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Impact of climatic change on steric sea level in the Mediterranean Sea

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The steric sea level through four layers in the Mediterranean Sea is estimated during the period of 1970 to 2005 by using hydrographic data from national world data center. Meteorological parameters are the principle factors that control the warming in the upper layer in the Mediterranean Sea. The annual sea level trends shows rising with calculated values which varies according to the different regions in the Mediterranean. The correlation between thermosteric component (TC), halosteric component (SC), total steric sea level variation (TSSL) and the coastal tide gauge records are unsatisfactory. The shift in formation of deep water in the Eastern Mediterranean is linked with the high salinity values detected in the Aegian Sea. Also, inter annual patterns of the total steric height was explained by using the spectral analysis.

Key words: Steric sea, thermosteric component (TC), halosteric component (SC), total steric sea level variation (TSSL), Mediterranean Sea.

INTRODUCTION

In recent years, there has been a lot of concern about sea level rise as a consequence of global climate change. Globally averaged sea level increased at an overall rate of 1 to 2 mm/yr^{-1} during the past century as attributed to the reduction of glaciers and the thermal expansion of the world ocean (Antonov, 2002). Cazenave and Llovel (2009) studied the variation of sea level by means of satellite altimetry and indicated a global average annual rise of more than 3 mm since the last decade of the 20th century. Church et al. (2004) computed the rate of global-averaged sea level rise from the reconstructed monthly time series as 1.8 ± 0.3 mm y_r^{-1}. At present, the increase of ocean water mass, mainly as a consequence of land ice ablation, is assumed to account for about 50% of the observed global sea level rise (Bindoff et al., 2007; Criado-Aldeanueva et al., 2008), but may become much more important in the future in a scenario of further global warming (Alley et al., 2005).

While the direct atmospheric contribution to sea level has been well documented (Tsimplis et al., 2005; Gomis et al., 2006). Mean sea level varies also by the sum of the steric effect due to density changes and hence the volume of the water column, and the mass induced sea level variation by addition/subtraction of water to and from the water column. Leuliette and Miller (2009) have estimated that, at global scale, roughly half of sea level rise is due to the steric component. In the Mediterranean Sea, Criado-Aldeanueva et al. (2008) and Tsimplis et al. (2009) have estimated respectively that, the steric effect contributes about 55 to 75% to the total sea level rise, with the thermosteric component (TC) largely dominating. In addition to steric effects, changes in salinity can be an indicator of changes in local and global hydrological cycles.

Mediterranean Sea, Figure 1, is semi-closed basin connected to the Atlantic Ocean only through the strait of Gibraltar; where sea level trends measured inside the basin differ from the global ones. Tsimplis and Baker (2000) by using a tide gauge data detected an increasing rate in the Mediterranean Sea of 1.2 to 1.5 mm yr^{-1} before 1960 and a decrease of -1.3 mm yr^{-1} between 1960 and 1998. They suggested a high correlation between sea

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Figure 1. Mediterranean Sea.

level in the Mediterranean and the local changes in temperature and salinity, which in turn, can be related to North Atlantic Oscillation (NAO) variability. They mainly attributed the negative trend to the increase of winter averaged atmospheric pressure over the region (Gomis et al., 2008). Another estimate of sea level increase at a rate of 0.7 ± 0.2 mm yr^{-1} over the period 1945 to 2000 was provided by Calafat and Gomis (2009). To estimate sea level rise in the Mediterranean basin under present and future conditions, Carillo et al. (2012) used a regional atmospheric–ocean coupled model through the period of 1958 to 2001 to give a future scenario simulation. They show that, the steric sea level averaged over the entire basin rises of about 2 or 7 cm in 50 years depending on the Atlantic boundary conditions. Passaro and Seitz (2011) studied the temporal variations of the sea level in the central eastern Mediterranean Sea by means of satellite altimetry for five years from the beginning of 2004 to the end of 2008 and *in-situ* data collected by the floats of the Mediterranean and Black Sea Argo Centre (Med Argo) established in 2003. The study revealed a sea level change at a rate of about 18 mm/yr^{-1} between 2004 and the end of 2008 in the Ionian Sea due to thermal expansion, while thermal and haline contributions show opposite trends in the eastern Mediterranean where both effects tend to counteract each other on inter-annual time scales that is, the halosteric effect has a significant influence on the sea level in closed basin at mid-latitude, like the Mediterranean Sea, due to high evaporation). Sea level trends and inter-annual variability in the Mediterranean for the period 1960 to 2000 was explored by Tsimplis et al. (2008) by comparing the observations from tide gauges with sea level hindcasts from a barotropic 2D circulation model, and two full primitive equation 3D ocean circulation models, In the 2D model, 50% of the sea level variance was found to result from the wind and atmospheric pressure forcing. In the 3D models, 20% of the sea level variance was explained by the steric effects.

