Mediterranean Sea level variability in the context of HyMeX

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Abstract

• Sea level is an integrating parameter that can be used for closing the water budget of the Mediterranean Sea, both at basin and sub-basin scale. In the framework of **the VANIMEDAT project** we have described the main features of Mediterranean sea level variability during the last decades, paying particular attention to the physical processes responsible for the observed changes. The first part of this presentation is devoted to highlight the main conclusions of VANIMEDAT.

• The second part shows the importance of **understanding sea level variability in the context of HyMeX**. We propose to study Mediterranean sea level variability on the basis of three different data sets: 1) in-situ sea level measurements (tide gauges) and altimetry data can be compared with steric estimates from hydrographic data and with the output of the improved models developed under HyMeX in order to evaluate the mass component of sea level variability. 2) The monitoring of the exchanges at the various Straits planned for the HyMeX intense period of observation altogether with observations of mass exchanges with the atmosphere and the land will also allow to close the water budget. 3) The results of 2 and 3 can be checked against direct measurements of the water mass component derived from gravimetry data.

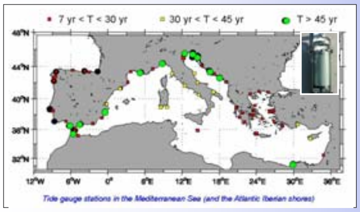
• Hence, the relation between sea level and other HyMeX tasks is clear: **on one hand we need of improved water budget estimates to understand sea level variability; on the other hand, sea level can be used to validate heat and mass exchanges, then providing the modellers with an additional validation parameter**.

Main results from the VANIMEDAT project (I):

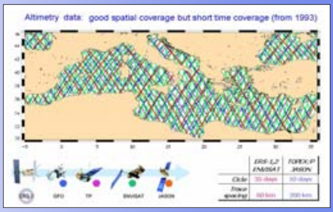
Describing the Mediterranean sea level variability of the last decades

• Tide gauges constitute the longest records available, but they only offer a partial coverage of the basin…

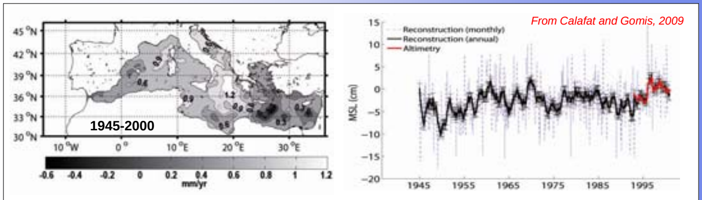
• Altimetry data have a good spatial coverage, but they only span the period 1993-present…



Tide gauge stations in the Mediterranean Sea (and the Atlantic Iberian shores)



The two data sets have been combined in a reduced-space optimal interpolation scheme to reconstruct the sea level fields of the last decades:



From Calafat and Gomis, 2009

Distribution of sea level trends during the last decades — *Evolution of Mediterranean mean sea level*

Main conclusions extracted from the measurements:

• The **mean sea level trend (for the period 1945-2000) is of order 0.7 mm/yr**, i.e. much smaller than global trends (1.6 mm/yr for the period 1950-2000)

• **Trends exhibit a significant inter-decadal variability**: moderate rise (similar to global trends) until the 60s, negative trends during the period 1960 and 1994 (between -0.5 and -1.0 mm/yr) and strong rise during the last decade (between 5 and 10 mm/yr).

• Trends also show large regional variability (e.g., the Aegean and the Ionian show drastic changes during the EMT)

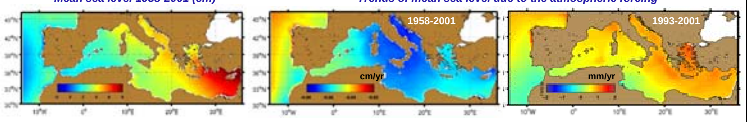
Main results from the VANIMEDAT project (II):

Quantifying the physical processes driving the observed sea level variability

The mechanical atmospheric forcing of sea level

It has been quantified from 44 years (1958-2001) of hourly data generated by the barotropic model HAMSOM forced by atmospheric pressure and wind fields. The atmospheric forcing was a downscaling (50 km) generated by the model REMO from a NCEP re-analysis. Examples of results:

Mean sea level 1958-2001 (cm) — *Trends of mean sea level due to the atmospheric forcing*



From Gomis et al, 2008

The trend in the atmospheric component of sea level has been evaluated in about **–0.6 mm/yr for the period 1958-2001** and in **–1.0 mm/yr between 1960 and 1994**. They negative values are due to a winter displacement of Atlantic high pressures over the Mediterranean region between the 1960s and the 1990s, a situation that reversed during the last decade.

