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LARGE-SCALE CIRCULATION ANOMALY INDICES IN RELATION TO VERY HIGH TEMPERATURE IN EGYPT DURING SUMMER SEASON 1998 (A CASE STUDY)

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Abstract: Based on daily and monthly data of surface temperature, zonal wind and vertical velocity obtained from NCEP/NCAR reanalysis, the author will try to investigate and understand some causes of extreme warming during August 1998. The interconnection between large scale anomaly indices (such as Hadley cell, zonal index, subtropical high pressure, Indian monsoon, subtropical jet stream) and surface temperature over Egypt were studied.

Keywords:

INTRODUCTION

In summer of 1998 heat waves and air pollution episodes plagued many regions of the world, particularly in Egypt and other Mediterranean countries, and in southern Europe (Trenberth, 1999). Local and regional climate in mid-latitude are influenced by both large-scale atmospheric circulation and surface features (e.g. Lolis *et al*., 1999). As spatial distribution of surface characteristics is relatively stable, it would be expected that large-scale climate plays an important role in causing changes in local climate. Studies of local climate change are often linked to variations in the atmospheric circulation (e.g. Yarnal, 1984). In characterizing large-scale circulation, an index which describes features of the large-scale circulation can be useful in explaining changes in surface climate elements (e.g. Kozuchowski, 1993). One such indices is the ZI, originally developed by Rossby (1941) which has been widely used in studying European climate (Kozuchowski *et al*., 1992).

It is well known that the 1997 and 1998 years were dominated by El Nino and La Nina respectively. But the big question is: why the summer 1998 is the warmest season in the 20th century, although many years were dominated by El Nino event? In this paper the author will try to investigate and understand the causes of summer warming especially in August 1998. The datasets and methodology are described in section 2. Section 3 is focused on the climatic extremes of summer 1998. Section 4 illustrates the association between surface temperatures pattern over Egypt and atmospheric circulation indices. Finally the conclusion is presented in section 5.

DATA AND METHODOLOGY

The observed data used in this study include: (a) surface temperature at the mean sea level pressure, 850, 500 and 200 hPa (b) sea level pressure (c) zonal wind at 250 hPa and (d) vertical velocity at 500 hPa. These data are obtained from the daily and monthly mean reanalysis dataset of the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) for August 1997 and August 1998 (Kalnay *et al*., 1996). The NCEP–NCAR reanalysis fields use a state-of-the-art global data assimilation system on a 2.5 ° longitude by 2.5 ° latitude grid.

Based on the daily data obtained from NCEP/NCAR, the derivation of the different index time series as a measure of the extratropical circulation modes is as follows. Based on the daily data of the sea level pressure we can calculate the ZI. The ZI is defined as the difference in sea level pressure (SLP) between the latitude circles 35 and 55 °averaged over the entire globe. Hasanean (2004) defined the subtropical high pressure centre index (SHCI) in summer season as the regional mean sea level pressure (SLP) averaged over the area 28 °W–45 °W and 30 °N–38 °N). Also, Hasanean (2005) defined the Indian monsoon index (INDMI) as the regional mean SLP averaged over the area 50 °-80 °E and 20 °-30 °N) in summer season. 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. The quantitative index of the subtropical jet stream (SJ) is defined as the maximum zonal wind of 250 hPa daily averaged over the area 42.5 °-82.5 °E and 40 °-45 °N) in summer season; this provides a measure of the strength center core of the subtropical jet stream.

The standardized anomalies *Zi* are computed for all indices simply by subtracting the sample mean of the batch ($\bar{x}$) from which the data are drawn (x), and dividing by the corresponding sample standard deviation *Sx*.

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

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

where *Xn* is the original value of the *n*th data and *Yn* is the smoothed value. This running mean is superior to an un-weighted running mean, in that it smoothes more effectively and it does not result in phase inversion, which may occur in case of an un-weighted running mean (Burroughs, 1978).

The analysis of the interactions between the atmospheric circulation indices intensity and sea surface temperatures over Egypt can be obtained from the correlation analysis. The coefficient of variation (CV) can be defined as the standard deviation (SD) divided by the arithmetic mean multiplied by 100.

CLIMATIC EXTREMES OF THE SUMMER 1998

The earth's global temperature in 1998 recorded to be the highest since 1860, according to the Intergovernmental Panel on Climate Change (IPCC, 2001). The global mean surface temperature is estimated to be 0.58 °C above the recent long-term average based on the period 1961-1990. It will be the 20th consecutive year with an above normal global surface temperature. The ten warmest years have all occurred since 1983, with seven of them since 1990 (IPCC, 2001). The IPCC (2001) also has shown that higher maximum temperatures and more hot days are likely to increase in frequency during the 21st century.

From the surface to 7 km altitude, record temperatures in 1998 were 0.47 °C higher than the average of the last 20 years, making 1998 by far the warmest year. In the lower stratosphere, 1998 was colder than usual, though not quite as cold as in the 1995-1997 period. Because of changes in climate extremes are expected with anthropogenic-induced climate change, it is important to keep in mind the difference between the detection of a change, and being able to attribute that change to some identifiable climate forcing factor. The detection of changes in extremes on the basis of climate statistics is much more likely than the detection of event-driven extremes. This also holds true in attempting to attribute a detected change to some forcing factor.