In this study, we try to estimate the change in steric sea level at different layers representing the different water masses in the Mediterranean Sea as a result of changing in temperature and salinity through the between of period 1970 and 2008 and compare the results with long sea level records obtained from tide gauge available at four locations distributed along the Mediterranean coast.

DATA AND METHODOLOGY

Data from the World Ocean Data Center (15,742,840 temperature and salinity records) are used to prepare objectively analyzed temperature and salinity anomaly for 5 years running composites for the period of 1970 to 2008.

The monthly mean values are calculated from different types of observations: mechanical bathythermograph (MBT), Nansen bottle data, expendable bathythermograph (XBT), and conductivity “salinity”- temperature-depth (CTD-STD) during the period from 1970 to 2008 for each 1° × 1° grid at each standard depth from surface to 1000 m depth, Rixen et al. (2001). Each calculated value is subtracted from each observed values to reduce the effect of the annual cycle. These anomalies are used to estimate the standard deviation (SD) of data in each 5° square to remove any anomaly exceeding 6 SD (Levitus et al., 2000). This statistical procedure was considered as tools to reject only grossly data. The mean anomalies for temperature and salinity are computed for overlapping 5 years periods (analogous to running–mean average) at each 1° square for 18 standard depths level from surface to 1000 m depth.

Water column variation in both temperature and salinity causes

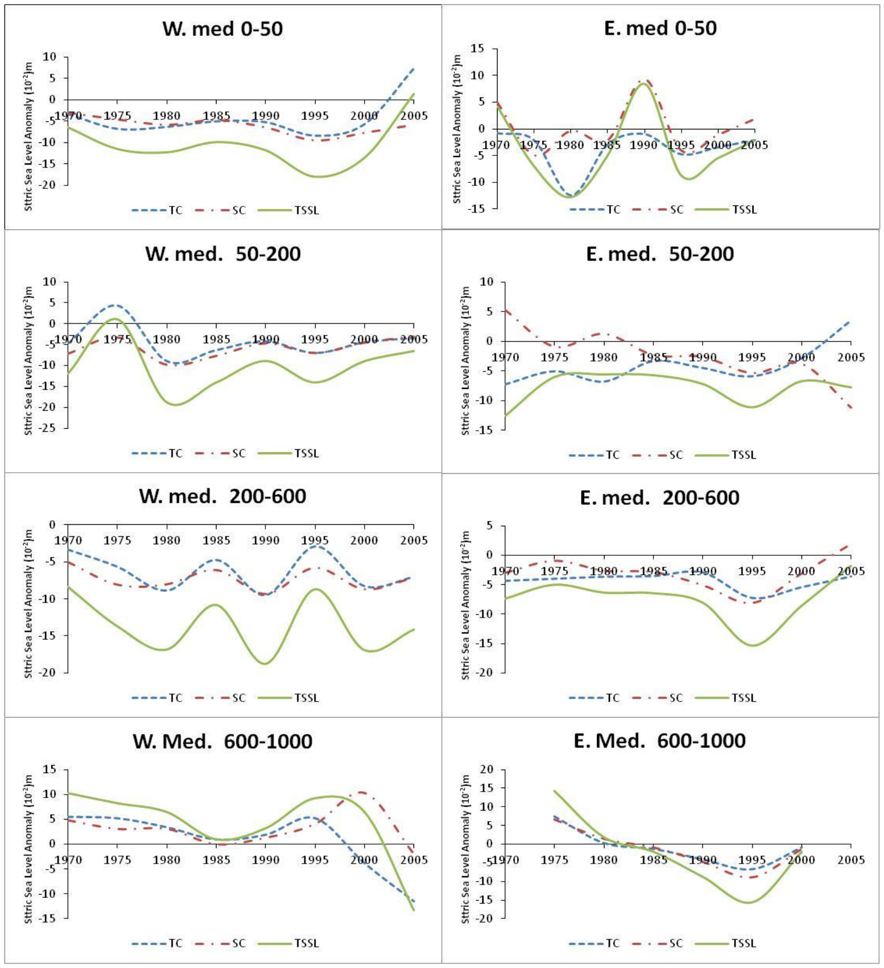

Figure 2. Time series of 5 years running of the TC, SC, and TSSC for the Surface layer (0 to 50 m), Atlantic layer (50 to 200 m), Intermediate layer (200 to 600 m) and Deep layer (600 to1000 m) for the Western and Eastern Mediterranean.

what are termed "steric" sea level variations, (Pattullo et al., 1955). In this paper, the change due to thermal expansion is considered as TC and change due to haline contraction as Halosteric component (SC). Both are expressed in units of height. Their sum is the Total steric sea level variation (TSSL).

