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RESEARCH ARTICLE

Sea water temperature in the North Aegean Sea (Gökçeada Island) between 1972 and 2018: an implication of global warming

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Abstract

Long-term oceanographical measurements are scarce in the eastern Mediterranean, including the Turkish water. This study evaluated the long-term measurements of surface sea water temperature, which is the most critical parameter in terms of global warming, at Gökçeada Island in the North Aegean Sea between 1972 and 2018. It has been determined that the sea surface temperature (SST) increased by 1.6°C from 1972 to 2018. This long term and regularly sampled dataset can be an important baseline data for future studies of climate change as well as for national oceanographic monitoring at the Turkish part of the North Aegean Sea.

Keywords: Climate change, sea water temperature, long-term monitoring

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Introduction

Climate change and global warming can be detected using various climatic parameters such as temperature, precipitation, stream flow, evaporation, humidity, solar intensity, wind. Generally, temperature is more significant than others among these parameters (Ficke *et al.* 2007).

The issue of climatic change in the Mediterranean region has rather sparsely been addressed in studies performed more than 10-15 years ago (Lionello *et al.* 2006). The region has recently received increasing scientific interest. In fact, the

Mediterranean has some particular characteristics that demand to put it high on the research agenda.

Recent accelerated climate change has exacerbated existing environmental problems in the Mediterranean Basin that are caused by the combination of changes in land use and increasing pollution. Increasing water temperatures in Mediterranean lead to changes in species composition and abundance. In general, cold-water species become less abundant or extinct and warm-water species become more abundant, leading to homogenization of the Mediterranean biota with warm-water species (Barange *et al.* 2018).

The geographic distribution of many native species has changed. Due to the warming of the Mediterranean, warm-water species, such as the *Caranx crysos*, *Sparisoma cretense*, *Coryphaena hippurus*, *Balistes capriscus* and *Sphyraena barracuda* are moving northwards (Azzurro *et al.* 2011).

Temperature changes in the ocean strongly impact fish communities' structure, thus fisheries is currently impacted by climate change and acidification (Dulvy *et al.* 2008; Cheung *et al.* 2013). Some cold-water small pelagic species such as sprat have virtually disappeared from commercial catches of the northwestern Mediterranean. The expected migration of species to cooler areas as the ocean warms up is limited in enclosed seas like the Mediterranean Sea. Keskin and Pauly (2014) re-expressed catch composition of two trawl surveys in the northeastern Aegean Sea, conducted in 1997 and 2007, according to "mean temperature of the catch". The result of the study confirmed that global warming effects fisheries catch in the northeastern Aegean Sea.

While many studies have shown that the temperature of the Mediterranean Sea surface water has increased in recent years, only a few studies mentioned surface warming of the Aegean Sea, especially the North Aegean Sea.

Poulos *et al.* (1997) conducted seasonal sea surface temperature (SST) observations in the Aegean Sea, using satellite images covering a 6-year period (1988-1994). Theoharatos and Tselepidaki (1990) cross-correlated monthly values of air and sea-surface temperature in the Aegean Sea between 1971-1975. One of the most detailed studies in the Aegean Sea was conducted by Skliris *et al.* (2011); the annual scale variability of the Aegean SST was investigated by means of long-term series of satellite-derived data. Average SST time series were raised using the ICOADS (International Comprehensive Ocean Atmosphere Data Set) between 1950 and 2006, and also monthly mean SST maps were constructed based on a re-analysis of AVHRR Oceans Pathfinder (version 5.0) over the 1985-2008 period.

Gökçeada Marine Research Unit, Faculty of Aquatic Sciences, Istanbul University, formerly known as Gökçeada Sponge Research Institute, was

established in 1971 under Hydrobiology Research Institute of the same university. Since then, the unit has been performing fauna and flora identification studies and conducting oceanographic measurements (temperature, salinity, pH and dissolved oxygen) around Gökçeada. In this study, sea surface temperature dataset was used because it was the only dataset collected regularly.

The relation between sea surface temperature and presence of tropical species has been widely investigated in the Mediterranean Sea. Native biota of the North Aegean Sea is also affected by sea temperature increase. Many immigrant tropical species has been reported around Gokceada Island (Gönülal and Güreşen 2014; Dalyan *et al.* 2021). Among these species, *Siganus rivulatus* was captured in 1964 and presented in the Gökçeada Marine Museum (Gönülal and Güreşen 2017). Most of the sepcimens of alien species (*Callinectes sapidus, Lagocephalus spadiceus, Sphoeroides pachygaster* and *Processa macrodactyla*) were gathered from studies carried out around Gökçeada Island between 2007 and 2016. Moreover, Güreşen *et al.* (2015), based on the review of the long-term researches between 1973 and 2016, reported Indo-West Pacific originated phytobenthos species (*Acanthophora nayadiformis, Asparagopsis armata, Caulerpa racemosa* and its variety *Caulerpa racemosa* var. *cylindracea*).

