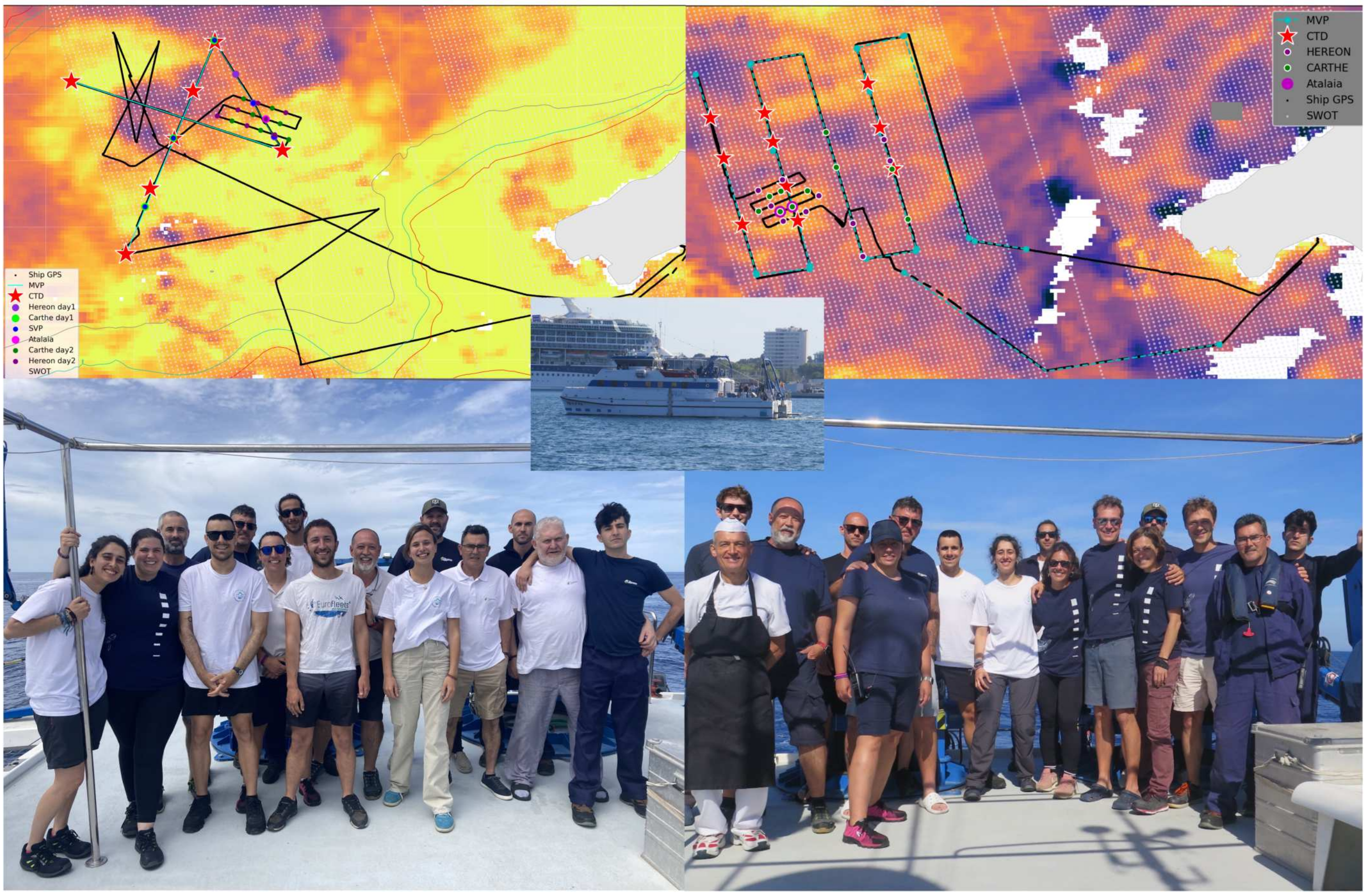

FaSt-SWOT 2023 Cruise Report

B. Mourre[1], A. Pascual[2], L. Gomez Navarro[2], P. Balaguer[1], B. Barcelo-Llull[2], N. Calafat[1], B. Casas[1], V. Combes[2], E. Cutolo[2], L. Diaz-Barroso[1], J.G. Fernández[1], M. García-Jove[1], M. Juza[1], I. Lizarán[1], G. López[1], A. Miralles[1], X. Notario[1], V. Ortiz[1], E. Reyes[1], L. Ribot[1], R. Rodríguez[1], P. Rossello[2], L. Secorun[3], N. Siegel[3], D.R. Tarry[2], J. Tintoré[1,2], E. Verger-Miralles[2], G. Vizoso[2], N. Wirth[1] and N. Zarokanellos[1]

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R/V SOCIB
Leg 1: 25-28 April 2023
Leg 2: 7-10 May 2023

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Abstract

The SWOT satellite mission (Surface Water and Ocean Topography), launched in December 2022, is measuring sea surface height with a resolution an order of magnitude higher than conventional altimeters, providing an unprecedented view of the variability of the sea surface topography. This document reports the activities carried out at sea during the two campaigns of the FaSt-SWOT project (PID2021-122417NB-I00 funded by MCIN/AEI/10.13039/501100011033/ FEDER,UE). These campaigns had two main objectives: 1) participate to the SWOT satellite cal/val activities by collecting in-situ observations of fine-scale structures in the area covered by the satellite during its initial fast-sampling phase, and 2) improve the characterization and understanding of these structures by combining in-situ multi-platform and satellite data with numerical models and other computational techniques.

The FaSt-SWOT experiments were conducted in the Balearic Sea (Western Mediterranean Sea) between 25-28 April and 7-10 May 2023, using R/V SOCIB. The experiments consisted in 2 legs both using multi-scale ship-based instruments (CTD, Moving Vessel Profiler, thermosalinograph, ADCP and GoPro action cameras), autonomous platforms (surface drifters and gliders), and satellite observations (SST, ocean color and altimetry). In addition, 2km-resolution data-assimilative modelling simulations were produced to provide a complementary representation of the fine-scale ocean variability. Finally, machine-learning-based optimization algorithms were also tested to define adaptive sampling strategies during the experiment.

The sampling first focused on a small anticyclonic eddy, with a diameter around 20-25km. Several cross-sections of the Moving Vessel Profiler and underwater gliders provided insights into the vertical structure of temperature and salinity fields and the associated signals in chlorophyll and dissolved oxygen. Two gliders were programmed to perform back-and-forth sections during a 3-week time with a 1-day delay between them, allowing to evaluate the temporal variability of the ocean fields at the period of repetitivity of the satellite. The second leg started 9 days after the end of the first one. A 48-hour dense radiator-like pattern was performed by R/V SOCIB, allowing to characterize the evolution of the small eddy observed during the first leg. A total of 45 surface drifters were deployed during the two phases to evaluate in-situ surface currents and their associated convergence and divergence in the vicinity of the eddy.

This report presents the details of the sampling strategy and collected measurements, also including data management aspects and description of the supporting numerical simulations and external communication activities associated with these field campaigns.

Contents

1 Context, objectives and summary

1.1 Context

Horizontal and vertical motions associated with fine-scale ocean features (10-100 km), such as mesoscale and submesoscale fronts, meanders, eddies, and filaments, play a crucial role in the distribution of heat, salt, gases, carbon, and nutrients in the ocean (e.g., Lévy et al., 2001; Mahadevan, 2016; Su et al., 2018; Siegelman et al., 2020). Understanding the three-dimensional (3D) dynamics of these fine-scale features and their impact on the large-scale ocean circulation and climate system is a major international challenge in oceanography (e.g., Young and Sikora, 2003; Kwon et al., 2010; Ma et al., 2016; Su et al., 2018; Bishop et al., 2020; Small et al., 2020). Integrated approaches that combine multi-platform in-situ data, remote sensing observations, and high-resolution model simulations have emerged as an innovative methodology to evaluate and comprehend the pathways associated with these structures (Mahadevan et al., 2020, Pascual et al., 2017, Barceló-Llull et al., 2021, Cutolo et al., 2022).

Over the past decades, remote sensing observations of sea surface height (SSH) have significantly advanced our understanding of the global ocean large and mesoscale circulation (e.g. Chelton et al., 2011, Le Traon et al., 2013; Mourre et al., 2023). However, the effective resolution of present gridded SSH maps from satellite altimetry is limited, especially in regions like the Mediterranean Sea (around 130 km, Ballarotta et al., 2019), where mesoscale dynamics occur over shorter temporal and spatial scales compared to the open ocean (e.g. Escudier, et al., 2016a; Gómez-Navarro et al., 2020, Barceló-Llull et al., 2019).

The Surface Water and Ocean Topography (SWOT) satellite mission, launched in December 2022, represents a significant advance in Earth observation (Morrow et al., 2019). The SWOT mission aims to provide SSH measurements with a spatial resolution one order of magnitude higher than present altimeters. With an expected effective resolution between 15 and 30 km, SWOT will provide an unprecedented view of mesoscale dynamics (Fu and Ubelmann, 2014; Morrow et al., 2019, d'Ovidio et al., 2019). This breakthrough in observational capabilities is expected to open a new era for understanding ocean dynamics at fine scales (Pascual and Macías, 2021). In the Western Mediterranean Sea, the region around the Balearic Islands was selected for SWOT validation, which means that SWOT has been collecting high-resolution sea level measurements with a daily repetitivity during the fast-sampling phase spanning the first 6 months of the mission from January to July 2023 (d'Ovidio et al., 2019).

1.2 Objectives

In this context, the FaSt-SWOT[1] sea trial experiments aimed at collecting multi-platform in-situ observations in the area covered by the SWOT satellite around the Balearic Islands during the initial fast-sampling phase. The general objectives of the FaSt-SWOT project are twofold: 1) participate to the satellite cal/val activities by collecting in-situ observations of fine-scale structures in the area covered by the satellite, and 2) improve the characterization and understanding of these structures by combining in-situ multi-platform and satellite data with numerical models and other computational techniques. The FaSt-SWOT campaigns brought together a unique multidisciplinary expertise in physical oceanography, satellite remote sensing, in-situ monitoring, and computational science.

[1]FaSt-SWOT: Fine-Scale ocean currents from integrated multi-platform experiments and numerical simulations: contribution to the new SWOT satellite mission

1.3 Summary of the experiments

The FaSt-SWOT experiments consisted in 2 phases which were conducted in the Balearic Sea between 25-28 April and 7-10 May 2023. The experiments were distinguished by the simultaneous use of multi-scale ship-based instruments (CTD, Moving Vessel Profiler, thermosalinograph, ADCP, GoPro action cameras), autonomous platforms (surface drifters and gliders), and satellite observations (sea surface temperature, ocean color, altimetry), in conjunction with high-resolution data-assimilative modelling simulations and machine-learning-based optimization algorithms. The study area was determined a few days before the start of the first phase based on satellite images and the trajectory of a surface drifter released previsously by SOCIB, all indicating the presence of a small anticyclonic eddy in one of the SWOT swath north of Ibiza Island. The first leg was dedicated to the sampling of this eddy with several cross-sections using R/V SOCIB ship-based observations, two gliders and the release of 25 surface drifters. The last day of the first leg was dedicated to the performance of an experimental adaptive sampling procedure based on advanced machine learning algorithms. The second leg started 9 days after the end of the first one. R/V SOCIB was used to perform a second high-resolution sampling of the same area. The small mesoscale structure was sampled through a radiator-like pattern combining CTD measurements using a Moving Vessel Profiler towed behind the ship (until 200m depth) and using the rosette at fixed stations (until 700m depth). The two gliders remained at sea between the two phases, providing several sections along the satellite track. The radiator pattern was performed in around 48h, just before the occurrence of strong winds over the study area. Twenty additional surface drifters were released during the third day of the second leg of the experiment in the southern edge of the frontal structure identified from satellite images and ship measurements. These drifters had been previously "adopted" by local schools which named the drifters and were able to track them in real-time through the *Boya al agua!* educative program.

2 Instrumentation

The FaSt-SWOT campaigns used both ship-based instruments (CTD, Moving Vessel Profiler, thermosalinograph, ADCP, GoPros, meteorological station) and autonomous platforms (surface drifters and gliders). The list of instruments is the following:

- Thermosalinograph (TSG)
  The TSG onboard R/V SOCIB was used to continuously monitor the water surface temperature and salinity along the ship track.

- Rosette conductivity-temperature-depth (CTD)
  CTD stations were performed to obtain measurements of temperature, salinity, oxygen and chlorophyll at fixed locations down to a depth of 700m. A few profiles were also extended down to 1500m.

- Moving Vessel Profiler (MVP)
  The MVP is a towed CTD which was used to collect underway measurements of temperature and salinity from the surface down to a depth of approximately 200m along the ship trajectory (100m during the first phase).

- Vessel Mounted Acoustic Doppler Profiler (VM-ADCP)
  R/V SOCIB ADCP was collecting observations of ocean currents in the upper 200m along the ship track.

- Gliders
  Two Slocum gliders were deployed in the area during the whole duration of the experiments. The gliders sampled the same transect separated by 25-30 km, collecting high-resolution measurements of temperature, salinity, oxygen, chlorophyll fluorescence, and backscatter.

- Drifters
  A total of 45 surface drifters were deployed during the two phases of the experiment. Several types were used, including CARTHE (20 units), HEREON (20 units) and SVP-B (5 units).

- Go Pro action cameras
  GoPro cameras were installed on R/V SOCIB deck in collaboration with the Ocean CleanUp (https://theoceancleanup.com) initiative. The cameras continuously monitored the sea surface during the daylight time with the objective to provide a means to detect the presence of floating macroplastics.

- Meteorological station
  R/V SOCIB meteorological station were providing continuous observations of air temperature, pressure and wind along the ship trajectory.

The details of the sampling conducted with each instrument is provided in Section 6.

3 Chronology of the experiments

The chronology of the two legs is listed below. Time is UTC.

- **Leg 1**
  - Tuesday 25 April 2023
    * 12:00 Reception of MVP instrument on R/V SOCIB, begining of installation
    * 16:00 MVP installed onboard R/V SOCIB
    * 16:30 R/V SOCIB leaves Palma harbour
    * 16:33 TSG activated
    * 16:45 ADCP activated
    * 18:40 Tests and adjustments of MVP instrument
    * 18:45 Issues with satellite communication
    * 19:39 Satellite communication restored
    * 20:45 Confirmation from SeaBed that the MVP pressure sensor is limited to 100m depth
    * 21:55 Deployment of Glider S1
    * 23:17 Deployment of Glider S8
  - Wednesday 26 April 2023
    * 01:15 Deployment of MVP for testing phase
    * 01:35 Start of MVP sampling
    * 08:14 CTD station #1-1
    * 10:08 Deployment of SVP SCB-SVP038
    * 10:59 CTD station #1-2

    * 13:24 CTD station #1-3
    * 14:00 Deployment of SVP SCB-SVP039
    * 16:14 CTD station #1-4
    * 17:40 CTD station #1-5
    * 18:03 Deployment of SVP SCB-SVP040
    * 18:57 Deployment of SVP SCB-SVP041
    * 19:42 Deployment of SVP SCB-SVP042
    * 21:01 CTD station #1-6
  - Thursday 27 April 2023
    * 10:05 CTD station #1-7
    * 14:50 CTD station #1-8
    * 20:00 End of MVP sampling
    * 21:19 Start of drifter array deployment
  - Friday 28 April 2023
    * 01:32 End of drifter array deployment
    * 02:01 Start of adaptive sampling experiment – part 1
    * 12:28 End of adaptive sampling experiment - part 1
    * 12:30 CTD station #1-9
    * 13:07 Start of adaptive sampling experiment – part 2
    * 13:47 End of adaptive sampling experiment – part 2
    * 13:55 CTD station #1-10
    * 15:11 CTD station #1-11
    * 16:27 CTD station #1-12
    * 22:18 End of MVP sampling
    * 23:20 End of TSG and ADCP sampling
  - Saturday 29 April 2023
    * 04:20 Arrrival at Palma harbour, end of FaSt-SWOT leg 1

- **Leg 2**
  - Sunday 7 May 2023
    * 21:20 R/V SOCIB leaves Palma harbour
  - Monday 8 May 2023
    * 00:30 MVP deployed, start of radiator pattern
    * 12:10 CTD station #2-1
    * 14:08 CTD station #2-2
    * 15:01 Deployment of drifter HEREON5
    * 14:08 CTD station #2-2
    * 16:00 CTD station #2-3
    * 16:41 Deployment of drifter CARTHE11
    * 18:15 Deployment of drifter CARTHE12
    * 20:35 Deployment of drifter HEREON13
    * 21:41 Deployment of drifter HEREON14

    * 23:36 Deployment of drifter CARTHE13

- Tuesday 9 May 2023
    * 00:50 Deployment of drifter CARTHE14
    * 07:02 CTD station #2-4
    * 08:33 CTD station #2-5
    * 10:05 CTD station #2-6
    * 12:18 CTD station #2-7
    * 17:40 CTD station #2-8
    * 19:41 CTD station #2-9
    * 21:25 CTD station #2-10
    * 23:25 End of MVP radiator sampling
- Wednesday 10 May 2023
    * 01:10 Start of drifter array deployment
    * 06:05 End of drifter array deployment
    * 09:25 Recovery of Glider S1
    * 10:10 Recovery of Glider S8
    * 18:45 Arrrival at Palma harbour, end of FaSt-SWOT leg 2

4 Meteorological conditions

The wind speed measured onboard R/V SOCIB is displayed in Figures 1 and 2.

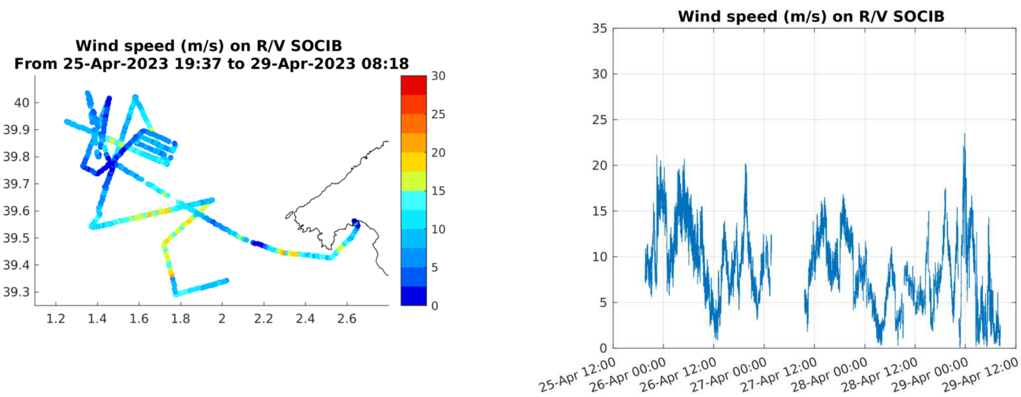


Figure 1: Time series of wind speed measured onboard R/V SOCIB during FaSt-SWOT leg 1.

The daily average wind speed was between 10 and 15m/s during leg 1 and during the first two days of leg 2. Strong winds (values over 30m/s) were faced during the final phase of Leg2 on 10 May in the morning, mainly coinciding with the drifter array deployment.

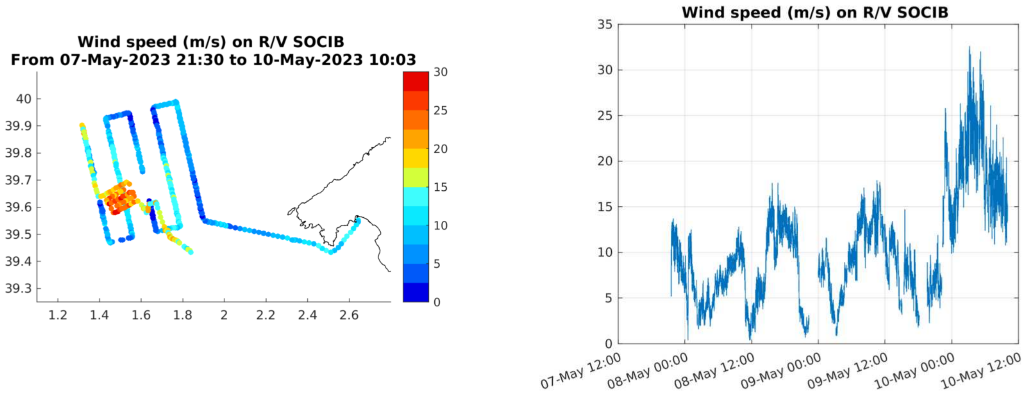


Figure 2: Time series of wind speed measured onboard R/V SOCIB during FaSt-SWOT leg 2.

