Analysis of Mediterranean sea level from satellite altimetry and tidal data

M. Haddad[a], M. F. Belbachir[b], S. Kahlouche[a], A. Rami[a], S. Khelifa[a]
[a]Centre of Space Techniques, 1 Avenue de Palestine, BP 13 Arzew. Oran, Algeria
[b]University of Science and Technology of Oran, Department of Electronics, Signals, Systems and Data Laboratory, BP 1505, Oran El M'Naouer. Oran, Algeria

ملخّص : الهدف من هذا المقال هوتقييم التغيّرات الفصلية للبحر الأبيض المتوّسط و إتجهاته من القّيم المسجّلة في السلسلة الأحداثية للمستوى المرفاعي للبحر و المستوى المتوسط لمد و جزر البحر.بيّن تحليل السلسلة الأحداثية المرفاعية ، من سنة 1992 إلى 2009 ، بأن سعة تغيّرات المستوى المتوسط للبحر الأبيض المتوّسط تقدر تقريبا بـ 15 سم . تنخفض في شهر جانفي و فيفري ، تبلغ الحد الأدنى في شهر مارس و أبريل و يلاحظ الحد الأقصى في شهر أكتوبر و نوفمبر . يحدد أجل إستجابة مستوى البحرلتغيّرات الحرارة على سطح البحر في حوالي شهرين يتطابق مع الوقت المتطلّب للحرارة المنتشرة من السطح إلى أعماق البحر.

تبيّن النتائج الشهرية لتحليل السلسلة الأحداثية PSMSL RLR بأن التغيّرية الفصلية لمستوى البحر الأبيض المتوسط تنخفض في فصل الخريف و ترتفع بين فصلي الصيف و الربيع . تسجّل القيّم الأكثر انخفاضا في شهر فيفري أومارس و القيّم الأكثر إرتفاعا في شهر أكتوبر أو نوفمبر بإستثناء بحر ايجه، أين تظهرأكبر قيمة في شهر أوت . معدّل إتجاه المستوى المتوسط للبحر الأبيض المتوّسط المتحصل عليه من معطيات مد و جزر البحر تقدر بحوالي 1.61 مم / سنة . تعد هذه القيمة أقرب لإتجاه المستوى المتوسط للبحر المتحصل عليه من المعطيات المرفاعية (1.32مم / سنة) .

الكلمات الأساسية : البحر الأبيض المتوسط ، مراقبة مستوى البحر، شذوذ مستوى البحر(SLA) ، حرارة سطح البحر (SST) ، المستوى المتوسط لمد و جزر البحر .

Résumé : L'objectif de cet article est d'évaluer la variabilité saisonnière de la mer Méditerranéenne et ses tendances à partir des enregistrements des séries chronologiques du niveau altimétrique de la mer et le niveau moyen de la marée de mer. L'analyse des séries chronologiques altimétriques, de 1992 à 2009, montre que l'amplitude de changements du niveau moyen de la mer méditerranéenne est environ de 15 cm. Il baisse en janvier-février, atteint le minimum en mars-avril et le maximum est observé en octobre-novembre. Le délai de la réponse du niveau de la mer aux variations de la température de la surface de la mer SST est environ de deux mois qui correspond aux temps exigés pour la température à diffuser de la surface aux profondeurs de la mer.

Les résultats de l'analyse mensuelle des séries chronologiques PSMSL RLR montrent que le comportement de la variabilité saisonnière du niveau de la mer Méditerranéenne baisse en automne et augmente entre les saisons de l'été et du printemps. Les plus basses valeurs se produisent en février ou en mars et les plus hautes valeurs en octobre ou en novembre à l'exception de la Mer Égée, où la valeur maximale paraît en août. La moyenne de la tendance du niveau moyen de la mer Méditerranéenne obtenue de données de la marée est environ de 1.61 mm / année. Cette valeur est proche de la tendance du niveau moyen de la mer obtenue de données altimétriques (1.32 mm / année).

Mots-clés : Mer Méditerranéenne, contrôle du niveau de la mer, anomalie du niveau de la mer (SLA), température de la surface de la mer (SST), Niveau moyen de la marée de mer.

Abstract : The purpose of this paper is to estimate the seasonal variability of Mediterranean Sea and its trends from time series of altimetric sea level and tidal mean sea level records. The altimetric time series analysis, from 1992 to 2009, shows that the amplitude of Mediterranean mean sea level changes is around 15 cm. It decreases in January-February, reaches the minimum in March-April and the maximum is observed in October-November. The response delay of sea level to SST variations is about two months which corresponds to the time required for the temperature to diffuse from the surface to sea depths.

The results of the monthly PSMSL RLR time series analysis show that the behavior of the seasonal variability of the Mediterranean Sea level decreases in the autumn and increases between spring and summer seasons. The lowest values occur in February or March and the highest values in October or November with an exception in the Aegean Sea, where the maximum value appears in August. The average of the mean Mediterranean Sea level trend obtained from tidal data is about 1.61 mm/year. This value is close to the average sea level trend obtained from altimetric data (1.32 mm/year).

Key words : Mediterranean Sea, Sea level monitoring, Sea level anomaly (SLA), Sea surface temperature (SST), Tidal Mean Sea Level.

1. Introduction

Recent analysis of tide gauge records and data from the Topex satellite altimeter indicate that Mediterranean Sea level has been rising by 0.5 to 1mm/yr [5] and it is expected to continue rising in the next century (mainly) due to thermal expansion of the oceans resulting from global warming.

Before the 1960s, the relative sea level of the Mediterranean Sea was increasing by about 1.2 mm/yr, a value within the range of the global trend. Nevertheless, between 1960 and 1994 the Mediterranean Sea level trend had reversed sign [11]. After the mid-1990s, altimetric measurements showed rapid rising of sea level in the Eastern Mediterranean Basin of the order of 20 mm/yr which has been associated with increases of the sea surface temperature [4]. Changes in the hydraulic conditions at the Strait of Gibraltar may also be important in the observed sea level rise during the recent years [10]. Important and rapid changes in the deep water formation in the eastern Mediterranean [8] as well as decadal scale changes in the deep water characteristics [9]; [2]; [3]; [11] may also be linked with the sea level changes.

