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Observed temperature evolution in the City of Sfax (Middle Eastern Tunisia) for the period 1950–2007

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Abstract This paper studies temperature evolution in the city of Sfax (Middle Eastern Tunisia, with more than 600 000 people) from 1950 to 2007. Daily maximum and minimum temperatures recorded at Sfax observatory from 1950 to 2007 are analysed by studying their homogeneity, possible trends and their statistical significance. Linear regression, Student and Mann–Kendall trend test were applied to annual mean minimum and maximum temperature data to determine the existence and significance of trends. Using a number of statistical tests, it is found that the data measured at the surface station represent a non homogenous time-series. Furthermore, mean annual and monthly temperatures are evaluated and a statistically significant trend starting from year 1950 was found. Important increase of the surface temperature in the City of Sfax was found after 1984. The increase in the surface temperature in the city of Sfax is further associated with global, regional (e.g. Mediterranean area) and meso-scale temperature increase. In addition, the spatial pattern of surface temperature in the city of Sfax from 1982 to 2007 shows that the overall land surface temperature increased with the expansion of Urban Heat Island (UHI) from urban areas to suburban districts.

1 Introduction

Long-term climate variability affects human activities and is important for predicting the future climate. Several studies published during the last 25 years direct their attention to the issue of temperature fluctuations. Some of them have addressed the problem at the global or hemispheric scale, e.g. Jones (1988) while others have studied the entire or major parts of the Mediterranean basin, e.g. Metaxas et al. (1991) or Maheras et al. (1996) for the entire Mediterranean; Repapis and Philandras (1988) for the eastern Mediterranean; or Maheras (1989) for the western basin. This problem was discussed at the national and local scale as

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well, e.g. Giles and Flocas (1984) for Greece, Lo Vecchio and Nanni (1995) for Italy, Hasanean (2004) for Egypt, Colacino and Rovelli (1983) for Rome, Carrega and Dauphiné (1984) for Lisbon and Marseille and Serra et al., for Barcelona (2001). Findings of these studies suggested that a shift in some climatic trends occurred around the end of 1970s. This paper examines the time evolution of daily minimum and maximum temperatures observed at Sfax (southern Mediterranean city, Tunisia) for the 1950 to 2007 period, using mainly linear regression technique. For step changes and trends, plausible explanations based on published work, large-scale atmospheric circulations and local-scale climate influences are provided. Changes on annual and monthly basis are analyzed. In addition to the city of Sfax, limited analysis for three other locations from Tunisia is also presented. Furthermore, the remarkable urbanization and other land use changes in the region have made it an ideal study area for investigating the possible impact of the urban growth on meso-scale climate, by studying the urban heat island (UHI) evolution.

2 Area description, data and methods

2.1 Area description

The city of Sfax, located in southern Middle East of Tunisia (34°.74′ N, 10°.78′ E) is characterized by important industrial activities (Fig. 1). During the last three decades, the agglomeration has experienced a notable urban expansion; the population rose from 225 000 in 1975 to more than 600 000 in 2011. The Mediterranean Sea has a significant impact on the weather and climate in this coastal plain which is characterized by rainy winters and dry and warm summers. It is also affected by the Westerlies mainly during the cold period of the year; whereas sea-land breeze circulation dominates in the warm season (Dahech et al. 2005). The annual average temperature calculated for the 1950–2007 period does not go below 18.7°C. For the same period, the monthly mean lowest temperature is found in January averaging 11.2°C and the highest in August averaging 26.6°C. The total of annual precipitations is 234 mm. The most important precipitation seasons are winter and autumn. The insolation is high in all seasons. Its average monthly duration is 265 h and the highest values are recorded in July (278 h).

2.2 Data

2.2.1 Meteorological data

Daily maximum and minimum temperatures, recorded continuously in the meteorological station (Sfax-el-Maou; 15 m high above sea level and located 4 km far from the Mediterranean Sea, Fig. 1) from 1950 to 2007, are used to calculate average daily temperature,[1] annual and monthly maximum and minimum temperatures. All station data are available in electronic format. The thermo-hygrometer is placed at a height of 2 m.

Meteorological data were analysed according to their homogeneity, possible trends and their statistical significance. Furthermore, to understand and justify the change in temperature, the Mediterranean Oscillation Index (MOI) and the North Atlantic Oscillation index (NAO) have been used. NAO is the difference in pressure at sea-level between the Azores