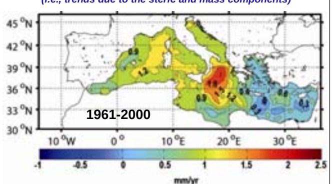
The steric component

When subtracting the effect of the atmospheric forcing, the remaining sea level signal is due to changes in the density (the steric component) and changes in the hydrological budget (the mass component). The resulting **(steric + mass) trends are of the order of 1 mm/yr for the period 1961-2000**.

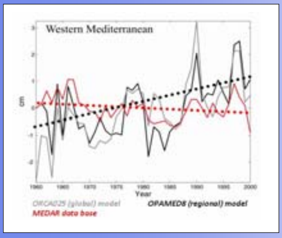
The steric component can be evaluated either from historical hydrographic data or from model simulations spanning the last decades. The results from these two sources are contradictory:

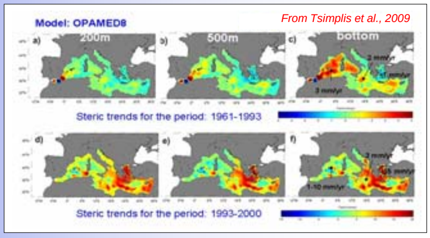
• **MEDAR data do not show very significant trends;** if any, they show a slight cooling, particularly between the 60s and the 90s.
• **Models show clear positive trends, but they are mostly due to temperature drifts at deep levels**. These drifts might result from the problems of the model to reproduce deep water formation, which in turn is due to the low resolution of the forcings.

Mean sea level trends when the atmospheric forcing is subtracted (i.e., trends due to the steric and mass components)



From Calafat et al., 2009





From Tsimplis et al., 2009

The mass component

The mass contribution is the most relevant one for HyMeX, since it is directly related to the hydrological cycle. So far it has been estimated (by other authors and only for the last few years):

i) subtracting the steric component provided by models from altimetry data (from which the atmospheric component has been previously subtracted);

ii) from gravimetry data, which have a much lower spatial resolution than the other sea-level components.

In principle the total mass component can also be derived from hydrographic and altimetry data, but it has never been attempted. The plans regarding its estimation in HyMeX are presented in the following.

Sea level variability in the context of HyMeX:

The relation between our sea level research and other HyMeX tasks: on one hand we need of improved water budget estimates to better understand sea level variability; on the other hand, sea level can be used to validate heat and mass exchanges, then providing HyMeX modellers with an additional validation parameter.

Our proposal bases on using the mass component of sea level variability inferred from different data sets, as a validation parameter. Namely,

1) **The atmospheric component of sea level** (inferred from state-of-the-art barotropic models) **and the steric component** (inferred from hydrographic data and from the output of improved baroclinic models developed under HyMeX) **can be subtracted from total sea level** (inferred from tide gauges and altimetry) in order to obtain the mass component of sea level variability.

Weak point: the steric component derived from baroclinic models may not be accurate enough (strong dependence on drifts), and the hydrographic data distribution may also be too poor to produce reliable estimates.

2) Under a few, reasonable assumptions, changes in the bottom pressure (and therefore changes in the total mass of the basin) **can also be inferred from hydrographic data and altimetry alone**.

Weak point: again, this is true only if hydrographic data can produce a reliable estimate of the 3D density field (e.g., provided ARGO buoys reach a suitable density in the region).

3) **The monitoring of the exchanges at the various Straits** planned for the HyMeX intense period of observation **altogether with observations of mass exchanges with the atmosphere and the land** should also allow to close the water budget.

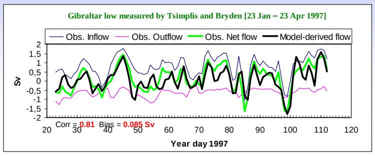
Weak point: producing accurate estimates of the evaporation-precipitation budget at open sea is a difficult task.

4) Finally, the water mass component can also be derived from **gravimetry data**.

Weak point: the low spatial resolution of gravimetry data is a serious handicap in small, semi-enclosed seas such as the Mediterranean.

Two examples of the close links between sea level variability and the water and heat budgets of the Mediterranean Sea:

i) at intra-seasonal time scales the atmospheric forcing of sea level completely dominates the barotropic exchange at Gibraltar (at seasonal and interannual time scales the E-P budget dominates over the atmospheric forcing).

