Mediterranean Marine Science

Vol 17, No 2 (2016)

Indication of recent warming process at the intermediate level in the Tyrrhenian Sea from SOOP XBT measurements

A. RIBOTTI, R. SORGENTE, A. OLITA, F. ORILIA, M. BORGHINI, F. RESEGHETTI

doi: [10.12681/mms.1196](https://doi.org/10.12681/mms.1196)

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.1196

Indication of recent warming process at the intermediate level in the Tyrrhenian Sea from SOOP XBT measurements

A. RIBOTTI[1], R. SORGENTE[1], A. OLITA[1], F. ORILIA[1], M. BORGHINI[2] and F. RESEGHETTI[3]

[1] IAMC-CNR, 09170 Oristano, Italy
[2] ISMAR-CNR, 19032 La Spezia, Italy
[3] ENEA, SSPT-PROTER-BES, 19032 La Spezia, Italy

Corresponding author: alberto.ribotti@cnr.it

Handling Editor: Miro Gacic

Received: 1 September 2015; Accepted: 28 Arpil 2016; Published on line: 18 July 2016

Abstract

The Tyrrhenian Sea is a sub-basin of the western Mediterranean crossed by intermediate and deep waters from the eastern basin. Across this sub-basin, temperature profiles of the water column from expendable bathythermographs (XBTs) have been acquired for fifteen years along transects realized by means of commercial vessels. Since 1999 two increases of temperature have been observed at intermediate depths interspersed with "colder" periods. These increases concern deeper and deeper depths over the course of the years, then involving the entire sub-basin in the 200-800 m range in September 2014, when the greatest anomalies over the entire period are found. The paper shows evidences of this rapid warming, giving insights into the origin and the diffusion of the warmer intermediate waters, then showing its evolution in the years.

Keywords: Circulation, intermediate water masses, Tyrrhenian Sea, western Mediterranean.

Introduction

The Tyrrhenian Sea is the deepest sub-basin of the western Mediterranean, measuring over 3700 m in its center and surrounded by lands that permit important exchanges between the western and the eastern Mediterranean, at surface and intermediate depths (0-1000 m), mainly from the shallow Strait of Sicily and the deep Sardinia Channel to the south and through the shallow Corsica Channel to the north. The inputs/outputs from/to the Straits of Bonifacio and Messina are negligible with respect to the other passages.

Its hydrodynamics has been studied for years (Krivosheya, 1983; Hopkins, 1988; Astraldi & Gasparini, 1994; Sparnocchia *et al.,* 1999; Budillon *et al.,* 2009; Millot, 2009; Vetrano *et al.,* 2010) but only since the end of the 1990s researchers have increased their studies due to the formation of the new deep waters in the western Mediterranean and their relationship with the climatological event known as Eastern Mediterranean Transient (EMT) (Sparnocchia *et al.,* 1999; Lascaratos *et al.,* 1999; Malanotte-Rizzoli *et al.,* 1999; Klein *et al.,* 1999; Theocharis *et al,* 2002; Gasparini *et al.*2005; Roether *et al.,* 2007). The circulation in the Tyrrhenian Sea can be seen with the typical Mediterranean three-layer system composed of surface, intermediate and deep waters. At the surface the water of Atlantic origin (AW) flows in the upper 100-150 m mainly coming from the west as the Algerian Current and identifiable by minimum salinity. Below the AW the Levantine Intermediate Water (LIW) is mixed with the Cretan Intermediate Water (CIW) forming the Eastern Intermediate Water (EIW) as outflow from the Strait of Sicily. Millot (2013) reports that EIW is formed from 2/3 to 3/4 of LIW and is identifiable by maximum salinity until 700-1000 m depth in the center of the sub-basin while its core is between 200-800 m near the Sicilian slope (Fuda *et al.,* 2002). Intermediate waters circulate northward counter-clockwise along the Italian peninsula continuously mixing with surrounding waters. EIW shows a salinity ranging from 38.76-38.77 (sθ=29.07-29.08 kg/m^3) and θ>14°C close to Sicily, coming from the eastern basin, about 38.88-38.90 (sθ=29.05-29.10 kg/m^3) in correspondence to Naples of 38.65 (sθ~29.10 kg/m^3) (Millot, 2013) near Sardinia coming from the western basin after its complete recirculation (Astraldi *et al.,* 2002). Its circulation is seasonal, as in winter it partly leaves the basin through the Corsica Channel and partly through the Sicily-Sardinia opening while in summer and autumn the southern opening is the main link with the rest of the western Mediterranean Sea (Astraldi & Gasparini, 1994; Sorgente *et al.,* 2011).

Below the LIW, the deep Tyrrhenian Deep Water (TDW) is the result of the mixing of the Western Mediterranean Deep Water (WMDW) entering from the Sardinia Channel, the transitional Eastern Mediterranean Deep Water (tEMDW) crossing the Strait of Sicily and partially the same EIW once entered in the Tyrrhenian sub-basin after cascading and mixing down to ~2000 m (Sparnocchia *et al.,* 1999; Gasparini *et al.,* 2005; Millot, 2013).

The aim of this paper is to describe, through a series of XBT observations across the Tyrrhenian sea over the course of 15 years, trend and variability of temperatures in intermediate layers and their possible relationships with past and current Mediterranean transients.

Materials and Methods

Over 2045 XBT probes have been deployed in the period September 1999 - September 2014 in the framework of the Voluntary Observing Ship Scheme of JCOMM. This monitoring activity began within Mediterranean Forecasting System projects. XBT probes were dropped mainly from commercial ferries along the transect Genova - Palermo, managed by the Italian shipping company Grandi Navi Veloci in over 55 cruises between September 1999 and September 2014, and 10 cruises by containerships, managed by Hapag Lloyd and CMA CGM Shipping companies, along the transect western Sicily - Corsica islands in the period April 2009 - September 2010 (Fig. 1).

