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Variability of teleconnections between the Atlantic subtropical high and the Indian monsoon low and related impacts on summer temperature over Egypt

H. M. Hasanean*†
Cairo University, Faculty of Science, Department of Astronomy and Meteorology, P.O. Box: 12613, Giza, Egypt

**Correspondence to:
H. M. Hasanean, Cairo University-Faculty of Science, Astronomy and Meteorology Department, P.O. Box: 12613, Giza, Egypt.
E-mail: hasanean@ictp.trieste.it/ h_eg2001@yahoo.com*

†Permanent address: abdus salam ICTP, Trieste, Italy.

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Abstract

A robust subtropical circulation index (SCI) is defined as the difference between the North Atlantic subtropical high and the Indian monsoon low. The SCI is negatively correlated to air temperatures over Egypt and is associated with large-scale climate indices of the tropical and subtropical Atlantic sector. Copyright © 2005 Royal Meteorological Society

Keywords: **teleconnection; subtropical high pressure; Indian monsoon low**

1. Introduction

Atmospheric teleconnections on the global or regional scales and their influence on temperature and precipitation regimes have been studied widely (Kutiel and Benaroch, 2002). The most prominent atmospheric teleconnection is the Southern Oscillation in the coupled El Niño Southern Oscillation (ENSO) phenomenon. The variability of individual teleconnection patterns has long been measured by defining indices on the basis of circulation intensities.

The main purpose of the present study is: (a) to define an index (referred to as the subtropical circulation index, SCI) and (b) to investigate the variability of the SCI and to correlate it with other teleconnection indices and summer temperatures over Egypt. The datasets and definition of SCI are described in Section 2 and Section 3 respectively. The methodology used in this study is described in Section 4. Section 5 focuses on the statistical characteristics of the standardized anomaly behavior of the index of the persistence of these standardized anomalies and the long-term trends on an interannual scale. Section 6 illustrates the association between the SCI and the atmospheric circulation indices. The effect of the SCI on the summer temperature over Egypt is shown in Section 7. Finally, conclusions are presented in Section 8.

2. Data

Key SST indices were obtained from the Climate Prediction Center (NOAA, USA). These are the NINO3 index (5 °N–5 °S, 150°–90 °W), a widely used ENSO indicator, 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°). The North Atlantic Oscillation (NAO) defines a large-scale meridional oscillation of atmospheric mass between a center of subtropical high surface pressure located near the Azores and a subpolar low surface pressure near Iceland.

Monthly mean surface temperatures for the Egyptian region were obtained from the Egyptian Meteorological Authority. A set of 19 Egyptian stations from 24 °N to 31.5 °N was selected because of the quality and extent of their temperature records. At each station, the author calculated the time series of the summer season by averaging the June, July and August surface temperatures for each year.

Figure 1 shows the climatological means of sea level pressure (SLP) during the summer season (June, July and August) over the area bounded by 80 °W–120 °E and 5°–50 °N. The most pronounced feature is that the surface circulation is dominated by a huge subtropical high-pressure atmospheric center of action in the west and by a huge Indian monsoon low pressure in the east. The strong anticyclone circulation system is centered over the western Atlantic in summer and the strong Indian monsoon low is centered over the Indian subcontinent (Figure 1). Hasanean (2004a) defined the subtropical high-pressure index (SHCI) as the regional mean SLP averaged over the 28°–45 °W and 30°–38 °N. Also, the author in this work generated the Indian monsoon index (INDMI).

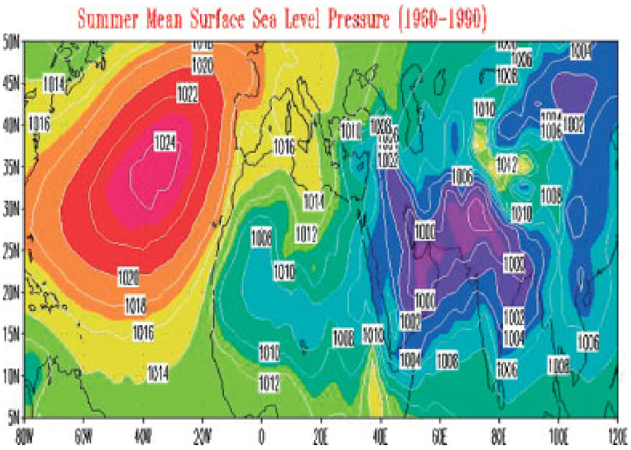

Figure 1. Mean sea level pressure climatology (reference period is 1960–1990) in summer season. Boxes indicate the areal averages used to compute the SCI

