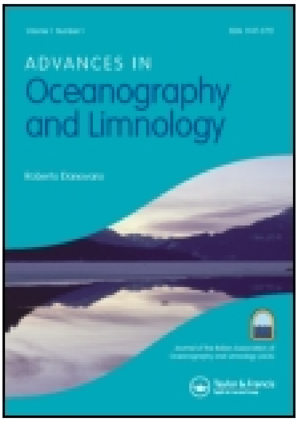

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Long-term sea surface temperature variability in the Aegean Sea

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The inter-annual/decadal scale variability of the Aegean Sea Surface Temperature (SST) is investigated by means of long-term series of satellite-derived and in situ data. Monthly mean declouded SST maps are constructed over the 1985–2008 period, based on a re-analysis of AVHRR Oceans Pathfinder optimally interpolated data over the Aegean Sea. Basin-average SST time series are also constructed using the ICOADS in situ data over 1950–2006. Results indicate a small SST decreasing trend until the early nineties, and then a rapid surface warming consistent with the acceleration of the SST rise observed on the global ocean scale. Decadal-scale SST anomalies were found to be negatively correlated with the winter North Atlantic Oscillation (NAO) index over the last 60 years suggesting that along with global warming effects on the regional scale, a part of the long-term SST variability in the Aegean Sea is driven by large scale atmospheric natural variability patterns. In particular, the acceleration of surface warming in the Aegean Sea began nearly simultaneously with the NAO index abrupt shift in the mid-nineties from strongly positive values to weakly positive/negative values.

Keywords: Aegean Sea; sea surface temperature; AVHRR; ICOADS; North Atlantic Oscillation; Indian Monsoon

1. Introduction

The Aegean Sea is located at the northeastern part of the Mediterranean to the east of the Ionian Sea and to northwest of the Levantine Sea, bounded to the north and west by the Greek mainland, to the east by the Turkish coasts and to the south by the islands of the Cretan Arc (Figure 1). The Aegean Sea displays a very irregular coastline and a very complicated topographic structure disclosing over 3000 islands and islets and introducing a wide-range of continental shelves and deep concavities. The most important water masses in the Aegean Sea are the brackish and cold Black Sea Water (BSW) entering the northeastern part of the domain through the Dardanelles Straits, the very saline and warm waters of Levantine origin entering the southern Aegean through the Cretan Arc straits and the very dense deep waters that fill the bottom of the various sub-basins. Both shelf and open sea convection processes have been proposed as the mechanisms involved in the Aegean deep water formation which presents strong inter-annual variability [1–3]. During the early nineties a large climatic transition occurred in the Mediterranean thermohaline

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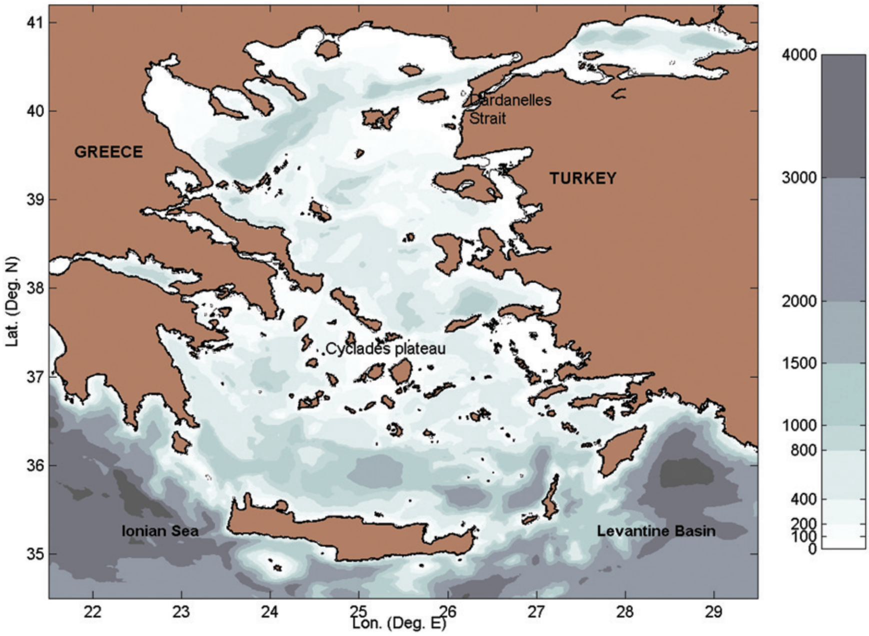

Figure 1. Bathymetry (m) and topographic features of the Aegean Sea region.

circulation, the so-called Eastern Mediterranean Transient (EMT) with the main source of Eastern Mediterranean Deep Water (EMDW) shifting from the Adriatic to the Aegean [2,4–6]. Very dense waters started to outflow from the Cretan arc straits spreading out into the deepest parts of the Eastern Mediterranean [1]. Although the Aegean Sea experiences strong inter-annual variability on different time scales, the EMT is the strongest signal of climatic variability, and is most probably connected with many different dynamical aspects of the circulation, water mass formation, and air-sea interaction. Some investigators of the EMT argued that there were two distinct phases, one preconditioning phase where the salinity of the Aegean Sea was considerably increased over the period 1987–1991 followed by an extreme surface cooling phase related to the exceptionally cold winters of 1992 and 1993 [1,2]. There is clear evidence that although considerably slowed down, the EMT is an ongoing process [7,8] but its effects on the thermohaline circulation of the Mediterranean Sea as well as its impact on the North Atlantic overturning circulation and its connection with large scale climatic processes such as the North Atlantic Oscillation (NAO) and Indian Monsoon (IM) remain open questions.

