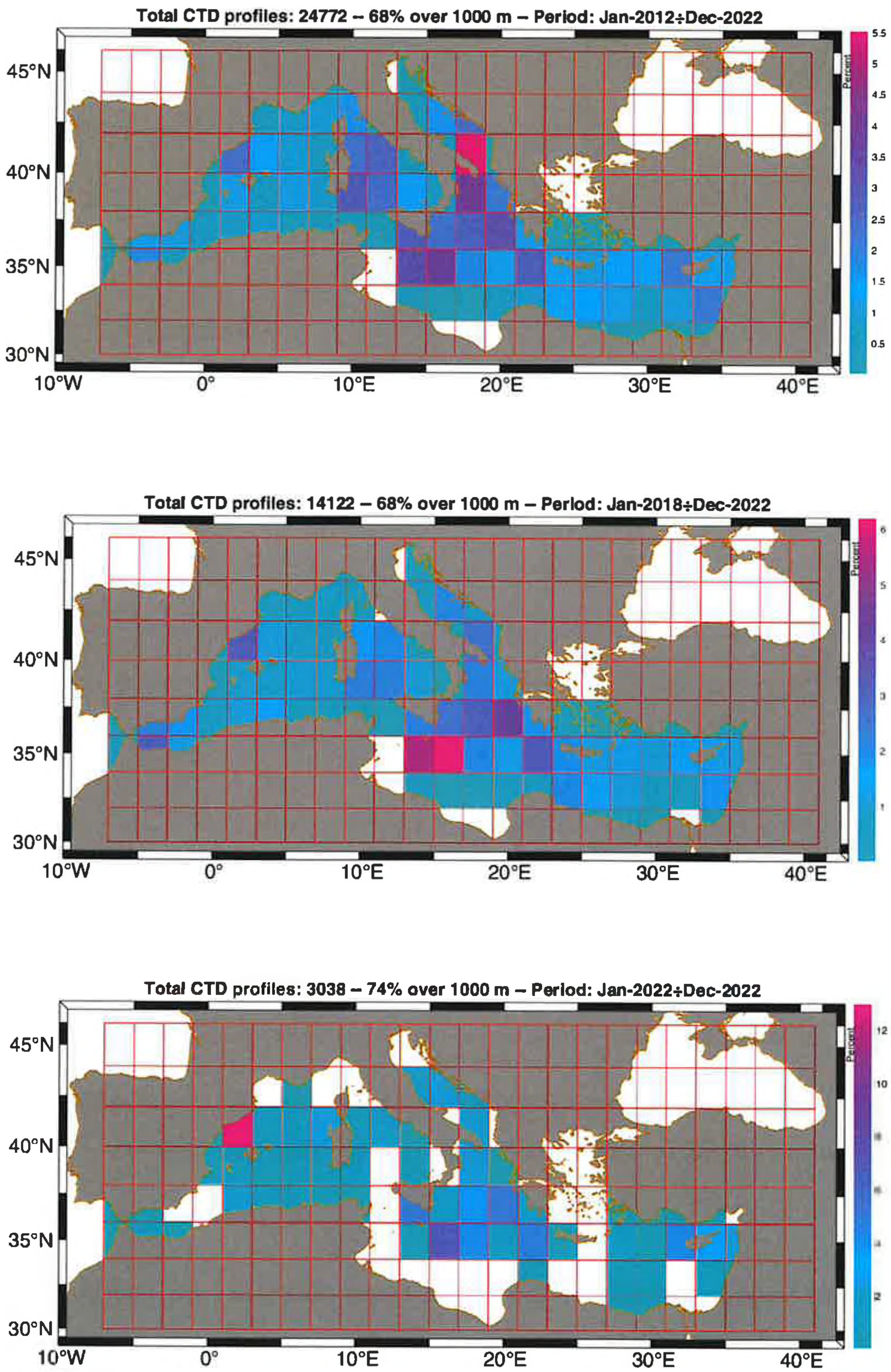


Figure 15. Population density maps.

In 2022, about 5000 CTD profiles were obtained with the Italian Argo floats. If all the profiles taken from floats in 2022 were added together, (considering only the ascent phase) the distance would be more than 6200 km. For the period 2012-2022, the 250 floats of Argo-Italy provided data over a total vertical distance of about 44800 km in 38100 profiles (see also figure 16).

