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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 twofold; long-term variations of the Levantine Intermediate Water (LIW) and the deep water masses of the Eastern Mediterranean Sea were investigated. 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 resolution of 6 nm and a vertical resolution of 1 dbar for the upper 800 m 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: 34–43° N, 6° W–26° E
Location Name: The Mediterranean Sea
Date/Time Start: 3. April 2014
Date/Time End: 28. April 2014

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1 Introduction

The Mediterranean Sea is a marginal sea, as it is separated 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 at its western sill is 550 m) Sicily Channel. Due to its relatively small size and its geographical location, enclosed between continents, the Mediterranean is very sensitive and responds relatively rapidly to atmospheric forcing and/or anthropogenic influences (Schroeder et al., 2013). The circulation of the Mediterranean Sea is driven by several forces, 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 basin (Robinson et al., 2001). The associated eddy field to the mesoscale circulation is constructed by 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 hydrographic conditions and circulation. Different attempts, based on observational evidences, to schematize surface as well as intermediate and deep paths of the circulation have been made in the past (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 $W\,m^{-2}$ and 0.7 $m\,y^{-1}$. The deficits are balanced by exchanges through the Strait of Gibraltar. The steady-state is a balance 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).

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The water mass formation cycle is characterized by the inflow of relatively low-salinity Atlantic Water (AW) in the upper 100 m of the water column and a return flow of salty water, the Levantine Intermediate Water (LIW), in the intermediate layer (typically depth of 200–600 m) which is formed in the Levantine Basin. The depth variability of the LIW salinity maximum is largely regional: generally, it increases westward. As the Sicily Channel with depth lower than 500 m is a natural barrier between the WMed and EMed, deep-water formation takes place separately for each of the basins. The abyssal water mass in the WMed, produced by shelf and open-ocean convection, is the Western Mediterranean Deep Water (WMDW), which is formed in the Gulf of Lyons (see, e.g., Leaman and Schott, 1991). The Adriatic Deep Water (AdDW) and water of Aegean origin named Cretan Deep Water (CDW) are deep-water masses which are produced in the two deep water formation regions of the EMed. Thus, the predominant water mass of the bottom layers, filling the abyssal plains of the Ionian and Levantine basins, 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 i.e. in Lascaratos et al. (1999), Klein et al. (2010), Hamad et al. (2005), Rubino and Hainbucher (2007), Gačić et al. (2011) and others. The basin went through drastic changes in the past. The largest climatic event took place in the EMed during the 1990s where the deep-water formation switched from the Adriatic to the Aegean Sea. This change was called the Eastern Mediterranean Transient (EMT) and a comparable event was never observed before (Roether et al., 2013). The EMT changed the outflow through the Strait of Sicily 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.

The principal scientific objective of the cruise is twofold: adding knowledge to the understanding of the dispersion of LIW water masses from the eastern basin of the

Mediterranean Sea to the Strait of Gibraltar, especially of its long-term variations and secondly, still continuing with the documentation and with 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 four of the five relevant objectives which the MED-Ship Programme aims to resolve:

- Determination of long-term variability and of controls of water mass properties;
- Determination of changes in circulation patterns
- Reduction of uncertainty in the heat and property budgets
- Augment the historical database of full water column observations necessary for understanding the Mediterranean Sea variability on multiple timescales and for numerical model evaluation.

To our knowledge there exist no further campaigns which cover an east–west transect through the whole Mediterranean Sea with such a high sampling rate. A cross-basin transect allows to investigate the processes relevant for the exchange of water masses between the WMed and EMed. These trans-basin sections permit also to individuate dramatic changes, which might occur in both basins so as the long-term variability. 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 to 28 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). Figures 2–4 show examples for the calibrated and quality controlled data of the UCTD, CTD and ADCP.

3 Methods and quality control

An east–west transect through the whole Mediterranean Sea is especially desired by the Med Ship Programme. The most recent campaign (April 2011) including such a transect 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.

Almost at all stations water samples were taken from 12 depth levels to the maximum through the water column. From all depth levels samples were taken for oxygen analysis, and from at least three depth levels samples were taken 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

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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, 1 dbar 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 small, 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 $\mu mol\,kg^{-1}$.

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 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 h keeping a ship's speed of 6 knots. The ship reduced speed to 2–3 knots while the probe is falling for a maximum of 480 s. The ship enhanced speed again to 6 knots

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during the recovery of the probe. We reached maximum depths of around 850 m, minimum depths of 500 m. The average depth was approximately 650 m. 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 which were carried out at positions of UCTD casts and 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 600–800 m 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 afterwards post-processed with the software package ossi14 (ocean surveyor sputum interpreter), developed by the Leibniz Institute of Marine Sciences (GEOMAR, Fischer, 2011), Kiel, which also corrects for the misalignment angle. The misalignment angle was calculated at approximately -3.5°.