Different XBT types and recording systems were used to obtain the temperature profile of a seawater column such as LM SippicanT4, DB, XTCD-1 and T5/20 probes with LM SippicanMK21 or Turo QUOLL recording systems.

The range of depth of good data profiles was about 450-550m depth for T4, about 720-890 m for DB and about 1600-1750 m for T5/20 probes. The sampling distance ranged in the period from about 10-12 nm on (A) to about 30 nm on (B) as in Figure 1.

Being without water pressure sensor, any XBT probe simply provides a correspondence between seawater temperature and time at each 0.1s (the standard temporal sampling rate) then converted into temperature - depth through a fall rate equation whose coefficients are dependent on XBT type. Here we used the fall rate coefficients indicated by IGOSS (Hanawa *et al.,* 1995) for T4 and DB probes whereas the manufacturer coefficients were applied to T5/20 probes. The performance of XBT recording systems has been constantly monitored by the use of a tester probe checking the amount of possible thermal bias due to electronics applied.

Complete XBT profiles (not decimated data, for example at 5-10-15-20m and so on) were constantly analyzed. Due to the peculiarity of Mediterranean seawater, quality control procedures based on Medar-Medatlas protocols (MedAtlas Group, 1994; Maillard & Fichaut, 2001) had been developed earlier (Manzella *et al.,* 2003). The protocols have a seven-step procedure (detection of end of profile, gross range check, position control, elimination of spikes, Gaussian smoothing and re-sampling at 1m intervals, general malfunction control, comparison with climatology) and final visual check.

The dataset used in this analysis includes only profiles specifically reprocessed with the last software version having a slightly poorer smoothing in the terminal part of the temperature profiles. We do not apply any correction to XBT depths or temperature and we refer to literature for discussions on uncertainties in XBT measurements (e.g. see Cowley *et al.,* 2013; Cheng *et al.,* 2014, 2015).We note that the robustness and consistency

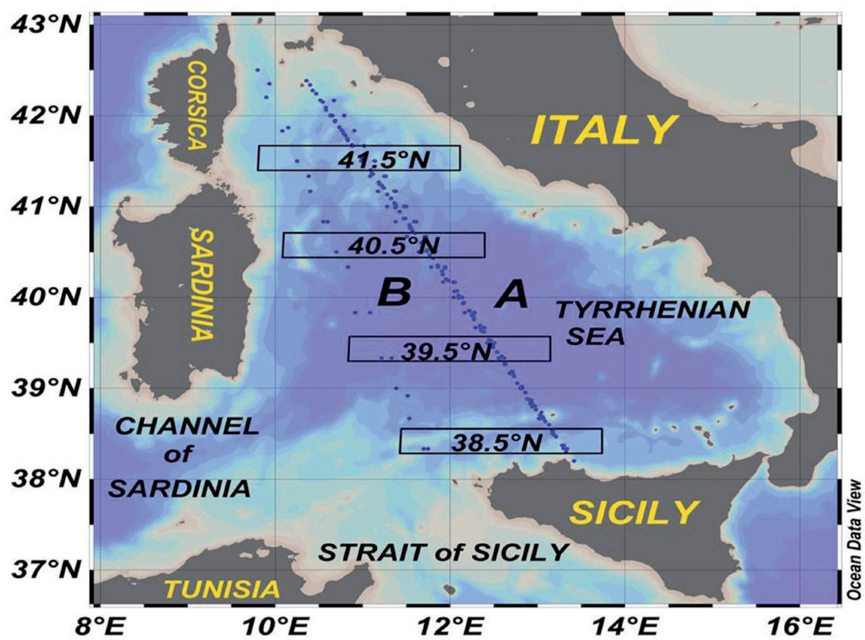


Fig. 1: The XBT transect (A) Genoa -Palermo and (B) Corsica - western Sicily. The four areas between 38.5°N and 41.5°N include casts from September 2009, 2012 and 2014, October 1999, 2000, 2004, 2005 and 2006, December 2010, 2011 and 2013 used in some analyses.

of XBT data has been a well-know problem for dozens of years. Several studies have been published on this subject (e.g. see Cheng *et al.,* 2014) but a general consensus on the possible solution (namely, a correction scheme of XBT data) is not currently available (as established in the most recent XBT science meeting in Beijing, November 2014; see Cheng *et al.,* 2015).

We highlight the results of an inter-comparison between XBT and ARGO profiles based on data recorded in 2004-2005 in the Mediterranean (Poulain & Barbanti, 2005). When the difference in geographical and temporal coordinates of XBT and ARGO profiles was smaller than 10km in distance and 5 days in time, a mean difference of 0.06°C over the entire profile is obtained with 0.32°C as standard deviation. On the other hand, an improvement of that analysis including only XBT and ARGO data from Ligurian and Tyrrhenian Seas under similar constraints does confirm that result (Raiteri & Reseghetti, in preparation). In detail, the XBT-ARGO temperature difference for data below 100m depth has a mean value of 0.042°C with 0.108°C as standard deviation and 0.045°C as median (Fig. 2). In summary, XBT profiles are a little warmer than ARGO profiles and the standard deviation is fully compatible with the overall accuracy of XBT measurements indicated by the manufacturer (± 0.20°C).

Results

For the data analysis, the depth has been limited at the intermediate level in the 200-900 m range, in order to avoid the high frequency variability of the upper levels and the inference of the atmospheric processes driving the seasonal cycle above the permanent thermocline. Analysis was further restricted to the period between September and December when over 40% (836 profiles) of the entire dataset was collected. This was to further reduce the weight of the seasonal signal.

The vertical profiles of temperature visible in Figure3 at about 38.5°N of latitude (Fig. 1) show the 1999 and 2009 stations on the left side of the plot (colder) and 2004, 2012 and 2014 stations in its right side (warmer). The profile in 2014 is the warmest than in the previous years in its entire "intermediate" column from 200 to 750 m depth.

