Annual and Decadal Temperature variability in Libya: A comprehensive Analysis (1931-2020)

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A R T I C L E   I N F O

A B S T R A C T

Air temperature is a crucial indicator of the most important and urgent subject i.e. climate change globally, regionally and locally. Thus, Libya's annual mean temperature has been investigated in terms of annual variability and also decadal variability over long time series covering the period 1931-2020. A significant increase in the annual mean temperature of magnitude 0.9 C ˚ was revealed over the whole period, whereas during the late 1991-2020 period alone, a remarkable 1.16 C ˚ warming has been recorded. The latter warming figure, however has been shown as the prime responsible for the whole period annual mean temperature increase. With respect to decadal variability, despite the streak of six colder than average decades which started from the decade 1931-1940 with (-0.1 C ˚) and ended at decade 1981-1990 with (-0.2 C ˚) standardized temperature anomaly considering the reference period (1931-2020), three significant hotter than normal decades have been identified which are 1991-2000, 2001-2010 and 2011-2020 with standardized temperature anomalies (+0.5 C ˚), (+1.6 C ˚) and (+0.9 C ˚), respectively. In addition to the confirmation of the world wide well documented hot recent era i.e. last 30 year period specifically, results of this study are crucial and very important for decision makers, particularly those in close touch with diverse life sectors e.g. human health, water management, agriculture etc.

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Keywords: Air temperature, Annual variability, Decadal variability, Standardized anomaly, Hotter than normal

1. Introduction

Air temperature is an important element of weather condition in any region and its long term variability might be considered as the prime determinant of climate change at that region. Numerous studies have been conducted on temperature trends and temperature variability in general since the mid of the last century till recently and the emerged outcomes have been beneficial, supportive and contributive. The spatial scale of those studies has however, differed from global e.g. (Jones, 1986 [1]; Hansen and Lebedeff, 1988 [2]; Folland et al.,1992 [3]; Easterling *et al*., 2000 [4]; Jones *et al.* 2001 [5]; Jones and Moberg 2003 [6]; Morice et al., 2012 [7]; IPCC, 2013 [8]; Jones *et al.* 2016 [9] to regional (Vuille et al. 2003[10]; Diaz et al. 2003 [11]; Bhutiyani *et al*., 2007 [12]; Brunet et al. 2007 [13]) and local e.g. (Mitchell *et al*., 2002 over Tunisia [14]; Kruger and Shongwe, 2004 over South Africa [15]; Kumar *et al*., 2005 over Italy [16]; Elkenawy et al., 2009 over Libya [17]; Nouaceur and Murărescu, 2014 over Algeria [18]). The results from those studies showed in general a noticeable rise in mean temperature which has been more evident since the late 70s of last century and in the early years of 21st century. A rise of 0.85° C magnitude (upward trend) in the global mean temperature has been revealed during the period 1880-2012 with a stunning 0.78 ° C increase during the decade 2003-2012 alone (IPCC, 2013 [8]). The continuing steady rise in the global mean temperature during the early period of 21st century has also been confirmed by (Jones *et al.* 2016 [9]). In their findings, the decade 1991-2000 was (0.274 °C) above the 1961-1990 average whereas (0.490 °C) above the 1961-1990 average was documented for the 2001-2010 decade which was (0.216 °C) warmer than 1991-2000 and has been described as the hottest decade on the whole record of the global mean temperature. Locally, (Mitchell *et al*., 2002 [14]) showed an approximate increase in the annual mean temperature for the whole

of Tunisia of 1.4° C during the twentieth century and most of which occurred after late 70s. Concerning the study area i.e. Libya, (Elkenawy et al., 2009 [17]) investigated the temperature trends in Libya focusing only on the spatial variability of those trends and covering the period (1951-1999). The results revealed a moderate increase in the annual mean temperature averaged for whole Libya of (+ 0.09 C°/Decade). Recently, (Ali, 2018 [19]) carried out a thorough study targeting three locations from north west, north east and south of Libya and aiming the detection of trends in annual mean, annual mean maximum and annual mean minimum temperatures over two periods, long term (1946-2010) and short term (1991-2010). The results concerning period (1946-2010) indicated an upward (warming) trend at every location although the extent of the trend was largest at southern site followed by north western site then the north eastern site. With respect to the short term period (1991-2010), increasing trends (warming) have been revealed in annual mean temperature at north western and southern sights but for the north eastern, a slight decreasing trend (cooling) was observed.

