Rapid increase of Mediterranean Sea Surface Temperature from 1982 to 2020

Azad Rasul (azad.rasul@soran.edu.iq)
Soran University https://orcid.org/0000-0001-5141-0577
Kaka Jaafar Aziz
Soran University

Research Article

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Abstract

Intergovernmental Panel on Climate Change (IPCC) considers Mediterranean Sea a climate change hotspot, particularly it is vulnerable to increasing sea surface temperature. The research aimed to highlight the trend of Sea Surface Temperature (SST) of Mediterranean and analysis spatial variability of SST change from 1982 to 2020. Forty years SST of NOAA of AVHRR Pathfinder version 5.3 was deployed in the study. The data is processed in Google Earth Engine, cloud based remote sensing platform. The results display a rapid increase of SST of the sea occurred in mean SST (1.49°C) followed by maximum SST (0.91°C). Spatially, highest increase of SST (1–2°C) mainly happened in the eastern part of the sea. Monthly data indicated the highest increase in mean SST happened during June, July and May by 2.51, 2.28 and 2.23°C, respectively. Increasing of SST affects evapotranspiration, precipitation, and marine life but is also influenced by the increasing salinity of the sea at the same time.

1- Introduction

Sea Surface Temperature (SST) is one of the essential climate and ocean variables (Merchant et al. 2019; Yang et al. 2021), contributing to the state of climate of our planet (Pastor 2021). Regards to climate change and warming global average of ocean temperatures, Mediterranean Sea is considered a climate change hotspot by Intergovernmental Panel on Climate Change (IPCC)(Bernstein et al. 2008), particularly it is vulnerable to increasing sea surface temperature because of increasing emissions of greenhouse gas (Shaltout and Omstedt 2014).

For more than 150 years, in situ SST data has been recorded using ships and drifting platforms. In addition, complementary to in situ data, satellite SST is derived from at-satellite radiances, which currently span around 50 years (Pastor et al. 2020), and it is advantage is spatial coverage of the globe. SST has many applications including quantification of climate change, models of climate and ocean, and understanding of marine ecology, and oceanography (Merchant et al. 2019).

Different authors have studied SST trend of the whole Mediterranean Sea and/or SST of Mediterranean sub-basins using in situ and/or satellite data. Results of the study Lelieveld et al. (2002), based on the in situ data, displayed that from 1970 to 1980, Mediterranean SST was decreased, and then up to 2000, it warmed significantly by 0.03°C /year. Based on satellite images, D’Ortenzio et al. (2000) claimed no significant trend in SST of the sea using AVHRR data from 1985 to 1996. In contrast, a decadal trend of average SST of Mediterranean was 0.035°C /year in (Pastor et al. 2020) and 0.037°C /year from 1985 to 2008 by Skliris et al (2012).

Spatial variability results of SST trend found that eastern part of Mediterranean is warming faster than western part (Nykjaer 2009; Skliris et al. 2012; Soto-Navarro et al. 2020). The rate of this increase SST was 0.037°C /year (from 1985 to 2008) (Skliris et al. 2012) and was 0.042°C /year in Soto Navarro et al (2020) study, while this rate was 0.026 in the western part of the sea. Results of majority of mentioned studies confirm increasing trend of Mediterranean SST since the beginning of 1980s (Pastor et al. 2020).

However, temporal analysis of SST of the sea using long period is still necessary to assess the increasing the rate of warming SST. In addition to annual variability, addressing the trend of the SST in seasons and months scale still needs attention.

The current research aimed to: 1) Analysis the trend of Sea Surface Temperature (SST) of Mediterranean. 2) Analysis spatial variability of SST change from 1982 to 2020. 3) Examine trend of SST of the sea at monthly level. These objectives are important because increasing SST affects evapotranspiration, precipitation, and marine life. To achieve these objectives, forty years SST of AVHRR was deployed in the study and process in GEE platform. Section 3.1 of the research presented the results of the spatial variability of SST of the sea while annual and monthly variation of SST is included in Section 3.2. Lastly, the discussion of the results and the main conclusions are displayed in Sections 4 and 5.

