Mediterranean Marine Science

Vol 23, No 3 (2022)

VOL 23, No 3 (2022)

Long-Term Variations of Air Temperature, SST, Surface Atmospheric Pressure, Surface Salinity and Wind Speed in the Aegean Sea

EMRE TUKENMEZ, HUSNE ALTIOK

doi: [10.12681/mms.25770](https://doi.org/10.12681/mms.25770)

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
www.hcmr.gr
DOI: http://doi.org/10.12681/mms.25770

Long-Term Variations of Air Temperature, SST, Surface Atmospheric Pressure, Surface Salinity and Wind Speed in the Aegean Sea

Emre TUKENMEZ and Hüsne ALTIOK

Istanbul University, Institute of Marine Science and Management, Istanbul, Türkiye

Corresponding author: Emre TUKENMEZ; etukenme@gmail.com

Contributing Editor: Sarantis SOFIANOS

Received: 08 January 2021; Accepted: 25 March 2022; Published online: 21 July 2022

Abstract

In this study, temporal and spatial trends of sea surface temperature (SST), wind speed, air temperature, sea surface salinity (SSS), sea-level pressure (SLP), and SST-based upwelling index are examined and compared with data from previous studies. Analyses of these parameters are performed for five critical locations that best illustrate the characteristic meteorological and oceanographic structures of the Aegean Sea. Upwelling index calculations are conducted with respect to latitude in order to reveal variations and detect upwelling strength easily. Long-term variations of all parameters are investigated using long-term ECMWF ERA-Interim data covering the period from 1979 to 2018; moreover, the Copernicus Marine Environment Monitoring Service (Global SSS/SSD L4) is used to obtain SSS data that cover the period of 2000-2015. Linear trend and Mann-Kendall tests are applied to identify tendencies and long-term variability. Monthly-average SST and air temperature data exhibit rising trends over the past 40 years. The results also reveal a decreasing trend in wind speed and SLP over the Aegean Sea. It is hard to determine, however, whether the current warming trend is a natural reaction of Earth or not.

Keywords: Aegean Sea; Trend Analysis; ECMWF; Upwelling Index.

Introduction

The Aegean Sea, a semi-enclosed sea with irregular coastlines, bays, peninsulas, narrow passages, and more than 3000 islands, has unique properties due to its interaction with two marginal seas (Black Sea and Mediterranean Sea) that have different temperature and salinity characteristics (Besiktepe *et al*., 1994; Ozsoy & Unluata, 1997). It has a connection with the Black Sea on its northeastern side and with the Ionian Sea and Eastern Mediterranean Sea in its southwestern and southeastern regions, respectively. Moreover, the Aegean Sea has an Etesian wind system, which blows from north to south and causes upwelling along its eastern coast. A low-pressure system extending from the Middle East to India and a high-pressure system over Southern Europe and the Balkan Peninsula create Etesian winds in the summer and the beginning of the autumn season (Savvidis *et al*., 2004; Ziv *et al*., 2004; Anagnostopoulou *et al*., 2014). Mountains in Türkiye and Greece create a channel effect that speeds up the winds over the flat surface of the Aegean (Poupkou *et al*., 2011).

The northeastern and central areas of the Aegean Sea are both under the influence of upwelling but have different wind speed, sea surface temperature (SST), and air temperature characteristics. Although the northeast and northwest regions of the Aegean Sea are at the same latitude, the air temperature in the northwest is warmer than that in the northeast and the same is true for SST in summer. The wind system of the central region is different from those in the south and north. In addition, the central region's surface waters are complex due to being under the influence of not only a thin surface layer of brackish waters but also northward-propagating Eastern Mediterranean waters and upwelling waters forced by local winds. The southeast region is affected by Etesian winds and the Eastern Mediterranean Sea; on the other hand, the southwest part at the same latitude is under the influence of the Ionian Sea from the western direction (Tyrlis & Lelieveld, 2013). The lowest wind speeds are found in the northwestern region, with greater values seen along the coasts of Türkiye in summer. Hasanean's (2001) study on air temperature fluctuations at eight locations with available data showed different trends for those locations in the Mediterranean Sea. In addition, studies on the northern, central, and southern regions of the Aegean Sea have confirmed differing characteristics (Eronat & Sayın, 2014). Besides these descriptions of atmospheric and surface ocean conditions, it is known that the general circulation of the Aegean Sea is cyclonic (Theocharis & Georgopoulos, 1993; Zervakis & Georgopoulos, 2002; Olson *et al*., 2007). The brackish waters coming through Turkish Straits System (TSS) shows an anticyclonic flow at the entrance of Aegean Sea due to Coriolis force. Anticyclonic motion of those brackish waters moves to a cyclonic pattern in northern and western parts of Aegean Sea as expected in Northern Hemisphere (Olson *et al*., 2007). The dominant and slow cyclonic circulation is completed with an inflow of Mediterranean Water which advects northward along the eastern side and reaches to the latitude of Cape Baba (northeastern Aegean Sea) where it mixes with brackish waters and sinks (Theocharis & Georgopoulos, 1993; Zervakis & Georgopoulos, 2002; Olson *et al*., 2007). Combination of buoyancy input from brackish waters and the effects of winds forces an overall cyclonic flow in Aegean Sea (Olson *et al*., 2007). Taken together, these previous observations support the idea that research at different locations is necessary to determine the overall trends.

As noted above, the sea surface of portions of the Aegean Sea is characterized by the presence of upwelling-favourable winds. The resulting upwelling circulation along the coast is one of the dominant drivers of ecosystem productivity in the Aegean Sea. The Eastern Aegean is forced by northerly winds that lead to upward movement due to the frictional stress of the Etesian winds on the sea surface, Coriolis force, and the presence of the coastal boundary. The offshore-moving surface water is replaced by ascending intermediate water, which flows from depths of ~40 m to the surface (Androulidakis *et al*., 2017; Mamoutos *et al*., 2017). In addition to supplying nutrients for the surface waters, upwelling along the Eastern Aegean Sea serves to cool surface waters (Skliris *et al*., 2010; Sayın *et al*., 2011), which can cover a large area down to the middle part of the sea in association with eddy features (Sayın *et al*., 2011).

The upwelling phenomenon in the Aegean Sea was first described by Unluata (1986). It is well known that this phenomenon can be identified by seasonally variable low SST, salinity, wind, and nutrient-rich water in coastal areas. Low SST along the east side of the Aegean Sea is the consequence of wind-driven upwelling. In this work we focus on the trend of upwelling strength by calculating an SST-based upwelling index (UI) to bring a new perspective to this phenomenon.

To address the meteorological and oceanographic conditions of the Aegean Sea, many studies have been conducted. Trend analyses of SST, air temperature, and wind speed were the main focuses in some of those studies as the effects of those parameters on people can be easily seen. In addition to those parameters, sea surface salinity (SSS) is also considered in the present study for the first time to reveal the trend of such data in the region. Monitoring SSS is crucial to investigate the water cycle and climate change; however, SSS has historically suffered from poor observational coverage, hindering accurate assessment of its trends. Different approaches have been suggested to fill these gaps, such as using a combination of *in situ* and satellite data. In the framework of the Copernicus Marine Environment Monitoring Service (CMEMS), the Global SSS/SSD L4 reprocessed dataset was produced by interpolating *in situ* SSS/SSD with a multi-dimensional covariance model. The high-pass filtered data are available on a 0.25 degree regular grid. The CMEMS includes satellite and *in situ* high-level products.

The effect of changing salinity is crucial for the ecosystem since salinities outside the tolerance range of species may help some organisms by reducing stress or may impede their survival by changing their behaviours and limiting reproduction. However, relatively few scientific studies to date have approached salinity effects as a variable worth investigating in spite of the fact that the salinity of sea water varies and will inevitably have negative or positive impacts on species. TSS has unique dynamics because the flow is driven not only by permanent sea-level difference between the Black Sea and Aegean Sea but also by density differences between those marginal seas. The Aegean Sea-level height is roughly 30 cm lower than that of the Black Sea. The brackish waters coming from the TSS regulate convection in the northern part of the Aegean Sea (Ilicak *et al*., 2021). With the influence of the combination of Etesian winds and the TSS, an east-west gradient and a north-south gradient in salinity are both seen in the Aegean Sea, unlike the Sea of Marmara.

The Eastern Mediterranean Transient (EMT) is another significant topic to be taken into consideration as the Aegean Sea basically took the place of the Adriatic Sea in the sense of the deep-water transient in the early 1990s. The EMT was first revealed by Roether *et al.* (1996). In this state, 20% of the deep and bottom waters of the Eastern Mediterranean Sea were replaced with deep water from the Aegean Sea, while before this change of flux, the Adriatic Sea was the only source of those waters (Roether *et al*., 1996). This change in flux resulted in an increase of the salinity of the Aegean Sea (Roether *et al*., 1996). After 1993, it was determined that there was an anomalously high amount of flow from the Aegean Sea to the Eastern Mediterranean (Roether *et al*., 2007). In another study, it was concluded that the EMT had occurred due to the high volume of salty waters entering the Aegean Sea from the Eastern Mediterranean Sea and to heat loss in the Aegean in the years between 1988 and 1995 (Incarbona *et al*., 2016). The same idea was also put forward by Klein *et al.* (1999), who reported 1993 as the beginning of the EMT that started in the Southern Aegean Sea. In the study of Eronat & Sayın (2014), it was stated that the EMT weakened in the early 2000s, and climate change in the Mediterranean Sea and abnormal changes in the air temperature of the Aegean during the EMT process were effective in altering the water structure of the Aegean Sea. It was mentioned in the same study that the salinity increased in the water columns in the period after the summer of 2007 when the EMT relaxed. Although the EMT has been mainly observed in the Aegean Sea's deep and intermediate waters, a variation of SSS is also expected.

The main objectives of this research were to conduct a trend analysis and depict the climate effects on SST, air temperature, wind speed, SSS, SLP, and UI (SST) over the last 40 years (1979-2018). If the effects of climate on meteorological and oceanographic parameters is of concern, SST and air temperature changes are among the first data to be considered. However, wind and SLP are the drivers of those parameters through processes such as upwelling. In other words, while SST and air temperature are results of concern, surface pressure and wind are the driving mechanisms behind those results. The studies referenced above confirm that the meteorological and oceanographic conditions are not the same at all locations. By performing monthly analyses, different perspectives are added to the trend analysis and temporal and spatial variations are also captured; this is important as most previous studies focused on a small or a single large area, or a certain parameter or one season, rather than the detailed analyses performed in this work. To our knowledge, no prior studies have examined trends of these parameters on a monthly basis in detail for separate locations, which is why this paper addresses detailed trend analyses for five critical locations. Five points with different oceanographic and meteorological characteristics representing the whole Aegean Sea have been chosen in accordance with previous research and the outcomes of our own observations and model output. This also provides an opportunity to plot time series for more accurate results.

