Monitoring the hydrological characteristics of the Mediterranean Outflow. A decade of θ-S data in the bottom layer of the Espartel Sill, Strait of Gibraltar.

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ABSTRACT

A long time series of temperature and salinity have been collected near the seafloor of the Strait of Gibraltar since 2004 until now. Data show a continuous positive temperature trend of the Mediterranean outflow, 0.0055ºC/yr, coinciding with the order of magnitude of the trend reported by other authors in the western basin. With respect to salinity, data show also a positive trend, $1x10^{-4}$psu/yr, nevertheless this trend is one order of magnitude smaller than the one reported for the western basin. Therefore the contribution of the Mediterranean outflow to the global circulation is now warmer and saltier than a decade before.

INTRODUCTION

The Mediterranean outflow is being monitored at the western exit of the Strait of Gibraltar since 2004. The monitoring station is located in the Espartel Sill, 35º 51.709' N and 5º 58.217' W (Fig. 1), and has been maintained by the Oceanography Group of the University of Málaga, the Spanish Institute of Oceanography (IEO) and the Science Marine Institute of Andalucía (ICMAN). The mooring line collects data of temperature and salinity near the seafloor, therefore measuring the densest outflowing water. Several works have dealt with the long term temperature and salinity trend in different basins of the Mediterranean Sea [1, 2, 3, 4, 5], and they all agree that the Mediterranean has been getting warmer and saltier in the last 40 years. Nevertheless no long term estimation has been presented yet in the Strait of Gibraltar. The present work analyzes an 11 year long temperature and salinity series in the Espartel Sill (Fig. 1), the last constriction the Mediterranean outflow found in its way toward the Atlantic Ocean.

MATERIAL AND METHODS

As mentioned above, the mooring line is located at the Espartel Sill (Fig. 1) at a mean depth of 362±4.6 meters, it is a short line with a total length of about 20 meters. The line consists of an up-looking Acoustic Doppler Current Profiler (ADCP) located about 17 meters above the seafloor, two SAMI sensors measuring the CO_2 and pH, a single point current meter and a CT probe (SBE37), the last four placed about 14 meters above the seafloor (352±6 meters depth). To the aim of this work only the temperature and salinity data collected by the CT probe, whose sampling interval is 30 minutes, will be analyzed.

The data cover the period September 2004 until March 2016, with a gap between March 2011 and August 2012. At the moment the mooring line continues deployed at the Espartel Sill collecting data, so that these series are becoming longer.
The CT has been regularly calibrated and the data corrected taking into account each calibration. This is a mandatory step before analyze the data, as the long term trends we are looking for are similar to the drift of the temperature and conductivity sensors of the CT. In the present case the mean drift of the temperature sensor was $O(10^{-3})$ ºC/yr and $O(10^{-3})$psu/yr for the conductivity sensor. The data presented in this work have been corrected until March 2014, the rest of the data are going to be revised as soon as the calibration of the CT is ready.

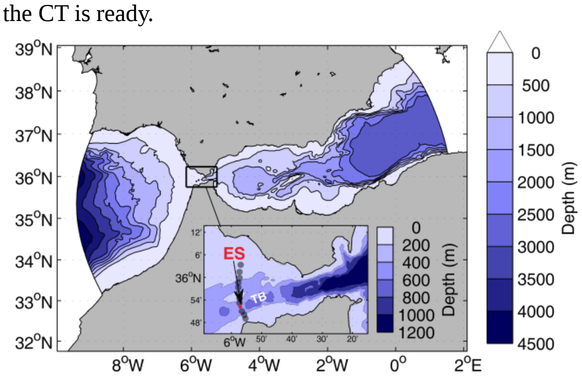

Fig. 1. Location of the monitoring station in the Strait of Gibraltar. The inset shows the detail of the Strait of Gibraltar highlighting with a red point the position of the mooring line in the Espartel Sill (ES). Grey dots mark the CTD section and TB indicates the position of the Tanger Basin.

Several repetitions of the Espartel CTD section have been made coinciding with the maintaining campaign when it was possible (grey circles in Fig.1). Since the CT position has slightly changed (±6m), the cast that correspond with the monitoring point has been analyzed (red point in Fig.1). We found that there were not significant changes in temperature or salinity in the depth range in which the CT was placed along this period.

RESULTS AND DISCUSSION

Positive significant trends have been detected for both potential temperature and salinity of the Mediterranean outflow. The temperature trend for the whole period is 0.0055ºC/yr, with the same order of magnitude that the one estimated by other authors (Table 1), and the same reported by [3] for the period 1995-2005 in the Ligurian Sea. The above indicates that the temperature of the deep Mediterranean water has experienced a continuous increase of 0.005ºC/yr since 1995 up to now. Furthermore, data suggests that this trend has been intensified in the last five years by one order of magnitude, reaching 0.022ºC/yr (Fig. 2). Since the monitoring station continues moored at this moment collecting data, this issue will be further investigated in the near future.

