Arab J Geosci (2016) 9: 476
DOI 10.1007/s12517-016-2497-4

ORIGINAL PAPER

Study of the relationship between African ITCZ variability and an extreme heat wave on Egypt in summer 2015

Y. Y. Hafez[1] **· M. Almazroui**[1]

Received: 4 November 2015 / Accepted: 25 April 2016 / Published online: 23 May 2016

Abstract An extreme heat wave hit Egypt in summer 2015. Abnormal hot weather conditions existed over Egypt for the entire summer season. The present paper investigates the relationship between the intertropical convergence zone (ITCZ) over Africa and a scorching heat wave that existed over Egypt in summer 2015. The National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data of mean surface air temperature for the domain of Egypt for the summer season from 1948 to 2015 were used in this study. In addition, data of the daily maximum and daily minimum temperature used for the summer season of the year 2015 were also used. Time cross-section analysis of the daily operational data of geopotential height at level 500 hPa over Egypt from 1 June to 31 August 2015 was done. Moreover, the African ITCZ, both the western and the eastern ITCZ, data for summer of 2015 were used for the said period. The time series, time cross-section, anomaly, and correlation coefficient techniques were used to analyze the datasets. The results revealed that a new climate change record of heat wave over Egypt existed in summer 2015. Moreover, there is an outstanding significant positive correlation between the abrupt shift of African ITCZ position and heat wave occurrence over Egypt in summer 2015. In particular, the southerly movement of the eastern African ITCZ controls the weather over Egypt and led to the extreme heat wave in summer 2015.

Keywords Heat wave · Surface air temperature · Geopotential height · African ITCZ · Egypt

✉ Y. Y. Hafez
ysalam@kau.edu.sa; mansour@kau.edu.sa

[1] Department of Meteorology, Center of Excellence for Climate Change Research, King Abdulaziz University, P.O. Box 80234, Jeddah 21589, Saudi Arabia

Introduction

The Middle East, including Egypt, was hit by a heat wave in late July of summer 2015. Egyptian summers are usually hot, but temperatures in the summer season of 2015 soared to an extreme high record of temperature (46 °C) in the south of the country due to which there was an unusual hot weather in that region. The heat wave maximized in mid-August over Egypt and the temperature reached a staggering value. The weather remained hot in the north of Egypt and was very hot in many parts of the country especially in Upper Egypt. The Egyptian Meteorological Authority and health ministry advised older people and children to avoid exposure to direct sunlight. According to the Egyptian Ministry of Health, at least 100 people died during the summer and most of them were elderly (Bloomberg 2015). Similarly, Central and Eastern Europe were in the grips of a record-breaking heat wave, with countries such as Germany, Czech Republic, and Poland with record-breaking temperature for summer 2015. Recently, there have been several studies in scientific literatures of heat waves and its impacts on several sectors and fields in distinct regions over the globe (e.g., Önol and Fredrick 2009; Garc'ia-Herrera et al. 2010; Kuglitsch et al. 2010; Stefanon et al. 2012; Unal et al. 2012; Lelieveld et al. 2012; Lelieveld et al. 2013; Lupo et al. 2014; Katsafados et al. 2014; Fontana et al. 2015;

Tanarhte et al. 2015; Keggenhoff et al. 2015a, b and Zittis et al. 2015). In summer 2015, the United Kingdom, France, Belgium, Netherlands, Luxembourg, Italy, Poland, Czech Republic, Hungary, Germany, and western parts of Russia were affected by a heat wave. Other boundary forcing also contributed to the 2003 European heat wave, including anomalous sea surface temperatures (SSTs) (Feudale and Shukla 2011). The 2003 European heat wave led to the hottest summer on record in Europe since 1540. This heat wave led to health crises in several European countries and, combined with drought, created a crop shortfall in parts of southern Europe. More than 70,000 people died in Europe (Robine et al. 2008). Stott et al. (Stott et al. 2004a, b) highlighted in a study the human contributions to the European heat wave of 2003. The 2006 European heat wave was a period of exceptionally hot weather that arrived at the end of June 2006 in certain European countries. Several records were broken. In Netherlands, Belgium, Germany, Ireland, and the United Kingdom, July 2006 was the warmest month since official measurements began. Moreover, to that, "mega heatwaves" such as the 2003 and 2010 events likely broke the 500-year-long seasonal temperature records over approximately 50 % of Europe (Barriopedro et al. 2011). Dole et al. (2011) studied the 2010 northern hemisphere summer. They found that the intense 2010 Russian heat wave was mainly due to natural internal atmospheric variability. Barriopedro et al. (Barriopedro et al. 2011) showed that the hot summer of 2010 redrew the temperature record map of Europe. Recently, Europe suffered two widespread heat waves which existed during the summer seasons of years 2010 and 2015. Hafez (2012b) found that the heat wave over Eastern Europe during the summer of the year 2010 was controlled by blocking systems over the northern atmosphere and climatic indices in the North Atlantic Oscillation Index (NAO) and Sothern Oscillation Index (SOI). However, a heat wave is a prolonged period of excessively hot weather. The term heat wave was applied both to routine weather variations and to extraordinary spells of heat, which may occur only once a century. Frich et al. (Frich et al. 2002) explained that a heat wave occurs when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5 °C, the normal period being in 1961–1990. This definition is difficult to apply in tropical regions, and therefore, a more flexible indicator of heat waves was proposed (Trewin 2009; Zhang et al. 2011). However, severe heat waves have caused catastrophic crop failures, thousands of deaths from hyperthermia, and widespread power outages due to increased usage of air conditioning (Meehl et al. 2004). There are several scientific kinds of literature that challenge the abnormal extreme weather conditions (e.g., Hafez 2007, 2012b; Rosting and Kristjansson 2008). Identification, migration, oscillation, and influence of the intertropical convergence zone (ITCZ) in the atmospheric distinct abnormal weather conditions have been studied. The climate simulations, using models with different levels of complexity, indicated that the north-south position of the ITCZ responds to changes in interhemispheric temperature contrast. Several scientific literatures support this (e.g., Bates 1970; Pike 1971; Citeau et al. 1988b; Gadgil and Guruprasad 1990; Waliser 1992; Waliser and Somerville 1994; Hess et al. 1993; Philander et al. 1996; Kraus 1997; Sultan and Janicot 2000; Hafez 2012a, 2003; Broccoli et al. 2006; Raymond et al. 2006). The ITCZ is one of the most recognizable aspects of the global circulation that influences the atmospheric weather and causes extreme abnormal weather conditions. The ITCZ forms a zonally elongated band of cloud at low latitudes near the equator, where the northeasterly and southeasterly trade winds converge. The ITCZ characteristics and its weather and climate impacts has been studied (e.g., Maloney and Shaman 2008; Nicholson 2009; Suzuki 2011; Gaetani et al. 2011; Gaetani and Fontaine 2013; Scott 2013; Nicholson 2013; Doherty et al. 2014; Schneider et al. 2014 and Baumberg et al. 2015). Black et al. (2004) studied the heat wave over Europe which existed in the summer season of 2003. They found that over the east Atlantic, during May, the Azores anticyclone and west African ITCZ were both displaced to the north, while the extratropical storm track was concentrated further south than normal. Recently, Keggenhoff et al. (2015a, b) have studied the heat waves over Georgia in the summer season. They found an evidence of a large anticyclonic blocking pattern over the southern Ural Mountains, which attracts warm air masses from the southwest, enhances subsidence and surface heating, shifts the African ITCZ northward, and causes a northward shift of the subtropical jet. For Egypt, there is a lack of meteorological stations mainly in central and Upper Egypt. El Afandi (2014) evaluated the National Centers for Environmental Prediction (NCEP) reanalysis data of meteorological parameters (minimum temperature, maximum temperature, and mean surface temperature etc.) with ground meteorological measurements of 23 meteorological stations over Egypt. He found that it is acceptable to use the NCEP dataset in case of lack of measured meteorological parameters for most weather stations. The details of the 23 meteorological stations is available in El Afandi (2014). However, Fig. 1 shows the map of the available meteorological stations over Egypt (Mortensen et al. 2006). The goal of the present work is to uncover the relationship between African ITCZ position and existence of the Egyptian heat wave in summer 2015.

Data and methodology

Data

The National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis

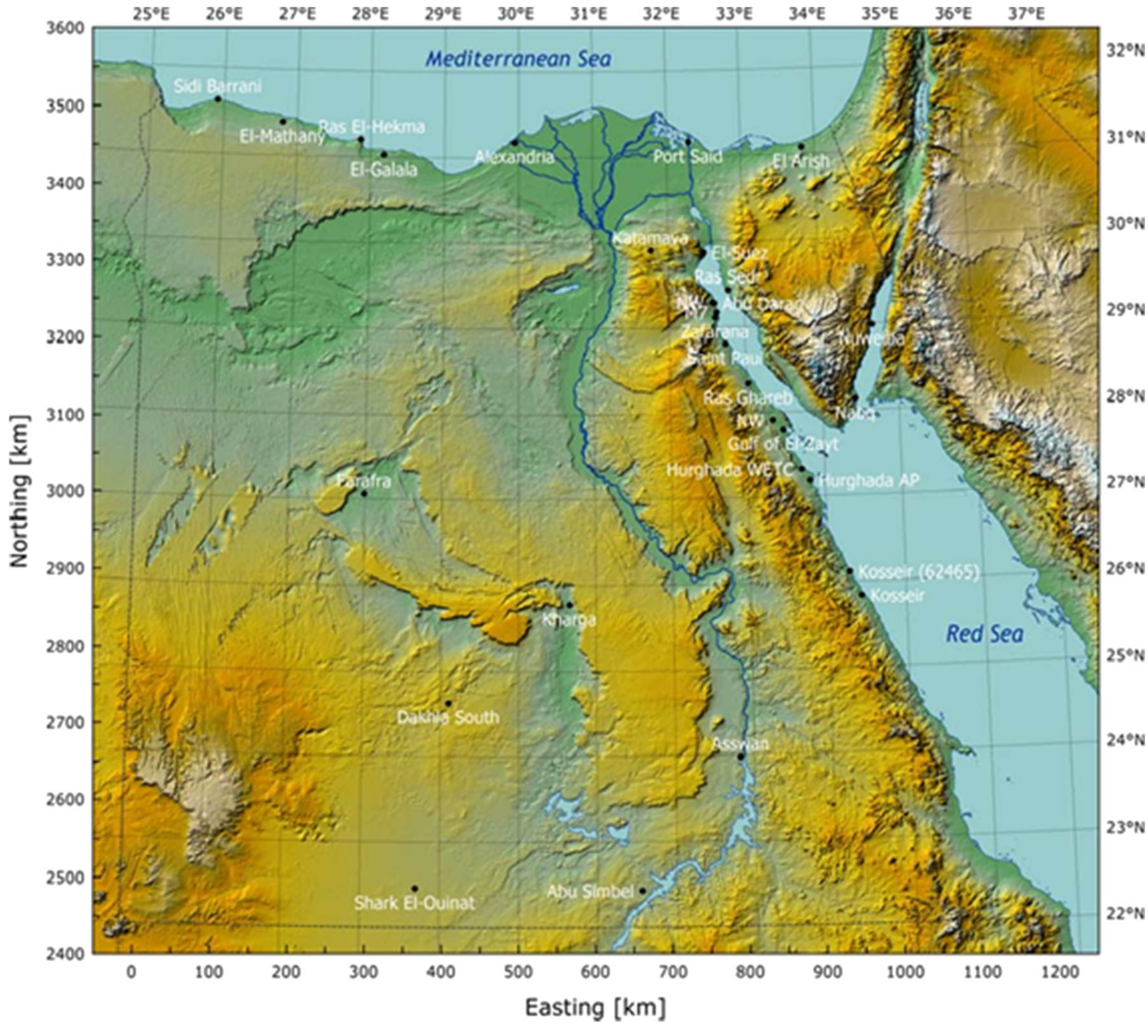


Fig. 1 Map of the study area of location [21° N–32° N, 24° E–37° E] including the available meteorological stations (Source: Mortensen et al. 2006)

