

Long-term changes in sea surface temperature (SST) within the southern Levantine Basin

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Received 30 November 2019; accepted 16 January 2020

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Abstract

Knowledge of sea surface temperature (SST) behaviour is vital for long-term climate scenarios. This study highlights essential outcomes about the distinguishable and unsurprising warming of the SST along the southern border of the Levantine Basin. The analysis is based on monthly SST data for the period 1948–2018. The southern Levantine Basin has undergone SST increase, during the last 71 years. In this study, a consistent warming trend has been found for the analysed SST data series, with a rate of 0.04°C/a, i.e., 0.4°C/(10 a). From 1975 to 1991 the mean annual SST was 17.1°C, and this increased to be 19.2°C, over the period 2002–2018. Results revealed two opposite trends of variability: a decreasing trend (−0.06°C/a) over the period 1975–1991, and an increasing trend (0.2°C/a) from 2002 to 2018. Over the period 1948–2018, positive mean annual SST anomalies had an average of 1.8°C, and negative anomalies had an average of −1.1°C. The lowest SST total increase was found from January to April, with values about 0.03°C, while the highest warming appeared from June to September. The driving mechanisms behind the SST changes need to be more investigated, to understand the future trends and impacts of climate change in the Levantine Basin.

Key words: Mediterranean Sea, Levantine Basin, sea surface temperature, anomaly, trends, warming

Citation: El-Geziry Tarek M. 2021. Long-term changes in sea surface temperature (SST) within the southern Levantine Basin. *Acta Oceanologica Sinica*, 40(3): 27–33, doi: 10.1007/s13131-021-1709-2

1 Introduction

Researchers have been intensively examining the various impacts of climate change on both biotic and abiotic bases (Sakalli, 2017). Studies on climate change highlighted worldwide warming as a direct result caused by anthropogenic activities since the starting of the industrial revolution. Results revealed a 0.3–4.8°C increment in the global surface temperature up to the year 2100 (Collins et al., 2013). This increase is detected on both the terrestrial and the aquatic ecosystems. Globally averaged sea surface temperature (SST) will probably increase in the near-term projection and on the extended long-term scale in all scenarios even if a reduction in or a control on the greenhouse gas emissions is fulfilled (Collins et al., 2013; Kirtman et al., 2013).

The huge storage of thermal energy in oceans (~93%) has led to an increase in the SST worldwide, and in a rise in the global sea level (IPCC, 2013). Also, variations in the SST encompass a solid interaction with the carbon biogeochemical cycle between the atmosphere and marine environment. This can be observed in a wide range of processes, e.g., the increase in the SST is associated with a decrease in pH, which is directly subjective to water temperature (Feely et al., 1988), the mixing of atmospheric CO₂ and its absorption capacity into the seawater (Bricaud et al., 2002), the primary production in the marine ecosystem (Gregg et al., 2003; Arrigo et al., 2008; Demarcq, 2009), and together with variations in the sea surface salinity, it may modify the thermohaline circulation in the oceans (Pisano et al., 2020). Moreover, the increase in the SST is strongly expected to result in more severe storms on the long-term projections, and in intensive extreme precipitation events as well as heatwaves (Collins et al.,

2013; Pastor et al., 2018).

The Mediterranean Sea (Fig. 1) is a semi-enclosed basin connected to the Atlantic Ocean through the Strait of Gibraltar in its western extremity. The Basin is divided into two major sub-basins: the western Mediterranean Sea and the eastern Mediterranean Sea. Four sub-seas are identified within the eastern Mediterranean Sea: the Ionian, the Adriatic, the Aegean, and the Levantine Basin. The Ionian Sea occupies the area between Italy and Greece (north), and Libya and Tunisia (south), with a maximum depth of about 5 000 m south of Greece (Millot and Taupier-letage, 2005). The Adriatic is stretched latitudinally between two mountain chains, the Apennine and the Balkans (Russo and Artegiani, 1996), and is connected to the Ionian Sea by the Strait of Otranto, whose width is about 75 km and whose sill depth is about 800 m (Zavatarielli and Mellor, 1995). The Aegean Sea has a maximum depth of about 1 500 m with very irregular coastlines and topography (Kourafalou and Barbopoulos, 2003). It joins the Levantine Basin through several passages located between Greece, Turkey, Crete, and Rhodes. Lastly, the Levantine Basin has depths varying between 2 500–3 000 m in its central part, and its maximum depth is about 4 500 m in a depression located southeast of Rhodes Island (Horvat et al., 2003).