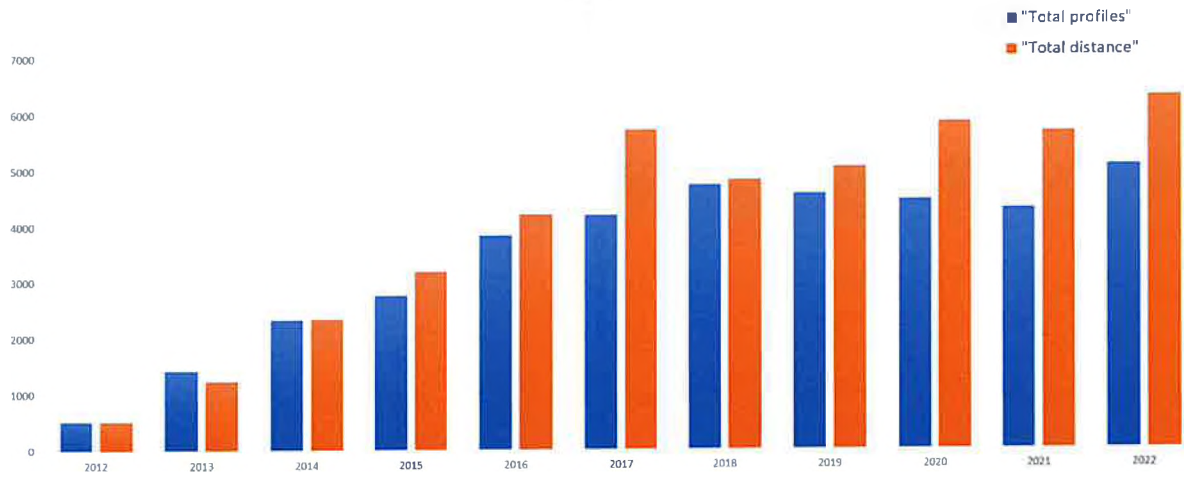


Figure 16. Evolution over the years of the total profiles and vertically traveled distance (in km, upward profiles only, since the upward direction is the typical direction of sampling) of the Argo-Italy floats.

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2012-2022
Deployments												
CTD floats deployed in Med	13	7	13	11	9	8	16	10	8	5	10	110
CTD floats deployed in BS	4	1	2	1	1	2	0	1	1	0	0	13
CTD floats deployed in SO, South Pacific and Atlantic	2	3	7	10	15	17	8	10	15	9	7	103
Bio floats deployed	0	0	3	4	1	0	5	0	0	1	3	17
Deep floats					2	0	1	2	0	1	1	7
Total floats deployed	**19**	**11**	**25**	**26**	**28**	**27**	**30**	**23**	**24**	**16**	**21**	**250**
CTD profiles												
CTD profiles in Med	400	1099	1560	1743	2358	2147	2962	2646	2213	2205	2867	22200
CTD profiles in BS	105	236	323	268	260	298	298	280	268	181	146	2663
CTD profiles in SO, South Pacific and Atlantic	6	90	205	475	815	1418	1087	1200	1615	1647	1806	10364
Bio profiles	0	0	244	266	373	261	360	410	287	175	172	2548
Deep profiles					15	65	11	20	75	87	73	346
Total profiles	**511**	**1425**	**2332**	**2752**	**3821**	**4189**	**4718**	**4556**	**4458**	**4295**	**5064**	**38121**
Vertical distances (km)												
Distance in Med	440	902	1485	1813	2195	2307	2156	2037	2109	2109	2472	20025
Distance in BS	71	210	283	257	247	294	295	287	300	242	197	2683
Distance in SO, Southern Pacific and Atlantic	2	125	380	875	1374	2658	2020	2260	2914	2886	3198	18692
Distance of bio floats	0	0	199	245	335	248	293	392	279	165	167	2323
Distance of deep floats					50	194	43	69	235	265	256	1112
Total distance (km)	**513**	**1237**	**2347**	**3190**	**4201**	**5701**	**4807**	**5045**	**5837**	**5667**	**6290**	**44835**

Table 3. Statistical information on the performance of the Argo-Italy floats in 2012-2022.

2.6 Italian contribution to Argo float bibliography and technical reports in 2022

Peer review papers

The Argo bibliography shows 560 publications of which we list below some of those related to the Italian community working on the Mediterranean Sea. The following list is not meant to be exhaustive.

Brewin, R. J. W., Dall'Olmo, G., Gittings, J., Sun, X., Lange, P. K., Raitsos, D. E., et al. (2022). A conceptual approach to partitioning a vertical profile of phytoplankton biomass into contributions from two communities. Journal of Geophysical Research: Oceans, 127, e2021JC018195. https://doi.org/10.1029/2021JC018195

Cossarini, G., et al. (2021), High-Resolution Reanalysis of the Mediterranean Sea Biogeochemistry (1999–2019), *Frontiers in Marine Science*, *8*(1537), doi: https://doi.org/10.3389/fmars.2021.741486

Dall'Olmo G, Bhaskar TVS U, Bittig H et al. Real-time quality control of optical backscattering data from Biogeochemical-Argo floats [version 1; peer review: 2 approved with reservations]. Open Res Europe 2022, 2:118, doi: 10.12688/openreseurope.15047.1

Di Biagio, V., S. Salon, L. Feudale, and G. Cossarini (2022), Subsurface oxygen maximum in oligotrophic marine ecosystems: mapping the interaction between physical and biogeochemical processes, *Biogeosciences*, *19*(23), 5553-5574, doi: https://doi.org/10.5194/bg-19-5553-2022