2- Data And Methodology

2 – 1 Study area

Astronomically, the Mediterranean Sea is located between the 31° 13' – 45° 87' latitudes of the northern hemisphere and 26° 20' E longitude and 5° 56' W longitude (Fig. 1). The area of the sea including the Sea of Marmara is about 2,510,000 km^2 (Boxer and Salah 2019). It is surrounded by land on three sides and connected to the Atlantic Ocean from the west. The eastern part of the sea consists Aegean, Levantine, Ionian and Adriatic Sea while the west part includes Ligurian, Tyrrhenian, Sicily, Balearic and the Alboran Sea. The Mediterranean climate describes as dry and hot during the summer, cold, and rainy during the winter. The highest temperature of the Mediterranean is 31°C, which was recorded in August in the Gulf of Sidra. While the minimum surface temperature of the sea is 5°C which was observed in February in the north of the Adriatic (Boxer and Salah 2019). Increasing emissions of greenhouse gas lead to the sea is vulnerable to increasing SST and making it a climate change hotspot (Shaltout and Omstedt 2014).

2-2 Data and methods

In the research, we used SST of NOAA of AVHRR Pathfinder version 5.3 to analyses the trend and spatial variation of Mediterranean SST. Used satellite images have a resolution of 4 KM per pixel and twice time passing. We used the SST NOAA from the start of availability of data in GEE (1982) to 2020.

The data processed in Google Earth Engine (GEE) cloud based remote sensing platform and the used code of JAVA Script is available in Appendix I. To find a trend of SST, we converted twice data to average, minimum and maximum of each month and year during the study period. Then we exported extracted results through Google Drive to local computer for further analysis in R programming. In addition, to extract spatial difference in the rate of SST change during the last period, we created average of five years (2016–2020) and average of twenty years (1982–2001) as a base then distracted average of 1982–2001 from 2016 – 2010 average to display the spatial change.

The quantification of the change in the direction of the SST of Mediterranean Sea has been carried out in the statistical program R using the Theil–Sen approach (TSA), according to Eq. (1). The significance of change was determined according to the Kendall test as shown in Eq. (2).

$$b = Median\left(\frac{x_j - x_l}{j - l}\right) \forall l < j (1)$$

where b is the estimation of the slope of the trend and x_l is the lth observation.

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) (2)$$

$$sign(x_j - x_i) = \begin{cases} 1 if x_j - x_i > 0 \\ 0 if x_j - x_i = 0 \\ -1 if x_j - x_i < 0 \end{cases}$$

where: $x_1, x_2 \ldots x_n$ represent n data points, x_j represents the data point at time j and S is the Mann-Kendall test.

3- Results

3 – 1 Spatial variation of trend of Mediterranean SST

Regarding the spatial variation of Mediterranean SST, between 1982 and 2020, there are huge differences (Fig. 2) due to location differences, the effects of sea waves and other factors. Category SST of 13.5 to 16.8°C is located in the west, north and central Mediterranean, while category 16.8 to 20°C covers central, south and eastern parts of the sea. The higher SST (20-23.3°C) is located in the east and south east of the sea, in the east and south of Cyprus. It is maybe due to closure of the sea in the east and opening it in the west and its interaction with Atlantic Ocean. The cold category (0.29–13.5°C) is located in the north part of the sea such as north of Corse Island, Adriatic and Aegean Sea.

Regarding the spatial trend of Mediterranean SST during the study period (1982 to 2020), we compared average of last five years (2016–2020) to average of 1982–2001 as base data. Figure 3 displays that SST of most parts of the Mediterranean warmed and most parts of the sea are in range 0–1°C increase category that covers all parts of the sea, especially in the centre, south and the west part of Mediterranean. The area with highest increase of SST (1–2°C) although it is partly located in the west, however, the largest part of this category is located in the eastern part of the sea, for instance, around Crete island and in the west of Cyprus. As for the areas and pixels with decreased SST, they are neglected and located in the coastal areas as in the northern part of the sea.

3-2 Temporal variation and trend of Mediterranean surface temperature

Regarding the temporal variation of SST in the study area, we divide it into annual and monthly subsections as follows.

3-2-1 The trend of SST of Mediterranean SST at annual level

From 1982 to 2020, the lowest annual SST was 13.32 °C that recorded in 1984 while the highest annual average SST was recorded in 2017 and was 15.51 °C and the average of mean SST was 14.54 °C. The lowest maximum SST was 21.21 °C that recorded in 1984 while the highest annual average SST was recorded in 2012 (22.77 °C) and the average of maximum SST was 22.16 °C. The highest minimum SST was 0.21 °C in 2012 while the lowest minimum SST was -1.65 as recorded in 1997. The average of minimum SST was -0.72 °C.