Moreover, no prior studies have sought to illustrate the efficiency of upwelling with an index in the Aegean Sea (the formula referred to here as the upwelling index or UI, based on SST, will be explained in the next section). An efficient method has been developed to identify upwelling days automatically with an index. To achieve these goals, changes in the Aegean Sea were analysed using ECMWF reanalysis and CMEMS data.

Material and Methods

Data

The meaning attributed to "climatic analysis" in the past and today is different. While this expression was formerly used for analysis of surface parameters with long-term data, today it may refer to analyses conducted with data from several months to thousands of years. Moreover, "long-term data" may have distinct definitions in different disciplines. While long-term change in geology is understood as change over the millennia, it may represent a thousand-year period or hourly change in atmospheric research.

If long-term changes in data are to be analysed, the existing system must be fully demonstrated. However, it is impossible to obtain such information in today's conditions. The most important problem experienced in scientific studies is the lack of measurements in the sea. Instead, efforts are made to define the system through sample data, or this deficiency is eliminated by means of models. In addition, there may be inconsistencies in data obtained from different sources. For example, while real data obtained from radiosonde measurements indicate warming, no such trend may be seen in the results obtained from satellites (Weisse & Storch, 2010). *In situ* measurements (on land, a ship, a buoy, etc.) present point data and cannot provide data that include all of the world's seas, as they are irregular. Bringing these irregular data into regular data grids to evaluate the sea or atmosphere by means of mathematical equations is called analysis (Glickman, 2000). Many studies have been conducted to compare ECMWF Era-Interim data with *in situ* data for reliability testing and they have shown the model results to be reliable (Berrisford *et al*., 2011; Shaltout *et al*., 2013). The accuracy and quality of this data analysis is constantly improving thanks to better and more observational data (Weisse & Storch, 2010). Since there are more observational data from the northern hemisphere, data analysis yields better results there. Especially in the late 1970s, the accuracy of data modelling began to increase with the use of satellite data. Models are used to explain and reflect real situations. It has been determined in many studies that these data can be used to obtain trends (Bengtsson *et al*., 2004; Bromwich *et al*., 2007; Weisse *et al*., 2009). The ECMWF performed the first reanalysis process for data generation in the early 1980s. Continuously improving itself, the ECMWF produced the ERA-Interim reanalysis data in 2009, which are also used in this study, with a different strategy. This dataset includes high-resolution data with an advanced model and a data assimilation system. The accuracy of SST, especially after 1979, has provided much more accurate results with the help of verification by satellite data. Due to the variability of atmospheric data, atmospheric data are less accurate than SST. In this study, data obtained after 1979, marking a new era in the production of model data, are taken as a basis.

At least 30 years of data should be used to obtain reasonable results and understand the climatological structure and trends of any area (WMO No. 1203, 2017). In this study, as stated by Weisse & Storch (2010) and the reports of the World Meteorological Organization (WMO), 40 years of ECMWF Era-Interim data available monthly from 1979 to 2018 have been used. Monthly SSS data of the CMEMS (Global SSS/SSD L4) that cover the period of 2000-2015 have been used to depict salinity trends. Locations of the specific data applied for trend analyses of SST, air temperature at 2 m above sea level, SLP, and wind speed at 10 m above sea level are shown in Figure 1.

In addition to point trend analyses, ECMWF Era-Interim data of SST for the area of 35-41°N and 22-28°E have been used for calculating UI (SST). UI (SST) calculations based on latitude were performed for selected sites and daily SST data were applied to capture the UI(SST) variations clearly because monthly averaged data may obscure upwelling events that depend on changes in wind speed and direction over the course of a few days.

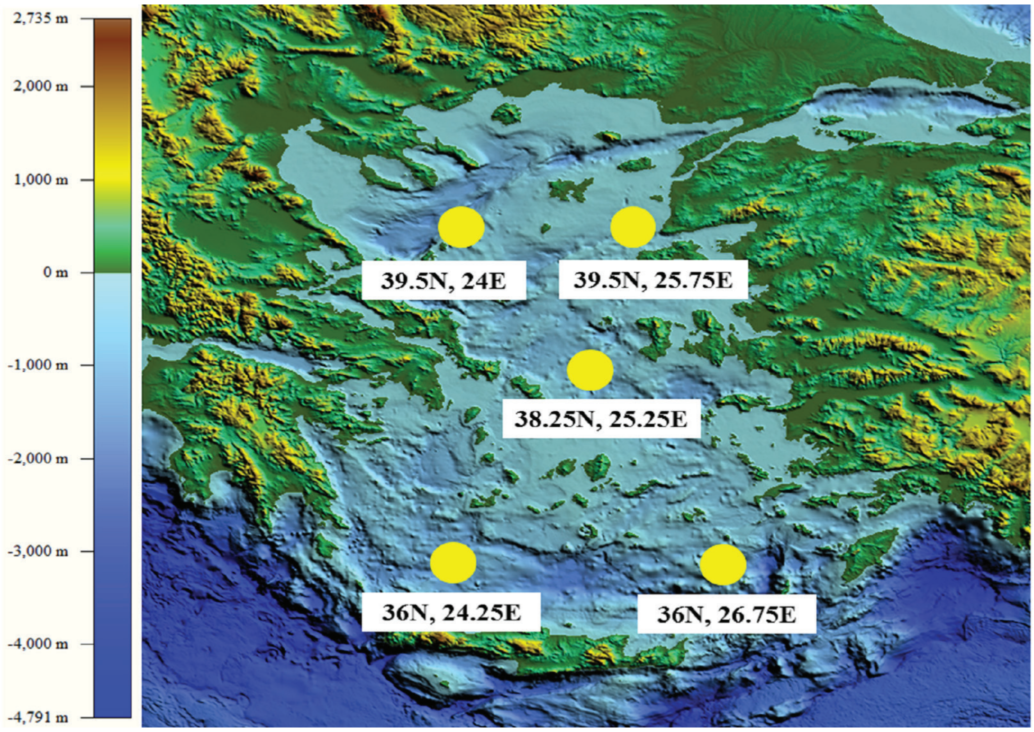

Fig. 1: Five positions that are used for trend analyses (Map produced from GEBCOdata).

Methods

Trend analyses

The existence of trends can be identified by plotting meteorological and oceanographic data, but statistical methods offer a more reliable approach. Trend analysis is a good and simple tool for analysts to predict future values by evaluating historical data. Both parametric (linear) and nonparametric (Mann-Kendall test at 5% significance level) methods were applied in this study for accurate and objective results.

Linear trend identification using historical data creates a function like $y=ax+b$ to interpret tendencies and the behaviour of the data. In this equation, "y" represents the prediction, "a" is the slope of the line, and "x" refers to time. For meaningful results, the number of data points must be at least 12. Linear trend identification is a classical statistical technique that assumes data are normally distributed and independent. A positive slope shows an upward trend while a negative one indicates a decreasing trend. The annual mean value of each parameter is calculated not only to get the interannual trend rates but also to make the graphs easier to read. Furthermore, monthly and seasonal trend rates are acquired from daily data for the purpose of detailed investigation and to look at phenomena from different perspectives. Estimated standard error calculation of trends is also performed in consideration of the statistical difference between the estimate and the model data. It reveals the size of the errors existing for the dataset. Standard error is calculated by dividing standard deviation by the square root of the sample size.

The Mann-Kendall test is a nonparametric test used to determine whether historical data are increasing or decreasing monotonically. This test does not require normally distributed data; it works for all distributions. The minimum number of data points should be at least 10 and the presence of more data implies more accurate trend determination. Basically, the Mann-Kendall test calculates differences between earlier and later data. The null hypothesis is "there is no trend" and the alternative hypothesis is "there is an increasing or decreasing trend". For the time series $x1, \ldots, xn$, the equation for the Mann-Kendall test is as shown below. If the resulting z value is greater than 0, there is an increasing trend, but if the reverse is true, earlier data values are greater than later ones.

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_i)$$

$$z = \{\frac{S-1}{\sqrt{\mathrm{Var(S)}}}, if\ S > 0\ ; \frac{S+1}{\sqrt{\mathrm{Var(S)}}}, if\ S < 0\}$$

In addition to their use in linear trend analyses to understand the nature of trends, daily data are also used here for the Mann-Kendall test.

Upwelling Index (UI)

Previous UI estimates were obtained based on the temperature difference between a geographically defined maximum and minimum temperature (Camp *et al*., 1991; Nykjær & Camp, 1994; Lathuilière *et al*., 2008; Santos *et al*., 2012; Von Schuckmann *et al*., 2016). To calculate upwelling intensity, those earlier studies focused on the temperature difference along a perpendicular line to the coastline within the area of the continental shelf. The most challenging aspect here is defining SSTmax and SSTmin. SSTmin is defined as the minimum along the perpendicular to the coastline and it is obtained from within the upwelling area. SSTmax is the maximum temperature offshore where upwelling is not expected to occur. SSTmax can be determined easily in studies conducted in open oceans, such as in the Atlantic or Pacific Ocean. In marginal seas, however, due to distance limitations (less than 5° latitude difference), it should be adapted with respect to the geometry and dynamics of the region. For example, previous studies have considered different distances from the coast within the range of 400-1000 km offshore (Camp *et al*., 1991; Nykjær & Camp, 1994; Lathuilière *et al*., 2008). The most easily identifiable and idealised SST profile orthogonal to the coast in upwelling areas is that it has inverse SST gradient from the shoreline to upwelling areas (SSTmin) and as it is moved away from SSTmin location, SST shifts towards greater numbers until it reaches to maximum value in offshore and stays constant (Demarcq & Faure, 2000).

In our work, such distances could not be used since the Aegean Sea's maximum width is ~400 km. That is why when UI was calculated, SSTwest and SSTeast were used as terminology defining the two sides of the Aegean Sea. UI as a function of latitude is defined as the difference in SST between the east and west coasts of the Aegean Sea:

$$UI(SST) = SST_w - SST_e$$

In this formula, SST_w represents a location where upwelling is not expected and SST_e represents the value within the upwelling area. A higher UI value indicates a stronger upwelling event. These presumptions are supported by the wind forcing pattern, which is the main factor behind the upwelling mechanism.