Furthermore, the AVISO merged products solutions for the Mediterranean Sea based on sea level anomaly measurements from different satellites/instruments, considered for the period from 2002 to 2007, shows that the trends in the Mediterranean mean sea level had a large amplitudes, around 20 cm. The amplitude level decreased in January-February and reached the minimum in March, and the maximum was observed in October-November [1].

In this paper, we estimate the sea level changes using the longer term sea level records available from altimetry (from 1992 to 2009) and tide gauges within the Mediterranean basin. This analysis aims principally to assess the seasonal variability and the mean sea level trends over the Mediterranean Sea along its coasts.

In section 2, we present the several reasons of long term sea level variability and the different measurement means of the sea level variations. Then, we describe the data used in our analysis. In section 4, we present the seasonal variability and the mean sea level trends of Mediterranean sea level derived from altimetry data. Following this section, the delay response of sea level to the sea surface temperature variations is illustrated. The seasonal variability and mean sea level trends at tide gauge stations situated along the Mediterranean coastlines are presented in section 6. Finally, we finished by a conclusion of our analysis.

2. Long term sea level variability

The sea level can vary over long periods for several reasons :

- Water mass variations: water can be added to the ocean, either by increased rain over the ocean, or run-off from the rivers ; glaciers melting can also add water. On the other hand, more artificial reservoirs lead to a run-off decrease, and thus to less water being brought to the ocean. Increased evaporation can also decrease the water mass (as well as glaciations, as it happened during last Ice age, when sea level was about 100 m below the nowadays level).
- Temperature variations : water dilates when it warms, which leads to higher sea level. Among other facts, it leads to sea level seasonal variations, and also year-to-year variations related to climate events (e.g. El Niño). Temperature changes over longer time scale (global warming) have also an impact.
- Salinity variations: the saltier the water, the denser it is; thus saltier water will have a lower level. Salinity variations can occur by fresh water addition (increased run-off, rain, or ice melting), which decreases salinity, either by increased evaporation, or by glaciations, which increase salinity.
- Ocean circulation changes: changes in sea level can be due to changes in the ocean circulation. Over periods of ten years or more, the currents can shift position.

The different means of measuring sea level variations do not in fact observe exactly the same things: altimetry for total part (steric and mass), Grace for mass and glacial Isostatic Adjustment (GIA) parts, temperature/salinity profiles for steric, thermosteric (temperature only) or halosteric (salinity only) part and Tide gauges total plus ground movements (including glacial isostatic adjustment) of mean sea level.

In our work, we have been interested in Mediterranean sea level changes (total part) and their trends using altimetry and tidal data.

2.1 Sea level variations from altimetry

The Sea Surface Height (SSH), referenced to an ellipsoid, is composed of a variable oceanic part, the Absolute Dynamic Topography (ADT), and a geophysical constant the geoid. Its small scales are not known with enough accuracy to permit the separation of the two components of the SSH.

Consequently, SSH is decomposed into a Mean Sea Surface (MSS) and a Sea Level Anomaly (SLA), which takes into account the variation of height around the MSS due to the variability of the ocean currents (eddies, mean sea level change, tides, ...).

Thanks to the global, continuous and repetitive set of altimetric observations allowed by the successive launches of ERS-2, Topex/Poseidon, Jason-1, Envisat, GFO and Jason-2, the ocean MSS is now computed with a sub-centimetric precision for a spatial resolution less than thirty kilometers. This makes it easy to estimate with an improved quality the variable part of sea level (SLA) as SSH minus the MSS.

The SLA is generally used as precious and main indicator for development of scientific applications which aim to study the ocean variability (mesoscale circulation, seasonal variation, El Niño…).

2.2 Sea level variations from PSMSL tide gauges network

Sea level is monitored using tide gauge for different applications: control of the national levelling system, oceanographic studies, climate change, operational purpose, harbor operations, and navigation. Also and from the beginning of the altimetric missions, tide gauges have been used to estimate the reliability and accuracy of the satellite altimeter. The main advantages provided by tide gauges are the high precision of the data and the short sampling rate.

However, the sparseness of tide gauge records, especially with long term series, is until now a global issue. In this context, the Permanent Service of Mean Sea Level (PSMSL) was established in 1933 as the global data bank for long term sea level change information from tide gauges and bottom pressure recorders. The objective of the PSMSL is to collect, publish, analyze and interpret sea level data from the global network of tide gauges.

In our study, we aimed to use all monthly mean sea level (RSL), monthly time series from PSMSL database to extract the seasonal variability and the mean sea level trend in the Mediterranean Sea.

3. Used data

The data used in our study was collected from several sources in order to analyse sea level behavior in the Mediterranean Sea :

- Altimetry data: sea level anomaly (SLA) measurements from different satellites/ instruments (ERS-1/2, Topex/Poseidon, Jason-1, Envisat, GFO and Jason-2) are considered through the use of the merged products from AVISO Altimetry. AVISO regional delayed-time solutions for the Mediterranean Sea are used, with 1/8 x 1/8 degrees of latitude and longitude resolutions and spanning the period October 14, 1992 - July 22, 2009 with a sampling rate of seven days (one week). The SLA data is available on the AVISO ftp site : *ftp://ftp.aviso.oceanobs.com*

- Revised Local Reference (RLR): This data is derived from PSMSL results of analysis of the global network of tide gauges. The 80 PSMSL stations situated along the Mediterranean coastline are considered with a monthly spanning. The RLR datum at each station is defined to be approximately 7000 mm below mean sea level [7], this arbitrary choice made many years ago in order to avoid negative numbers in the resulting RLR monthly and annual mean values. The RLR data are available on the PSMSL site: *http://www.psmsl.org/*

- Sea Surface Temperature (SST): from NOAA optimum interpolation dataset version 2, with a spatial resolution of 1x1 degree and weekly spanning the period from 1990 to 2010. The OIv2 SST analysis uses in situ and satellite SST's plus SST's simulated by sea-ice cover. The OI analysis is carried out over all ocean areas and the Great Lakes. There is no analysis over land. The land values are filled by a Cressman interpolation (NOAA Website) to produce a complete grid for possible interpolation to other grids. The ocean and land areas are defined by a land sea mask. The SST data is available on the NOAA web site [6].