The quantitative index of the INDMI is defined as the regional mean SLP averaged over the area (50°–80 °E and 20°–30 °N) in summer; this provides a measure of the strength of the Indian monsoon low pressure. These rectangular areas generally cover the central regions of the cyclone where the pressure is generally less than 1000 hPa.

3. Defining the subtropical circulation index (SCI)

During the past several years, the impacts of monsoon condensational heating on the formation of the subtropical anticyclone have been reported by different studies (e.g. Liu *et al.*, 2001; Rodwell and Hoskins, 2001). The summer subtropical circulation in the lower troposphere is characterized by continental monsoon rains and anticyclones over the oceans. Rodwell and Hoskins (2001) demonstrated the duality between the monsoon condensational heating and the low-level subtropical circulation in the sense that either one would be very different without the other.

To focus on the subtropical circulation system over North Africa and the Mediterranean regions, the author defines a new index called SCI, defined as the difference between SHCI and INDMI. The SCI is calculated from the original data as the difference between standardized anomalies time series of subtropical high-pressure index (SHCI) and standardized anomalies time series of INDMI. The standardized anomalies z_i are computed simply as $z_i = (x_i - \overline{x})/s_x = x_i'/s_x$, where x_i' and s_x are anomalies and standard deviation of the time series of SLP at each of the centers of the circulation system respectively. Area-averaged indices are usually more reliable and can provide more insight than single-point indices such as those used by Sahsamanoglou *et al.* (1991) and Mokhov and Petukhov (1999). This is because errors at single locations get averaged out and the area-averaged indices represent variability in a center of action rather than at a single location only (Panagiotopoulos *et al.*, 2005).

4. Methods

Data in the present study are smoothed by a nine-pentad (or 9 year) triangularly weighted running mean. This running mean is described as:

$$y_n = \frac{1}{25}(x_{n-4} + 2x_{n-3} + 3x_{n-2} + 4x_{n-1} + 5x_n + 4x_{n+1} + 3x_{n+2} + 2x_{n+3} + x_{n+4}) \ldots\ldots \quad (1)$$

where x_n is the original value of the n data and y_n is the smoothed value. This running mean is superior to an unweighted running mean, in that it smoothes more effectively and it does not result in phase inversion, which may occur in the case of an unweighted running mean (Burroughs, 1978). The identification of an abrupt climatic change can be made by using the sequential version of the Mann-Kendall rank statistic (Sneyers, 1975, 1990). This test seems to be the most appropriate method for analyzing climatic changes in climatological time series (Goossens and Berger, 1986).

The power spectrum of the SCI time series was computed using autocorrelation spectral analysis (ASA; Mitchell *et al.*, 1966). ASA is smoother and more accurate than fast Fourier transformation (FFT), but the amplitude relationship is poorly reflected (Padmanabhan, 1991). The statistical confidence of the power spectra is tested using Markov red noise theory and χ-tests (Mitchell *et al.*, 1966).

5. Variability of the subtropical circulation index (SCI)

5.1. Changes in intensity of the SCI

The evaluation of the trend analysis is based on the nine-pentad running mean method. In addition to a large amount of interannual variability, there have been several periods when the SCI persisted in strong or weak states over many years. SCI intensity for the summer season, as well as the smoothing for the period 1950–2002, is shown in Figure 2. Striking features are the high values during the period 1950 up to the first few years of the 1970s and the low values during the period 1973–1987. From 1987 to the end of the record, a gradual upward trend is found. The mean upward trend and/or downward trend over the periods mentioned above are around 1 hPa. Using the Mann-Kendall rank statistical test, nonlinear trend, (Sneyers, 1990; Huth, 1999) the magnitude of trend for the SCI is found to be equal to −0.30. The trend is statistically significant at the 5% confidence level.

