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Climatological Trend of Sea Surface Salinity Anomalies in the South Eastern Mediterranean Sea

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Abstract. Linear and quadratic regressions have been used to investigate the relationship between SSSA and time to get the general SSSA possible trends using a series of observed data of 63 years, for a limited geographic area (South Eastern Mediterranean Sea). The results reveal a very slight increase of SSSA (salinification) with time of $\simeq$0.161/63 years (1948-2010) *i.e.* ~0.0026/yr. The quadratic regression trend of the mean monthly SSSA has a parabola form. It shows a decrease in SSSA in the period 1948 to 1980 then increasing forward. Both negative ($SSSA^-$) and amplitude SSSA are developed in summer and early autumn, with maximum value during August (-0.63 and 0.98 respectively). As for positive SSSA, the mean $SSSA^+$ shows a slight development, with highest values in August (0.33). Generally, there is an active period extended from July to October. The annual distribution of SSSA shows some years with developing positive anomaly such as 1961, 1964, 1984 and 2006, while 1959, 1971, 1987 and 1991 can be considered as years of developing negative anomaly. It is to be mentioned that the development of annual anomaly can be attributed to large individual value in a limited period of the year such as 1964^+ and 1971^- or lower values extend for many months such as 2006^+ and 1996^-.

Keywords: Mediterranean, Physical Oceanography, Sea surface salinity anomaly, Trend.

Introduction

The study of sea surface temperature -and salinity- anomalies (SSTA & SSSA) is fairly essential for solving many metrological and oceanographic problems (Heburn, 1985). The duration and wide occupation of that anomaly gives the reason to study it as one of the main factors affecting climatic system of the earth (Fedrouich, 1985 and Levitus, 1995). Also the study of Sea Surface Salinity Anomaly (SSSA) has the same importance due to the temperature-salinity interaction. Levitus (1989) studied the temporal variability of salinity in the upper layer for the North Atlantic Ocean and concluded that the northern portion of the subtropical gyre (nearly at the same latitude of the present area under study) increased in salinity as much as 0.4%. Millot (2007) stated that the Atlantic water, in the extreme western Mediterranean Sea, has encountered a huge salinification (~0.05/yr).

In their work about the mechanisms behind salinity anomaly signals of the North Atlantic, Sundby and Drinkwater (2007) stated that typical feature of the ocean is the large amplitude of inter-annual to decadal-scale variations compared to the multi-decadal and centennial-scale variations. Maiyza & Kamel (2009) support the suggestion of oscillating sea surface temperature (SST) with time rather than continuous increasing due to the so-called global warming. The cycle of that oscillation must have a period that may reach to centuries. Marullo *et al* (2007) and Salat & Pascual (2007) suggested both increasing and oscillating of the mean sea surface temperature (SST) with time. Maiyza (1984) and Maiyza *et al* (1995) studied the Long term variation of water temperature in the eastern and western Mediterranean Sea. Time distribution of SSTA values display both positive and negative cycles. The periods of these cycles fluctuated between 8 and 15 years. These cycles are nearly associated with the 11 year cycle of sun-spots activities (Maiyza *et al.*, 2010).

In this paper, the Linear and quadratic regressions have been used to investigate the relationship between SSSA and time (months) to get the general SSSA possible trends (increasing or decreasing sea surface salinity). The long period trends in series of SSSA are used as an indicator of salinity change regardless the present propaganda concerning increasing or oscillating of climate parameters. The work will depend on analyzing series of observed data (63 years) for a limited geographic area (South Eastern Mediterranean Sea).

Data and Method of Analysis

The area under study is the south eastern Mediterranean Sea in front of the Egyptian Mediterranean coast (the southern part of the Levantine

Basin). It lies between Egyptian northern coast - 33°N and 25 - 34°E (Fig. 1).

