The Libyan Journal of Science (An International Journal): Volume 21A, 2018

Trends in Annual Mean, Maximum and Minimum Air Temperatures At Tripoli Airport, Shahat and Sebha (Libya): 1946-2010

Abdalla Abdulhafid Milad Ali

Department of Atmospheric Science, Faculty of Science, University of Tripoli
E-mail: abdula.milad439@gmail.com

Abstract

Annual mean, annual mean maximum and annual mean minimum temperatures covering the period 1946-2010 at 3 locations in Libya have been analyzed to detect temporal and spatial patterns of long and short term trends. Over the long term period (1946-2010), the annual mean temperature has increased at every site, however the extent of mean temperature upward trend (warming) varied from region to region. The largest trend was found at Sebha followed by Tripoli Airport then Shahat. With respect to trends in maximum and minimum temperatures, the results showed that at northern sites annual mean minimum temperature has experienced more increase than that in the annual mean maximum temperature, whereas at south of Libya maximum temperature increased more than minimum temperature, although for Sebha station, they were comparable. For the short term period, 1991-2010, remarkable increasing trends (warming) were found in annual mean temperature at Tripoli airport and Sebha but for Shahat slight decreasing trend (cooling) was observed. Significant increasing trends occurred in the annual mean maximum temperature at the three regions, whereas for the annual mean minimum temperature increasing significant trends have been found at both North Western Region and Southern Region but for the North Eastern Region non-significant decreasing trend was observed.

Keywords: Climate variability; Temperature anomaly; Upward trend; Global climate; Warming.

المستخلص

في هذه الدراسة تم تحليل بيانات درجات الحرارة السنوية : المتوسطة و الدنيا والعظمى لثلاث مدن متباعدة جغرافياً في ليبيا وهي مطار طرابلس، شحات، سبها وذلك لكشف الأنماط الزمنية والمكانية للإتجاه الحراري العام لهذه المتغيرات على المدى الطويل (1946–2010) والمدى القصير (1991–2010). على المدى الطويل، أثبتت نتائج الدراسة زيادة واضحة في درجة الحرارة السنوية المتوسطة في المواقع الثلاث، بالرغم من تفاوت مقدار الإتجاه التصاعدي (التسخين) من مكان لأخر. أكبر تسخين لوحظ في مدينة سبها (جنوب ليبيا) يليه مطار طرابلس (شمال غرب ليبيا) ثم شحات (شمال شرق ليبيا). بالنسبة لإتجاه درجتي الحرارة الدنيا والعظمى، أوضحت النتائج أنه في المواقع التي تقع في شمال ليبيا كانت الزيادة في درجة الحرارة الدنيا أكبر من تلك في الحرارة العظمى، بينما العكس

Accepted for publication: 24/6/2018

في الجنوب (تسخين أكبر في درجة الحرارة العظمى). أما على المدى القصير، فقد لوحظت إتجاهات تزايدية في درجة الحرارة السنوية المتوسطة في كلاً من مطار طرابلس و سبها بينما الإتجاه كان تناقصي (تبريد) في مدينة شحات. حدثت زيادات معنوية بالنسبة لدرجات الحرارة العظمى في كل المواقع بينما الزيادة لوحظت فقط في مطار طرابلس و سبها مقابل تناقص غير معنوي في شحات بالنسبة لدرجات الحرارة الدنيا.

Introduction

In recent times, climate variability studies and temperature trend analysis, in particular, received a great deal of attention from large number of researchers. Whether studied on global scale or on regional scale there has been a wide and general agreement that air temperature has experienced a remarkable rise in the last century.

In some of these studies, the results revealed a global warming of a magnitude of 0.85°C over the period 1880-2012 with an uncertainty range between 0.65°C and 1.06°C. The mean temperature increase (trend) during the decade 2003-2012 alone was +0.78°C (0.72°C for the minimum temperature and 0.85 °C for the maximum temperature) [1]. The remarkable continuing rise in the early period of the 21st century showed that the period 2001-2010 was the hottest on the whole record so far with an increase of 0.49°C above the 1961-90 average, which was 0.22°C warmer than the 1991-2000 decade (0.27°C above the 1961-90 average) [2].

On regional scale, the annual mean temperature for the whole of Tunisia increased by approximately 1.4° C during the twentieth century. Most of such warming occurred since the late 70s [3]. A clear rising tendency since the beginning of the 1980s for the minimum temperatures was recorded in Algeria where, the increase in maximum temperatures has commenced after 1987 [4].

