# CURRENTS AND THERMOHALINE PROPERTIES IN THE TUSCAN ARCHIPELAGO WATERS (NORTHERN TYRRHENIAN SEA) IN OCTOBER 2011

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## 1. Introduction

An oceanographic experiment called MILONGA (MIsure Lagrangiane OceaNoGrafiche nell’Arcipelago sud toscano) was carried out in the waters of the Tuscan Archipelago (northern Tyrhennian Sea) in October 2011 as part the MOMAR (sistema integrato per il MOnitoraggio e il controllo dell'ambiente MARino; www.lamma.rete.toscana.it/progetti/momar) project. The goal was to monitor with state-of-the-art Lagrangian instrumentation the thermohaline structure and the circulation in this coastal area during a period of about 2 weeks. The experiment was planned and conducted by the LAMMA consortium (www.lamma.rete.toscana.it) with OGS as sub-contractor. In addition, measurements of vertical profiles of currents close to the surface and on sea state (surface waves) were made by OGS and SIO. Ifremer (international partner within MOMAR) was also involved during the same period to collect other physical and biogeochemical data. These are not described in this report.

This report contains information about the oceanographic instruments used during MILONGA (Section 2) and about the measurements obtained during the experiment in October 2011 (Section 3). A brief discussion of the results in provided in Section 4.

## 2. Oceanographic instrumentation

### 2.1 CODE and SVP drifters

Two kinds of satellite-tracked surface drifters were operated during MILONGA. The first design is the so-called Coastal Ocean Dynamics Experiment (CODE) drifter developed by Davis (1985) in the early 1980’s to measure coastal surface currents in the northeastern Pacific. The second is the standard Surface Velocity Program (SVP) drifter with mini-drogue used worldwide as part of the Global Drifter Programme (GDP, Lumpkin and Pazos, 2007).

CODE drifters consist of a slender, vertical, 1-m-long negatively buoyant tube with four drag-producing vanes extending radially from the tube over its entire length and four small spherical surface floats attached to the upper extremities of the vanes to provide buoyancy (Poulain, 1999). Comparisons with current meter measurements (Davis, 1985) and studies using dye to measure relative water movements (D. Olson 1991, personal communication) showed that the CODE drifters follow the surface currents to within 3 cm $s^{-1}$, even during strong wind conditions. More recent slippage measurements (Poulain et al., 2002) with acoustic current meters positioned at the top and at the bottom of the drifter showed that the CODE drifters follow the surface currents within 2 cm $s^{-1}$ and that they move in a manner consistent with the near-surface Ekman dynamics with a velocity component to the right of the prevailing wind. The CODE drifters used during MILONGA were produced by DBI (Florida). A schematic diagram and pictures of CODE drifters are shown in Fig. 1.

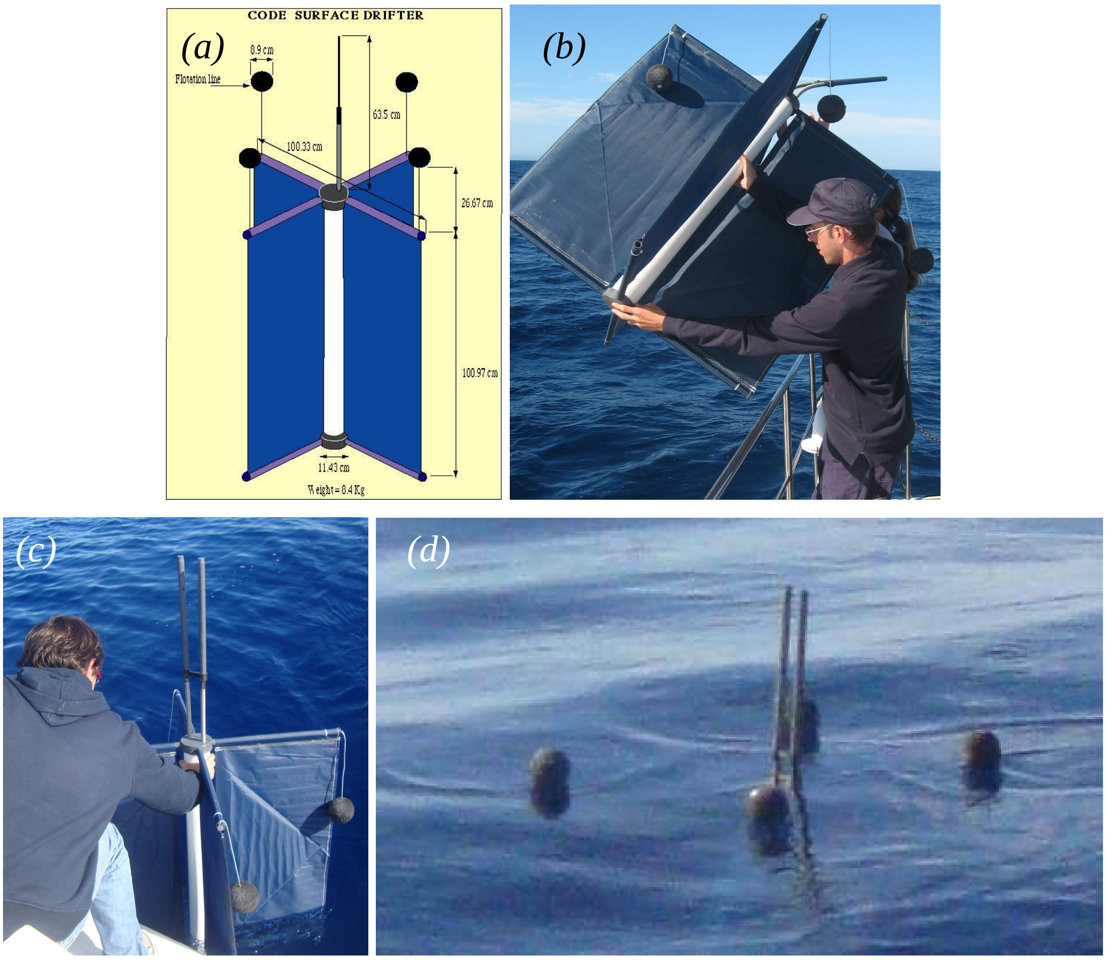


*Figure 1. (a) Schematic diagram of a CODE drifter. (b) and (c) Pictures of the deployments of CODE drifters during MILONGA. (d) CODE drifter deployed at sea.*

The SVP drifters consist of a surface buoy that is tethered to a holey-sock drogue, centered at a nominal depth of 15 m. Details on the original SVP design can be found in Sybrandy and Niiler (1991). The SVP drifters used during MILONGA were manufactured by SIO. They were of the SVP “mini” drifter design. They have a drag area ratio of the drogue to the tether and surface buoy in excess of 40. A tension sensor, located below the surface buoy where the drogue tether is attached, indicates the presence or absence of the drogue. Measurements of the water-following capabilities of the SVP have shown that when the drogue is attached, they follow the water to within 1 cm $s^{-1}$ in 10 m/s winds (Niiler et al., 1995). A schematic diagram and pictures of the SVP “mini” drifter are depicted as Figure 2.

*Figure 2. (a) Schematic diagram of the SVP “mini” drifter. (b) Two SVP drifters ready to be deployed on the ship’s deck. (c) Deployments of a SVP drifter during MILONGA. (d) SVP drifter just deployed at sea.*

All drifters were localized by the Global Positioning System (GPS) and transmitted data (GPS position, sea surface temperature, voltage, drogue presence indicator, etc.) to the Iridium satellite telephone system. The CODE drifters were programmed to get GPS positions and transmit to Iridium every 15 min. The SVP units transmitted every 2 hours.

The drifter positions were edited for outliers and spikes using statistical and manual techniques with criteria mainly based on maximum speed and zonal and meridional displacements, as described in Gerin and Bussani (2011) and Gerin et al. (2011). Velocities were estimated by central finite differencing the positions.

### 2.2 Arvor-C float

One coastal autonomous profiler, called Arvor-C, was operated during MILONGA to collect data of temperature and salinity profiles. The Arvor-C (André et al., 2010) is manufactured by NKE (France). It is the coastal version of the Arvor float used for open sea monitoring as part of the global Argo programme (www.argo.ucsd.edu). The main difference is that the Arvor-C can execute short cycles (chosen here as 3 hours) in shallow water (down to about 400 m) and has claws to prevent drifting when it sits on the seafloor. The Arvor-C weighs less than 20 kg, is 2.1 m high and has a diameter of 11 cm. The scientific payload (Seabird pumped CTD) is located on the upper end cap, as well as a bi-band Iridium-GPS antenna (for data transmission, remote control and positioning), and a Bluetooth antenna (for configuration and testing). An external bladder is fitted on the bottom end cap, to adjust the buoyancy when descending and ascending along the water column, as well as anti-drift claws. Its ascending speed reaches 15 to 20 cm/s. For instance, a 2-s sampling period provides one single measurement every ~35 cm. Data are then averaged into 1-m high slices to reduce transmission duration. A schematic diagram and pictures of the Arvor-C are shown in Figure 3.

The float data were received via Iridium and decoded at OGS. Several spikes and outliers in the temperature and salinity profiles were discarded using a manual editing procedure and the first meter of data was discarded. Density was calculated using standard formulas (UNESCO, 1983).

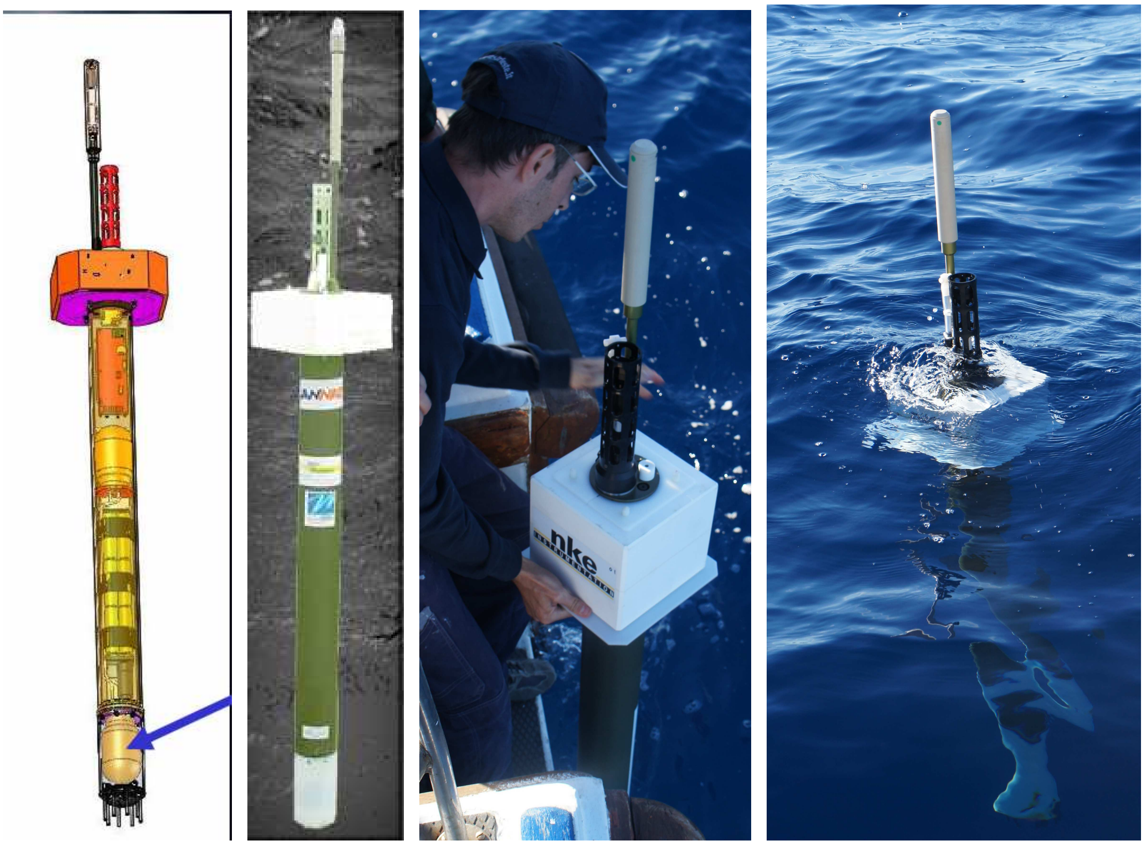


*Figure 3. Schematic diagram of the Arvor-C profiling float (left). Pictures of the Arvor-C and its deployment during MILONGA (right).*

## 2.3 SIO river and OGS prototype drifters

The SIO river drifter is a surface drifter with compact CODE type design, 67-cm-long negatively buoyant tubular hull with four sails extending radially from the tube. The upper extremities of the sails are spars fitted with floating material to provide positive buoyancy. Spring-loaded spars allow quick deployment and easy stowage. The following components are integrated into the drifter hull; Nortek Aquadopp vertical profiling Acoustic Doppler Current Profiler (ADCP), LDG-SIO Barramundi controller, u-blox NEO-6 GPS and Iridium 9602 SBD modem. The GPS receiver sampled positions at 1 Hz.

Two river drifters were operated during MILONGA. One was fitted with a downward-looking 1 MHz ADCP to measure the relative currents below the drifters. The drifter was set to measure every 15 min and take 90 s averages. The number of cells was set to 20 and the thickness of each cell was set to 1 m. The other river drifter was equipped with a upward-looking 2 MHz ADCP to measure the relative currents near the surface and assess the slip of the instrument due to the combined effect of wind and waves. The drifter was programmed to measure every 15 min and take 90 s averages. The number of cells was set to 28 of thickness 11 cm. Both units were also fit with additional spare GPS and Iridium modems. Photographs of the SIO river drifter are shown in Figure 4.

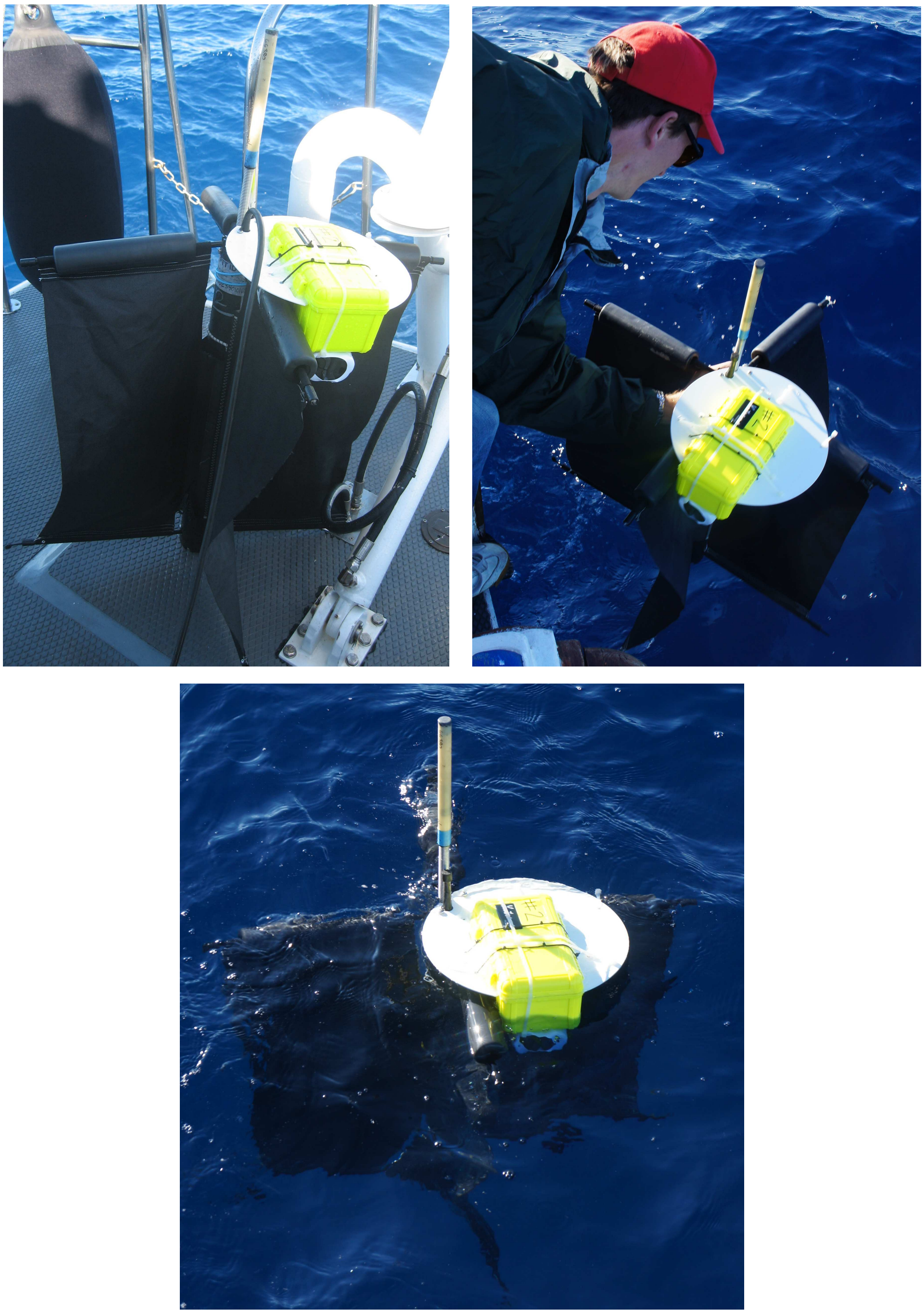


*Figure 4. Pictures of one the SIO river drifter deployed during MILONGA. The yellow case is the additional spare GPS and Iridium modem.*

The OGS prototype drifter (Gerin and Poulain, 2011) has the mechanical structure of the CODE design but includes in the hull one downward-looking Nortek Aquadopp ADCP near the bottom with acoustic frequency of 1 MHz, and one Nortek velocimeter near the top (frequency of 2 MHz). An small independent module is mounted near the top, above the velocimeter, including a GPS receiver, a GSM/GPRS modem, battery pack and an antenna (Brunetti and Zuppelli, 2011). For MILONGA the drifter ADCP was programmed so as to collect the average of 3-minute measurements every 15 minutes in 30 cells of 50 cm size. GPS position data were stored in a flash memory inside the module every 5 minutes and transmitted through SMS messages every 15 min. A schematic diagram of the OGS drifter is shown in Figure 5, as well as several pictures of the drifter before, during and after deployment.

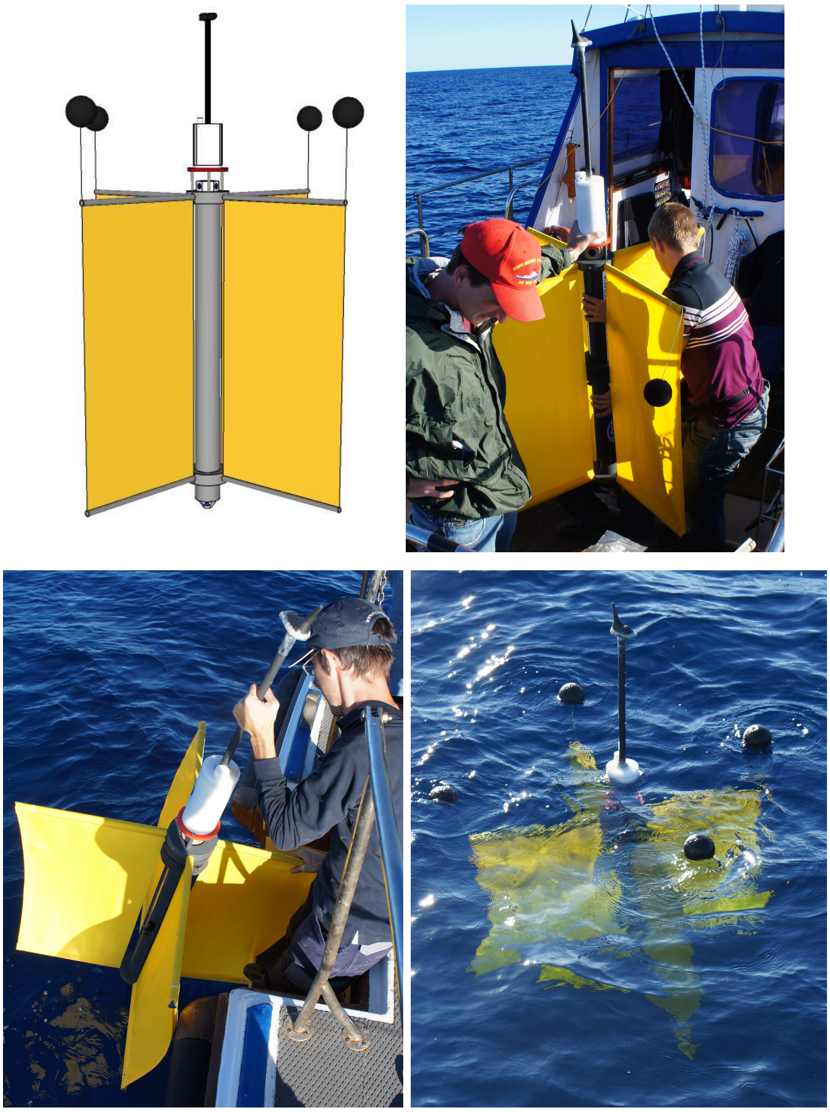


*Figure 5. Schematic diagram and pictures of the OGS prototype drifter deployed during MILONGA. The white case on top of the drifter contains the GPS and GSM/GPRS modem.*

## 2.4 Waverider buoy

A datawell (model DWR-G4) mini directional waverider GPS buoy was operated to measure the characteristics of the surface gravity waves during the MILONGA experiment. The waverider was loosely anchored and moved freely with the waves. It measured relative displacements in the three directions (north, west, vertical) by using a single GPS (precision of about 1 cm and sampling frequency 1 Hz). The following wave parameters were obtained every 30 min: significant wave height, peak period, direction of the peak wave, and wave spectra. Directional and spectral data were stored in a flash memory inside the buoy, and were not transmitted on land via HF link. The waverider used during MILONGA is depicted in Figure 6.

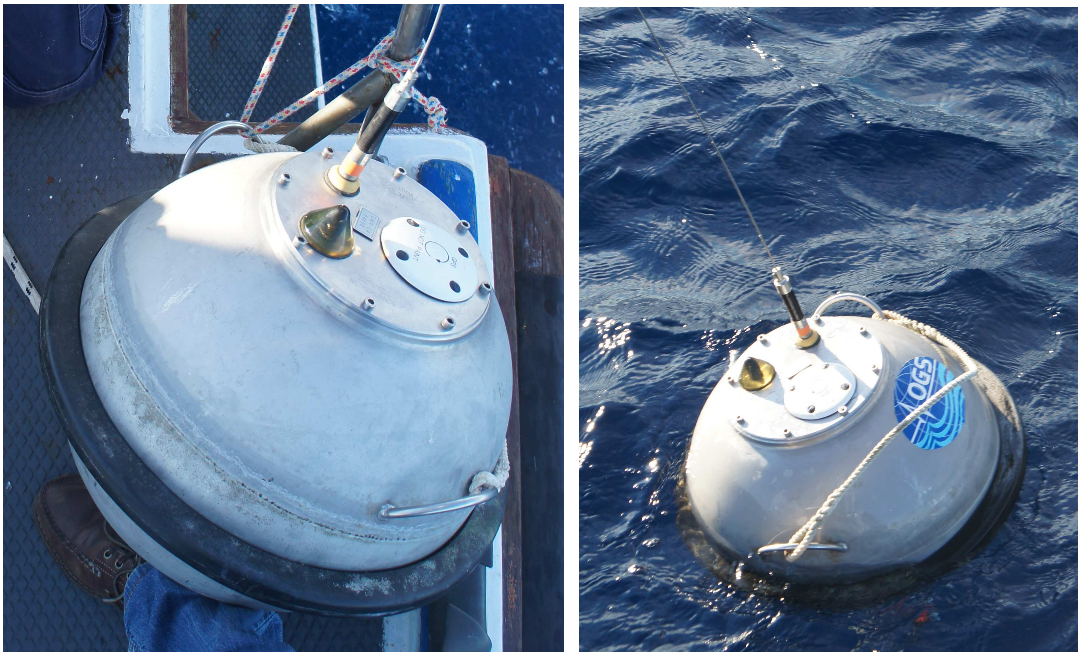


*Figure 6. Pictures of the waverider buoy deployed during MILONGA.*

## 3. Experiment in the northern Tyrrhenian Sea (Tuscan Archipelago area)

### 3.1 Trajectories, currents and sea surface temperature from the CODE/SVP drifters

The 15 CODE and 2 SVP drifters were deployed on 11 October 2011 more or less uniformly throughout the study area (uniform grid with typical distance between drifters of 10 km) using two boats, the Poseidon of ARPAT and a rented motor boat. The array of deployment locations is shown in Figure 7, along with the initial trajectories of the drifters in the Tuscan Archipelago area. The 15 CODE drifters were deployed north of the Montecristo-Giglio-Argentario latitude (~42.3°N) whereas the two SVP units were released in deeper waters south of this latitude.

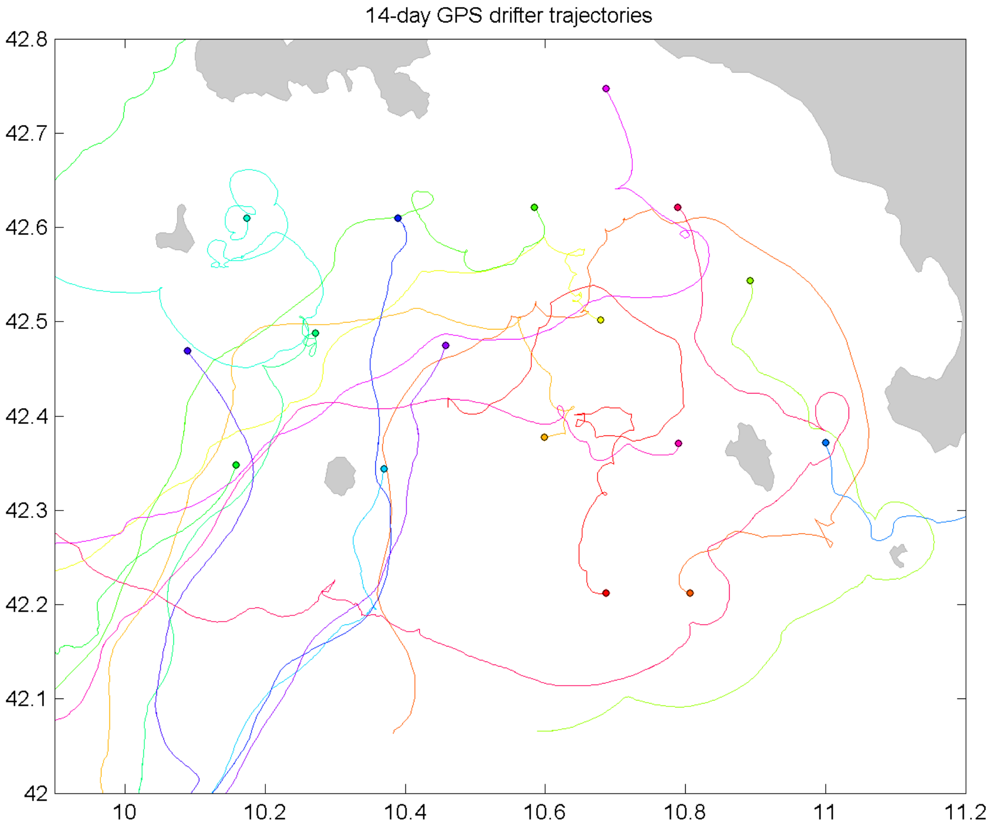


*Figure 7. Deployment locations (dots) and initial trajectories (colored curves) of the drifters deployed on 11 October 2011 in the Tuscan Archipelago waters. The 15 CODE drifters were deployed north of the Montecristo-Giglio-Argentario latitude (~42.3°N) whereas the two SVP units were released in deeper waters south of this latitude.*

The deployment and last fix (as of 3 January 2012) coordinates of the MILONGA drifters are listed in Table 1. Five units had GPS failures before 25 October 2012, that is less than 14 days after deployment. Note that Iridium transmissions continued beyond the GPS failure dates and tracks can possibly be reconstructed from the Iridium data (see Appendix 5.1).

| IMEI Number | Deploy Date GMT | Lat N | Lon E | Last Date GMT | Lat N | Lon E | Type |
|---|---|---|---|---|---|---|---|
| 300234010751060 | 11-Oct-2011 08:16 | 42.75 | 10.68 | 21-Dec-2011 02:47 | 42.08 | 3.97 | CODE |
| **300234010652970** | **11-Oct-2011 16:46** | **42.5** | **10.48** | **17-Oct-2011 15:04** | **41.21** | **9.41** | **CODE** |
| **300234010479080** | **11-Oct-2011 14:24** | **42.5** | **10.06** | **24-Oct-2011 09:45** | **40.99** | **10.52** | **CODE** |
| 300234010479070 | 11-Oct-2011 15:35 | 42.63 | 10.38 | 03-Nov-2011 00:45 | 41.97 | 9.9 | CODE |
| **300234010478080** | **11-Oct-2011 15:30** | **42.37** | **11.00** | **14-Oct-2011 01:30** | **42.36** | **11.21** | **CODE** |
| **300234010477080** | **11-Oct-2011 13:12** | **42.38** | **10.38** | **23-Oct-2011 10:01** | **40.92** | **10.09** | **CODE** |
| 300234010476080 | 11-Oct-2011 14:59 | 42.63 | 10.17 | 03-Jan-2012 01:49 | 40.74 | 6.11 | CODE |
| 300234010475080 | 11-Oct-2011 16:10 | 42.5 | 10.27 | 26-Oct-2011 23:00 | 41.4 | 9.09 | CODE |
| 300234010474090 | 11-Oct-2011 13:49 | 42.38 | 10.17 | 05-Nov-2011 08:00 | 44.39 | 8.84 | CODE |
| 300234010473090 | 11-Oct-2011 09:46 | 42.62 | 10.58 | 27-Oct-2011 18:15 | 41.09 | 8.51 | CODE |
| **300234010472090** | **10-Oct-2011 16:45** | **42.54** | **10.89** | **16-Oct-2011 12:45** | **42.07** | **10.59** | **CODE** |
| 300234010471090 | 11-Oct-2011 17:23 | 42.5 | 10.69 | 05-Dec-2011 18:30 | 42.27 | 7.44 | CODE |
| 300234010873500 | 11-Oct-2011 13:00 | 42.37 | 10.79 | 29-Oct-2011 00:15 | 41.03 | 9.55 | CODE |
| 300234010879490 | 11-Oct-2011 10:44 | 42.62 | 10.79 | 12-Nov-2011 23:30 | 43.03 | 5.94 | CODE |
| 300234010274890 | 11-Oct-2011 12:35 | 42.38 | 10.58 | 03-Nov-2011 09:00 | 41.34 | 10.52 | CODE |
| 300234010168380 | 11-Oct-2011 14:22 | 42.21 | 10.81 | 03-Jan-2012 02:38 | 41.06 | 10.29 | SVP |
| 300234010169380 | 11-Oct-2011 13:53 | 42.21 | 10.69 | 03-Jan-2012 05:51 | 40.94 | 1.03 | SVP |

*Table 1. Iridium IMEI numbers, dates/times and positions of deployments and last fixes (as of 3 January 2012) for the drifters operated during MILONGA. In total, 5 drifters (in bold) had GPS failure before 25 October 2012 (less than 14 days after deployment).*

The entire tracks for the first 14 days after deployment, that is until 25 October 2011 at 00 GMT, are depicted in Figure 8. Most drifters moved to the southwest and explored the waters east of Corsica, in the vicinity of the Strait of Bonifacio and northeast of Sardinia. Three drifters entered the Strait of Bonifacio, 4 units veered to the southeast and were trapped by a cyclonic gyre in the northern Tyrrhenian. Two drifters eventually moved northward into the Corsica

Channel (between Corsica and Elba) and reached the southeastern Ligurian Sea. In addition to basin-scale and mesoscale motions, many drifters show ubiquitous meandering and looping movements corresponding to sub-mesocale, inertial or tidal currents.

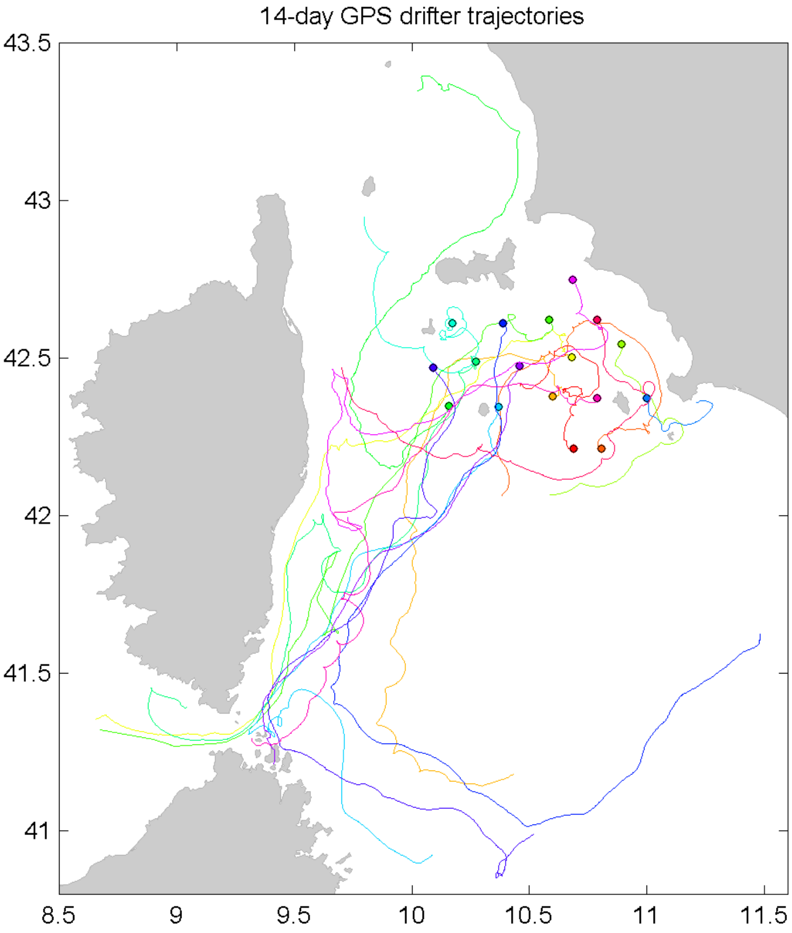
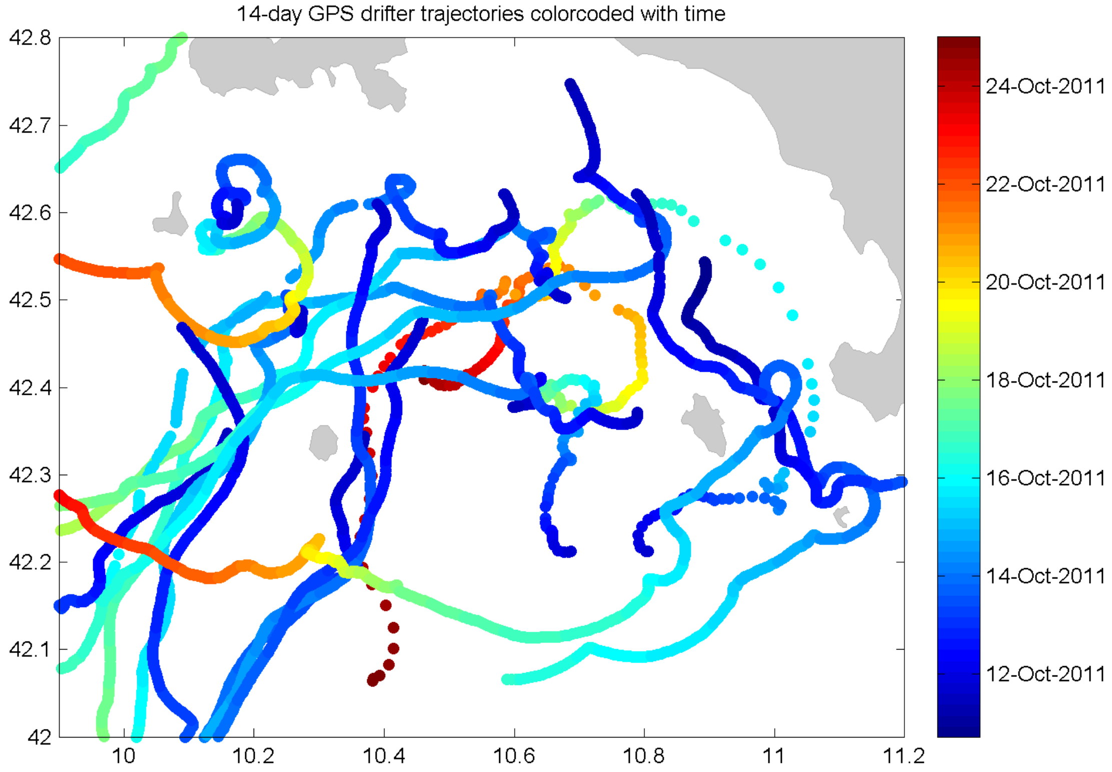


*Figure 8. Same as Figure 7 but for the extended area in the northern Tyrrhenian Sea and southeastern Ligurian Sea showing the entire drifter tracks for the first 14 days.*

The drifter positions sampled every 15 minutes are depicted with dots in Figure 9. The dots are color-coded as a function of time. The drifter position dots can also be color-coded with the measured sea surface temperature (SST) (Figure 10). SST values range between 23.5°C (first few days after deployment) and about 19°C (2 weeks after deployment).