The above mentioned studies however, have focused mainly on the temperature trend direction in general i.e. judging temperature variability in any time series according to their trend type, whether it was positive (upward) or negative (downward) without identifying sequence of years that characterize colder than average and hotter than average periods. In the context of largely documented global warming era it has become evident that any shift in mean and variability of air temperature could largely influence and enforce the intensity of extreme weather and climate events e.g. (Shneider et al., 2015[20]; Van der Wiel and Bintanja, 2021[21]; Zhang et al., 2021[22]). Moreover, significant correlation has been found between

temperature rise and increase in the frequency of heat waves during the last decades e.g. (Dobricic et al., 2020[23]). In addition and more importantly considering Libya, no information is available about the type and scale of climate variability during the early two decades of the 21st century, a period that has widely been showed as the hottest on record e.g. (Jones *et al.* 2016 [9]). Thus, the aim of the present study is (i) to investigate the type of variability of the annual mean temperature averaged over Libya for the long period 1931-2020. (ii) to evaluate decadal standardized mean temperature anomalies for the 9 decades starting with decade 1931-1940 and ending with decade 2011-2020, which allows the identification of cold and warm decades using the long term mean temperature average and long term standard deviation.

2. Data and Methodology

The data that has been used in this study was available and obtained from version 4 monthly CRU (Climatic Research Unit) data set (Harris et al., 2020 [24]). The initial data sets were in fact monthly mean temperatures representing 25 regions which cover the whole of Libya over the lengthy period 1931-2020, see Fig.(1). The CRU dataset is based on the interpolation of observed values from extensive networks of weather stations (Harris et al., 2020 [24]). The advantages of using CRU data set are:

(i) Full coverage of the study targeted period (1931-2020)

(ii) No missing data

(iii) Homogenous time series, well treated in terms of quality and efficiency

The monthly mean temperature for every region was firstly transformed to annual means then averaged for whole Libya so that the resulted time series are indeed

the annual mean temperature for Libya from 1931 through 2020.

Secondly, a reference average and reference standard deviation were computed from the lengthy reference period (1931-2020), see table (1).

Thirdly, using the reference period mean, annual mean temperature anomalies for every year was calculated and standardized through the division of anomalies by the standard deviation mentioned above which conform with the approach of (Pant and Kumar, 1997 [25]; Buhitiyani et al. 2007 [26]).

Finally, the resulted standardized anomalies of annual mean temperatures were averaged on decadal basis so that each of the nine decades between 1931 and 2020 is represented by an average value of the annual mean standardized temperature. The nine decades are listed as follows: 1931-1940, 1941-1950, 1951-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010, 2011-2020.
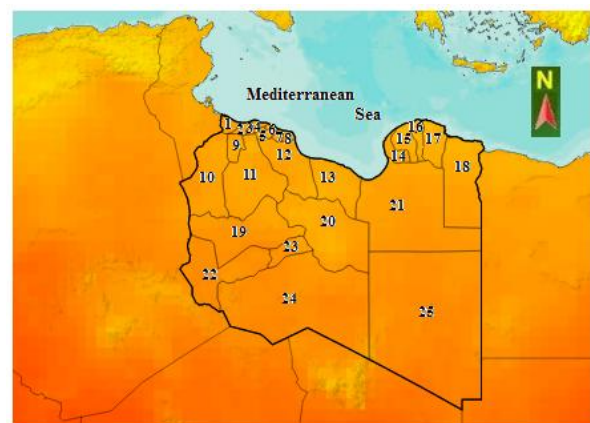
Fig.1. The twenty five regions (source of initial data) depicted on the map of Libya. Source (Version 4 of the CRU TS monthly climate Data Set, Harris et al., 2020 (24)).