4. Analysis of the Mediterranean sea level changes revealed by satellite altimetry

4.1 SLA Seasonal variability

In order to extract the general patterns of the Mediterranean sea level behaviour, the weekly SLA averaged over the Mediterranean Sea were computed from the multimission weekly maps of delayed-time SLA. We obtained one SLA datum for each week. The obtained averaged SLA are shown in Fig.1.

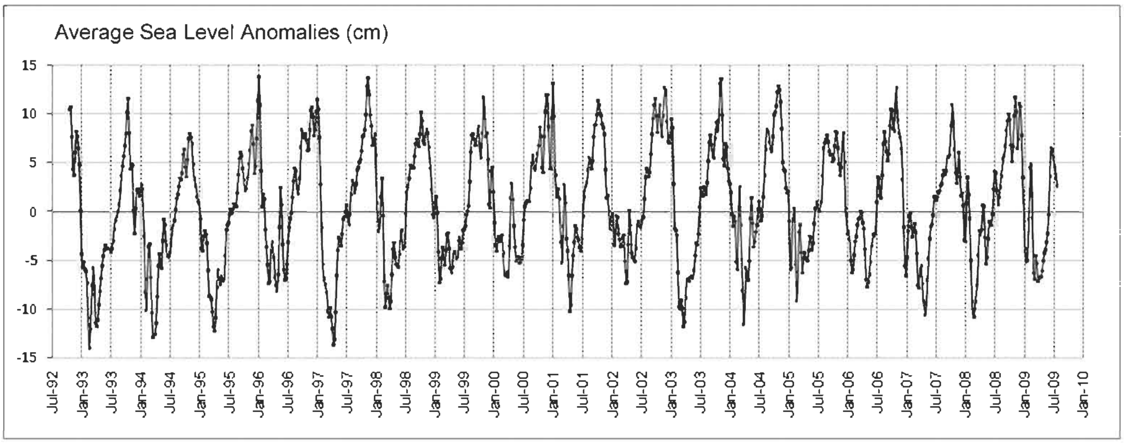

Fig. 1 Sea Level Anomalies averaged over the Mediterranean Sea.

It can be seen from the Fig.1 that the amplitude of Mediterranean mean sea level changes are large, it is around 15 cm, with a maximum in October-November, a decrease in January-February, and a minimum observed in March-April.

For the year 2008, the minima and maxima of the Sea Level Anomalies over Mediterranean Sea are observed in February 20, 2008 (averaged SLA of -10.79 cm) and November 05, 2008 (averaged SLA of -11.72 cm), respectively.

The Fig.2 illustrates the observed SLA situation in February 20, 2008 and November 05, 2008. The SLA occured in February 20, 2008 over the Mediterranean Sea which presents variations range of 40 cm. The averaged SLA value is about -10.79 cm. The lowest values of sea level are observed in the oriental Mediterranean Sea. When the mean sea level reached its maximum in November 05, 2008, the average SLA value becomes 11.71cm.

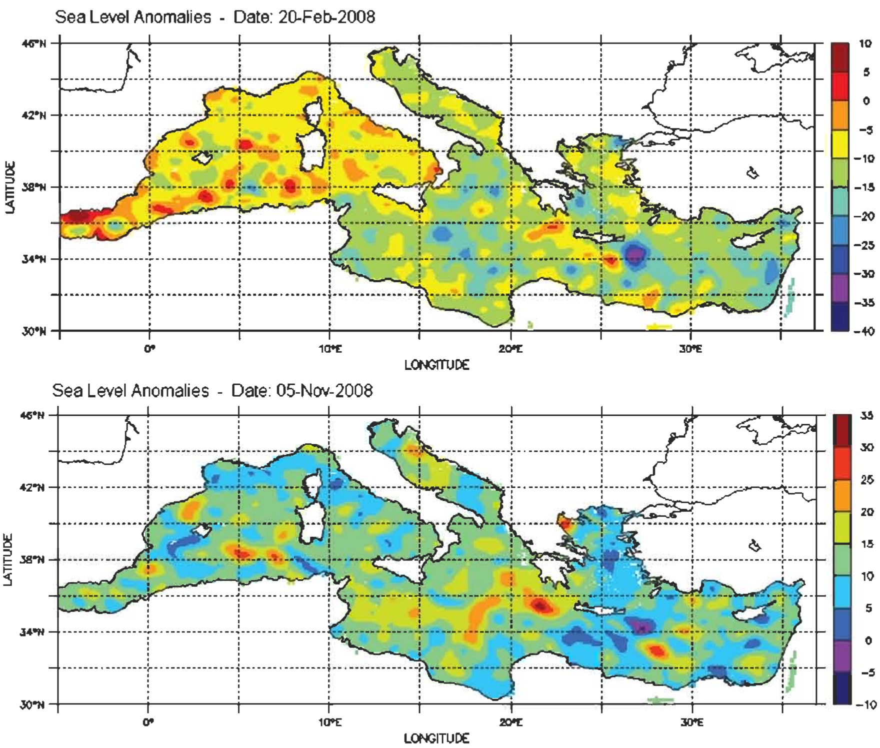

Fig. 2 Minima (20-Feb-2008) and Maxima (05-Nov-2008) of the Sea Level Anomalies.