The dotted plot line of Figure 4 displays that the direction of trend all of maximum, mean and minimum of SST of the sea is going up. Average SST of Mediterranean Sea statistically significantly increased by 1.49 °C (p-value <0.01) during forty years (1982 to 2020) with the increase of 0.038 °C/year (Figure 4). The maximum SST of the sea increased by 0.91 °C (p-value <0.01) and 0.023 °C/year during the same period, while insignificant low increase (0.08 °C/year, p-value = 0.78) happened in minimum SST of the sea.

3-2-2 The trend of SST of Mediterranean SST at monthly level

The lowest monthly average of SST of Mediterranean Sea was 7.9 °C and recorded during February, which faced the most fluctuations during the study period, while the highest SST temperature was recorded during August with 28.8 °C of maximum and 24.3 °C of average SST. As we mentioned before, from 1982 to 2020 the average SST of the sea increased by 1.49 °C (p-value <0.01), however, this change is not the same during different months of the year. The highest significant (p-value < 0.01) increase in mean SST happened during June, July and May by 2.51, 2.28 and 2.23 °C, respectively (Figure 5 and Table 1). In contrast, the lowest insignificant increase of mean SST recorded during September (0.13 °C; p-value = 0.63) and January 0.36 °C (p-value = 0.45).

Table 1: rate and yearly increase of Mediterranean SST from 1982 to 2020 in different months.

Months	Increase(1982-2020) °C	Annual increase °C	P-Value
Jan	0.36	0.009	0.451
Feb	1	0.026	0.466
Mar	0.94	0.024	0.315
Apr	2.09	0.054	0.000
May	2.23	0.057	0.007
Jun	2.51	0.064	0.000
Jul	2.28	0.058	0.000
Aug	1.79	0.046	0.002
Sep	0.13	0.003	0.633
Oct	1.33	0.034	0.131
Nov	1.82	0.047	0.004
Dec	1.27	0.033	0.031

4- Discussion

The research aimed to analyses spatiotemporal variation and trend of SST of Mediterranean Sea from 1982 to 2020. The results indicate that a rapid increase of SST of Mediterranean occurred in mean SST (1.49°C) followed by increasing maximum SST (0.91°C). The spatial analysis of the data suggested highest increase of SST (1–2°C) mostly happened in the eastern part of the sea, which already has a higher temperature than the north and west parts of the sea. Occurring the highest increase of SST in the eastern part of the sea may be due to surrounding the sea in this part by the land.

A decadal trend of average SST of our research was 0.38°C and yearly trend was 0.038°C a slightly higher than 0.037°C /year satellite-derived mean warming rate from 1985 to 2008 by Skliris et al (2012). In addition, our SST increasing rate is higher than 0.035°C /year of (Pastor et al. 2020). Our spatial variability result of SST trend that found eastern part of Mediterranean rise higher than western part in consistent with (Nykjaer 2009; Skliris et al. 2012; Soto-Navarro et al. 2020). For instance, Soto-Navarro et al. (2020) result that found the trend is 0.042°C /year in eastern part while 0.026°C /year in western part. Increase of SST leads to more evapotranspiration but it is combined with increasing salinity of the sea (Bindoff et al. 2007) that influences evapotranspiration and precipitation.

Soto-Navarro et al (2020) found the highest rate of increasing SST of Mediterranean in order occurred in spring (0.054°C/year), summer (0.044°C/year), autumn (0.027°C/year), and winter (0.023°C/year). Our monthly rate of SST indicates that the highest rate of SST increase occurred during summer months (June and July; Table 1) in agreement with (Nykjaer 2009) while the lowest increase rate happened during winter months (January February and March). It means increasing SST of the sea during warm months faster than increasing SST during cold months.

Used PATHFINDER SST satellite data only has two values per day and daily average is only calculated from these two values. In addition, while satellite image is advantageous for spatial analysis, it has a level of uncertainty related to the climatic situation at the time of satellite pass over the sea. Future research should address the influence of the rapid increase of Mediterranean SST on climatic elements such as evaporation, and precipitation in addition to marine life.

5- Conclusions

At the end of this study, based on analysis of forty years SST of AVHRR Pathfinder V. 5.3 data, we reached following conclusions:

1. Average SST of Mediterranean from 1982 to 2020 increased by 1.49 °C and annual increase by 0.038 °C.
2. During the same period, maximum SST of the sea raised by 0.91 °C, while minimum SST increased by 0.08 °C.
3. The highest increase of SST (1-2 °C) mostly happened in the eastern part of the sea around Create Island.
4. The southeastern part of the Mediterranean has a higher SST (13.5-26.6 °C) than other parts of the sea.
5. The highest increase in mean SST happened during June, July and May by 2.51, 2.28 and 2.23 °C, respectively.