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4 Discussion and conclusion

Figures 2 and 4 nicely reflect the mesoscale variability in both basins during the cruise. In the WMed both Alboran gyres and high eddy activity further on along the section through the WMed can be identified. Some of these structures can be related to well-known features like the Almera-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).

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 other show positions changed, new or never mentioned. This leads to the assumption that a lot of the gyres are semi- or non-permanent and that even the location of the permanent eddies are subject to high spatial variability. 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. They give new insight in the variability of the eddy field and can additionally verify the model results.

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. PI abbreviation stands for name: Dagmar Hainbucher.

Parameter Name	Short name	Unit	PI*	Method	Comments
DATE/TIME	Date/Time				Geocode
LATITUDE	Latitude				Geocode
LONGITUDE	Longitude				
Pressure, water	Press	dbar	DH	CTD, SEA_BIRD SBE 911plus	
Temperature, water	Temp	°C	DH	CTD, SEA_BIRD SBE 911plus	
Salinity	Sal	DH		CTD, SEA_BIRD SBE 911plus	PSU
Oxygen	O_2	$\mu mol\,L^{-1}$	DH	CTD with attached oxygen sensor calibrated, corrected using Winkler titration	
Pressure, water	Press	dbar	DH	UnderwayCTD (UCTD), Oceanscience	
Temperature, water	Temp	°C	DH	UnderwayCTD (UCTD), Oceanscience	
Salinity	Sal	DH		UnderwayCTD (UCTD), Oceanscience	PSU
DEPTH, water	Depth water	m			Geocode
Current velocity east–west	UC	$cm\,s^{-1}$	DH	Shipboard Acoustic Doppler Current Profiling (SADCP)	
Current velocity north–south	VC	$cm\,s^{-1}$	DH	Shipboard Acoustic Doppler Current Profiling (SADCP)	

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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)

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Table 3. Used UCTD sensors.

Probe 1	Device Type	Serial Number
0068	90560 UCTD/SBE49 FastCat CTD	70200068
0155	90745 UCTD/SBE 37 MicroCat	70200155
0183	90745 UCTD/SBE 49 FastCat CTD	70200183

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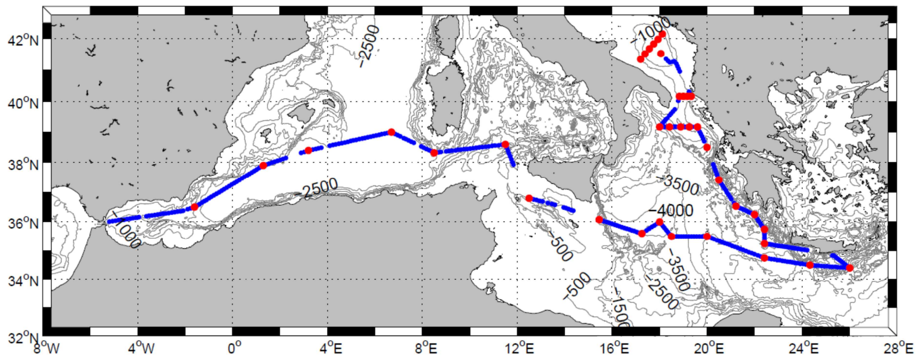

Figure 1. Cruise track of P468 with CTD stations marked in red and uCTD stations marked in blue.

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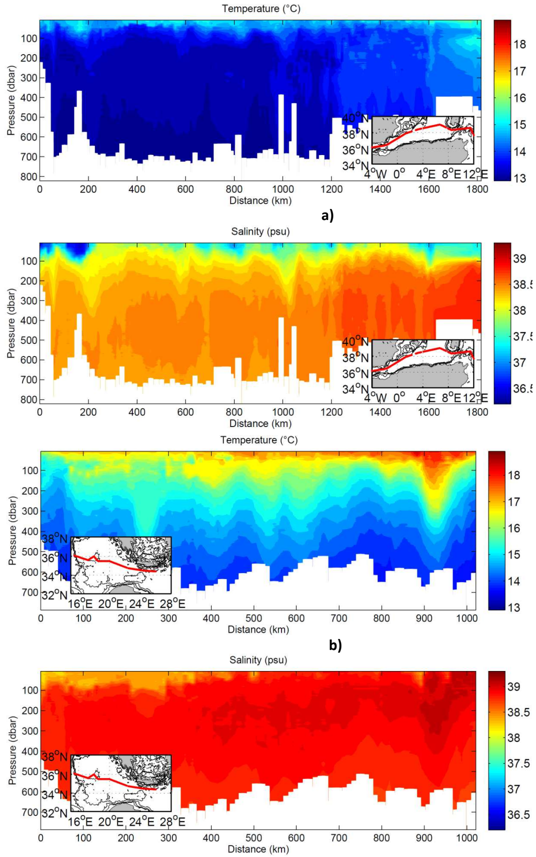

Figure 2. Temperature and salinity distribution along a west–east section through **(a)** the western Mediterranean and **(b)** the eastern Mediterranean Sea. Data are gained by an underway CTD. Inner panels show the location of uCTD stations. White areas: data are out of instrument range.

