Steric sea level, ocean heat and freshater content in the Mediterranean Sea during the last decade

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The Mediterranean Sea occupies 0.7% of the global ocean in surface, and has only a restricted communication with the world ocean, through the narrow and shallow Strait of Gibraltar. It is subdivided into two main basins, the Eastern Mediterranean (EMED) and the Western Mediterranean (WMED), communicating through the Sicily Channel. Due to its relatively small size, its geographical location, and its semi-land locked nature, the Mediterranean Sea is very sensitive and responds quickly to atmospheric forcings and/or anthropogenic influences. Demographic growth, climate change and overexploitation are exerting exceptional pressure on the Mediterranean environment, its ecosystems, services and resources.

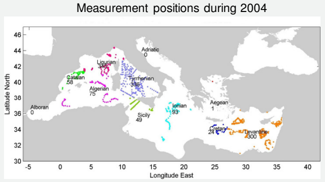
Hydrographic variability at interannual and longer time scales have been identified – related to North Atlantic Oscillation, or the Eastern Mediterranean Transient - but several points are not clear enough yet. The temperature and salinity in the deep layer has increased in both the EMED and WMED while no conclusive results are obtained for the upper and intermediate layers which contribute to the deep layer formation. Heat losses through the sea surface do not balance the heat transport through Gibraltar which would produce an increase in the heat content of the Mediterranean at a rate of a few W m-2 during the last decades. Numerical models considering IPCC scenarios predict the warming of the upper layers.

However it is important to analyze regional and basin-wide variability and understand how it changes with time. It is particularly important in vulnerable populated area such as the Mediterranean basin. In this study, we develop a method to estimate basin-wide values of ocean heat content (OHC), steric sea level (SSL) and ocean freshwater content (OFC) from in situ measurements during the last decade.

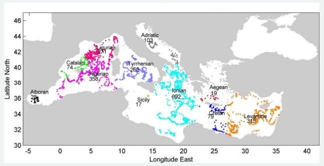
Data

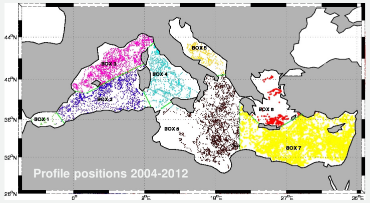
Data collected from Apex, Provor, Arvor and Nemo design floats have been used for this work. The profilers are equipped with CTD sensors and the telecommunication system used is Argos and Iridium. Most of the floats are programmed following the specifications of the MedArgo program that include a cycle length of 5 days, a parking depth of 350 meters and a maximal profiling depth of 2000 meters. We downloaded the data from the Coriolis Data centre IFREMER and a delayed-mode quality control of pressure, temperature and salinity data has been applied to several floats in accordance to the Argo Quality Control Manual 2013. In addition, other in situ data collected under various oceanographic campaigns up to 2010 have been used. The data have been quality controlled to remove any remaining spikes.

Measurement positions during 2004

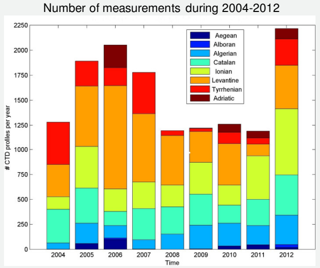


Measurement positions during 2012





Number of measurements during 2004-2012

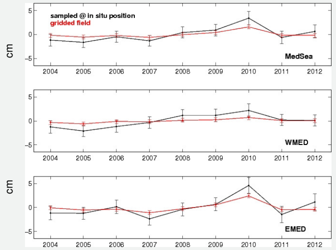


Method

For each box in the Mediterranean Sea, mean parameters are calculated using a weighted average which takes into account the spatial (50km) and temporal correlations (10 days) of the observations inside a box (Bretherton et al., 1976). Index value for the box is given by the average of all the observations above a bathymetry of 300m depth: $<\Theta_{box}> = \Sigma_{i,j} A_{i,j}^{-1}\Phi_i / \Sigma_{i,j} A_{i,j}^{-1}$, Φ_i = observations, $A_{i,j}^{-1} = <\Phi_i \Phi_j>$. Missing values at depth are filled before using the SeaDataNet climatology.