This distinction between warmer and colder profiles is corroborated by the two graphs in Figure 4 showing the change of temperatures at two different latitudes (Fig. 1), around 41.5°N (Fig. 4a) and around 38.5°N (Fig. 4b) at 300 and 500 m depth. In the southernmost area the two peaks in 2004 and 2014 at 300 m depth are clearly visible with a particularly evident increase in 2014. Here we measure a $DT_{1999\text{-}2014}$ of 0.6 °C passing from about 14.0°C in 1999 (the coldest year) to about 14.6°C in 2014. Such a maximum in 2014 is visible in both graphs and depths. At 41.5°N the difference between 1999 and 2004 is about 0.2°C at 300 m, a value that doubles the standard deviation of the error of measurement, as described above.

In the Hovmoller diagrams (time-depth) of Figure 5 (for the four areas identified in Fig. 1), the differences in temperature values, and extent between the two warm events of 2004 and 2014, are clearly visible. This is even more evident at the lowest latitude (Fig. 5a at 38.5°N) where at 300 m depth the temperature moves from 14.01°C in 1999 to 14.35°C in 2004, then again to 14.070°C in 2009 to increase to 14.590°C in 2014. Going northward, these two warming events are less and

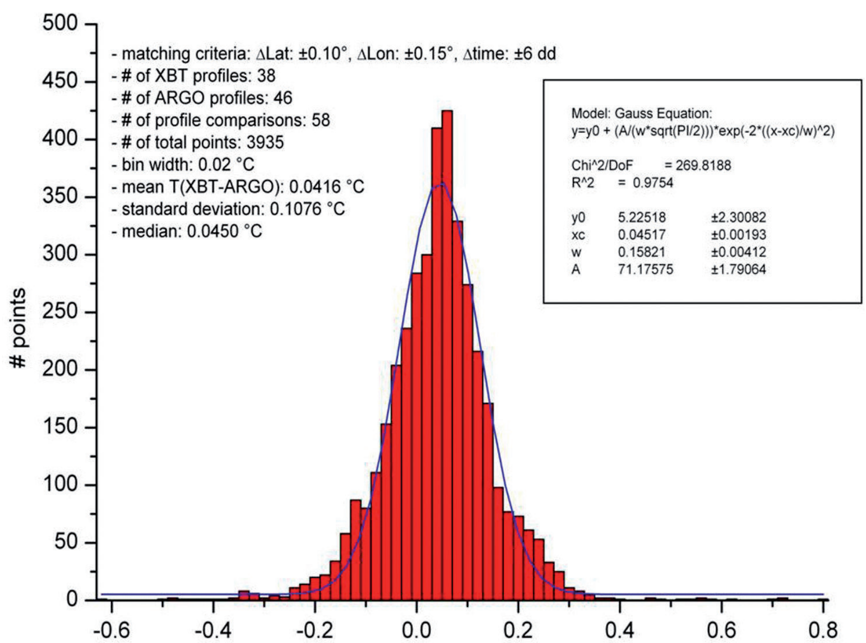


Fig. 2: Temperature differences XBT-ARGO for depths 100 m - bottom in°C.

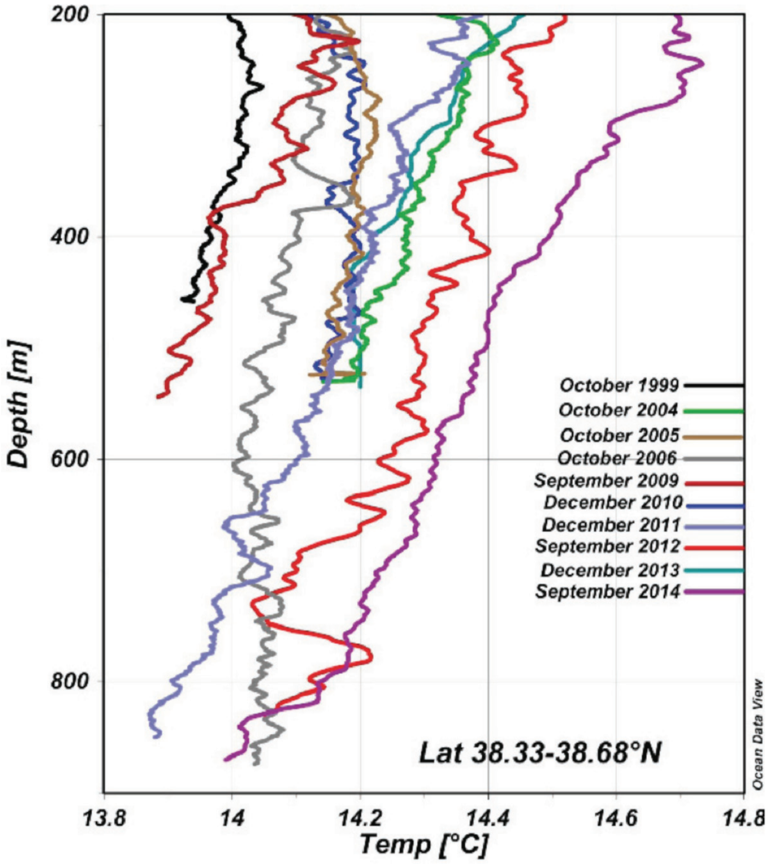


Fig. 3: Temperature profiles in the range 200-900 m depth at 38.5°N between October 1999 and September 2014.

