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Seasonal Variability of Precipitation and Temperature over Egypt During 2014 Using Climate Monitoring Tool (CMT)

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Abstract
Climate Monitoring Tool (CMT) is used to generate time series and spatial analysis of both rainfall and temperature at different time scales for 12 Egyptian climate stations. The daily mean observations and monthly mean reanalysis data during the period 1974-2014 are used to discuss climatic distribution of precipitation and temperature over Egypt. This article aims to detect the behavior of winter and summer season in 2014 with respect to climate base period of 1981-2010 for observations. The study also investigates correlations between the NAO, ONI and precipitation, temperature in both north and south of Egypt during the winter and summer seasons. The results showed that, 2014 was characterized by a sequence of warm waves during the winter and summer seasons. Precipitation was marked by a strong regional disparity with a rainfall deficit in the south and surplus in the north. In overall, precipitation was below normal and the temperature was above-normal in 2014 based on climatology period (1981-2010).

Keywords: North Atlantic Oscillation; Oceanic Nino Index; Climate Monitoring tool; Seasonal variability; Egypt

1. Introduction

Egypt is an African country in the vicinity of Asia and the Mediterranean region. It occupies an area of about one million Km², between Lat. 22° and 32° N and Long 25° and 35° E, under arid and hyper-arid climatic conditions, of which only a small portion (3% of the total area) is agriculturally productive. Geographically, Egypt can be distinguished into four main geographic regions; Nile Valley & Delta, Sinai Peninsula, the Eastern Desert and Western Desert. The location of Egypt is characterized by annual rainfall in most parts of less than 50mm (Hegazi *et al.*, 2005). In January 2010, heavy rain exceeding 80 mm/day, led to the worst flash-floods, that affected the Sinai Peninsula, the Red Sea coast and the Aswan Governorate in southern Egypt since 1994 (Attaher and Medany, 2011).

The National Climatic Data Center, NCDC, considers the year 2014 as the warmest ever recorded, with an anomaly of +0.69° C (calculated for the period 1880–2014) (NOAA, 2015). The World Meteorological Organization (WMO, 2016) considers the period 2011 – 2015 as the hottest on record, and the year 2015 as the hottest since modern observations began in the late 1800s. In fact, the hydrological cycle acceleration under the influence of strong temperatures might lead to more rainfall and evaporation (WMO, 2013). The results of several studies on rainfall evolution in many areas of the globe, as it happens in North Africa, show that climate change translates into wetter conditions (Dore, 2005; Alexander *et al.*, 2006) as well as into a rainfall increase and repetition of extreme events in the recent decades 1991 – 2010 (WMO, 2013; Christensen *et al.*, 2007).

North Atlantic Oscillation (NAO), as the air mass displacement between the Arctic and the subtropical Atlantic plays an important role of climate variability in the northern hemisphere (Barnstorn and Livezey 1987). The strength of the NAO is generally expressed through an index (Hurrell 1995; Jones *et al*., 1997). Climatic anomalies associated with the NAO have also strong impacts on the regional hydrology and river floods (Kundzewicz *et al*., 2010), with subsequent effects on the local economies, as shown for North African precipitation (Lamb and Peppler, 1991; Meddi *et al*., 2010). Xoplaki *et al*. (2001) used observed data for 50 years during the period 1949-1999 and found, that the Eastern Mediterranean temperature is negatively correlated with the NAOI, whereas stations mainly North of the Mediterranean Sea (North of 40°N and East of 5°E) show a positive connection to the NAO. Oceanic Niño Index (ONI) is the primary indicator for detecting El Niño and La Niña event. NOAA considers El Niño conditions to be present when ONI is +0.5^{o} C or higher, while La Niña conditions exist when ONI is -0.5^{o} C or lower. A positive correlation between the Niño3.4 index and the extreme precipitation frequency over the Iberian Peninsula and the Middle East was revealed by Krichak *et al*. (2014). Hafez (2016) examines the relationship between ONI and temperature and precipitation over the Kingdom of Saudi Arabia (KSA). His results revealed that the KSA climate parameters, temperature and precipitation rates are controlled by ONI mainly in the autumn and winter seasons. The World Meteorological Organization (WMO) reports show that most places around the world experienced a marked rise in temperature during 2014. Hence, this work focuses on analyzing the characteristics of temperature and rainfall variability and their link to the ENSO and NAO events during the northern hemisphere winter and summer 2014.

2.Methodology

2.1 The data used in this study

a) Daily and monthly average observed of 2meter mean, maximum and minimum temperature (^{o}C) at 2 m, as well as the daily precipitation (mm/day) depending on 8 measurements for selected 12 stations in Egypt during the period (1974 - 2014). These selected stations are scattered within the region of the Egyptian border as shown in Table 1

b) Monthly mean reanalysis of sea surface temperature (^{o}C) from NCEP/NCAR with horizontal resolution 2^{o} latitude and longitude during the same period (1974-2014). Monthly north Atlantic oscillation index (NAOI) during the period (1974-2014) according to Jones *et al*. (1997) accessed from: https://crudata. uea. ac.uk / cru /data /nao /nao. dat

c) Three-months moving average anomaly over Nino3.4, Oceanic Nino Index (ONI), for 1974 to 2014 period. This three-month running mean of sea surface temperature (SST) anomalies of Nino 3.4 is according to ERSST.v4, 1974-2014 base periods (Huang *et al*., 2015). http:// www. cpc. Ncep. noaa. gov /data /indices/oni.ascii.txt

Table 1. Location and altitude of selected stations in Egypt

Stn. (ID) In Zone 362	Stn. name North Egypt	Lat. (egree)	Lon. (degree)	Alt. (meter)	Stn. (ID) In Zone 362	Stn. name South Egypt	Lat. (degree)	Lon. (degree)	Alt. (meter)
HEMM (306)	Mersa Matruh	31.33	27.21	25	MINYA (387)	Minya	28.08	30.73	40
DABAA (309)	Dabaa	30.93	28.46	18	HEAT (393)	Asyut	27.05	31.01	226
HEAX (318)	Alexandria	31.2	29.95	-2	HELX (405)	Luxor	25.66	32.7	93
HEPS (333)	Port Said	31.26	32.29	6	HESN (414)	Aswan	23.96	32.78	200
HEAR (337)	El Arish	31.08	33.83	31	HEGN (463)	Hurguad	27.15	33.71	16
HECA (366)	Cairo	30.13	31.4	64	KHARGA (435)	Kharga	25.45	30.53	73

2.2 Climate monitoring tool

The climate monitoring tool (CMT) is developed to improve data in NOAA/Climate Prediction Center/ International Desks. In this study CMT uses as analytical tools capable of simulating and generation of data for weather/ climate monitoring purposes. The tool was developed using various software; FORTRAN, OpenGrADS, and WatCom C++ Compiler, Word Processing, and Excel. Reformatting and generation of new data to be analyzed, executable programs, and time series and spatial analysis were made by the program scripts. Monthly averages of both temperature and precipitation were analyzed during the summer and winter seasons by CMT. Accumulated daily precipitation of 12 stations, six stations to the north of Egypt and the other six stations to the south Egypt during winter season of 2013/14. Moving daily average temperature for the same 12 stations during the winter and summer seasons. This information provides guidance in quantifying the impacts of weather on agriculture, hydrology, environmental and social economic activities. Data entry, processing, analysis and outputs on CMT program, and its validation using MS-excel are summarized in Figure 1. Basic program files are listed at each stage of the process; text files (.txt), control files (.ctl), grads (.gs), compiler (.c), and MS-DOS batch (.bat) files.

2.3 Statistical approaches are used

a) Standardized Precipitation Index (SPI) (McKee 1993), Standardized Temperature Index (STI) is used as:

$$Z = \frac{X_i - \bar{X}}{S} = \frac{X_i - \bar{X}}{\frac{1}{n-1}\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}}$$

S is the standard deviation, to be compatible with both NAO and ONI.