Globally, preliminary surface data indicate that August 1998 remains at record warm levels with respect to 1880-1997 long-term mean. Preliminary August land station temperature were 1.2 °C above the mean, while sea surface temperature readings (including ship, buoy, and satellite measurements) were nearly 0.57 °C above the mean, for a combined index value of 0.72 °C above the average.

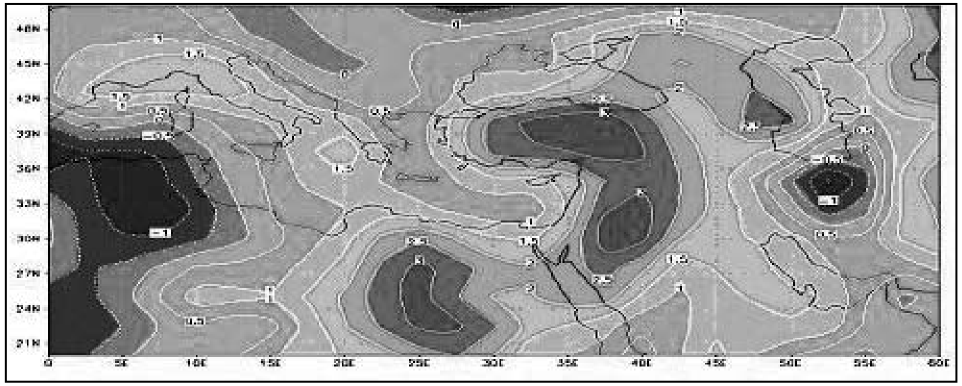


Figure 1. (a) Surface temperature (August 1998 - mean).

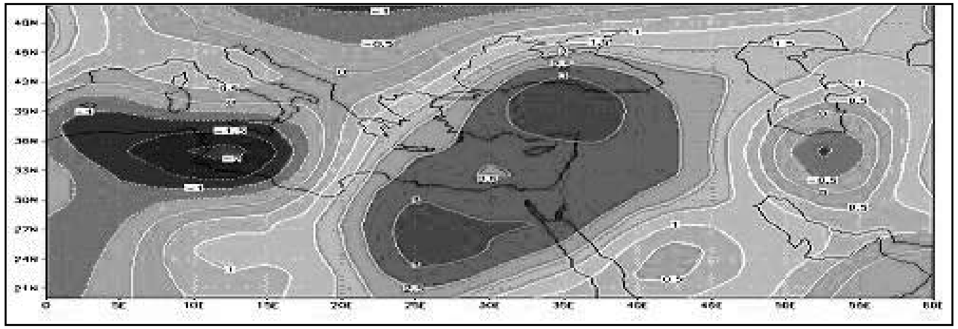


Figure 1. (b) Air temperature (August 1998 - mean) 850 hPa.

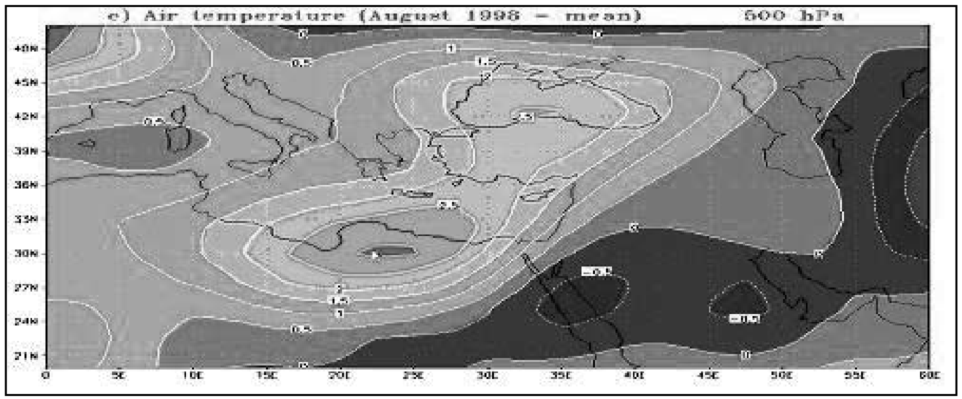


Figure 1. (c) Air temperature (August 1998 - mean) 500 hPa.

Figure 1 illustrates the differences between the temperature pattern of August 1998 and the average of 1960-2000 at the mean sea level pressure, 850, 500 and 200 hPa. It is clear that August 1998 was warmer than the mean throughout all levels and from longitude 15 °E to 50 °E. The maximum difference (positive values) occurs at the surface and 850 hPa especially over Egypt and north east and east of Mediterranean. There are small negative values of temperature recorded over south east of Egypt, Red sea, Saudi Arabia and over the Gulf area at 500 hPa level.

