# Hydrography in the Mediterranean Sea during a Cruise with RV POSEIDON in April 2014

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## Abstract

We report on data from an oceanographic cruise in the Mediterranean Sea on the German research vessel POSEIDON in April 2014. Data were taken on a west-east section, starting at the Strait of Gibraltar and ending south-east of Crete, as well on sections in the Ionian and Adriatic Sea. The objectives of the cruise were threefold: to contribute to the investigation of the spatial evolution of the Levantine Intermediate Water (LIW) properties and of the deep water masses in the Eastern Mediterranean Sea, and to investigate the mesoscale variability of the upper water column. The measurements include salinity, temperature, oxygen and currents and were conducted with a CTD/rosette system, an underway CTD and an ADCP. The sections are on tracks which have been sampled during several other cruises, thus supporting the opportunity to investigate the long term temporal development of the different variables. The use of an underway CTD made it possible to conduct measurements of temperature and salinity with a high horizontal spacing of 6 nm between stations and a vertical spacing of 1 dbar for the upper 800m of the water column.

## Data coverage and parameter measured

Repository-Reference:

http://doi.pangaea.de/10.1594/PANGAEA.838923 (for CTD)

http://doi.pangaea.de/10.1594/PANGAEA.838924 (for UCTD)

http://doi.pangaea.de/10.1594/PANGAEA.838934 (for ADCP)

Coverage: 34°N-43°N, 6°W-26°E

Location Name: The Mediterranean Sea

Date/Time Start: 3. April 2014

Date/Time End: 28. April 2014

## 1. Introduction

The Mediterranean Sea is a marginal sea, as it is partly isolated from the Atlantic Ocean through the narrow Strait of Gibraltar. It consists of two sub-basins, the Western (WMed) and the Eastern (EMed) Mediterranean, which communicate through the broad (145 km) and shallow (maximum depth 550 m) Sicily Channel. Due to its dimensions (2.500.000 km²) and position, i.e. enclosed by continents, it can rapidly be affected by atmospheric forcing and anthropogenic influences (Schroeder et al., 2013). Several forces drive the circulation, external ones like wind-stress, strong topographic constraints and internal dynamic processes (Robinson et al., 2001, Pinardi et al., 2013). The emerging Mediterranean general circulation, therefore, encloses three predominant and interacting spatial scales: basin scale, sub-basin scale and mesoscale. Free and boundary currents and jets, permanent and recurrent, sub-basin scale, cyclonic and anticyclonic gyres populate both basins (Robinson et al., 2001). The associated eddy field to the mesoscale circulation consists of semi-permanent eddies with a spatial scale of about 120 km in diameter (Hecht et al., 1988).

The WMed and EMed show distinct differences, both in their hydrography and circulation. Different attempts to schematize surface as well as intermediate and deep paths of the circulation have been made in the past, based on observational evidences (see e.g. Malanotte-Rizzoli et al., 1997, 1999; Robinson et al., 2001; Roether et al., 2007; Schroeder et al., 2012).

The heat and freshwater budgets in the Mediterranean Sea are negative with a net loss of about 5 $Wm^{-2}$ and 0.7 $my^{-1}$. The deficits are balanced by exchanges through the Strait of Gibraltar. The steady-state is balanced at multi-decadal time scales; at seasonal and interannual time scales heat loss and gain is possible due to single wintertime large evaporation events (Garrett et al., 1993; Pettenuzzo et al., 2010, Pinardi et al., 2013). However, it might be questionable if a steady state is a reliable assumption for the Mediterranean Sea circulation. As known the EMed went through drastic changes in the past. The largest climatic event, named Eastern Mediterranean Transient (EMT), took place in the EMed during the end of the eighties and beginning of the nineties, where the deep-water formation switched from the Adriatic to the Aegean Sea. This episode changed the thermohaline characteristics of the outflow through the Sicily Channel significantly, which consequently modified the characteristics of the WMed (Millot et al. 2006, Schroeder et al., 2006). Thus, since 2005 the deep waters of the WMed experienced significant physical changes, which are comparable to the EMT, both in terms of intensity and observed effects (Schroeder et al., 2008). This event is often called the Western Mediterranean Transient (WMT). Therefore, the existence of both transients contradicts this assumption. On the other hand, it was proven that the EMT was never observed before (Roether et al., 2013).

