Decadal Variability of Net Water Flux at the Mediterranean Sea Gibraltar Strait

L. Fenoglio-Marc[1], A. Mariotti[2], G. Sannino[3], B. Meyssignac[4], A. Carillo[3], M.V. Struglia[3]

1) Institute of Physical Geodesy, TU Darmstadt, Germany (fenoglio@ipg.tu-darmstadt.de)
2) National Oceanic and Atmospheric Administration (NOAA/OAR), Silver Spring, USA;
3) Italian Agency for Energy and Environment (ENEA), Rome; 4) LEGOS, Toulouse

Introduction

Long-term variability of the net water flux into the Mediterranean Sea at the Gibraltar Strait over the period 1960-2011 is explored based on an approach combining multiple observational datasets and results from a regional climate model simulation. The goal of this work is to study the decadal variations in net water flux at the Strait of Gibraltar and to indirectly explore the correctness of the equilibrium condition assumption made in state-of-art models.

Direct mass estimation from GRACE

Direct estimates of water mass variation in the Mediterranean Sea over the last decade have been derived from GRACE measurements finding a good agreement with steric-corrected sea level from altimetry [5]. Two composite time-series representing the basin averaged mass change signal have been constructed by

1. correcting the GRACE signal for the continental hydrology contaminating the GRACE basin averages,
2. removing the steric component from total sea level.

- In the Mediterranean Sea the GRACE-derived seawater mass signal has an annual amplitude of 23±5 mm peaking in December and a positive linear trend of 6.3±3 mm/yr. It is consistent with the steric-corrected altimeter derived seawater mass signal with agreement in amplitude, phase and trend within 1 mm, 40 days and 3 mm/yr. Correlation and RMS are 0.85 and 15 mm for the de-seasoned time-series (Fig. 1a).
- The Black Sea has a stronger interannual variability in water mass, the sea level increases between 2003 and 2005 and decreases between 2006 and 2008. Correlation and RMS differences of the de-seasoned composite time-series are 0.62 and 71 mm (Fig. 1b).
- The Bosporus (B) and the Gibraltar (G) net fluxes are derived from closure of the total water budget (Eq. 1,2, Fig. 2a). The resulting net inflows in Mediterranean Sea from Black Sea and from Atlantic Ocean have annual amplitudes of 0.01 Sv and 0.06 Sv peaking in March-April and October respectively.

$$B = P_B - E_B + R_B - \frac{dM_B}{dt} \qquad (1)$$

$$G = E_M - P_M - R_M - B + \frac{dM_M}{dt} \qquad (2)$$

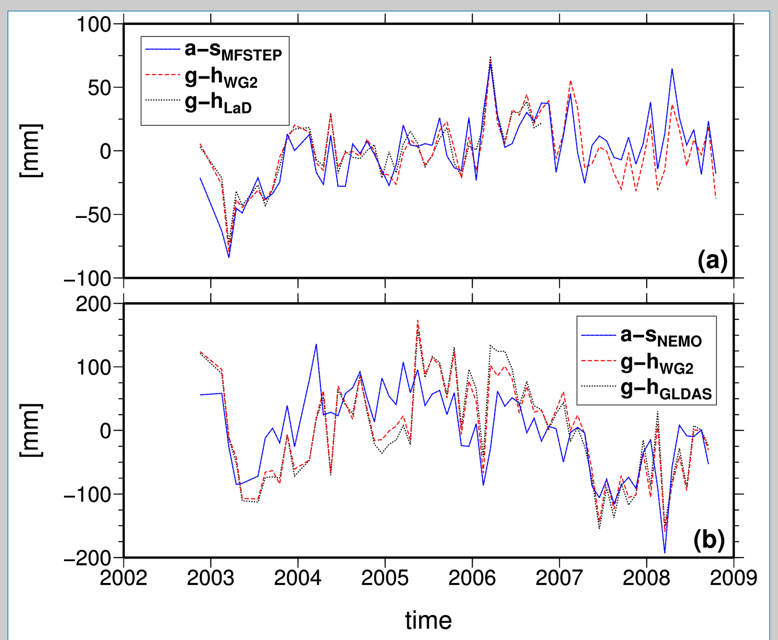

Fig. 1 Basin average of de-seasonalized seawater mass anomalies from steric-corrected altimetry (gray) and hydrology-corrected GRACE (triangle)