5 Satellite observations

Satellite remote sensing imagery played a crucial role in the design of the experiments. In the days previous to the experiments, the precise locations of the targeted oceanic features were determined using conventional along-track altimetry and high-resolution sea surface temperature (SST) and ocean color (OC) maps obtained from the Copernicus Marine Service Catalogue (`https://marine.copernicus.eu/`).

During the experiment, satellite images were regularly updated and made available in the following Google Drive folders:

- SST - OC - SSH: `https://drive.google.com/drive/folders/1BoMyXxMhw9Qw9ZEyLf80A0EqpSg4G` `usp=share_link`
- Along-track altimetry: `https://drive.google.com/drive/folders/1klf-FQEdS1aKoZhXeFN81zM` `usp=share_link`

Complementary SST and OC images were also displayed on the following SOCIB webpages:

- FaSt-SWOT dedicated situational awareness page: `https://www.socib.es/?seccion=modelling&facility=fast-swot`
- Satellite imagery application: `https://apps.socib.es/satellite-imagery/daily_bulletin.htm`

5.1 Sea Surface Temperature

Maps of SST were key to determine the target fine-scale features to be sampled during both experiments. A few days before starting leg 1, a small anticyclonic eddy was detected within a swath of SWOT northwest of Ibiza Island (Figure 3). This structure was the target of FaSt-SWOT leg 1. Subsequent SST maps showed a temporal evolution of the sampled eddy, as illustrated in Figure 4. Based on these maps, together with maps of ocean color, we defined the sampling strategy to be conducted during leg 2.

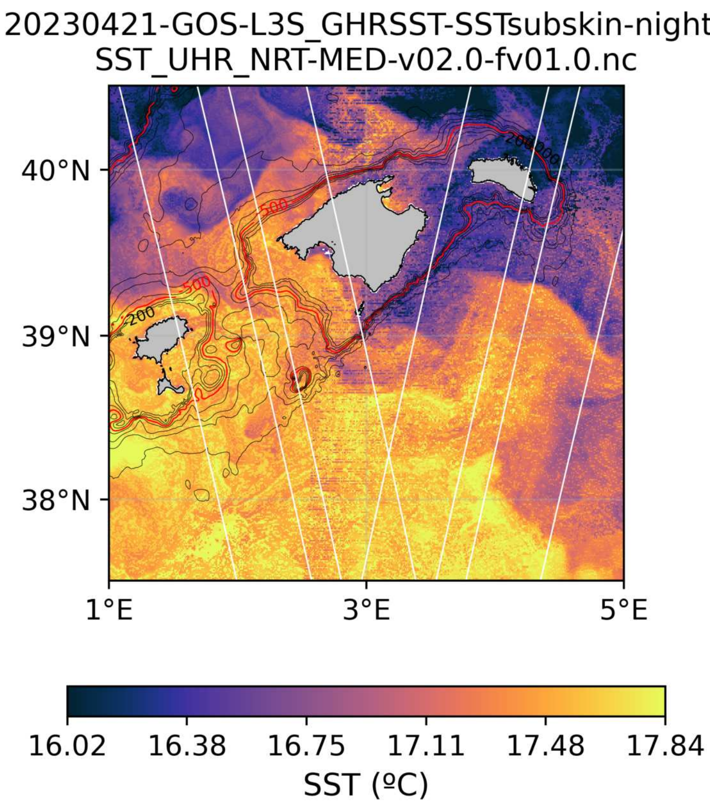


Figure 3: Sea Surface Temperature (SST) map on 21 April 2023. White lines delimit the swaths of SWOT.

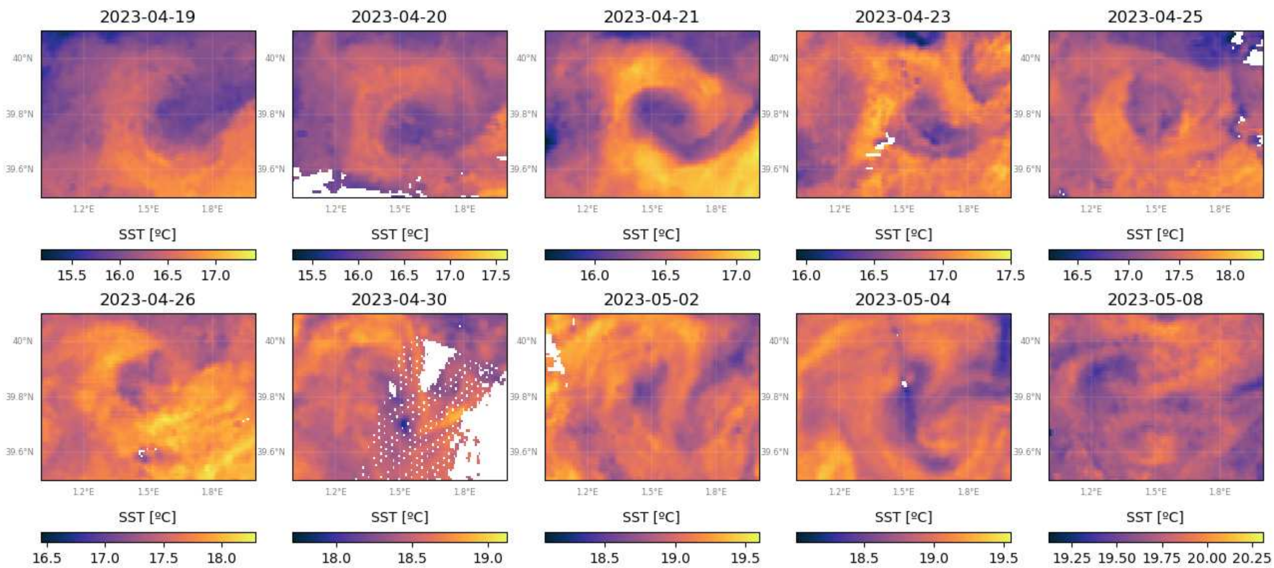


Figure 4: Sea Surface Temperature (SST) maps over the study region showing the temporal evolution of the eddy sampled in FaSt-SWOT leg 1.

5.2 Ocean Color

Several clear ocean color images were available during the experiment, providing useful insights into the shape of oceanic structures and position of associated density gradients.

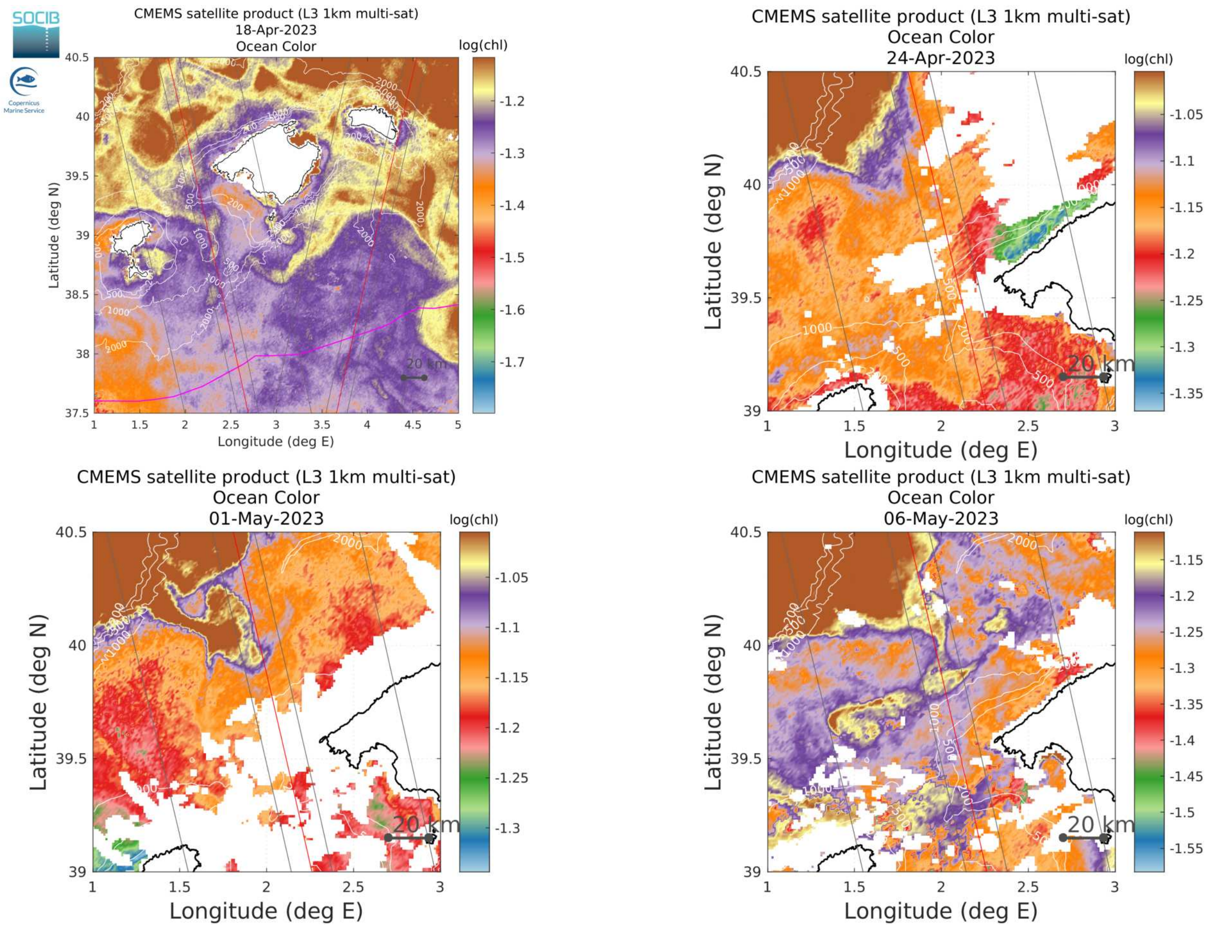
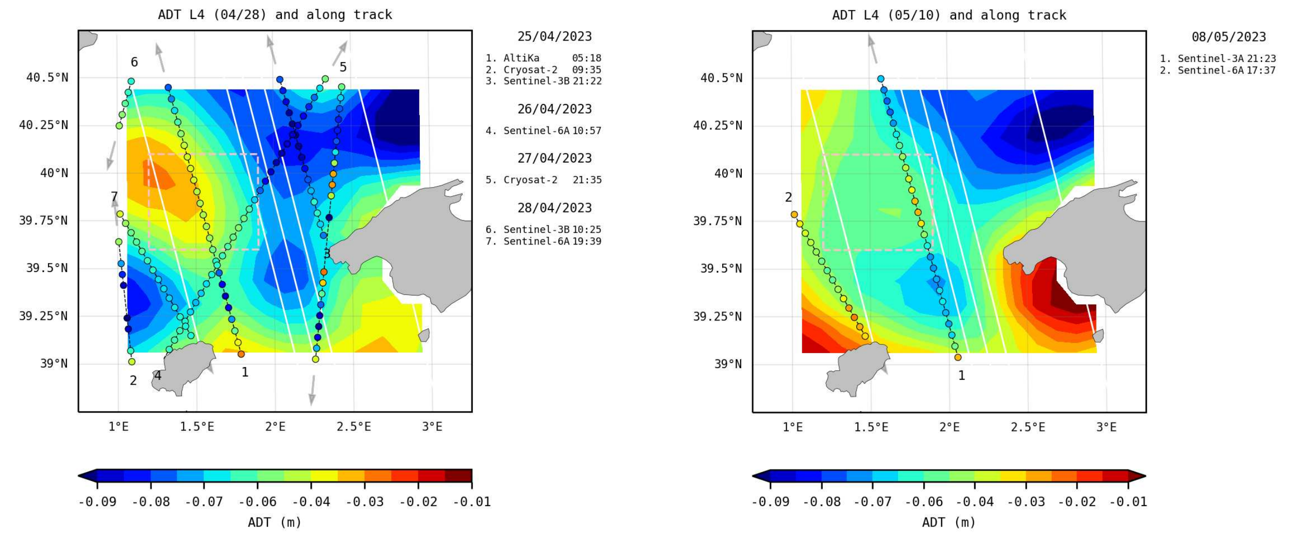


Figure 5: Ocean color images before leg 1 (18 April), at the beginning of leg 1 (24 April), between both legs (1 May) and at the beginning of leg 2 (6 May). Data come from the Copernicus Marine Service 1km resolution multi satellite L1 product.

5.3 Conventional altimetry

Several conventional altimeter missions (Cryosat-2, SARAL/AltiKa, Haiyang-2B, Jason-3, Sentinel-3A, Sentinel-3B, and Sentinel-6A) provided along-track sea level anomalies over the study area. Figure 6 shows these data together with the gridded L4 product. The interpolated L4 altimetric map corresponds to the product (`SEALEVEL_EUR_PHY_L4_NRT_OBSERVATIONS_008_060`) with a resolution of $0.125^{\circ}\times0.125^{\circ}$. L3 along track satellite data (`SEALEVEL_EUR_PHY_L3_NRT_OBSERVATIONS_008_0` is shown for the satellites whose orbits lay in the region of interest during the campaign dates. Both L4 and L3 products were downloaded from the Copernicus Marine Service.



(a) Altimetric L4 map for 28 April with along-track data from 25 to 28 April (leg1).

(b) Altimetric L4 map for 10 May with along-track data from 7 to 10 May (leg2).

Figure 6: Altimetric data over the region of interest during the two legs. The pink dashed rectangle, denoted by coordinates 1.2E–1.9E and 39.6N–40.1N, designates the specific sampling region where these campaigns were conducted. White lines correspond to the nadir and swath tracks of SWOT.

5.4 SWOT

SWOT observations were not available at the time of the experiments. However, preliminary images from beta products were occasionally provided through the AVISO website together with a comparison with conventional altimeter maps: `https://bulletin.aviso.altimetry.fr/html/produits/swot/adac/welcome_uk.php`. These products seemed to indicate that SWOT measurements were able to represent the eddy structure observed during FaSt-SWOT experiments.

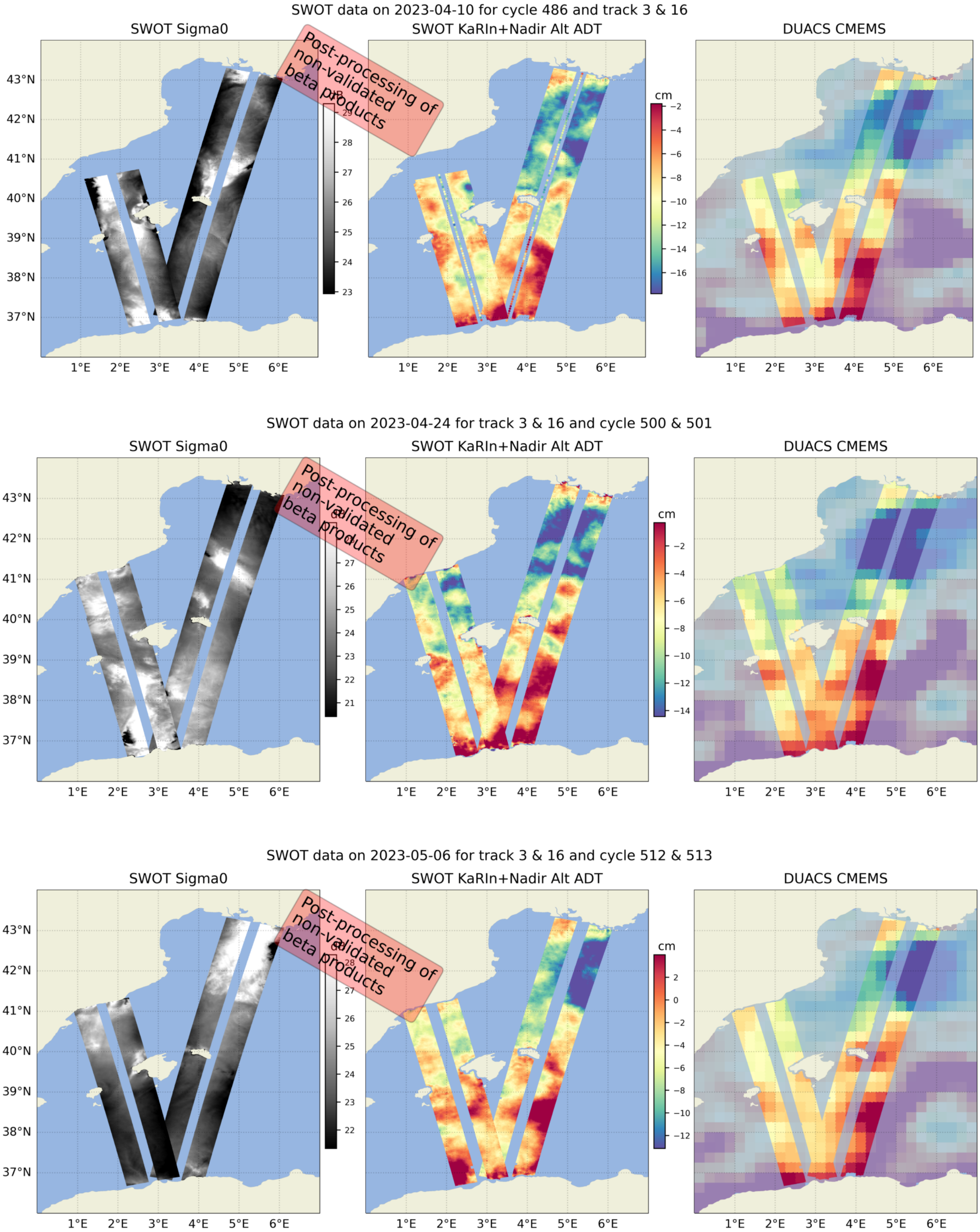


Figure 7: SWOT images provided by AVISO on 10 April (upper panel), 24 April (middle) and 6 May 2023 (bottom).

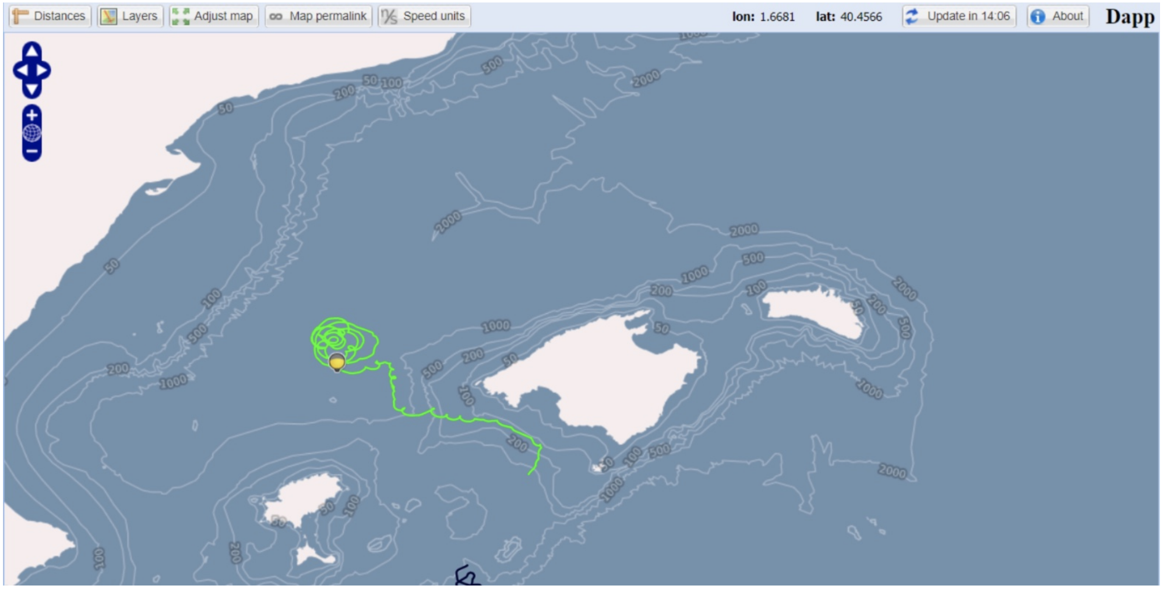
6 Instrument deployments and first results

6.1 Overall sampling strategy

The sampling strategy decided for each leg was based on the oceanic structures observed from satellite (SST and OC) and *in situ* data (in particular drifter data). Based on the objectives of FaSt-SWOT (see Section 1) it was decided to sample the western SWOT swath in the western Mediterranean cross-over (pass/track number 16), focusing on the region north of the Mallorca channel. As the FaSt-SWOT campaign was organized in two legs, approximately 10 days apart, the sampling strategy was slightly adapted for each leg with respect to the oceanic features and data available.

