In: Sea Level Rise, Coastal Engineering, Shorelines and Tides ISBN: 978-1-61728-655-1
Editor: Linda L. Wright

Chapter 12

SEA LEVEL TREND CHANGES IN THE IONIAN SEA IN RELATION TO THE EASTERN MEDITERRANEAN TRANSIENT

J. Soto-Navarro[1], J. Del Río Vera[1], F. Criado-Aldeanueva[1], J. García-Lafuente[1], C. Naranjo-Rosa[1], C. Calero-Quesada[1] and A. Sanchez-Roman[1]

[1]Physical Oceanography Group, University of Malaga, Spain.

ABSTRACT

Altimetry measurements over the Ionian region have been used to analyse the negative sea level trend over the Ionian basin in the last decades. The apparent decreasing trend should be better understood as an abrupt sea level drop in 1998 probably linked to changes in the surface circulation in the Ionian basin induced by the Eastern Mediterranean Transient, which changed from anticyclonic to cyclonic about March 1998. From then onwards, a rising rate of 7.9 ± 0.9 mm/year is observed over the basin.

Keywords: sea level trends; altimetry; Eastern Mediterranean Transient; Ionian Sea

1. INTRODUCTION

The Mediterranean Sea, a semi-enclosed basin that extends over 3000 km in longitude and over 1500 km in latitude, is separated into the eastern and western basins by the Strait of Sicily (Figure 1). The average sea level trends estimated for the last years in the entire basin range from 7±1.5 mm/year reported by Cazenave et al. (2002) from 6 years (1993–1998) of T/P and ERS-1 merged altimetry data to 2.2 mm/year and 2.1±0.6 mm/year obtained by Fenoglio-Marc (2002) and Criado-Aldeanueva et al. (2008) from 8 years (09/1992–08/2000) and 13 years (1993–2005) of altimetry data, respectively. Trends considerably vary with location: sea level rise of thermosteric origin is particularly important in the Levantine basin south of Crete with values up to 10±1 mm/year; in contrast, the Ionian basin has been identified as a falling sea level region. Cazenave et al. (2002) reported a decreasing trend of 15–20 mm/year over the area for the period 1993–1998. Using longer data series, Fenoglio-Marc (2002) and Criado-Aldeanueva et al. (2008) found more moderate values: −11.9 mm/year for 1992–2000 and −10±0.8 mm/year for 1993–2005, respectively. Due to the relatively short time series, regional trends depend both on the length of the series and on the boundaries of the area selected to compute the regional mean sea level. The Ionian negative trend is more probably related to mass redistribution than to a thermosteric forcing, which suggests an origin related to changes of the circulation pattern in this basin during the last decade, probably linked to the Eastern Mediterranean Climate Transient (EMT, Pinardi et al., 1997; Malanotte-Rizzoli et al., 1997, 1999; Manca, 2000). In this paper, some features of this decreasing trend are revisited using altimetry records over the Ionian region.

2. DATA

The total sea level has been determined from altimetry data from diverse satellite/missions (T/P, ERS-1/2, GFO, ENVISAT and JASON 1) collected through the merged AVISO (Archiving Validation and Interpretation of Satellite Oceanographic data) products, freely available on www.aviso.oceanobs.com. The data consist of sea level anomalies referred to a 7-year average (1993–1999) and combine information from different missions, which significantly improves the estimation of mesoscale signals (Le Traon and Dibarboure, 1999; Le Traon et al., 2001). The AVISO regional solution for the Mediterranean Sea for the period 1992–2007, with 1/8×1/8° spatial resolution and weekly time resolution has been used. To focus on seasonal variations, a low-pass Butterworth filter (cut-off frequency 60 days−1) has been applied. All standard geophysical and environmental corrections including ionospheric, dry and wet tropospheric corrections, solid Earth and ocean tides, ocean tide loading, pole tide, electromagnetic bias, instrumental corrections, orbit error reduction and inverse barometer have been applied by AVISO processing algorithms (AVISO, 1996).

3. RESULTS AND DISCUSSION

Figure 1A displays the total spatially averaged sea level anomaly over the Ionian Sea (solid rectangle) from altimetry data. More than 700 altimetry grid points have been extracted so the results are thought to be representative of the Ionian basin. To diagnose trends, the signal has been least squares fitted to the following function:

$$y(t) = a_0 + a_1 t + A_1 \cos(\omega_1 t - \varphi_1) + A_2 \cos(\omega_2 t - \varphi_2) \tag{1}$$