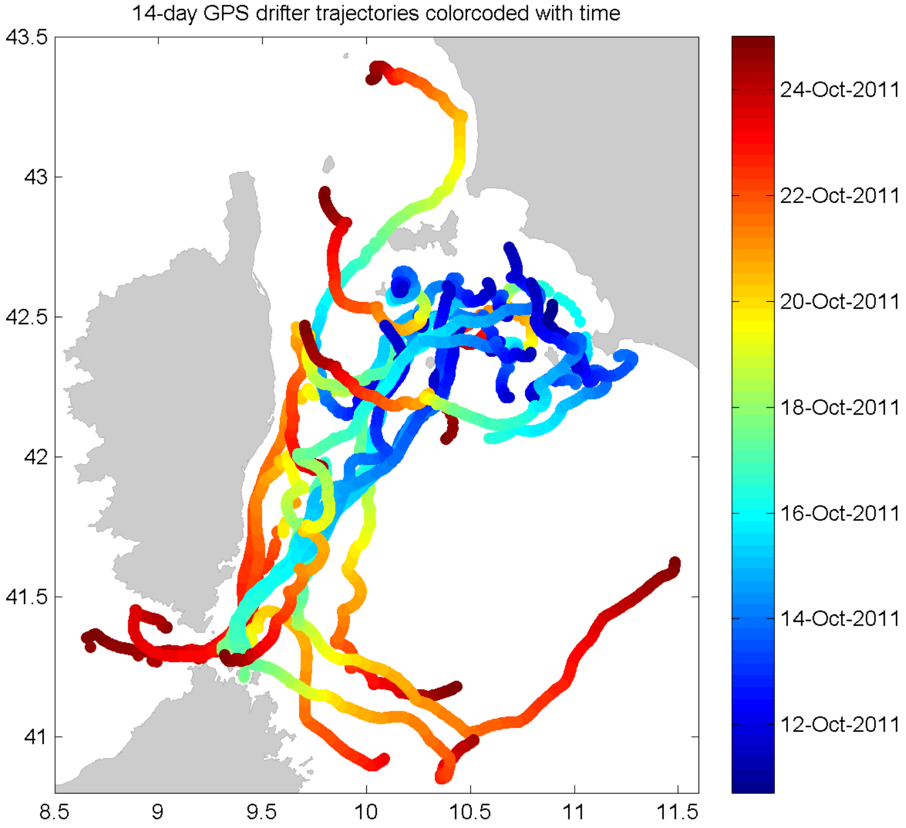


*Figure 9. Positions of the MILONGA drifters color-coded with time.*

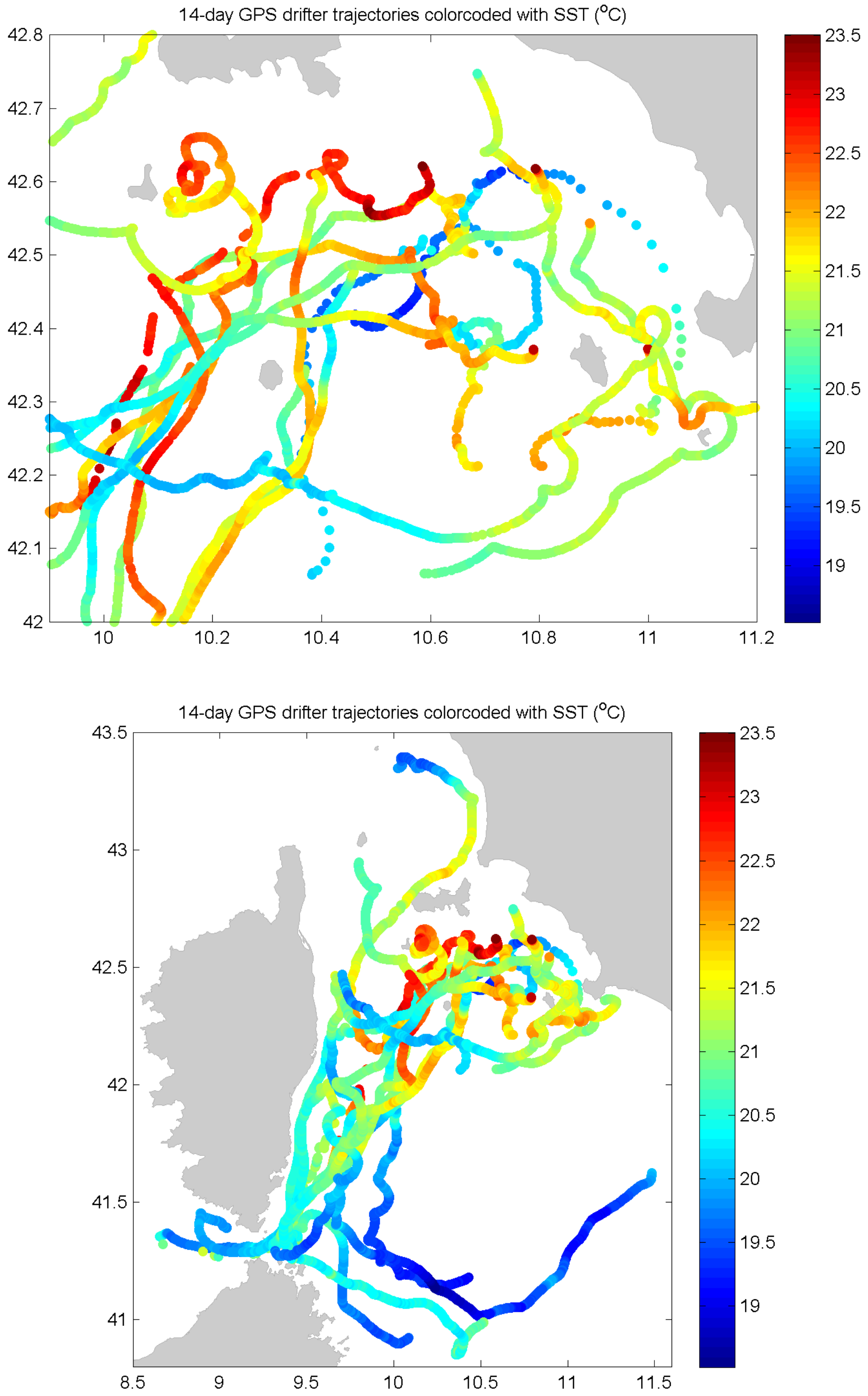


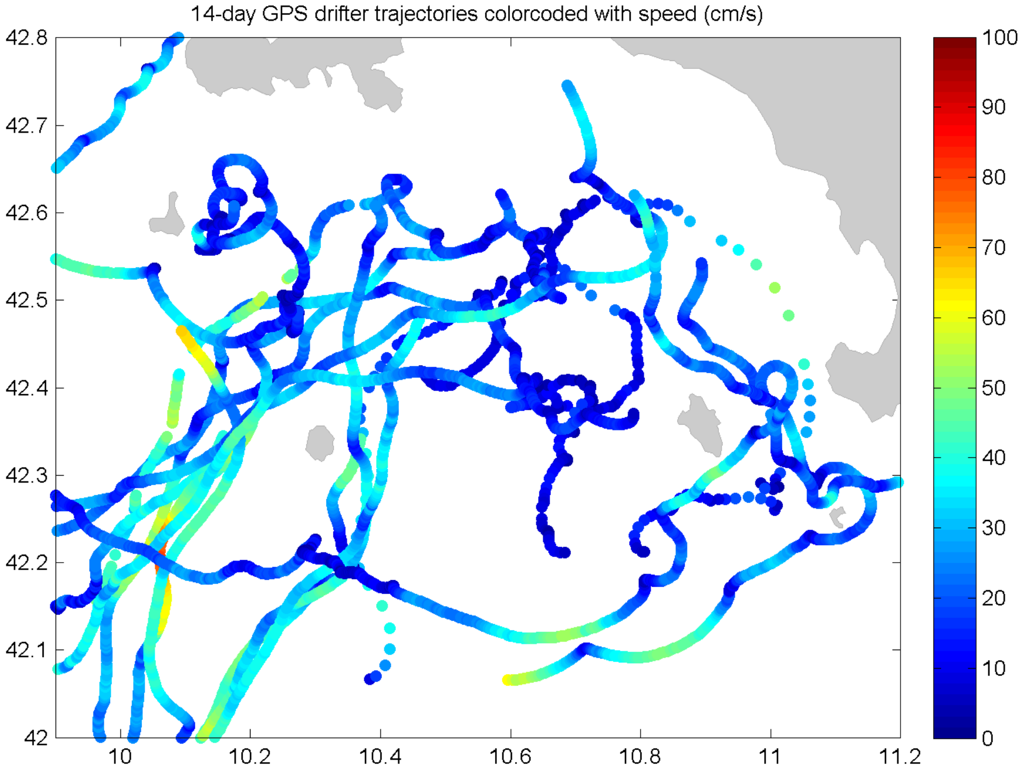
*Figure 10. Positions of the MILONGA drifters color-coded with the sea surface temperature.*

Velocities were estimated by finite differencing the edited drifter positions (central difference with delta-t of 30 minutes for the CODE and 4 hours for the SVP). Their magnitudes, or speeds, are color-coded along the drifter tracks in Figure 11. Most speeds are bounded by 50 cm/s in the Tuscan Archipelago waters. In contrast, currents can be much faster east of Corsica, in the Strait of Bonifacio and in the Tyrrhenian, reaching 100 cm/s.

Pseudo-Eulerian statistics of the surface velocities derived from the drifters were also calculated. The drifter velocities were averaged in bins of 0.1° x 0.1° overlapped by 50%. The definitions of the pseudo-Eulerian statistics can be found in Poulain (2001). The number of drifter observations (every 15 min and 2 hours for the CODE and SVP drifters, respectively) and the number of drifters in the bins are shown in Figures 12 and 13, respectively. The area between Montecristo and Pianosa (eastern Tuscan Archipelago) are the most sampled with about 1000 drifter measurements and 10 drifters providing observations in some bins.

The mean flow and mean kinetic energy (MKE) are illustrated in Figure 14. Velocity vectors are drawn at the center of mass of the observations in each bin. Southward flow prevails in the eastern sector off the continental Italian coast, and in particular between the Argentario and Giglio. More to the west, prevailing mean currents are directed towards the southwest. Mean currents can reach 20 cm/s and the corresponding mean kinetic energy can reach 400 $cm^2/s^2$ in the Tuscan Archipelago area. More to the south, in the Tyrrhenian Sea and Strait of Bonifacio, mean currents can reach 70 cm/s and the MKE can be larger than 1000 $cm^2/s^2$.

The temporal variability of the currents can be described in terms of the velocity variance ellipses and the kinetic energy of the fluctuating currents (also called the eddy kinetic energy, EKE). These statistics are depicted in Figure 15. In the Tuscan Archipelago area, the EKE is essentially limited to values less than 300 $cm^2/s^2$. In other areas, for instance in the Strait of Bonifacio, currents can become very variable and hence the velocity variance ellipses and EKE levels can be large (> 1500 $cm^2/s^2$).



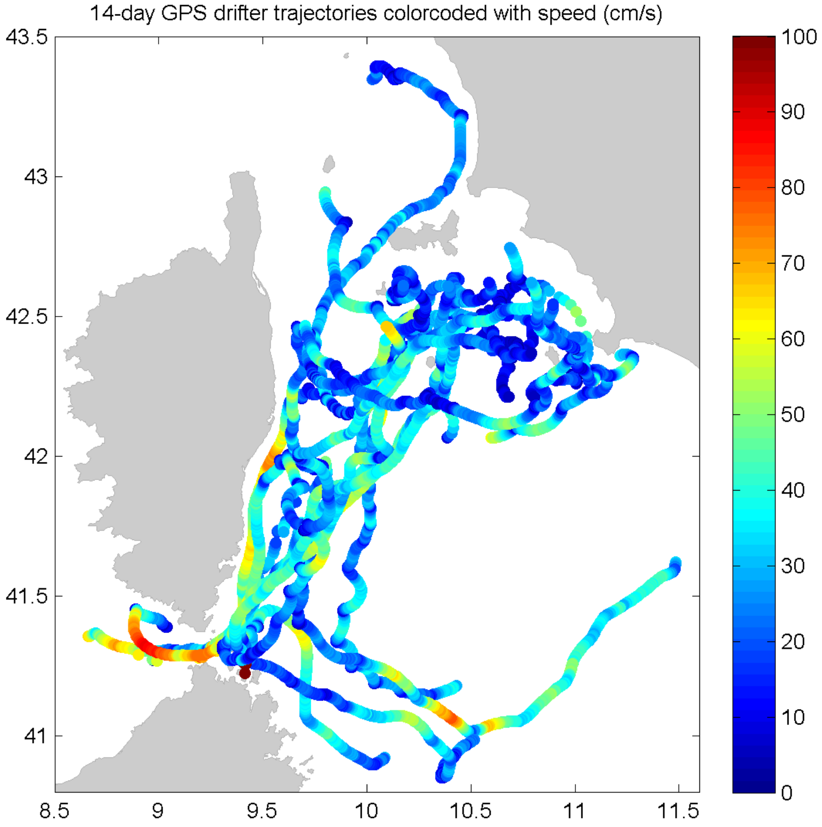
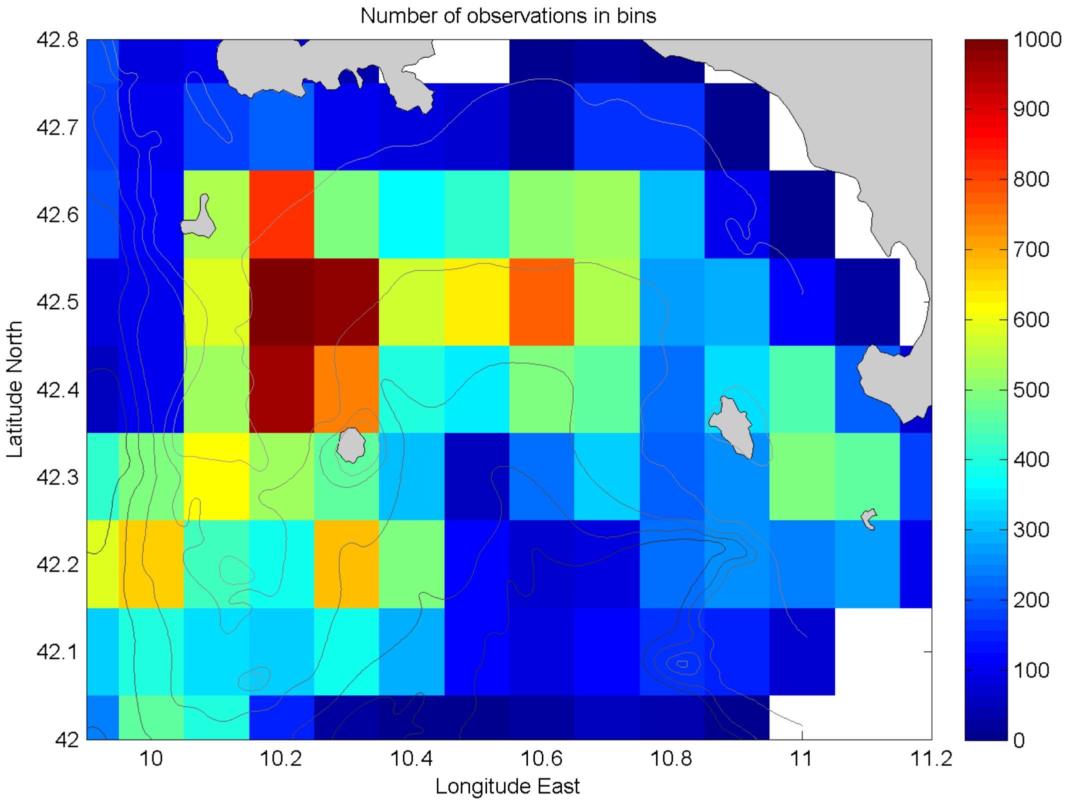


*Figure 11. Positions of the MILONGA drifters color-coded with the speed.*



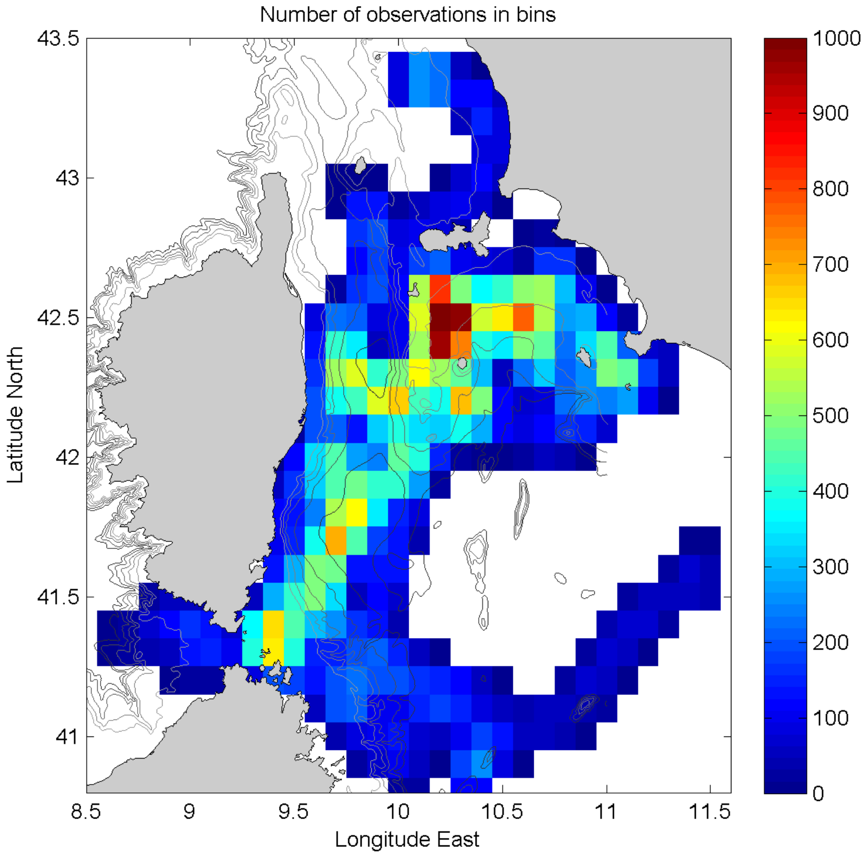


*Figure 12. Number of drifter observations in 0.1° x 0.1° bins.*

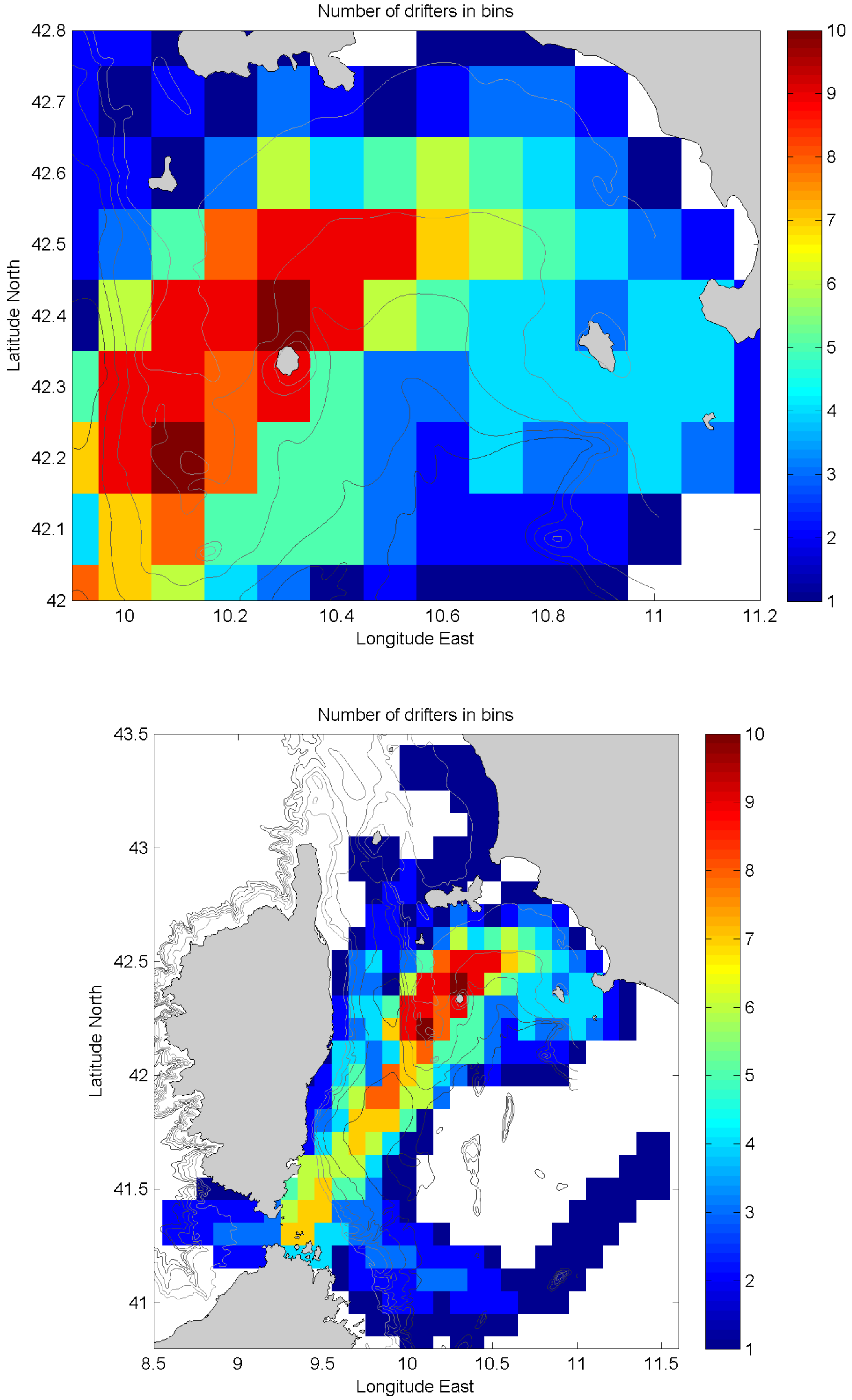


*Figure 13. Number of individual drifters in 0.1° x 0.1° bins.*

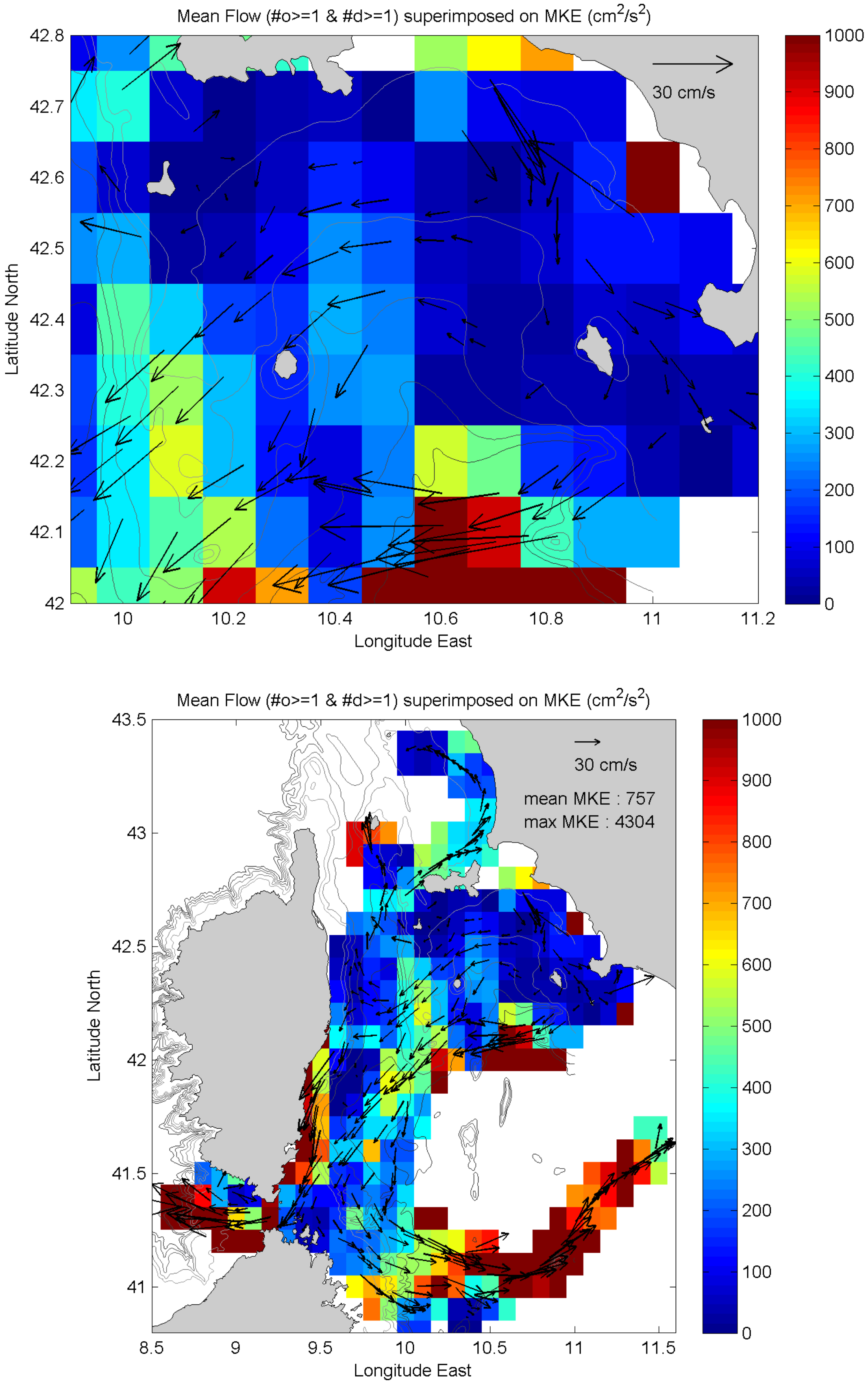


*Figure 14. Mean flow (arrows) and mean kinetic energy (MKE, colors) in 0.1° x 0.1° bins.*

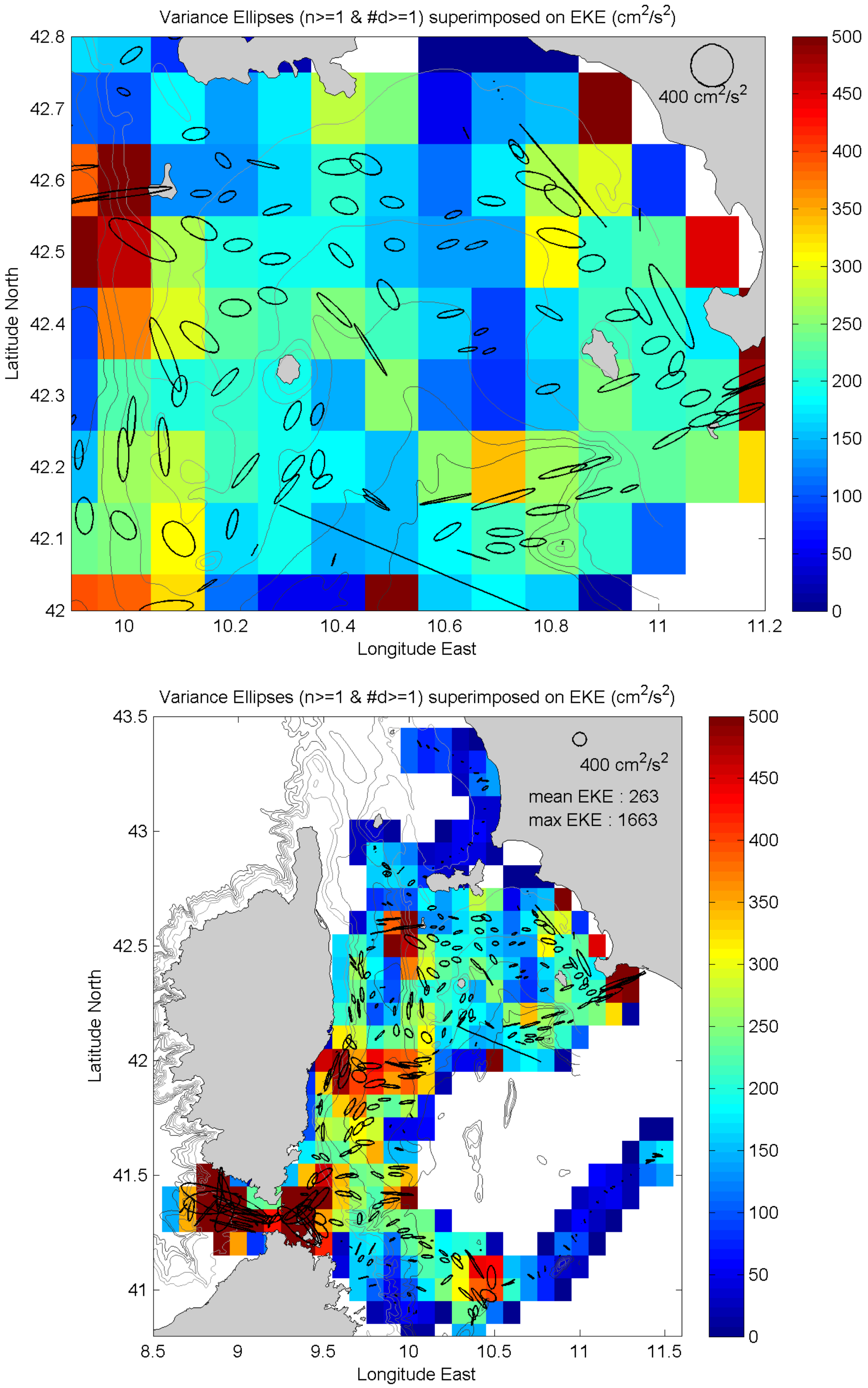


*Figure 15. Velocity variance (ellipses) and eddy kinetic energy (MKE, colors) in 0.1° x 0.1° bins.*

## 3.2 Trajectories and temperature and salinity profiles from the Arvor-C float

The Arvor-C float was deployed on 10 October 2011 from the Cappellini (Istituto Nautico di Livorno) and provided temperature and salinity profiles every 3 h until 24 October 2011 (Table 2). In total, the float executed 136 CTD profiles between the surface (0 m) and a maximal depth of about 400 m.

| Model | Deploy Date GMT | Lat | Lon | Last Date GMT | Lat | Lon | Files | Profiles |
|---|---|---|---|---|---|---|---|---|
| Arvor C | 10-Oct-2011 14:35 | 42.64 | 10.68 | 24-Oct-2011 13:12 | 42.09 | 10.45 | 320 | 136 |

*Table 2. Deployment and last fix coordinates of the Arvor-C float operated during MILONGA.*

The track of the Arvor-C is shown in Figure 16. It essentially moved to the southwest and then southward, left the Tuscan Archipelago waters passing between Montecristo and Giglio on 21 October 2011 and continued drifting in the deeper waters of the northern Tyrrhenian Sea. It executed the last profile on 24 October 2011 at 13:12 GMT and stayed at the surface until it was recovered on 27 October 2011.

The temperature and salinity profiles measured by the Arvor-C show a surface mixed layer as deep as 30-40 m above a thermocline extending as deep as 150 m (Figure 17). The surface temperatures span roughly 19-22°C. The temperature of the water between 150 and 450 m depth is in 13.87-13.94°C The sea surface salinity is about 38.19. There is a salinity minimum (37.92) near 30-50 m depth. Below, the salinity increases with depth to reach a value of 38.68 near 400 m depth. These measurements can be illustrated in a temperature-salinity diagram (Figure 18) in which we see the near-surface waters characterized by temperatures in 17-22°C and salinities between 37.81 and 38.26 and corresponding to densities in excess of 1027.8 kg $m^{-3}$. The coldest (13.85°C) and saltiest (38.68) waters are encountered below 400 m depth.

The spatio-temporal variability of the thermohaline structure of the waters along the trajectory of the float can be represented in contour diagrams with color-coded temperature, salinity and density plotted versus time and depth (Figures 19-21). The mixed-layer depth varies from about 30 m on 10-14 October to 45 m on 16-17 October and back to about 28 m on 23-24 October. There is a gradual cooling of the mixed-layer and weakening of the thermocline. High-frequency variations (undulations of the thermocline) are also seen in the thermohaline structure, possibly related to internal waves.

Note that another profiling float Arvor-I was deployed during the experiment. This float is not considered in the report.

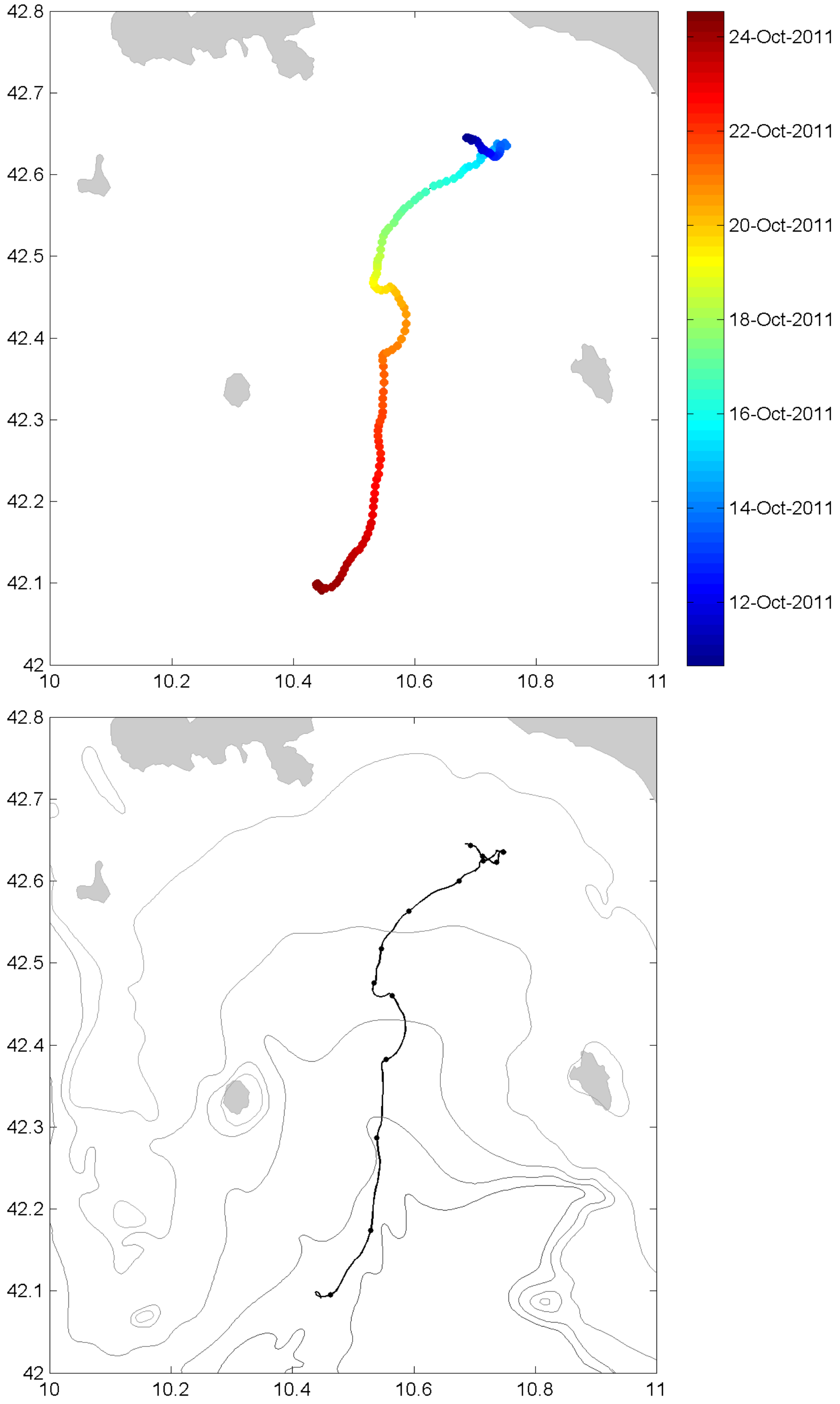


*Figure 16. Track of the Arvor-C with position dots color-coded with time (top panel) and with a dot at daily interval (bottom panel).*

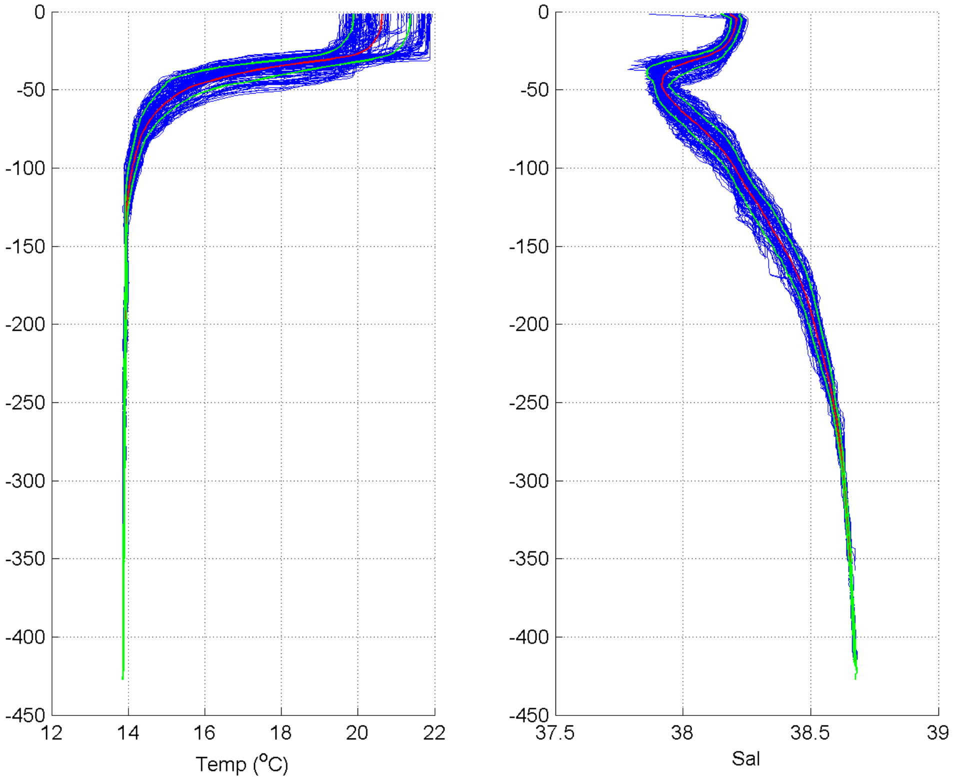


*Figure 17. Profiles of temperature (left) and salinity (right) measured by the Arvor-C float. Depths are in meters. Mean profiles are in red, with ± one standard deviation (green curves).*