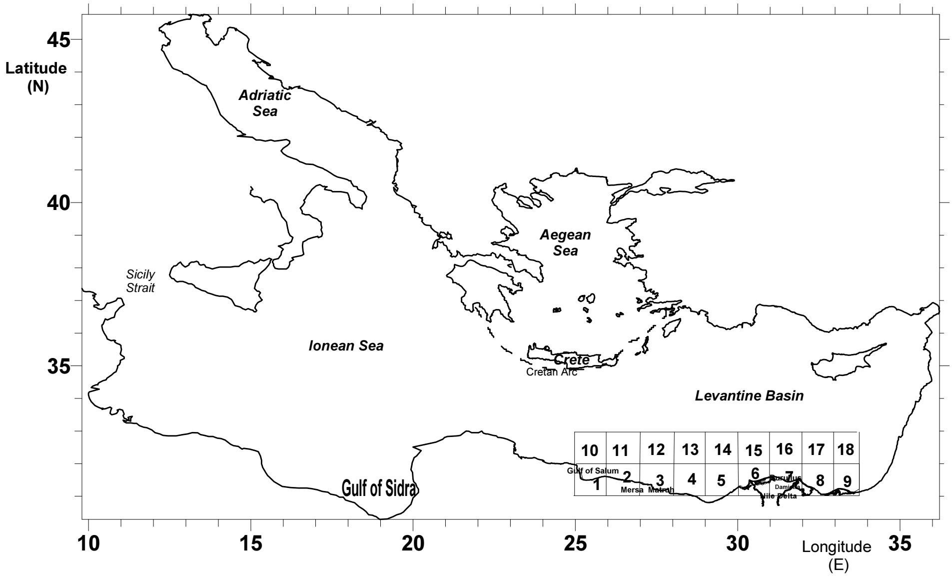

Fig. 1. Area of investigation in the south eastern Mediterranean Sea.

The vertical mean salinity of the upper 20m layer is considered as SSS. The monthly mean sea surface water salinity (S) is calculated for each 1°x1° grid 18 grids, (Fig. 1) for every individual month in the period from April 1948 to April 2010 using the available historical WDC-A (Washington D C), WDC-B (Moscow) and Egyptian National Oceanographic Data Centre (ENODC) Data files. The mean monthly Sea surface salinity (S**) is obtained from the Climatological Atlas of the Mediterranean Sea (Maiyza *et al.,* 1993). The monthly deviation from the mean (ΔS_m) is computed and considered as monthly SSSA for every grid.

$$\Delta S_m = S - S^{**} \qquad (1)$$

The mean monthly SSSA of all grids is considered as the monthly SSSA of the area under study.

Linear and quadratic regressions have been used, on the calculated mean monthly SSSA to investigate and model the relationship between SSSA (y) and time (t) to get the SSSA possible trends through the period of investigation. The two regression equations for the long-term tendency of a SSSA series to rise or fall (upward trend or downward trend) are calculated and presented.

The mean monthly positive and negative SSSA segment through the investigated period are determined, from which the SSSA amplitude (signal) are calculated using the following equation:

$$\text{Amplitude} = \text{SSSA}^{+} + |\text{SSSA}^{-}| \qquad (2)$$

Results and Discussion

The linear regression relationship between mean monthly SSSA with time for the period of investigation is shown in Fig. 2. The result reveals a trend of general very slight increase of SSSA, and consequently SSS, with time in the order of $\simeq$0.161/63 years (1948-2010). It seems that the South Eastern Mediterranean Sea has encountered some kind of salinification ($\simeq$0.0026/yr). This value is considerably lower than the values $\simeq$0.0093/yr and $\simeq$0.05/yr presented by Levitus (1989) and Millot (2007) respectively. The present value ($\simeq$0.0026/yr) may be more reasonable since it depends on a longer period and limited area besides the anomalies is calculated for a 1^{o}x1^{o} grid rather than 5^{o}x5^{o} grid.

The linear model for the mean monthly SSSA trend has the form:

$$y(t) = -0.134451 + 0.000144651\, t \qquad (3)$$

Where: t(1 – 745) = t(April, 1948 – April, 2010).

The linear mode shows a trend of continuous increase of SSSA with time and consequently SSS when applying the reverse of Equation (1) in the form:

$$S = \Delta Sm + S^{**} \qquad (4)$$

Figure 3 shows the quadratic regression and model the relationship between ΔSm and ΔSa respectively with time (month) for the period of investigation.

The present linear trend agrees with that of the Global Monitoring and Forecasting Center (Fig. 4) for the Mediterranean Sea and the works of Levitus (1989) and Millot (2007) with some differences in magnitude.