Dionisi D. , Bucci S., Cesarini C., Colella S., D'Alimonte D. , Di Ciolo L. , Di Girolamo P., Di Paolantonio M., Franco N., Gostinicchi G., Kajiyama T. , Liberti G., Organelli E., Santoleri R. (2022). "COLOR: CDOM-proxy retrieval from aeOLus ObseRvations". Ocean From Space 2022, Venice (Italy). https://www.oceansfromspacevenice2020.org/wp-content/uploads/2022/10/OFS_2022_FINAL_PROGRAM-17-10-2022.pdf

Fedele, G., Mauri, E., Notarstefano, G., and Poulain, P. M.: Characterization of the Atlantic Water and Levantine Intermediate Water in the Mediterranean Sea using 20 years of Argo data, Ocean Sci., 18, 129–142, https://doi.org/10.5194/os-18-129-2022, 2022.

Menna, M., Martellucci, R., Reale, M. et al. A case study of impacts of an extreme weather system on the Mediterranean Sea circulation features: Medicane Apollo (2021). Sci Rep 13, 3870 (2023). https://doi.org/10.1038/s41598-023-29942-w

Menna, M.; Gacic, M.; Martellucci, R.; Notarstefano, G.; Fedele, G.; Mauri, E.; Gerin, R.; Poulain, P.-M. Climatic, Decadal, and Interannual Variability in the Upper Layer of the Mediterranean Sea Using Remotely Sensed and In-Situ Data. Remote Sens. 2022, 14, 1322. https://doi.org/10.3390/rs14061322

Organelli E., Bellacicco M., Landolfi A., Marullo S., Mignot A., Pisano A., Van Gennip S., Yang C., Santoleri R. (2022). BGC-Argo and Earth Observation to assess the impact on, and the resilience of, marine ecosystems after a Marine Heat Wave. ESA Living Planet Symposium 2022, Bonn (Germany). https://lps22.eu/

Pietropolli, G., Cossarini, G., & Manzoni, L. (2022, September). GANs for Integration of Deterministic Model and Observations in Marine Ecosystem. In *Progress in Artificial Intelligence: 21st EPIA Conference on Artificial Intelligence, EPIA 2022, Lisbon, Portugal, August 31–September 2, 2022, Proceedings* (pp. 452-463). Cham: Springer International Publishing.

Teruzzi, A., G. Bolzon, L. Feudale, and G. Cossarini (2021), Deep chlorophyll maximum and nutricline in the Mediterranean Sea: emerging properties from a multi-platform assimilated biogeochemical model experiment, *Biogeosciences*, *18*(23), 6147-6166, doi: https://doi.org/10.5194/bg-18-6147-2021

Terzić, E., S. Salon, G. Cossarini, C. Solidoro, A. Teruzzi, A. Miró, and P. Lazzari (2021), Impact of interannually variable diffuse attenuation coefficients for downwelling irradiance on biogeochemical modelling, *Ocean Model.*, *161*, 101793, doi: https://doi.org/10.1016/j.ocemod.2021.101793

OGS technical reports

GALLO A., NOTARSTEFANO G. AND MARTELLUCCI R. (2022). Rel. 2022/55 SEZ. OCE 45. Preliminary results of shallow coastal Argo floats data DMQC activity in the North Adriatic Sea.

GALLO A. AND NOTARSTEFANO G. (2022). Rel. 2022/54 sez. OCE 44. Preliminary work on DMQC activity of Deep Argo data in the Mediterranean Sea.

PACCIARONI M., NOTARSTEFANO G. AND GALLO A. (2022). Rel. 2022/94 Sez. OCE 63. DMQC on four MOCCA-EU floats deployed in the southern Pacific ocean.

3. Drifter activities in 2022

No drifters were purchased in 2022 with funds from Argo-Italy; all activities in 2022 were conducted with drifters purchased in 2021. However, in 2022, OGS has been working to sign a research agreement with our leading drifter manufacturers (SIO, La Jolla, University of California, USA). This agreement was signed in January 2023 and will facilitate the procurement of drifters in the future.

Table 4 shows the status information of the seven SVP drifters deployed in the South Atlantic in January 2022 as a contribution to the PNRA project (Programma Nazionale di Ricerca in Antartide). These drifters were deployed along the Good Hope Transect (figure 17; Table 4) from the R/V Agulhas II.