- **Leg 1**

  The trajectory of a SVP-B drifter deployed several weeks before (SCB-SVPB035 / wmo 6102812) confirmed the presence of the small anticyclonic eddy north of Ibiza Island. The drifter was trapped in the eddy, following a circular trajectory of around 20-25km diameter with a rotation period around 4 days (Figure 8).



(a) Trajectory since deployment till 24/04/2023.

(b) Trajectory from 20 to 24 April 2023).

Figure 8: SVP-B drifter (SCB-SVPB035 (wmo 6102812)) trajectory used to identify the small mesoscale eddy (screenshot from `http://apps.socib.es/dapp/?deployments=2142-30-0`).

Ship measurements were then used to sample the small mesoscale eddy through several cross-sections. Figure 9 shows the sampling performed with all the different instruments:

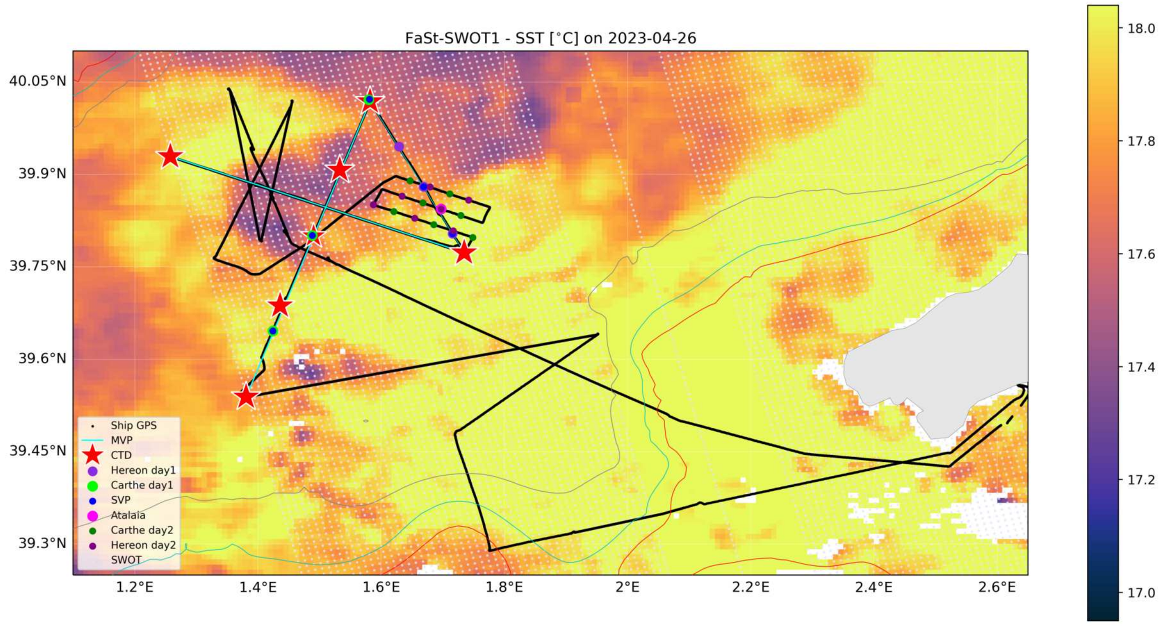


Figure 9: SST image for 26 April 2023 with sampling of leg 1, including MVP transects, CTD casts and drifter deployment locations.

- **Leg 2**

  For leg 2 it was decided to re-sample the same area as leg 1 as the small eddy identified during leg 1 was still present. Also, the gliders and drifters deployed during leg 1 were still sampling this area. A radiator-pattern sampling (Barcelo-Lull et al., 2023) was defined within the western swath of SWOT based on the structures identified in the most recent available SST and OC satellite images (see section 5 for further details). Figure 10 shows the sampling performed with the different instruments.

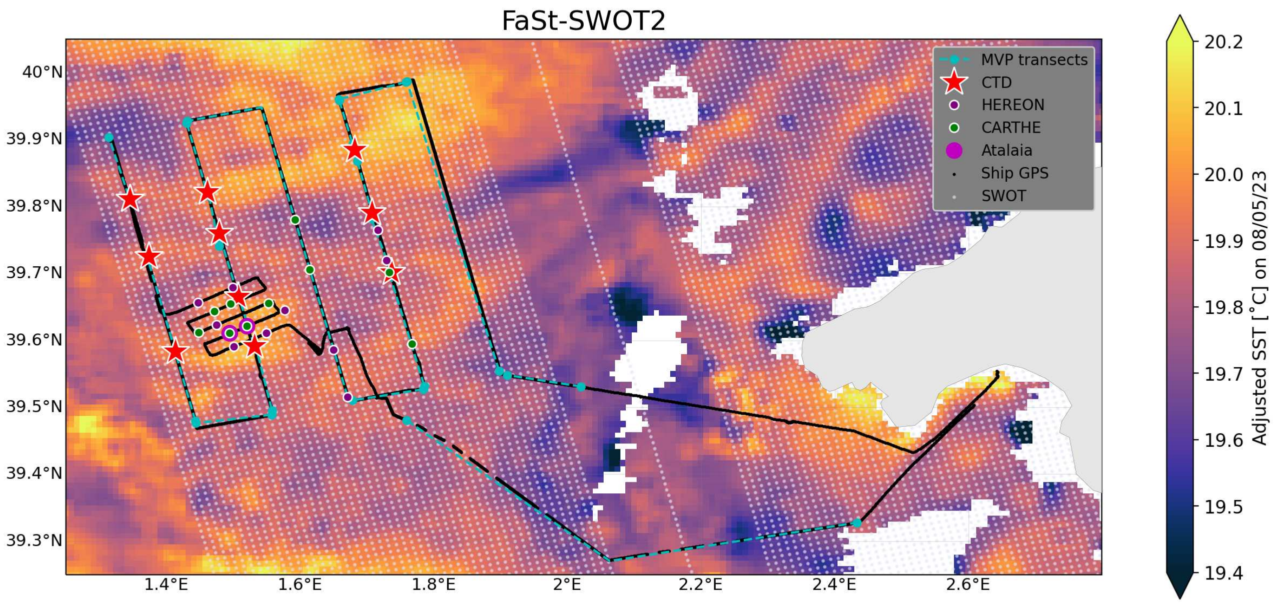


Figure 10: SST image for 8 May 2023 with the sampling of leg 2, including MVP transects, CTD cast and drifter deployment locations.

The ship sampling was completed by the transects of two slocum gliders deployed at the beginning of leg 1 and recovered at the end of leg 2. The gliders were maintained in an

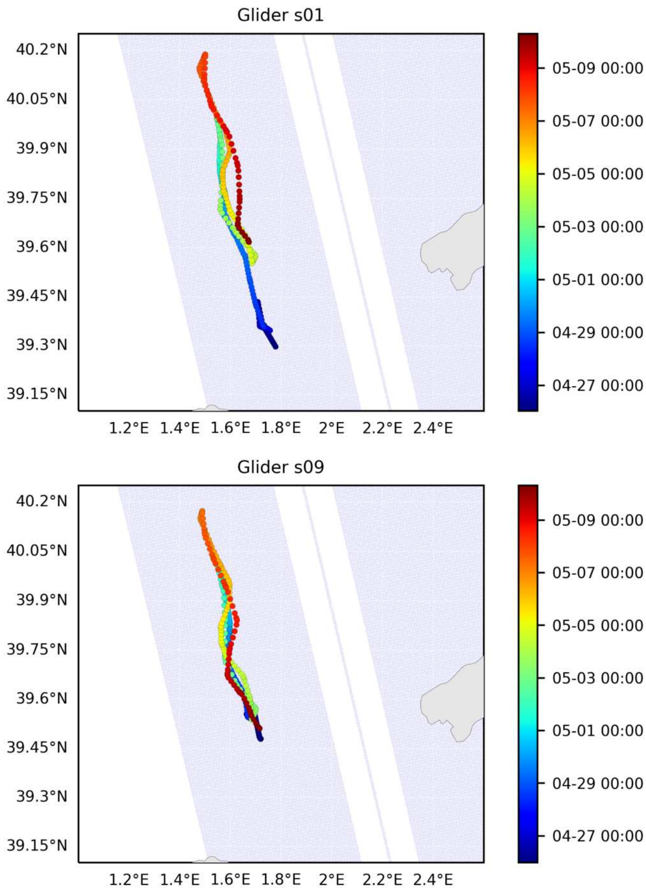


Figure 11: Tracks of gliders s01 (upper panel) and s09 (lower panel) during the FaSt-SWOT experiments. The colors indicate the time between 26 April and 10 May 2023.

approximate central position of the western SWOT swath, performing four back-and-forth sections of around 90 km length across the eddy structure. The tracks of the two gliders is provided in Figure 11.

6.2 Thermosalinograph

The thermosalinograph (TSG) continuously measured temperature and conductivity along the ship's trajectory. Near surface salinity is then derived from these data. There are two temperature sensors, one on the vessel bow and another in the dry lab. The sensor on the bow is used to retrieve temperature data. For the calculation of the salinity the temperature values from the sensor in the dry lab are used to be consistent with the location of the conductivity sensor in the dry lab. The dry lab temperature and conductivity sensor instrument model is a SBE21. It also includes a debubbler at the inlet so that no bubbles that could affect the accuracy of the measurement enter the system. The sensor on the bow is a SBE38 and it is mounted on the inlet pipe of the continuous pump (the one that collects seawater from the surface) at 2m depth.

The observations collected by the thermosalinograph are illustrated in Figure 12.

The variation of surface temperature and salinity with time is shown in Figures 13 and 14 for leg 1 and 2, respectively. The temperature of the dry lab sensor is plotted due to an error in the sensor of the bow during leg 1. Values are re-sampled to a 5 minute frequency by calculating the median.

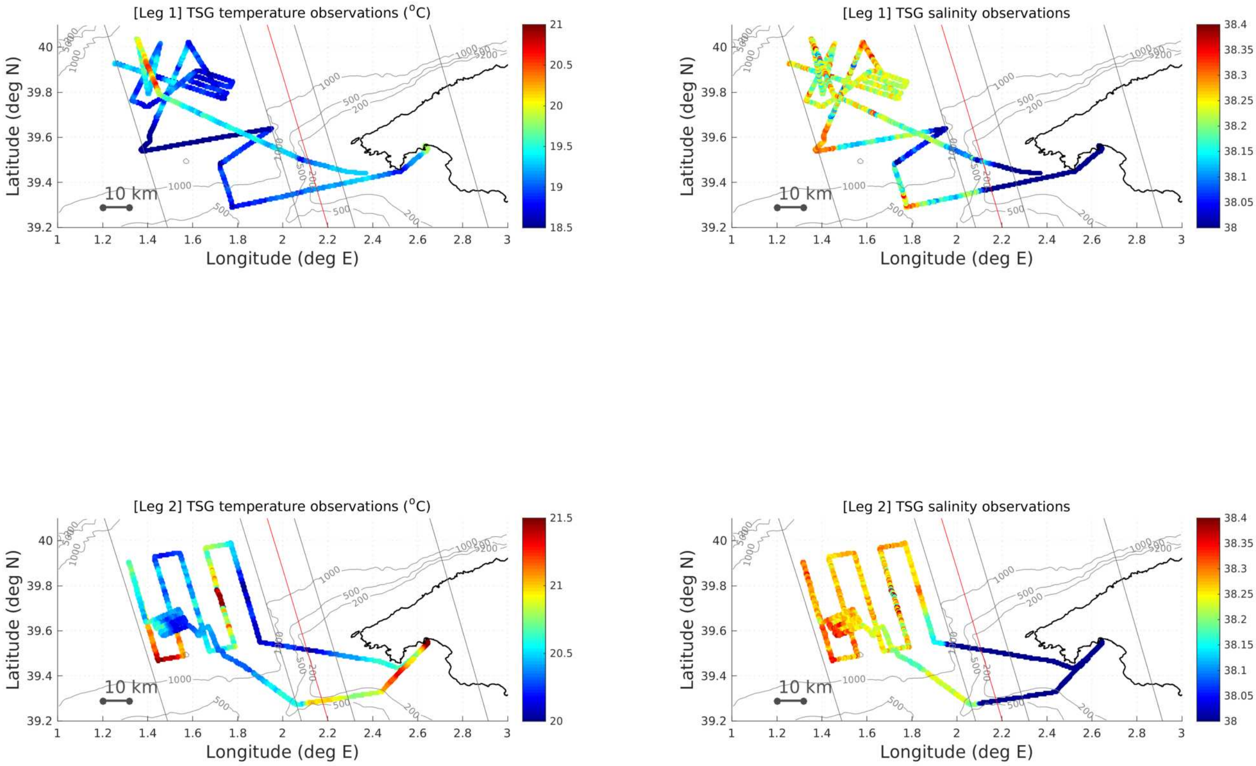


Figure 12: SOCIB R/V thermosalinograph observations (L1 data from SOCIB's data catalogue) for temperature (left) and salinity (right) during leg 1 (upper panels) and leg 2 (lower panels).

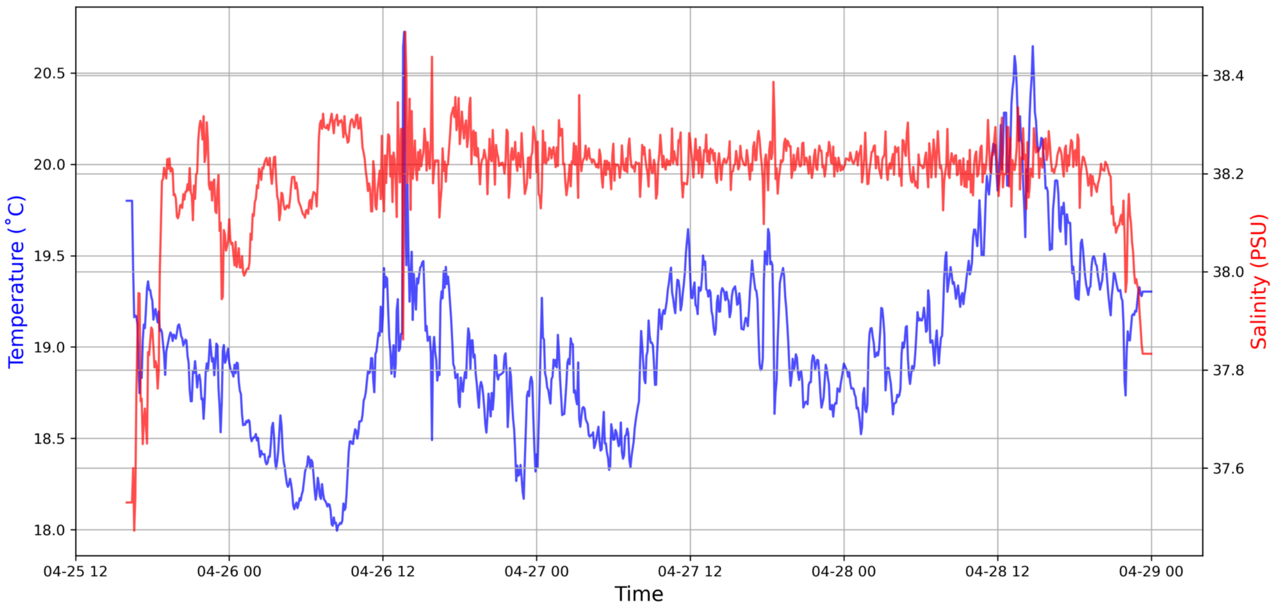


Figure 13: Thermosalinograph leg 1 surface temperature and salinity variation with time. L1 SOCIB products re-sampled to 5 minutes median are plotted.

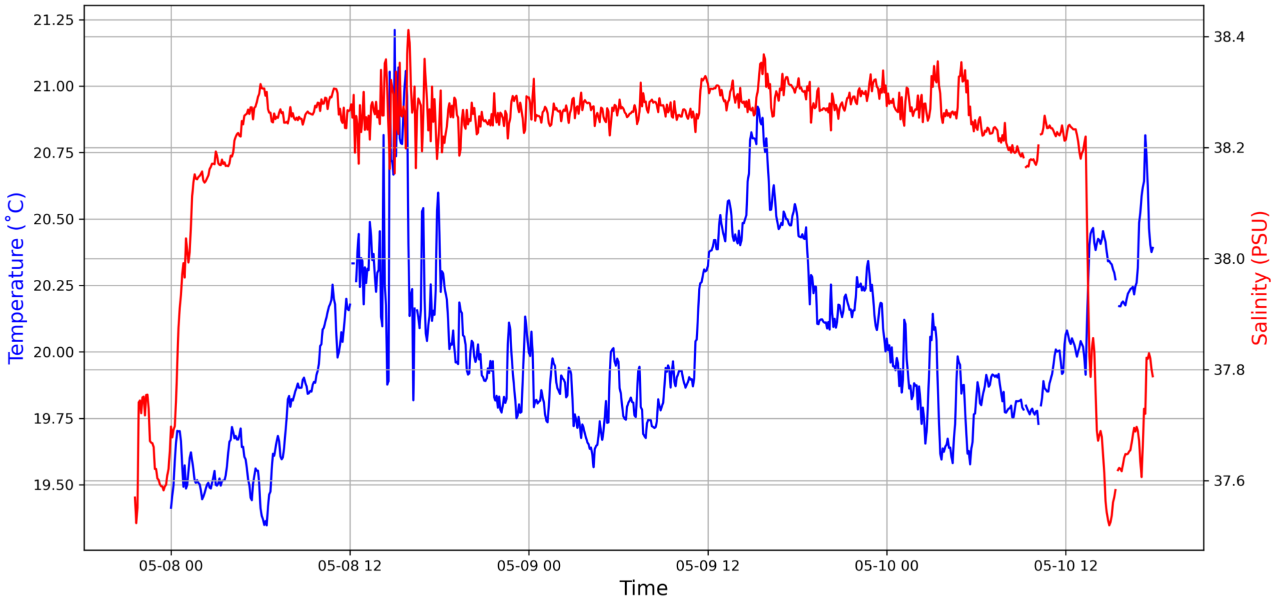


Figure 14: Thermosalinograph leg 2 surface temperature and salinity variation with time. L1 SOCIB products re-sampled to 5 minutes median are plotted.

6.3 ADCP

ADCP (Acoustic Doppler Current Profiler) measurements were collected along the trajectory of the R/V SOCIB. The Teledyne RD Ocean Surveyor vessel-mounted ADCP instrument operates at 150 kHz and provides ocean current measurements from the surface to approximately 200 m depth in 5 m vertical thickness cells. Data are corrected for pitch, roll, and heading effects using the GPS 3D high-precision positioning system. The short time average (STA) is 120 seconds, while the long time average (LTA) is set to 600 seconds. Calibration from the bottom track mode resulted in an amplitude of 1.0020 ± 0.0033 and a phase of 0.0009 ± 0.1723.

