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VARIABILITY OF SUMMER TEMPERATURE OVER EGYPT

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ABSTRACT

Variations of summer temperature over Egypt have been studied using the data of 19 stations. The analysis of these data shows that the surface temperature is a stable climate element where its coefficient of variation (COV) is found to be low during summer. The time sequence of cumulative seasonal mean (CSM) is shown to exhibit bounded, oscillatory, nonperiodic behavior. The boundedness of the oscillation supports the notion of climate compensation; i.e. that spells of cold must eventually follow spells of warm. The trend analysis of the time series of our stations shows striking positive trend values during the last 20 years; this could be attributed not only to human activities but also to atmospheric circulation changes. Spectral analyses of the monthly values of the 19 stations were made. It was found that the first harmonic plays a dominant role in the regional climatological variations in Egypt; it explains more than 38% of the amplitude variations and may be related to the sunspot cycle, which affects summer temperature over Egypt. Other harmonics may be related to El Nino southern oscillation (ENSO) cycle, quasi-biennial oscillation (QBO) cycle, and solar inertial motion cycle. Each of them contribute approximately 9% to summer temperature in Egypt and so their influence on summer temperatures in the area is not so much. Copyright © 2006 Royal Meteorological Society.

KEY WORDS: summer temperature; cumulative periodogram; trends; spectral analysis; ENSO

1. INTRODUCTION

Summer air temperature is an issue of great concern, since its variability and extremes have important economical and social implications. Heatwaves, which have occurred during the summers of 1987 and 2000 with disastrous consequences on humans and forests, are likely to reduce the traditional peak summer demand at Mediterranean holiday destinations (IPCC Technical Summary, 2001).

Human-induced climate change and changes in climatic variability continue to be major global change issues not only for the present generation but also for future generations. On the basis of the latest scientific assessment of the Earth's climate system, Folland *et al.* (2001) have revealed that the average global surface temperature has increased by about $0.6 \pm 0.2\,^{\circ}\mathrm{C}$ since the late nineteenth century. The Northern Hemisphere experienced cooling during the period from 1946 to 1975. They pointed out that the recent 1976–2000 warming was largely globally synchronous, but was more pronounced in the continents of the Northern Hemisphere during winter and spring.

One aspect of climate change is change in variability of weather elements, such as temperature. Adaptation to climate change and efforts to mitigate the impacts of climate change need to emphasize not only changes in long-term mean weather attributes but also trends in the variability of climatic variables (Bryant *et al.*, 2000). Given that climatic conditions vary from one period to another, variability is an integral part of climate change. Consequently, response strategies and adaptations to climatic change, both at the regional and global levels, must address climatic variability. According to Giorgi (2002), the impact of climatic variability on human and natural systems is more important than that of mean changes in climate.

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Natural variability in climate on decadal-to-century timescales 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 cold have been linked to variations in solar output, manifested by a decrease in sunspot activity, which affects 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). 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 midtropospheric levels determine monthly air temperature anomalies. Therefore, advective processes exerted by the atmospheric circulation are crucial factors controlling the 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).

In this work, we study the interannual and decadal variability of summer surface temperatures over Egypt. Sections 2 and 3 describe the data and the methods that are used in our study, while Section 4 contains the results of studying the summer temperature changes and variability over Egypt. Section 5 discuss the interaction between summer temperatures over Egypt and atmospheric circulation indices.

2. DATA

Monthly mean surface temperatures for the 19 stations were obtained from the Egyptian Meteorological Authority (Figure 1). The selection of these stations (most stations) is based on their quality and the length of their records. The longest record starts in 1905 (Asuit station) while the shortest one starts in 1982 (Sharm-Elshiekh station). The end of the time series in all the stations is the year 2000 except for Al-Salum station (Table I). From the monthly values of each station, we calculate the summer time series by averaging the values of surface temperature in June, July, and August for each year.

Atmospheric circulation indices were obtained from the Climate Prediction Center (National Oceanic and Atmospheric Administration, NOAA, US). These indices are the NINO3 index (5 °N–5 °S, 150–90 °W), a widely used El Nino southern oscillation (ENSO) indicator (Camberlin *et al.*, 2001); a North Atlantic oscillation (NAO) index, an equatorial South Atlantic index (SATL; 0°–20 °S, 30 °W–10 °E); a tropical North Atlantic index (NATL; 5°–20 °N, 60°–30 °W); and a tropical Atlantic index (TATL; 10 °S–10 °N, 0°–360°).

3. HOMOGENEITY

Lack of homogeneity in data series creates a big problem for studying time series. A time series of a climatological variable, where the variations are caused by variations of weather and climate only is said to be homogeneous (Conrad and Pollack, 1962). However, long time series without artificial changes in their statistical characteristics are rare (e.g. Heino, 1994). Nonhomogeneities may be abrupt, caused by relocations of instruments or changes in instruments, observers and observation practices, etc. Slow changes in the surroundings of the observation site may cause nonhomogeneities to be gradual, e.g. in the case of urbanization. The timing and size of significant nonhomogeneities can be estimated with statistical tests. We used the short-cut Bartlett test (Mitchell *et al.*, 1966) to examine the homogeneity of the surface air temperature series at designated stations. The short-cut Bartlett test of homogeneity of variance for summer surface air temperatures is applied by dividing the series into k equal subperiods, where $k \geq 2$. In each of