After the abrupt surface cooling period that probably contributed to the EMT during the early nineties, a long-term intense surface warming period began. Several observational studies based on in situ and/or satellite-derived data have demonstrated the rapid surface warming of the Mediterranean Sea during the last two decades [9–11]. The SST increasing trend was shown to be much larger in the eastern Mediterranean (as compared to the western basin) reaching about 0.05°C/yr during 1985–2006 [11] whilst even larger warming trends were obtained in the adjacent Black Sea [10,12]. These long-term SST warming trends were mainly associated with the global warming effects on the regional scale [10]. However, on decadal timescales it is difficult to discriminate between signals of change associated with global warming effects and signals of change associated with anomalies induced by natural modes of large-scale atmospheric variability such as the NAO and IM patterns. NAO, known as the most important teleconnection pattern in the Northern hemisphere, exerts a dominant influence on sea level, precipitation, as well as wintertime air-temperature and SST of the Mediterranean Sea [13–16]. Rixen et al. [17] provided observational evidence for consistent temperature changes in the Western Mediterranean and the North Atlantic, explained by similarities in the atmospheric heat fluxes anomalies strongly correlated to NAO. On the other hand, negative correlations were found between NAO and both the SST in the Eastern Mediterranean [18,19] and the temperature in the upper and intermediate layers of the Aegean Sea [20]. A high positive (negative) NAO index is often associated with cooler (warmer) conditions over the eastern part of the Mediterranean [15]. The Indian Monsoon is also considered to be an important factor influencing the precipitation and wind regime of the eastern Mediterranean during summer [21,22]. Rodwell and Hoskins [23] found that the Indian Monsoon activity can induce a Rossby wave response, which produces an adiabatic descent amplified over the eastern Mediterranean. Raicich et al. [24] found a high negative correlation between the Indian Monsoon precipitation index and the sea-level pressure distribution in summer over the Eastern Mediterranean on an inter-annual timescale. The air-sea heat flux in the eastern Mediterranean Sea is also found to be correlated with the summer IM index [25]. Therefore, along with global warming effects on the regional scale, both the North Atlantic and South Asian natural climate variability are expected to play a role in driving long-term SST trends in the Aegean Sea. Moreover, variability signals associated with the Black Sea and Levantine surface water heat inputs are expected to be superimposed on atmospheric variability signals, contributing to the SST long-term variability of the Aegean Sea.

In the present study the SST inter-annual/decadal-scale variability in the Aegean Sea is analysed by means of available long-term time-series of AVHRR-derived and in situ data. The obtained SST trends are investigated and discussed in relation to global warming effects, large-scale atmospheric natural variability patterns, such as NAO and IM, and variations in the lateral heat inputs.

2. Data and methods

The AVHRR Oceans Pathfinder dataset provides an accurate high-resolution SST product adequate for investigating the long-term sea surface variability. Nykjaer [11] found a high observation density of the Pathfinder SST dataset for the Mediterranean Sea with the monthly mean number of highest quality SST observations per 4 km pixel varying from about 10 in winter to about 30 in summer. The construction of the satellite-derived SST data for the Aegean Sea considered herein is based on a re-analysis of the AVHRR Pathfinder (version 5.0) SST timeseries of the Mediterranean Sea [26]. The 1985–2008 spatiotemporal dataset for the Aegean Sea consists of optimally interpolated declouded monthly SST maps at a 1/16° resolution-grid (~6 km), provided by the Gruppo Oceanografia da Satellite (GOS) of the CNR-ISAC (Istituto di Scienze dell'Atmosfera e del Clima) (http://gos.ifa.rm.cnr.it). Marullo et al. [26] validated the optimally interpolated Pathfinder SST dataset for the Mediterranean Sea using in situ data from 1985 to 2005, and they found a mean bias of less than 0.1 K with a root mean square error of about 0.5 K, whilst they showed that errors were weakly dependent upon season and did not drift with time. Moreover the spatial distribution of the in situ and satellite-derived temperature difference and its standard deviation was found to be quite uniform in the Mediterranean

Sea with few hot spots greater than 0.5 K mostly located near the coasts [26]. Basin-average seasonal and yearly mean timeseries are constructed from the monthly time-series in order to investigate the SST inter-annual/decadal scale variability, the long-term linear trends and their seasonality. The typical representation of seasons used in the oceanography of the Mediterranean (January-February-March for winter, April-May-June for spring etc) is chosen to construct the seasonal mean timeseries.

Longer SST timeseries but with much lower horizontal resolution are also constructed based on in situ data obtained from the International Comprehensive Ocean Atmosphere Data Set (ICOADS) [27]. A 2° × 2° dataset covering the Aegean Sea (9 grid-cells in total) is created using the ICOADS SST raw data for the period 1950–2006, provided by the National Center for Atmospheric Research (NCAR) (http://icoads.noaa.gov). Due to the much lower spatial resolution and observations density of the ICOADS-derived SST dataset (i.e. the total number of observations is at least one order of magnitude lower as compared with the satellite-derived SST dataset), the spatial SST variability within the Aegean Sea is not investigated in this case and only temporal variations of the basin-average SST are considered. Since SST spatial gradients are very pronounced within the Aegean Sea, in order to minimise biases in the calculation of the basin-average seasonal/annual mean SSTs the following procedure is adopted: Before calculating seasonal/annual basin-scale spatial averages, monthly values are first computed for each grid cell, using a threshold-criterion of at least three available observations per month. For the few temporal gaps encountered in the monthly timeseries (i.e. when the monthly three values threshold-criterion was not met in a grid cell), the monthly value of that year for the specific grid cell is obtained by linear temporal interpolation using the monthly values of the adjacent years for the same grid-cell. In addition, due to the complicated coastline and the numerous islands of the Aegean Sea, the proportion of sea and land in each grid point is also taken into account (i.e. using a sea/land weighted value) when calculating the Aegean basin average SST. Figure 2 depicts the ICOADS-derived basin-average yearly-mean SST and the total annual number of observations used in the calculation of the yearly means. There is a strong variation in the yearly observation density and consequently in the associated standard errors in calculating the yearly means with much larger uncertainty during both the first and last decade of the 1950–2006 record.