that includes annual ($\omega 1$) and semi-annual ($\omega 2$) frequencies. The semi-annual amplitude turned out to be an order of magnitude smaller than the annual amplitude and results do not vary significantly when considering only the annual oscillation. A total trend of −4.6±0.7 mm/year (95% confidence interval) is computed for the entire period superposed to the seasonal oscillation. This value is lower than reported in the literature (Cazenave et al., 2002; Fenoglio-Marc, 2002; Criado-Aldeanueva et al., 2008) because sea level has a positive trend in the last years (Figure 1A), thus reducing the overall trend. A remarkable feature is the presence of two well-differentiated periods before and after 1998. If the fitting process is performed separately, no significant trend and an annual amplitude of 9.1 cm is observed before 1998, whereas from 1998 onwards a positive trend of 7.9±0.9 mm/year is observed superposed to an annual amplitude of 7.1 cm. In 1998, an abrupt sea level change occurred with a drop of 10–15 cm between maxima that appears to be responsible for the negative trend reported by different authors (Cazenave et al., 2002; Fenoglio-Marc, 2002; Criado-Aldeanueva et al., 2008) using time series spanning over this jump. Actually, the decreasing trend over the Ionian basin in the last decades is somewhat deceitful since from 1998 onwards, sea level is rising in the Ionian basin as well. This picture would explain the anomalously high negative trend of Cazenave et al. (2002), since the abrupt fall was at the end of the time series usedin their analysis.

The question then arises as which could have been the physical forcing mechanism behind this sudden sea level drop. We propose that it was related to the EMT. A shift in the formation site of deep and bottom waters from the Adriatic to the Aegean Sea (Roether et al., 1996; Malanotte-Rizzoli et al., 1999; Theocharis et al., 1999) have altered both the deep and upper conveyor belts of the Eastern Mediterranean. Different hypothesis such as internal redistribution of salt (Klein et al., 1999), changes in the local atmospheric forcing combined with long term salinity change (Theocharis et al., 1999) or changes in circulation patterns (Malanotte-Rizzoli et al., 1999) have been proposed as possible causes of this unique event. At the same time, noticeable changes in circulation patterns over the Ionian basin have been reported in the last decades: a switch of the surface circulation in the Ionian basin from cyclonic to anticyclonic took place around 1986–87 (Pinardi et al., 1997; Malanotte-Rizzoli et al., 1997, 1999) and forced variations in the path of the Atlantic Ionian Stream (AIS) along the Ionian basin. This circulation pattern was well established until about March 1998, when it returned to cyclonic (Manca, 2000). The coincidence in time of the sea level drop and the switch of the circulation pattern over the Ionian basin suggests a cause–effect relationship between these two events. A rough estimation of the sea level drop associated to such change in the circulation pattern can be achieved by means of the geostrophic balance:

$$\Delta h = \frac{\Delta x}{g} \cdot fv \tag{2}$$

where v is a reference velocity of the flow (~0.3 m s^{-1} is representative for the mean velocity of the AIS in the Ionian Sea (Robinson et al., 1999)), Δx is a typical across stream distance over which the velocity vanishes (~5 104 m for the core of the AIS), f the Coriolis parameter (~9 10^{-5} s^{-1} for a latitude of 38 °N) and g the gravity acceleration. With these values, Eq. (2) gives Δh~0.13 m, which must be doubled to account for the change from anticyclonic to cyclonic circulation. Therefore, the computed drop is about 0.3 m, a value in good agreement (within the same order of magnitude) with the observed drop. This simple estimation supports the physical mechanism invoked.

