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Temperature and surface pressure anomalies in Israel and the North Atlantic Oscillation

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With 5 Figures

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Summary

Teleconnections associated with changing patterns of temperature and pressure anomalies over Israel during the second half of the 20th century are investigated. Relatively high, statistically significant, correlation coefficients of −0.8 and +0.9 were found between the North Atlantic Oscillation (NAO) Index anomalies and smoothed (5 year running mean) cool season temperature and surface pressure anomalies in Israel, respectively.

A relatively high positive correlation, ($r = 0.8$) was also found between the NAO Index anomalies and smoothed geopotential height of the 1000 hPa pressure level, during the cool season at Bet Dagan radiosonde station located on the Israel Mediterranean coastal plain. Correlation coefficients between NAO Index anomalies and the higher standard pressure levels, 850 and 700 hPa, decrease gradually and become negative (not statistically significant) for the 500 hPa level.

1. Introduction

Recent studies indicate that the interannual variability of atmospheric circulation patterns in the northern hemisphere may be affected by differences in sea level pressure (SLP) between the Atlantic subtropical high, centered near the Azores, and the Atlantic subpolar low near Iceland. This seesaw of atmospheric mass is referred to as the North Atlantic Oscillation (NAO) (e.g. Walker and Bliss, 1932; Van Loon and Rogers, 1978; Wallace and Gutzler, 1981; Barnston and Livezey, 1987; Kushnir and Wallace, 1989; Hurrell, 1995).

The NAO is also considered to regulate heat and moisture fluxes from the Atlantic to the Mediterranean sector in winter time, under the westerlies regime, and therefore responsible for rainfall and temperature variability in this region (Rogers, 1990; Hurrell, 1995, 1996; Turkes, 1996). During high (positive) NAO winters, the subtropical-subpolar SLP gradient is enhanced, westerlies over Europe are stronger than during low NAO winters, becoming more meridional, and thus advecting, warm moist Atlantic air over northern Europe and drier airmasses over the Mediterranean. During low (negative) NAO winters, the gradient is weakened and Atlantic westerlies assume a more zonal trajectory, bringing wetter and warmer conditions to the Mediterranean region (Rogers, 1990; Hurrell, 1995, 1996; Turkes, 1996; Hurrell and Van Loon, 1997).

In addition to interannual variability, several periods of persistently anomalous circulation have been observed. Anomalously low NAO conditions were observed from the 1940's, and an upward trend from the early 1960's. A strong positive

NAO Index was observed since 1980 up to the early 1990's (Kushnir, 1994; Wallace et al., 1995, 1996; Hurrell, 1995, 1996; Hurrell and Van Loon, 1997). Several studies indicate that changes in circulation over the Atlantic, that may have contributed to the recent warm winters across Europe, are the cause of lower temperatures over the eastern Mediterranean since the 1960's (Arseni-Papadimitriou and Maheras, 1991; Metaxas et al., 1991; Sahsamanoglou and Makrogiannis, 1992; Cullen and deMenocal, 2000). Cullen and deMenocal, (2000), found a decrease in Turkish winter temperature and precipitation and considered it consistent with the persistently positive trend of the NAO.

Also worthwhile noting is that according to a number of studies (Metaxas et al., 1991; Sahsamanoglou and Makrogiannis, 1992; Steinberger and Gazit-Yaary, 1995), the sea level pressure (SLP) over the eastern Mediterranean shows an increasing trend during recent decades, while Sea Surface Temperatures (SST) show a decreasing trend.

The SSTs in the Mediterranean seem to be related to the phase of the NAO. During the positive (high) phase of the NAO, SSTs in the eastern Mediterranean and the subtropical Atlantic show a negative anomaly of about 0.5–1.0 degrees Kelvin (Parker and Folland, 1988; Wallace et al., 1995, 1996; Hurrell, 1995, 1996; Cullen and deMenocal, 2000).

Several studies indicate a decrease in SST in the Mediterranean during the recent decades (Lascaratos et al., 1991; Kutiel and Bar-Tuv, 1992; Sahsamanoglou and Makrogiannis, 1992). SSTs in the Mediterranean sea are an important cyclogenesis factor in the region, mainly during the cold period of the year (Alpert et al., 1995; Stein and Alpert, 1991). Metaxas et al. (1991) found strong connections between SST and air temperature trends.