In Libya, the temperature trends were investigated, focusing on the spatial variability and the studied period lasted only to the end of the last century (1951-1999)[5]. Although the results have revealed a moderate increase in the annual mean temperature which averaged for whole Libya + 0.09°C/Decade and a significant upward rise in the minimum temperature (+ 0.23°C/Decade), maximum temperature, however, has experienced a non-significant downward trend (- 0.06 °C/Decade).

This latter investigation, however, contains few shortages that need to be filled. Firstly, the study has treated temperature trends according to their spatial variability and not temporal variability which misses the understanding of the annual and decadal variability. Secondly, the study does not include the starting period of the 21st century which as it was showed above by several studies contains the hottest years and the hottest decade (2001-2010) so far and resulted in unprecedented increase in both minimum and maximum temperatures [6,7].

Therefore, the aim of this study is to update the study period to include the first decade of the 21st century, i.e. 2001-2010, a period that has been widely reported and agreed as a very hot, in order to detect and asses the amount of change in the annual mean, annual mean maximum and annual mean minimum temperatures for a long term (1946-2010) and short term (1991-2010) periods. The study will target three sites which represent different geographical locations in Libya namely: Tripoli

Airport (Northwest region), Shahat (Northeast region) and Sebha (Southern region).

Data and Methodology

Data Source

Data for this study has been obtained from the archives of the Libyan National Meteorological Centre (LNMC). It covered the period 1946-2010. Type of data is simply monthly averages of mean temperature, maximum temperature and minimum temperature for three climatic stations which have been chosen carefully to represent three regions of Libya so that Tripoli Airport Station represents the northwestern part, Shahat Station represents the northeastern part and finally Sebha station which represents the southern part (Fig. 1). One additional reason for the selection is the quality of their surface temperature data and also their extent.

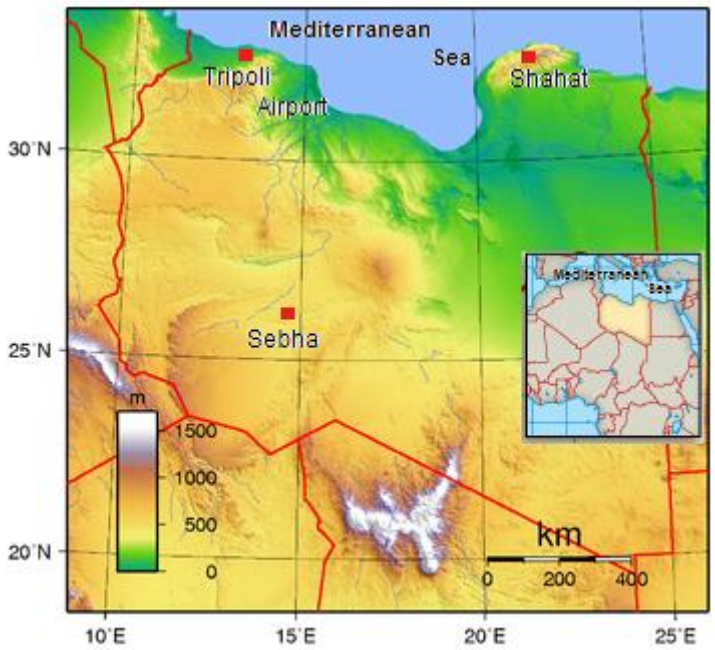

Fig.1. Location of the climatic stations Tripoli Airport, Sebha and Shahat on the map of Libya. The left vertical bar represents elevation above mean sea level (in meters) and the right horizontal scale shows distance (in kilometers).

Data Quality and Homogeneity Test

Although the acquired temperature data for the three climatic stations has adequately covered the targeted study period, there were few years which have contained missing monthly data and therefore, appropriate adjustments were made to fill those missing values, particularly for Sebha station as some years in the 1960s and also 1980 had such gaps with respect to monthly means of both maximum and minimum

temperatures. Hence, gaps were filled using the temporal interpolation method so that monthly value is evaluated as an average of the same variable for the two pre-years and two after years or in other meaning, ± 2 years [8]. In addition, because of the spread of the 3 climatic stations from each other over the vast geographical area of Libya, the data of each individual station (mean temperature) had to be subject to a homogeneity test with other stations to ensure compatibility [9]. Simple linear regression analyses on data of all three stations with each other was carried out (Table 1). The positive bivariate correlations (statistically significant at 95% confidence level) in simple linear regression analyses showed straight lines. This confirmed the high temporal and spatial consistency in the inter-annual variability of temperature at all three stations.