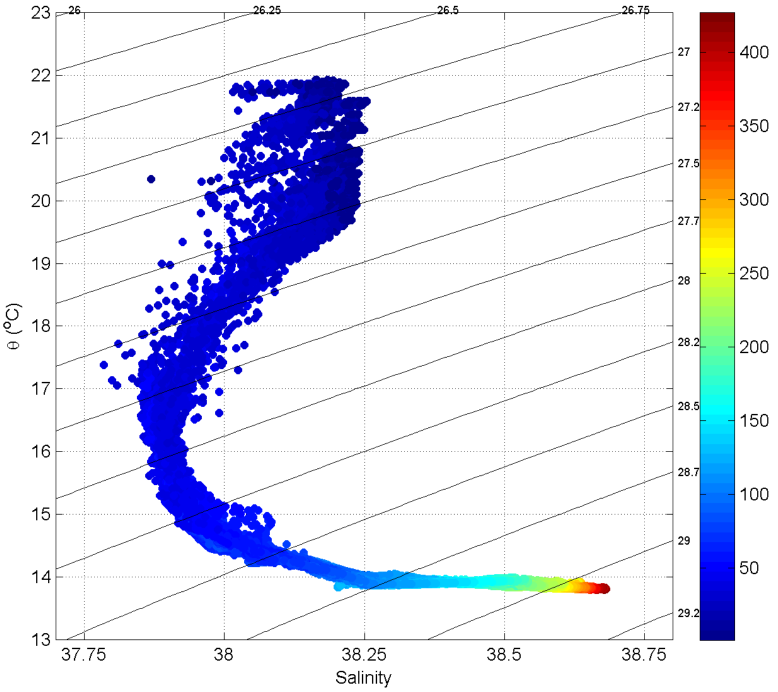


*Figure 18. Temperature-salinity diagram based on the Arvor-C measurements. Depths (in meters) are color-coded. Isopycnals are overlaid.*

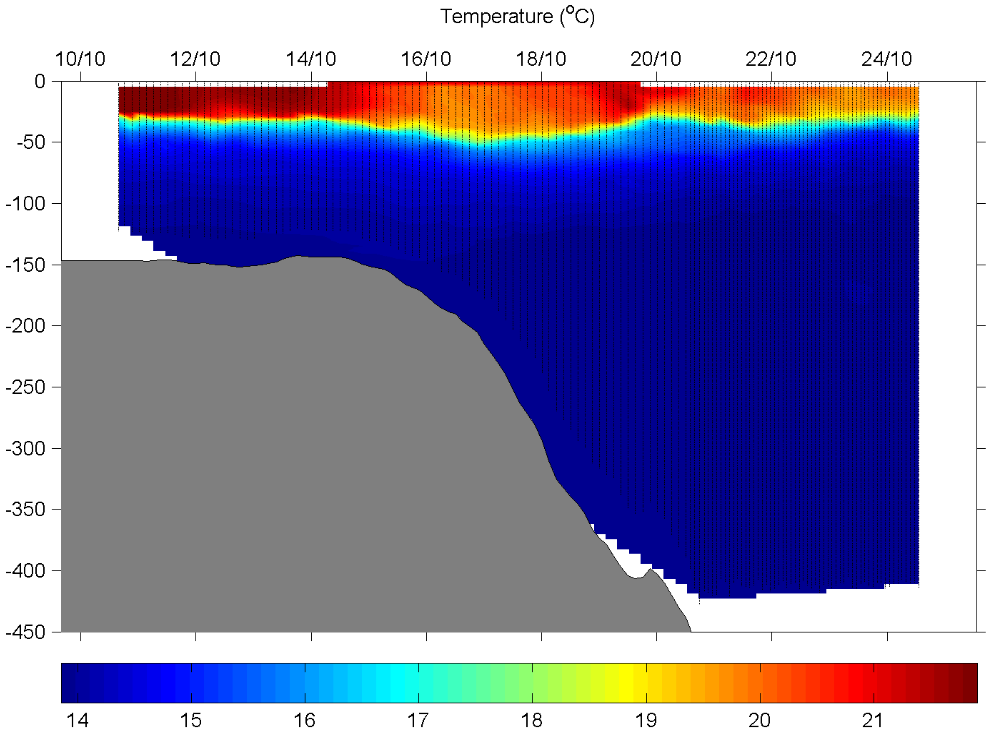


*Figure 19. Cross-section of temperature (colored contours) versus time (following the float) and depth (meters).*

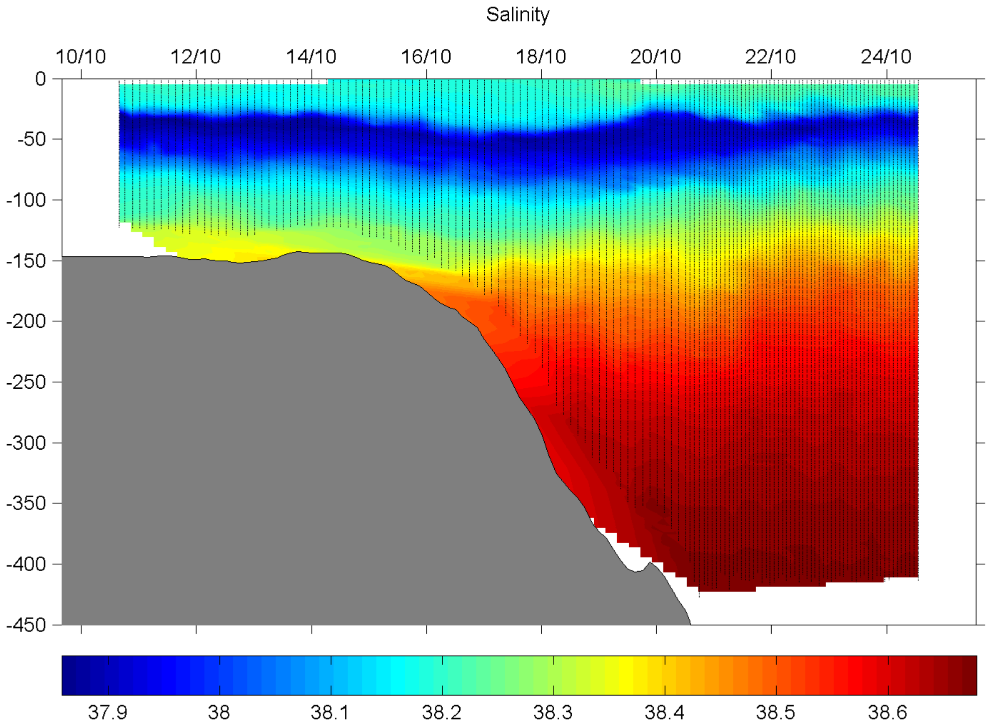


*Figure 20. Same as Figure 19 but for salinity.*

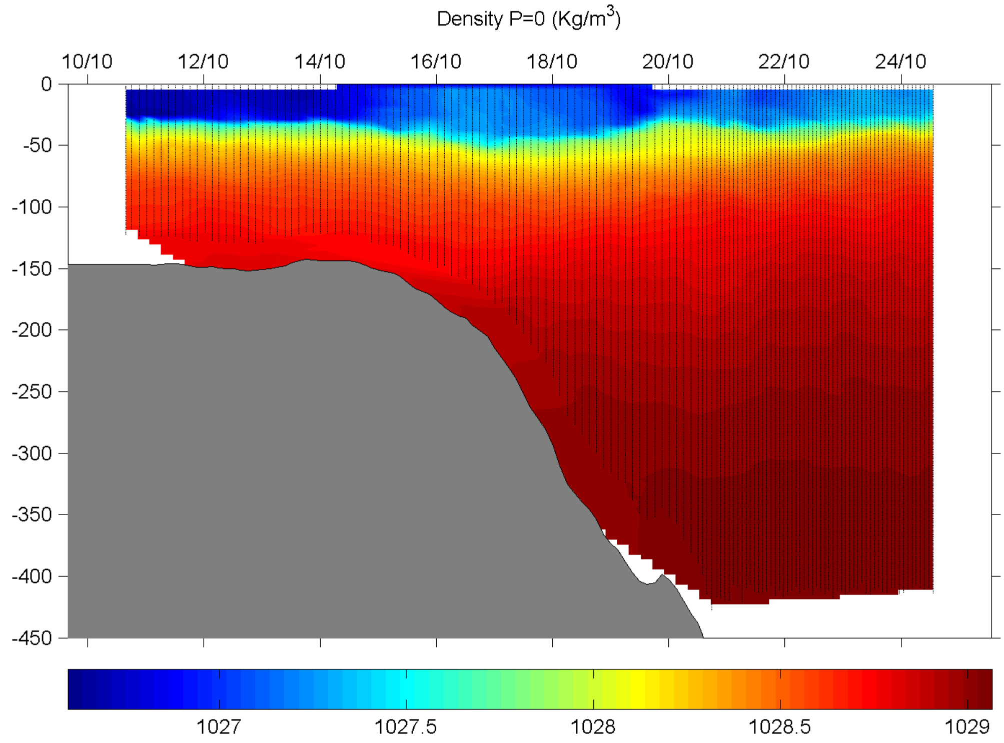


*Figure 21. Same as Figure 19 but for density.*

### 3.3 Trajectories and relative current profiles from the river and prototype drifters

The river and prototype drifters were deployed on 10 October 2011 in the vicinity of the waverider buoy (Table 3) using Cappellini. All drifters were recovered the next day to check their functioning and to redeploy them closer to the waverider buoy. The SIO river drifter with downward-looking ADCP and the OGS prototype were redeployed within about 1 h. However, the SIO river drifter with upward-looking ADCP was not redeployed due to problems with GPS fixes.

The trajectories of the drifters are depicted in Figure 22, along with the location of the waverider buoy.

| Drifter | Deploy Date GMT | Lat N | Lon E | Recovery Date GMT | Lat N | Lon E |
|---|---|---|---|---|---|---|
| SIO River ADCP down | 10-Oct-2011 14:40 | 42.64 | 10.68 | 11-Oct-2011 10:28 | 42.61 | 10.75 |
| SIO River ADCP up | 10-Oct-2011 14:45 | 42.64 | 10.68 | 11-Oct-2011 10:31 | 42.61 | 10.75 |
| OGS prototype | 10-Oct-2011 14:50 | 42.64 | 10.68 | 11-Oct-2011 08:55 | 42.64 | 10.73 |
| OGS prototype | 11-Oct-2011 11:48 | 42.65 | 10.70 | 13-Oct-2011 07:48 | 42.56 | 10.74 |
| SIO River ADCP down | 11-Oct-2011 11:48 | 42.65 | 10.70 | 13-Oct-2011 08:15 | 42.58 | 10.75 |

*Table 3. Dates/times and positions of deployments and recoveries of the SIO river and OGS prototype drifters operated during MILONGA.*

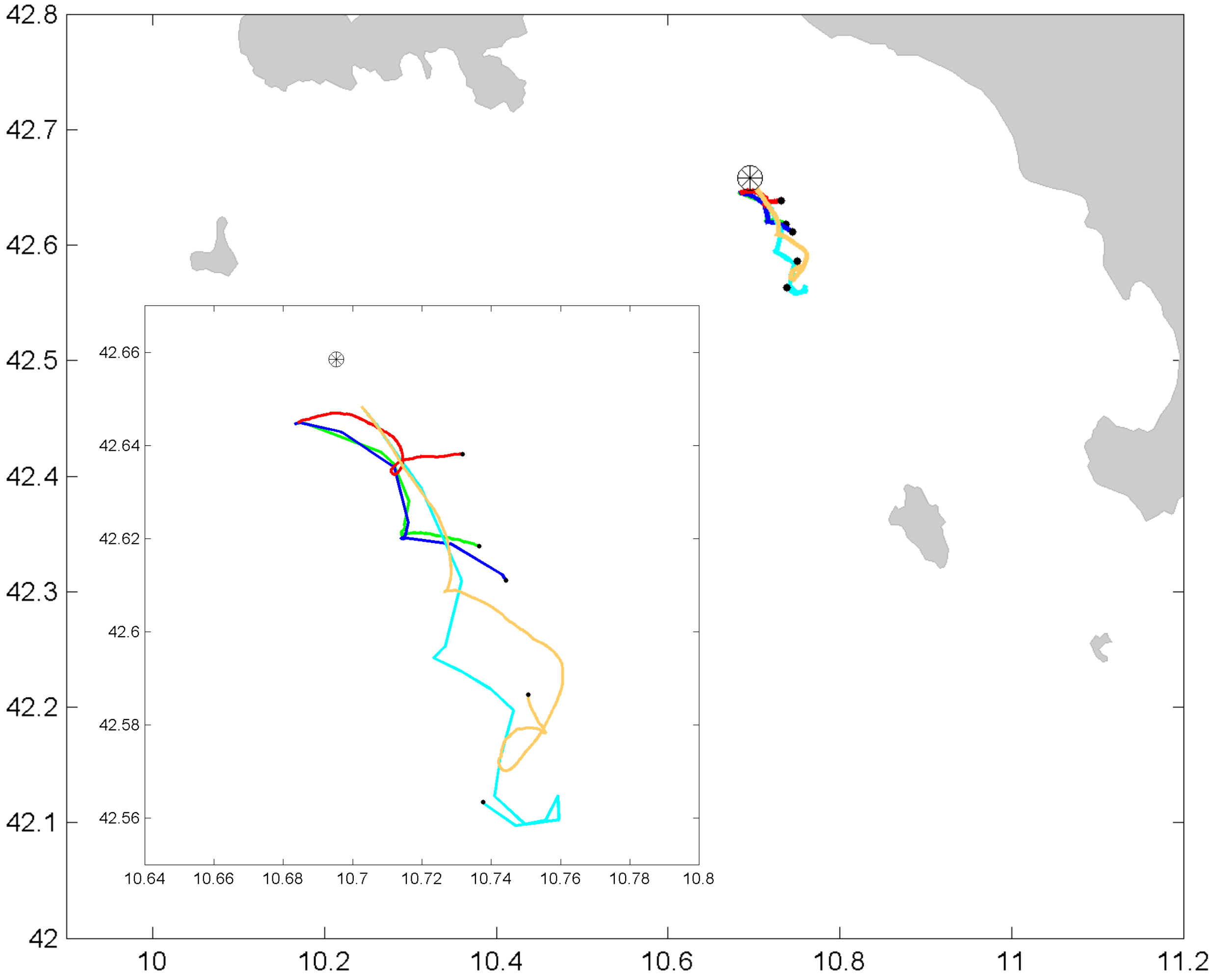


*Figure 22. Trajectories and recovery locations (black dots) of the SIO drifters with downward-looking ADCP (first deployment in blue and second deployment in cyan) and with upward-looking ADCP (in green), and of the OGS prototype drifter (first deployment in red and second deployment in orange). The position of the waverider buoy is depicted by a star-circle symbol.*

The data collected by the ADCPs fitted on the SIO river and OGS prototype drifters were downloaded after the final recovery. Unfortunately, it appeared that no data were actually recorded for the OGS drifter, probably due to an error in the setting or programming of the ADCP. For the SIO river drifter with downward-looking ADCP, the data was lost for the first deployment due to an internal firmware error. For the second deployment the ADCP data was successfully recorded and downloaded. Graphical summaries of the ADCP data collected by the river drifter during the second deployment are shown as Figures 23 to 26. The SIO river drifter with downward-looking ADCP moved approximately southward following a cycloidal path characteristics of the superposition of a large-scale drift with motions of near-inertial or tidal nature (Figure 22). The good quality of the data is testified by the ADCP amplitude plot (Figure 23).

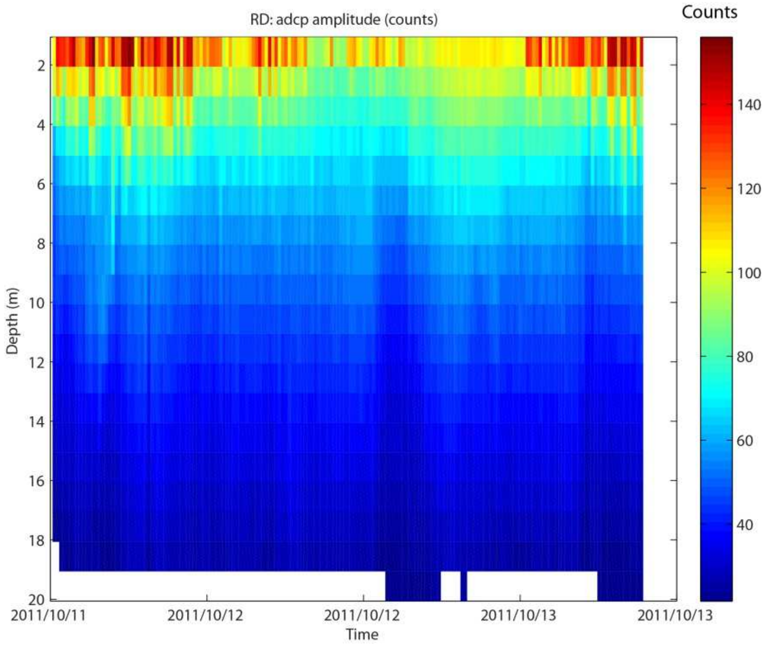


*Figure 23: Acoustic intensity measured by the downward-looking ADCP mounted on the SIO river drifter versus depth and time.*

The swift southward drift of the river drifter at the beginning of its mission is reflected in the negative, southward current measured by the ADCP and corrected for the motion of the instrument, the latter being measured with the onboard 1Hz GPS (Figure 24). Note the periodicity of both the eastward and westward velocity components (Figures 24 and 25). Our preliminary analysis suggests a periodicity of about 16.5 hours. Since the inertial frequency at the experiment location is approximately 17.7 hours, the cycloidal river drifter path and the periodical measured currents should result from near-inertial currents.

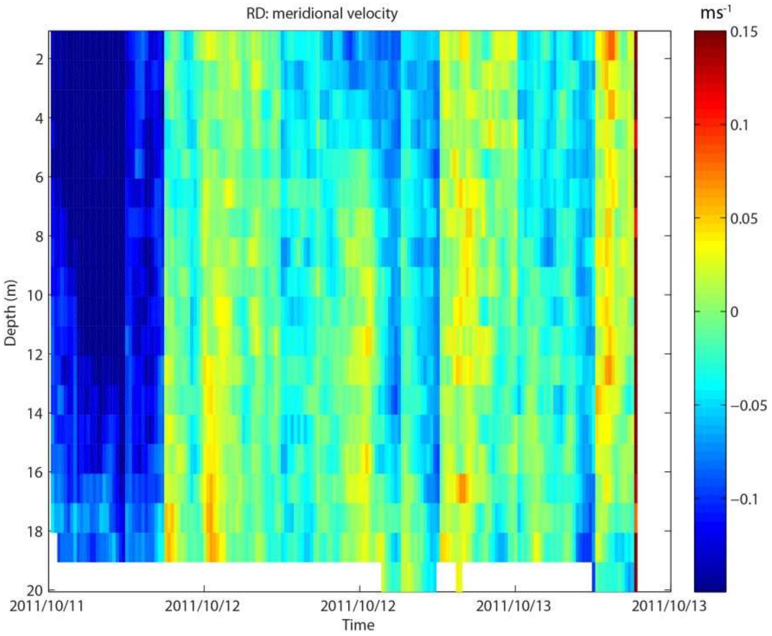


*Figure 24: Meridional velocity versus depth and time as measured with ADCP and corrected for the drifter motion (using the onboard GPS data).*

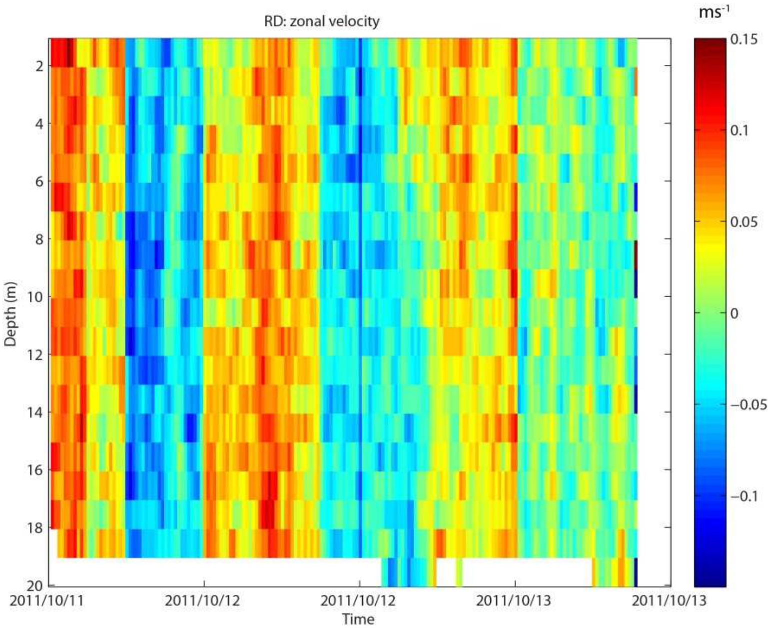


*Figure 25: Same as Fig. 24 but for the zonal velocity.*

The vertical velocity (Figure 26) shows at least three downwelling events, with the strongest one occurring just before midnight on 11 October 2011.

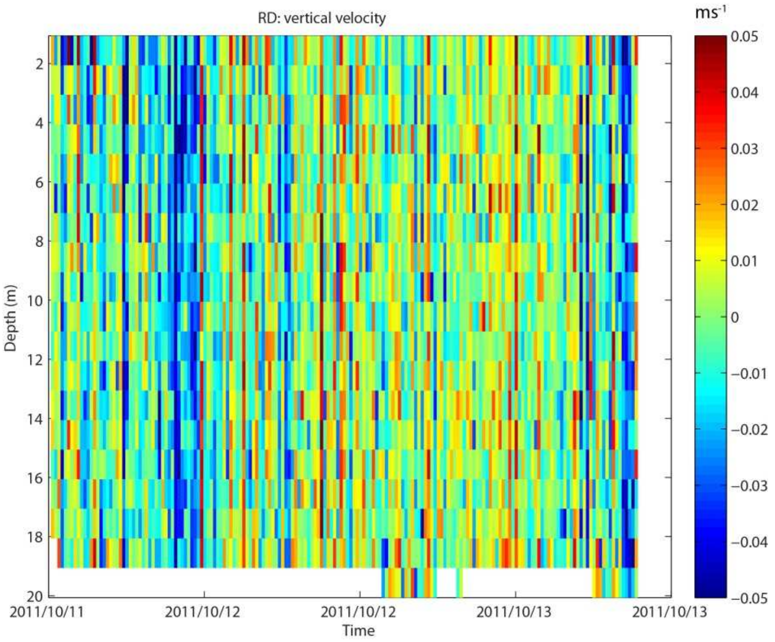


*Figure 26. Vertical velocity measured by the downward-looking ADCP mounted on the SIO river drifter versus depth and time.*

## 3.4 Surface wave measurements from the waverider buoy

The waverider buoy was anchored in the Tuscan Archipelago waters on 10 October and was recovered on 13 October (see Table 4 and Figure 22). The data collected by the buoy are only illustrated as an example for a 30-min time period on 11 October 2011 at 1.40 GMT. The exact positions of the buoy during the period are depicted in Figure 27. These are the distances in m sampled every second with respect to a mean position during the period of 30 minutes. Time series of the 3D displacements of the buoy (vertical or heave, zonal and meridional displacements) sampled at 1 Hz are shown in Figure 28. The distribution of the heave displacements as well as the normal distribution which best fits the data are shown in Figure 29. The directional spectrum is depicted as Figure 30. The significant wave height for this period is 35 cm, whereas the peak wave period is 2.7 seconds and direction of the peak wave is from the northwest.

| Deploy Date GMT | Lat N | Lon E | Recovery Date GMT | Lat N | Lon E |
|---|---|---|---|---|---|
| 10-Oct-2011 15:40 | 42.66 | 10.70 | 13-Oct-2011 10.10 | 42.66 | 10.70 |

*Table 4. Dates/times and positions of deployments and recoveries of Datawell waverider buoy operated during MILONGA.*

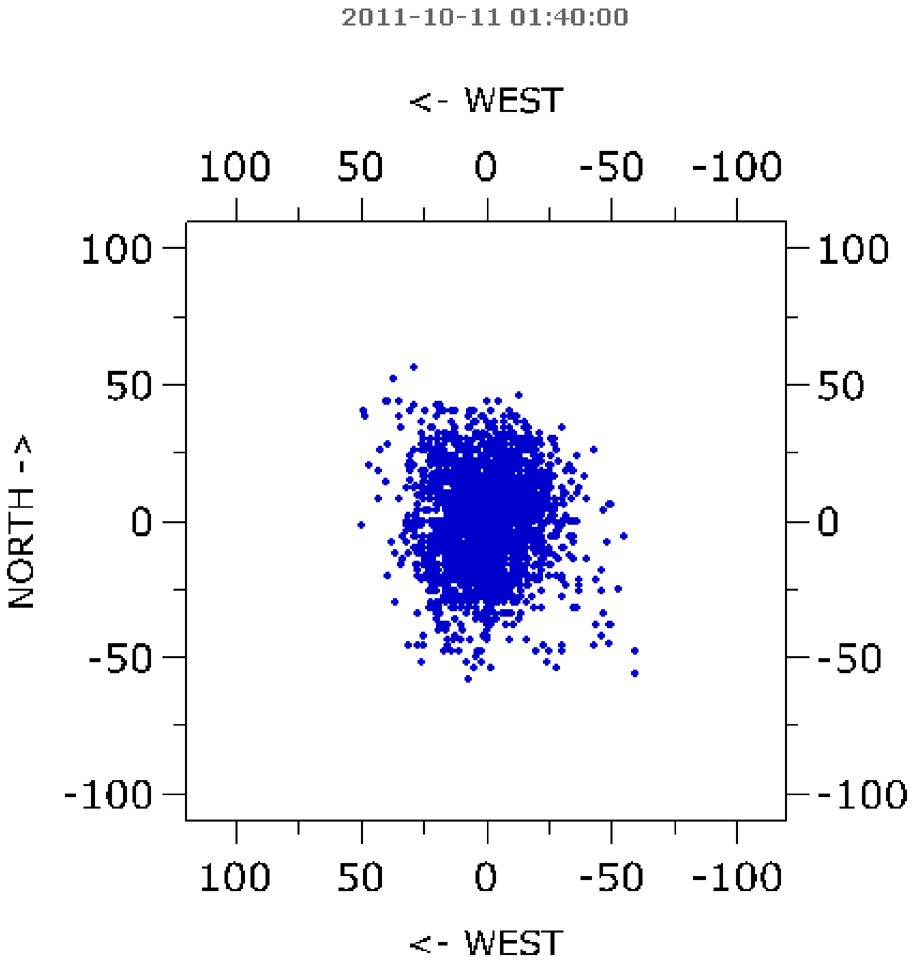


*Figure 27: Relative positions of the waverider buoy during 30-min period on 11 October 2011 at 1.40 GMT. Positions are sampled every second and are deviations with respect to a mean location calculated over the period.*

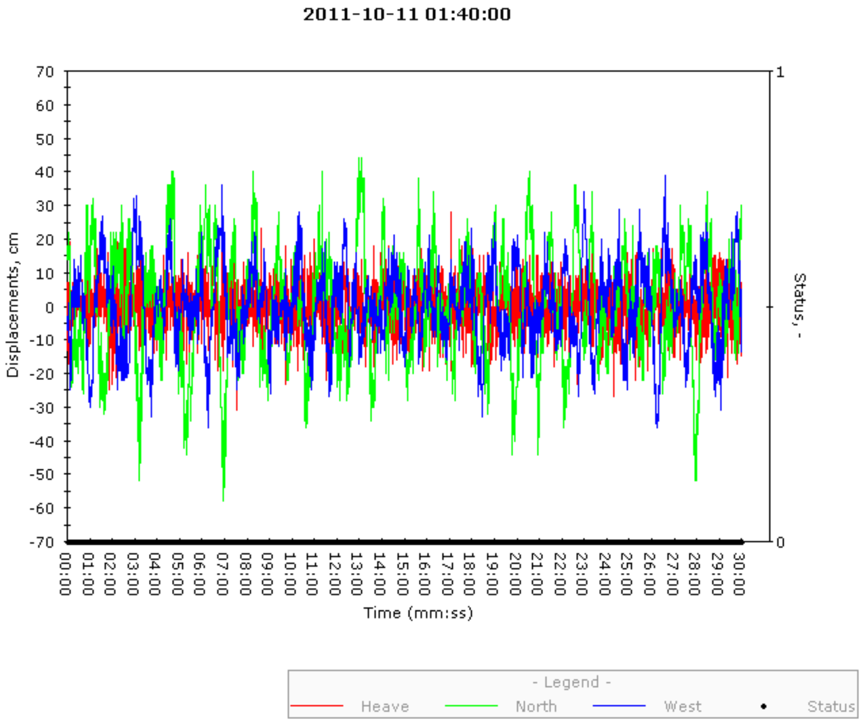


*Figure 28: Time series of vertical (heave, red) and horizontal (meridional – green and zonal – blue) displacements of the waverider buoy during 30-min period on 11 October 2011 at 1.40 GMT.*

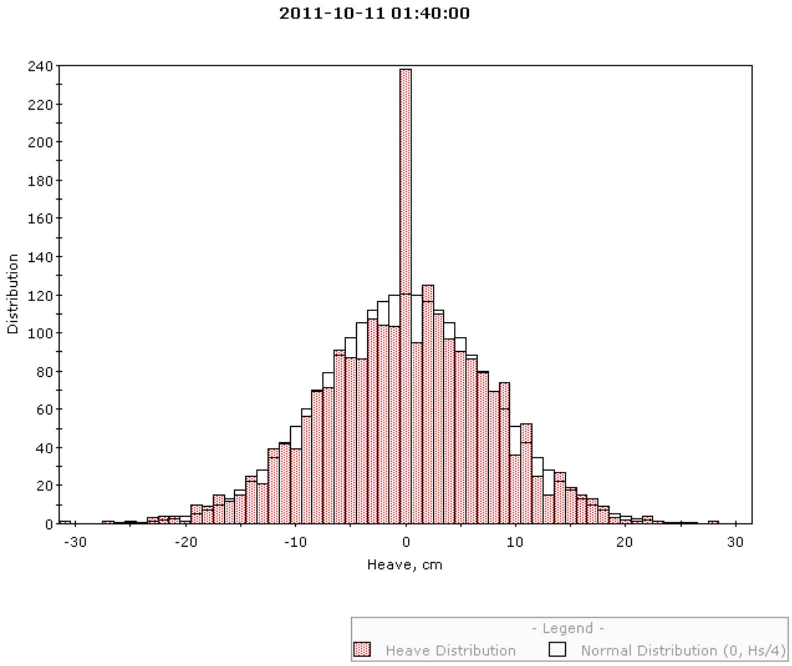


*Figure 29: Distribution of the heave vertical displacements of the waverider buoy during 30-min period on 11 October 2011 at 1.40 GMT. The normal distribution which fits the data is also shown.*

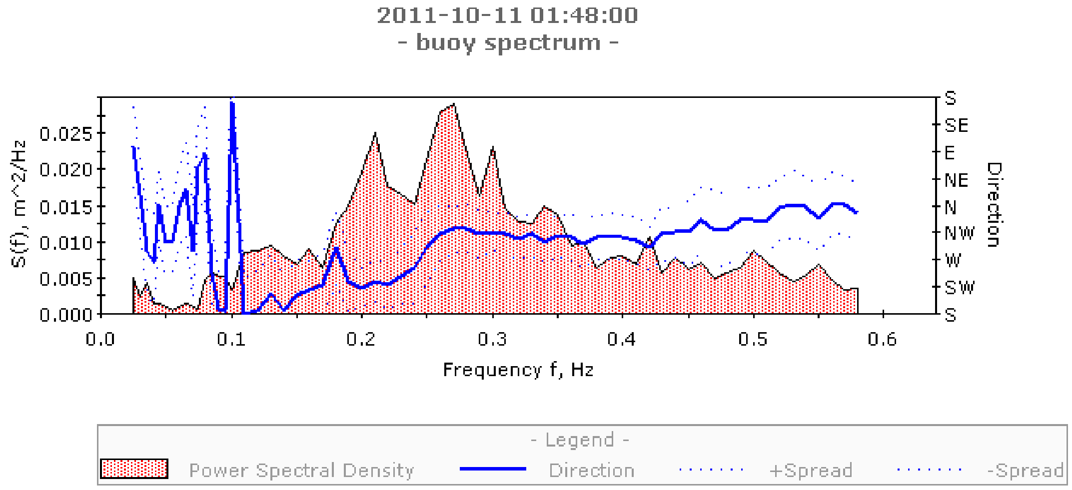


*Figure 30: Directional spectrum of the surface waves as measured by the waverider buoy during 30-min period on 11 October 2011 at 1.40 GMT.*

Figure 31 shows the significant wave height and the peak period during the MILONGA experiment (10-13 October 2011). It can be seen that the last day the significant wave height increase from about 15 cm to more than 80 cm. The peak period remained mostly between 2 and 4 seconds.

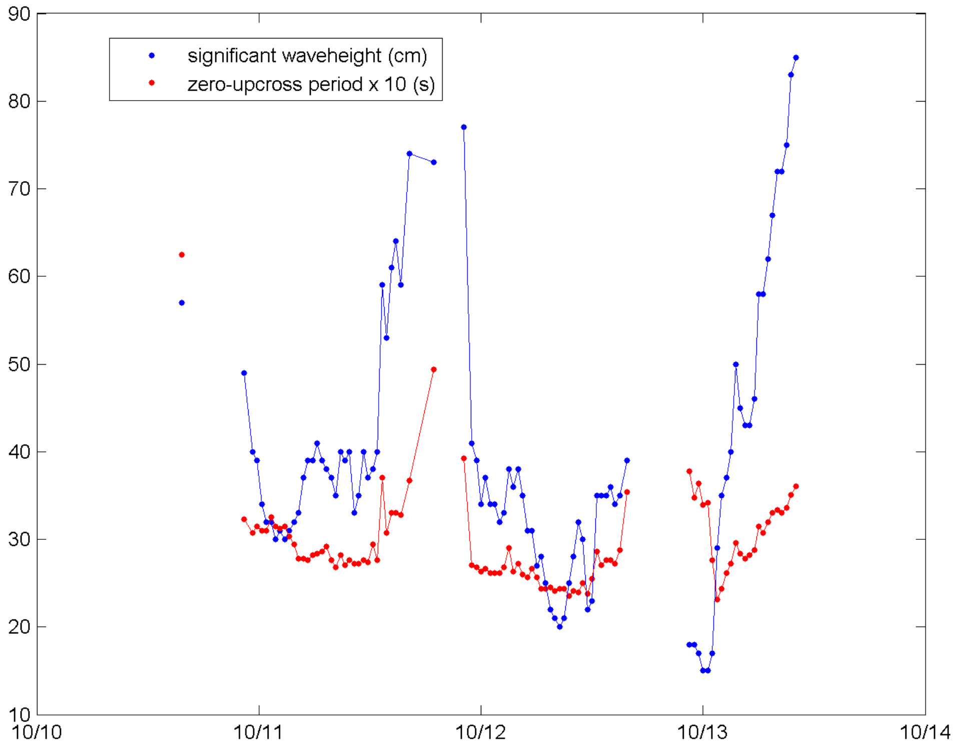


*Figure 31: Significant wave height and peak period as measured by the waverider buoy during the period 10-13 October 2011.*

## 4. Discussion and conclusions

Oceanographic physical properties, such as near-surface currents, profiles of temperature and salinity and surface wave characteristics, have been successfully measured in the area of the Tuscan Archipelago in the northern Tyrrhenian Sea for a period of about 2 weeks starting on 10 October 2011. The following data have been collected:

1) Drifter Data: A total of 17 drifters were released in the area and provided data of surface currents and sea surface temperature. After 2 weeks of drift, only one drifter remained in the study area. At least 2 drifters crossed the Corsica Channel and moved northward into the Ligurian Sea. The majority of the drifters moved to the southwest in the direction of the Bonicafio Strait. Three units crossed the strait and moved westward between Corsica and Sardinia. Four drifters circulated anticyclonically in the northern Tyrrhenian Sea. The surface circulation in the Tuscan Archipelago waters during the period of study was mainly to the south with some intensification near the Tuscan coast. In addition, time-variable mesoscale, submesoscale, and inertial/ tidal motions prevailed.

2) Float Data: The Arvor-c float measured a total of 136 temperature and salinity profiles between the surface and a maximal depth near 400 m. A mixed layer is dominant with depth of 30-45 m on top of a thermocline (as deep as 150 m) and a salinity minimum centered near 40 m depth. In two weeks the thermocline is seen to weaken. High-frequency variability is also evident in the temperature and salinity profiles. It can be speculated that they are the signature of internal waves.

3) ADCP Data: The river drifter measured current profiles between the surface and 20 m depth. Besides mean and mesoscale currents, inertial currents are dominant in the records. The currents appear to be quite barotropic in the near-surface layer.

4) Waverider Data: The significant wave height and the peak period of the surface gravity waves in the area of study range from 25 cm to about 85 cm, and from 2 to 4 seconds, respectively.

# 5. Appendices

## 5.1 Recovery of drifter positions using Iridium

It is interesting to assess the accuracy of the positions provided by the Iridium system since many drifters had premature GPS failures but kept moving with the currents and transmitting to satellites. Drifter with IMEI number 3002340101 is considered as an example. The GPS positions (magenta track) and Iridium positions (colored dots) for this drifter are depicted in Figure A1. The color-coding for the Iridium positions correspond to the accuracy of the position in km. It can be seen that the Iridium longitudes are noisier than the latitudes, and that the accuracy parameter provided by Iridium is not necessary a good quality indicator as this parameter does not systematically increase for points far away from the real track. Figure A2 shows the time series of the positions. It is obvious that the Iridium longitude are less accurate than the latitudes.