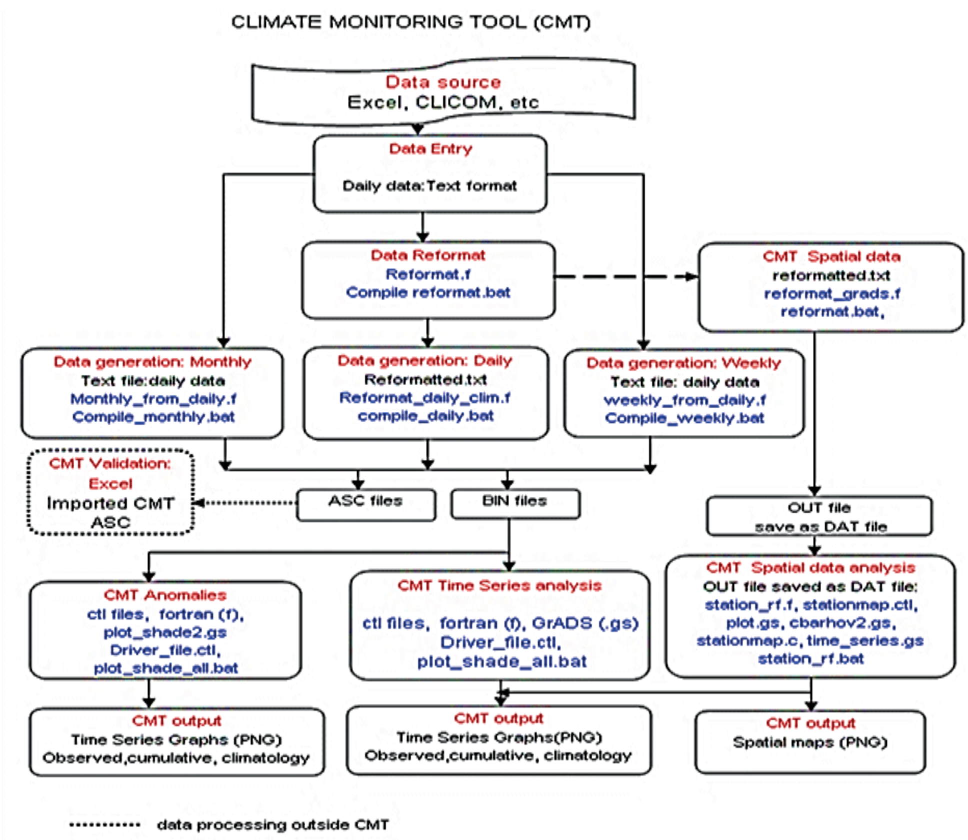

Figure 1. CMT structure and the basic program involved at each stage of the process; text files (.txt), control files (.ctl), grads (.gs), compiler (.c), and MS-DOS batch (.bat) files. (Yonah, 2010)

b) Pearson correlation to find a different correlation between SPI, STI and NAO, ONI at north and south Egypt.

$$CC = r_{xy} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

3. Results and Discussion

3.1 Climatic patterns of precipitation over Egypt

Figure 2a shows, annual cycle of monthly precipitation for the averaged over the first six stations in northern Egypt shown in table (1). It is clear from figure that, the maximum precipitation occurs from autumn (SON) to spring (MAM) season with maximum values in winter season (DJF) over northern Egypt. Maximum accumulated precipitation at north of Egypt occurs in January with the largest value of 164 mm. Mediterranean cyclones associated with successive cold fronts are the main synoptic feature that extends across northern and central Egypt, leading to heavy rainfall over the northern coastal areas, and the rains decrease gradually southward in winter season. Figure 2b shows, annual cycle of monthly precipitation averaged over the second six stations in the southern Egypt. There is a strong regional contrast between low rainfall amount in the South and higher rainfall amounting the North. In general, a real average monthly rainfall over southern Egypt doesn’t exceed 5 mm.

3.2 Climatic patterns of temperature over Egypt

Figure 2c is the same as Figure 2a but for mean temperature of the first six stations in the north of Egypt. The figure illustrates that, the maximum temperature occurs in summer season (JJA) with values of 27.2° C in August in the northern Egypt. The higher values of temperature over the following six stations in the southern part of Egypt occur in July, one month earlier than the stations in the northern Egypt, with values as high as 32.16 ° C, as shown in Figure 2d

3.3 Winter and summer season of 2014

The link between winter atmospheric modes of variability and monthly winter temperature in Egypt is examined using correlation analysis by Hasanean, 2004. The

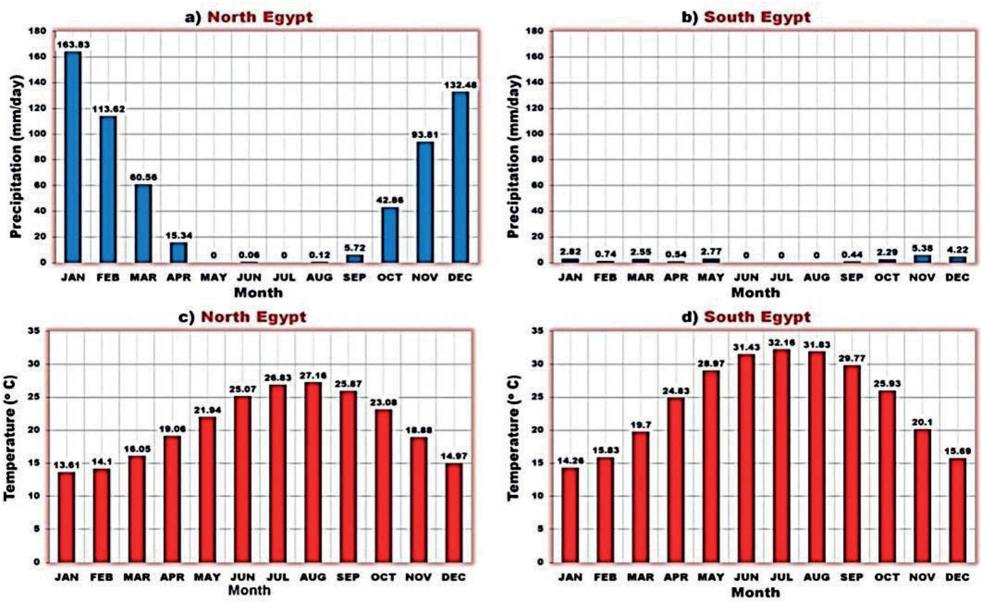

Figure 2. Observed monthly accumulated precipitation over north Egypt (a), and southern Egypt (b). Observed monthly mean temperature over north Egypt (c), and southern Egypt (d), averaged over the period 1981-2010

study reveals that ENSO and NAO indices have negative correlations with wintertime temperature over 12 stations in Egypt. Hafez and Robaa, 2008 investigate the impacts of NAO and ENSO on the mean surface air temperature over Egypt using monthly mean NCEP/NCAR reanalysis data of the surface air temperature over Egypt during the period (1948-2005). They concluded that the surface air temperature is significantly correlated with NAO index and ENSO over the southern part of Egypt. Figure 3 (a, and b) shows the relation between the seasonal variability of the Standardized Precipitation Index (SPI), with the North Atlantic Oscillation (NAO), and Oceanic Nino Index (ONI) over northern and southern Egypt during winter season. While, Figure 3 (c to f) is the same as upper panels (a, and b) but for the Standardized Temperature Index (STI), during the winter and summer seasons. The correlation coefficient (CC) between SPI and NAO at the northern part of Egypt 0.40 which is larger than the values over the southern part (0.22). While SPI correlation with ONI is weaker than that of the NAO. The temperature, during DJF season has a significant correlation with NAO over northern (-0.6) and southern (-0.55) Egypt, whereas ONI doesn't significant correlation in the winter season over Egypt. Summer temperature in the northern part of Egypt is linked to ONI with CC by -0.42, while the southern part is linked to NAO with CC value of -0.37. Drought and wet years classification for the rainy season (DJF), according to McKee (1993) is shown in Table 2. Based on this the table, 2013/14 is classified under slightly below normal rainfall category for northern, and normal category for southern Egypt.