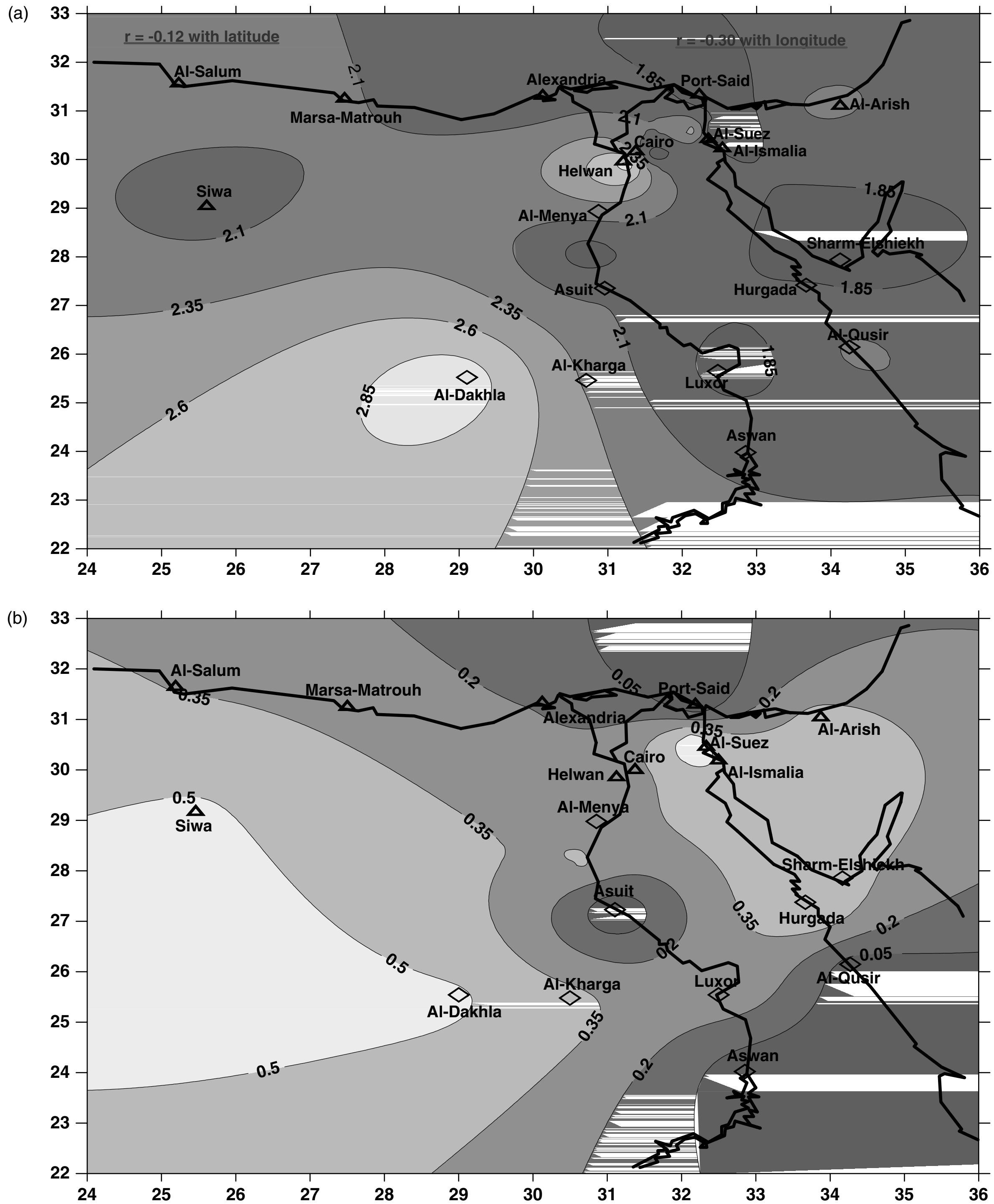

Figure 1. Coefficient of variation pattern (a) and trend pattern (b) of summertime temperature for 19 Egyptian stations (r means correlation coefficient)

Table I. Egyptian stations: location and record

Stations	Latitude north	Longitude east	Height MSLP	Period	Region
Al-Salum	31.5	25.2	6	1945–1994	Lower Egypt
Marsa-Matrouh	31.4	27.2	28	1956–2000	Lower Egypt
Port-Said	31.3	32.2	6	1941–2000	Lower Egypt
Alexandria	31.2	30.0	7	1942–2000	Lower Egypt
Al-Arish	31.1	33.8	32	1979–2000	Lower Egypt
Al-Ismalia	30.6	32.3	13	1974–2000	Lower Egypt
Al-Suez	30.6	32.2	3	1968–2000	Lower Egypt
Cairo	30.1	31.6	74	1968–2000	Lower Egypt
Helwan	29.9	31.3	141	1906–2000	Lower Egypt
Siwa	29.2	25.5	0	1968–2000	Lower Egypt
Al-Menya	28.1	30.7	40	1945–2000	Upper Egypt
Sharm-Elshiekh	28.0	34.4	51	1982–2000	Upper Egypt
Asuit	27.2	31.1	52	1905–2000	Upper Egypt
Hurgada	27.2	33.8	7	1951–2000	Upper Egypt
Al-Qusir	26.1	34.3	11	1931–2000	Upper Egypt
Luxor	25.7	32.7	99	1936–2000	Upper Egypt
Al-Dakhla	25.5	29.0	111	1968–2000	Upper Egypt
Al-Kharga	25.4	30.6	73	1931–2000	Upper Egypt
Aswan	24.0	32.8	108	1905–2000	Upper Egypt

these subperiods, the sample variance is calculated, i.e;

$$S_{\mathrm{k}} = \frac{1}{n}\left\{\sum x_i - \frac{1}{n}\left(\sum x_i\right)^2\right\} \quad (1)$$

where the summations range over the n values of the series in the subperiod k. Let S^2_{max} and S^2_{min} denote the maximum and the minimum values of S^2_{k}, respectively. The 95% significance points ratio $S^2_{\mathrm{max}}/S^2_{\mathrm{min}}$ can be obtained by comparing this ratio with the values given in Biometrika Table 31 (Pearson and Hartley, 1958). All time series used are found to be homogenous as shown in Table II.

4. METHODOLOGY

A coefficient of variation (COV) for each individual station has been determined as follows:

$$COV = 100 \times SD/\mu \quad (2)$$

where, SD is the standard deviation and μ is the temporal mean for N years.

To visualize the decadal and interdecadal fluctuations or 'persistence' in the behavior of the Egypt summertime temperature, cumulative seasonal means (CSMs) method is used (Pavia and Graef, 2002). The advantage of this method is to reveal time varying structures in time series. The CSMs time series can be defined as;

$$y_j = \frac{1}{j}\sum_{i=1}^{j} x_i, \qquad j = 1, 2, \ldots, N \quad (3)$$

Where, x_i is the total summertime temperature and N is the number of years of data used. Of course, $y_{j=N} = \overline{x}(N)$.

