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ORIGINAL PAPER

Present climate trend analysis of the Etesian winds in the Aegean Sea

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Abstract The main objective of the present study is to perform a trend analysis and investigate the possible changes in the frequency and wind intensity of the Etesians during June to September of the years 1979 to 2009. The analysis is based mainly on the use of Reanalysis-1 data from the National Centers for Environmental Prediction/ National Center for Atmospheric Research. The results are indicative of negative trends in the frequency and wind speed (WS) of the Etesians. During the 31-year period studied, the total number of Etesian days from June to September decreased by about 4.6 days, while the monthly maximum intensity of the daily WS was reduced by almost 1 ms^{-1}. The above indications are strengthened by similar results derived from the trend analysis of observational wind data in the central Aegean for the years 1955 to 2002. The negative trend in the frequency of the Etesian days could be explained by a decreasing trend in the pressure gradient between the central and southern Europe high-pressure center and the Middle East low-pressure center, which cause the Etesians system. In the study, a possible association between the Southern Oscillation and the Etesian winds is also revealed. The negative trend in the frequency and WS of the Etesian winds could imply a reduced cooling mechanism in the eastern Mediterranean in the summer period due to climate change.

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1 Introduction

The Etesian winds (annual winds) are northern sector winds of the lower atmosphere that flow over the Aegean Sea during summer and early autumn (Kallos et al. 1998; Repapis et al. 1978; Tritakis 1982). They are mainly northeasterly in the northern Aegean, northerly in the central and southern Aegean, and become northwesterly near the southwestern Turkish coasts (Kotroni et al. 2001). The Etesians are the consequence of a low-pressure system that extends from Turkey to northwest India and of a high-pressure center in the central and south Europe (Metaxas and Bartzokas 1994; Pezzoli 2005; Tritakis 1984). The north–south orientation of the narrow Aegean Sea basin and the high mountains in continental Greece, southern Balkans, and Turkey provide a channel for the north direction of the Etesians flow. The Etesian winds could be characterized as a monsoonal type of wind, in spite of their large diurnal variation, prevailing over a large area of the eastern Mediterranean.

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The Etesian winds are a major climatic element because they moderate the summer heat since they are cool and dry winds over the Aegean Sea (Metaxas and Bartzokas 1994). The wind speed associated with the Etesians might reach gale force, creating problems to sea transport in the Aegean Sea during the high touristic season (Koletsis et al. 2009). The Etesians act positively to the dispersion of pollutants and can clean the atmosphere in Athens, which is heavily polluted when sea breezes (with a strong inversion) prevail (Giakoumi et al. 2009; Melas et al. 1998; Metaxas and Bartzokas 1994; Retalis and Retalis 1998; Ziomas 1998). At a regional level, in the case of strong Etesians, the eastern Mediterranean is characterized by very low aerosol loads (Zerefos et al. 2001).

There have been previous studies focusing on the analysis of the synoptic conditions leading to the formation of Etesian winds over the Aegean Sea (Brody and Nestor 1985; Burlando 2009; Karapiperis 1951; Maheras 1980; Makrogiannis and Dikaiakos 1990; Metaxas 1977; Meteorological Office 1962; Nastos et al. 1997). Metaxas and Bartzokas (1994) studied the frequency variability of the Etesian winds and found that during July and August, their frequency depended upon the pressure over the central Mediterranean and central Europe, with a center over the northern Adriatic or former Yugoslavia. High pressure over these regions corresponded to high frequency of Etesian days and low pressure to low frequency of Etesian days. Koletsis et al. (2009), Kotroni et al. (2001), and Zecchetto and Cappa (2001) presented an observational and numerical study of the interaction of the wind flow under an Etesian wind regime with the topographic features in the Aegean Sea (e.g., the island of Crete). However, the trends in the frequency and wind intensity of the Etesians as a probable implication of the climate change issue over the area have never been studied before.

The main objective of the present study is to investigate the possible changes in the frequency and wind intensity of the Etesians during the most recent 31-year period (1979–2009) through a trend analysis in the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis-1 data. The paper is organized as follows: In Section 2, the data used are described and a criterion for the identification of the Etesian days is selected. In Section 3, the climatology of the Etesian winds is presented along with the results of the trend analysis of the NCEP/NCAR Reanalysis-1 data and of an available measured wind dataset in the Central Aegean for the years 1955–2002. In Section 4, the possible connection between the estimated trends in the frequency and wind speed of the Etesian winds and the trends in the pressure at sea level at the pressure centers that determine the Etesians system is examined. Also, the association of the Etesians with the quasi-periodic climate pattern of Southern Oscillation is investigated. Finally, the conclusions of the study are drawn in Section 5.

2 Data and methods

The study was based mainly on the use of the NCEP/NCAR Reanalysis-1 daily mean data of zonal (u) and meridional (v) wind speed at 1,000 mbar, sea level pressure (SLP), and surface temperature (T) (Kalnay et al. 1996; Kistler et al. 2001). The NCEP/NCAR Reanalysis-1 data have a spatial resolution of 2.5×2.5° and cover a time period extending from 1 January, 1948 until present. However, in the framework of this study, the data used refer to the 31-year period extending from 1 January, 1979 until 31 December, 2009. The present study focuses on the climatology of Etesian winds through a trend analysis for the frequency and WS. Kistler et al. (2001) suggest that because of the changes in the observing system, trend analysis with the use of NCEP/NCAR Reanalysis-1 should involve the estimation of trends for the periods before and after 1979 separately. The same study indicates that the climatology before 1979 is more dominated by the model climatology in data-sparse areas, leading to the generation of spurious trends.

In the beginning of the study, the Etesian days had to be identified and as a result an identification criterion had to be set. The criterion was selected based on the description of the Etesian winds being northern sector winds blowing over the Aegean Sea during summer and early autumn (Kotroni et al. 2001) and on a measure of the Etesian winds frequency according to Karapiperis (1951), defining an "Etesian day" as one with day-long northerly winds blowing at the National Observatory of Athens (NOA; Fig. 1). Several studies agree about the good correspondence between Etesians observed in NOA and in the Aegean Sea (Metaxas and Bartzokas 1994; Tritakis 1982, 1985). Repapis et al. (1978) detected a high correlation between the Etesian days observed in Athens and the north component of the wind velocity observed in the Aegean Sea, a fact which implies that the Etesian days in Athens could be a good estimator of strong Etesians flow over the Aegean Sea.

Based on the above, the daily WS and wind direction (WDIR) were calculated at a grid point of the NCEP/NCAR Reanalysis-1 grid, located in the central Aegean Sea (latitude=37.5° N, longitude=25° E; Fig. 1) for all days of the months from June to September for the years 1979 to 2009. The days with NW to NE WDIR (more particularly northwest (NW), north–northwest (NNW), north (N), north–northeast (NNE), and northeast (NE) sectors) were identified, and then WS and WDIR time series were created for the following WS limit values:

(a) Criterion A: no WS limit value, NW to NE WDIR
(b) Criterion B: WS≥4 ms^{-1}, NW to NE WDIR
(c) Criterion C: WS≥5 ms^{-1}, NW to NE WDIR
(d) Criterion D: WS≥6 ms^{-1}, NW to NE WDIR

Fig. 1 The eastern Mediterranean basin where the Etesian winds flow

The WS limit values used, i.e., 4, 5, and 6 ms^{-1}, represent respectively the 25th, 50th, and 75th percentiles of the time series created using criterion A. The dataset with the total number of days in each month characterized as Etesian days according to Karapiperis (1951) (also referred to as parameter *L* (Repapis et al. 1978) (*L*-days)) from June to September of the years 1979 to 2009 was also accessed (Philandras 2010, personal communication).

