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On the Relationships between Sea Surface Temperature and Atmospheric Conditions over the Southern Levantine Basin

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ABSTRACT

This study provides comprehensive results on the relationship between sea surface temperature (SST) and the atmospheric parameters affecting the southern Levantine Basin, over the period 2007-2018. Such investigation is essential to understand the variations in both the ocean and the atmosphere. Over the study period, the SST showed an increasing trend with a rate of +0.3°C/yr. The mean annual SST was weakly correlated with the mean annual surface air temperature with a correlation coefficient of only +0.15, while the seasonal correlation coefficient between the two parameters was as strong as +0.91. There was a significant negative seasonal correlation (-0.71) between SST and air pressure. The inverse relationship between the SST and surface wind speed was revealed, with a correlation coefficient of -0.54. Meanwhile, there was a substantial seasonal correlation of +0.25 between the SST and wind directions. This study produced empirical relationships that can be applied within the southern Levantine Basin; to calculate SST from the surface atmospheric parameters on a seasonal basis. Results revealed that seasonal correlations between the SST and atmospheric conditions in the southern Levantine Basin are more reliable to investigate the SST changeability tied to these conditions than the annual ones.

INTRODUCTION

Oceans, land and atmosphere, are the three major components of the Earth's climate system. Understanding and then expressing the relationships between processes and components of these components is essential for creating climate model systems **(Gettelman and Rood, 2016)**. Naturally, the observed large-scale variations in the aquatic system occur on a monthly to multi-decadal time scales, compared to variations in the overlying atmospheric conditions **(Jaswal *et al.*, 2012)**. In the Mediterranean basin, the dominant atmospheric conditions greatly impact the surface hydrographic conditions; leading to excess in water loss and heat gain, and in the meantime to an increase in salinity and surface temperature compared to the neighboring Atlantic Ocean **(Malanotte-Rizzoli *et al.*, 2014)**. Thus, the Mediterranean is considered a 'hot spot' region expected to experience major climatic changes in the twenty-first century due to global still-uncontrolled greenhouse gas (GHG) emissions **(Mariotti, 2011)**. These emissions are anticipated to impact not only on the atmospheric parameters in the Mediterranean region, but also on the surface hydrographic properties of the basin, especially the sea surface temperature (SST). It is therefore essential to investigate the relationship between SST and the controlling atmospheric conditions; to understand the variations and the possible interconnections between the ocean and the atmosphere.

Within the Mediterranean basin, one can explore more than six major sub-basins, as depicted in Figure (1). The Levantine Sea is the southeastern most sub-basin of the Mediterranean Sea (Fig. 1). This sub-sea is enclosed between the Cretan Archipelago and Asia Minor northward, the Middle East eastward, and the north-east Africa southward. The Levantine is connected through the Cretan passage, of 300 km width and more than 2000 m depth, to the Ionian Sea to the west. It is also connected through three northwestern passages to the Aegean Sea, the islands of Karpathos and Rhodes, and to Rhodes and Turkey **(Tchernia, 1980; Ozsoy *et al*., 1989; Alhammoud *et al*., 2005)**. The importance of the Levantine Basin stems from being the region of formation of the Levantine Intermediate Water (LIW), which is formed by transformation processes (evaporation and cooling) and sinking of surface water in the Levantine Basin in the south-southeast area of Rhodes **(Lascartos *et al*. 1999; Schroeder *et al*. 2017)**. This water mass spreads from 150 to 600 m depth, and streams westward to invade the Atlantic Ocean through the Strait of Gibraltar **(Maiyza 1984; Millot and Taupier-Letage 2005)**.