Moreover, in order to investigate the impact of large-scale natural climatic variability processes on the Aegean SST, two major seasonal climatic indexes known to affect the Mediterranean climate, namely the winter NAO index [13] and the summer IM index [28], are considered over the 1950–2008 period. The winter NAO index is defined as the difference between the normalized mean winter (December–March) sea level pressure anomalies at Lisbon, Portugal and Stykkisholmur, Iceland [13]. The summer Indian Monsoon (IM) index is defined herein as the normalised mean summer (June–August) difference between the wind field at 850 HPa of two areas within the South Asian domain (i.e. defined by 40E–80E, 5N–15N and 70E–90E, 20N–30N, respectively) [28]. A correlational analysis is then performed to investigate the co-variability of these two indexes with the obtained time-series of the satellite-derived and in situ SST anomalies in the Aegean Sea.

3. Results and discussion

Figure 3 depicts the variability of the temporal and spatial means of the satellite-derived SST monthly dataset over 1985–2008. The spatial distribution of the temporal mean shows

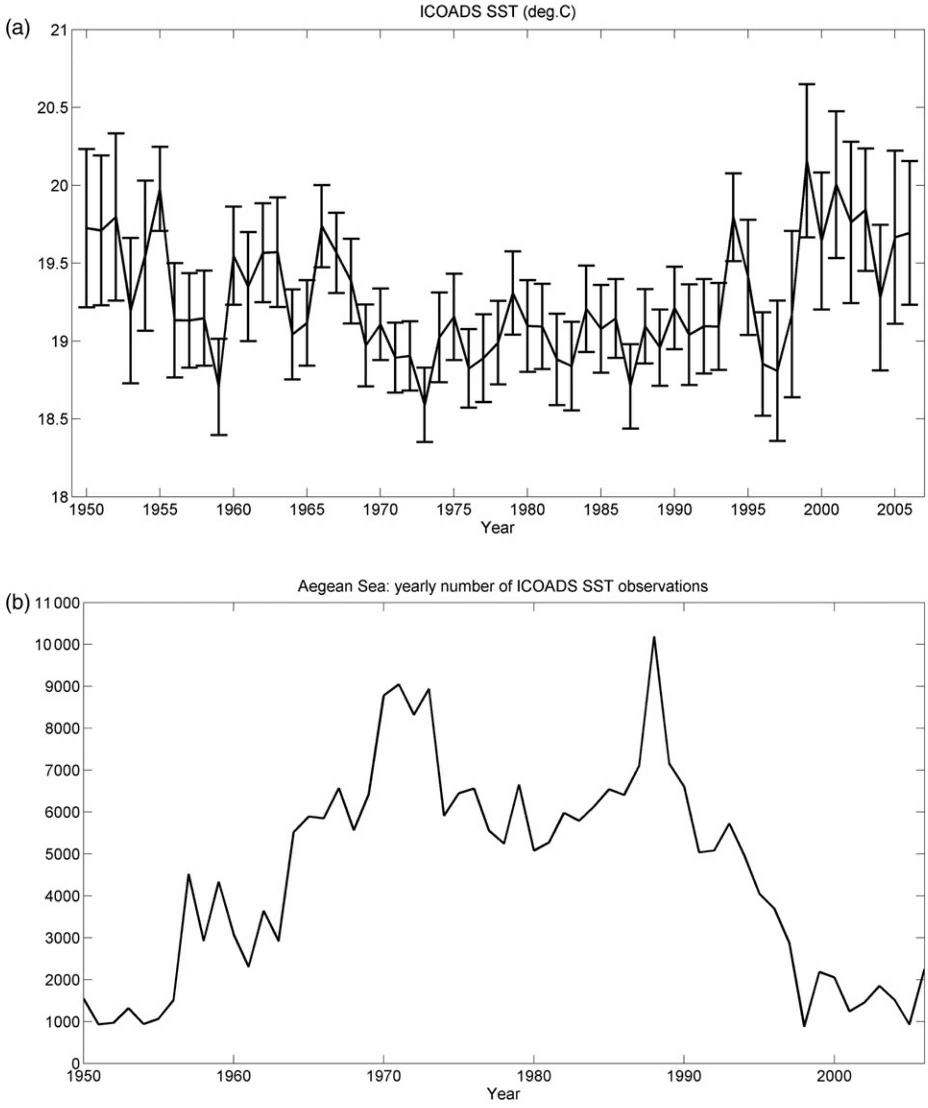

Figure 2. Aegean Sea ICOADS-derived SST dataset: (a) Yearly-mean basin-average SSTs and associated standard errors (vertical error bars), and (b) Yearly number of ICOADS SST observations in the Aegean Sea.

a clear positive southward gradient with minimum values around the Dardanelles Strait and in the northeastern part of the Aegean Sea, and maximum values in the Cretan Sea. Spatial variability of SST is mainly determined by the input of external surface water masses, such as the Black Sea cold waters entering the basin through the Dardanelles Strait and the Levantine warm waters entering the Cretan Sea through the eastern Cretan arc straits, 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 [29,30]. The temporal variation of the spatial mean during the 1985–2008 period shows