The water mass formation cycle is characterized by the inflow of low-salinity Atlantic Water (AW) in the upper 100 m of the water column and with identification values of S = 36.0-36.5 psu in the Strait of Gibraltar (Said et al., 2011), and a return flow of the salty Levantine Intermediate Water (LIW), formed in the Levantine Basin and positioned in the intermediate layer (typically at a depth of 200-600m). The depth variability of the LIW salinity maximum is largely regional: generally, depths increase westward. The Sicily Channel, with a depth lower than 550m, acts as a natural barrier between the WMed and EMed. Deep and intermediate water formation takes place in each of the basins. In the WMed the abyssal water mass is produced by shelf and open-ocean convection in the Gulf of Lyons, namely the Western Mediterranean Deep Water (WMDW, see e.g., Leaman and Schott, 1991). The EMed instead is characterized by two deep-water formation regions, where the Adriatic Deep Water (AdDW) and the Cretan Deep Water (CDW) are produced. Thus, the predominant water mass of the bottom layers, filling the abyssal plains of the Ionian and Levantine basins, namely the Eastern Mediterranean Deep Water (EMDW), is a mixture of AdDW, CDW and shallower water masses. Detailed descriptions of the general circulation and hydrography of the EMed can be found in Lascaratos et al., 1999, Hamad et al., 2005, Rubino and Hainbucher, 2007, Klein et al., 2010, Gačić et al., 2011, Cardin et al. 2015 and others.

The principal scientific objective of the cruise is threefold:

a) To add knowledge to the understanding of the dispersion of LIW water masses from the eastern basin of the Mediterranean Sea to the Strait of Gibraltar
b) To investigate the mesoscale variability of the upper water columns of the two basins of the Mediterranean Sea
c) To continue the documentation and to contribute to the understanding of the evolution of the deep water masses in the EMed since the appearance of the Eastern Mediterranean Transient.

According to the Med-Ship Program (CIESM Monographs 43, 2012) the cruise supports the investigation of its relevant objectives which are, amongst others, engaged in the determination of changes and of long-term variability of hydrographic parameters in the Mediterranean Sea. Although most of the data of this campaign are not “full water column observations”, this survey is a valuable contribution to improve the database of the Mediterranean Sea for a better understanding of the variability on multiple time scales and for numerical model evaluations.

To our knowledge, there exists just one further campaign which covers an east-west transect through the whole Mediterranean Sea but with a much lower sampling rate (Meteor cruise M84-3, Tanhua et al., 2013). More frequently, several campaigns at the level of sub-basin for both the WMed (Schroeder et al., 2008) and the EMed (Cardin et al., 2015) have been carried out during the past decades.

## 2. Data Provenance

The survey was carried out on the German RV POSEIDON from 3$^{rd}$ of April to 28$^{th}$ of April 2014. The cruise started in Portimão, Portugal and ended in Bari, Italy (fig. 1). The data set is composed of three components: profiles from a CTD, profiles from an underway CTD (UCTD) and velocity profiles from an ADCP (table 1). Figure 2, 3 and 4 show examples for the calibrated and quality controlled data of the UCTD, CTD and ADCP.

## 3. Methods and Quality Control

The most recent campaign (April 2011), including an east-west transect through the whole Mediterranean Sea, was the RV METEOR cruise M84/3 (Tanhua et al., 2013). On M84/3 CTD and ADCP measurements were conducted. Additionally to the physical parameters, chemical variables like nutrients, helium, tritium, $SF_6$, CFC-12 and others were taken. Compared to the cruise here, the sampling rate of M84-3 was coarse accommodating the demand to take a variety of parameters during a reasonable time. Contrariwise, the campaign of POSEIDON was restricted to measurements of physical components, but with the aim to achieve a high horizontal resolution in order to resolve hydrographic phenomena on mesoscales.