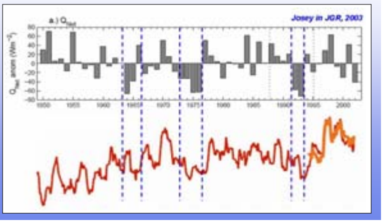


→ The Figure shows a very good agreement between the flow derived from changes in the basin-mean sea level (given by a barotropic model forced by atmospheric pressure and wind) and the actual net flow trough Gibraltar

From Gomis et al., 2006

ii) the interannual variability of basin-mean sea level is strongly related to the heat budget:

The Figure shows a comparison between heat fluxes in the Mediterranean and the basin mean sea level reconstructed by Calafat and Gomis (2009). Of the three cold periods, the last one corresponds to the EMT. →



VANIMEDAT sea level papers:

• Calafat, F. M., D. Gomis, 2009: Reconstruction of Mediterranean sea level fields for the period 1945-2000. *Global and Planetary Change*, 66 (3-4), 225-234 .

• Calafat, F. M., D. Gomis, M. Marcos, 2009: Comparison of Mediterranean Sea levels fields for the period 1961-2000 as given by a data reconstruction and a 3D model. *Global and Planetary Change*.(en prensa).

• Gomis, D., M. N. Tsimplis, B. Martín-Míguez, A. W. Ratsimandresy, J. García- Lafuente, S. A. Josey, 2006: Mediterranean Sea level and barotropic flow through the Strait of Gibraltar for the period 1958-2001 and reconstructed since 1659. *J. Geophys. Res.,* 111, C11005, doi:10.1029/2005JC003186.

• Gomis, D., S. Ruiz, M. G. Sotillo, E. Álvarez-Fanjul, J. Terradas, 2008: Low frequency Mediterranean sea level variability: the contribution of atmospheric pressure and wind. *Global and Planetary Change*, 63 (2-3), 215-229.

• Marcos, M., M. Tsimplis, 2007: Variations of the seasonal sea level cycle in Southern Europe. *J. Geophys. Res.,* 112, C12011, doi:10.1029/2006JC004049.

• Marcos, M., M. Tsimplis, 2007: The forcing of coastal sea-level rise patterns in the North Atlantic and the Mediterranean Sea. *Geophys. Res. Let.*, 34, L18604, doi:10.1029/ 2007GL030641.

• Marcos, M., M. Tsimplis, 2008: Comparison of results of AOGCMs in the Mediterranean Sea during the 21st century. *J. Geophys. Res.,* 113, C12028, doi:10.1029/2008JC004820.

• Marcos, M., M. Tsimplis, A. G. P. Shaw, 2009: Sea level extremes in Southern Europe *J. Geophys. Res.,* 114, C01007, doi:10.1029/2008JC004912.

• Marcos, M., G. Woppelmann, W. Bosch, R. Savcenko, 2007: Decadal sea level trends in the Bay of Biscay from tide gauges, GPS and altimetry. *J. Mar. Sys*., 68, 529-536.

• Pascual, A., M. Marcos, D. Gomis, 2008: Comparing the sea level response to pressure and wind forcing of two barotropic models: validation with tide gauge and altimetry data. *J. Geophys. Res.*, 113, C07011, doi:10.1029/2007JC004459.

• Ruiz, S., D. Gomis, M. G. Sotillo, S. A. Josey, 2007: Characterization of surface heat fluxes in the Mediterranean Sea from a 44 year high-resolution atmospheric data set. *Global and Planetary Change,* 63 (2-3), 258-274.

• Tsimplis, M. N., M. Marcos, S. Somot, 2008: 21st century Mediterranean sea level rise. Regional model predictions. *Global and Planetary Change* , 63, 105-111.

• Tsimplis, M. N., M. Marcos, S. Somot, B. Barnier, 2008:Sea level forcing in the Mediterranean Sea between 1960-2000. *Global and Planetary Change*, 63, 325-332.

• Tsimplis, M. N., M. Marcos, J. Colin, S. Somot, A Pascual, A.G.P. Shaw, 2009: Sea level variability in the Mediterranean Sea during the 1990s on the basis of two 2D and one 3d model. J. Mar. Sys., doi: 10.1016/j.jmarsys.2009.04.003.

• Tsimplis, M. N., A.. Shaw, A. Pascual, M. Marcos, M. Pasaric, L. Fenoglio-Marc. Can we reconstruct the 20th century sea level variability in the Mediterranean Sea on the basis of recent altimetric measurements?. In *Remote Sensing of the European Seas* (in press).

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