ARGO-ITALY ANNUAL REPORT 2023

CONTRIBUTION TO EURO-ARGO ERIC

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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).

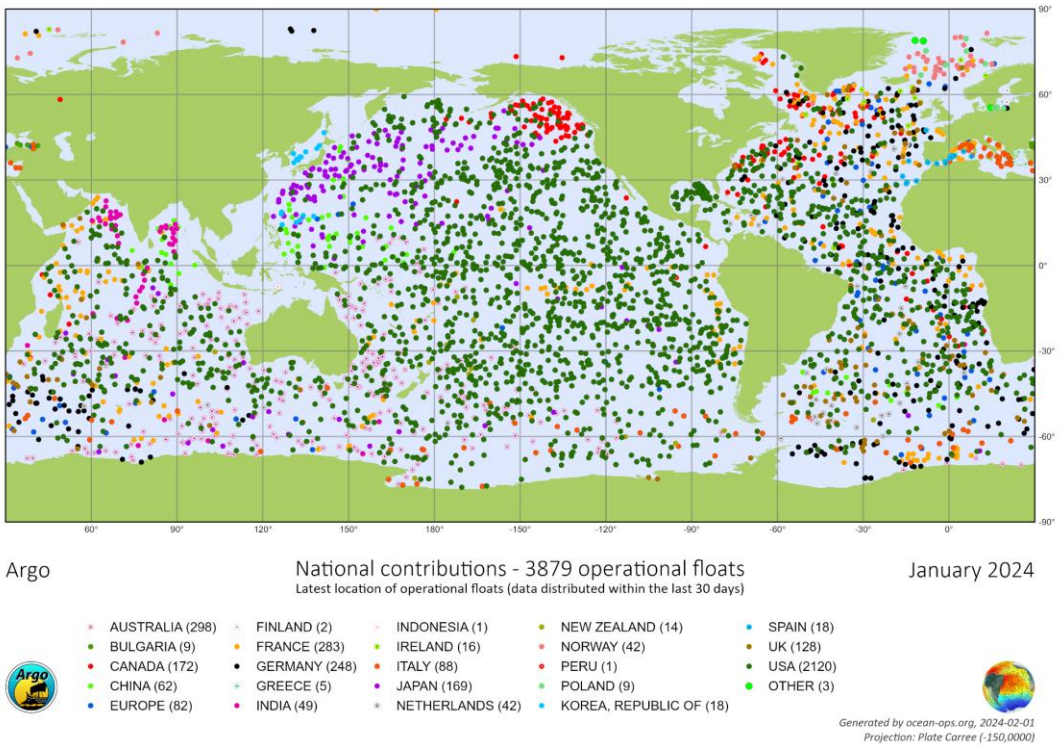


Figure 1. World wide distribution of active Argo floats as of January 2024.

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 centers. Argo is one of the most cost-effective ways to monitor the ocean interior on a long-term basis.

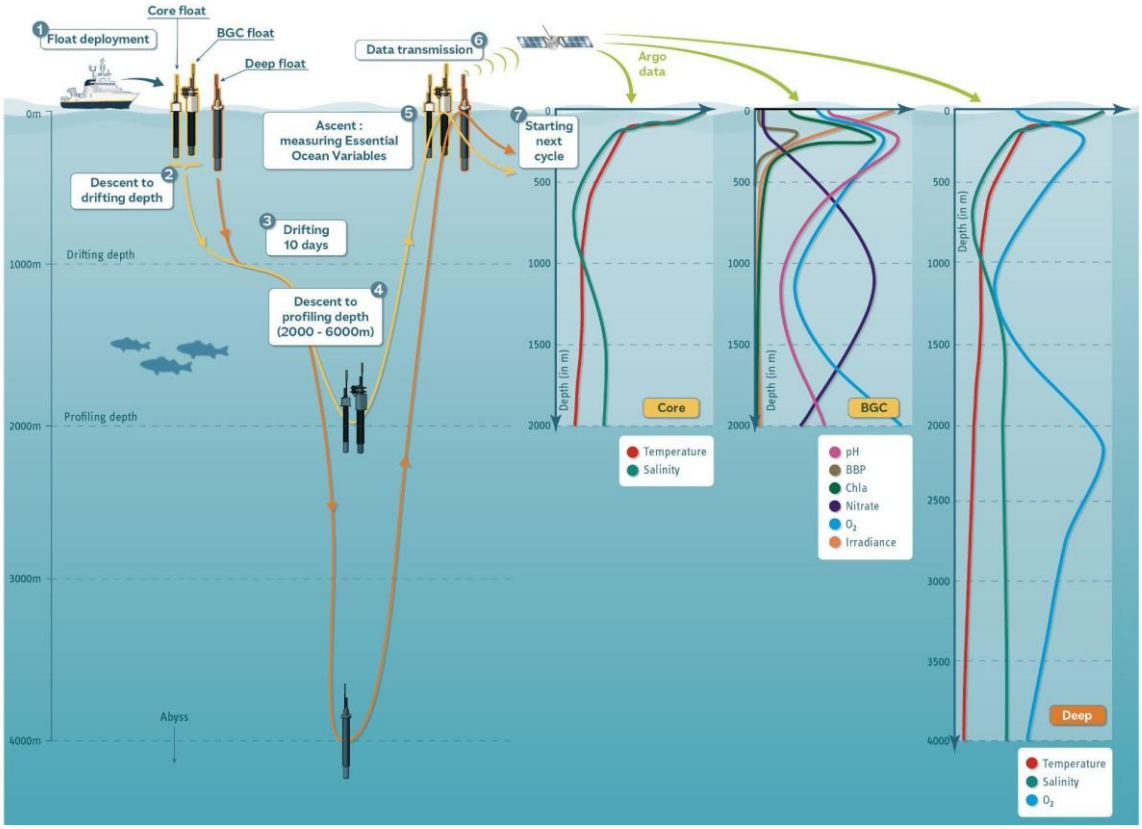


Figure 2. Typical cycle and measured parameters of the three Argo float types: Core-Argo, BGC-Argo and Deep-Argo.

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-Argo and Deep-Argo focus on collecting profiles of temperature and salinity between 2000 (Core-Argo) or 6000 m (Deep-Argo) 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).
- To support physical and biogeochemical operational ocean forecasts in the Mediterranean Sea.

b. Platforms

Argo-Italy is an autonomous and integrated system of multidisciplinary marine observations mainly carried out by profiling buoys (Argo). Surface drifters, and ocean glider activities are included to a much lesser extent to complement 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 autonomous underwater vehicles (AUV) that use changes of their 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 traditional shipboard techniques, gliders provide a large amount of data on a finer temporal and spatial scale, with very low power consumption and management costs.

- **Drifters**

  Drifters are lagrangian buoys that remain 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**.

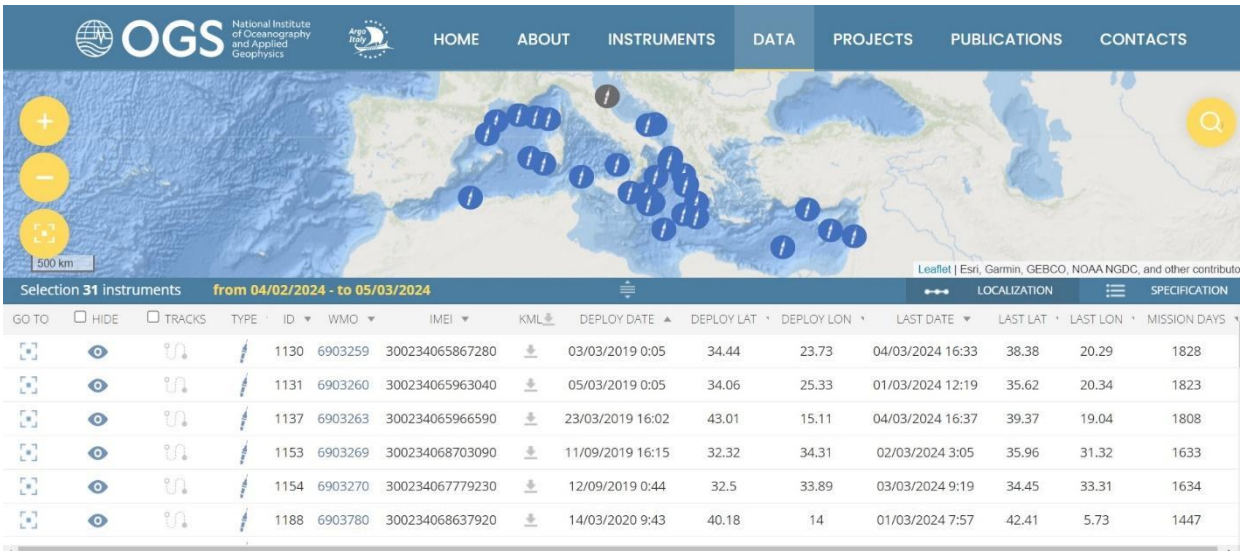
- Argo-Italy data are distributed in near real time on the **Global Telecommunication System** (GTS) that is a communication network critical for **forecasting and warnings of hydrometeorological hazards** (https://argo.ucsd.edu/organization/argo-data-system/).
- Argo-Italy **contributes to other international 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 and is providing 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, see also Menna et al., 2023) 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). These groundbreaking data have allowed us to study specific processes, which has recently generated a manuscript submitted to a prestigious scientific journal.
- BGC-Argo data provided by Argo Italy contribute to studying key processes of the **carbon cycle** and to understand and quantify carbon sequestration.
- Argo-Italy promotes outreach activities (interviews at schools, divulgation at public events) and programs (Adopt-a-Float, https://argo.ogs.it/adopt_a_float/#) to attract the interest of

people (mostly students) regarding the importance of the ocean and how crucial its study is to better understand and protect it.

- Argo-Italy promotes training/education of new young scientists through doctoral programs in collaboration with universities.

1.2 Webpage of Argo-Italy data and activities

The operation of the instruments at sea and data collection began in February 2012, and a dedicated website was developed to support the activities and display the collected data on Argo-Italy in real time, to post graphical and tabular summaries, news and 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). The 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 scientific data collected are plotted for each specific float (figure 4).