The quadratic model for the mean monthly SSSA trend has the form:

$$y(t) = 0.0499328 - 0.000927544\, t + 1.257733E\text{-}06\, t^{2} \qquad (5)$$

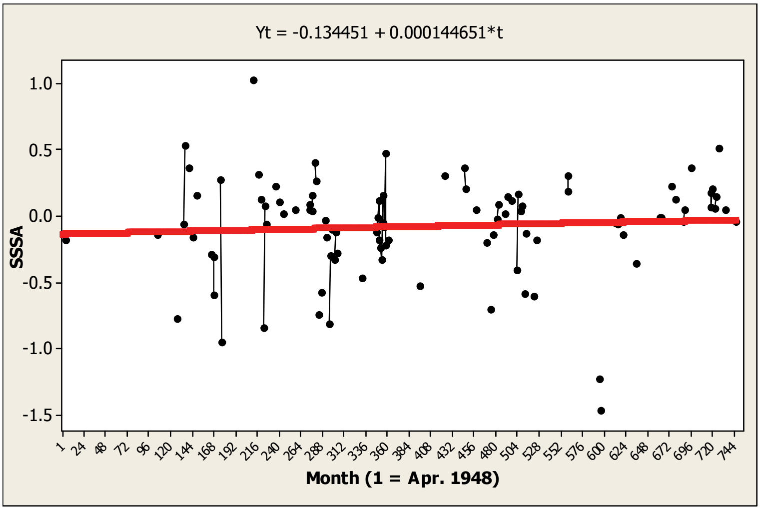

Fig. 2. Linear trend analysis plot for onthly SSSA.

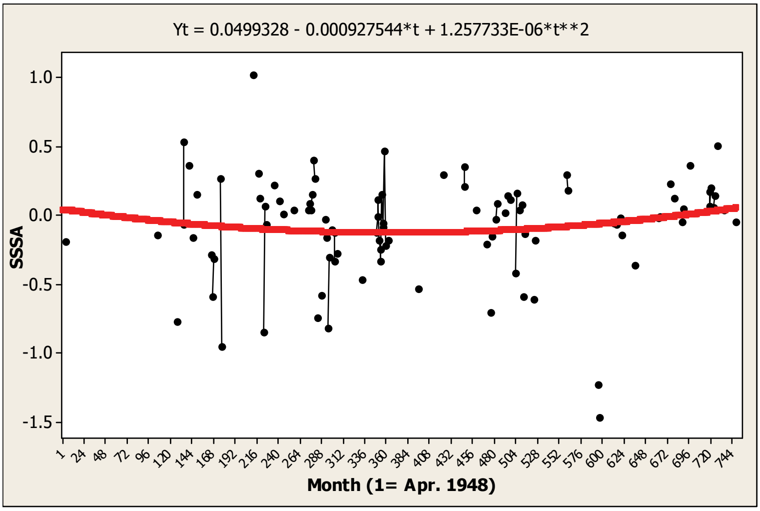

Fig. 3. Quadratic trend analysis plot for monthly SSSA.

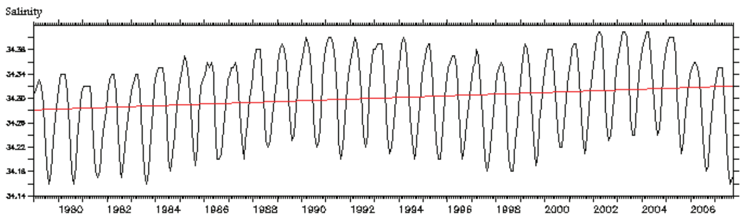

Fig. 4. Evolution of the salinity monthly mean over the last 30 years (psu-model/black - regression/red), *(Global Monitoring and Forecasting Center*).

The quadratic regression trend of the mean monthly SSSA has a parabola form. It shows a decrease in SSSA, and consequently SSS, in the period 1948 to 1980 then increasing forward.

The SSSA linear mode indicates the reverse SSTA trend while the quadratic regression has nearly the same for that of SSTA presented by Maiyza & Kamel (2009). This can be attributed to the horizontal displacement or/and vertical convection induced by thermohaline effect on surface water density (Maiyza, 1984).

The monthly distribution of positive, negative and amplitude SSSA are shown in Fig. 5. Both negative (**SSSA$^-$**) and amplitude SSSA are developed in summer and early autumn besides the month of December, with maximum value during August (-0.63 and 0.98 respectively). As for positive SSSA, the mean **SSSA$^+$** shows a slight development, with highest values in August (0.33). Generally, there is an active period extended from July to October.