Table 2. SPI for DJF Precipitation of Egypt

Category	Definition		Frequency (%) North	Years (41) (North) 1974-2014	Frequency (%) South	Years (41) (South) 1974-2014
DRY CASES	Extreme	SPI9 < -2	0	-	0	-
	Severe	-2 < SPI9 < -1.5	2.44	2009/10	0	-
	Moderate	-1.5 < SPI9< -1	14.63	1976/77, 1978/79, 1983/84, 1998/99, 2008/09, 2010/11	0	-
	Slight	-1 < SPI9 < -0.5	14.63	1981/82, 1986/87, 1993/94, 1995/96, 2011/12, 2013/14	43.9	1975/76, 1976/77, 1977/78, 1979/80, 1980/81, 1981/82, 1982/83, 1983/84, 1984/85, 1986/87, 1995/96, 1997/98, 2000/01, 2002/03, 2005/06, 2006/07, 2008/09, 2011/12
NORMAL CASES	Normal	-0.5 < SPI9< 0.5	43.9	1975/76, 1979/80, 1980/81, 1984/85, 1985/86, 1989/90, 1990/91, 1994/95, 1996/97, 1997/98, 1999/00, 2000/01, 2002/03, 2004/05, 2005/06, 2006/07, 2007/08, 2012/13,	34.15	1973/74, 1978/79, 1987/88, 1989/90, 1991/92, 1992/93, 1994/95, 1998/99, 1999/00, 2001/02, 2003/04, 2004/05, 2009/10, 2013/14
WET CASES	Slight	0.5 < SPI9 < 1	9.76	1973/74, 1977/78, 2001/02, 2003/04	2.44	1993/94
	Moderate	1 < SPI9 < 1.5	9.76	1974/75, 1982/83, 1987/88, 1992/93	7.32	1985/86, 1988/89, 1996/97
	Severe	1.5 < SPI9 < 2	2.44	1988/89	0	-
	Extreme	SPI9 > 2	2.44	1991/92	12.2	1974/75, 1990/91, 2007/08, 2010/11, 2012/13

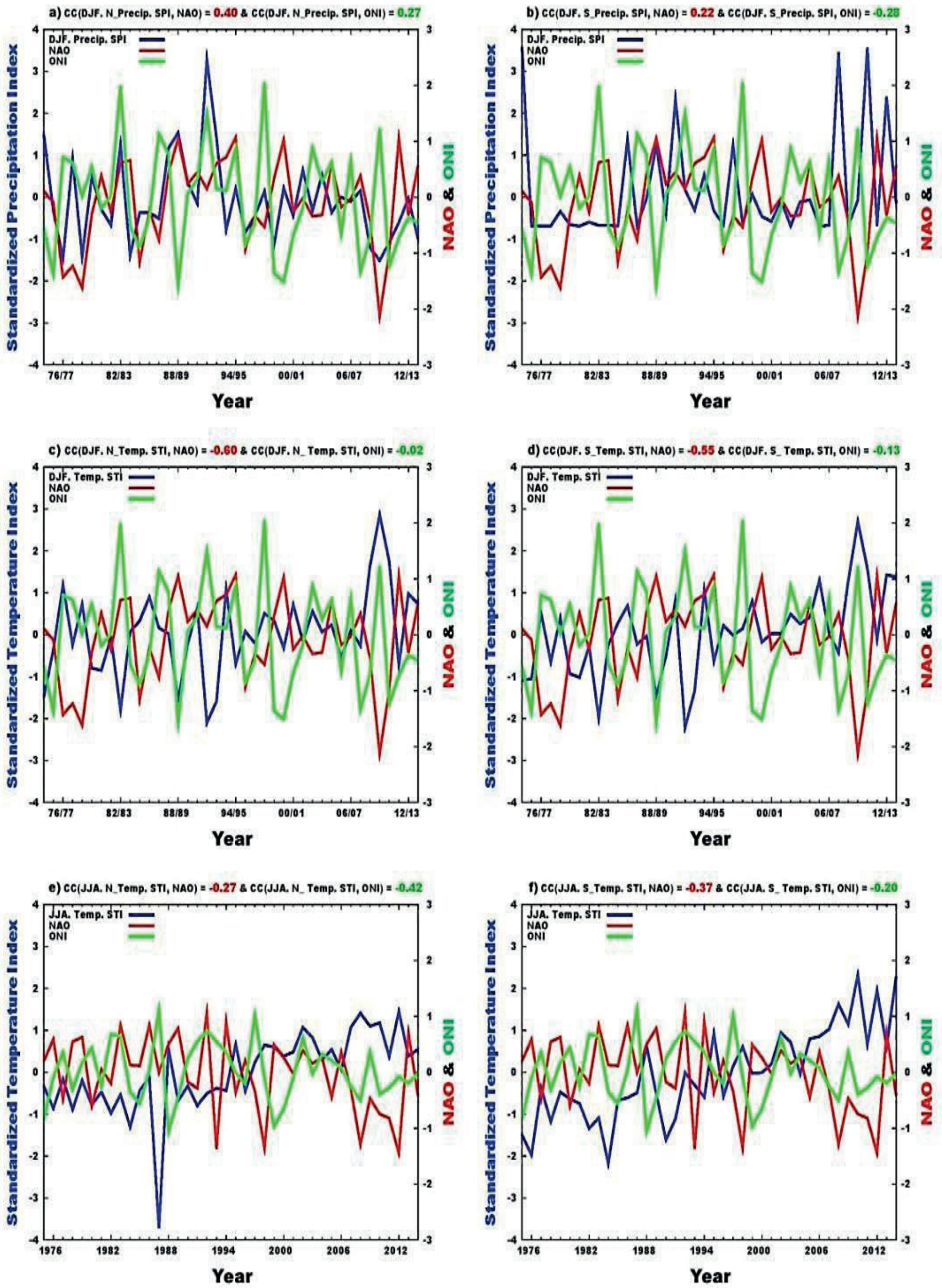

Figure 3. Seasonal average of SPI, NAO and ONI during winter (DJF) over north Egypt a) and south Egypt b), STI, NAO and ONI during winter (DJF) over north Egypt c) and south Egypt d), and summer (JJA) of STI, NAO and ONI over north Egypt e) and south Egypt f) during the period from 1974 to 2014

3.3.1 Precipitation

Monthly and seasonal total precipitation and their anomalies during the winter season of year 2013/14 are illustrated in Figure 4. Normally heavy rainfall events occur in January, while the largest rainfall was recorded during December 2013 of the winter season of 2013/14 over Egypt as in Figure 4 (a, e). Overall, winter precipitation was below average by -39.3 % over the northern sector of the region. Mersa Matruh station in Egypt received 87.9 percent above normal rainfall in December 2013.

Accumulated daily precipitation is analyzed using CMT for six stations over northern Egypt, which is represented in Figure 5. The results of the CMT analysis using daily rainfall is consistent with results discussed in the previous paragraph. Accumulated daily precipitation is below normal along winter season of 2013/14 except Mersa Matruh and Port Said stations, which received above normal rainfall during December. Analysis over the remaining six stations from southern Egypt is shown in figure in Figure 6. All stations in southern Egypt had below normal rainfall, except Hurguada station, which received above normal during winter.