Declarations

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Conflicts of Interest: The authors declare no conflict of interest.

Availability of data and material: not aplicable.

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Figures

Figure 1

Location of the study area.

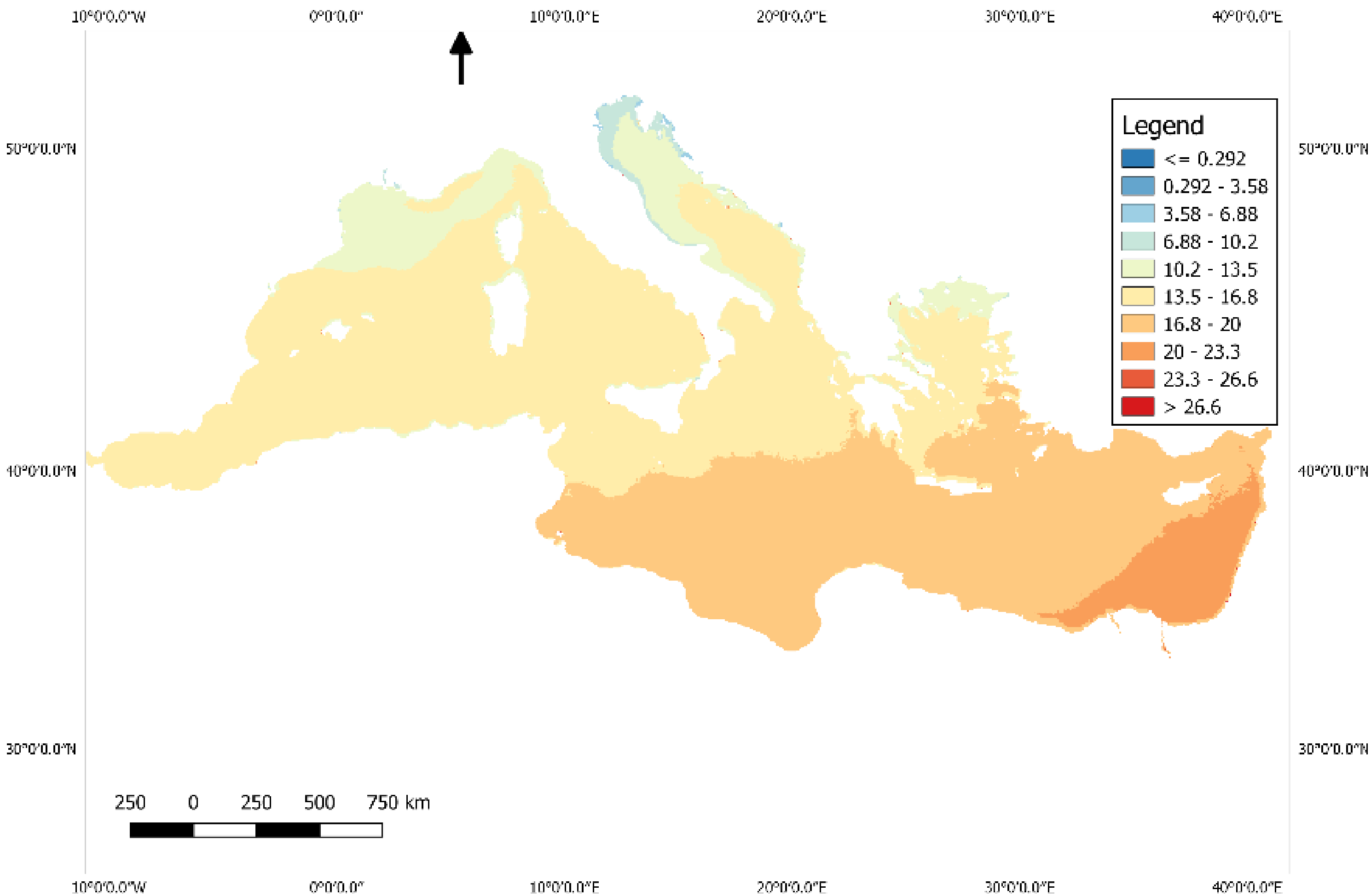

Figure 2

Spatial variation of Mediterranean SST based on average of 1982 to 2020 (AVHRR Pathfinder V. 5.3).

