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ORIGINAL PAPER

Temperature trends in Libya over the second half of the 20th century

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Abstract This paper investigates spatial variability of temperature trends over Libya in the second half of the 20th century. The study is based on complete and homogeneous time series of minimum, maximum, and mean temperature for ten observatories. During the investigated period (1951–1999), temperature trend analyses have experienced a downward trend in the maximum surface temperature (about –0.06°C decade^{-1}) and an upward trend in the minimum surface temperature (about 0.23°C decade^{-1}). Cooling tendency in maximum temperature is spatially more pronounced in inland stations compared to coastal stations. At the seasonal scale, maximum temperature cooling is more obvious in winter and spring, meanwhile minimum temperature warming is more pronounced in summer and fall. In accordance with global trends, the surface mean temperature has moderately risen at an average rate of 0.09°C decade^{-1}. However, this trend has shown considerable temporal variability considering a more pronounced upward trend in summer and fall. In conjunction with other regional and global investigations, clear trends towards smaller diurnal range are presented (–0.28°C decade^{-1}).

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1 Introduction

Numerous studies have indicated direction and significance of temporal trends of temperature at various spatial scales from the global to the local (e.g., Jones et al. 1999; Hansen et al. 2002; Alexander et al. 2006; Brown et al. 2008). They all pointed to the fact that there is a general upward (warming) trend in the global mean surface temperature at a rate fluctuating between 0.3°C and 0.6°C over the last century. Nevertheless, this large-scale trend is not spatially or temporally identical (Jones and Moberg 2003). For instance, upward trends in land-based locations in winter are generally higher than marine observatories, particularly at higher latitudes (Solomon et al. 2007).

The Mediterranean region is considered a *transitional* climate region between the deserts of North Africa in the south and moderate climates in central and Northern Europe in the north (Xoplaki 2002). Therefore, climate change investigations in the Mediterranean have likely received earlier and much more concern (e.g., Metaxas 1974; Colacino and Rovelli 1983; Katsoulis 1987; Xoplaki et al. 2003). Trends of temperature in the Mediterranean have been demonstrated extensively in many studies over the last few decades (e.g., Repapis and Philanders 1988; Maheras 1989; Kutiel and Maheras 1998; Ben-Gai et al. 1999; Maheras et al. 1999; Xoplaki et al. 2002; Founda et al. 2004; Turkes and Sumer 2004; Miro and Millan 2006: Toreti and Desiato 2008; Brunetti et al. 2006; Brunet et al. 2007). Overall, the findings have not only revealed a significant positive trend in the annual mean temperature over the Mediterranean region at an average rate of 0.07°C decade^{-1} but also considerable differences between the trends of maximum and minimum temperature (e.g., Kutiel and Maheras 1998; Maheras et al. 1999; Giorgi 2002). A noticeable decrease in the diurnal temperature range throughout the 20th century has noticeably been identified as well (Vose et al. 2005).

However, it is noteworthy that most of the previous studies were mainly focused on the northern Mediterranean area due to the availability of long and homogeneous climatic records from a relatively dense network of observatories. Unlike many northern Mediterranean countries, most of the southern and eastern Mediterranean regions do not have a dense and homogeneous network of observatories. Furthermore, access to long-term and good-quality climatic records is difficult in many countries. Accordingly, adequate knowledge of climate variability in this region is insufficient. In recent years, there have been a few studies covering the southern and eastern Mediterranean basin (e.g., Aesawy and Hassanean 1997; Hassanean 2004; Hassanean and Abdel Basset 2006) but these studies do not cover the complete region. In this sense, there have been no published results on temperature variability and trends in Libya. For this reason, this investigation seems to demand a step towards in better understanding of regional temperature behavior in the south of the Mediterranean and to complete the gaps in the existing studies. The objectives of this study are to detect the patterns of spatial trends of temperature and to define the possible seasonal differences in Libya over the last half of the 20th century. To date, this study presents the first analysis that focuses attention on the temporal trends of temperature in Libya.