Argos/IMEI	Deploy Date	Lat	Lon	Last Date	Lat	Lon	Type	Depth (m)
a300534061493090	21-Jan-2022 23:02	-61.01	0.03	25-Mar-2022 15:20	-60.58	0.4	SVP	15
a300534061493080	22-Jan-2022 23:26	-55.99	0.03	28-Apr-2023 05:00	-43.97	79.96	SVP	15
a300534061493050	21-Jan-2022 11:10	-64.01	-0.02	11-Jul-2022 02:00	-61.03	-0.88	SVP	15
a300534061493130	21-Jan-2022 14:54	-63	-0	21-Jul-2022 23:15	-58.89	1.01	SVP	15
a300534061493110	21-Jan-2022 18:24	-62	0	21-Jul-2022 23:00	-58.03	0.56	SVP	15
a300534061493140	22-Jan-2022 02:36	-60.01	0	29-Aug-2022 18:50	-55.59	13.15	SVP	15
a300534061493160	22-Jan-2022 14:51	-58	0.01	26-Jan-2023 18:04	-51.73	44.33	SVP	15

Table 4. Status information for the Italian drifters deployed in the South Atlantic (Southern Ocean) in January 2022.

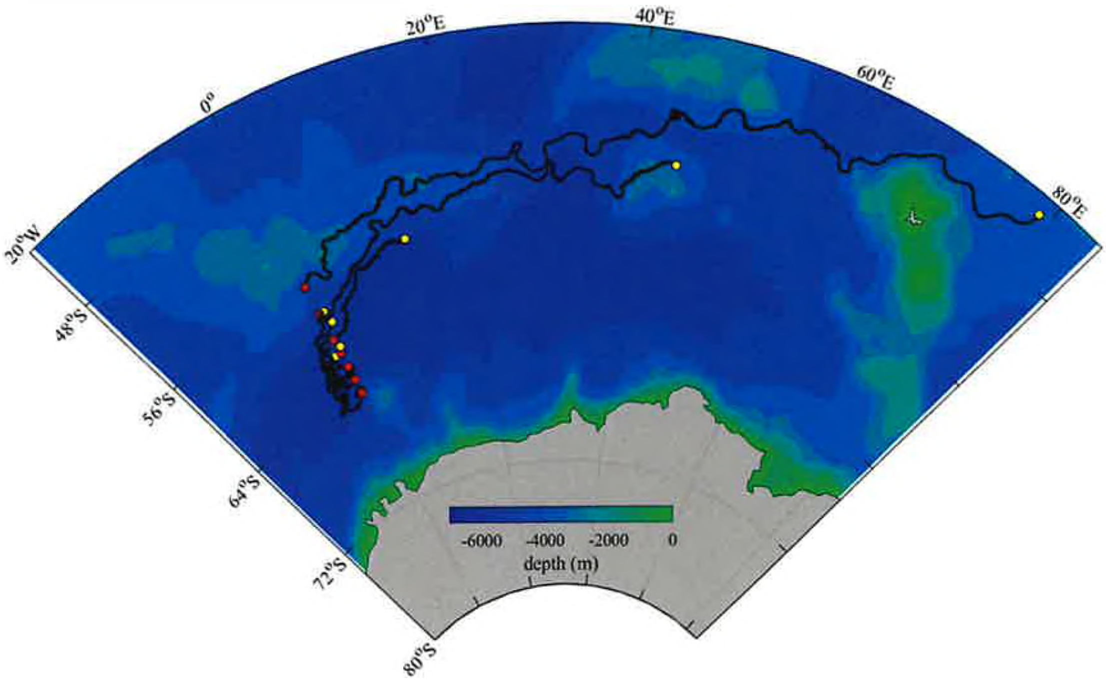


Figure 17. Trajectories, deployment positions (red dots) and last position (yellow dots) of the seven Italian drifters deployed in the South Atlantic in January 2022. Drifter data are updated to April 2022.

In January 2022, additional 8 Italian drifters were deployed from the R/V Laura Bassi in the South Pacific (figure 18; Table 5). Three of them are still alive in May 2023.

Argos/IMEI	Deploy Date	Lat	Lon	Last Date	Lat	Lon	Type	Depth (m)
a300534061494060	10-Jan-2022 14:00	-56.03	172.49	08-Apr-2023 05:04	-49.19	-136.95	SVP	15
a300534061493420	10-Jan-2022 19:00	-57	173.04	01-May-2023 17:00	-44.91	-144.1	SVP	15
a300534061494090	11-Jan-2022 00:00	-58.02	173.56	03-Jul-2022 14:04	-50.42	179.93	SVP	15
a300534061493380	11-Jan-2022 04:00	-59.01	174.18	19-Sep-2022 19:00	-53.24	-145.66	SVP	15
a300534061494040	11-Jan-2022 09:41	-60.01	174.72	02-May-2023 05:04	-55.88	-102.86	SVP	15
a300534061494070	11-Jan-2022 16:54	-61.01	175.34	18-Nov-2022 03:01	-53.16	-139.43	SVP	15
a300534061493400	11-Jan-2022 23:56	-62.03	176.04	29-Jan-2023 14:00	-53.55	-105.76	SVP	15
a300534061493390	12-Jan-2022 06:41	-63.02	176.69	02-May-2023 05:04	-47.81	-125.14	SVP	15

Table 5. Status information for the Italian drifters deployed in the South Pacific (Southern Ocean) in January 2022.