Following the criterion given by Wigley (1985), the change in the mean value may be expressed in terms of the standard deviation of the reference period. Thus, the change C is calculated as $C = \overline{X} - \overline{X}_{ref}/S_{ref}$, where $\overline{X}_{ref}$ and S_{ref} are respectively the mean value and the standard deviation of the reference period

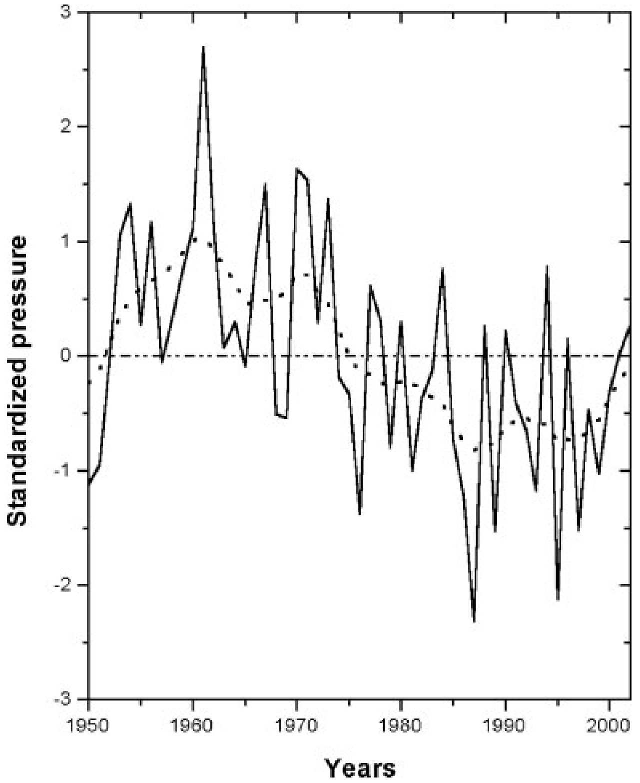

Figure 2. Standardized anomalies summertime series of sea level pressure of subtropical circulation index, SCI (solid curve), mean of SCI (line dashed double dot), and nine-pentad running mean (dashed curve)

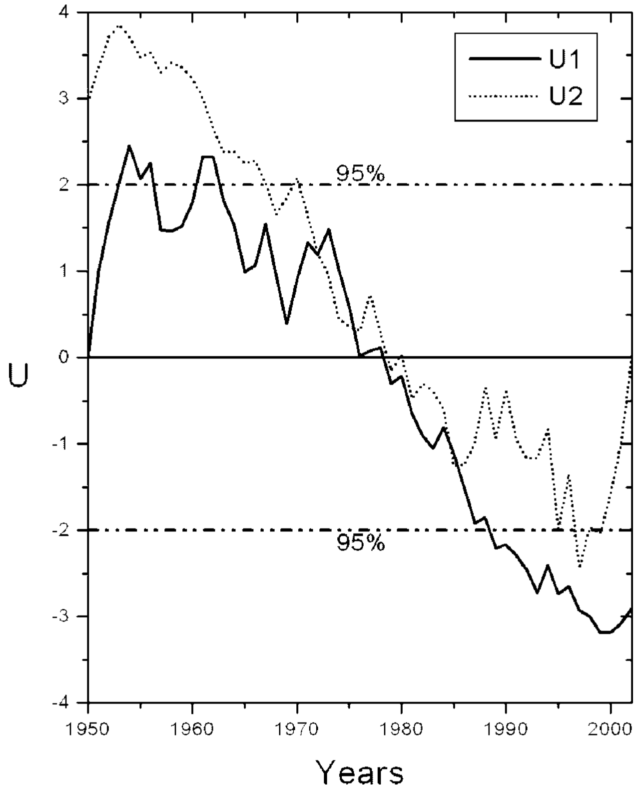

Figure 3. Abrupt change for subtropical circulation index time series in summer as derived from sequential version of the Mann-Kendall test. (U1 forward sequential statistic and U2 backward sequential statistic)

1961–1990. Positive/negative changes in *C* indicate an increase/decrease in the mean value. The mean over the entire period is near zero (−0.002), but the change in the mean has a negative value (−0.12). The standard deviation value over the entire period under study has a relatively high value (1.4); this is due to the high variability from year to year as also shown in Figure 2.