Table II. Bartlet test (short-cut) result for 19 stations over Egypt (n is the number of terms in each subperiod k, and k is the number of the subperiod)

Station		95% significant point	S^2_{max}/S^2_{min}
Al-Salum	$n = 16, k = 3$	3.54	1.93
Marsa-Matrouh	$n = 15, k = 3$	3.54	1.57
Port-Said	$n = 20, k = 3$	2.32	1.62
Alexandria	$n = 20, k = 3$	2.32	1.45
Al-Arish	$n = 11, k = 2$	2.21	1.65
Al-Ismalia	$n = 14, k = 2$	2.23	2.00
Al-Suez	$n = 16, k = 2$	2.31	1.84
Cairo	$n = 16, k = 2$	2.31	1.56
Helwan	$n = 19, k = 5$	3.21	2.84
Siwa	$n = 16, k = 2$	2.31	1.52
Al-Menya	$n = 19, k = 3$	2.31	1.80
Sharm-Elshiekh	$n = 10, k = 2$	2.23	1.42
Asuit	$n = 19, k = 5$	3.21	3.10
Hurgada	$n = 16, k = 3$	3.54	1.41
Al-Qusir	$n = 23, k = 3$	2.38	2.21
Luxor	$n = 22, k = 3$	2.36	1.72
Al-Dakhla	$n = 16, k = 2$	2.31	1.80
Al-Kharga	$n = 23, k = 3$	2.38	1.64
Aswan	$n = 19, k = 5$	3.21	2.90

The nonparametric Mann–Kendall (M–K) rank correlation test (Sneyers, 1990; Schonwiese and Rapp, 1997; Hasanean, 2004) has been used to detect any possible trend in temperature series, and to test whether such trends are statistically significant.

Among alternative methods in selecting significant harmonics in the literature, the cumulative periodogram test was applied as suggested by Salas *et al.* (1980). In this test, the harmonics are ordered in a decreasing manner with respect to their contribution ($V_i i = 1, \ldots, h$) to the total variance ($\sum V_i$), where h is the maximum number of harmonics. A harmonic with the highest amplitude (denoted by V_1) has the highest contribution to the total variance. Similarly, a harmonic with the smallest amplitude (denoted by V_h) possesses the lowest contribution. The sum of $V_i / \sum V_i$ values (each designated by P_i) is plotted against the order of harmonics i to obtain the cumulative periodogram. The variation of P_i values with respect to i is assumed to be composed of two parts: the periodic part of rapid increase of P_i and the sampling part of slow increase of P_i. In general, the first part of the cumulative periodogram may be perceived to represent significant harmonics, that is to say the deterministic components of a seasonal temperature time series (i.e. due to astronomical cycles). The second part of the cumulative periodogram is considered to have the stochastic components owing to sampling variations. The separation of these two curves may sometimes be difficult if both parts of the cumulative periodogram follow one continuous curve. In this study, this approach aims to detect possible substantial harmonics by cross-checking it with its power spectrum.

5. INTERANNUAL AND INTERDECADAL VARIABILITY OF SUMMER TEMPERATURE

5.1. Coefficient of variation

The COV of summer temperature is displayed in Table III and Figure 1(a). It is clear that the COV generally increases from the north of Egypt (Lower Egypt) to the south of Egypt (Upper Egypt). The higher values of COV occur southwest of Egypt over the desert region (Al-Dakhla, Al-Kharga, and Al-Qusir) and also over Helwan. The areas of low variability are observed along both the Mediterranean and Red Sea coasts of Egypt.

This indicates that the main reason for the spatial variations in COV is the effect of surrounding seas that moderate the temperature variability.

Table III also illustrates that the COV ranged from 1.66% at Cairo airport and Sharm-Elshiekh to 3.04% at Al-Dakhla, and the average of the COV of summer temperature is usually about 2%. The higher and lower values of the standard deviations (SD) are associated with the higher and lower values of the COV (Table III). Generally, the COV of summer temperatures is less than those of winter temperatures (Hasanean, 2004). Therefore, the summer temperature is more stable than the winter temperature over Egypt.

Figure 1(a) illustrates the relationship between the COV pattern and the latitudes and longitudes of our area of study. It is obvious that the COV decreases with increasing latitude (the values of COV at the south stations are more than those at the north) and increases with decreasing longitudes (the values of COV at the west stations are more than those at the east). The relationship between COV and latitude is not significant, while with longitude it is significant. This result is reasonable in the summer season where the north of Egypt has a considerable difference of temperature than in the south, while the difference in temperature from west to east is small. In general, most of Egypt has low COV values during the summer season. So the analysis of the COV exemplifies the known low COV that characterizes arid climate, especially during the summer season.

5.2. Trend analysis

The evaluation of the trend is based on the M–K rank statistical test. M–K rank statistics, which make no assumption about probability distribution for the original data, are tested for significance using a standard normal distribution. The spatial distribution pattern is not complex, even though the resultant statistics of the M–K test give both negative and positive trends. Table III and Figure 1(b) show the M–K statistics for the 19 sites in Egypt. The values of M–K trend test (u) were computed according to Sneyers (1990). Positive trends (warming) are observed over most stations. Negative trends (cooling) are observed mainly over Upper

Table III. Standard deviation (SD), mean temperature, coefficient of variation (COV), and trend at 19 stations over Egypt

Stations	SD	Mean	COV	Trend different lengths	Trend 22 year length
Al-Salum	0.61	25.99	2.33	0.35[b]	–
Marsa-Matrouh	0.53	27.2	2.14	0.31[b]	0.35[b]
Port-Said	0.45	26.65	1.70	−0.10	0.32[b]
Alexandria	0.49	25.82	1.91	0.20	0.40[a]
Al-Arish	0.55	25.60	2.17	0.39[a]	0.39[a]
Al-Ismalia	0.49	28.30	1.74	0.46[a]	0.47[a]
Al-Suez	0.75	29.62	2.54	0.63[a]	0.47[a]
Cairo	0.47	28.03	1.66	0.39[a]	0.62[a]
Helwan	0.84	28.16	2.98	0.22	0.65[a]
Siwa	0.57	29.47	1.93	0.52[a]	0.53[a]
Al-Menya	0.49	28.47	1.71	0.36[b]	0.20
Sharm-Elshiekh	0.54	32.36	1.66	0.38[a]	–
Asuit	0.61	29.45	2.07	−0.10	0.36[b]
Hurgada	0.59	30.93	1.91	0.51[a]	0.53[a]
Al-Qusir	0.63	29.51	2.15	−0.04	0.64[a]
Luxor	0.55	32.06	1.71	0.35[b]	0.41[a]
Al-Dakhla	0.93	30.64	3.04	0.52[a]	0.43[a]
Al-Kharga	0.75	31.66	2.36	0.40[a]	0.14
Aswan	0.67	33.62	2.00	−0.05	0.42[a]

[a] Significant at 99% confidence level.
[b] Significant at 95% confidence level.

Egypt, Asuit, Al-Qusier, and Aswan. Table III and Figure 1(b) indicate that the trend is significant in most stations. Also, the trend is high and significant over 22 years in most stations as shown in Table III. The values of the M–K statistic are significantly different from zero at the 5% and/or 1% level.