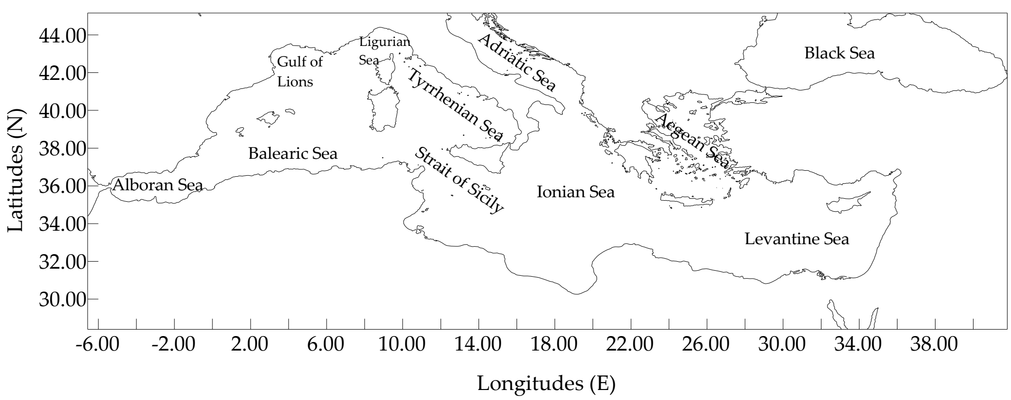

Figure 1. Basin of the Mediterranean Sea and its diverse sub-basins

The Levantine Sea is featured by its well-known seasonal SST variations **(Samuel-Rhoads *et al*., 2013)**. The general SST seasonal distribution in the Levantine reveals northwest to southeast (NW-SE) increase in autumn and winter, and an increase in a west to east (W-E) in spring **(Shaltout and Omstedt, 2014)**. In summer, the SST increases on both meridional (W-E) and zonal (N-S) scales, in the western and eastern Levantine, respectively **(Shaltout and Omstedt, 2014)**. Also, along its southern border, the

Levantine examines long-term variations in the SST **(Maiyza and Kamel, 2009; Maiyza *et al*., 2010; El-Geziry, 2021)**.

Although many authors have investigated the trends and behavior of variations in air temperature and SST in the Mediterranean, no one has focused or correlated the two variables along the southern region of its eastern basin. Therefore, the importance of this research stems from being the first to shed light on the relationship between the SST and not only the air temperature but also with the other two meteorological parameters impacting its variations, namely: atmospheric pressure and wind regime. The study represents the general distribution and investigates the relationship between the SST and atmospheric parameters (air temperature, surface atmospheric pressure and wind regime) within the southern Levantine basin, over the period 2007-2018.

MATERIALS AND METHODS

The Egyptian Mediterranean Coast borders the southern Levantine Basin, stretching from Sallum (west) to Rafah (east) between longitudes 24°-35°E. The area of examination latitudinally extends between 31° 00’ N and 33° 00’ N and longitudinally between 25° 00’ E and 34° 00’ E. The entire surface area is divided into 18 grids of 1° x 1° each, with five coastal meteorological stations distributed over the coastline, as shown in Figure (2).

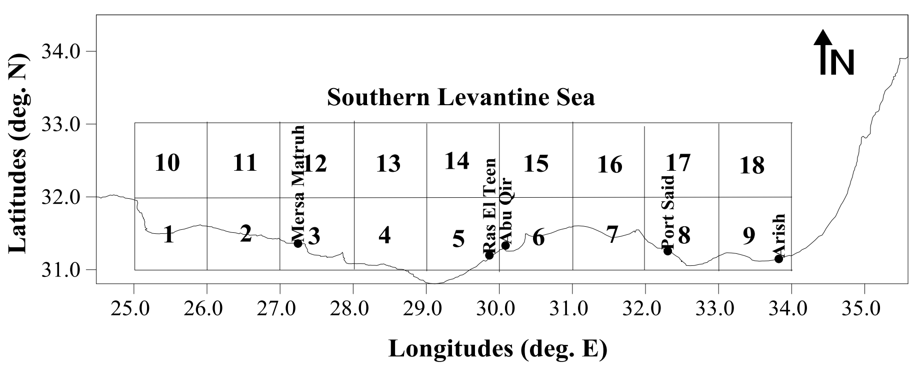

Figure 2. The gridded area of investigation and the five meteorological stations

The surface ocean layer is the mean of the upper 20 m, where the SST is recordable **(Soloviev and Lukas, 2006; Maiyza *et al*., 2010; Güçlü 2013; Maiyza *et al.*, 2015; Sakalli, 2017)**. The data in this work were collected to cover the gridded area (Fig. 2) over the period 2007-2018, i.e. 12 years. These comprised data from the Egyptian National Oceanographic Data Centre (ENODC), and the Argo records from buoys No. 6900849, 6901889, 6901897, 6903175, 6903176 and 6903198, which entered the Egyptian Mediterranean territory. The applied gridded data were of monthly origin with some gaps attributed to the well-known corrupted in-situ data collection in oceanography on both spatial and temporal scales. Figure (3) depicts the present data availability on both a monthly and annual basis.