The upper 400 m in the Mediterranean Sea is characterized by temperatures varying between 15.0°C and 17.0°C in the winter season. In summer, the warming effect increases the Mediterranean SST (30–50 m) up to 28.0°C and a strong thermocline is developed (Millot and Taupier-Letage, 2005). The SST in the Mediterranean Sea is specified as a key factor for the observed heavy precipitation events, especially in its western basin (Pastor

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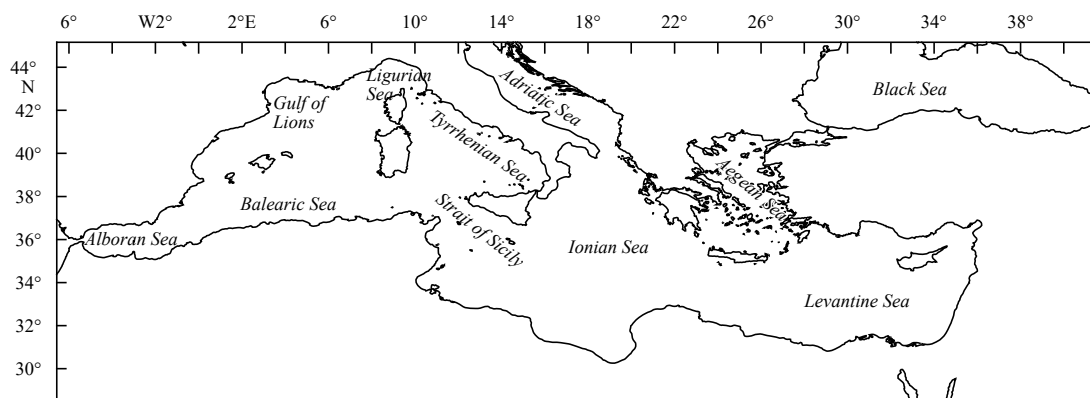


Fig. 1. The Mediterranean Sea and its distinctive sub-seas.

et al., 2018), and over central Europe (Volosciuk et al., 2016). On the other hand, other authors, e.g., Feudale and Shukla (2007) shed light on the role of the Mediterranean SST in the observed heat waves over central Europe. In recent years, many studies have examined the increasing SST in the Mediterranean Sea. Emeis et al. (2000) reported that the SST of the Mediterranean Sea varied between 12.3°C and 24.4°C over the last 16 000 years. Also, the annual average of the SST in the last glacier period showed a variation from 9°C to 19°C in the Mediterranean Sea as reported by Hayes et al. (2005). Based on field measurements, Rixen et al. (2005) reported an increase of about 0.5°C, over the period 1980–2000, in the upper 150 m of the Mediterranean Sea. Results revealed a general increase in the Mediterranean SST by 0.6°C in the two decades (1985–2005, Marullo et al., 2007). The same trend of temperature increase, extended to sub-layers of the Mediterranean Sea has been confirmed through a thermohaline investigation, between 2000 and 2006 (Poulain and Barbanti, 2007). Increasing SST rates of 0.03°C/a and 0.05°C/a were reported for the western and eastern Mediterranean sub-basins, respectively, between 1985 and 2006 (Nykjaer, 2009). Belkin (2009) estimated a high increase of 1.4°C in the Mediterranean Sea between 1978 and 2003. Skliris et al. (2012) derived an increasing SST rate of about 0.04°C/a for the Mediterranean Sea from 1985 to 2008. The same rate was reported by Pastor et al. (2018) for the Mediterranean Sea over the period 1982–2016 and by Mohamed et al. (2019) for the period 1993–2017. Shaltout and Omstedt (2014) analyzed the change and anomalies of the remote sensed SST in the Mediterranean Sea over the period 1986–2005, and concluded an approximately 0.24°C temperature increase in the Mediterranean Sea per decade, with a general change in the SST in the whole Mediterranean Basin from 13.8°C to 22°C.