GO TO	HIDE	TRACKS	TYPE	ID	WMO	IMEI	KML	DEPLOY DATE	DEPLOY LAT	DEPLOY LON	LAST DATE	LAST LAT	LAST LON	MISSION DAYS
				1130	6903259	300234065867280		03/03/2019 0:05	34.44	23.73	04/03/2024 16:33	38.38	20.29	1828
				1131	6903260	300234065963040		05/03/2019 0:05	34.06	25.33	01/03/2024 12:19	35.62	20.34	1823
				1137	6903263	300234065966590		23/03/2019 16:02	43.01	15.11	04/03/2024 16:37	39.37	19.04	1808
				1153	6903269	300234068703090		11/09/2019 16:15	32.32	34.31	02/03/2024 3:05	35.96	31.32	1633
				1154	6903270	300234067779230		12/09/2019 0:44	32.5	33.89	03/03/2024 9:19	34.45	33.31	1634
				1188	6903780	300234068637920		14/03/2020 9:43	40.18	14	01/03/2024 7:57	42.41	5.73	1447

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

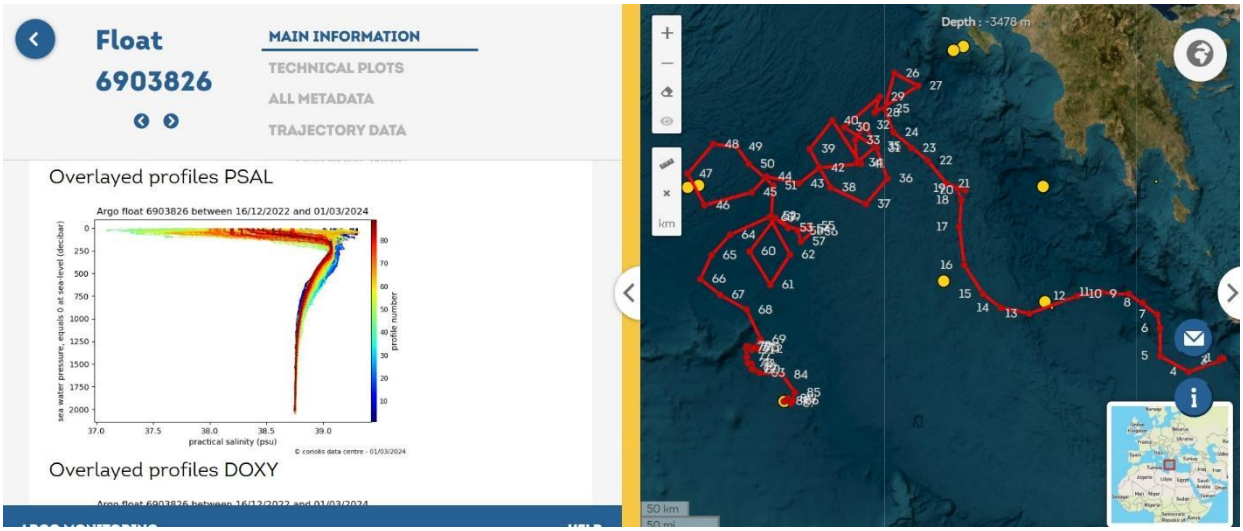


Figure 4. Selected Argo-Italy float displayed on the Euro-Argo monitoring tool (https://fleetmonitoring.euro-argo.eu/dashboard).

2. Argo float activities in 2023

This report summarizes the 2023 activities of Argo-Italy, funded by the Ministry of University and Research (MUR), in terms of procurements of the instruments, their preparation and deployments. Information about data processing and archiving is also given. Plans for 2024 and beyond are included in the last section.

2.1 Float procurement

OGS purchased 27 floats in 2023 with funds provided by the Italian Ministry of Research, including 15 Core-Argo with dissolved oxygen sensors, 2 Deep-Argo with dissolved oxygen sensors, 9 Core-Argo with dissolved oxygen sensors and with Ice Detection Algorithm implemented, and 1 Core-Argo equipped with the RBR CTD.

2.2 Float deployments

A total of 18 Italian floats were deployed in 2023 (see Tables 1 and 2 for details). The float designs are Arvor-I, Arvor-Ice, Provor CTS4, Provor CTS5 (1 unit from CNR-ISMAR), and Deep-Arvor manufactured by NKE (France). All floats transmit data via Iridium telemetry.

Mediterranean and Black Sea deployments

Nine units were released in the Mediterranean (Table 1). The Core-Argo floats have a park pressure at 350 dbar and maximal profiling depth at 2000 dbar. BGC-Argo floats have a park pressure at 1000 dbar and the maximal profiling pressure was set to 2000 dbar. An Arvor-I float (WMO 4903680) was deployed in the Sicily Channel and parked on the seafloor to limit horizontal displacement and sample the water column of the shallow area. The cycle time was set to 5 days and the parking depth was adjusted so that it is always greater than the maximum bathymetry.

Most floats were deployed from research vessels of opportunity (i.e., R/V Atalante, R/V Aegaeo, Speedboat (Malta), fishing vessel (Cyprus) and R/V Laura Bassi for the Mediterranean and R/V Agulhas II and Laura Bassi for the South Atlantic and Southern Ocean with the help of colleagues from France (figure 5), Greece (figure 6), Malta, Italy and Cyprus.

Issues encountered in the Mediterranean Sea in 2023

The sampling of Arvor DO 7901019 failed after 2 cycles due to lack of communication with SBE41.

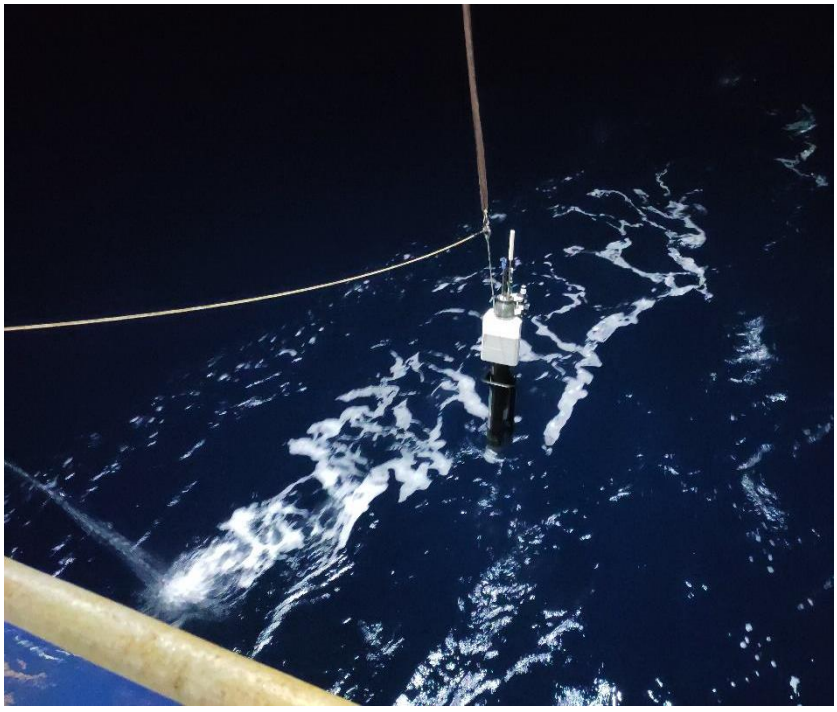


Figure 5. Provor CTS4 WMO 1902605 deployed from R/V Atalante in the Balearic Sea within the BIOSWOT project, April 2023 (credit Andrea M. Doglioli).

Figure 6. Arvor-D DO WMO 3902483 in the Ionian Sea from M/Y AEGAEO (credit HCMR).

Model	WMO	Depl. Date	Lat	Lon	Cycles	Last Date	Lat	Lon	Status*	Cyc.**
Arvor- T/S Diss. Oxy	7901019	02-Mar-2023 10:07	33.90	33.00	2	08-Mar-2023 07:44	33.84	33.29	D	5
Arvor - T/S Diss. Oxy	2903795	24-Apr-2023 17:08	40.94	4.26	195	04-Feb-2024 22:09	41.31	03.61	A	5
PROVOR CTS4	1902605	28-Apr-2023 22:04	42.14	07.48	152	05-Feb-2024 12:05	42.17	07.27	A	5
Arvor - T/S Diss. Oxy	3902500	05-May-2023 04:08	40.84	04.95	152	04-Feb-2024 07:44	41.58	08.23	A	5
Arvor - T/S Core	4903680	08-Jul-2023 08:50	35.70	14.41	33	18-Dec-2023 22:09	36.34	14.04	D	5
Arvor – I DEEP	3902483	25-Oct-2023 14:46	36.50	21.58	16	02-Feb-2024 06:11	36.53	21.48	A	5
Arvor - T/S Diss. Oxy	4903679	25-Nov-2023 22:47	38.99	15.20	15	05-Feb-2024 09:49	39.19	14.54	A	5
Arvor – I DEEP	5906993	26-Nov-2023 12:56	37.06	17.88	8	30-Jan-2024 23:04	37.03	17.44	A	10
PROVOR CTS4	5907088	26-Nov-2023 13:16	37.06	17.89	16	02-Feb-2024 11:26	36.11	17.15	A	5

**Status in early February 2024: A = active, D = dead.*
***Cycle: Length of cycle in days.*

Table 1. Status information for the 9 Italian floats funded by MUR deployed in the Mediterranean Sea during 2023.

South Atlantic, South Pacific and Southern Ocean

A total of 5 Arvor-I equipped with ice-detection software were deployed with the help of Italian colleagues on board the R/V Laura Bassi (Table 2): three along the Ross Ice Shelf (6903831, which failed due to lack of communication with the SBE41 probe, 6903832 operated regularly, and 6903833 re-deployed as WMO 6903810), two during the crossing of the Circumpolar Current (6903829, 6903830 which operated regularly). The adopted configuration in the Ross Ice Shelf Polynya consisted of a cycle time of 7 days and a park and maximum profile pressure of 1000 dbar (i.e. a park pressure at the seafloor). One float (6903794) was recovered for maintenance purposes.

In collaboration with the *Parthenope* University, three Arvor-I with ice detection were successfully deployed in the southern Atlantic sector (5906980, 5906979, 4903650).

Model	WMO	Depl. Date	Lat	Lon	Cycles	Last Date	Lat	Lon	Status*	Cyc.**
Arvor-T/S ICE	6903829	09-Jan-2023 20:00	-63.02	172.73	40	05-Feb-2024 01:44	-63.98	-169.51	A	10
Arvor-T/S ICE	6903830	10-Jan-2023 13:02	-65.03	176.15	39	29-Jan-2024 03:22	-64.83	164.59	A	10
Arvor-T/S ICE	**6903831**	**26-Jan-2023 15:05**	**-77.16**	**168.90**	**2**	**03-Feb-2023 05:45**	**-77.04**	**168.93**	**D**	**7**
Arvor-T/S ICE	**6903832**	**27-Jan-2023 08:16**	**-77.41**	**174.38**	**56**	**04-Feb-2024 05:46**	**-76.67**	**173.84**	**A**	**7**
Arvor-T/S ICE	**6903833**	**29-Jan-2023 17:15**	**-77.96**	**-160.23**	**60**	**31-Jan-2024 16:42**	**-77.47**	**-163.21**	**recovered**	**7**
Arvor-T/S ICE	5906980	08-Feb-2023 03:07	-50.37	-0.29	-	08-Feb-2023 03:07	-50.37	-0.29	D	10
Arvor-T/S ICE	5906979	08-Feb-2023 16:52	-48.04	-0.98	37	05-Feb-2024 23:35	-53.93	36.39	A	10
Arvor-T/S ICE	4903650	08-Feb-2023 16:52	-48.05	-0.98	37	05-Feb-2024 23:51	-53.16	38.00	A	10

**Status in early February 2024: A = active, D = dead.*
***Cycle: Length of cycle in days.*

Table 2. Status information for the 8 Italian floats funded by MUR deployed in the Southern Ocean, South Atlantic and South Pacific during 2023.