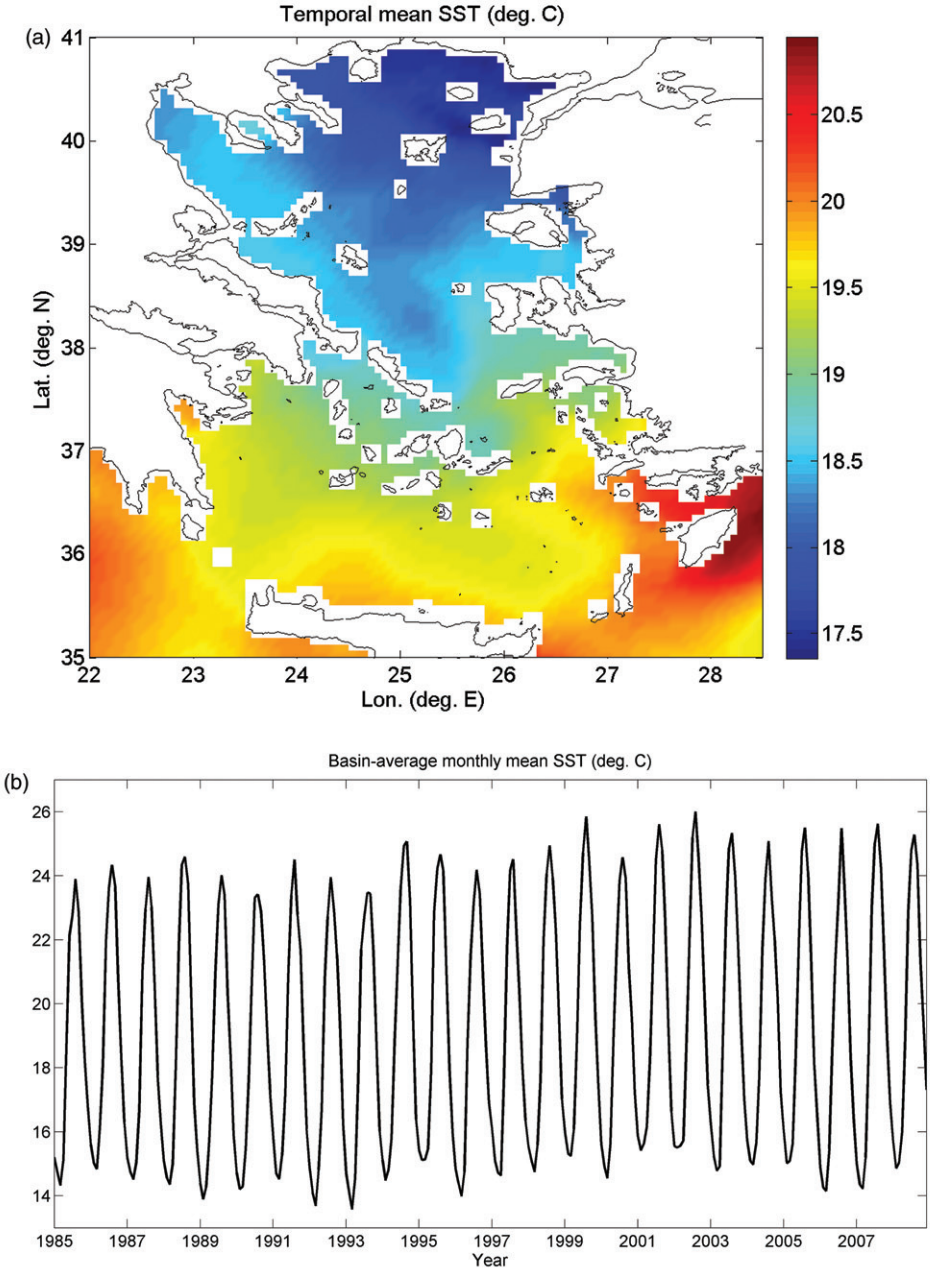

Figure 3. Statistics of the AVHRR-derived SST monthly dataset (1985–2008): (a) spatial distribution of temporal mean, (b) time variation of spatial mean.

important inter-annual/decadal scale variability signals which are largely masked by a clear sinusoidal-type seasonal cycle, with a maximum value obtained in August and the minimum value in March. SST seasonal and yearly spatial averages are calculated and investigated separately for the northern and southern sub-basins (i.e. defined by the

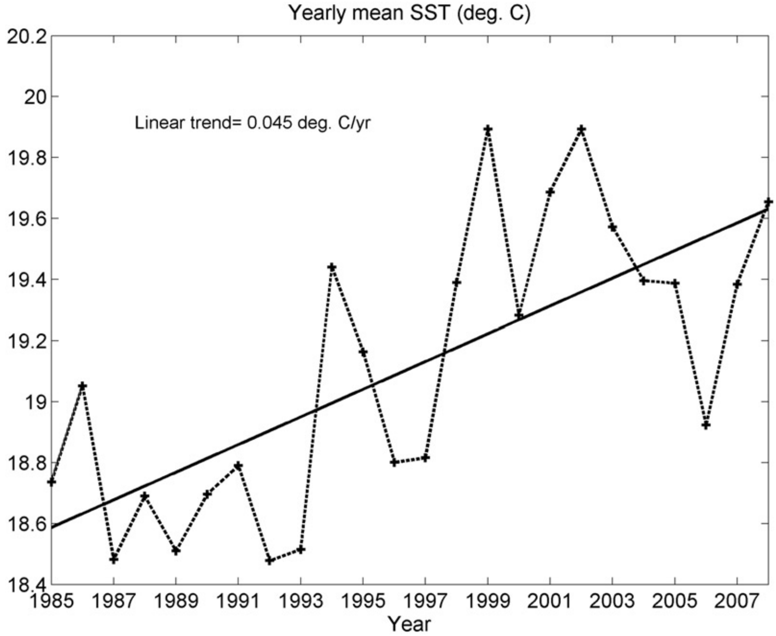

Figure 4. Aegean Sea basin-average yearly mean satellite-derived SST variations and linear trend over 1985–2008.

latitudinal boundary of 38° N on the Cyclades plateau) in order to investigate a possible different behaviour of these two sub-basins in terms of inter-annual/decadal-scale variability, as they are generally characterised by the influence of different water masses (i.e. the cold low-salinity BSW in the northern basin and the warm and very saline waters of Levantine origin in the southern basin) as well as different dynamical features. Although the thermohaline exchange between the north and south Aegean sub-basins through the Cyclades plateau is generally low [29], Zervakis et al. [3] suggested that during periods of massive dense water formation in the North Aegean the north-south exchange is greatly enhanced and the thermohaline circulation of the Aegean is accelerated.

