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WINTERTIME SURFACE TEMPERATURE IN EGYPT IN RELATION TO THE ASSOCIATED ATMOSPHERIC CIRCULATION

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ABSTRACT

Mean wintertime temperatures (December, January, February) recorded during the period 1905–2000 at 18 weather stations distributed across Egypt were analysed to reveal spatial and temporal patterns of long-term trends. The relationship between winter atmospheric circulation indices and winter temperature in Egypt is examined using correlation analysis. The atmospheric circulation is represented by four indices: the well-known El Niño–southern oscillation (ENSO), North Atlantic oscillation (NAO) index, East Atlantic–West Russia (EAWR) index, and East Atlantic (EA) index.

Surface temperature is a stable climatic element whose coefficient of variation (COV) is lower during winter. A statistically significant relation between COV and latitude indicates that stations in the south, Upper Egypt, are more variable than stations in the north, Lower Egypt. Increasing and decreasing winter surface temperature trends were found. In general, wintertime temperature has increased (warming) at most stations. Decreasing trends (cooling) are observed mainly over Upper Egypt. The upward trends in mean winter temperature during the 1910s–30s, mid 1970s, and early 1980s–2000 and the downward trends during the 1940s and 1960s are prominent features of the temporal distributions. The warming period that occurred early in the century may be explained by changes in circulation. Striking upward trends are most remarkable during the last 20 years. This could be attributed not only to human activities, but also to atmospheric circulation changes. No detectable connection between Egypt temperature and either ENSO or EA index was found during winter. A statistically significant negative relationship between winter temperature and winter NAO index can be observed. The NAO index is more dominant in determining winter temperature than ENSO circulation. A significantly stronger negative relationship between temperature over Egypt and the winter EAWR index values is detected. Copyright © 2004 Royal Meteorological Society.

KEY WORDS: wintertime temperature; long-term trends; atmospheric circulation indices

1. INTRODUCTION

Given the current concerns about climate change, particularly the anthropogenic influence on climate, it is of fundamental importance to investigate past climates and determine the role of natural variability in climate change. Natural variability in climate on decadal-to-century time scales is caused by changes in solar output, volcanic activity, and internal interactions between the different components of the climate system (the atmosphere, ocean, cryosphere and biosphere). Periods of cooler conditions have been linked to variations in solar output, manifested by a decrease in sunspot activity, affecting the amount of solar radiation reaching the Earth. Some of the coldest phases of the last 500 years occurred during a period known as the Maunder Minimum, when almost no sunspots occurred (Lean *et al*., 1995). Increased volcanic activity also decreases global temperatures, as dust and aerosols emitted to the atmosphere by volcanoes block and scatter the amount of solar radiation reaching the Earth, as occurred for example in 1650–1710 (Briffa *et al*., 1998) or the 1810s (Harrington, 1992). Anthropogenic climate change is due to increasing concentrations of greenhouses gases

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and sulphates in the atmosphere and alteration of the Earth's surface through deforestation or desertification (Jones, 1988; Mann *et al*., 1998; Houghton *et al*., 2001). All of these factors affect the radiative balance at the Earth's surface and the sensible and latent heat exchange and transport, which in turn influence the temperature and atmospheric circulation at the Earth's surface.

In addition to these external influences on climate, fluctuations and changes in atmospheric circulation are important elements of the climate. Namias (1948) was among the first to state that the mean monthly geopotential height fields for mid tropospheric levels determine monthly air temperature anomalies. Therefore, advective processes exerted by the atmospheric circulation are a crucial factor controlling regional air temperature changes (e.g. Trenberth 1990, 1995; Xu, 1993; Hurrell 1995; Hurrell and van Loon, 1997; Slonosky *et al*., 2001; Xoplaki *et al*., 2000, 2002; Jacobeit *et al*., 2001; Pozo-Vazquez *et al*., 2001; Slonosky and Yiou, 2002; Xoplaki, 2002).

Mediterranean climate constitutes an issue of particular concern within the context of regional climate variability and change. Houghton *et al*. (2001) have shown that higher maximum temperatures and more hot days are likely to increase in frequency during the 21st century. Over the last few decades, extended heat waves and droughts appear to have become more frequent in the Mediterranean (Houghton *et al*., 2001).

Many studies have been published relating changes in Mediterranean air temperature regimes to the large-scale atmospheric circulation (Corte-Real *et al*., 1995, 1998; Reddaway and Bigg, 1996; Hurrell and van Loon, 1997; Kutiel and Maheras, 1998; Maheras *et al*., 1999; Saenz *et al*., 2001; Kutiel and Benaroch, 2002; Xoplaki, 2002; Xoplaki *et al*., 2002). Some of these papers evaluated the fraction of air temperature variability explained by major sea-level pressure (SLP) and/or upper-air large-scale anomalies. Other studies analysed the air temperature variability patterns over a specific geographical area in the Mediterranean and identified the surface and upper-air large-scale anomalies such as the North Atlantic oscillation (NAO), the Eastern Atlantic (EA) pattern, the Scandinavian pattern, the Eurasian pattern (Barnston and Livezey, 1987) and the El Niño–southern oscillation (ENSO).

In this study, we extend our analysis over the Egyptian region to improve our understanding of interannual and interdecadal variability of Egyptian wintertime surface temperature and its relationship with atmospheric circulation indices. In Sections 2 and 3 the data set and details of the methods and calculations are described. Section 4 includes the results related to the wintertime temperature variability. In Section 5, the results of correlation analysis between long temperature series and atmospheric circulation indices are presented. Conclusions are presented in Section 6.