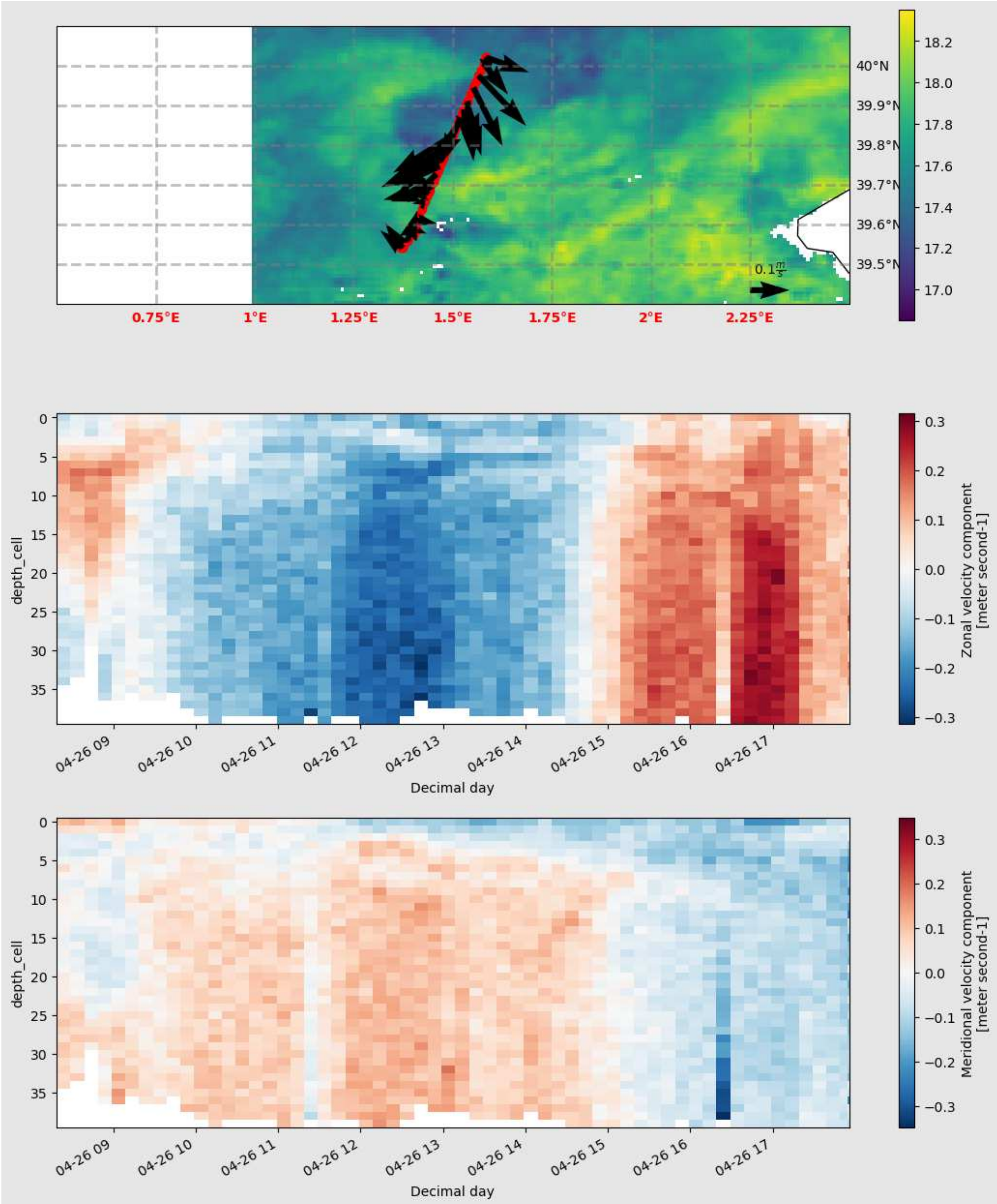


Figure 15: Horizontal currents observed from the vessel mounted ADCP across the eddy on 26 April 2023.

6.4 MVP

A Moving Vessel Profiler (MVP, AML Oceanographic) was deployed behind R/V SOCIB during most of the time of the FaSt-SWOT campaigns. It provided underway profiles of temperature and salinity. The profiles were limited to the upper 100m during leg 1 due to the inadequate pressure sensor provided by the instrument supplier. The sensor was changed between the two legs and profiles were collected in the upper 200m during leg 2. Fixed stations CTD profiles were collected at the beginning of the MVP sampling to help calibrate and validate the MVP measurements.

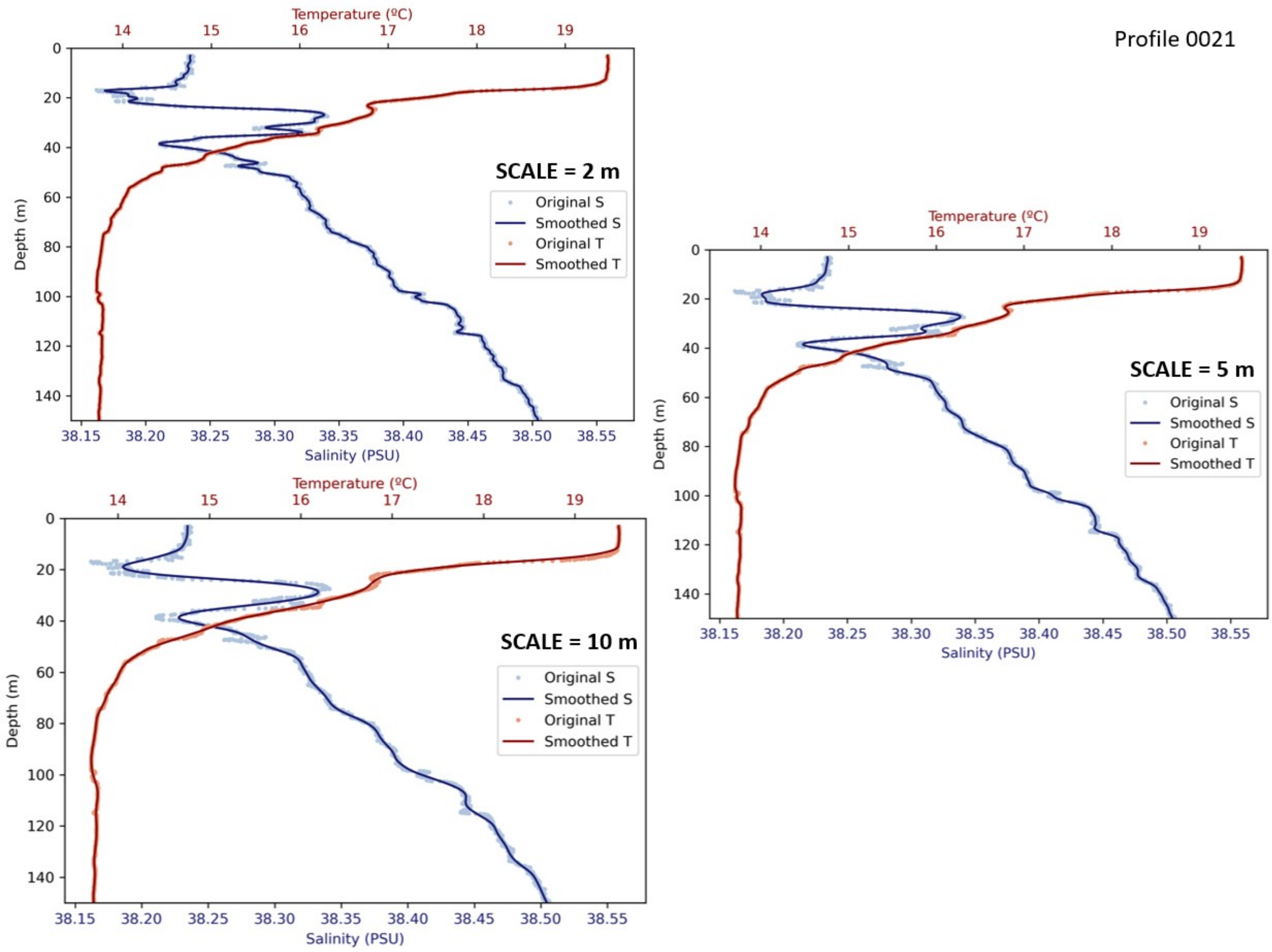


Figure 16: Example of MVP smoothed temperature and salinity profiles for different filtering scales: 2, 5 and 10 meters

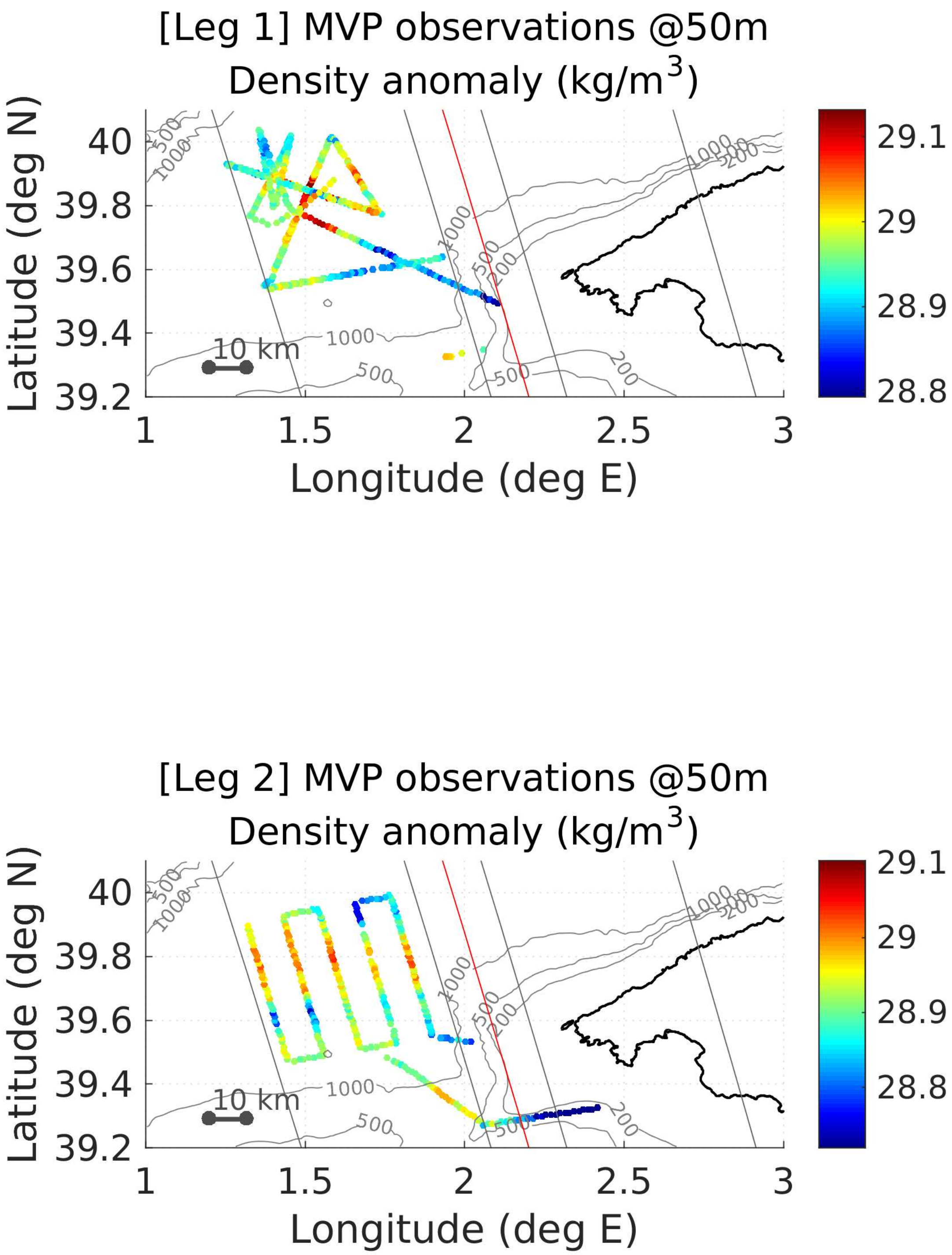


Figure 17: MVP water density anomaly observations at 50m depth collected during leg 1 (left) and leg 2 (right).

6.5 CTDs

Vertical profiles of water properties, including temperature and salinity, were collected using a SeaBird SBE9plus conductivity-temperature-depth (CTD) sensor at selected stations. To ensure accurate salinity measurements, water samples for salinity calibration were collected at various depths of the CTD profiles. The aim was to cover the entire range of measured salinities and ensure reliable calibration of the CTD sensor's conductivity measurements. Further details on the salinity calibration procedure can be found in Section 6.6.

Leg 1

The CTD rosette was deployed at selected stations to conduct vertical profiles of temperature, salinity, chlorophyll and dissolved oxygen down to approximately 500 or 700 m depth. A total of 12 CTD casts were performed during leg 1. The sampling locations were carefully chosen to capture the vertical structure of the eddy at its center, middle, and exterior positions, providing valuable data on the water properties within the eddy.

Table 1: Details of CTD casts performed during leg 1.

CTD cast #	Start			End			Depth (m)	Max. CTD depth (m)
	Lat. (°N)	Lon. (°E)	Date and time (UTC)	Lat. (°N)	Lon. (°E)	Date and time (UTC)		
1	39.5415	1.3762	26/04/23 08:14	39.5432	1.5345	26/04/23 08:43	1500	700
2	39.6868	1.4410	26/04/23 10:59	39.6876	1.4362	26/04/23 11:15	1500	510
3	39.8014	1.4896	26/04/23 13:24	39.7999	1.4860	26/04/23 13:44	1553	517
4	39.9060	1.5347	26/04/23 15:50	39.9058	1.5348	26/04/23 16:14	1540	503
5	40.0219	1.5839	26/04/23 17:40	-	-	-	1544	502
6	39.7760	1.7334	26/04/23 21:01	39.7777	1.7284	26/04/23 21:21	1493	500
7	39.9295	1.2534	27/04/23 10:05	39.9302	1.2524	27/04/23 10:30	1401	536
8	39.7750	1.7335	27/04/23 14:50	39.7770	1.7298	27/04/23 15:410	1410	500
9	39.9404	1.3927	28/04/23 12:30	39.9433	1.3899	28/04/23 12:58	1488	714
10	39.8610	1.4248	28/04/23 13:55	39.8660	1.4210	28/04/23 14:22	1511	703
11	39.8044	1.4464	28/04/23 15:11	39.8086	1.4430	28/04/23 15:38	1528	700
12	39.7599	1.5170	28/04/23 16:27	39.7643	1.5132	28/04/23 17:21	1534	1555

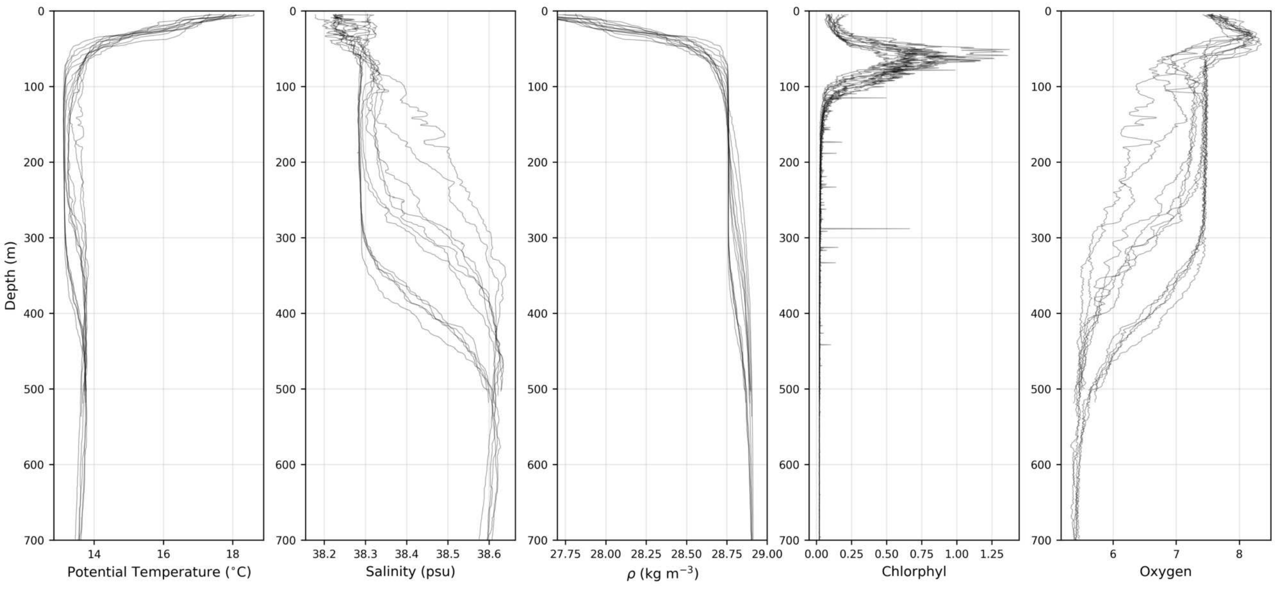


Figure 18: Vertical profiles of potential temperature, salinity, density, chlorophyll, and oxygen from CTD casts during leg 1.

Leg 2

The CTD rosette was released in selected stations down to approximately 700 m depth. In selected stations vertical profiles were done down to 1500 m to better identify the deep water masses. In total, 10 CTD casts were performed at specific locations selected along the ship radiator track based on available SST and ocean color images.

Table 2: Details of CTD casts performed during FaSt-SWOT leg 2.

CTD cast #	Start			End			Depth (m)	Max. CTD depth (m)
	Lat. (°N)	Lon. (°E)	Date and time (UTC)	Lat. (°N)	Lon. (°E)	Date and time (UTC)		
1	39.8848	1.6819	08/05/23 12:10	39.8803	1.6831	08/05/23 12:38	1600	700
2	39.7908	1.7075	08/05/23 14:08	39.7831	1.7061	08/05/23 14:41	1508	705
3	39.7014	1.7368	08/05/23 16:00	39.7013	1.7332	08/05/23 16:41	1398	700
4	39.8215	1.4609	09/05/23 06:20	39.8204	1.4618	09/05/23 06:56	1533	700
5	39.7601	1.4791	09/05/23 08:01	39.75	1.48	09/05/23 08:31	1550	700
6	39.6652	1.5074	09/05/23 10:05	39.6741	1.5047	09/05/23 10:46	1540	1541
7	39.5915	1.5316	09/05/23 12:18	39.5977	1.5330	09/05/23 12:46	1546	1545
8	39.5835	1.4134	09/05/23 17:10	39.5863	1.4149	09/05/23 17:40	1513	702
9	39.7258	1.3711	09/05/23 19:41	39.7261	1.3737	09/05/23 20:04	1500	700
10	39.8112	1.3447	09/05/23 21:25	39.8131	1.3450	09/05/23 -	1474	700

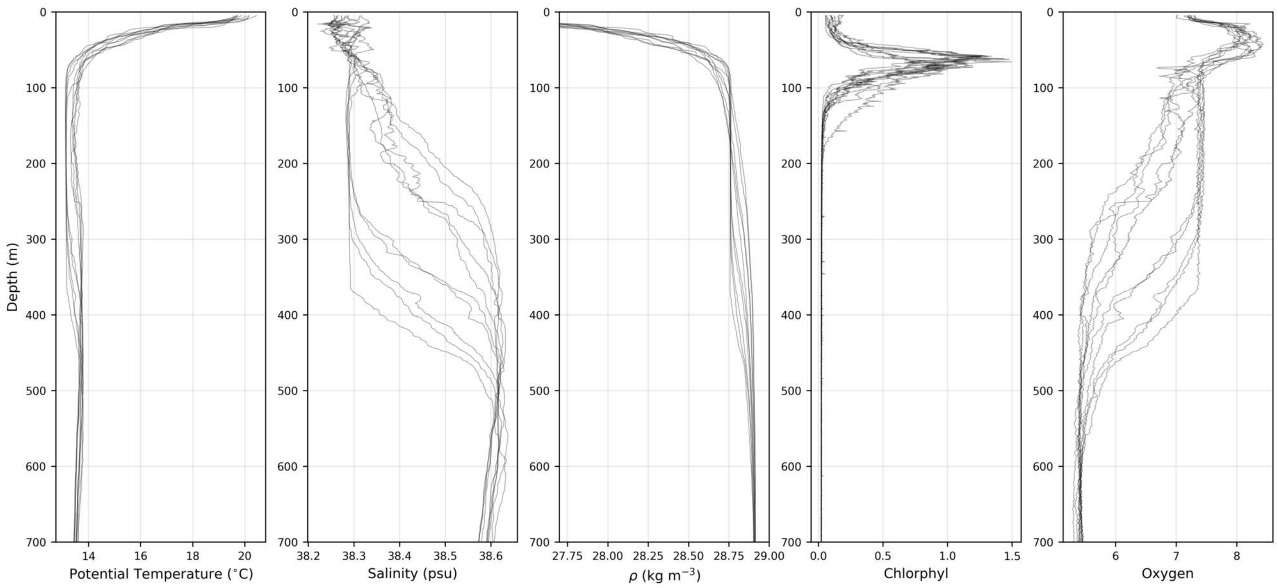


Figure 19: Vertical profiles of potential temperature, salinity, density, chlorophyll, and oxygen from CTD casts during leg 2.