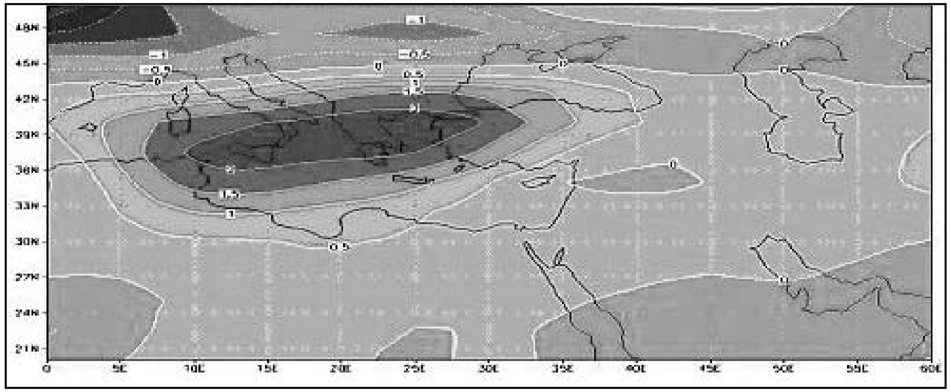


Figure 1. (d) Air temperature (August 1998 - mean) 200 hPa.

The lasting global surface warmth, likely related to the recent El Nino, has persisted, as central equatorial Pacific sea surface temperatures cool down to La Nina levels. However, ocean temperatures of the NW South American coast remain quite warm. Near surface global land and ocean temperatures for the month of August 1998 established in all times high records. Temperatures averaged more than 0.7 °C above the 1880-1997 long-term mean. The high temperatures were particularly evident over the land as temperatures averaged over two degrees above the long-term mean.

TELECONNECTION BETWEEN SURFACE TEMPERATURE AND ATMOSPHERIC CIRCULATION PATTERNS

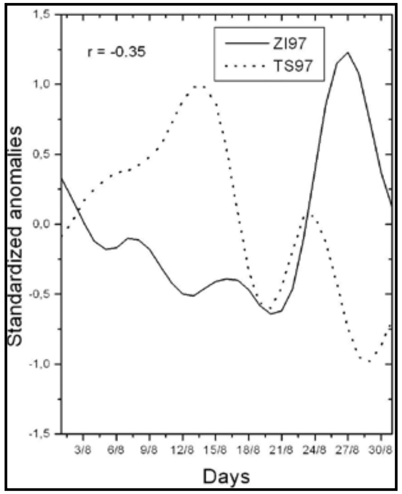
Sea level pressure teleconnection patterns

a) Zonal index (ZI) pattern

The basic flow in the mid-latitudes is from the west; hence most investigators have examined the circulation features upstream on intra-seasonal time-scales (Kripalani *et al*., 1997). On this time scale, the mid-latitude atmosphere shows a semi-regular alternation between high index periods of predominantly zonal flow and low index periods when large amplitude waves or blocking regimes are dominant.

Figure 2(a, b) represents the relationship between surface temperature pattern over Egypt and ZI in August 1997 and August 1998 respectively. The results in Figure 2 (a, b) shows an inverse relationship (*r* = -0.4 in August 1998 and *r* = -0.35 in August 1997) between two patterns with statistically high significant confidence level. Thus, for high values of the ZI the surface temperature is low and vise versa. Time series values of ZI exhibits high variability during August 1997 (coefficient of variation is 63 %) and low variability during August 1998 (coefficient of variation is 45%). And consequently zonal mean waves during August 1998 are situated for the long period to give extreme heat waves over our area. In general, ZI in August 1998 tend to be zonal. So, the flow in August 1998 is mainly westerly with long wavelengths and low amplitudes.

At such times the polar low is intense and located far north. Surface lows and highs are elongated in an east-west direction and cyclones move rapidly in the zonal flow. A large sensitivity of the extratropics climate may be due to slight zonal flow shifts (Ting *et al*., 1996). The extratropical regional climate "signal" associated with perturbed zonal mean circulation states is shown to exceed the signal associated with extreme phases of ENSO (Ting *et al.,* 1996).



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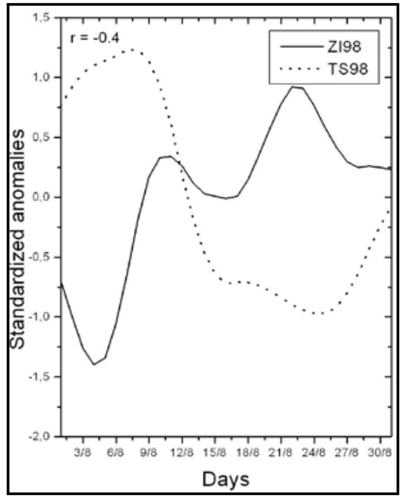
b) Subtropical high pressure and Indian monsoon indices patterns

Rodwell and Hoskins (2001) examined the dynamics of each of the summertime subtropical highs observed over the whole globe as a nonlinear model response to regionally assigned diabatic heating with realistic topography. They concluded that the combined effect of the topography and monsoonal heating to the east (i.e., the Mexican monsoon for the North Pacific high and the Indian monsoon for the Azores high) is of primary importance for the generation of the surface subtropical highs and subsidence aloft, under the reinforcement by local cooling over the eastern oceans. They thus emphasized the upstream influence of monsoonal heating as the primary external forcing that can trigger the summertime formation of a subtropical high. Shaffrey *et al*. (2002) reached the same conclusion based on AGCM experiments. There is a clear "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. Nevertheless, since the monsoons are essentially an amplification of summertime land–sea sensible heating contrasts, their heating have been taken as given, and the investigation has focused on how they affect the summer subtropical circulation.