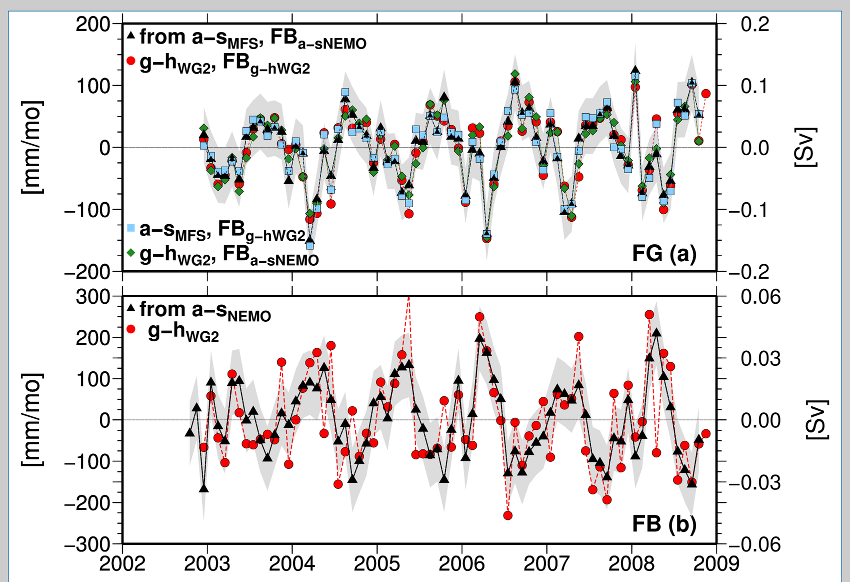

Fig. 2 Net inflows in Mediterranean Sea at Gibraltar (FG) and at Bosphorus (FB) derived from mass change and water budget

Long-term water budget variability

Before 2002 direct water mass measurements are not available. The mass change can be estimated from steric-corrected altimeter data in 1993-2002 and from a steric-corrected sea level reconstruction before 1993

- Sea level:
  To determine the sea level trend patterns variability over the last decades (1970-2006) we use the sea level reconstruction by [7]. Original in this reconstruction is the use of long-term sea level patterns (EOFs) deduced from a 33-year long run of the ARPERA-forced NEMOMED8 ocean model [9] instead of the short altimetry record (13 years in [1]. Its agreement with the altimeter measurements in 1993-2006 is shown by a comparison of the basin averages (Figure 5).