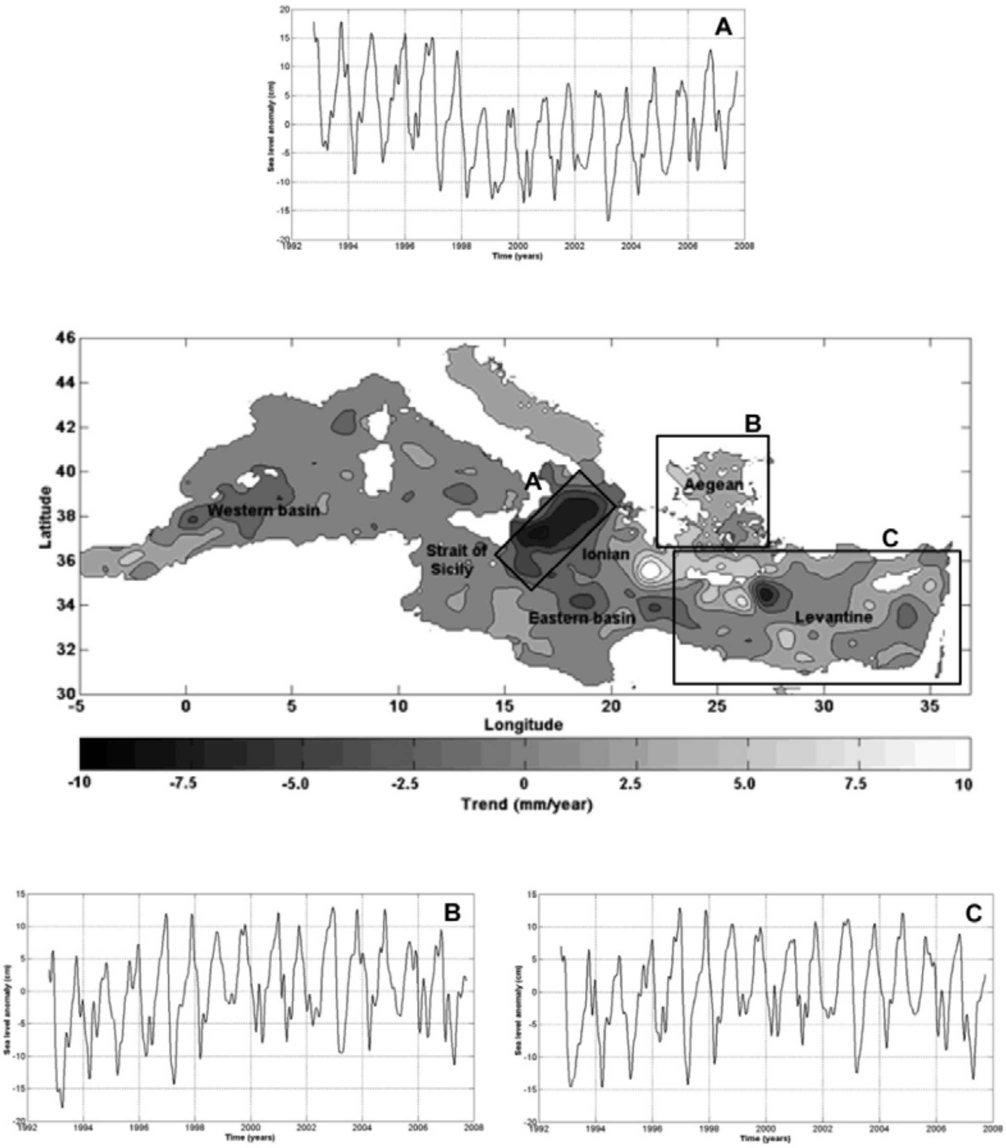

Figure 1. Spatial distribution of sea level trend in the Mediterranean Sea from 1992 to 2007 altimetry data. The rectangles limit the areas selected for the low-passed spatially averaged altimetry time series shown in panels A (Ionian basin), B (Aegean basin) and C (Levantine basin)

The EMT did not only affect the Ionian Sea but the whole Eastern basin. Larnicol et al. (2002) suggested that the changes observed in the sea level during the period between 1995 and 1999 in the Levantine basin and between 1997 and 1999 in the Ionian Sea are related to variations in the deep and intermediate water masses distribution in the whole Eastern basin. Vigo et al. (2005) show a sort of time–space coupled oscillation between the Ionian Sea and the Levantine basin in which a sea level rise in the Levantine basin is connected to a sea level drop in the Ionian Sea before 1998, while after 1999 the behavior seems to be the opposite. With longer time series available, we can now confirm and specify these findings. Figure 1B–

C shows the low-passed sea level anomaly over the Aegean (panel B) and Levantine (panel C) basins. Different behaviours before and after 1998 are again revealed in both regions. Positive trends of 12±2.5 mm/year and 14±2.5 mm/year are obtained for the period 1993–1998 in the Aegean and Levantine basins that change into negative trends of −2.0±0.8 mm/year and −2.9±0.8 mm/year, respectively for the period 1998–2008, which strongly contrast with the Ionian sea level rise. Trends before 1998 are in good agreement with previous results of Vigo et al. (2005) but those for the period 1998–2008 are lower than reported by these authors from time series until 11/2003. An explanation for this could be that the rebound effect after the 1998 event extends during the 3–4 subsequent years (see, for instance the reduction of amplitude in the seasonal oscillations in Figure 1B–C), then recovering the usual behaviour. Although the change in trend has also been evidenced in the eastern basins, its magnitude was not as significant as in the Ionian basin (Figure 1A), this suggesting that this basin was more sensitive to the 1998 event, probably due to the changes of the path of the AIS flowing through the Ionian Sea.

4. Conclusions

In this work altimetry data from 1992 to 2007 have been analysed to investigate an abrupt sea level drop in the Ionian basin by the late 90s, concretely a ~10 cm drop found in 1998. The data analysis shows that the historically reported sea level decreasing trend over the Ionian basin in the last decades stems from this punctual event rather than a continuous negative trend. Actually, the sharp drop was followed by a sea level rise from 1998 onwards. This unique event was provably linked to the EMT that induced noticeable changes in the surface circulation in the Ionian basin, which changed from anticyclonic to cyclonic about 1998.