2. DATA

The area of Egypt is about 1×10^6 km^2. Of this area, about 93% is desert. The northerly running River Nile roughly bisects the country, and divides into two branches in the Nile Delta. Some parts of the delta surface are below mean sea level, but the delta rises gradually southward. Most of Egypt's Mediterranean coastline is fringed by cliffs of a stony plateau. The Red Sea coast is mountainous everywhere, and some of the peaks are over 2000 m high. The desert plateau extends on either side of the Nile Valley. To the east the desert extends from the river to the line of mountains, which run parallel to the Red Sea. The western region is a part of the vast Sahara, and is called the Libyan Desert. The northern parts of the desert plateau are comparatively low, but from Cairo southward they rise almost to 500 m above mean sea level.

Monthly mean surface temperatures for the Egyptian region were obtained from the Egyptian Meteorological Authority (18 weather stations; Figure 1). A set of 18 Egyptian stations from 24 °N to 31.5 °N have been selected because of the quality and extent of their temperature records. The longest record starts in 1905, and the shortest starts in 1979. All series extend up to 2000, with the exception of Al-Salum station; see Table I.

Atmospheric indices were obtained from the Climate Prediction Center (National Oceanic and Atmospheric Administration (NOAA), USA). These are the Niño3 index (5 °N–5 °S, 150–90 °W), a widely used ENSO indicator (Camberlin *et al*., 2001); an NAO index; East Atlantic–West Russia (EAWR) index; and an EA index.

El Niño refers to the occasional 'anomalous' warming of the eastern tropical Pacific Ocean, but it is commonly linked to a basin-scale warming extending from the coast of South America to the International

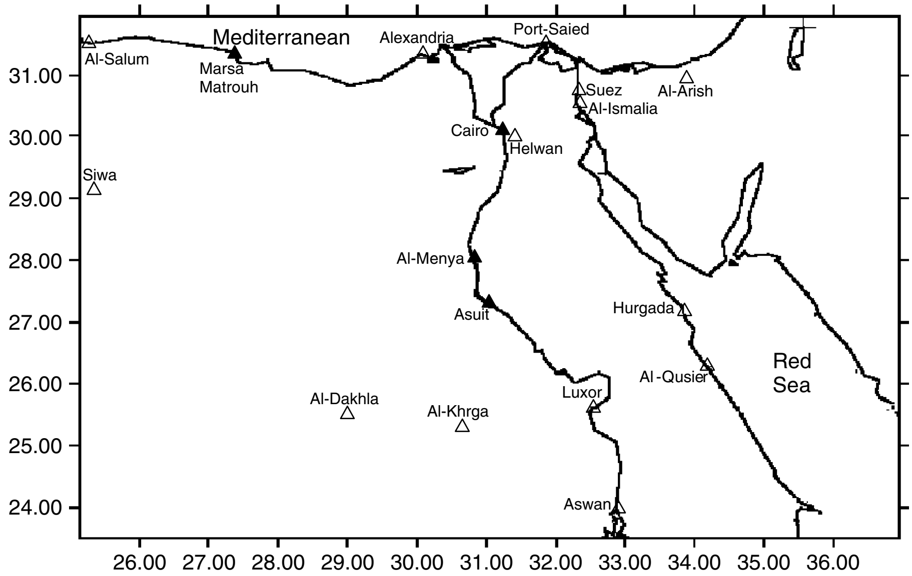

Figure 1. Station location map

Table I. Egyptian stations: location and record

Station	Latitude (°N)	Longitude (°E)	Period
Al-Salum	31.5	25.2	1945–94
Marsa-Matrouh	31.4	27.2	1956–2000
Port-Saied	31.3	32.2	1941–2000
Alexandria	31.2	30.0	1942–2000
Al-Arish	31.1	33.8	1979–2000
Al-Ismalia	30.6	32.3	1974–2000
Suez	30.6	32.2	1968–2000
Cairo airport	30.1	31.6	1968–2000
Helwan	29.9	31.3	1906–2000
Siwa	29.2	25.5	1968–2000
Al-Menya	28.1	30.7	1973–2000
Asuit	27.2	31.1	1905–2000
Hurgada	27.2	33.8	1973–2000
Al-Qusier	26.1	34.3	1931–2000
Luxor	25.7	32.7	1936–2000
Al-Dakhla	25.5	29.0	1968–2000
Al-Khrga	25.4	30.6	1931–2000
Aswan	24.0	32.8	1905–2000

Dateline. La Niña refers to the opposite phase, where sea-surface temperatures (SSTs) are well below average. Both events are defined only when the SST departures from average are reasonably large. A common working definition is that if the SSTs depart from the normal by more than 0.5 °C for more than six consecutive months over some region then an event is considered to have taken place (Trenberth and Hurrell, 1994). Both El Niño and La Niña events are a normal part of the behaviour of SSTs in the tropical Pacific, where the main variations occur through atmosphere–ocean interactions on interannual time scales (Philander, 1990). It is the basin-scale phenomenon, however, that is linked to the global atmospheric circulation and associated weather anomalies.

The NAO, like ENSO, is one of the large-scale modes of climate variability in the Northern Hemisphere. It defines a large-scale meridional oscillation of atmospheric mass between a centre of subtropical high surface pressure located near the Azores and a sub-polar low surface pressure near Iceland. Synchronous strengthening (positive NAO state) and weakening (negative NAO state) have been shown to result in distinct, dipole-like climate-change patterns between western Greenland, the Mediterranean and northern Europe–northeast USA and Scandinavia (Walker, 1924; Walker and Bliss, 1932; van Loon and Rogers, 1978; Rogers and van Loon, 1979).