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Subtropical anticyclones and monsoons play a major role in the global circulation of the atmosphere and oceans (Rodwell and Hoskins 2001). A significant negative relationship between subtropical high pressure center index (SHCI) and Indian monsoon low pressure center index (INDMI) are found in both periods (Figure 3a, b). So, when the SHCI is strong the INDMI is weak and vise versa. The existence of the subtropical anticyclones has often been attributed to the Hadley circulation. Rodwell and Hoskins (1996) found that the Indian monsoon activity can induce a Rossby wave response, which produces an adiabatic descent amplified over the eastern Mediterranean.

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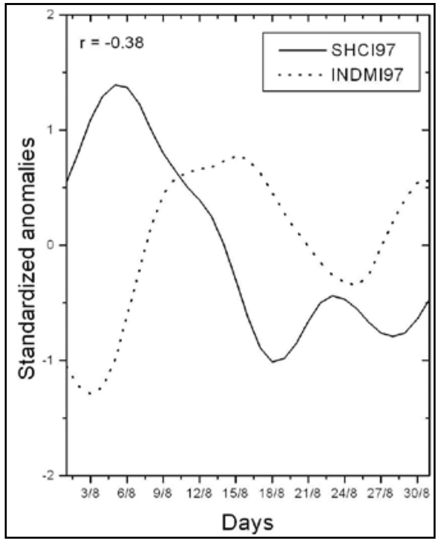

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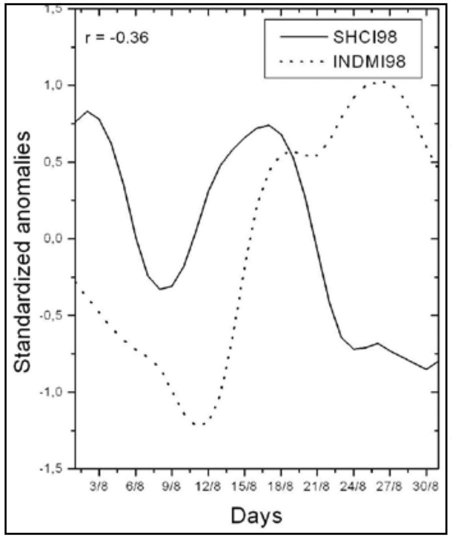
In this section, we look further into the changes of atmospheric circulation system in relation to the rapid warming of the August 1998. We first examine the changes in the centres of the Indian monsoon and North Atlantic subtropical high in order to determine the significance of these systems, and also exhibit major changes in relation to the extreme warming. Figure 4(a, b) shows mean sea level pressure distribution pattern of the North Atlantic subtropical high pressure and Indian monsoon low pressure during August 1997 and August 1998 respectively. The distribution pattern shows a weakening and northward drift of the high center in August 1998.



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While it exhibits strong and southward drift in August 1997. On the other side, in August 1998 the Indian monsoon low pressure system shows up a generally lower central pressure (i.e. deepening) (Figure 4b). Indian monsoon low pressure is weakened during August 1997 as presented in Figure 4a. The Indian monsoon low pressure exhibits undergoing a southward shift through August 1998 (Figure 4b). While it is illustrated undergoing a northward shift through the most of August 1997 (Figure 4a). Figures 4(a, b) suggests that a major change of atmospheric circulation systems occurred at roughly the same time in 1997, 1998. These results are in agreement with Tanaka *et al*. (2004). Relationship between surface temperature over Egypt and each of atmospheric circulation system, Subtropical high pressure center index (SHCI) and Indian monsoon low pressure centre index (INDMI) are presented in Figure 5. The duality of the relationship between SHCI and INDMI is shown in Figure 5. A strong and high significant negative relationship (r = -0.55) between INDMI and surface temperature over Egypt are found during August 1998 (Figure 5d). Whereas a weak and non significant positive relationship (r = 0.15) between them during August 1997 (Figure 5c) is found. Consequently in the period of extreme change (i.e. warming) the trough of Indian monsoon is deepened significantly. On the other side, the relationship between SHCI and surface temperature over Egypt is poor and non significant during August 1998 and it is high and significant during August 1997. Consequently, when INDMI is deepening and dominant over our region the surface temperature is increased and vise versa. Therefore the surface temperature over Egypt was lower in August 1997.

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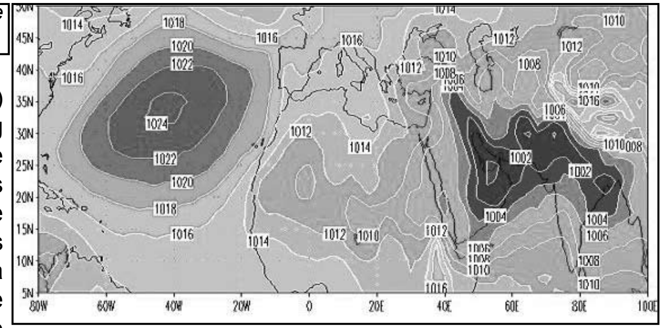
Figure 4. (a) Sea Level pressure - August 1997



Fu *et al*. (1999) found that, the warming period 1920s is due to the weakening of the westerlies and trade wind system. The Asian monsoon troughs deepened substantially on a situation generally favorable to the development of active monsoon.