2 Data and methodology

2.1 Study area

Libya is located in North Africa along the southern Mediterranean coast. The area extends between 20° and 34° N and 10° to 25° E encompassing a geographical area of 1.76×10^{6} km^{2} within which 95% is extremely arid deserts (Fig. 1). The elevation ranges from –59 m to 2,314 m, with an average altitude of 423 m a.s.l. The climate is generally described as arid to semi-arid, with hot and dry summers and moderate winters with eratic rainfall. The mean annual temperature varies given the fact that the north of the study area corresponding to the Mediterranean Sea is milder (16.9°C in Shahat) compared to the south (22.8°C in El Kufra), which is a proportion of the extremely arid Sahara of Africa (Table 1).

2.2 Data description and quality control

Minimum and maximum temperature of 12 observatories between 1951 and 1999 was obtained from the Libyan Meteorological Department, Tripoli. The geographical distribution of the stations is shown in Fig. 1. The number of stations is uneven to give a complete picture of temperature variability in Libya. Also, the stations are not fairly well distributed since station density is higher north of the country than elsewhere, which is due to the fact that

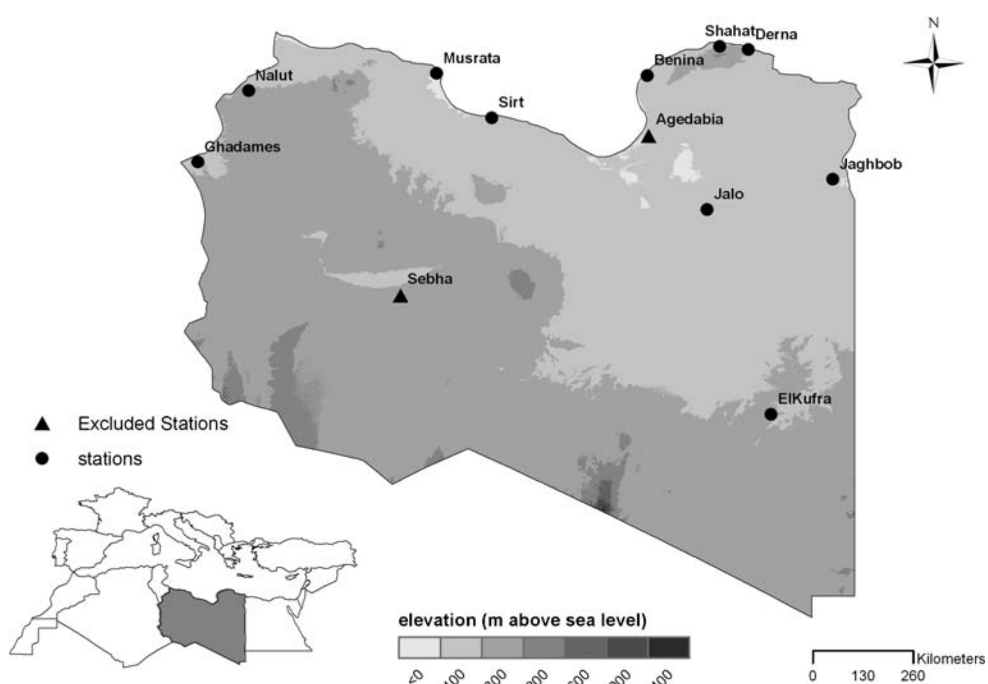

Fig. 1 Location of the study area and available stations (▲ denotes excluded stations following quality control procedures)

Table 1 List of stations with mean annual temperature (T_{mean}) during the period (1951–1999)