Results and Discussion

Annual changes and trends

Trend analyses and upwelling are not simple phenomena due to the Aegean Sea's geographical and oceanographic features and its rapid responses to meteorological changes (Georgiou *et al*., 2015). Analyses were conducted for different areas in accordance with the best positions representing the oceanographic and meteorological dynamics of the Aegean Sea.

A comparison of trend rates with those of previous studies for each parameter at five different locations are presented in Table 1. The time series of Figures 2-3 demonstrate that SST, air temperature, wind speed, and SLP varied over the last 40 years.

In general, air temperature shows a definite increasing trend in accordance with both linear trend identification and the Mann-Kendall test. A monotonic trend can be detected and all z values are greater than 0. The results of the monthly air temperature analyses indicate positive trends with rates of 0.017-0.03°C/year for the last 40 years. From other studies, it is known that air temperature has increased since 1860 and especially since 1990, representing the hottest period in the northern hemisphere (IPCC, 2001). According to a special report of the Intergovernmental Panel on Climate Change (IPCC), the rate of global mean warming is 1.5°C above preindustrial levels (IPCC, 2019). According to the present results, air temperature has increased 0.68-1.2°C over 40 years, which is consistent with the IPCC's report. In addition to that of the IPCC, many similar studies have been conducted for the Aegean Sea and its neighbours, all revealing an upward trend for air temperature. For instance, Good *et al.* (2008) concluded that air temperature increased in the period of 1982-2002. The Annual Report of the Turkish State Meteorological Service published in 2019 stated that SST and air temperature values were both

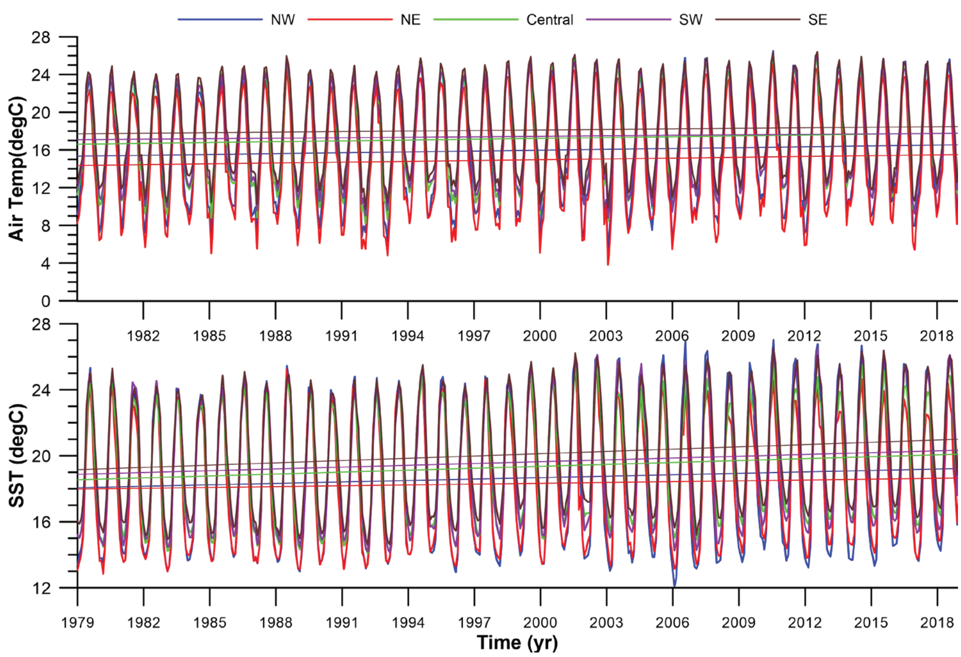

Fig. 2: Linear trend analysis of air temperature & SST.

Table 1. Trend analyses of all monthly mean data.

Data type	Locs.	Linear Trend Rates	Previous Studies		Mann-Kendall Test	
					Is there any monotonic trend? $p<0.05$	"z" value
SST	NE	+ 0.017°C/yr	Shaltout & Omstedt (2014)	+0.038°C/yr (all locs.)	Yes	8.15
			Skliris *et al.* (2011)	+0.035°C/yr		
			Bengil & Mavruk (2018)	+0.032°C/yr		
	NW	+0,029°C/yr	Shaltout & Omstedt (2014)	+0.038 °C/yr (all locs.)	Yes	8.19
			Skliris *et al.* (2011)	+0.05°C/yr		
	Central	+0,039°C/yr	Shaltout & Omstedt (2014)	+0.038°C/yr (all locs.)	Yes	7.59
			Skliris *et al.* (2011)	+0.03°C/yr		
	SE	+0,046°C/yr	Kuleli & Bayazit (2020)	+0.110°C/yr (summer)	Yes	7.806
			Shaltout & Omstedt (2014)	+0.038°C/yr (all locs.)		
			Skliris *et al.* (2011)	+0.04°C/yr		
			Bengil & Mavruk (2018)	+0.032°C/yr		
	SW	+0,036°C/yr	Shaltout & Omstedt (2014)	+0.038°C/yr (all locs.)	Yes	7.56
			Skliris *et al.* (2011)	+0.05°C/yr		

Continued

Table 1 continued

Data type	Locs.	Linear Trend Rates	Previous Studies		Mann-Kendall Test	
					Is there any monotonic trend? $p<0.05$	"z" value
AirTemp.	NE	+0,029°C/yr	Mamara *et al.* (2015)	+0.031°C/yr	Yes	6.37
			Philandras *et al.*(2008)	+0.017°C/yr		
	NW	+0,030°C/yr	Mamara *et al.* (2015)	+0.026°C/yr	Yes	6.48
	Central	+0,029°C/yr	Mamara *et al.* (2015)	+0.028°C/yr	Yes	7.71
	SE	+ 0.019°C/yr	Mamara *et al.* (2015)	+0.033°C/yr	Yes	4.9
			Philandras *et al.* (2008)	+0.008°C/yr		
	SW	+ 0.017°C/yr	Mamara *et al.* (2015)	+0.031°C/yr	Yes	5.51
			Philandras *et al* .(2008)	+0.035°C/yr		
Wind Spd.	NE	-0.008 kts/yr	--		Yes	-1.707
	NW	+0.012 kts/yr	--		Yes	2.26
	Central	-0.014 kts/yr	Poupkou *et al.* (2011)	-0.013kts/yr (summer)	Yes	-2.96
	SE	-0.007 kts/yr	--		Yes	-3.42
	SW	-0.016 kts/yr	--		No	-1.51
SSS	NE	-0,00072 psu/yr	--		No	-0,0618
	NW	-0,00072 psu/yr	--		No	-0,06
	Central	-0,00096 psu/yr	--		No	-0,031
	SE	+0,0096 psu/yr	--		Yes	6.68
	SW	+0,0036 psu/yr	--		Yes	3.176
SLP	NE	-0.028 mb/yr	--		Yes	-6.76
	NW	-0.032 mb/yr	--		Yes	-6.49
	Central	-0.030 mb/yr	--		Yes	-8.05
	SE	-0.027 mb/yr	--		Yes	-7.902
	SW	-0.028 mb/yr	--		Yes	-7.245

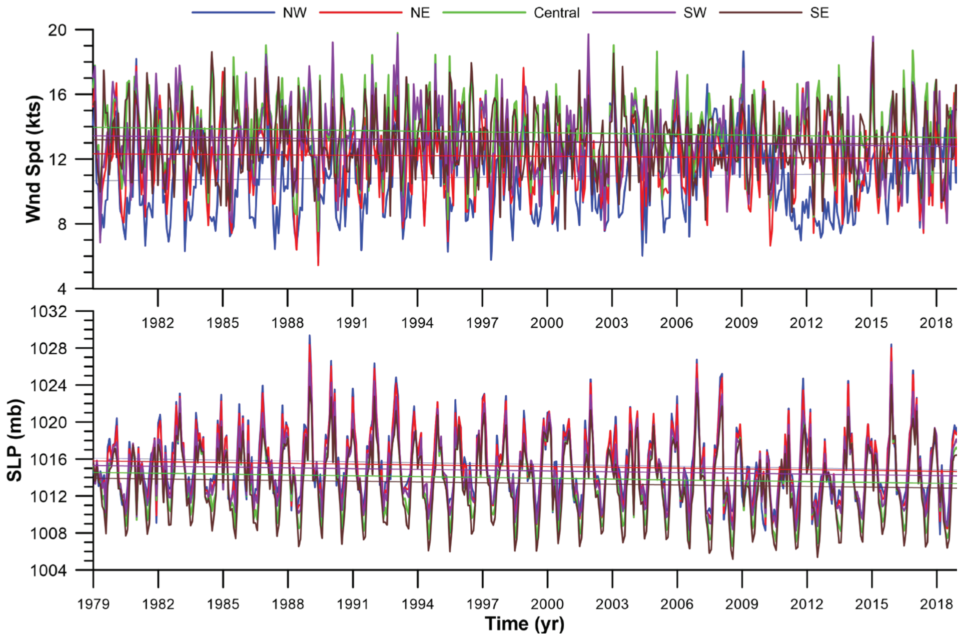

Fig. 3: Linear trend analysis of wind speed & SLP.

rising. Even though cooling of 0.3°C is expected according to NASA reports with respect to sunspot activities, an upward trend is obviously detected (NASA, 2019). This provides a clue that the warming is not nature's routine response to interannual forcing. The air temperature values at southern locations reported here are lower than those reported at the closest points in the study conducted by Mamara *et al*. (2015) based on observed data, but for the rest of the locations the values are almost the same, as shown in Table 1. Another study based on observed data conducted by Philandras *et al.* (2008) presented a lower rate (half the value) for the northeast and southeast and a higher rate (twice the value) for the southwest.

According to linear and Mann-Kendall trend analyses of SST data, there is a significant increasing trend in both cases. At the 95% significance level, p values show a monotonic trend with an upward tendency ($z > 0$). SST has increased by 0.68-1.84°C over the last 40 years. SST analyses have been conducted for the Aegean Sea with different datasets for different periods of time (Vlahakis & Pollatou, 1993; Mexatas & Bartzokas, 1994; Lelieveld *et al*., 2002). Nonetheless, these studies all state that SST has an upward trend. Skliris *et al.* (2011) and Shaltout & Omstedt (2014) conducted studies with satellite-based data while Bengil & Mavruk (2018) performed work with the *in situ* and satellite platforms of the North Carolina Institute for Climate Studies, providing results compatible with ours. The research of Skliris *et al.* (2011) yielded different trend rates for different locations. SST trend rates indicate that the southeast has the maximum and the northeast has the minimum rising trend. While SST and air temperature values were low in the 1980s, these values were higher in the 2010s. Trend rates of SST and air temperature are increasing together, as expected, since these data are strongly correlated and in harmony with each other.