Issues encountered in the Global and Southern Ocean in 2023

Global Ocean

The Core Arvor 5906980 failed after deployment for unknown cause.

Southern Ocean

The Core Arvor 6903831 failed after 2 cycles due to a lack of communication with the SBE41 probe.

In summary, the Argo-Italy program had a total of 86 active floats at the end of 2023, 35 of which were in the Mediterranean Sea, one in the Atlantic Ocean (it left the Mediterranean through the Strait of Gibraltar), 2 in the Black Sea (figure 7) and a total of 48 in the South Pacific, South Atlantic and Southern Oceans (south of 60°S, see figure 8).

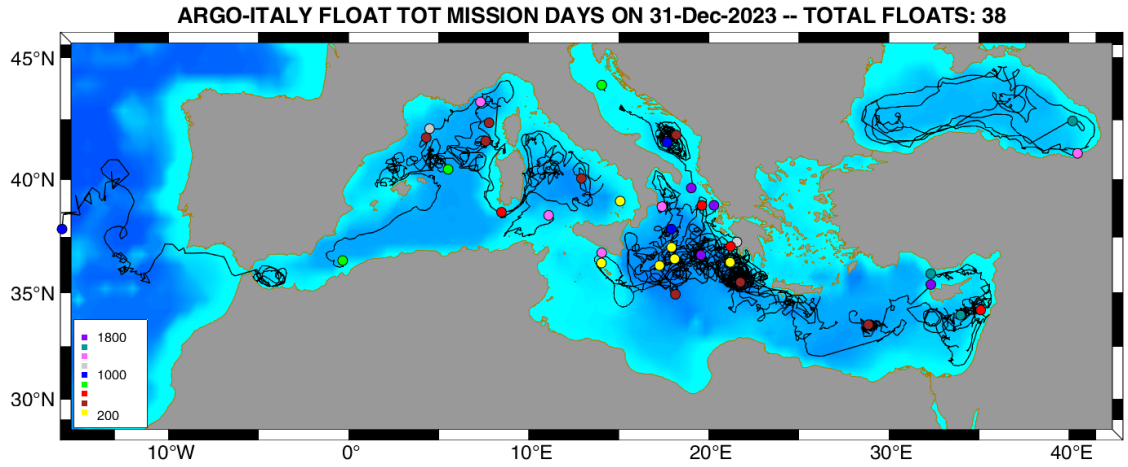


Figure 7. Trajectories and positions (circle symbols) on 31 December 2023 of the 38 Argo-Italy floats active in the Mediterranean and Black Seas (one float escaped in the Atlantic Ocean). Circles are color coded as a function of float age in days.

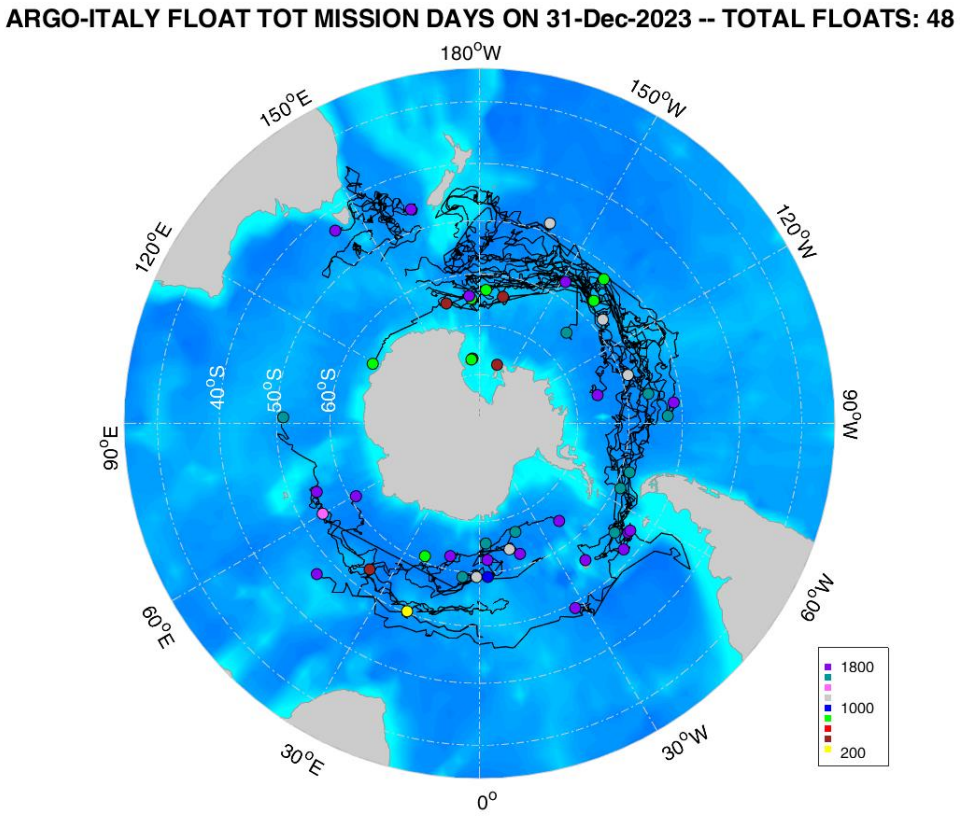


Figure 8. Trajectories and positions (circle symbols) on 31 December 2023 of the 48 Argo-Italy floats in the South Pacific, South Atlantic and Southern Oceans. Circles are color coded as a function of float age in days.

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. Argo float and ocean glider data after a real time quality control performed by Coriolis are sent to Copernicus Marine Service.

The data of BGC-Argo 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

OGS team is committed to carrying out DMQC (delayed mode quality control) for physical parameters on all the Core-Argo floats of the Mediterranean and Black Seas, on Italian Core-Argo floats and on some Core-Argo floats in the world ocean part of the MOCCA and other European projects over the coming years. The DMQC analysis are also conducted on the shallow-coastal floats deployed in the Mediterranean Sea, in the framework of the European H2020 Euro-Argo RISE project.

The DMQC of the physical data (pressure, temperature and salinity) provided by the Italian floats was done for approximately 83% of eligible floats (208 out of 252 eligible floats, see figure 9 and 10) deployed between 2009 and 2022 in the Mediterranean and Black Seas, and Southern Ocean. The quality-controlled files produced (D-files) are sent to Coriolis.
The standard Argo DMQC procedure - OWC (Wong Annie, Keeley Robert, Carval Thierry, Argo Data Management Team (2024). Argo Quality Control Manual for CTD and Trajectory Data. https://doi.org/10.13155/33951) was adopted. In case the reference data are quite old, for specific sub basins, the PCM (Profile Classification Model) method has been adopted to better face the QC. Indeed, this approach makes it possible to select reference data belonging to similar water masses, even if they are older than the float profile. The OWC statistical procedure is based on the comparison between the newly acquired float salinity profiles and an accurate historical reference dataset. Additional qualitative analysis are also performed to better interpret results and hence provide an improved quality control analysis.
Big effort has been put into identifying new high-quality ship-based CTD data (from near-surface to depths deeper than 2000 m) in the Mediterranean and Black seas. The data are collected from several research institutes at regional level and from the main European Marine Services. The new reference quality controlled dataset potentiated with recent data, ensures an improved homogeneous spatial and temporal coverage of the Mediterranean Sea in particular of intermediate layers of the water column.

As mentioned before, in marginal seas the DMQC is particularly critical and other methods have been tested and adapted like the one developed by the German Institute BSH (https://www.bsh.de/EN/Home/home_node.html) to detect suspicious data.

In very shallow areas in addition to the qualitative analyses (comparison between float profiles and CTD at deployment or the nearest CTD), the procedure developed for the Baltic sea are adapted to the Adriatic Sea in order to improve the qualitative analysis (https://zenodo.org/records/8366257). This approach is still under development and the quality-controlled files are produced at the moment.

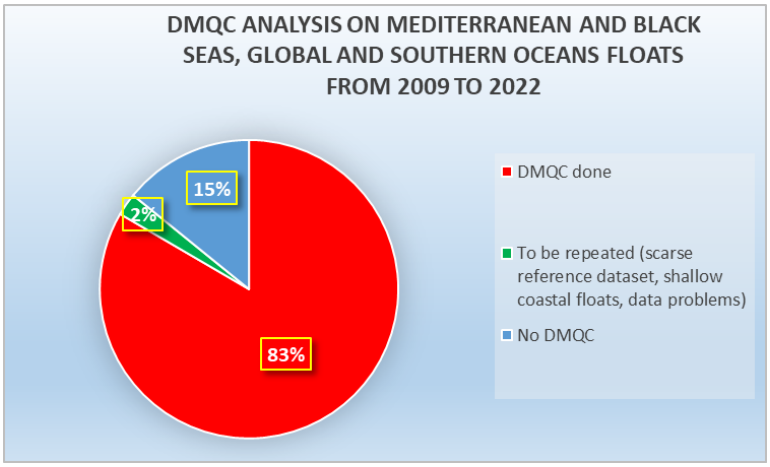


Figure 9: Status of the DMQC.