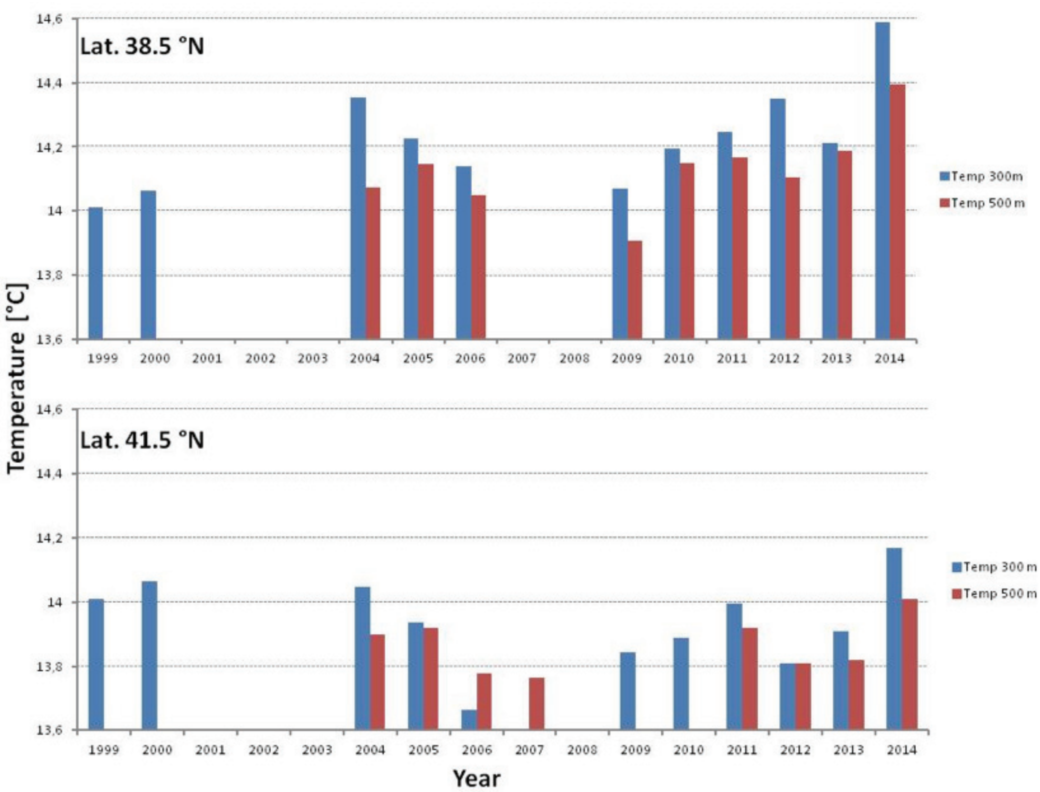


Fig. 4: Time evolution of temperature at 300 m and 500 m depth from the casts at 38.5°N (top) and at 41.5°N (bottom).

less evident but present for the years 2004 and 2014 until 41.5°N (Fig. 5c) with temperatures surpassing 14.0°C. The main events in October 2004 and September 2014 are also visible in the sections of Figures 5d) and k), respectively. Panels of Figure 6 represent the anomalies recorded during each single cruise (selected examples are reported in Figures) with respect to a cumulative weighted average built from the entire dataset of 2054

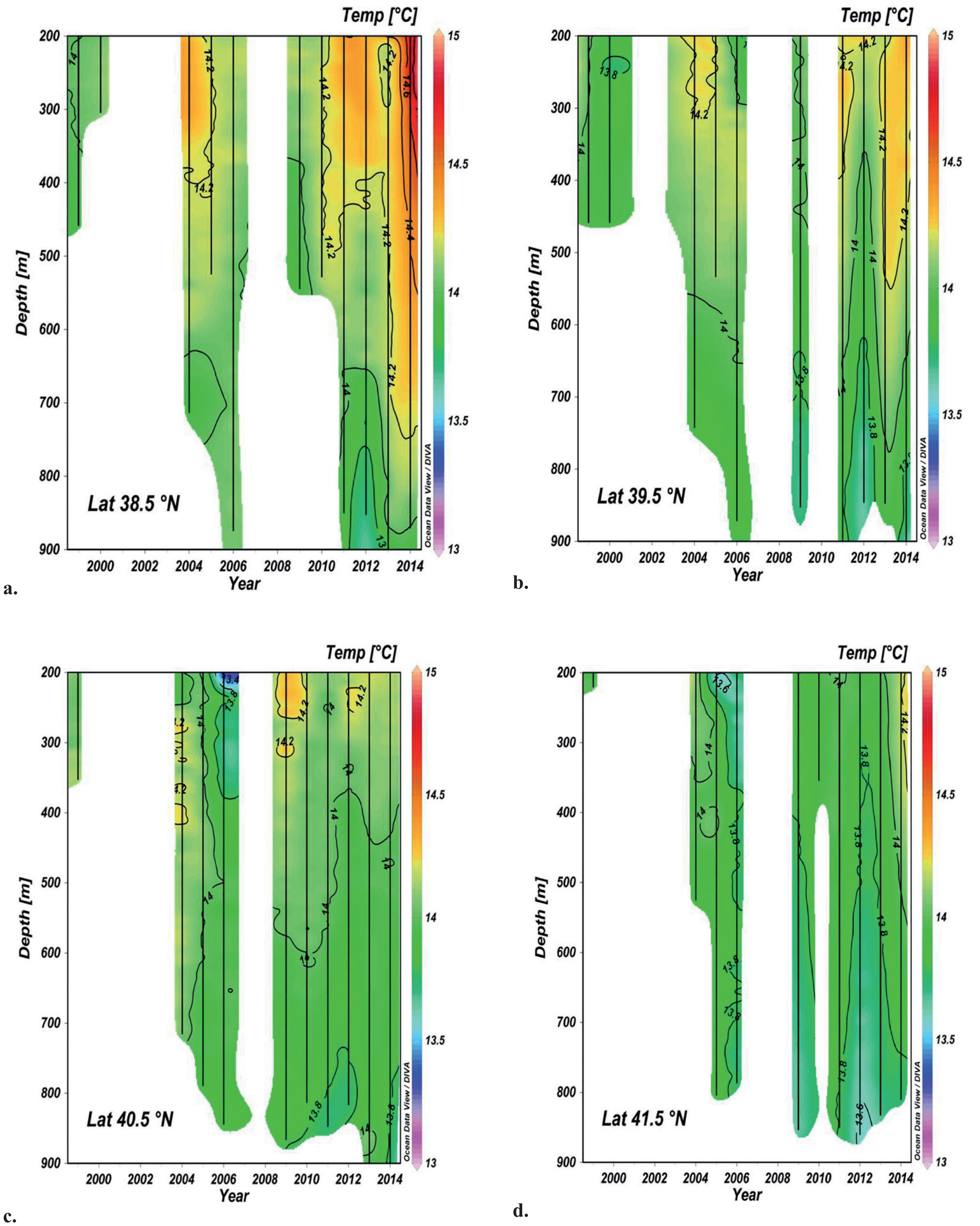


Fig. 5: Hovmoller diagrams of the temperature in the depth range of 200-900 m at a) 38.5°N; b) 39.5°N; c) 40.5°N; d) 41.5°N.