project is using a state-of-the-art analysis/forecast system to perform data assimilation, within the resolution of 2.5° × 2.5° lat/long grid, using past data from 1948 to 2015. The local ingestion process took only the 0Z, 6Z, 12Z, and 18Z forecasted values, and thus only those were used to make the daily time series and monthly means here. By using this data, climate/weather statistics and dynamic processes were examined. For the present study, the NCEP/NCAR reanalysis monthly data of surface air temperature and geopotential height at 500 hPa for Egypt through the period of 1948–2015 for the summer season and its months (June, July, and August) were used. In addition, a composite daily data of surface air temperature, maximum temperature, minimum temperature, geopotential height at 500 hPa, etc., over Egypt for the summer season of 2015 through the period from 1 June to 31 August is used. The data is a 2.5° × 2.5° degree lat/long gridded resolution. The range used for this data is 22.5 to 32.5° latitude and 25 to 37.5° longitude north. It is a 5 × 6 grid mesh of meteorological elements for the area of study. Data was provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA and Kalnay et al. 1996. Another type of data used in the present study was the daily operational data for geopotential height at 500 hPa. The time cross-section analysis of the daily operational data of geopotential height at 500 hPa over Egypt from 1 June to 31 August 2015 was done. However, NCEP data set domain considered in the present work are extended to 21° N–32° N, 24° E–37° E for Egypt (see Fig. 1). Moreover, the African ITCZ, western, and eastern ITCZ data for the summer season of 2015 was used. The western African ITCZ's (10° W–10° E) mean position data for the summer months June, July, and August 2015 were used. Moreover, to that, the eastern African ITCZ [20° E–35° E] mean position data for that period are used. The movement of the African ITCZ over Africa was monitored by plotting the daily location of the surface 15 °C dew point temperature at 1200 UTC for every 5° of longitude (Ilesanmi 1971). Over Africa, a mean position for each 10-day period was calculated for the area from 15° W longitude to 35° E longitude. However, African climatic mean position of ITCZ data was taken for the period of 1979–2001. This ITCZ dataset was obtained from the Climate Prediction Centre (http://www.cpc.ncep.noaa.gov/products/monitoring_data/).

Methodology

A. Anomaly methodology

The anomaly method is used to analyze the meteorological elements in the present study. The anomaly in the mean meteorological element, e.g., daily surface air temperature, is (A') for each grid point in the domain of Egypt. This anomaly is calculated as the difference between the mean of daily surface air temperature (A) and its climatic mean value ($\bar{A}$) for each grid point. The climatic mean value of the surface air temperature is taken through the periods of 1981–2010.

B. In addition, the time series analysis and the linear correlation method according to Pearson correlation method, Kendall and Stuart (1973) are used. However, the term correlation coefficient (r) is a measure of the linear correlation between two variables. When a change in the value of one item involves a change in another item, the values of the two items cannot combine in every random way. If the relationship between the two items is strictly proportionate, then the correlation is said to be perfect. If the proportion is direct, r is +1; if the proportion is inversed, r is −1. If there is no correlation, r is 0. The trends for all indices were calculated using a simple least-squares linear regression. Statistical significance was determined using the Kendall-tau test. A trend was deemed “statistically significant” if it has at least 90 % significance.

C. Definition of a heat wave

For the purpose of the present study, a heat wave was defined according to the daily composite anomaly of mean surface air temperature and successive persistence days of this anomaly. A heat wave occurred when the daily composite mean of surface air temperature anomaly becomes more than or equal to +3 °C and persist for five successive days or more over the area of study (Ballester et al. 2011).

D. Climate change indicators

To determine the new record of climate change that exists in the summer season over Egypt in the year of 2015, we used the climate change indicators, the percentile-based temperature indices. The temperature percentile-based indices are the lower deciles (90th decile) of daily minimum and maximum temperatures. These are calculated each day through episodes of heat wave over Egypt in the period of 30 July 2015 to 23 August 2015.The two indices are the occurrence of warm nights (TN90p) and the occurrence of warm days (TX90p) (Zhang et al. 2005). On the other hand, TN90p is the percentage of days when TN >90th percentile for the base period (1981–2010).

Results

The variability of mean surface air temperature over Egypt during summer season of periods 1948–2015

The NCEP/NCAR reanalysis monthly data of surface air temperature for Egypt through the period (1948–2015) for the summer season and its months (June, July, and August) were used. These data were analyzed by the time series method. The results revealed the following:

1. For the summer season through the period of 1948–2015, the mean surface air temperature over Egypt varied from year to year. The lowest mean surface temperature is 27.2 °C for the year of 1964.The highest mean surface air temperature is 29.9 °C for the 2 years, that is, 2010 and 2012. The climatological mean surface air temperature of the summer season through this period is 28.9 °C. Mean surface air temperature of summer 2015 is 29.5 °C. The trend of the summer season temperature through this period is a positive linear trend with slope (+0.014 °C year^{-1}) as shown in Fig. 2a. Analysis of decadal trend of surface air temperature in summer season shows that there is a positive trend of slope (+0.015 °C decade^{-1}).
2. For the month of June of the period of 1948–2015, the mean surface air temperature over Egypt varied dramatically from year to year. The lowest value is 26.3 °C in 1963. Meanwhile, the highest value is 29.6 °C for the year of 1995. The climatological mean surface air temperature is 28.3 °C. The year of 2015 has a mean surface air temperature of 27.4 °C. The trend of the mean surface air temperature is a positive trend of slope (+0.008 °C year^{-1}) as can clearly be seen from Fig. 2b. Analysis of decadal trend of surface air temperature in June shows that there is a positive trend of slope (+0.098 °C decade^{-1}).
3. For the month of July of the period from 1948 to 2015, the mean surface air temperature over Egypt varied through it from year to year with a positive linear trend of slope (+0.016 °C year^{-1}). The lowest value is 27.4 °C in 1964. Moreover, the highest value is 30.9 °C for the year 2002. The climatological mean of surface air temperature is 29.2 °C. The year 2015 had a mean surface air temperature of 29.4 °C as illustrated in Fig. 2c. Analysis of decadal

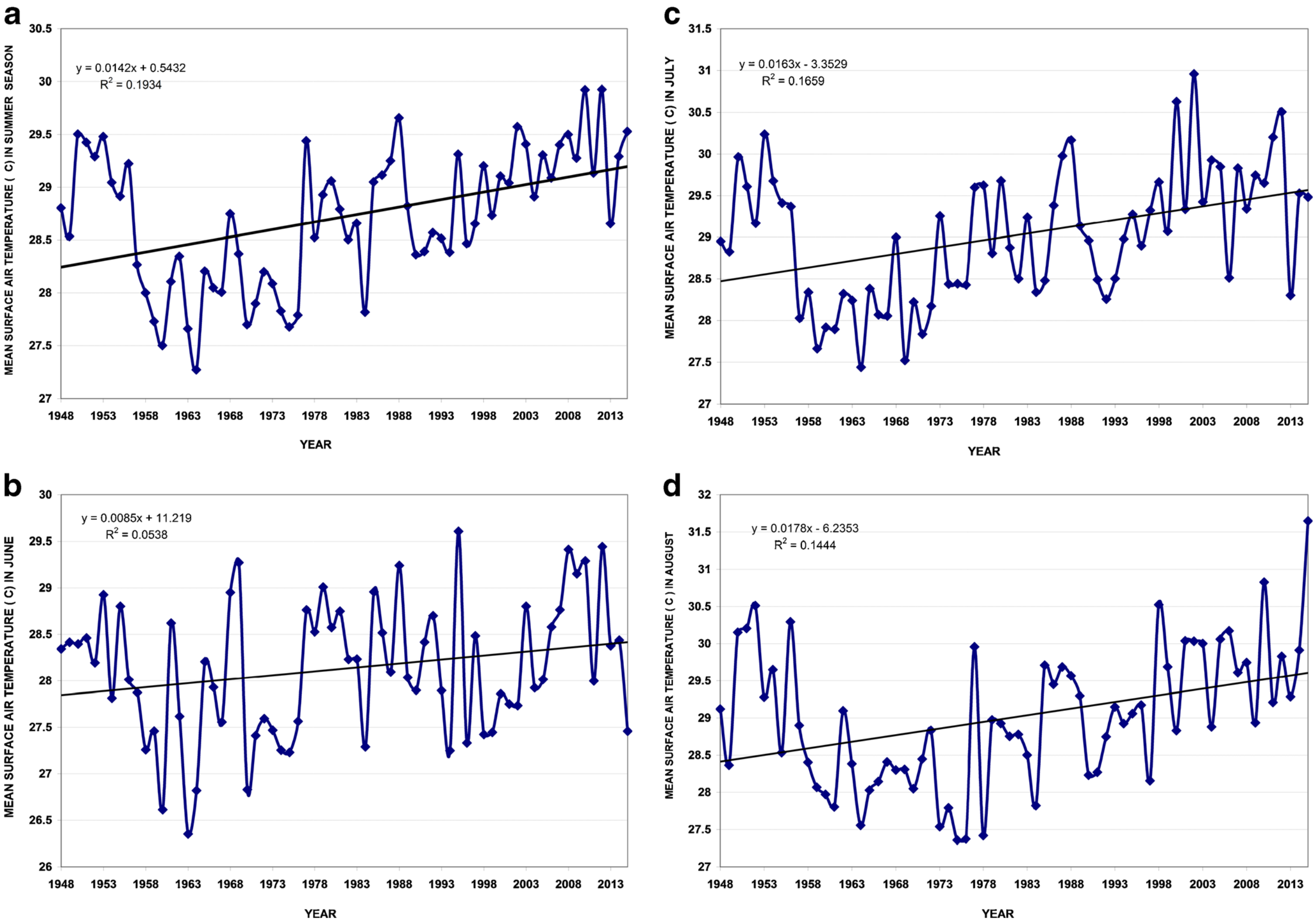


Fig. 2 The variability of mean surface air temperature and its linear trend over Egypt for **a** summer season, **b** June, **c** July, and **d** August months through the period of 1948–2015. The source of this data is the reanalysis NCEP/NCAR data

trend of surface air temperature in the month of July shows that there is a positive trend of slope (+0.017 °C decade^{-1}).