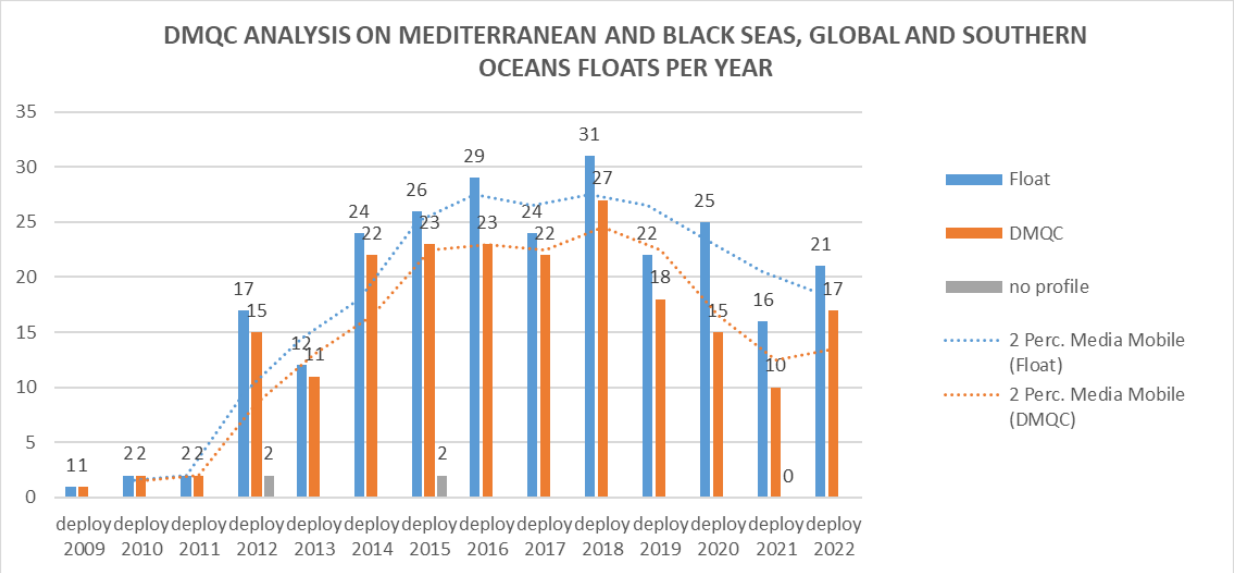


Figure 10: Status of the DMQC per year (from 2009 to 2022).

2.5 Long term Argo float statistics

The temporal evolution of the number of active floats is shown in figure 11 with a weekly resolution, along with the annual numbers of float deployments and deaths in the period 2012-2023. The float population in 2023 is in the range 80-90 active instruments. In 2023, the number of dead floats is well balanced by new deployments.

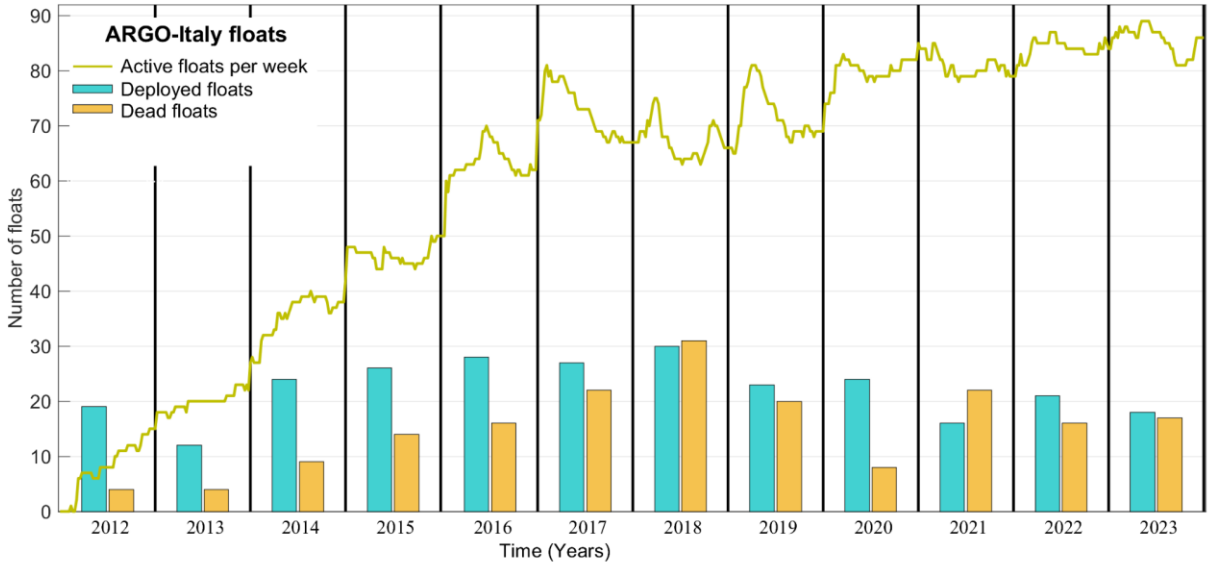


Figure 11. Temporal evolution of the number of Argo-Italy active floats with weekly resolution and histogram of the annual float deployments and losses.

Since 18 February 2012, a total of 268 Argo-Italy floats have been deployed, 157 in the Mediterranean and Black Seas and 111 in the Southern Hemisphere oceans (figure 12). Over a 12 year period, they have provided about 43,000 CTD profiles. The histogram of the number of floats in selected CTD profile classes is shown in figure 13. The number of float profiles sorted by the main floats types shows the evolution in time of the Italian fleet (Figure 14). In this diagram, Core-Argo and Core-Argo DO floats are grouped together; BGC-Argo floats are intended as floats equipped with sensors for measuring from 2 to 6 biogeochemical parameters.

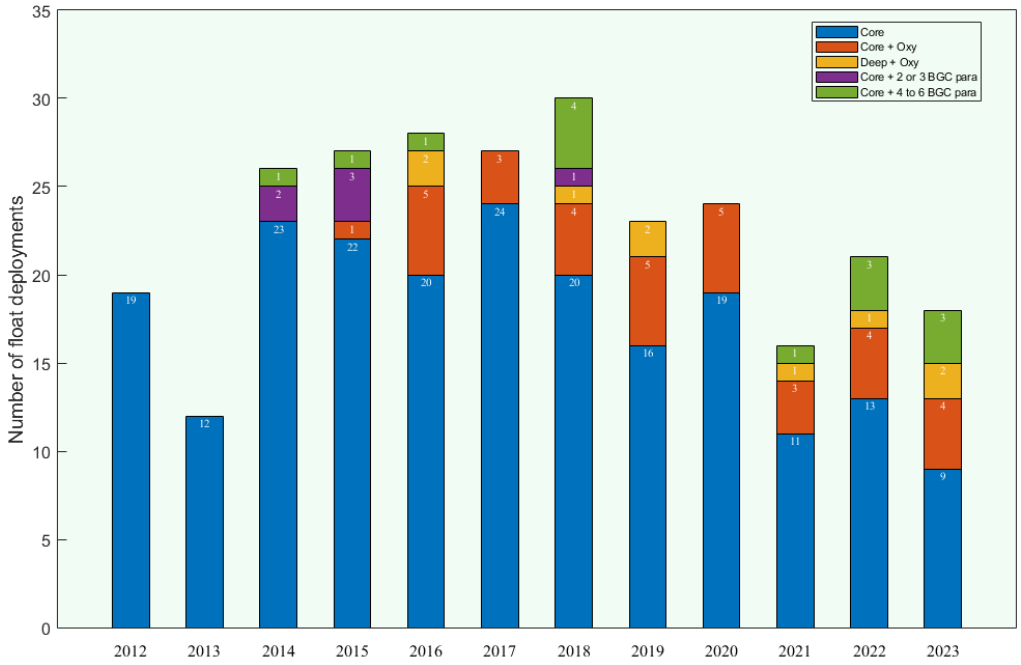


Figure 12. Histogram of the number of floats deployed since 2012, sorted per float type.

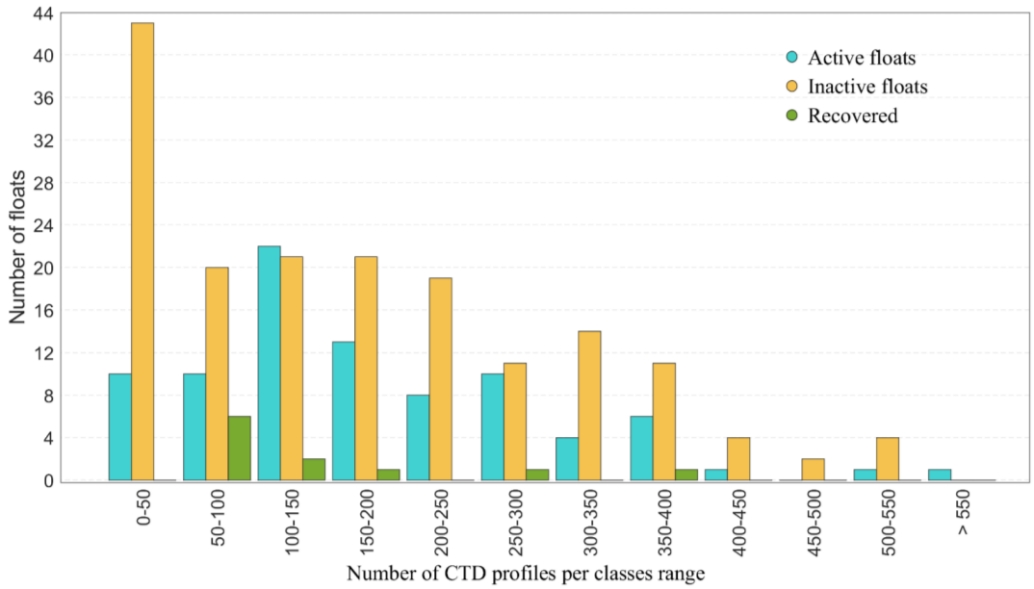


Figure 13. Histogram of the number of floats in selected CTD profile classes at the end of 2023 (orange: dead float, cyan: alive at the end of 2023, green: recovered).

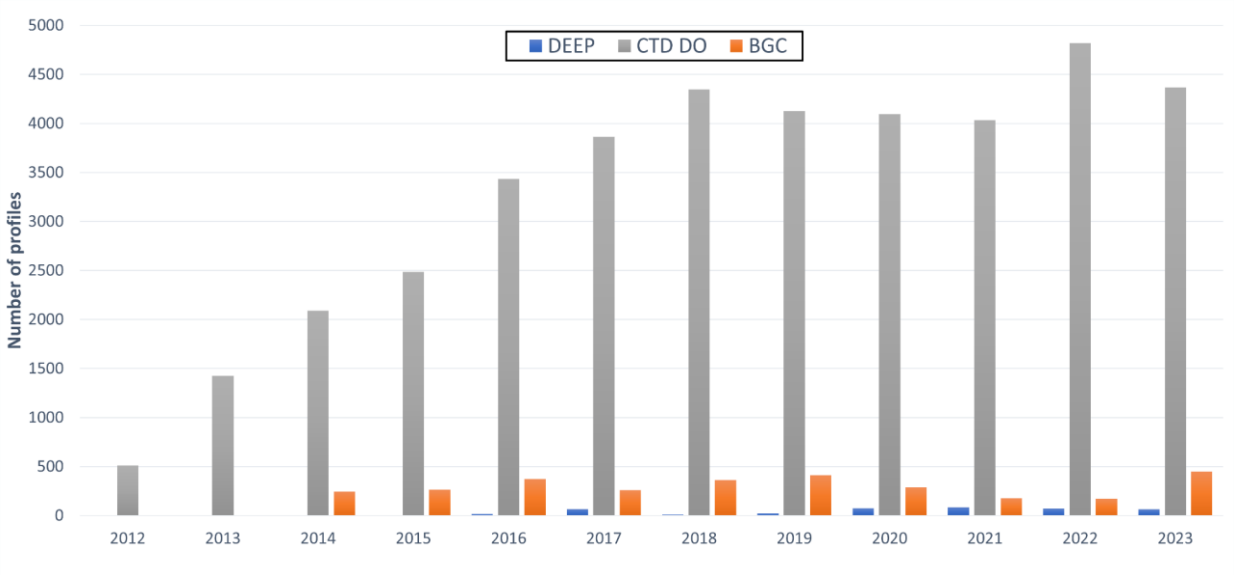


Figure 14. Number of float profiles from 2012 to 2023 sorted by main float types (orange: BGC floats, blue: Deep floats, grey: Core-Argo and Core-Argo DO floats).