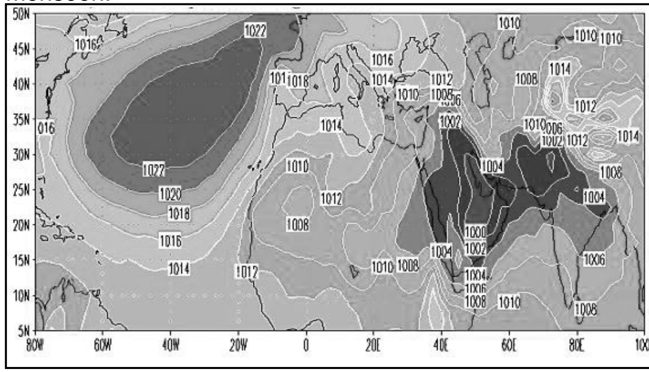


Figure 4. (b) Sea Level pressure - August 1998.

It is thought that the combination of these two features enhanced continental monsoons and implied lowered vertical wind shear over the oceans. It would tend to enhance the release of latent heat in the tropics, representing strengthened Hadley and Walker circulations. At least it may partly be responsible for greater aridity in subtropical land areas of both hemispheres during that period. The latter is also consistent with an expansion and/or strengthening of the subtropical high-pressure belt into the continents. 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).

Wind teleconnections

a) Hadley cell index pattern

The Hadley circulation has long been defined as a zonally symmetric meridional circulation with an ascending motion over the Intertropical Convergence Zone (ITCZ) and a descending motion over the subtropical high pressure belt (e.g. Trenberth *et al*., 2000). In the context of the general circulation, it is driven by the meridional differential heating in the global radiative process. The peak value occurs in early February and August. Perhaps this peak is not surprisingly as it is close to these times in the year when the annual cycle in surface temperature has peak (Trenberth, 1983).

Figure 6 (a, b) represents the relationship between surface temperature over Egypt and Hadley cell index. Inverse relationship between Hadley cell index and surface temperature are found in both two months of El Nino and La Nina year (r = -0.36 in August 1998 and r = -0.25 in August 1997). But it is more evident in La Nina Year, when it is statistically significant. In general, the Hadley circulation weakened in 1998 La Nina year (Figure 6c). This result is in agreement with Tanaka *et al*. (2004). Therefore the subsidence of the north branch of Hadley circulation is weakened and thus the subtropical high pressure also is weakened.

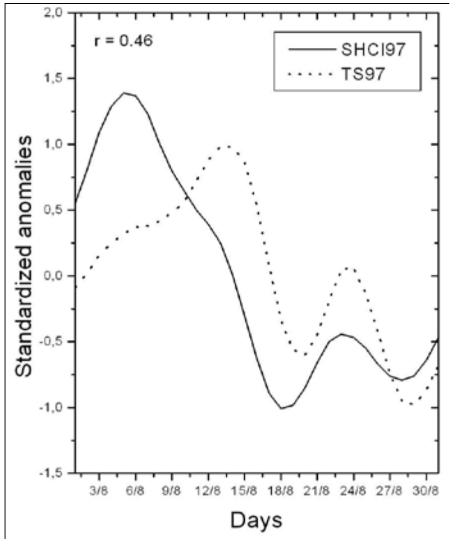
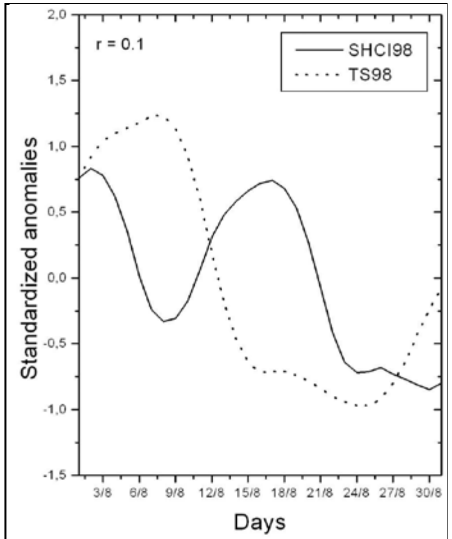


Figure 5. (a)



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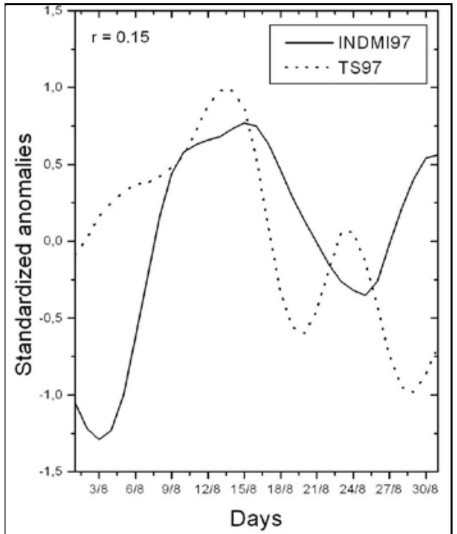