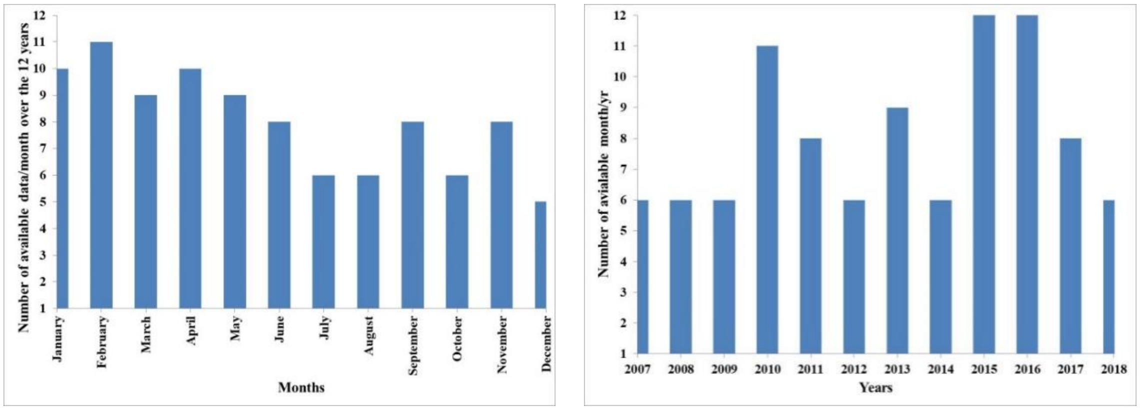

Figure 3. SST data availability on a monthly (left) and annual (right) basis over the period 2007-2018

According to **Holton (1979)**, the surface atmospheric layer is defined as the layer of the lowest few meters of the atmosphere (typically the bottom 10%, where the horizontal frictional stress is independent of altitudes). The present meteorological data comprised surface air temperature (SAT), surface air pressure (SAP) and surface wind regime, on a continuous hourly interval over the same period (2007-2018), with 0% missing data, from the five coastal meteorological stations shown in Figure (2). The geographical information for each coastal meteorological station is given in Table (1). It worth mentioning these are the only coastal stations available with continuous hourly records along the coast of the Egyptian Mediterranean Sea. The region-average monthly means were calculated from the monthly SST and meteorology time series over the 12 years of interest; to examine the seasonal variability and their correlations.

Table 1. Information on the Coastal Meteorological Stations Used in the Present Study

	Station Name	Station No.	Latitude (N)	Longitude (E)	Height above Sea Level (m)
1	**Mersa Matruh**	62304	31° 21' 34''	27° 14' 43''	20.00
2	**Ras El-Teen**	62317	31° 11' 50''	29° 51' 49''	21.95
3	**Abu-Qir**	62320	31° 19' 55''	30° 05' 06''	26.60
4	**Port Said**	62334	31° 15' 19''	32° 18' 17''	19.75
5	**Arish**	62331	31° 08' 54''	33° 49' 27''	15.00

RESULTS

1. The SST Distribution

The SST is a key player in controlling sea's heat content and regulating the surrounding climate. Figure (4) displays the mean monthly SST variations over the 12 years of investigation. The Figure reflects the seasonality in the mean monthly SST behaviour over the period of interest, with the lowest means in winter and highest in summer. The highest winter mean monthly SST of 18.9 °C occurred in January 2016, and the highest spring mean monthly SST of 25.3 °C occurred in June 2016. The highest summer mean monthly SST was 27.9 °C in September 2015, and it was 26.8 °C in October 2015 for autumn. The lowest mean monthly SST values, on the other hand, were 16.0 °C (January 2011), 16.8 °C (April 2011), 18.5 °C (August 2010) and 16.1 °C (December 2013) for winter, spring, summer and autumn, respectively.