Annual Temperature Mean and Annual Temperature Standard Deviation for the ninety years Reference Period (1931-2020).

Table 1. Reference Period length, reference period means temperature average and reference period mean temperature standard deviation.
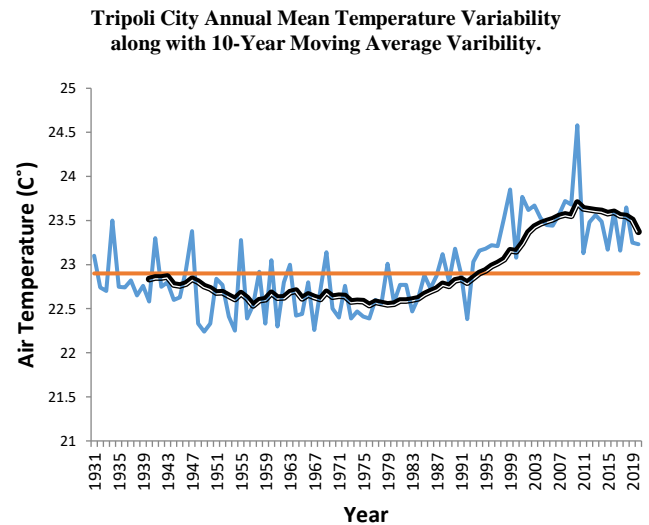
Reference period	Reference Period Average (C°)	Reference Period standard deviation
1931-2020	22.9	0.5

2. Results and Discussions

2.1. inter annual Variability

The results of analysis of Libya annual mean temperature variability are shown on fig (2). Despite the fluctuation around the long term average during the early years of the study period i.e. from 1931 to about 1944, a noticeable decline below average has been recorded afterwards in the annual mean temperature. This decrease however, has been dominant up to 1983 and after which a remarkable increase has occurred so that since 1991 in precise, all annual temperatures through year 2020 were above average marking an era of 3 decades of warming. The annual mean temperature showed an overall increase of 0.9 C ° during period 1931-2020. Such magnitude of temperature increase would not of course be uniform across different regions in Libya as some would have been more warmer and others less warm than that over the whole of Libya. However, during the recent arguably hottest period on record i.e. (1991-2020), the significant increase has surged to 1.16 C ° between 1991 and 2010 followed by stability condition around the mean during the last 10 years. The latter result can clearly be identified following the path of the 10-year moving average line which demonstrates the two distinct cold and warm periods but in particular the steep incline above the mean line since 1991 onwards, see fig. (2). These results suggest that the mentioned significant annual

temperature increase (warming) over long term period could confidently be attributed to the highly significant temperature rise during (1991-2020). These results agree with latest finding by (Alizadeh, 2023[27]) in a study aimed to analyze variability of temperature and precipitation over global land areas during the recent period (1991-2020).

Tripoli City Annual Mean Temperature Variability along with 10-Year Moving Average Varibility.


Fig.2. Inter annual variability of Libya annual mean temperature. Red straight line is the reference period average and thick black line represents 10-year moving average of annual mean temperature

2.2. Decadal Variability

Fig.3. depicts the results of investigation of decadal variability of Libya's annual mean temperature. Similar to what has been shown in section 2.1, a very long period of colder than average decades dominated since 1931 up to 1990. It is interesting to notice, considering those lengthy cold decades, the regular increase in the amount of coolness from decade to decade up to (1971-1980) which was the coldest decade on record with a standardized temperature anomaly (-0.7 C°), see table (2). The rate of temperature decrease (negative anomaly) between decades starting from decade (1931-1940) to (1971-1980) ranged between (-0.1 C° to -0.2 C°). During decade (1981-1990), however the

calculated standardized temperature anomaly showed only (-0.2 C°) which marks a beginning of return to normality. These results suggest that since the beginning of record, Libya has experienced a very long period of colder than average temperatures (six decades below normal). The two coldest decades have been (1971-1980) and (1961-1970) with -0.7 C° and -0.5 C°, respectively. Regarding the hot period since the early 90s, all three decades have been above normal started with 0.5 C° in1991-2000 followed by a remarkable and unprecedented increase of 1.6 C° during 2001-2010 then 0.9 C° in 2011-2020, see table (2). Thus, Libya has been subject to a long spell of hotter than normal weather spanned over three decades.