The EAWR pattern (Barnston and Livezey, 1987), which occurs in winter, has two main anomaly centres located over the Caspian Sea and western Europe. Positive phases of the pattern are characterized by negative height anomalies throughout western and southwestern Russia, and positive height anomalies over northwestern Europe. Negative phases of the pattern are associated with positive height anomalies over the Caspian Sea and western Russia and negative height anomalies over northwestern Europe.

Similar to the NAO, the EA pattern consists of a north–south dipole, but it extends across the entire North Atlantic basin with a line of separation through the UK and France (Barnston and Livezey, 1987). The EA pattern is distinct, in that the anomaly centres are concentrated near the nodal lines of the NAO dipole, resembling a southward shifted NAO, so that the subtropical component is part of the subtropical ridge of the North Atlantic (Barnston and Livezey, 1987).

3. METHODOLOGY

A coefficient of variation (COV) for each individual station has been determined. This is defined as

$$\mathrm{COV} = 100 \times SD/\overline{T} \tag{1}$$

where SD is the standard deviation, defined as

$$\mathrm{SD} = \left[(N-1)^{-1}\sum_{i=1}^{n}(T_i - \overline{T})^2\right]^{1/2} \tag{2}$$

T_i is the winter temperature, and $\overline{T}$ is the temporal mean for n years.

The non-parametric Mann–Kendall (M–K) rank correlation test (Sneyers, 1990; Schonwiese and Rapp, 1997) has been used to detect any possible trend in temperature series, and to test whether or not such trends are statistically significant. A detailed assessment for testing of climatic data unevenly distributed in time and a comparison of methods for estimating the significance level of any trend can be found in a recent study performed by Huth (1999). The M–K statistical test $u(t)$ is a value that indicates direction (or sign) and statistical magnitude of the trend in a series. When the value of $u(t)$ is significant at the 5% significance level, it can be decided whether it is an increasing or a decreasing trend depending on whether $u(t) > 0.0$ or $u(t) < 0.0$. A 1% level of significance was also taken into consideration. In order to obtain such a time series plot, sequential values of the statistic $u(t)$ were computed from the progressive analysis of the M–K test. Following Sneyers (1990), this procedure is formulated as follows: first, original observations are replaced by their corresponding rank y_i, ranged in ascending order. Then, for each term y_i, the number n_k of terms y_j preceding it ($i > j$) is calculated with ($y_i > y_j$), and the test statistic t_i is written as

$$t_i = \sum_{k=1}^{i} n_k \tag{3}$$

The distribution function of the statistical test t_i has a mean and variance defined by

$$E(t_i) = \frac{i(i-1)}{4} \quad \text{and} \quad \mathrm{var}(t_i) = \frac{i(i-1)(2i+5)}{72} \tag{4}$$

Values of the statistic $u(t_i)$ are then computed as

$$u(t_i) = \frac{[t_i - E(t_i)]}{\sqrt{\mathrm{var}(t_i)}} \tag{5}$$

The statistical test $u(t_i)$ is

$$u(t_i)_t = \pm t_{\mathrm{g}}\sqrt{\frac{4N+10}{N(N-1)}} \tag{6}$$

Here, t_{g} is the value of t at the probability point in the Gaussian distribution appropriate to the two-tailed test.

The evaluation of the trend analysis is based on the Hu *et al.* (1998) method. The 11 year running mean is a filtering method. It removes variations with periods shorter than 10 years in a time series and retains variations on interdecadal time scales, which are the focus of this study. To preserve as much information as possible of the time series in the winter temperature (year) of the 11 year running window, different weights are assigned to each of the 11 years in the running mean. These weights, from the first through to the 11th year in the running window, are 1/24, 1/24, 1/12, 1/8, 1/8, 1/6, 1/8, 1/8, 1/12, 1/24 and 1/24 respectively. The symmetry of the weight distribution guarantees no phase shift of the variations in the time series after the filter is applied. The response function of the running mean is similar to that of an ordinary filter, e.g. Shapiro (1975). Furthermore, it has a small effect on variations whose frequencies are lower than the cutoff frequency of the filter but has a large effect on variations of frequency near its cutoff frequency, e.g. the 12 year variation.

Finally, the classical correlation method was used to detect the relationship between wintertime temperature over Egypt and atmospheric circulation indices. Programs for all computations and statistical analyses were prepared using the FORTRAN programming language.

4. WINTERTIME TEMPERATURE VARIABILITY

4.1. Coefficient of variation

In order to obtain a clear and representative analysis of the winter temperature in Egypt, the COV is adopted to assess the durability and stability of the temperature regime at all Egyptian stations. The COV is a good way to evaluate variability of temperature. Also, the COV offers an indication of the reliability of the average. The higher the COV, the less reliable the average is; and the lower the COV, the more dependable the average is.

The coefficient of variation's distribution over Egypt in wintertime is presented in Table II. The COV ranged from 3.94% at Cairo airport to 10.84% at Al-Dakhla. The COV of winter temperature is usually about 5%. Comparisons of the COV show that there is difference in variability among climatic reporting stations (Table II). The SD is high, and consequently so is the COV all over Upper Egypt. In general, the COV of wintertime temperature values is low over Egypt, with the exception of three stations (Al-Dakhla, Aswan, and Al-Menya). Also, the COV in Lower Egypt (Al-Arish, Port-Saied, Al-Ismalia, Alexandria, Marsa-Matrouh, Siwa, Al-Salum, Cairo, Helwan, and Suez) is lower than it is for Upper Egypt (Al-Kharga, Al-Dakhla, Aswan, Luxor, Asuit, and Al-Menya). This indicates that the wintertime temperature for Lower Egypt possesses more stability than the wintertime temperature for Upper Egypt. This pattern of increased variability in the Upper Egypt areas, in contrast to decreased variability in the Lower Egypt areas, indicates that there can be significant spatial differences in variability across Egyptian regions.