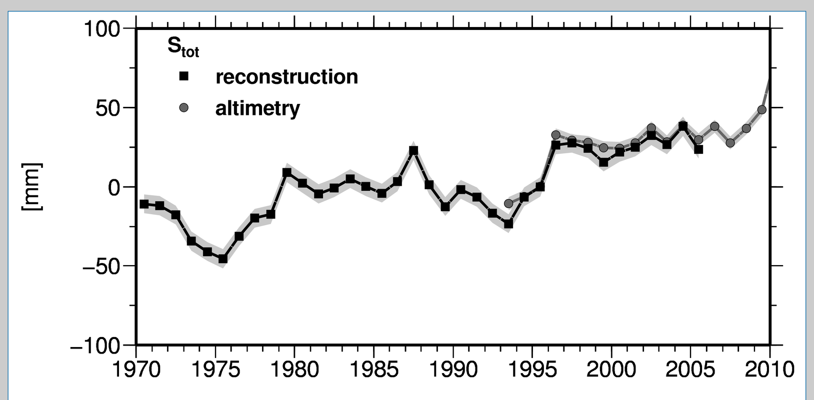

Fig. 3 Sea level

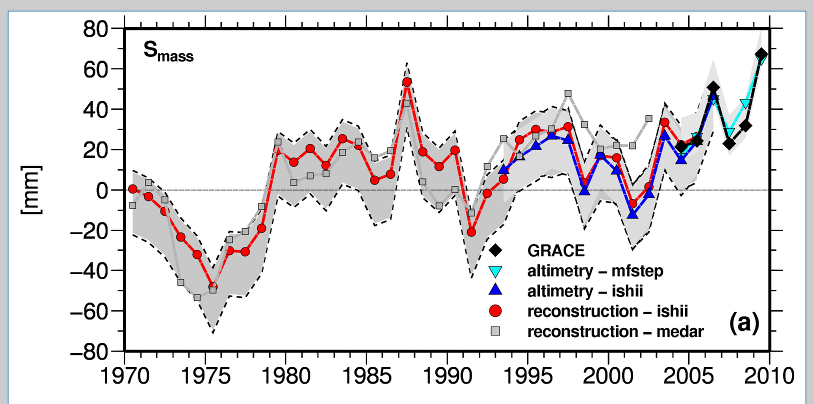

Fig. 4 Mass component

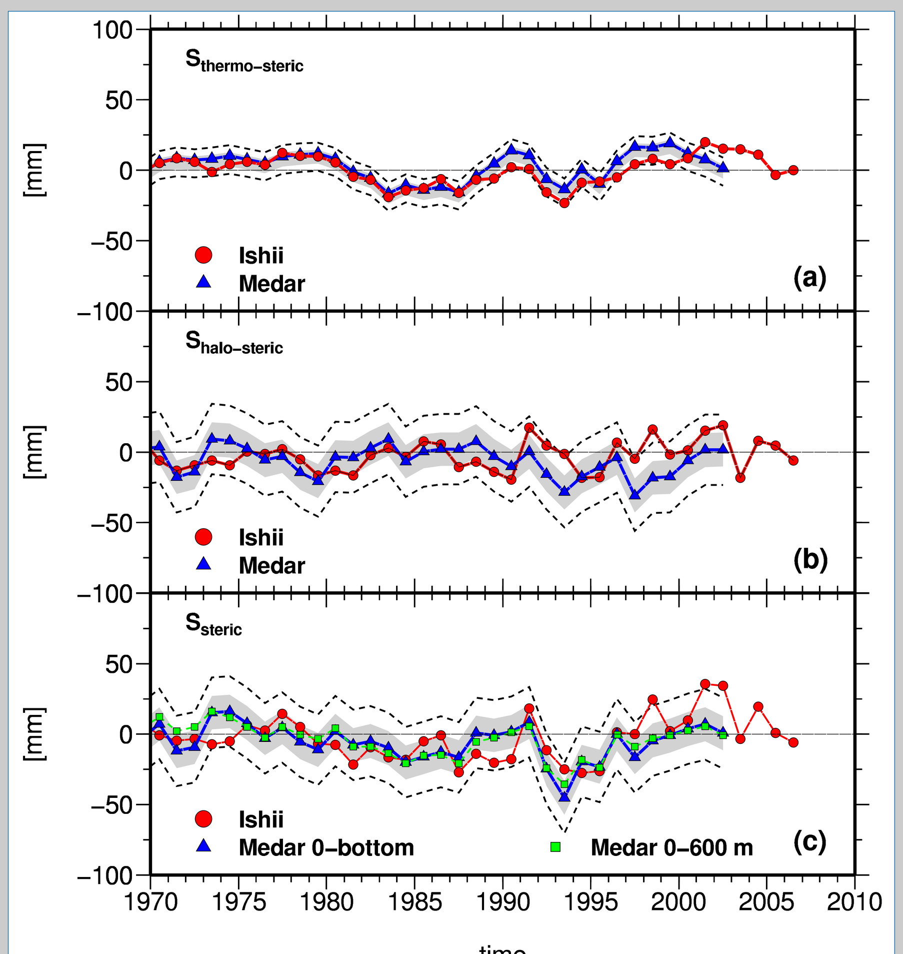

Fig. 5 Yearly mean thermo-steric (a), halo-steric (b), total steric (c) sea level anomalies in the Mediterranean Sea from Ishii version 6.7 (circle) and Medar/Medatlas integrated until 4000 meter depth (triangle). In c) Medar/Medatlas integrated until 600 (square) is shown. Error bounds are from Medar/Medatlas (dashed line) and correspond both to the RMS difference of input data (grey shadow).