4. For the month of August (1948–2015), the mean surface air temperature over Egypt varied sharply from year to year with a clear positive linear trend with slope (+0.017 °C year^{-1}). The lowest value of mean temperature is 27.3 °C for 1975. Meanwhile, the highest value is 31.6 °C for the year 2015. The climatological mean surface air temperature is 29.2 °C, as can be clearly seen from Fig. 2d. Analysis of decadal trend of surface air temperature in the month of August shows that there is a positive trend of slope (+0.183 °C decade^{-1}). However, the certainty of significance of these trends is more than 90 %.

5. Table 1 shows the mean surface air temperature, climatological mean values, and anomalies of temperature over Egypt through the summer season for the period of 1948–2015. It is found that the monthly mean surface air temperature over Egypt has a negative anomaly of −0.8 °C, less than its normal value (28.3 °C) through June of 2015. Meanwhile, the two months of July and August for the year 2015 have a positive temperature anomaly of +0.2 and +2.3 °C, respectively. In addition, the summer season of 2015 has a positive anomaly of more than +0.5 °C.

Table 1 The climatic mean of temperature, mean surface air temperature and anomaly of temperature over Egypt for summer months and summer season of the year 2015 through the period from 1 June2015 to 31 August 2015).

Month/summer season	Average of surface air temperature (°C) in 2015	Climatic mean of surface air temperature (°C) (1981–2010)	Temperature anomaly (°C)
June	27.46	28.30	−0.84
July	29.48	29.29	+0.19
August	31.64	29.28	+2.36
Summer season	29.53	28.96	+0.57

The variability of mean geopotential height at 500 hpa over Egypt during the summer season of period of 1948–2015

The NCEP/NCAR reanalysis monthly data of geopotential height at 500 hPa for Egypt through the period of 1948–2015 for the summer season and its months (June, July, and August) are used. This data was analyzed by the time series method. The results revealed the following:

1. For the summer season through the period of 1948–2015, the mean geopotential height over Egypt varied from year to year and tended to increase. The lowest mean geopotential height is 5844 m for the year of 1964.The highest mean geopotential height is 5898 m for the year of 2010. The climatological geopotential height of the summer season through this period is 5882 m. The year of 2015 has a mean geopotential height of 5893 m. The trend of summer geopotential height through this period is a positive linear trend with slope (+0.527 m year^{-1}) as shown in Fig. 3a. Analysis of decadal trend of geopotential height in the summer season shows that there is a positive trend of slope (+5.33m decade^{-1}).
2. For the month of June (1948–2015), the mean geopotential height over Egypt varied from year to year. The lowest value is 5824 m in 1964. Meanwhile, the highest value is 5889 for the year of 1995. The climatological mean geopotential height is 5873 m. The year of 2015 has a mean geopotential height of 5874 m. The trend of the mean geopotential height is a positive trend of slope (+0.421 m year^{-1}) as can be clearly seen from Fig. 3b. Analysis of decadal trend of geopotential height in June shows that there is a positive trend of slope (+4.33 m decade^{-1}).
3. For the month of July (1948–2015), the mean geopotential height over Egypt varied through it from year to year with a positive linear trend of slope (+0.528 m year^{-1}). The lowest value is 5840 m in 1959. Moreover, the highest value is 5900 m for the year 2010. The climatological mean of geopotential height is 5883 m. The year 2015 had a mean geopotential height of 5890 m as illustrated in Fig. 3c. Analysis of decadal trend of geopotential height in July shows that there is a positive trend of slope (+5.39 m decade^{-1}).
4. For the month of August (1948–2015), the mean geopotential height over Egypt varied sharply from year to year with a clear positive linear trend with slope

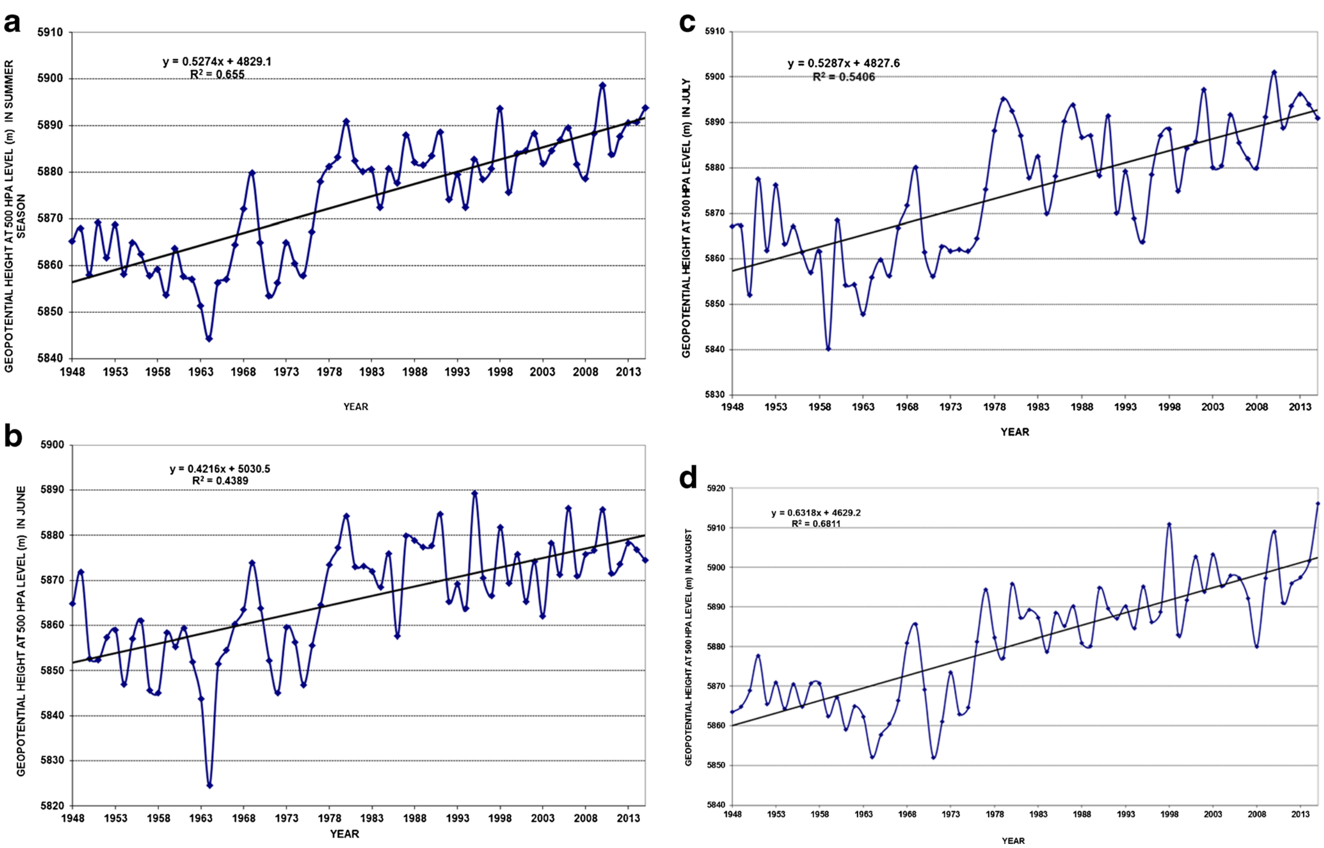


Fig. 3 The variability of mean geopotential height (m) at level 500 hPa and its linear trend over Egypt for **a** summer season, **b** June, **c** July and **d** August months through the period of 1948–2015. The source of this data is the reanalysis NCEP/NCAR data

($+0.631$ m year^{-1}). The lowest value of mean geopotential height is 5851 m for 1971. Meanwhile, the highest value is 5916 m for the year 2015, as can be clearly seen from Fig. 3d. The climatological mean geopotential height is 5891 m. Analysis of decadal trend of geopotential height in August shows that there is a positive trend of slope ($+6.26$ m decade^{-1}). However, the certainty of significance of these trends is more than 90 %.

The variability of daily mean surface air temperature over Egypt during the summer season of 2015

The daily NCEP/NCAR data of the gridded 2.5° × 2.5° lat./long. of mean surface air temperature of the domain of Egypt through the period from 1 June to 31 August 2015 has been used in the present study. The distribution of daily mean surface air temperature over Egypt through that period was analyzed. Time cross-section and anomaly methods processed this data set. The results revealed the following:

1- Over Egypt, for the month of June of 2015, daily mean surface air temperature is less than its normal values. There are non-successive 6 days that have a temperature above its normal values. There are only 2 days that has the positive temperature anomaly reached +5 °C, as can be clearly seen in Fig. 4.

2- Through the first 10 days of July 2015, the temperature is less than its normal values over Egypt. After that (from 15 to 31 July), the temperature becomes more than its normal values with positive anomaly reaching +3.5 °C, as shown in Fig. 4.

3- For the month of August (from 1 to 24 August), the mean surface air temperature recorded an extreme positive anomaly which reached its maximum value of +7 °C on 10 August, as illustrated in Fig. 4.

4- Since 24 August, the temperature becomes around its normal value.

5- On 10 August, a maximum mean surface air temperature (46 °C) through summer of 2015 with about +7 °C more than its normal value was recorded, as can be seen in Fig. 4.

6- According to the definition of a heat wave applied, it becomes clear that a heat wave with 25 days of duration existed over Egypt through the period from 30 July to 23 August 2015.