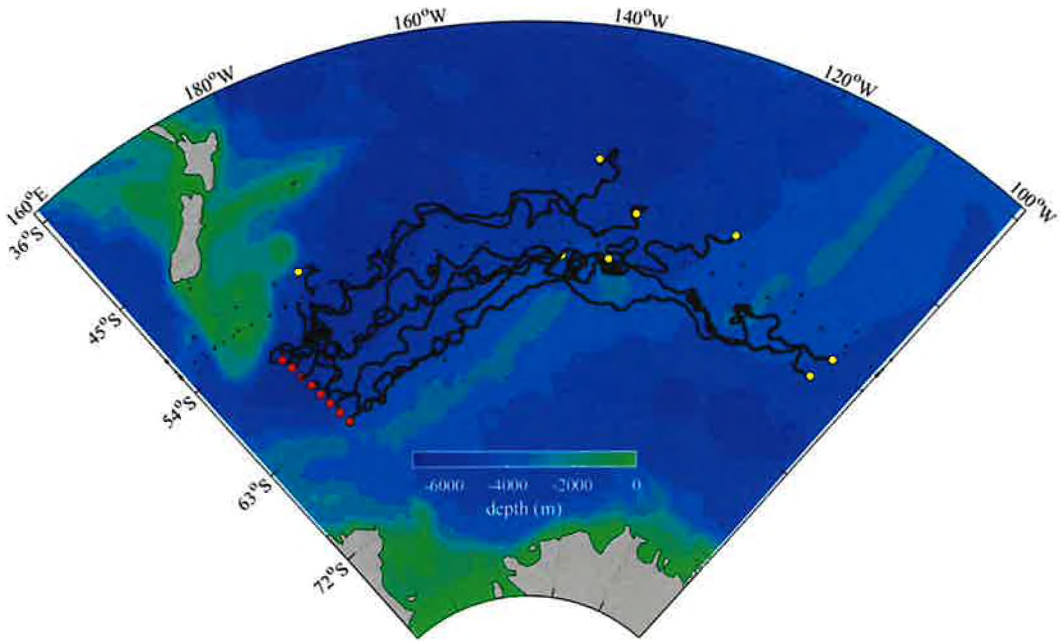


Figure 18. Trajectories, deployment positions (red dots) and last position (yellow dots) of the eight Italian drifters deployed in the South Pacific in January 2022. Drifter data are updated to April 2023.

The main goal of the CALYPSO project (https://argo.ogs.it/#/projects/calypso) is to improve our understanding on the 3D dynamics in the upper ocean through which water and properties are transported from the surface to depths below the mixed layer, by exploring the dynamics of the frontal areas in southwest Mediterranean Sea at scales ranging between 1 and 100 km using data collected by ship-born instruments (CTD, underway-CTD, ADCP, etc.), Lagrangian platforms (drifters and floats), gliders and satellites. The Calypso2022 experiment led to the deployment of more than 300 drifters of different types and nationalities between February and March 2022. The Argo-Italy program contributed eight SVP drifters (Table 6; figure 19) and two ADOS drifters, equipped with a thermistor chain able to measure temperature and water pressure up to 200 m depth. In figure 20 trajectories and deployment positions of the ADOS drifters, as well as the drifter picture is displayed.

Argos/IMEI	Deploy Date	Lat	Lon	Last Date	Lat	Lon	Type	Depth (m)
a300234066212310	01-Mar-2022 11:07	40.34	2.59	16-Jun-2022 19:30	40.91	4.24	ADOS	
a300234066212350	03-Mar-2022 09:43	40.76	2.71	29-Apr-2022 22:30	40.31	3.05	ADOS	
a300534061494110	18-Feb-2022 06:59	41.68	4.67	14-Aug-2022 16:00	41.46	9.28	SVP	15
a300534061494380	18-Feb-2022 09:44	41.52	4.42	07-Sep-2022 00:00	43.5	3.99	SVP	15
a300534061494510	18-Feb-2022 18:02	41.54	4.17	04-Jun-2022 06:00	40.63	0.77	SVP	15
a300534061494930	18-Feb-2022 22:38	41.33	4.41	15-Jun-2022 00:00	40.99	9.63	SVP	15
a300534061494960	19-Feb-2022 06:25	41.36	3.9	16-Jun-2022 04:00	43.18	6.78	SVP	15
a300534061495030	19-Feb-2022 10:26	41.15	4.13	18-Apr-2022 04:00	40.14	6.67	SVP	15
a300534061495040	19-Feb-2022 17:18	41.18	3.63	29-May-2022 18:00	41.53	2.46	SVP	15
a300534061495060	19-Feb-2022 21:06	40.98	3.86	22-Jul-2022 03:00	42.7	8.65	SVP	15

Table 6. Status information for the Italian drifters deployed in the Mediterranean Sea in February 2022.