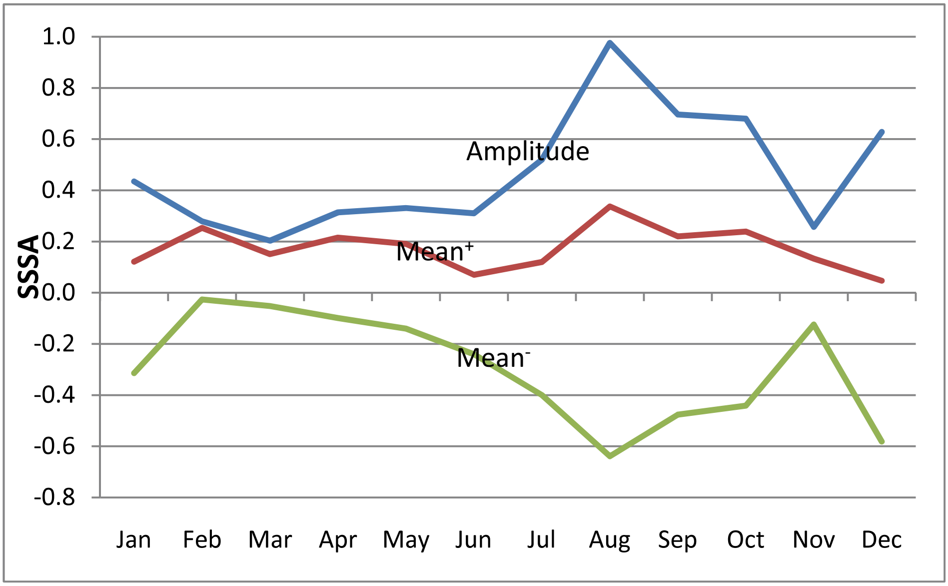

Fig. 5. Monthly distribution of positive, negative and amplitude SSSA.

The annual distribution of SSSA are illustrated in Fig. 6 showing some years with developing positive anomaly such as 1961, 1964, 1984 and 2006, while 1959, 1971, 1987 and 1991 can be considered as years of developing negative anomaly. It is to be mentioned that the development of annual anomaly can be attributed to large individual value in a limited period of the year such as 1964^{+} and 1971^{-} or lower values extend for many months such as 2006^{+} and 1996^{-}.

Summary and Conclusions

Linear and quadratic regressions have been used to investigate the relationship between SSSA and time (months) to get the general SSSA possible trends (increasing or decreasing sea surface salinity). The long period trends in series of SSSA are used as an indicator of salinity change regardless the present propaganda concerning increasing or oscillating of climate parameters. The work depends on analyzing series of observed data (63 years) for a limited geographic area (South Eastern Mediterranean Sea).

The results reveal a linear trend of general very slight increase of SSSA (salinification) with time in the order of $\simeq$0.161/63 years (1948-2010) *i.e.* $\simeq$0.0026/yr. This value is considerably lower than the values $\simeq$0.0093/yr and $\simeq$0.05/yr presented by Levitus (1989) and Millot (2007) respectively. The present value ($\simeq$0.0026/yr) may be more reasonable since it depends on a longer period and limited area besides the anomalies is calculated for a 1^{o}x1^{o} grid rather than 5^{o}x5^{o} grid.