Station	Latitude (N)	Longitude (E)	Altitude (m a.s.l.)	T_{mean}
Benina	32.08	20.27	129	19.9
Derna	32.78	22.58	26	20.1
El Kufra	24.22	23.30	436	22.8
Ghadames	30.13	09.50	357	21.5
Jaghboub	29.75	24.53	–1	21.2
Jalo	29.03	21.57	60	22.4
Musrata	32.32	15.05	32	20.7
Nalut	31.87	10.98	621	18.8
Shahat	32.82	21.85	621	16.9
Sirt	31.20	16.58	13	20.2

the meteorological stations in Libya are spatially associated with main human settlements in the northern coastal plains and the few disperse southern depressions. However, those stations represent the available complete series with acceptable quality data in the country. To guarantee quality of the data, the homogeneity of each time series was checked against a reference series. The reference series was created by selecting five of the neighboring stations whose difference series are significantly and highly correlated with the base (candidate) series following the method presented by Peterson and Easterling (1994). Inhomogeneities caused by changes in instrumentation, station location, observation practice or other non-climatic factors were checked based on the Standard Normal Homogeneity Test (SNHT, Alexandersson 1986; Alexandersson and Moberg 1997). The AnClim (V.4, 97) (Stipanek 2004) was used to carry out the test and make further adjustments to eliminate effects of inhomogeneity. Each time series of the monthly maximum and minimum temperature for each station was independently checked according to the test. Only two stations, Agedabia and Sebha, showed considerable inhomogeneities which cannot be corrected and, thus, they were discarded from the analysis. Therefore, the analysis was performed based on ten stations with complete, homogeneous and reliable datasets covering the second half of the 20th century (1951–1999). The homogenized maximum and minimum temperatures were then used to extract the mean monthly temperature and daily temperature range (DTR).

2.3 Statistical analysis

The Spearman's (*Rho*) rank correlation was used to determine significance of trends for maximum, minimum, mean and daily range temperature (DRT) on monthly, seasonal, and annual timescales. Seasons are defined as follows: winter (December–February), spring (March–May), summer (June–August) and fall (September–November). This statistic is a non-parametric measure of correlation which makes no assumptions about the probability distribution of the investigated data since it is less affected by outliers or any form of data discontinuity (Bonnett and Manoukian 1986; Lanzante 1996). The statistical significance was assessed at the two-tailed *t*-test at the 5% confidence level. The magnitude of the trend was calculated by the slopes of the linear trends using ordinary least-square fitting and expressed in °C decade^{-1}.