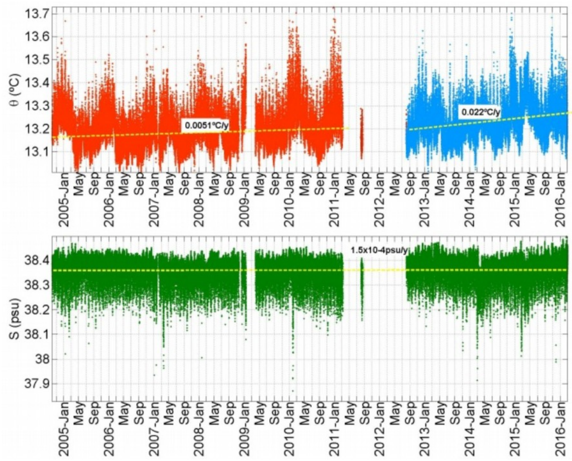

Fig. 2. Upper panel shows the potential temperature measured at a mean depth of 352 meters at the Espartel Sill (Fig.1). Colors indicate the different periods, red for the 2004-2011 period and blue for the 2012-2016 period. The dashed yellow line indicates the trend of each subset, both being significant at 99% of confidence. The trend of the whole period is 0.0055ºC/yr (not shown). The bottom panel shows the practical salinity for the whole period, the yellow line and the text above it indicating the salinity trend.

On the other hand the practical salinity shows a positive trend of 1.5x10^{-4} psu/yr, which is one order of magnitude smaller than the trend found for the Mediterranean according to several authors (Table 1). This lower salinity trend is a consequence of the erosion of the salinity signal, due to the great mixing the Mediterranean water undergoes in the Tangier basin (TB in Fig.1) [6], where it mixes with the fresher North Atlantic Central Water (NACW).

Table 1. Estimations of the temperature and salinity trends in different places of the Western Mediterranean Sea.

Author	θ trend (ºC/yr)	S trend (psu/yr)	Period of time	Area in the Mediterranean
[1]	0.0035	0.0010	[1995-1997]	Algero-Provençal basin (200-2700m)
[2]	0.0035	0.0010	[1959-1997]	Balearic Sea
[3]	0.005	0.0022	[1995-2005]	Ligurian Sea (2000m)
[4]	0.012	0.0043	[1995-2004]	Ligurian Sea (400-2000m)
[5]	0.004	0.0015	[1961-2008]	Entrance to the Alboran Sea (below 200m)

In view of the above the data presented in this work show that the contribution of the Mediterranean to the Atlantic Ocean is now warmer and slightly saltier than a decade before. However, following other authors, density does not show a trend in the western Mediterranean, while the data at Espartel Sill suggest a small negative trend $O(10^{-3})$, likely related with the erosion of the salinity signal when it mixes with NACW. Using a subsampling of the maximum salinity every 15 days we select the saltiest samples, getting a salinity trend of $O(10^{-3})$, closer to that reported in other works.

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REFERENCES

1 – Bethoux, J.P., et al., 1998. Warming and freshwater budget change in the Mediterranean since the 1940s, their possible relation to the greenhouse effect. Geophys. Res. Let., 25:1023-1026.
2 - López-Jurado, J.-L., et al., 2005, Observation of an abrupt disruption of the long-term warming trend at the Balearic Sea, western Mediterranean Sea, in summer 2005, Geophys. Res. Lett., 32, L24606, doi:10.1029/2005GL024430.
3 - Marty, J. C. and Chiavérini, J.: Hydrological changes in the Ligurian Sea (NW Mediterranean, DYFAMED site) during 1995–2007 and biogeochemical consequences, 2010. Biogeosciences, 7, 2117-2128, doi:10.5194/bg-7-2117-2010.
4 - Grignon, L., et al., 2010. Importance of the variability of hydrographic preconditioning for deep convection in the Gulf of Lion, NW Mediterranean, Ocean Sci., 6, 573-586, doi:10.5194/os-6-573-2010.
5 - Borghini, M., et al., 2014. The Mediterranean is becoming saltier, Ocean Sci., 10, 693-700, doi:10.5194/os-10-693-2014.
6 - García-Lafuente J., et al., 2011. The very first transformation of the Mediterranean outflow in the Strait of Gibraltar. J. Geophys. Res., C07010, 116, doi: 10.1029/2011JC006967.