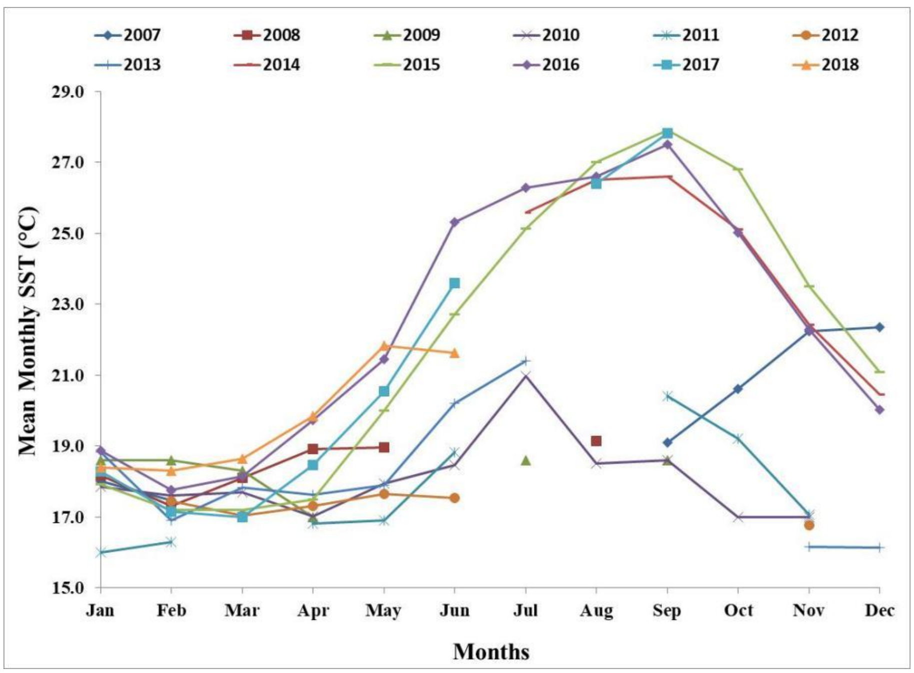

Figure 4. The mean monthly SST variations over the study period (2007-2018)

The mean annual SST fluctuated between a minimum of 17.3 °C in 2012 and a maximum of 24.4 °C in 2014, as shown in Figure (5). The linear trend of this annual variation reflects an overall increase in the SST over the period 2007-2018, with a rate of +0.3°C/yr.

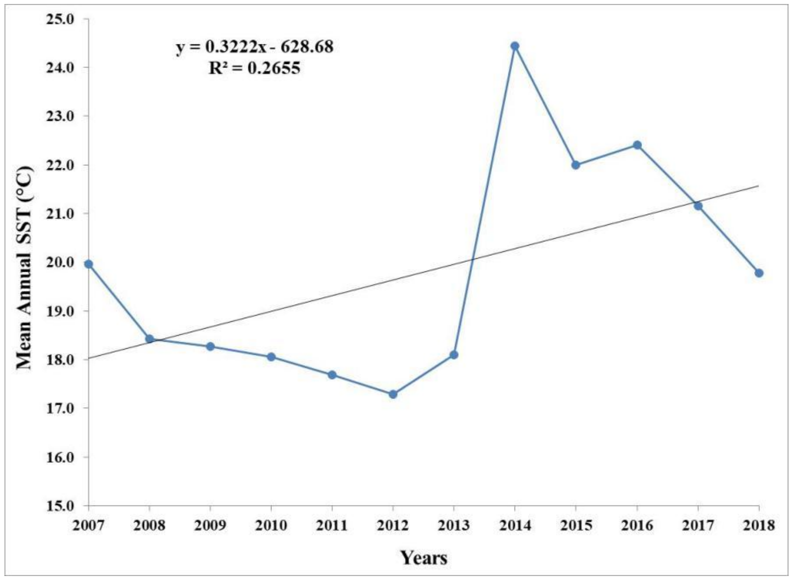

Figure 5. Mean annual SST variations over the study period (2007-2018)

2. Relationship between SST and surface air temperature

The surface air temperature (SAT) is the air temperature of the lower atmospheric layer in contact with the sea surface layer. The mean monthly SAT varied between 14.9 °C (January) and 27.9 °C (August), with a general mean monthly SAT of 21.5 °C, over the study area. The mean annual SAT, on the other hand, fluctuated between 21.0 °C in 2011 and 22.3 °C in 2010, with an overall mean annual SAT of 21.5 °C, over the study period.

Figure (6) depicts the mean monthly variations in the two parameters: SAT and SST, over the period of investigation. The Figure reflects higher monthly variations in the SAT than in the SST. The difference between the SST and SAT is considered an indicator of the vertical stability in the near-surface zone between sea and air (Cayan, 1980). Results revealed that exchange from the sea surface to the atmosphere occurred in the four months (December-March) of the winter, while the reverse is true for the remaining period of the year (April-November), as shown in Figure (7).