According to the monthly mean wind speed plot, the analyses illustrate a downward trend for all other parts of the study area but an upward trend for the northwestern part. The study of Vagenas *et al.* (2017) with 1980-2000 RegCM and real data from the western part of the Aegean Sea and the study of Poupkou *et al.* (2011) with 1979-2011 NCEP/NCAR reanalysis data on Etesian winds revealed a decreasing trend for wind speed data. The trend rate reported by Poupkou *et al.* (2011) is similar to our findings, as presented in Table 1. Wind speed data have geographically different trend rates, and it is obvious that there is a significant decrease (from -0.008 to -0.016 kts/yr) along the route where the Etesian winds blow.

Monthly mean data for SLP follow the same pattern

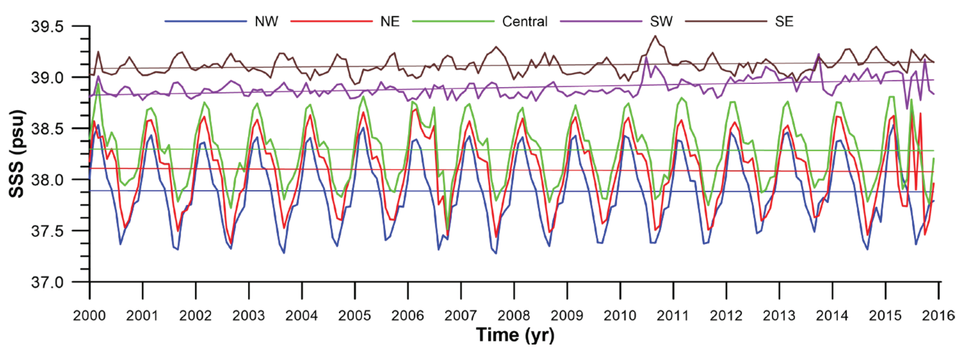

Fig. 4: Linear trend analysis of SSS.

with minor differences in a decreasing trend at all locations with rates ranging from -0.032 to -0.027 mb/yr. In general, annual variations of wind speed and SLP were 0.28-0.68 kts and 1.08-1.28 mb for the entire 40-year period. SLP and wind speed are two parameters that are in a close relationship since the pressure difference is the driver of wind speed. The results obtained in this research indicate that both parameters have a negative tendency.

When the changes in SSS trend rates (Fig. 4) are examined, it can be seen that there is an increase with a rate of 0.0036 psu/yr for the southeastern and southwestern locations and a decrease for the northeastern, northwestern, and central parts at rates of -0.00072 psu/yr, -0.00072 psu/yr, and -0.00096 psu/yr, respectively. Variations of SSS at the five considered locations are the consequence of not only water exchange between the Black Sea and the Eastern Mediterranean but also the cyclonic movement of water. The northeastern and central parts of the Aegean Sea are under the influence of upwelling and have different wind speed, SST, and air temperature data. The effect of Black Sea waters was seen on the coasts of Greek mainland (Kourafalou & Barbopoulos, 2003) and upwelling is expected near Cape Baba in the northeast (Zervoudaki *et al*., 1999; Androulidakis *et al*., 2017). Additionally, the northern and central regions have sinusoidal seasonal variations, but the southern region does not have that kind of seasonal response. Due to the increased effect of Black Sea waters in summer and spring, there is a decrease in salinity values in those months. In addition, the northwest and central positions are located directly on the route followed by the Black Sea waters at the exit of the TSS. Due to both the effects of upwelling and the fact that it is not on the route of brackish waters, it is expected to have higher SSS (~39 psu); however, the CMEMS reports a lower SSS (~38 psu). The parameterization method may cause loss of accuracy for small-scale data since it replaces complex values for representation in the model. Over the past 20 years, models have evolved in terms of parameterizations, environmental monitoring, and data assimilation, but parameterization still results in possible poor results in areas with complex coastlines, and especially in the Aegean Sea, where spatial resolution plays a key role. Higher resolution in observational data assimilation could provide better results for SSS.

The issues noted in the introduction of this paper about EMT were investigated in the presented research while monthly average air temperatures were examined. It was seen that 1991-1993 (i.e., the early 1990s) were the years in which air temperature decreased significantly. No significant change in air temperature data can be seen in the early 2000s, when the EMT subsided. This result is consistent with the study of Eronat & Sayın (2014). It was also seen that there was an increasing trend in SSS after 2007, as also mentioned by Eronat & Sayın (2014). It is remarkable that an increase in SSS could be seen in surface waters, too; however, this finding is pertinent to the southern locations, not the northern regions.

Upwelling index calculations and trends

For a better understanding of SST variations, surface maps of SST were plotted for all months. In these plots, mean values of each grid with 0.75° resolution were calculated for the period of 1979-2018. Figure 5 demonstrates that SST exhibits changes with respect to not

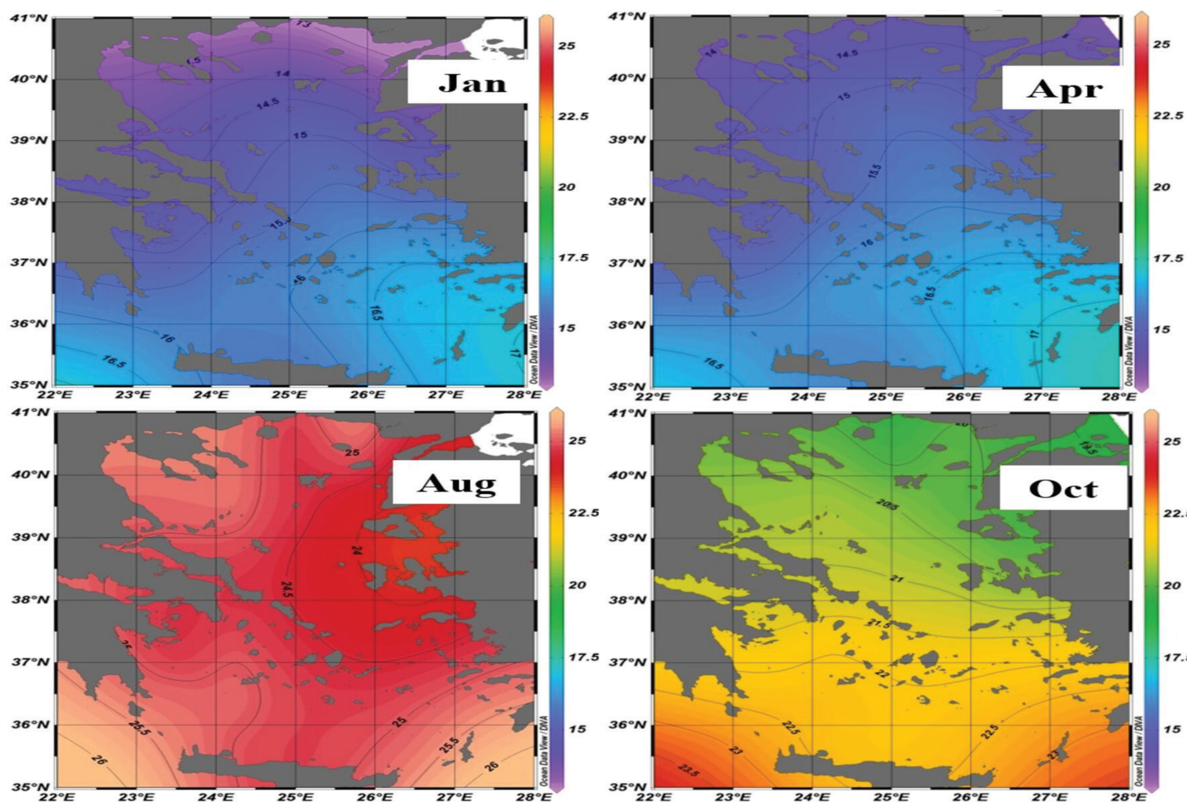

Fig. 5: Seasonal variations of SST.

only latitude but also, and more importantly, longitude. Although obscured by the monthly average, upwelling is obviously seen on the eastern side of the Aegean Sea in summer. A map of average SST values for the 40-year period was prepared to choose the locations of SST_w and SST_e as SST is the easiest way to determine upwelling. Latitude is considered for upwelling since the movement of water is expected to occur from east to west due to synoptic scale dynamics of the region, as mentioned in the introduction.

Defining upwelling by examining SST maps might appear to be the easiest way; however, other techniques and methods should be used to define it mathematically and systematically. First, horizontal variations of SST data at each latitude were investigated to see the behaviour of SST on the eastern and western coasts of Türkiye by applying the approach of Demarcq & Faure (2000) with minor changes. Horizontal monthly mean SST values for all latitudes were calculated and plotted with respect to Demarcq & Faure's (2000) method. Every value in Figures 6-7 represents the monthly average of 40 years of data for each grid. Figure 6 was created for 38.75°N, where upwelling is expected, and indicates that the eastern side of the Aegean Sea has lower SST values in June, July, August, September, and October. However, other months have different slopes since SST increases from west to east, especially in winter and spring, not descending dramatically as seen in summer. It is not possible to consider a horizontally negative gradient from east to west for Figure 7, where upwelling is not expected; on the contrary, a positive gradient exists.

To better see the SST change and its characteristics perpendicular to the coastline, the SST-based UI described above was applied. The locations used to obtain data for calculating UI(SST) are shown in Figure 8. The 40-year monthly average of SST values of the western and eastern sides of the Aegean Sea were subtracted and Figure 9 was obtained. According to monthly SST maps, the intensity of upwelling increases in May and peaks in August before declining in September. The latitudes of 38.75°N, 39.5°N, and 38°N have particularly strong upwelling activity, following the same pattern. The northernmost (40.25°N) and southernmost (36.5°N, 35.75°N) latitudes exhibit different behaviours; it seems that these regions are not upwelling areas.