Yearly-mean satellite-derived SST variations indicate a general warming trend of about 0.045°C/yr ($r = 0.7, p < 0.01$) over the whole 1985–2008 period (Figure 4). However, a more thorough examination of the timeseries reveals a very small SST cooling trend until the early nineties and then a strong warming trend throughout the rest of the record. The obtained satellite-derived Aegean Sea surface warming rate during 1992–2008 is about 0.055°C/yr ($r = 0.54, p = 0.03$) which is comparable with the warming rate found by Criado-Aldeanueva et al. [9] for the whole Mediterranean Sea over 1992–2005 (i.e. 0.061°C/yr) also based on satellite observations. The spatial patterns of the satellite-derived SST linear trend over the 1985–2008 period, as well as over the 1985–1992 and 1992–2008 sub-periods, are depicted in Figure 5. Except from the southeastern part of the basin, the largest part of the Aegean Sea surface is cooling between 1985 and 1992 whilst a general warming is obtained throughout the basin after 1992. Maximum SST warming trends are observed in the Cretan Sea and particularly around the Cretan Arc Straits. Criado-Aldeanueva et al. [9] studying the sea-level changes of the whole Mediterranean Sea during 1992–2005 found maximum rates of both sea surface warming and sea level rise (i.e. mainly driven by the steric

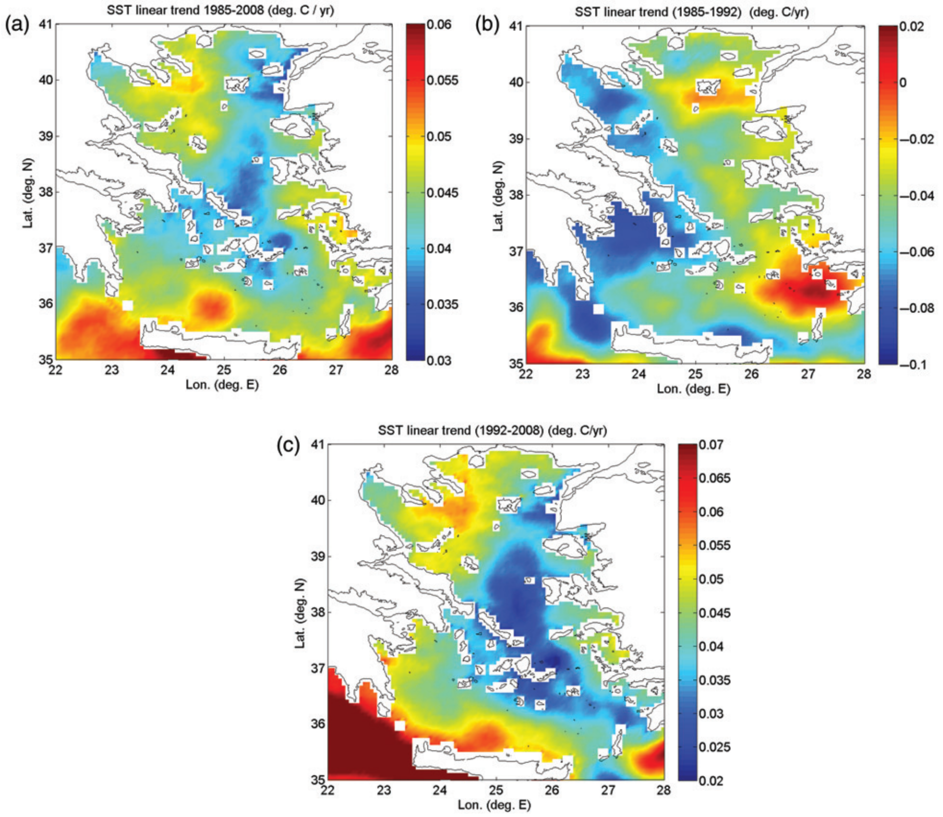

Figure 5. Horizontal distribution of the satellite-derived SST annual linear trend (°C/yr) in the Aegean Sea over (a) 1985–2008, (b) 1985–1992, and (c) 1992–2008.

contribution of thermal origin) in the northern Levantine basin south of Crete. On the other hand, much lower SST increasing trends are obtained herein around the Dardanelles straits and in the central part of the Aegean along the path of the inflowing BSW. The co-variability between south and north basin-average yearly SST is very high ($r = 0.90$) indicating a similar behaviour in terms of SST variations in the two sub-basins over 1985–2008. However, 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, $r = 0.68$, $p < 0.01$). More interestingly the estimated increasing SST linear trend at the grid-point adjacent to the Dardanelles Straits over the same period (~0.026°C/yr, $r = 0.41$, $p = 0.05$) is about half of the Aegean basin-average trend. These findings suggest that the observed SST increase in the Aegean over the considered period is mainly induced by increased heat transports through the Cretan Arc straits and/or by the atmospheric forcing variability rather than an increased warming of the BSW inflow.