Criteria A to D were examined in order to select the most suitable and to better identify the Etesian days based on wind data in the central Aegean Sea. Figure 2 presents a time series comparison between the number of days in each month from June to September of the years 1979 to 2009 that satisfy criteria A to D and the *L*-days. Figure 2 reveals that the time series according to criterion C coincide better with the time series of *L*-days. Table 1 presents a statistical comparison between the *L*-days and the number of days in each month that satisfy criteria A to D. In Table 1, the statistical measure mean absolute gross error (MAGE) is defined as:

$$MAGE = \frac{\sum_{i=1}^{i=N} \text{abs}(X_i - Y_i)}{N} \tag{1}$$

where *X* represents the *L*-days and *Y* represents the number of days in each month identified according to criteria A to D. *N* is the number of pairs (*X*,*Y*) (*N* is equal to 124 for this analysis). MAGE is used in order to measure how close the time series identified according to criteria A to D are to the time series of the *L*-days. In the case of perfect agreement between the variables *X* and *Y*, the value of MAGE should be 0. The correlation coefficient takes rather high values which are very similar for all criteria examined. However, MAGE is the smallest in the case of criterion C.

The above analysis suggests that a summer or early autumn day could be identified as an Etesian day when criterion C is satisfied, that is, the daily wind at 1,000 mbar to be of NW to NE WDIR and the WS to take values greater than or equal to 5 ms^{-1}.

3 Results

3.1 Climatology of Etesian winds

The criterion C was applied in order to identify the Etesian days. Over the period June to September of the years 1979 to 2009, the numbers of Etesian days in July (465 days) and August (420 days) are comparable and almost double than those in June (242 days) and in September (253 days). The average total number of Etesian days from June to September is about 45 days.

The daily mean composite wind vector maps were created from the NCEP/NCAR Reanalysis-1 data for each month from June to September of the period 1979 to 2009. Figure 3 provides evidence that the criterion selected for the identification of the Etesian days is a successful one since the composite wind vector maps reveal, for all months in the studied period, the presence of north sector winds that are mainly northeasterly in the northern Aegean Sea, northerly in the central and southern Aegean Sea, and tend to become northwesterly near the south Turkish coast. WS increases from north to south along the Aegean Sea, and the maximum WS values are found mainly over the southern Aegean Sea and the Libyan Sea. In the northern Aegean

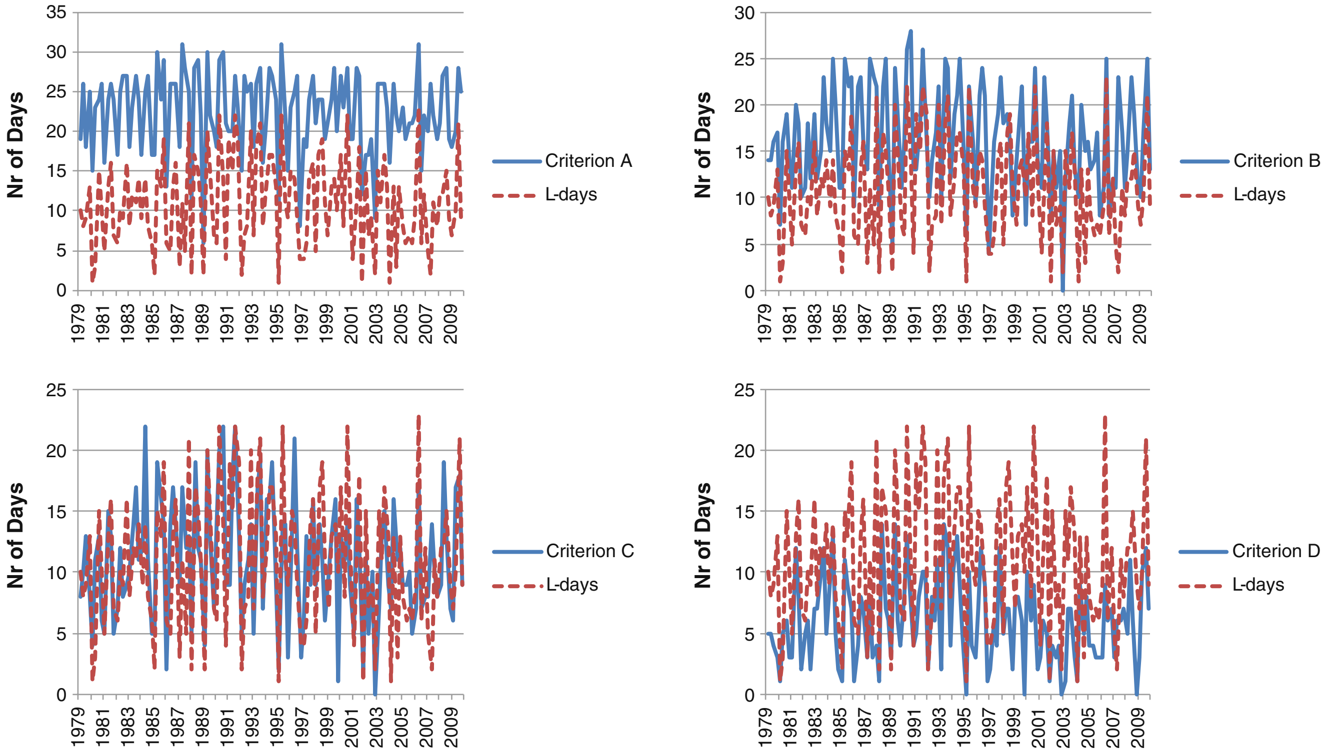


Fig. 2 Time series of *L*-days and the number of days in each month from June to September that satisfy criteria A to D

Sea, WS mean values range between 4.5 and 6 ms^{-1} while in the southern Aegean Sea, WS values can be greater than 6 ms^{-1}.

Following, the climatology of daily WS and WDIR at 1,000 mbar during the Etesian days is given with a focus mainly on the central Aegean Sea (a NCEP/NCAR grid point with latitude 37.5° N and longitude 25° E, see Fig. 1). Figure 4 shows the frequency distribution of daily WS values in central Aegean for the days when Etesian winds blow in the Aegean Sea. Daily WS values range between 5 and 11.5 ms^{-1}; the most frequent daily WS values are those ranging between 5 and 6 ms^{-1} (Fig. 4a). The frequency of the daily WS classes is reduced as WS increases. On a monthly basis, the total frequency of WS values ranging from 7 to 11.5 ms^{-1} is greater in July compared to June, August, and September by 4.6%, 9.5%, and 2.8%, respectively. Strong Etesian winds with WS equal to or greater than 9 ms^{-1} are more frequent in September compared to that in the other months (Fig. 4b). Monthly mean WS does not present significant monthly variation and is about 6.3 ms^{-1}. The mean value of the monthly maximum WS data is 8.2 ms^{-1} in July and is greater than in June and August by 0.7 and 0.5 ms^{-1}, respectively, while it is comparable with that in September. Over the whole period from June to September, N is the most frequent WDIR followed by the NNW direction (Fig. 4c). Similar are the WDIR results on a monthly basis except for September when the NNE direction is second in frequency. NW Etesian winds in the central Aegean Sea are more frequent than the NE ones. The frequency distribution of WDIR per WS class (not shown here) indicates that WSs ranging from 5 to 8 ms^{-1} are mainly associated with N and NNW WDIR, while stronger winds are mainly of N and NNE WDIR.