We used the 1° latitude-longitude temperature and salinity anomaly fields to compute TC, SC, and TSSL in each 1° latitude-longitude square water column by;

$$TC = \int_{z1}^{z2} \frac{1}{v}\frac{\partial v}{\partial T}\Delta T\,dz \quad SC = \int_{z1}^{z2} \frac{1}{v}\frac{\partial v}{\partial S}\Delta S\,dz \quad TSSL = TC + SC$$

When, v is specific volume $\partial v/\partial T > 0$ for temperature $T > 0$°C and salinity S > 20 and $\partial v/\partial S < 0$ for any sea-water T and S), z is depth, z_1 and z_2 are the lower and upper limits of depth of integration, and ΔT and ΔS are the 5 years composite temperature and salinity anomalies at any particular standard depth level. Specific volume v has been computed at each standard depth level in each 1° square as a function of climatologically annual mean temperature (Antonov et al., 1998) and salinity fields and pressure using the 1980 equation of state for seawater (UNESCO, 1987).

Four layers represented the different water masses in the Mediterranean: Surface layer (0 to 50 m), Atlantic layer (50 to 200 m), Intermediate water (200 to 600 m) and deep water (600 to 1000 m). The annual mean sea level records at four tide gauges "Malaga station in the Alboran Sea, Marseille station in the Baleric Sea "represent the Western Mediterranean Sea", Split-Luka station located at Adriatic Sea, and finally Alexandria station to represents the Levantine Sea "represent the Eastern Mediterranean Sea" are used as representative of the coastal sea level variability. All stations are revised local reference (RLR) stations, that is, information on the local datum is included in the database.

RESULTS

The mean steric height anomalies vary between -10 and 10 cm for the western and eastern Mediterranean. Figure 2 illustrate the 5 years running of the TC, SC, and TSSL for the four layers" the surface layer (0 to 50), Atlantic layer (50 to 200), Intermediate layer (200 to 600), and Deep layer (600 to 1000)" for the Western and Eastern Mediterranean.

The variability in the surface layer in the Western

Mediterranean is clearly due to both temperature and salinity effect during the period of 1970 to 2000. After 2000 the temperature effect is mainly dominate in steric sea level at the surface layer. The steric height was approximately not changing from 1960 to 1995 which coincide with the result of Tsimplis and Baker (2000), who referred this trend to atmospheric pressure changed during the winter period (Tsimplis and Josey, 2001; Woolf et al., 2003). The steric height of the surface layer of the Eastern Mediterranean depends on both temperature and salinity. While the temperature has greater effect on surface layer from 1970 to 1985, the salinity has a dominant effect through the period of 1985 to 1995. After 1995, a rapid increase in steric sea level can be detected as a result of effect of both temperature and salinity.

The steric level of the Atlantic water occupied the layer between 50 and 200m depth in the western Mediterranean indicates a warming period around 1975 followed by a cooling one at 1982. A gradual warming and slow increasing in salinity could be detected in the western basin from 1982 until 2005. This moderate pattern for steric sea level was due to the significant effect of temperature while salinity balanced with temperature after 1980 until 2005. In the Eastern Mediterranean, steric sea level due to temperature and salinity are fluctuated in influencing at the period between 1975 and 2000. Before and after this period, temperature variation has dominant effect on steric sea level.

In the Intermediate layer (200 to 600 m), three consecutive cooling periods are observed at 1978, 1990, and 2000 in the western basin while the steric height was slightly reduced due to cooling around 1995 in the Eastern Mediterranean. In the Western and Eastern Mediterranean, the steric sea level changes follow mainly both temperature and salinity curves. The high salinity and lower values of temperature exist in this layer mainly responsible about the balance between the effects of the two parameters on the steric height.

In deep layer (600 to 1000 m), the total steric values in the Western Mediterranean have positive values until 2002 while it has negative values at 1982 in the eastern basin. Also, TSSL and TC values decreased until it were approximately zero around 1985 and 1982 in western and eastern basins, respectively. SC decrease to reached a maximum negative values (-10.0 cm) around 1995 in the eastern basin and maximum positive values (10.0 cm) around 2000 in the western basin. The effect of this depression detected in steric sea level values around 1982 in Eastern basin may be linked with Eastern Mediterranean transient (EMT) that linked with specific atmospheric conditions which created anomalously large buoyancy fluxes cover the central parts of the Eastern Basin (Romanski et al., 2012). Notably, after and before 1982 the high temperature and salinity values would be more important than the EMT for the steric sea level.

The calculation of steric sea level height was repeated for the four layers at seven small areas to give more details about the steric sea level variation at the two basins of the Mediterranean (Figures 3 and 4). These areas are: the Adriatic, Ionian, Aegean, and Levantine Seas at the Eastern Basin and Alboran, Baleric, and Tyrrhenian Seas at the western basin.