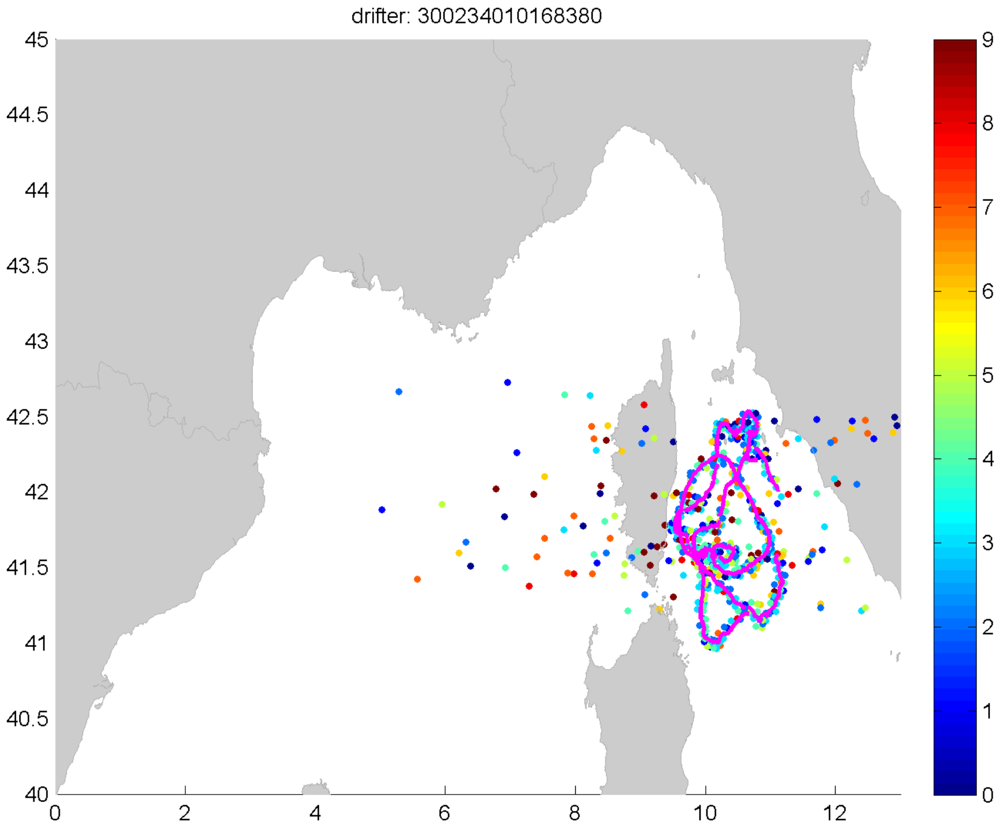


*Figure A1: GPS (magenta track) and Iridium positions (colored dots) of drifter 300234010168380. The color-coding for the Iridium positions correspond to the accuracy of the position in km.*

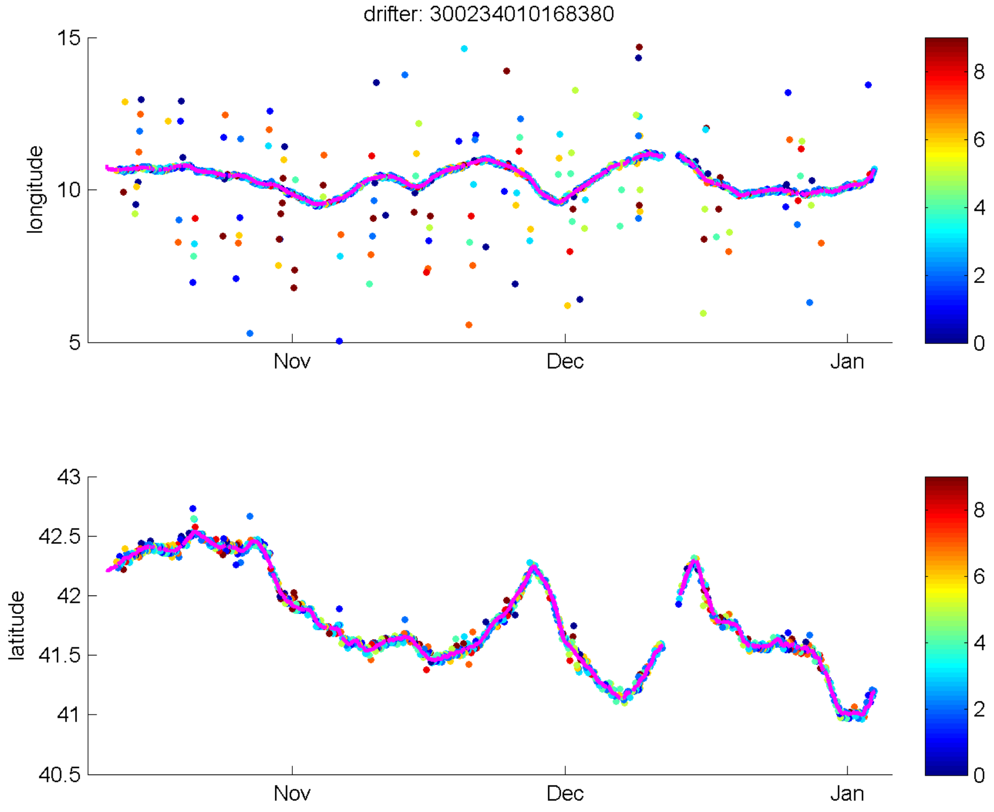


*Figure A2: Time series of the GPS (magenta track) and Iridium positions (colored dots) of drifter 300234010168380. The color-coding for the Iridium positions correspond to the accuracy of the position in km.*

A simple editing can be applied to remove Iridium position outliers by excluding positions corresponding to speed in excess of 200 cm $s^{-1}$. These points are shown in black in the following plots showing the positions (geographical maps and time series) of all the CODE drifters operated during MILONGA (Figures A3 to A20). Edited trajectories still include some noise (generally less than 1 km) and will be low-pass filtered. In this way, full low-pass filtered trajectories can be used for possible recovery of the drifters (those still alive as of 3 January 2012) and for the study of low-frequency surface currents.

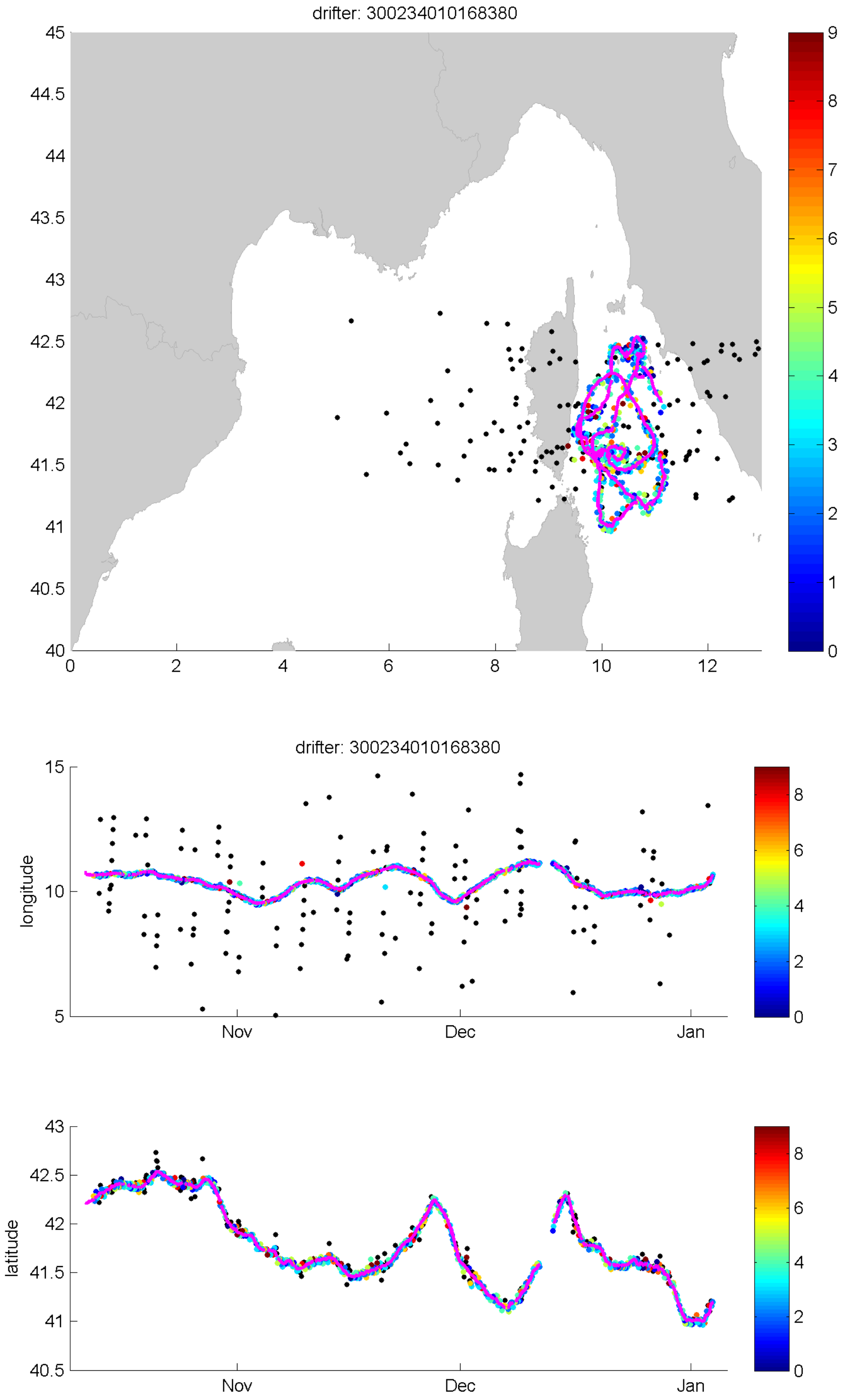


*Figure A3: GPS (magenta track) and Iridium positions (colored dots) of drifter 300234010168380. The color-coding for the Iridium positions correspond to the accuracy of the position in km. Black positions indicated points corresponding to speed > 200 cm* $s^{-1}$.