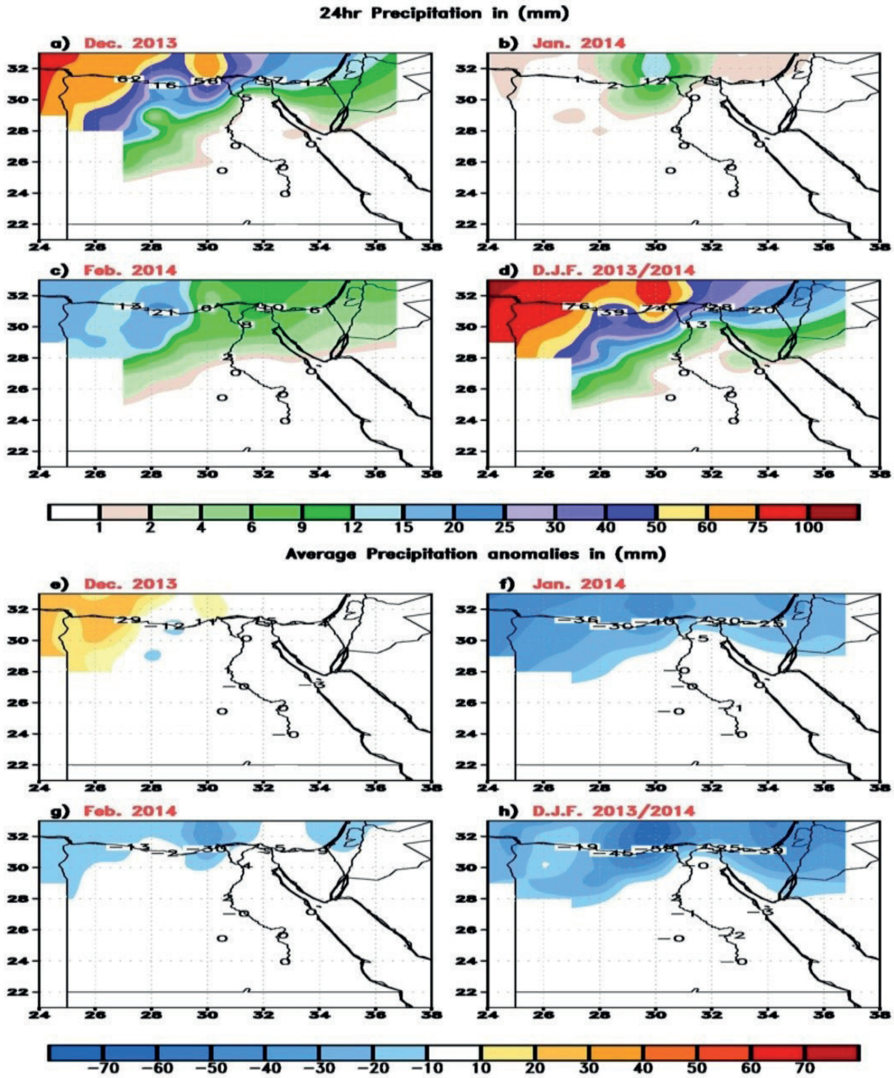

Figure 4. Monthly mean rainfall (mm) for Egypt during (a) Dec 2013, (b) Jan 2014, (c) Feb 2014, and (d) DJF 2013/14 and rainfall anomalies (mm) for the same months, according to climatic period (1981–2010)

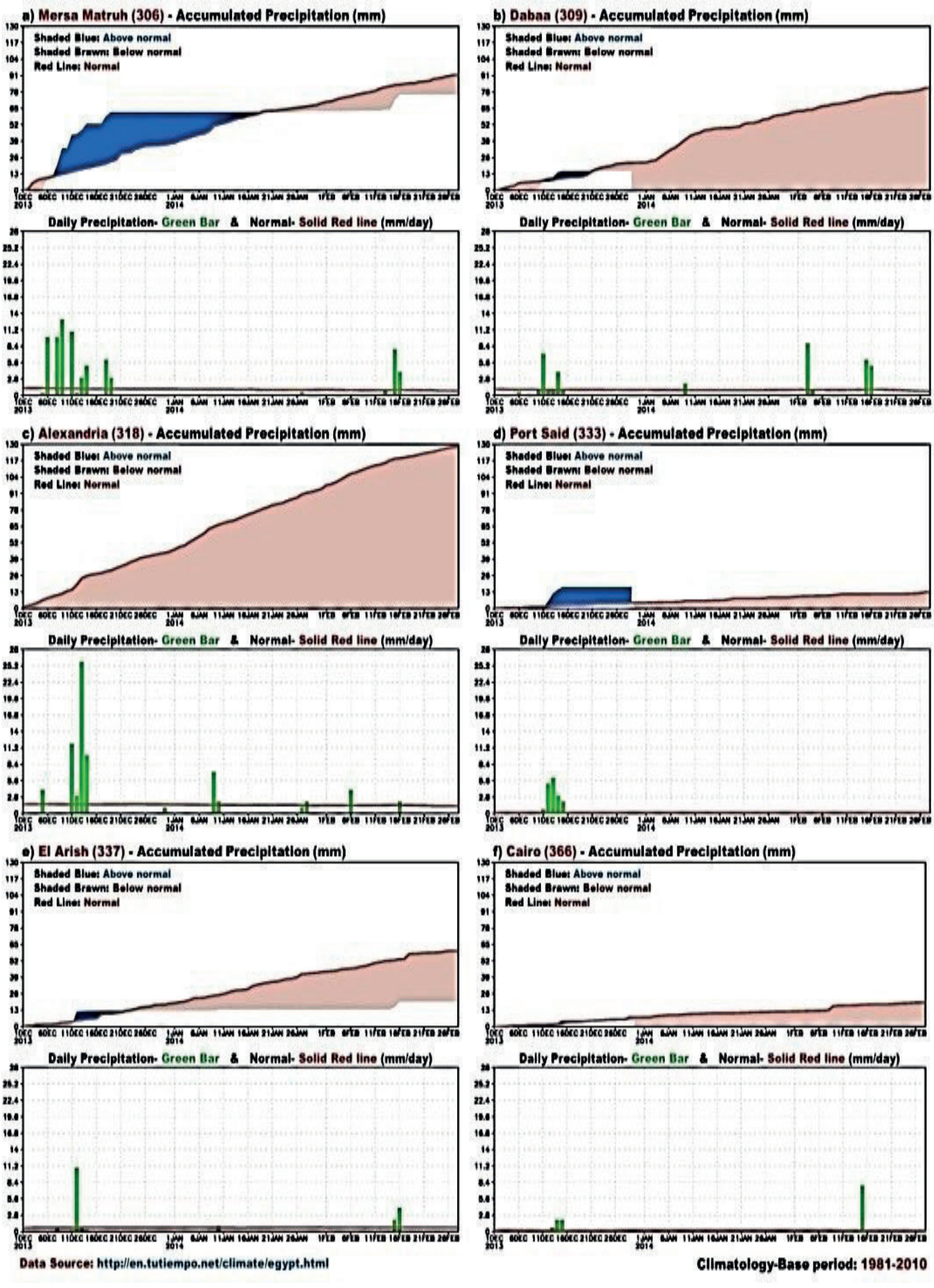

Figure 5. CMT analysis of observed daily and accumulated precipitation at six stations in northern Egypt during Dec-Jan-Feb (DJF) 2013/14 based on climatology period from 1981 to 2010