The results of UI(SST) trend analyses at each latitude are shown in Table 2. The general trends of daily UI(SST) at 39.5°N and 40.25°N are positive with a rate of ~0.015°C/yr; the trends are downward for other latitudes with rates from 0.005 to 0.014°C/yr (Fig. 10). Seasonal UI(SST) trend rates of all latitudes (except 40.25°N and 35.75°N) show similar tendencies in terms of increases and decreases as the rates increase in summer and decrease in winter (Fig. 11). The highest rising trend rate was recorded in August, being 0.0065°C/yr at 39.5°N. In general, the greatest monthly downward trend rates are seen in January and December. Results from the Mann-Kendall test and linear trends are compatible with each other. The UI(SST) trend graph presents an interesting result with a staggering jump from about 2°C to

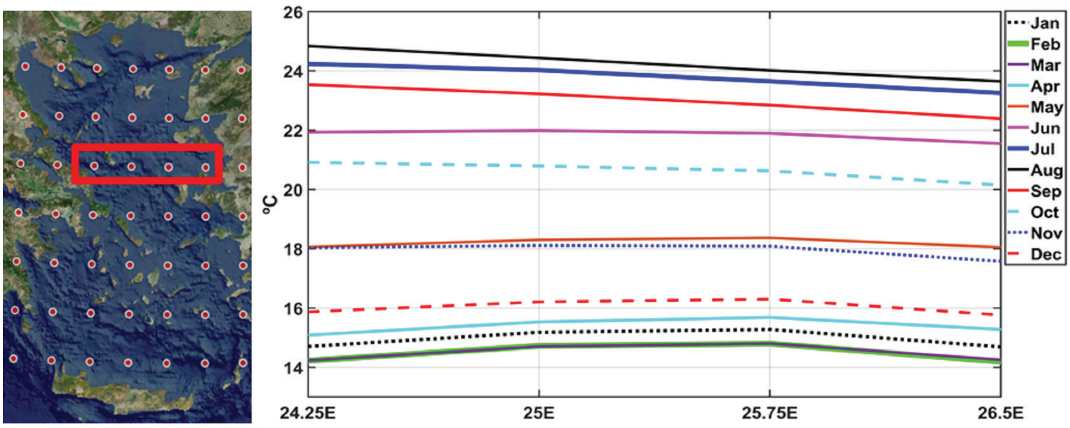

Fig. 6: 40 years mean of SST at 38.75°N latitude.

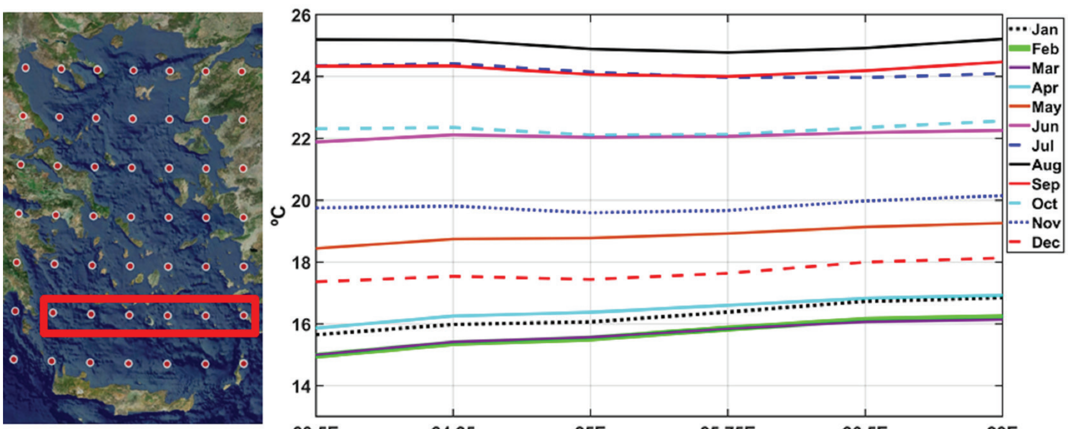

Fig. 7: 40 years mean of SST at 36.5°N latitude.

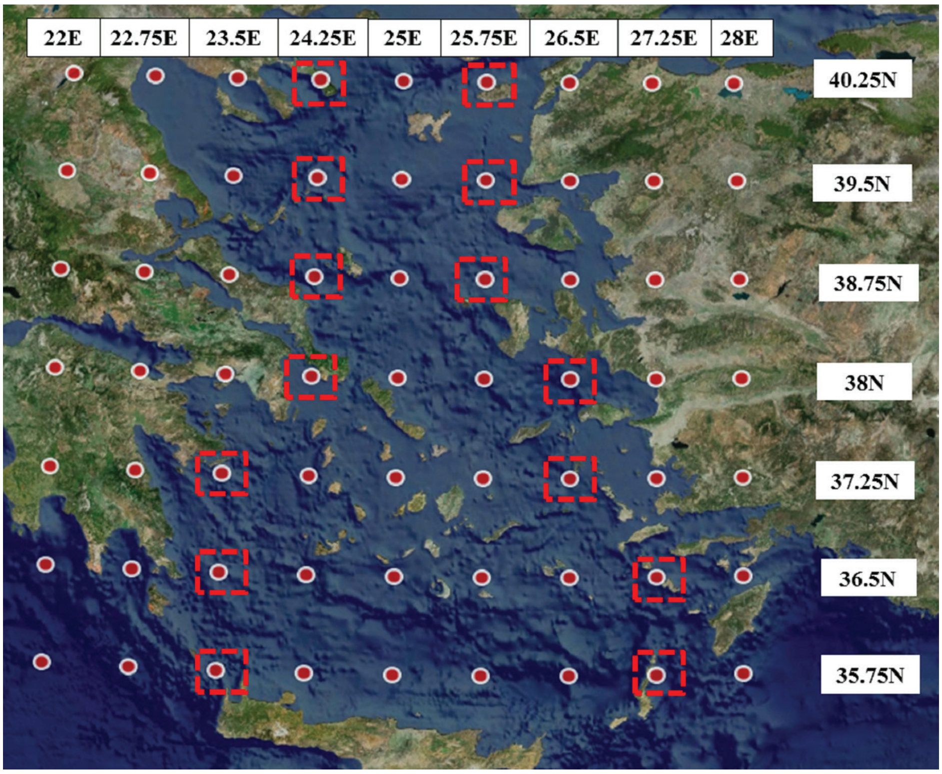

Fig. 8: Locations of the data used for UI trend analyses.

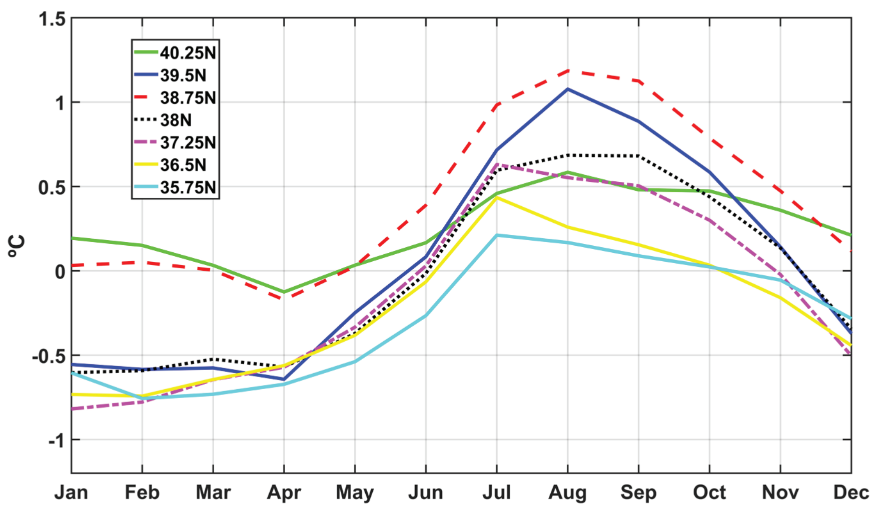

Fig. 9: 40 years monthly mean of UI(SST) at each latitude.

Table 2. Trend rates of daily UI(SST).

Latitudes	Linear Trend Rates	Mann-Kendall (alpha=0.05)	
		Is there a monotonic trend (p<0.05) ?	z value
40.25N	+0.0175°C/yr	Yes	53
39.5N	+0.0143°C/yr	Yes	2.88
38.75N	-0.0142°C/yr	Yes	-17
38N	-0.0041°C/yr	Yes	-19
37.25N	-0.0042°C/yr	Yes	-17
36.5N	-0.0054°C/yr	Yes	-22
35.75N	-0.0025°C/yr	Yes	-12

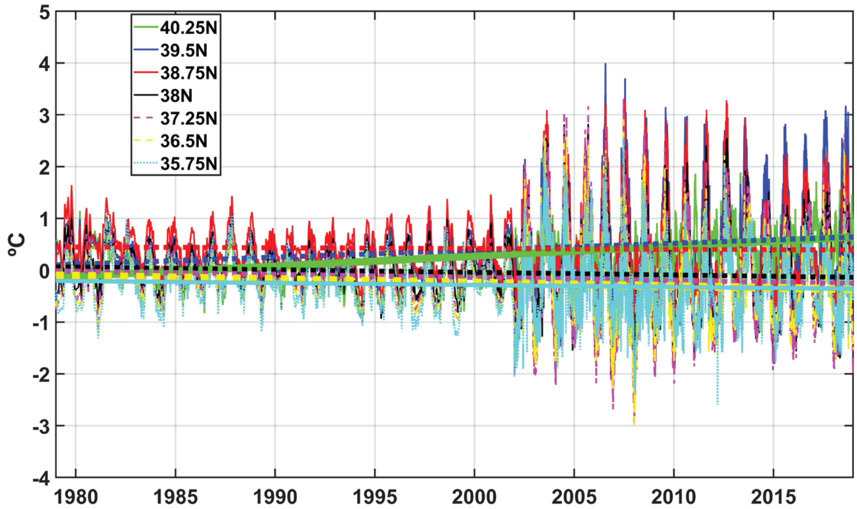

Fig. 10: Linear trend analyses of daily UI(SST).