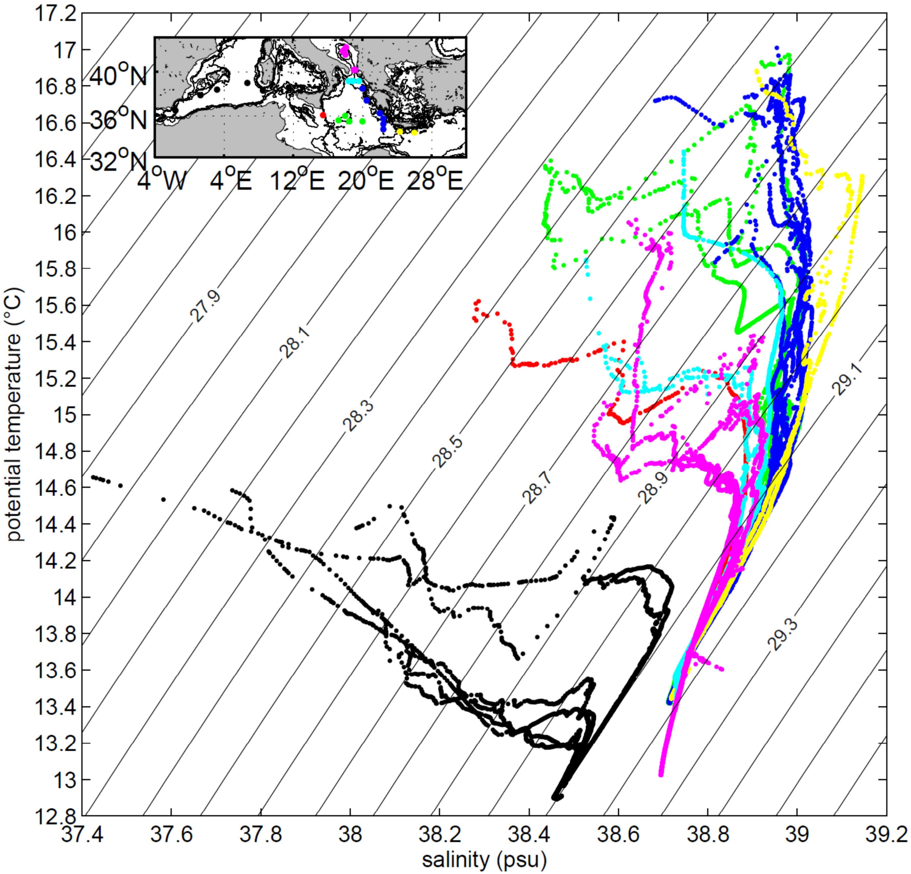

Figure 3. TS diagram determined by CTD data. The inner panel shows the location of CTD stations. The colors correspond with the colors of the profiles.

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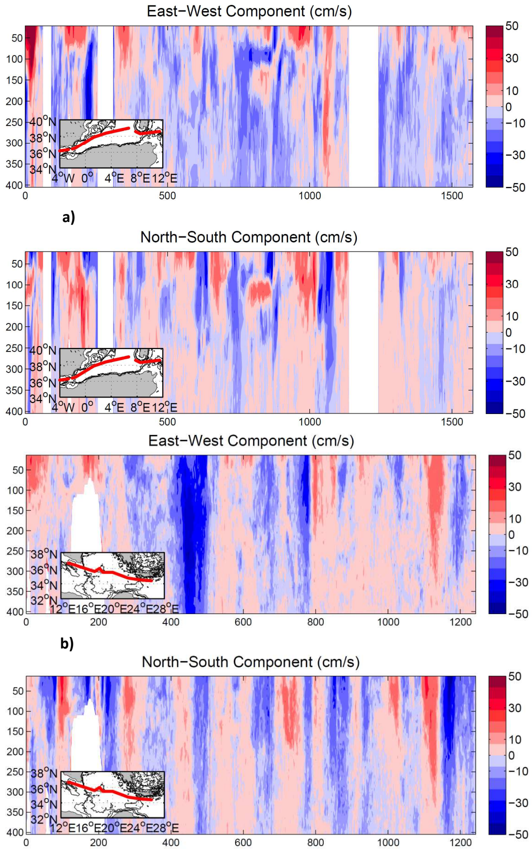

Figure 4. Velocity distribution of the upper 400 m of the water column along a west–east section through **(a)** the western Mediterranean and **(b)** the eastern Mediterranean Sea. Data are gained by a shipborne ADCP. Shown are the east–west and north–south velocity component, respectively. Inner panels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

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