XBT profiles, represented in Figure 6 (panel a). This average was built by re-gridding the synoptic XBT profiles on a regular depth-latitude mesh through a linear interpolation of the data, then producing annual averages. This was done to avoid as much as possible biases due to the non-monotonic sampling in time. Then, anomalies have been computed subtracting such a weighted average to the gridded synoptic XBT transects. In the anomalies

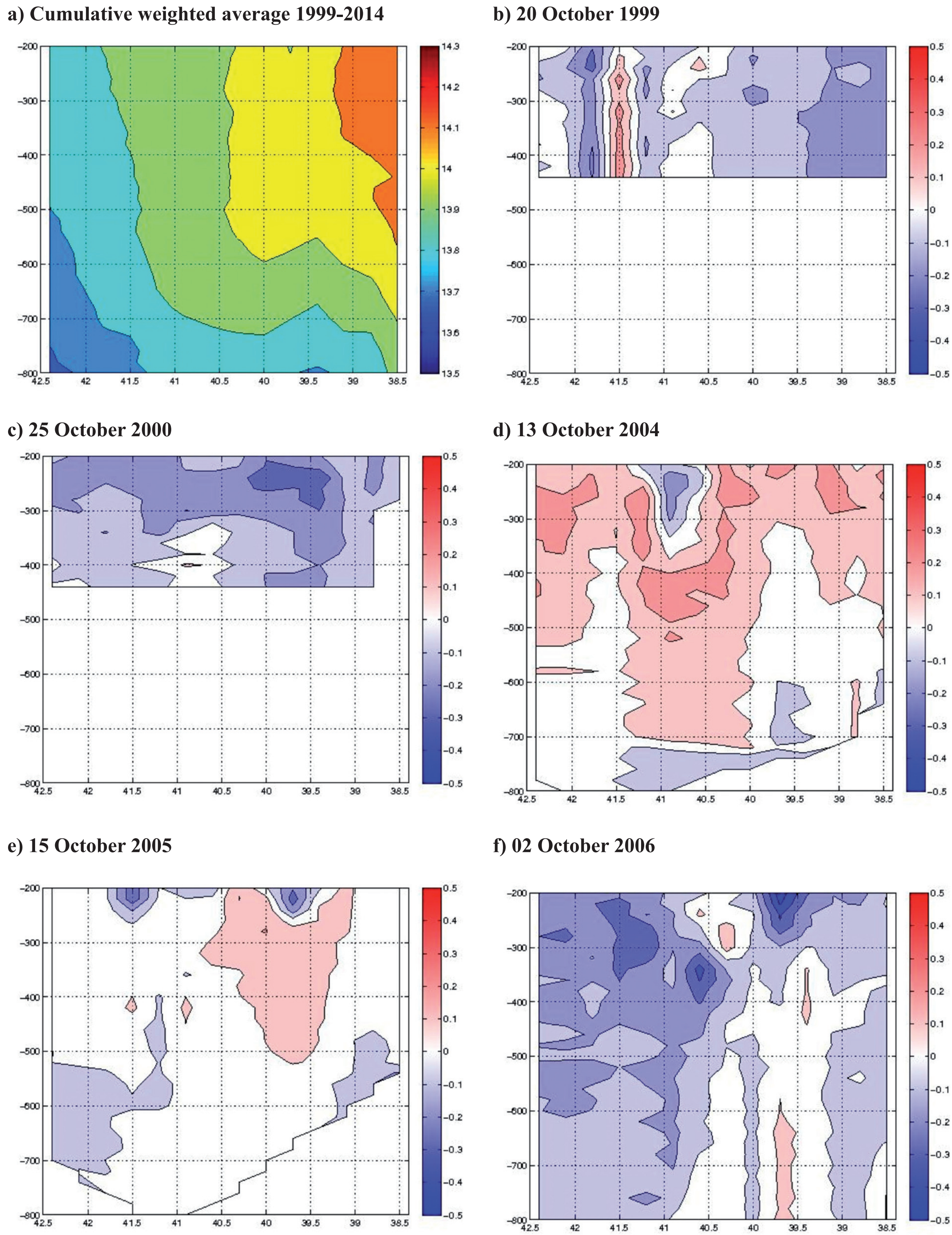
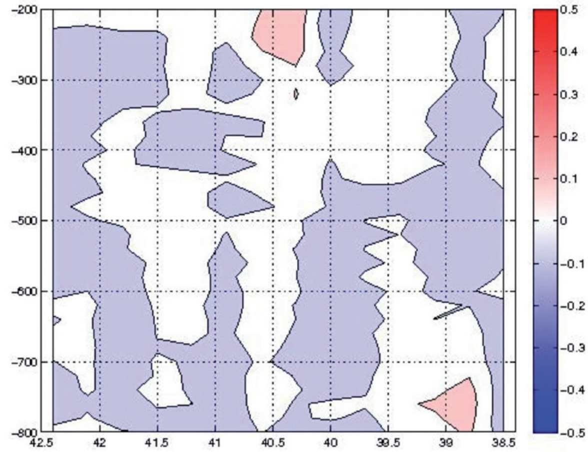