The COV correlates with other climatic and geographic measures (Figure 2). It increases with decreasing mean winter temperature (cool stations are more variable than warm stations), decreasing latitude (stations in the south are more variable than stations in the north), and decreasing longitude (stations in the east are more

Table II. Standard deviation (SD), mean temperature and coefficient of variation (COV) at 18 stations over Egypt

Station	SD	Mean	COV
Al-Salum	0.78	14.89	5.24
Marsa-Matrouh	0.61	13.95	4.37
Port-Saied	0.77	15.46	4.98
Alexandria	0.66	14.37	6.28
Al-Arish	0.86	13.70	4.59
Al-Ismalia	0.78	14.46	5.39
Suez	0.72	15.92	4.52
Cairo airport	0.57	14.79	3.94
Helwan	0.81	14.46	5.60
Siwa	0.56	13.56	4.13
Al-Menya	0.79	13.27	5.95
Asuit	0.98	14.07	6.97
Hurgada	0.90	16.91	5.33
Al-Qusier	0.81	18.80	4.31
Luxor	0.91	15.51	5.87
Al-Dakhla	1.55	14.30	10.84
Al-Khrga	0.93	15.24	6.10
Aswan	1.25	17.40	7.18

variable than stations in the west). The relationship between COV and latitude is highly significant, whereas it is non-significant with longitude and mean temperature.

4.2. Trend analysis

The evaluation of the trend is based on the M–K rank statistical test and fitting method of Hu *et al.* (1998). M–K rank statistics, which make no assumption about the probability distribution of the original data, are tested for significance using a standard normal distribution. The spatial distribution pattern is not complex, even though the resultant test statistics of the M–K test give both negative and positive trends. Table III shows the M–K statistics for the 18 sites in Egypt. The values of the M–K trend test u were computed according to Sneyers (1990). Increasing trends (warming) are observed at most stations. Decreasing trends (cooling) are observed mainly over Upper Egypt, Asuit, Luxor, and Aswan and over Alexandria and Cairo airport stations. It is also indicated in Table III that, for values of the M–K statistic that are significantly different from zero at the 5% and/or 1% level, trends are not significant at all stations.

Time series of wintertime temperature for the 18 stations over Egypt are presented in Figure 3. They show both the wintertime surface temperature and its running mean, which retains only variations over periods longer than 10 years. The main feature of Figure 3 is the presence of distinctive interdecadal variations in the wintertime temperature. Among these variations, there appears to be a fairly regular variation of a quasi-20-year period, although its amplitude varies between different cycles. Another noteworthy feature is a significant warming around 1912, which began at stations with a long record, namely Helwan, Asuit, and Aswan. However, it is seen that marked increases in the wintertime temperature of most stations after 1990 have controlled the direction, or nature (sign), of the trend. These results are also in agreement with Folland *et al.* (1990), Arseni-Papadiomitriou and Maheras (1991), Aesawy and Hasanean (1998) and Hasanean (2001), who found warming during the 1970s. The warming, however, is not of the same order at all stations under investigation and was neither uniform nor continuous. The 1940s and 1960s appear as the coldest period at most stations in the 20th century.

A significant warming began at Helwan, Asuit and Aswan around 1912 (Figure 3(a)). The warming gradually increased up to the mid 1940s. Cooling is observed from the mid 1940s to the early 1960s,

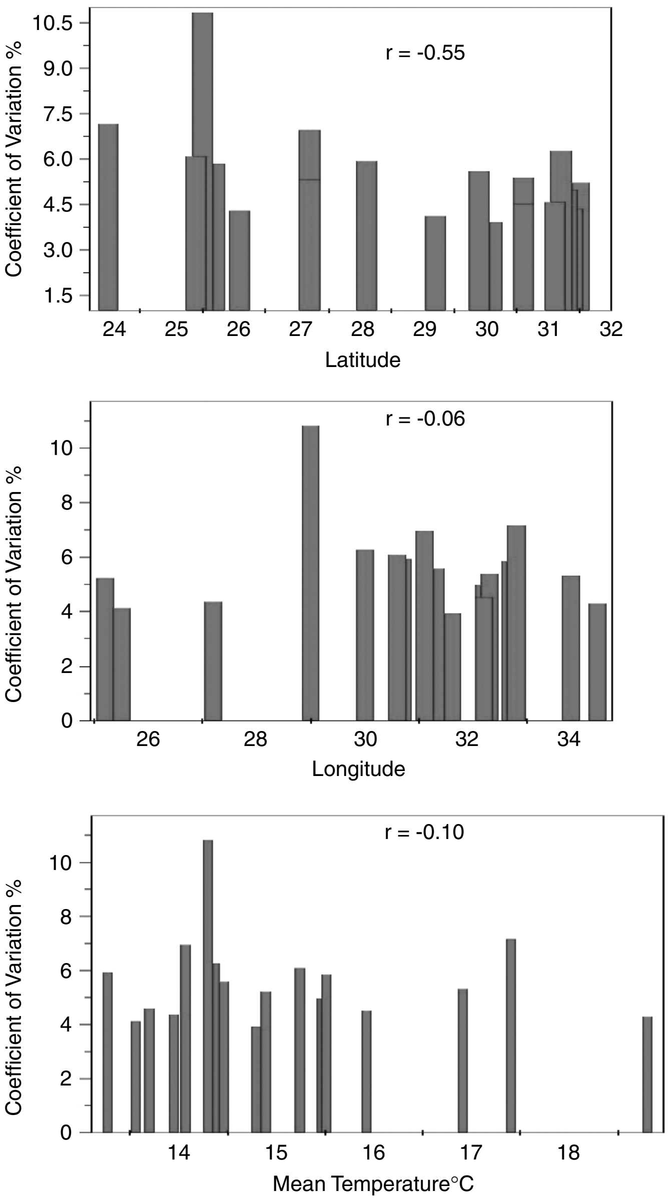

Figure 2. Correlation of the coefficient of variation of wintertime temperature for 18 Egyptian stations with average wintertime temperature, latitude, and longitude