## 3.1 CTD/rosette

During the cruise, altogether, 37 full depth standard hydrographic stations (fig. 1) were collected with a 24 Hz sampling Sea-Bird SBE 911 plus CTD, fastened to a 12 bottles SBE 32 Carousel Water Sampler. The instrument was equipped with double conductivity and temperature sensors and two SBE 43 dissolved oxygen sensors. Specifications for the CTD sensors are given in table 2.

At almost all stations water samples were taken at 12 pre-defined depths along the water column for oxygen analysis and at three of which also for salinity analysis. The salinity samples were analysed on board using a Guildline Autosal Salinometer. The batch–no. of the standard seawater samples is 38H11 which have a K15-factor of 1.07631 (24°C). An explanation of standard seawater definitions can be found in Bacon et al. (2007).

Temperature and salinity CTD data were post-processed by applying standard Seabird software and MATLAB routines. At this stage spikes were removed, 1dbar averages calculated, and the downcast profiles of temperature and salinity were corrected with a regression analysis. Data from the double sensors were correlated, and the salinity measurements were additionally corrected by comparison with the discrete salinity water samples to improve the level of precision. Since the corrections to the parameters were negligible, the data quality was excellent. Overall accuracies are within expected ranges: 0.002°C for temperature and 0.003 for salinity.

Dissolved oxygen samples were analysed on board by means of the Winkler potentiometric method. The dissolved oxygen CTD data were treated in the same way as for temperature and salinity. A comparison between CTD oxygen sensors and the discrete water samples was carried out also for this parameter. The accuracy of the data reached approximately 2 $\mu molkg^{-1}$.

All procedures fit the guidelines of the GO-SHIP Repeat Hydrography Manual (McTaggart et al., 2010)

## 3.2 Underway-CTD

Underway measurements of pressure, temperature and conductivity profiles were made with an Ocean Science UCTD system in order to increase the spatial resolution of the survey, but without having to perform several additional time-consuming CTD casts. Altogether, we took 378 casts (fig. 1). Initially we used three probes (s/n 0068, 0155 and 0183), but after the loss of a probe right at the beginning of the cruise, we decided to use only the Tow-Yo (Ullman and Hebert, 2014) deployment procedure in the following, where no spooling on the probe's spindle was carried out. The sampling strategy included a sampling distance between UCTD casts of approximately 6 nm or about 1 hour keeping a ship's speed of 6 knots. The ship reduced speed to 2-3 knots, while the probe was falling for a maximum of 480 sec. The ship enhanced speed again to 6 knots during the recovery of the probe. We reached maximum depths of around 850m, minimum depths of 500m. The average depth was approximately 650m. Specifications for the UCTD sensors are given in table 3.

The data are logged internally and are downloaded to a computer after recovery of the instrument. No processing is done internally. Since the probes are not georeferenced, ship navigation data were used. During processing one has to account for mainly two factors which cause inaccuracies: Different probes show different offsets to the CTD, and the accuracy of results depends on the variable descent rate during deployment. For the correction of the offset we used data of CTD stations, as we carried out a UCTD measurement at each CTD position. Additionally, we run one CTD station with the remaining two UCTD probes installed at the CTD rosette. For each probe we determined the mean deviation from the UCTD with respect to the CTD casts and corrected all UCTD results accordingly. To account for the variable descent rate, we carried out the steps suggested by Ullman and Hebert, 2014. Hence, we corrected for a descent-rate-dependent alignment of temperature and conductivity, for the effect of viscous heating and for the conductivity cell thermal mass.

### 3.3 Shipborne ADCP

Underway current measurements were taken with a vessel-mounted 75 kHz Ocean Surveyor (ADCP) from RDI in narrow band mode covering approximately the top 600-800m of the water column. The bin size was set to 8 m. The instrument was controlled by computers using the conventional VMDAS software under a MS Windows system. Pinging was set as fast as possible. No interferences with other used acoustical instruments were observed. The ADCP data was post-processed with the software package ossi14 (ocean surveyor sputum interpreter) developed by the Leibniz Institute of Marine Sciences (GEOMAR, T. Fischer, 2011), Kiel, which also corrects for the misalignment angle. The misalignment angle was calculated at approximately -3.5 degrees.