6.6 Water samples

Salinity is a fundamental EOV (Essential Ocean Variable) for water mass property determination and characterization. SOCIB instruments and platforms measure practical salinity electronically according to international standards. In situ water bottle sample salinity determination is essential for validation of these multi-platform observations, for the validation process and for the determination and correction of long-term sensor drifts.

Water samples for salinity calibration were collected at different depths simultaneously with the SBE9plus CTD profiles using the Seabird SBE32 carousel water sampler with 12 bottles up to 5 liters, trying to cover the whole range of measured salinity. In addition, water samples were also collected from the thermosalinograph, which continuously measured temperature and conductivity along the ship's trajectory, from which the near surface salinity is derived.

The analytical salinity determination of sea water samples (collected by the thermosalinigraph and from the Seabird SBE32 carousel) has been done operating a Portasal salinometer 8410A. It measures accurate conductivity ratios and displays calculated salinity directly as well as measured parameters. The analytical results obtained from the in situ water samples will be used for a delayed mode field calibration of the ship-based lowered and underway CTD sensors.

The salinity determination comprises different steps:

- 1.- Preparation steps at least 24 hours before the sea water sample analysis in the laboratory. This implies the setting up the of the temperature and humidity controlled room (at 23 ºC and 50-60%, respectively) for tempering the water samples during 24h and the Portasal assembly and preparation.

- 2.- Analytical determination, which involves the: i) preparation of the file, ensuring that the communication and configuration settings are correct; ii) the standardization by running the calibration standard with the 'Salinometer Data Logger'; iii) the test of linearity in order to detect potential malfunction of the instrument. This test consists in reading the 38H-Series IAPSO Standard Seawater (OSIL), right after the first standardization of the day; iv) the preparation for running the samples, obtaining up to 3 readings for each analysed sampled; v) finalizing the analyses: To check for potential drifts in the instrument performance, P-Series IAPSO standard seawater is run and compared with the obtained readings in the standardization steps.

- 3.- Data archival and storage: four data files are generated after each analytical determination with the following file extensions:

  - Filename.raw: Binary file that includes all the information.

  - Filename.hfr: File containing all the analyses metadata.

  - Filename.dat: File containing the obtained analytical results.

  - Filename.xlsx: Excel format where all previous files are exported.

  Those files have been created and saved in *.zip mode and sent to the project Principal Investigator.

The list of all water sample measurements collected during the first and the second legs, including the number of the water bottle, the date/time, the location, the station name, the depth and the staff in charge of the measurement are provided in the tables below.

Bottle #	Date	Time (UTC)	Coordinates (Lat./Long.)	Station name (CTD/Termosal)	CTD bottle	Depth (m)	Salinidad (Termosal)	Staff
1.	26/04/2023	08:44	39°32.490' N 01°22.570' E	Station_01	1	700	-	Benjamín
2.	26/04/2023	08:44	39°32.490' N 01°22.570' E	Station_01	4	270	-	Benjamín
3.	26/04/2023	08:44	39°32.490' N 01°22.570' E	Station_01	5	26	-	Benjamín
4.	26/04/2023	11:18	39°41.210' N 01°26.460' E	Station_02	1	510	-	Daniel
5.	26/04/2023	11:18	39°41.210' N 01°26.460' E	Station_02	4	450	-	Daniel
6.	26/04/2023	11:18	39°41.210' N 01°26.460' E	Station_02	6	170	-	Irene
7.	26/04/2023	11:42	39°42,400 'N 01°26,974' E	TERMOSAL	N/A	surface	38.184	Irene Benjamín
8.	26/04/2023	11:42	39°42,400' N 01°26,974' E	TERMOSAL	N/A	surface	38.184	Irene Benjamín
9.	26/04/2023	13:45	39°48,086' N 01°29,374' E	Station_03	1	507	-	Daniel
10.	26/04/2023	13:45	39°48,086' N 01°29,374' E	Station_03	4	300	-	Irene
11.	26/04/2023	16:30	39°54,361' N 01°32,086' E	Station_04	1	503	-	Laura
12.	26/04/2023	16:30	39°54,361' N 01°32,086' E	Station_04	5	220	-	Laura
13.	26/04/2023	18:14	40°01,314' N 01°35.034' E	Station_05	1	502	-	Benjamín
14.	26/04/2023	18:17	40°01,314' N 01°35.034' E	Station_05	4	440	-	Benjamín
15.	26/04/2023	18:20	40°01,314' N 01°35.034' E	Station_05	7	140	-	Benjamín
16.	26/04/2023	21:27	39°46.661' N 01°43,705' E	Station_06	1	500	-	Benjamín
17.	26/04/2023	21:29	39°46.661' N 01°43,705' E	Station_06	4	175	-	Benjamín
18.	27/04/2023	11:03	39°55,814' N 01°15,145' E	Station_07	1	536	-	Daniel
19.	27/04/2023	11:03	39°55,814' N 01°15,145' E	Station_07	4	415	-	Elisabeth
20.	27/04/2023	11:03	39°55,814' N 01°15,145' E	Station_07	5	118	-	Elisabeth
21.	27/04/2023	15:20	39°46,501' N 01°44,007' E	Station_08	1	500	-	Irene
22.	27/04/2023	15:20	39°46,501' N 01°44,007' E	Station_08	4	140	-	Irene
23.	27/04/2023	15:20	39°46,501' N 01°44,007' E	Station_08	6	22	-	Laura
24.	27/04/2023	15:27	-	TERMOSAL	N/A	surface	38.217	Irene Laura
25.	28/04/2023	19:22	N39°38.83 E01° 45.52	TERMOSAL	N/A	surface	38.150	Irene Laura

Figure 20: List of water samples collected during leg 1.

Bottle #	Date	Time (UTC)	Coordinates (Lat./Long.)	Station name (CTD/Termosal)	CTD bottle	Depth (m)	Salinidad (Termosal)	Staff
26.	08/05/2023	12:10	39° 53.089'N 01° 40.915'E	CTD S2-01	1	700	-	Emma
27.	08/05/2023	12:10	39° 53.089'N 01° 40.915'E	CTD S2-01	5	163	-	Daniel
28.	08/05/2023	14:40	39° 46.984'N 01° 42.368'E	CTD S2-02	1	705	-	Noemí
29.	08/05/2023	14:40	39° 46.984'N 01° 42.368'E	CTD S2-02	5	142	-	Laura
30.	08/05/2023	16:40	39° 42.077'N 01° 43.991'E	CTD S2-03	2	440	-	Emma
31.	08/05/2023	17:25	39° 39.016'N 01° 45.034'E	TERMOSAL	N/A	surface	38.179	Laura
32.	08/05/2023	17:25	39° 39.016'N 01° 45.034'E	TERMOSAL	N/A	surface	38.180	Laura
33.	09/05/2023	07:02	39° 49.223'N 01° 27.706'E	CTD S4-04	1	593	-	Noemí
34.	09/05/2023	07:02	39° 49.223'N 01° 27.706'E	CTD S4-04	4	330	-	Noemi
35.	09/05/2023	08:33	39° 45.000'N 01° 28.800'E	CTD S4-05	1	560	-	Niko
36.	09/05/2023	08:33	39° 45.000'N 01° 28.800'E	CTD S4-05	3	156	-	Niko
37.	09/05/2023	10:27	39° 40.290'N 01° 30.294'E	CTD S4-06	1,2,3	559	-	Emma
38.	09/05/2023	10:34	39° 40.290'N 01° 30.294'E	CTD S4-06	4,5	437	-	Emma
39.	09/05/2023	17:05	39° 34.678'N 01° 24.847'E	TERMOSAL	N/A	surface	38.328	Emma Laura
40.	09/05/2023	16:59	39° 34.581'N 01° 24.875'E	TERMOSAL	N/A	surface	38.319	Emma Laura
41.	09/05/2023	17:05	39° 35.178'N 01° 24.814'E	CTD S4-08	2	430	-	Noemí Laura
42.	09/05/2023	21:56	39° 48.786'N 01° 20.700'E	CTD S5-10	1	560	-	Niko Baptiste
43.	09/05/2023	21:56	39° 48.786'N 01° 20.700'E	CTD S5-10	3	340	-	Niko Baptiste
44.	09/05/2023	12:37	39° 35.736'N 01° 31.962'E	CTD S4-07	2	485	-	Daniel Emma
45.	09/05/2023	12:37	39° 35.736'N 01° 31.962'E	CTD S4-07	5	370	-	Daniel Emma

Figure 21: List of water samples collected during leg 2.

6.7 Gliders

Two slocum ocean gliders (SDEEP01 and SDEEP09) were deployed from 25 April until 10 May, 2023 (16-day mission). Both gliders have been sampling the same transect one after the other (Figure 22), separated by 20-25 km apart. Their distance separation in time is about 1 day, which corresponds to the repetitivity of SWOT measurements during the fast-sampling phase. Both Slocum gliders are equipped with CTD and Oxygen sensors. In addition, the G3 Slocum (SDEEP09) carries an FL3 to measure chlorophyll fluorescence (CHL), Colored dissolved organic matter (CDOM), and backscatter (bbp at 700 nm), and a PAR sensor. The other Slocum glider is a G2 (SDEEP01) equipped with an FLNTU sensor (to measure turbidity NTU, and chlorophyll fluorescence). During this period the gliders were able to complete 4 transects of about 90km along the direction of SWOT satellite track.

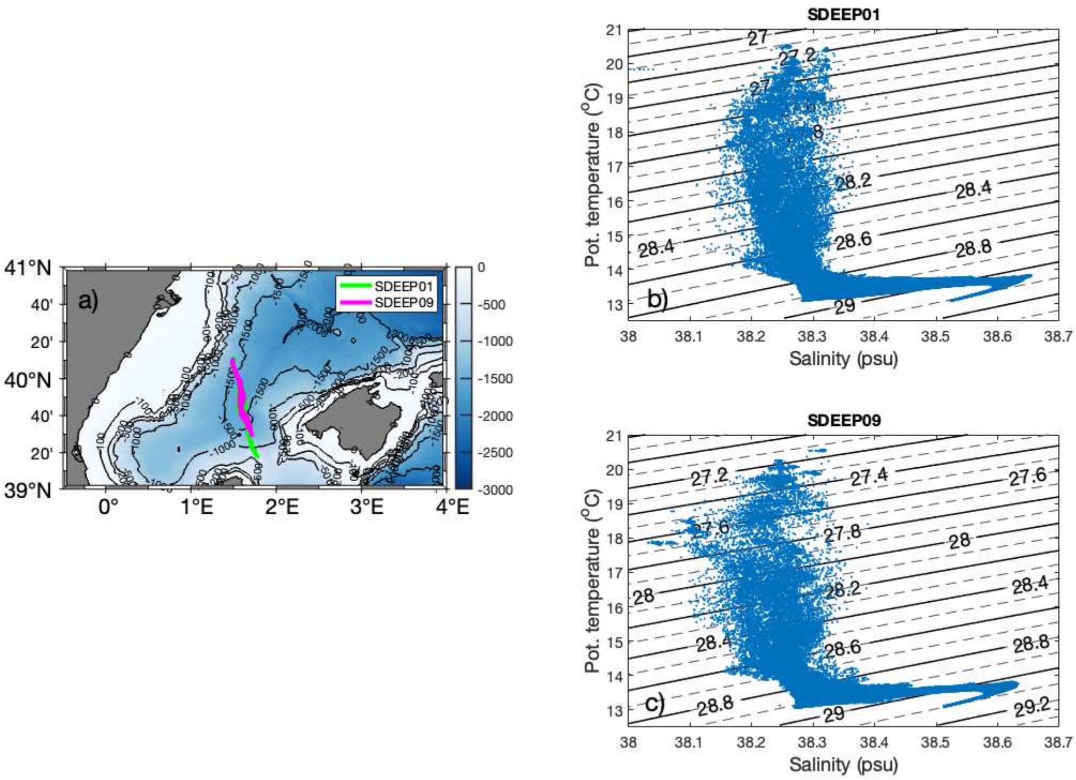


Figure 22: a) Position of glider measurements over the bathymetry of the study region, b) and c) temperature/salinity diagrams for the SDEEP01 and SDEEP09 data, respectively.

The sampling has been adapted to the oceanographic conditions until both gliders have been recovered on 10 May 2023. The two gliders have been programmed to profile from the surface down to 900 m at a nominal vertical speed of 0.18 ± 0.02 m/s. This resulted in an horizontal motion at approximately 20–24 km per/day. The potential temperature-salinity diagrams show the different water mass characteristics that are present during the observation period from both gliders (Figure 22b and c). Obvious unrealistic spikes in the physical data were removed and replaced by an absent data value (i.e. Nan) The vertical distribution of temperature for both gliders reveals compelling evidence of warming in the upper 30m of the water column of 2 °C in a period of two weeks. Below the thermocline and between 100m and 350m, patches of low-temperature waters that were associated with salinity of 38.3 psu and oxygen of 240 ml/l were observed (Figure 23). This low temperature has origin from the Gulf of Lion where it has been recently ventilated (Figures 23b, c, e and f). Also, the vertical distributions of oxygen suggest enhanced photosynthetic activity between 20 to 70m (where DCM is located, not shown here) that contributes to the production of oxygen through photosynthesis (Figures 23e and f).

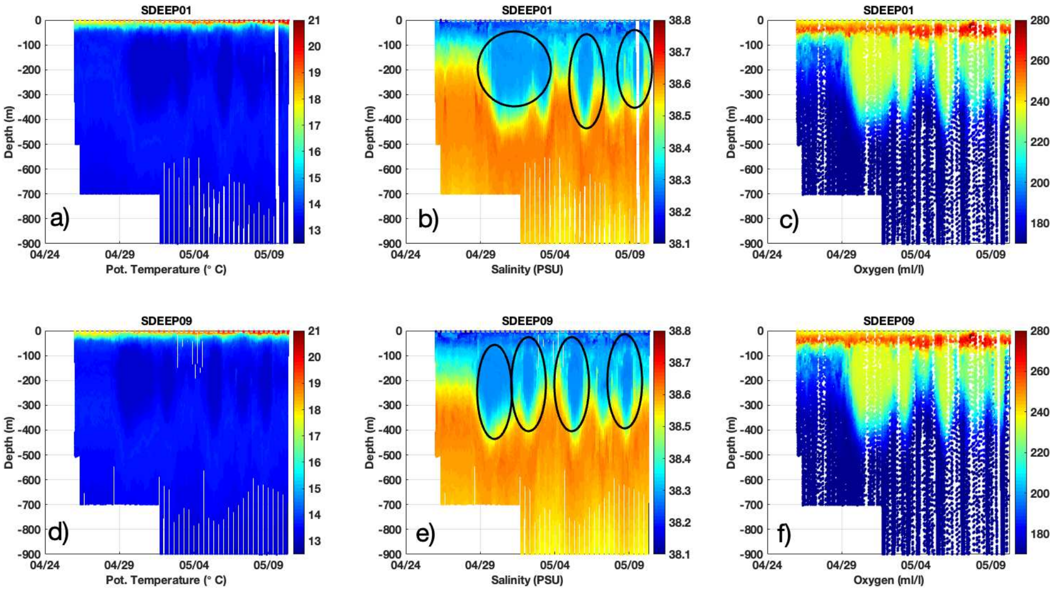


Figure 23: Vertical sections of observations from the SDEEP01 and SDEEP09 gliders for potential temperature (°C; panels a and d), salinity (psu; panels b and d) and oxygen (ml/l, panels c and e). The solid black ellipses indicate the location of patches of Winter Intermediate Water (WIW).

6.8 Drifters

During the experiment, a total of 45 surface drifters were deployed. Surface currents derived from drifters will be used to study the temporal and spatial variability of fronts and filaments, and ideally to detect surface flow convergence and divergence. The different drifter types used were:

- Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE) drifters (Novelli et al. 2017): This is a type of surface drifter from Pacific Gyre (`https://www.pacificgyre.com/carthe-drifter.aspx`). These drifters are designed for data transmission and tracking using Low-Cost Globalstar Simplex telemetry. They have a robust construction made of durable ABS plastic, ensuring their longevity. Powered by alkaline batteries, these drifters can operate for up to 3 months and report their positions at regular intervals of 5 minutes. Deployment is simplified through a magnetic switch activation mechanism, and their stability in different conditions is ensured by a drogue depth of 40 cm. Weighing approximately 4 kg in air, these drifters are lightweight and easy to handle. Their assembly is made convenient with a 3-part kit design, ultimately contributing to their overall effectiveness and reliability in data collection and tracking.
- Hereon (Horstmann et al., 2022): These drifters were specifically designed and constructed to track the upper surface flow within a range of approximately 50 cm. These drifters feature a cylindrical tube measuring 20 cm x 7.5 cm, equipped with a flotation ring positioned at the top to ensure buoyancy. Additionally, a drogue measuring 35 cm in both length and diameter is attached to the tube at a distance of 20 cm using a flexible

cord. When deployed, the drifters extend about 5 cm above the water surface. The tube of the drifters houses a battery pack and an electronic board responsible for acquiring and reporting GPS positions. These positions are obtained every 5 minutes and transmitted in near real time through a global satellite network. This enables accurate and up-to-date tracking of the drifters' movements and positions.

- Surface Velocity Program Barometer (SVP-B) drifters (Niiler, 2001; Maximenko et al, 2013; Centuroni et al., 2017; Horányi et al, 2017): These drifters, developed by the Lagrangian Drifter Laboratory at the Scripps Institution of Oceanography (SIO), are technologically advanced instruments designed for precise Lagrangian observations in oceanographic research. They feature a 35 cm sphere surface float and utilize GPS-based tracking with Iridium Short Burst Data (SBD) telemetry for efficient data transmission. Equipped with a sea surface temperature sensor (±0.05 K accuracy) and a sea level barometric pressure sensor (±0.4 hPa accuracy), they provide detailed environmental measurements. A holey sock drogue centered at 15 m depth ensures stability, while a variable sampling rate down to 5 minutes allows for flexible data collection. With a two-year lifespan, the SVP-B drifter offers a durable and reliable solution for long-term oceanographic studies.