Changes in surface temperature should be reflected in the lower troposphere. In fact, changes in atmospheric circulation (horizontal thermal advection), including an increase in SLP over the Mediterranean area in recent years, have been noticed by Makrogiannis and Sahsamanoglou (1990); Metaxas et al. (1991); Sahsamanoglou and Makrogiannis, (1992), and Kutiel and Kay, (1992).

In a previous study (Ben-Gai et al., 1999), it was shown that since the early 1960's the maximum and minimum temperatures over Israel have exhibited a decreasing trend during the cool season, and an opposite, warming trend during the warm season, thus resulting notable increase in the intraseasonal range. Trend patterns of Maximum and Minimum temperatures over Israel, based on data records from 40 stations, show considerable spatial variability, presumably caused by extensive changes in land use (mesoscale forces) during recent decades (Ben-Gai et al., 1998, 1999). However, a rather general opposite trend seems to imply macroscale forcing factors are at work.

In the present study, an attempt is made to examine teleconnections between observed patterns of Maximum and Minimum temperatures, as well as atmospheric pressure variations over Israel and Northern Hemisphere pressure anomalies. The potential effects of NAO variability, and the effects of NAO persistent phases, on surface temperature and pressure regimes over Israel will be investigated.

2. Data and methodology

The database for the present study consists of maximum and minimum monthly temperatures from 6 stations in Israel covering a period of 45 years (1950–1994), and 34 stations with 31 years (1964–1994); monthly surface pressure from 16 stations (1964–1994), and the Bet Dagan radiosonde data record (1964–1994) from the Israel Meteorological Service station network. The total number of temperature stations available was much higher (60), but only continuous and homogeneous records were used (Ben-Gai et al., 1999). The spatial variability of the maximum and minimum daily temperature data, largely reflecting microclimatic effects caused by local topography, station environment, urbanization, agricultural activities and other local factors surrounding the station, may offset or obscure the impact of external forcing.

To reduce the impact of these factors and obtain a more general temperature pattern for the region as a whole, the temperature data for all stations were stratified into a single time series of *cool* season anomalies. The following computational procedure was applied to achieve this goal.

Monthly maximum and minimum temperatures for the cool season months of December, January, February and March for the 45 and 31 year periods for each station ($T_{i,j,k}$) were used separately to calculate multi-year averages ($\bar{M}_{i,k}$) for each month (index *i*), at each station (index *k*) Eq. (1), where *j* is the year index. Monthly anomalies for each year and each station ($A_{i,j,k}$) during the period of record were then calculated Eq. (2). Monthly anomalies of all stations for each year were then averaged ($\bar{A}_{i,j}$); Eq. (3). Average anomalies for the cool season for each year were then calculated ($\bar{W}_j$) Eq. (4). The two time series of cool season minimum and maximum temperature anomalies were then smoothed using a 5 year running mean.

$$\bar{M}_{i,k} = \frac{\sum_{j=1}^{n} T_{i,j,k}}{n} \tag{1}$$

$n =$ number of years for each station

$$A_{i,j,k} = T_{i,j,k} - \bar{M}_{i,k} \tag{2}$$

$$\bar{A}_{i,j} = \frac{\sum_{k=1}^{n} A_{i,j,k}}{n} \tag{3}$$

$n =$ number of stations for each year

$$\bar{W}_j = \frac{\sum_{i=1}^{4} \bar{A}_{i,j}}{4} \tag{4}$$

where:

$i =$ months
$j =$ year
$k =$ station

A similar data reduction procedure was also applied to the surface pressure data for 16 stations in Israel. The normalized NAO Index (Hurrell, 1995), defined as the difference between the normalized mean winter (December–March) sea level pressure anomalies at Lisbon in Portugal and Stykkisholmur in Iceland, was taken from Hurrel's CLIMLIST (Hurrell, 1995).