According to Tsimplis and Rixen (2002), steric sea level variability in the upper waters of the Mediterranean Sea for the second half of the 20th century has been driven mainly by changes in water temperature.

This result coincides partially with the pattern obtained from Alboran Sea and not coincides with the results detected from Tyrrhenian Seas. Temperature and salinity has balance effects on steric sea level in Baleric Sea, moreover significantly different regional behavior can be identified at each of the three regions analyzed. The Baleric Sea can represent the Western Basin.

At Atlantic layer, a great difference could be detected for salinity between the three regions. Atlantic water after passes from Gibraltar has exposed to turbulent mixing and more evaporation. So, salinity values increased as it moves to the east direction and consequently it becomes more effective on steric sea level as detected for the Tyrrhenian Sea. Both temperature and salinity play important roles on steric height at Alboran and Balearic Seas.

The high degree of significant correlation between TC and SC in the Intermediate layer indicates the tendency of TC and SC to compensate each other. Many consecutive cooling periods are observed around 1980 and 1990 at Alboran Sea and 1980, 1990, and 2000 at Balearic Sea. In Balearic Sea, the cooling intervals are compensated with high values of salinity that fit with the picture of deep water formation in the north of the Balearic Sea. The deep water steric height changes in the Alboran Sea around 1975, 1990, and 2005 are linked with changes in temperature and salinity. This change may be referring to the changes in the out flowing Mediterranean water. Also, this pattern can be also detected in the Tyrrhenian Sea

The estimation of the steric sea level for the four smaller areas in the Eastern Mediterranean is shown in Figure 4. Both temperature and salinity has effect on steric sea level in the upper layer. High TC values are detected between 1987 and 1995 in the Adriatic Sea. In the same period a gradual increase in TC height is observed in the other three areas. In Adriatic Sea, high values of SC of about -6.0 mm detected in 1991 while it increased to 15.0 mm at the same year in the Ionian Sea. SC has maximum values in the Aegean Sea (-18.0 mm) at 1980. This gradual increase of salinity between the three basins support the results obtained by Romanski et al. (2012) which indicated a shift of the deep water formation in the Mediterranean Sea from its usual location in the Adriatic Sea to the Aegean Sea during the late 1980 and early 1990.