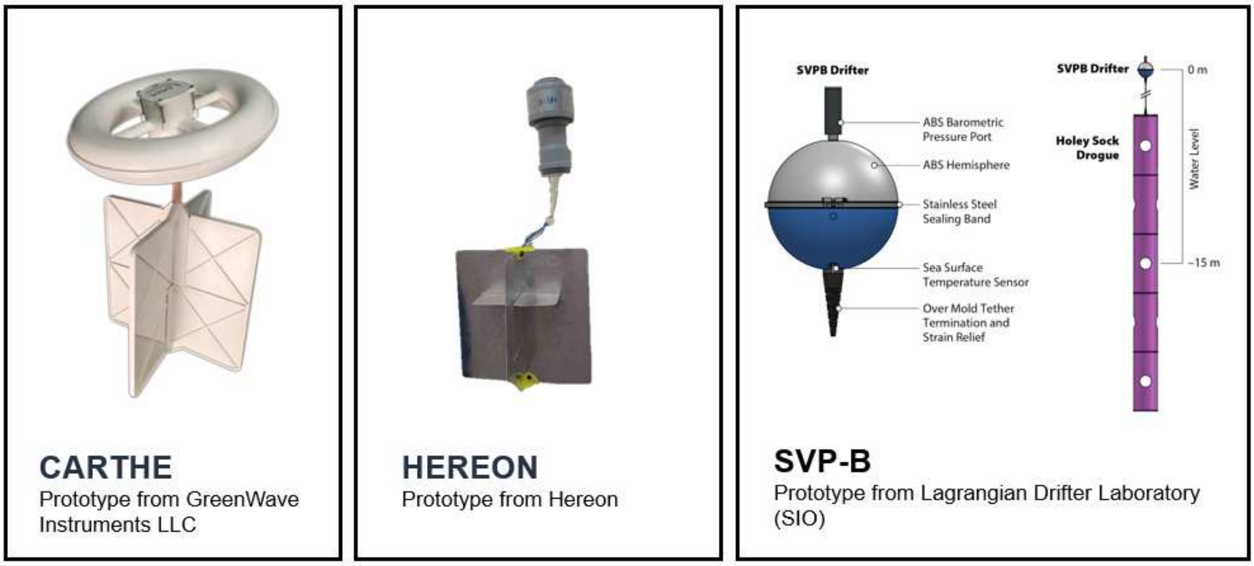


Figure 24: Drifter types used during FaSt-SWOT experiment

A specific working group was formed to address the following tasks before and during the experiment:

1. Identify and complete the metadata attributes following the FAIR -Findability, Accessibility, Interoperability, and Reusability- data principles (`https://www.go-fair.org/fair-principles/`).

2. Review of instruments' state (missing or damaged pieces, etc.) and communication tests

3. Send the cruise plan to NOAA and OceanOPS in order to activate the SVP-B iridium communication for the deployment. The FaSt-SWOT cruise was used as a ship-of-opportunity to deploy the SVP-Bs, as part of the Global Drifter Program.

4. Identify the deployments locations following the scientific criteria and meteorological conditions.

5. Activate manually the deployments from the ship stern.
6. Send deployment specifications to the SOCIB Data Centre Facility (id, date, time, position, weather conditions).
7. Start deployments.
8. Send the deployment confirmation to NOAA and OceanOPS (only for the SVP-B).
9. Recover any beached drifter when possible.

The location of the deployments of surface and near-surface drifters is depicted in Figure 25). These drifters were utilized to analyze surface currents and investigate the temporal and spatial variations of fronts and filaments. Moreover, they aimed to examine the kinematic characteristics of the flow, such as divergence, vorticity, and strain. Additionally, the observations obtained from the drifters would serve as valuable data for validating altimetry, glider measurements, models, and geostrophic velocities derived from Conductivity, Temperature, and Depth (CTD) measurements.

To effectively sample fine-scale oceanographic structures like fronts or eddies, the deployment strategy incorporated an adaptable approach used to define the deployment array based on the observed structure. If the structure of interest was a jet or front, a triangular configuration with side lengths ranging from 5 to 10 km was employed. In the case of an eddy, a linear deployment pattern was implemented, with the possibility of repeated transects depending on the diameter of the eddy and logistical constraints. The length of the triangle or transect was never smaller than the minimum expected resolved wavelength by the Surface Water and Ocean Topography (SWOT) mission, which is 15 km (corresponding to structures of 7.5 km in diameter).

The precise deployment locations were determined based on the identification of frontal areas through satellite imagery analysis.

- **leg 1**
  - deployment of 5 SVP-B, 10 Hereon and 10 CARTHE
- **leg 2**
  - deployment of 10 Hereon and 10 CARTHE

Details of the drifter IDs, deployment time, and end-of-mission characteristics are provided in Tables 3 and 4. Drifters deployed during leg 2 were part of the "¡Boya al agua!" educational program (`https://imedea.uib-csic.es/divulgacion-y-comunicacion/noticias/?new_id=2007`, in which students assigned specific names to the drifters. These names are listed in Table 5.

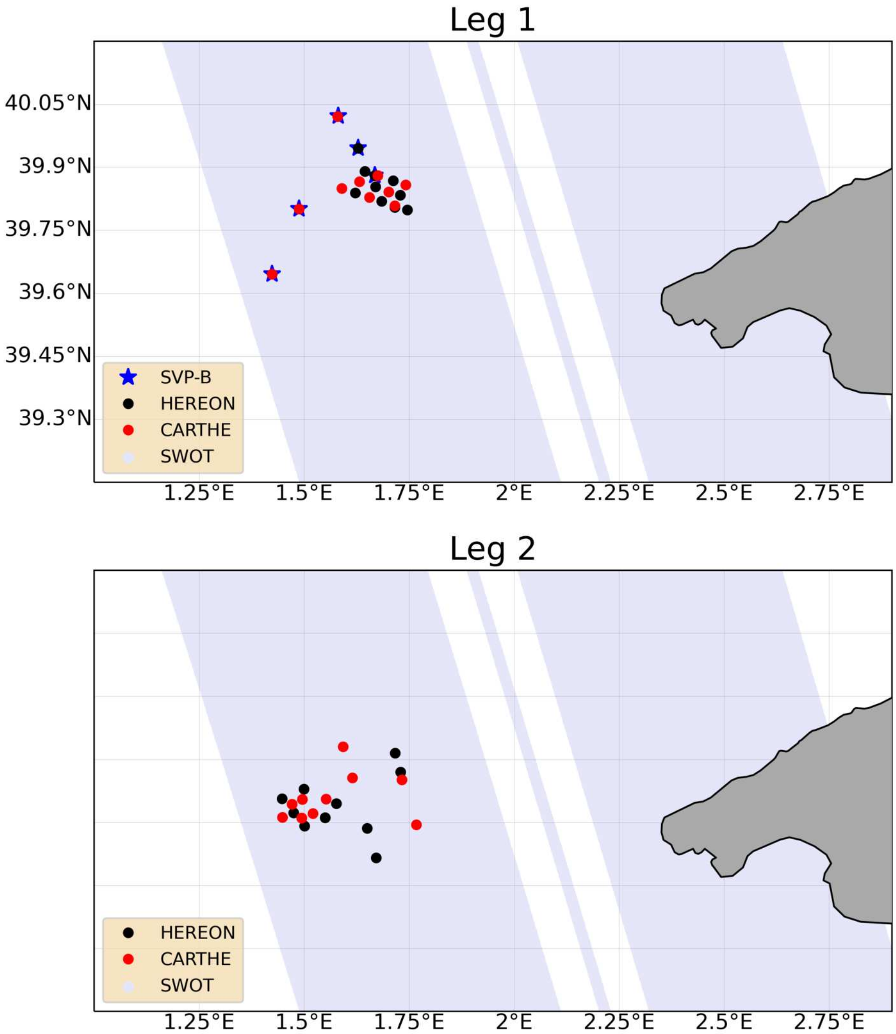


Figure 25: Locations of drifter deployments during leg 1 (upper panel) and leg 2 (lower panel).

Table 3: Deployment and recovery information - FaSt-SWOT leg 1, last updated 19/10/2023 Eugenio:add Atalaia drfiter?

Drifter ID	**Deployment Date, Time (UTC) and Location**		**End-of-Deployment Reason**	**Recovery**
	Start	**End**		
		SVP-B		
WMO 6204604	26/04/2023 10:08 39.6456°N 1.4236°E	-	-	-
WMO 6204605	26/04/2023 13:48 39.8007°N 1.4877°E	-	-	-
WMO 6204606	26/04/2023 18:03 40.0216°N 1.5810°E	26/05/2023 14:00 39.7836°N 1.6084°E	End of Communications	No
WMO 6204607	26/04/2023 18:57 39.9449°N 1.6288°E	-	-	-
WMO 6204608	26/04/2023 19:42 39.8800°N 1.6687°E	03/08/2023 14:00 39.9306°N 0.0054°E	Beaching	No
		CARTHE		
SN 0-4694040	26/04/2023 10:08 39.6456°N 1.4236°E	28/05/2023 19:14 39.4150°N 0.0388°W	End of Communications	No
SN 0-4694103	26/04/2023 14:01 39.8007°N 1.4877°E	19/05/2023 00:30 39.7661°N 3.1616°E	Beaching	No
SN 0-4694122	26/04/2023 18:03 40.0208°N 1.5800°E	04/06/2023 17:14 38.4350°N 0.3063°W	End of Communications	No
SN 0-4694188	27/04/2023 21:34 39.8087°N 1.7155°E	01/05/2023 07:48 39.8902°N 1.3147°E	End of Communications	No
SN 0-4694189	27/04/2023 22:01 39.8284°N 1.6552°E	05/06/2023 01:44 38.7194°N 0.2535°E	End of Communications	Yes
SN 0-4694193	27/04/2023 22:32 30.8494°N 1.5898°E	22/05/2023 08:14 39.7669°N 3.1561°E	Beaching	Yes
SN 0-4694198	27/04/2023 23:15 39.8657°N 1.6316°E	23/05/2023 07:10 39.1199°N 1.9063°E	End of Communications	No
SN 0-4694199	27/04/2023 23:38 39.8414°N 1.7012°E	01/06/2023 02:14 39.1744°N 1.8997°E	End of Communications	No
SN 0-4694201	28/04/2023 00:42 39.8582°N 1.7416°E	13/07/2023 10:57 39.5789°N 0.2721°W	Beaching	No
SN 0-4694203	28/04/2023 01:15 39.8803°N 1.6756°E	14/09/2023 10:22 36.7102°N 5.5371°E	Beaching	No
		HEREON		
ID 278	26/04/2023 18:57 39.9449°N 1.6288°E	23/05/2023 01:44 38.9166°N 1.4790°E	Beaching	No
ID 279	26/04/2023 19:42 39.8800°N 1.6687°E	04/06/2023 13:13 38.1288°N 0.6379°W	Beaching	No
ID 280	26/04/2023 20:34 39.8044°N 1.7158°E	11/06/2023 11:20 41.1933°N 1.6563°E	Beaching	No
ID 281	27/04/2023 21:19 39.7987°N 1.7459°E	28/09/2023 09:04 39.7917°N 0.1728°E	End of Communications	No
ID 283	27/04/2023 21:47 39.8187°N 1.6846°E	21/05/2023 19:20 39.7704°N 3.1510°E	Beaching	No
ID 284	27/04/2023 22:17 39.8393°N 1.6221°E	27/06/2023 12:28 40.4924°N 2.2275°E	End of Communications	No
ID 285	27/04/2023 23:20 39.8533°N 1.6696°E	27/05/2023 09:10 40.1857°N 2.4723°E	End of Communications	No
ID 286	27/04/2023 23:52 39.8332°N 1.7291°E	19/05/2023 17:19 39.8912°N 3.1897°E	Beaching	No
ID 287	28/04/2023 00:58 39.8679°N 1.7119°E	21/05/2023 13:52 39.8141°N 2.7098°E	Beaching	No
ID 288	28/04/2023 01:32 39.8900°N 1.6450°E	22/06/2023 14:30 39.6536°N 0.2074°W	Beaching	No

Table 4: Deployment and recovery information - FaSt-SWOT leg 2, last updated 19/10/2023

Drifter ID	Deployment Date, Time (UTC) and Location		End-of-Deployment Reason	Recovery
	Start	End		
CARTHE				
SN 0-4694206	08/05/2023 16:41 39.7014°N 1.7331°E	26/06/2023 22:57 40.5506°N 0.6259°E	Beaching	Yes
SN 0-4694223	08/05/2023 18:15 39.5947°N 1.7673°E	18/07/2023 14:24 41.0826°N 1.2197°E	Beaching	No
SN 0-4694458	08/05/2023 23:36 39.7058°N 1.6147°E	21/05/2023 15:01 38.7360°N 1.4472°E	Beaching	Yes
SN 0-4694461	09/05/2023 00:50 39.7803°N 1.5925°E	13/06/2023 00:00 39.7596°N 2.6229°E	End of communications	No
SN 0-4694462	10/05/2023 02:34 39.6548°N 1.4959°E	28/05/2023 09:20 38.7529°N 1.4378°E	Beaching	No
SN 0-4694473	10/05/2023 02:45 39.6437°N 1.4714°E	19/07/2023 22:44 40.3236°N 1.4102°E	End of communications	Yes
SN 0-4694474	10/05/2023 03:09 39.6120°N 1.4481°E	11/07/2023 03:01 40.4613°N 0.4728°E	Beaching	No
SN 0-4694475	10/05/2023 03:59 39.6556°N 1.5526°E	01/07/2023 16:01 40.2856°N 4.4341°E	End of communications	Yes
SN 0-4694476	10/05/2023 04:26 39.6215°N 1.5207°E	10/05/2023 19:00 39.6633°N 1.3829°E	End of communications	No
SN 0-4695850	10/05/2023 04:37 39.6107°N 1.4945°E	18/06/2023 14:45 40.5666°N 0.5953°E	Beaching	Yes
HEREON				
ID 282	08/05/2023 15:01 39.7645°N 1.7164°E	03/06/2023 21:07 39.3636°N 0.3170°W	Beaching	No
ID 289	08/05/2023 15:41 39.7199°N 1.7298°E	05/10/2023 09:32 41.0910°N 7.8017°E	End of communications	No
ID 290	08/05/2023 19:34 39.5155°N 1.6714°E	23/05/2023 17:17 38.7776°N 1.4337°E	Beaching	No
ID 291	08/05/2023 21:41 39.5860°N 1.6500°E	25/06/2023 12:44 N39.5384°N 0.3050°W	Beaching	No
ID 292	10/05/2023 01:32 39.6563°N 1.4475°E	04/06/2023 17:37 38.6848°N 0.1537°E	Beaching	No
ID 293	10/05/2023 01:54 39.6791°N 1.4997°E	02/06/2023 20:12 38.2872°N 0.5194°W	Beaching	No
ID 294	10/05/2023 03:23 39.6230°N 1.4749°E	06/07/2023 18:33 39.9402°N 0.0021°E	Beaching	No
ID 295	10/05/2023 03:47 39.6451°N 1.5768°E	30/07/2023 12:41 41.1881°N 1.5930°E	Beaching	No
ID 296	10/05/2023 05:16 39.5911°N 1.5013°E	13/07/2023 11:05 39.6432°N 0.2031°W	Possibly caught by a ship	No
ID 297	10/05/2023 05:37 39.6114°N 1.5498°E	25/05/2023 19:00 39.1077°N 1.5388°E	Beaching	No

Table 5: Drifter names assigned by students in the ”¡Boya al agua!” educational program

Drifter ID	Assigned name
CARTHE	
SN 0-4694206	Tortuga llaüt
SN 0-4694223	Adella / Perry Platyrus
SN 0-4694458	Na Piltrafa
SN 0-4694461	Mar- T
SN 0-4694462	Posidònia
SN 0-4694473	Cafifú
SN 0-4694474	IES Manacor
SN 0-4694475	Consell 6È
SN 0-4694476	Bisbe Verger
SN 0-4695850	Dorothea Bale / Rosalind Franklin
HEREON	
ID 282	Gràtil
ID 289	Ses Bassetes
ID 290	Blau verd
ID 291	Suret
ID 292	Velella Binissalemis
ID 293	Bob Esponja
ID 294	En Vit / Na Catalineta
ID 295	Planeta
ID 296	ET
ID 297	Gaspar Fuster

Figure 26 shows how the different drifters were trapped within the smallanticyclonic eddy during leg 1. Figures 27 to 29 show the whole drifter trajectories. Most drifters were trapped at some point in the eddy, but for different periods of time. Figure 30 shows the trajectories of all the drifters during leg 2 with the corresponding chlorophyll satellite image in the background. At that time, most of the drifters were not anymore trapped in the eddy.

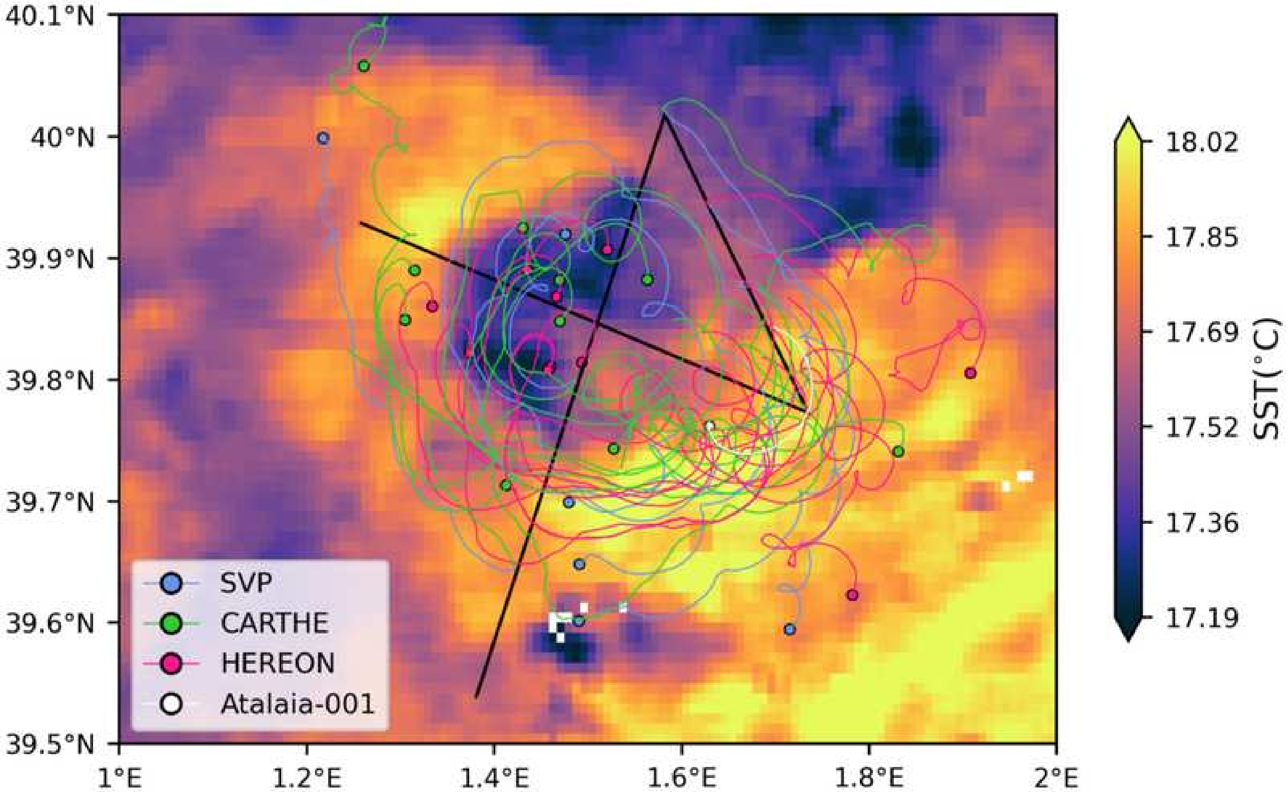


Figure 26: SST map on 26 April 2023 with the trajectories of the drifters deployed during leg 1 until 2 May 2023.