followed by a slight warming and again a return to cooling from the mid 1960s to the early 1980s. Cooling of about 2.6 °C at Asuit station was observed in this period. In the last two decades, wintertime temperature has gradually increased. The beginning of the 1930s, 1950s, and 1990s present the three clusters with warmer than normal wintertime temperature for Al-Kharga, Al-Qusier, and Luxor (Figure 3(b)). The downward trend since the early 1940s is well pronounced, especially for Al-Khrga station. The warmest period in Alexandria, Port-Saied, Marsa-Matrouh, and Al-Salum was the 1950s up to the early 1960s, whereas the coolest period was from the early 1960s up to the early 1970s (Figure 3(c)). Cooling of about 0.9 °C over Alexandria was found in this period. Also, it is shown that a marked increase in wintertime temperature occurred in the first half of the 1980s and the period from the early 1990s up to the end of the period under study. Figure 3(d) shows that for Al-Dakhla there is a gradual warming during the

Table III. M–K rank statistic at 18 stations over Egypt

Station	Trend
Al-Salum	0.17
Marsa-Matrouh	0.21
Port-Saied	0.01
Alexandria	−0.12
Al-Arish	0.26
Al-Ismalia	0.27
Suez	0.26
Cairo airport	−0.05
Helwan	0.11
Siwa	0.11
Al-Menya	0.10
Asuit	−0.14
Hurgada	0.28
Al-Qusier	0.01
Luxor	−0.06
Al-Dakhla	0.40
Al-Khrga	0.05
Aswan	−0.17

period from the early 1980s up to the end of the period under study. Wintertime temperature at Cairo airport and Siwa stations oscillated around the mean from late 1960s up to the early 1990s, then tended to cool at the end of the period under study. At Suez there is a rise (warming) in temperature during the 1990s. From Figure 3(e) it is seen that a gradual increase in wintertime temperature occurred at Al-Ismalia, Hurgada, Al-Menya, and Al-Arish in the period from the early 1980s to the end of the period under study.

Upward trends in mean winter temperature during the 1910s–30s, mid 1970s, and 1980s–90s are dominant features of the temporal distribution (Figure 3). These trends are in general agreement with trends in the global mean surface temperature since the late 19th century, which show the most rapid increase during the periods of 1920–40 and since the mid 1970s (Houghton *et al*., 1996; Fu *et al*., 1999; Jones *et al*., 1999). The warming of the 1920s–30s was particularly strong in the North Atlantic sector. Peterssen (1949) suggested that it was accompanied by a shift of the atmospheric circulation over the northern North Atlantic from a zonal to a more meridional one, and the extent to which the temperature increase in the 1920s may be explained by changes in circulation was further studied by several workers (Rogers, 1985; Moses *et al*., 1987; Fu *et al*., 1999). Recent rapid warming since the 1970s has been well documented in a number of studies (e.g. Jones *et al*., 1999; Karl *et al*., 2000). It is likely that this is more or less associated with the dominant patterns of atmospheric circulation variability and their anomalous behaviour in recent decades; however, it cannot be readily explained by natural climate variability. Barnett *et al*. (1999), in their paper dealing with attributing the causes of recent climate change, concluded that the most probable cause of the observed warming is a combination of internally and externally forced natural variability and anthropogenic sources.

Downward trends in mean winter temperatures show that the 1940s and 1960s appear as the coldest periods at all stations in the 20th century. For the changes in circulation over the Atlantic, that may have contributed to the cool temperatures over the eastern Mediterranean in the 1940s and 1960s (Arseni-Papadiomitriou and Maheras, 1991; Cullen and deMenocal, 2000; Karl *et al*., 2000). Xoplaki *et al*. (2003) found that large-scale variability strongly influences the variability of local temperature in the eastern Mediterranean.