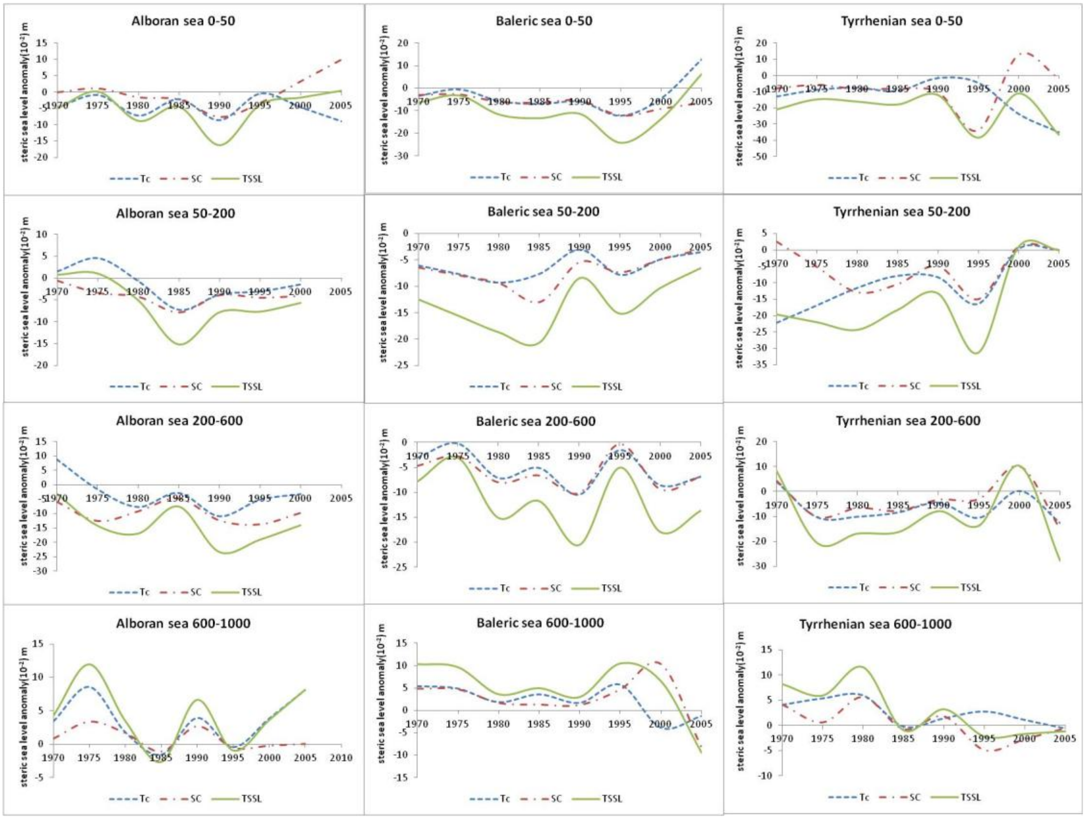

Figure 3. Time series of 5 years running of the TC, SC, and TSSL for the surface layer (0 to 50 m), Atlantic layer (50 to 200 m), Intermediate layer (200 to 600 m) and Deep layer (600 to 1000 m) for the smaller basins in the Western Mediterranean.

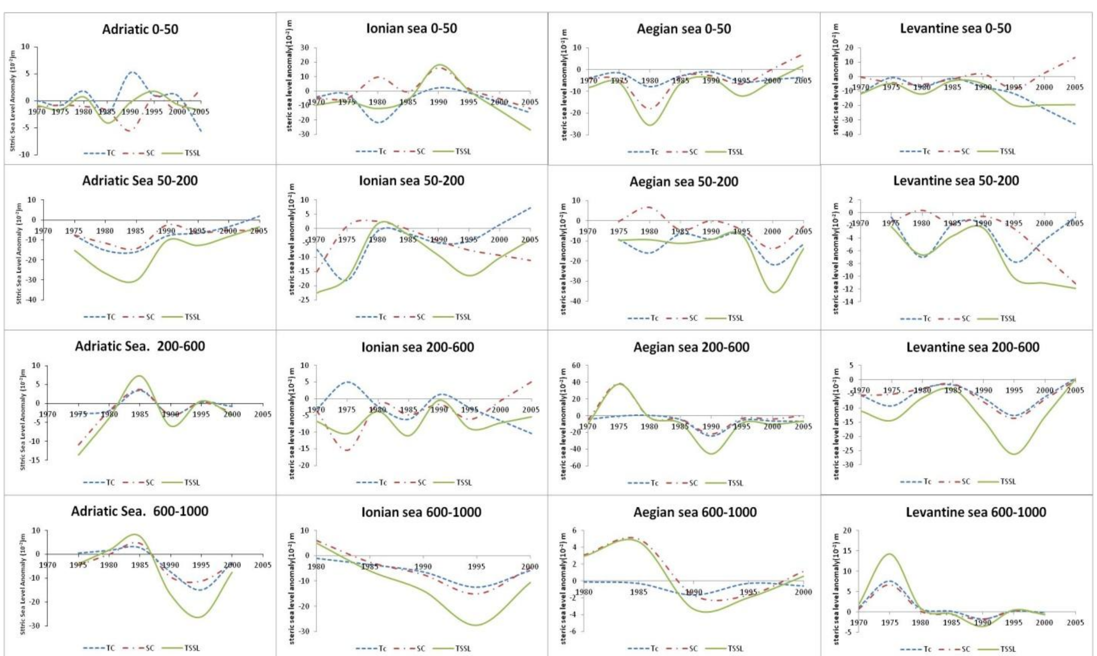

Figure 4. Time series of 5 years running of the TC, SC, and TSSL for the Surface layer (0 to 50 m), Atlantic layer (50 to 200 m), Intermediate layer (200 to 600 m), and Deep layer (600 to 1000 m) for the smaller basin in the Eastern Mediterranean.

Table 1. Name, country, longitude, latitude, and period of the records of the four tide gauge stations.

Station number	Station name	Station country	Longitude	Latitude	Station period
1	Malaga	Spain	-4.4167	36.717	1944-2010
2	Marseille	France	5.354	43.279	1885-2011
3	Split-Luka	Croatia	16.442	43.507	1945-2011
4	Alexandria	Egypt	29.942	31.330	1973-2007