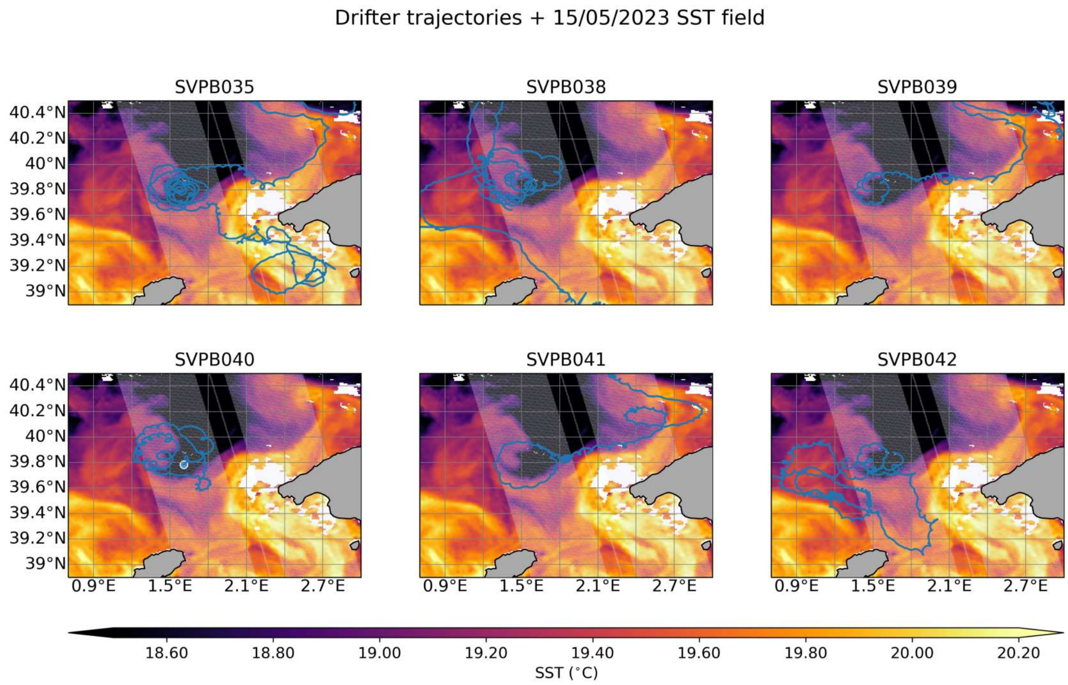


Figure 27: SST map on 15 May 2023 with the trajectories of SVP-B drifters deployed during leg 1 until 15 May 2023.

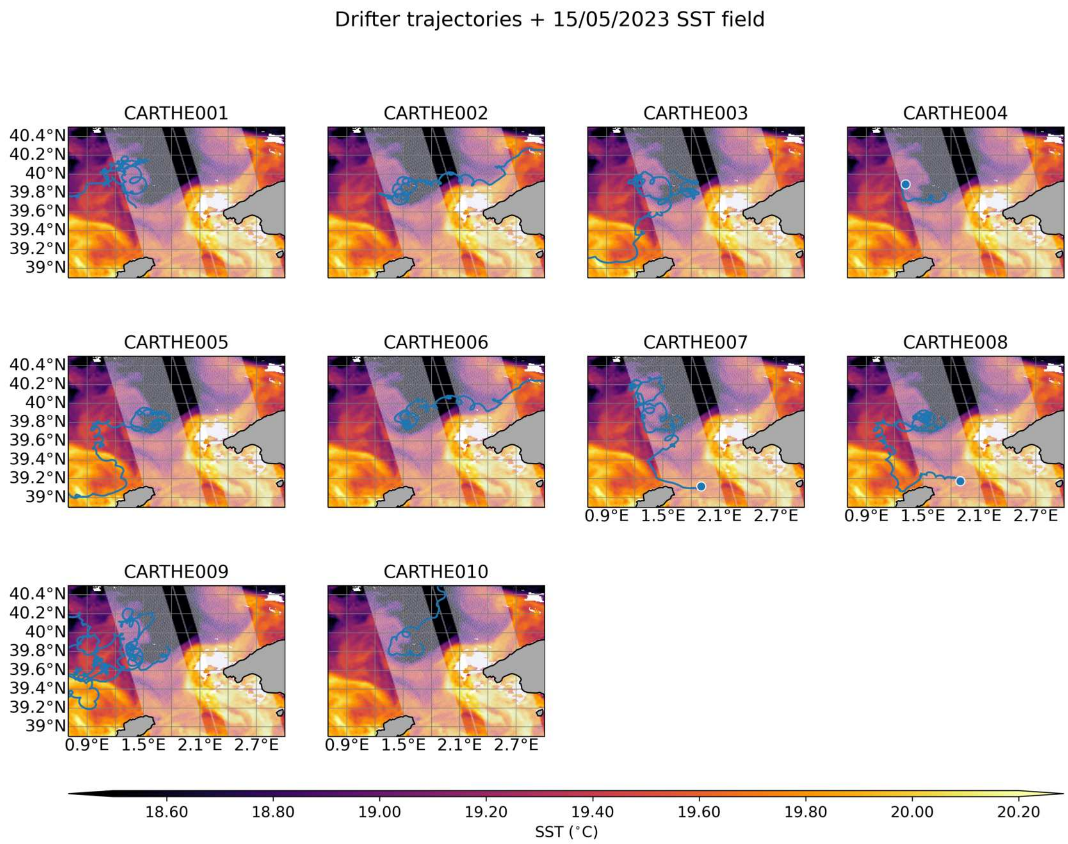


Figure 28: SST map on 15 May 2023 with the trajectories of CARTHE drifters deployed during leg 1 until 15 May 2023.

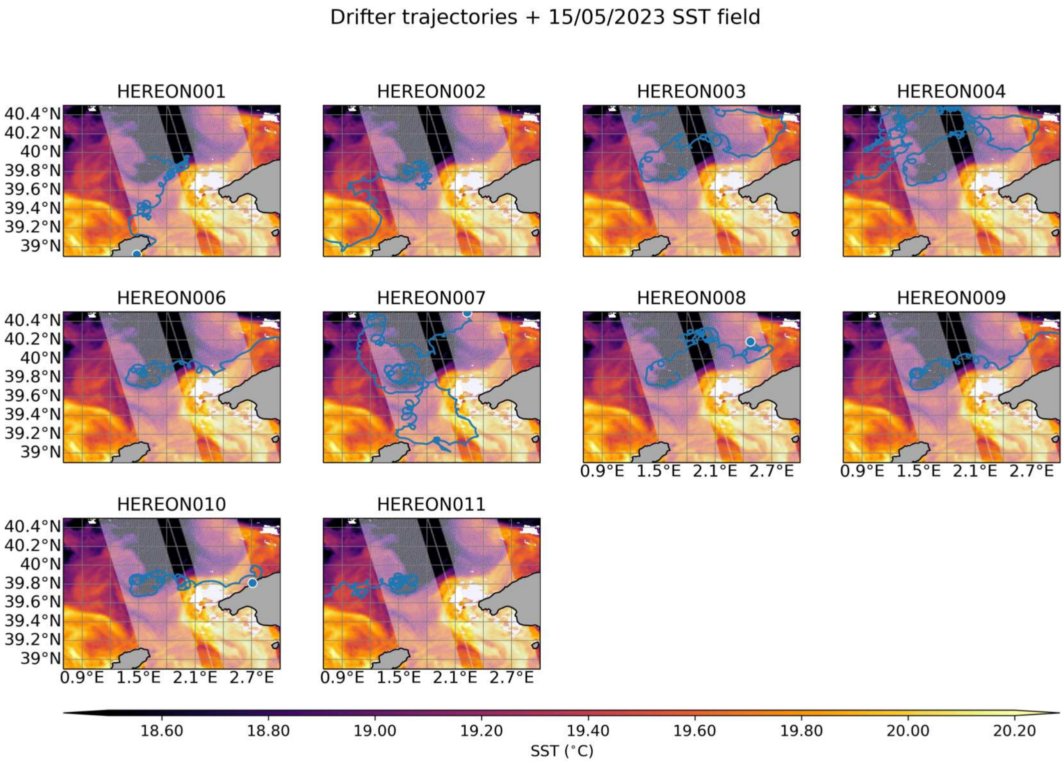


Figure 29: SST map on 15 May 2023 with the trajectories of Hereon drifters deployed during leg 1 until 15 May 2023.

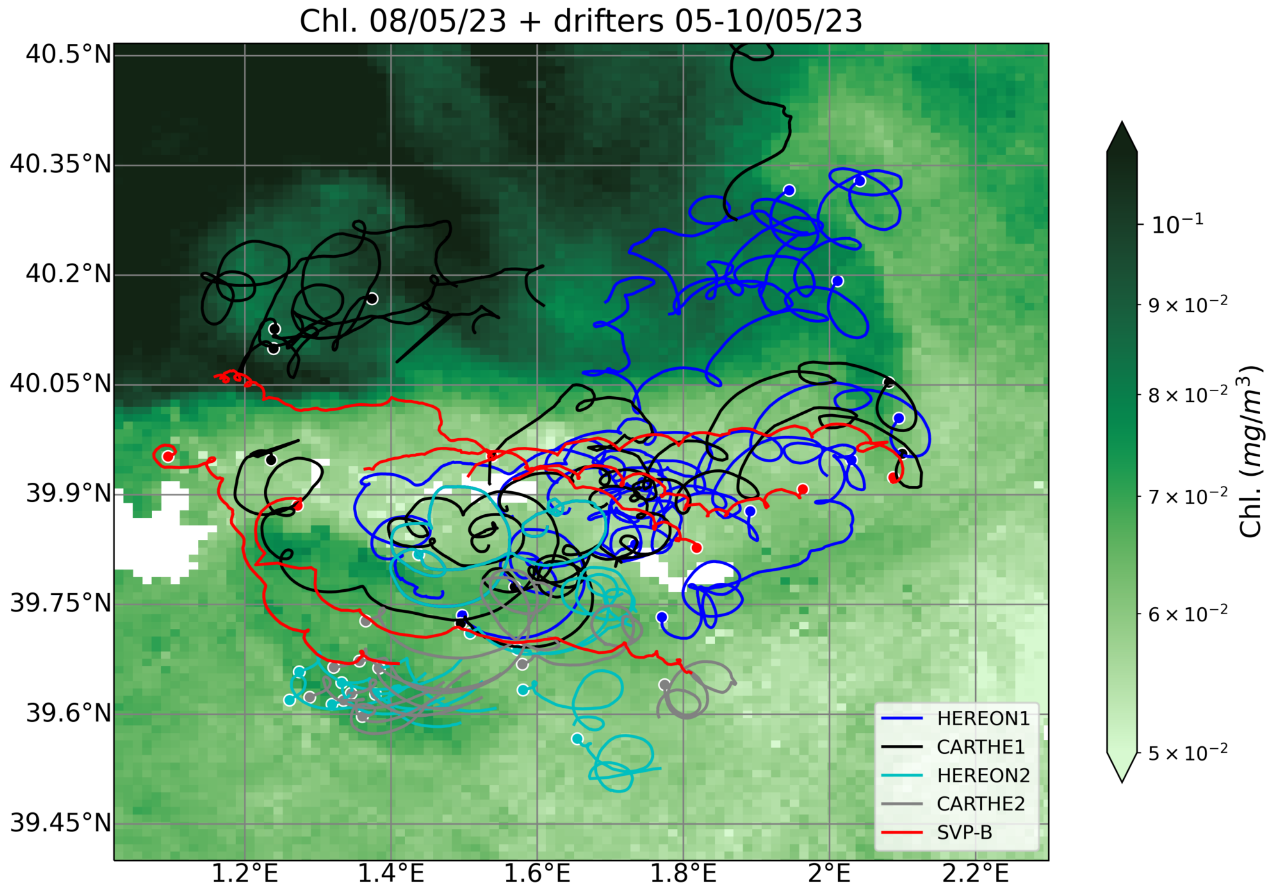


Figure 30: Chlorophyll (Chl.) map on 8 May 2023 with the trajectories of leg 1 and leg 2 drifters, from 5 May to 10 May 2023. The circles indicate the final position of the drifters on 10 May.

6.9 GoPro action cameras

Two GoPro action cameras from The Ocean CleanUp initiative (`https://theoceancleanup.com`) recorded continuously during the daylight hours. They were set-up on the main deck, one portship and one starship on the vessel railing. Fig. 31 shows the GoPro installation on the SOCIB vessel railing. Cables and connections were waterproofed as much as possible using plastic zip-locked bags, parafilm and tape. This installation needed to be done every day (following the GoPro protocol from The Ocean CleanUp). Plastic items will be detected from the time-lapse photos recorded, and drift velocities will be derived for each object if a series is observed. This will provide data on the total surface velocities and give insights into surface accumulation patterns, in combination with other datasets (namely TSG, ADCP and satellite data). At sunrise the time-lapse recording was started and at sunset stopped, so the cameras were recording from approximately 8 a.m. to 8 p.m. (UTC +2). Every day after sunset the external batteries were charged, and the data transferred to two different external disks. During the day (daylight time) it was important to verify that the GoPro lens did not get dirty or splashed, and that it was recording correctly. The GoPro data saved in external disks will be sent back to The Netherlands to be processed by Robin de Vries from The Ocean Cleanup. Support with the instrumentation was also provided by Helen Wolter and Mattia Romero.

Figure 31: GoPro installation on the SOCIB vessel railing. The GoPro in its clamp can be seen at the right, the power-bank can be seen to the left. Cables and connections are waterproofed as much as possible using plastic bags and tape.

Approximately 89 hours of GoPro data were collected during leg 1 and 81 hours during leg 2. During leg 2, on the last day of the campaign (08/05/23), the GoPro data was collected later in the day due to rough sea state conditions that did not allow an earlier installation of the GoPros.

7 Numerical modelling

The predictions of the WMOP high-resolution model were used to support the experiment (Juza et al., 2016; Mourre et al., 2018, Hernández-Lasheras et al., 2021). WMOP is based on a 2 km-resolution regional ocean configuration of the ROMS model implemented over the Western Mediterranean Sea. The model was forced by high-resolution winds (2.5 km, hourly) from the Spanish Meteorological Agency (AEMET) HARMONIE-AROME model. During the experiment WMOP assimilated observations from conventional satellite along-track altimetry, sea surface temperature, Argo temperature and salinity profiles, surface velocities from the Ibiza Channel HF radar, with a daily cycle. The Local Multimodel Ensemble Optimal Interpolation scheme (Hernández-Lasheras and Mourre, 2018) was used for the assimilation. WMOP model outputs and validations were displayed on the WMOP general webpage as well as through the interactive lw4nc2 interface. Moreover, a specific FaSt-SWOT visualization webpage was developed to provide easy access to WMOP predictions of density, temperature, salinity, sea level and velocity fields, as well as derived variables such as divergence, vorticity or Finite-Size Lyapunov Exponents over the sampling area. The webpage also provided satellite images for model validation and a quick view of the latest assimilated altimeter and profile data.

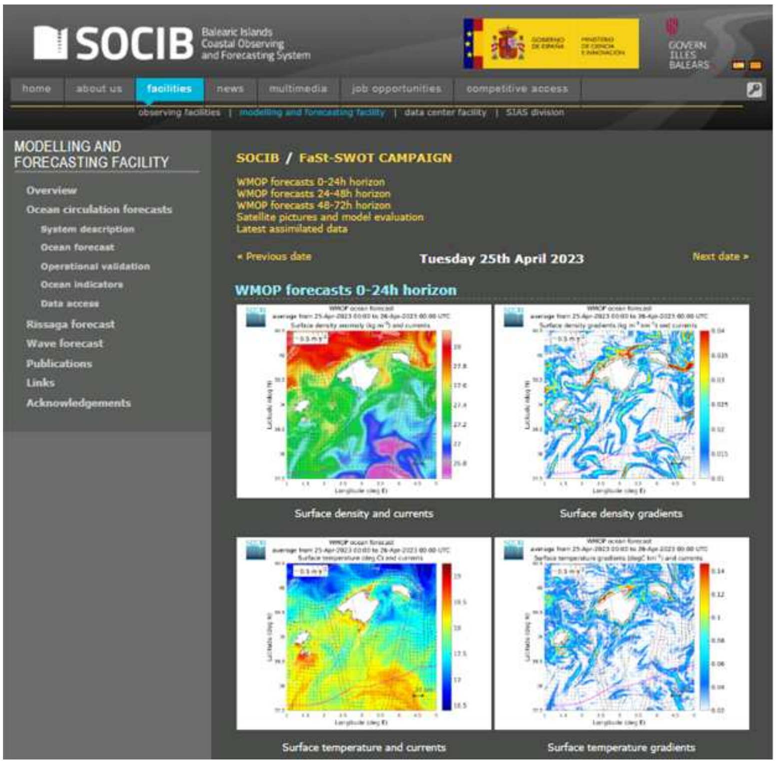


Figure 32: Screenshot of WMOP visualization webpage accessible at `https://www.socib.es/?seccion=modelling&facility=fast-swot`

WMOP model snapshots for 25 April 2023 are displayed in Figure 33. These surface fields represent a small anticyclonic eddy with similar characteristics as the eddy observed by satellite and in-situ measurements. This eddy originated from a meander of the Balearic current at the transition between relatively warm and fresh waters of recent Atlantic origin on the souther side and saltier and colder water coming from the Gulf of Lion on the northern side.
The elevation in sea surface height related to this small mesoscale structure is around 5cm. The cross-section of meridional velocities (Figure 34) provides insights into the vertical extension of the eddy. While the main core is located in the upper 300m, the signature of the eddy is still visible down to 1000m depth in the model. Finally, Figure 35 illustrates the evolution of the eddy during the four days of leg 1.

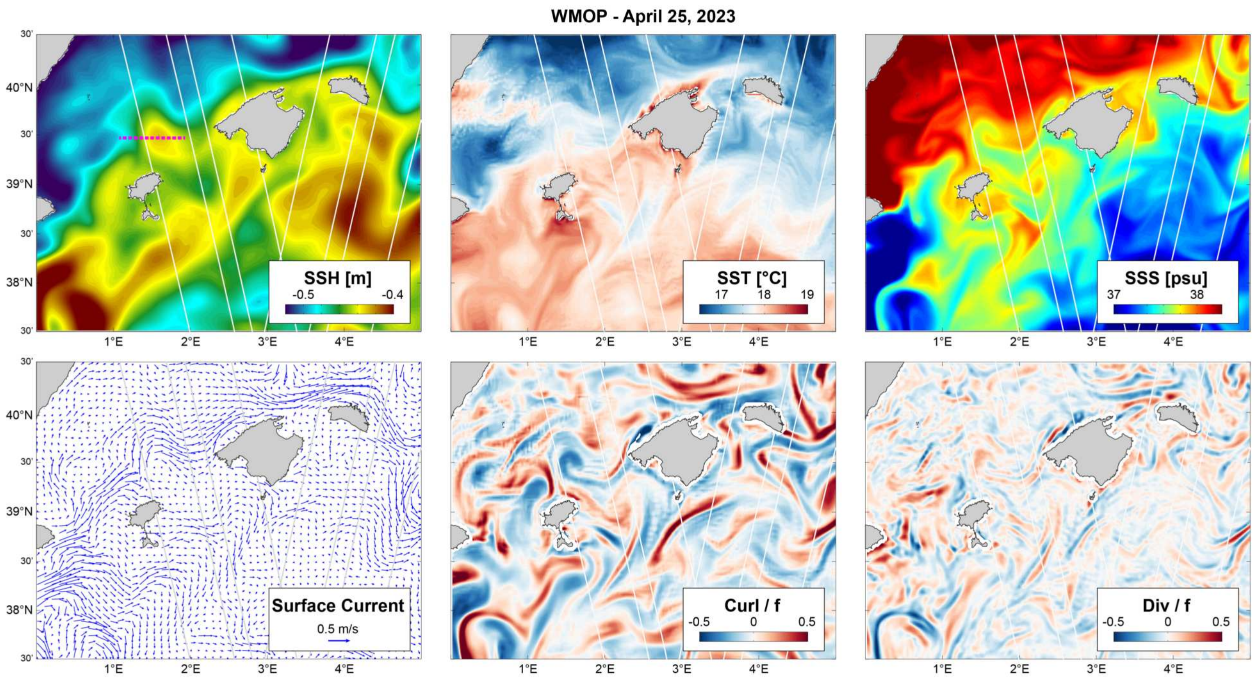


Figure 33: WMOP model output for April 25 (1st day of the leg 1) for SSH, SST, Sea Surface Salinity (SSS), surface currents, vorticity and divergence. SWOT tracks are shown in white.