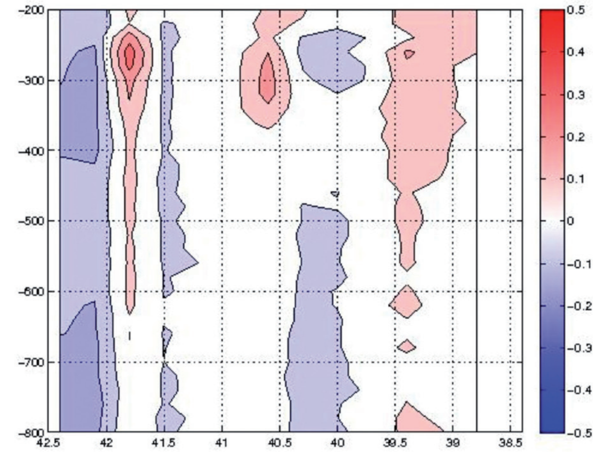
Fig. 6: (a) cumulative weighted average built from the entire dataset of 2054 XBT profiles between 42.5°N and 38.5°N in the range 200-800 m depth for the period 1999-2014. (b) to (k) anomalies recorded during representative single cruises in the period September-December with respect to a). Values in color bar are in °C.

Fig. 6 continued

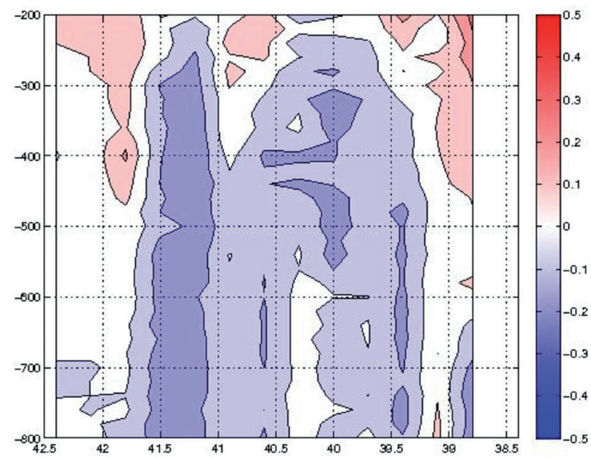
g) 14 December 2010



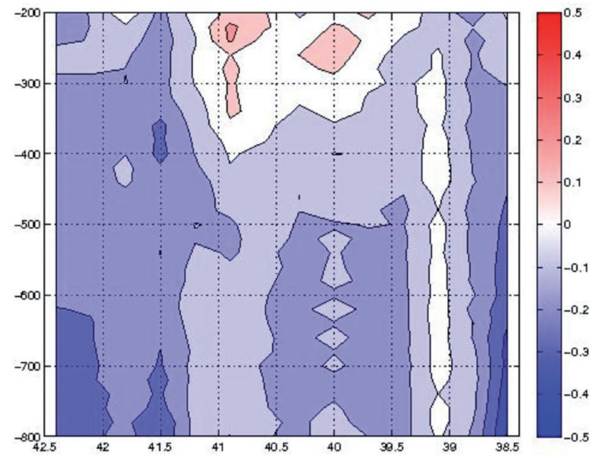
h) 13 December 2011



i) 24 September 2012



j) 19 September 2013



k) 25 September 2014

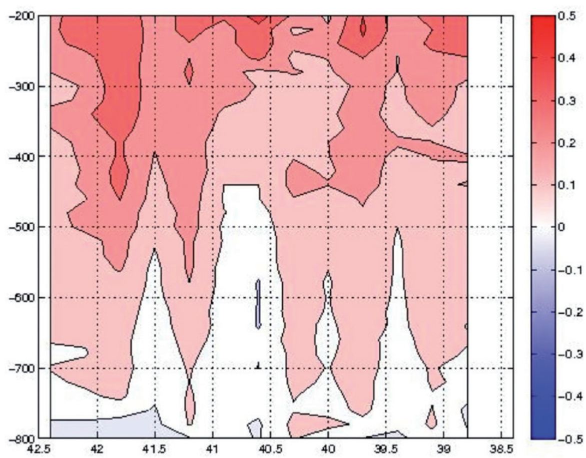


Fig. 6: (a) cumulative weighted average built from the entire dataset of 2054 XBT profiles between 42.5°N and 38.5°N in the range 200-800 m depth for the period 1999-2014. (b) to (k) anomalies recorded during representative single cruises in the period September-December with respect to a). Values in color bar are in °C.

calculated in this way, the two events in 2004 and 2014 are clearly depicted in their spatial extent and magnitude. Data show a warming in 2004 that covers the months between mid-2004 (no data available for early 2004) and early 2005 (not shown). At 38.5°N of latitude a new, quite constant increase started with a small fluctuation in 2013 at lower depths, reaching its highest values in September 2014. In the northern part of the sub-basin, at

41.5°N, this signal is present but with a lower increase in temperature from 200 to 800 m, thus involving the whole of the intermediate water. The two warming events in 2004 and 2014 mainly differ in their spatial and temporal amplitude and in the values of temperature reached at the different depths. The first one (2004) involved the entire Tyrrhenian Sea. It was more clearly visible in its central and southern part with an increase of about 0.4°C with respect to that in 1999 but it was confined to the upper 400 m depth. The temperature anomaly, with respect to the weighted average of the studied period, shows an increase ranging between 0.1°C and 0.45°C in the first 400 m depth. Only in the central Tyrrhenian is there a signal of such warming down to 700 m depth. The second warming event in 2014 shows a bias over 0.45°C until 450 m depth in the entire Tyrrhenian Sea and it reaches 800 m depth all along the meridional transect crossing the Tyrrhenian sub-basin.

Discussion

Temperature profiles spanning a period of about 15 years (1999-2014), with some gaps between 2001 and 2003 and in 2007-2008, have been recorded along a meridional transect crossing the Tyrrhenian Sea between the Corsica Channel to the north and the island of Sicily to the south. This was possible thanks to the launch of XBT probes from vessels of opportunity throughout this time period.