3.2 Climatic trends

In this section, the frequency and the WS of Etesian winds in the central Aegean Sea are analyzed in terms of their trend. Linear trend analysis was used, and the trends of the time series were tested for statistical significance through a nonparametric Mann–Kendall tau test (Kioutsioukis et al. 2010; Sen 1968). The test assumes a significance level (α) equal to 0.05. If the test of significance gives a p-value

Table 1 Statistical comparison between the *L*-days and the number of days in each month from June to September that satisfy criteria A to D

Measure	Criterion A	Criterion B	Criterion C	Criterion D
Correlation coefficient	0.68	0.69	0.67	0.66
MAGE	11.48	5.77	3.52	5.14

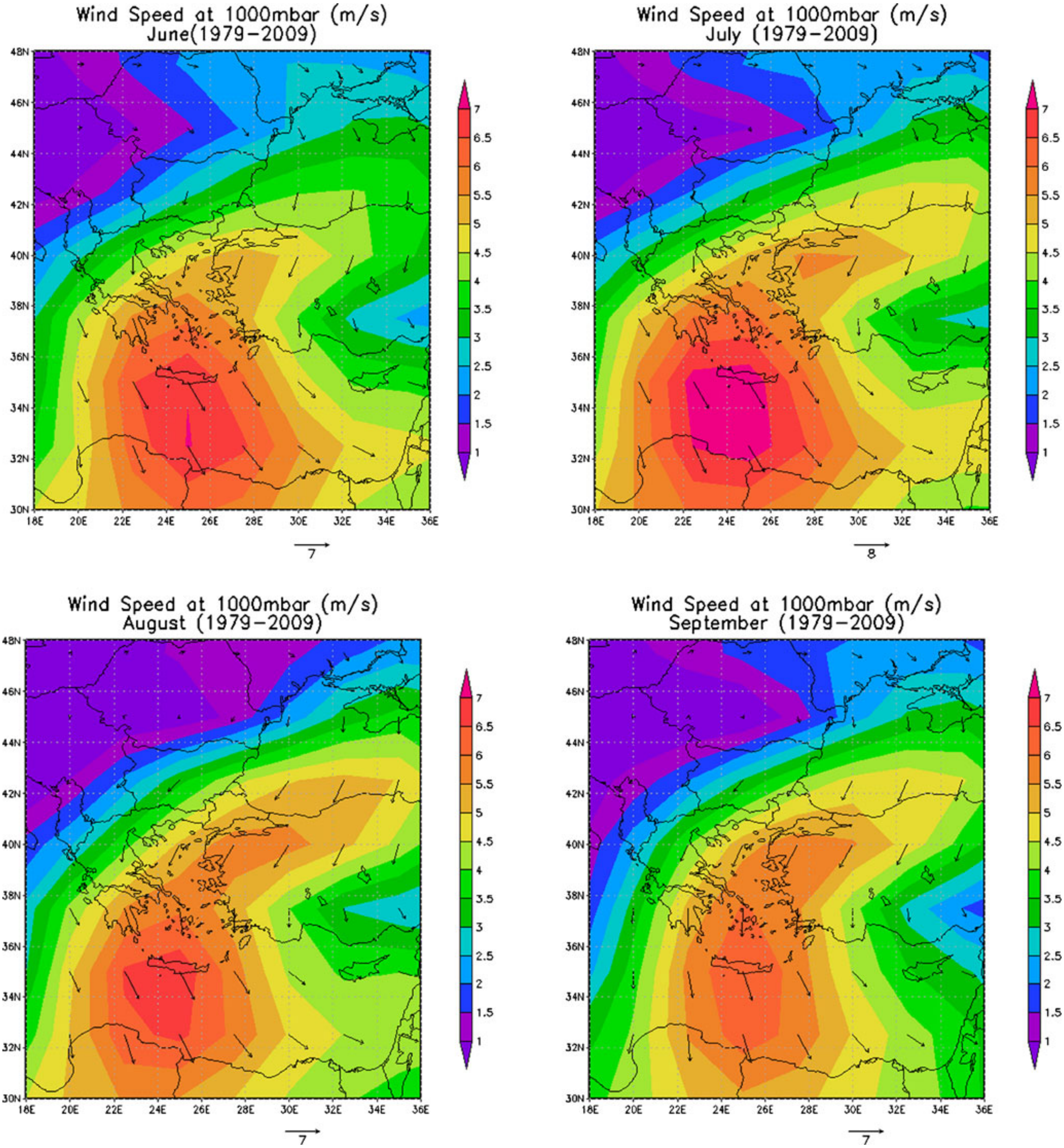


Fig. 3 Daily mean composite wind vector maps for the Etesian days (identified according to criterion C)

(probability of obtaining a test statistic at least as large as the one actually observed) lower than the α-level, then the results (trend) are considered statistically significant at the 95% significance level.

Figure 5 shows the trends of the deseasonalized anomalies in the monthly frequency of Etesian days and in the monthly maximum and mean intensity of the daily WS during the Etesian days in the central Aegean. The deseasonalized anomalies are defined as the differences between the value of the variable for a month and the 1979–2009 average value of the variable for the same month. The calculated trends are negative. The analysis shows that the monthly frequency is reduced by 0.37 days per decade (or by 0.037 days per year as shown in Fig. 5a)