The Levantine Basin is one of the major eastern Mediterranean sub-seas. It is bordered by the Cretan Archipelago and the Asia Minor to the north, the Middle East to the east, and the north-eastern Africa to the south. The Levantine Basin is connected with the Ionian Sea to the west through the Cretan passage of 300 km width and more than 2 000 m depth between the Cretan and Libyan coasts. The sea is connected northwest to the Aegean Sea through three passages between the islands of Crete and Karpathos, the islands of Karpathos and Rhodes, and Rhodes and Turkey (Tchernia, 1980; Özsoy et al., 1989; Alhammoud et al., 2005). The Levantine Basin is characterised by strong seasonal SST variations (Samuel-Rhoads et al., 2013). The general behaviour of the SST distribution in the Levantine Basin reflects an NW-SE increase in autumn and winter, and an increase W-E in

spring (Shaltout and Omstedt, 2014). In summer, the SST has a meridional increase (W-E) in the western Levantine Basin and a zonal increase (N-S) in its eastern region (Shaltout and Omstedt, 2014). Along the Egyptian Mediterranean coast, the southern border of the Levantine Basin, variations in the SST was previously examined by Maiya and Kamel (2009) over the period 1948–2008. Their results revealed a trend of general decrease in the SST with a rate of $-0.05^{\circ}\text{C}/\text{a}$. Maiya et al. (2010) evaluated the regular formation of SST anomaly (1948–2008) off the Egyptian Mediterranean coast. They determined 21.41%, 32.9% and 45.69% occurrence for normal, positive and negative SST anomaly, respectively over the period of investigation.

In this paper, the SST inter-annual/decadal-scale variability in the southern Levantine Sea is analysed using an extended SST data set over 71 years (1948–2018). The paper consists of five sections including this introductory one. Section 2 describes the data and the applied approach of analysis. Results and discussion are displayed in Sections 3 and 4, respectively. Lastly, Section 5 is the derived conclusion from the present study.

2 Data and methods of analysis

The southern Levantine Basin is bounded by the Egyptian Mediterranean Coast stretching from Rafah (east) to Sallum (west) between longitudes 24°E and 35°E. The present area of investigation extends between latitudes 31°N and 33°N and longitudes 25°E and 34°E. The whole surface area is divided into 18 grids of $1^{\circ} \times 1^{\circ}$ each (Fig. 2).

According to Soloviev and Lukas (2006), Maiya et al. (2010, 2015), Güçlü (2013) and Sakalli (2017), the surface ocean layer is defined as the mean of the upper 20 m, where the SST is recordable.

To examine changes in the SST along the southern border of the Levantine Basin, SST records from all possible sources were used. This comprises data from the World Ocean Data Centres: A (Washington) and B (Moscow), the Egyptian National Ocean-

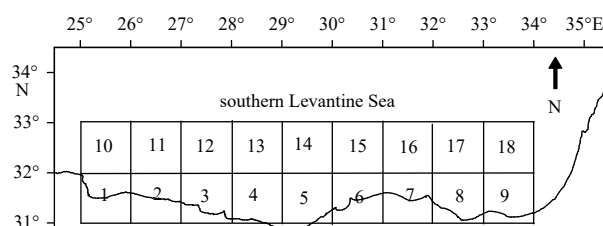


Fig. 2. The southern border of the Levantine Basin with the 18 grids of $1^{\circ} \times 1^{\circ}$ each.

graphic Data Centre (ENODC), and the Argo readings from buoys Nos 6900849, 6901889, 6901897, 6903175, 6903176 and 6903198, which entered the Egyptian Mediterranean territory. The data period extends from 1948 to 2018, i.e., 71 years. The applied grid-

ded data are on monthly basis with some gaps due to the well-known bad spatial and temporal *in-situ* data collection in the field of oceanography. The monthly availability for each year (1948–2018) is shown in [Table 1](#).