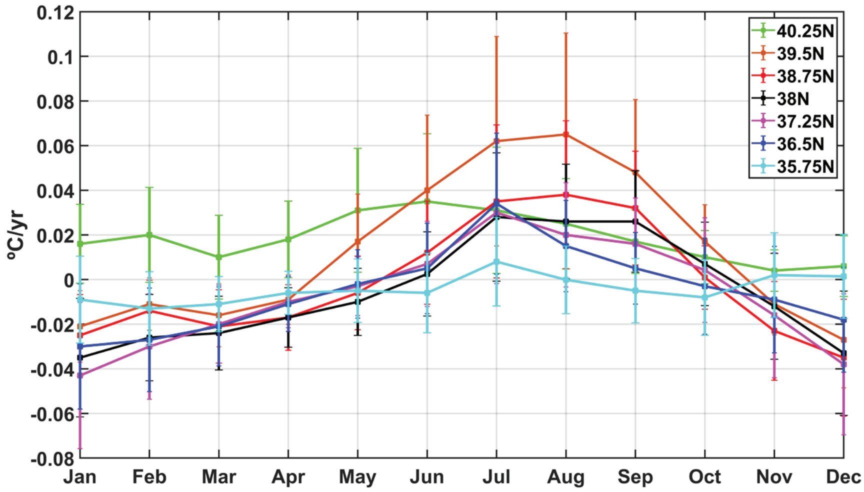

Fig. 11: Monthly linear trend rates of UI(SST) with its estimate of error.

about 6°C in the range of the seasonal cycle after 2003. This jump could be explained by the different increasing and decreasing trend rates on the east-west axis. The increasing rate of the SST trend in the northwestern part (+0.029°C/yr) is significantly greater than that in the northeastern part (+0.017°C/yr). Such a jump from smaller to greater differences might have impacts on the global climate system. Recently detected fingerprints of fluctuations indicate a gradual strengthening over the last decade, but the exact reasons for that strengthening remain uncertain.

UI(SST) has the largest prediction error for August at 39.5°N with a value of 0.065°C/yr and the lowest in August at 35.75°N with 0.0001 °C/yr. In general, the standard errors of central and northern latitudes (40.25°N, 39.5°N, 38.75°N, 38°N, 37.25°N) are greater than those of southern latitudes (36.5°N, 35.75°N).

UI calculations at each latitude were applied to determine not only upwelling strength but also spatial and temporal variations of upwelling. By looking at these results, new perspectives on the tendency and characterization of upwelling in the Aegean Sea can be developed. The results suggest that the UI will decrease where upwelling is expected, except for 39.5°N. To understand the positive slope at 39.5°N, further comprehensive investigation is needed due to the complex dynamics and relationships of the Aegean Sea with the TSS and the Mediterranean Sea. Hence, further studies may be recommended on UI(wind) in order to focus on the driver of upwelling rather than a visible output parameter such as SST. In general, coastal upwelling systems provide high productivity in nutrient-rich waters (Ryther, 1969; Cushing, 1971; Millan-Numez *et al*., 1982; Freon *et al*., 2009). However, this does not make a significant impact in the Aegean Sea since the upwelling depth is not sufficient to bring nutrients to the surface (Mamoutos *et al*., 2017). Thus, a nutrient-based UI, like that used by Garcia-Reyes *et al*. (2014) for the Gulf of Farallones, is not recommended for this region.

Seasonal variations in trends

Detailed monthly trend rates with an estimate of the standard error present different results for different months and seasons. Monthly trend rates vary both spatially and temporally. According to Figure 12, there is a decreasing trend at the southeastern (Jan, Feb, Mar, Apr, Oct (nearly flat) Nov, Dec) and southwestern (Jan, Oct

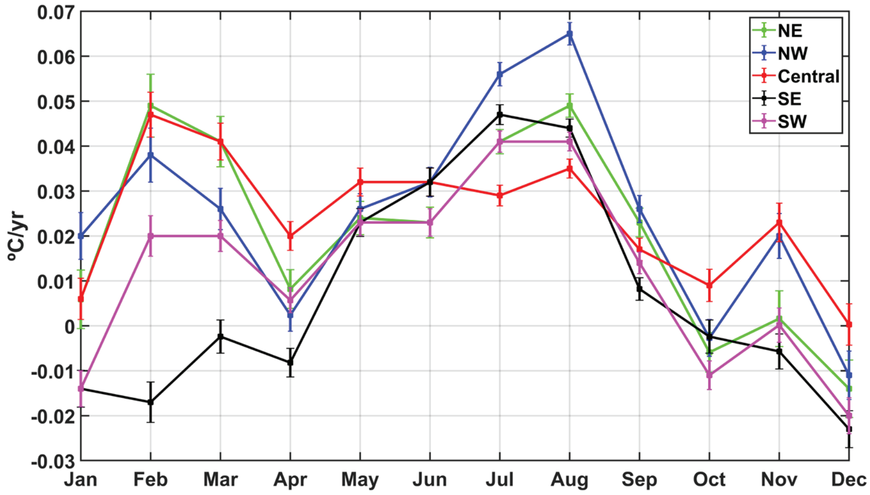

Fig. 12: Monthly linear trend rates of air temperature with its estimate of error.

(nearly flat), Nov, Dec) locations for air temperature, especially in winter. In other seasons, an upward trend is seen, and in summer all locations have a strong increasing trend with rates above 0.036°C/yr. The highest increasing rate is seen at 0.065°C/yr in the northwestern region in August. It seems that the temperature difference between summer and winter will continue to increase in future years due to the difference in the rising rates. The largest standard error (0.007°C/yr) was obtained in February at the northeastern location and the smallest (0.002°C/yr) was obtained from the southeastern location in August. The mean value of the standard errors of northern points (>0.004°C/yr) was greater than that of the southern and central locations (~0.003°C/yr).

The monthly trends of air temperature obtained here are generally compatible with those of previous studies (Frich *et al.*, 2002; Domonkos *et al.*, 2003; Good *et al.*, 2008). It should be clearly stated, however, that air temperature has different patterns and trends with respect to geographical positions. The monthly trends are well synchronized in upward and downward directions. In summer, all locations have a strong increasing tendency with rates above 0.03°C/yr. In October and December, a cooling trend is obvious for all parts except the central part as presented in Figure 12.

Monthly examination of SST trends reveals the existence of downward trends for the months of March and April in the northwestern part and June, July, August, and September in the northeastern part even though the slopes are nearly flat. Other than that, all months have a rising slope. Monthly SST plots (Fig. 13) indicate that the warming period is significant in all seasons. In the research conducted by Kuleli & Bayazit (2020), which covered the summer season and a small part of the Aegean Sea based on 30 years of Landsat data, SST was found to exhibit a rising trend with a rate of +0.11°C per year, which is greater than our result (~0.045°C/yr) obtained from the point closest to the area they studied. According to seasonal trend rates, our results are consistent with those of Skliris *et al*. (2011) and Shaltout & Omstedt (2014) in terms of warming even though the rates are not exactly the same. The comparisons shown in Table 1 suggest that general trend rates for the whole of the Aegean Sea will not give accurate results; detailed regional investigations are necessary for a better understanding of the trends. We observed the highest standard error (0.00259°C/yr) in May at the northwestern location and the lowest (0.00096°C/yr) in March at the northwestern

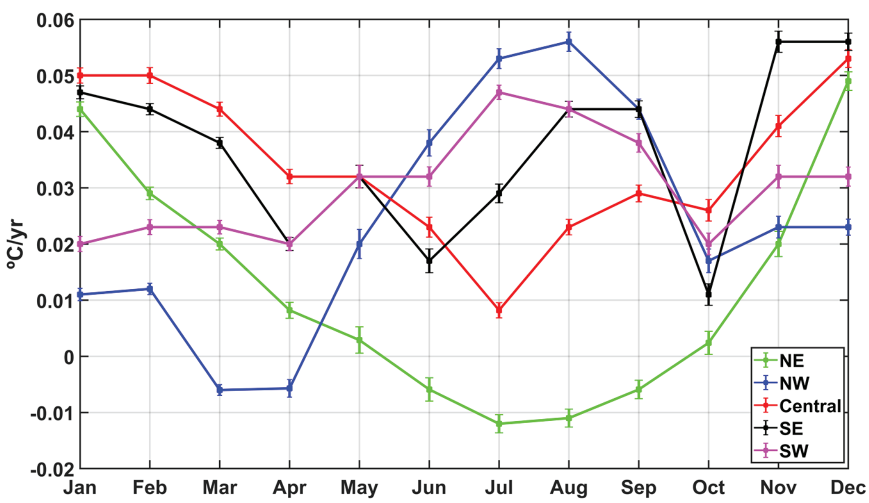

Fig. 13: Monthly linear trend rates of SST with its estimate of error.

and southeastern locations. The average standard errors of all locations do not vary, fluctuating between 0.0015 and 0.0016°C/yr.

The maximum upward trend in SST was observed in August (+0.056°C/yr) in the northwestern region, while the maximum downward trend was detected for July and August (-0.011°C/yr) in the northeast. The negative tendency of SST and the positive slope for air temperature along the sea's northeastern side are interesting points to consider. To understand this apparent contradiction, UI calculations and wind speed were investigated. UI(SST) and wind speed show upward trends at the same latitude of the northeastern area in summer. A decreasing trend is detected in winter, autumn, and spring, but a tendency toward an increasing trend (0.0081 kts/yr, nearly flat) is seen in summer for the northeastern area. Wind is the mechanism behind upwelling, so the increasing trend for that mechanism provides a clue. However, further analyses should be performed on a synoptic scale for surface pressure to identify the reason for this result definitively. To our knowledge, the reason is not merely surface pressure or wind speed as the water comes from the Black Sea and the Mediterranean Sea and is further influenced by the thermohaline circulation of the Aegean Sea.

The findings for SST and air temperature indicate a continuous upward trend for all parts of the Aegean Sea at different rates. Seasonal and monthly trends (Fig. 14) of wind speed are much more complicated than SST and air temperature trends because the wind speed varies from season to season for each location. Generally, it has a downward trend for all seasons with the following exceptions: southwestern in winter, northwestern in summer and autumn, and northeastern in summer, being nearly flat in the latter case. The highest decreasing trend (-0.057 kts/yr) is obvious in the southwestern region in July. On the other hand, the greatest increasing trend (+0.047 kts/yr) was detected in the northwestern region in August. For the period in which the Etesian winds blow, there is a decreasing trend reaching -0.053 kts/year in September for all locations except in the northwestern part, which has a positive trend with a rate of +0.03 kts/year in that month. The estimated standard error of wind speed is largest in September in the central part with a value of 0.0507 kts/yr and smallest in February at 0.013 kts/yr, again in the central area. The mean of the standard errors is 0.098 kts/yr.