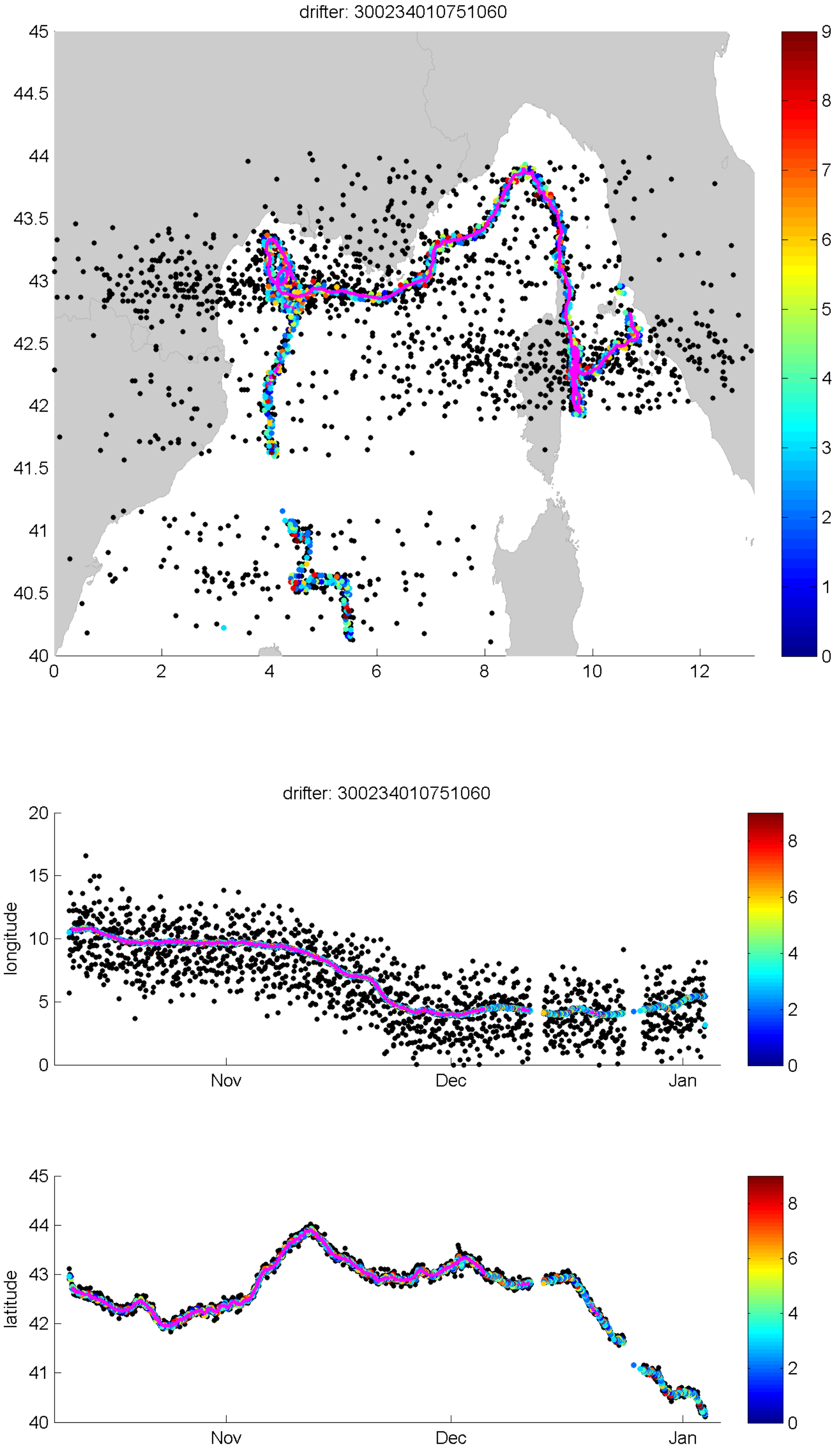


*Figure A4: Same as Figure A3 but for drifter 300234010751060.*

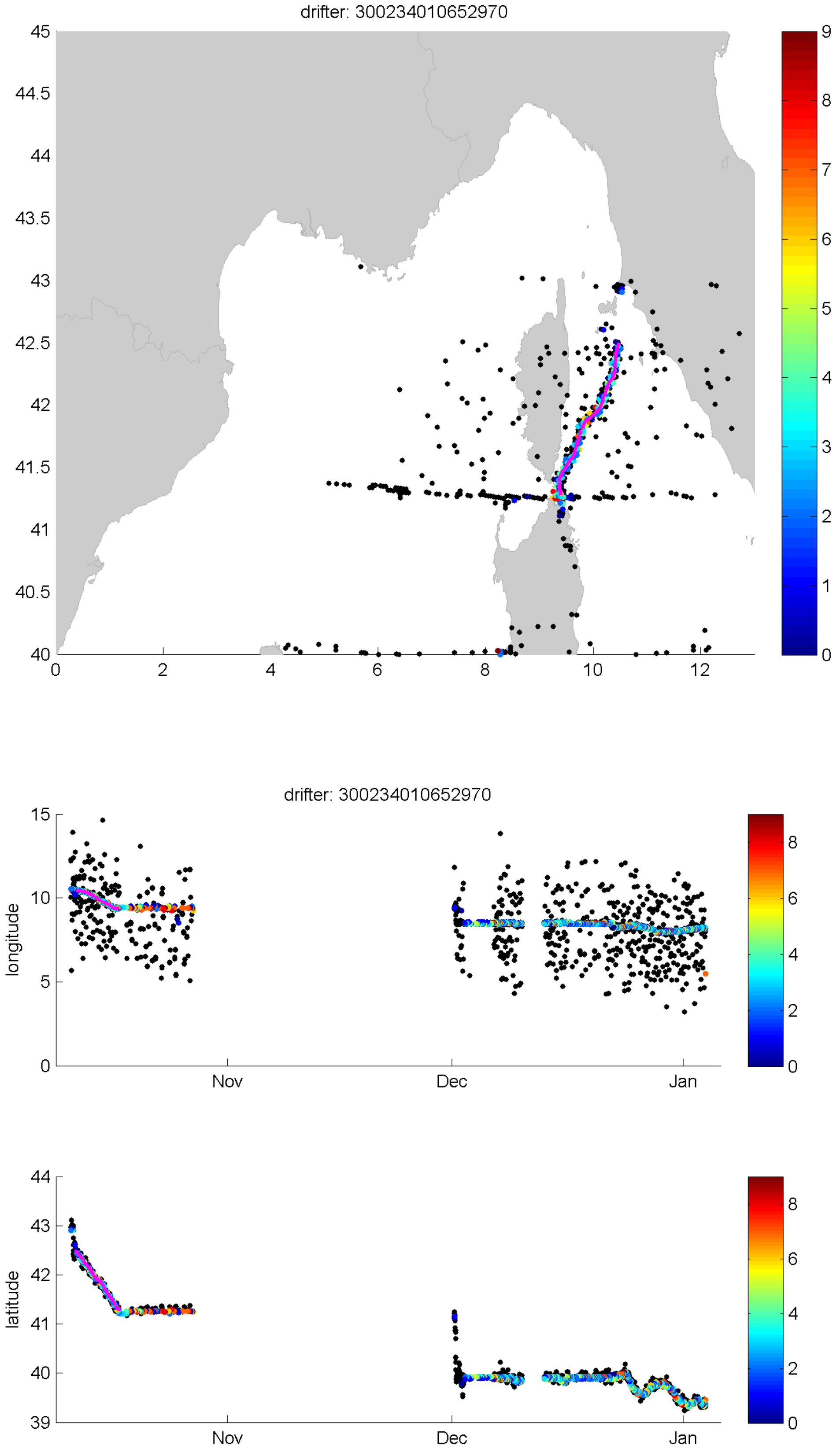


*Figure A5: Same as Figure A3 but for drifter 300234010652970.*

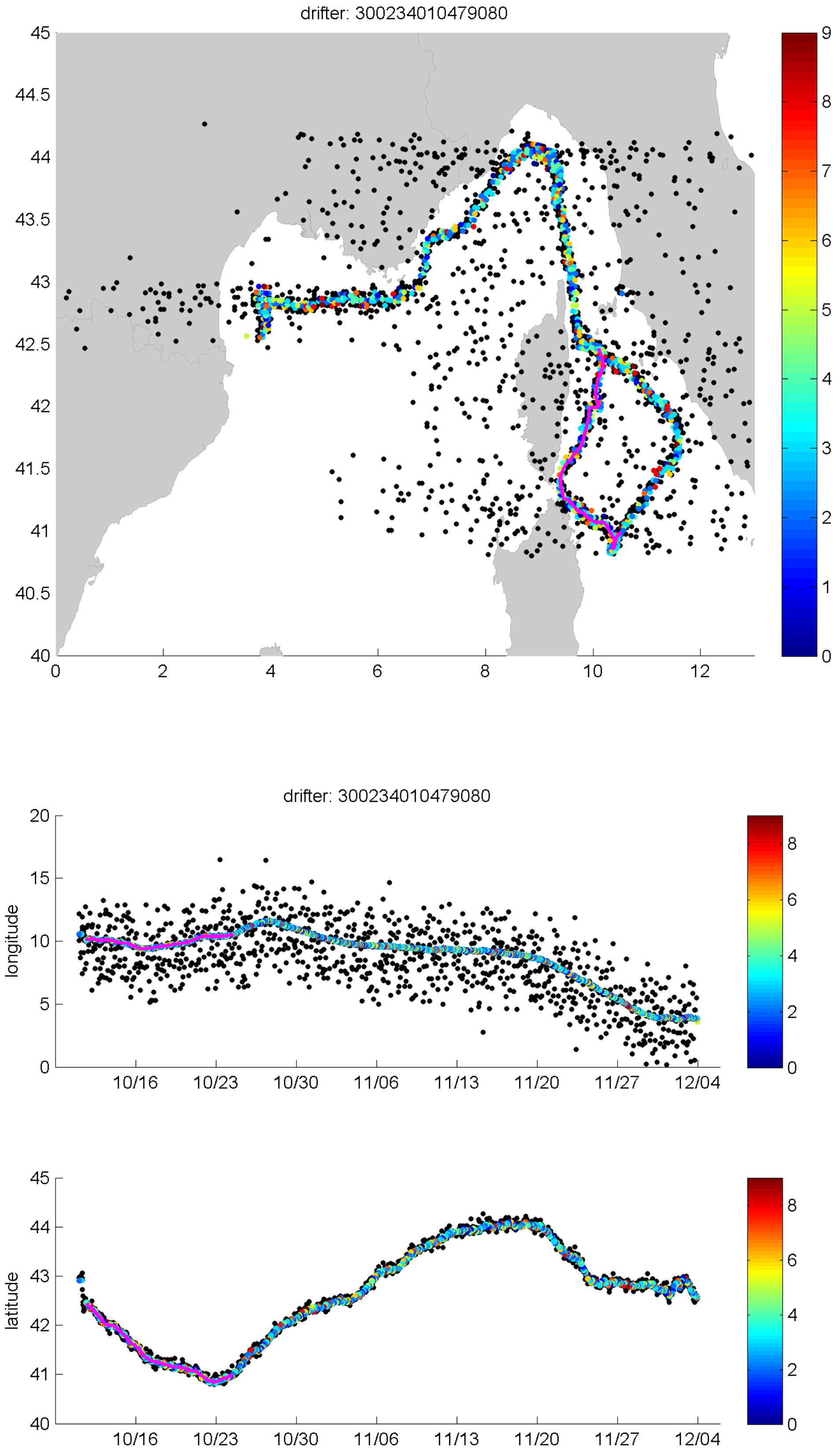


*Figure A6: Same as Figure A3 but for drifter 300234010479080.*

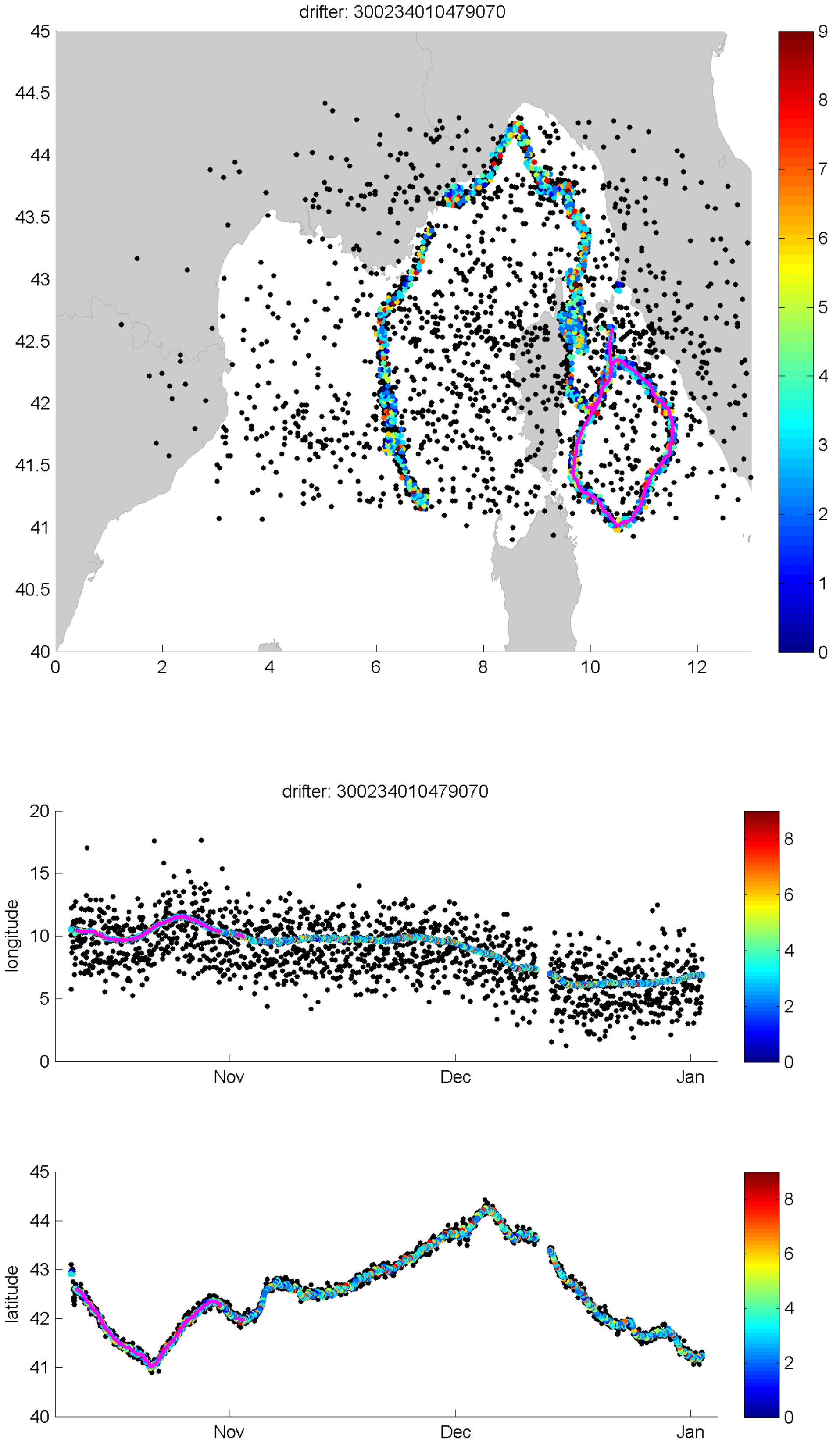


*Figure A7: Same as Figure A3 but for drifter 300234010479070.*

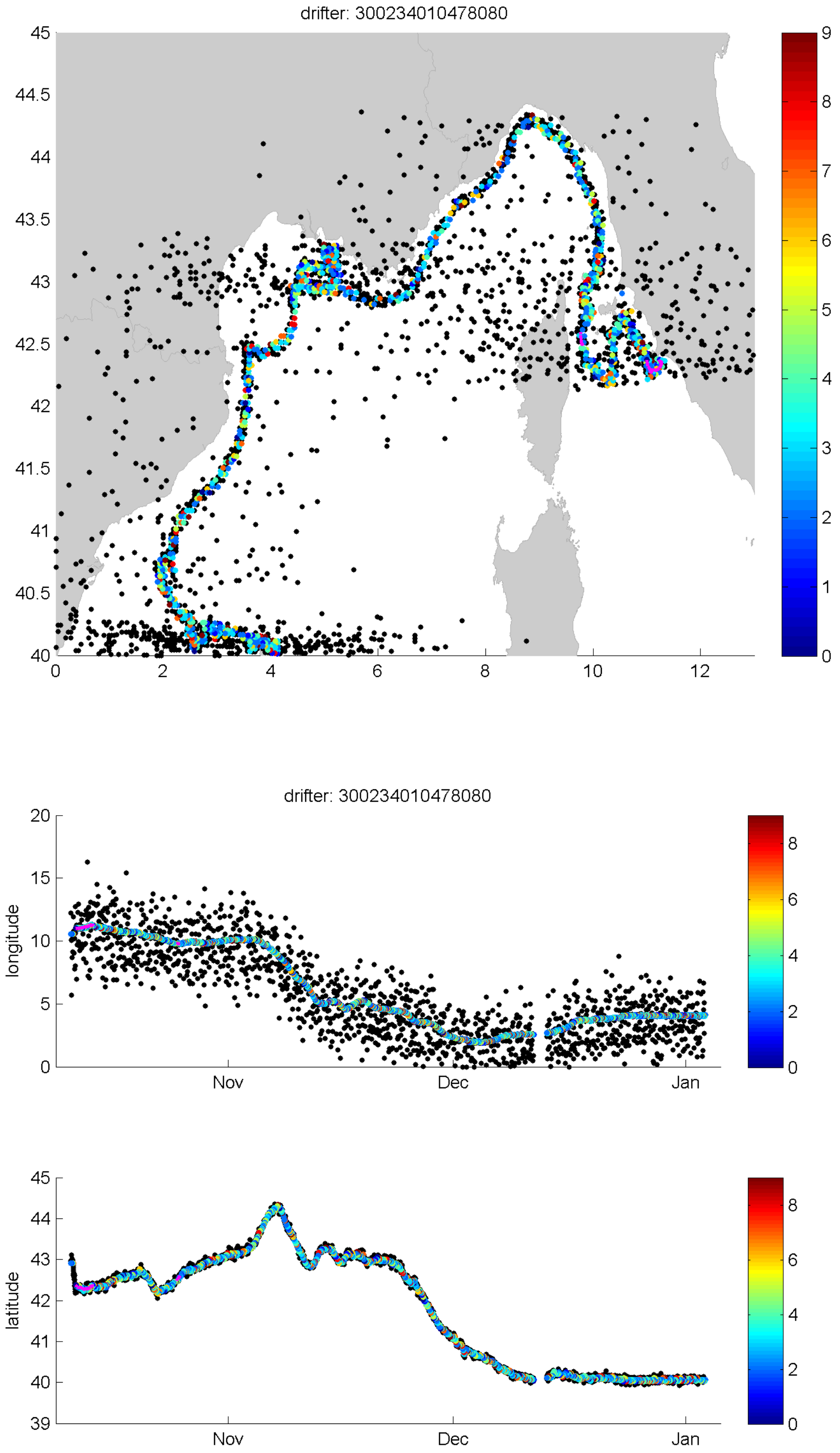


*Figure A8: Same as Figure A3 but for drifter 300234010478080.*

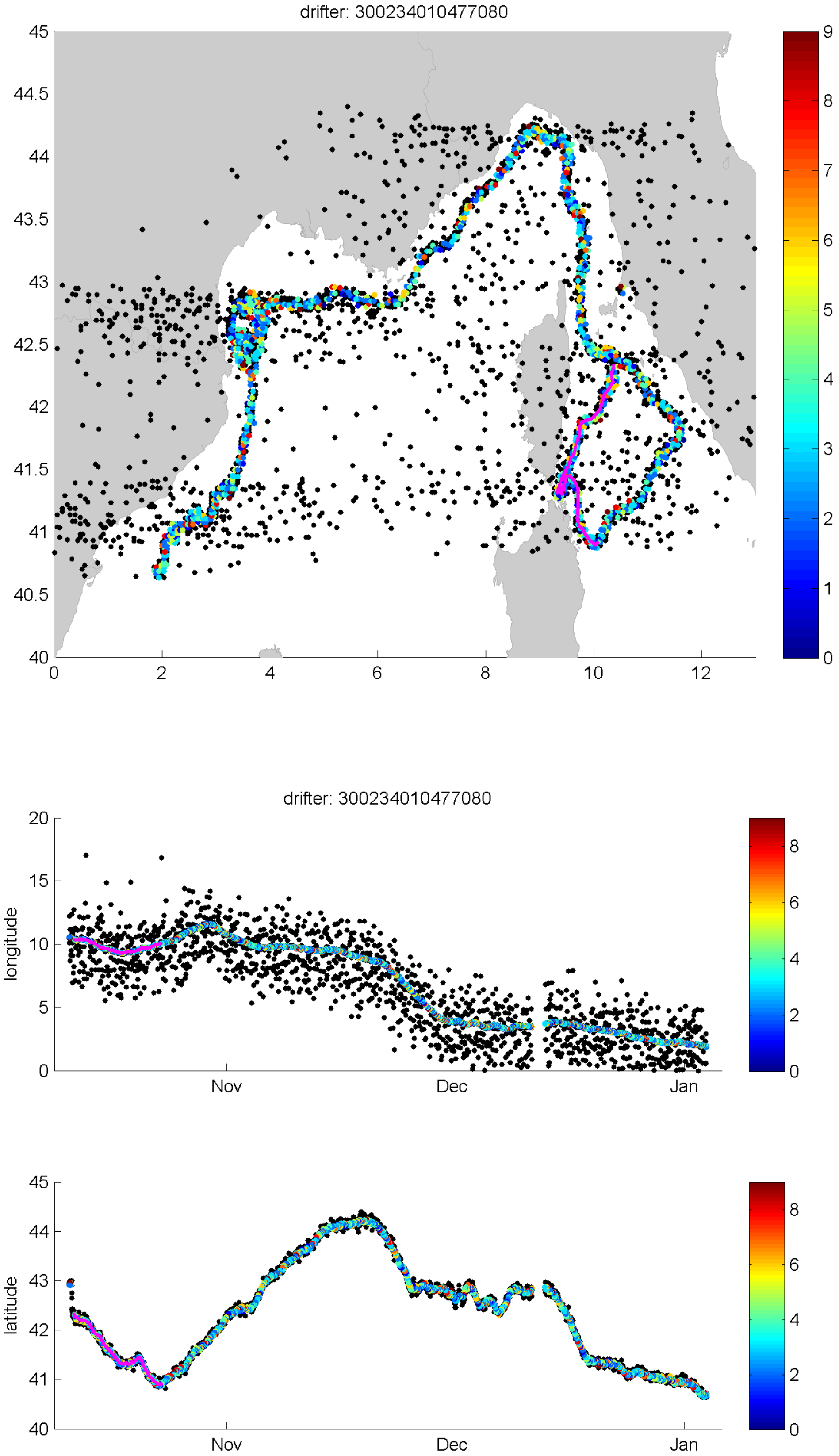


*Figure A9: Same as Figure A3 but for drifter 300234010477080.*

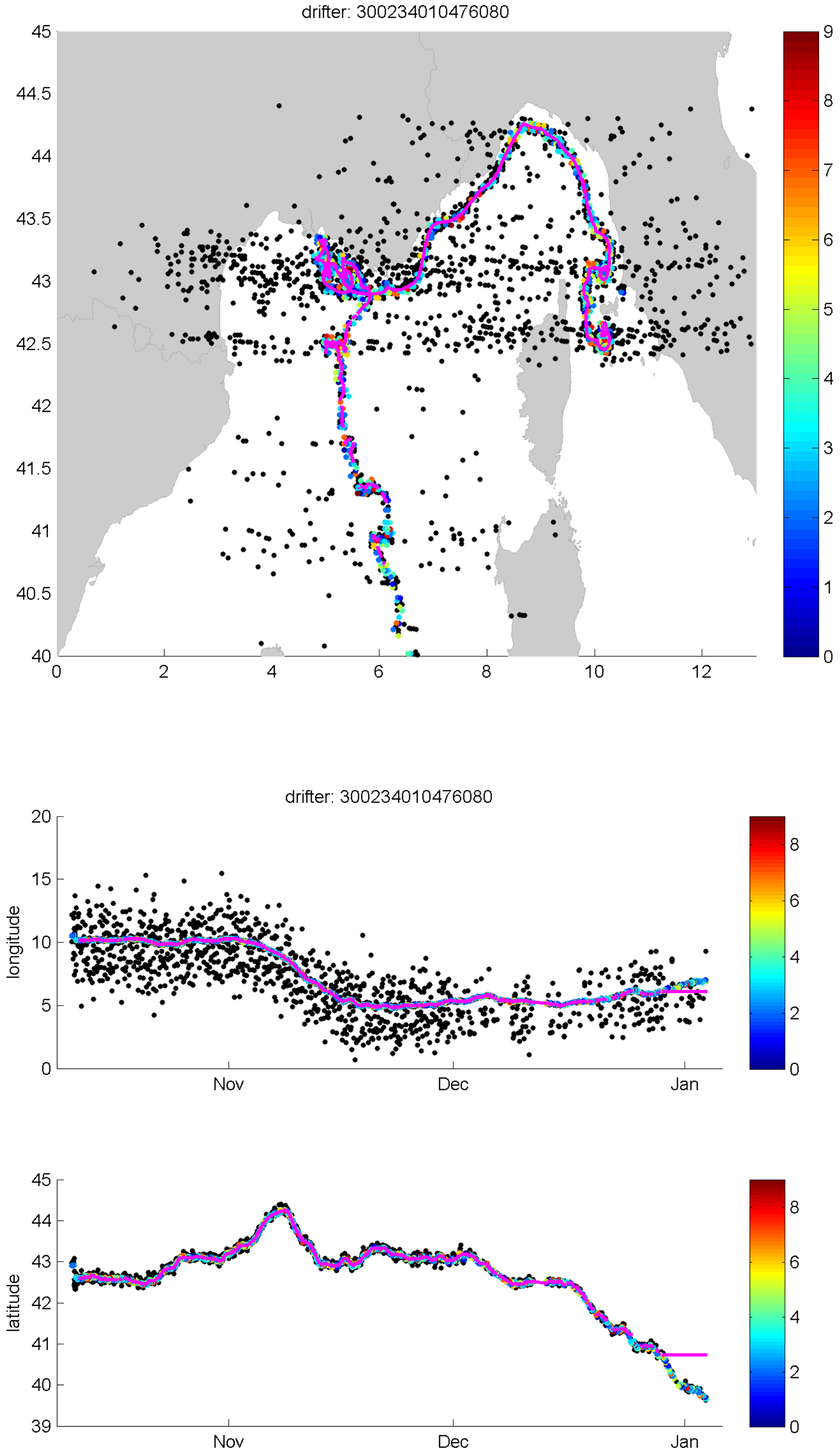


*Figure A10: Same as Figure A3 but for drifter 300234010476080.*

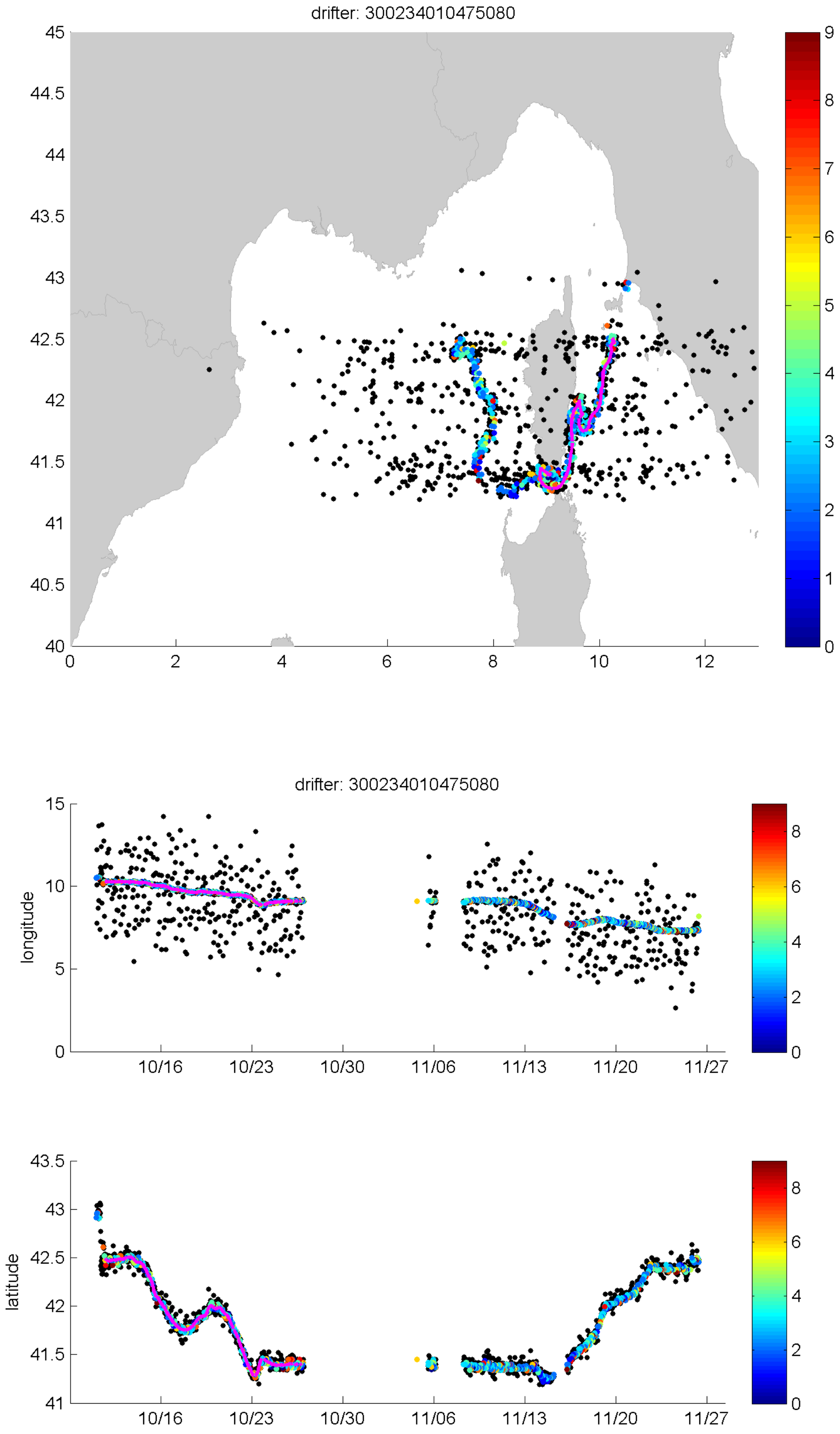


*Figure A11: Same as Figure A3 but for drifter 300234010475080.*

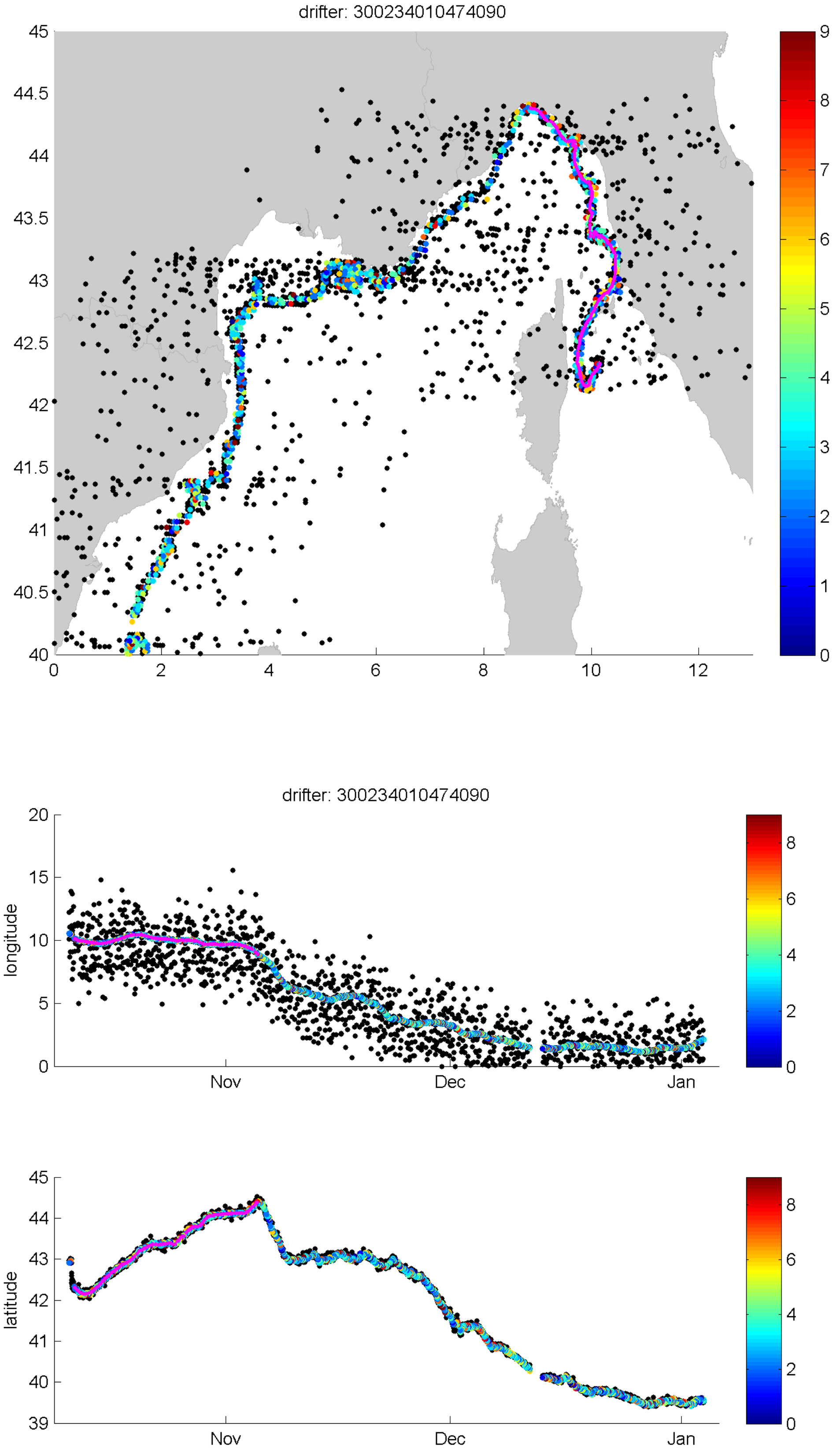


*Figure A12: Same as Figure A3 but for drifter 300234010474090.*

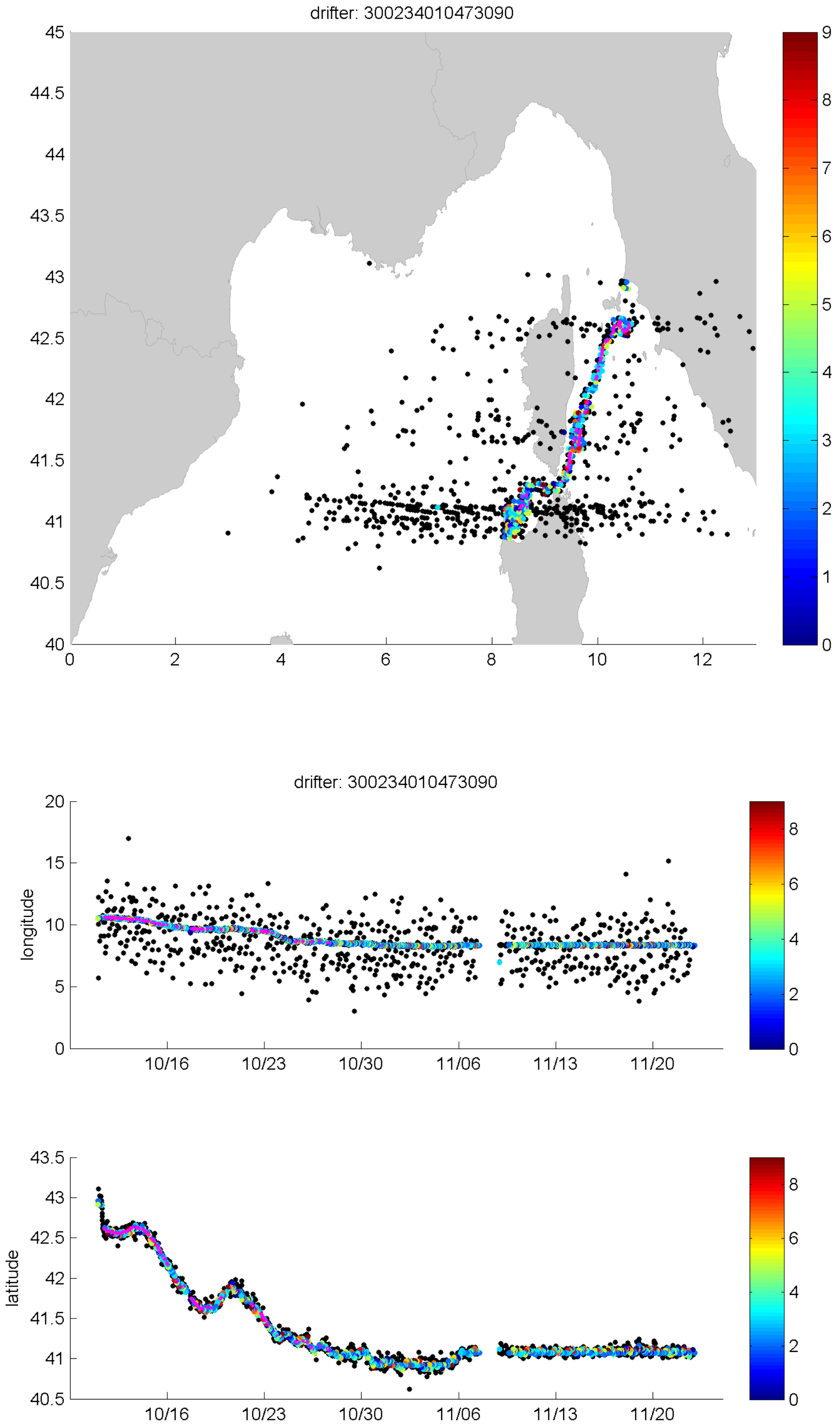


*Figure A13: Same as Figure A3 but for drifter 300234010473090.*

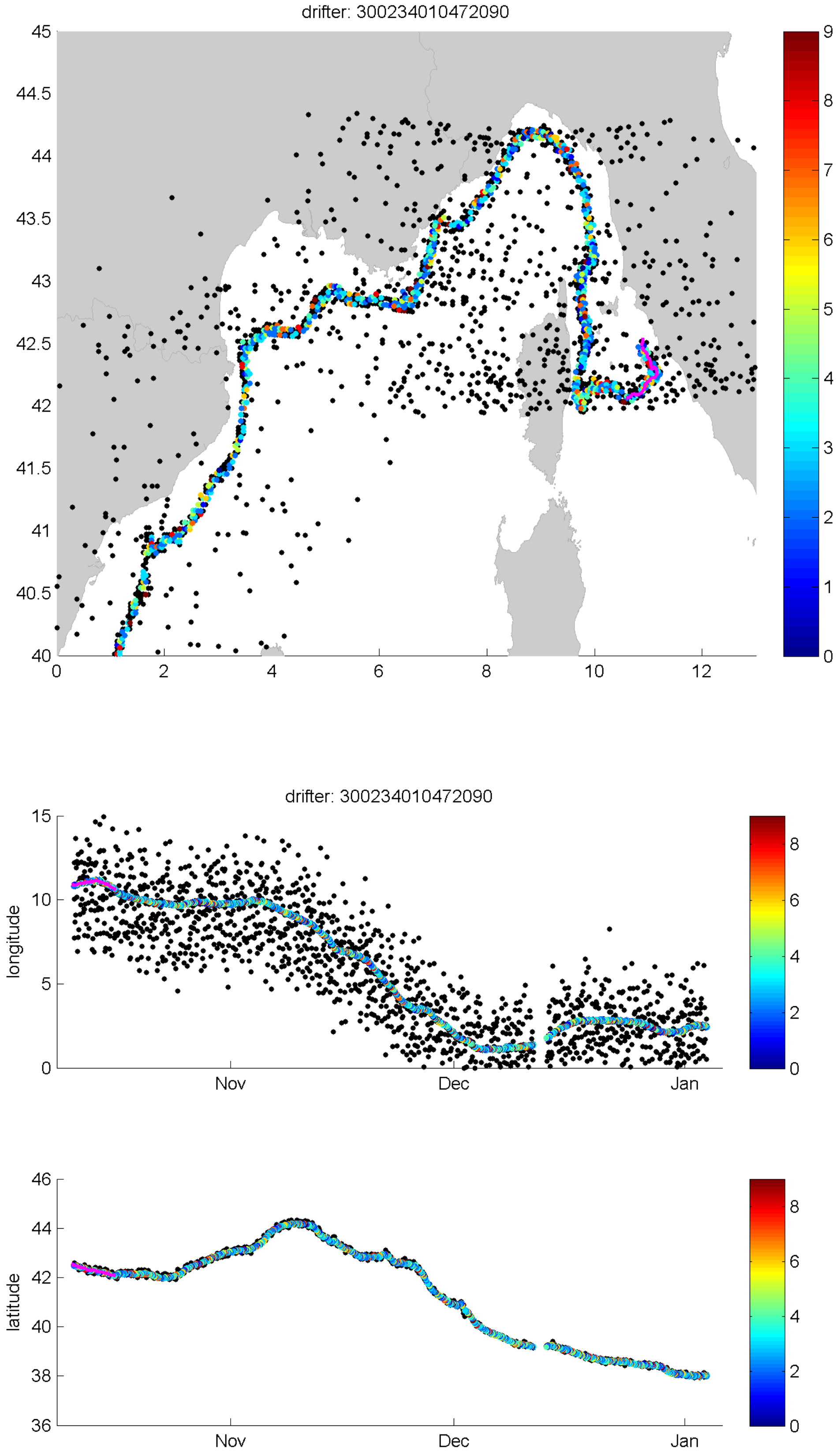


*Figure A14: Same as Figure A3 but for drifter 300234010472090.*

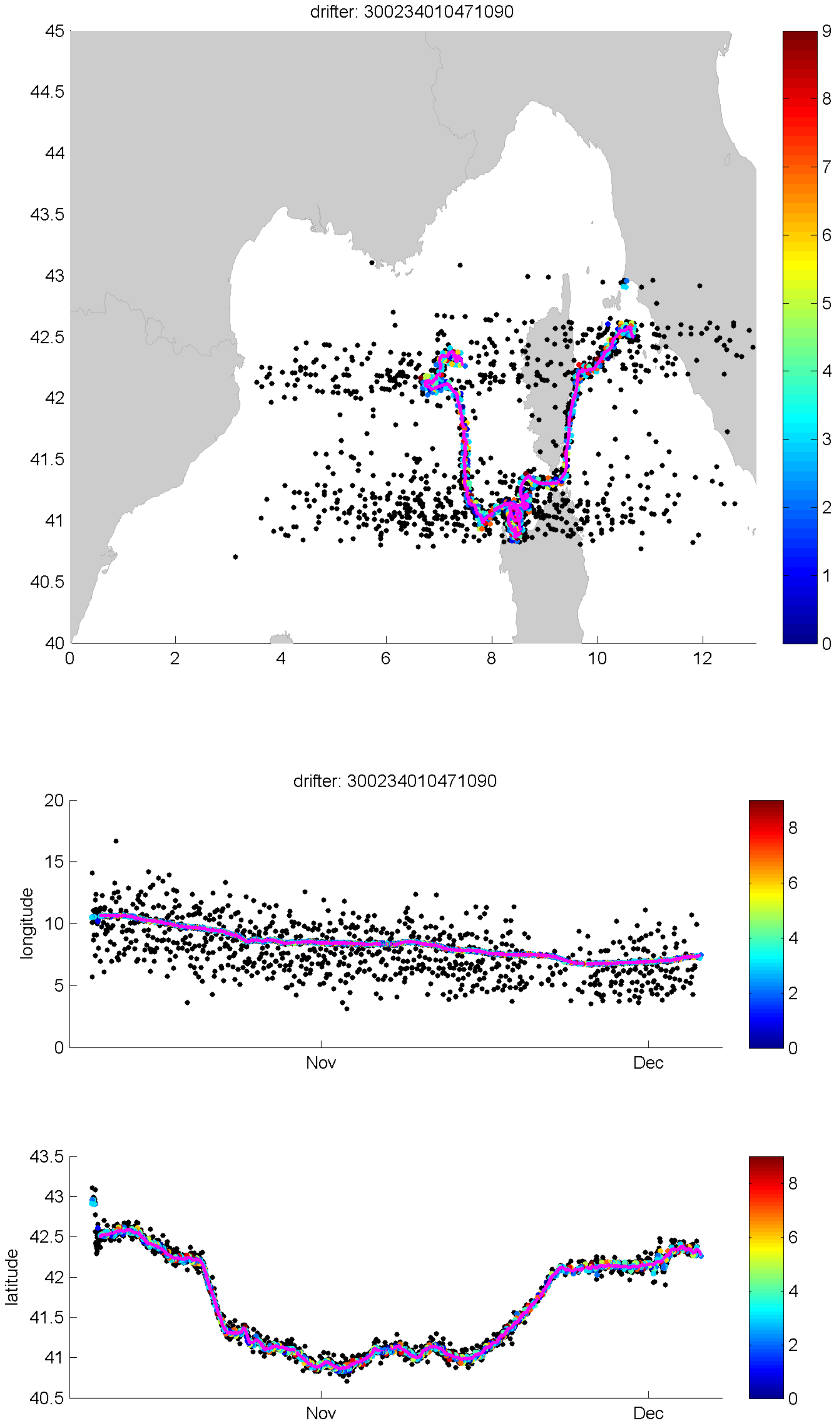


*Figure A15: Same as Figure A3 but for drifter 300234010471090.*

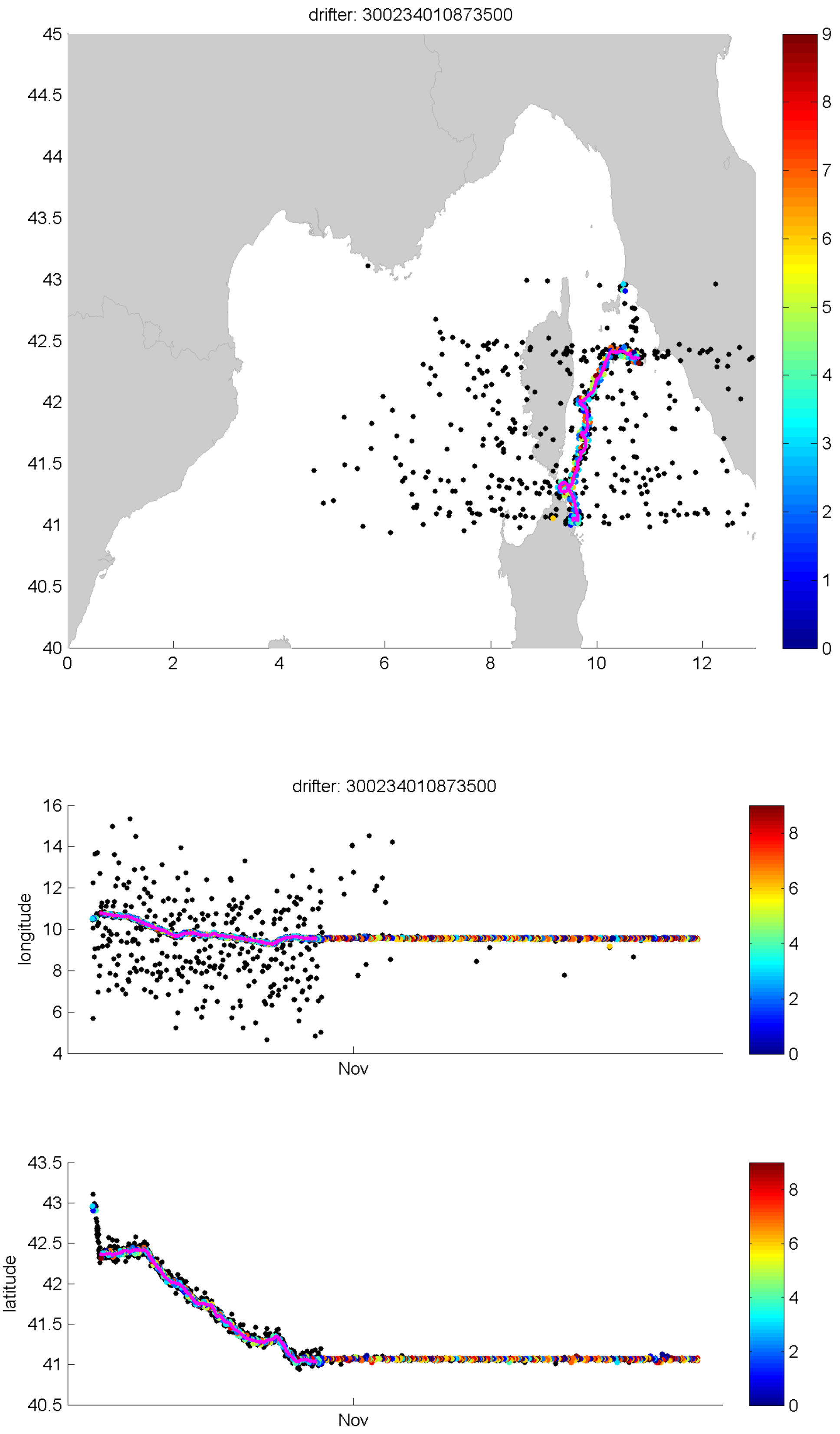


*Figure A16: Same as Figure A3 but for drifter 300234010873500.*

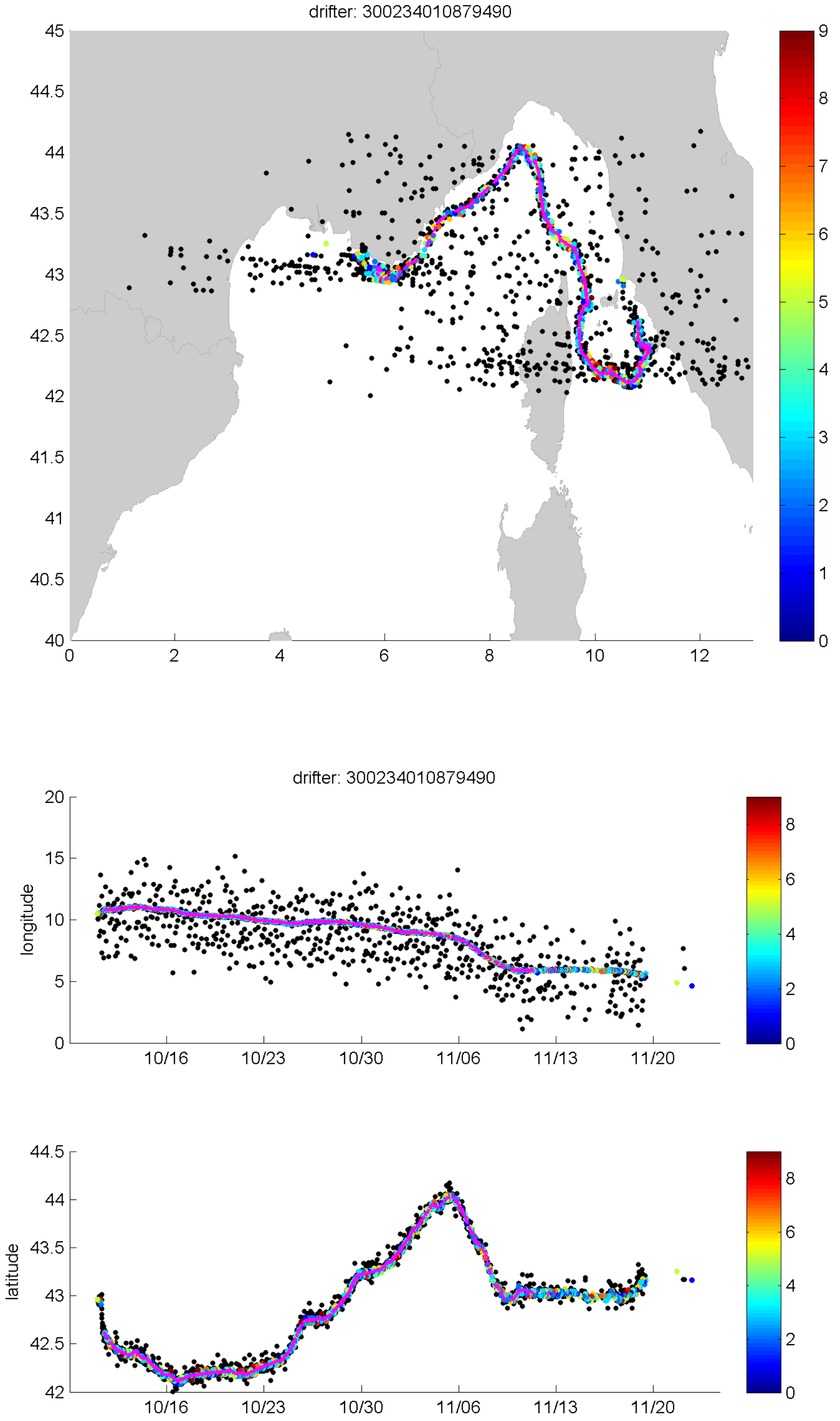


*Figure A17: Same as Figure A3 but for drifter 300234010879490.*

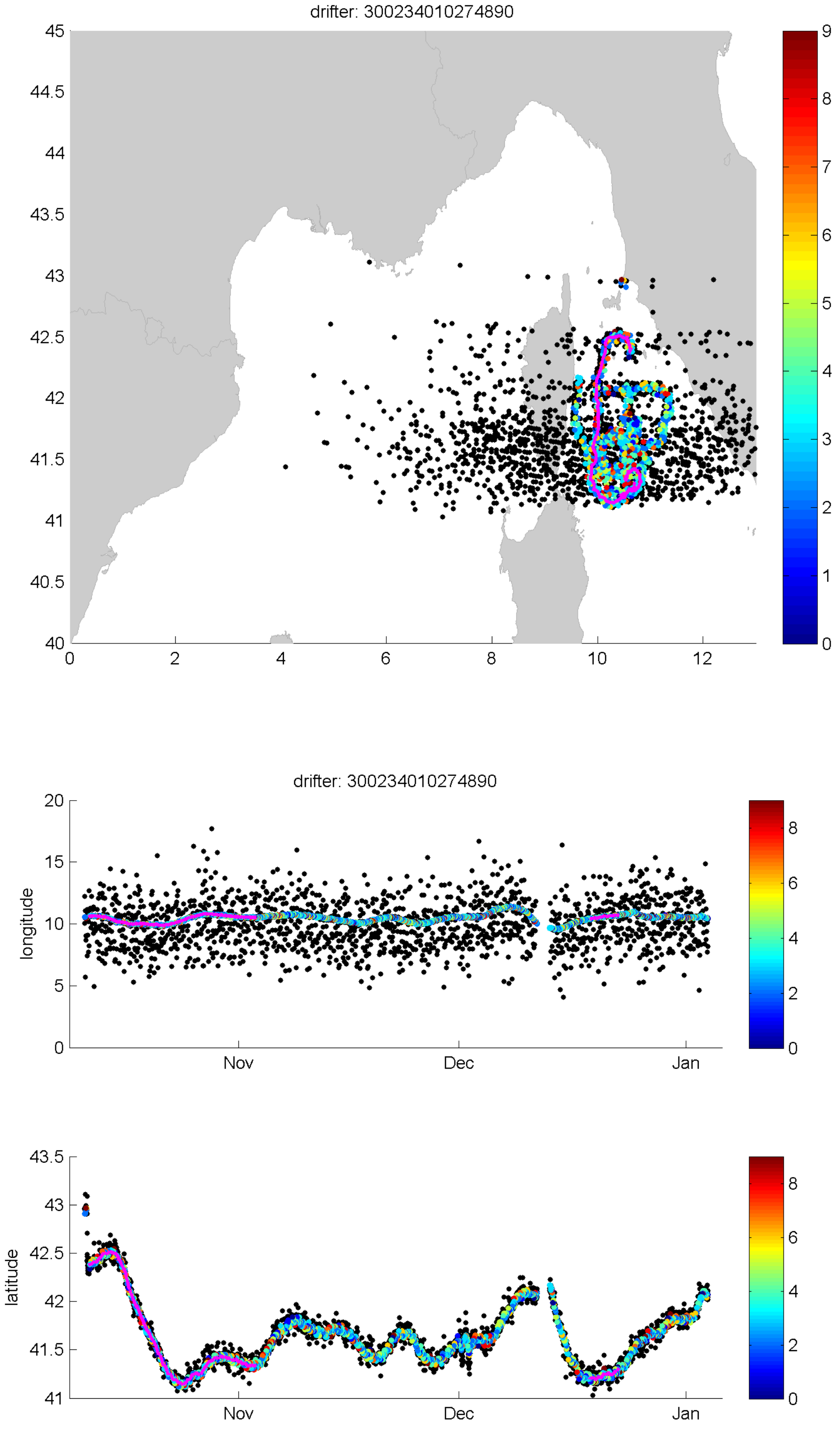


*Figure A18: Same as Figure A3 but for drifter 300234010274890.*

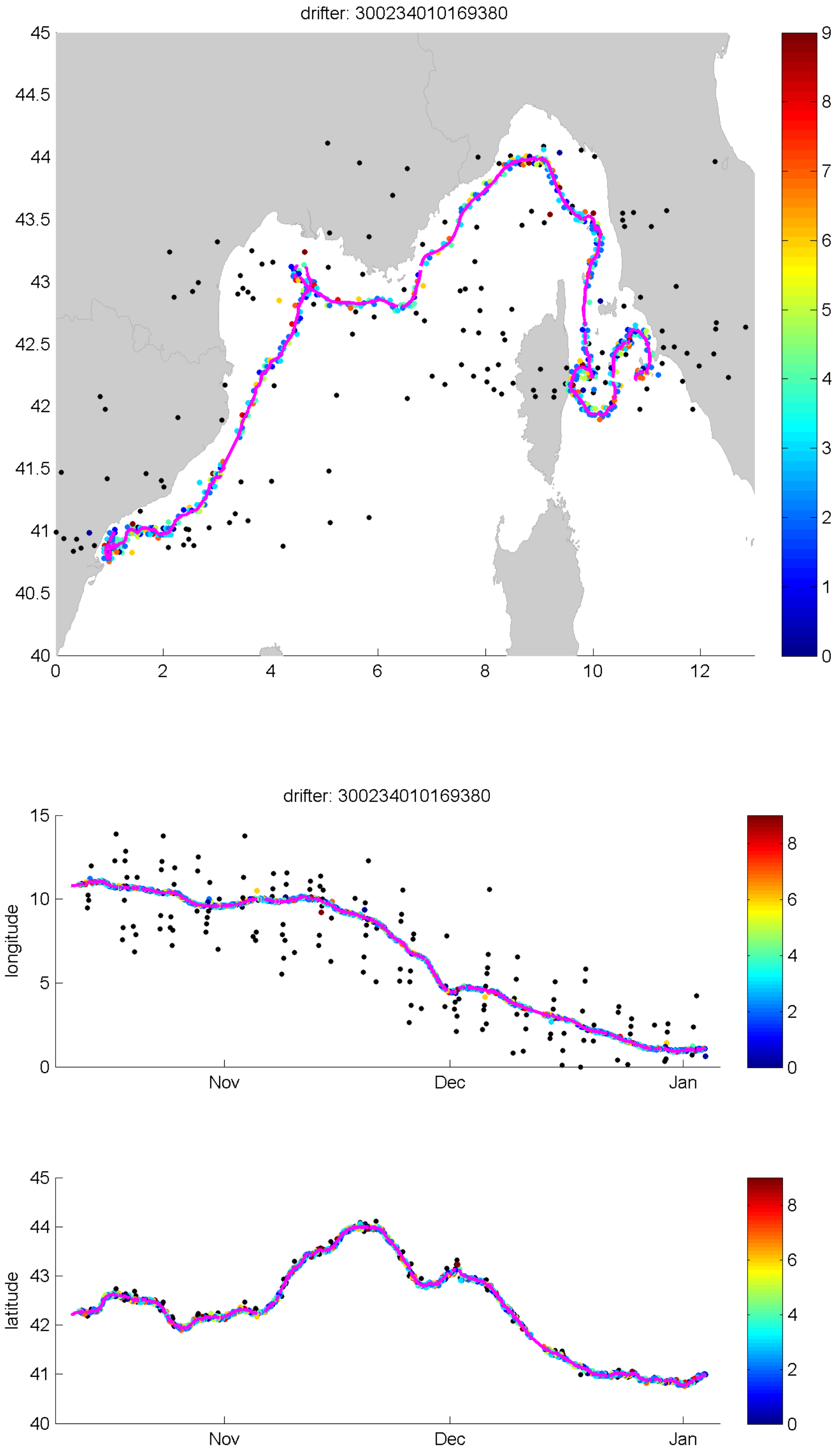
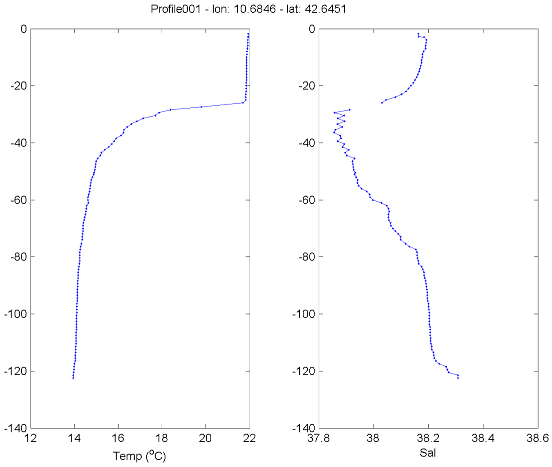
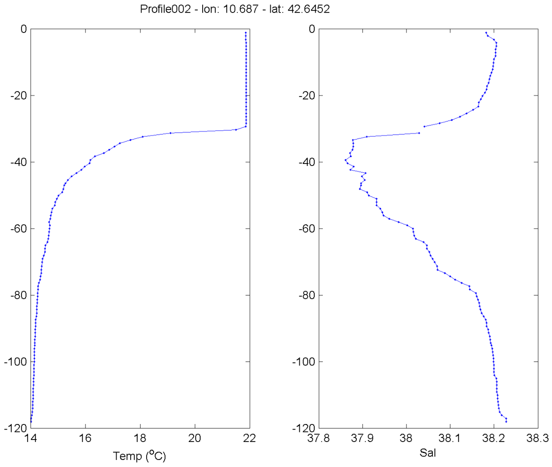


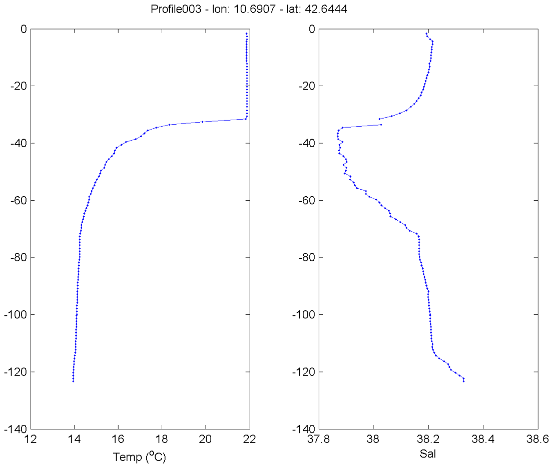
*Figure A19: Same as Figure A3 but for drifter 300234010169380.*

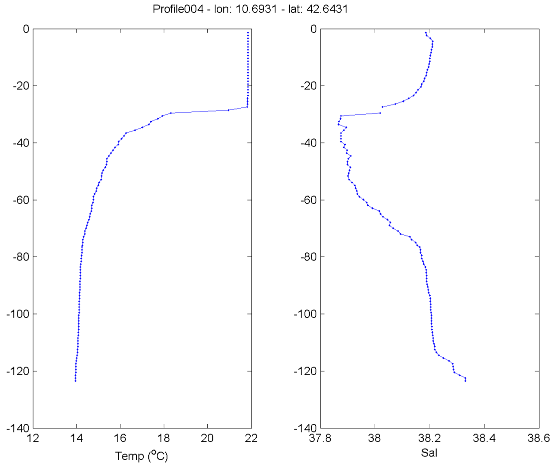
## 5.2 Individual temperature and salinity profiles measured by the Arvor-C

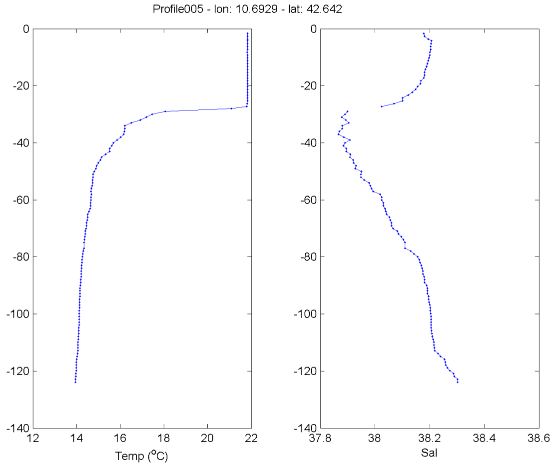
The following plots depict the 191 individual profiles of temperature and salinity measured by the Arvor-C between 11 October 2011 and 24 October 2011. Significant spikes have been removed.