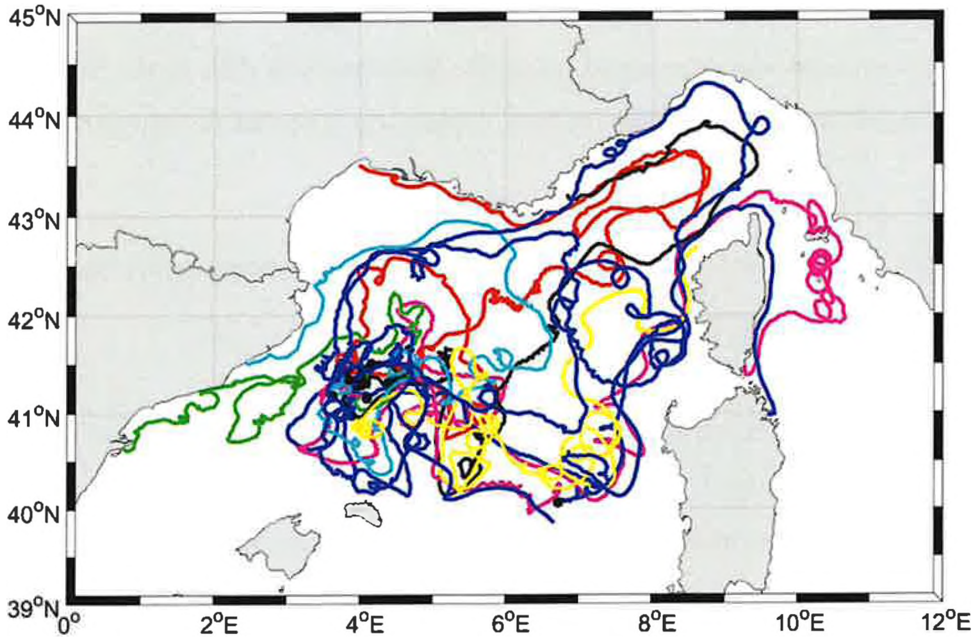


Figure 19. Trajectories and deployment positions (black dots) of the eight Italian SVP drifters deployed in the Western Mediterranean in February 2022. Drifter data are updated to April 2023.

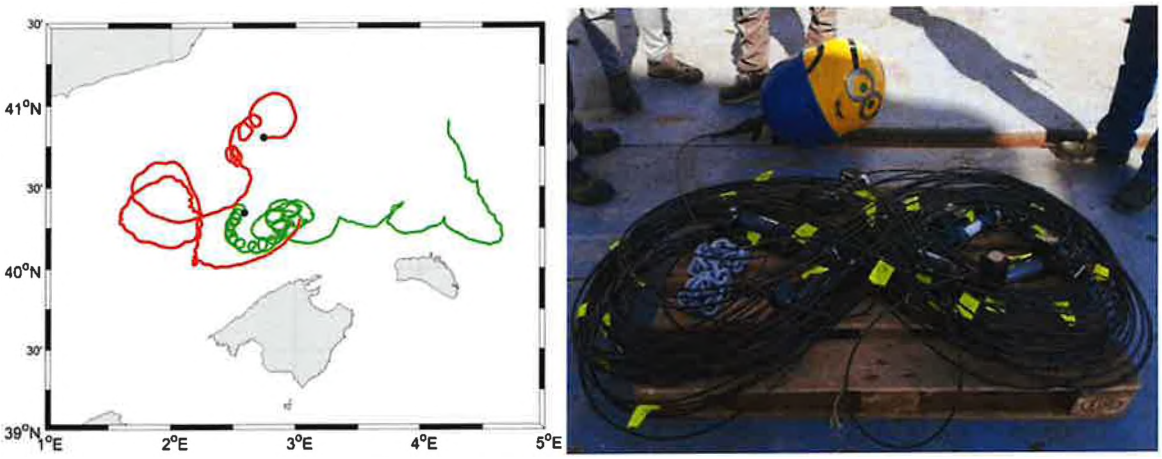


Figure 20. Trajectories and deployment positions (right) of the ADOS drifters (left) deployed in the Western Mediterranean in February 2022 .

4. Glider activities in 2022

In 2022, one glider mission was performed using the SeaGliders SG554 in the South Adriatic between January and February 2022. The mission is part of a repeated section performed since 2014.

After the SeaGlider SG554 refurbishment, a standard test was performed before the deployment in the South Adriatic Sea. Receiving stations were set up.

During the mission in the South Adriatic Sea the SeaGlider SG554 was operated for 36 days from 28 January to 25 February (figure 21) in the framework of the Convex22 experiment to assess the hydrographical characteristics present during winter. The mission was conceived to identify smaller-scale processes that occur during the convection period. The sampling plan, in addition to the Bari-Dubrovnik transects, consisted in shorter transects repeated over time, in order to better assess the time scale of the phenomena occurring during the convective process (figure 21).