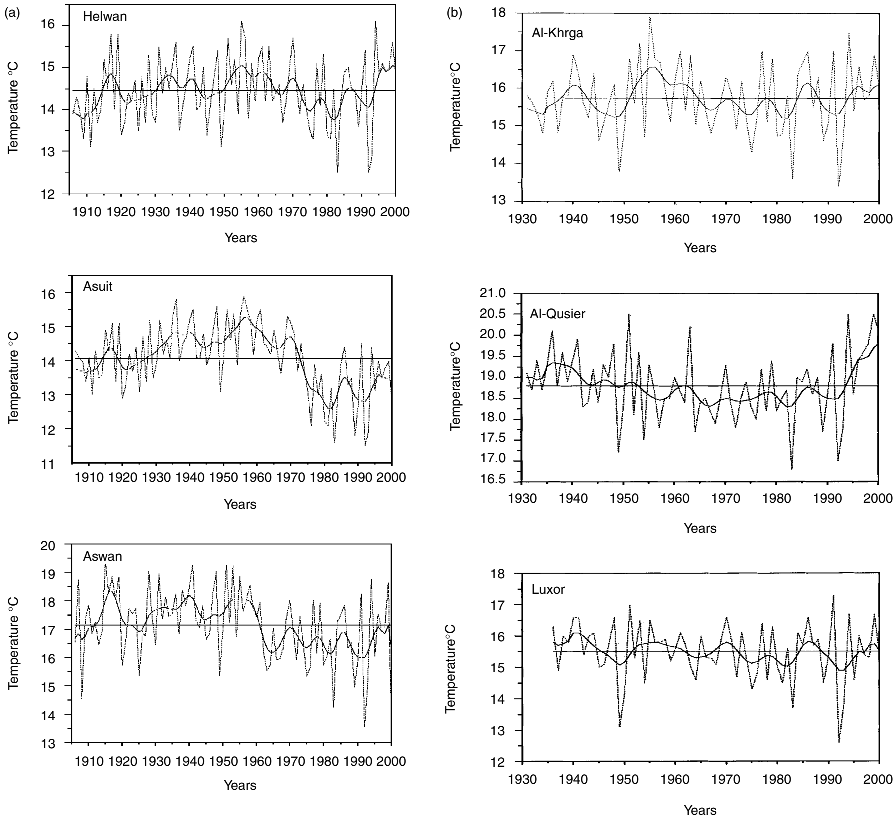

Figure 3. (a) Interannual variations in winter temperature series of Helwan, Asuit, and Aswan stations. (b) As (a), but for Al-Kharga, Al-Qusier, and Luxor stations. As (c), but for Alexandria, Port-Saied, Marsa-Matrouh, and Al-Salum stations. (d) As (a), but for Cairo airport, Suez, Siwa, and Al-Dakhla stations. (e) As (a), but for Al-Ismalia, Hurgada, Al-Menya, and Al-Arish stations

5. RELATIONSHIP BETWEEN WINTERTIME TEMPERATURE AND ATMOSPHERIC CIRCULATION

Local changes in meteorological variables in mid-latitudes are mainly controlled by the atmospheric circulation (Parker *et al*., 1994; Hurrell, 1995; Hurrell and van Loon, 1997). As a consequence, a significant fraction of local variability can be explained by more predictable large-scale oscillation patterns. This also applies to temperature, in spite of its great time and space variability, as shown by some workers who evaluated the correlation of temperature with indices describing some well-known planetary-scale oscillations, like the NAO and ENSO (Hurrell, 1995; Kutiel *et al*., 1996; Mayes, 1996; Valero *et al*., 1996).

5.1. Relationship between wintertime temperature and ENSO

ENSO is the largest climate oscillation on Earth on the time scale of months to a few years. It influences the weather in large parts of the globe. The Niño3 index (5 °N–5 °S, 150–90 °W) is a widely used ENSO indicator (Camberlin *et al*., 2001). Therefore Niño3 is used here to investigate the relationships between ENSO and wintertime surface temperature over Egypt.

Table IV shows the association between ENSO and wintertime temperature at 18 stations. Inverse relationships between ENSO and surface temperature are found at all stations. The absence of significant correlations between wintertime temperatures at most Egyptian stations and winter ENSO is due to ENSO's highly indirect influence on Egyptian climate.

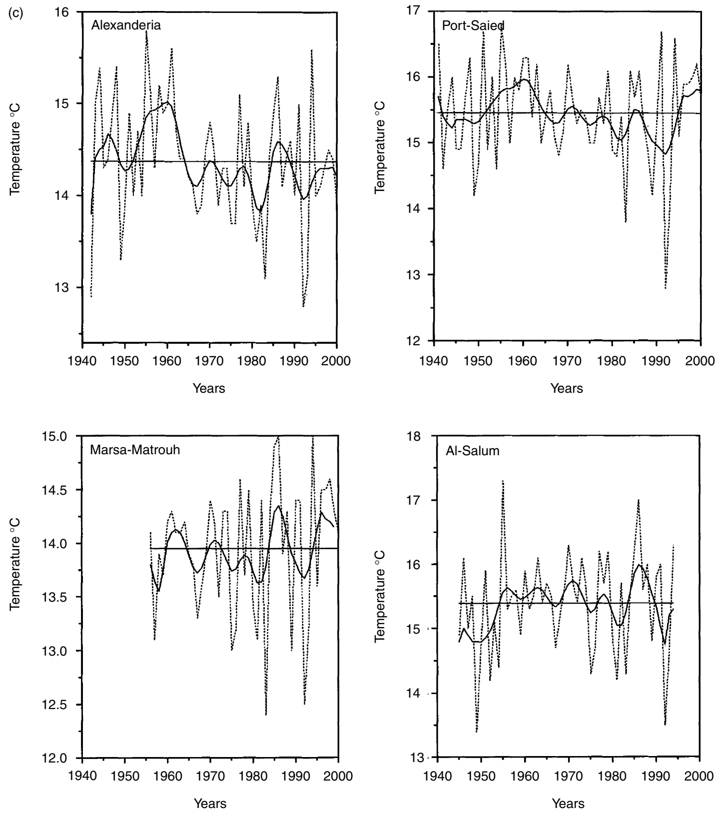

Figure 3. (*Continued*)

5.2. *Relationship between wintertime temperature and NAO*

The NAO is most pronounced in winter, but it is detectable as a characteristic pattern in all months. The winter NAO pattern contributes the largest fraction of the Northern Hemisphere temperature variability of any mid-latitude or tropical mode of fluctuation.

Correlations were calculated between the winter NAO index and winter temperature for the 18 Egyptian stations, and these are shown in Table IV. Negative relationships between the NAO and winter temperature time series over Egypt were found. So, during positive NAO years, Egypt becomes cooler. Also, the more zonal trajectories of Atlantic heat during negative NAO years bring anomalously warmer periods to Egypt. This result is in agreement with Cullen and deMenocal (2000). A statistically significant negative relationship was found between the winter NAO index and winter temperature over western Egypt (Al-Salum, Marsa-Matrouh, Alexandria, and Siwa) and Middle Egypt (Cairo airport, Helwan, Al-Ismalia, and Suez). However, no significant relationship was found at stations in Upper Egypt (with the exception of Asuit and Al-Dakhla stations) and stations along the Red Sea coast (Port-Saied, Al-Arish, Hurgada, and Al-Qusier) in eastern Egypt.