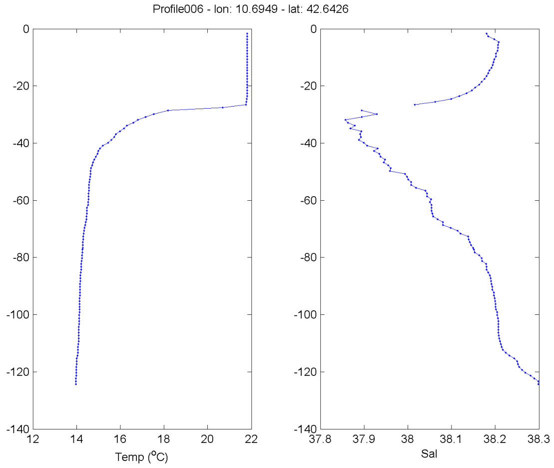


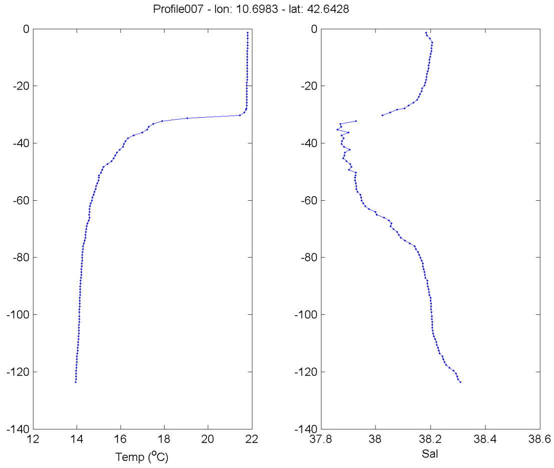








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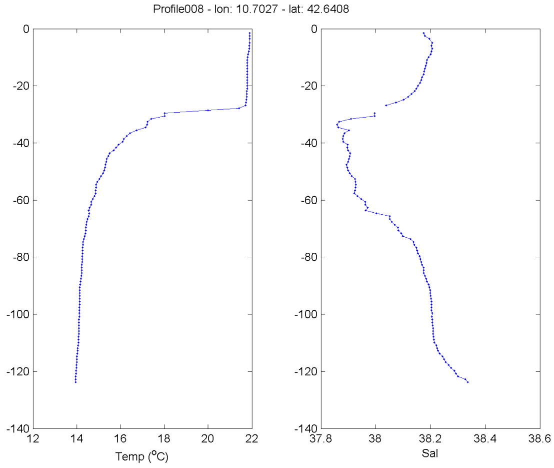
0
-20
-40
-60
-80
-100
-120
-140
12
14
16
18
20
22
Temp ($^oC$)
37.8
38
38.2
38.4
38.6
Sal


Profile008 - lon: 10.7027 - lat: 42.6408
0
-20
-40
-60
-80
-100
-120
-140
12
14
16
18
20
22
Temp ($^oC$)
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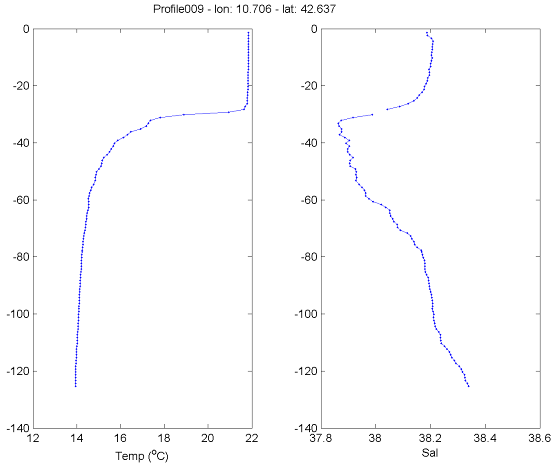
38
38.2
38.4
38.6
Sal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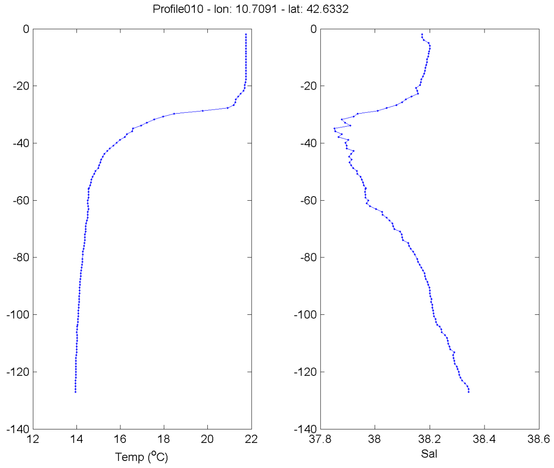
-20
-40
-60
-80
-100
-120
-140
12
14
16
18
20
22
Temp ($^oC$)
37.8
38
38.2
38.4
38.6
Sal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-60
-80
-100
-120
-140
12
14
16
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Temp ($^oC$)
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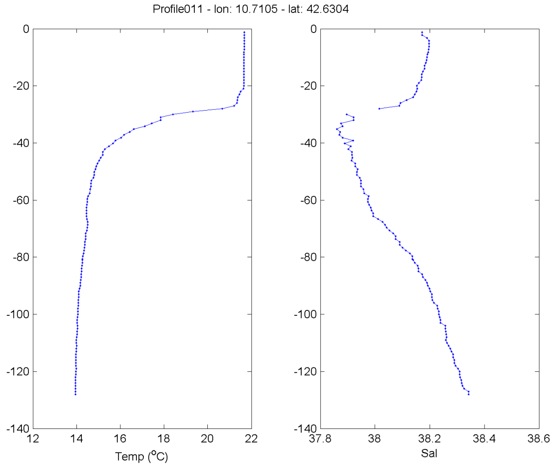
38
38.2
38.4
38.6
Sal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-20
-40
-60
-80
-100
-120
-140
12
14
16
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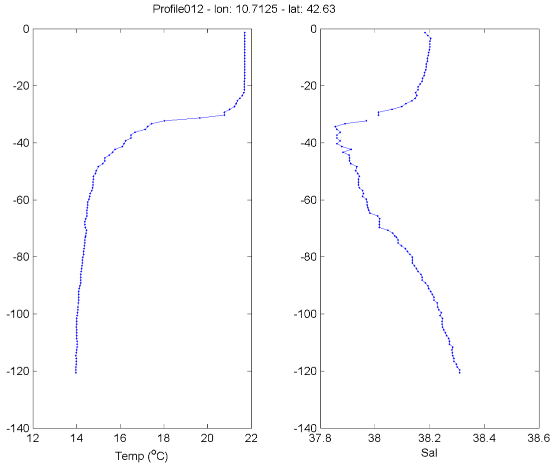
22
Temp ($^oC$)
37.8
38
38.2
38.4
38.6
Sal


Profile012 - lon: 10.7125 - lat: 42.63
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-60
-80
-100
-120
-140
12
14
16
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Temp ($^oC$)
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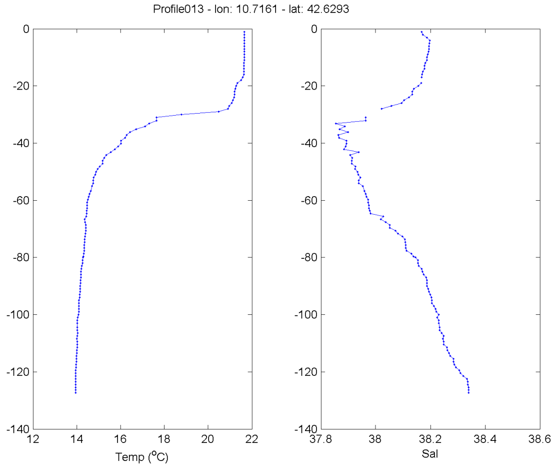
38
38.2
38.4
38.6
Sal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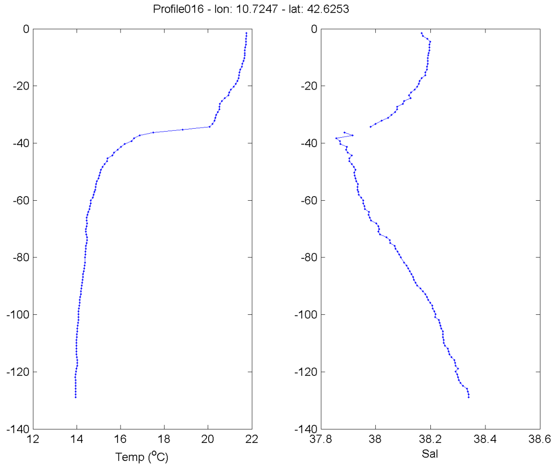
0
-20
-40
-60
-80
-100
-120
-140
12
14
16
18
20
22
Temp (°C)
37.8
38
38.2
38.4
38.6
Sal


Profile016 - lon: 10.7247 - lat: 42.6253
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Temp (°C)
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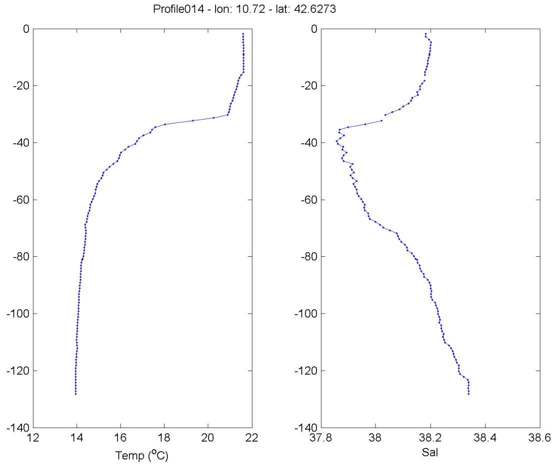
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Temp (°C)
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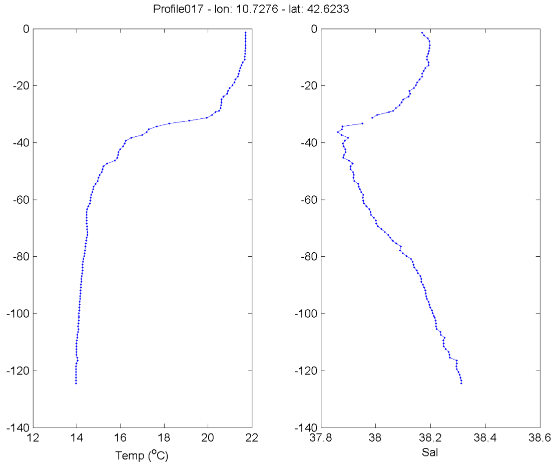
Sal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Temp (°C)
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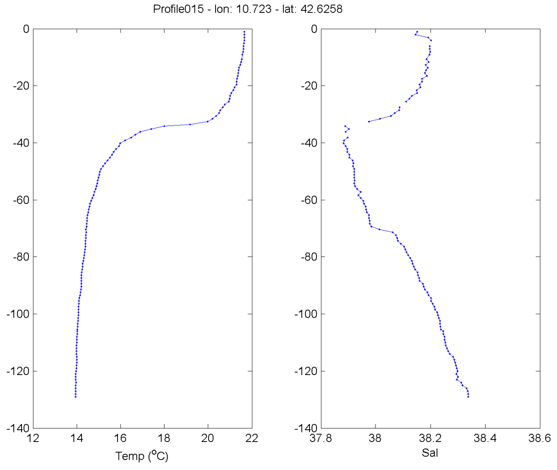
Sal


Profile015 - lon: 10.723 - lat: 42.6258
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Temp (°C)
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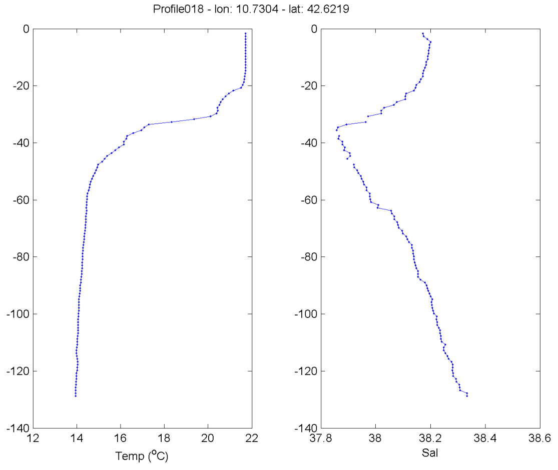
Sal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Temp (°C)
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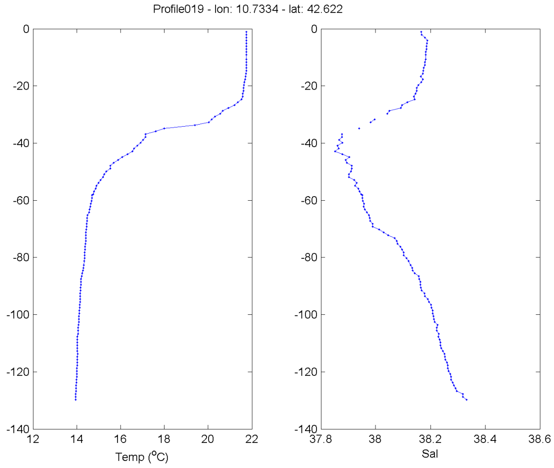
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Temp (°C)
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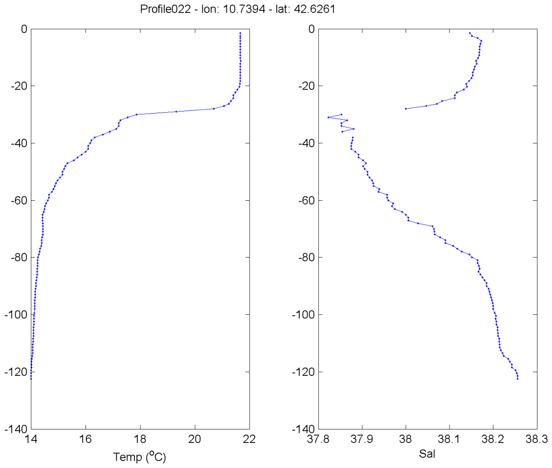
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Temp (°C)
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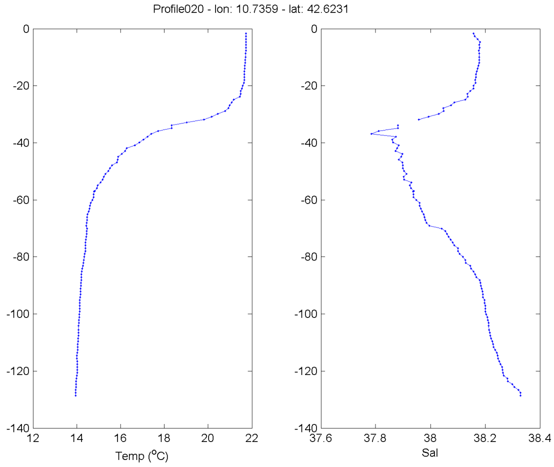
38.2
38.3
Sal


Profile020 - lon: 10.7359 - lat: 42.6231
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Temp (°C)
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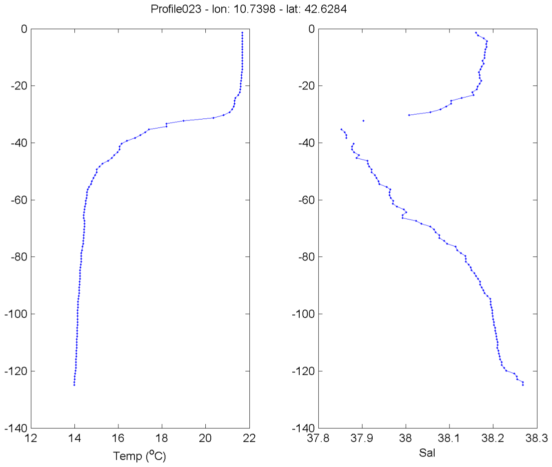
Sal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Temp (°C)
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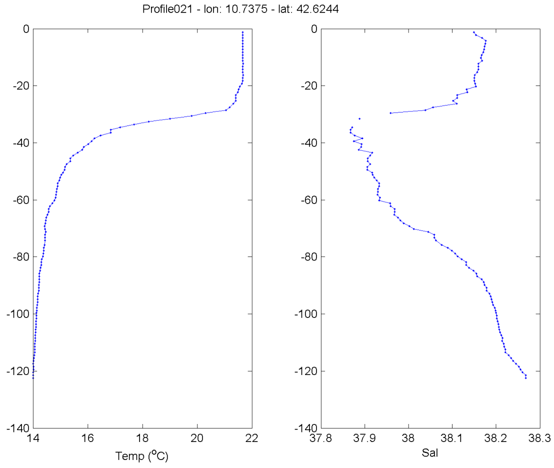
Sal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Temp (°C)
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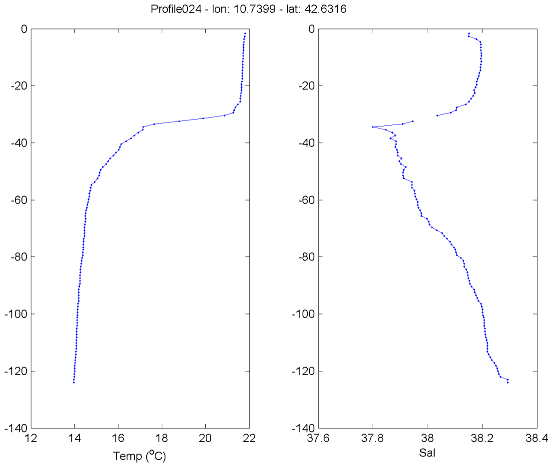
Sal


Profile024 - lon: 10.7399 - lat: 42.6316
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Temp (°C)
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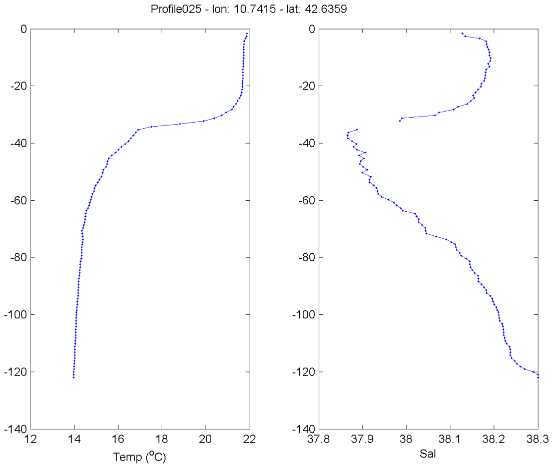
38
38.2
38.4
Sal


Profile025 - lon: 10.7415 - lat: 42.6359
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Temp (°C)
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37.9
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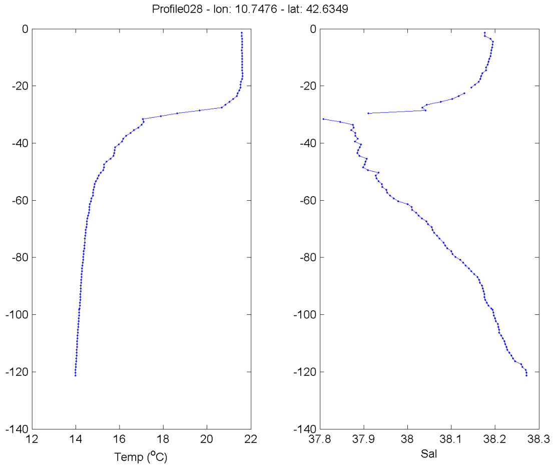
38.1
38.2
38.3
Sal


Profile028 - lon: 10.7476 - lat: 42.6349
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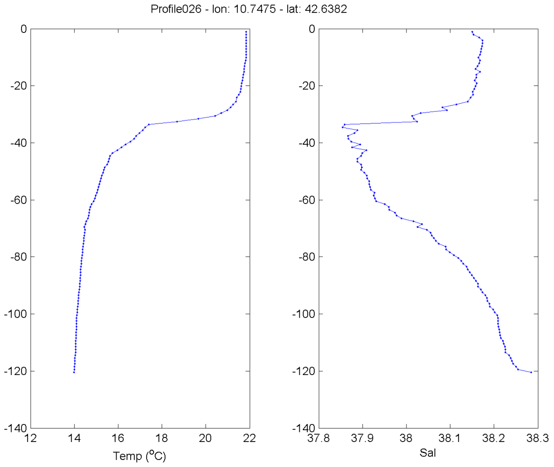
Temp (°C)
37.8
37.9
38
38.1
38.2
38.3
Sal


Profile026 - lon: 10.7475 - lat: 42.6382
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Temp (°C)
37.8
37.9
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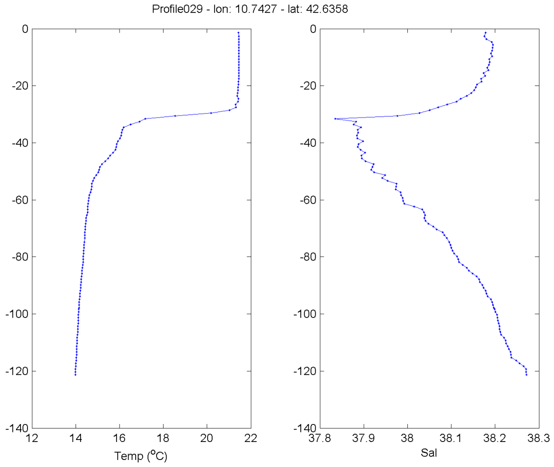
38.1
38.2
38.3
Sal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Temp (°C)
37.8
37.9
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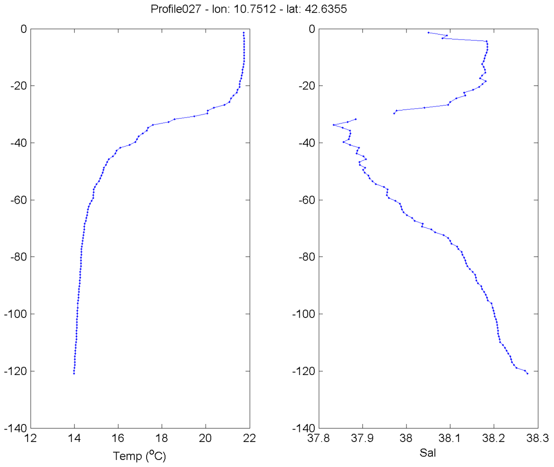
38.1
38.2
38.3
Sal


Profile027 - lon: 10.7512 - lat: 42.6355
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Temp (°C)
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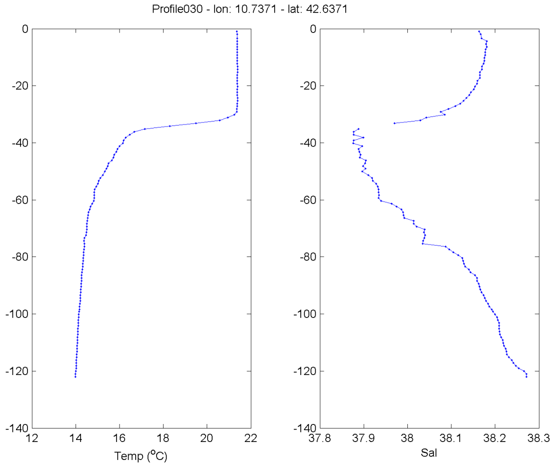
38.3
Sal


Profile030 - lon: 10.7371 - lat: 42.6371
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Temp (°C)
37.8
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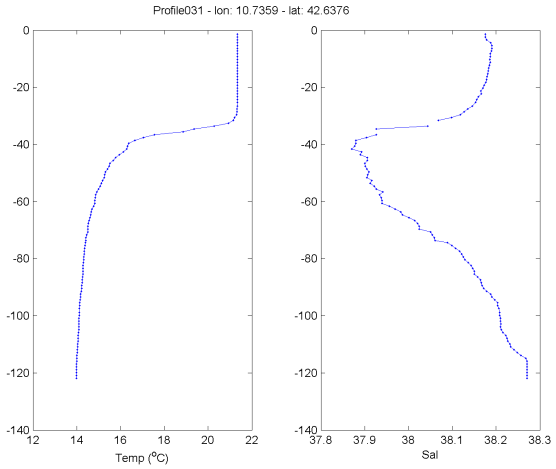
38.1
38.2
38.3
Sal


Profile031 - lon: 10.7359 - lat: 42.6376
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Temp (°C)
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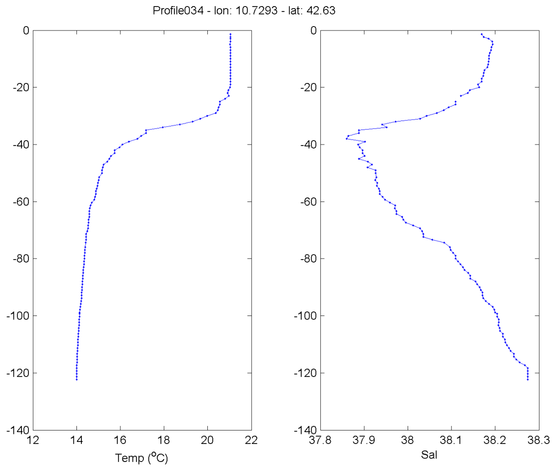
Sal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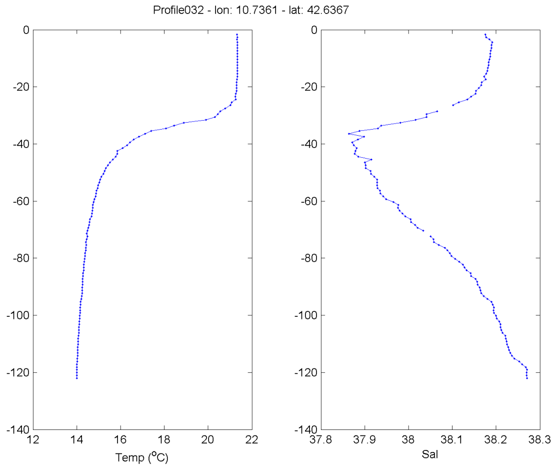
Temp (°C)
37.8
37.9
38
38.1
38.2
38.3
Sal


Profile032 - lon: 10.7361 - lat: 42.6367
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Temp (°C)
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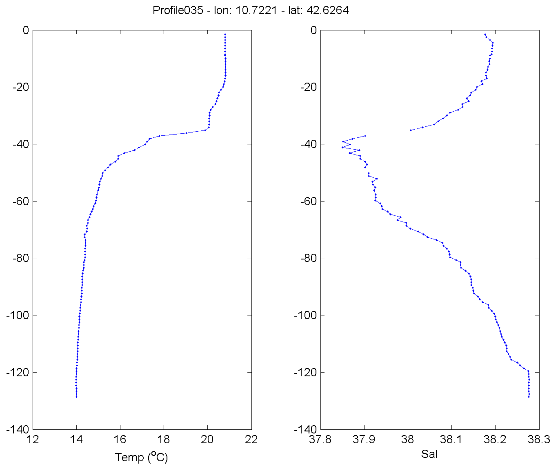
38.2
38.3
Sal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Temp (°C)
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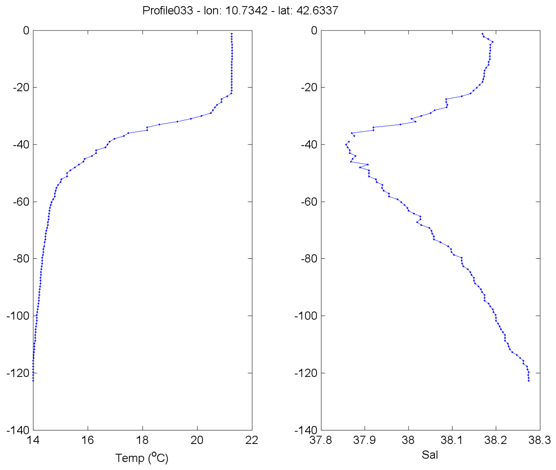
38.2
38.3
Sal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Temp (°C)
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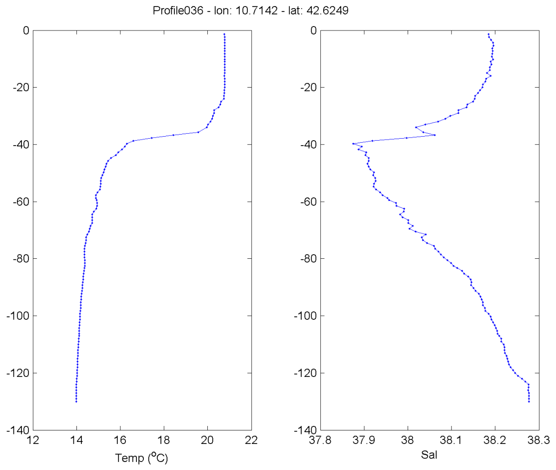
Sal


Profile036 - lon: 10.7142 - lat: 42.6249
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Temp (°C)
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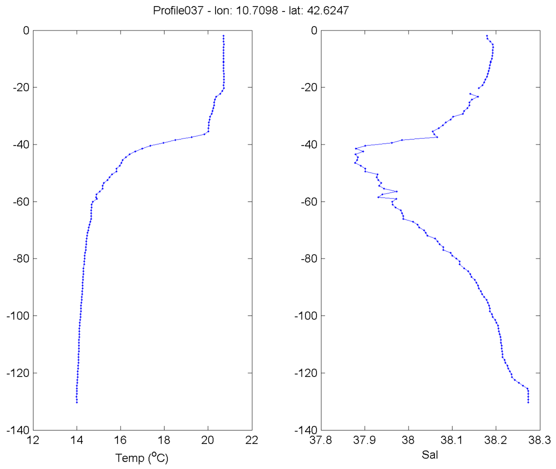
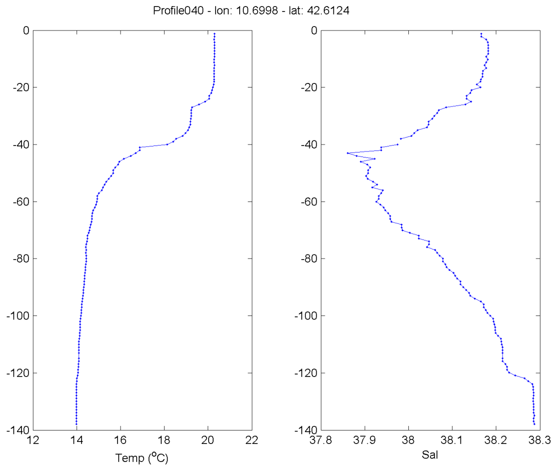
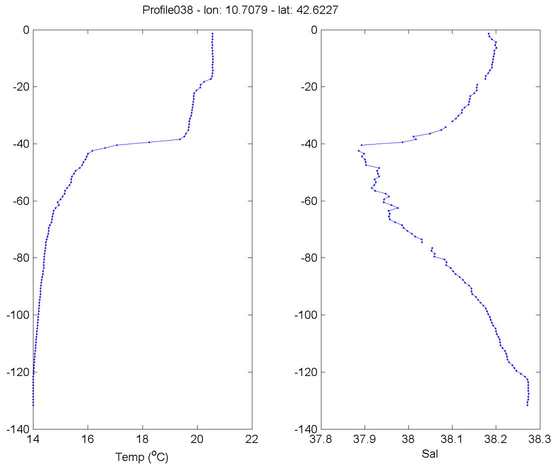
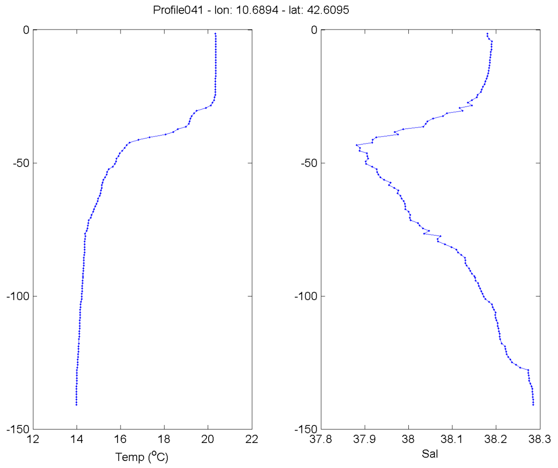
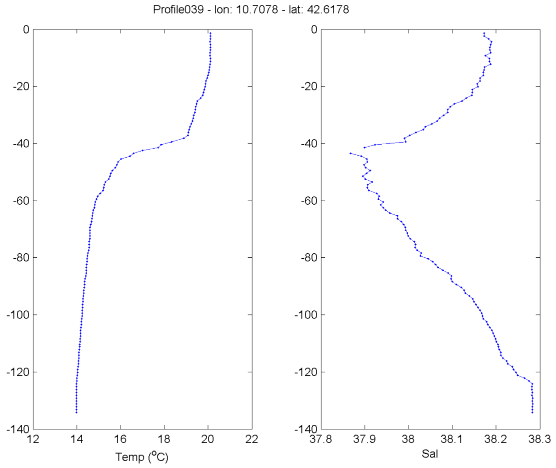
Sal