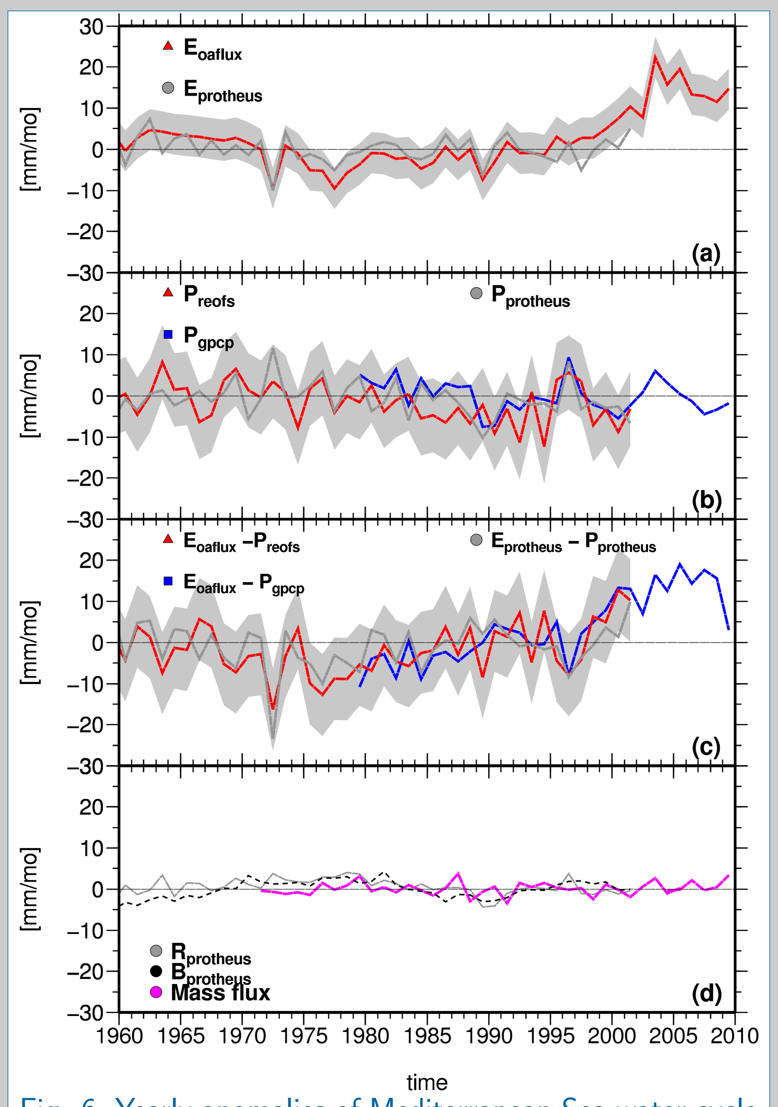

Fig. 6 Yearly anomalies of Mediterranean Sea water cycle components in water budget equation (Eq. 1) during 1960-2009 relative to the period 1979-2001.

Long-term water budget variability

- Steric sea level:
  the steric component of sea level is evaluated from the global Ishii and from the regional Medar/Medatlas climatologies ([8], [6]). The steric component estimated by the Medar and Ishi database show a similar interannual variability, with some disagreement in 1970-1980 (Figure 5).