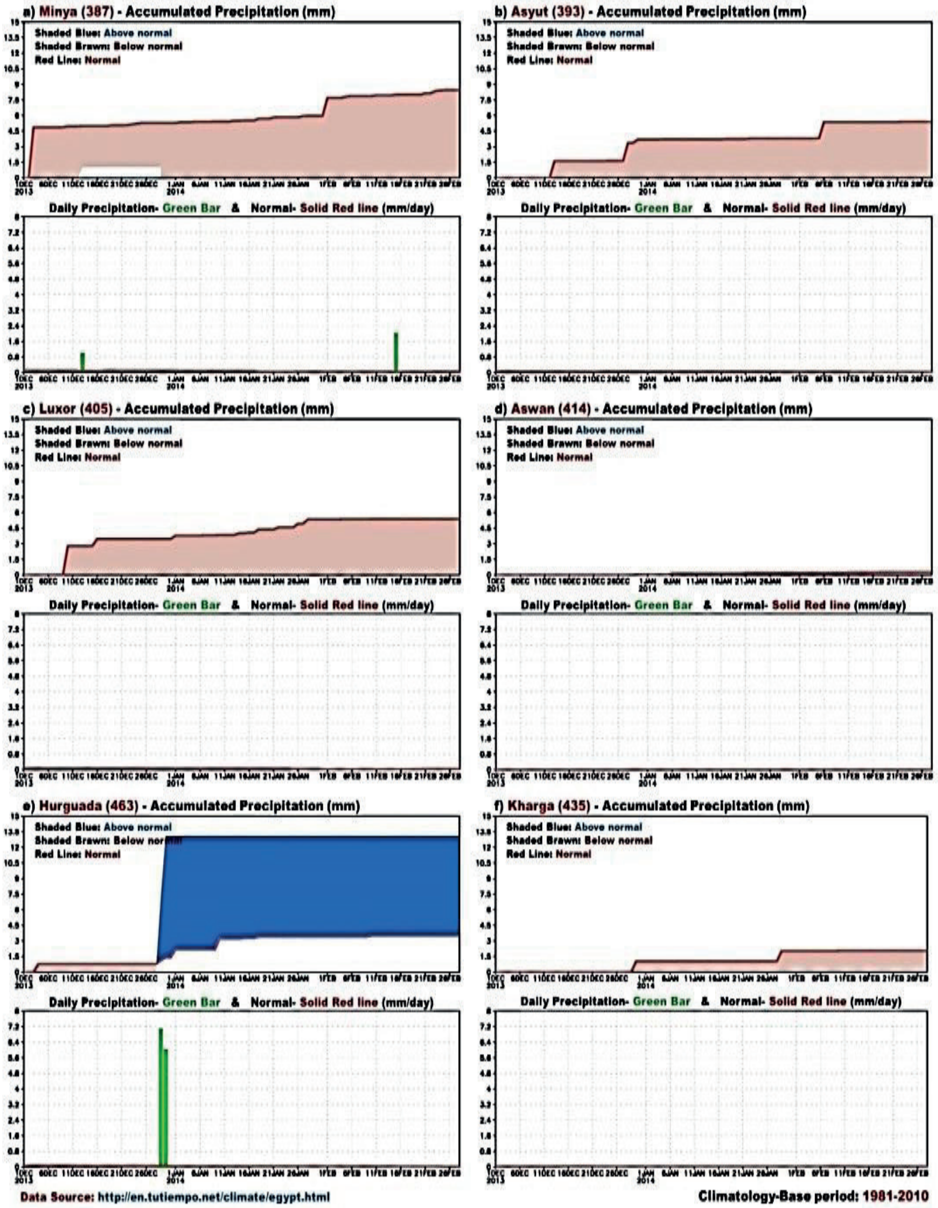

Figure 6. CMT analysis of observed daily and accumulated precipitation at six stations in southern Egypt during Dec-Jan-Feb (DJF) 2013/14 based on climatology period from 1981 to 2010

3.3.2 Temperature

Monthly and seasonal average temperature and their anomalies during the winter season of year 2013/14 are illustrated in Figure 7. Overall, winter temperature was above normal in all three months for most of the study area except Delta region, which showed below normal temperature in December 2013. The CMT moving daily average temperature analysis over the six stations in northern Egypt Figure 8. shows that temperature was above normal during first 10 days of December 2013, while it remained near normal in the rest of the season. The similar temperature pattern is noticed in southern Egypt during December 2013, with slightly above normal temperature observed toward the period as in Figure 9.

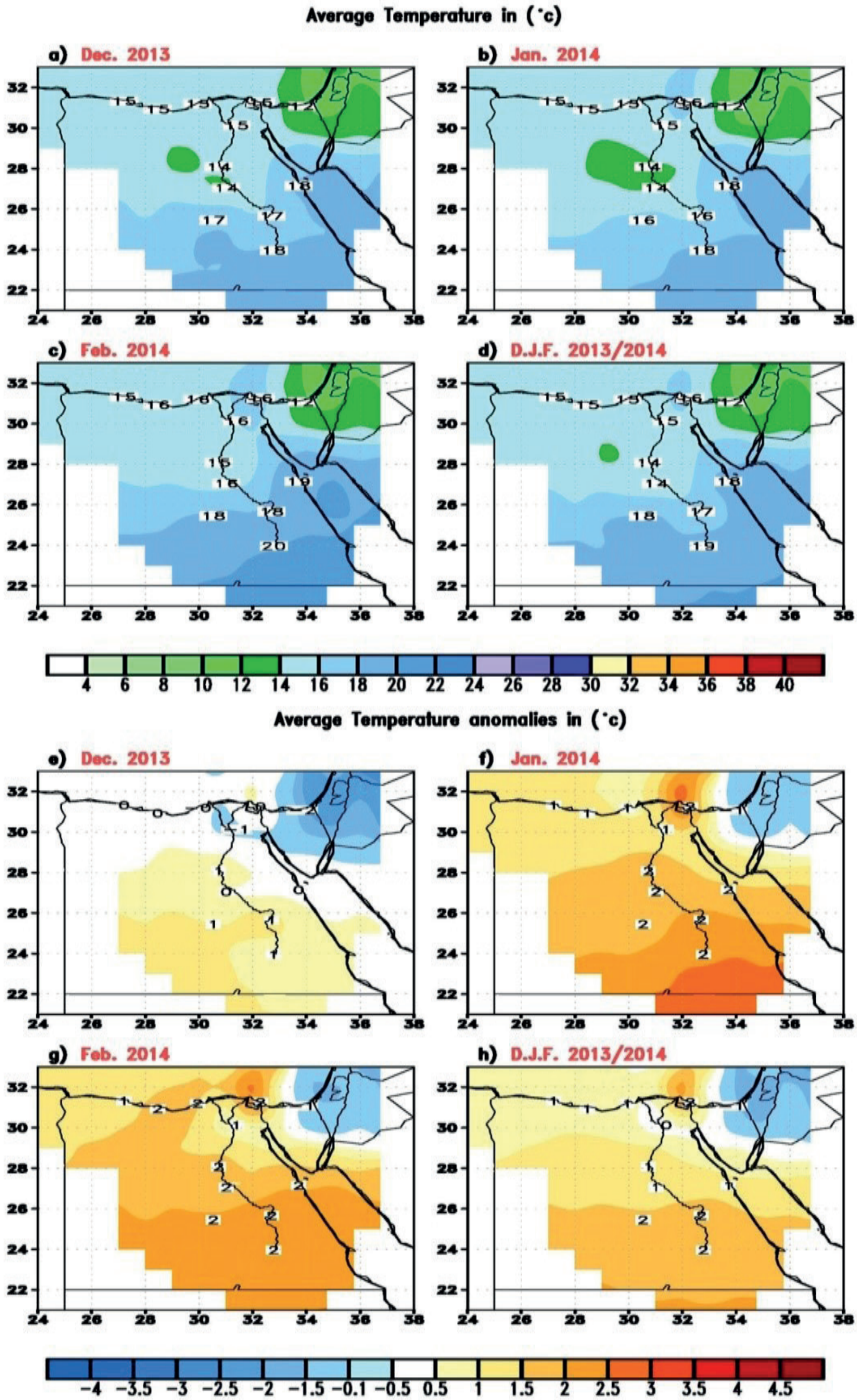

Figure 7. Monthly mean temperature (°C) for Egypt during (a) Dec 2013, (b) Jan 2014, (c) Feb 2014, and (d) DJF 2013/14 and temperature anomalies (°C) for the same months, according to climatic period (1981–2010)