From a seasonal perspective, the highest rate of decline (-0.063 mb/yr) for SLP is seen at the central loca-

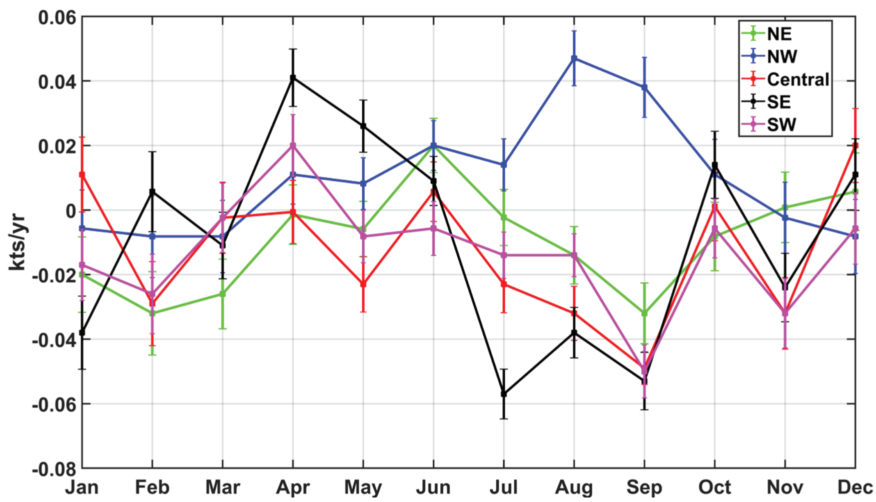

Fig. 14: Monthly linear trend rates of wind speed with its estimate of error.

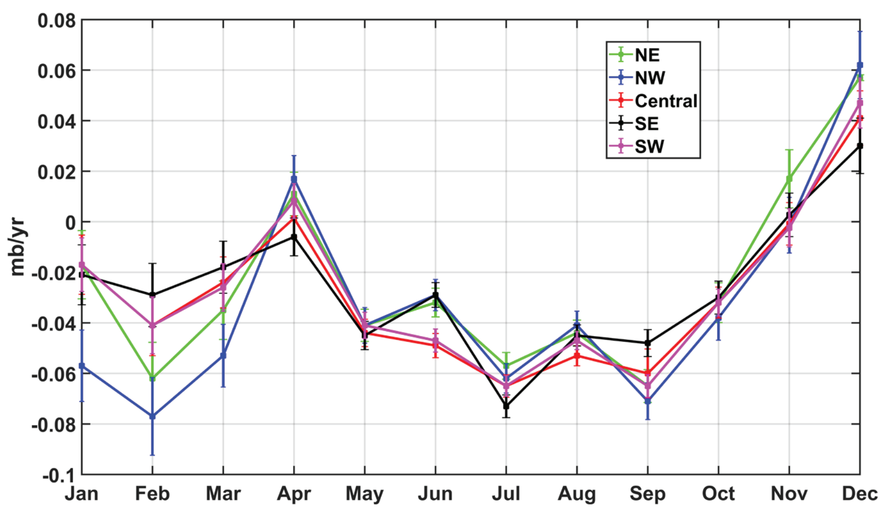

Fig. 15: Monthly linear trend rates of SLP with its estimate of error.

tions in summer. April, November, and December are the months with rising trends. In other months, clear declining trends are observed. Monthly SLP trend rates (Fig. 15) for all locations follow similar patterns. The highest upward trend rate is seen in December (~0.047 mb/yr) and the highest downward trends were detected in July and September (~0.07 mb/yr) for all locations. The maximum standard error (0.0154 mb/yr) was obtained in February at the northeastern location and the lowest (0.00114 mb/yr) was obtained from the northeastern location in December. The mean values of standard errors of the southwestern (0.0069 mb/yr), southeastern (0.0077 mb/yr), and central (0.0079 mb/yr) locations were lower than those of the northeast (0.0081 mb/yr) and northwest (0.096 mb/yr).

The SSS at the southern locations does not change much in accordance with the seasons, whereas seasonal responses are evident for the northern locations and absolute values are lower there than in the southern parts. The lowest SSS was observed in the northwestern region.

Conclusion

In this study, the Aegean Sea was investigated meteorologically and oceanographically using ECMWF ERA-Interim data for the years 1979-2018 and CMEMS (Global SSS/SSD L4) data for 2000-2015. Time series were created from these datasets at five points that represent the meteorological and oceanographic features of the Aegean Sea, averages were calculated, and analysis was performed for upwelling together with trend analysis. One of the main objectives of this study has been to reveal the trends of SST, air temperature, wind speed, and SLP. Thanks to studies performed at critical locations, fruitful analyses could be conducted by creating time series. In those analyses, it was revealed that there have been considerable changes in SST, air temperature, SLP, wind speed, and UI values for different locations over a 40-year period.

This study has shown that broad warming is evident in the first quarter of the 21st century, similarly to previous studies. According to our calculations, there has been a decrease in wind speed and SLP. From a seasonal perspective, the highest decrease in SLP (-0.063 mb/year) was observed at the central location in summer. Although April, November, and December are the months with increasing trends, there is generally a decreasing trend in SLP. It was determined that the maximum upward SST trend occurred at the northwestern location in August (+0.056°C/year), while the highest cooling trend was detected in the northeast in July and August (-0.011°C/year). When detailed monthly analysis was performed for air temperature, a decreasing trend was observed in the southwestern and southeastern regions, especially in winter, with an increasing trend in other seasons. The most prominent result regarding monthly trend rates for wind speed data is the significant decrease (reaching -0.053 kts/year) detected at all locations (except the northwest) during the time period in which the Etesian winds blow. The reason for the decrease in air temperature in winter and increase in summer may be the increasing trend of SLP in winter and decreasing trend of SLP in summer.

Wind speed and direction vary across the seasons and wind mostly tends to blow from north. Changes in the synoptic scale are determinative in the origin of all these effects. The decrease in the difference between the SLP values over the Balkans and Siberia is one of the reasons for the decrease in wind speed. In addition to the synoptic effects, the seasonal amount of water coming from the Black Sea and the route it follows are other reasons for regionally different trends in the Aegean Sea, as are the interactions with the Mediterranean Sea and the Ionian Sea. Moreover, the upward tendency in SSS could be seen in the CMEMS data for the southern part of the sea. Regarding standard errors, it may be stated that the error values of air temperature, SST, and wind speed data are generally stable while the SLP and UI(SST) error values are unstable.

To our best knowledge, UI calculations, which were previously only applied for open seas, were conducted in this study for the first time for the Aegean Sea and their effectiveness was tested. With the friction force created by the Etesian winds on the sea's surface and the help of the Coriolis force, the surface waters are replaced by waters from the intermediate layer (Androulidakis *et al*., 2017; Mamoutos *et al*., 2017). Those upwelled waters are denser and colder than the offshore deflected surface waters and so, to detect upwelling strength, a low SST is good output for analyses.

While trend analyses were performed for five designated locations, UI calculations were made on a latitudinal basis over SST. Calculations for UI(SST) show that strong upwelling events occurred at latitudes of 38.75°N, 39.5°N, and 38°N. According to these results, upwelling starts to increase in May and reaches its highest level in August, decreasing in September. UI(SST) provides a rough estimate of the latitudes of the upwelling areas and UI(SST) is therefore not a final algorithm to be put forward for detecting upwelling. Currents and winds, which are the mechanisms behind upwelling, must be considered for UI calculations. In this context, the development and use of a new upwelling index in which current and wind data are taken into account in addition to SST, with calculations performed for the unique dynamics of the Aegean Sea, will give more accurate results for the region. The existence of many small cyclonic/anticyclonic cycles and the effect of the coastal structure of the region on the surface water necessitate the investigation of vertical current variations related to depth and wind stress. Hence, further studies on UI are recommended to focus on the driving parameters of upwelling instead of visible output parameters such as SST.

All of the findings obtained in this study show that the variability of the SST, air temperature, SSS, SLP, and wind speed data of the ECMWF and CMEMS represent realistic results, although there are some differences in previous studies.

Acknowledgements

We would like to express our gratitude to Office of Navigation, Hydrography and Oceanography and Istanbul University that led to make this research happen. Also, we wish to say "thank you" to scientists who add value to understand the dynamics of Aegean Sea.

References

Anagnostopoulou, C., Zanis, P., Katragkou, E., Tegoulias, I., Tolika, K., 2014. Recent past and future patterns of the Etesian winds based on regional scale climate model simulations. *Climate Dynamics*, 42 (7), 1819-1836.

Androulidakis, Y., Krestenitis, Y., Psarra, S., 2017. Coastal Upwelling Over the North Aegean Sea: Observations and Simulations. *Continental Shelf Research*, 149, 32-51.

Bengtsson, L., Hagemann, S., Hodges, K., 2004. Can climate trends be calculated from reanalysis data?. *Journal of Geophysical Research*, 109.

Bengil, F., Mavruk, S., 2018. Warming in Turkish Seas: Comparative Multidecadal Assessment. *Turkish Journal of Fisheries & Aquatic Science*, 19 (1), 51-57.

Berrisford, P., Dee, D., Poli, P., Brugge, R., Fielding, K. *et al*., 2011. The ERA-Interim Archive, Version 2.0, ERA Rep. Ser.No.1(Tech. Rep.).

Besiktepe, S.T., Sur, H.I., Ozsoy, E., Latif, M.A., Oguz, E. *et al*., 1994. The circulation and hydrography of the Marmara Sea. *Progress in Oceanography,* 34 (4), 285-334.

Bromwich, D., Fogt, R., Hodges, K., Walsh, J., 2007. Tropospheric assessment of ERA-40, NCEP, and JRA-25 global reanalyses in the polar regions. *Journal of Geophysical Research*, 112, D10111.

Camp, L.V., Nykjaer, L., Mittelstaedt, E., Schlittenhardt, P., 1991. Upwelling and boundary circulation off northwest Africa as depicted by infrared and visible satellite observations. *Progress in Oceanography*, 26 (4), 357-402.

Cushing, D.H., 1971. Upwelling and the production of fish. *Advances in Marine Biology,* 9, 255-334.

Eronat, C., Sayın, E., 2014. Temporal evolution of the water characteristics in the bays along coast of the Aegean Sea: Saros, Izmir, Gökova bays. *Turkish Journal of Earth Sciences,* 23, 53-66.

Demarcq, H., Faure, V., 2000. Coastal upwelling and associated retention indices derived from satellite SST. Application to Octopus vulgaris recruitment. *Oceanologica Acta*, 23 (4), 391-408.

