MedCLIVAR – Mediterranean CLImate VARiability: Sea Level Rise and its Forcing in the Mediterranean Sea

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Abstract

Atmosphere-Ocean Sea level change is one of the major risks for coastal regions. At global scale, climate change is expected to rise sea level by increasing the oceanic mass from melting ice-caps and glaciers and also by increasing the oceanic volume through thermal expansion. At regional scale, changes in the atmospheric forcing and in the ocean circulation make that sea level rise is not expected to be spatially uniform. Land movements further increase the spatial variability of sea level rise as it can be observed at the coast, amplifying or reducing the consequences of the climate contributions. The Mediterranean Sea in particular, being a semi-enclosed basin, has been experiencing sea level rise differently from the global mean. **This presentation intends to report the progress achieved during the last years in understanding Mediterranean long-term (interannual to interdecadal) sea level variability, paying particular attention to the processes responsible for the observed changes.** The nucleus of the presentation focuses on mean sea level changes and its different contributors: the steric component (changes in the density of the water column due to changes in temperature and salinity), the mass component (accounting for the addition/subtraction of both, water and salt) and the atmospheric component (due to the mechanical forcing of atmospheric pressure and wind). The estimated trends indicate that **Mediterranean mean sea level has been rising at a lower rate than global mean sea level during the second half of the 20th century due to both, the negative contribution of the atmospheric component and the slightly negative steric component.**

This contribution reflects part of the contents of Chapter 4 of the book entitled *Mediterranean Climate. From Past to Future (ed. P. Lionello, Elsevier)* promoted by MEDCLIVAR. Changes in the seasonal sea level cycle and in the distribution of extreme events are also covered in the book, but not in this poster.

The atmospheric component of mean sea level variability

The atmospheric contribution to sea level has been computed from the output of a **barotropic ocean hindcast** forced by a dynamical downscaling (0.5º x 0.5º) of atmospheric pressure and wind fields generated from a NCEP re-analysis spanning the period 1958-2001 (Ratsimandresy et al, 2008). The trends are negative everywhere (**Fig. 4**), the basin mean value being **-0.60 ±0.04 mm/yr**. The mean trend computed over the period 1960-1993 is **-1.0 mm/yr** and would be therefore partially responsible for the reduced sea level rise observed in the Mediterranean with respect to the global mean *.

The trends of the atmospheric component of sea level are related to the NAO positive anomaly between the 1960s and mid 1990s and hence they are strongly seasonally dependent: trends are markedly negative in winter (December-March) and around zero in summer (June-September, see **Fig. 4**).

* These values are presently under revision, since other reanalysis such as ERA40 give trends that are of the order of 0.3 mm/yr lower than those obtained from NCEP.

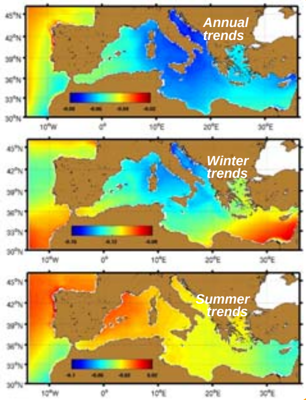


Fig. 4: Annual and seasonal trends of the atmospheric contribution to sea level. Note that color scales are different for each panel in order to highlight regional variability; all values are cm/yr. [From Gomis et al. (2008).]

The steric component of mean sea level variability

The interannual variability of steric sea level has been obtained from **historical hydrographic data bases** and from **baroclinic ocean hindcasts** (see the caption of **Fig. 5**). At sub-basin scale there are significant differences among the hindcasts, but they partly smooth out when averaging the steric sea level over the whole basin (**Fig. 5**). The trends computed for the common period between the hindcasts and the observations (1961-2000) are **-0.5±0.1 mm/yr** when computed from Ishii and Kimoto (2009) data and **-0.8 ±0.2 mm/yr** when computed from MEDAR (2002) data. Conversely, all the hindcasts show positive trends (about **+1.3 mm/yr**) mainly due to the increase in the temperature of the deep waters of the western basin, which is thought to be an artifact of the models.

Observed trends are also negative when computed for the whole second half of the 20th century. The reason is that while temperature shows positive and negative trends at different layers, salinity would have increased at all levels. Nevertheless, the scarcity of deep observations (particularly for salinity) suggests to take the above results with some caution.

The Mediterranean negative steric trends contrast with the values obtained for the global ocean, which are around **+0.7 mm/yr** (Domingues et al., 2008).

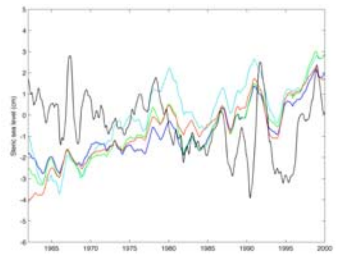


Fig. 5: Steric component of Mediterranean mean sea level as given by three regional baroclinic simulations: MITgcm (cyan; Artale et al., 2009), OM8 (green; Somot et al., 2006), VANIMEDAT (blue) and by a global simulation: ORCA (red; Barnier et al., 2006). The steric component derived from the Ishii and Kimoto (2009) data base (upper 700 m) is also plotted (black).