5.2. Abrupt change of the SCI

Figure 3 shows the Mann-Kendall *t* test for the SCI in the summer season. It shows that for the summer season, an abrupt climatic change took place. Negative and positive values (decreasing and increasing SLP) occur in the periods of the 1970s and of the 1980s. A change toward decreasing SLP (negative sign) occurs in 1972 and a change toward increasing SLP (positive sign) occurs in 1975 and 1987. These change points in the SCI may be related to the El Niño and La Nina events that took place in those years.

The episodic or abrupt changes of extratropical circulation pattern are documented in many observational studies (e.g. Namias, 1990; Zeng *et al.*, 1994), but the overall characterization, let alone understanding, of abrupt changes remains unresolved. Congbin *et al.* (1999) suggested that a major change of atmospheric circulation occurred at roughly the same time of the abrupt change in SCI throughout the northern oceanic subtropics. They also noted that the change in baroclinicity resulting from a reduced level of available potential energy leads to changes in position and strength of the subtropical highs. Janicot *et al.* (1998) noted that the period from 1970 to 1988 is characterized by large ENSO warm and cold episodes, which may contribute to explaining the abrupt change in SCI during this period.

5.3. Spectral analysis of the SCI

The graphs of the five-pentad triangularly weighted running mean of the SCI suggest the existence of 'persistent' alternating spells of high and low SLP. The power spectrum of the summer SCI series is depicted in Figure 4. The SCI spectrum reveals that peaks above the 95% confidence level occur at 53-, 5.2- and 2.1-year periods. A 53-year cycle has been identified from summer SCI series that connected it with solar inertial motion cycle of Saturn and Uranus (Charvatova and Strestik, 2004). A physical explanation of the 2.1-year periodicity seems to be associated with the quasi-biennial oscillation (QBO). This connection has been mentioned by Lamb (1972).

6. Interaction between the SCI and the atmospheric, oceanic circulation

Consider the oceanic and atmospheric indices of the ENSO, the NAO, the sea surface temperature of

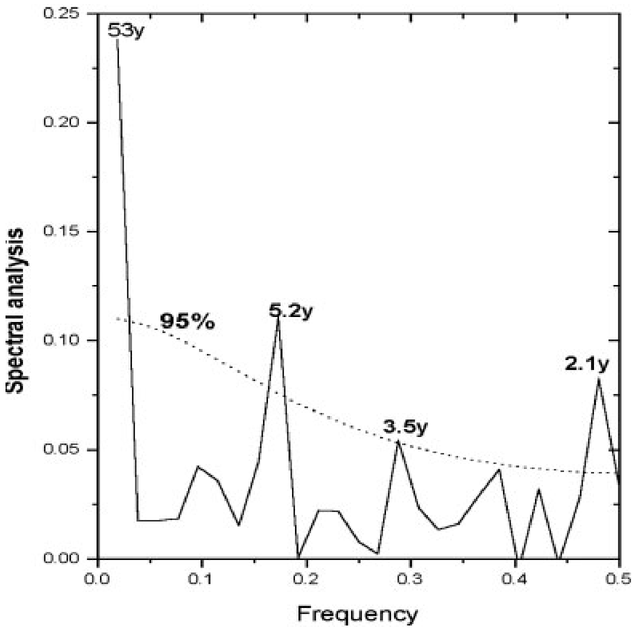

Figure 4. Power spectra of summer SCI using autocorrelation spectral analysis

the tropical Atlantic [tropical North Atlantic (NATL), tropical South Atlantic (SATL) and tropical Atlantic (TATL)] and the Hadley circulation cell index. The Hadley cell index is defined by Wang (2002) as the 500 hPa vertical velocity anomaly difference between the regions of 2.5°–7.5 °S, 40°–20 °W and 25°–30 °N, 40°–20 °W. Interactions between the SCI intensity and the sea surface temperatures (SSTs) over the tropical Atlantic, the east equatorial Pacific North Atlantic and the Hadley cell index can be studied using correlation analysis. Figure 5 shows that the time series of the SCI correlated with the trend removed is nearly the same as the plotted values. Also, these correlations depend on the strong 53-year cycle, which may or may not repeat during the next 53 years.