Lastly and most importantly, two individuals of *Champsodon nudivittis* were captured about two months apart at the north of Gokceada Island in 2020 (Dalyan *et al.* 2021). *Champsodon nudivittis* is known as a predatory fish and have an opportunistic character, hence can be invasive in their newly arrived areas.

Materials and Methods

Long-term oceanographic measurements (1972-2018) of Gökçeada Island were collected by Gökçeada Marine Research Unit, Faculty of Aquatic Sciences, Istanbul University. Temperature data were obtained at Kaleköy station in the north-east of the island (Figure 1). The North Aegean Sea is mainly influenced by the Black Sea water that is cooler and having less saline characteristics. The Black Sea water mass reaches the east of Lemnos Island, crosses the channel between the northeast of Lemnos and west of Gökçeada Island, while a well-formed anticyclone is observed in the north-east corner of the basin, around the island of Samothraki Island (Oğuz 2015). However, it effects relatively less on the north-east of Gökçeada Island where the station is located. Black Sea water begins to be effective in the North Aegean Sea in September and lasts for about a month (Yüce 1987).

Until 2006, sea water samples were taken at depths to 50 m (depth range: 0, 10, 25, 50 m) by Nansen bottles with a pair of reversing thermometer. After 2006, a multi parameter device (HACH HQ40D) was used instead of reversing thermometer. Since the sea water temperature in lower layers were not regular, the data evaluated in the present study were SST only.

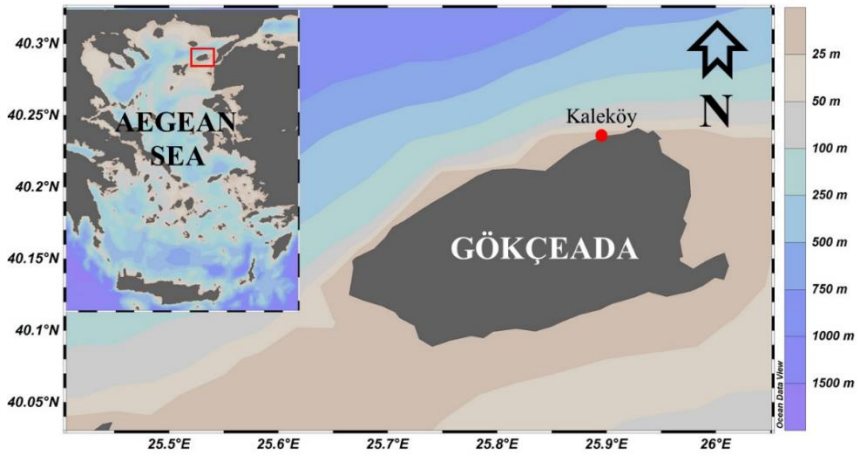

Figure 1. Kaleköy sampling station at Gökçeada Island, North Aegean Sea

The measurement data had been collected and reported, but not published until now. The reports are archived in the library of Gökçeada Marine Research Unit (Figure 2).

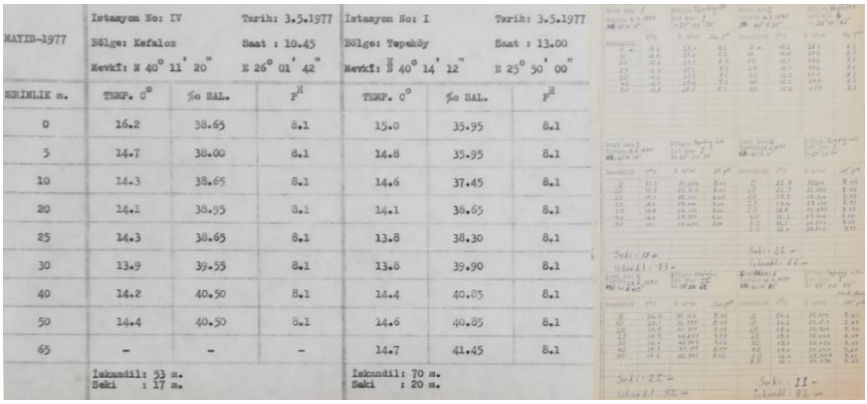

Figure 2. Some pages of the measurement reports

The Mann-Kendall correlation test is widely used and has shown good performance in determining a trend for hydro-meteorological variables. In this study, between 1972 and 2018, a trend in monthly average temperatures at Kaleköy station in Gökçeada Island was examined using Mann-Kendall correlation test. In addition, regression analysis was applied to quantify an increasing temperature trend. All statistical tests were made using an SPSS Statistics 20 program.