Study of the upper air stability condition over Egypt in summer 2015

Here, we are using the operational data of geopotential height parameter at 500 hPa to indicate the stability condition over Egypt on the summer months for the year 2015. Analysis of time latitudinal and longitudinal cross-section analysis of the daily mean geopotential height anomaly shows the following:

1. From the latitudinal cross-section analysis of geopotential height parameter at 500 hPa, it is clear that in June 2015, all of Egypt has a positive geopotential height from 6 to 10 June, after that, it becomes negative anomaly through all this month. From 1 to 11 July, the anomalies became positive. The anomaly becomes less than its normal value

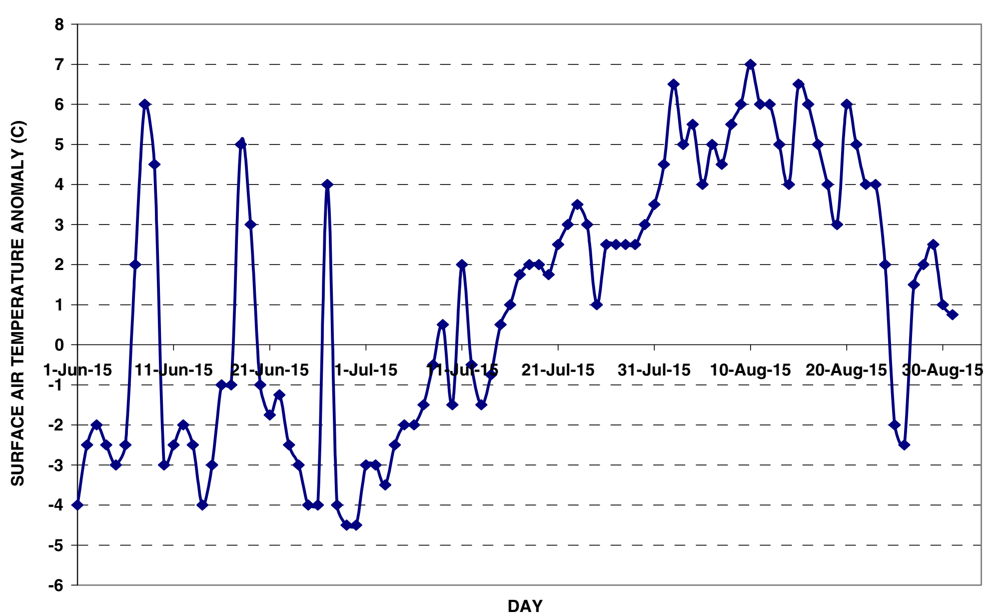


Fig. 4 The daily variation of mean surface air temperature (°C) over Egypt through the months June, July, and August of summer 2015. The source of this daily data is the repressing of the stations data over Egypt (gridded 2.5° latitude and longitude of operational data)

through the period of 12 July to 21 July. The period of 22–26 July has a positive anomaly. After that, it is less than its normal value until the end of July. For August, the positive anomaly recorded extreme values reached its maximum value (+50 m) through the period from 8 to 12 August, as can be clearly seen in Fig. 5a.

2. From the longitudinal cross-section analysis of geopotential height parameter at 500 hPa, it is noticed that in June 2015, Egypt has a negative geopotential height for June. From 1 to 12 July and from 18 to 26 July, there is a positive anomaly sign. For the month of August, the anomaly becomes positive from 1 to 26. The positive anomaly is very high and reaches its maximum value (+60 m) through the period of 8–12 August, as shown in Fig. 5b.
3. In fact, the positive anomaly of geopotential height over Egypt causes the high pressure system stability conditions over the earth's surface and creates increasing of accumulated surface air temperature due to the lower temperature inversion.

Study of the variability of African ITCZ position in summer 2015

The movement of the ITCZ over Africa monitored by plotting the daily location of the surface 15 °C dew point temperature at 1200 UTC for every 5° longitude, (Ilesanmi 1971). Over the western and eastern parts of Africa, a mean position for each 10-day period was calculated for the area from 15° W longitude to 35° E longitude. The western Africa ITCZ position extended from 10° W to 10° E. Moreover, to that, the eastern Africa ITCZ includes longitudes from 20° E to 35° E. In the present study, the changes of African ITCZ variability through the period from 1 June 2015 to 31August 2015 were analyzed using the time series and anomaly methodologies. The result shows the following:

1. The location of the western African ITCZ has shifted to the northward direction rather than the normal position with a positive anomaly value for the period of study except on 11–20 June where it has a little shift southward of its normal

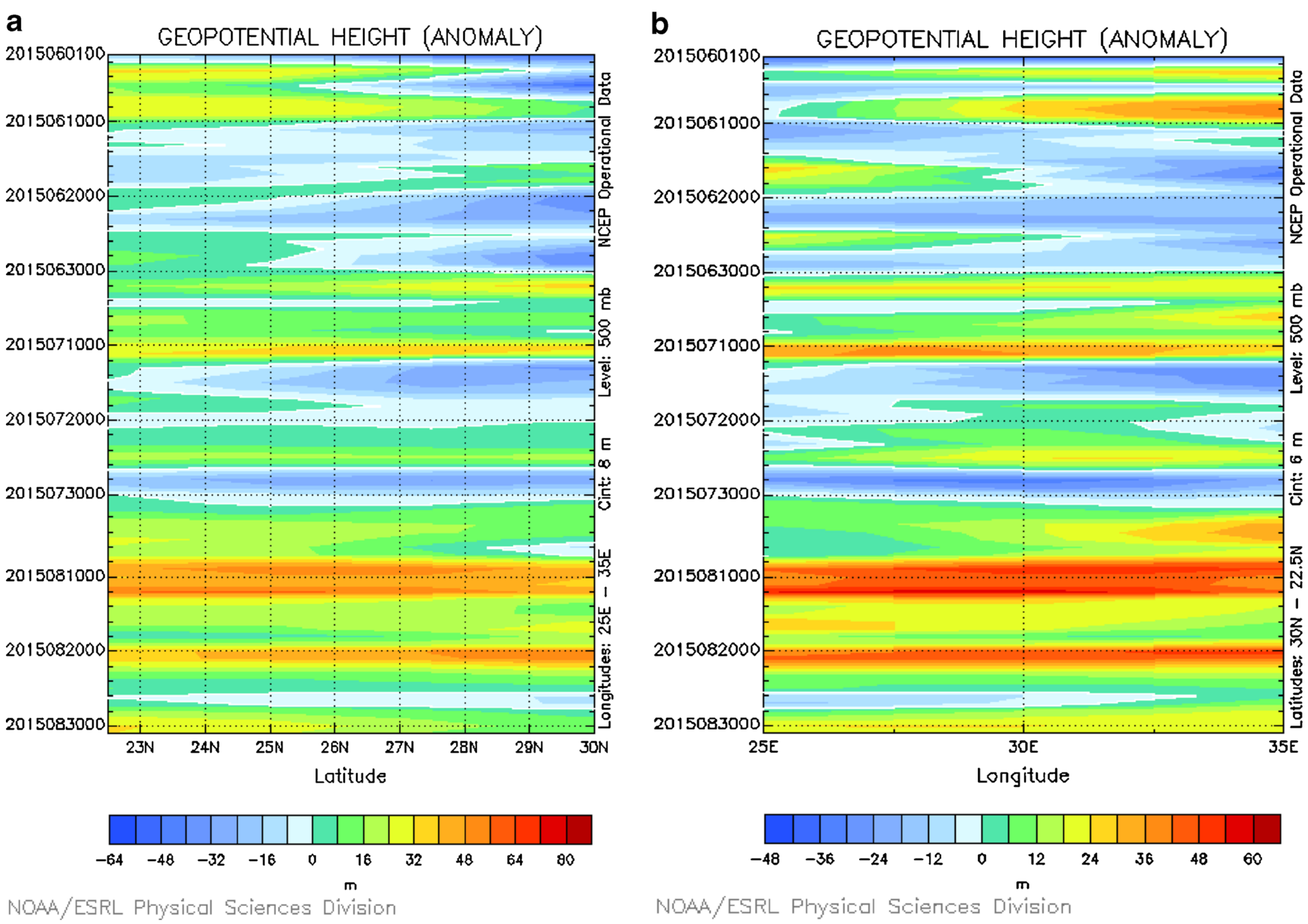


Fig. 5 The time cross-section analysis of daily mean of geopotential height anomaly (m) at level 500 hPa over Egypt through the summer months of 2015 (1 June 2015–31 August 2015). **a** For time–latitudinal cross-section and **b** for time–longitudinal section. The source of this data is the gridded 2.5° latitude and longitude of the observed operational meteorological stations data

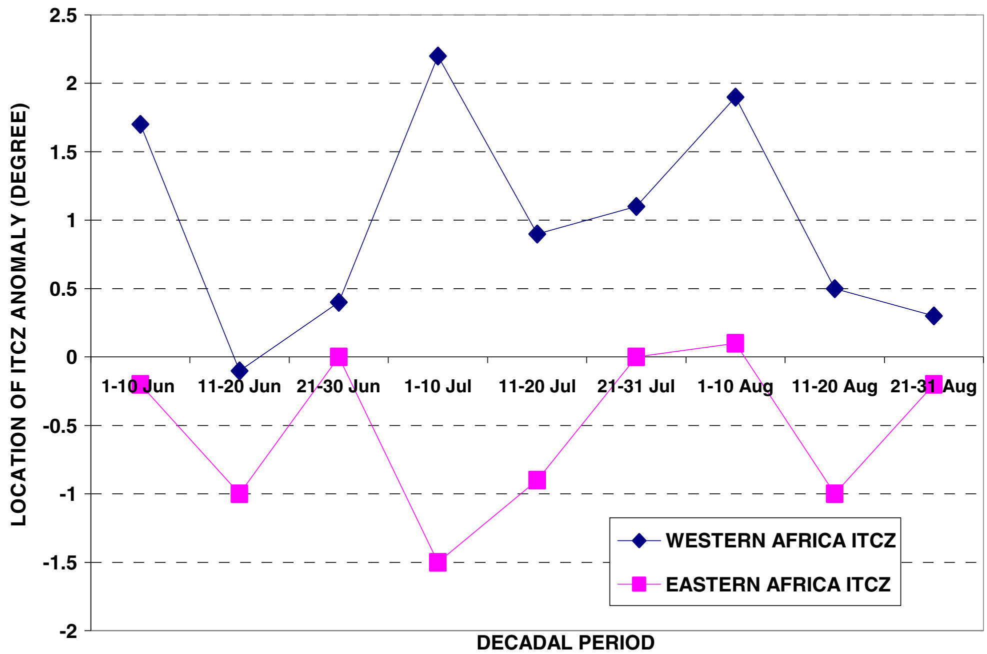


Fig. 6 The decadal variation of the western and eastern African ITCZ latitudinal position anomaly through the summer season of 2015 (1 June 2015–31 August 2015). The source of this data is the climate prediction center

position. The outstanding northward shift of western Africa ITCZ location existed through two intervals. The first one is on 1–10 July and the second one in 1–10 August for 2015, as can be clearly seen in Fig. 6 and Table 2.

2. In contrast, the eastern African ITCZ position becomes less than or equal to its normal value. It becomes more than its normal value through the interval (1–10) July with an anomaly value of −1.5° latitude. There existed two additional minima of −1.0° latitude negative anomaly to the south through two intervals: 11–20 June and 11–20 August during the summer of 2015, as illustrated in Fig. 6 and Table 2.
3. Analysis of the decade longitudinal distribution of the African ITCZ (15° W–35° E) position through the summer months for the year 2015 show that the position of Africa ITCZ varies dramatically from west of Africa to the east of Africa. It is moved north in the west and moved to the south in the east like a wave. The peak values are located over Greenwich and bottom values located at 25° E for all decadal of African ITCZ datasets as can be clearly seen in Fig. 7.