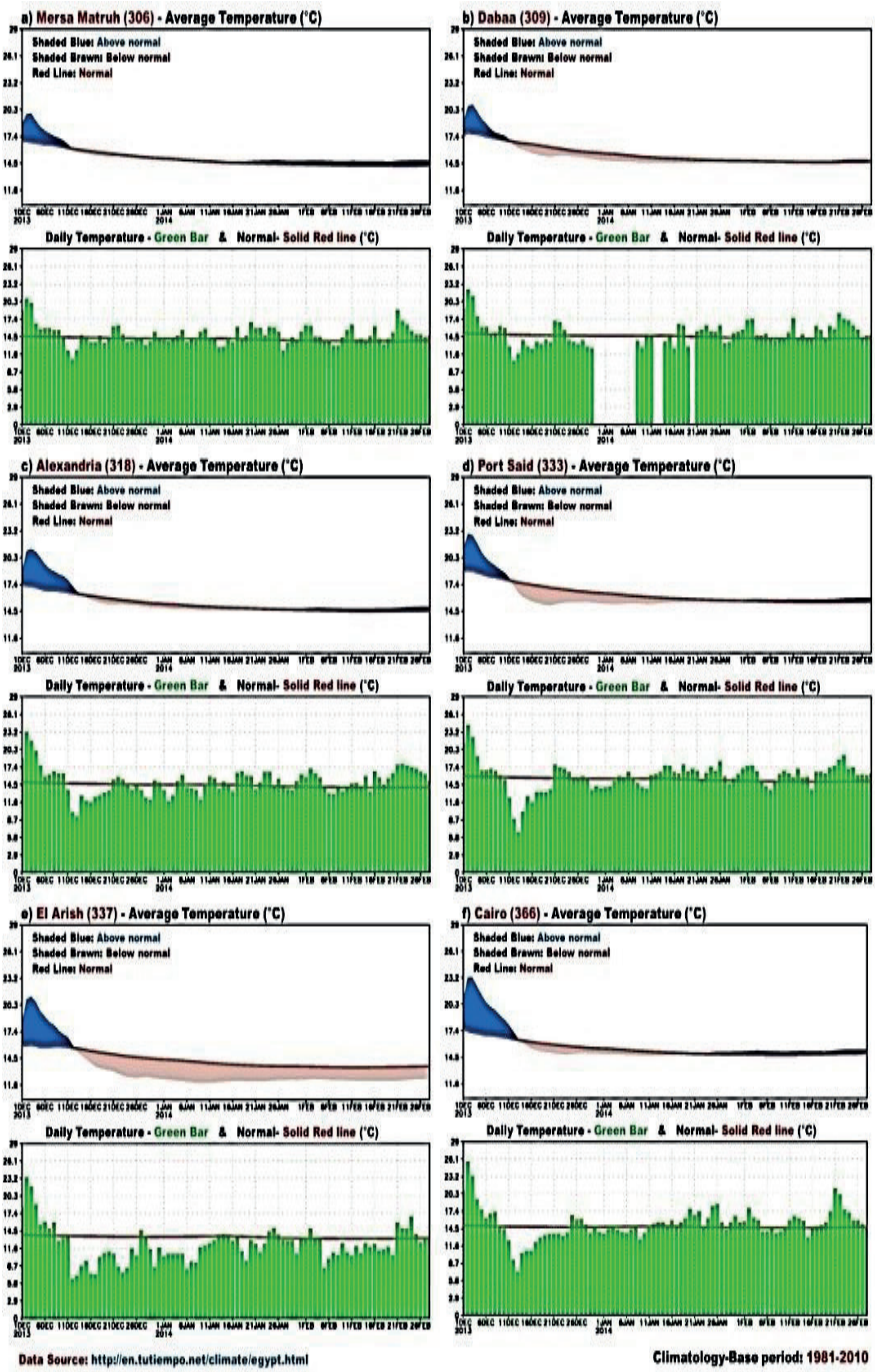

Figure 8. CMT analysis of observed daily and moving average temperature at six stations in northern Egypt during Dec-Jan-Feb (DJF) 2013/14 based on climatology period from 1981 to 2010

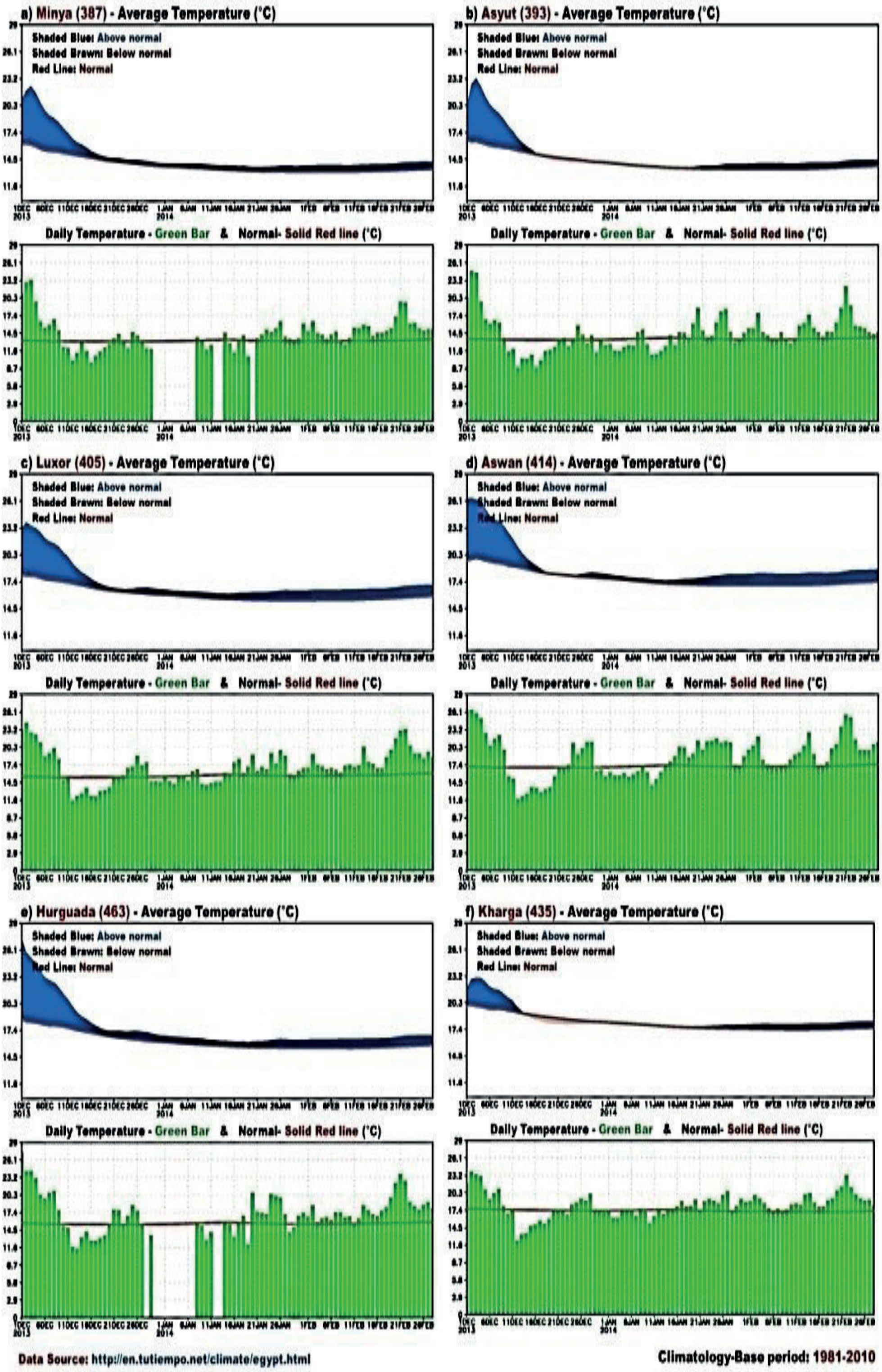

Figure 9. CMT analysis of observed daily and moving average temperature at six stations in southern Egypt during Dec-Jan-Feb (DJF) 2013/14 based on climatology period from 1981 to 2010