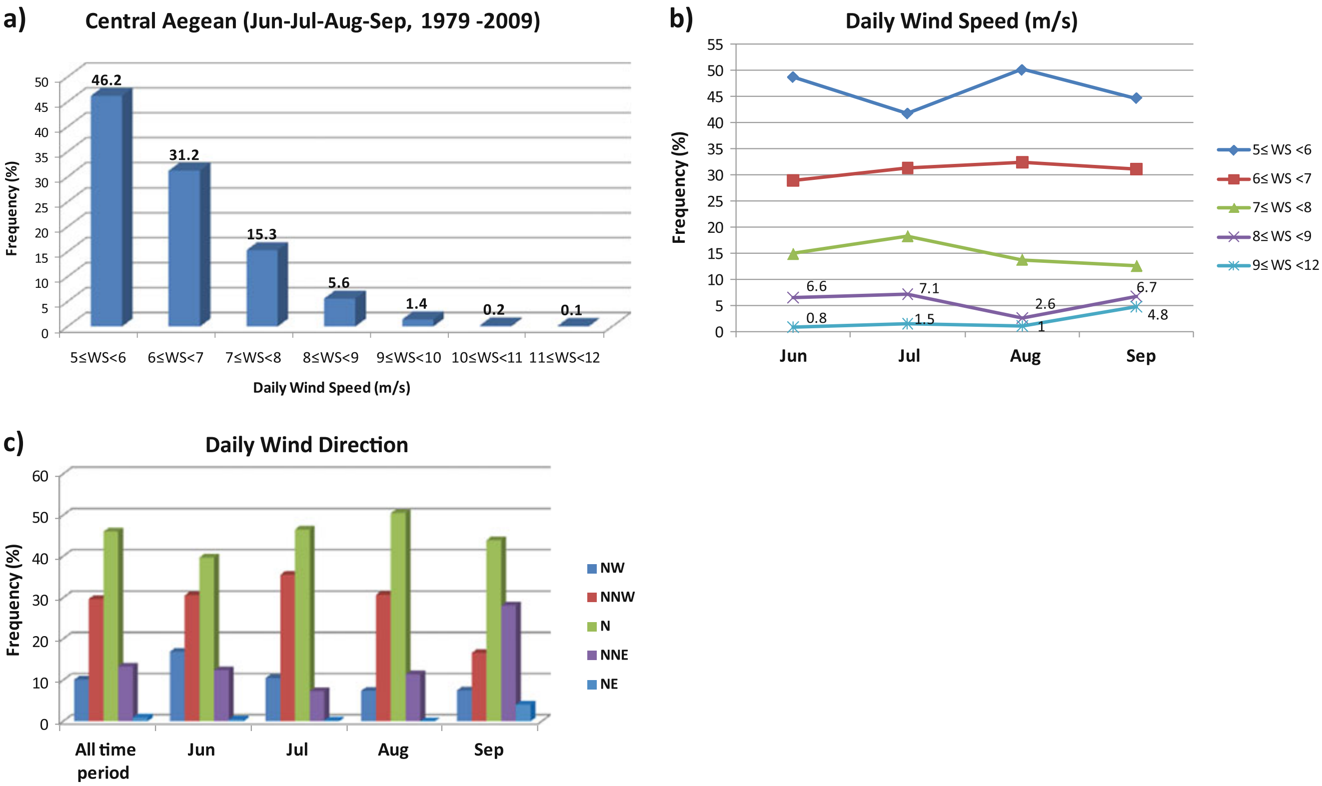


Fig. 4 Frequency distribution of daily WS (**a** and **b**) and WDIR (**c**) in the central Aegean Sea during the Etesian days (identified according to criterion C)

suggesting a June to September frequency decrease of 1.48 days per decade or an about 4.6 days reduction in the total number of Etesian days from June to September during the 31-year period examined. Although the estimated trend in the frequency of Etesian days is not statistically significant at the 95% significance level, it still provides an indication of a possible reduction in the number of days when Etesian winds blow in the Aegean Sea. The negative trend lines in Fig. 5b suggest a long-term decrease in the WS of the Etesian winds. The trend in the monthly maximum WS of the Etesian winds is −0.28 ms^{-1} per decade (or −0.028 ms^{-1} per year, see Fig. 5b) while the negative trend in the monthly mean WS is less pronounced (approximately −0.07 ms^{-1} per decade). During the 31-year period examined, the monthly maximum WS has been reduced by almost 1 ms^{-1} (more particularly about 0.9 ms^{-1}) while the reduction in the monthly mean WS has been approximately 0.2 ms^{-1}. The calculated trend for the maximum WS values is statically significant at the 95% significance level while the trend for the mean values is not.

The trend in the frequency and the intensity of the Etesian winds was examined using an additional available three hourly time series of WS and WDIR measured in the island of Naxos over the years 1955 to 2002. The meteorological station is operated by the Hellenic National Meteorological Service and is located at 37.1° N and 25.4° E, very close to the NCEP/NCAR Reanalysis-1 grid point in the central Aegean (Fig. 1). The three hourly observational data were processed in order for the daily WS and WDIR values to be calculated. The criterion C was applied in order the Etesian days to be identified. In the trend analysis presented below, only the years with a full dataset of daily WS and WDIR values for the period from June to September were used. The calculated monthly frequency of the Etesian days when using the data from the Naxos station has a high correlation (0.73) with the corresponding frequency derived when using the Reanalysis-1 data. Also the correlation coefficients of the monthly maximum and mean WSs between the two different datasets are moderate to high (0.64 and 0.57, respectively).

Figure 6 shows the trends of the deseasonalized anomalies in the monthly frequency of Etesian days and in the monthly maximum and mean intensity of the daily WS during the Etesian days when using the observational data in Naxos. The trend in the monthly frequency of the Etesian winds is negative and comparable with that calculated with the use of the NCAEP/NCAR Reanalysis-1 data. The monthly frequency of the Etesians is reduced by 0.43 days per decade (or by 0.043 days per year) suggesting a June to September frequency decrease of 1.72 days per decade (Fig. 6a). The estimated p-value is equal to 0.085, slightly greater from the 0.05 limit value which defines

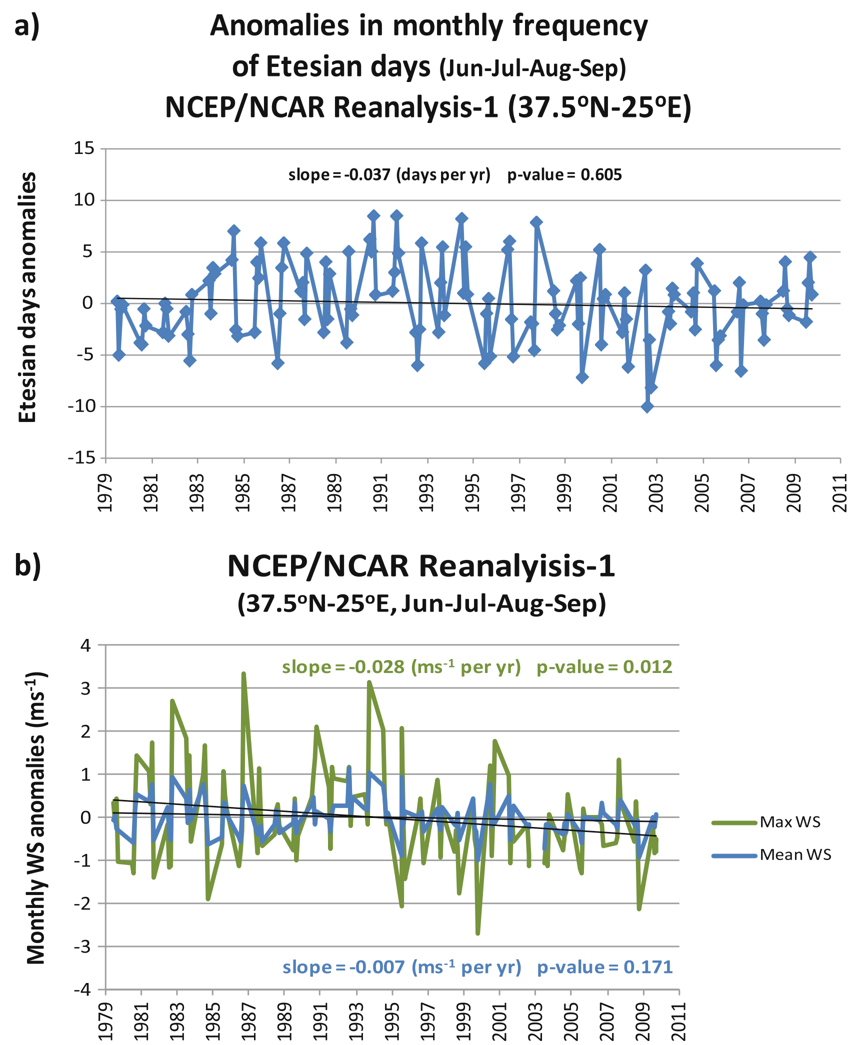


Fig. 5 Time series and trends of the deseasonalized anomalies in **a** the monthly frequency of the Etesian days and **b** the monthly maximum and mean intensity of the daily WS during the Etesian days in the central Aegean using the NCEP/NCAR Reanalysis-1 dataset

statistical significant results at a 95% significance level. This fact suggests that the indication of a possible reduction in the number of Etesian days, introduced from the trend analysis of the NCAEP/NCAR Reanalysis-1 data, is strong. The decreasing trend in the WS of the Etesian winds, estimated from the analysis of the wind measurements in Naxos, is more pronounced compared with that derived from the Reanalysis-1 data (especially for the monthly mean WS). The decrease in the monthly maximum WS of the Etesian winds is 0.49 ms^{-1} per decade (or 0.049 ms^{-1} per year), while the reduction in the monthly mean WS is 0.27 ms^{-1} per decade (or 0.027 ms^{-1} per year) (Fig. 6b). Both trends are statically significant at the 95% significance level.