The relationship between African ITCZ and extreme heating over Egypt in summer 2015

Through this section, the longitudinal position of the African ITCZ and anomalies in mean air surface temperature over Egypt through months of summer 2015 was analyzed. These datasets have been correlated with each other to obtain the relationship between the African ITCZ variability and

Table 2 The 10-day average, climatic mean and anomaly of the western and eastern African ITCZ latitudinal position during summer months of 2015 through the period from 1 June 2015 to 31 August 2015

Time Period	Average of ITCZ position		Climatic mean of ITCZ position		Anomalies in ITCZ position	
	West Africa	East Africa	West Africa	East Africa	West Africa	East Africa
1–10 June	15.9	13.1	14.2	13.3	1.7	−0.2
11–20 June	15.8	13	15.9	14	−0.1	−1
21–30 June	16.5	14.1	16.1	14.1	0.4	0
1–10 July	19.2	14	17	15.5	2.2	−1.5
11–20 July	18.7	15.2	17.8	16.1	0.9	−0.9
21–31 July	20.3	16.6	19.2	16.6	1.1	0
1–10 August	21.4	17.5	19.5	17.4	1.9	0.1
11–20 August	20.2	16.3	19.7	17.3	0.5	−1
21–31 August	19.9	16.1	19.6	16.3	0.3	−0.2

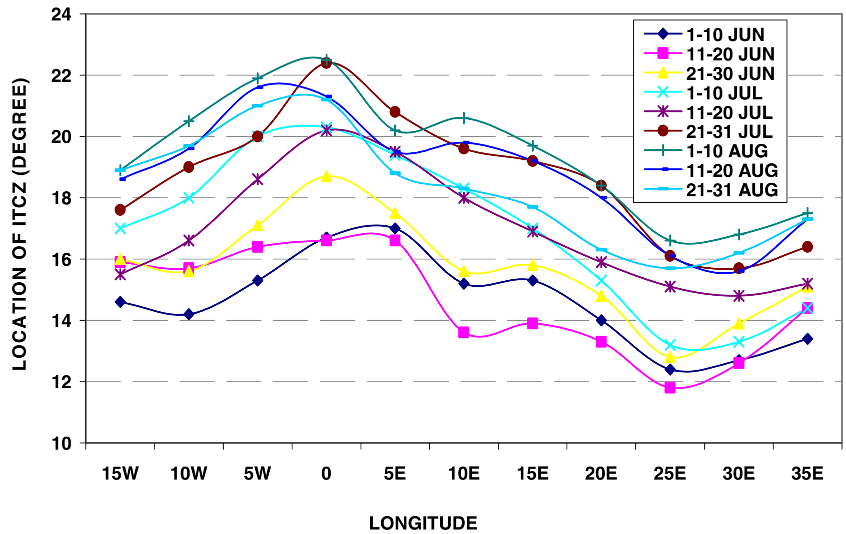


Fig. 7 The distribution of latitudinal variation of ITCZ position over Africa each 10 days through the summer months of 2015 through the period from 1 June 2015 to 31 August 2015. The source of this data is the climate prediction center

abnormal heating "heat wave" that existed over Egypt through the summer of 2015. The decadal position of the African ITCZ and anomaly in temperature over Egypt tabulated and analyzed by time series analysis and correlation coefficient technique. The results revealed that it is clear that the heat waves existed over Egypt occurred for the period starting from 11–20 July and remains until 21–31 August, intervals that have a positive temperature anomaly. The peak of the extreme heat wave over Egypt existed through the period from 1 August to 20 August with anomaly of mean surface air temperature of more than 5 °C. The correlation between the longitudinal position of the African ITCZ (15° W–35° W) and mean surface temperature anomaly over Egypt is positive correlation for all longitudes. The magnitude of correlation coefficient increases from the West African region to east African region and reach its maximum value (+ 0.87) for the longitudinal position of ITCZ at 25° E. The maximum correlation coefficient between the West African ITCZ and temperature anomaly over Egypt is +0.78 at 10° W. The correlation coefficient between the eastern African ITCZ and anomaly of mean surface air temperature over Egypt is more than +0.82 for the study period. Table 3 and Fig. 8 show clearly the outstanding significant relationship between the longitudinal variability of African ITCZ position and temperature anomaly over Egypt through the summer of 2015.

Study of the characteristics and weather condition through the period of a heat wave (30 July–23 August 2015) over Egypt

Study of the climate change indicators TX90p and TN90p

The NCEP/NCAR daily data of maximum temperature (T_{MAX}) and minimum temperature (T_{MIN}) over Egypt through the period from 30 July 2015 to 23 August 2015 has been analyzed. The results show the following:

1. The climate normal through the period of 1981–2010 for T_{MAX} is 36 °C and for T_{MIN} is 27 °C.
2. The climate normal through the summer of the year 2015 for T_{MAX} is 38 °C and for T_{MIN} is 29 °C.
3. The climate normal through the period 30 July 2015 to 23 August 2015 for T_{MAX} is 41 °C and for T_{MIN} is 32 °C
4. The days of extreme high temperature during the day (TX90) is 11.25 days for the heat wave duration (30 July–23 August 2015).
5. The days of extreme high temperature at night (TN90) is 11 days for the heat wave duration (30 July–23 August 2015).
6. The probability of days of extreme high temperature during the day (TX90p) is 45 %.
7. The probability of days of extreme high temperature at night (TN90p) is 44 %.

These results provide that the heat wave which existed over Egypt during 30 July to 23 August of summer 2015 is a new climate change heat wave record over Egypt.

Synoptic situation over Europe, Africa, and Middle East through the period of heat wave (30 July–23 August 2015)

The daily NCEP/NCAR data of the meteorological parameters (surface air temperature, sea level pressure, surface wind vector, 500 hPa temperature, 500 hpa geopotential height, and 500 hpa level wind vector) of the domain including Europe, Africa, and Middle East including Egypt [0–70 N] latitude and [15 W - 70 E] through the period 30 July to 23 August of the year of

Table 3 The correlation coefficient between the decadal longitudinal position of African ITCZ from 15° W to 35° E and mean surface air temperature anomaly over Egypt during summer months of the year 2015

The period (decade)	Longitudinal position of African ITCZ (degree)											Mean surface air Temperature anomaly over Egypt (°C)
	15W	10W	5W	0	5E	10E	15E	20E	25E	30E	35E	
01–10 June	14.6	14.2	15.3	16.7	17.0	15.2	15.3	14	12.4	12.7	13.4	−0.70
11–20 June	15.9	15.7	16.4	16.6	16.6	13.6	13.9	13.3	11.8	12.6	14.4	−0.90
21–30 June	16.0	15.6	17.1	18.7	17.5	15.6	15.8	14.8	12.8	13.9	15.1	−2.55
1–10 July	17.0	18.0	20.0	20.3	19.4	18.3	17.0	15.3	13.2	13.3	14.4	−1.90
11–20 July	15.5	16.6	18.6	20.2	19.5	18.0	16.9	15.9	15.1	14.8	15.2	0.82
21–31 July	17.6	19.0	20.0	22.4	20.8	19.6	19.2	18.4	16.1	15.7	16.4	2.68
1–10 August	18.9	20.5	21.9	22.5	20.2	20.6	19.7	18.4	16.6	16.8	17.5	5.35
11–20 August	18.6	19.6	21.6	21.3	19.5	19.8	19.2	18.0	16.1	15.6	17.3	5.15
21–31 August	18.9	19.7	21.0	21.2	18.8	18.3	17.7	16.3	15.7	16.2	17.3	1.65
Correlation coefficient	0.73	0.78	0.75	0.80	0.71	0.77	0.83	0.86	0.87	0.82	0.83	
Certainty %	96	99.1	98	99.3	98	99.4	99.6	99.8	99.9	99.1	99.6	
Corr. significance (*p* value) one-tail	0.0119	0.0061	0.0095	0.0146	0.0263	0.0066	0.0027	0.0015	0.0009	0.0029	0.0025	
Corr. significance (*p* value) two-tail	0.0238	0.0123	0.019	0.0291	0.0526	0.0132	0.0053	0.0029	0.0019	0.0059	0.0051	

The confidence level of these correlations is more than 95 %. *T* test and *p* values for significant correlations were calculated using Pearson correlation method

2015 has been used. Analysis of anomaly of these parameters revealed the following:

1. During the period from 30 July to 23 August 2015, the mean surface air temperature over Central Europe and Middle East have a positive anomaly values that reached +4 °C more than its normal values. Meanwhile, at upper air at 500 hPa level, Egypt and Middle East have a negative temperature anomaly that reached −2.5 °C. Europe has an upper air positive anomaly in temperature that reached +2.5 °C more than its normal values, as shown in Fig. 9.
2. Analysis of mean sea level pressure shows that there are no changes in mean sea level pressure over the northern Africa. Europe has high-pressure system with a positive pressure anomaly that reached +7 hPa. Al level of 500 hPa, there exist a huge positive anomaly in geopotential height over

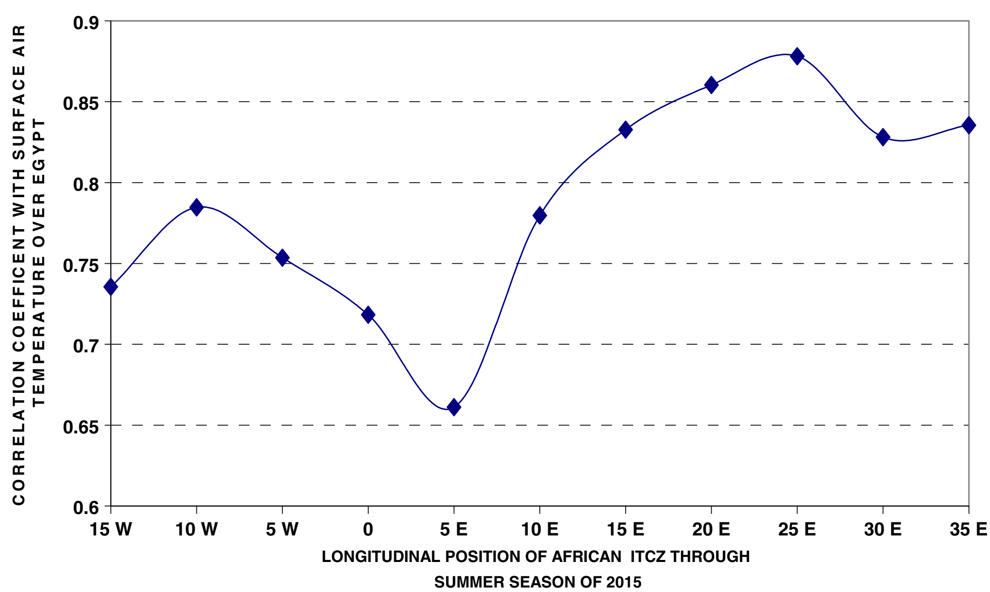


Fig. 8 The correlation coefficient between the decadal mean latitudinal position of the African ITCZ and the surface air temperature anomaly over Egypt through the summer of 2015 through the period from 1 June 2015 to 31 August 2015. The correlation coefficients calculated by Pearson correlation method