Although that the findings of the present study conform in large extent with most of the outcomes of global, regional and local studies presented in the literature of this research, they agree in particular with those from (IPCC, 2013 [8], Jones *et al*. 2016 [9] and Ali, 2018 [19]) concerning the above normal (hot) recent period. Moreover, these results confirm the findings of a very recent study by (Alizadeh, 2023[27]) on the annual mean temperature variability over global land areas in the recent period (1991-2020). Those findings revealed an evident rise in all global land areas with the highest increase has been detected in subtropical and mid latitudinal regions.
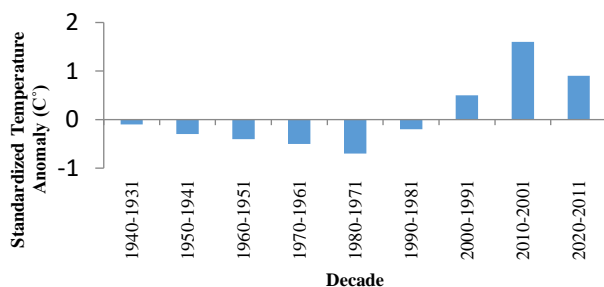
Fig.3. The amount of temperature excess (+ Anomaly) and temperature deficit (- Anomaly) in (C°) for each decade, starting with (1931-1940) and ending with (2011-2020).

Table 2. The calculated standardized temperature anomalies (C°) for all decades along with their decadal mean temperatures.

Decade	Mean Temperature (C °)	Standardized Anomaly (C °)
1931-1940	22.23	-0.1
1941-1950	22.13	-0.3
1951-1960	22.08	-0.4
1961-1970	22.04	-0.5
1971-1980	21.96	-0.7
1981-1990	22.22	-0.2
1991-2000	22.55	0.5
2001-2010	23.10	1.6
2011-2020	22.77	0.9

3.Conclusion

The inter annual variability and decadal variability of Libya annual mean temperature have been investigated over the lengthy period 1931-2020 using CRU data set. The annual mean temperature showed an increase of 0.9 C ° over the whole period 1931-2020 whereas during 1991-2020, a significant increase was revealed of magnitude 1.16 C °. The fact that a noticeable cold period has stretched from the beginning of the study period through late 80s, it can be suggested that the recorded warming over the whole period is thoroughly attributed to the unprecedented mean annual temperature rise above average in recent period from 1991 to 2020 which has showed a magnitude of up to 1.16 C °.On decadal variability basis, all the first six successive decades have been colder than average with a noticeable increase in the cooling rate from (-0.1 C°) in 1931-1940 decade to (-0.7 C°) in 1971-1980 decade. During such dominating cold era, the coldest decade was 1971-1980 with (-0.7 C°) standardized annual mean temperature anomaly below the average followed by the preceding decade i.e. 1961-1970 with an anomaly of magnitude (-0.5 C°). In regards to the well documented

all over the world i.e. the hot era since late 80s through very recent years, the present study revealed three consecutive hotter than normal decades, 1991-2000, 2001-2010, 2011-2020 with standardized anomalies of (0.5 C°., 1.6 C°., 0.9 C°), respectively. The latter results in particular means that Libya has experienced thirty continuous warm years and in comparison to the long cold period from 1931 to 1990, it might confidently be suggested that the overall warming trend during the whole study period 1931-2020 i.e. (0.9 C °) has been solely due to the contribution of the late 1991-2020 evident temperature rise. The continuation of air temperature rise over years and decades leads to heat waves occurrence very often and last longer which is so dangerous in terms of human health in particular, as they could cause heat stroke, heat cramps and even deaths. Moreover, above normal temperatures result in chain reaction of other changes globally and locally as they affect oceans and seas, weather patterns, snow and ice cover and most importantly plants and animals.

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