Results and Discussion

Monthly average temperature data and annual average SST data both showed a significantly increasing trend. The average SST increment at the North Aegean Sea was currently estimated 1.6°C for the period between 1972 and 2018 (Figure 3). In other words, annual average temperature was determined to increase 0.035°C/year. Correlation coefficient between months and temperature was 0.305 and monthly average temperature increase was found statistically significant (P<0.01) (Table 1).

However, a more thorough examination of the time series revealed a very small SST fluctuation trend until the early 1990's and then a warming trend throughout the rest of the record especially during the last decade.

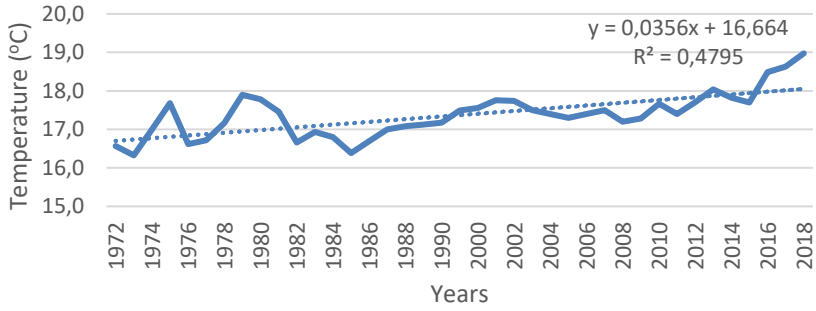

Figure 3. Mean annual sea surface temperature at Gökçeada Island

Table 1. Correlation between mean sea surface temperature (SST) and months/years (Mann-Kendall test)

		Years	Months
SST	Correlation Coefficient	0.59	0.305
	Probability (2-tailed)	0.60	<0.001*
	N	468	468

*Statistically significant p<0.001

The Mediterranean Sea is recognized as one of regions most sensitive to climate change. Moreover, the increasing pressure of other human activities further reduces the resilience and adaptability of ecosystems, habitats and biota related future climate change impacts acts (UNEP 2009). According to satellite observations from 1985-2006, SST of the Mediterranean Sea has been increasing at an average rate of 0.4°C per decade (+0.03°C, ± 0.008°C yr^{-1} for the western basin and +0.05 ± 0.009°C yr^{-1} for the eastern basin) (Nykjaer 2009). The increases in temperature are not constant throughout the year but occur primarily during May, June and July (Nykjaer 2009). Maximum increases of 0.16°C yr^{-1} are found in June in the Tyrrhenian, Ligurian and Adriatic Seas and close to the African coast (MedEEC 2019). Adloff *et al.* (2015) also claim that the warming

is not going to be homogenous in the Mediterranean Sea in the future. In addition, the region of the Balearic Islands, the Northwest Ionian, the Aegean and Levantine Seas become warmer than the average. The projections for 2100 vary between +1.8°C and +3.5°C in average compared to the period between 1961 and 1990 (MedEEC 2019).

The Aegean Sea is connected with the Ionian and Levantine Basins through the Cretan Arc and with the Black Sea through the Turkish Straits System. Due to its small size, the Aegean Sea surface rapidly responds to the meteorological changes and the variability of the lateral fluxes and this variability propagates in the thermohaline characteristics of the deep water masses of the basin through deep water formation processes (Georgiou *et al.* 2015). It is not well known that exchange fluxes through the straits especially at the intermediate and deep layers. Black Sea water enters the Aegean Sea at the Çanakkale Strait junction region within the west-southwest sector, crosses the channel between the Limni and Gökçeada Islands (Oğuz 2015). Black Sea water has a controlling function on the vertical stability and mixing in the North Aegean Sea. Seasonal and interannual variations of the Black Sea water outflow may effect the thermohaline circulation and SST in the North Aegean Sea.

Poulos *et al.* (1997) estimated the annual net heat flux is 26 w/m^2 in the Aegean Sea. The wind climate of the Aegean is subject to winds associated with the cold outbreaks arriving from the north and cyclones arriving from the west as well as local and regional winds due to the influence of the orography (Beşiktepe 2015). Aegean Sea water masses are formed from combinations of Black Sea and Levantine Sea as well as locally formed water masses due to the atmospheric cooling/heating. River inputs can also contribute to the Aegean Sea waters but is limited (Oğuz 2015). The Aegean Sea surface heat losses are balanced by the advection of warmer water masses through its open boundaries, mainly by the inflow of warm Levantine waters at the surface and intermediate layers. Black Sea water flow may effect the thermohaline circulation in the North Aegean Sea (Lionello *et al.* 2006).