The glider covered about 500 km, performing 300 dives. The maximum depths varied from 20 to 950 m. The glider was equipped with sensors for temperature, salinity, dissolved oxygen fluorescence of chlorophyll *a*, backscattering and Colored Dissolved Organic Matter (CDOM).

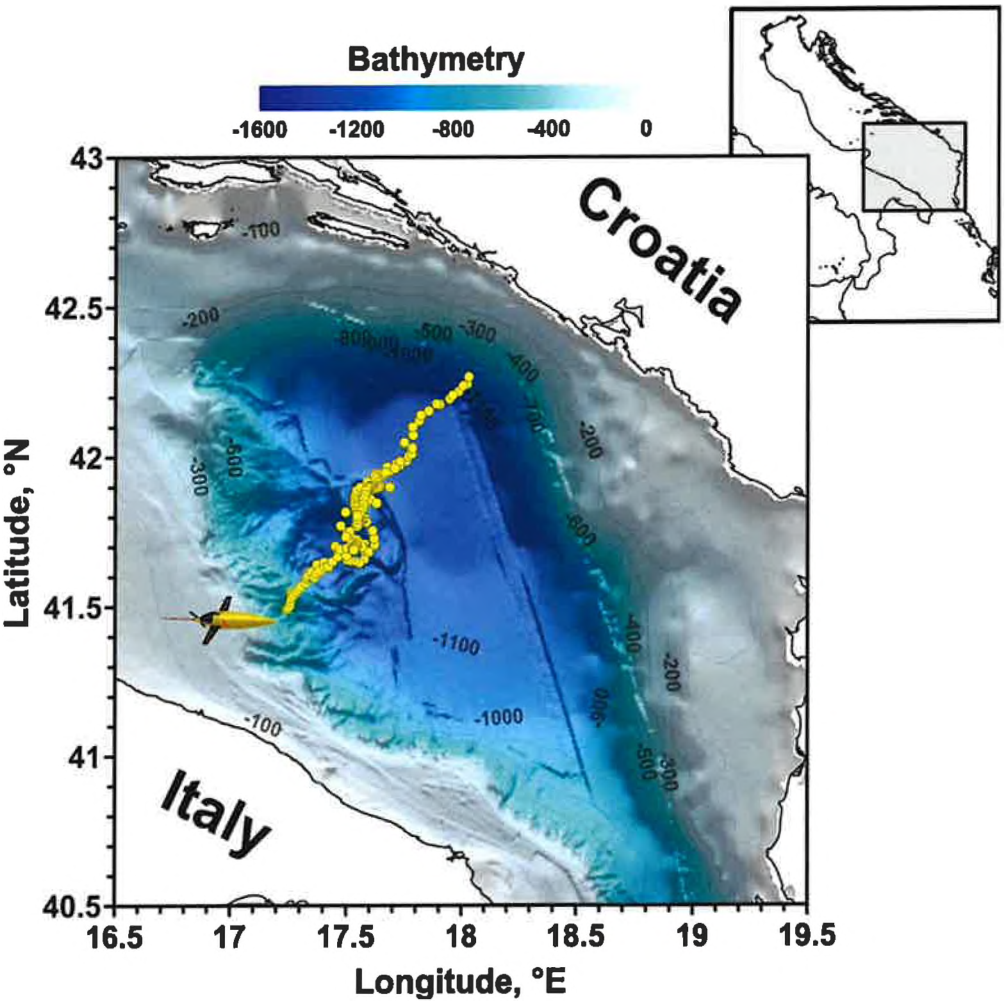


Figure 21: The study area and geographical position of the glider surfacing (yellow dot). The glider symbol indicates the last position of the instrument.

The glider data acquired during the mission was processed and displayed in real time on the webpage: http://argo.ogs.it/glider/history.php

Scripts and web pages have been improved and optimized for real-time data processing and image generation to standardize glider data format and parameter naming. The oxygen concentration data set was corrected using validated in situ oxygen measurements (Winkler samples, Winkler calibrated float data). The detailed calculation, which involves a complex procedure, is reported in two papers: Gerin R. et al. (2020 a,b) and Gerin R. and Martellucci R, (2020).

5. Plans for 2023 and beyond

5.1 Floats

The procurement of 25 standard floats (24 equipped also with dissolved oxygen sensors), and 2 Deep floats will be done with the funds provided by the Italian Ministry of Research to sustain the core-Argo activity in the framework of the Euro-Argo Research Infrastructure Consortium. The Italian Ministry of Research has recognized Euro Argo as a high priority infrastructure for the Piano Nazionale Infrastrutture di Ricerca (PNIR 2021-2027) which is integral part of the Piano Nazionale di Ricerca (PNR).