Although the correlation between the mean annual SST and SAT was positive over the study period, it was as low as +0.15. The correlation between the mean monthly SST and SAT, on the other hand, was as high as +0.91. This imitates the high level of seasonal thermal communication at the interface between the sea surface and the overlying air layer in the Levantine Basin. To examine the seasonal relationship between the mean monthly SST and SAT, the regression lines were produced for the cases when the SST exceeds the SAT (4 months) and when the reverse is true (8 months). The correlation coefficients between the SST and SAT were +0.37 (SST>SAT) and +0.96 (SST<SAT). The representative equations for the two situations are, respectively, as follows:

$$SST = 0.3832\ SAT + 12.154\ (SST > SAT) \quad (1)$$

$$SST = 0.6567\ SAT + 5.4271\ (SST < SAT) \quad (2)$$

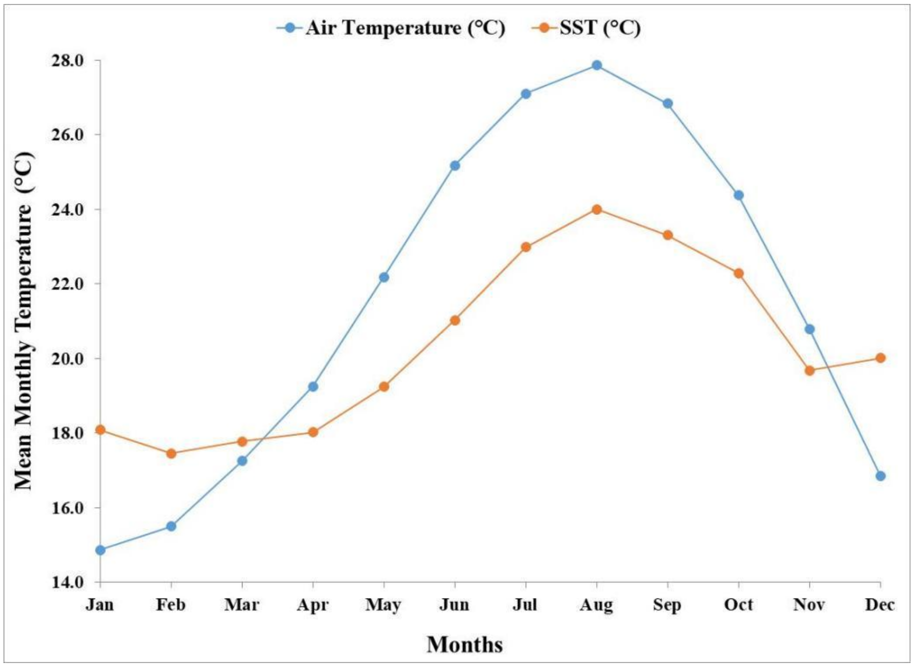

Figure 6. The mean monthly SST and SAT variations over the study period (2007-2018)

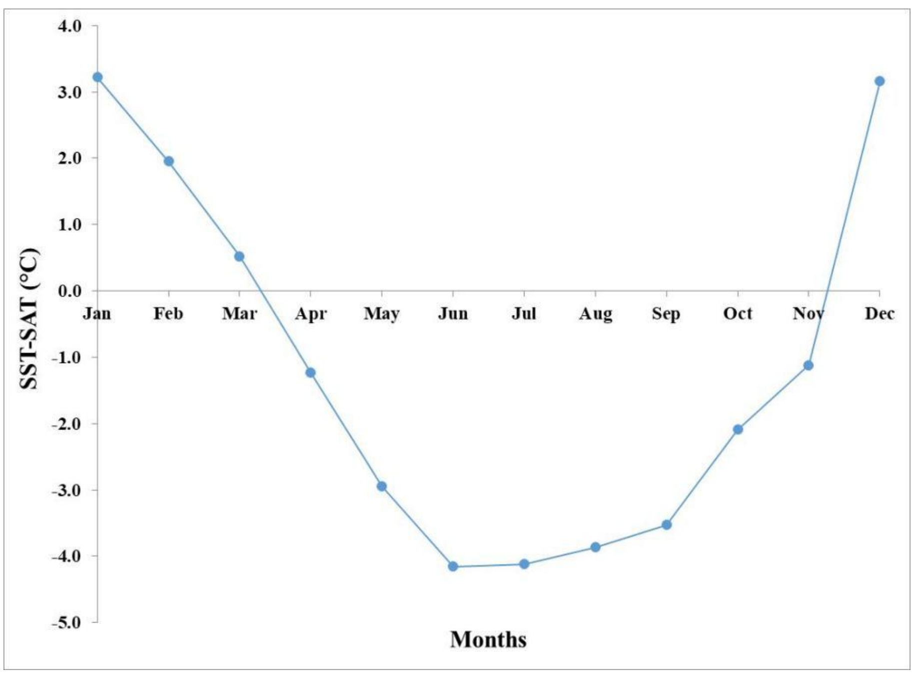

Figure 7. Seasonal differences between SST and SAT over the study period (2007-2018)