In Skliris *et al.* (2011), spatial variability of SST in the Aegean Sea shows minimum values around the Dardanelles Strait and in the north-eastern part of the Aegean Sea, and maximum values in the Cretan Sea. This variation in SST is mainly determined by the input of external surface water masses, such as the Black Sea cold waters and the Levantine warm waters as well as by the spatial variability of air-sea heat fluxes and the upward vertical transports of intermediate (cold) water due to turbulent mixing and/or upwelling processes (Poulos *et al.* 1997; Skliris *et al.* 2010).

In parallel with that, the southern sub-basin shows a slightly larger increasing trend (0.047°C/yr, $r=0.71$, $p<0.01$) with respect to the northern sub-basin (0.042 °C/yr, $r=0.68$, $p<0.01$) in the Aegean Sea (Skliris *et al.* 2011). For the whole

Aegean Sea over 1985-2008 period, yearly-mean satellite-derived SST variations indicate a general warming trend of about 0.045°C/yr. A more thorough examination of the time series reveals a very small SST cooling trend until the early nineties and then a strong warming trend throughout the rest of the record. In addition, the obtained satellite-derived Aegean Sea surface warming rate during 1992-2008 was about 0.055°C/yr which is comparable to our results from the North Aegean Sea in the same period (about 0.0525°C/yr).

According to Poulos *et al.* (1997) the main factor effecting sea surface temperatures are the seasonal atmospheric conditions and air temperature. Theoharatos and Tselepidaki (1990) examined possibly existing relation between the air and sea-surface temperature in the Aegean Sea, in monthly intervals for the five year period 1971-1975. Consequently, the annual course of sea-temperature observed to be lagging in relation to that of the air on the order of one month. Poulos *et al.* (1997) conducted an investigation used satellite images, between 1988 and 1994, have analysed the monthly SST distribution in the Aegean Sea. As a result, the annual maximum SST values (>24°C) occur around August; minimum values (<13°C) are reached in February. In our study, minimum SST was measured 9.7°C in January 1985 and maximum SST was measured 27.5°C in August 2017.

Conclusion

Temperature data collected in Gökçeada Island were compared with those collected by research ships since the 1970s. Since the early period, techniques to collect ocean temperatures have evolved substantially. Before the 2000s, temperatures were derived from pressure-protected reversing thermometers. After that observations are from electronic multi parameter There are no known biases between different temperature measurement techniques. Although the methods and techniques used were different from those used in the above mentioned studies, the results come up similar. This study reveals its difference by exclusively focusing on the North Aegean Sea.

In summary, the increase rate of the SST data obtained through the long-term oceanographic measurement between 1972 and 2018 in Gökçeada Island (North Aegean Sea) was about 0.035°C/year, which is comparable to the warming rate for the northern Aegean basin over 1985-2008 (~0.042°C/yr,) Çanakkale Strait over the same period (~0.026°C/yr) reported by Skliris *et al.* (2011). When the warming rate of the North Aegean Sea was compared with the rate for the whole Mediterranean Sea over 1992-2005 (~0.061°C/yr), the Mediterranean Sea showed a larger increasing trend with respect to the North Aegean Sea, which is mainly under the influence of the cold Black Sea water inflow.

The Aegean Sea has an important role as the main driver of the hydrographic and ecological changes in the Mediterranean basin as it is connected with the Black

Sea to the north. However, there are very few studies that focus on the development of the dynamical changes in sea surface temperature and its fluctuations.

All related studies show that after a long-term of slow cooling period from the late 1960's to the early 1990's, the Aegean Sea started to warm rapidly. In our study, long term and regular dataset can be a baseline data for studies of climate change as well as for national oceanographic monitoring of the Turkish part of the Aegean Sea.

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Kuzey Ege Denizi'nde (Gökçeada) 1972-2018 yılları arasında iklim değişikliği açısından deniz suyu sıcaklığı

Öz

Bu çalışma, Kuzey Ege Denizi'nde bulunan Gökçeada çevresinde gerçekleşen ve yayınlanmamış uzun süreli oşinografik ölçüm (1972-2018) sonuçlarına dayanarak gerçekleştirilmiştir. En kritik parametre olan yüzey suyu sıcak verileri, 1972-2018 yılları arasında Gökçeada'daki Kaleköy istasyonundan elde edildi. Bu uzun süreli ve düzenli olarak örneklenen veri seti, iklim değişikliği ile ilgili gelecekteki çalışmalar için ve Kuzey Ege Denizi'nin Türkiye kıyılarındaki ulusal oşinografik izleme için önemli bir temel veri kaynağı olabilir. Deniz yüzeyi su sıcaklığı 1972'den 2018'e kadar 1,6°C arttığı tespit edildi.

Anahtar kelimeler: İklim değişikliği, deniz suyu sıcaklığı, uzun erimli izleme

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