In 2022, the Italian Ministry of Research has funded a 2.5-year grant (ITINERIS - Italian Integrated Environmental Research Infrastructures System) for the implementation of the environmental research infrastructures and their integration, in which Euro-Argo takes part. The project will build the Italian Hub of Research Infrastructures in the environmental scientific domain for the observation and study of environmental processes in the atmosphere, marine domain, terrestrial biosphere, and geosphere, providing access to data and services and supporting the Country to address current and expected environmental challenges.

The ITINERIS project involves OGS as well as CNR with the purpose to extend to the biogeochemical component of Argo and will allow the purchase in 2023 BGC floats (16 units by OGS and 9 units by CNR) to be deployed mainly in the Mediterranean. The scientific objectives range from biogeochemical to bio-optical issues related to climate change and include modeling and satellite components.

The project gives the opportunity to put in place the Deep-Argo extension in the Mediterranean Sea since only a few in situ data are available at those depths. Rapid changes in thermohaline characteristics require us to explore even these parts of the sea that have for years been considered a place where changes are particularly slow. The deep float data will allow us to have a more precise estimate of Ocean Heat Content (OHC) and thus the amount of heat the sea is able to store and to monitor the OHC change over time. There are several sub-basin areas with a depth between 2000 and 5000 meters that will be explored by the Argo platforms (Algerian, Ligurian, Tyrrhenian, Ionian, Cretan and Levantine sub-basins).

The Italian deployment plans for 2023 and estimates for 2024 are detailed in Table 7. The main areas of interest are the Mediterranean and the Southern Ocean. Deployments in the Black Sea are suspended at the moment due to the political crisis in the area. CNR has purchased one BGC-Argo float that will be deployed in the Mediterranean Sea in 2023.

Year	T/S floats (some with DO)		BGC floats		Deep floats		Total
	Quantity	Area	Quantity	Area	Quantity	Area	
2023	6-7 0 3 5	Mediterranean Black Sea South. Ocean Global	2 0	Mediterranean Black Sea	1-2	Mediterranean	**18-19**
2024	6 0 2 4	Mediterranean Black Sea South. Ocean Global	6-8 0	Mediterranean Black Sea	2	Mediterranean	**20-22**

Table 7. Italian float deployment plans for 2023-2024.

Over a longer time frame, Italy is interested in maintaining contributions to the Argo Core mission and the BGC and Deep Argo Extension with numbers similar to those listed in Table 7. OGS is committed to carry out DMQC of the physical variables on all the Argo floats of the Mediterranean and Black seas, and on some floats in the World Ocean, as part of the Euro-Argo RISE, MOCCA project and other European projects over the coming years.

5.2 Drifters

With funds allocated in the previous years, we have purchased 60 SVP and 7 CODE drifters. Plans for drifter deployment in 2023 and 2024 are described in Table 8.

Year	Drifters	
	Quantity	Area
2023	20 SVP 10 SVP	Southern Ocean Mediterranean
2024	10 SVP 20 SVP	Southern Ocean Mediterranean

Table 8. Argo-Italy drifter deployment plans for 2023-2024.

5.3 Gliders

In 2023, we expect to run the south Adriatic Sea missions using the SeaGlider SG554 and SG661 to monitor pre and post dense water formation phases and to refurbish the SG554 at the factory. There are plans to deploy a glider in the Ross Sea as part of the PNRA Signature project. The ITINERIS project included an expansion of the glider fleet by increasing the number of longer-life endurance vehicles that allow exploration of the northern and central Ionian Sea to better understand the dynamics of the area and the impact of extreme events.

6. Acknowledgements

We would like to thank the following people for their help with the logistics of drifter, float and glider operations:

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- Adam Gauci, University of Malta
- Daniel Hayes, Cyprus Subsea Consulting and Services C.S.C.S. Limited, Nicosia, Cyprus
- Pierre-Marie Poulain, Centre for Maritime Research and Experimentation (CMRE), La Spezia, Italy
- Katrin Schroeder, Consiglio Nazionale delle Ricerche - Istituto di Scienze Marine (CNR ISMAR), Venezia, Italy
- Vanessa Rossana Cardin, Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS), Trieste, Italy
- Captain of the M/V ROE Luca Triggiani
- The captains and crews of R/V Dallaporta, R/V Laura Bassi, Alliance, R/V Aegaeo, Malta Coast Guard Boat, Belgica II, VTS Ammochostos, M/Y ROE

7. References

Gerin R. and Martellucci (2020) Float 6901865 oxygen data calibration. REL. 2020/35 OCE 10 MAOS 6 pp.

Gerin R., Martellucci R., Mauri E., Kokkini Z., Medeot N., Nair R., Zuppelli P., Comici C. and Pachou A. (2020). Oxygen concentration in the South Adriatic Sea: the gliders measurements. Rel. 2020/36 Sez. OCE 11 MAOS 31 pp.

Gerin R., Martellucci R., Notarstefano G. and Mauri E. (2020) Float oxygen data calibration with discrete Winkler samples in the South Adriatic Sea. REL. 2020/30 OCE 9 MAOS, Trieste, Italy 21 pp.