Table 1. Data availability over the study period (1948–2018)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1948				*	*	*	*	*	*	*	*	*
1949												
1950		*		*	*		*			*	*	
1951			*	*			*	*			*	*
1952	*			*	*	*	*	*	*	*		
1953												
1954		*		*	*	*					*	*
1955												
1956		*	*	*	*	*		*		*	*	
1957			*	*	*	*	*		*	*	*	*
1958	*	*	*	*	*		*	*	*	*	*	
1959		*	*	*			*		*			*
1960				*	*	*	*			*	*	
1961	*		*	*	*	*				*		
1962											*	
1963	*	*	*		*	*	*	*	*	*	*	*
1964												
1965		*		*			*	*	*	*		
1966		*		*	*	*	*	*	*	*	*	
1967		*		*	*	*	*	*				
1968	*	*	*		*	*	*			*	*	*
1969	*	*		*	*		*	*	*		*	*
1970		*	*	*	*	*			*	*	*	
1971	*	*	*	*	*			*	*	*	*	*
1972		*			*	*		*		*	*	
1973	*	*	*	*	*					*		
1974												
1975			*	*	*			*	*		*	
1976	*	*	*	*	*	*	*	*		*		*
1977	*	*	*	*	*	*	*	*	*	*	*	*
1978	*			*		*	*	*	*	*		
1979	*		*	*	*	*	*	*	*	*	*	*
1980	*	*	*			*					*	*
1981	*			*	*		*	*	*	*	*	*
1982	*	*	*	*		*	*	*	*	*	*	*
1983	*	*	*	*	*	*	*	*	*	*	*	*
1984	*	*	*	*	*	*	*	*	*	*	*	*
1985				*	*	*	*	*	*		*	*
1986	*	*	*	*	*	*	*	*	*	*	*	*
1987	*	*	*	*	*	*	*	*		*	*	*
1988	*	*	*	*	*	*	*	*	*	*	*	*
1989	*		*		*		*			*	*	
1990	*	*	*	*	*	*	*	*	*	*	*	
1991	*				*			*	*	*		*
1992												
1993	*	*	*	*	*	*	*				*	*
1994			*	*			*	*	*	*		
1995		*	*			*	*	*				*
1996	*	*			*			*	*			*
1997												
1998												

to be continued

Continued from Table 1

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1999				*	*	*	*	*	*			
2000												
2001												
2002	*	*	*	*			*	*				
2003			*		*							
2004				*					*	*		*
2005	*	*		*	*	*		*		*		
2006		*							*			
2007											*	*
2008	*			*	*			*				
2009			*									
2010				*								
2011											*	
2012		*	*	*	*	*					*	
2013	*											*
2014							*	*	*	*	*	*
2015	*	*	*	*	*	*	*	*	*	*	*	*
2016	*	*	*	*	*	*	*	*	*	*	*	*
2017	*	*	*	*	*	*	*	*				
2018	*	*	*	*	*	*						

Note: * means data available.

The region-average monthly and annual means were constructed from the monthly SST time series over the 71 years of investigation; to examine the decadal and inter-annual SST variabilities and their linear trends. Moreover, SST anomalies were calculated on an annual basis, and monthly SST anomaly trends were examined.

3 Results

The inter-annual SST variability along the southern border of the Levantine Basin over the 71 years of investigation is shown in Fig. 3. The linear trend of the mean annual SST reflects a general trend of increase over the investigated period with a rate of 0.04°C/a, i.e., 0.4°C/(10 a). This trend can be mathematically expressed by the following equation:

$$y = 0.044 1x - 69.672, \quad R = 0.48. \quad (1)$$

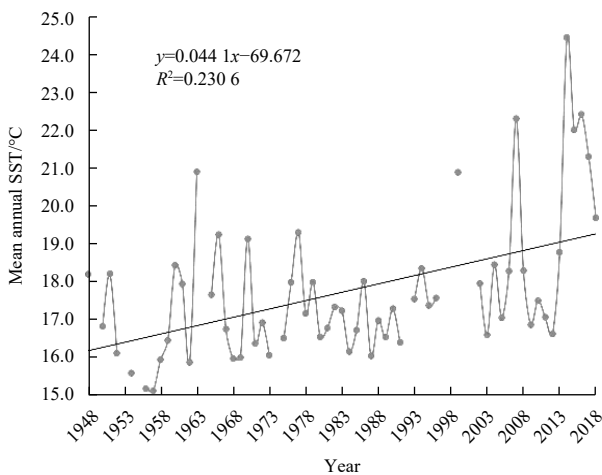


Fig. 3. Mean annual SST along the southern border of the Levantine Basin over the period of 1948–2018.

The 71 years of investigation comprises two continuous data sets of 17 years each, from 1975 to 1991 and from 2002 to 2018. These are examined to check variations in the trend of mean annual SST variations within the southern Levantine Basin. From 1975 to 1991 the mean annual SST was 17.1°C, and this increased to be 19.2°C, over the period of 2002–2018. This means a difference of 2.1°C between the two periods. Results revealed two opposite trends of variability. While the mean annual SST exhibited a decreasing trend over the period of 1975–1991 with a rate of -0.06°C/a, it displayed an increasing trend from 2002 to 2018 with a rate of 0.2°C/a. Figure 4 depicts the mean annual SST variabilities and their trends over the two periods of 1975–1991 (Fig. 4a) and 2002–2018 (Fig. 4b).