The effect of the NAO on temperatures extends to the countries of the Mediterranean basin (WMO, 1993). The NAO negative mode produces high-pressure blocking in the northeast Atlantic, and a more meridional circulation than the opposite NAO positive mode (Jacobeit, 1987; Moses *et al.*, 1987). Upper-air troughs and incursions of polar air over the Mediterranean are more frequent and the Atlantic storm tracks are displaced south. All these factors may be conducive to warmer conditions in Egypt, and vice-versa with a positive NAO.

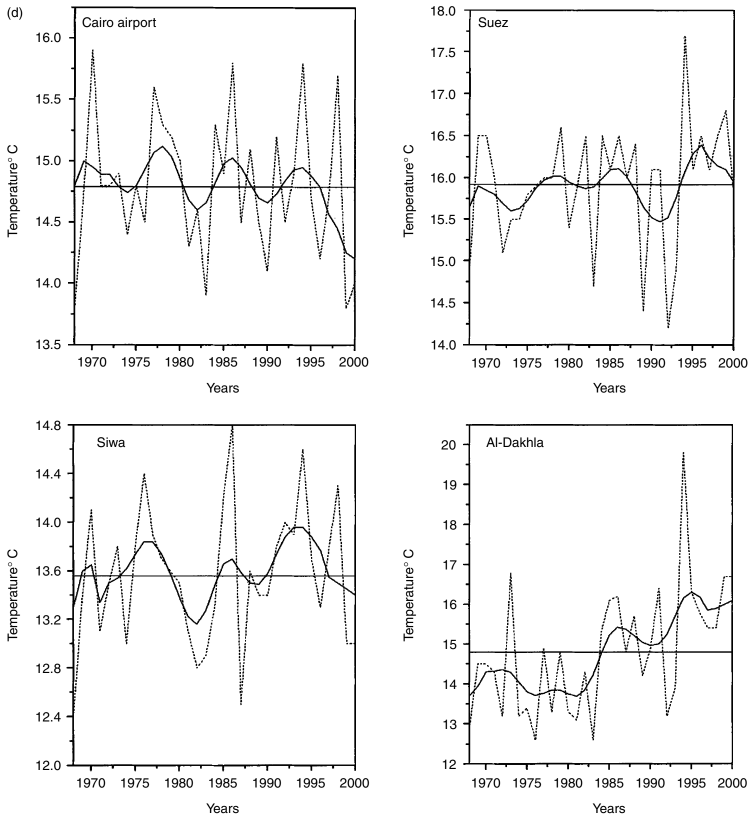

Figure 3. (*Continued*)

5.3. Relationship between winter temperature and EAWR index

The role of another prominent European sea-level pressure anomaly system, i.e. the EAWR dipole pattern (Barnston and Livezey, 1987), also appears to be important in the east Mediterranean region. The role of EAWR teleconnection, however, in influencing the climate of the Mediterranean in general, and of its eastern basin in particular, has seldom been studied.

The correlation coefficient between wintertime temperature at 18 stations over Egypt and the winter EAWR index is presented in Table IV. An inverse relationship between wintertime temperature at 18 stations over Egypt and EAWR is found. Over the period 1950–2000, highly significant (at the 95% and 99% levels) correlations occur at 17 of the 18 stations. All correlations are highest: the highest correlation is 0.60 at Port-Saied station. So, the Egyptian temperature is affected more by the EAWR index in the winter season. A positive EAWR index leads to cooling and a negative EAWR index leads to warming of wintertime temperature.

Krichak *et al.* (2002) noted that, during the positive EAWR period, negative sea-level pressure influences the eastern Mediterranean weather processes over the area, with a maximum over the Caspian region. A more intensive southward propagation of cold air masses from central Europe to the eastern Mediterranean may be expected during such a period.

5.4. Relationship between wintertime temperature and EA index

The EA pattern is the second of three prominent modes of low-frequency variability over the North Atlantic, appearing in all months except May–August. The pattern is structurally similar to the NAO, and consists of a north–south dipole of anomaly centres that span the entire North Atlantic Ocean from east to west. However,

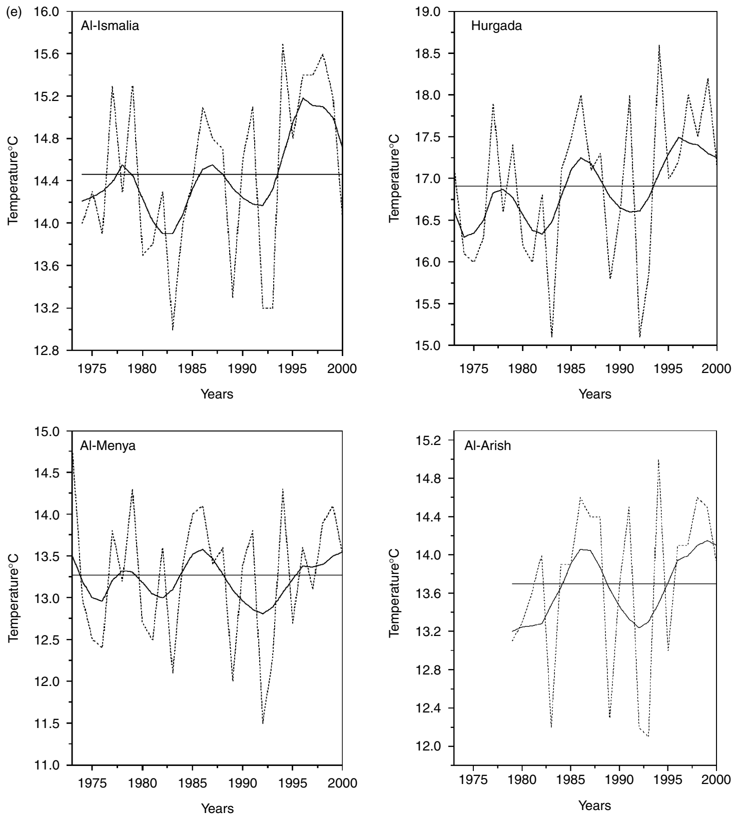

Figure 3. (*Continued*)