After about 12 years of activities in the Mediterranean and Black seas, the maximum operating life of the Argo-Italy floats is about 5.9 years (~2150 days, see figure 15). In order to obtain a robust statistic of the survival rate of floats in the Mediterranean and Black seas, floats still alive (that is with a life <= 850 days that corresponds approximately at the mean half-life [life-time of 50% of the fleet]) and recovered floats were excluded by the computation. In this way, the estimate of the mean half-life is more than 950 days (figure 15). Arvor's floats show the longest performance, exceeding the threshold of 2000 mission days threshold (figure 15, bottom).

For floats deployed in the South Pacific, South Atlantic, and Southern Ocean, the maximum operational lifetime is more than 6.5 years, and the mean half-life approaches four years (figure 16). The longest service is attributed to the Arvor floats with more than 2500 mission days (figure 16, bottom).

These statistical survival rates should be interpreted with caution because most of the floats are still alive (38 floats out of 157 units in the Mediterranean and Black Seas, 48 floats out of 111 in the Southern Hemisphere). In addition, these statistics include the floats with all types of “end of service” (low battery power, stranding, involuntary recovery, etc.).

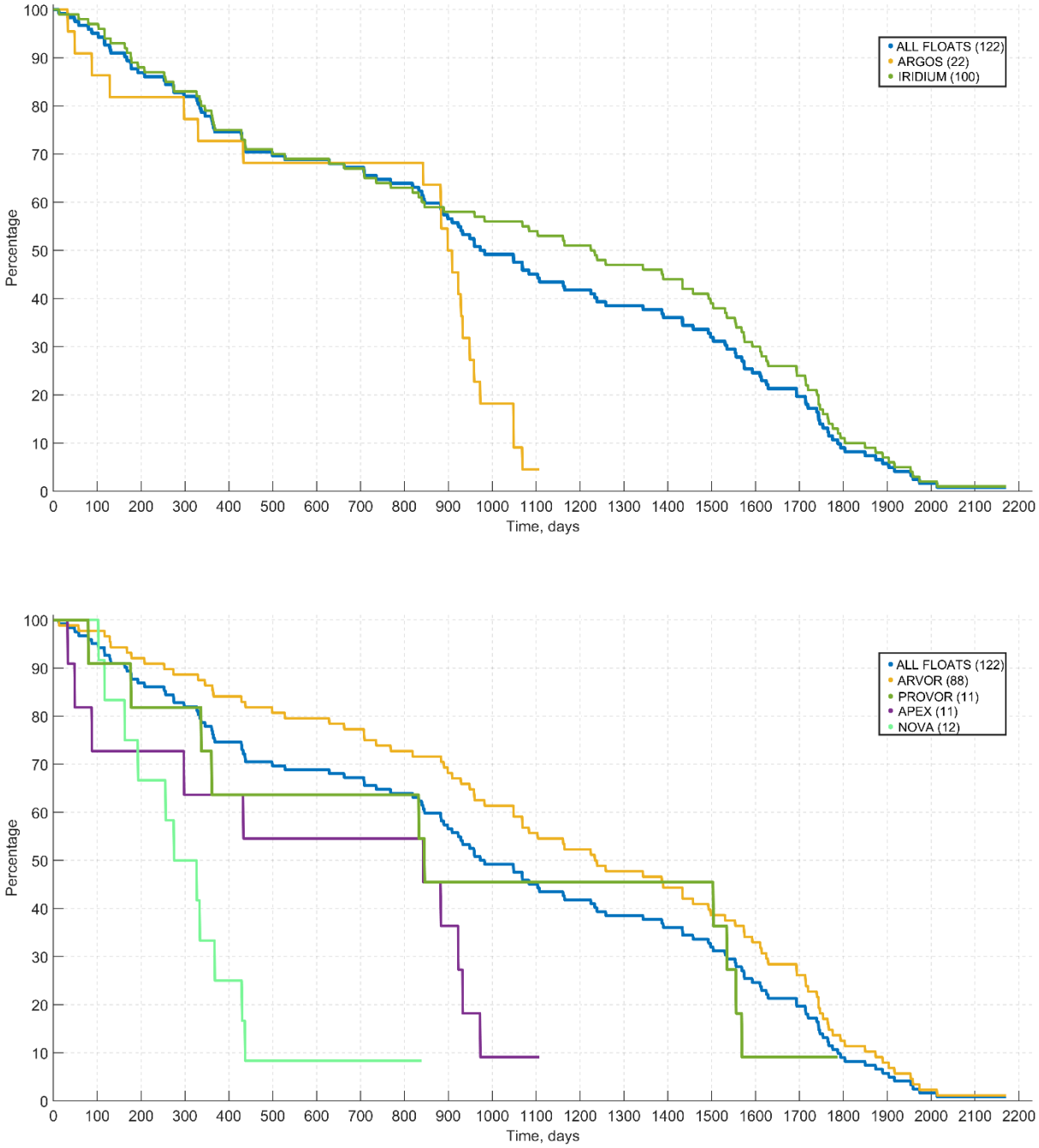


Figure 15. Survival rate diagrams for Argo-Italy floats in the Mediterranean and Black seas, by transmission mode (top) and float type (bottom).

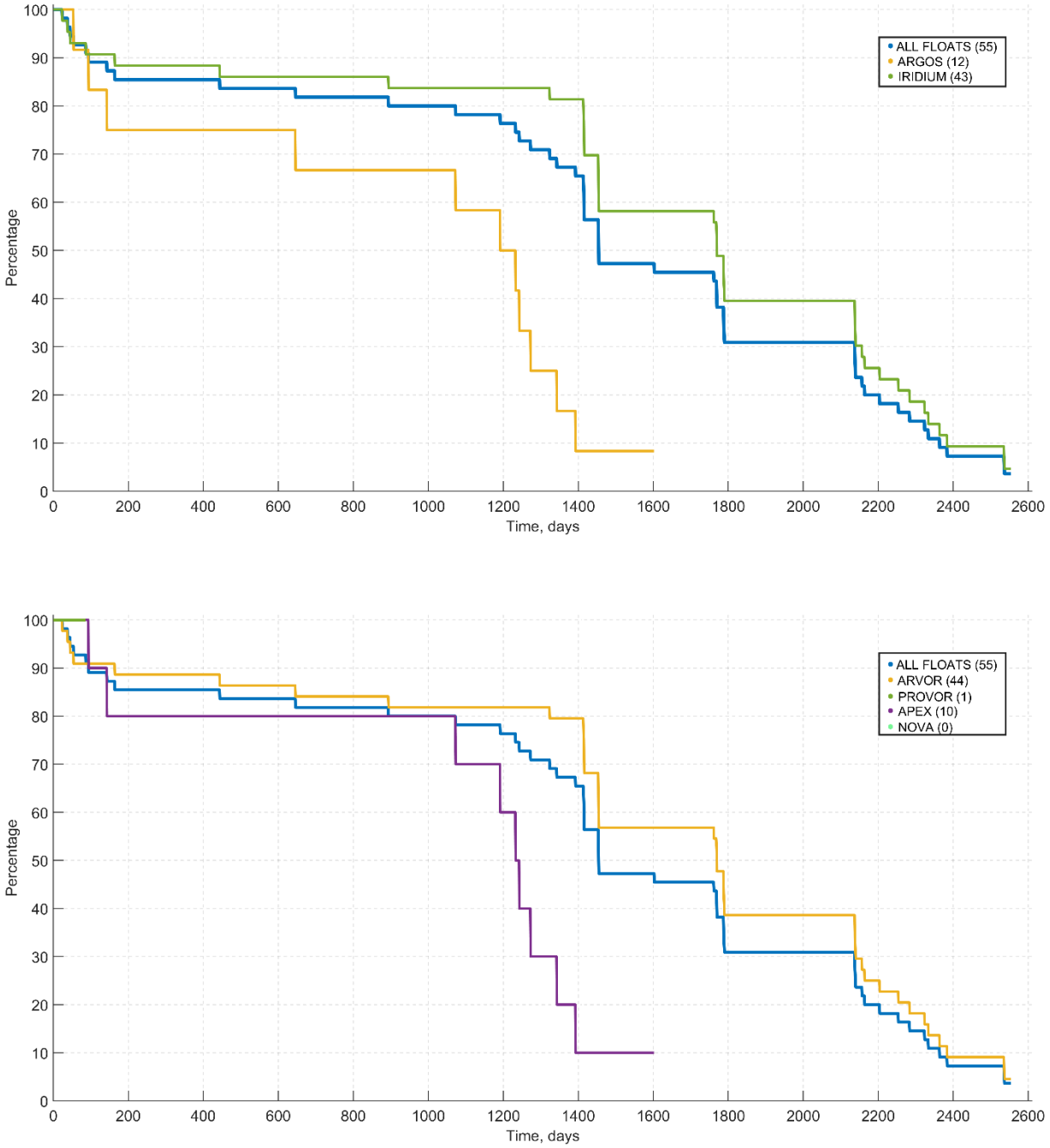


Figure 16. Survival rates for all Argo-Italy floats in the South Pacific, South Atlantic and Southern Ocean, by transmission mode (top) and float type (bottom).

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 17) considering two periods: Jan_2012-Dec_2023, and Jan_2023-Dec_2023, see figure 17. The spatial coverage provided in 2023 (figure 17, bottom) is quite uniform in the

Mediterranean Sea with the exception of a small region in the Balearic sub-basin where a more intensive sampling took place as planned in the BIOSWOT Project.