5.3. *Cumulative seasonal mean*

In this section, the long-term variability of the behavior of the summertime temperature is analyzed with regard to the time variations of summer temperature. To visualize the decadal and interdecadal fluctuations in the behavior of the summertime temperature, CSMs are used, because they advantageously reveal time varying structures in time series, which are not readily recognizable in raw data. Moreover, the cumulative means have a smoothing effect, similar to low-pass filters (Lozowski *et al*., 1989).

Persistent phases of alternating increase or decrease of the temperature, which vary in length, are recognizable in the time series of the summer temperature. Figure 2 illustrates the behavior of temperature during the available data period of each station.

Positive trend values in summer temperature are the dominant features during the 1910s–1930s, mid-1970s, and 1980s–1990s at all stations (Figure 2). These trends are, in general, consistent with trends in the global mean surface temperature since the late nineteenth century, which show the most rapid increase during the periods 1920–1940 and since the mid-1970s (Houghton *et al*., 1996; Fu *et al*., 1999; Jones *et al*., 1999). The warming of the 1920s–1930s was particularly strong in the North Atlantic (NATL) sector. Peterssen (1949) suggested that this was accompanied with a shift of the atmospheric circulation over the northern NATL from a zonal to a more meridional one. The extent to which the temperature increased in the 1920s may be explained by changes in circulation (Rogers, 1985; Moses *et al*., 1987; Fu *et al*., 1999). Recent rapid warming since the 1970s in this study as shown in Table III is in agreement with many 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 behavior in recent decades; however, it cannot be readily explained by natural climate variability. Barnett *et al*. (1999), in their paper dealing with the attributing 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 summer temperatures show that the 1940s and 1960s appear as the coldest periods at most stations in the twentieth century. The changes in circulation over the Atlantic may have contributed to the cool temperatures over the eastern Mediterranean since the 1940s and 1960s (Arseni-Papadiomitriou and Maheras, 1991; Cullen and deMenocal, 2000; Karl *et al*., 2000). Xoplaki *et al*. (2003) found that the large-scale variability strongly influences the variability of local temperatures in the eastern Mediterranean.

5.4. *Spectral analysis*

The graphs of the CSM of the summertime temperature suggest the existence of 'persistent' alternating spells between increase and decrease in temperature. However, their statistical significance cannot be obtained from this graphical presentation. More detailed information can be given by a spectral variance analysis of these time series and the analysis of their periodical behavior. The elegance of harmonic analysis is that the data are split into orthogonal components in the form of harmonics, which explain totally the variation in the original data. They provide the decomposition of the range between the maximum and the minimum values within the data variability and the occurrence instances of these extremes along the time axis. In practice, few harmonic components are often sufficient for the explanation of the whole variability.

The power spectrum and cumulative periodogram of the summer temperature series for the 19 Egyptian stations in the period ranging from 1971 to 2000 are depicted in Figures 3 and 4. From an overview of these figures, it can be noted that the first harmonic is the major contributor of summer temperature time series over Egypt. The values of the first harmonic are ranged between 24% over Upper Egypt and 38% over Lower Egypt. High contributions of the first harmonic appear along Lower Egypt while low contributions appear in Upper Egypt. A 30-year cycle was identified from the summer temperature series, which connected it with the third harmonic of the 10-year sunspot period (Lamb, 1972). Also, it has been noticed that the