## 4. Discussion and Conclusion

The TS-diagram (fig. 3) gives an overview of the TS characteristics in the whole Mediterranean Sea during April 2014. The results are comparable to those we found already in April and June 2011 on cruises with RV Meteor and RV Poseidon (Hainbucher et al., 2013), and they highlight the differences which exist between the EMed and WMed. The horizontal distance between CTD stations were too coarse to consider the transects reliable, yet, the high resolution of UCTD (figure 2) and ADCP data (figure 4) show nicely the mesoscale variability in both basins during the cruise. Both Alboran gyres and high eddy activity along the section through the WMed can be identified. Some of these structures can be related to well-known features like the Almeria-Oran Gyre or the South-Western Tyrrhenian Gyre (Pinardi et al., 2013). In the EMed we found a lot of mesoscale eddies along the track between Sicily and Crete. Presumably, we touched, amongst others, the Western Cretan Cyclonic Gyre and the Ierapetra Gyre (Pinardi, et al., 2013). Hence, some of the positions of the gyres, that we found, have confirmed those already present in the literature by observations or results of models. But not all of the gyres can be related to well-known features. We conclude from this fact, that a lot of the gyres are non-permanent, and that even the location of the permanent eddies are subject to high spatial variability. This has to be concretized and proofed further on. The tool for the investigation of such highly variable phenomena were up to now numerical models, but with such UCTD measurements it is possible to resolve the structures with a reasonable effort in time and money.

The salinity distribution (figure 2) furthermore reflects the spatial development of LIW from east to west. The LIW signal is stronger in the EMed than in the WMed and can be identified by the salinity maximum in the 100-600 m depth layer.

## 5. Data access

Data are published at the information system PANGAEA; http://doi.pangaea.de/10.1594/PANGAEA.838923 for CTD data, http://doi.pangaea.de/10.1594/PANGAEA.838924 for UCTD data and http://doi.pangaea.de/10.1594/PANGAEA.838934 for ADCP data.

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Table 1. List of parameters from Poseidon cruise P468 as seen in the PANGAEA database.
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| Parameter Name | Short name | Unit | Method | Comments |
|---|---|---|---|---|
| **DATE/TIME** | Date/Time | | | Geocode |
| **LATITUDE** | Latitude | | | Geocode |
| **LONGITUDE** | Longitude | | | |
| **Pressure, water** | Press | dbar | CTD, SEA_BIRD SBE 911plus | |
| **Temperature, water** | Temp | °C | CTD, SEA_BIRD SBE 911plus | |
| **Salinity** | Sal | | CTD, SEA_BIRD SBE 911plus | PSU |
| **Oxygen** | O2 | µmol/l | CTD with attached oxygen sensor calibrated, corrected using Winkler titration | |
| **Pressure, water** | Press | dbar | UnderwayCTD (UCTD), Oceanscience | |
| **Temperature, water** | Temp | °C | UnderwayCTD (UCTD), Oceanscience | |
| **Salinity** | Sal | | UnderwayCTD (UCTD), Oceanscience | PSU |
| **DEPTH, water** | Depth water | m | | Geocode |
| **Current velocity east-west** | UC | cm/s | Shipboard Acoustic Doppler Current Profiling (SADCP) | |
| **Current velocity north-south** | VC | cm/s | Shipboard Acoustic Doppler Current Profiling (SADCP) | |

Table 2: Used CTD instrument and sensors. Owner of instruments are either the University of Hamburg, Germany (IFM-CEN) or the National Institute of Oceanography and Geophysics (OGS), Italy.