Monthly mean temperature, seasonal average and their anomalies during summer season (JJA) 2014 are illustrated in Figure 10. Temperature distribution shows a gradual increase from north to south and ranges from 24° to 36° C in all summer months. Temperature anomaly shows that, the area of study is above normal with the maximum surpluses of 4° C in middle Egypt closest to Asyut station. Moving daily average temperature near normal according to CMT, based analysis over northern stations Figure 11. While Asyut station, records significant above normal temperature as compared to the other stations in southern Egypt as shown in Figure 12.

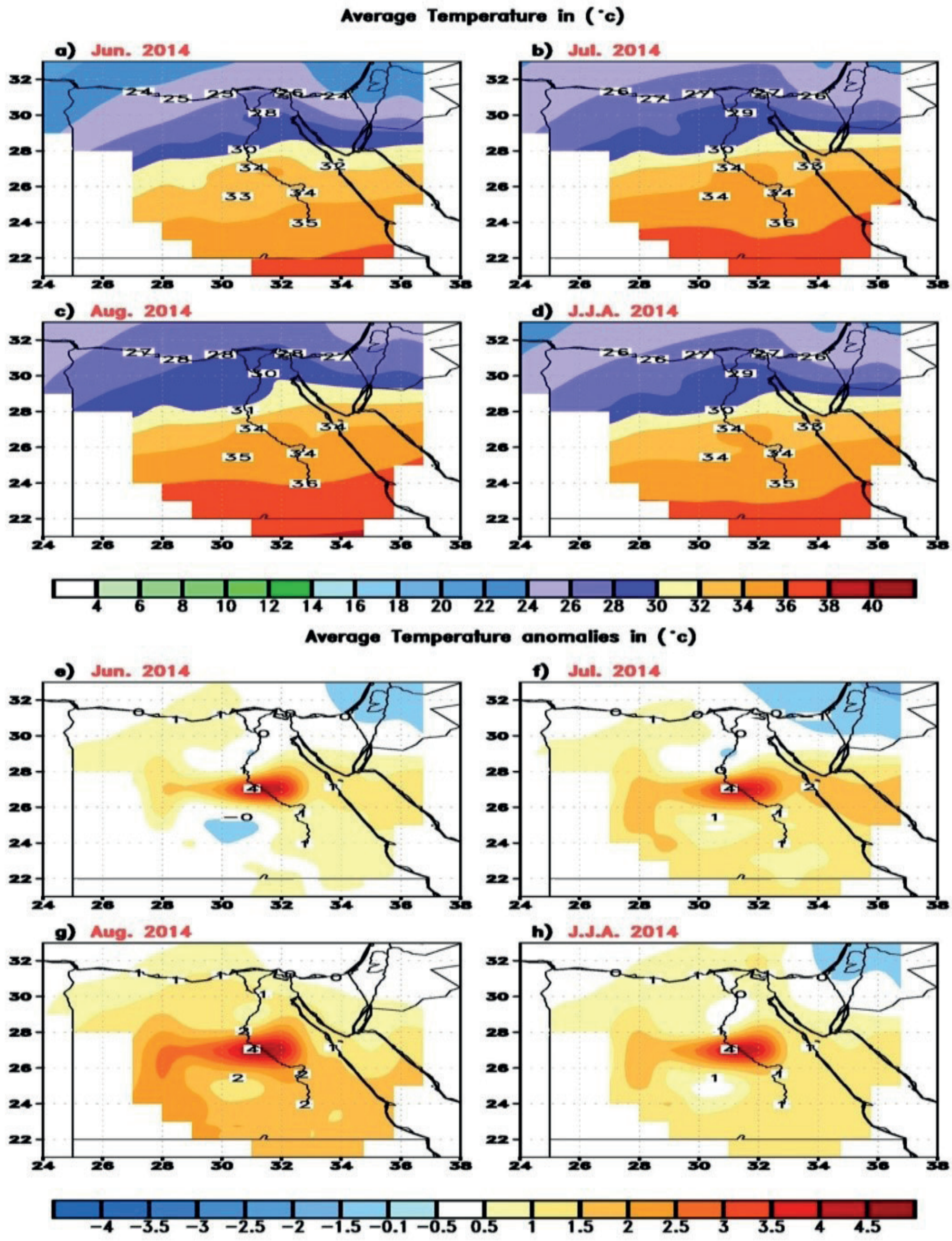

Figure 10. Monthly mean temperature (°C) for Egypt during (a) Jun, (b) July 2014, (c) August 2014, and (d) JJA 2014 and temperature anomalies (°C) for the same months, according to climatic period (1981–2010)