Domonkos, P., Kysely, J., Piotrowicz, K., Petrovic, P., Likso, T., 2003. Variability of the extreme temperature events in South-Central Europe during the 20th century and its relationship with large scale circulation. *International Journal of Climatology,* 23, 987-1010.

Freon, P., Barange, M., Aristegui, J., 2009. Eastern boundary upwelling ecosystems: Integrative and comparative approaches. *Progress in Oceanography,* 83 (1-4), 1-14.

Frich, P., Alexander, L.V., Della-Marta, P., Gleason, B., Haylock, M. *et al*., 2002. Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research,* 19 (3), 193-212.

Garcia-Reyes, M., Largier, J.L., Sydeman, W.S., 2014. Synoptic-scale upwelling indices and predictions of phyto- and zooplankton populations. *Progress in Oceanography*, 120, 177-188.

Georgiou, S., Mantziafou, A., Sofianos, S., Gertman, I., Ozsoy, E. *et al*., 2015. Climate variability and deep water mass characteristics in the Aegean Sea. *Atmospheric Research,* 152, 146-158.

Glickman, T. (Ed.), 2000. *Glossary of Meteorology*. American Meteorological Society, Boston, USA, 850 pp.

Good, P., Giannakopoulos, C., Flocas, H., Tolika, K., Anagnostopoulou, C. *et al*., 2008. Significant changes in the regional climate of the Aegean during 1961-2002. *International Journal of Climatology,* 28 (13), 1735-1749.

Hasanean, H.M., 2001. Fluctuations of surface air temperature in the Eastern Mediterranean. *Theoretical and Applied Climatology,* 68, 75-87.

Ilicak, M., Federico, I., Barletta, I., Mutlu, S., Karan, H. *et al*., 2021. Modeling of the Turkish Strait System Using a High Resolution Unstructured Grid Ocean Circulation Model. *Journal of Marine Science and Engineering*, 9 (7), 769.

Incarbona, A., Marrat, B., Mortyn, P.G., Sprovieri, M., Ziveri, P. *et al*., 2016. Mediterranean circulation perturbations over the last five centuries: Relevance to past Eastern Mediterranean Transient - type events. *Scientific Reports*, 1-10.

IPCC Climate Change, 2001. *The Scientific Basis Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, UK and USA.

IPCC, 2019. *Global Warming of 1.5°C*. Cambridge University Press, UK and USA.

Klein, B., Roether, W., Manca, B., Bregant, D., Beitze, V. *et al*., 1999. The large deep water transient in the Eastern Mediterranean. *Deep-Sea Research Part-I: Oceanographic Research Papers,* 46 (3), 371-414.

Kourafalou, V.H., Barbopoulos, K., 2003. High resolution simulations on the North Aegean Sea seasonal circulation. *Annals of Geophysics*, 21 (1), 251-265.

Kuleli, T., Bayazit, S., 2020. Summer season sea surface temperature changes in the Aegean Sea based on 30 years (1989-2019) of Landsat thermal infrared data. *Environmental Monitoring Assessment*, 192, 716.

Lathuilière, C., Echevin, V., Lèvy, M., 2008. Seasonal and intraseasonal surface chlorophyll-a variability along the northwest African coast. *Journal of Geophysical Research: Oceans*, 113, C05007.

Lelieveld, J., Berresheim, H., Borrmann, S., Crutzen, P., Dentener, P. *et al.,* 2002. Global air pollution crossroads over the Mediterranean. *Science,* 298 (5594), 794-799.

Mamara, A., Argiriou, A.A., Anadranistakis, M., 2015. Recent trend analysis of mean air temperature in Greece based homogonized data. *Theoretical and Applied Climatology,* 126 (3-4), 543-573.

Mamoutos, I., Zervakis, V., Tragou, E., Karydis, M., Frangoulis, C. *et al*., 2017. The role of wind-forced coastal upwelling on the termohaline functioning of the North Aegean Sea. *Continental Shelf Research,* 149, 52-68.

Mexatas, A., Bartzokas, A., 1994. Pressure covariability over the Atlantic, Europe and N.Africa Application: Centers of action for temperature, winter precipitation and summer winds in Athens, Greece. *Theoretical and Applied Climatology,* 49 (1), 9-18.

Millan-Nunez, R., Alvarez-Borrego, S., Nelson, D.M., 1982. Effects of physical phenomena on the distribution of nutrients and phytoplankton productivity in a coastal lagoon. *Estuarine Coastal Shelf Science*, 15 (3), 317-335.

NASA Global Climate Change Website, 2019. *What is the Sun's Role in Climate Change.* https://climate.nasa.gov/ask-nasa-climate/2910/what-is-the-suns-role-in-climate-change/ (Accessed 6 September 2019)

Nykjær, L., Camp, V.L., 1994. Seasonal and interannual variability of coastal upwelling along northwest Africa and Portugal from 1981 to 1991. *Journal of Geophysical Research: Oceans*, 99 (C7), 14197-14207.

Olson, D.B., Kourafalou, V.H., Johns, W.W., Samuels, G., Veneziani, M., 2007. Aegean surface circulation from a satellite-tracked drifter array. *Journal of Physical Oceanography*, 37 (7), 1898-1917.

Ozsoy, E., Unluata, U., 1997. Oceanography of the Blacksea. *Earth Science Reviews* 42 (4), 231-272.

Philandras, C.M., Nastos, P.T., Repapis, C.C., 2008. Air temperature variability and trends over Greece. *Global NEST Journal*, 10 (2), 273-285.

Poupkou, A., Zanis, P., Nastos, P., Papanastasiou, D., Melas, D. *et al*., 2011. Present Climate Trend Analysis of Etesian Winds in the Aegean Sea. *Theoretical Applied Climatology*, 106 (3), 459-472.

Roether, W., Klein, B., Manca, B.B., Theocharis, A., Kioroglou, S., 2007. Transient Eastern Mediterranean deep waters in response to the massive dense-water output of the Aegean Sea in the 1990s. *Progress in Oceanography*, 74 (4), 540-571.

Roether, W., Manca, B.B., Klein, B., Bregant, D., Georgopoulos, D. *et al*.,1996. Recent changes in the Eastern Mediterranean deep waters. *Science,* 271 (5247), 333-335.

Ryther, J.H., 1969. Photosynthesis and fish production in the sea. *Science,* 166 (3901), 72-76.

Santos, F., DeCastro, M., Gomez-Gesteira, M., Alvarez, I., 2012. Differences in coastal and oceanic SST warming rates along the Canary upwelling ecosystem from 1982 to 2010. *Continental Shelf Research,* 47, 1-6.

Savvidis, Y.G., Dodou, M.G., Krestenitis, Y.N., Koutitas, C.G., 2004. Modeling of the upwelling hydrodynamics in the Aegean Sea. *Mediterranean Marine Science,* 5 (1), 5-18.

Sayın, E., Eronat, C., Uckac, S., Besiktepe, S., 2011. Hydrography of the Eastern Part of the Aegean Sea during the Eastern Mediterranean Transient (EMT). *Journal of Marine Systems,* 88 (4), 502-515.

Shaltout, M., El Gindy, A., Omstedt, A., 2013. Recent climate trends and future scenarios along the Egyptian Mediterranean coast. *Geofizika*, 30 (1), 19-40.

Shaltout, M., Omstedt, A., 2014. Recent sea surface temperature trends and future scenarios for the Mediterranean Sea. *Oceanologia,* 56 (3), 411-443.

Skliris, N., Mantziafou, A., Sofianos, S., Gkanasos, A., 2010. Satellite-derived variability of the Aegean Sea ecohydrodynamics. *Continental Shelf Research,* 30 (5), 403-418.

Skliris, N., Sofianos, S., Gkanasos, A., Mantziafon, A., Axaopoulos, P. *et al*., 2011. Long-term sea surface temperature variability in the Aegean Sea. *Advances in Oceanography Limnology,* 2 (2), 125-139.

Theocharis, A., Georgopoulos, D., 1993. Dense water formation over the Samothraki and Limnos Plateaux in the North Aegean Sea(Eastern Mediterranean Sea). *Continental Shelf Research*, 13 (8-9), 919-939.

Tyrlis, E., Lelieveld, J., 2013. Climatology and Dynamics of the Summer Etesian Winds over Eastern Mediterranean. *Journal of Atmospheric Sciences,* 70 (11), 3374-3396.

Unluata, U., 1986. *A Review of the Physical Oceanography of the Levantine and the Aegean Basins of the Eastern Mediterranean in Relation to Monitoring and Control of Pollution*. METU Institute of Marine Science Technical Report, 55.

Vagenas, C., Anagnostopoulou, C., Tolika, K., 2017. Climate study of the marine surface wind field and extreme winds over the Greek seas with the use of a High Resolution RCM Focusing on Extreme Winds. *Climate,* 5 (2), 29.

Vlahakis, G.N., Pollatou, R.S., 1993. Temporal variability and spatial distribution of the sea surface temperatures in the Aegean Sea. *Theoretical Applied Climatology*, 47, 15-23.

Von Schuckmann, K., Le Traon, P.Y., Fanjul, E.A., Axell, L.B., Balmaseda, M.A. *et al*., 2016. The Copernicus Marine Environment Monitoring Service Ocean State Report. *Journal of Operational Oceanography*, 9 (sup2), 235-320.

Weisse, R., Storch, H., Callies, U., Chrastansky, A., Feser, F. *et al*., 2009. Regional meteorological-marine reanalyses and climate change projections: Results for Northern Europe and potentials for coastal and offshore applications. *Bulletin of American Meteorological Society*, 90, 849-860.

Weisse, R., Storch H., 2010. *Marine Climate and Change Storms, Wind Waves and Storm Surges*. Praxis Publishing, Chichester, UK, 247 pp.

World Meteorological Organization, 2017. Guidelines on the Calculation of Climate Normals, No-1203.

Zervakis, V., Georgopoulos, D., 2002. Hydrology and circulation in the North Aegean (Eastern Mediterranean) throughout 1997-1998. *Mediterranean Marine Science*, 3 (1), 7-21.

Zervoudaki, S., Kaliva, K., Apostolopoulou-Moraitou, M., 1999. Seasonal variation of hydrobiochemical variables in a coastal area of an ichthyoculture. In: *Proceedings of the 6th International Conference on Environmental Science and Technology*, 100, 474-481.

Ziv, B., Saaroni, H., Alpert, P., 2004. The Factors Governing The Summer Regime of the Eastern Mediterranean. *International Journal of Climatology*, 24, 1859-1871.