The statistical significance of the correlation between the NAO and: maximum temperature, minimum temperature, surface pressure, and the Bet Dagan radiosonde geopotetial heights was checked using a two sample t-test at the significance level of 0.05.

3. Results

Monthly maximum and minimum temperature anomalies for the cool season, as well as the 5 year running mean for the period 1950–1994, are shown in Fig. 1a and 1b, respectively. The downward trend since the early 1960's is well pronounced, especially for maximum temperatures. The slope of the decreasing trend was found to be statistically significant (at the 5% confidence level) both for the smoothed and raw maximum temperature series, but only for the smoothed minimum temperature series.

NAO Index anomalies since 1950, raw smoothed by a 5 year running mean, are shown in Fig. 2. A clear pronounced downward trend appears upto the 1960's, and an upward trend occurs from then on. Opposite tendencies in the maximum and minimum temperature anomaly series for Israel occur with respect to the NAO anomaly patterns, for the period of 1950–1994. The correlation coefficients between the NAO Index anomalies and the raw maximum and minimum temperature anomalies for Israel, are statistically significant (at less than the 1% confidence level), at −0.60 and −0.63, respectively. For the smoothed data, the correlation coefficients, are statistically significant (less than 1% confidence level), at −0.86 and −0.79 respectively (Fig. 3a and 3b).

Relatively high positive correlation was found between the NAO Index anomalies and the surface pressure anomalies at 16 stations in Israel, for the period 1964–1994. Correlations reached 0.65 for the raw data, (statistically significant at less than the 1% confidence level), and 0.89 for the smoothed data, also highly statistically significant. The trend of the NAO Index and surface pressure anomalies for Israel smoothed using a 5 year running mean are shown in Fig. 4.

The NAO Index trend was also examined with respect to the geopotential heights of the standard pressure levels, 1000, 850, 700 and 500 hPa, observed at the Bet Dagan Radiosonde Station located on the Mediterranean coastal plain in Israel, during the period 1957–1994. The results are presented in Fig. 5. As can be seen, relatively high positive correlations were found between the NAO Index anomalies and the Bet Dagan 1000 hPa geopotential heights, with 0.57 and 0.82 for the raw and smoothed data, respectively, (both statistically significant at the 1% confidence level). The correlation coefficients, however, weaken with the increasing altitude: at 850 hPa the correlation coefficient is 0.45 for the smoothed data (statistically significant) and 0.25 for the un-