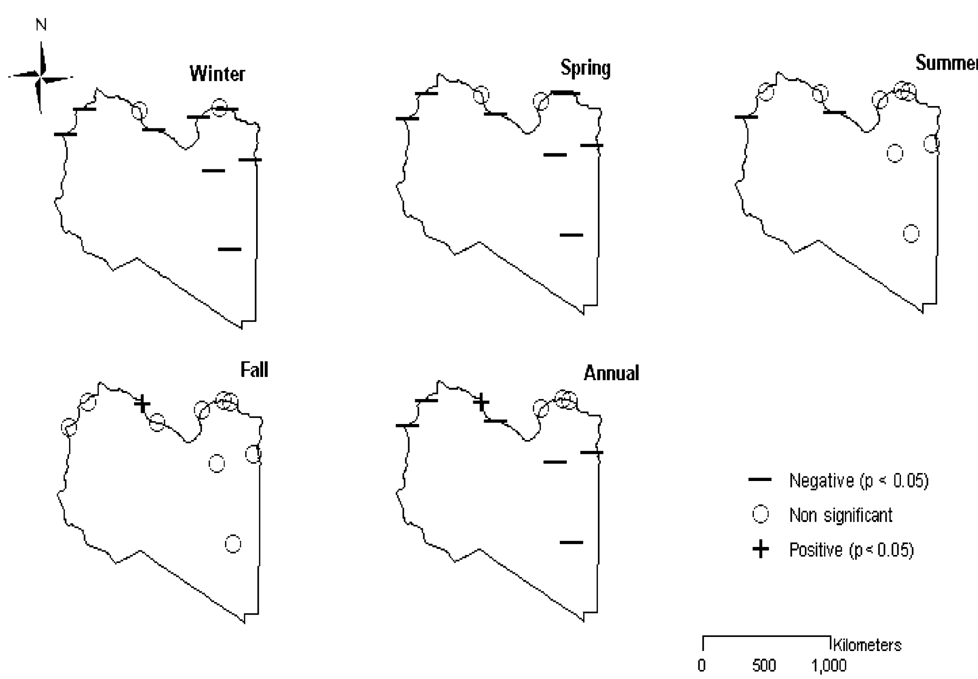

Fig. 2 Spatial distribution of seasonal and annual maximum temperature trends

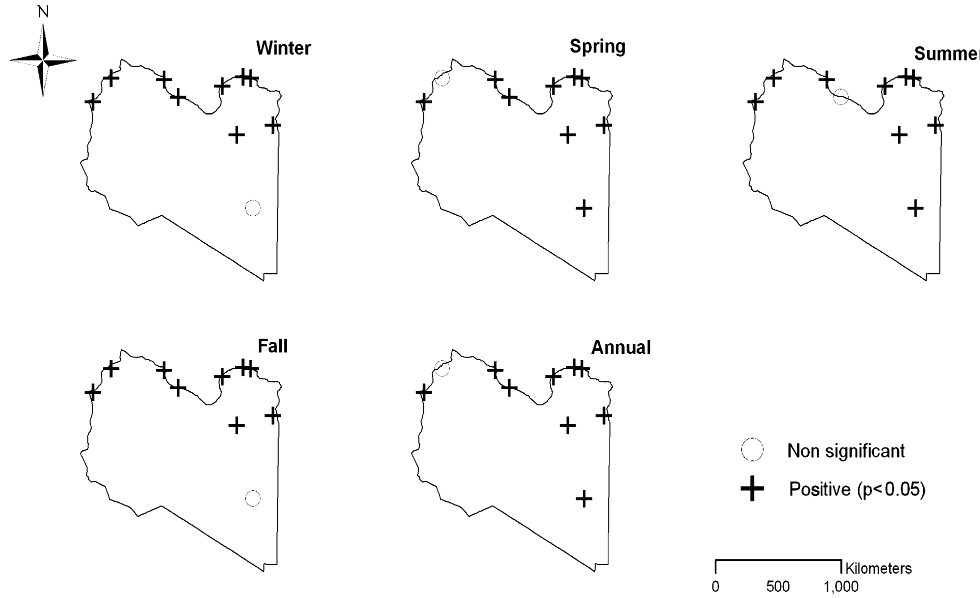

Fig. 3 Spatial distribution of seasonal and annual minimum temperature trends

Prior to evaluating trends, the dataset was filtered using a Gaussian binominal low-pass filtering of 7 years. This is a conventional procedure for temporal change detection in climate studies (Sneyers 1990) since it allows filtering the year-to-year variations to reveal more persistent trends (e.g., Wheeler and Martín-Vide 1992; Salinger et al. 1995; De Luis et al. 2000).

3 Results and discussion

Spatial patterns of temperature trends are shown in Figs. 2, 3, and 4, contrasting seasonal and annual trends for the investigated period (1951–1999). The magnitude of trends is shown in Table 2.

3.1 Spatial distribution of maximum temperature trends (1951–1999)

In winter, all stations except for Musrata and Shahat show a significant negative trend. No positive trends are observed in that season. The feature is almost the same in the spring with only one exception since Benina replaces Shahat as a non-significant station. It is also observed that inland stations show clearer downward tendency in both winter and spring in comparison with coastal stations (Table 2). In