Evident interannual variability strongly emerged from the data. The potential role of the quality of XBT data in determining part of such variability was addressed: estimated error of XBT data is about 1 order of magnitude in the strongest anomalies observed, which is the focus of the paper. Furthermore, the strongest anomalies (about 0.45°C at more than 200 m depth) are 4-5 times the estimated standard deviation of the instrumental error.

The analysis of the data of the intermediate layers clearly show two warming events with maximum values of temperature in 2004, also observed by Marty & Chiaverini (2010) at the DYFAMED location in the Ligurian-Provençal basin, and in 2014.

The two warming events differ in their horizontal and vertical extent with a maximum deviation with respect to the XBT weighted average exceeding 0.45°C at depth greater than 200 m. In 2004 the maximum anomaly was observed between 200-300 m while in 2014 it further extends in depth and latitude covering the entire sub-basin between 200-500 m, reaching 800 m (with anomalies not exceeding 0.2 °C) in many parts of the domain.

Gačić *et al.* (2013) calculated that the LIW moving from the Levantine basin takes about 10-13 years to reach the Sicily Channel area and about 10-12 years from the Sicily Channel to the Gulf of Lions. Borzelli's (Borzelli *et al.,* 2009) findings show that in early 1990s, and with a decadal periodicity, the circulation in the Ionian Sea was anticyclonic, situation that represents a preconditioning mechanism for EMT-like events in the Cretan Sea (Gačić *et al,* 2011).

The 2004 warm event could be a signal of the modified (warmed) EMT intermediate waters coming from the Strait of Sicily/eastern Mediterranean basin and moving northward throughout the Tyrrhenian Sea, as also described by Gasparini *et al.* (2005) and widely described by other authors focusing on the formation of a new WMDW (Schröeder *et al.,* 2006, 2008, 2009*;* Zunino *et al.,* 2009*;* Herrmann *et al.,* 2010).

The 2014 event in the Tyrrhenian Sea has characteristics similar to the 2004 event, but even more intense and wide spread. The 10 years' time lag with the past event make us hypothesize an accordance with the decadal periodicity of the EMT's favorable conditions described above.

An actual confirmation of the EMT character of the 2014 anomaly we observed can be provided only by intensive modeling (atmosphere and ocean) and observational studies able to describe generation and spread of a possible EMT-like event.

Acknowledgements

The authors thank the Grandi Navi Veloci (GNV) Shipping Company, the Captains and the crew of the ferries that, in the years, have permitted measurements and presence of scientists onboard. This work has been supported by the RITMARE Italian flagship Project, funded by MIUR under the NRP 2011-2013, approved by CIPE Resolution 2/2011 of 23/03/2011. Part of XBT probes deployed in 2010 and 2011 were kindly provided by AOML/NOAA in the framework of JCOMM/SOOP activities. Data are available at the portal http://moon.santateresa.enea.it/MMD/MMD.html and addressed to franco.reseghetti@enea.it.

References

Astraldi, M., Gasparini, G.P., 1994. The seasonal characteristics of the circulation in the Tyrrhenian Sea. p. 115-134. In: *Seasonal and interannual variability of the Western Mediterranean Sea, Coastal and Estuarine Studies*. Coastal and Estuarine Studies book series, La Violette P. E. (Eds.), 46, DOI: 10.1029/CE046.

Astraldi, M., Conversano, F., Civitarese, G., Gasparini, G.P., Ribera d'Alcalà, M. *et al.,* 2002. Water mass properties and chemical signatures in the central Mediterranean region. *Journal of Marine Systems*, 33-34, 155-177.

Borzelli, G.L.E., Gačić, M., Cardin, V., Civitarese, G., 2009. Eastern Mediterranean transient and reversal of the Ionian Sea circulation. *Geophysical Research Letters*, 36, L15108, doi:10.1029/2009GL039261.

Budillon, G., Gasparini, G.P., Schröeder,K., 2009. Persistence of an eddy signature in the central Tyrrhenian basin. *Deep-Sea Research Part II*, 56 (11-12), 713-724.

Cheng, L., Zhu, J., Cowley, R., Boyer, T., Wijffels, S., 2014. Time, Probe Type, and Temperature Variable Bias Corrections to Historical Expendable Bathythermograph Observations. *Journal of Atmospheric and Oceanic Technology*, 31, 1793-1825.

Cheng, L., Abraham, J., Goni, G., Boyer, T., Wijffels, S. *et al.,* 2015. XBT Science: assessment of instrumental biases and errors. *Bulletin of the American Meteorological Society, DOI: http://dx.doi.org/10.1175/BAMS-D-15-00031.1*

Cowley, R., Wijffels, S., Cheng, L., Boyer, T., Kizu, S., 2013. Biases in expendable bathythermograph data: A new view based on historical side-by-side comparisons. *Journal of Atmospheric and Oceanic Technology*, 30, 1195-1225.

Fuda, J.-L., Etiope, G., Millot, C., Favali, P., Calcara, M. *et al.,* 2002. Warming, salting and origin of the Tyrrhenian Deep Water. *Geophysical Research Letters*, 29 (19), doi:10.1029/2001GL014072

Gačić, M., Civitarese, G., Eusebi Borzelli, G.L., Kovacevic, V., Poulain, P.-M. *et al.,* 2011. On the relationship between the decadal oscillations of the Northern Ionian Sea and the salinity distributions in the Eastern Mediterranean. *Journal of Geophysical Research*, 116, C12002, doi:10.1029/2011JC007280.

Gačić, M., Schröeder, K., Civitarese, G., Cosoli, S., Vetrano, A. *et al.,* 2013. Salinity in the Sicily Channel corroborates the role of the Adriatic–Ionian Bimodal Oscillating System (BiOS) in shaping the decadal variability of the Mediterranean overturning circulation. *Ocean Science*, 9 (1), 83-90.