Statistical Approach

To ease the comparison and also to bring uniformity to the three different stations, particularly in their altitudes, the temperature data were standardized using a technique similar to the approach outlined in Pant and Kumar [10] and Bhutiyani et al. [8], which utilizes the base period means of a climatic variable. The base period mean which is commonly known as a reference period mean is the 1961-1990 average of each of the variables mentioned above. Therefore, the first step of our study method is the evaluation of those base means called, sometimes, normals (T) and also the evaluation of the standard deviation (SD) for the reference period 1961-1990 for every variable, i.e. mean temperature, maximum temperature and minimum temperature which is made to all the three stations (Table 2). The second step was the subtraction of base means from the annual averages and this procedure again has been made for every variable and to all stations.

Table 1. Variation of coefficients of linear correlation (r^2) between annual mean temperature series of Tripoli Airport, Sebha, Shahat (*, Significant at 95% confidence level).

	Tripoli Airport	Sebha	Shahat
Trpoli Airport	1.00*	0.55*	0.42*
Sebha	0.55*	1.00*	0.35*
Shahat	0.42*	0.35*	1.00*

Next, the subtracted annual values are divided by the reference period standard deviation. Hence, the resulting values were in fact time series of standardized anomalies of annual mean temperature, annual mean maximum temperature and finally

annual mean minimum temperature in Celsius degrees from their reference period means.

In climate change studies, particularly for temporal change detection which is the main focus of our study, smoothing (filtering) the data over number of years is widely used and very common and this is to avoid large annual variability and also to bring more persistency for trend detection [11,12]. Therefore, before the computation of the different trends, time series of standardized anomalies of annual mean temperature, annual mean maximum temperature and annual mean minimum temperature have been averaged or filtered over a 10-year average basis. The final step was to determine possible trends in those time series. Trends were computed for the different temperature variables by means of least-square fitting equation as the sign of slopes in such equation determine the type (upward or downward) of the trend [5,13]. To determine the rate of temperature change (trend) for every 10 years or per decade, the b coefficients in linear regression equations, which indicate the rate of change in temperature with time, were multiplied by 10 [13]. Then all trends were tested for significance by a two-sided *t* –test at the 5% level.

Figures 2-4, show, for the three stations, the time variability of the annual mean temperature over the long term period (1946-2010) and short term period (1991-2010) respectively. Also shown are the temperature trends for both periods.

Results

Tripoli Airport (North Western Region)

Annual Mean Temperature Trends

It can be noticed (Fig. 2A) that the annual mean temperature has been relatively stable but below its 1961-1990 mean from the starting year up to 1980. The average anomaly for such period has been negative (-0.3˚C). Since 1980, the mean temperature started to rise gradually and continuously all the way through 2010. It is evident that after 1986 all the annual mean temperatures have been above the normal, i.e. above the 1961-1990, mean which simply indicates that the period 1986-2010 is warm and the extent of the warming increases year after year until the end of the study period, or at the year 2010 where the mean temperature anomaly recorded (+1.9˚C). The estimated long term trend for the annual mean temperature was significantly positive; upward (+ 0.36˚C/Decade). As for the short term (Fig. 2B), and in accordance to what has been stated above, the mean temperature experienced a noticeable warming from the beginning to the end of the period and every year was above normal. It is worth mentioning that the continuous yearly increase of the mean temperature as it soars from +0.3˚C at 1991 to 1.9˚C at 2010 suggests that the last two decades have been the hottest over the whole period. Therefore, the estimated trend for the short term period has been positive (+0.75˚C/Decade) and was highly significant.

Annual Mean Maximum Temperature Trends

For the long term period, maximum temperature was relatively stable (Fig. 2C); around the mean, from the beginning of the study period until the year 1968 and after

which suffered a steady decline up to 1980 where the anomaly at this year recorded -0.8˚C. Then a sharp increase for ten years occurred through 1990 where the anomaly soared to +0.9˚C and followed by another drop all the way to 1998 as the annual mean maximum temperature of this year equaled the 1961-1990 mean. From 1998 up to 2010, the maximum temperature has been subject to a very sharp and continuous lift to register an anomaly (+1.8 ˚C) at the last year of the study period. The estimated long term trend for the annual mean maximum temperature was significantly positive (+ 0.30˚C/Decade). As for to the short term period (Fig. 2D), a clear fall has been witnessed during the first seven years, i.e. from 1991, with maximum temperature anomaly +0.9˚C to 1998 with zero anomaly. But since the year 1998, as it was demonstrated earlier, a sudden and rapid year after year increase has dominated up to 2008 as the anomaly during this year (+ 1.9˚C) has been the highest during the whole period and the average anomaly of the last two years was as high as + 1.7˚C. The estimated trend for this period was positively high and significant (+ 0.89˚C/Decade).