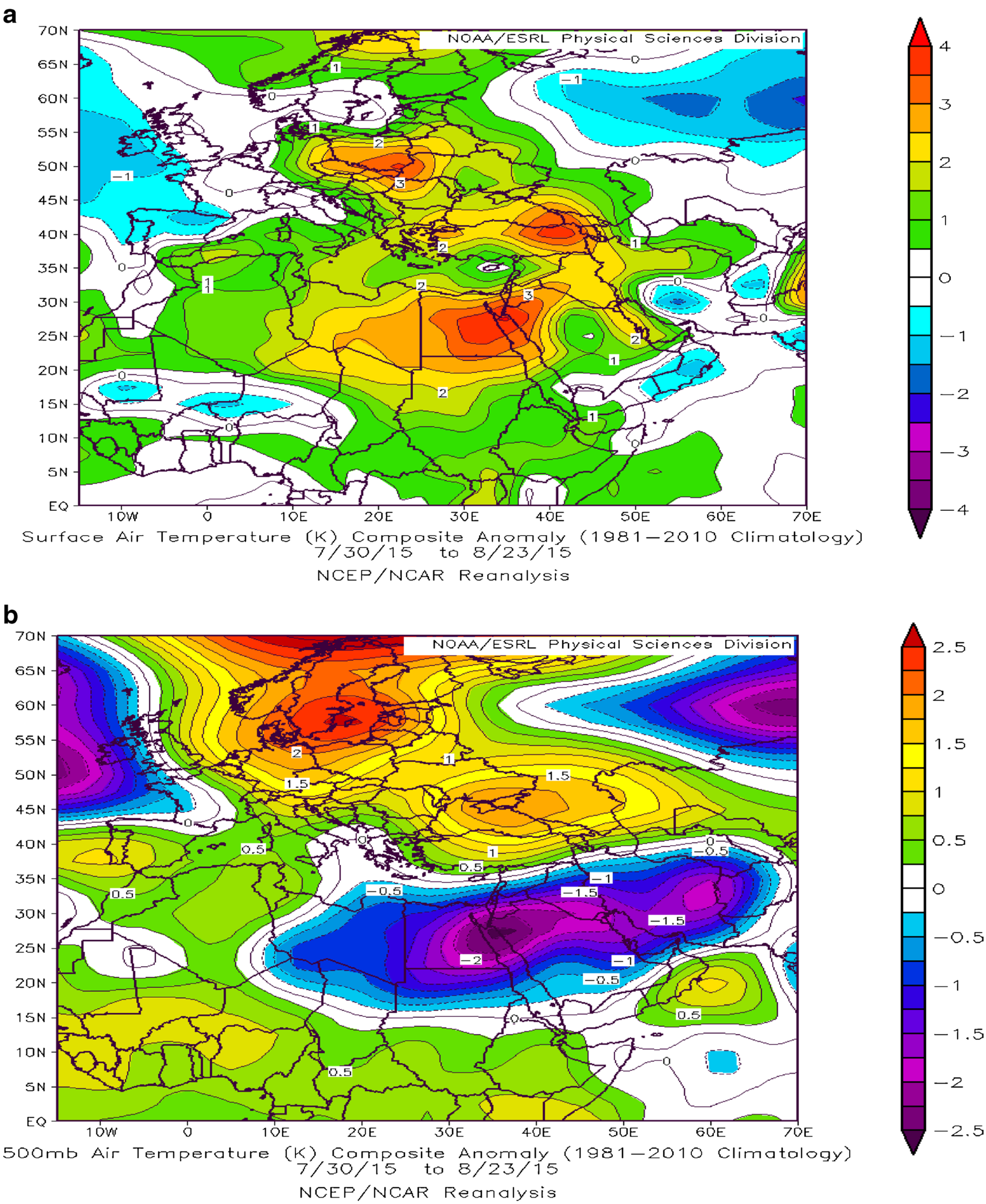


Fig. 9 The daily composite mean of air temperature anomaly (K) over the domain [Equator–70 N] latitude and [15 W–70 E] longitude through the period of heat wave (30 July to 23 August of the year 2015). **a** For surface air temperature and (**b**) for air temperature at 500 hPa level

Europe which reached +80 m above the normal value and extended southward to cover the north of Africa and the Middle East as illustrated in Fig. 10.

3. Analysis of wind field anomaly of the surface vector wind revealed the oscillation of ITCZ like a wave over the North Africa. There is an extreme northward extension of west African ITCZ and southward extension of east African ITCZ mainly over Egypt. Europe has a strong westerly air current reaching a speed of +6 m/s above its normal speed as shown in Fig. 11a, b. shows that the upper westerly air current is very huge and the wind speed reached +11 m/s more than its normal value over western Europe during that period. This westerly air current aloft extended to southeastward to reach the eastern Mediterranean region.

Discussion and conclusion

The relationship between African ITCZ and heat wave over Egypt in summer 2015 was studied in the present study. The

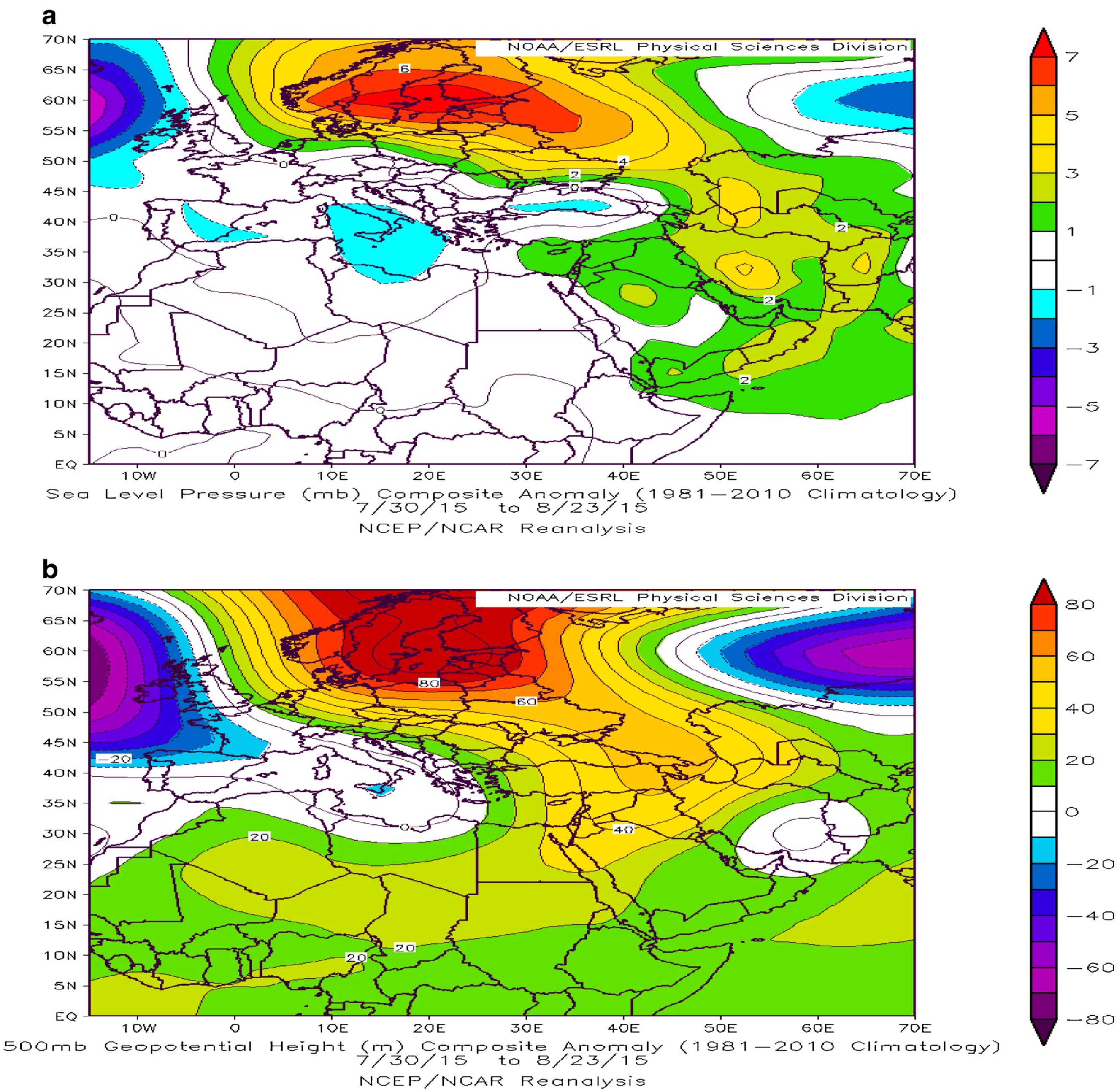
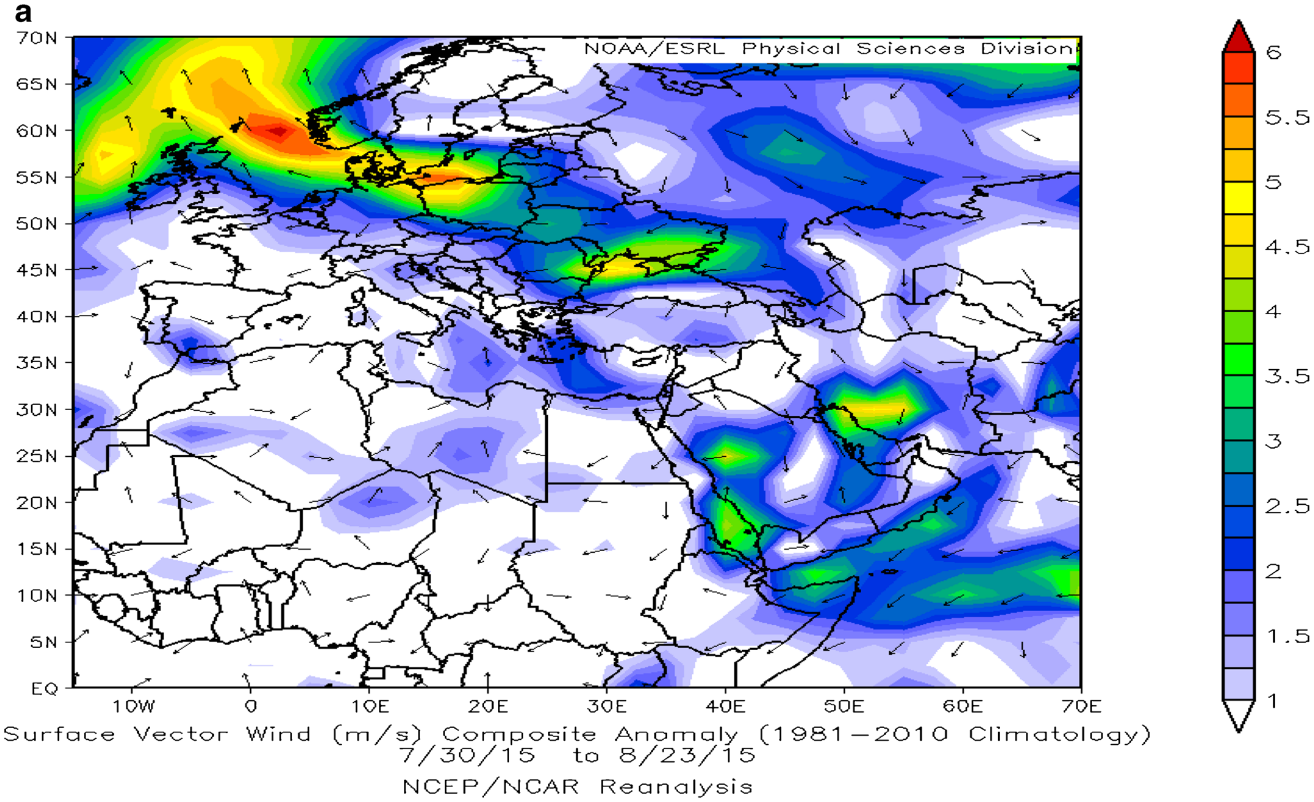