Figure 5 illustrates mean annual SST anomalies over the period of investigation. The largest mean annual SST anomaly was found in 2014 (6.7°C), whilst the lowest was found in 1965 (-0.1°C). The figure also illustrates that even with the pronounced positive mean annual SST anomaly from 2013 to 2018; there is an irregular pattern for these positive anomalies. One can also conclude an average of 1.8°C for positive mean annual SST anomalies and of -1.1°C for the negative ones.

The minimum, maximum and mean monthly SST within the southern Levantine Basin over the period of investigation are portrayed in Fig. 6. The minimum monthly SST was 12.7°C in January, whilst the maximum monthly SST was 27.9°C in August. The mean monthly SST fluctuated between 16.3°C in February and 19.4°C in August. The mean monthly SST reflects a seasonal variability with lowest mean values in winter/early spring and highest means in summer/early autumn.

Table 2 shows the statistical characteristics calculated in the present work for the southern coasts of the Levantine Basin (1948–2018) with those calculated by Shaltout and Omstedt (2014) for the whole Levantine Basin (1982–2012). Moreover, Table 3 displays the SST rates of increase on seasonal basis calculated in the present study and those calculated for the entire Levantine Basin by Shaltout and Omstedt (2014).

Examination of the monthly trends for the whole data series

(Fig. 7) revealed that the lowest SST total increase is found from January to April, with values about 0.03°C, while the highest warming appears from June to September, with almost twice the averaged mean anomaly of 0.05°C. The monthly SST trends in May, October, November and December are the closest to the monthly mean averaged anomaly trend.

4 Discussion

Warming of the Mediterranean Sea surface was estimated at 0.03°C/a for the period 1985–2005 (Marullo et al., 2007), at 0.05°C/a between 1978 and 2003 (Belkin, 2009), at 0.04°C/a from 1985 to 2008 (Skirris et al., 2012), from 1982 to 2016 (Pastor et al.,

2018) and over the period 1993–2017 (Mohamed et al., 2019). This warming was also reported by Shaltout and Omsted (2014) to be 0.24°C/(10 a); i.e., 0.024°C/a from 1982 to 2011. However, this warming is not homogeneous over the whole Mediterranean Basin. Increasing SST rates of 0.03°C/a and 0.05°C/a were reported for the western and eastern Mediterranean sub-basins, respectively, between 1985 and 2006 (Nykjaer, 2009). This rate has been raised to 0.04°C/a for the western sub-basin over the period 1982–2018 (Pisano et al., 2020). Factually, the regions of the Balearic Islands, the Northwest Ionian, the Aegean and Levantine Basin seem to get warmer than the average (Adloff et al., 2015). The Levantine Basin examined an SST rate of increase of