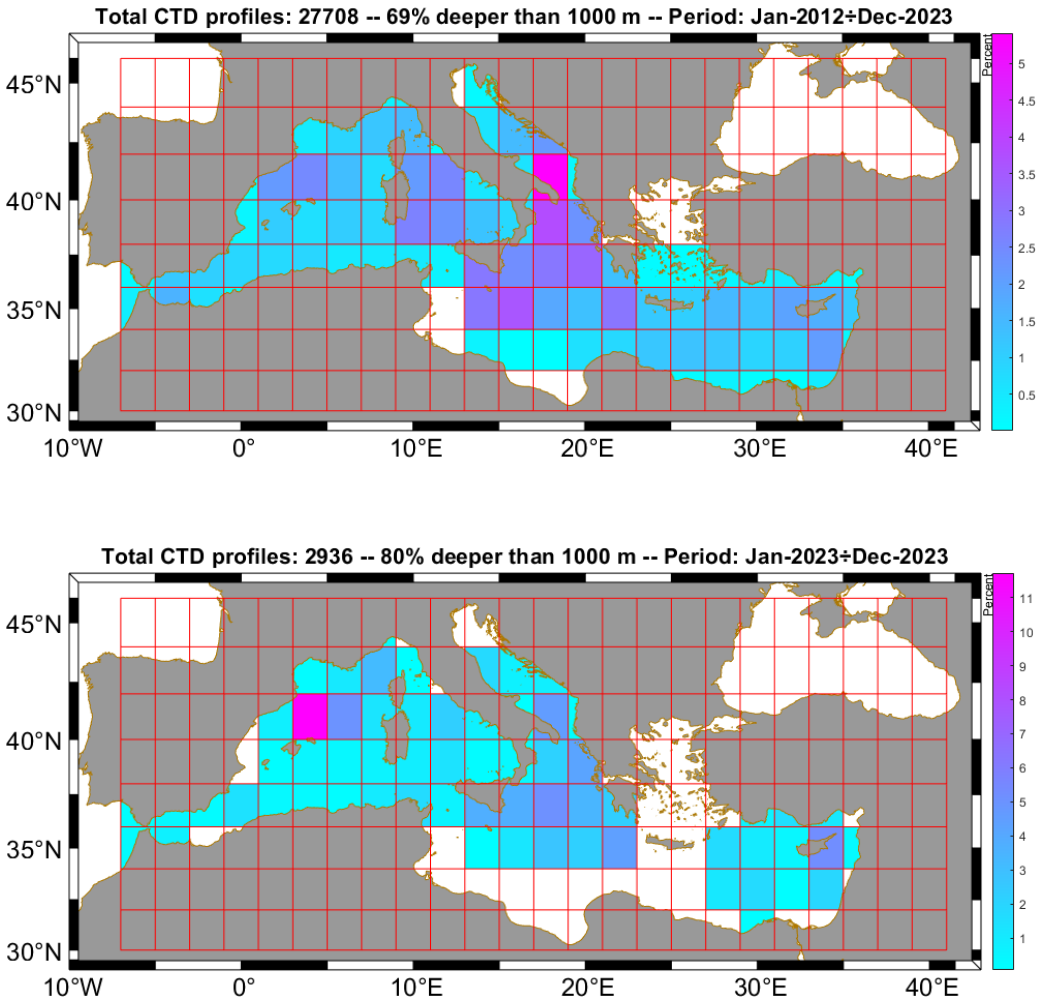


Figure 17. Population density maps.

In 2023, about 5,000 CTD profiles were obtained with the Italian Argo floats. If all the profiles taken from floats in 2023 were added together, (considering only the ascent phase) the distance would be more than 6,600 km. For the period 2012-2023, the 268 floats of Argo-Italy provided data over a total vertical distance of about 51,400 km in 43,000 profiles (see figure 18).

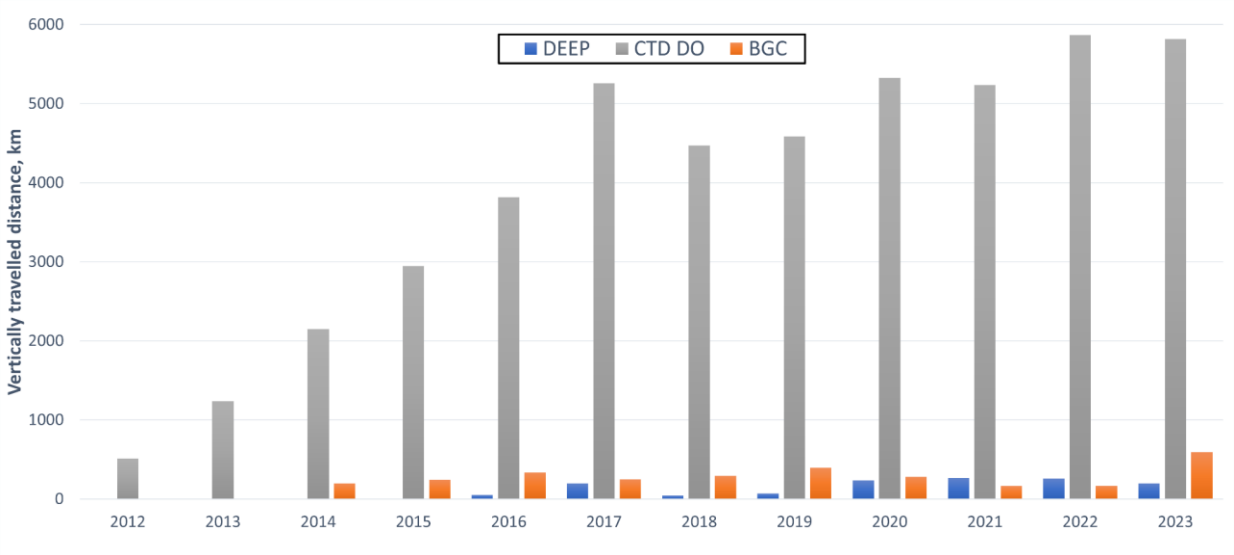


Figure 18. Evolution over the years of the vertically traveled distance (in km, upward profiles only, since the upward direction is the typical direction of sampling) of the Argo-Italy floats, sorted per float type.

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2012-2023
Deployments													
CTD floats deployed in Med	13	7	13	11	9	8	16	10	8	5	10	5	115
CTD floats deployed in BS	4	1	2	1	1	2	0	1	1	0	0	0	13
CTD floats deployed in SO, South Pacific and Atlantic	2	3	7	10	15	17	8	10	15	9	7	8	111
Bio floats deployed	0	0	3	4	1	0	5	0	0	1	3	3	20
Deep floats					2	0	1	2	0	1	1	2	9
Total floats deployed	**19**	**11**	**25**	**26**	**28**	**27**	**30**	**23**	**24**	**16**	**21**	**18**	**268**
CTD profiles													
CTD profiles in Med	400	1099	1560	1743	2358	2147	2962	2646	2213	2205	2867	2423	24623
CTD profiles in BS	105	236	323	268	260	298	298	280	268	181	146	144	2807
CTD profiles in SO, South Pacific and Atlantic	6	90	205	475	815	1418	1087	1200	1615	1647	1806	1801	12165
Bio profiles	0	0	244	266	373	261	360	410	287	175	172	449	2997
Deep profiles					15	65	11	20	75	87	73	64	410
Total profiles	**511**	**1425**	**2332**	**2752**	**3821**	**4189**	**4718**	**4556**	**4458**	**4295**	**5064**	**4881**	**43002**
Vertical distances (km)													
Distance in Med	440	902	1485	1813	2195	2307	2156	2037	2109	2109	2472	2471	22496
Distance in BS	71	210	283	257	247	294	295	287	300	242	197	168	2851
Distance in SO, Southern Pacific and Atlantic	2	125	380	875	1374	2658	2020	2260	2914	2886	3198	3174	21866
Distance of bio floats	0	0	199	245	335	248	293	392	279	165	167	592	2915
Distance of deep floats					50	194	43	69	235	265	256	199	1311
Total distance (km)	**513**	**1237**	**2347**	**3190**	**4201**	**5701**	**4807**	**5045**	**5837**	**5667**	**6290**	**6604**	**51439**

Table 3. Statistical information on the performance of the Argo-Italy floats in 2012-2023.

2.6 Italian contribution to Argo float bibliography and technical reports in 2023

Peer review papers

The Argo bibliography in 2023 shows 526 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.

Amadio, C., Teruzzi, A., Pietropolli, G., Manzoni, L., Coidessa, G., Cossarini, G., 2023. Combining Neural Networks and Data Assimilation to enhance the spatial impact of Argo floats in the Copernicus Mediterranean biogeochemical model. EGUsphere 1–28. https://doi.org/10.5194/egusphere-2023-1588

Cossarini, G., Skakala, J., Wakamatsu, T., Teruzzi, A., Spada, S., & Yumruktepe, C. (2023). Guidelines on space-in situ data assimilation (D5.1). Deliverable report of project H2020 SEAMLESS. Zenodo. https://doi.org/10.5281/zenodo.7684591

Cox, I., Brewin, R.J.W., Dall'Olmo, G., Sheen, K., Sathyendranath, S., Rasse, R. and Ulloa, O. (2023), Distinct habitat and biogeochemical properties of low-oxygen-adapted tropical oceanic phytoplankton. Limnol Oceanogr, 68: 2022-2039. https://doi.org/10.1002/lno.12404

Ford, D. J., Tilstone, G. H., Shutler, J. D., Kitidis, V., Sheen, K. L., Dall'Olmo, G., & Orselli, I. B. M. (2023). Mesoscale eddies enhance the air-sea CO2 sink in the South Atlantic Ocean. Geophysical Research Letters, 50, e2022GL102137. https://doi.org/10.1029/2022GL102137

Gonzalez-Santana A., Oosterbaan M., Clavelle T., Maze G., Notarstefano G., Poffa N. and Velez-Belchi P., (2023). Analysis of the global shipping traffic for the feasibility of a structural recovery program of Argo floats. Front. Mar. Sci. 10:1161580. doi:10.3389/fmars.2023.1161580

Kubin E., Menna M., Mauri E., Notarstefano G., Mieruch S. and Poulain P.-M. (2023). Heat content and temperature trends in the Mediterranean Sea as derived from Argo float data. Front. Mar. Sci. 10:1271638. doi:10.3389/fmars.2023.1271638

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

Pietropolli, G., Manzoni, L., Cossarini, G., 2023a. PPCon 1.0: Biogeochemical Argo Profile Prediction with 1D Convolutional Networks. EGUsphere 1–23. https://doi.org/10.5194/egusphere-2023-1876

Pietropolli, G., Manzoni, L., Cossarini, G., 2023b. Multivariate Relationship in Big Data Collection of Ocean Observing System. Applied Sciences 13, 5634. argohttps://doi.org/10.3390/app13095634