Results of the satellite-derived seasonal SST analysis also show that there is a marked seasonality in the linear trends (1985–2008) (Figure 6) with much higher warming rates obtained during summer (~0.068°C/yr, $r = 0.72$, $p < 0.01$) and autumn (~0.050°C/yr, $r = 0.56$, $p < 0.01$) than those obtained during spring (~0.037°C/yr, $r = 0.55$, $p < 0.01$) and winter (~0.026°C/yr, $r = 0.40$, $p = 0.05$). The highest positive seasonal SST anomaly is

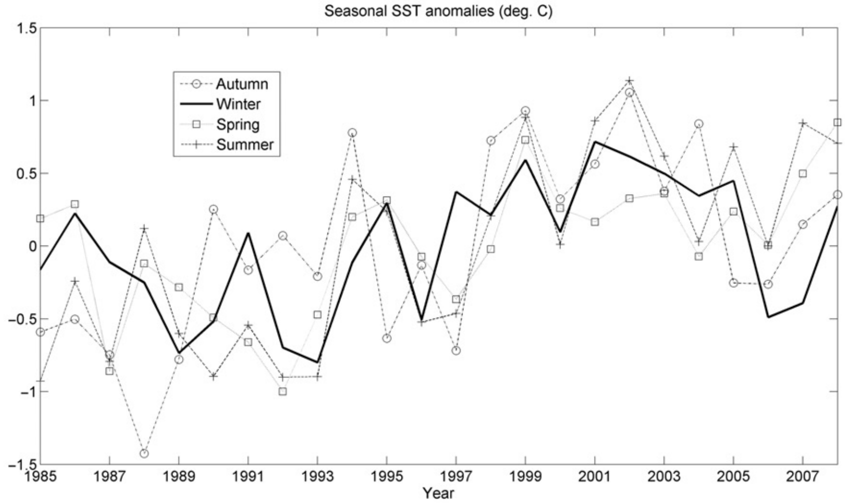

Figure 6. Basin-average seasonal mean satellite-derived SST in the Aegean Sea over the 1985–2008 period in winter (solid line), spring (squares), summer (crosses), and autumn (circles).

obtained in summer 2002 with the obtained mean summer SST being about 1°C higher than the long-term (1985–2008) summer mean. These findings are consistent with observational and modelling studies of the Euro-Mediterranean region climatic variability showing maximum seasonal warming rates over the northern Mediterranean Sea during the summer period [31]. The climatic scenario model projections in the 21st century indicate that summer SSTs will increase well above the already high present values in the Mediterranean Sea with large impacts on the regional climate [31,32]. The obtained winter SST anomalies clearly show the signatures of the exceptionally cold winters of 1992 and 1993. The largest negative anomaly is evidenced in winter 1993 with the obtained mean winter SST being about 0.8°C lower than the long-term (1985–2008) winter mean. Intense surface cooling during these two winters in the Aegean Sea is proven to be a key factor triggering the EMT [2,5].

The ICOADS derived yearly basin-average SST time-series shows an important inter-decadal variability over 1950–2006 with a very small positive overall mean linear trend (~0.003°C/yr, not statistical significant at the 95% confidence level). Results indicate a prolonged period of relatively cold SSTs in the Aegean Sea from the late sixties to the early nineties in between two warm periods (the first during 1950s and most of the 1960s and the second from mid-nineties onwards). Surface cooling along with the combined salt content increase of the Eastern Mediterranean induced by increased net evaporation during this period [14,33] may gradually decrease stratification in the Aegean Sea resulting in larger deep water formation rates favouring the EMT. This long-term preconditioning period (i.e. from late 1960s to early 1990s) roughly coincides with the exceptionally high rise of NAO index from negative to high positive values. A high positive NAO index is generally associated with decreased precipitation [13] and cooler winter conditions over the eastern Mediterranean [15] and thus its high rise may largely contributed to lower temperatures and increased salinities in the upper layers of the Aegean Sea. Although showing some inter-annual differences with the satellite-derived timeseries, ICOADS SST timeseries demonstrates a similar temporal behavior over their common period (1985–2006)

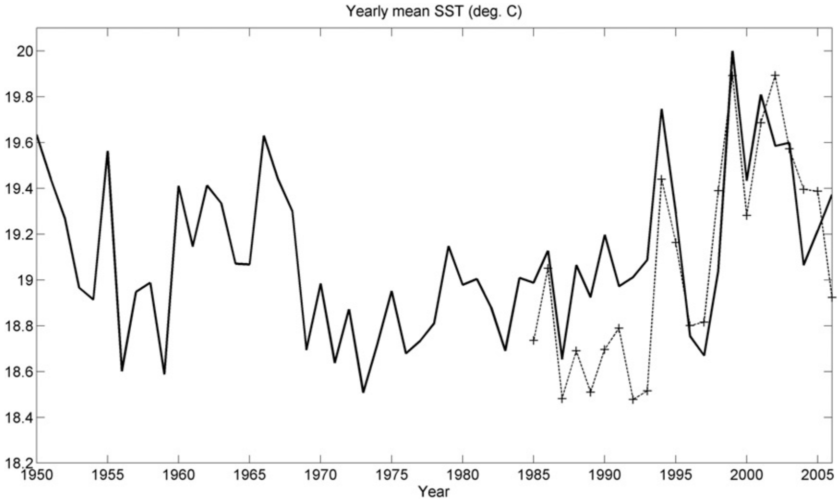

Figure 7. Time-series of basin-average yearly mean SST in the Aegean Sea derived from ICOADS in situ data (1950–2006) (solid line). Satellite-derived SST time-series over 1985–2006 are also depicted (crosses).

indicating a period with relatively cold SSTs until the early nineties and then an accelerated warming from the mid-nineties onwards (Figure 7). The correlation coefficient between yearly basin-average in situ and satellite-derived SSTs over 1985–2006 is quite large ($r = 0.82$, $p < 0.01$) denoting the close relationship of the two estimated parameters. The less strong correlation of the two parameters in recent years is probably due to the poor observational density of the ICOADS dataset over this period (see Figure 2b).