The SCI and the Hadley circulation cell index exhibit very similar variations. The time series of the vertical velocity anomaly closely resembles the pressure series. The similarity is evident not only in the year-to-year variation but also in the secular trends. The two curves correlate at 0.67 above the 99% significance level (Figure 5(a)). The monsoon dynamics are coupled to the summer Hadley circulation dynamics through controls on the magnitude of the subtropical highs in the Northern Hemisphere (Cook, 2003). Figure 5(b) indicates a strong negative relationship between the SCI and the ENSO on the interdecadal timescale. The correlation between the two curves is −0.45 above the 99% significance level. The ENSO events modulate the atmospheric circulation patterns at the middle and high latitude (Bengtsson *et al*., 1996). The absence of significant correlation between the summer SCI and the summer NAO may be due to the NAO being more dominant in the winter season than in the summer season.

Atlantic climate variability shows many important phenomena on different time scale. Unlike the tropical Pacific, the seasonal cycle dominates the ocean-atmosphere signal in the tropical Atlantic. A phenomenon similar to, but weaker than, the Pacific El Niño also occur in the Atlantic (Latif and Grötzner, 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 Niño) (Wang, 2002). The correlation coefficients are generally high between the SCI and the SSTs of the tropical Atlantic (Figure 5(c), (d)). The negative correlations between the two time series of the SCI and each of the SSTs for the TATL and the NATL are statistically significant. Cold SSTs over the TATL (10 °S–10 °N, 0°–360°) and the NATL (5°–20 °N, 60°–30 °W) occur with an increase in the SLP of the SCI and vise versa. This suggests that the tropical Atlantic SSTs may be the regulator of the SCI. Wang (2002) noted that the changes of the Atlantic subtropical high induce variations of the northeast trade winds on its southern flank and then affect the tropical North Atlantic SST anomalies. The atmospheric circulation cell changes result in anomalous ascending motion in the tropical North Atlantic. It decreases the SLP and pushes the subtropical anticyclone northward, then decreases the northeast trade winds and latent heat flux. This increases the tropical North Atlantic sea surface temperature anomalies. Also, Wang (2002) noted that the tropical Atlantic meridional gradient mode is associated with the variations of the Northern Hemisphere Hadley circulation in the tropical North Atlantic and south tropical Atlantic.

7. Relationship between the SCI index and the summer temperature over Egypt

Local changes in the meteorological variables in the midlatitudes are mainly controlled by the atmospheric circulation (Hurrell and Van Loon, 1997). As a consequence, a significant fraction of local variability can be explained by large-scale oscillation patterns. This also applies to temperature, in spite of its great time and space variability, as shown by some authors who evaluated the correlation of temperature with indices describing some well-known planetary-scale oscillations, like the NAO and El Niño–Southern Oscillation (Valero *et al*., 1996).

Some previous studies found that almost half of the wintertime (December–February) temperature variance over Egypt could be explained by the East Atlantic–West Russia (EAWR) index and NAO (Hasanean, 2004a). The time series associated with the first pattern showed an increasing (warming) trend at most stations in summer temperature, especially in the last two decades (Hasanean, 2004b). In addition to