Figure 5. (c)

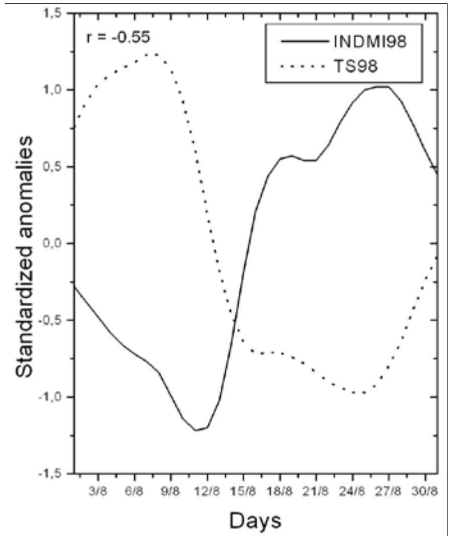


Figure 5. (d)

The intensity of the Hadley circulation measured by the intensity and location of the subtropical high has increased in the last two decades. And the recent trend is argued in connection with recent global warming (Tanaka *et al*., 2004). The result of Goswami *et al*. (1999) implies that the intensity of the Hadley circulation controls the intensity of the large scale monsoon. Intense of Hadley cell circulation leads to intense subtropical jet stream (Figure 7). Hadley cell index exhibits weakening during August 1998 and so the subtropical jet stream is found weak and vise versa during August 1997.

Significant positive correlation between un-weighted two time series of Hadley cell index and subtropical jet index is found during August 1998 (Figure 7b). Hou and Lindzen (1992) found that concentration in the thermal forcing within the Hadley cell can lead to a substantial increase in the strength of the Hadley circulation resulting in a much more intense subtropical jet.

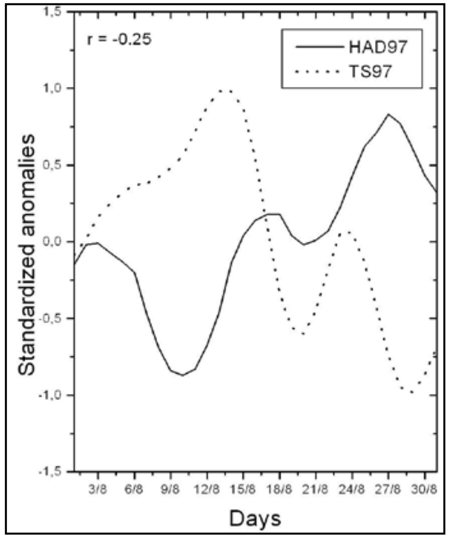


Figure 6. (a)

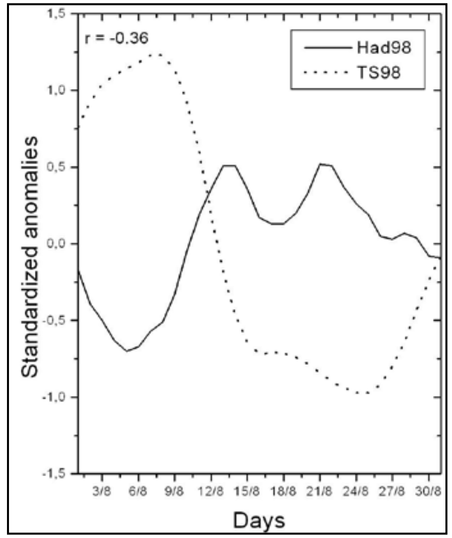


Figure 6. (b)

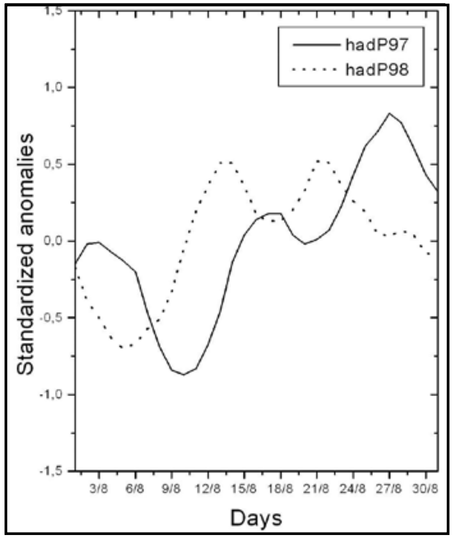


Figure 6. (c)

b) Subtropical jet stream index pattern

It is plausible that a connection may exist between acceleration of the subtropical jet by the Hadley cell and the eddy-induced heat transport outside the tropics (Hou, 1998). Black and Dole (1993) showed that modest zonal variations near the subtropical jet lead to relatively strong modulations in the amplitude of the stationary wave field in the mid-latitude troposphere.