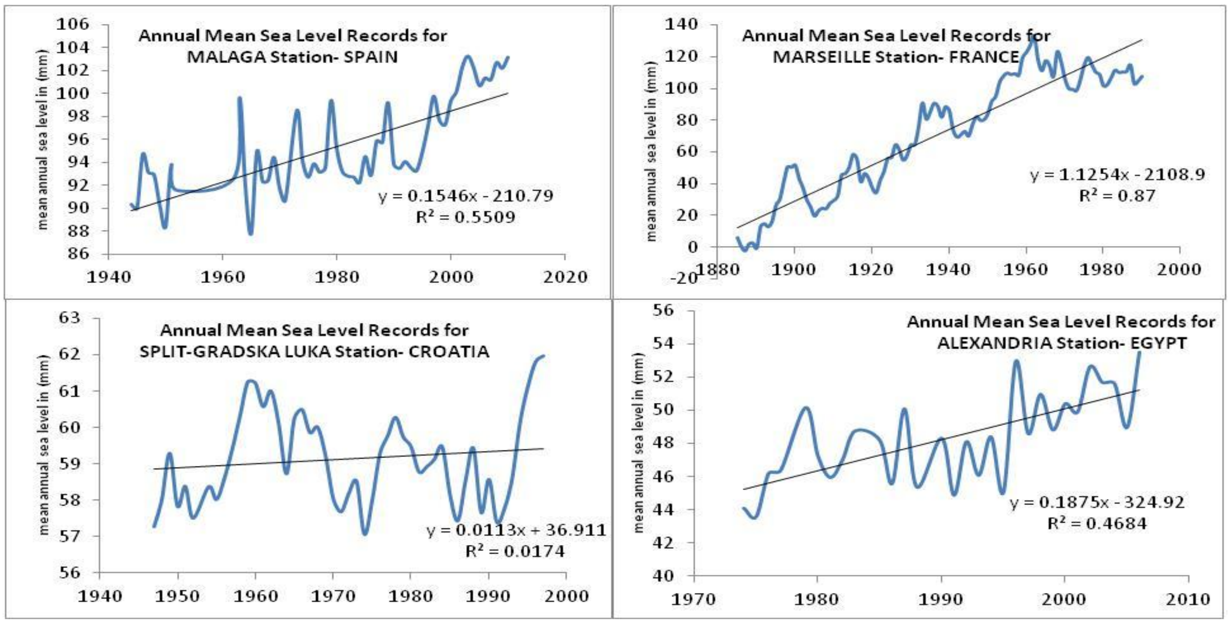

Figure 5. The five years running of annual mean sea level records at the four tide gauge locations.

As the salinity values become less salty in the Atlantic layer, the heating occupies the main dominant parameter effect on steric sea level at the four areas.

In intermediate layer, high and gradual increase of SC values can be observed through the four areas and reach its maximum values at the Aegean Sea 38 mm in 1975. At the same year, it has about -25 mm at the Ionian Sea and -12 mm at the Adriatic Sea. At Levantine Sea, the TC and SC has its maximum value of about 15.0 mm at 1995. These changes in salinity fit with the picture of deep water formation in the Aegean Sea due to increased salinity and cooling while in the Adriatic the strong reduction in salinity accompanies the interruption of deep water formation.

SC effect is dominant on steric sea level at the deep water especially at the Aegean Sea while the TC has a nearly constant low values at this basin. TC and SC have the same effect on the steric sea level at the three other areas.

The five years running of annual mean sea level records at four tide gauge (Table 1) are plotted in Figure 5. The coefficient of determination R^2 in Marseille shows a measure of how well the trend line represents the data and how it would be able to explain all the variation. The coefficient of determination at each of Malaga and Alexandria stations show that, trend line can moderately represents the variation of data while the regression line at Croatia station cannot be able to explain all the variation. As trends vary considerably with locations, the accepted global range is 1 to 2 mm/yr^{-1} (Church et al., 2001). A gradual trend of sea level rise of about 1.12 mm/yr^{-1} can be detected at Marseille while a value of about 1.55 mm/yr^{-1} was observed at Malaga station. A weak trend found at each of Alexandria and Luka stations, (0.19 and 0.01 mm/yr^{-1}). This result differs in values with that of Cazenave et al. (2001) who has estimated that, the trends in the Mediterranean varies between 7 and 30 mm/yr^{-1} according to the nature of each basin and nearly coincide with the results of Marc (2002) who found more moderate trends: 2.2 mm/yr^{-1} for the entire Mediterranean with lower values in the western basin (about 0.4 mm/yr^{-1}).

The correlation coefficient between 5 years average of annual sea level anomaly for the four records of tide

Table 2. Correlation coefficient between 5 years average of annual sea level anomaly of Tide gauge and the TSSL of the Surface, Atlantic, Intermediate, and Deep layer at the four basins represented the locations of tide gauge.

Layer	St. Malaga / Alboran	Marseille / Baleric	Split-Luka / Adriatic	Alexandria / Levantine
Surface layer	-0.75963	0.027899	0.543465	0.722467
Atlantic layer	0.187956	-0.5208	-0.38016	0.850794
Intermediate layer	-0.18527	0.457437	-0.09032	-0.30242
Deep Layer	0.294069	0.034843	-0.64222	0.47969

gauge and the TSSL results of the Surface layer, Atlantic, Intermediate, and deep at the four basins "Alboran, Baleric, Adriatic and Levantine" represented the locations of tide gauge are shown in Table 2.