Stoer, A.C., Takeshita, Y., Maurer, T.L., Begouen Demeaux, C., Bittig, H.C., Boss, E., Claustre, H., Dall'Olmo, G., Gordon, C., Greenan, B.J.W, Johnson, K.S., Organelli, E., Sauzède, R.,

Schmechtig, C.M., and Fennel, K. (2023) A census of quality-controlled Biogeochemical-Argo float measurements. Front. Mar. Sci. 10:1233289. doi: 10.3389/fmars.2023.1233289

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

Zilberman NV, Thierry V, King B, Alford M, André X, Balem K, Briggs N, Chen Z, Cabanes C, Coppola L, Dall'Olmo G, Desbruyères D, Fernandez D, Foppert A, Gardner W, Gasparin F, Hally B, Hosoda S, Johnson GC, Kobayashi T, Le Boyer A, Llovel W, Oke P, Purkey S, Remy E, Roemmich D, Scanderbeg M, Sutton P, Walicka K, Wallace L and van Wijk EM (2023) Observing the full ocean volume using Deep-Argo floats. Front. Mar. Sci. 10:1287867. doi: 10.3389/fmars.2023.1287867

3. Drifter activities in 2023

In 2023, a total of 40 SVP drifters, each equipped with surface temperature sensors, were purchased from the Lagrangian Drifter Laboratory at the Scripps Institution of Oceanography (SIO) in La Jolla, University of California, USA. This procurement was made possible by funding from Argo-Italy in the period 2021 to 2022. Subsequently, all these drifters were shipped to Italy; ten of them were used in the BIO-SWOT-Med cruise in April-May 2023, and the remaining part is available for use in activities in 2024.

Table 4 shows the status information of the eight SVP drifters deployed in the South Atlantic in January-February 2023 as a contribution to the PNRA project (Programma Nazionale di Ricerca in Antartide). These drifters were deployed along the Good Hope Transect (figure 19; table 4) from the R/V Agulhas II.

In January 2023, additional 8 Italian drifters were deployed from the R/V Laura Bassi in the South Pacific (figure 20; table 5). Three of them are still alive in May 2023.

Argos/IMEI	Deploy Date	Lat	Lon	Last Date	Lat	Lon	Type	Depth (m)
a300534061495090	06-Feb-2023 14:34	-57.77	0	23-Apr-2024 05:00	-60.81	166.28	SVP	15
a300534061495070	07-Feb-2023 02:21	-55	0	10-Apr-2024 05:00	-44.85	77.46	SVP	15
a300534061495120	08-Feb-2023 03:08	-50.37	-0.29	10-Apr-2024 05:04	-43.75	70.66	SVP	15
a300534061495390	08-Feb-2023 14:40	-48.42	-0	11-Nov-2023 10:04	-47.24	36.29	SVP	15
a300534061495380	08-Feb-2023 14:40	-48.42	-0	10-Apr-2024 05:04	-43.54	77.02	SVP	15
a300534061495150	08-Feb-2023 19:35	-47.61	-1.61	10-Apr-2024 00:04	-42.87	34.19	SVP	15
a300534061495140	08-Feb-2023 23:00	-47.57	-1.27	10-Apr-2024 05:04	-45.02	56.13	SVP	15
a300534061495110	08-Jan-2023 16:52	-48.04	-0.99	23/04/2024 5:04	-40.30	66.89	SVP	15

Table 4. Status information of SVP drifters deployed in the South Atlantic in January-February 2023.

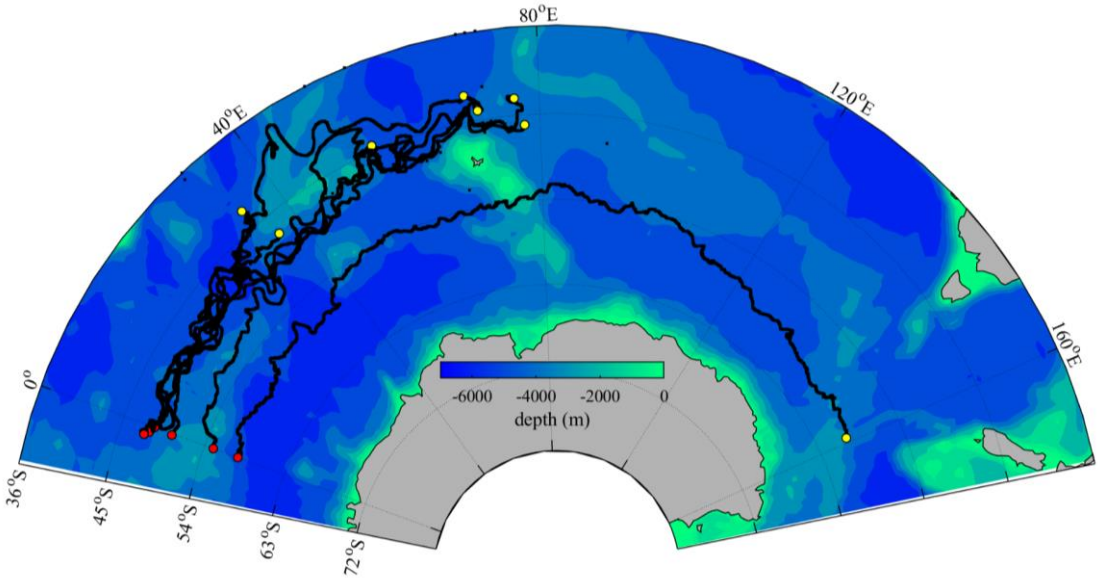


Figure 19. Trajectories, deployment positions (red dots) and last position (yellow dots) of the eight Italian drifters deployed in the South Atlantic in January-February 2023. Drifter data are updated to April 2024.

Argos/IMEI	Deploy Date	Lat	Lon	Last Date	Lat	Lon	Type	Depth (m)
a300534061496010	08-Jan-2023 21:20	-59.08	169.75	27-Feb-2024 01:00	-46.54	-119.5	SVP	15
a300534061495430	09-Jan-2023 01:50	-60.4	170.25	10-Apr-2024 05:04	-50.52	-110.97	SVP	15
a300534061495960	09-Jan-2023 02:00	-57.89	169.55	10-Apr-2024 04:04	-48	-146.11	SVP	15
a300534061496040	09-Jan-2023 06:29	-61.06	170.69	10-Apr-2024 05:04	-55.79	-100.13	SVP	15
a300534061495970	09-Jan-2023 12:00	-62.05	171.16	10-Apr-2024 05:02	-54.97	-112.6	SVP	15
a300534061495470	10-Jan-2023 04:10	-64	174.34	10-Apr-2024 05:04	-56.71	-113.24	SVP	15
a300534061495840	10-Jan-2023 14:00	-65	176.09	10-Apr-2024 05:00	-59.58	-133.62	SVP	15
a300534061496060	27-Feb-2023 05:31	-63	164.46	22-Apr-2024 05:00	-58.58	-138.49	SVP	15

Table 5. Status information for the Italian drifters deployed in the South Pacific (Southern Ocean) in January 2023.

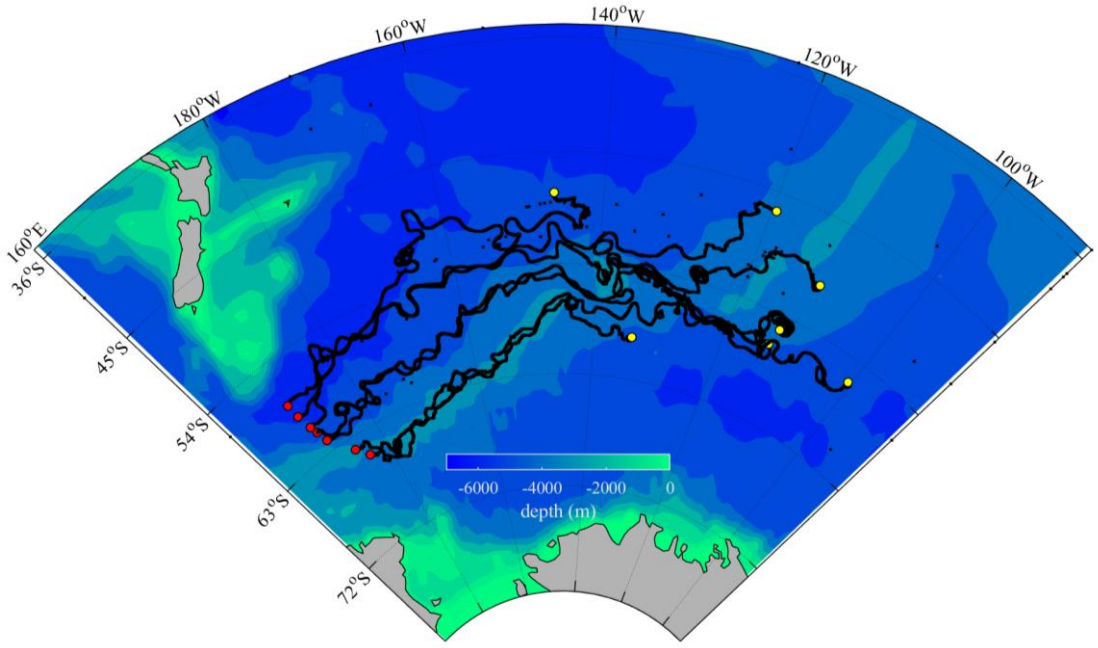


Figure 20. Trajectories, deployment positions (red dots) and last position (yellow dots) of the eight Italian drifters deployed in the South Pacific in January 2023. Drifter data are updated to April 2024.

Ten SVP drifters were deployed in 2023 in the Mediterranean Sea in the framework of the BIOSWOT-Med cruise. The objective of the BIOSWOT project is the scientific exploitation of the very first observations from the SWOT satellite (Surface Water and Ocean Topography) beyond physical oceanography, focusing in particular on current biophysical issues. The SWOT satellite was launched in 2022 and researchers from the international BIOSWOT Adopt a Cross Over consortium planned a series of oceanographic cruises at several sites in the global ocean to develop multidisciplinary in situ experiments to study the fine-scale dynamics of ocean currents and their role in structuring marine biodiversity. The BIOSWOT-Med cruise, occurred in Spring 2023, aims at exploiting SWOT observations for unveiling the drivers of phytoplankton diversity in the Western Mediterranean. The western Mediterranean Sea is characterized by high plankton diversity, low nutrient concentration, and weak oceanic circulation. Here, finescale features, even if weak and short-lived, can strongly modulate the microbial community structure.