The obtained rapid surface warming of the Aegean Sea from the early-nineties onwards is consistent with the acceleration of the SST rise observed on the global ocean scale over the same period and particularly with the much higher warming rates (i.e. with respect to the global average warming) observed in both the Mediterranean and Black Seas [10]. The air-temperature over-land anomalies in the Mediterranean region during the last five centuries indicate an unprecedented strong warming from the mid-1970s onwards, featuring the hottest summer decade 1994–2003 in the entire record (1500–2003) [18,34]. In a recent study Vargas-Yanez et al. [35] showed that the long-term temperature variability in the upper 200 m layer of the Mediterranean Sea significantly correlates with surface air temperature in the northern hemisphere as well as with the heat absorbed by the upper North Atlantic ocean, reflecting the present heat absorption of the oceans in the context of global warming. Belkin et al. [10] argued that the observed rapid surface warming in the enclosed and semi-enclosed European Seas such as the Mediterranean and the Black Seas, surrounded by major industrial/population agglomerations, may have resulted from the observed large terrestrial warming directly affecting the adjacent coastal seas. However this signal of global warming effects on the local scale of the Aegean Sea seems to be superimposed on natural climate variability signals such as those linked with the NAO regime. NAO exhibits a strong decadal variability which may induce important delayed climate anomalies over the North Atlantic and surrounding regions such as the Mediterranean [36]. In the present study a correlational analysis is performed on an inter-annual time scale between seasonal/yearly SSTs of both satellite and

Table 1. Correlation coefficients between satellite-derived SST (1985–2008), ICOADS-derived SST (1950–2006) yearly/seasonal anomalies and winter NAO/summer IM index. Unfiltered and filtered (5-year running means) timeseries are considered. Statistically significant correlation coefficients at the 95% confidence level ($p < 0.05$) are depicted in bold characters.

	Yearly/seasonal means	5-year running means
Satellite SST (1985–2008)		
Winter NAO – yearly SST	−0.12 ($p = 0.53$)	**−0.80** (**$p < 0.01$**)
Winter NAO – winter SST	−0.33 ($p = 0.11$)	
Summer IM – yearly SST	−0.06 ($p = 0.76$)	−0.29 ($p = 0.20$)
Summer IM – summer SST	−0.07 ($p = 0.73$)	
ICOADS SST (1950–2006)		
Winter NAO – yearly SST	−0.14 ($p = 0.38$)	**−0.36** (**$p = 0.02$**)
Winter NAO – winter SST	**−0.39** (**$p < 0.01$**)	
Summer IM – yearly SST	−0.11 ($p = 0.42$)	−0.21 ($p = 0.17$)
Summer IM – summer SST	−0.15 ($p = 0.26$)	

ICOADS-derived datasets and NAO/IM indexes (Table 1). A correlational analysis is also performed using the filtered timeseries (i.e. 5-year running means) of the yearly means in order to properly represent decadal-scale variability patterns. On the inter-annual time scale the only statistical significant correlation (i.e. at the conventional 95% confidence interval) was found between winter NAO and ICOADS-derived winter SSTs over 1950–2006 ($r = -0.39$, $p < 0.01$). The obtained negative correlation shows that NAO exerts a significant influence on wintertime surface temperatures of the Aegean Sea and supports the hypothesis that the high rise of NAO between late sixties and early nineties played an important role in the prolonged winter cooling of the Aegean Sea contributing to the EMT. Furthermore, on decadal time scales, a high and statistically significant negative correlation was found between filtered timeseries of satellite-derived SST yearly anomalies and winter NAO index over 1985-2008 ($r = -0.80$, $p < 0.01$). Decadal-scale variability of the ICOADS-derived yearly SSTs (1950–2006) (Figure 8) shows again a statistically significant negative correlation with the winter NAO index ($r = -0.36$, $p = 0.02$), though much lower as compared to that between NAO and satellite-derived SSTs over 1985–2008 (Figure 9). The acceleration of surface warming in the Aegean Sea seems to begin nearly simultaneously with the NAO index abrupt switch in the mid-nineties from strongly positive values to negative or weakly positive values afterwards (see Figure 9). This period is also characterised by a relatively low summer IM index associated with a weakening of the cool Etesian winds during summer [22] that could also contributed to the surface warming. However, a relatively low and not statistically significant negative correlation was obtained herein between satellite-derived SST anomalies and summer IM index decadal variations ($r = -0.29$, $p = 0.20$). Moreover, a low and not statistically significant negative correlation was also found between ICOADS SSTs and summer IM index decadal-scale variations ($r = -0.21$, $p = 0.17$). Results suggest that the decadal scale variability of the Aegean SST can be mainly explained by the superposition of a long-term global warming signal and a decadal scale variability signal linked to NAO. The variability signal associated with the enhanced positive NAO phase from the late 1960s to the early 1990s (inducing a cooling effect on the eastern Mediterranean) may largely counteracted