In order to identify the periodic signals in the SLA, we have used the spectral density analysis (periodogram). The most important peak of the periodogram indicates the existence of a clear dominant annual signal in the Mediterranean sea level time series variations which is about 48.67 weeks (see Fig.3).

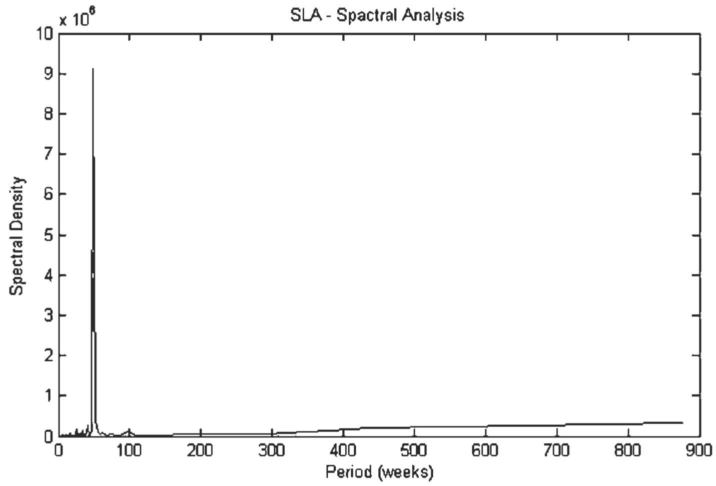

Fig. 3 Periodogram of Mediterranean sea level.

To illustrate the general seasonal variations of the Mediterranean mean sea level, monthly SLA are computed by averaging the weekly maps of delayed-time sea level anomalies over a same month from January 1993 to December 2008. We obtained one averaged data for each month.

As mentioned previously (periodogram analysis), the average SLA by month (Fig.4) shows the evident annual variability of the sea level over the Mediterranean Sea, where a minimum sea level occurs in March and maximum in October.

Half of this signal is due to steric effects, i.e. contraction and dilation of the surface waters resulting from heat fluxes at the ocean-atmosphere boundary layer. The remaining signal is probably due to an imbalance between the in-flow/out-flows at Gibraltar, evaporation and precipitation [1].

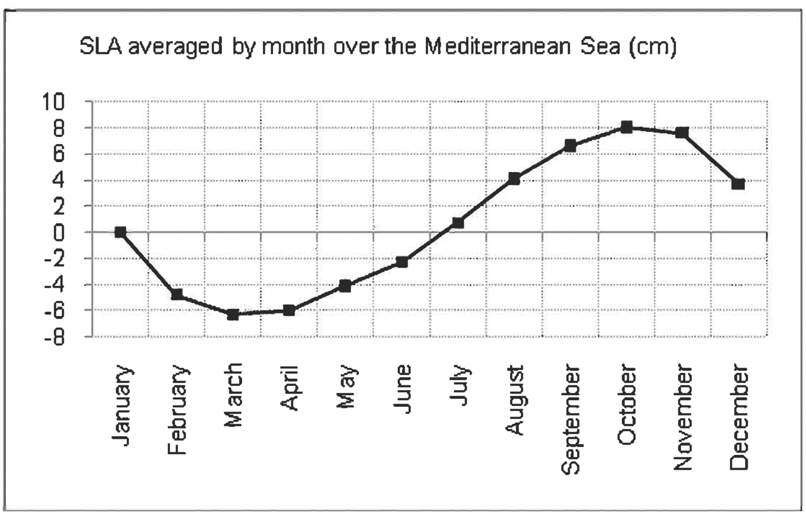

Fig. 4 SLA averaged by month from 1993 to 2008 over the Mediterranean Sea.

4.2 Mean sea level trends

AVISO regional gridded SLA delayed-time solutions for the Mediterranean are used in order to illustrate the sea level variations behavior. Each grid cell corresponds to SLA time series of 876 data (from October 14, 1992 to July 22, 2009).

A trend for each grid cell is computed under the simple linear regression model using DRLINE subroutine of the Microsoft IMSL Libraries. The obtained trends grid, with 1/8 x 1/8 degrees of latitude and longitude resolutions, is shown in Fig.5.

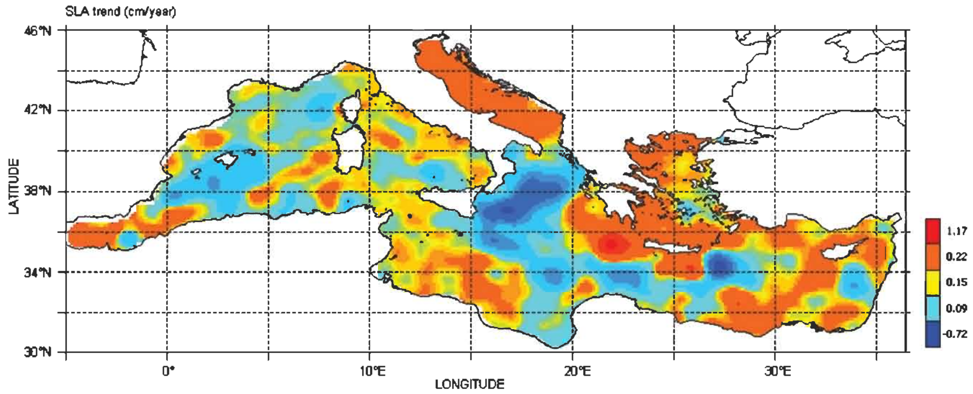

Fig. 5 Sea level trend from October 14, 1992 to July 22, 2009 over the Mediterranean Sea.

Through the Fig.5, the lowest sea level trend values appear in Ionian Sea (lowest value of -5.33 mm/year). Negative values are also observed in the middle of Balearic Sea (lowest value of -1.56 cm/year) and in the West of Levantine Sea (lowest value of -5.33 mm/year). The highest sea level trend appears in South-East of Ionian Sea and exhibits a value of 9.77 mm/year. The averaged variation of sea level trend is about 1.32 mm/year, that means an increase of Mediterranean sea level about 22.44 mm over the spanning period 1992-2009.