The error on the averaged physical parameter Φ_i in each box is calculated as:

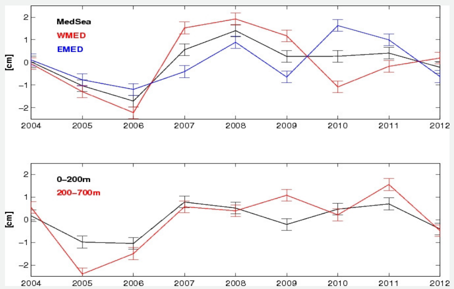
$$\varepsilon_{i,j}^{2} = \frac{1}{\sum_{i,j} A_{i,j}^{-1}} \sigma_{i,j}^{2} \quad with \quad \sigma_{i,j}^{2} =$$ variance of Φ_i within each box

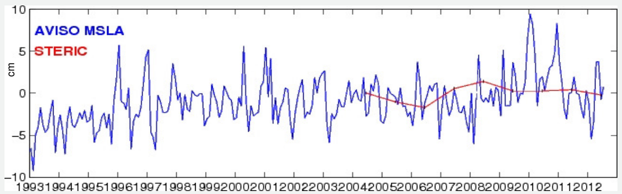


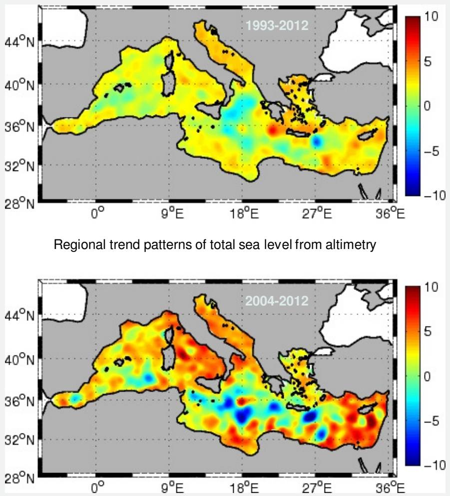
The method is validated using AVISO altimeter MSLA data as a proxy: gridded MSLA are sampled in time and space on each profile position and averaged using our method.

Steric sea level and comparison to total sea level from altimetry

Amplitudes of interannual fluctations are dominant in both, the EMED and WMED. A basin-wide mean trend of 1.2±0.2 mm/year is observed during 2004-2012 for steric sea level. Steric sea level compares well to total sea level and sea level rise can be observed in the WMED and estern part of he EMED basins.



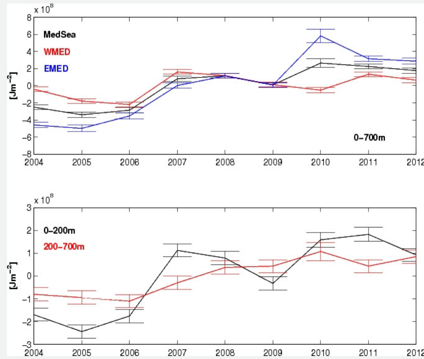




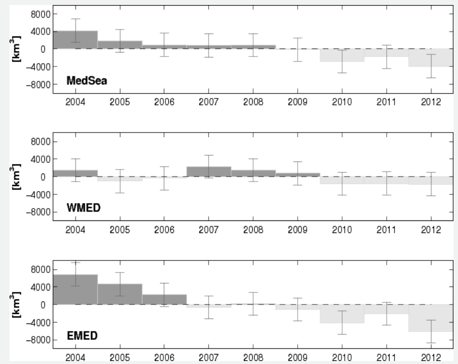
Regional trend patterns of total sea level from altimetry

Ocean heat content and ocean freshwater content

Ocean heat content



Ocean freshwater content



Interannual fluctuations of OHC dominate in the EMED basin and are concentrated in the upper layer of the Mediterranean basin, and amplitudes decrease with increasing depth. Over the last decade, a warming signature can be observed of 2.2±0.2 Wm^{-2}, predominantly due to changes in the EMED basin, and in both, the surface and intermediate layer.

Our results show a negative basin-wide trend of ocean freshwater content during the period 2004-2012 which accounts to 900±30 km^3/year. This signature is dominated by changes in the EMED. Further work is needed to interpret these results, especially by a decomposition of the halosteric and thermosteric sea level components.

However, time series are short, and the longer time series from satellite altimetry indicates that especially in the Mediterranean basin, the uncertainty of short-term trend estimations due interannual variability plays an important role and needs to be addressed in future work.