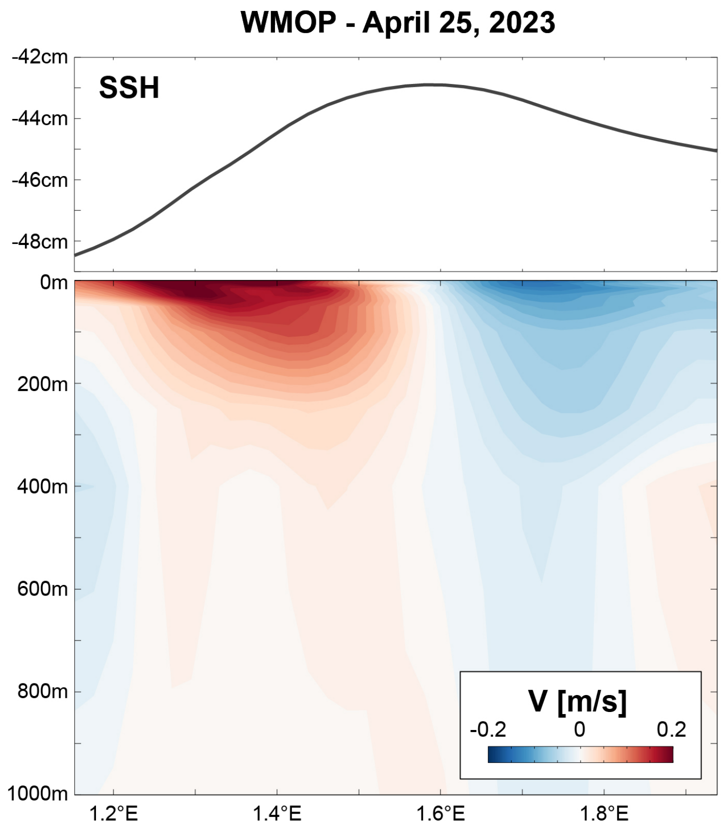


Figure 34: WMOP model section of sea surface height and meridional velocities across the magenta section shown in Figure 33 on 25 April 2023.

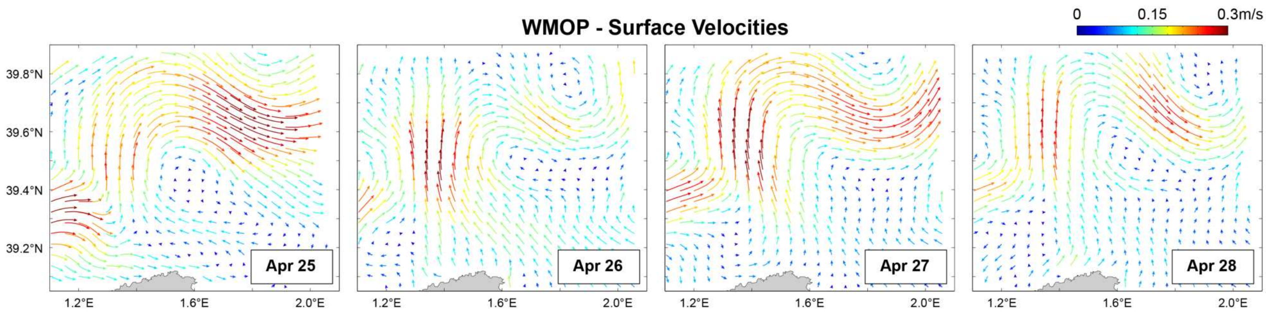


Figure 35: Evolution of WMOP surface velocities in the study area over the 4 days of leg 1.

8 Adaptive sampling experiment

The last day of leg 1 was dedicated to the implementation of an adaptive sampling procedure driven by a deep-learning scheme. The CLuster enhanced Optimal Interpolation Network (CLOINet; Cutolo et al., 2023) algorithm was used to select the most relevant sampling locations from available high-resolution remote-sensing images (SST, OC). The algorithm was developed to achieve an optimal 3D reconstruction of the ocean state by combining in-situ observations with remote-sensing data. As a first step, the network classifies the spatial domain points into fuzzy clusters according to their values and positions in the remote-sensing images. The algorithm then computes how much a specific point belongs to different clusters, and estimates how much the different locations represent larger areas and are thus relevant for the sampling. Finally, given the domain's points relevance, the algorithm solves the traveling salesperson problem to compute the optimal sampling route. The adaptive sampling performed during leg 1 is illustrated in Figure 36.

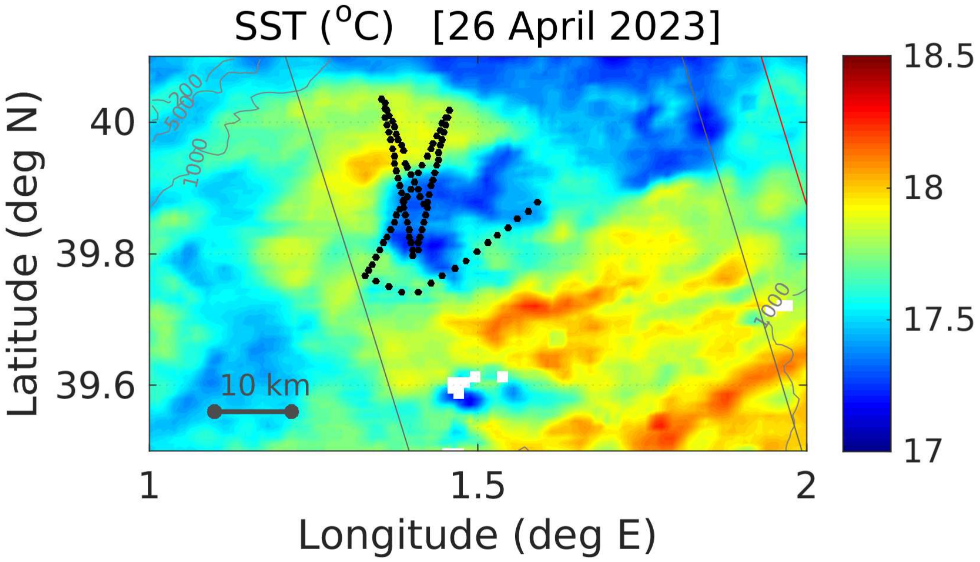


Figure 36: Adaptive sampling pattern performed approximately from 02:00 to 14:00 UTC on 28 April 2023 (black dots), plotted over the SST map for 26 April 2023.

9 Data management

Overall, the data management plan (DMP) of this project relies on the current data management practices in use in the context of the SOCIB Data Repository, which holds the CoreTrustSeal certification. This is a guarantee for long-term preservation to application of data management standard practices and delivery of data services.

More specifically, observational data included in the SOCIB Data Repository is transformed from raw data to processed data as follows: the process of re-formatting (raw to netCDF files) consists in implementing the originally transmitted/stored data (with additional derived and/or quality control variables) or/and reshaping them (trajectory into grids) independently from the data generation mode (RT, DT or DM). Files are stored as netCDF, according to the specifications of the SOCIB In-situ measurements NetCDF Format Manual (work-in-progress document). NetCDF files are implicitly linked through the different processing levels. For instance, a RT netCDF file has L0 and L1 data levels, and in some cases, a L1_corr and a L2. This chain is derived from the file name (see SPEC_DCF_SOCIB-netcdf-file-naming-convention). The SOCIB file processing levels are identified depending on the platform and instrument type (Table 2), and can be classified as follows:

- L0: set of variables included within the raw data (e.g. cnv, ascii, binary).
- L1: set of variables which can include derived, and quality controlled variables. The complete set of quality control tests are described in SOCIB Quality Control flagging convention.
- L1_corr: set of variables which includes L1 and complementary variables whose corrections are performed by dedicated scientific teams. At time of writing, this processing level is tied to the DM data generation mode.
- L2: set of variables containing the processed L1 data in a gridded format (only for the glider data).

The specificities of each type of platform that generates data in the context of this project are listed below:

- Research Vessel data: based on the data management practices in the context of the SOCIB Data Repository. The only exception is the management of data generated by the MVP, which will be limited to the archiving of the raw data. The latter implies that the MVP data will not be publicly available (although specific data requests may be managed on demand).
- Glider data: based on the SOCIB Glider Canales Endurance Line Data Management Plan (Marasco, M. et al., 2021a).
- SVPB drifters data: based on the SOCIB - Global Drifter Program Data Management Plan (Marasco, M. et al., 2022).
- Carthe and Hereon drifters data: based on the data management practices in the context of the SOCIB Data Repository. Specific procedures have been implemented to incorporate the Hereon drifter data within the SOCIB Data Management System. The latter includes the provision of raw data in Real Time through the SOCIB web portal during the duration of the 2 campaigns and will be operational while the drifters are deployed. In addition, the processed data in RT will be improved through a delayed mode processing and will be included in the first version of the data product if possible.
- HF radar data: based on the SOCIB - Coastal High Frequency Radar Data Management Plan (Marasco, M. et al., 2021b). The related data product can be accessed in *Tintoré, J., Lana, A., Marmain, J., Fernández, V., Casas, B., & Reyes, E. (2020). HF Radar Ibiza data from date 2012-06-01 (Version 1.0.2) [Data set]. Balearic Islands Coastal Observing and Forecasting System, SOCIB. https://doi.org/10.25704/17GS-2B59*
- WMOP forecast model data: 3-hourly surface and daily-average 3-dimensional fields are available through SOCIB thredds server `http://thredds.socib.es/thredds/catalog/operational_models/oceanographical/hydrodynamics/wmop_surface/catalog.html` and `https://thredds.socib.es/thredds/catalog/operational_models/oceanographical/hydrodynamics/wmop_3d/catalog.html`.

A data assessment and curation process will be carried out by the PIs and the SOCIB Data Center data officials in order to generate the final data product. The data product will include the specific data produced during the 2 campaigns and will be published through the SOCIB Data Catalog (including the minting of a DOI by SOCIB).

Finally, it is worth noting that the data will be distributed to the main European data systems (e.g. Coriolis, Copernicus In Situ, EMODnet, Argo Reference DB), as part of the procedures in place in the SOCIB Data Management System.

10 Outreach activities

Nathan Siegel (Ona agency) was embarked on R/V SOCIB during both legs of FaSt-SWOT campaigns with the aim to produce a short movie documenting the experiment from an inside perspective. This movie was made publicly available on 8 November 2023. It is accessible on the following Youtube links `https://www.youtube.com/watch?v=WQd9LeIdLSk&t=56s` and `https://www.youtube.com/watch?v=odBLN1Rx7MO&t=210s`.

Moreover, several outreach activities were performed to communicate about the importance of FaSt-SWOT experiments to support SWOT satellite measurements and improve our understanding of ocean dynamics and its role on climate and marine ecosystems. These activities are listed below:

1. Press release 15/12/2022
   (a) *Actualidad CSIC*
   (b) IMEDEA news
   (c) SOCIB news
   (d) Europa press
   (e) *La Vanguardia*
   (f) *Diario de Mallorca*
   (g) *El Diario*
   (h) *Diario de Ibiza*
2. IB3 TV news and Meteo Program 15/12/2022
   `https://ib3.org/meteo-2?pl=1&cont=91bdf2ae-812d-11ed-9117-c437725f29d4` (from min 3'50")
   `https://ib3.org/noticiesmigdia?pl=1&cont=8d04153d-8113-11ed-9117-c437725f29d4` (from min 29'15")
3. IB3 radio interview, Entre aviu i dema, 16/12/2022 (from min 15'30")
   `https://ib3.org/entre-avui-i-dema?pl=1&cont=0de6d3e6-7d87-11ed-9117-c437725f29d4`
4. RTVE radio interview, Españoles en la mar, Radio 5, 26/1/2023 (from min 14'00")
5. *¡Boya al agua!* educational program
   (a) *El Español*
   (b) IMEDEA news
   (c) SOCIB news
   (d) *Ultima Hora*

6. IB3 radio interview, Nautilus, 13/5/2023 (from min 19'30")
   https://ib3.org/nautilus?pl=1&cont=de921ad8-f17f-11ed-9e42-c437725f29d4
7. IB3 TV news and meteo program 16/5/2023
   https://ib3.org/coneixem-el-projecte-fast-swot
   https://ib3.org/noticiesmigdia?pl=1&cont=4b1cde33-f3f6-11ed-9e42-c437725f29d4 (from min 35'35")
8. Facebook video for World ocean day 8/6/2023
   https://www.facebook.com/CreateandCraft/videos/279842047739818/
9. Youtube direct Q&A with FaSt-SWOT participants on World Ocean Day 8/6/2023
   https://imedea.uib-csic.es/divulgacion-y-comunicacion/noticias/?new_id=2007
   https://www.youtube.com/watch?v=__mim-lSua4
10. Tweets through both institutional and individual channels
11. Public event at IMEDEA for the publication of the short documentary: "FaSt-SWOT - From space to the ocean: chasing marine currents" organized in the framework of the science Week on 8 November 2023
    https://www.socib.es/index.php?seccion=detalle_noticia&id_noticia=568
12. IB3 TV news and meteo program 9/11/2023
    https://ib3alacarta.com/tv/meteo/e525 (from min 3'30")
13. Communication event in Soller train on 11 November 2023 - Ciència a tot tren https://www.csic.es/es/agenda-del-csic/ciencia-tot-tren-te-subes-un-viaje-cientifico-en-el

11 Participants

The participants onboard R/V SOCIB during legs 1 and 2, and those providing support from land, are listed in the tables below.

NAME	INSTITUTION	ROLE/TASK
Benjamín Casas	SOCIB	Head of campaign, technical coordination
Daniel Rodríguez-Tarry	IMEDEA	Drifter deployment strategy, MVP, GoPros, data processing
Eugenio Cutolo	Atalaia	ADCP, CTD, optimal sampling, data processing and analysis
Irene Lizarán	SOCIB	Drifters, CTD, MVP, salinity samples and analysis
Laura Gómez-Navarro	IMEDEA	GoPros, drifters
Elisabet Verger-Miralles	IMEDEA	MVP, CTD, satellite data, salinity samples, sampling strategy
Nathan Siegel	Ona Agency	Camera/interviews

Figure 37: FaSt-SWOT leg 1 cruise participants.

NAME	INSTITUTION	ROLE/TASK
Baptiste Mourre	SOCIB	Co-principal investigator, Chief Scientist
Niko Wirth	SOCIB	Technical coordination
Emma Reyes	SOCIB	Drifters
Daniel Rodríguez-Tarry	IMEDEA	Drifter deployment strategy, satellite data, CTD, MVP, ADCP, GoPros, salinity samples, data processing and analysis
Noemí Calafat	SOCIB	Drifters, salinity samples, CTD, MVP
Laura Gómez-Navarro	IMEDEA	GoPros, drifter deployment strategy, satellite data, CTD, MVP, ADCP, salinity samples, data processing and analysis
Nathan Siegel	Ona Agency	Camera/interviews

Figure 38: FaSt-SWOT leg 2 cruise participants.

NAME	INSTITUTION	ROLE/TASK
Ananda Pascual	IMEDEA	Principal investigator, science lead FaSt-SWOT1
Bàrbara Barceló-Llull	IMEDEA	Sampling strategy, data analysis
Albert Miralles	SOCIB	Glider preparation and piloting
Nikolao Zarokanellos	SOCIB	Scientific glider support
Manuel Rubio	SOCIB	Glider preparation and piloting
Patricia Rivera	SOCIB	Glider preparation and piloting
Juan Gabriel Fernández	SOCIB	Data management
Lara Díaz Barroso	SOCIB	Drifter data manager
Juan Miguel Villoria	SOCIB	Data processing
Melanie Juza	SOCIB	Satellite imagery
Pablo Balaguer	SOCIB	Ship logistics
Pere Rosselló	IMEDEA	Satellite imagery/Biogeochemistry
Antonio Sánchez-Román	IMEDEA	Sampling strategy, data analysis
Joaquín Tintoré	IMEDEA & SOCIB	Scientific & Operational support
Vincent Combes	IMEDEA	Data processing

Figure 39: FaSt-SWOT participants providing support from land during the experiments.

Figure 40: Pictures of the participants and crew members of legs 1 (left) and 2 (right).

12 Acknowledgements

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13 Annex: Sampling onboard R/V Sarmiento de Gamboa in collaboration with MARBEFES project

During the campaign onboard the R/V Sarmiento de Gamboa funded by the MARBEFES European project, we took the opportunity to conduct opportunistic sampling in conjunction with the goals of the FaSt-SWOT experiment. Positioned between Mallorca and Menorca, near one of the SWOT satellite's calibration/validation (cal/val) areas, we performed several CTD transects within this biologically important area.

This additional sampling had two primary objectives. Firstly, we actively participated in the satellite's cal/val activities, gathering first-hand observations of the fine-scale structures in the region observed by the SWOT satellite. Secondly, we sought to deepen our understanding of these structures, merging data from various platforms, including satellite imagery and deep-learning techniques. Most of this work happened during the nighttime hours of the MARBEFES campaign, where we pursued targeted transects in the SWOT region. These expeditions involved repeated CTD transects in order to resolve as much as possible the spatio-temporal variability of the region under study by the SWOT satellite. On the final day, we dedicated a full 24 hours to CTD sampling, implementing an adaptive strategy guided by the deep-learning CLOINet algorithm (Cutolo et al., 2023). Utilizing high-resolution satellite imagery of sea surface temperature, the algorithm was used to determine the optimal sampling locations for a detailed 3D representation of ocean conditions. This pioneering approach involved identifying and grouping spatial points from the satellite images into clusters based on their characteristics and geographical position. After evaluating each point's importance and how well it represented larger areas, we used the data to identify the best sampling locations. We applied the CLOINet system to determine the most efficient path for sampling, solving the problem of the traveling salesperson. Furthermore, during this 24-hour sampling one of the experimental drifters made with biodegradable components was deployed in order to understand the currents around the sampled structures.

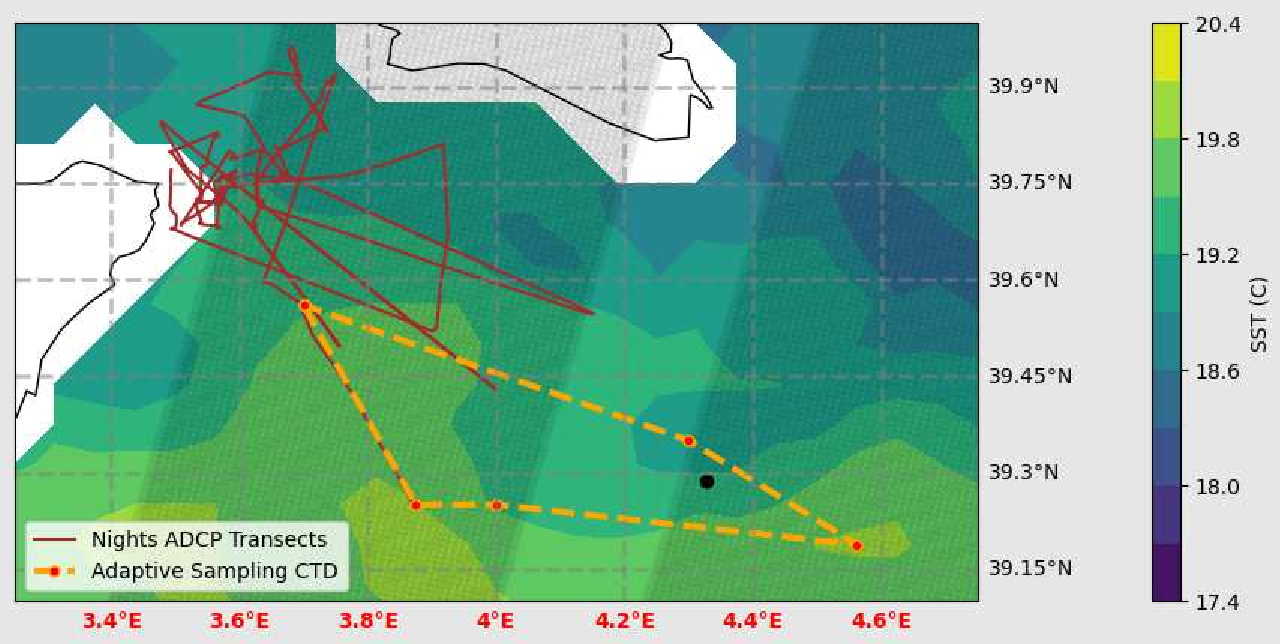

Figure 41: Opportunistic sampling performed during the MARBEFES campaign. The initial ADCP sampling is represented by the solid brown line, with repeated transects in the SWOT passing area (shaded region). The 24-hour CTD sampling based on CLOINet optimization from the 9th of May is indicated by the red dots and orange dashed line. The algorithm utilized the SST image from the 8th of May as input, which is displayed in the background.

14 References

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