5. Response of sea level to the sea surface temperature

To analyse the sea surface temperature variations, the averaged SST over the Mediterranean Sea are computed. The obtained SST averages are shown in Fig.6.

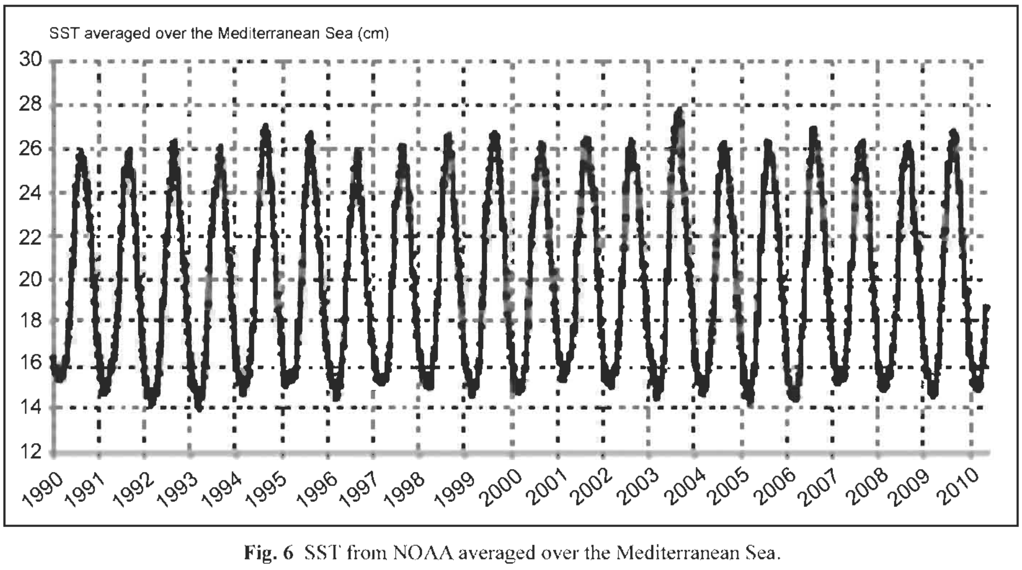

Fig. 6 SST from NOAA averaged over the Mediterranean Sea.

The SST (Fig.6) shows a uniform variations over the considered period (1990 to 2009) with a minimum value in end February (or in beginning March) and a maximum value in August. SST exhibits an average trend of 0.029 °C/yr which means an increase of approximately 0.59° C over the last 20 years. The biased value for the year 2003 (27 august, SST = 27.8° Celsius) corresponds to the exceptional heat wave which affected Europe. This extreme weather condition was caused by an anti-cyclone which stayed in Western Europe for more than 20 days during summertime.
The Fig.7 illustrates the differences in the sea surface temperatures around the Mediterranean Sea between the monthly mean values in August 2003 and the average sea surface temperatures in August from 1971 to 2000 (nominal SST value). It can be seen from Fig.7 that most sea areas have SST above the nominal value. In the Mediterranean Sea across the south of France through the west of Italy, the temperature values were 3 to 4 degrees Celsius higher than the average.

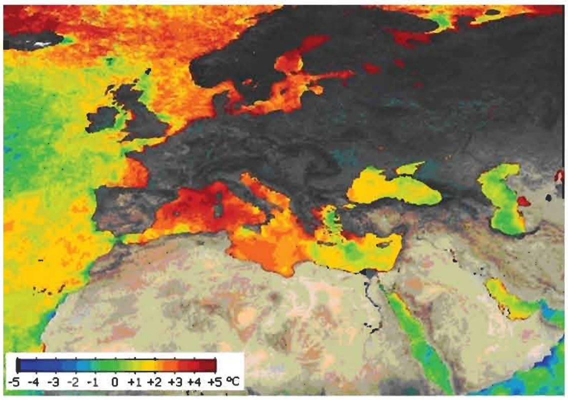

Fig. 7 Differences in the sea surface temperatures between the monthly mean values in August 2003 and the nominal value. Image source: Japan Aerospace Exploration Agency (http://www.eorc.jaxa.jp/)

It is known that changes in water temperature have an influence on changes in sea level. Water expands when heated, which causes an increase in its volume, and therefore a rise of sea level. However, it can be seen from Figs.1 and 6 a delay of two months between these two variables (a maximum SST value in August and a maximum SLA value in October-November), corresponding to the time required for the temperature to diffuse from the surface to the depths of the sea. So, there is no agreement between SST and temperature in the water sea indicating that the higher peaks in SST does not necessarily corresponds to the mean higher water absorption. Therefore, the oceans are able to respond in a few months to a few years to global warming.

6. Analysis of the Mediterranean sea level changes revealed by tide gauges

6.1 Seasonal variability

The seasonal variability has a close relation with climatologic conditions, such as wind and atmospheric pressure. To estimate this variability in Mediterranean Sea, the monthly RLR data of 9 PSMSL stations, which have a last reported data in 2008, are used: Tarifa and Ceuta (in Strait of Gibraltar), Malaga (in Alboran sea), Marseille (in Balearic Sea), Monaco-Condamine (in Ligurian Sea), Valletta (in Malta Chanel), Trieste (North in Adriatic Sea), Alexandroupolis and Khios (in Aegean Sea). An averaged value for each month is computed through three years (2006 to 2008).

The behavior of the seasonal variability is schown in Fig.8. The results are grouped by sea region according to their geographic location.

The seasonal variability in the Strait of Gibraltar and in the North Alboran Sea shows a gradual increase in the sea level between March and October. Then it begins to decrease until March. The ranges are about 15.8 cm, 13.7 cm and 19.9 cm for Tarifa, Ceuta and Malaga stations, respectively. In Balearic Sea and Ligurian Sea, the seasonal variability shows a gradual increase in the sea level between February and November. Then it begins to decrease until February. The ranges are about 13.5 cm for Marseille station and 14.1 cm for Monaco-Condamine station. The seasonal variability of sea level in Valletta station at Malta Chanel presents its minimum in February and its maximum in October, while the range of the variability is of 17.9 cm. In the North Adriatic Sea, the Trieste station presents an annual range of sea level variability of 13.7 cm. The lower value of sea level occurs in February and the higher in November.