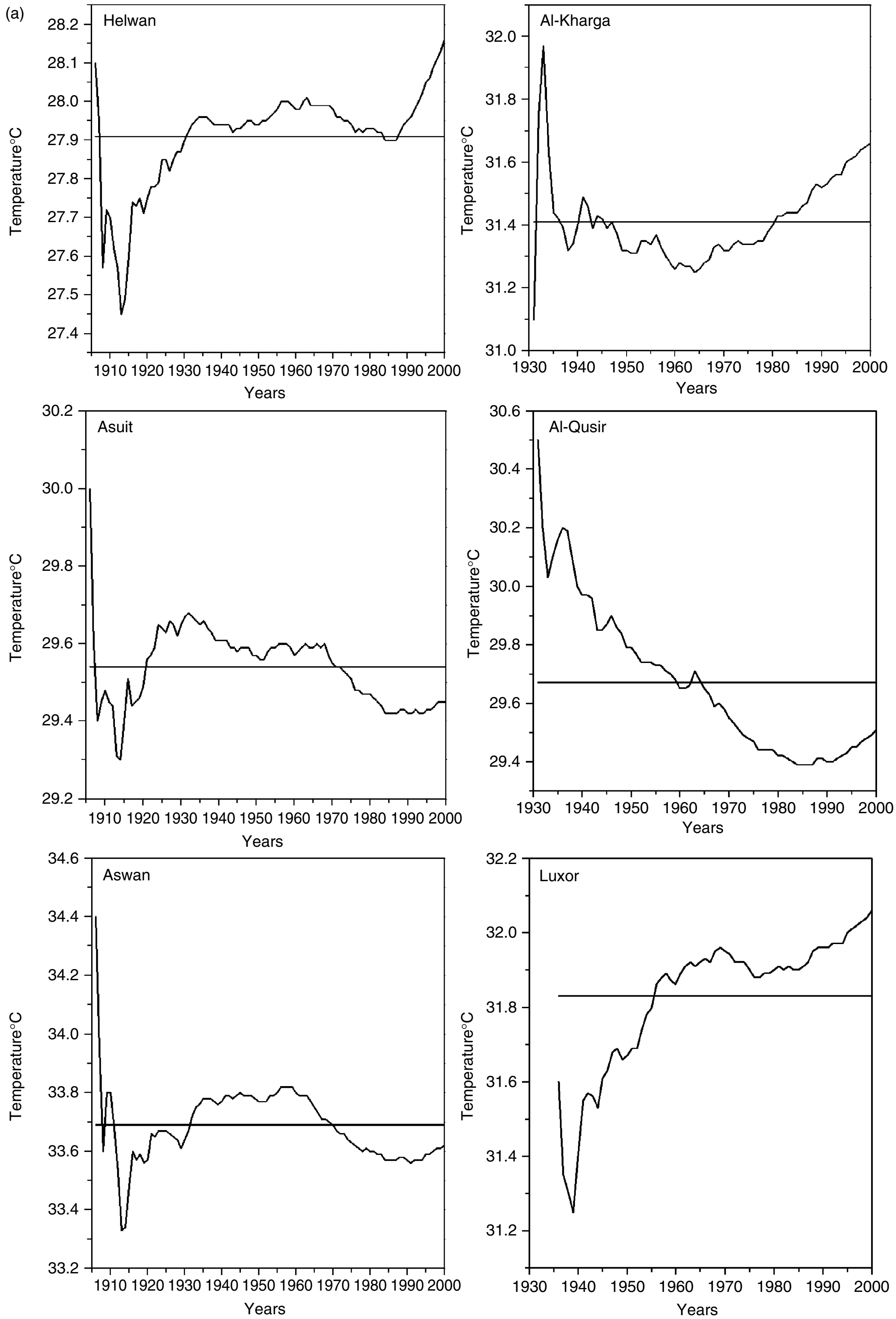

Figure 2. (a) The cumulative seasonal mean (CSM) time series and the averaged CSM in Helwan, Asuit, Aswan, Al-Kharga, Al-Qusir, and Luxor stations. (b) As Figure 2(a) but for Alexandria, Port-Said, Al-Salum, Marsa-Matrouh, Al-Menya and Hurgada stations. (c) As Figure 2(a) but for Siwa, Cairo, Al-Suez, Al-Dakhla, Al-Ismalia, Al-Arish and Sharm-Elshiekh

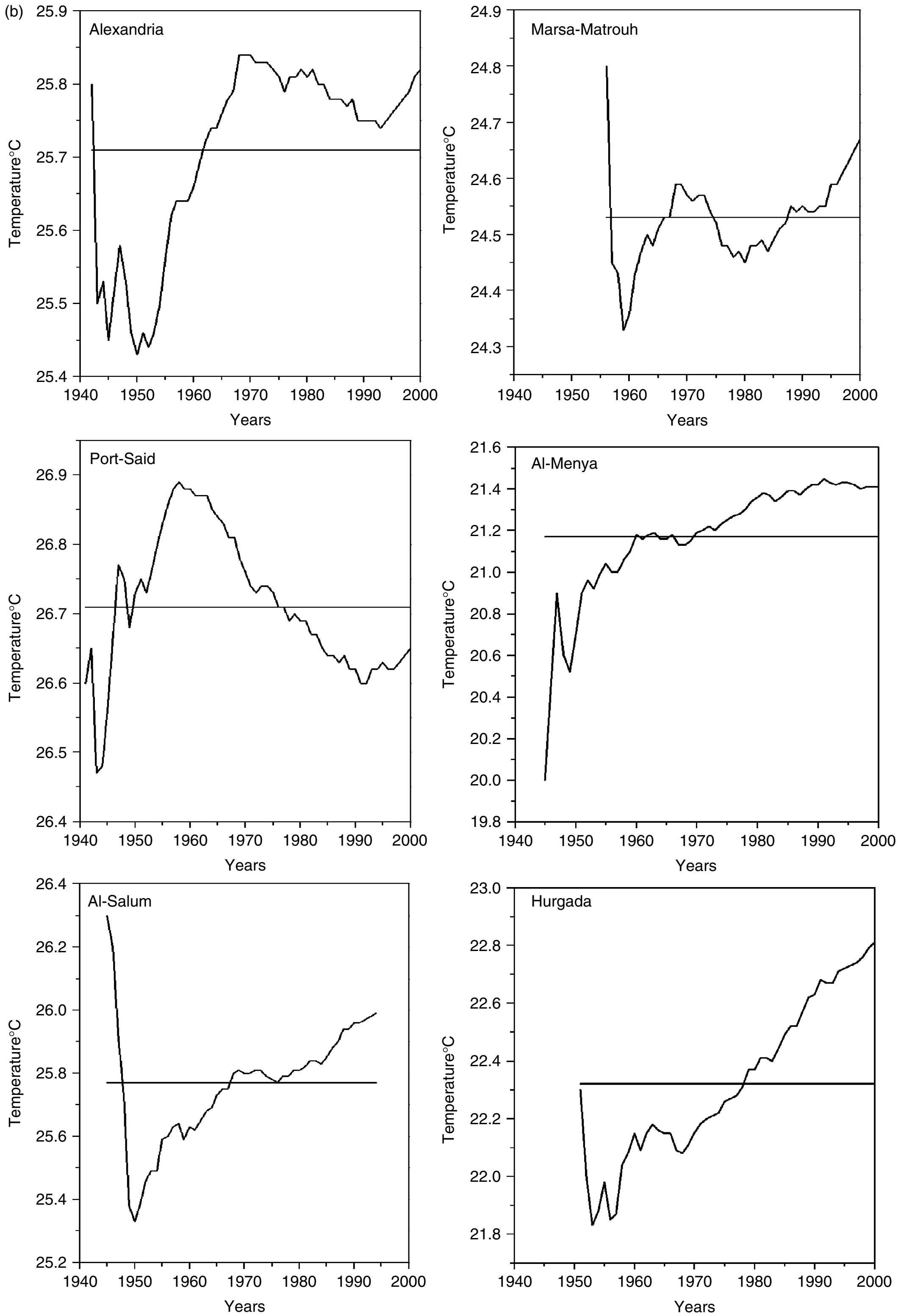

Figure 2. (*Continued*)