Argos/IMEI	Deploy Date	Lat	Lon	Last Date	Lat	Lon	Type	Depth (m)
a300534064107880	26-Apr-2023 06:41	41.2	4.54	21-Apr-2024 17:00	41.01	8.87	SVP	15
a300534064107900	26-Apr-2023 11:43	41.07	4.38	21-Apr-2024 17:00	41.01	8.87	SVP	15
a300534064109890	27-Apr-2023 17:41	40.88	4.39	29-Apr-2024 09:00	36.23	20.52	SVP	15
a300534064109870	28-Apr-2023 22:08	40.82	4.67	05-Mar-2024 16:00	40.01	8.4	SVP	15
a300534064108950	29-Apr-2023 06:02	41.3	4.45	29-Apr-2024 09:00	35.3	34.55	SVP	15
a300534064103920	06-May-2023 12:35	41.2	5.08	31-Jul-2023 00:00	42.84	10.76	SVP	15
a300534064103890	06-May-2023 13:15	41.23	5.14	03-Jan-2024 18:00	36.4	13.17	SVP	15
a300534064104890	06-May-2023 14:03	41.16	5.12	16-Oct-2023 13:00	39.61	3.39	SVP	15
a300534064104920	06-May-2023 14:51	41.17	5.03	08-Jul-2023 09:00	39.2	8.3	SVP	15
a300534064106800	06-May-2023 15:39	41.24	5.05	13-Jan-2024 07:00	38.73	16.03	SVP	15

Table 6. Status information for the Italian drifters deployed in the Western Mediterranean Sea in April-May 2023.

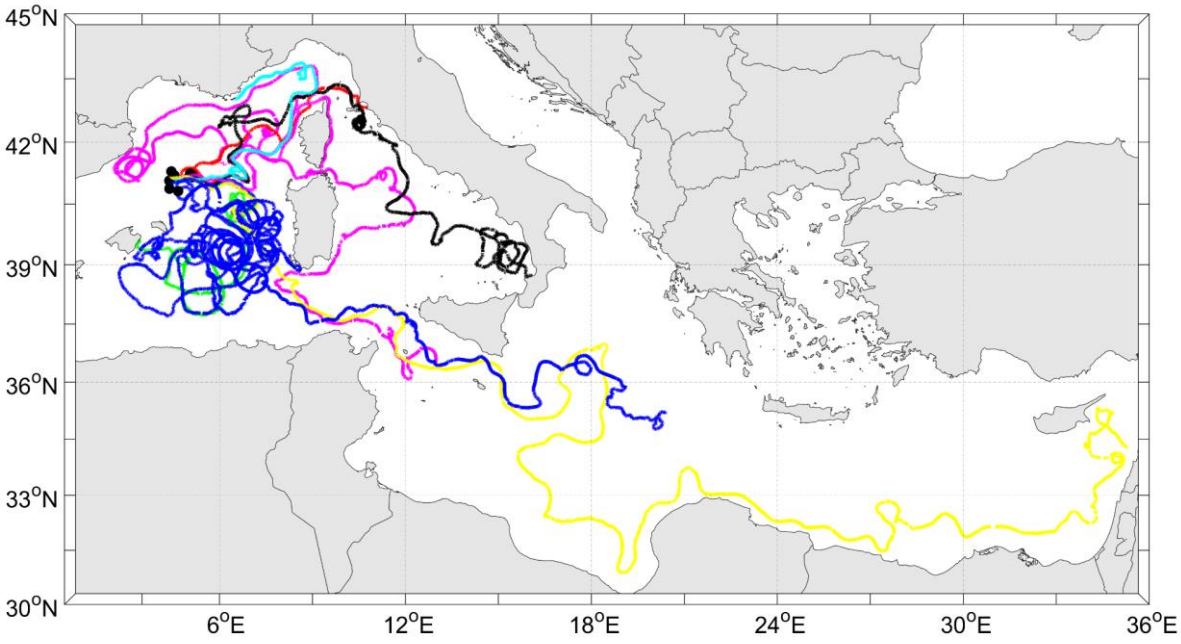


Figure 21. Trajectories and deployment positions (black dots) of the eight Italian SVP drifters deployed in the Western Mediterranean in April-May 2023 during the BIO-SWOT-Med cruise. Drifter data are updated to April 2024.

4. Glider activities in 2023

In 2023, 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 22) in the framework of the Convex22 experiment to assess the hydrographical characteristics of the South Adriatic water during the winter period. The mission was conceived to identify physical and biogeochemical small-scale processes that are at the base of the dense water formation 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. The glider covered about 500 km, performing 300 dives. The maximum depths varied from 20 to 950 m. Temperature, salinity, dissolved oxygen fluorescence of chlorophyll *a*, backscattering and Colored Dissolved Organic Matter (CDOM) data were acquired.

The 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, 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).

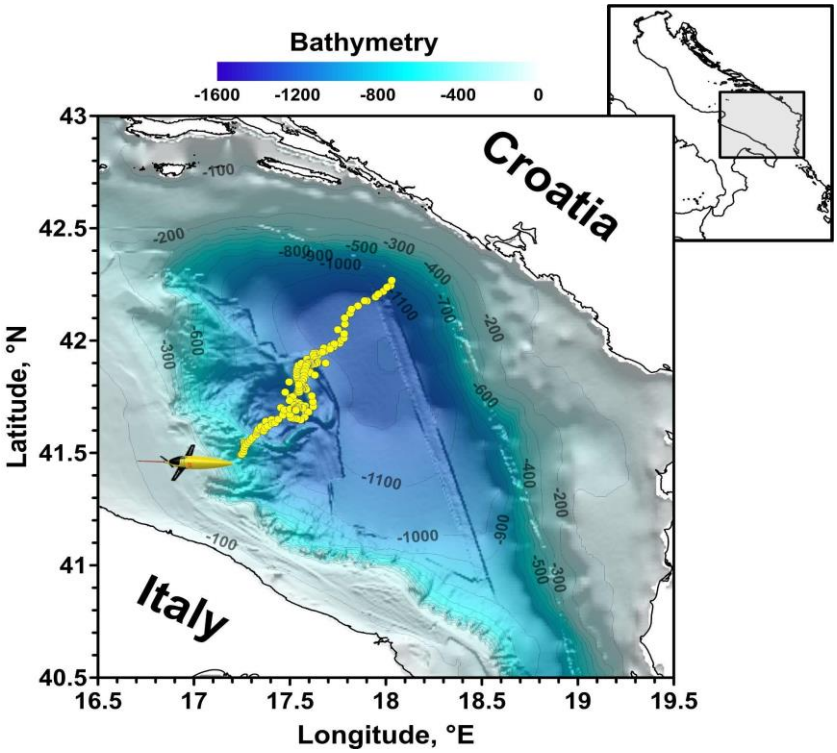


Figure 22: The study area and geographical position of the glider surfacing (yellow dot). The glider symbol indicates the last position of the instrument.

5. Plans for 2024 and beyond

5.1 Floats

- ***Rational***

The MUR has recognized Euro-Argo ERIC as a high priority infrastructure for the Piano Nazionale Infrastrutture di Ricerca (PNIR 2021-2027) which is an integral part of the Piano Nazionale di Ricerca (PNR). **The annual effort sustained by the Italian ministry guarantees the contribution to the European and worldwide infrastructure following the guidelines that emphasize the importance of maximum space-time coverage through Core-Argo floats. As internationally recognised the highest priority is to sustain the Core-Argo array (ideally with oxygen) while maintaining limited regional pilot arrays for Deep and BGC Argo**.

In 2024 the funds provided by the MUR will allow the procurement of Core-Argo floats equipped with a dissolved oxygen sensor to sustain the Core-Argo activity.
In the framework of PNRR funds, the MUR provided a 2.5-year grant in 2022 (ITINERIS PNRR project) to purchase BGC and Deep Argo floats (34 units by OGS and 9 units by CNR) to be deployed mainly in the Mediterranean and in key regions of our open seas. The scientific aims span from biogeochemical to bio-optical studies related to climate change, as well as more accurate reproduction of the marine environment through modelling and ultimately the creation of the Digital Tween of the Ocean. Furthermore, the deep data will be used to investigate the heat content stored in the deepest layers of the water column particularly in the Mediterranean Sea.
Our overall strategy will be to explore the key areas of the Mediterranean with BGC-Argo floats to characterise and provide new information to both experimental and modelling scientists. The BGC-Argo floats will provide the opportunity to quantitatively assess the importance of these measurements and better calibrate future funding in BGC and Deep-Argo in the Mediterranean Sea and in areas of multi-year interest. In doing so, we will estimate the optimal sustained, long-term funding for the BGC and Deep extensions of the Argo array. To realize this strategy, we are strengthening the interactions between the Italian observational Argo teams (OGS and CNR-ISMAR), the national and the European satellite community, and the operational biogeochemical modelling group at OGS. The ITINERIS floats are expected to be deployed in 2024-2026.

The Italian deployment plans for 2024 and estimates for 2025 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.

Year	T/S floats (most with DO)		BGC-Argo floats		Deep-Argo floats		Total
	Quantity	Area	Quantity	Area	Quantity	Area	
2024	9 0 8 0	Mediterranean Black Sea South. Ocean Global	3 0	Mediterranean Black Sea	2	Mediterranean	**22**
2025	3 0 5 3	Mediterranean Black Sea South. Ocean Global	9 0 1 2	Mediterranean Black Sea South. Ocean Global	6	Mediterranean	**29**

Table 7. Italian float deployment plans for 2024-2025.

The OGS team will also be 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
2024	8 SVP 8 SVP	Southern Ocean Mediterranean
2025	20 SVP 10 SVP	Southern Ocean Mediterranean

Table 8. Argo-Italy drifter deployment plans for 2024-2025.

5.3 Gliders

In 2024, we expect to perform 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. In addition, we plan to deploy a glider in the Ross Sea as part of the GLOB-PNRA project. Within the ITINERIS project an expansion of the glider fleet is considered. By increasing the number of longer-life endurance vehicles, we plan to explore the northern and central Ionian Sea water to better understand the dynamics of the area and the impact that this region has on potential medicanes and how they react to extreme weather events.

6. Acknowledgements

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

- Stefano Kuckler, Stefano Gustin and Riccardo Gerin for the glider activity. Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS), Trieste, Italy
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- Adam Gauci, University of Malta
- Daniel Hayes, Cyprus Subsea Consulting and Services C.S.C.S. Limited, Nicosia, Cyprus
- The captains and crews of R/V Laura Bassi, R/V Aegaeo, Malta Coast Guard Boat, VTS Ammochostos, R/V Agulhas 2
- Andrea Doglioli, Université d'Aix-Marseille (France)
- Pierpaolo Falco (Polytechnic University of Marche, Italy) and Pasquale Castagno (Parthenope University, Naples, Italy)

7. References

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