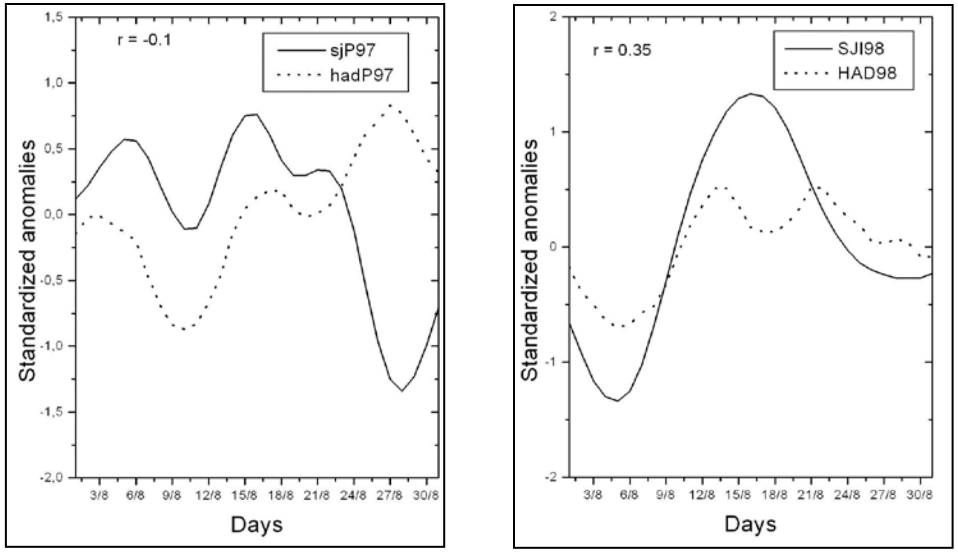
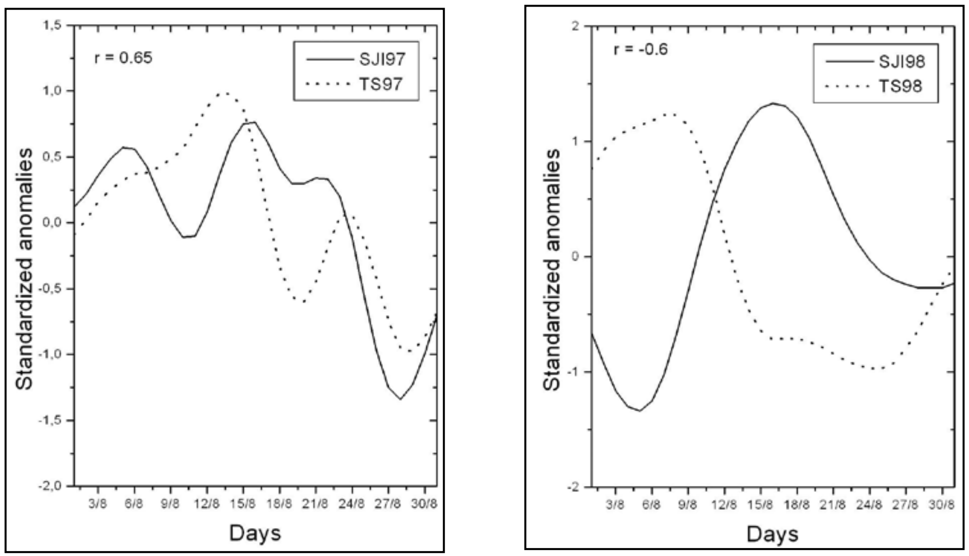


Figure 7. (a and b)

Relationship between surface temperature pattern over Egypt and subtropical jet stream index pattern (SJI) is shown in Figure 8 (a, b). Inverse relationship (*r* = -0.6) between surface temperature pattern and SJI pattern during August 1998 is shown in Figure 8b. While it is illustrated positive relationship (*r* = 0.65) between SJI and surface temperature pattern during August 1997 as shown in Figure 8a. Both relationships are statistically high significant. The inverse relationship between SJI pattern and surface temperature pattern may be related to the effect of the zonal index on the SJI.

Figure 8. (a and b)



The relationship between SIJ pattern and ZI pattern is positive in August 1998 (*r* = 0.45) and vise versa in August 1997 (*r* = -0.56) (Figure 9a, b). Lee and Feldstein (1996) noticed that the *Zi* is associated with latitudinal shifts of the westerly jet. The strength of subtropical jet stream is shifted northward (southward) during August 1998 (August 1997) as shown in Figure 10(a, b). Also, the subtropical jet stream is weakened and linked with polar jet stream during August 1998 as seen in Figure 10b. Xoplaki *et al*. (2003) found that high index, low index type lead to a weakened, intensified zonal flow to the Mediterranean respectively and northward, southward shift of the subtropical jet stream respectively. ZI type high and/ or low is affected on zonal mean of subtropical jet stream as shown in Figure 9 (a, b). Significant positive, negative relationship between ZI and SJI during August 1998, August 1997 respectively are found (Figure 9a, b). Thus high index in August 1998 leads to drift northward of SJI in agreement with Xoplaki *et al*. (2003). Ko and Vincent (1996) showed that the subtropical jet stream across the south Pacific is much stronger, weaker in the (1986-1987), (1988-1989) periods respectively of the ENSO cycle. Furthermore, the jet stream over southern Australia is the weakest during El Nino year.