- Mass change:
  The mass change derived from steric-corrected altimetry and from GRACE in 2002-2010 are in good agreement, the same for the mass change obtained from the reconstruction and steric-corrected altimetry in 1992-2006 (Figure 4). The mass change estimated from the reconstruction corrected for the steric component has a trend of 1.17 +/- 0.15 mm/yr in the interval 1970-2006, in agreement with [1].

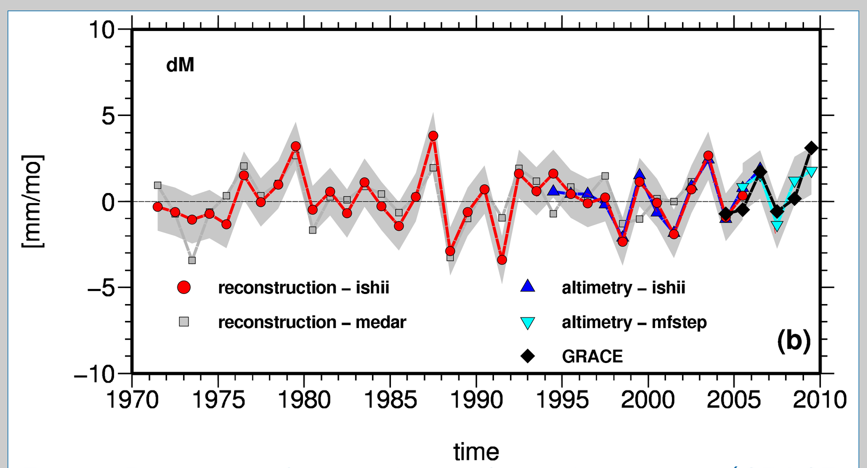

Fig. 7 Derivative of mass change from observations (GRACE, altimetry, reconstruction, temperature, salinity)

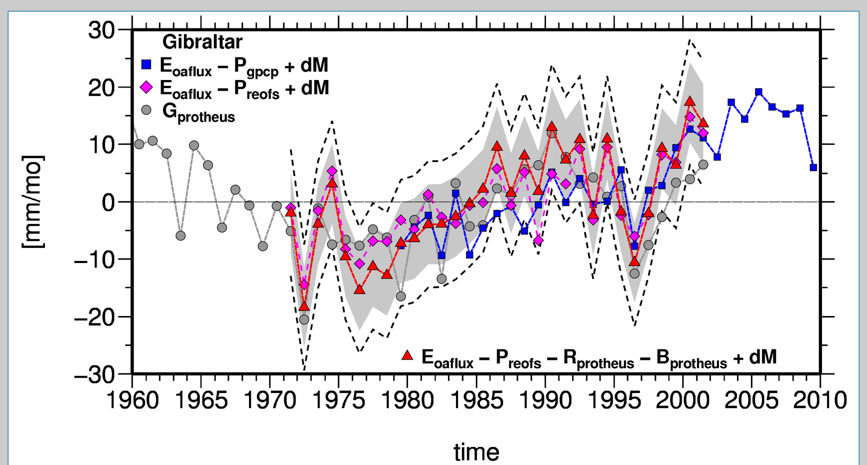

Fig. 8 Net Gibraltar Flux from E, P, mass change and from the PROTHEUS model

- Rate of mass change and water budget:
  The basin averaged water mass change per month dm/dt (difference for successive months) has no long-term trend. An estimate of the Gibraltar Flow is obtained from Eq. 2 by neglecting B and R. The basin average of E-P in 1970-2006 (E from OAFlux and P from REOFS datasets) has larger amplitude than the mass change at low frequency. The net flow at Gibraltar has variability very similar to E-P (Figure 6).
  This estimation is in good agreement with the net transport at Gibraltar as simulated by the regional Protheus coupled system in 1970-2001 with atmospheric model forced laterally by ERA40 and ocean model forced by the MedAltas monthly climatological data (Figure 8).
- Large-scale influences:
  In winter, we find an anti-correlation between the NAO index and regionally averaged sea level pressure SLP (-0.81) and also a significant anti-correlation between the NAO and Mediterranean rate of mass change (-0.64). These results suggests that the NAO may affect the mass component of sea level Smass through mechanisms associated to redistribution of water, other than the atmospheric pressure changes. Those mechanisms could be associated to winds near the Gibraltar strait (Menemenlis et al., 2007) and to ocean circulation.
  Because of the impact temperature can have on the humidity gradient and sea surface evaporation, we investigate the linkage between the AMO and Mediterranean Sea evaporation variability. Figure 6b, shows 6-years running means of OAFLUX annual Mediterranean Sea evaporation anomalies together with those of the AMO index. We find significant positive correlation between evaporation and the AMO (0.9) which is consistent with the thermodynamical linkage hypothesized above.