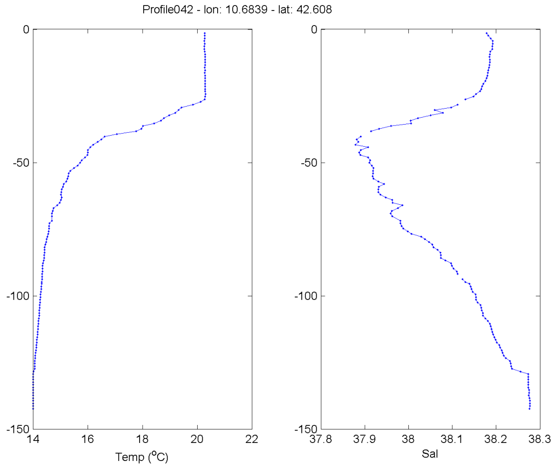

Profile037 - lon: 10.7098 - lat: 42.6247

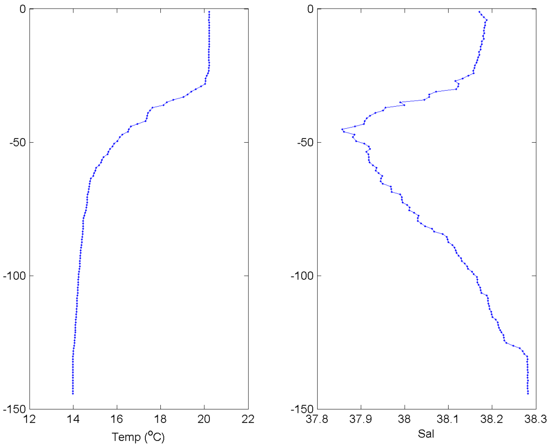

Profile040 - lon: 10.6998 - lat: 42.6124

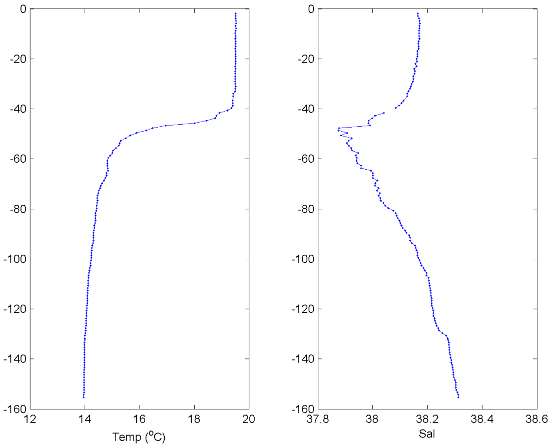

Profile038 - lon: 10.7079 - lat: 42.6227

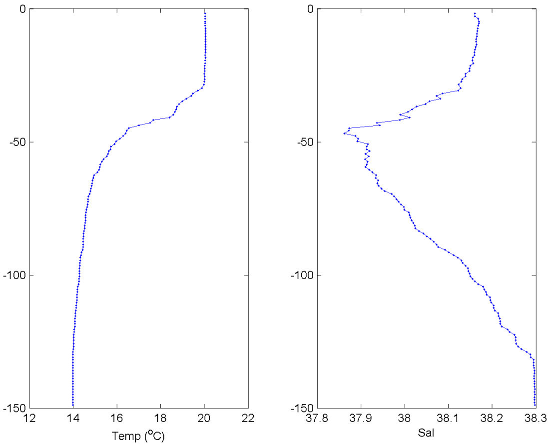

Profile041 - lon: 10.6894 - lat: 42.6095

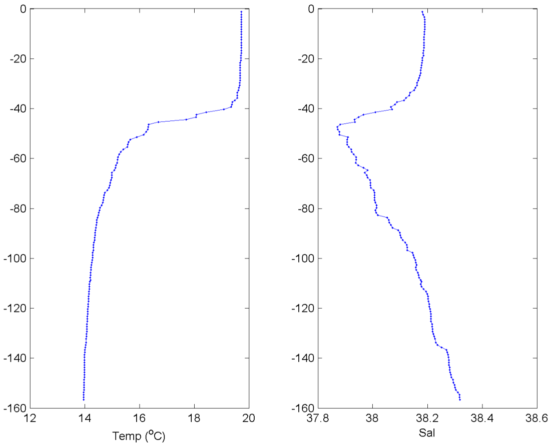

Profile039 - lon: 10.7078 - lat: 42.6178

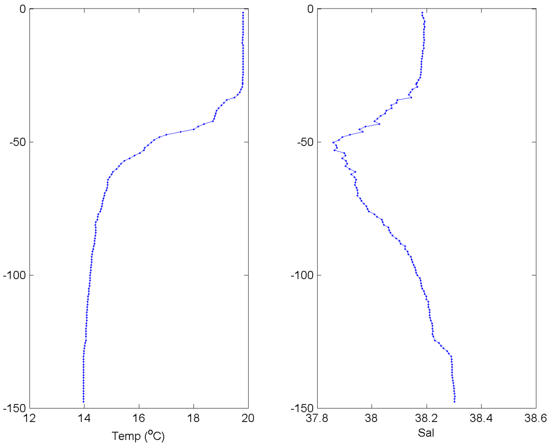

Profile042 - lon: 10.6839 - lat: 42.608

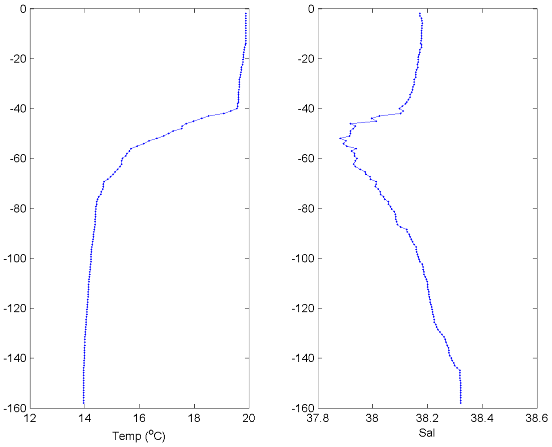

Profile043 - lon: 10.6805 - lat: 42.6053

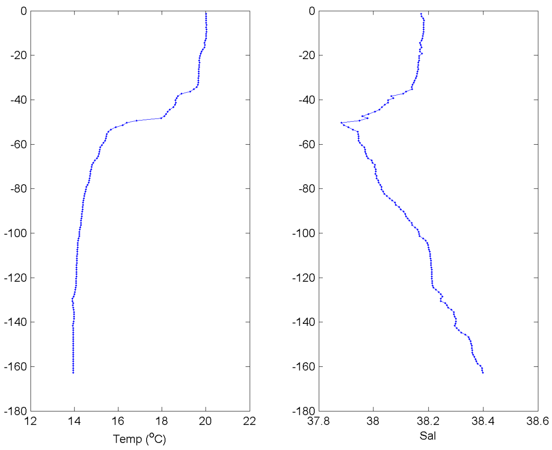

Profile046 - lon: 10.6516 - lat: 42.5916

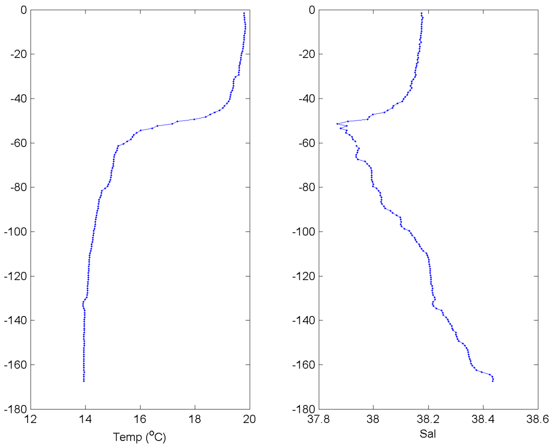

Profile044 - lon: 10.674 - lat: 42.6002

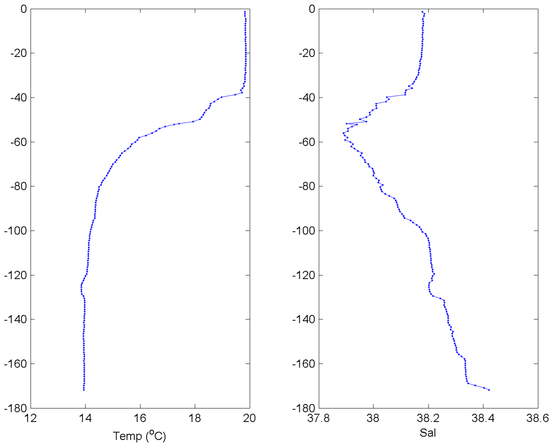

Profile047 - lon: 10.6406 - lat: 42.5886

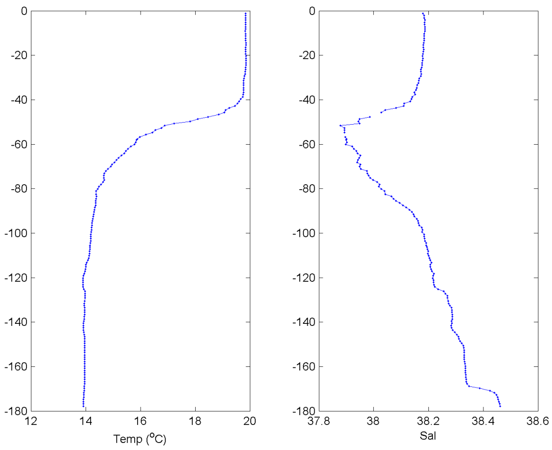

Profile045 - lon: 10.6635 - lat: 42.5949

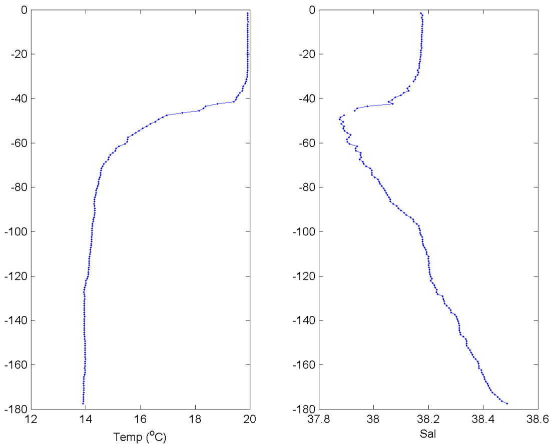

Profile048 - lon: 10.6305 - lat: 42.586

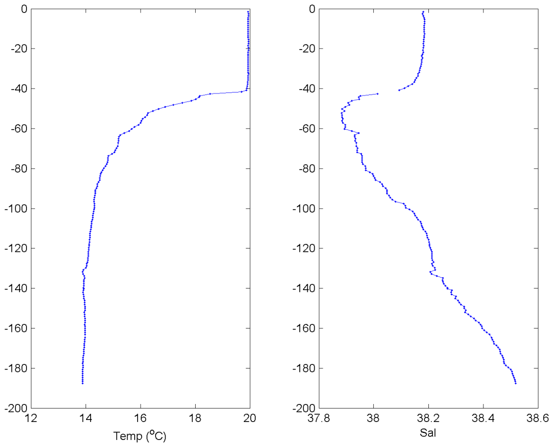

Profile049 - lon: 10.6173 - lat: 42.5787

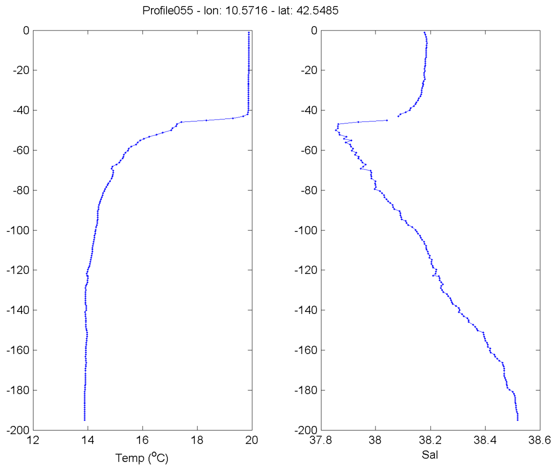

Profile050 - lon: 10.6079 - lat: 42.5735


Profile051 - lon: 10.6 - lat: 42.5687


Profile052 - lon: 10.5911 - lat: 42.5628


Profile053 - lon: 10.5821 - lat: 42.5583


Profile054 - lon: 10.5768 - lat: 42.5536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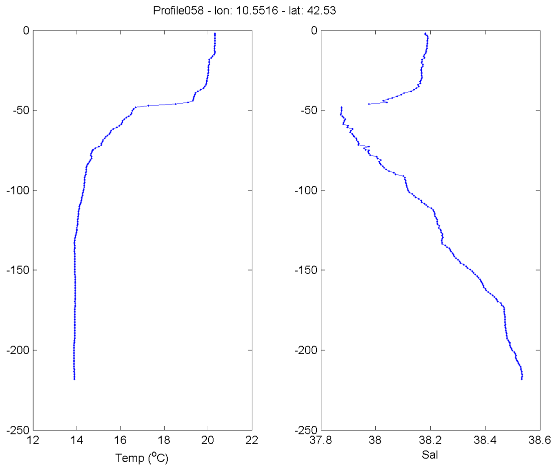
Temp (°C)
37.8
38
38.2
38.4
38.6
Sal


Profile058 - lon: 10.5516 - lat: 42.53
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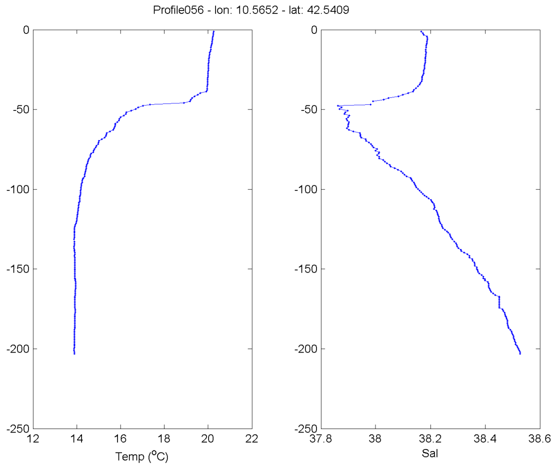
18
20
22
Temp (°C)
37.8
38
38.2
38.4
38.6
Sal


Profile056 - lon: 10.5652 - lat: 42.5409
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Temp (°C)
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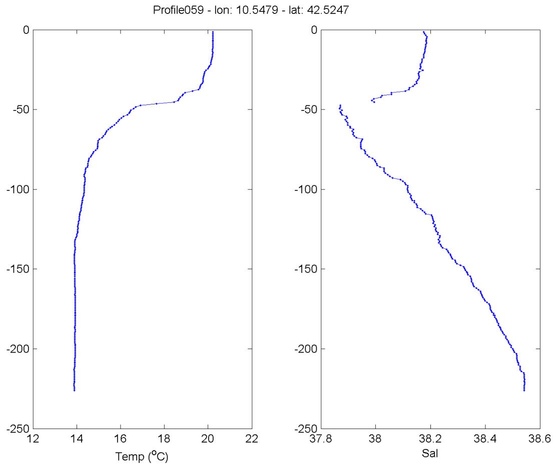
38.2
38.4
38.6
Sal


Profile059 - lon: 10.5479 - lat: 42.5247
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Temp (°C)
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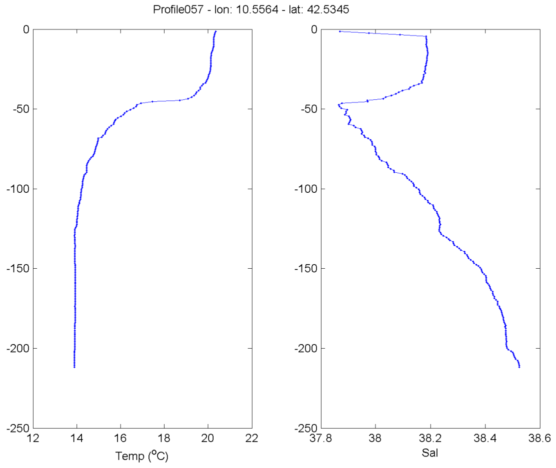
38.2
38.4
38.6
Sal


Profile057 - lon: 10.5564 - lat: 42.5345
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Temp (°C)
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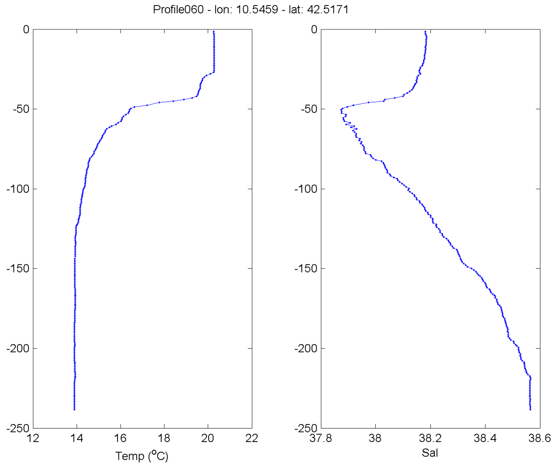
38.2
38.4
38.6
Sal


Profile060 - lon: 10.5459 - lat: 42.5171
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Temp (°C)
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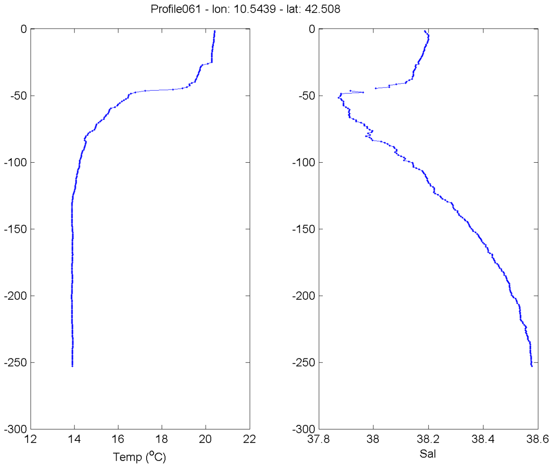
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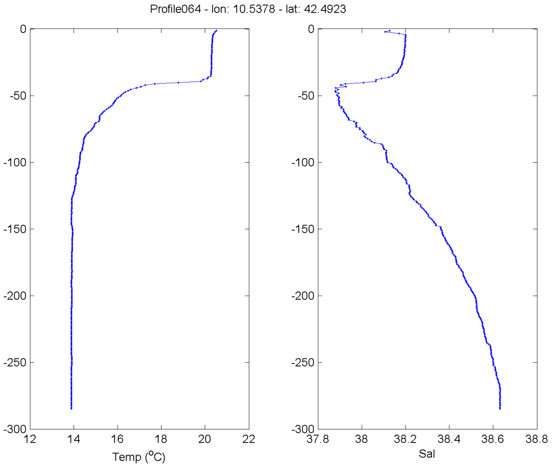
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Temp (°C)
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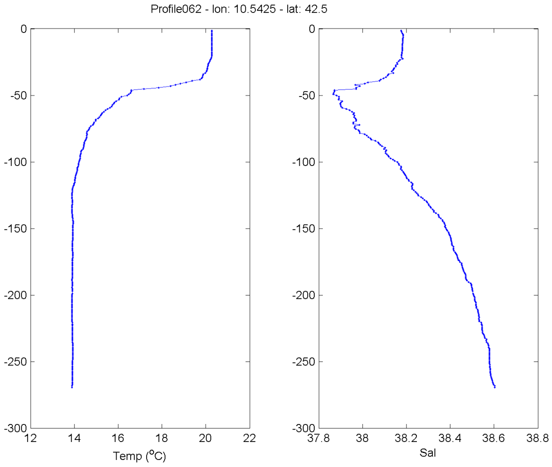
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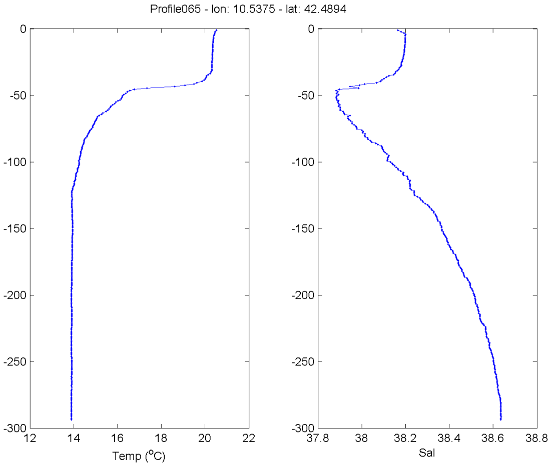
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Temp (°C)
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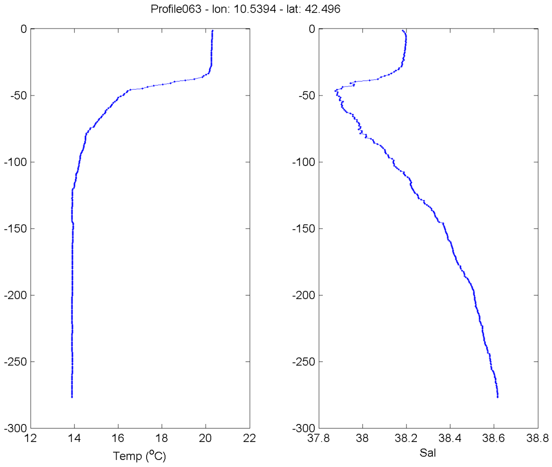
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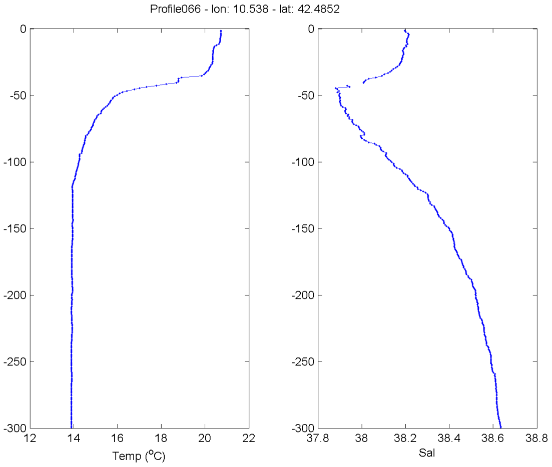
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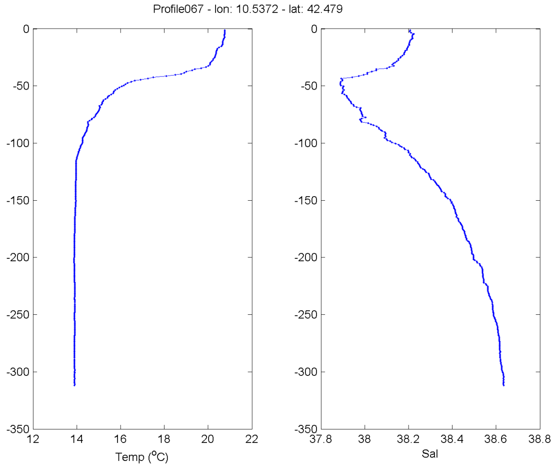
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Temp (°C)
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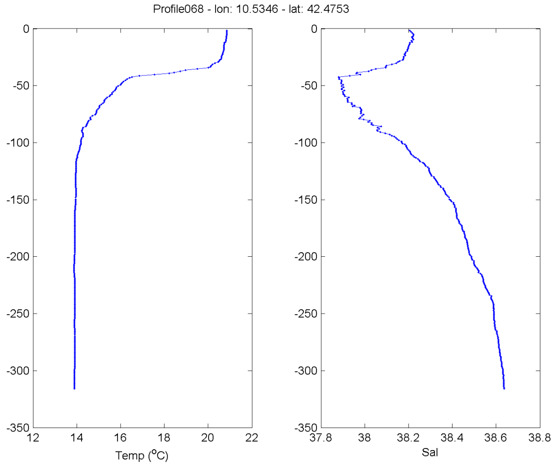
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Temp (°C)
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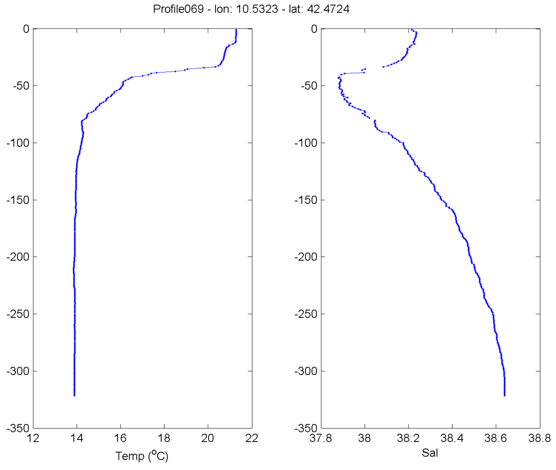
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Temp (°C)
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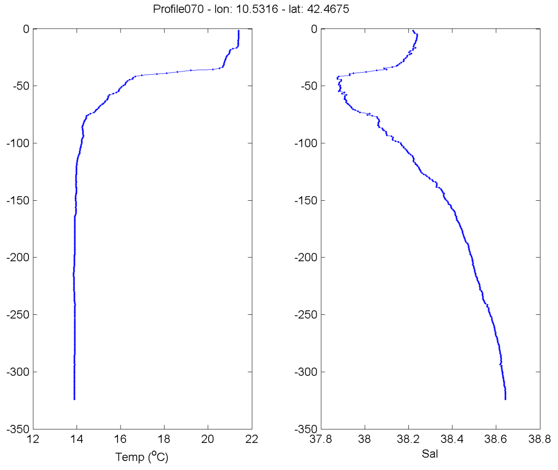
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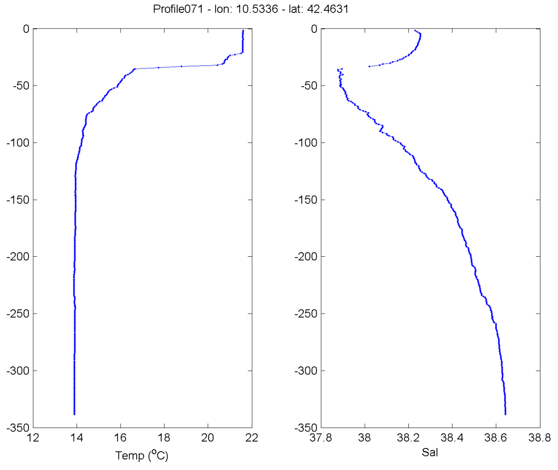
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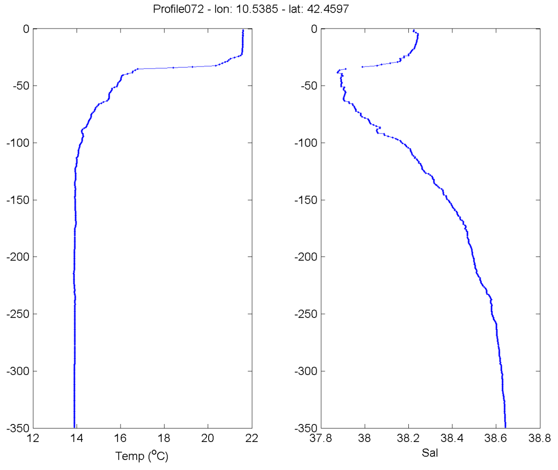
Sal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12 14 16 18 20 22
Temp (°C)
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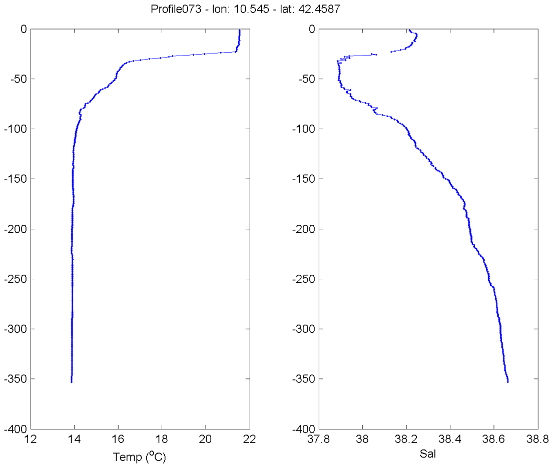
Sal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Temp ($^{o}$C)
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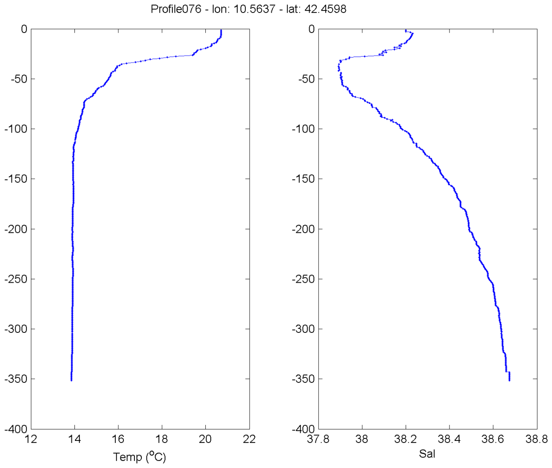
Sal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Temp ($^{o}$C)
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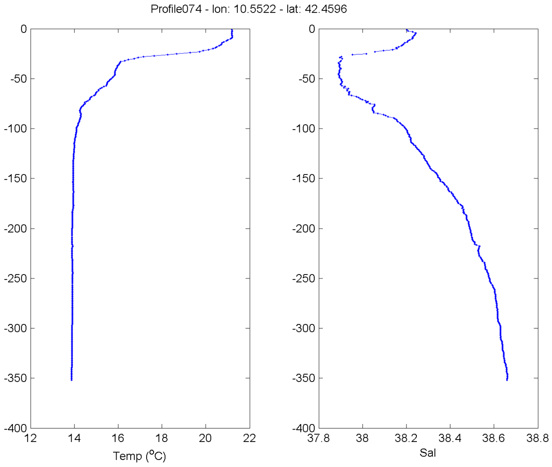
Sal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Temp ($^{o}$C)
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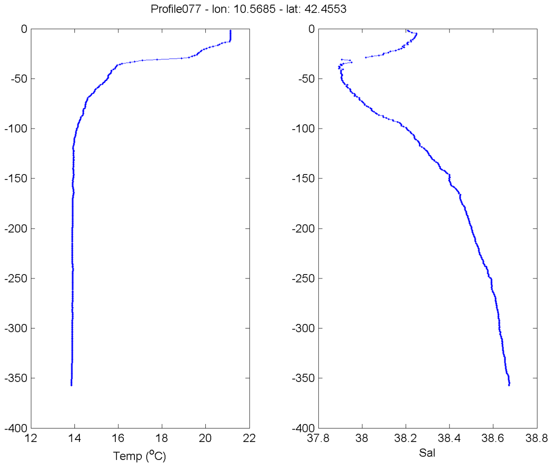
Sal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Temp ($^{o}$C)
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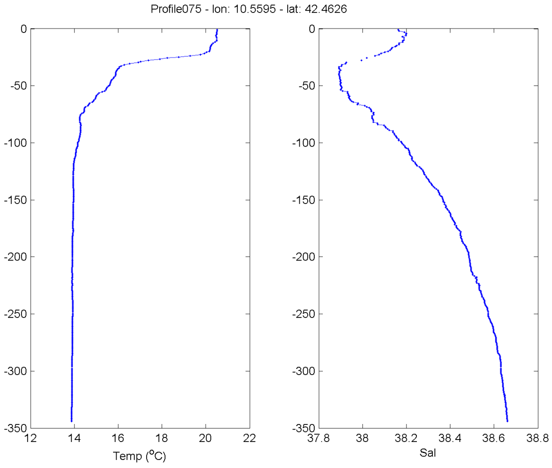
Sal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Temp ($^{o}$C)
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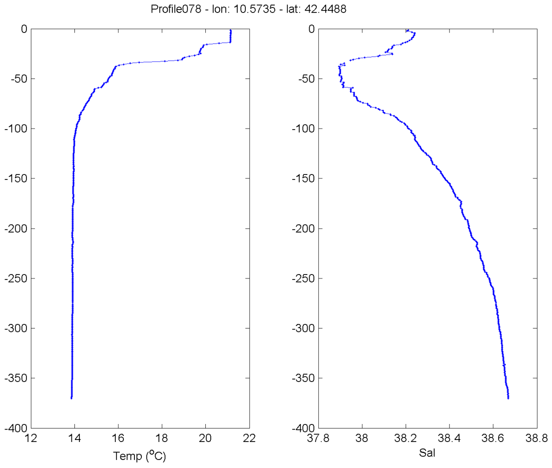
Sal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Temp ($^{o}$C)
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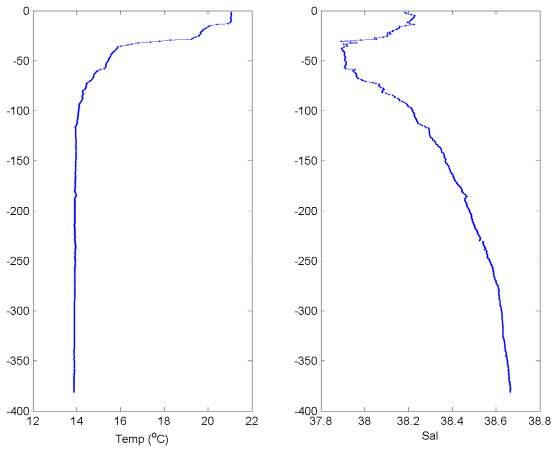
Sal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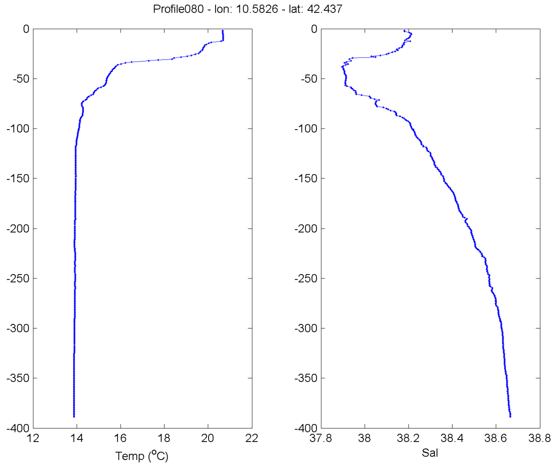
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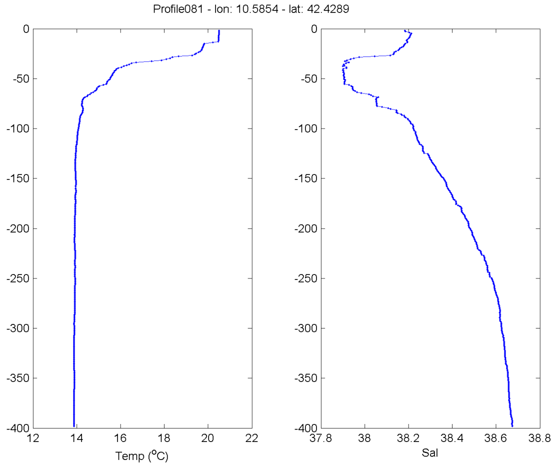
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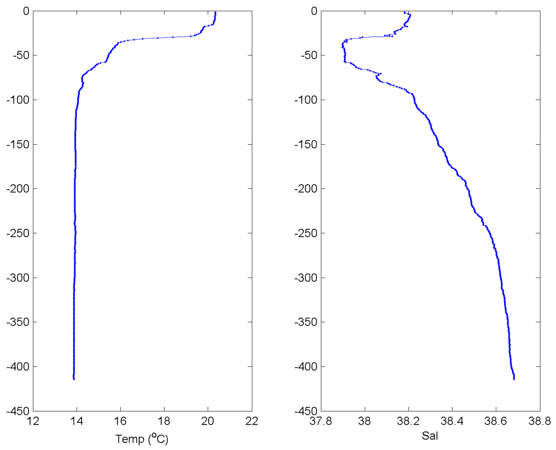
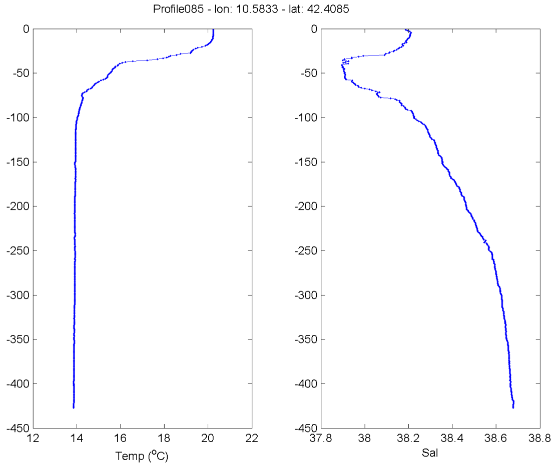
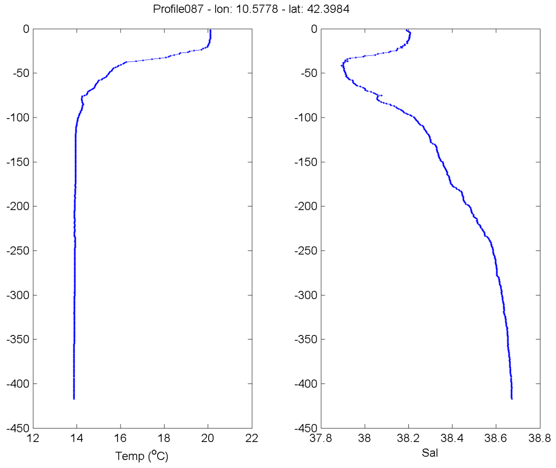
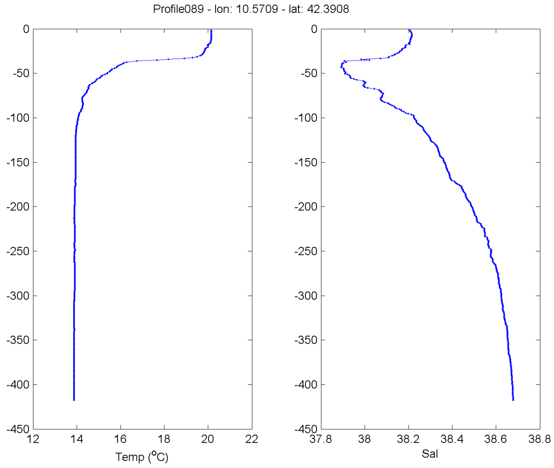