4 Discussion

An attempt is made in order to connect the negative trends in the frequency and WS of Etesians with the trends in the SLP over the high- and low-pressure systems that contribute to the occurrence of the Etesian winds. Figure 7 presents the daily mean composite SLP map for the Etesian days in the months from June to September of the years 1979 to 2009 (days as identified according to criterion C using the NCEP/NCAR Reanalysis-1 data). The map is extended so as to cover the areas where the pressure centers that produce the Etesians are found. In Fig. 7, a high-pressure system that is located over the northern Balkan Peninsula and central Europe is identified along with a low-pressure system that extends over Iraq and the Persian Gulf. This pressure pattern is similar for each individual month from June to September. Repapis et al. (1978) and Tritakis (1984) report that the Etesians occur when a low-pressure system is located in central Iraq in conjunction with a high-pressure center in the north Balkans–central Europe area, in agreement with the results of the present study shown in Fig. 7. According to Metaxas and Bartzokas (1994), the center of action for the Etesian winds and their interannual

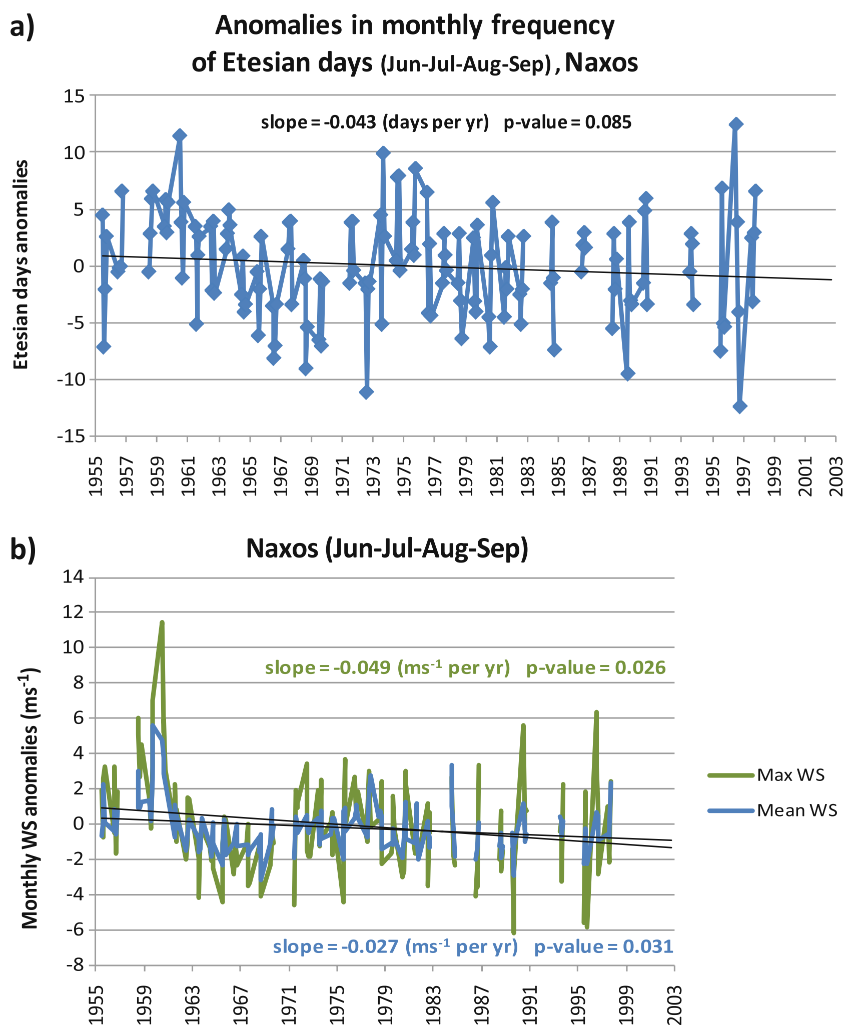


Fig. 6 As in Fig. 5, but for Naxos station

frequency variability is found over the northern Adriatic and northern former Yugoslavia, a finding very close to that in Fig. 7.

In the framework of the present study, a high-pressure center was selected that extends from 7.5° E to 27.5° E and from 42.5° N to 50° N (9×4 grid points of the NCEP/NCAR Reanalysis-1 grid). Similarly, a selected low-pressure center extends from 42.5° E to 55.0° E and from 22.5° N to 35° N (6×6 grid points of the NCEP/NCAR Reanalysis-1 grid) (Fig. 7). The gridded daily SLP values for the Etesian days were spatially averaged separately for each pressure center. The spatially averaged daily SLP time series were processed in order to be linked with the frequency and WS of the Etesian winds.

Figure 8 shows the trend of the monthly SLP values from the NCEP/NCAR Reanalysis-1 dataset for July and August of the years 1979 to 2009. A negative trend is observed over central and southeastern Europe and over Levant and western Asia. However, in the former areas, the negative trend is more pronounced than in the latter ones. This result is indicative of a reduction in the pressure gradient between the two pressure systems that create the Etesian winds. Mind that the general negative trends in SLP values in Mediterranean and southern Europe are in accordance with the negative SLP anomalies in the Mediterranean in future climate change simulations (IPCC 2007). For example, the negative SLP anomalies in Mediterranean during summer is a common feature in future regional climate projections under A2, B2, and A1B IPCC scenarios carried out within PRUDENCE and ENSEMBLES EU projects (Vidale et al. 2007; Zanis et al. 2009).

Figure 9 depicts the time series and trends of the deseasonalized anomalies in the monthly SLP values for the high- and low-pressure centers shown in Fig. 7. Monthly SLP values represent average daily values only for the Etesian days as they are identified from the NCEP/NCAR Reanalysis-1 data using the criterion C. The trend of the SLP anomalies in both pressure centers is negative, and it is statistically significant at the 95% significance level. However, the decreasing trend is more enhanced for the high-pressure center rather than for the low-pressure one.