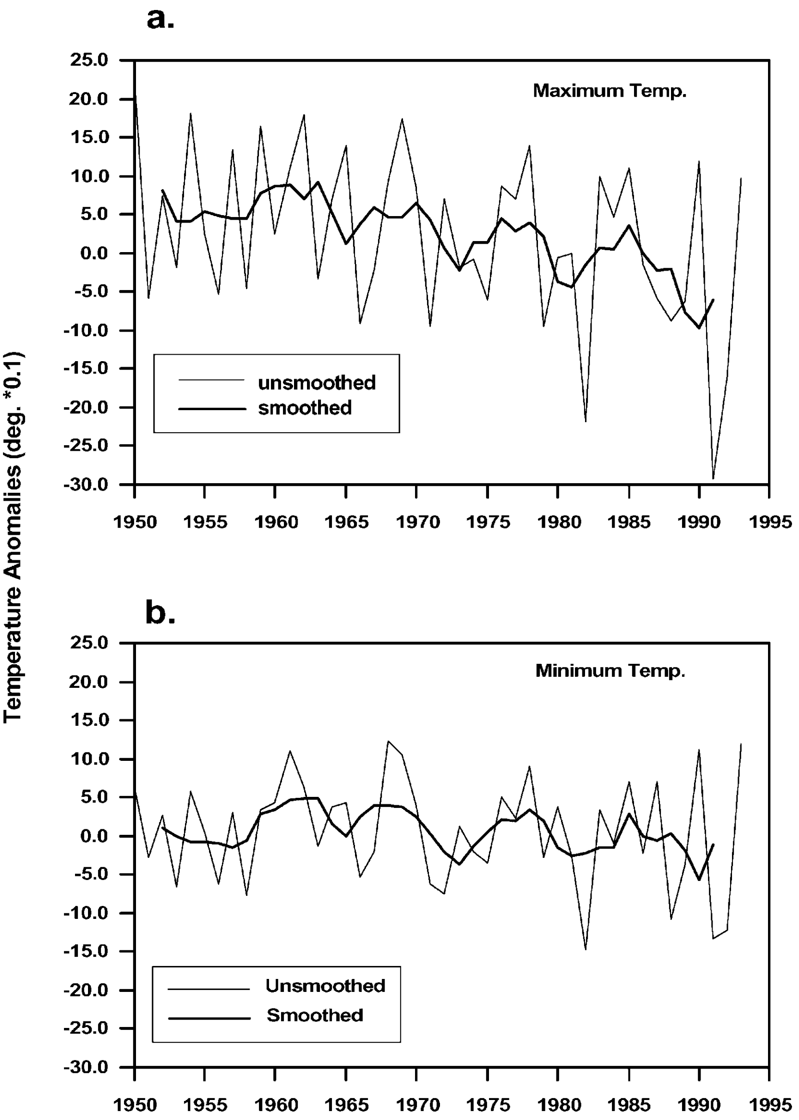

Fig. 1. Average of winter (December to March) temperature anomalies of 40 stations in Israel and their 5 year running mean for the period 1950–1994, (6 stations) and 1964–1994 (34 stations): **a** Maximum temperature. **b** Minimum temperature

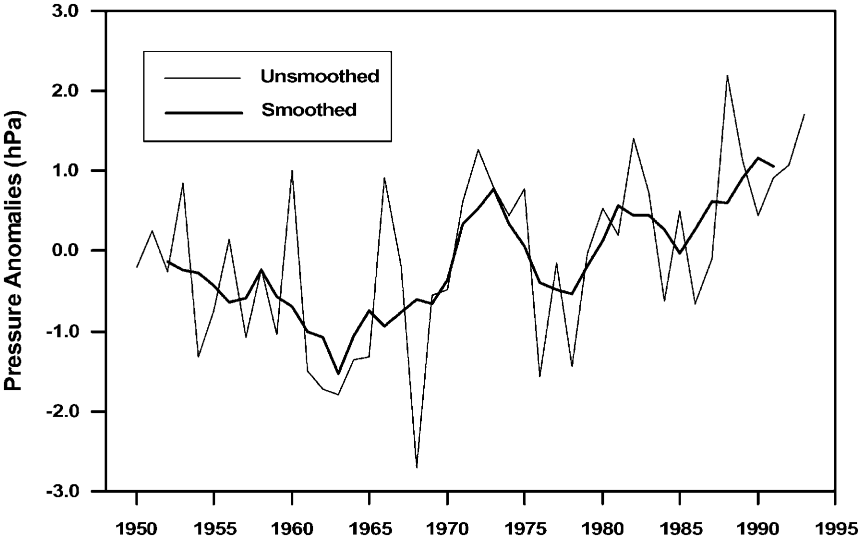

Fig. 2. NAO Index between 1950–1994 for December-March with 5 year running mean. (Hurrell, 1995)