The seasonal variability in the Aegean Sea presents its minimum in February and its maximum in August instead of October-November. The range of the variability is of 14.3 cm for Alexandroupolis Sea and 16.7 cm for Khios station.

Therefore, the behavior of the seasonal variability of Mediterranean sea level shows a decrease of sea level in the autumn and an increase between spring to summer seasons. The Lowest values occurs in February or March and the highest in October or November. However, Aegean Sea presents an exception in the maximum value of the sea level, which appears in August instead of October or November.

The range of the sea level variability is about 13.5 to 19.9 cm with an average value of 15.5 cm. Although the Mediterranean coastlines are more known for their weakness tides rather than for their intensity, these results show, against conventional ideas, that the tides exist well and truly along Mediterranean coastlines and engender averaged seasonal variability of 15.5 cm.

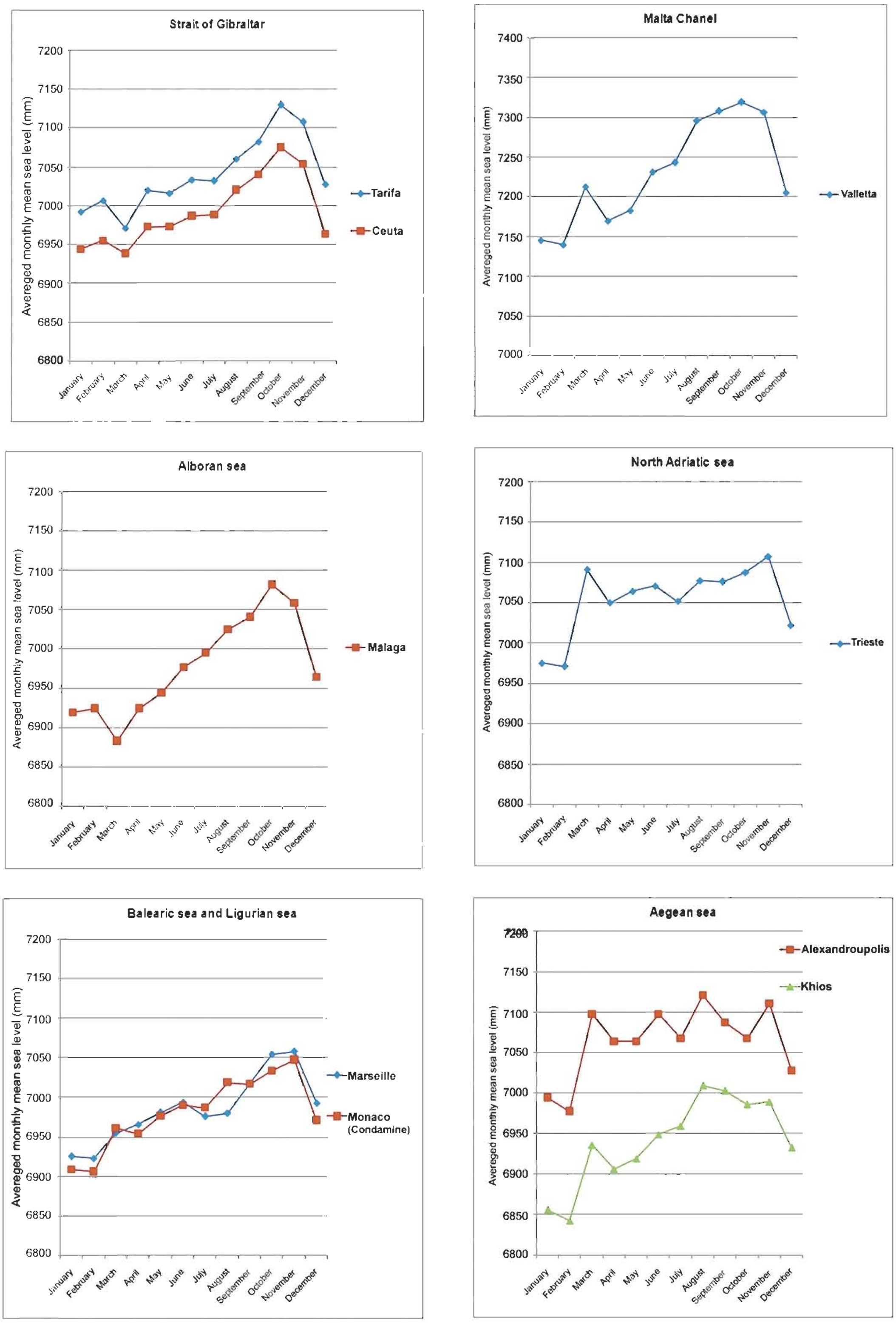

Fig. 8 Mean seasonal variability derived from PSMSL monthly RLR Data (2006 to 2008).

6.2 Mean sea level trends

Mean values of sea level in the monthly PSMSL RLR data have been employed to estimate the rate of change of sea level by a simple linear regression model using DRLINE subroutine of the Microsoft IMSL Libraries. Note, the trends were computed without any correction (land movements, unexplained instrumental datum shifts, etc.).

Table 1 gives the obtained trends at 80 stations situated along Mediterranean coasts. The columns of this table indicate: PSMSL country/station code, number of months of data used to compute the trend, range of used period in decimal format, trend slop and their standard error in mm/year, latitude and longitude in degree and station name. The stations are ordered in PSMSL country/station code order. This starts essentially from Strait of Gibraltar and progresses around the Mediterranean coastline in an eastward direction.