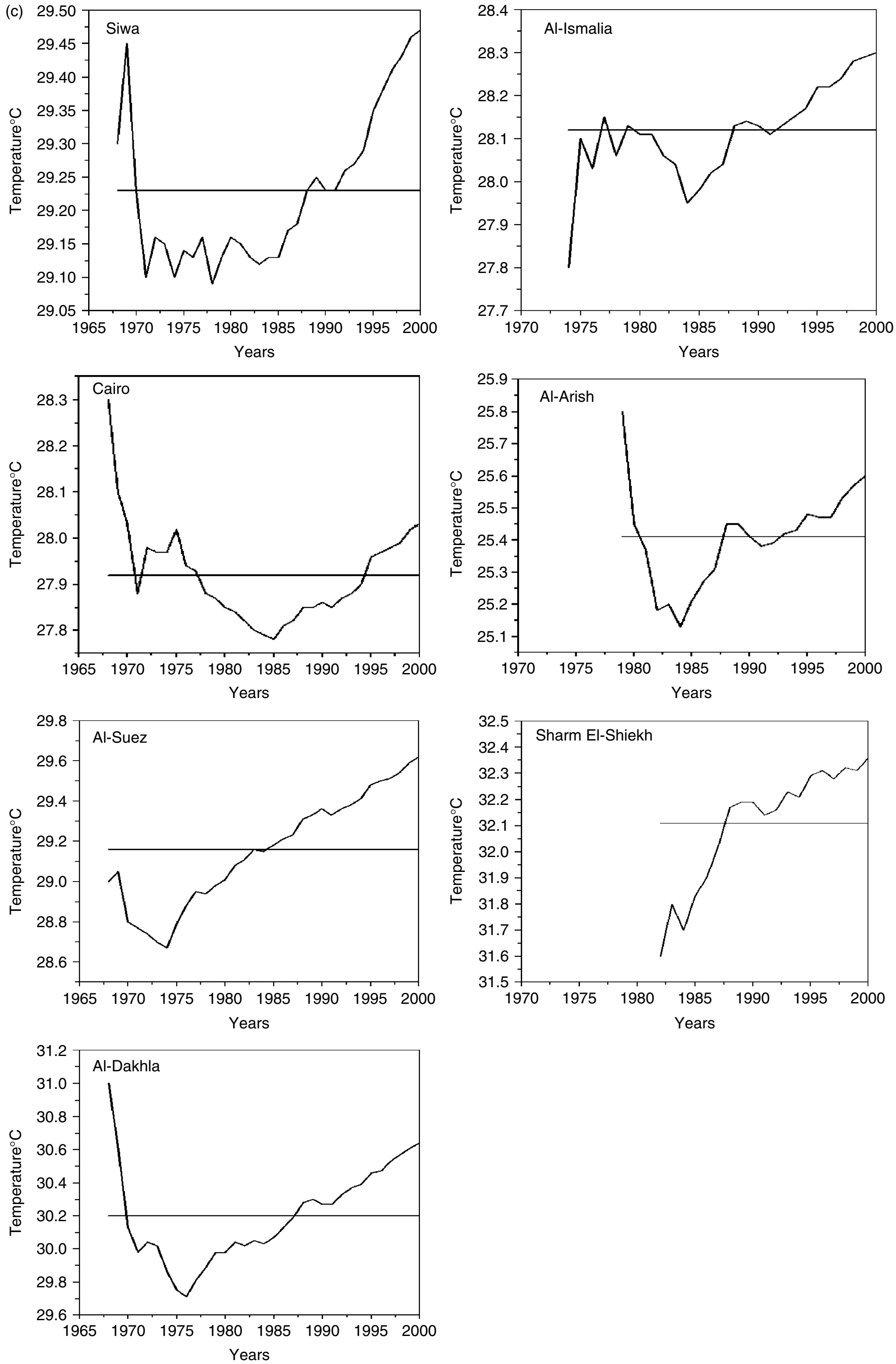

Figure 2. (*Continued*)

contribution of ENSO cycle, in the 3–8 year period, to summer temperature is around 9%. It has also been noticed that the contribution of quasi-biennial oscillation (QBO) cycle, in the 2–3 year period is around 10%. The contribution of solar inertial motion cycle (up to 16 years, in this case, 15 years) is within 6 to 9%. Charvatova and Strestik (2004) found that the periodicity between 6 and 16 years in surface air temperature is possibly related to solar inertial motion.

Inspection of Figure 3 for Lower Egypt reveals three categories–$V_i / \sum V_i$ value is above 0.35 for the first, between 0.05 and 0.1 for the second; and less than 0.05 for the third. The presence of these categories can be visualized by means of four inflection points in the magnified view of the cumulative spectrum curve (Figure 3(b)). In the power spectrum of the temperature series, the first harmonic with 30-year periods in the

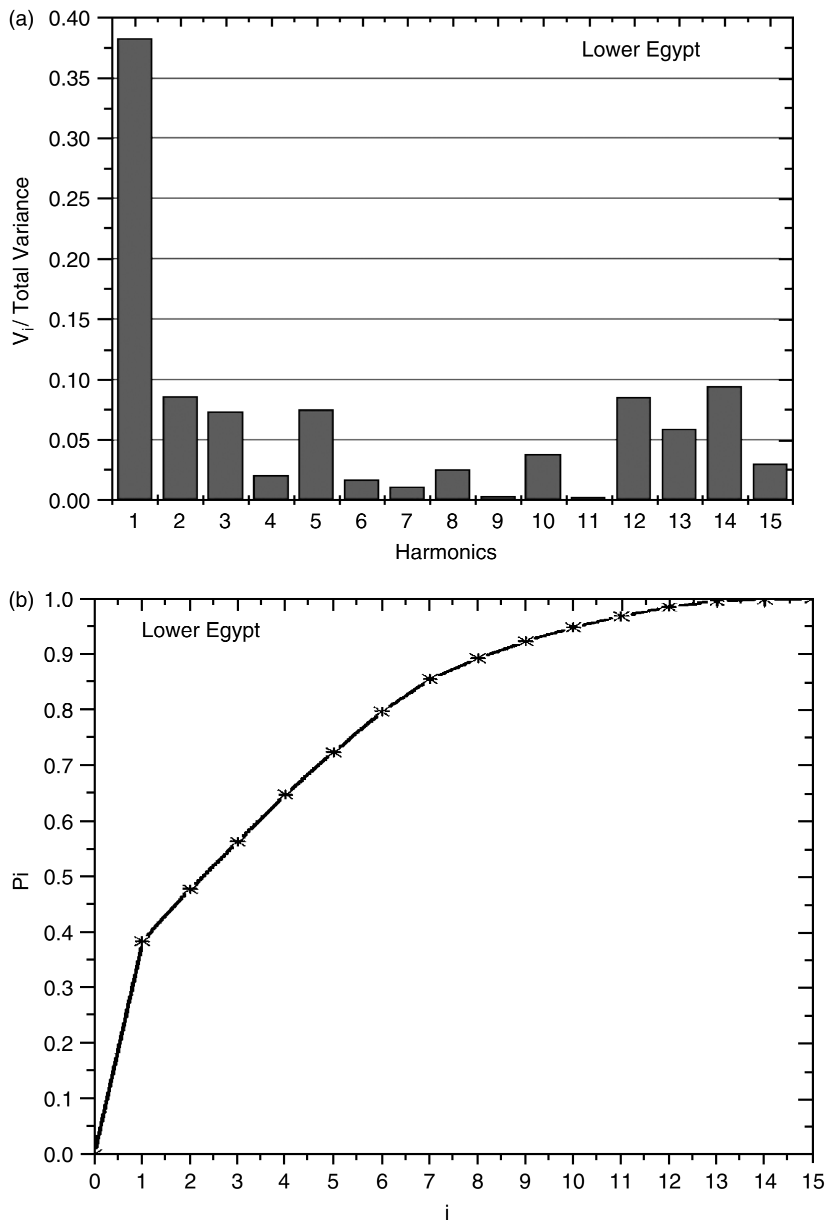

Figure 3. (a) Line spectrum and (b) cumulative periodogram of summer temperature over Lower Egypt

first category appears to be the most notable one. This explains at least 38% of the total variance by itself and is said to be related to the sunspot cycles with great confidence. It should be noted that the 2nd, 3rd, 5th, 12th, 13th and 14th harmonics take place in the second category, and the former six, to some extent, have been potentially linked to the QBO, ENSO, and solar inertial motion cycle provided supporting climatic evidence exists. It is not worthwhile evaluating the remaining harmonics.