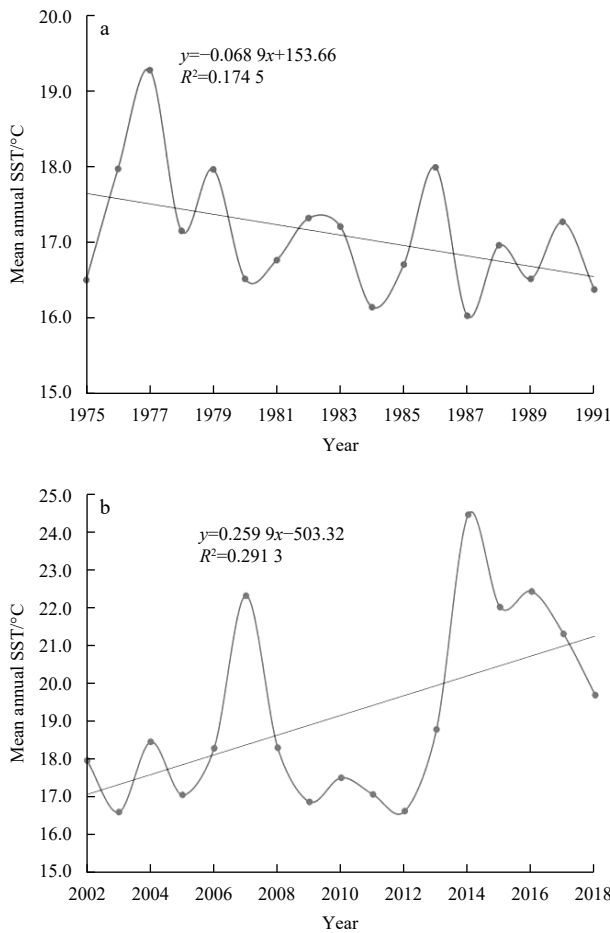


Fig. 4. The mean annual SST variabilities and their trends over the two periods of 1975–1991 (a) and 2002–2018 (b).

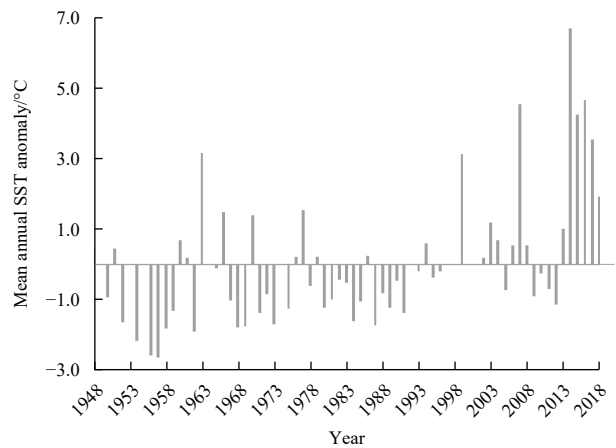


Fig. 5. Mean annual SST anomaly along the southern border of the Levantine Basin from 1948 to 2018.

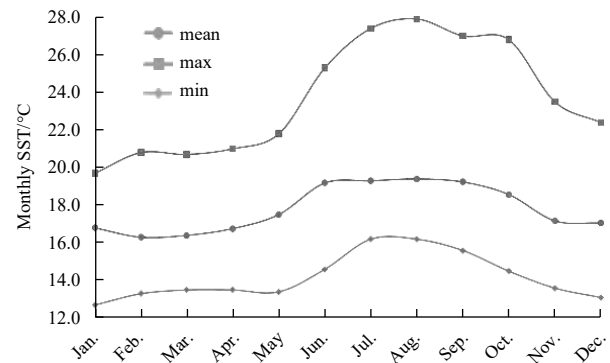


Fig. 6. Minimum, maximum and mean monthly SST within the southern Levantine Basin.

Table 2. Minimum and maximum SST in the Levantine Basin

	Winter		Spring		Summer		Autumn	
	Present work	Result of Shaltout and Omstedt (2014)	Present work	Result of Shaltout and Omstedt (2014)	Present work	Result of Shaltout and Omstedt (2014)	Present work	Result of Shaltout and Omstedt (2014)
Min. SST/°C	12.7 (1968)	16.1 (1993)	13.4 (1957)	19.1 (1987)	15.6 (1950)	25 (1984)	13.1 (1985)	20.8 (1988)
Max. SST/°C	20.8 (1963)	17.6 (2012)	25.3 (2016)	20.8 (2003)	27.9 (2015)	27.1 (2012)	26.8 (2015)	22.8 (2010)

Table 3. Seasonal SST rates of increase in the Levantine Basin

	Winter		Spring		Summer		Autumn	
	Present work	Result of Shaltout and Omstedt (2014)	Present work	Result of Shaltout and Omstedt (2014)	Present work	Result of Shaltout and Omstedt (2014)	Present work	Result of Shaltout and Omstedt (2014)
SST rate of increase/°C	0.022	0.028	0.030	0.031	0.020	0.041	0.032	0.038

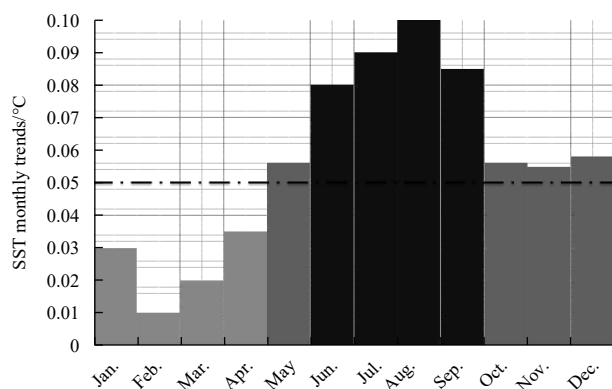


Fig. 7. Southern Levantine SST monthly trends of increase for the 1948–2018 of period.