3. Relationship between SST and surface atmospheric pressure

The mean monthly surface atmospheric pressure (SAP) varied between 1008.5 mb (July) and 1019 mb (January) over the study period, with an average of 1014.2 mb. The mean monthly SAP over the southern Levantine Basin varied seasonally, with higher values recorded in winter and lower values in summer. The seasonal inverse relationship between SST and SAP is shown in Figure (8). The two parameters were inversely correlated with a coefficient of r = -071. Based on the present mean monthly values, the mathematical equation, which relates the two mean monthly surface parameters, can be expressed as:

$$SST = 495.21 – 0.4682\ SAP \qquad (3)$$

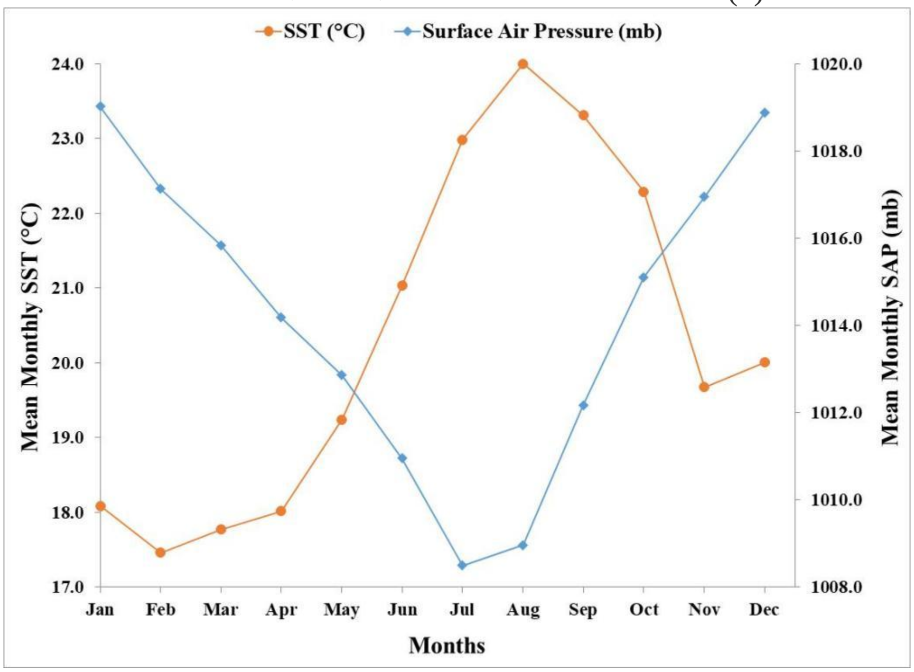

Figure 8. Seasonal relationship between SST and SAP over the study period (2007-2018)

4. Relationship between SST and surface wind regime

The Mediterranean Sea occupies the southern boundaries of Europe and the temperate latitudes, where the westerlies principally impact throughout the cold periods of the year (Lolis et al., 2002). This westerly system was proved for the southern Levantine Basin over this study period (Fig. 9), where the westerly wind, comprising the west (W), west-northwest (WNW), northwest (NW) and north-northwest (NNW) wind components, had the major contribution to the produced rose. There was a substantial correlation coefficient of +0.25 between seasonal variations in SST and wind direction. The seasonal wind speed varied between 8.5 kt in autumn (November) and 10.1 kt late winter (March), with an overall average of 9.4 kt. There was an inverse relationship between the seasonal variations in both SST and surface wind speed (SWS) in the southern Levantine basin, with a correlation coefficient of -0.54 (Fig. 10). The empirical relationship between the two parameters can be expressed as the following:

$$SST = 43.9 – 2.5189\ SWS \qquad (4)$$

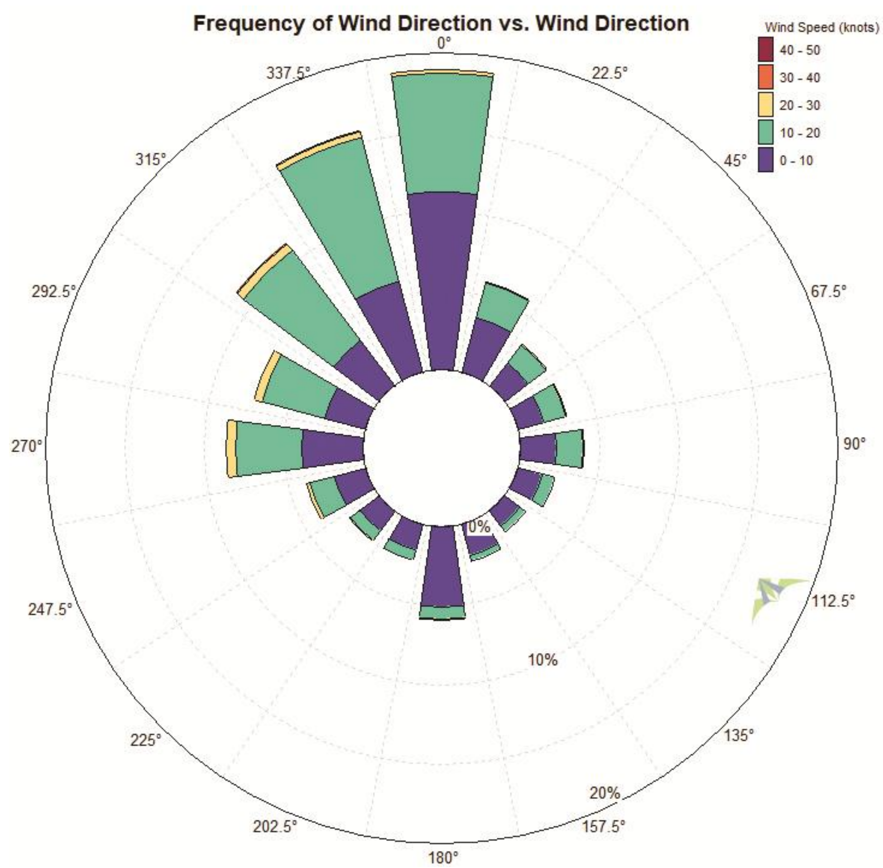

Figure 9. Wind Rose over the southern Levantine Basin during the study period (2007-2018)

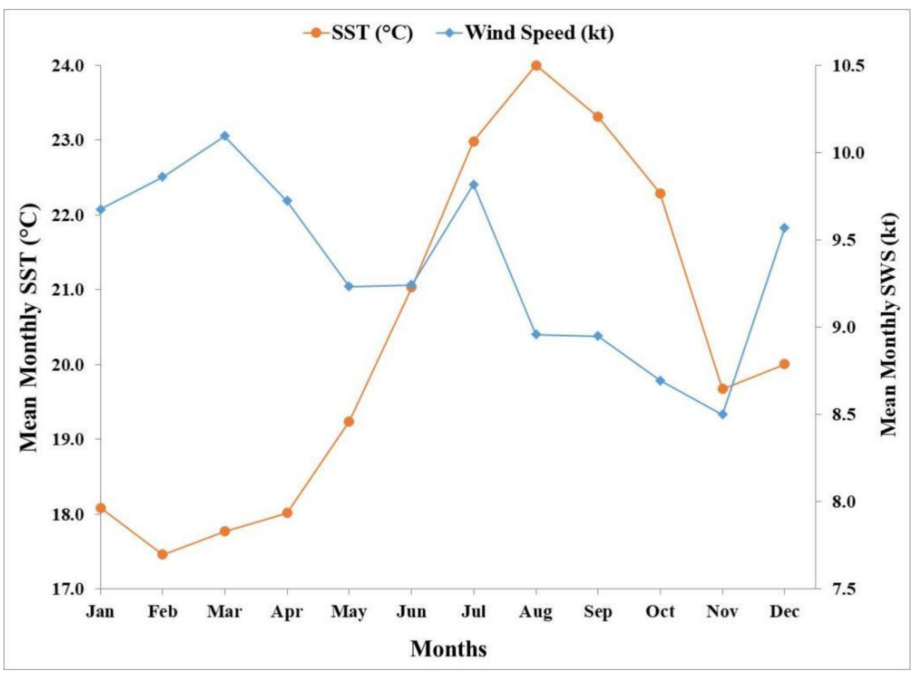

Figure 10. The seasonal relationship between SST and SWS over the study period (2007-2018)

DISCUSSION

Examining the relationship between the two adjacent layers of the ocean and the atmosphere is a key element in correlating the sea surface temperature (SST) and different parameters in the surface atmospheric layer **(Cayan, 1980)**. This relationship has been examined in the Mediterranean since the 80s, and on both temporal and spatial scales. The present study sheds light on the relationship between SST and three surface atmospheric parameters, namely: surface air temperature (SAT), surface air pressure (SAP) and surface wind regime, within the Levantine Basin. The work is based on the region-averaged monthly means of in-situ SST records and meteorological time series over 12 years (2007-2018) in the southern Levantine Basin.