Table 2. Calculated reference period (1961-1990) means (T C˚) and standard deviations (SD) related to the (annual mean, annual mean maximum, annual mean minimum) temperatures for the Tripoli Airport, Sebha and Shahat climatic stations.

Station	**Base Mean Temperature (T C˚)**			**Standard Deviation (SD)**		
	Mean Temp.	Maximum Temp.	Minimum Temp.	Mean Temp	Maximum Temp	Minimum Temp.
Tripoli Airport	20.4	26.9	13.9	0.4	0.6	0.4
Sebha	22.9	30.2	15.2	0.6	0.4	0.6
Shahat	16.4	20.9	12.0	0.4	0.5	0.5

Annual Mean Minimum Temperature Trends

It can be seen (Fig. 2E), that a slight and short decline up to 1957 has happened as the annual mean minimum temperature anomaly for this year valued -0.74˚C. After that, small but steady increase has continued from 1957 to 1977 although that during this somewhat lengthy period (20 years), the temperature anomalies have been below the normal and only at year 1977 when the minimum temperature anomaly was positive and above the normal (+0.21˚C). From 1977 to 1987, the minimum temperature suffered a steady drop to register at 1987 a below normal anomaly (-0.53 ˚C). Since then, a clear increase has been experienced which was sharp enough to make the minimum temperature reach a highly positive anomaly at year 1997 (+1.54˚C). Then a small slide in the opposite direction took place between 1997 and 2000 which resulted in the drop of minimum temperature to +1.01˚C at year 2000. Afterwards, another rise has prevailed all the way from 2000 up to 2010 where at the last year of the study period, the anomaly in the minimum temperature recorded its highest value during study period (+2.02˚C). The estimated long term annual mean temperature trend

was highly significant and positive (+0.43˚C/Decade).

Similar to what has been demonstrated above, considering the late two decades of the long term period, the annual mean minimum temperature has been subject to unprecedented warming during those two decades (Fig. 2F). Over those twenty years, fifteen of them recorded anomalies (> +1.0˚C) and the closer the end of the period, the larger the anomaly value. The resulting short term trend in the annual mean minimum therefore has been upward, significant and positive one (+0.60˚C/Decade).

Shahat (North Eastern Region)

Annual Mean Temperature Trends

Over the whole period of study (Fig. 3A), it can be seen that Shahat's annual mean temperature has experienced a sharp increase from the beginning up to year 1960 where the temperature anomaly recorded + 0.4 ˚C, then followed by similar change but in the opposite direction to go back to its normal at 1961. Repeating the same rise of the mean temperature in the beginning, it has increased again to reach an anomaly (+ 0.4˚C) in 1964 which was followed by another sharp drop (-0.1˚C) in 1965. From this year, steady small increase was noticed up to 1971 (+0.2˚C). The annual mean temperature has been relatively stable around the mean up to the year 1977, after which it suffered a decline through 1983 where the calculated value of the temperature anomaly at this year was below normal (-0.5˚C). Since then, a significant steady sharp rise has been noticed all the way up to the year 2001 with temperature anomaly above the normal (+1.5˚C) followed by nine years significant decline to become +0.5˚C at year 2009 and another rise during 2010 with +0.9˚C anomaly. It is important to emphasize that all the years after 1988 through the end of study period (consecutive 22 years) were above normal, i.e. warm years. The estimated long term trend for the annual mean temperature was significantly +ve upward trend (+0.23˚C/Decade).

With respect to the mean temperature variability during the short term period, it seemed (Fig. 3B) that it has almost been divided between an increase in the first half and decease in the second half. As a result however, the total trend for this period has not been significant, very small and in the negative direction (-0.02˚C/Decade). It is worth mentioning that the anomalies during last two decades were all positive, ranged from a highest at 1999 (+1.6˚C) to a lowest at 1993 (+0.3˚C) which simply means that this period has been warm and also includes the hottest years during the whole period of study.

Annual Mean Maximum Temperature Trends

Figure 3C, demonstrates that the maximum temperature variability starting from the beginning to the end of the period of study has been profoundly clear; fluctuation between decrease and increase, particularly in the early years although the anomalies of maximum temperature during those years have been below normal. However, since the year 1965, a rapid increase has taken place continuously up to 1979 where the maximum temperature anomaly soared to + 0.4˚C.

Afterwards, the maximum temperature suffered a sharp fall for about thirteen consecutive years to end up with a record negative anomaly (the lowest over the whole period) of -0.6˚ at year 1992. From this year, the maximum temperature has experienced a steady warming until the year 2002 followed by a short four year decline between 2002 and 2006 and then another very strong and sharp rise up to the last year of the study period.