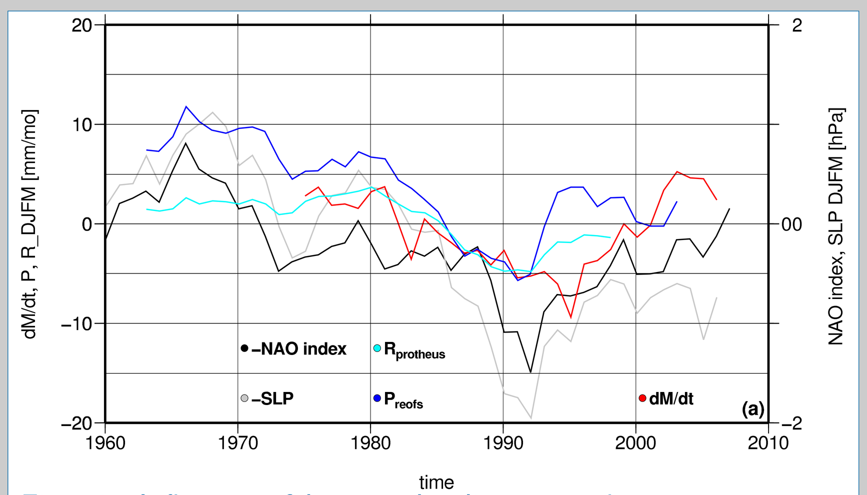

Fig. 9 Influence of large-scale climate modes on water mass budget components: NAO

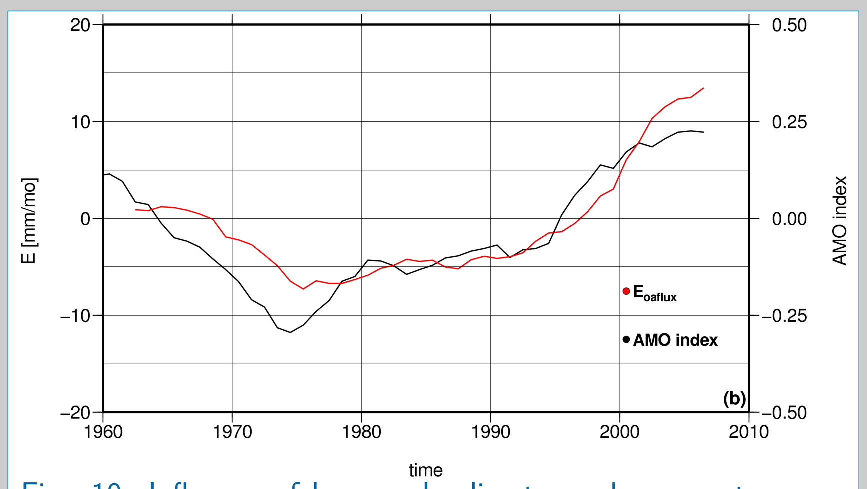

Fig. 10 Influence of large-scale climate modes on water mass budget components: AMO