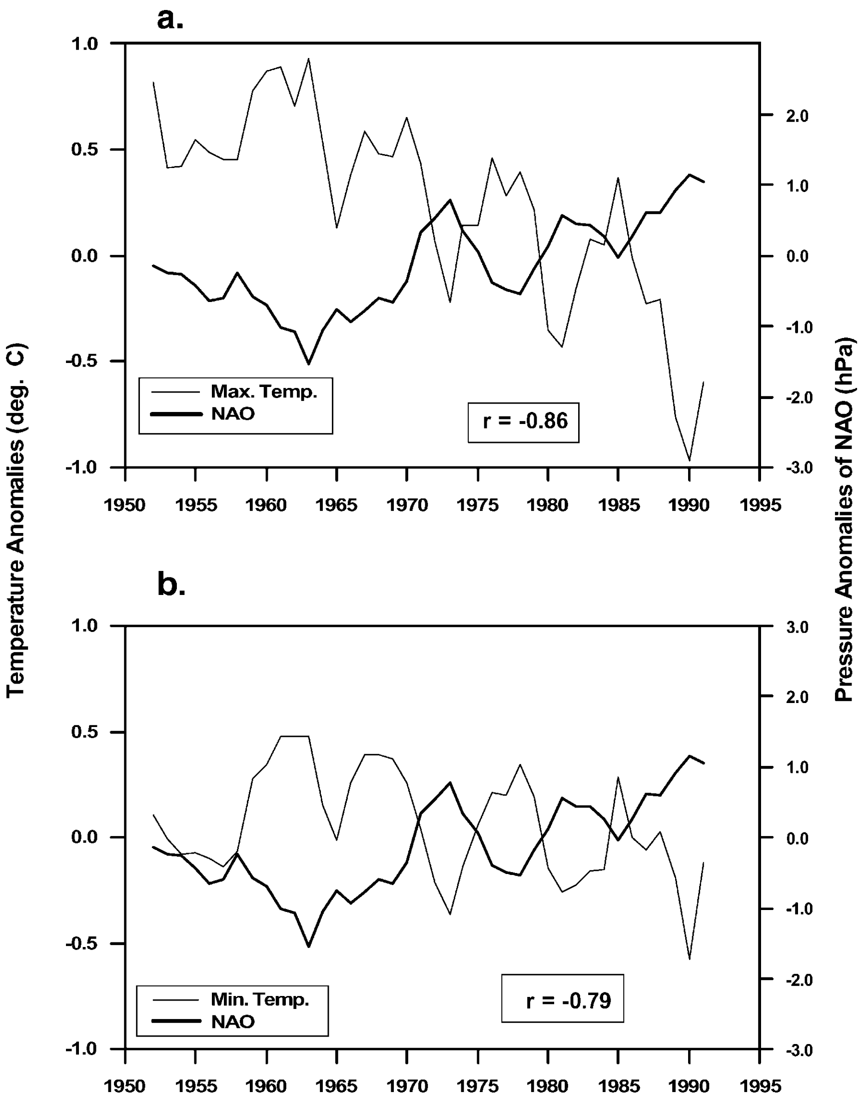

Fig. 3. Smoothed anomalies (5 year running mean) of Israel Maximum and Minimum winter temperature (December-March) and the NAO Index. Coefficients of correlation between NAO Index and anomalies of Maximum and Minimum temperature are −0.86 (**a**), and −0.79 (**b**), respectively

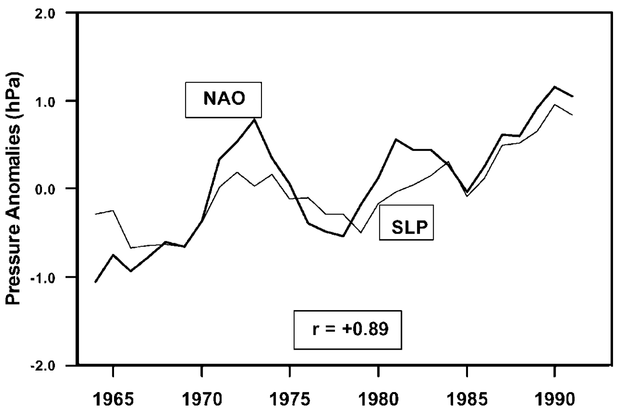

Fig. 4. Smoothed anomalies (5 year running mean) of the winter (December-March) Sea level pressure in Israel and the NAO Index. The coefficient of correlation is 0.89

smoothed data (statistically insignificant). For the 700 hPa levels and 500 hPa the correlation coefficient is around 0, (not significant).

4. Summary and conclusions

The onset of the winter season in Israel and the eastern Mediterranean, (usually in December) is characterized by the retreat of a blocking subtropical high, and prevalence of the westerlies regime. This change in circulation system allows teleconnections between the North Atlantic Oscillation phase and the maximum and minimum temperatures and atmospheric pressure over Israel during the second half of the 20th century.