Fig. 2. Temporal variability of anomalies of annual mean (A-B), annual mean maximum (C-D) and annual mean minimum (E-F) temperatures (˚C) along with their trend lines for Tripoli Airport site.

Due to the well noticed large variability in the annual mean maximum temperature between ups and downs over the whole period, the resulting trend was very small (+0.01˚C/Decade) and not significant. As for the short term period, as it was mentioned above, the whole period has been subject to a steady rapid increase with a very significant positive trend valued +0.35˚C/Decade (Fig. 3D).

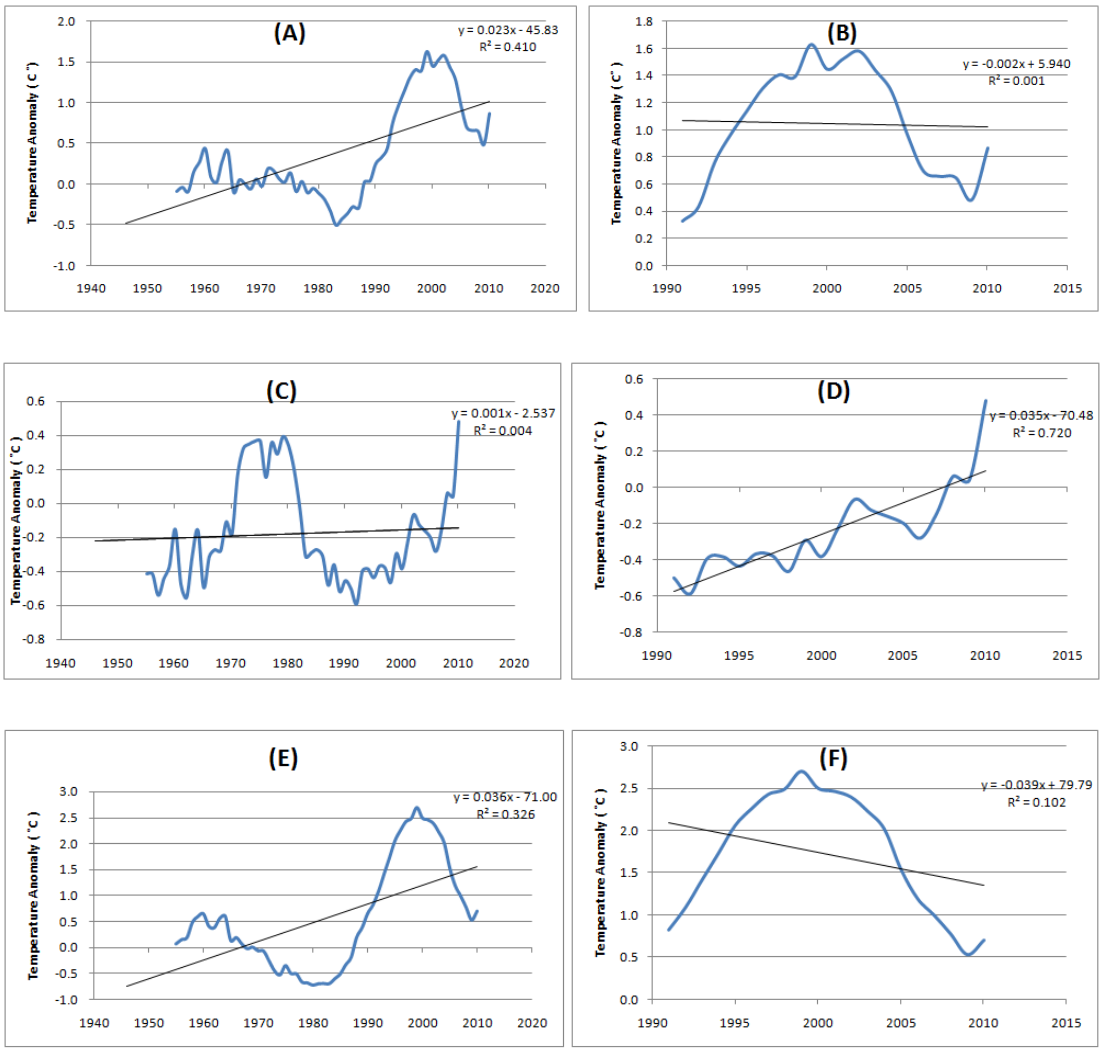

Fig. 3. Temporal variability of anomalies of annual mean (A-B), annual mean maximum (C-D) and annual mean minimum (E-F) temperatures (˚ C) along with their trend lines for Shahat site.