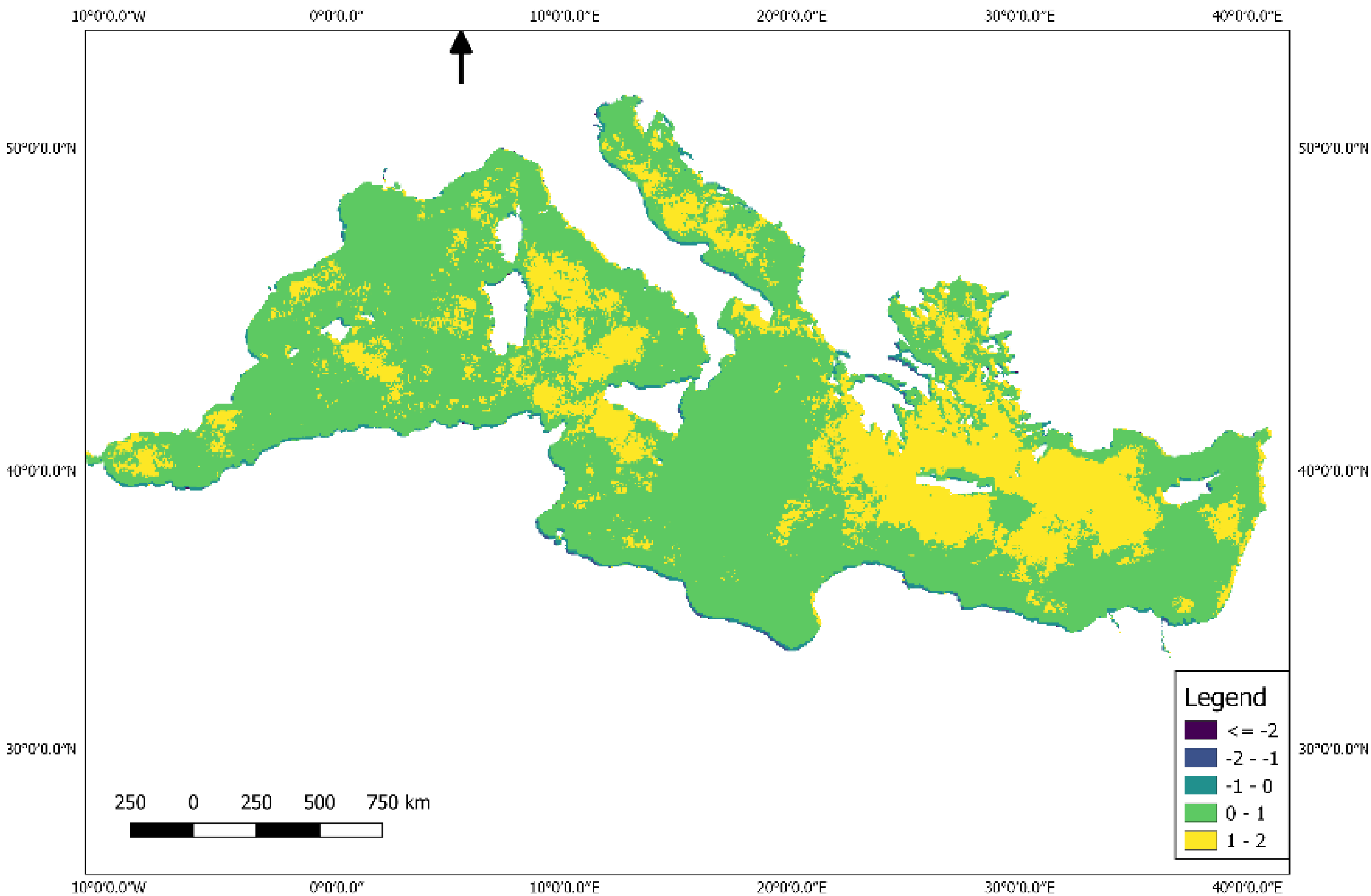

Figure 3

Spatial variation of the trend of SST of Mediterranean based on comparing average of 2016-2020 to average of 1982-2001 (AVHRR Pathfinder V. 5.3).

Figure 4

Annual variation of Mediterranean SST from 1982 to 2020 (AVHRR Pathfinder V. 5.3).

Figure 5

Monthly variation of Mediterranean SST from 1982 to 2020 (AVHRR Pathfinder V. 5.3).

Supplementary Files

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