Table 1 shows a minimum trend slop value of -44.44 mm/year in Manfredonia/Italy station and a maximum trend slop value of 37.03 mm/year in Girne/Cyprus station. However, these two extreme values are uncertain, relatively to their important standard errors : 11.57 mm/year and 14.16 mm/year, respectively.

The important standard errors observed in the three recent tide gauge stations: Mellieha Bay/Malta (50.31 mm/year), Ploce/Croatia (19.47 mm/year) and Girne/Cyprus (14.16 mm/year), is due probably to the short range of used data : 12 months for Mellieha Bay station, 24 months for Ploce station and 27 un-continuous months for Girne stations.

In the RLR data analysis an averaged mean sea level trend for the Mediterranean sea of 1.61 mm/year is observed. This value is close to the average trend obtained from altimetric data analysis (1.32 mm/year).

Table 1. Mean sea level trends derived from PSMSL monthly RLR data.

PSMSL country / station	Number of used data	Range of data used	Trend slope (mm/year)	Std. (mm/year)	Latitude (°)	Longitude (°)	Station name
215/001	369	1961.5416-2008.9584	0.91	0.29	36.133331	-5.350000	Gibraltar
220/011	584	1943.5416-2002.7084	0.37	0.13	36.116669	-5.433333	Algeciras
220/021	734	1943.7084-2008.9584	0.59	0.20	36.000000	-5.600000	Tarifa
220/031	637	1944.0416-2008.9584	0.41	0.15	36.716667	-4.416667	Malaga
220/032	182	1992.5416-2007.9584	4.81	1.05	36.716667	-4.416667	Malaga II
220/041	225	1977.8750-1997.9584	0.32	0.74	36.833332	-2.483333	Almeria
220/046	111	1977.3750-1987.8750	-0.64	1.81	37.599998	-0.966667	Cartagena
220/051	376	1952.0416-1996.9584	-1.13	0.27	38.333332	-0.483333	Alicante I
220/052	442	1960.0416-1997.9584	-0.10	0.30	38.333332	-0.483333	Alicante II
220/056	142	1992.8750-2005.9584	14.16	2.00	39.466667	-0.333333	Valencia
220/061	176	1992.7084-2007.9584	6.05	1.31	41.349998	2.166667	Barcelona
220/081	144	1990.0416-2001.9584	5.58	1.85	42.049999	3.200000	L'Estartit
230/021	132	1996.0416-2008.9584	1.35	2.02	43.400002	3.700000	Sete
230/051	1449	1885.1250-2008.9584	1.20	0.05	43.299999	5.350000	Marseille
230/061	287	1961.0416-2008.9584	0.30	0.24	43.116669	5.916667	Toulon
230/081	321	1978.0416-2008.9584	2.23	0.41	43.700001	7.266667	Nice
232/001	52	2003.0416-2009.9584	10.5	4.92	41.916668	8.766667	Ajaccio
233/011	207	1956.0416-2008.9584	-0.36	0.20	43.733334	7.416667	Monaco (Condamine)
240/001	192	1896.0416-1913.9584	1.29	0.99	41.233334	9.366667	La Maddalena
240/011	433	1896.6250-1934.9584	1.93	0.28	39.200001	9.166667	Cagliari
250/001	309	1896.6250-1922.5416	1.57	0.45	43.866669	8.016667	Porto Maurizio
250/011	1071	1884.0416-1997.9584	1.21	0.06	44.400002	8.900000	Genova
250/031	304	1896.5416-1922.4584	0.71	0.47	42.049999	11.816667	Civitavecchia
250/041	263	1899.0416-1922.4584	2.72	0.52	40.866669	14.266667	Napoli (Arsenale)
250/051	301	1896.4584-1922.4584	2.53	0.47	40.866669	14.266667	Napoli (Mandraccio)
250/061	165	1951.0416-1967.9584	-2.51	1.29	38.099998	15.650000	Reggio Calabria
260/011	294	1896.4584-1922.4584	0.69	0.43	38.133331	13.333333	Palermo
260/028	139	1957.0416-1969.9584	12.32	1.85	36.666668	15.300000	Capo Passero
260/031	144	1960.0416-1971.9584	-2.45	1.59	37.500000	15.133333	Catania
265/001	222	1988.8750-2008.9584	6.12	0.97	35.900002	14.516667	Valletta