Annual Mean Minimum Temperature Trends

The temporal variability of the annual mean minimum temperature during the long term period (Fig. 3E), resembles that of the annual mean temperature (Fig. 3A) to a large extent. In every stage of its variability, somewhat warming in the early years up to 1964, the relative stability up to 1977 then the sharp decline up to about 1983, followed

by significant rapid rise through 2001. Also the nine years drop of minimum temperature from 2001 to 2009 and even the 2010 increase which makes the similarity so evident between both temperatures. There has been, however superiority for the minimum temperature on mean temperature with respect to anomalies. For instance, the highest decline below normal at year 1983 for the annual mean minimum temperature was - 0.7˚C compared to -0.5˚C for the annual mean temperature. Also the highest rise above the normal at year 1999 was as large as +2.7˚C for the annual mean minimum temperature compared to +1.6˚C for the annual mean temperature.

The computed long term annual mean minimum temperature trend was significantly positive or upward (+ 0.36˚C/Decade).

Over the short term period (Fig. 3F), the annual mean minimum temperature is of similar manner to what happened to annual mean temperature in the same period, has suffered from double different variability with a sharp rise between 1991 and 1999, where minimum temperature anomalies at both years were +0.8˚C and +2.7˚C respectively, and a sharp fall from +2.7˚C at 1999 to +0.8˚C at 2010. Therefore, the resulting trend has biased the downward style and the last two decades annual mean minimum temperature calculated trend has been strongly towards the negative direction, although not significant (-0.39˚C/Decade).

Sebha (Southern Region)

Annual Mean Temperature Trends

The annual mean temperature during the start of the period has suffered a clear drop down to its lowest value at year 1957 with an approximate anomaly of -1.0˚C, but from 1957 there has been a steady rise up to 1964 as the anomaly of this year was very close to the mean (Fig. 4A-B). Between 1964 and 1974, mean temperature was still below normal and slight decline occurred in general although it was associated with annual variability. Since 1974 mean temperature has been subject to a gradual annual increase up to 1988 where the anomaly was positive (+ 0.3˚C) but after that, the increase has been remarkably sharp all the way till the last year of the study period as mean temperature anomaly of this year was +2.8˚C above the normal (Fig. 4A). It is also evident from the same figure, that prior to year 1984 all anomalies were below normal whereas all anomalies starting with 1984, and after, were above normal and the massive rise has begun since 1988. The overall annual mean temperature trend (1946-2010) has been significantly positive (+0.55˚C/Decade).

Over the short term period (Fig. 4B), annual mean temperature has experienced an incredible rapid lift from the first year (1991) with anomaly of just +0.2˚C to the last year 2010 when the anomaly soared to an immense value (+2.8˚C) above the normal. In fact, it is interesting to observe (Fig. 4A-B) that except for the three years (1988-1990) which were slightly above normal, warming in the annual mean temperature has occurred mainly during the last twenty years. The estimated short term annual mean temperature trend has been a high and upward significant one (+1.43˚C/Decade).

Annual Mean Maximum Temperature Trends

It is clear (Fig. 4C) that the annual mean maximum temperature has undergone an annual variability similar to that of the mean temperature in general. However, the difference is that between 1964 and 1974 for the maximum temperature there has been an increase unlike the noticeable decrease that has occurred during the same period with respect to the annual mean temperature. Since 1974, maximum temperature has steadily fluctuated around the mean up to 1994 as the average anomaly for the whole period (1974-1994) recorded just -0.08˚C but afterwards, it was subject to a very sharp lift through 2010 where the anomaly of this last year of the study period was approximately +2.9˚C above the normal. Recalling what has been demonstrated above, regarding the mean temperature, it is evident (Fig. 4C) that the warming in the annual mean maximum temperature for Sebha has begun in the 90s and increased annually since then. The long term period trend in the annual mean maximum temperature was positively significant (+0.57˚C/Decade). During the short period (Fig. 4D), the increase is so obvious from the beginning to the end. The lifting of maximum temperature started from below normal temperature at year1991 (-0.2˚C) and ended with noticeable above high temperature at year 2010 as the anomaly soared (+2.9˚C) above the normal. The 1991-2010 annual mean maximum temperature trend magnitude has been as large as +1.89˚C/Decade and highly significant.