Gasparini, G.P., Ortona, A., Budillon, G., Astraldi, M., Sansone, E., 2005. The effect of the Eastern Mediterranean Transient on the hydrographic characteristics in the Strait of Sicily and in the Tyrrhenian Sea. *Deep-Sea Research Part I*, 52 (6), 915-935.

Hanawa, K., Rual, P., Bailey, R., Sy, A., Szabados, M., 1995. A new depth time equation for Sippican or TSK T-7, T-6 and T-4 expendable bathythermographs (XBT). *Deep-Sea Research Part I*, 42.8, 1423-1451.

Herrmann, M., Sevault, F., Beuvier, J., Somot, S., 2010. What induced the exceptional 2005 convection event in the northwestern Mediterranean basin? Answers from a modeling study. *Journal of Geophysical Research*, 115, C12051 doi:10.1029/2010JC006162.

Hopkins, T.S., 1988. Recent observations on the intermediate and deep water circulation in the Southern Tyrrhenian Sea. *Oceanologica Acta*, Special Issue, 9, 41-50.

Klein, B., Roether, W., Manca, B.B., Bregant, D., Beitzel, V. *et al.,* 1999. The large deep water transient in the Eastern Mediterranean. *Deep-Sea Research Part I*, 46, 3, 371-414.

Krivosheya, V.G., 1983. Winter circulation and structure in the Tyrrhenian Sea. *Oceanology*, 23, 166-171.

Lascaratos, A., Roether, W., Nittis, K., Klein, B., 1999. Recent changes in deep water formation and spreading in the Mediterranean Sea: a review. *Progress in Oceanography*, 44 (1-3), 5-36.

Maillard, C., Fichaut, M., 2001. MEDAR-MEDATLAS Protocol. Part I. Exchange format and quality checks for observed profiles. Ifremer Rep. R.INT.TMSI/IDM/SISMER/SIS00–084, 48 pp.

Malanotte-Rizzoli, P., Manca, B.B., Ribera d'Alcalà, M., Theocharis, A., Brenner, S. *et al.,* 1999. The Eastern Mediterranean in the 80s and in the 90s: the big transition in the intermediate and deep circulation. *Dynamics of Atmosphere and Oceans*, 29 (2-4), 365-395.

Manzella, G.M.R., Scoccimarro, E., Pinardi, N., Tonani, M., 2003. Improved near real time data management procedures for the Mediterranean ocean Forecasting System – Voluntary Observing Ship Program. *Annales Geophysicae*, 21 (1), 49-62.

Marty, J.C., Chiaverini, J., 2010. Hydrological changes in the Ligurian Sea (NW Mediterranean, DYFAMED site) during 1995-2007 and biogeochemical consequences. *Biogeosciences*, 7 (7), 2117-2128.

MedAtlas Group, 1994. Specification for Mediterranean banking and regional quality controls. IFREMER, Direction Scientific, Sismer-Brest, *SISMER/IS/94-014*, pp. 29

Millot, C., 2009. Another description of the Mediterranean Sea outflow. *Progress in Oceanography*, 82 (2), 101-124.

Millot, C., 2013. Levantine Intermediate Water characteristics: an astounding general misunderstanding! *Scientia Marina,* 77 (2), 217-232.

Poulain, P.M., Barbanti, R., 2005. Comparison between VOS/XBT and MEDARGO temperatures. *INOGS report REL 61/2005 - OGA-31.*

Roether, W., Klein, B., Manca, B.B., Theocharis, A., Kioroglou, S., 2007. Transient Eastern Mediterranean deep waters in response to the massive dense-water output of the Aegean Sea in the 1990s. *Progress in Oceanography,* 74 (4), 540-571.

Schröeder, K., Gasparini, G.P., Tangherlini, M., Astraldi, M., 2006. Deep and intermediate water in the western Mediterranean under the influence of the Eastern Mediterranean Transient. *Geophysical Research Letters,* 33, L21607, doi:10.1029/2006GL027121.

Schröeder, K., Ribotti, A., Borghini, M., Sorgente, R., Perilli, A. *et al.,* 2008. An extensive western Mediterranean deep water renewal between 2004 and 2006. *Geophysical Research Letters*, 35, L18605, doi:10.1029/2008GL035146.

Schröeder, K., Gasparini, G.P., Borghini, M., Ribotti, A., 2009. Experimental evidence of recent abrupt changes in the deep Western Mediterranean Sea.. In: *Dynamics of Mediterranean deep waters.* In: CIESM Workshop Monographs n. 38, F. Briand (Eds.), Monaco, Malta, 27-30 May 2009, 51-56.

Sorgente, R., Olita, A., Oddo, P., Fazioli, L., Ribotti, A., 2011. Numerical simulation and decomposition of kinetic energies in the central Mediterranean: insight on mesoscale circulation and energy conversion. *Ocean Science*, Special Issue, 7 (4), 503-519.

Sparnocchia, S., Gasparini, G.P., Astraldi, M., Borghini, M., Pistek, P., 1999. Dynamics and mixing of the Eastern Mediterranean outflow in the Tyrrhenian basin. *Journal of Marine Systems,* 20 (1-4), 301-317.

Theocharis, A., Klein, B., Nittis, K., Roether, W., 2002. Evolution and status of the Eastern Mediterranean Transient (1997-1999). *Journal of Marine Systems,* 33-34, 91-116.

Vetrano, A., Napolitano, E., Iacono, R., Schröeder, K., Gasparini, G.P., 2010. Tyrrhenian Sea Circulation and water mass fluxes in spring 2004: observations and model results. *Journal of Geophysical Research*, 115, C06023, doi:10.1029/2009JC005680.

Zunino, P., Vargas-Yanez, M., Moya, F., García-Martínez, M.C., Plaza, F., 2009. Deep and intermediate layer warming in the western, Mediterranean: Water mass changes and heaving. *Geophysical Research Letters,* 36, L20608, doi:10.1029/2009GL039578.