Fig. 10 The daily composite mean of sea level pressure (hPa) anomaly (Fig. 10a) and the daily composite mean of geopotential height (m) (Fig. 10b) for the domain [Equator–70 N] latitude and [15 W–70 E] longitude through the period of heat wave (30 July to 23 August 2015)

a



b

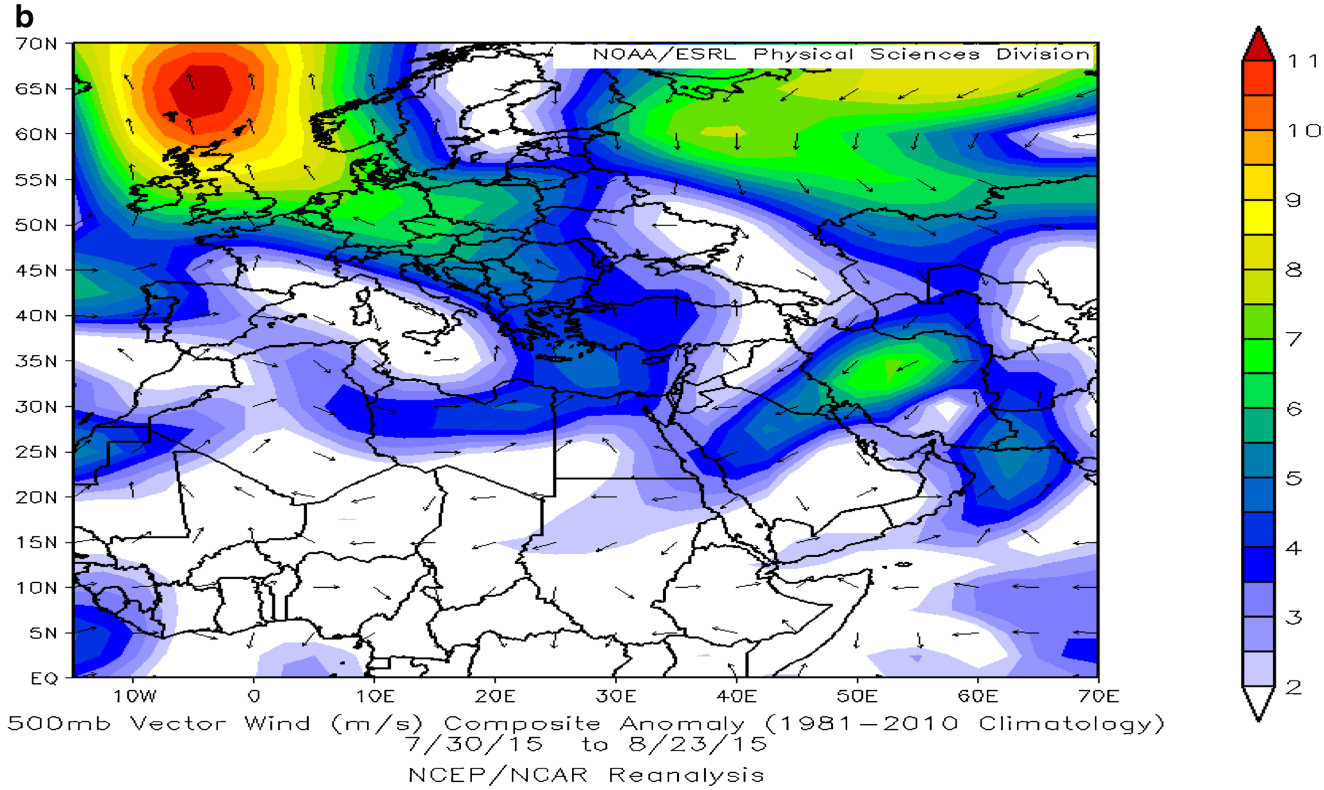


Fig. 11 The daily composite mean of wind vector anomaly (m/s) over the domain [Equator–70 N] latitude and [15 W–70 E] longitude through the period of heat wave (30 July to 23 August of the year 2015). **a** For surface wind vector and (**b**) for 500 hPa level wind vector

NCEP/NCAR reanalysis daily and monthly data of mean surface air temperature for the domain of Egypt in summer season for the period of 1948–2015 were analyzed to set out the main feature and temperature variability. In addition, the daily operational datasets of geopotential height at 500 hPa over Egypt for the period from 1 June to 31 August of 2015 were used and analyzed. Similarly, the decade data of the African ITCZ from 1–10 June to 21–31 August 2015 has been analyzed using the time series and anomaly techniques. The correlation coefficient technique was used to study the relationship between the African ITCZ position and the existence of heat wave over Egypt through the summer of 2015. The results show that maximum summer air temperatures recorded were in June 1995 and July 2002. August 2015 mean surface air temperature over Egypt recorded a unique extreme high record for all the study periods (1948–2015). The extreme mean surface air temperature reached +2.3 °C more than its normal value. In addition, the heat wave over Egypt started from 30 July to 23 of August 2015 according to the applied definition of a heat wave. The 10 August has the maximum record of temperature (46 °C) through that summer season. Over Egypt, a massive heat wave persisted for 25 days (see Fig. 4). Moreover, the results revealed that there is an outstanding relationship between the longitudinal positions of African ITCZ and temperature anomaly over Egypt particularly in the eastern part of Africa for the summer of 2015. On the other hand, through the summer season of 2015, the African ITCZ shifts to the north of its normal position over the western part of Africa, while it shifts to the south of its normal position over the eastern part of Africa. The shift of African ITCZ persisted almost for the time of a heat wave over Egypt. This persistence affects the weather regime and mechanism of south and north trade winds over North Africa. The subtropical high pressure shifts to the southward direction and persists over Egypt. The geopotential height at a 500-hPa anomaly becomes positive for the period of a heat wave over Egypt for the summer season. This condition is a stability condition over Egypt and leads to the persistence of a positive anomaly of surface temperature over Egypt on the summer season of the year 2015. As mentioned above, based on the results of Black et al.'s (2004) studies, it is clear that the northward shifts of the west African ITCZ and stability condition of the high pressure system over the east Atlantic played a great role in the heat wave of summer 2003. Also, recent findings of Keggenhoff et al. (2015a, b) showed that an evidence of a large anticyclonic blocking pattern over the southern Ural Mountains enhances subsidence and surface heating and shifts the African ITCZ northwards that cause the heat waves over Georgia in the summer season. The present study is the case of an extreme heat wave over Egypt during summer 2015. It has never recorded extreme heat wave over Egypt like it before for more than 6 decades. There are no similar cases in Egypt recorded. Summer of 2015 has a mean surface air temperature that is 29.5 °C with increasing of +0.5 °C more than its normal value over Egypt. However, the normal value of Egypt surface air temperature for the summer season is 28.9 °C for the period of 1981–2010. Study of climate change indicates $TX90_P$ and $TN90_P$ records that a new climatic change heat wave existed over Egypt through the period from 30 July to 23 August of the year 2015. It is observed that from synoptic situation analysis of surface air temperature, mean sea level pressure, surface wind vector, and upper air parameters at 500 hPa level of air temperature, geopotential height, and wind field during this heat wave, there are surface and upper air weather stability conditions over Egypt. The stability conditions of high pressure system in the upper atmosphere over Egypt create lower inversion of temperature near the surface and cause the heat accumulation over Egypt. Analysis of wind field anomaly of the surface vector wind reveals the oscillation of ITCZ like a wave over the North Africa. There is an extreme northward extension of west Africa ITCZ and southward extension of east Africa ITCZ mainly over Egypt. This shift of ITCZ over North Africa leads to the huge westerly air current over Europe to extend to southeastward to reach to the eastern Mediterranean region. This teleconnection study between African ITCZ and extreme heat wave existing over Egypt during summer 2015 encourage future studies about the relationship between the shifts of the ITCZ and existence of heat waves over Egypt. Moreover, the predictability of African ITCZ oscillations will lead to forecasting of the extreme heat waves over Egypt. It is concluded that the extreme shifts of the longitudinal position of African ITCZ cause changes in the eastern Mediterranean weather regime and cause the extreme weather conditions over Egypt and generate a massive heat wave over Egypt in summer 2015.

Acknowledgments It is a pleasure for the authors to thank the Climate Diagnostics Centre for supporting the data used throughout the present study. Plots and images were provided by the NOAA-CIRES Climate Diagnostics Centre, Boulder, Colorado, the USA from their Web site at http://www.cdc.noaa.gov. Also, thanks to the Climate Prediction Centre for supporting the summer African ITCZ data obtained through the website http://www.cpc.ncep.noaa.gov/products/monitoring _data.

References

Ballester J, Robine JM, Herrmann FR, Rod X (2011) Long-term projections and acclimatization scenarios of temperature-related mortality in Europe. Nat Commun 2:358. doi:10.1038/ncomms1360

Barriopedro D, Fischer EM, Luterbacher J, Trigo RM, Herrera GR (2011) The hot summer of 2010: redrawing the temperature record map of Europe. Science 332:220–224. doi:10.1126/science. 1201224

Bates JR (1970) Dynamics of disturbances on the intertropical convergence zone, quart. J R Meteorol Soc 96:677–701

Baumberg V, Weber T, Helmschrot J (2015) Assessing the Change in Rainfall Characteristics and Trends for the Southern African ITCZ Region. Geophys Res Abstr 17:EGU2015–E1434-1

Black E, Blackburn M, Harrison G, Hoskins B, Methven J (2004) Factors contributing to the summer 2003 European heat wave. Weather 59(8):217–223. doi:10.1256/wea.74.04

Bloomberg (2015) Egypt Heat Wave Kills Almost 100 People in August, 2015 Ministry Says.