Annual Mean Minimum Temperature Trends

Figure 4E-F, demonstrates the long and short term variability in the annual mean minimum temperature. The slight fall in the annual mean minimum temperature from the beginning to year 1957 was followed by relatively steady rise up to 1964, then it dropped again all the way up to year 1974 followed by an incredible sharp increase up to 2010. This has undoubtedly resembled the temporal variability of the annual mean temperature (Fig. 4E & 4A). Nevertheless, the year that has witnessed lowest annual mean minimum temperature over the whole study period (-0.93˚C) was 1974 compared to year 1957 of the lowest annual mean temperature with an approximate anomaly (-1.0˚C). It seems (Fig. 4E) that the annual mean minimum temperature sharp decline from 1964 down to 1974 has been the reason for lowering the long term mean minimum temperature trend which otherwise would be larger than both the annual mean and the annual mean maximum temperatures. The long term minimum temperature trend was significantly upward (+0.53˚C/Decade). As for the short term period (Fig. 4F), all minimum temperature anomalies were clearly above normal and the year after year increase in their values reveals the extent of the sharpness in the annual mean minimum temperature curve of variability.

Similar to the shape of variability and also to the extent of warming during the last two decades for both mean and maximum temperatures, it can be said (Fig. 4F) that the increase which has commenced at 1991 (+0.7˚C) through 2010 (+2.6˚C) could be considered as the cause for the total minimum temperature significant warming over the whole study period. Therefore, short term trend has been relatively large (upward trend) and highly significant (+0.98˚C/Decade).

Discussion

It was found during the long term (1946-2010) period that the annual mean temperature has increased significantly at the three sites and the largest trend was seen at Sebha, south of Libya (+0.55˚C/Decade) followed by Tripoli airport in the north west of Libya (+0.36˚C/Decade) then Shahat in the north east of Libya (+0.23˚C/Decade). These results agree to a large extent with the outcomes of many climatic analyses conducted on the globe e.g. Jones et al. [14], Hansen and Lebedeff [15], Jones and Briffa [16], Jones et al. [2] and with those made for the northern hemisphere e.g. Parker et al. [17], Jones and Briffa [18], El Kenawy et al. [5].

Fig. 4. Temporal variability of anomalies of annual mean (A-B), annual mean maximum (C-D) and annual mean minimum (E-F) temperatures (˚C) along with their trend lines for Sebha site.

It has been revealed also during the same period that the trend in annual minimum temperature has been highly significant (+ve) at every station compared to maximum

temperature where the trend was only significant at Tripoli air port and Sebha with nearly no trend in Shahat. The increasing trend in the annual mean minimum temperature at each of the three studied stations clearly confirms the results obtained by El Kenawy et al. [5], for whole Libya. However, it is evident that the value of minimum temperature trend averaged for the three sites in this study +0.44˚C/Decade is nearly double the trend of the same variable presented in El Kenawy et al. [5]. It could be argued that the inclusion of the last decade (2001-2010) into our period of study which has been reported in latest analysis on global climate variability as the warmest decade on record [2], might be the cause for the remarkable trend increase. In addition, stations that showed higher trends in their annual mean minimum temperatures compared to their trends in annual mean maximum temperatures are the ones closer to coast; Tripoli Airport and Shahat, whereas stations with larger trends in their annual mean maximum temperatures than minimum temperature are found to be situated in the deep central interior; Sebha station. These results confirm the findings of a regional study by Kruger and Shongwe [19]. In the short term period, the annual mean temperatures showed highly significant increase in both Tripoli airport and Sebha with trends of +0.75˚C/Decade and +1.43˚C/Decade, respectively, and this increase was associated with a significant rise in their annual mean maximum and minimum temperatures. In contrast, for Shahat station, a very marginal insignificant decrease (-0.02˚C/Decade) occurred in its annual mean temperature which was associated with a significant rise in the maximum temperature but with a clear decline trend in the minimum temperature although it was non-significant. Interestingly, during the last two decades, the increase in the maximum temperature has occurred at each of the three sites and it has been larger than that in the minimum temperature. These results conform with many recent regional studies such as Maugeri and Nanni [20], Kumar et al. [21] and Bhutiyani et al. [8]. Moreover, the incredible increase in both minimum and maximum temperatures during the last two decades in particular agrees with latest findings of the IPCC [1], Nouaceur et al. [7], Nouaceur and Muraresc [4] and Jones et al. [2].

Conclusion

The outcome of our analysis of temperature trend considering the three sites in Libya; Tripoli Airport, Sebha and Shahat, has agreed to a large extent to previous results presented by many studies carried out regarding climatic variability on various scales; global, regional and local. Firstly, the continuous rapid warming since the mid 80s, clearly represented in the three stations, has been widely reported. Secondly, the relatively general cold period prior to 1980 which has dominated all studied stations agrees with results from several studies. Thirdly the updated data, up to 2010, resulted in high values of trends for annual mean and annual mean minimum temperatures and also a remarkable rise in the annual mean maximum temperature trend, as the latter result contrasts with the findings of El Kenawy et al. [5]. The inclusion of the decade 1991-2010 temperature data which was presented by Jones et al. [2] in their latest study as the warmest on global record could undoubtedly have contributed in the trend strengthening and in particular shifted the trends in the annual mean maximum

temperature from a lower than to a higher than the annual mean minimum temperature trends.