Most of the correlation coefficient results are far from statistically significant. The time series used for the correlation are 32 pairs of point. Dividing by 5 year averaged period, we get conservative estimate of 6° of freedom which requires correlation coefficient of 0.83 or higher to be consider significant at the 99% level of significant. The only layer that achieved this condition and has 99% level of significant is the Atlantic layer in the Levantine Basin. The upper layer of Alboran and Levantine basins gives considerable significant level at 95%.

DISCUSSION

Mediterranean Sea level is driven by meteorological factors that control the warming in the upper layers. In addition to the impact of the changes in the meteorological parameters especially in winter, the temperature reduction and salinity changes linked to the NAO have been claimed as contributing factors. Also, our result and that of Cazenave et al. (2001) indicate increase in sea level in Mediterranean driven by warming in the upper layer. In comparing our results with the global records, Cabanes et al. (2001) detected that, after 1993 the temperature changes are the dominant factor globally and no other forcing parameters seems to matter. Thus, our appreciation is that, the dependency of sea level on the various forcing factors is not only complicated but it also varies with time and space, so that a good understanding of the oceanic circulation is needed in order to interpret it.

The lake of correlation between the tide gauge data and the total steric variation at almost different layers in the Mediterranean indicates that, this correspondence between the steric heights and the coastal measurements has been taken place. Thus, at least for the coastal sea level in the Mediterranean we cannot conclude that the direct effect of heating is the only factor responsible. Also, in the present case, it is possible that, one of the forcing parameters may become particularly important for some period of time.

Climatic change and the different meteorological pattern accompanied over the Mediterranean rises the values of temperature and rate of evaporation that consequently affect salinity. The gradual high values of salinity detected in different regions inside the Mediterranean are linked with the shift of the deep water formation in the Eastern Mediterranean.

In order to examine the inter-decadal fluctuation cycle of annual mean of total steric height the spectral analysis technique has been extensively used. The spectral analysis on mean annual steric height in Mediterranean gives that over the 35 years, the mean annual variability is mainly dominated by oscillations in low frequency time of 11.76, 3.56, 2.4, 1.45, and 0.70 per year.

The varying length of the 11 years cycle has been found to be strongly correlated with long-term variations of the northern hemisphere land surface air temperature since the beginning of systematic temperature variations from a global network that is, during the past 130 years (Lassen and Friis-Christensen, 1995). This is related to sunspot cycle. According to Geerts and Linacre (1997), there is a strong radial magnetic field within a sunspot, and the direction of the field reverses in alternate years within the leading sunspots of a group. So the true sunspot cycle is 22.2 years. These results are compatible with that obtained by Ebtessam and Beltagy (2009). Annual sea level trends increase with values which fluctuate between 0.19 and 2.8 mm according to the nature of the different regions inside the Mediterranean Sea.

REFERENCES

Alley R, Clark P, Huybrechts P, Joughin I (2005). Ice-sheet and sea-level changes. Science, 310:456-460, doi:10.1126/science.1114613.

Antonov JI (2002). Steric sea level variations during 1957–1994: Importance of salinity J. Geophy. Res. P. 107, NO. C12, 8013, doi: 10.1029/2001JC000964, 2002.

Antonov JI, Levitus S, Boyer TP, Conkright ME, O'Brien TC (1998). Stephens, World Ocean Atlas vols. 1 –3, Temperature of Atlantic, Pacific and Indian Oceans, U.S. Govt. Print. Off., Washington, D. C.P. 498.

Bindoff NL, Willebrand J, Artale V, Cazenave A, Gregory J, Gulev S, Hanawa K, Le Quéré C. Levitus S, Nojiri Y, Shum CK, Talley LD, Unnikrishnan A (2007). Observations: Oceanic Climate Change and Sea Level. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Cabanes C, Cazenave A, Le Provost C (2001). Sea level during past 40years determined from satellite and *in situ* observation, Science 294(5543):840-845.

Calafat FM, Gomis D (2009). Reconstruction of Mediterranean Sea level fields for the period 1945-2000. Glob plant change 66:225-234, doi: 10-1016/j- gloplacha-2008-12-015.

Carillo A, Sannino G, Ruti PM, Calmanti S, Dell Aquila A (2012). Steric sea level rise over the Mediterranean Sea: Present climate and scenario simulations. Climate Dynamics J. Springer Verlag, Clim Dyn, DOI 10-1007/s00382-012-1369-1.

Cazenave A, Cabanes C, Dominh K, Mangiarotti S (2001). Recent sea level changes in the Mediterranean Sea revealed by TOPEX/POSEIDON satellite altimetry. Geophys. Res. Lett. 28(8):1607-1610.

Cazenave A, Llovel W (2009). Contemporary sea level rise. Ann. Rev. Mar. Sci. 2:145-173.