The power spectrum and cumulative periodogram of the Upper Egypt region for the sunspot signal are given in Figure 4. Figure 4(a) implies three categories ($V_i/\sum V_i$ values are close to 0.25 for the first, very close to 0.1 for the second and other values for the third category). This can also be observed in Figure 4(b), which can be segmented into four pieces at three inflection points under a careful inspection. The first and third harmonics were found in the first category, which may be related to the sunspot cycle. There are four harmonics (with numbers 2, 4, 10 and 12) that fall into the second category. The second harmonic may be

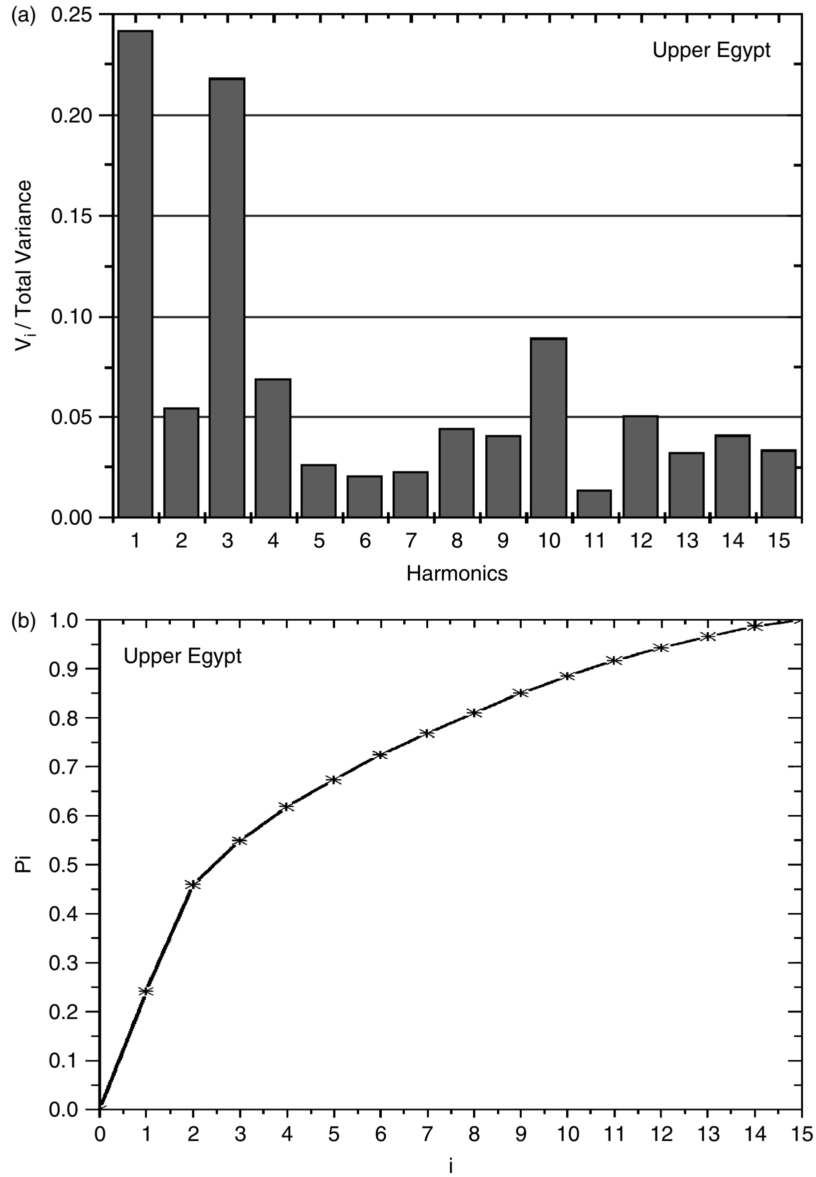

Figure 4. As Figure 3 but for Upper Egypt

related to solar inertial motion cycle. The fourth harmonics may possibly be linked to ENSO events, while the 10th and 12th harmonics seem to be related to QBO.

Compared to the case of the Lower Egypt region, the results of the spectrum analysis for the Upper Egypt region seem to be adequate for confirming the existence of the signal previously found. This is because of the fact that separation of the significant and stochastic components is not very obvious, as in the Lower Egypt region (Figure 3). On the other hand, there are some indications of the sunspot cycle, QBO, and El Nino signals for the summer temperature data in the Upper Egypt region, as seen in Figure 4.

6. INTERACTION BETWEEN SUMMER TEMPERATURE AND ATMOSPHERIC CIRCULATION INDICES

As an expected result of concern over climate change, there has been an increasing number of studies in the last 10 years dealing with long-term surface air temperature variations and trends, and variations and anomalies associated with circulation types across the Mediterranean basin, particularly for the eastern basin and individual countries (Metaxas *et al*., 1991; Arseni-Papadiomitriou and Maheras, 1991; Esteban-Parra and Rodrigo, 1995; Turkes, 1996; Proedrou *et al*., 1997; Kutiel and Maheras, 1998; Ben-Gai *et al*., 1999; Maheras *et al*., 1999; Quereda Sala *et al*., 2000). The explanatory indices are the ENSO, NAO, sea-surface temperature (SST) of tropical Atlantic (TATL), tropical NATL, tropical South Atlantic (SATL), and tropical Atlantic (TATL). The analysis of the interactions between the summer temperature and SSTs over the TATL, and east equatorial Pacific NATL can be obtained from the correlation analysis, Table IV.