Results revealed an increasing trend in the SST over the study period, with a rate of +0.3°C/yr. This is believed to be much higher than those previously calculated either for the entire Mediterranean Basin or for its eastern basin solely over different spans. **Adloff *et al.*, (2015)** concluded that SST in the Mediterranean Sea is increasing in a range of +1.73 - +2.97°C for the period 2070-2099 compared to the period 1961-1990. The entire basin examined a SST increase with a rate of +0.041°C/yr over the period 1982-2018, according to **Pissano *et al.*,(2020)**, who declared inequality between the two sub-basins of the Mediterranean, with the eastern one examining higher rate (+0.048°C/yr) than the western (+0.036°C/yr). The Eastern Mediterranean Basin examined a SST trend of increase of +0.39°C/decade (+0.039°C/yr) over the period 1979-2010 **(Mansour *et al.*, 2015)**. Samuel-Rhoads et al. (2013) calculated an increasing rate of +0.065°C/yr in the Levantine Basin over the period 1996-2011, and concluded a broad warming on both seasonal and interannual scales. In contrast, results of Maiyza and Kamel (2009) revealed a general decrease in the SST anomalies in the southern Levantine basin, with a rate of -0.05°C/yr over the period 1948-2008. This contradiction may be attributed to the calculated gridded mean and the only 10 m averaged gridded data. The results of **El-Geziry (2021)** revealed an SST increase in the southern Levantine basin, during the last 71 years (1948-2018), with a rate of +0.4 °C/decade, i.e. +0.04 °C/yr. His results revealed two opposite trends of variability: decreasing trend (–0.06°C/yr) over the period 1975–1991, and an increasing trend (0.2°C/yr) from 2002 to 2018. The latter is consistent with the present rate of +0.3°C/year. This increasing rate in the SST is considered an indicator of the presence of climate change that can be experienced within the southern Levantine Basin.

The mean annual SST is correlated with the mean annual SAT with a weak correlation coefficient of +0.15 over the period of investigation. However, the seasonal (monthly) correlation coefficient between the two parameters was as strong as +0.91. This agrees with **Shaltout and Omstedt (2014)** who calculated a correlation of more than +0.95 between monthly SST and air temperature in the Levantine Basin. This demonstrates that the annual relationship between the two variables in the southern Levantine Basin clarifies less SST inconstancy than does the month-to-month correlation. The present results also revealed that the seasonal exchange from the sea surface to the atmosphere occurred in 4 months (December-March), while the reverse is true in the remaining period (April-November). This is consistent with the conclusions of **Josey (2003)** and **Josey et al.,(2011)** who concluded the same behavior. The significant negative seasonal correlation between the SST and SAP of -0.71 in this study is in agreement with that concluded for the Levantine Basin (-0.40) by **Shaltout and Omstedt (2014)**. The relationship between the SST and the surface wind speed (SWS) has previously been examined worldwide and in the Mediterranean Sea. Results of previous research revealed a general negative relationship between the two parameters. This comprises, but not limited to, results of **Shukla and Misra (1977)**; **Hurell (1995)**; **Huang and Qiao (2009)**; **Qu *et al.,(*2012)**; **Tonbol and El-Geziry (2015)**. This inverse relationship is proved in the present study for the southern Levantine Basin, with a correlation coefficient of -0.54 between the seasonal SST and SWS. This was previously calculated for the Levantine Basin to be -0.40 **(Shaltout and Omstedt, 2014)**. This negative relationship implies that an increase in the SWS would in consequence decrease in the SST.

A privilege of this work is the production of empirical relationships that can be applied within the southern Levantine Basin; to calculate SST from the surface atmospheric parameters, on a seasonal basis.

CONCLUSION

To conclude, the seasonal variations in the SST in the southern Levantine Basin follow the well-known general pattern of relationship with the atmospheric parameters, with a positive correlation to the air temperature and negative correlations to both the air pressure and wind speed. Meanwhile, there is a substantial correlation of +0.25 between the seasonal SST variations and the seasonal wind directions. The month-to-month (seasonal) correlations between the SST and atmospheric conditions in the southern Levantine Basin are more reliable to investigate the SST changeability tied to these conditions than the annual ones. A worth to mention point is that the study on the relationship between the atmosphere and the ocean will help better understand the possible impact of global warming. Therefore, a longer study period, with a larger data set, should be extended to better understand the potential influence of global warming. This is a recommendation for further work in the area of the southern Levantine Basin.

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