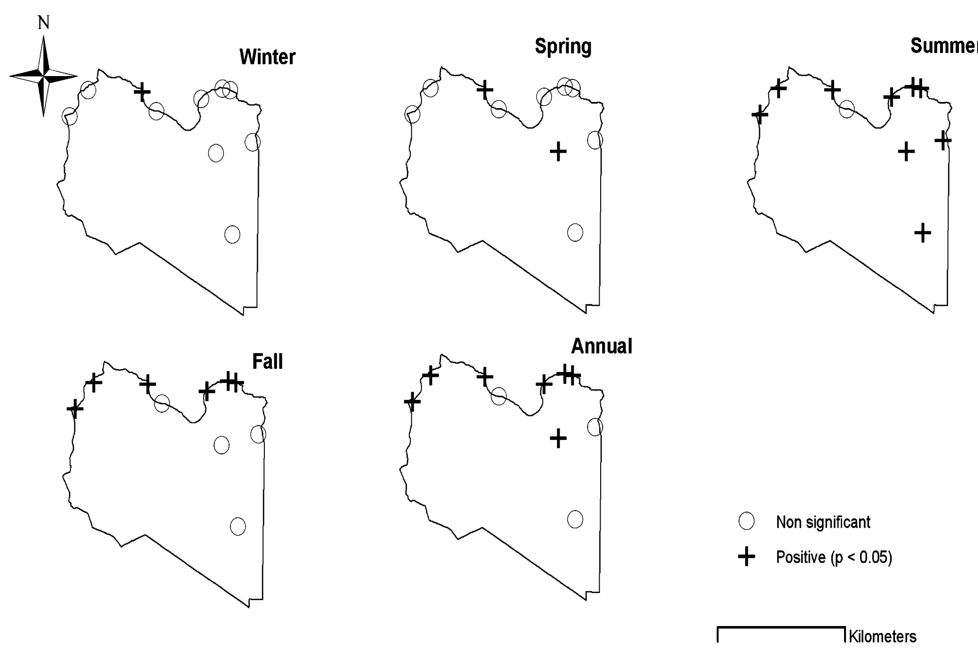

Fig. 4 Spatial distributions of seasonal and annual mean temperature trends

Table 2 Trends of the seasonal and annual maximum, minimum, mean, and the DTR (°C decade^{-1})