Profile083 - lon: 10.5858 - lat: 42.4179


Profile085 - lon: 10.5833 - lat: 42.4085


Profile087 - lon: 10.5778 - lat: 42.3984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Temp (°C)
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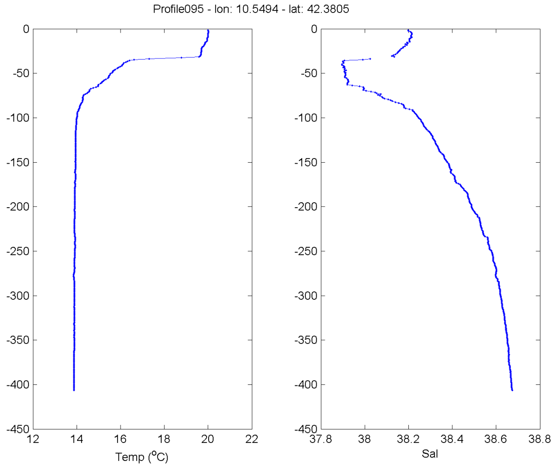
Sal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Temp (°C)
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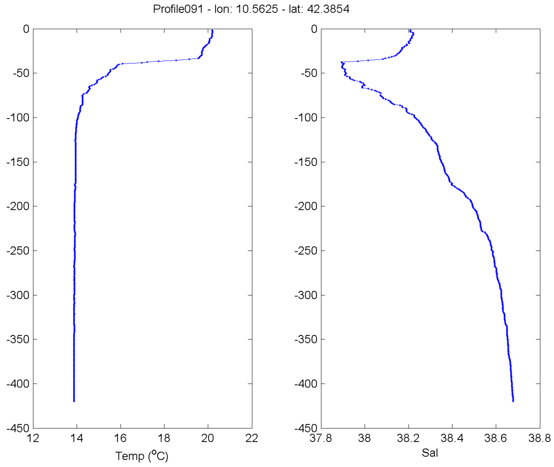
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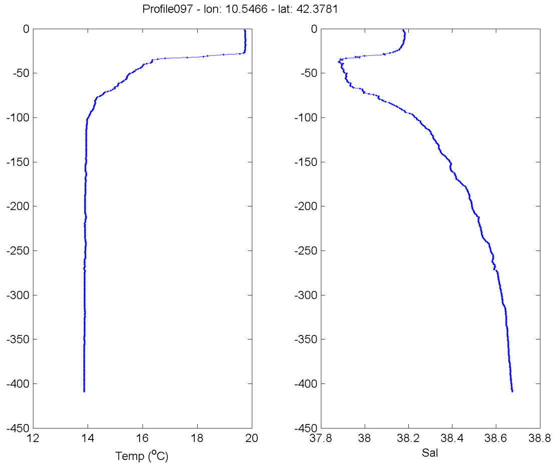
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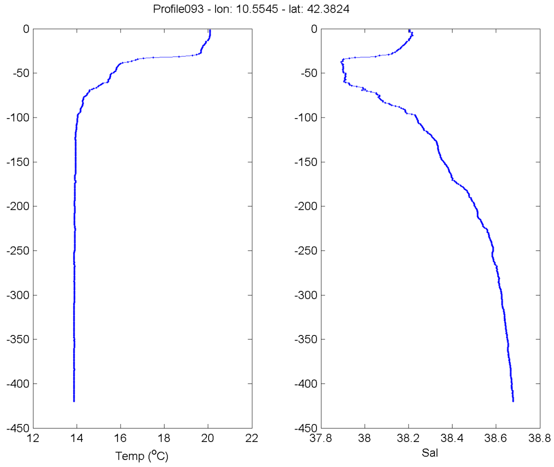
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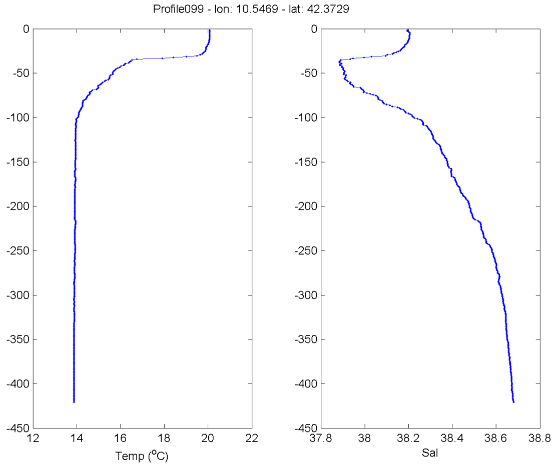
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Temp (°C)
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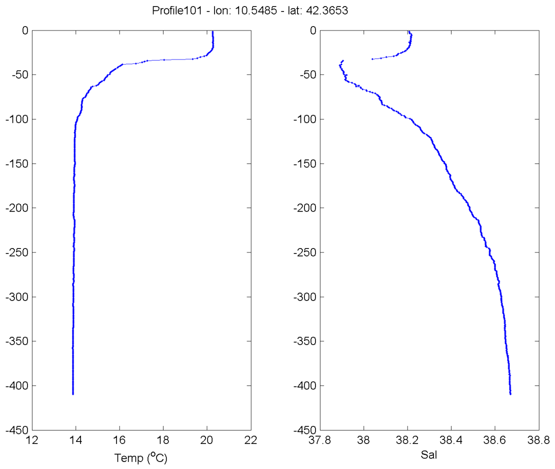
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Temp (°C)
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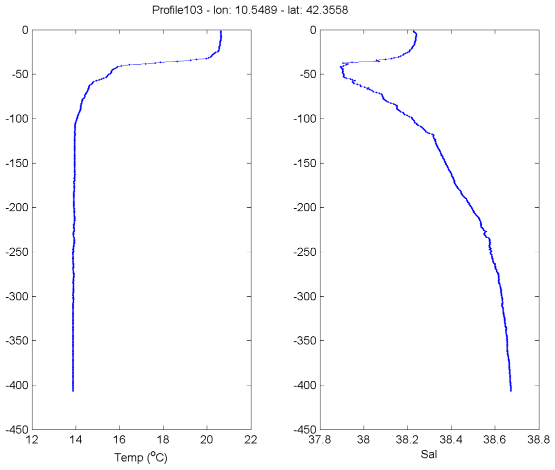
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Temp (°C)
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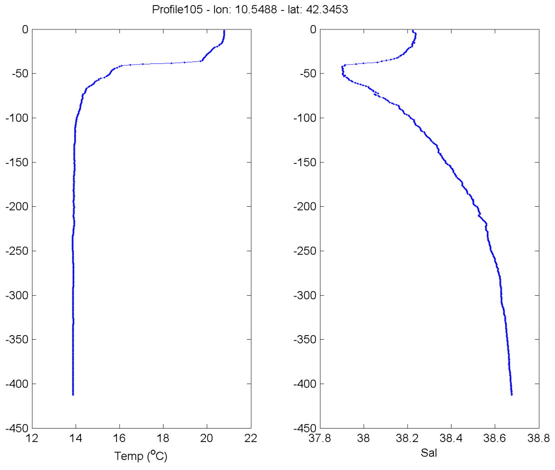
Sal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Temp (°C)
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38.2
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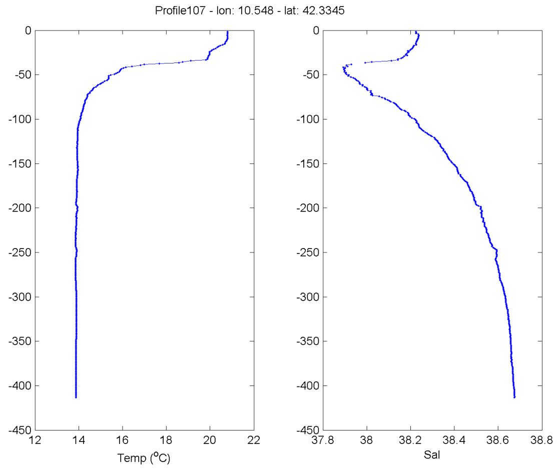
Sal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Temp (°C)
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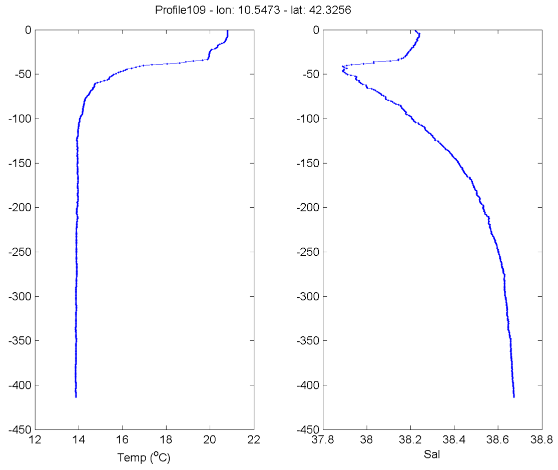
Sal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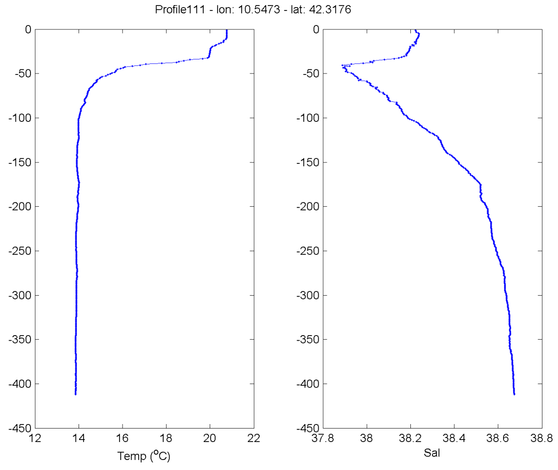
Sal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Temp (°C)
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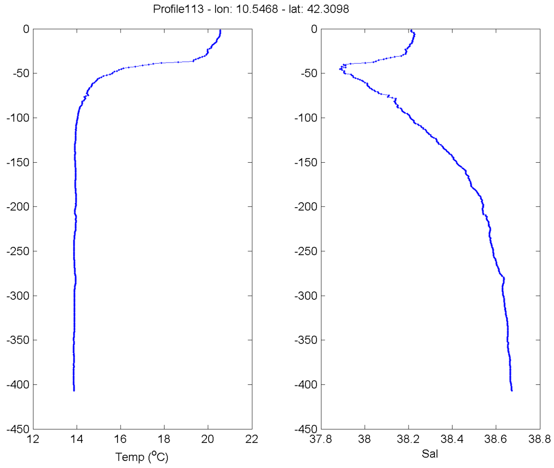
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Temp (°C)
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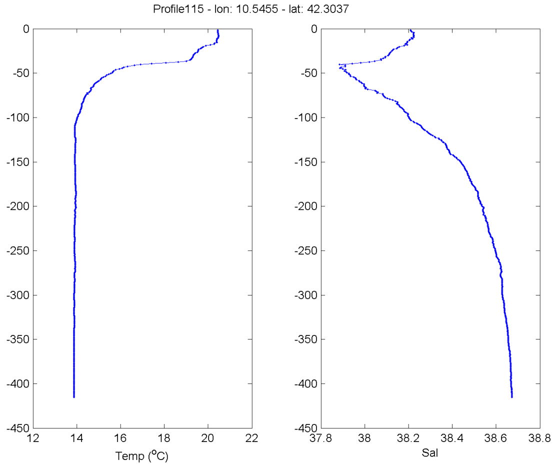
Sal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Temp (°C)
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38.2
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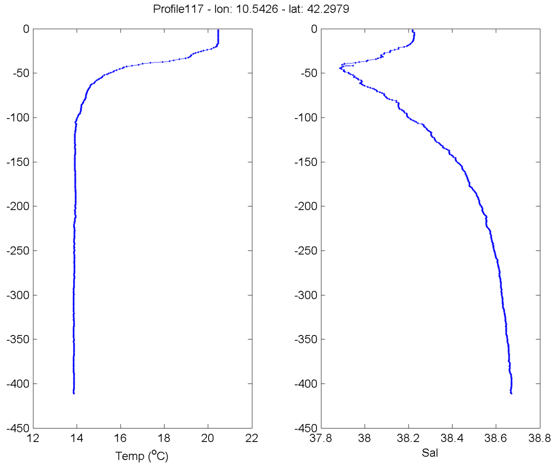
Sal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Temp (°C)
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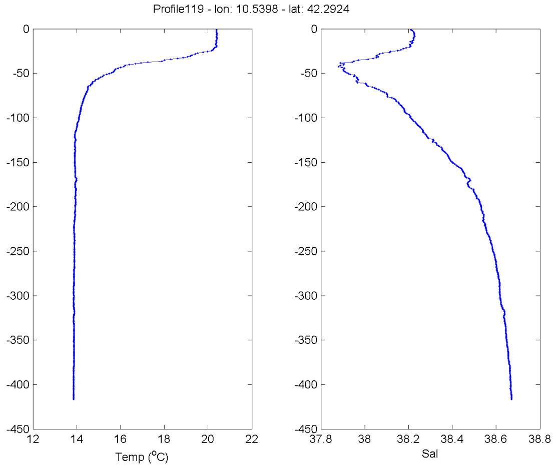
Sal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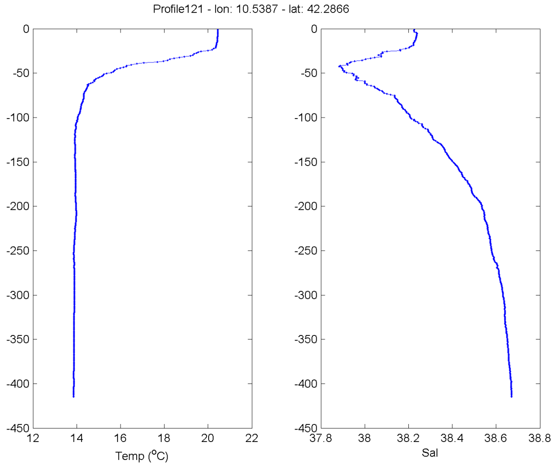
Sal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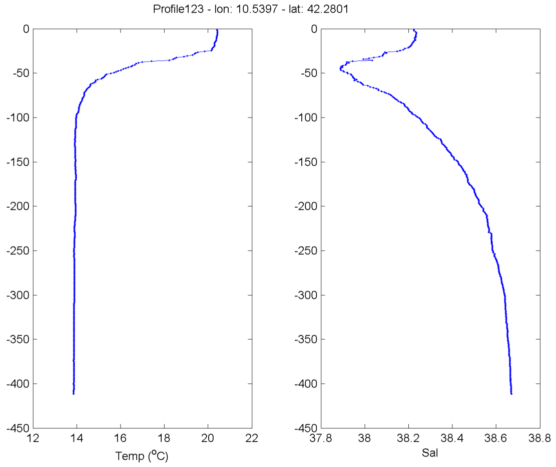
Sal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0
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-100
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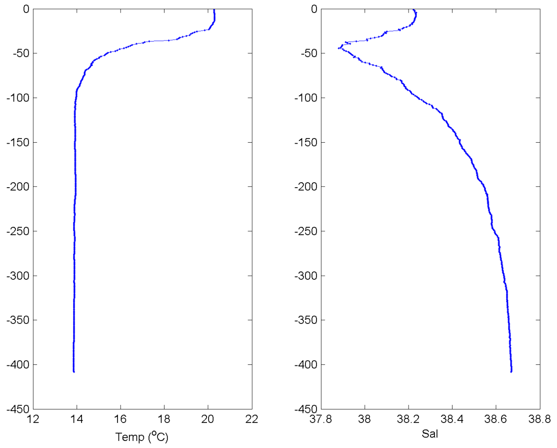
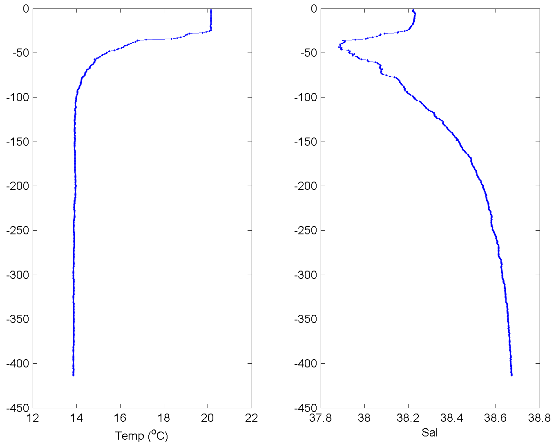
-450
12
14
16
18
20
22
Temp (°C)
37.8
38
38.2
38.4
38.6
38.8
Sal

Profile125 - lon: 10.5405 - lat: 42.2735



Profile127 - lon: 10.5416 - lat: 42.2668



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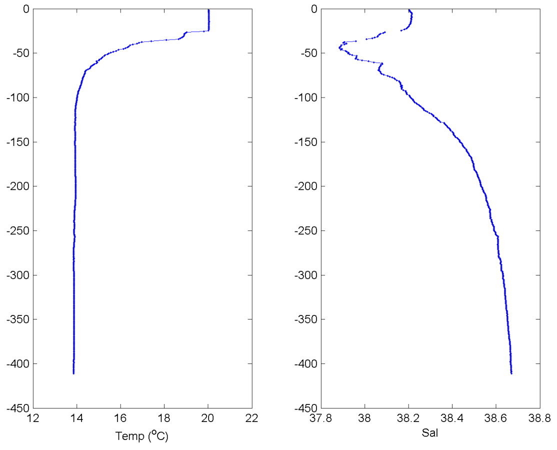
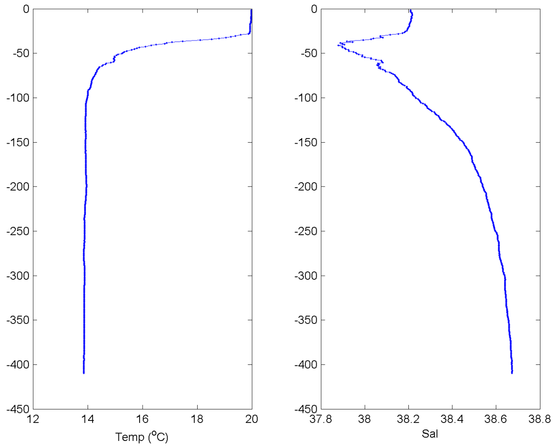
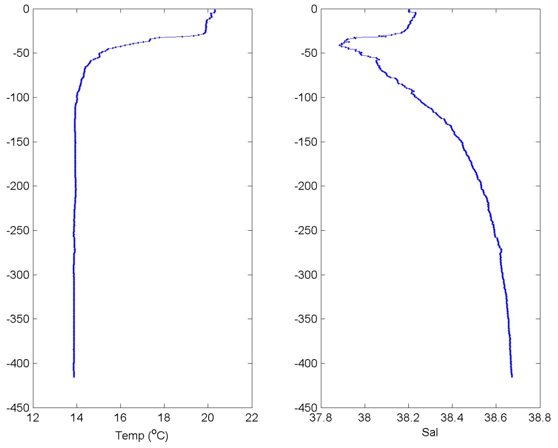


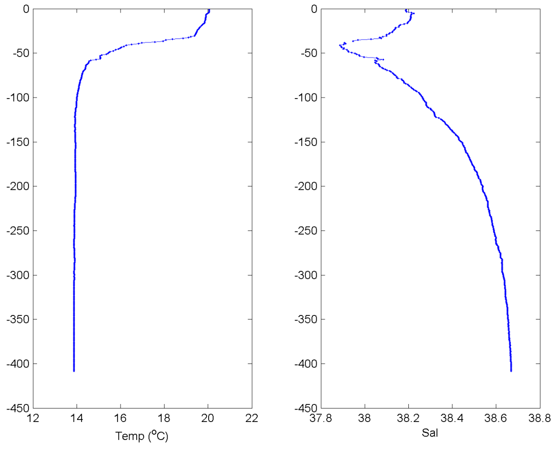
Profile131 - lon: 10.5432 - lat: 42.2518

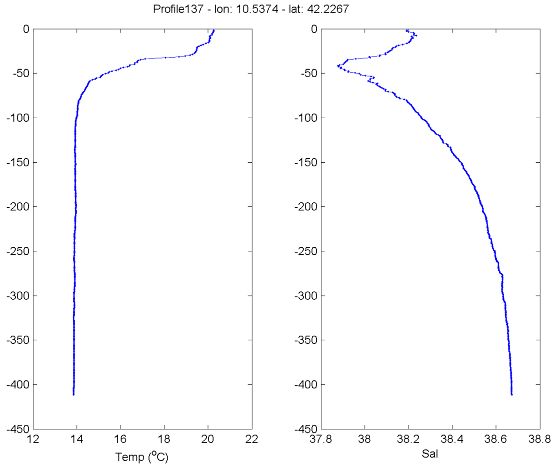


Profile133 - lon: 10.5415 - lat: 42.2432



Profile135 - lon: 10.5401 - lat: 42.2338




Profile137 - lon: 10.5374 - lat: 42.2267
0
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Temp (°C)
37.8
38
38.2
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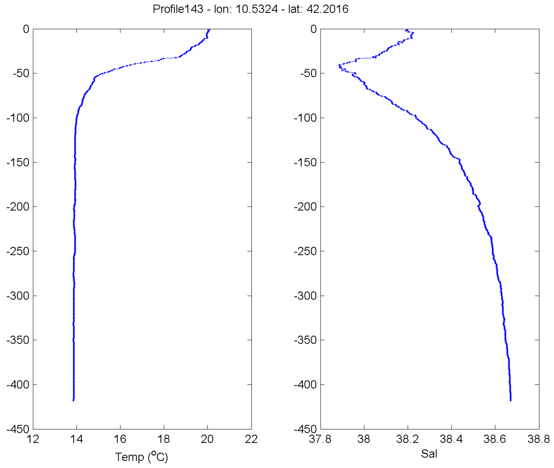
38.6
38.8
Sal


Profile143 - lon: 10.5324 - lat: 42.2016
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Temp (°C)
37.8
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38.2
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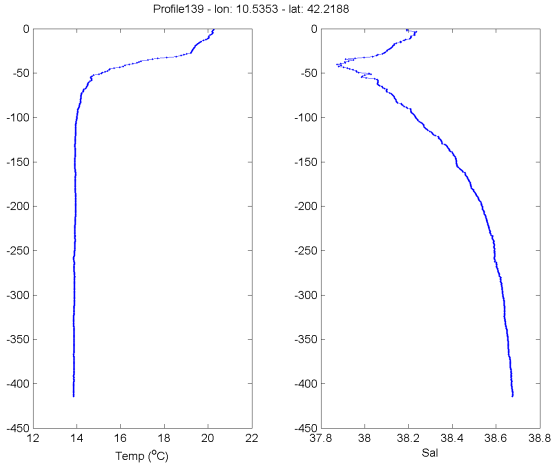
Sal


Profile139 - lon: 10.5353 - lat: 42.2188
0
-50
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12
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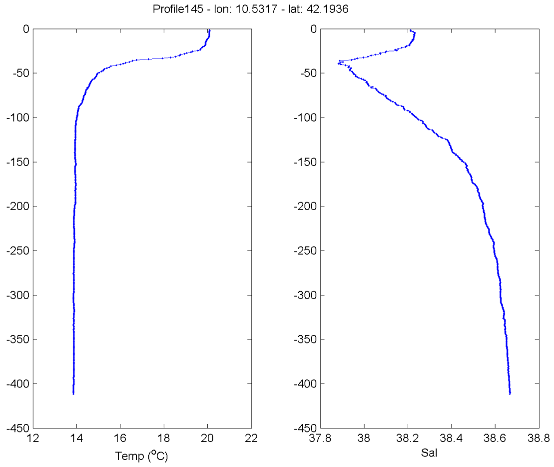
Temp (°C)
37.8
38
38.2
38.4
38.6
38.8
Sal


Profile145 - lon: 10.5317 - lat: 42.1936
0
-50
-100
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-400
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12
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Temp (°C)
37.8
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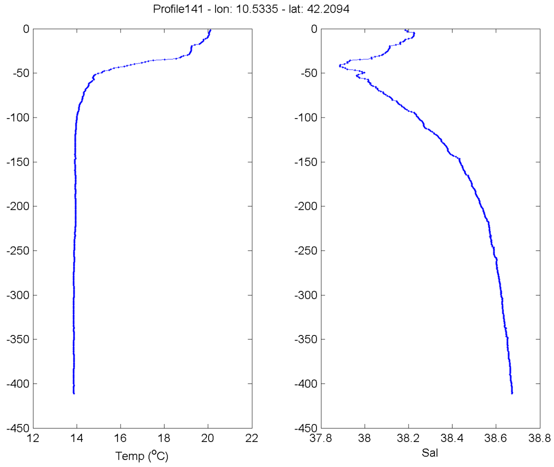
38.2
38.4
38.6
38.8
Sal


Profile141 - lon: 10.5335 - lat: 42.2094
0
-50
-100
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-200
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-350
-400
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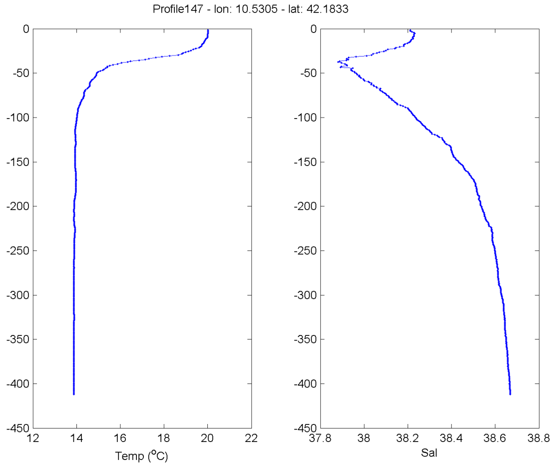
Temp (°C)
37.8
38
38.2
38.4
38.6
38.8
Sal


Profile147 - lon: 10.5305 - lat: 42.1833
0
-50
-100
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-400
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12
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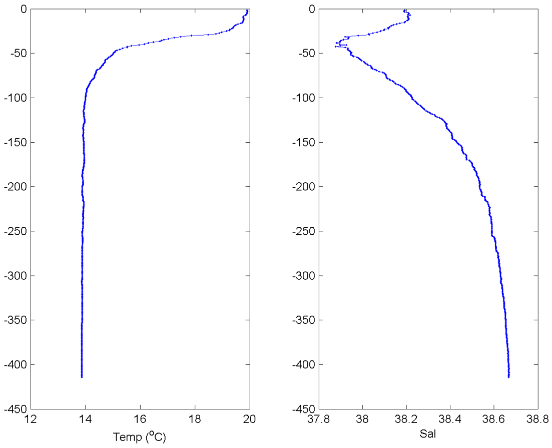
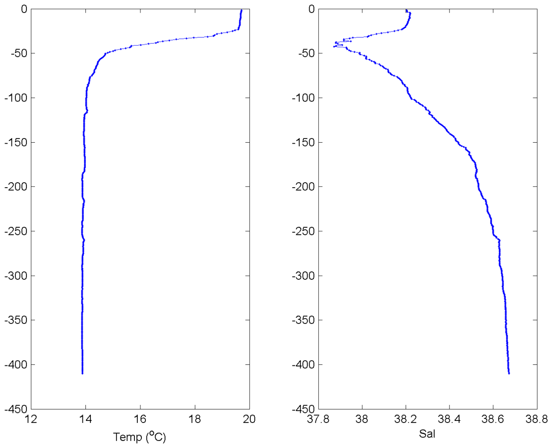
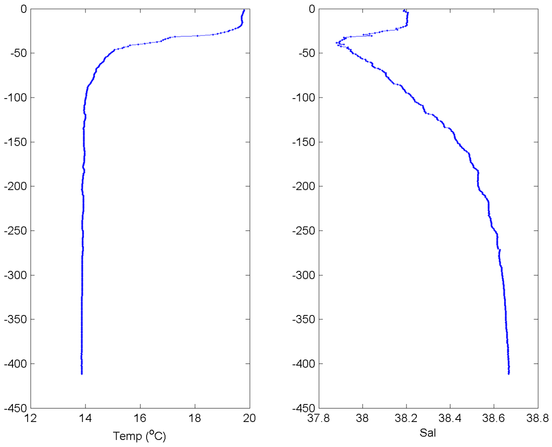
Temp (°C)
37.8
38
38.2
38.4
38.6
38.8
Sal



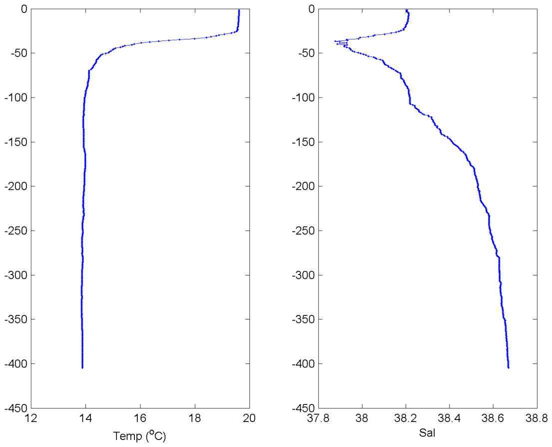
Profile149 - lon: 10.5285 - lat: 42.1737



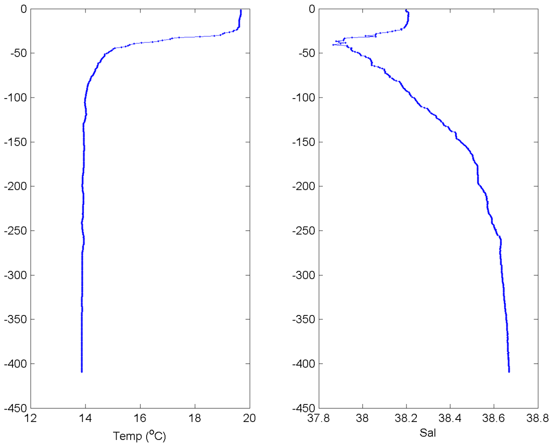
Profile155 - lon: 10.5194 - lat: 42.1551



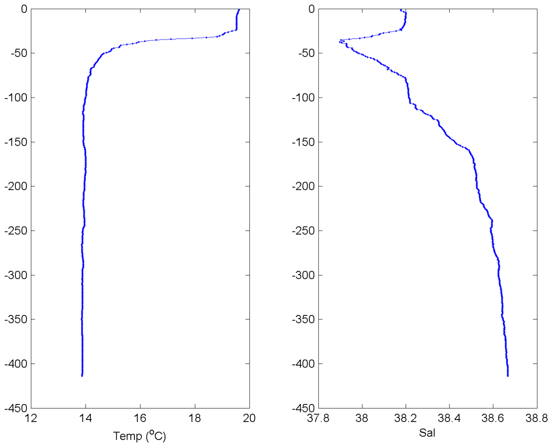
Profile151 - lon: 10.5256 - lat: 42.1679



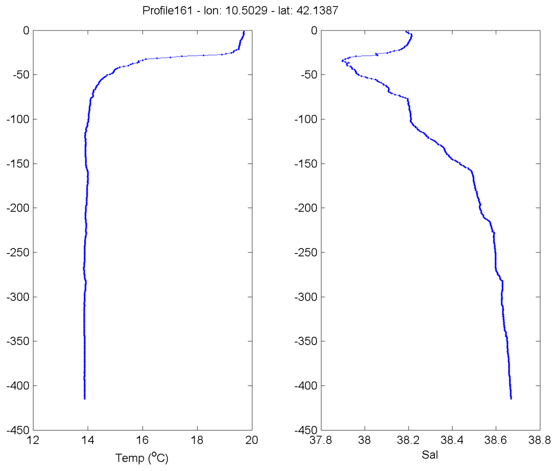
Profile157 - lon: 10.5141 - lat: 42.1474

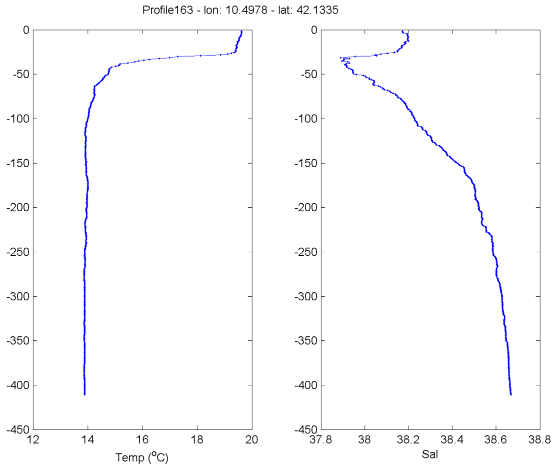


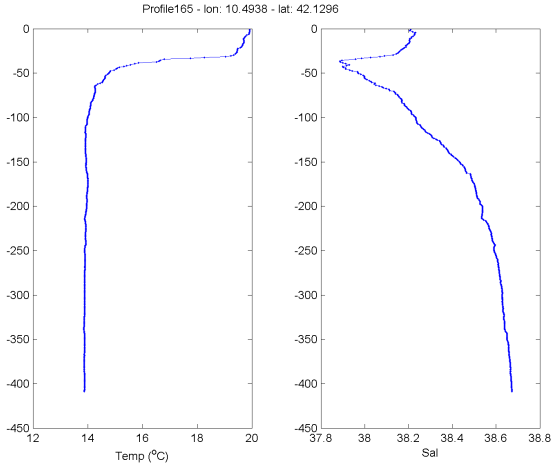
Profile153 - lon: 10.5228 - lat: 42.1611

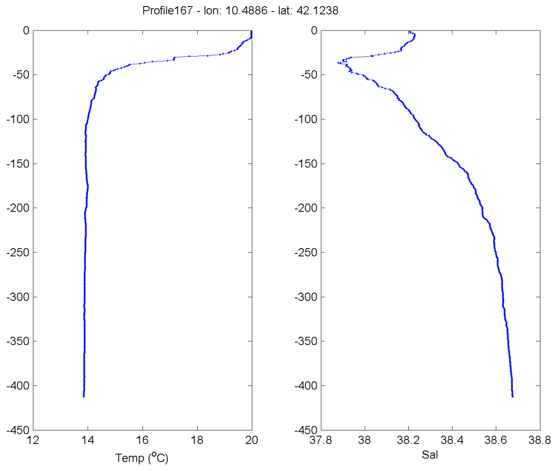


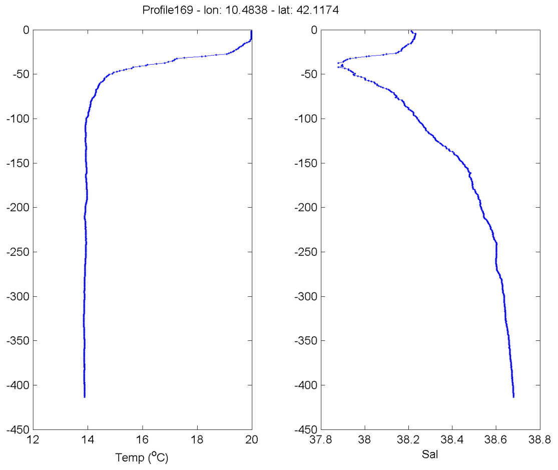
Profile159 - lon: 10.5078 - lat: 42.1415

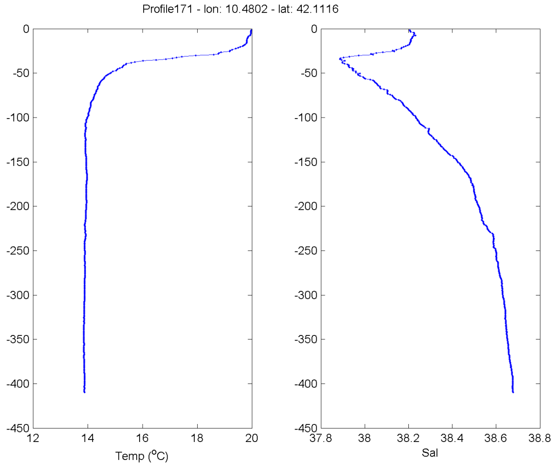

Profile161 - lon: 10.5029 - lat: 42.1387

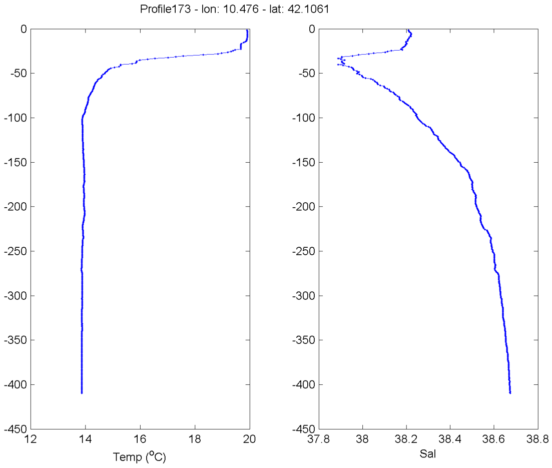

Profile163 - lon: 10.4978 - lat: 42.1335

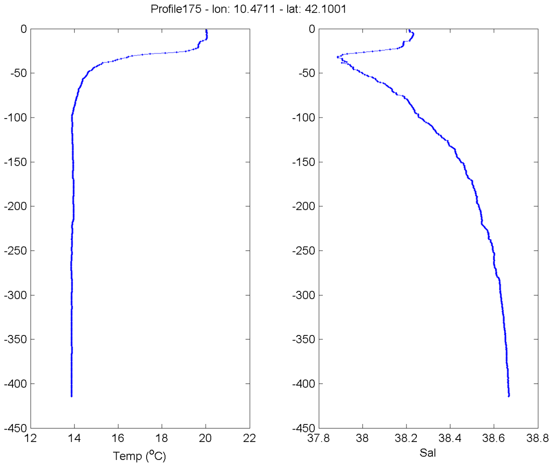

Profile165 - lon: 10.4938 - lat: 42.1296

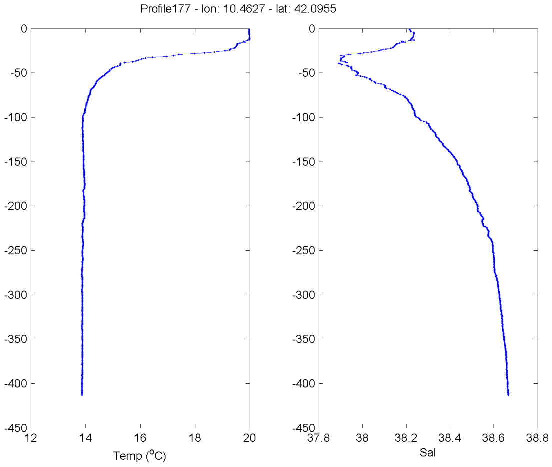

Profile167 - lon: 10.4886 - lat: 42.1238

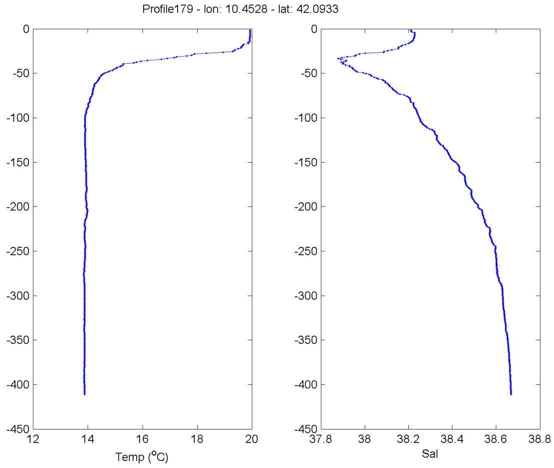

Profile169 - lon: 10.4838 - lat: 42.1174

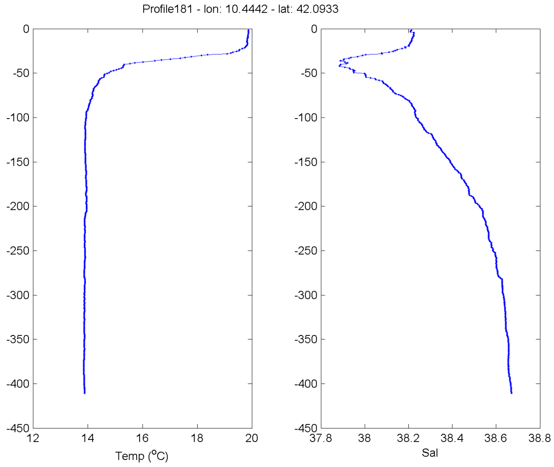

Profile171 - lon: 10.4802 - lat: 42.1116

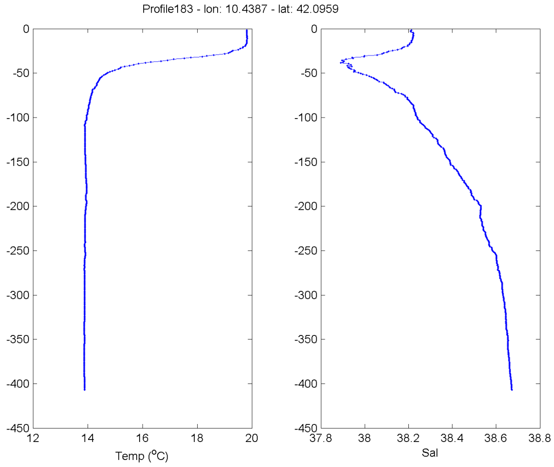

Profile173 - lon: 10.476 - lat: 42.1061


Profile175 - lon: 10.4711 - lat: 42.1001

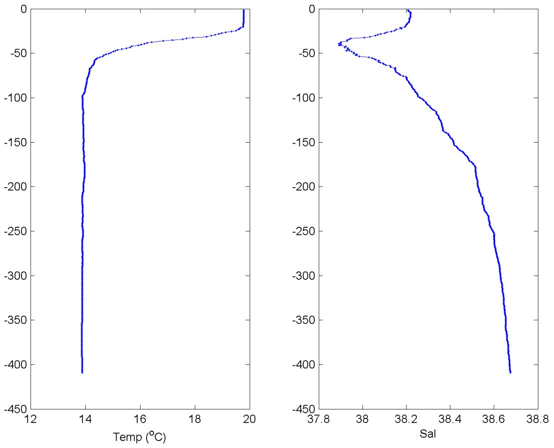

Profile177 - lon: 10.4627 - lat: 42.0955


Profile179 - lon: 10.4528 - lat: 42.0933

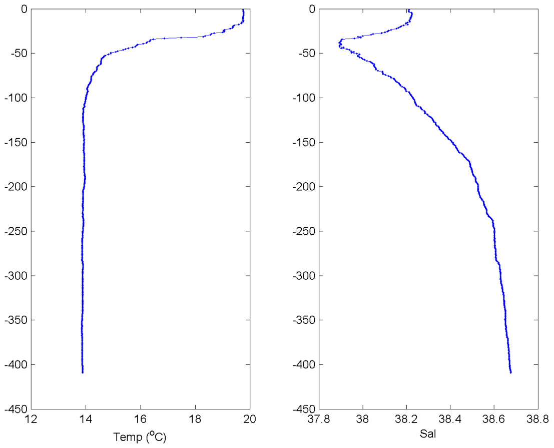

Profile181 - lon: 10.4442 - lat: 42.0933


Profile183 - lon: 10.4387 - lat: 42.0959

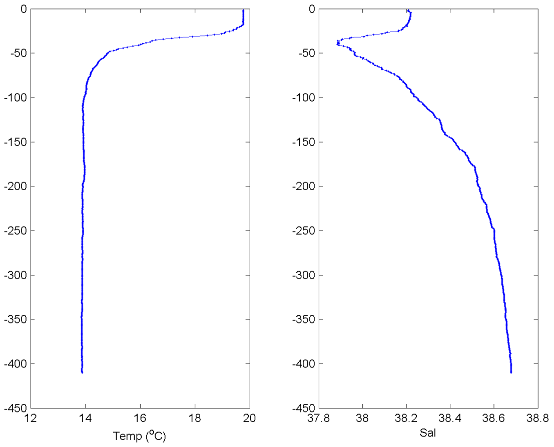
Profile185 - lon: 10.4379 - lat: 42.0983



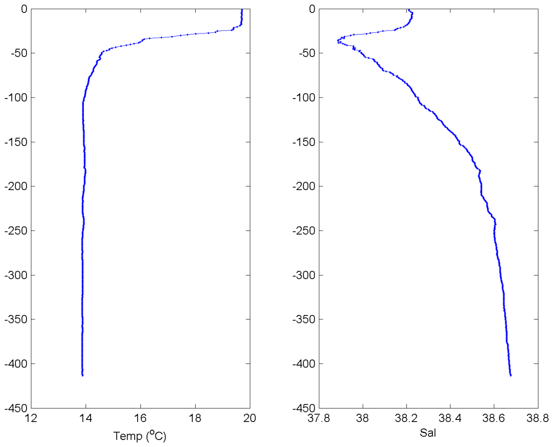
Profile189 - lon: 10.4439 - lat: 42.0964



Profile187 - lon: 10.4399 - lat: 42.099



Profile191 - lon: 10.4466 - lat: 42.0912



## 6. Acknowledgments

We would like to acknowledge all the people who were involved in the MILONGA experiment and helped to make it a success. In particular, we thank the colleagues and personnel from LAMMA, ARPAT and the Istituto Nautico di Livorno for their help with the deployment and recovery operations of the instruments. We thank the captains and crew of the Poseidon and Cappellini for their enthusiastic cooperation. Thanks are also extended to S. Kuechler and P. Mansutti for the recovery of the Arvor-C float and Antonio Bussani for the data processing.

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