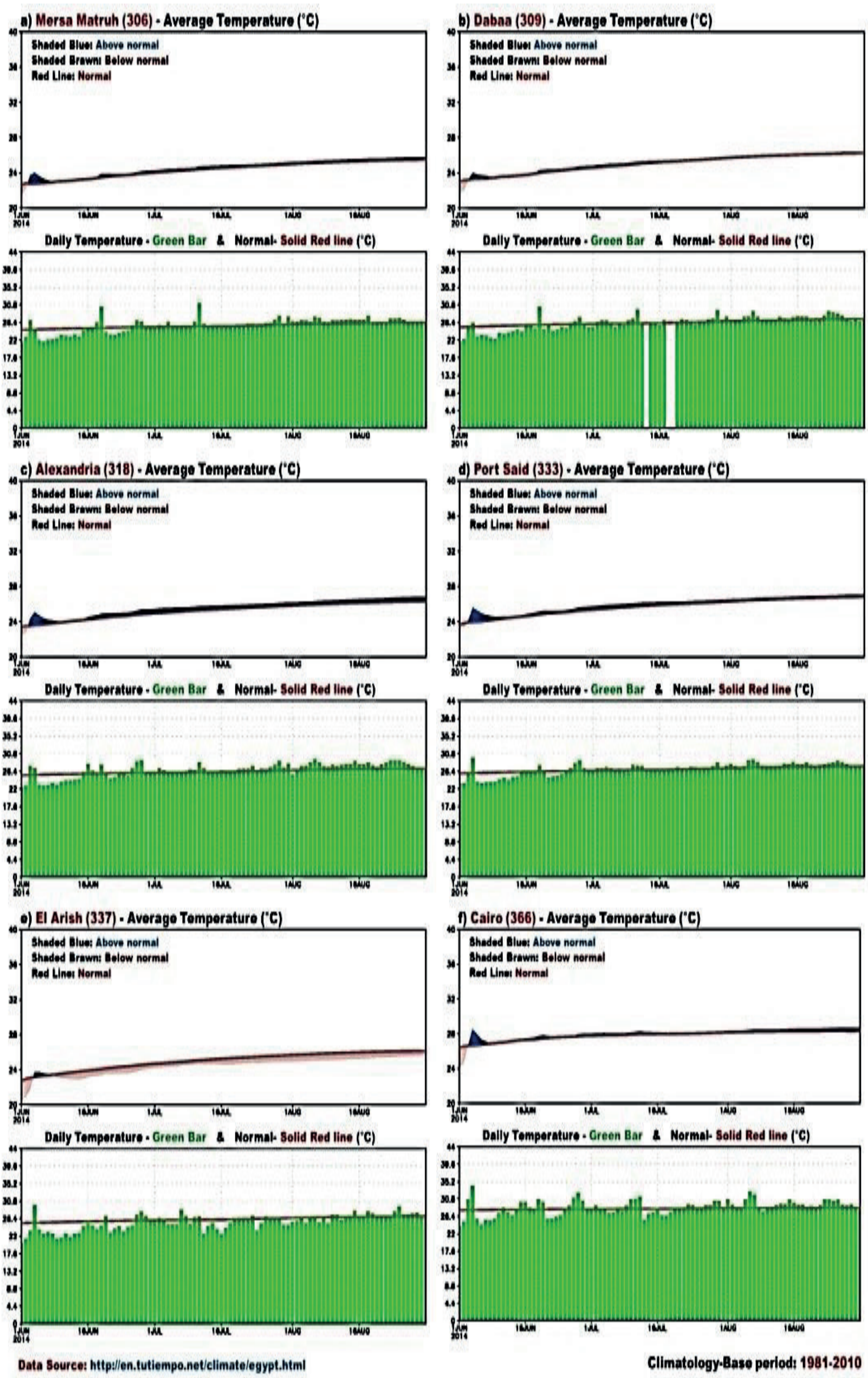

Figure 11. CMT analysis of observed daily and moving average temperature at six stations in northern Egypt during Jun-Jul-Aug (JJA) 2014 based on climatology period from 1981 to 2010

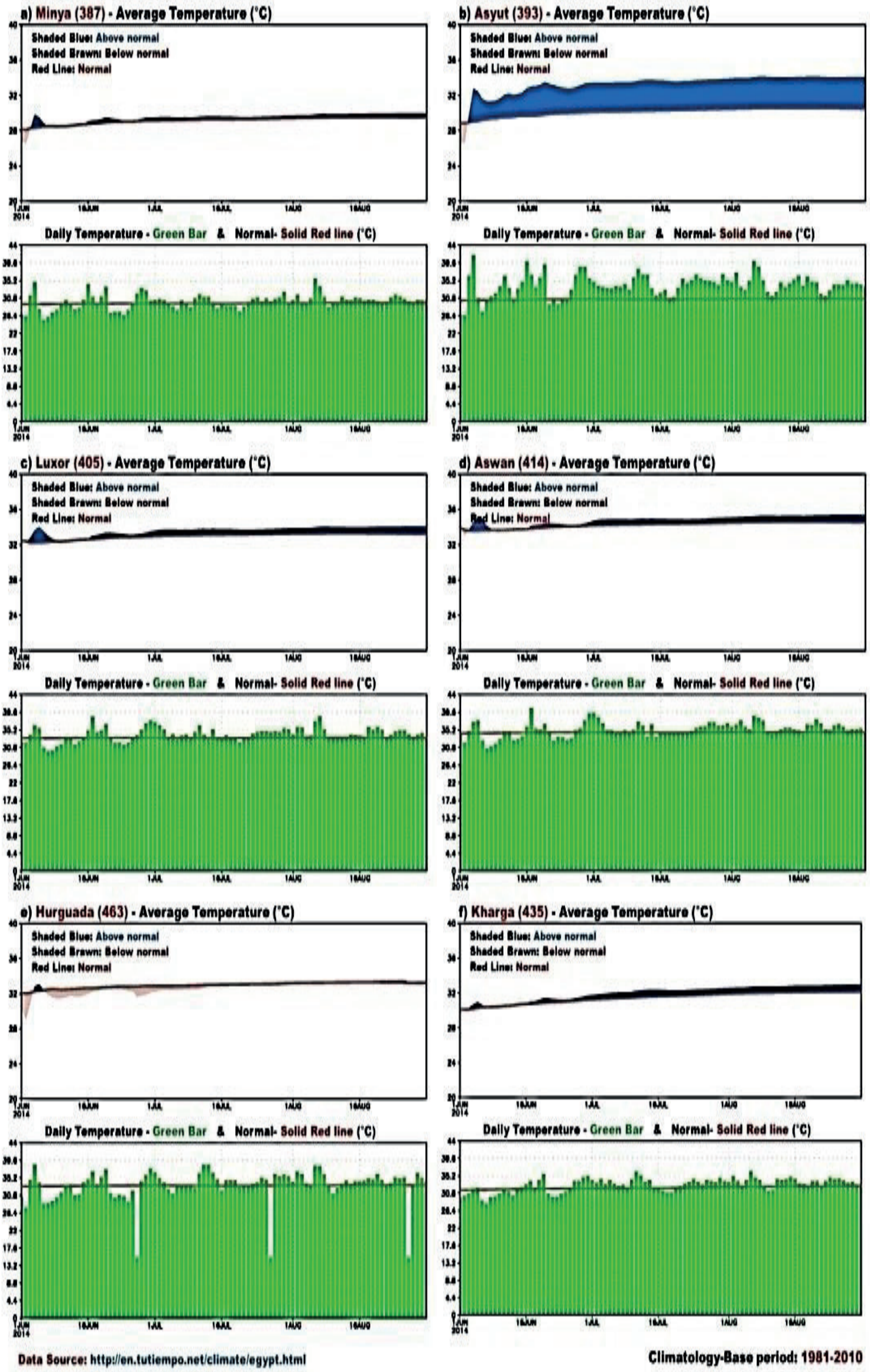

Figure 12. CMT analysis of observed daily and moving average temperature at six stations in southern Egypt during Jun-Jul-Aug (JJA) 2014 based on climatology period from 1981 to 2010

4. Conclusion and Recommendations

In this study, the Climate Monitoring Tool (CMT) is used to analyses the daily and seasonal rainfall and temperature variability over Egypt during winter 2013/14 and summer 2014. Historical atmospheric indices, rainfall and temperature data are used to study the impacts of atmospheric modes variability on Egypt rainfall and temperature climate. The results of our study have shown that there is a link between atmospheric indices such as NAO and ONI, and rainfall and temperature anomalies in Egypt. Wetter (drier) rainfall conditions are linked to positive (negative) NAO and ONI events over north Egypt. In contrast, wetter (drier) rainfall conditions are linked to positive (negative) NAO events and negative (positive) ONI events over southern Egypt during winter season (DJF). Warmer (colder) temperature conditions are linked to negative (positive) NAO events over northern and southern Egypt, while the link to ONI is not that significant over Egypt during winter season (DJF).

For summer season (JJA) warmer (colder) temperature conditions are linked to negative (positive) NAO, and ONI is linked to warmer (colder) temperature in both north, and south region of Egypt. Results also indicate positive extreme DJF precipitation anomalies for the northern Egypt during 1991/92 and of the southern Egypt during 1974/75, 1990/91, 2007/08, 2010/11, and 2012/13. Positive Extreme DJF temperature anomalies were observed during 2009/10 and negative Extreme DJF temperature anomalies were observed during the 1991/92 for northern and southern Egypt. Positive Extreme JJA temperature anomalies were observed during 2010, and 2014. Negative Extreme anomalies were observed during 1987 for the northern Egypt, and during 1984 for the southern Egypt. The CMT tool is run using daily observation to analyses the evolution of rainfall, temperature in a given season. In general, below normal precipitation and above-normal temperature was observed over Egypt during the year 2014.

Recommendations

1) The quality of such improved by increasing data size (number of years and stations)
2) Consistent and reliable data flow are required for daily CMT data and product updates

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