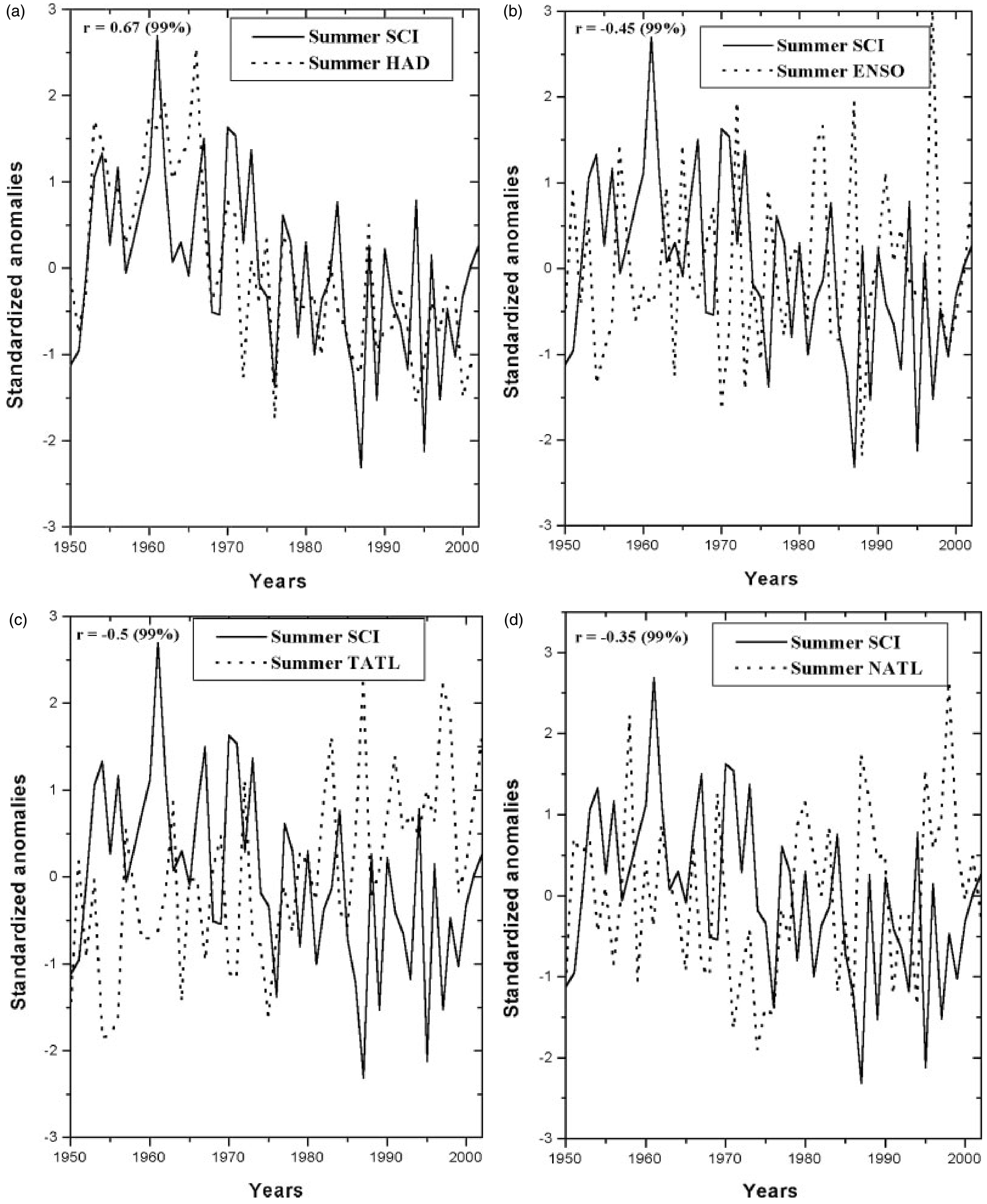

Figure 5. Standardized summer time series of sea level pressure of subtropical circulation index correlated with standardized anomalies of (a) Hadley circulation cell index; (b) ENSO; (c) tropical Atlantic index; and (d) North Atlantic index

the link between the SCI and these atmospheric systems, which are somewhat distant from the Eurasian continent and North Atlantic Ocean, there is also a strong coupling between the SCI and the summer surface temperature across Egypt. The correlation coefficient pattern between summertime temperature at 19 stations over Egypt and summer SCI is presented in Figure 6. A negative relationship between the summertime temperature at 19 stations over Egypt and the SCI is found. Over the period 1950–2000, high significant (at the 99% level) correlations occurred at 14 out of the 19 stations. The highest correlations