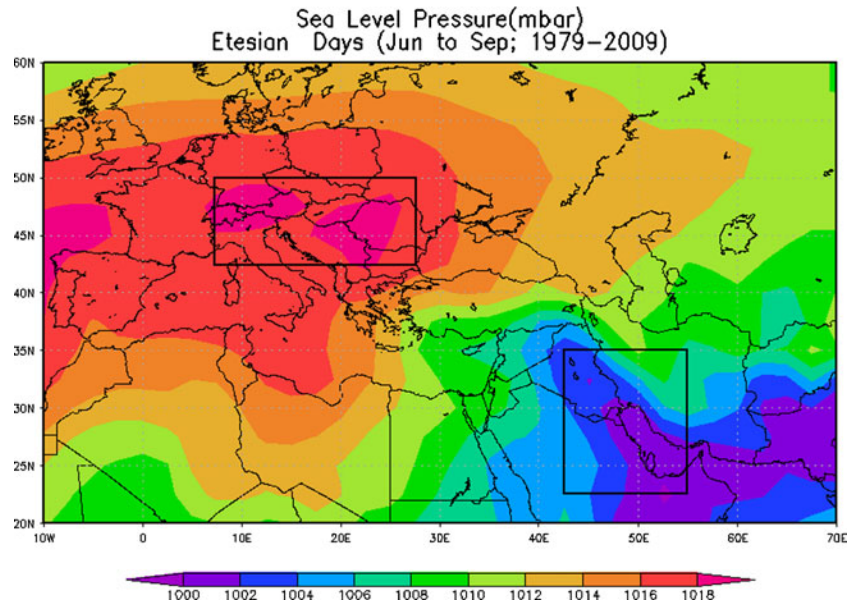


Fig. 7 Daily mean composite SLP map when the Etesians blow in the Aegean Sea (from June to September in the period 1979 to 2009)

The above result provides an indication that the pressure gradient between the two pressure centers that cause the Etesians system has a tendency to decrease.

The above fact could explain the estimated negative trend in the frequency of the Etesian days. The possible critical role of the negative trend in the pressure gradient between the pressure systems in the determination of the trend in the frequency of Etesian winds is also supported by the moderate value of the correlation coefficient between the monthly SLP difference of the high- from the low-pressure center and the monthly frequency of Etesian days which is equal to +0.50.

The negative trend in the monthly maximum and mean WS of the Etesian winds could also be linked to the negative trend in the pressure gradient between the pressure centers. However, such a result is tentative. The correlation coefficient between the monthly maximum or mean WS and the monthly SLP difference of the pressure centers is low (+0.33) but statistically significant at the 95% significance level and comparable with the correlation between WS and monthly SLP at the high-pressure center (+0.36). Repapis et al. (1978) found that more than half (55%) of the total variance of the broadscale background of the Etesians in the Aegean (defined by the average of monthly meridional wind data measured at three stations in northern and central Aegean Sea during the months July to September of the decade 1961–1970) was explained by the pressure difference between northern Balkans and the valley of Iraq. In the same study, a correlation coefficient equal to +0.66 (−0.54) was found between the background of the Etesians and the monthly SLP departures from the mean of the decade 1961–1970 averaged over the northern Balkans (over the valley of Iraq).

Following, the possible role that the quasi-periodic climate pattern of El Niño/La Niña–Southern Oscillation (ENSO) could have on the Etesian winds is investigated. The strength of the Southern Oscillation is measured by the Southern Oscillation Index (SOI). The SOI is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin (Australia). Sustained negative values of the SOI often indicate El Niño episodes. Positive values of the SOI are known as a La Niña episode.

Repapis and Zerefos (1990) and Tourpali et al. (1994) found a statistically significant association between the interannual variation of the monsoon-like circulation in the eastern Mediterranean and the Southern Oscillation. The possible linkage between the Southern Oscillation with the Etesians could be inferred due to the known influence of the Southern Oscillation on the Asian monsoon circulation and rainfall (Chattopadhyay and Bhatla 1993; Webster et al. 1998) and consequently on the low-pressure system representing one of the two pressure centers that determine the north direction air flow in the Aegean Sea.

Figure 10 depicts the seasonal correlation (for July and August being the months when the frequency of Etesians is maximum) between SOI and SLP in central Europe, eastern Mediterranean, and Middle East for the years 1979–2009 based on the NCEP/NCAR Reanalysis-1 dataset. An anti-correlation between SOI and SLP exists over Middle East and over the selected low-pressure center of the Etesians, with the correlation coefficient ranging between −0.1 and −0.6. The correlation coefficient is statistically significant at the 95% confidence level when it takes values less than −0.36. The high-pressure system of the Etesians is not affected by the Southern Oscillation since there is no correlation between SOI and SLP in this area.

Monthly SOI data, taken from the Bureau of Meteorology of the Australian Government (http://www.bom.gov.au/climate/current/soihtm1.shtml), were used and the total

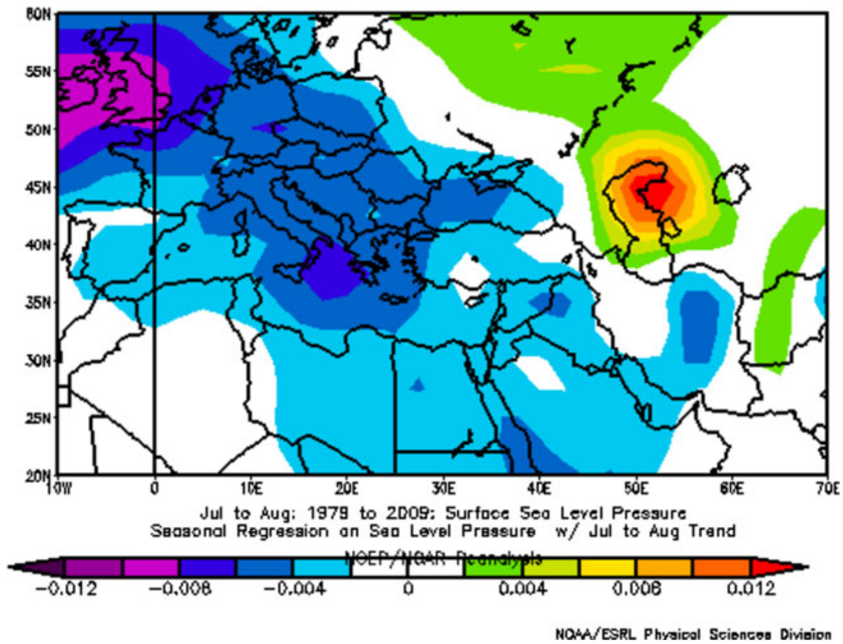


Fig. 8 Trend in SLP values during July to August, 1979–2009

frequency of Etesian days in July and August was correlated with the mean value of monthly SOI for July and August for the period 1979–2009. The estimated correlation coefficient is equal to 0.23, and it is not statistically significant at the 95% significance level. In a previous study by Tourpali (1994), it was found that a small (but statistically significant) linear correlation exists between the number of *L*-days from June through August and the SOI for the period 1892 to 1987. In the same study, cross-spectral analysis revealed that the connection is highly significant at the dominant frequencies of the SOI (3–7 years).