| ***Instrument/Sensor*** | ***Serial Number (owner)*** |
|---|---|
| SBE 911plus / 917plus CTD | 285 (IFM-CEN) |
| Temperature 1: SBE-3-02/F | 1294 (IFM-CEN) |
| Conductivity 1: SBE-4-02/2 | 1106 (IFM-CEN) |
| Pressure 410K-105 | 50633 (IFM-CEN) |
| Temperature 2: SBE-3-02/F | 1717 (OGS) |
| Conductivity 2: SBE-4-02/2 | 3442 (OGS) |
| Altimeter PSA 916D | 885 (IFM-CEN) |
| Oxygen 1 SBE 43 | 1761 (IFM-CEN) |
| Oxygen 2 SBE 43 | 2513 (OGS) |

Table 3: Used UCTD sensors.

| Probe 1 | Device Type | Serial Number (owner) |
|---|---|---|
| 0068 | 90560 UCTD /SBE49 FastCat CTD | 70200068 (IFM-CEN) |
| 0155 | 90745 UCTD / SBE 37 MicroCat | 70200155 (IFM-CEN) |
| 0183 | 90745 UCTD / SBE 49 FastCat CTD | 70200183 (IFM-CEN) |

## Figure Legend

Figure 1: Cruise track of P468 with CTD stations marked in red and UCTD stations marked in blue.

Figure 2: Temperature and salinity distribution along a west-east section through a) the western Mediterranean and b) the eastern Mediterranean Sea. Data are gained by an underway CTD. Inner panels show the location of UCTD stations. White areas: data are out of instrument range.

Figure 3: TS diagram determined by CTD data. The inner panel shows the location of CTD stations. The colors correspond with the colors of the profiles.

Figure 4: Velocity distribution of the upper 400m of the water column along a west-east section through a) the western Mediterranean and b) the eastern Mediterranean Sea. Data are gained by a shipborne ADCP. Shown are the east-west and north-south velocity component, respectively. Inner panels indicate the location of the ship track. White areas: no data are available. X-axes: east-west distance (km). Y-axes: depth (dbar).

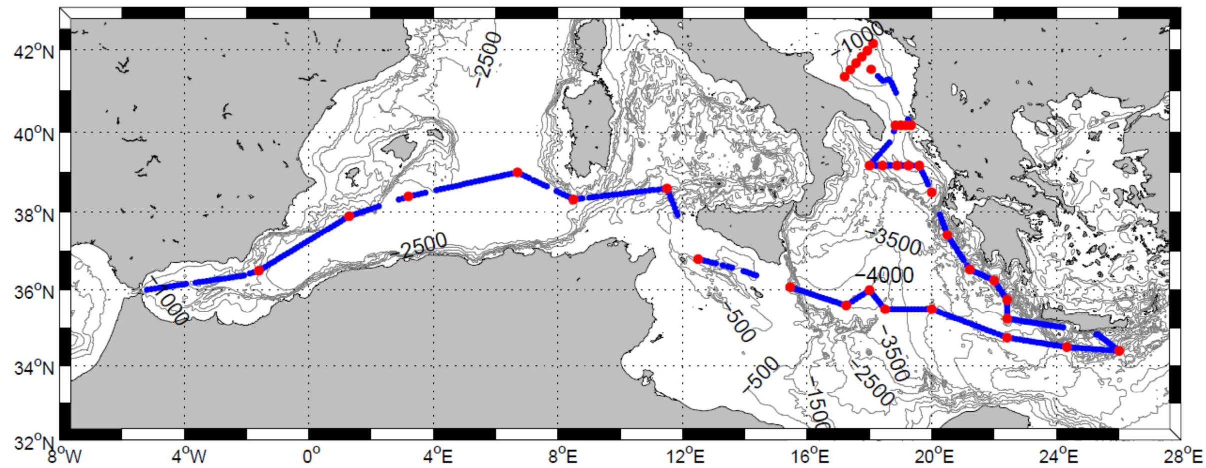


Figure 1: Cruise track of P468 with CTD stations marked in red and UCTD stations marked in blue.