0.03°C/a (0.3°C/(10 a)) concluded by Samuel-Rhoads et al. (2013) and of 0.04°C/a (0.4°C/(10 a)) concluded by Shaltout and Omstedt (2014). In contrast, Maiyza and Kamel (2009) concluded an SST decrease with a rate of $-0.003^{\circ}\text{C}/\text{a}$ in the southern region of the Levantine Basin from 1948 to 2008. In the present study, results revealed a rate of increase in the SST of $0.04^{\circ}\text{C}/\text{a}$. The difference between the SST rates of the different studies might be attributed to the differences in spatial resolution and origin of the datasets. The causes of this increasing SST rate within the southern Levantine Basin may be attributed to both natural and anthropogenic factors. While the former can be represented by variations in natural processes like evaporation and precipitation, the latter can be a direct result from the wide human-activity along the Egyptian Mediterranean coast, e.g., maritime trade through ports like Alexandria and Port Said, the international maritime traffic in the Levantine, the industrial activities in coastal cities such as Alexandria and Damietta, the resort activities in Al-Alamein and Mersa Matrouh, etc.

The present study has investigated two continuous sets of SST in the southern Levantine Basin, each of 17 years. The first set covers the period (1975–1991) and the second covers the period (2002–2018). Results revealed a decreasing SST trend over the period of 1975–1991 with a rate of $-0.06^{\circ}\text{C}/\text{a}$, and an increasing trend from 2002 to 2018 with a rate of $0.2^{\circ}\text{C}/\text{a}$. This latter is considered as an alarm for the warming process that might be examined by our aquatic ecosystem and the anticipated severe impact which accompanies this warming on both the fauna and flora of the basin. The decreasing rate of the first period is in agreement with the results of Maiyza et al. (2010) who concluded general negative anomaly behaviour of the SST in the southeastern Mediterranean Sea over the decade of 1980–1989.

This study examined seasonal variations in the SST in the southern Levantine Basin. The results are in good agreement with those seasonal rates calculated for the Levantine Basin by Shaltout and Omstedt (2014), except for the summer. This may be attributed to the missed annual data for this season in the present work (106 out of 213). In meanwhile, present results are generally consistent with the conclusions and the general patterns previously drawn for the seasonal SST in the Levantine Basin by Nykjaer (2009), Adloff et al. (2015) and Pastor et al. (2018). Within the present analysis, annual SST mostly shows high negative anomalies before 1998, and high positive anomalies afterward, which can point to a warming of the sea surface in the southern Levantine Basin. This result agrees with that achieved by Samuel-Rhoads et al. (2013) for the Levantine Basin

between 1996 and 2011. The common positive SST anomaly years reported in the two studies are 1999, 2002, 2003 and 2008. The present study adds the years of 2004, 2006 and 2007, in addition to the whole period of 2013–2018.

5 Conclusions

Variations in the sea surface temperature in the Mediterranean Sea and its sub-seas are influenced to a large extent by climate change. The present results revealed that the increase of the SST is about $0.04^{\circ}\text{C}/\text{a}$; i.e., $0.4^{\circ}\text{C}/(10 \text{ a})$ in the southern Levantine Basin of the Mediterranean Sea. This agrees with the results of previous rates calculated for the same basin. Fluctuations in inter-annual SST and anomalies appear particularly in the southern Levantine Basin SST from June to September. The importance of the present results stem from the wide operational activities that can be affected by the variations in the SST within the Levantine Basin, e.g., climate forecast and modelling, validation of atmospheric models, investigation of extreme events, tracking marine organisms and mammals, coastal management, fisheries management. The door remains open to reach an answer on whether inter-annual or decadal variations has the upper hand on the observed SST variations in the Mediterranean Sea and its sub-seas, which needs further investigation and research. Moreover, further work is strongly recommended to be performed to examine possible relationships between the SST variations and meteorological conditions (atmospheric pressure, air temperature and rates of precipitation) within the Levantine Basin; to update and consolidate our knowledge about climate and environmental changes, and the role of climate in this basin.

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