Maximum	Station	Season				
		Winter	Spring	Summer	Fall	Annual
	Benina	**–0.14**	–0.07	0.04	0.01	–0.02
	Derna	**–0.14**	**–0.10**	0.06	0.07	–0.03
	Galo	**–0.24**	**–0.15**	–0.04	–0.08	**–0.12**
	Ghadames	**–0.11**	**–0.10**	**–0.05**	0.04	**–0.05**
	Ghaghboub	**–0.24**	**–0.20**	–0.02	–0.04	**–0.12**
	Kufra	**–0.18**	**–0.20**	0.02	–0.05	**–0.10**
	Musrata	–0.05	0.01	0.10	**0.15**	**0.06**
	Nalut	**–0.12**	**–0.13**	0.01	0.03	**–0.05**
	Shehat	–0.11	**–0.10**	0.03	0.08	–0.03
	Sirt	–0.10	–0.12	–0.08	–0.04	**–0.08**
Average		*–0.14*	*–0.12*	*0.01*	*0.02*	*–0.06*
Minimum	Benina	0.15	0.13	0.24	0.25	0.19
	Derna	**0.24**	**0.20**	**0.22**	**0.32**	**0.23**
	Galo	**0.18**	**0.28**	**0.37**	**0.25**	**0.27**
	Ghadames	**0.21**	**0.22**	**0.30**	**0.30**	**0.26**
	Ghaghboub	**0.12**	**0.20**	**0.30**	**0.21**	**0.21**
	Kufra	0.09	**0.16**	**0.31**	0.22	**0.20**
	Musrata	**0.24**	**0.18**	**0.25**	**0.31**	**0.25**
	Nalut	**0.23**	0.17	**0.26**	**0.33**	0.25
	Shehat	**0.17**	**0.15**	**0.24**	**0.24**	**0.20**
	Sirt	**0.24**	**0.19**	0.21	**0.29**	**0.23**
Average		*0.19*	*0.19*	*0.27*	*0.27*	*0.23*
Mean	Benina	0.00	0.03	0.14	0.18	0.09
	Derna	0.05	0.02	**0.14**	**0.20**	**0.10**
	Galo	–0.03	**0.06**	**0.17**	0.09	**0.07**
	Ghadames	0.05	0.06	**0.12**	**0.17**	**0.10**
	Ghaghboub	–0.07	0.00	**0.14**	0.09	0.04
	Kufra	–0.05	–0.02	**0.16**	0.09	0.05
	Musrata	**0.10**	**0.10**	**0.18**	**0.23**	**0.15**
	Nalut	0.06	0.02	**0.14**	**0.18**	**0.10**
	Shehat	0.03	0.02	**0.13**	**0.16**	**0.09**
	Sirt	0.07	0.04	0.07	0.13	0.08
Average		*0.02*	*0.03*	*0.14*	*0.15*	*0.09*
Range	Benina	–0.29	–0.20	–0.21	–0.16	–0.21
	Derna	**–0.38**	**–0.23**	**–0.16**	**–0.25**	**–0.25**
	Galo	**–0.41**	**–0.43**	**–0.41**	**–0.33**	**–0.39**
	Ghadames	**–0.32**	**–0.32**	**–0.35**	**–0.26**	**–0.31**
	Ghaghboub	**–0.36**	**–0.40**	**–0.32**	**–0.25**	**–0.33**
	Kufra	**–0.27**	**–0.37**	**–0.29**	**–0.27**	**–0.30**
	Musrata	**–0.28**	**–0.17**	**–0.15**	**–0.16**	**–0.20**
	Nalut	**–0.35**	**–0.30**	**–0.24**	**–0.30**	**–0.30**
	Shehat	**–0.28**	**–0.25**	**–0.22**	**–0.16**	**–0.23**
	Sirt	**–0.34**	**–0.31**	**–0.26**	**–0.33**	**–0.32**
Average		*–0.33*	*–0.30*	*–0.26*	*–0.25*	*–0.28*

Only highlighted values are significant at the 0.05 level following Rho-Spearman test

summer and fall, the picture is completely different. In summer, apart from Sirt in the north and Ghadames in the west, all stations have experienced non-significant variability in maximum temperature. In fall, almost all stations have non-significant trends. At the annual timescale, the upward trend is only presented in one series, Musrata (0.06°C decade^{-1}), which is mainly attributed to variability in fall and summer (0.15°C decade^{-1}, 0.10°C decade^{-1}), respectively. In brief, it is clearly observed that the cooling pattern spatially prevails in most series in winter and spring. On the contrary, a pattern of non-significant trends predominates in summer and fall. It is also worth mentioning that stations located at a distance from the coast have recorded descending trends in winter and spring and non-significant trends in summer and fall. Most series show strong evidence of negative trend in the annual maximum temperature. As presented in Table 2, it can be seen that the rise in the annual maximum trend is more coherent in inland stations (i.e., El Kufra, Jalo, and Ghaghboub) than that of coastal stations. A remarkable non-significant trend is also presented in the northeastern coast, which is mainly more controlled by variability in summer and fall than winter and spring. Also, of particular concern is the fact that Musrata is the only station showing a positive trend. Spatially, there is an agreement between the trends of the annual maximum temperature and the trends in winter and spring. This result suggests that the pattern of annual maximum temperature trends is associated with the pattern observed in winter and spring. Generally, the behavior of the annual maximum trend in Libya (an average of –0.06°C decade^{-1}) comes in general agreement with areas located in the same latitudes. For instance, a downward trend of about –0.22°C decade^{-1} in the 1971–2000 period was detected in Egypt (Domroes and El Tantawi 2005). However, this behavior contrasts to the observations in the north and east of the Mediterranean Basin, e.g., Italy (Brunetti et al. 2000,2006), the Iberian Peninsula (Brunet et al. 2005), Greece (Philandras et al. 2008), and the Balkans (Gajic-Capka and Zaninovic 1997; Unkašević et al. 2005).