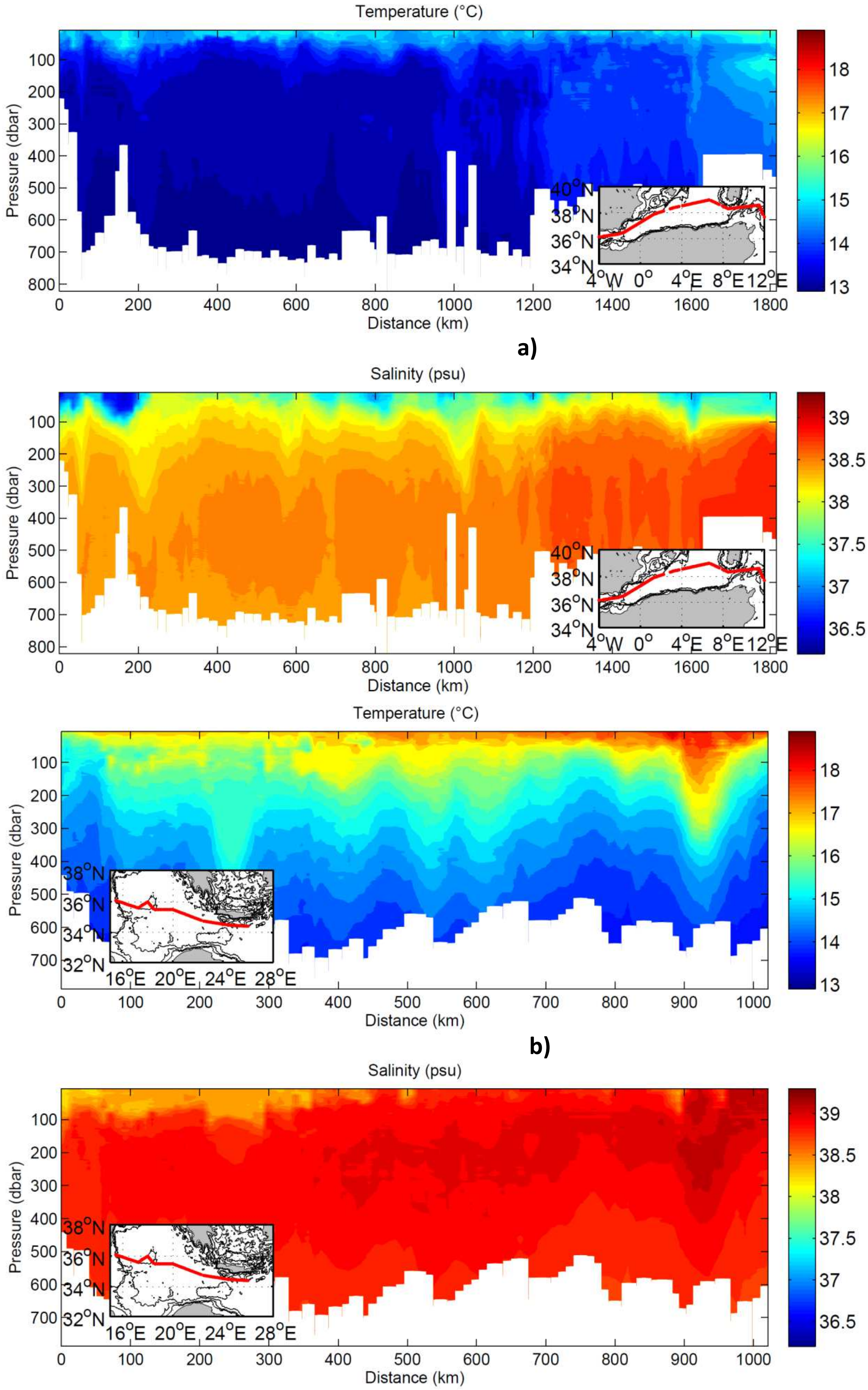


Figure 2: Temperature and salinity distribution along a west-east section through a) the western Mediterranean and b) the eastern Mediterranean Sea. Data are recorded by an underway CTD. Inner panels show the location of UCTD stations. White areas: data are out of instrument range.