Atlantic climate variability shows many important phenomena on different timescales. Unlike the tropical Pacific, the seasonal cycle dominates the ocean–atmosphere signal in the TATL. A phenomenon similar to but weaker than the Pacific El Nino also occurs in the Atlantic (Latif and Grotzner, 2000). During a warm phase, trade winds in the equatorial western Atlantic are weak and SST is high in the equatorial eastern Atlantic. The converse occurs during a cold phase. This phenomenon is called the Atlantic zonal equatorial mode (or the Atlantic El Nino) (Wang, 2002). Strong positive relationships between summer temperature and SSTs of

Table IV. Relationship between atmospheric circulation indices and summer temperature over Egypt in the last 22 years

Stations	ENSO	NATL	SATL	TATL	NAO
Marsa-Matrouh	−0.35[b]	0.39[b]	0.21	0.10	−0.21
Port-Said	−0.50[a]	0.33[b]	0.20	0.15	−0.32[b]
Alexandria	−0.41[a]	0.34[b]	0.13	0.01	−0.12
Al-Arish	−0.51[a]	0.42[a]	0.43[a]	0.01	−0.37[b]
Al-Ismalia	−0.40[a]	0.50[a]	0.21	0.13	−0.26
Al-Suez	−0.45[a]	0.45[a]	0.23	0.03	−0.10
Cairo	−0.33[b]	0.30[b]	0.30[b]	0.03	−0.10
Helwan	−0.30[b]	0.35[b]	0.13	0.16	−0.10
Siwa	−0.24	0.37[b]	0.34[b]	0.14	−0.10
Al-Menya	−0.32[b]	0.55[a]	0.10	0.10	−0.35[b]
Asuit	−0.20	0.55[a]	0.00	0.27	−0.14
Hurgada	−0.31[b]	0.30[b]	0.17	0.20	−0.24
Al-Qusir	−0.30[b]	0.30[b]	0.14	0.21	−0.10
Luxor	−0.36[b]	0.66[a]	0.33[b]	0.13	−0.30[b]
Al-Dakhla	−0.22	0.40[a]	0.13	0.23	−0.21
Al-Kharga	−0.21	0.56[a]	0.10	0.10	−0.10
Aswan	−0.30[b]	0.57[a]	0.13	0.19	−0.32[b]

[a] Significant at 99% confidence level.
[b] Significant at 95% confidence level.

NATL is found as shown in Table IV. The correlation between summer temperature and each of the SSTs for SATL and TATL are found to be weak. And consequently, warm SSTs over NATL (5°–20 °N, 60°–30 °W) lead to the warm summer temperatures. So the tropical Atlantic SSTs may regulate summer temperature over Egypt and is probably a reason for warming summer temperatures over Egypt in the last 20 years. Wang 2002 noted that the changes in the Atlantic subtropical high induces variations in the northeast trade winds on its southern flank and then affects the tropical North Atlantic SST anomalies. The atmospheric circulation cell changes result in an anomalous ascending motion in the tropical North Atlantic, which decreases sea-level pressure and pushes the subtropical anticyclone northward, then decreases the northeast trade winds and latent heat flux, and thus increases the tropical North Atlantic SST anomalies.

An inverse relationship between summertime temperatures at 17 stations over Egypt and ENSO is found. Over the period 1979–2000, high significant (at the 95% and 99% levels) correlations occur at 13 of the 17 stations. The highest correlations are found over Lower Egypt. The desert region of Egypt (Siwa, Al-Dakhla, Al-Kharga, and Asuit) is less affected by ENSO, which explains the poor correlation coefficient (Table IV). So, maybe during La Nina (cool SSTs of Nino3) summer temperature leads to warming.

A negative relationship between summer temperature and NAO index is found. There is an absence of a significant correlation between summer temperature and summer NAO with an exception of five stations, two of which are over the east Mediterranean sea (Port-Said, Al-Arish) and the other over Upper Egypt (Al-Menya, Luxor, Aswan). This maybe because the NAO index is more dominant in the winter season than in the summer season.

7. CONCLUSIONS

Variability in the summer temperature over Egypt has been investigated throughout the available data period of 19 stations. In order to get a clear and representative picture of the summer temperature in Egypt, the COV is adopted to assess the durability and stability of the temperature in different regions of Egypt. We found that the COV of summer temperature over Egypt ranged from 1.66 to 3.04%, and it is usually about 2%. Also, we found that the reason for the spatial variations of COV is the effect of the surrounding seas that moderate the temperature variability. The relationship between COV and latitudes is not significant, while with longitudes it is significant. The M–K statistical rank test illustrates that positive trends (warming) in summer temperature series occur over most stations, while negative trends (cooling) are observed mainly over Upper Egypt and summertime temperature trends are significant at most stations.

The use of cumulative seasonally mean temperatures is a worthwhile approach to studying inter-annual climate fluctuations, because they reveal time varying structures in the raw data or in the more traditional statistical analyses. Examination of the cumulative summer temperature over Egypt has revealed support for the notion of extended 'persistence' over several years, even though simple year-to-year persistence may be evident. It has also revealed a bounded, nonperiodic, oscillatory behavior that exhibits, from time to time, certain characteristic structural features. The boundedness of the oscillation supports the notion of climate compensation, i.e. that spells of cold must eventually follow spells of warm. The summertime temperature of the area is characterized by warm periods 1912–1930, and 1982–2000 and rather cool 1940s, and 1960s. A warm period began almost simultaneously at the stations with long records. A warm period was found during the 1970s, but it was not uniform, continuous or of the same order. Recent warming has only occurred during the last two decades at most stations. These trends are in general consistence with trends in the global mean surface temperatures since the late nineteenth century. The most probable cause of the observed warming in recent climate change is a combination of internally and externally forced natural variability and anthropogenic sources.

According to the cumulative periodogram, the first harmonic plays a dominant role in the regional climatological variations in Egypt. It explains more than 38% and 24% of the amplitude variations for Lower and Upper Egypt respectively. The first harmonic may be related to the sunspot cycle, which affects summer temperatures over Egypt. Recent satellite measurements of solar brightness, analyzed by Willson (1997), show an increase from the previous cycle of sunspot activity to the current one, indicating that the Earth receives more energy from the Sun. Willson (1997) indicates that if the current rate of increase of solar irradiance continues until the mid twenty-first century, then the surface temperatures will increase by about 0.5 °C. This is small, but not a negligible fraction of the expected greenhouse warming. The relationship between cycle length and Earth temperatures is not well understood. Lower-than normal temperatures tend to occur in years when the sunspot cycle is longest. ENSO cycle, QBO cycle, and solar inertial motion cycle are small contributors to summer temperatures in Egypt.

The interaction between summer temperature and atmospheric circulation indices is found for North TATL SST and ENSO in the last two decades.

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