However, for a more comprehensive investigation of the association between the Etesian winds and the Southern Oscillation, a 10-year period with the highest positive mean SOI values for July and August was selected along with a 10-year period with the lowest negative mean SOI values in order to be studied (years shown in Fig. 11). Based on the Multivariate ENSO Index ranking for July and August (Wolter and Timlin 1993, 1998; http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/rank.html), in the 10-year period with the lowest negative SOI values, the years 1982, 1987, and 1997 represent strong El Niño events, the years 1993 and 2002 moderate or stronger, while the years 1979, 2004, and 2006 are considered as representative of weak El Niño conditions. According to the same ranking, in the 10-year period with the highest positive SOI values, the year 1988 is a strong La Niña year, the year 1999 is moderate or stronger, while the years 1985 and 1989 are weak La Niña years. In Fig. 11, the seasonal (July and August) composites of the anomalies of SLP and meridional wind speed from the

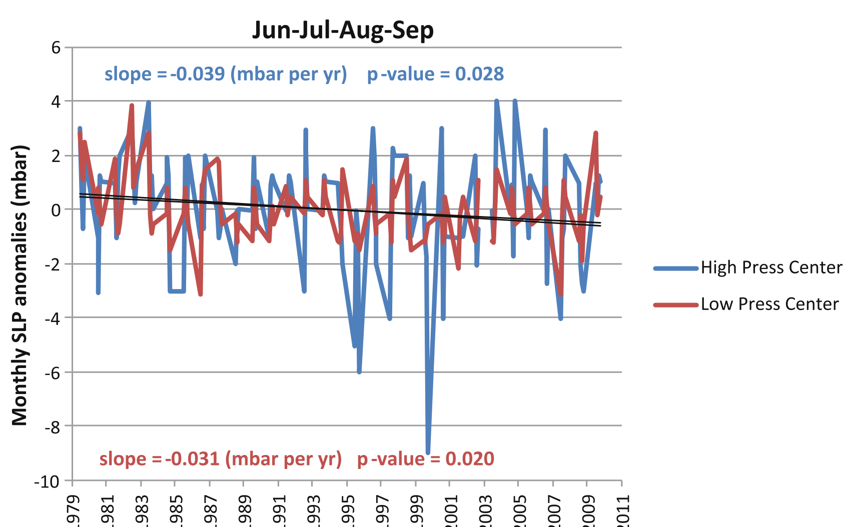


Fig. 9 Time series and trends of the deseasonalized anomalies in the monthly SLP values for the high- and low-pressure centers (monthly SLP values are average daily values only for the Etesian days)

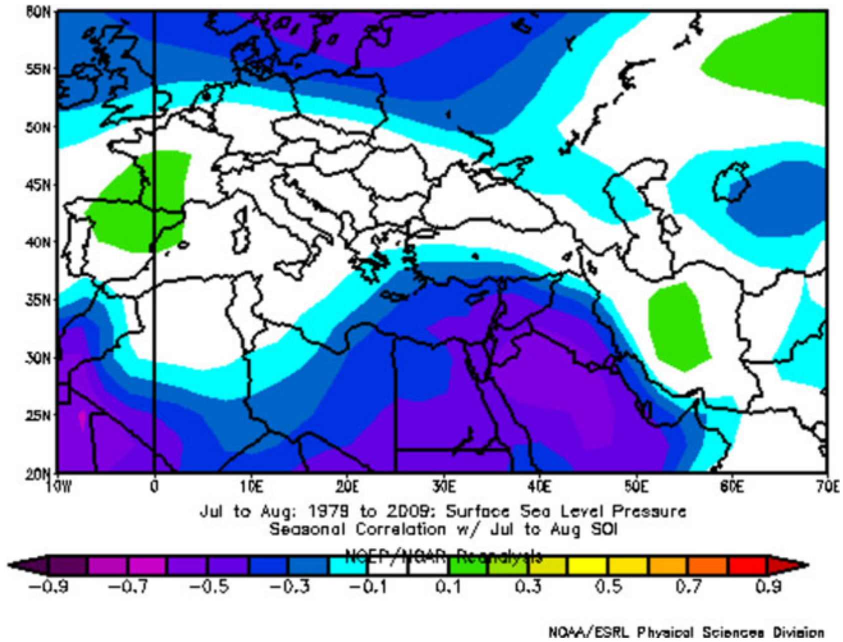


Fig. 10 Seasonal correlation (July and August) between SOI and SLP for the period 1979–2009

NCEP/NCAR mean climatology (1968–1996) are plotted for the SOI lowest negative and highest positive 10-year periods. In the 10-year period with the lowest negative SOI values, SLP increases in the Etesians low-pressure system are found along with SLP reductions in the northern Balkans and central Europe (Fig. 11a). As a result, reductions of the pressure gradient between the Etesians high- and low-pressure systems are expected leading to possible decreases in the frequency of the Etesian days. This is also illustrated in Fig. 11b, which shows that in the Aegean Sea the *v*-wind vector is enhanced suggesting a probable decline in the frequency and/or in the intensity of the north direction winds in this area. In the 10-year period with the highest positive SOI values, the changes in the pressure gradient between the Etesians high- and low-pressure centers are not so clear due to a more complicated pattern of the SLP anomalies (Fig. 11c). However, Fig. 11d shows reduction of the *v*-wind vector in the Aegean Sea, which could be due to an increase in the frequency and/or intensity of the north direction winds in this area.

During the last several decades, the number of El Niño events increased and the number of La Niña events decreased (Trenberth and Hoar 1996). There are questions whether this is a random fluctuation or a normal instance of variation for that phenomenon, or the result of global climate changes toward global warming. Recent results have shown that even after subtracting the positive influence of decadal variation, shown to be possibly present in the ENSO trend (Fedorov and Philander 2000), the amplitude of the ENSO variability in the observed data still increases, by as much as 60% in the recent 50 years; therefore, the impact of global warming on ENSO properties cannot be neglected (Zhang et al. 2008). These results, in conjunction with the previous discussion on the possible impact of Southern Oscillation on the Etesian winds, could support the negative trend in the frequency and WS of the Etesians.

The Etesian winds are beneficial because they moderate temperatures in coastal regions (Pezzoli 2005). The air masses regularly originate from the region of southern Russia and the Caspian Sea and they are dry and relatively cool, contributing to the decrease of surface temperature and the moderation of summer heat and discomfort (Meteorological Office 1962). Ziv et al. (2004) reported that the Etesian winds yielded a continual cool advection from eastern Europe and the Mediterranean into the Levant, which implied an average temperature drop of over 2 $\mathrm{K\,day^{-1}}$. Figure 12 shows the monthly mean surface temperature data in the central Aegean for the non-Etesian and for the Etesian days. The difference in temperature data between the non-Etesian and the Etesian days is also shown in the same figure. The Etesian winds contribute to a temperature reduction since 70% of the temperature difference values are positive. The average temperature decrease is estimated to be 0.65 K. The negative trend in the frequency and WS of the Etesian winds could imply a reduced cooling mechanism in the eastern Mediterranean in the summer period due to climate change.