In general, it seems to have a different evolution between the north (increasing) and the south (decreasing) of the Mediterranean Basin. The reason for the lack of maximum temperature increase in the south of the Mediterranean Basin, and in concrete in Libya, could be related to the high temperatures commonly recorded in this region (the global maximum values have been recorded in this country). It seems to have a resistance of temperatures to increase of a high temperature threshold given the common high maximum temperature values in Libya (annual average=27°C). This is in agreement with what has been observed in other warm Mediterranean areas. For example, in the Spanish Mediterranean coastland, no tendency to exceed the records of absolute maximum temperatures in the summer warm months since 1958 was shown. In other "colder" regions, as many of those located in the north of the Mediterranean Basin, it seems to have a certain range of the maximum temperature to increase.

3.2 Spatial distribution of minimum temperature trends (1951–1999)

There is a general tendency for the warming trend in annual and seasonal minimum temperature (Fig. 3 and Table 2). It is evident that the observed tends are either positive (as shown in the majority of stations) or non-significant as presented in a few stations (i.e., El Kufra in winter and fall, Nalut in spring, and Sirt in summer). No differences are observed between the coastal and inland stations in response to both fall and annual minimum temperature variability. Nevertheless, warming trends in inland stations are much more marked in winter and, conversely, more coherent in spring and summer with corresponding to coastal stations (Table 2). Annual trends of minimum temperature are evidently positive in most of stations. Overall, the minimum surface temperature has risen at an average rate of 0.23°C decade^{-1}, which is almost four times as large as the rate of maximum temperature. Seasonal trend analyses reveal that most of the warming is found in summer and fall (0.27°C decade^{-1}). Regionally, Ben-Gai et al. (1999) also showed a warming tendency (0.05°C decade^{-1}) in Israeli minimum temperatures during the second half of the 20th century. However, this warming only took place in the warm season (April–October), whilst the rest of the year experienced a cooling trend. The increase in the minimum temperature seems to be more homogeneous over the whole Mediterranean area than the observed for maximum temperature as has been demonstrated in several studies (e.g., Brunet et al. 2005).

3.3 Spatial distribution of mean temperature trends (1951–1999)

Regarding the mean temperature, more seasonal variability is defined in the spatial distribution of trends (Fig. 4). In winter, non-significant trends could be generally identified. However, solely inland stations show a downward but non-significant trend (Table 2). The same behavior of trend in winter is maintained in spring. Interestingly, Musrata is the only station in which a significant warming is defined in both winter and spring (0.10°C decade$^{-1,}$ 0.10°C decade^{-1}, Table 2), respectively. In summer, a significant upward trend is observed in most series. In fall, most of the coastal stations show positive trends, meanwhile the eastern inland stations (i.e., Jalo, Ghaghboub, El Kufra) show weak and non-significant trends. In particular, most series experienced significant and stronger warming summers and falls over the study period in comparison to weak and non-significant winters and springs (Table 2). Moreover, it is spatially apparent that positive trends are of greater magnitude in coastal stations compared with inland stations. As indicated in Table 2, a warming trend is observed in the mean temperature (an average rate of 0.09°C decade^{-1}). Amongst the findings of Jones and Moberg (2003) was the observed warming trend in the mean surface temperature of the northern hemisphere (0.05°C decade^{-1}) in the second half of the 20th century, which is roughly weaker than Libya (0.09°C decade^{-1}). Also, this finding reinforces what has been observed in many other parts of Africa towards a mean temperature increase between 0.05°C and 0.1°C per decade (e.g., Unganai 1997; King'-uyu et al. 2000; Kruger and Shongwe 2004; Conway et al. 2004; Samba et al. 2008). Over the Mediterranean region, the upward trend in the mean temperature seems to be spatially uniform. For instance, in the north of the basin, trends have likely similar magnitude. In Spain, Quereda et al. (2000) found a significant positive trend in the annual mean temperature in the Spanish Mediterranean region (0.07°C decade^{-1}) for the period 1870–1996, similar to what was observed by Brunet et al. (2005), who showed an upward trend in the entire country at a rate of 0.05°C decade^{-1} from 1973 to 2003. Moreover, Toreti and Desiato (2008) defined a positive trend (0.05°C decade^{-1}) in Italian mean temperature in the period from 1981 to 2004. These particular analyses seem to agree with the general trend found over the whole Mediterranean Basin, since Giorgi (2002) also observed an annual warming trend (0.07°C decade^{-1}) in the surface mean temperature over the Mediterranean for the period 1901–1998. In brief, the earlier studies provide some degree of consistency between the Libyan trend and other regional and sub-regional trends.