Conclusions

- the changes in the Mediterranean mass-induced sea level are relatively small compared to water fluxes at the sea surface and with no long-term trend over 1970-2009. Hence, the equilibrium condition assumption, common to many Mediterranean Sea models is indeed a reasonable one.
- decadal variations in net evaporation (E-P) at the sea-surface drive changes in net inflow at Gibraltar as dictated by the water budget equation, while changes in river runoff and net inflow at the Bosphorus Strait have a secondary modulating effect
- the accuracy of the Gibraltar Strait flow is virtually independent from the accuracy in the rate of change of mass in the basin, river runoff and Bosphorus strait flow, as their effect on the resulting Gibraltar net flux is small compared to the effect of evaporation and precipitationthe
- we identify an important role for large-scale climate variability, specifically the Atlantic Multi-decadal Oscillation (AMO) and the North Atlantic Oscillation (NAO) climate modes, in driving observed Gibraltar fluxes. These climate modes appear to influence net water flux at Gibraltar indirectly via the influence they bear on regional evaporation, precipitation and runoff.
- It results a significant increase in the net flow at Gibraltar, which interannual variability is mainly related to the evolution of E, P
- the long term trend of the water cycle parameters shows an evolution towards a more dry regime and an increase in the loss of freshwater over the Mediterranean Sea

References

[1] D. Calafat, F.AND Gomis. Reconstruction of mediterranean sea level fields for the period 19452000. *Global and Planetary Change*, 66:225234, 2009.

[2] L. Fenoglio-Marc, J. Kusche, and M. Becker. Mass variation in the Mediterranean Sea from GRACE and its validation by altimetry, steric and hydrologic fields. *Geophysical Research Letters*, 33:19606–+, October 2006.

[3] L. Fenoglio-Marc, J. Kusche, M. Becker, and I. Fukumori. Comment on "On the steric and mass-induced contributions to the annual sea level variations in the Mediterranean Sea" by D. Garcia et al. *Journal of Geophysical Research*, 112, October 2007.

[4] L. Fenoglio-Marc, A. Mariotti, G. Sannino, B. Meyssignac, A. Carillo, and M.V. Decadal variability of the net water flux at the Mediterranean Gibraltar Strait Struglia. Decadal variability of the net water flux at the mediterranean gibraltar strait. *Global and Planetary Change*, 2012.

[5] L. Fenoglio-Marc, R. Rietbroek, S. Grayek, M. Becker, J. Kusche, and E Stanev. Water mass variation in the mediterranean and black sea. *J. of Geodynamics*, 2012.

[6] Massayoshi Ishii and Masahide Kimoto. Reevaluation of Historical Ocean Heat Content Variations with Time-Varying XBT and MBT Depth Bias Corrections. *Journal of Oceanography*, 65(5):587–299, June 2009.

[7] B. Meyssignac, F. M. Calafat, S. Somot, V. Rupolo, P. Stocchi, W. Llovel, and A. Cazenave. Two-dimensional reconstruction of the Mediterranean sea level over 1970 - 2006 from tide gauge data and regional ocean circulation model outputs . *Global and Planetary Change*, accepted, 2011.

[8] M. Rixen, J.-M. Beckers, S. Levitus, J. Antonov, T. Boyer, C. Maillard, M. Fichaud, E. Balopoulos, S. Iona, H. Dooley, M.-J. Garcia, B. Manca, A. Giorgetti, G. Manzella, N. Mikhailov, N. Pinardi, and M. Zavatarelli. The western mediterranean deep water: A proxy for climate change. *Geophysical Research Letters*, 32:4, 2005.

[9] F Sevault, S. Somot, and J. Beuvier. A regional version of the nemo ocean engine on the mediterranean sea: Nemomed8 users guide. note de centre n107, cnrm, toulouse, france. 2009.

Acknowledgements

We acknowledge ESA, JPL/CNES and RADS for the altimeter data, GFZ and NASA for the GRACE data. This study was partly carried out in the frame of the projects STREMP funded by the DFG/SPP1257 and TOPO-EUROPE funded by the EU. The PROTHEUS model simulation has been performed as part the CIRCE Integrated Project, funded under the European Commission Sixth Frame-work Program.

IPGD LEGOS

Poster N. 54, Sessions: Others
OSTST 2012
Venice, 27-28 September 2012