Observed mean sea level changes

The longest **tide gauge series** available in the Mediterranean Sea indicate that sea level variability over the last century can be separated into three periods (**Fig. 4.1**). Before the 1960s, trends were equivalent to those at the open ocean stations. Between the 1960s and the beginning of the 1990s, the sea level was either not changing or even decreasing. The third period, between 1993 and the early 2000s, is characterized by a fast sea level rise in the Eastern Mediterranean. The period from 1993 onwards can also be analyzed on the basis of **altimetry data**. The sea level trends computed over the last 16 years reveal a picture much more complicated than that of a coherently varying basin (**Fig. 2**). The range of values is quite wide due to strong interannual variability embedded in the measurements.

The information on sea level trends provided by altimetry and tide gauges is synthesized in the 1945-2000 **sea level reconstruction** of Calafat and Gomis (2009) reproduced in **Fig. 3**. The trend for the basin mean sea level over this period is **+0.6±0.1 mm/yr**; for the period 1961-2000 the Mediterranean trend is **+0.2±0.1 mm/yr**, much lower than the global mean sea level trend of **+1.6±0.2 mm/yr**. Understanding the contribution of each component to the observed long-term sea level variability and trends is essential to explain why Mediterranean sea level has been rising at a lower rate than the global mean.

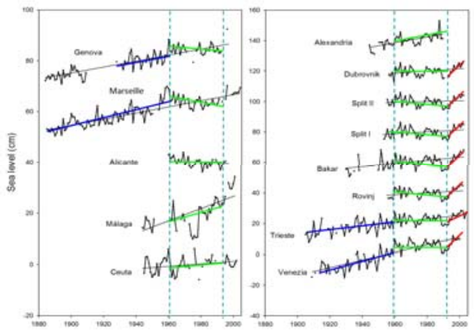


Fig. 1: The longest Mediterranean tide gauge records. Linear trends have been subjectively fitted for each of the three distinct periods referred in the text (before 1960 in blue; between 1960-1993 in green; after 1993, in red) as well as for the total period (thin black line). [Adapted from Marcos and Tsimplis (2008).]

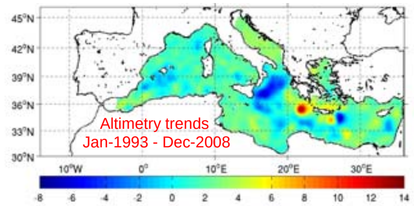
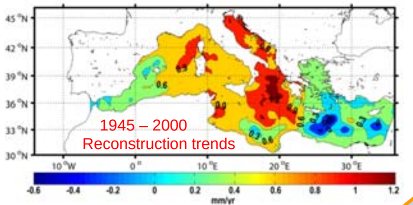


Fig. 2: sea level trends derived from AVISO satellite altimetry gridded products (1/8º resolution). The data are monthly sea level anomalies obtained from the combination of 4 satellites and referred to a 7-year mean.

Fig. 3: sea level trends derived from the sea level reconstruction of Calafat and Gomis (2009).



The mass component

Direct measurements of ocean mass changes are presently given by the **gravimetric satellite mission GRACE**, but the record is too short (starts in 2002) to permit any estimation of the long term variability. An indirect approach to the mass component consists of subtracting the atmospheric and steric components from total sea level, but the consistency of all the signals must be first proved.

Fig. 6 shows that the result of subtracting the atmospheric and steric components from total sea level is consistent with GRACE observations.

Fig. 7 makes use of that consistency to obtain the evolution of the mass component of sea level along the second half of the 20th century. The result shows a more marked interannual variability than for the steric component, being in fact similar to total sea level (neither the atmospheric component shows pronounced interannual variability). The mass trend estimated for the period 1948-2000 (and expressed in terms of sea surface height) is **+1.2 ±0.2 mm/yr** (Calafat et al., 2010), larger than the global mean sea level rise attributed to ice melting (about **+0.8 mm/yr**; Domingues et al., 2008).

Therefore, part of the lower steric sea level rise observed in the Mediterranean with respect the open ocean would have been compensated by a mass entrance trough Gibraltar.

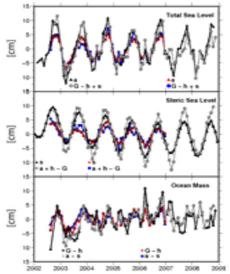


Fig. 6: Mediterranean mean sea level components as estimated in two works: an extension of the work of Fenoglio-Marc et al. (2006) that uses data until 2009 (in black/grey) and the work of Calafat et al. (2010), which covers until 2007 (in red/blue).
- Upper panel: (Atmospherically corrected) total sea level obtained from altimetry data (triangles). The dots are the sum of the steric and mass components.
- Middle panel: steric sea from a baroclinic hindcast (black triangles, Fenoglio-Marc et al., 2006) and from the Ishii data set (red triangles, Calafat et al., 2010). The dots are total sea level minus the mass component.
- Bottom panel: mass component of sea level as derived from GRACE data (triangles). The dots are total sea level minus the steric component.

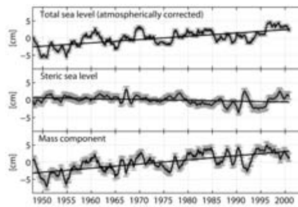


Fig. 7: Mediterranean mean sea level and its components (with error bars in grey) for the period 1948-2000:
- Top: atmospherically-corrected total sea level as given by the reconstruction of Calafat and Gomis (2009).
- Middle: steric component derived from the Ishii and Kimoto (2009) dataset.
- Bottom: total minus atmospheric and minus steric sea level, which is assumed to be a good approximation to the mass component (see Fig. 6).
Mean values are removed from each series; the series are also smoothed using a 12-month running average.

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