the anomaly centres in the EA pattern are displaced southeastward to the approximate nodal lines of the NAO pattern. For this reason, the EA pattern is often mistaken as simply a slightly 'southward-shifted' NAO pattern. Also, the lower-latitude centre contains a strong subtropical link, reflecting large-scale modulations in the strength and location of the subtropical ridge. This subtropical link also makes the EA pattern distinct from its NAO counterpart. The role of the EA teleconnection, however, in influencing the climate of the Mediterranean in general, and of its eastern basin in particular, has seldom been studied. The correlation coefficient between wintertime temperature at 18 stations over Egypt and winter EA index is presented in Table IV. A positive relationship between wintertime temperature and winter EA was found. No significant relationship between wintertime temperature and winter EA was found at most stations.

6. CONCLUSIONS

The interannual and interdecadal wintertime surface temperature variability over Egypt and its connection to large-scale atmospheric circulation is investigated. The study of the coefficient of variability over Egypt in wintertime shows that it ranged from 3.94 to 10.84%. The COV of winter temperature is usually about 5%. This indicates that the wintertime temperature for Lower Egypt shows more stability than the wintertime temperature for Upper Egypt. The pattern of increased variability in the Upper Egypt areas contrasted with the decrease of variability in the Lower Egypt areas, and indicates that there can be significant spatial differences in variability across Egyptian regions. The correlations between COV and mean wintertime temperature, latitude, and longitude indicate that cool stations are more variable than warm stations; that stations in the south are more variable than stations in the north; and that stations in the east are more variable than stations

Table IV. Correlation coefficient between the four atmospheric indices of ENSO, NAO, EAWR, and EA and surface temperature at 18 stations over Egypt during winter

Station	ENSO	NAO	EAWR	EA
Al-Salum	−0.13	−0.34**	−0.50**	0.17
Marsa-Matrouh	−0.13	−0.25*	−0.43**	0.20*
Port-Saied	−0.19	−0.17	−0.60**	0.03
Alexandria	−0.15	−0.24*	−0.53**	0.08
Al-Arish	−0.18	−0.08	−0.35*	0.22
Al-Ismalia	−0.02	−0.38**	−0.44**	0.24
Cairo airport	−0.26*	−0.30*	−0.28*	0.25
Suez	−0.06	−0.24*	−0.58**	0.20
Helwan	−0.11	−0.23*	−0.57**	0.03
Siwa	−0.12	−0.24*	−0.08	0.01
Al-Menya	−0.01	−0.19	−0.48**	0.22
Asuit	−0.12	−0.27**	−0.40**	0.12
Hurgada	−0.16	−0.12	−0.44**	0.18
Al-Qusier	−0.21*	−0.03	−0.41**	0.06
Luxor	−0.15	−0.08	−0.57**	0.01
Al-Dakhla	−0.01	−0.27**	−0.27*	0.39**
Al-Khrga	−0.21*	−0.11	−0.48**	0.06
Aswan	−0.08	−0.14	−0.51**	0.01

* Significant at 95% confidence level.
** Significant at 99% confidence level.

in the west. The relationship between COV and latitude is highly significant, whereas it is non-significant with longitude and mean temperature.

The results of the M–K statistical rank test shows that the wintertime temperature has increased at most stations. Decreasing trends are observed mainly over Upper Egypt. Trends in wintertime temperature are not significant at all stations.

The wintertime temperature of the area is characterized by warm periods in 1912–1940 and 1982–2000, and rather cool periods in the 1940s and 1960s. A warm period began almost simultaneously at the stations with long records. This warming extends from the beginning of the record to 1940, but it is not continuous. A warm period has been found during the 1970s, but it was not uniform, continuous or of the same order. Distinctive interdecadal variations in the wintertime temperature are found. Among these variations, fairly regular variations of a quasi-20-year periodicity exist, although its amplitude varies between different cycles. Recent warming has only occurred during the last two decades at most stations. These trends are in general agreement with trends in the global mean surface temperature since the late 19th century. The most probable cause of the recent observed warming is a combination of internally and externally forced natural variability and anthropogenic sources.

The study of the interrelation between wintertime temperature over Egypt and winter atmospheric circulation reveals that negative relationships between the ENSO index, NAO index and EAWR index with wintertime temperature are found at all 18 stations, whereas there is a positive relationship between wintertime temperature over Egypt and winter EA index. The NAO is more dominant in wintertime temperature than ENSO, and is highly significant for many stations over Egypt. A strong relationship between winter EAWR and wintertime temperature is found. Variations in local climate may be responding to changes in the circulation index strength, but may also be due to competing influences from other circulation types. Some of the variability in the correlation between temperature and circulation may be due to different circulation types influencing temperature; whereas zonal circulation usually has a dominant influence on temperature, there were periods such as the 1920s when meridional circulation appeared to have a greater influence (Slonosky *et al*., 2001).

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