Church JA, Gregory JM, Huybrechts P, Kuhn M, Lambeck K, Nhuan MT, Qin, D, Woodworth PL (2001). Changes in sea level. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden, P, Dai X, Maskell K, Johnson CL (Eds), Climate change 2001. The Scientific Basis. Contribution of working group 1 to the third Assessment Report of the Intergovernmental Panel on Climatic Change. Cambridge University Press, pp. 639-694.

Church JA, White N, Coleman R, Lambeck K, Mitrovica J (2004). Estimates of the regional distribution of sea level rise over the 1950-2000 period. J. Clim. 17:2609-2625.

Criado-Aldeanueva F, Del Rio Vera J, Garcia-Lafuentea J (2008). Steric and mass-induced Mediterranean sea level trends from 14 years of altimetry data. Glob. Planet. Change, 60:563-575, doi:10.1016/j.gloplacha. 2007.07.003.

Ebtessam EM, Beltagy AI (2009). Analysis of long-term air temperature in Alexandria. Egypt. J. Aquat. Res. 35(4):461-474.

Geerts B, Linacre E (1997). Sunspots and climate. http://www-das.uwyo.edu/~geerts/cwx/notes /chap02/ sunspots.html.

Gomis D, Ruiz S, Sotillo MG, Alvavez-Fanjul E, Terradas J (2008). Low frequency sea level variabilitynin the Mediterranean Sea: The contribution of atmospheric pressure and wind. Glob planet change 63(2-3):215-229.

Gomis D, Tsimplis MN, Martin-Miguez B, Ratsimandresy AW, Garcia-Lafuente J, Josey SA (2006). Mediterranean Sea level and barotropic flowthrough the Strait of Gibraltar for the period 1958–2001 and reconstructed since 1659. J. Geophys. Res. (OCEANS) 111(C11) Art. No. C11005 NOV 8.

Lassen K, Friis-Christensen E (1995). Variabilty of the solar cycle length during the past five centuries and the apparent association with terrestrial climate. J. Atmos. Solar Terr. Phys. 57:835-845.

Leuliette EW, Miller L (2009). Closing the sea level rise budget with altimetry, Argo, and GRACE, Geophys. Res. Lett. P. 36, L04608, doi: 10.1029/2008GL036010.

Levitus S, Antonov JL, Boyer TP, Stephens C (2000). Warming of the world ocean. Science 287:2225-2229.

Marc LF (2002). Long-term sea level change in the Mediterranean Sea from multi-satellite altimetry and tide gauges. Phys. Chem. Earth 27:1419-1431.

Passaro M, Seitz F (2011). Steric sea level variations in the central-eastern Mediterranean Sea from Argo observations, Bollettino di Geofisica Teorica ed Applicata 52(1):131-147.

Pattullo J, Munk W, Revelle R, Strong E (1955). The seasonal oscillation in sea level. J. Mar. Res. 14:88-156.

Rixen M, Beckers JM, Brankart JM, Brasseur PA (2001). Anumerically efficient data analysis method with error map generation. Ocean Modell. 2(1-2):45-60.

Romanski J, Romanou A, Bauer M, Tselioudis G (2012). Atmospheric forcing of the Eastern Mediterranean Transient by midlatitude cyclones Geophysical Research Letters, P. 39, L03703, doi:10.1029/2011GL050298, 2012.

Tsimplis M, Marcos M, Colin J., Somot, S, Pascuel A, Shaw AGP (2009). Sea level Variability in the Mediterranean Sea during the 1990s on the basis to 2D and one 3D model. J. Mar. Syst. 78(1):109-123.

Tsimplis M, Marcos M, Somot S, Barnier B (2008). Sea level forcing in the Mediterranean Sea between 1960 and 2000. Global Planet. Change 63:325-332.

Tsimplis MN, Alvarez-Fanjul E, Gomis D, Fenoglio-Marc L, Perez B (2005). Mediterranean sea level trends: atmospheric pressure and wind contribution. Geophys. Res. Lett. 32, L20602. doi:10.1029/2005GL023867.

Tsimplis MN, Baker TF (2000). Sea level drop in the Mediterranean Sea: an indicator of deep water salinity and temperature changes. Geophys. Res. Lett. 27(12):1731-1734.

Tsimplis MN, Josey S (2001). Forcing the Mediterranean Sea by atmospheric oscillations over the North Atlantic. Geophys. Res. Lett. 28(5):803-806.

Tsimplis MN, Rixen M (2002). Sea level in the Mediterranean Sea: the contribution of temperature and salinity changes. Geophys. Res. Lett. 29:2123-2136.

UNESCO, International Oceanographic Tables, P. 4, Paris, 1987.

Woolf DK, Shaw AGP, Tsimplis MN (2003). The influence of the North Atlantic Oscillation on sea level variability in the North Atlantic region. J. Atmos. Ocean Sci. 9(4):145-167.