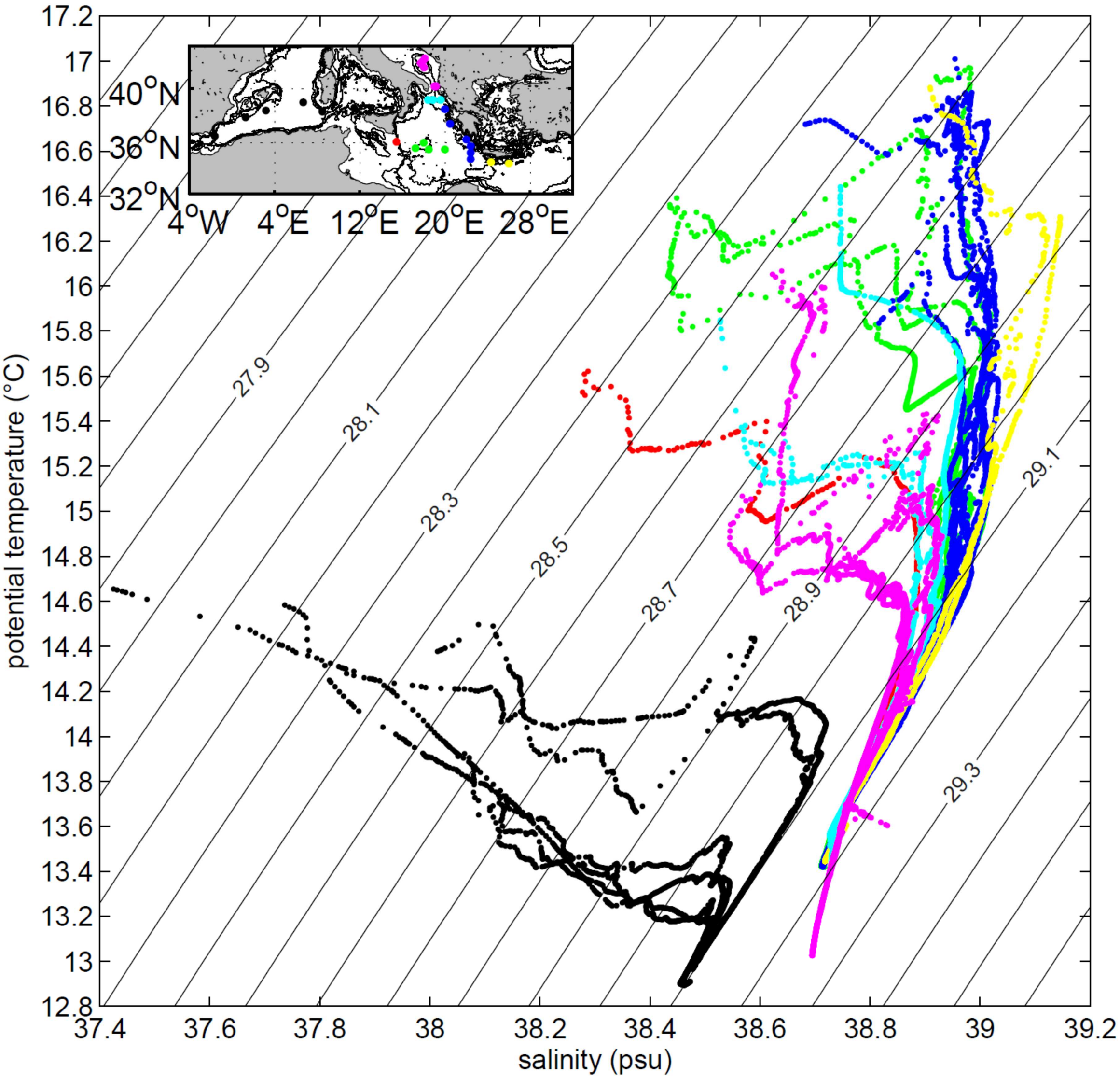


Figure 3: TS diagram determined by CTD data. The inner panel shows the location of CTD stations. The colors correspond with the colors of the profiles.