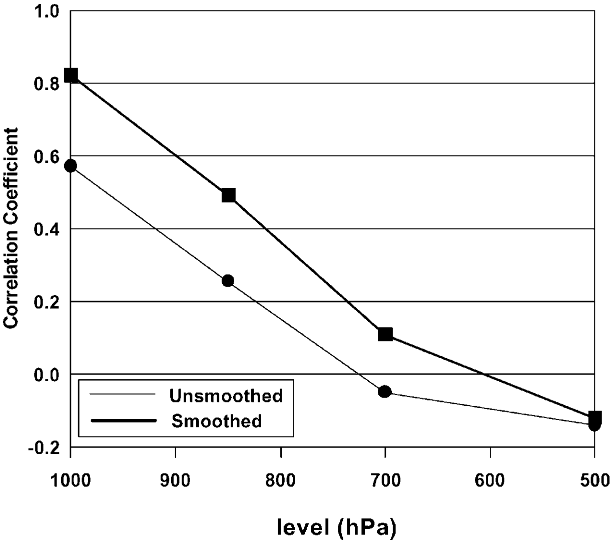

Fig. 5. Correlation between NAO Index and geopotential heights of pressure levels of 1000, 850, 700 and 500 hPa. The coefficient of correlation between NAO Index and geopotential height of 1000 hPa is 0.57 for the "raw" data, and 0.82 for the 5 year running mean. The correlation is gradually decreasing upwards for the 850, 700 and 500 hPa levels

The impact of the NAO on climatic variability in the North Atlantic and Western Europe has been studied extensively, but the geographic extent has not yet been mapped clearly. The importance of this present study lies in highlighting the NAO influence over Israel and the eastern Mediterranean.

The surface connection between the NAO and Israel can be seen in figures published recently in the work by Hurrell (1995) and Hurrel and van Loon in (1997). These figures show that the NAO is a large scale perturbation in the atmospheric circulation influencing a considerable section of the Northern Hemisphere. While the center of influence is the North Atlantic and Western Europe, considerable effects on pressure and temperature occur over North America, Eastern Europe, Asia, the Mediterranean and North Africa. The question of how and why these effects exist is linked to an understanding of atmospheric dynamics and has not yet been fully answered. However, a recent explanation has been made by De Weaver and Nigam (in press) which shows that cooling in the Middle East is a result of changes in advection patterns and tracks of weather disturbances, that is, the convergence of heat in the mean winter circulation and high frequency perturbations on sub-monthly time scale.

Maximum and minimum temperatures and pressure patterns for Israel during the period 1950–1994 match the low frequency behavior of the NAO, especially the positive phase from the 1960s to the 1990s. These findings support the results of Cullen and deMenocal (2000), regarding the impact of the NAO phase on climate variability over the eastern Mediterranean region.

As for the reduced relationship between the NAO and geopotential heights with increasing attitude, this can be explained by the difference in the pattern of the NAO at the surface and that aloft: Kushnir and Wallace (1989) showed using 500 hPa geopotential heights that the region over Greenland (the northern center of the NAO) is positively correlated with a center over Iraq and negatively correlated with a center over eastern Europe. This pattern shifts with respect to the surface, and leaves Israel in a region of weak correlation. It should also be noticed that this shift is consistent with the fact that while sea level pressure in Israel is positively correlated with the NAO, surface temperature is negatively correlated. This means that when the NAO is positive, there is a cold high pressure system over Israel. According to the hydrostatic relationship, a cold high is a feature that diminishes with height, thus explaining the decreased relationship with height. The opposite happens when the NAO is negative, when a warm low occurs. Further studies, both empirical and theoretical may by necessary to explain this phenomenom.

References

Alpert P, Stein U, Tsidulko M (1995) Role of sea fluxes and topography in eastern Mediterranean cyclogenesis. The Global Atmospheric-Ocean System 3: 55–79

Arseni-Papadimitriou A, Maheras P (1991) Some statistical characteristics of air temperature variations at four Mediterranean stations. Theor Appl Climatol 43: 105–112

Ben-Gai T, Bitan A, Manes A, Alpert P, Israeli A (1998) Aircraft measurements of surface albedo in relation to climate change in southern Israel. Theor Appl Climatol 61: 177–190