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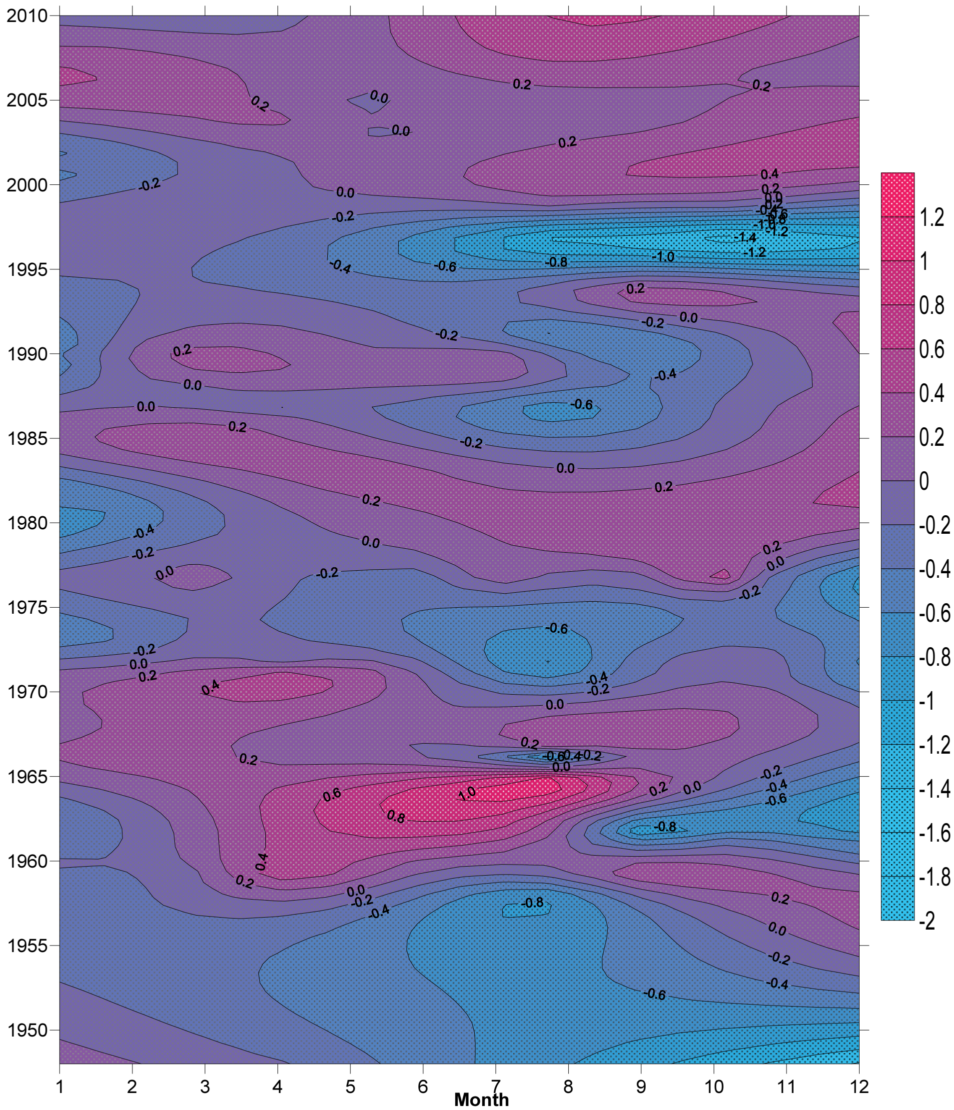

Fig. 6. Annual distribution of SSSA.

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اتجاه حيود ملوحة المياه السطحية في جنوب شرق البحر المتوسط

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المستخلص. استخدم التدرج الخطى والتربيعي الإحصائي لدراسة العلاقة بين المتوسطات الشهرية لحيود ملوحة المياه السطحية مع الزمن للحصول على اتجاه الانحدار العام لهذه المتوسطات (زيادة أو نقصان أو ثبات). وأعتمد هذا العمل على تحليل بيانات 63 سنة ميلادية بدءًا من أبريل ١٩٤٨ وحتى أبريل ٢٠١٠م لمنطقة محددة وهى جنوب شرق البحر المتوسط أمام الساحل المصري بعيدا عن الجدل المثار حاليا عن ارتفاع أو تذبذب العناصر الجوية والبحرية. وقد اتضح من التدرج الخطى أن هناك ارتفاعاً في قيم ملوحة المياه السطحية مع الزمن بمقدار ٠,١٦١ خلال الثلاث وستين عاما أي حوالي ٠,٠٠٢٦/عام. وقد أظهر الانحدار التربيعي أن هناك تذبذباً في قيم الملوحة للمياه مع الزمن وأنها ليست زيادة مستمرة, وقد يتعدى زمن التذبذب الثلاث وستين عاما بكثير، وربما يصل إلى قرون. وقد كانت فترة الصيف وبداية الخريف اكبر فترة لنمو الحيود الملحي السالب والعام. أما الحيود الموجب فلم يظهر نمواً محدداً بفترة. وعلى كل فإن شهر أغسطس هو شهر أكبر حيود بصفة عامة. كما لوحظ أن أسباب الحيود داخل السنوات الشاذة أما أن يكون لقيم كبيرو لفترة محددة أو قيم أقل لفترات طويلة.