3.4 Spatial distribution of diurnal temperature range trends (1951–1999)

The sharp decrease in the DTR shows a spatially uniform pattern of significant negative trends across the country at both seasonal and annual timescales. All the stations show negative and significant trends. The descending trend is more coherent in winter with a range between –0.27°C decade^{-1} in El Kufra and –0.41°C decade^{-1} in Galo. A comparison of Figs. 2 and 3 implies that the downward trend of DTR is mainly caused by the distinct positive trend in minimum temperature. This result is broadly consistent with the findings of previous global studies (e.g., Easterling et al. 1997, 2000; Folland et al. 2001) and other studies in the Mediterranean region (e.g., Quereda et al. 2000; Jones 1995) in which minimum temperature increases faster than maximum temperature, causing a significant decline in the diurnal range of temperature. At the national level, diurnal temperature range (DTR) is generally characterized by a sharp negative trend (–0.28°C decade^{-1}) (Table 2), as a consequence of the faster increase in the minimum temperature with respect to the role of maximum temperature. However, for all seasons, the greatest decrease has occurred in both winter and spring (–0.33°C decade^{-1}, –0.30°C decade^{-1}), respectively. Regionally, particular seasonal differences are found with other Mediterranean regions. For example, in Turkey, Turkes and Sumer (2004) observed a higher downward trend in DTR in fall and summer compared to winter and spring. Nevertheless, over the second half of the 20th century, many Mediterranean regions have experienced similar findings such as the Iberian Peninsula and Turkey (Easterling et al. 1997; Quereda et al. 2000; Jones 1995). However, it seems to have a high variability over the Mediterranean region since other regions (e.g., central and southeastern Europe, Israel, Italy, and Switzerland) have exhibited DTR-positive trends (Brazdil et al. 1998; Ben-Gai et al. 1999; Toreti and Desiato 2008; Beniston et al. 1994).

4 Summary and conclusion

In this work, a focus has mainly been placed on analyzing spatial variability of temperature trends in Libya, a country with very limited number of climatic investigations. The findings of interannual and annual temperature variability are adequately well-matched with those observed over the last half of the 20th century. In accordance with the global trend, there is strong evidence that a significant warming trend in annual minimum temperature as well as diurnal temperature range (DTR) occurs in Libya (0.23°C decade^{-1}, –0.28°C decade^{-1}, respectively). On the contrary, a moderate significant downward trend in the surface maximum temperature is observed (–0.06°C decade^{-1}). Increasing minimum temperatures and cooler maximum temperatures lead to an increase in the mean surface temperature, especially in the last two decades, at an annual average rate (0.09°C decade^{-1}). Analysis of seasonal mean temperature shows that most of the warming took place in summer and fall, and these results are similar to those observed in other Mediterranean regional studies. However, it also seems that warming trends are more apparent in Libyan Mediterranean stations than in inland stations, particularly in fall. On the contrary, non-significant trends in mean temperature are defined in winter and spring over the entire country. To conclude, this work provides a concrete picture of Libyan temperature variability over the last five decades and, hence, may contribute to a better understanding of variations in temperature regime across the southern Mediterranean region as well as Africa.

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