Ben-Gai T, Bitan A, Manes A, Alpert P, Rubin R (1999) Temporal and spatial trends of temperature patterns in Israel. Theor Appl Climatol 64: 163–177

Barnston A, Livezey RE (1987) Classification, seasonality and persistence of low-frequency circulation patterns. Mon Wea Rev 115: 1083–1126

Cullen H, deMenocal PB (2000) North Atlantic influence on the middle eastern climate and water supply. Int J Climatol (in press)

DeWeaver E, Nigan S (2000) Zonal eddy coupling and the dynamics of the North Atlantic Oscillation. J Clim (in press)

Hurrell JW (1995) Decadal trends in the North Atlantic Oscillation regional temperature and precipitation. Science 269: 676–679

Hurrell JW (1996) Influence of variations in extratropical wintertime teleconnections on northern hemisphere temperature. Geophys Res Lett 23: 665–668

Hurrell JW, Van Loon H (1997) Decadal variations in climate associated with the North Atlantic Oscillation. Clim Change 36: 301–326

Kushnir Y (1994) Interdecadal variations in north Atlantic sea surface temperature and associated atmospheric conditions. J Climate 7: 141–157

Kushnir Y, Lau NG (1992) The General Circulation Model Response to a North Pacific SST anomaly: Dependence on time scale and pattern polarity. J Appl Meteor 5: 271–284

Kushnir Y, Wallace JM (1989) Low-frequency variability in the northern hemisphere winter: geopotential distribution, structure and time-scale dependence. J Atmos Sci 46: 3122–3142

Kutiel H, Bar-Tuv A (1992) Recent trends of decreasing autumnal Sea Surface Temperature (SST) in the eastern Mediterranean basin. Isr J Earth Sci 41: 51–53

Kutiel H, Kay PA (1992) Recent Variations in 700 hPa geopotential height in summer over Europe and the Middle East, and their influence on other meteorological factors. Theor Appl Climatol 46: 99–108

Lascaratos A, Gacic M, Oguz T (1991) Recent atmospheric and oceanic oscillations in the Northeastern Mediterranean and the Black Sea. Proceedings: International Workshop on Regional Implications of Future Climate Change. 28 April–2 May, 1991, Rehovot, Israel

Makrogiannis TJ, Sahsamanoglou CS (1990) Time variation of the mean sea level pressure over the major Mediterranean area. Theor Appl Climatol 41: 149–156

Metaxas DA, Bartzokas A, Vitsas A (1991) Temperature fluctuations in the Mediterranean area during the last 120 years. Int J Climatol 11: 897–908

Parker DE, Folland CK (1988) The nature of climatic variability. Met Mag 117: 201–210

Rogers JC (1990) Patterns of low frequency monthly sea level pressure variability (1899–1986) and association with Cyclone Frequency. J Clim 3: 1364–1379

Sahsamanoglou HS, Makrogiannis TJ (1992) Temperature trends over the Mediterranean region, 1950–88. Theor Appl Climatol 45: 183–192

Stein U, Alpert P (1991) Inclusion of sea moisture flux in the Antmes-Kuo cumulus parameterization. Contrib Atmos Phys 64: 231–243

Steinberger EH, Gazit-Yaary N (1995) Recent changes in spatial distribution of annual precipitation in Israel. J Clim 9: 3328–3336

Turkes M (1996) Spatial and temporal analysis of annual rainfall variations in Turkey. Int J Climatol 16: 1057–1076

Van Loon H, Rogers JC (1978) The seesaw in winter temperatures between Greenland and Northern Europe, Part I: General description. Mon Wea Rev 106: 296–310

Walker GT, Bliss EW (1932) 'World weather V'. Mem Roy Meteor Soc 44: 53–84

Wallace JM, Gutzler DS (1981) Teleconnections in the geopotential height field during the Northern Hemisphere winter. Mon Wea Rev 109: 784–812

Wallace JM, Zhang Y, Bajuk L (1996) Interpretation of interdecadal trends in Northern Hemisphere surface air temperature. J Clim 9: 249–259

Wallace JM, Zhang Y, Renwick JA (1995) Dynamic contribution to Hemispheric mean temperature trends. Science 270: 780–783

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