Acknowledgement

This work has been carried out in the frame of the Junta de Andalucía Spanish funded P07-RNM-02938 project.

References

AVISO,(1996). *AVISOUserHandbook: Merged TOPEX/POSEIDON Products. 201*. Available at www.aviso.oceanobs. com/ donnees/tools/hdbk._gdrm.pdf.

Cazenave, A., Bonnefond, P., Mercier, F., Dominh, K. & Toumazou, V. (2002). Sea level variations in the Mediterranean Sea and Black Sea from satellite altimetry and tide gauges. *Global and Planetary Change, 34*, 59-86.

Criado-Aldeanueva, F., Del Río, J. & García-Lafuente, J. (2008). Steric and mass induced Mediterranean Sea level trends from 14 years of altimetry data. *Global and Planetary Change, 60*, 563-575.

Del Rio, J. (2007). *Satellite and In Situ Monitoring of Ocean Magnitudes: Application to the Mediterranean Sea*. PhD University of Malaga, *234*.

Fenoglio-Marc, L. (2002). Long-term sea level change in the Mediterranean Sea from multi-satellite altimetry and tide gauges. *Physics and Chemistry of the Earth, 27*, 1419-1431.

Klein, B., Roether,W., Manca, B., Bregant, D., Beitzel, V., Kovacevic, V. & Luchetta, A. (1999). The large deep water transient in the Eastern Mediterranean. *Deep-Sea Research I, 46*, 371-414.

Larnicol, G., Ayoub, N. & Le Traon, P. Y. (2002). Major changes in Mediterranean Sea level variability from 7 years of TOPEX/Poseidon and ERS-1/2 data. *Journal of Marine Systems,* 33-34, 63-89.

Le Traon, P. Y. & Dibarboure, G. (1999). Mesoscale mapping capabilities of multi-satellite altimeter missions. *Journal of Atmospheric and Oceanic Technology, 16*, 1208-1223.

Le Traon, P. Y., Dibarboure, G. & Ducet, N. (2001). Use of a high resolution model to analyse the mapping capabilities of multi-altimeter missions. *Journal of Atmospheric and Oceanic Technology, 18*, 1277-1288.

Malanotte-Rizzoli, P.,Manca, B. B., D'Alcala, M. R., Theocharis, A., Bergamasco, A., Bregant, D., Budillon, G., Civitarese, G., Georgopoulos, D., Michelato, A., Sansone, E., Scarazzato, P. & Souvermezoglou, E. (1997). A synthesis of the Ionian hydrography, circulation and water mass pathways during POEM-phase I. *Progress in Oceanography, 39*, 153-204.

Malanotte-Rizzoli, P., Manca, B. B., D'Alcala, M. R., Theocharis, A., Brenner, S., Budillon, G. & Ozsoy, E. (1999). The Eastern Mediterranean in the 80s and in the 90s: the big transition in the intermediate and deep circulations. *Dynamics of Atmospheres and Oceans, 29(2-4)*, 365-395.

Manca, B. M. (2000). Recent changes in dynamics of the EasternMediterranean affecting the water characteristics of adjacent basins. *CIESMWorkshop Series,* 2000, 27-31.

Pinardi, N., Korres, G., Lascaratos, A., Stanev, E. & Roussenov, V. (1997). Evidence for interannual variability of the Mediterranean Sea upper ocean circulation. *Geophysical Research Letters, 24(4)*, 245-247.

Robinson, A. R., Sellschopp, J., Warn-Varnas, A., Leslie, W. G., Lozano, C. J., Haley Jr., P. J., Anderson, L. A. & Lermusiaux, P. F. J. (1999). The Atlantic Ionian Stream. *Journal of Marine Systems, 20*, 129-156.

Roether, W., Manca, B. B., Klein, B., Bregant, D., Georgopoulos, D., Beitzel, V., Kovacevic, V. & Luchetta, A. (1996). Recent changes in eastern Mediterranean Deep Waters. *Science, 271*, 333-335.

Theocharis, A., Nittis, K., Kontoyiannis, H., Papageorgiou, E. & Balopoulos, E. (1999). Climatic changes in the Aegean Sea influence the Eastern Mediterranean thermohaline circulation (1986-1997). *Geophysical Research Letters, 26(11)*, 1617-1620.

Vigo, I., García, D. & Chao, B. F. (2005). Change of sea level trend in the Mediterranean and Black seas. *Journal of Marine Research, 63*, 1085-1100.