References

[1] IPCC (Intergovernmental Panel on Climate Change) (2013). Climate Change, The Physical Science Basis. http://www.climatechange 2013.org/

[2] Jones, P. D., Parker, T. J. and Briffa, K. R. (2016). Global and hemispheric temperature anomalies—land and marine instrumental records. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A., doi: 10.3334/CDIAC/cli.002

[3] Mitchell, J. M., New. L. and Hulme, M. (2002). Climatic change in Tunisia. http//www.cru.ueaac.uk/-timm/data/index-table.html.

[4] Nouaceur, Z. and Murăresc, O. (2014). The Recent Climate Change in Algeria (North Africa)., 2nd International Conference - Water resources and wetlands. 11-13 Tulcea (Romania).

[5] El Kenawy, A. M., Moreno, J. L., Vicente-Serrano, S. M. and Mekid, M. S. (2009). Temperature trends in Libya over the second half of the 20th century. Theor. Appl. Climatol., **98**, 1–8.

[6] Morice, C. P., Kennedy, J. J., Rayner, N. A. and Jones, P. D. (2012). Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: the HadCRUT4 dataset. Journal of Geophysical Research, 117, D08101, doi:10.1029/2011JD017187.

[7] Nouaceur, Z., Laignel, B. and Turki, I. (2013). Physio-Géohttp://physio-geo.revues.org/3686; DOI: 10.4000/physio-geo.3686, Changements climatiques au Maghreb: vers des conditions plus humides et plus chaudes sur le littoral algérien, Volume **7**.

[8] Bhutiyani, M. R., Vishwas, S. K. and Pawar, N. J. (2007). Long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century. Climatic Change, **85**, 159–177

[9] Van der Made, J. W. (1987). Casebook of methods for computing hydrological parameters for water projects. In: Lowing M. J. (ed), A contribution to the International Hydrological Program. UNESCO, Paris.

[10] Pant, G. B. and Rupa Kumar, K. (1997). Climates of South Asia. Behavior Studies In Climatology. Wiley, New York, 126–127.

[11] Salinger, M. J., Basber, R. E., Fitzbarris, B. B., Hay, J. E., Jones, P.D., Maceight, J.P. and Schmidely-Leleu, I. (1995). Climatic trends in the South-West Pacific. Int. J. Climatol., **15**, 285–302

[12] Sneyers, R. (1990). On the statistical analysis of series of observations. WMO Technical Note, No.**143**.

[13] Pant, G. B., Borgaonkar, H. P., and Rupa Kumar, K. (1999). Climate variability over the Western Himalaya since little ice age: dendro-climatic implications. In: Proceedings of national snow science workshop "Technology in support of snow and avalanche research", Manali (India).

[14] Jones, P. D., Wigley, T. M. L. and Wright, P. B. (1986). Global temperature variations between 1861 and 1984. Nature, **322**, 430- 434

[15] Hansen, J. and Lebedeff, S. (1988). Global surface air temperatures: update through 1987. Geophys. Res. Letters, **15**, 323-326.

[16] Jones, P. D. and Briffa, K. R. (1992). Global surface air temperature variations during the twentieth century. Part 1 spatial, temporal and seasonal details. The Holocene, **2**, 174-188.

[17] Parker, D. E., Jones, P. D., Folland, C. K. and Bevan, A. (1994). Inter-decadal changes of surface temperature since the late nineteenth century. Journal of Geophysical Research, **99**, 14373–14399.

[18] Jones, P. D. and Briffa, K. R. (1996). Decadal-to-century timescale variability of regional and hemispheric-scale temperature. In: The Natural Variability of the Climate System on 10-100 Year Timescales. Washington D. C., National Academic Press.

[19] Kruger, A. C. and Shongwe, S. (2004). Temperature Trends in South Africa 1960-2003. Int. J. Climatol., **24**, 1929–1945

[20] Maugeri, A. and Nanni, T. (1998). Surface Air Temperature Variations in Italy: Recent Trends and an Update to 1993. Theor. Appl. Climatol., **61**, 191-196.

[21] Kumar, P. V., Bindi, M., Alfonso, C. and Giampiero, M. (2005). Detection Of Variations In Air Temperature At Time Scales during The Period 1889–1998 At Firenze, Italy. Climatic Change, **72**, 123–150

[22] Hansen, J. and Lebedeff, S. (1987). Global trends of measured surface air temperature. J. Geophys. Res., **92**, 13345-13372.