Broccoli AJ, Dahl KA, Stouffer RJ (2006) Response of the ITCZ to northern hemisphere cooling. Geophys Res Lett 33:L01702. doi: 10.1029/2005GL024546

Citeau J, Berges JC, Demarcq H, Mahe G (1988b) The Watch of ITCZ Migrations over Tropical Atlantic as an Indicator in Drought Forecast over Sahelian area. Ocean-Atmos News 45:1–3

Doherty OM, Riemer N, Hameed S (2014) Role of the convergence zone over West Africa in controlling Saharan mineral dust load and transport in the boreal summer. Tellus B 66:23191

Dole RM, Hoerling J, Perlwitz J, Eischeid P, Pegion T, Zhang X-W, Quan T, Xu MD (2011) Was there a basis for anticipating the 2010 Russian heat have? Geophys Res Lett 38:L06702

El Afandi GS (2014) Evaluation of NCEP Climate Forecast System Reanalysis (CFSR) against Surface Observations over Egypt. Am J Sci Technol 1(4):157–167

Feudale L, Shukla J (2011) (2011) Influence of sea surface temperature on the European heat wave of 2003 summer. Part I: an observational study. Clim Dyn 36:1691–1703. doi:10.1007/s00382-010-0788-0

Fontana G, Toreti A, Ceglar A, De Sanctis G (2015) Early heat waves over Italy and their impacts on durum wheat yields. Nat Hazards Earth Syst Sci 15:1631–1637. doi:10.5194/nhess-15-1631-2015

Frich A, Alexander LV, Della-Marta P, Gleason B, Haylock M, Klein Tank AMG, Peterson T (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. Clim Res 19:193–212

Gadgil S, Guruprasad A (1990) An objective method for identification of the intertropical convergence zone. J Clim 3:558–567

Gaetani M, Fontaine B (2013) Interaction between the west African monsoon and the summer Mediterranean climate: an overview. Física de la Tierra 25, doi: 10.5209/rev_FITE.2013.v25.43434.

Gaetani M, Poh B, Douville H, Fontaine B (2011) West African monsoon influence on the summer euro-Atlantic circulation. Geophys Res Lett 38:9. doi:10.1029/2011GL047150

Garc'ia-Herrera R, D'iaz J, Tricgo RM, Luterbacher J, Fischer EM (2010) A review of the European summer heat wave of 2003. Crit Rev Environ Sci Technol 40:4. doi:10.1080/10643380802238137

Hafez YY (2003) Changes in Atlantic - Western Africa ITCZ variability and its influence on the precipitation rate in Europe on sever rainy summer 2002. J Meteorol UK 28(282):299–307

Hafez YY (2007) The connection between the 500 hPa geopotential height anomalies over Europe and the abnormal weather in eastern Mediterranean during winter 2006. I J Meteorol U K 32(324):335–348

Hafez YY (2012a) Variability of intertropical convergence zone (ITCZ) and extreme weather events. Atmos Model Appl . doi:10.5772/33809ISBN: 978–953–51-0488-9, InTech

Hafez YY (2012b) Blocking systems persist over north hemisphere and its role in extreme hot waves over Russia during summer 2010. Atmos Model Appl . doi:10.5772/33810ISBN: 978–953–51-0488-9, InTech

Hess PG, Battisti DS, Rasch PJ (1993) The maintenance of the intertropical convergence zones and the large-scale tropical circulation on a water covered earth. J Atmos Sci 50:691–713

Ilesanmi OO (1971) An empirical formulation of an ITD rainfall model for the tropics: a case study of Nigeria. J Appl Meteorol 10:882–891

Kalnay E, Kanamitsu M, Kistler R, et al. (1996) The NCEP/NCAR 40-year reanalysis project. Bull Am Meteorol Soc 77(3):437–471

Katsafados P, Papadopoulos A, Varlas G, Papadopoulou E, Mavromatidis E (2014) Seasonal predictability of the 2010 Russian heat wave. Nat Hazards Earth Syst Sci 14:1531–1542. doi:10.5194/nhess-14-1531-2014

Keggenhoff I, Elizbarashvili M, King L (2015a) Heat wave events over Georgia since 1961: climatology, changes, and severity. Climate 3(2):308–328. doi:10.3390/cli3020308

Keggenhoff I, Elizbarashvili M, King L (2015b) Severe summer heat waves over Georgia: trends, patterns and driving forces. Earth Syst Dyn 6:2273–2322. doi:10.5194/esdd-6-2273-2015

Kendall MG, Stuart A (1973) The advanced theory of statistics, volume 2: inference and relationship, Griffin. ISBN 0–85264–215-6.

Kraus EB (1997) The seasonal excursions of the intertropical convergence zone. Mon Weather Rev 105:1009–1018

Kuglitsch FG, Toreti A, Xoplaki E, Della-Marta PM, Zerefos CS, Türkeş M, Luterbacher J (2010) Heat wave changes in the eastern Mediterranean since 1960. Geophys Res Lett 37:L04802. doi:10.1029/2009GL041841

Lelieveld J, Hadjinicolaou P, Kostopoulou E, Chenoweth J, El Maayar M, Giannakopoulos C, Hannides C, Lange MA, Tanarhte M, Tyrlis E, Xoplaki E (2012) Climate change and impacts in the eastern Mediterranean and the Middle East. Clim Chang 114:667–687. doi:10.1007/s10584-012-0418-4

Lelieveld J, Hadjinicolaou P, Kostopoulou E, Giannakopoulos C, Pozzer A, Tanarhte M, Tyrlis E (2013) Model projected heat extremes and air pollution in the eastern Mediterranean and Middle East in the twenty-first century. Reg Environ Chang (2014) 14:1937–1949. doi 10.1007/s10113-013-0444-4.

Lupo AR, Mokhov II, Yury G, Lebedeva CMG, Akperov M, Hubbart JA (2014) Studying summer season drought in western Russia advances in meteorology, 2014, Article ID 942027, 9 pages doi: 10.1155/2014/942027.

Maloney ED, Shaman J (2008) Intraseasonal variability of the west African monsoon and Atlantic ITCZ. J Clim 21:2898–2918

Meehl GA, Washington WM, Ammann CM, Arblaster JM, Wigley TML, Tebaldi C (2004) Combinations of natural and anthropogenic forcings in twentieth-century. Climate. J Climate 17:3721–3727

Mortensen, NG, Hansen, J C,Badger, J, Jørgensen, Bo H, Hasager, CB, Paulsen US, Hansen, OF, Enevoldsen, K, Youssef, LG, Said, US, Moussa, AAE-S, Mahmoud MA, Yousef, AES, Awad AM, Ahmed MA-ER, Sayed MAM, Korany MH, Tarad MA-EB (2006) Wind atlas for Egypt: measurements, micro- and mesoscale modelling. Brussels, European Wind Energy Association (EWEA)

Nicholson SE (2009) A revised picture of the structure of the "monsoon" and land ITCZ over West Africa. Clim Dyn 32:1155–1171. doi:10.1007/s00382-008-0514-3

Nicholson SE (2013) The west African Sahel: a review of recent studies on the rainfall regime and its interannual variability. ISRN Meteorol 1–32. doi: 10.1155/2013/453521.

Önol B, Fredrick HMS (2009) Regionalization of climate change simulations over the Eastern Mediterranean. J Clim, 22, 1944–1961. doi: doi: 10.1175/2008JCLI1807.1.

Philander SGH et al. (1996) The role of low-level stratus clouds in keeping the ITCZ mostly north of the equator. J Clim 9:2958–2972

Pike AC (1971) Intertropical convergence zone studied with an interacting atmosphere and ocean model. Mon Weather Rev 99:469–477

Raymond DJ, Bretherton CS, Molinari J (2006) Dynamics of the intertropical convergence zone of the East Pacific. J Atmos Sci 63(2):582–597

Robine JM, Cheung SL, Le Roy S, Van Oyen H, Griffiths C, Michel JP, Herrmann FR (2008) Death toll exceeded 70,000 in Europe during the summer of 2003. C R Biol 331(2):171–178. doi:10.1016/j.crvi.2007.12.001 ISSN 1631–0691

Rosting B, Kristjansson (2008) A successful resimulation of the 7-8 January 2005 winter storm through initial potential vorticity modification in sensitive regions. Tellus A 60(4):604–619

Schneider T, Bischoff T, Haug GH (2014) Migrations and dynamics of the intertropical convergence zone. Review. doi:10.1038/nature13636

Scott AA (2013) The intertropical convergence zone over the Middle East and North Africa: detection and trends. MSc Thesis, KAU of Science and Technology, Thuwal, KSA.

Stefanon M, D'Andrea F, Drobinski P (2012) Heat wave classification over Europe and the Mediterranean region. Environ Res Lett 7 (2012) 014023 (9pp). doi:10.1088/1748-9326/7/1/014023.

Stott PA, Stone DA, Allen MR (2004a) Human contribution to the European heat wave of 2003. Nature 432(7017):610–614. doi:10.1038/nature03089

Stott PA, Stone DA, Allen MR (2004b) Human contribution to the European heat wave of 2003. Nature 432:610–614

Sultan B, Janicot S (2000) Abrupt shift of the ITCZ over West Africa and intra-seasonal variability. Geophys Res Lett 27:3353–3356

Suzuki T (2011) (2011) seasonal variation of the ITCZ and its characteristics over Central Africa. Theor Appl Climatol 103:39–60. doi:10.1007/s00704-010-0276-9

Tanarhte M, Hadjinicolaou P, Lelieveld J (2015) Heat wave characteristics in the eastern Mediterranean and Middle East using extreme value theory. Int Res Clim Res 63(2):99–113

Trewin (2009) BC. A new index for monitoring changes in heatwaves and extended cold spells. In: 9th International Conference on Southern Hemisphere Meteorology and Oceanography. Melbourne.

Unal YS, Tan E, Mentes SS (2012) Summer heat waves over western Turkey between 1965 and 2006. Theor Appl Climatol (2013) 112:339–350. doi:10.1007/s00704-012-0704-0

Waliser DE (1992) The preferred latitudes of the intertropical convergence zone: observations and theory. Ph. D. Dissertation, Scripps Institution of Oceanography, University of California, San Diego.

Waliser DE, Somerville CJ (1994) Preferred latitudes of the intertropical convergence zone. J Atmos Sci 51:1619–1639

Zhang X, Aguilar E, Sensoy S, Melkonyan H, Tagiyeva U, Ahmed N, Kutaladze N, Rahimzadeh F, Taghipour A, Hantosh TH, et al. (2005) Trends in Middle East climate extremes indices during 1930–2003. J Geophys Res 110:D22104

Zhang X, Alexander L, Heger GC, Philip J, Tank AK, Peterson TC, Trewin B, Zwiers FW (2011) Indices for monitoring changes in extremes based on daily temperature and precipitation data. WIREs Clim Change 2:851–870. doi:10.1002/wcc.147

Zittis G, Hadjinicolaou P, Lelieveld J (2015) Projected changes in heat wave characteristics in the eastern Mediterranean and the Middle East. Reg Environ Chang. doi:10.1007/s10113-014-0753-2