CONCLUSION

In summarizing the results from the above sections, a schematic picture is proposed of some of the principal mechanisms associated with the extreme warming during August 1998. There is statistically high significant confidence level between ZI and surface temperature across Egypt during both months of August 1997 and August 1998 respectively. Inverse relationship between pattern of ZI and pattern of surface temperature over Egypt is found.

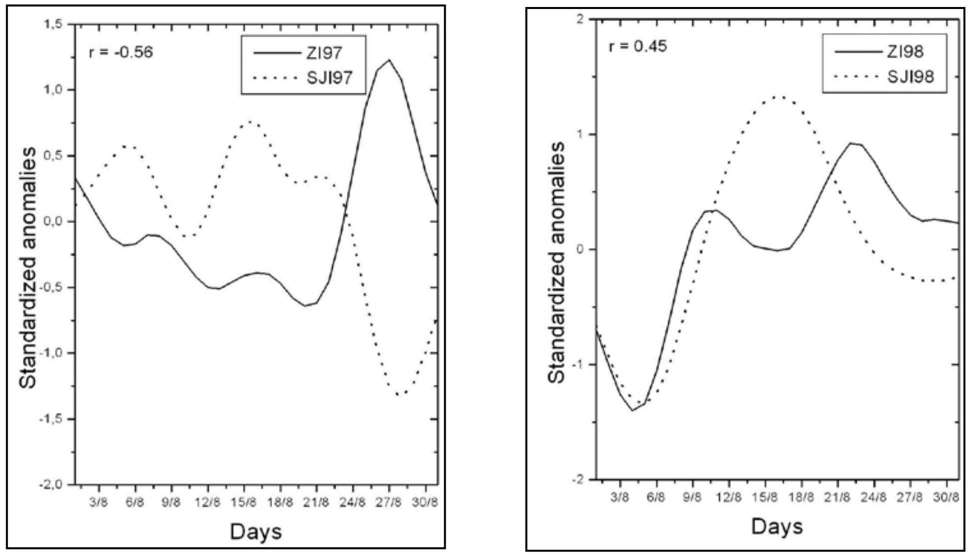


Figure 9. (a and b)

Concerning atmospheric circulation system, the correlations with Indian monsoon and surface temperature over Egypt show different structures. The August 1998 exhibits strong negative correlation, whereas the weaker positive correlation is simultaneous in August 1997. Hence in the period of extreme warming (August 1998) the trough of Indian monsoon is deepened significantly.

The surface temperature is associated with subtropical high pressure center index pattern (SHCI). This relationship between surface temperature and SHCI suggests that the change of the sea level pressure of the SHCI induced the surface temperature change. During August 1997, the SHCI is intensified and highly affects surface temperature over Egypt and in turn supported the area by cold air. During August 1998 the situation is reversed. There is a clear duality between the Indian monsoon low pressure index (INDMI) and SHCI.

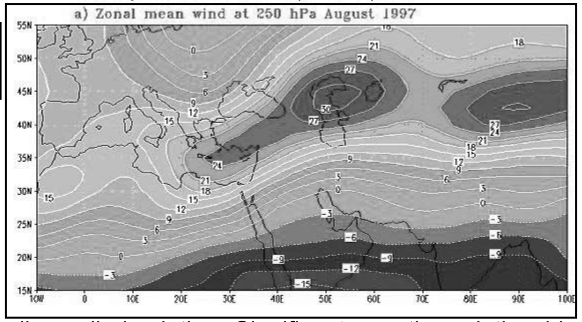


Figure 10. (a) Zonal mean wind at 250 hPa August 1997.

The mid-latitude temperature response to a subtropical Hadley circulation anomaly is dominated by enhanced power in low-frequency planetary waves (Hou, 1998). The increase in temperature in Egypt may be associated with the weakness in Hadley cell circulation. Significant negative relationship between Hadley cell index and surface temperature is found during August 1998. Hadley circulation affects North Atlantic subtropical high pressure and the recent trend is argued in connection with recent global warming. During extreme warming of surface temperature the intensity of Hadley cell circulation can lead to intensify the subtropical jet stream.

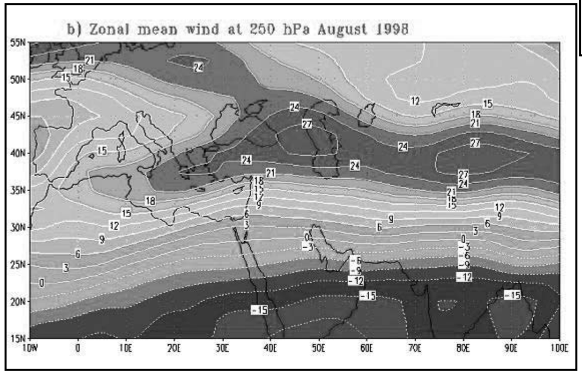


Figure 10. (b) Zonal mean wind at 250 hPa August 1998.

Extreme warming may be related to the change of location and strength of the subtropical jet stream. High significant negative, positive correlations between subtropical jet stream index and surface temperature pattern over Egypt during August 1998, August 1997) are found. The anti-correlation between surface temperature and subtropical jet stream index may be related to the effect of the ZIon the subtropical jet stream. The strength of subtropical jet stream is shifted to the northward and weakened during August 1998, while it is shifted to the southward and intensified during August 1997.

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