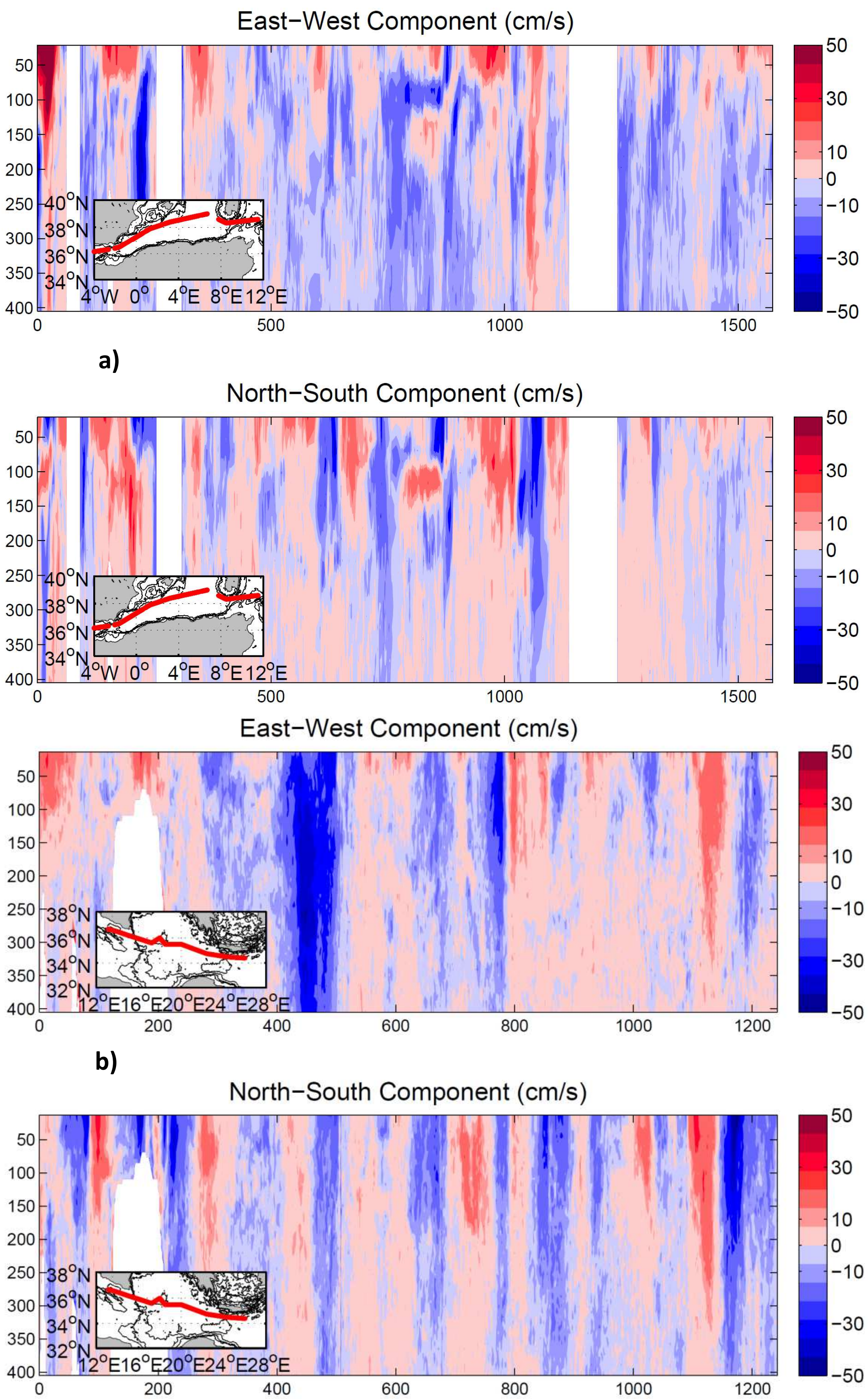


Figure 4: Velocity distribution of the upper 400m of the water column along a west-east section through a) the western Mediterranean and b) the eastern Mediterranean Sea. Data are recorded by a shipborne ADCP. Shown are the east-west and north-south velocity component,

respectively. Inner panels indicate the location of the ship track. White areas: no data are available. X-axes: east-west distance (km). Y-axes: depth (dbar).