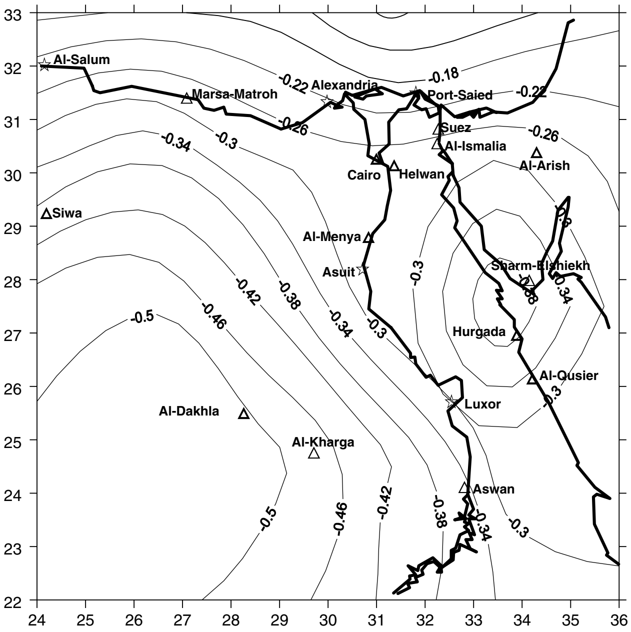

Figure 6. Spatial distribution patterns of correlation coefficient between subtropical circulation index (SCI) and summer temperature over Egypt. Triangles indicate significant correlation and stars indicate nonsignificant correlation

are found over the desert region of Egypt. The north coast of Egypt is less affected by the SCI, as seen by the poor correlation coefficient (Figure 6). Positive SCI leads to cooling and negative SCI leads to warming summertime temperature. That is because in the case of positive SCI, subtropical high pressure is dominant over the INDMI, so that subsidence of cold air is invaded. In the case of negative SCI, the Indian monsoon low pressure is more dominant than subtropical high — pressure; consequently, the northeast trade wind causes warming over Egypt.

8. Conclusions

This study investigated the variability in the intensity of the SCI over the 53-year period from 1950 to 2002 by carefully defining a robust SCI and then using it in the correlation studies of teleconnection indices and meteorological fields. The major findings are as follows:

(1) For the variability of the SCI

The year-to-year variation in the SCI is considerably high. Also, the SCI fluctuated from epoch to epoch, exhibiting an increasing trend by 1.0 hPa in the period 1950–1972 and in the period 1988–2002, and a decreasing trend by −1.0 hPa in the period 1973–1987. According to a 9-pentad running mean analysis, the most important feature is the change of the temporal mean from below to above average during the periods 1950–1972 and 1988–2002, and downward in the period 1973–1987. The magnitude of the trend in the SCI is equal to 0.3 hPa with 95% significant confidence level. Examining the SCI time series reveals a significant abrupt climatic change. Increasing episodes occurred in the summer SCI in 1972. On the other hand, decreasing changes took place in the summer SCI in 1975 and 1985–1987. According to the power spectrum, the first harmonic plays a dominant role in the SCI. The first harmonic explains 33% of the amplitude variations. The first harmonic may be related to the solar inertial motion, which may affect the summer SCI. The relationship between cycle length and atmospheric circulation is not well understood. Other harmonics may be related to the ENSO cycle and the QBO cycle. The ENSO cycle has approximately 15% contribution to the SCI while the QBO cycle has approximately 8% contribution to the SCI.

(2) For the interaction between SCI and atmospheric circulation indices

The SCI is associated with the Hadley cell index patterns whose linear combination can explain year-to-year variability in the SCI. Also, the pattern of SSTs over the Tropical Atlantic (TATL) and the North Tropical Atlantic (NATL) is associated with SCI. These relationships between the TATL index and the NATL index with the SCI suggest that the change of the SLP of the SCI induced the change in the tropical north and the tropical Atlantic SSTs. The summer ENSO has links with the SCI, while there is no connection between the SCI and the summer NAO index.

(3) For the association between the SCI and the summer surface temperature over Egypt

There is strong coupling between the SCI and the summer surface temperature across Egypt. A negative relationship between the pattern of the SCI and the pattern of the summer temperature over Egypt is found. Variations in local climate may be responding to changes in 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. While zonal circulation usually has a dominant influence on temperature, there were periods such as the 1920s when meridional circulation appeared to have greater influence (Slonosky and Yiou, 2002).

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