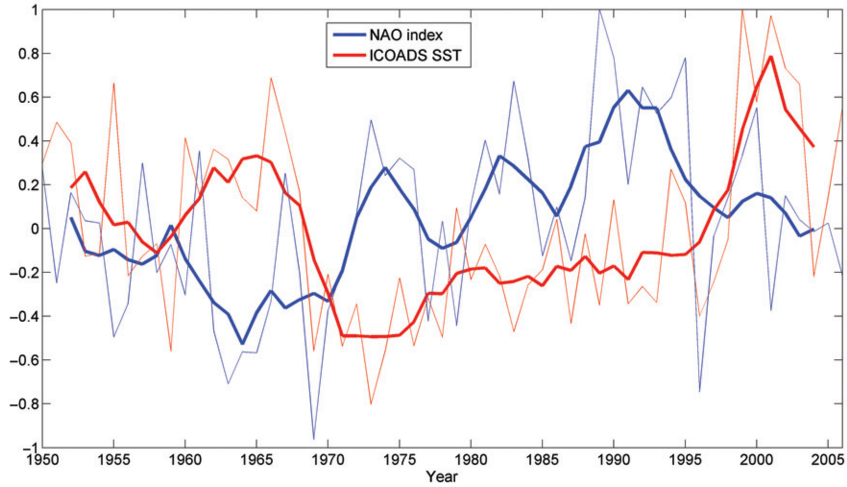

Figure 8. Normalised unfiltered (thin lines) and filtered (5-year running means) (thick lines) time-series of winter NAO index (blue) and ICOADS-derived SST anomalies (red) over 1950–2006.

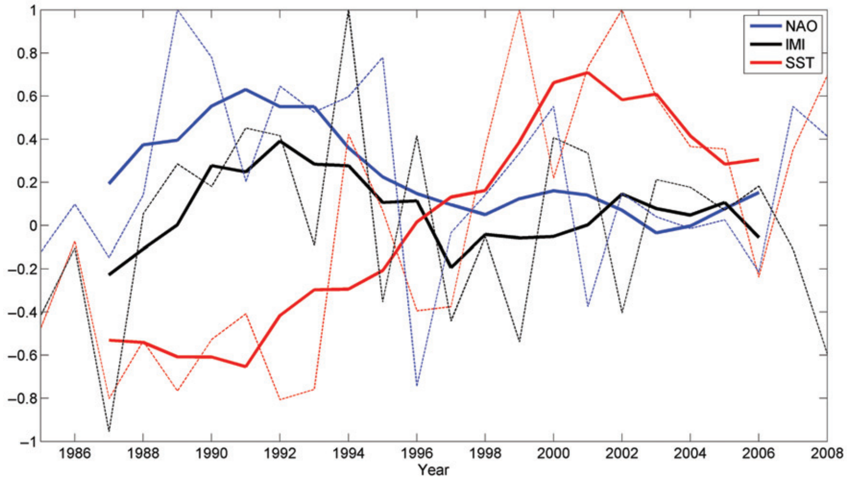

Figure 9. Normalised unfiltered (thin lines) and filtered (5-year running means) (thick lines) time-series of winter NAO index (blue), summer IM index (black) and satellite-derived SST anomalies (red) over 1985–2008.

the global warming signal resulting in the small SST decreasing trend in the Aegean Sea. On the other hand, from mid-1990s onwards with the abrupt shift of NAO from a high positive to a weakly positive/negative NAO phase (inducing a warming effect on the eastern Mediterranean) the superposition of the two signals may resulted in the accelerated surface warming of the Aegean Sea.

The increasing warming of the Aegean Sea may have important implications for the local plankton ecosystem. Satellite-derived chlorophyll observations in the Aegean Sea after 1997 show a discernible decreasing chlorophyll trend [29]. A similar decreasing trend is also reported by Barale et al. [37] for the Mediterranean basin interior. The above authors suggested that the decreased chlorophyll levels were mainly associated with the increasing SST over the same period. Surface warming may enhance stratification in the upper layers, which, in turn, may result in lower upward nutrient transports and thus in reduced primary productivity levels within the oligotrophic Aegean Sea. SST variability in the Aegean Sea may affect the Mediterranean climate and/or even larger scale climatic processes. During the cooling period of the late eighties/early nineties exceptionally large deep water formation took place in the Aegean Sea that transformed the whole thermohaline circulation of the Mediterranean Sea. After the intense surface warming started in the mid-nineties there is observational evidence that the Aegean deep water formation considerably reduced and the thermohaline circulation of the Mediterranean slowed down [7,8]. These large changes in the Mediterranean thermohaline circulation during the recent decades may have resulted in a much warmer and more saline Mediterranean outflow into the North Atlantic [38,39] and thus may even have a significant impact on this major deep water formation site controlling the global thermohaline circulation.

4. Conclusions

In situ and satellite-derived SST timeseries show that after a long-term slow cooling period from the late sixties to the early nineties the Aegean Sea started to warm rapidly. The warming rate over 1992–2008 is several times larger than the estimated global mean warming rate over the same period. Results also indicate a pronounced spatial variability of the SST increasing linear trend with the southern part of the basin, mainly affected by the Levantine water inputs, presenting a much higher warming trend than the northeastern part which is mainly under the influence of the BSW inflow. A relatively small but statistically significant negative correlation was found between decadal-scale SST anomalies and the winter NAO index over the last 60 years suggesting that along with global warming effects on the regional scale a considerable part of the SST variability in the Aegean Sea is driven by the large scale atmospheric natural variability modes. In particular, the enhanced positive NAO phase from the late 1960s to the early 1990s inducing a cooling effect on the eastern Mediterranean may have largely counteracted the global warming signal resulting in the small SST decreasing trend in the Aegean Sea. This prolonged cooling period along with the salt content increase in the Aegean Sea probably acted as a preconditioning factor triggering the EMT in the early nineties. On the other hand, the NAO index time-series shows a clear shift in the mid-nineties from a very high positive to a low positive/negative phase which is closely followed by the acceleration of the warming rate in the Aegean Sea.

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