5 Conclusions

The Etesian winds represent an important climatic element in the eastern Mediterranean during summer and early

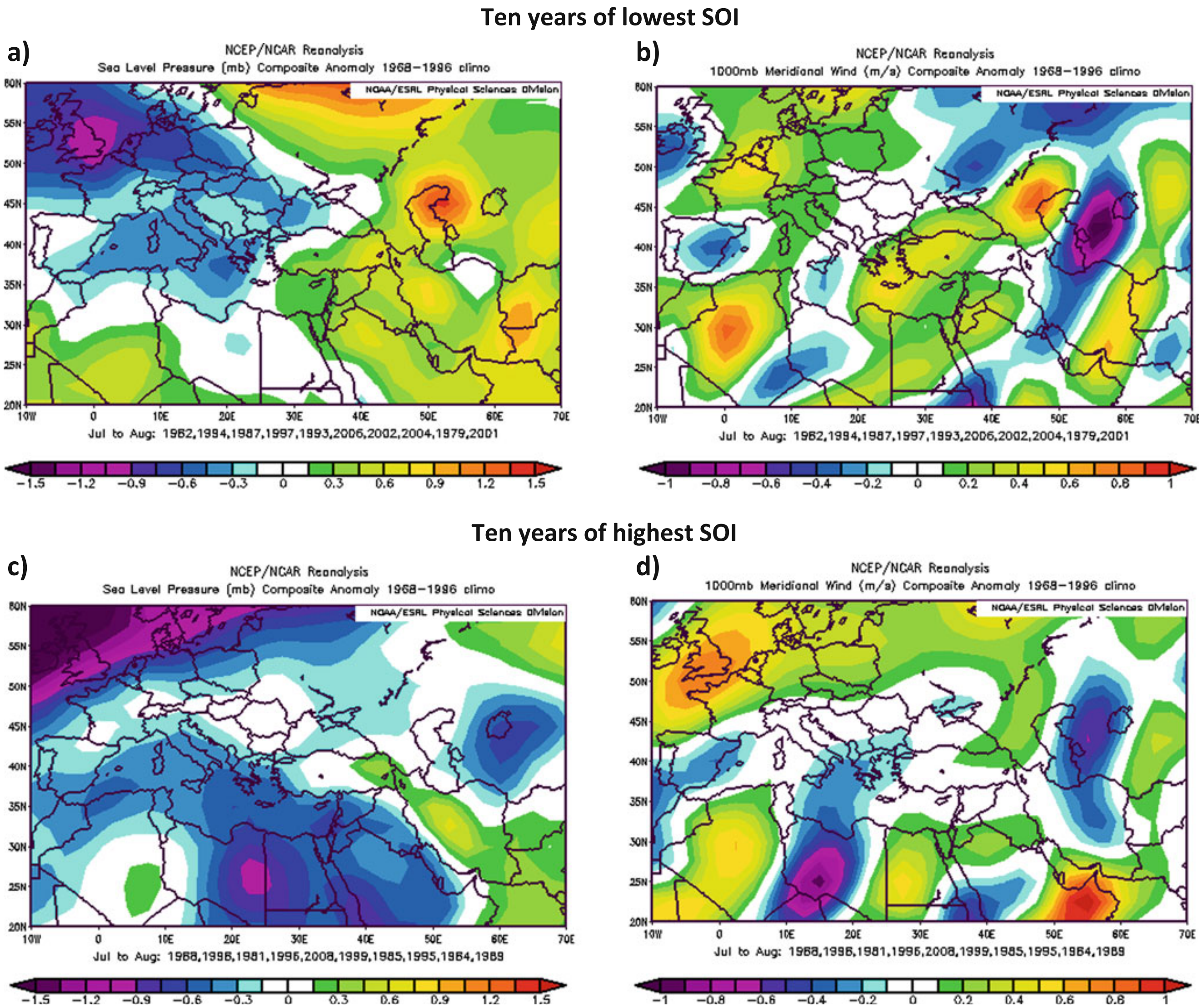
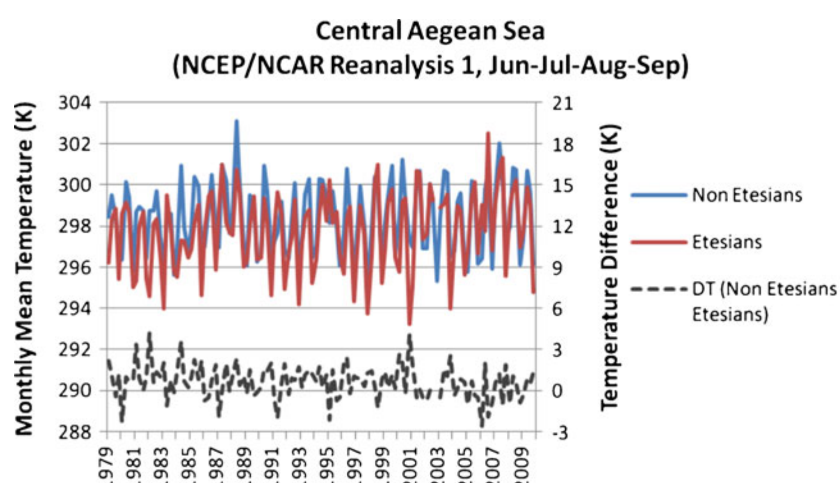


Fig. 11 Seasonal composites of the anomalies of SLP and meridional wind speed from the NCEP/NCAR mean climatology for the SOI lowest negative (**a** and **b**) and highest positive (**c** and **d**) 10-year periods

Fig. 12 Impact of Etesian winds on monthly temperature data



autumn. They are northerly, moderate to strong, cool and dry winds blowing over the Aegean Sea that moderate summer heat and discomfort. The main objective of the present study was to perform a trend analysis and investigate the possible changes in the frequency and wind intensity of the Etesians during the most recent 31-year period (1979–2009) also as a probable implication of the climate change. The analysis was based mainly on the NCEP/NCAR Reanalysis-1 data.

The results of the trend analysis provided indications of negative trends in the frequency and wind speed of the Etesians. The total number of Etesian days from June to September and the monthly maximum WS decreased by 1.48 days per decade and 0.28 ms^{-1} per decade, respectively. So, during the 31-year period studied, an almost 4.6-day reduction in the frequency of Etesian days and an almost 1-m s^{-1} reduction in the monthly maximum intensity of daily WS were estimated. The above indications are strengthened by similar results derived from the trend analysis of observational wind data in the central Aegean for the years 1955 to 2002.

The study also provided an indication of a decreasing trend in the pressure gradient between the two pressure centers that form the Etesians system. This trend could explain the estimated negative trend in the frequency of the Etesian days, given also the moderate value of the correlation coefficient between the monthly SLP difference between the high- and low-pressure centers and the monthly frequency of the Etesian days which was equal to +0.50.

The correlation coefficient between the monthly maximum or mean intensity of daily WS and the monthly SLP difference of the pressure centers was relatively low (+0.33) but statistically significant at the 95% significance. It was comparable though with the correlation coefficient between WS and monthly SLP at the high-pressure center (+0.36), suggesting that the negative trend in the monthly maximum and mean WS of the Etesian winds is more difficult to be explained.

The possible association between the Southern Oscillation and the Etesian winds was also revealed. During the 10 years with the lowest negative average SOI values for July and August, a reduction of the pressure gradient between the Etesians high- and low-pressure centers was identified, inducing possible decreases in the frequency and/or in the intensity of the Etesians. During the 10 years with the highest positive SOI values, reductions of the meridional wind in the Aegean Sea were found, which could be due to an increase in the frequency and/or in the intensity of the north direction winds in the area. Consequently, a negative trend in the frequency and WS of the Etesians the last 30 years could also be linked to the increased number of El Niño events and the decreased number of La Niña events of the last several decades.

The Etesian winds contributed to an average temperature decrease of 0.65 K in the central Aegean during the 31-year period examined. The negative trend in the frequency and WS of the Etesian winds could imply a reduced cooling mechanism in the eastern Mediterranean in the summer period due to climate change. Future work will include the investigation of the frequency and intensity of the Etesian winds in projections of General Circulation Models and Regional Climate Models.

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