265/002	12	2000.2916-2001.2084	10.98	50.31	35.983334	14.350000	Mellieha Bay
270/006	72	1906.0416-1911.9584	-1.01	4.87	40.433334	17.266666	Taranto
270/011	48	1961.0416-1970.9584	-0.18	2.08	40.133331	18.500000	Otranto
270/019	35	1969.0416-1971.9584	-44.44	11.57	41.616669	15.916667	Manfredonia
270/026	75	1960.4584-1972.9584	-0.53	2.2	42.349998	14.400000	Ortona
270/030	62	1966.5416-1972.9584	-9.18	6.62	43.583332	13.483333	Ancona
270/035	45	1969.1250-1972.9584	-6.21	8.30	44.500000	12.283333	Porto Corsini
270/041	287	1889.0416-1913.9584	2.58	0.75	45.416668	12.350000	Venezia (Arsenale)
270/051	576	1872.0416-1920.6250	2.64	0.28	45.416668	12.333333	Venezia (S.Stefano)
270/054	1039	1909.0416-2000.9584	2.44	0.10	45.433334	12.333333	Venezia (Punta Della Salute)
270/061	1188	1905.0416-2009.9584	1.21	0.08	45.650002	13.750000	Trieste
279/002	344	1962.0416-1991.9584	-0.04	0.48	45.566666	13.750000	Koper
279/003	132	1992.0416-2003.9584	-0.20	2.42	45.566666	13.750000	Luka Koper
280/006	628	1955.4584-2007.9584	0.50	0.21	45.083332	13.633333	Rovinj
280/011	804	1930.0416-2007.9584	0.92	0.14	45.299999	14.533333	Bakar
280/013	161	1994.4584-2007.9584	0.72	1.55	44.116669	15.233333	Zadar
280/014	72	1983.0416-1988.9584	-0.64	3.99	44.083332	15.266667	Gazenica
280/017	65	1983.0416-1988.3750	6.98	4.74	43.700001	15.666667	Zlarin
280/021	666	1952.3750-2007.9584	0.62	0.18	43.500000	16.383333	Split Rt Marjana
280/031	646	1954.2084-2007.9584	0.41	0.19	43.500000	16.433332	Split Harbour
280/040	97	1983.0416-1991.4584	-6.33	2.59	43.066666	16.200001	Vis-Ceska Vila
280/046	222	1987.0416-2005.7084	5.55	0.97	43.133331	17.200001	Sucuraj
280/056	56	1987.0416-1991.6250	-18.11	6.34	42.750000	16.833332	Ubli
280/075	24	2006.0416-2007.9584	-2.05	19.47	43.049999	17.416668	Ploce
280/081	619	1956.0416-2007.9584	0.92	0.19	42.666668	18.066668	Dubrovnik
281/011	319	1964.5416-1991.0416	1.36	0.52	42.083332	19.083332	Bar
290/014	392	1969.0416-2006.9584	15.97	0.35	38.233334	21.733334	Patrai
290/017	435	1969.0416-2009.9584	1.68	0.27	37.633331	21.316668	Katakolon
290/030	181	1984.0416-2000.8750	2.71	1.26	37.950001	23.500000	North Salaminos
290/031	311	1969.0416-2002.9584	-5.75	0.54	37.933334	23.616667	Piraievs
290/032	46	1986.0416-1989.9584	-3.52	8.70	38.033333	24.000000	Rafina
290/033	233	1977.7084-2001.7084	-2.59	0.79	38.466667	23.600000	Khalkis South
290/034	433	1969.0416-2009.9584	0.02	0.32	38.466667	23.600000	Khalkis North
290/037	96	1999.7084-2009.9584	-2.16	3.36	39.116669	23.733334	Skopelos
290/051	442	1969.0416-2009.9584	3.62	0.30	40.616669	23.033333	Thessaloniki
290/061	406	1969.0416-2009.9584	-6.84	0.54	40.916668	24.416668	Kavalla
290/065	431	1969.0416-2009.9584	1.52	0.30	40.849998	25.883333	Alexandroupolis
290/071	433	1969.0416-2009.9584	3.37	0.28	38.383331	26.150000	Khios
290/081	282	1969.0416-2009.9584	4.13	0.39	37.433334	24.916668	Siros
290/091	388	1969.2916-2009.9584	0.69	0.27	37.083332	26.883333	Leros
290/097	374	1969.0416-2001.9584	-1.14	0.41	35.500000	24.049999	Soudhas
290/110	343	1969.2916-2008.6250	0.05	0.32	36.433334	28.233334	Rodhos
310/042	103	1995.0416-2004.9584	6.07	2.18	38.433334	26.716667	MENTES/IZMIR
310/046	182	1986.0416-2004.9584	3.02	0.99	37.033333	27.416668	Bodrum II
310/052	202	1986.0416-2004.9584	7.72	1.11	36.833332	30.616667	Antalya II
315/001	27	1938.7916-1940.9584	30.91	18.78	35.116669	33.950001	Famagusta
315/010	28	2000.8750-2003.8750	37.03	14.16	35.349998	33.333332	Girne
330/001	287	1923.0416-1946.9584	5.05	0.71	31.250000	32.299999	Port Said
340/001	750	1944.2084-2008.9584	0.50	0.11	35.900002	-5.316667	Ceuta
340/004	71	1944.0416-1949.8750	5.80	4.73	35.250000	-3.916667	Villa Sanjurjo

7. Conclusion

The analysis of AVISO regional delayed-time solutions data allowed us to characterize the trends of the mean sea level change in the Mediterranean Sea. The inter-annual mean sea level anomalies during 1992-2009 show large amplitudes around 15 cm, with a maximum in October-November, a decrease in January-February, and a minimum observed in March-April. The periodogram analysis applied to the sea level anomalies time series (1992 to 2009) indicates the existence of a clear dominant annual signal in the Mediterranean of 48.67 weeks.

However, the computed mean sea level trends using AVISO gridded SLA indicates an averaged variation of sea level of 1.32 mm/year. That means an increase of Mediterranean sea level about 22.44 mm over the spanning period 1992-2009.

The NOAA sea surface temperature data analysis during the period 1990-2009 over the Mediterranean Sea exhibits an average trend of 0.029 °C/yr which means an increase of approximately 0.59° C over the last 20 years (1990-2009). Furthermore, this analysis shows a response delay of sea level to SST variations of about two months. Therefore, the oceans are able to respond in a few months to few years to global warming.

Taking into account three years (2006 to 2008), the monthly PSMSL RLR data analysis of 9 stations (Tarifa, Ceuta, Malaga, Marseille, Monaco-Condamine, Valletta, Trieste, Alexandroupolis and Khios) indicate that the behavior of the seasonal variability of Mediterranean sea level shows a decrease of sea level in the autumn and an increase between spring to summer seasons. Lowest values occurs in February or March and highest in October or November. However, Aegean Sea presents an exception in the maximum value of the sea level, which appears in August instead of October or November.

These results show that the seasonal scale, the mass of the Mediterranean Sea is not totally preserved. The regular followed of the average level and consequently the balance in water of the Mediterranean Sea will be a precious indicator of possible climatic changes in the Mediterranean basin.

Sea level in the long-term monthly PSMSL RLR data of 80 stations situated along Mediterranean coasts have been employed to estimate the rate of change of Mediterranean sea level. An average mean sea level trend of 1.61 mm/year is observed. This value is close to the average sea level trend obtained from altimetric data analysis (1.32 mm/year).

Finally, we should hold the necessity to establish a tide gauges network along North African coasts, where we have no data. This network, once established, will be an important tool for sea level studies in this area.

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