[1] Average daily temperature = maximum + minimum temperatures/2

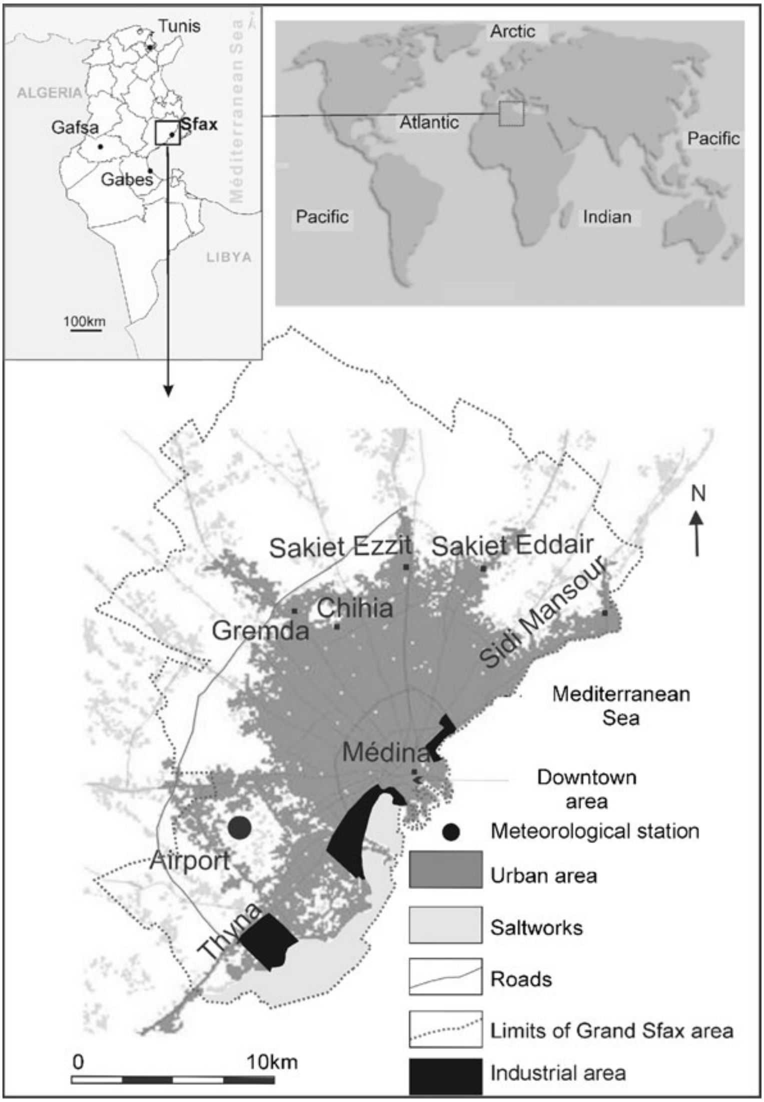


Fig. 1 Location of Sfax

and Iceland, and MOI is the standardized geopotential height difference between Algiers and Cairo (Maheras et al. 1999).

Monthly and yearly NAO and MOI index and sea level pressure in western Mediterranean basin, extending back to 1950, were taken from Climatic Research Unit (CRU, www.cru.uea.ac.uk).

2.2.2 Mobile surveys and NOAA-AVHRR imagery to assess urban heat island

Urban heat island which is defined as the temperature difference between the urban area (Tu) and its rural (Tr) surroundings is a result of the physical properties of buildings and other structures, and the emission of heat by human activities (Hamdi and Schayes 2008). In order to have a better understanding of how the land use in the city of Sfax impacts the air temperature, mobile surveys were conducted to map out the temperature profiles at the various regions, so that correlation can be established between the land use and the ambient conditions. The mobile survey was conducted by 3 teams travelling by car and equipped with "Testo 400" sensors. Teams were taking 2 min temperature measurements at one mile spatial frequencies for the selected regions of the Sfax city. Observation sites were selected to represent a wide range of urban morphologies which included the predominant types of residential areas in Sfax. This homogeneity helps us to ensure that the observations represent the microclimate of specific lands. Observations were performed between March 2003 and September 2006 during seven clear sky nights from 2 a.m. to 3 a.m. In all sites, sensors were placed 2 m above surface level. In urban environments, sensors were placed 2 m from roads and walls to avoid vandalism, theft, or traffic interference. Signals were sampled every 10 s. Calibration of instruments was done before and after fieldwork to ensure data accuracy. Comparisons showed small systematic errors in T (<0.15°C) between individual sensors, which were subsequently adjusted for.

In addition, this study tries to examine the influence of land use change on UHI in Sfax from 1982 to 2007 by analyzing NOAA-AVHRR (National Oceanic and Atmospheric Agency-Advanced-Very High Resolution Radiometer) satellite data. The satellite is in a sun-synchronous, near-polar orbit, passing over at local times of approximately 13:30 h and 01:30 h. We use full resolution satellite data (Local Area Coverage data, LAC, resolution 1.1 km at nadir) recorded at night. To make atmospheric correction and calculate surface temperature we use the Split Window method developed by Deschamps and Phulpin (1980). Several studies as (Gallo et al. 1993) and (Charfi et al. 2010) show that, during clear night, there is a strong relationship between the brightness temperature provided by NOAA-AVHRR image and air temperatures given by car survey records. NOAA-AVHRR data enable us to detect the dynamics of UHI, three images are selected: the first is registered in June 1982, the second in June 1995 and the third in June 2007 during clear weather conditions. In addition, Landsat visible and near infrared bands at 30-m resolution are used to study land cover and vegetation properties (Hu and Jia 2010).

2.3 Statistical methods

- Descriptive statistics: The yearly average of maximum and minimum temperature is calculated on an annual and monthly scale using daily data. Anomalies (= average deviations from a mean temperature over the period 1950–2007) of averaged annual and monthly maximum and minimum temperatures are also evaluated (Fig. 2).
- Homogeneity: Before testing the long-term observations of temperature homogeneity, the few missing daily observations (0.06%) are replaced by climatological averages on the same dates. After that, starting from the daily series of maximum and minimum temperatures, monthly and annual averages are computed as well as their standardized values.

The homogeneity of the series is tested on annual scale using four statistical discontinuity detection tests. Buishand range test (Buishand 1982), nonparametric Pettitt's method (Pettitt 1979), Lee and Heghinian's Bayesian method (Lee and Heghnian 1977) and Hubert's (Hubert et al. 1989) segmentation are applied. A 'discontinuity' can be defined by a change in the probability law of a chronological series at a given moment. We were only interested in discontinuities affecting the annual average value. Each of these mathematical tools is

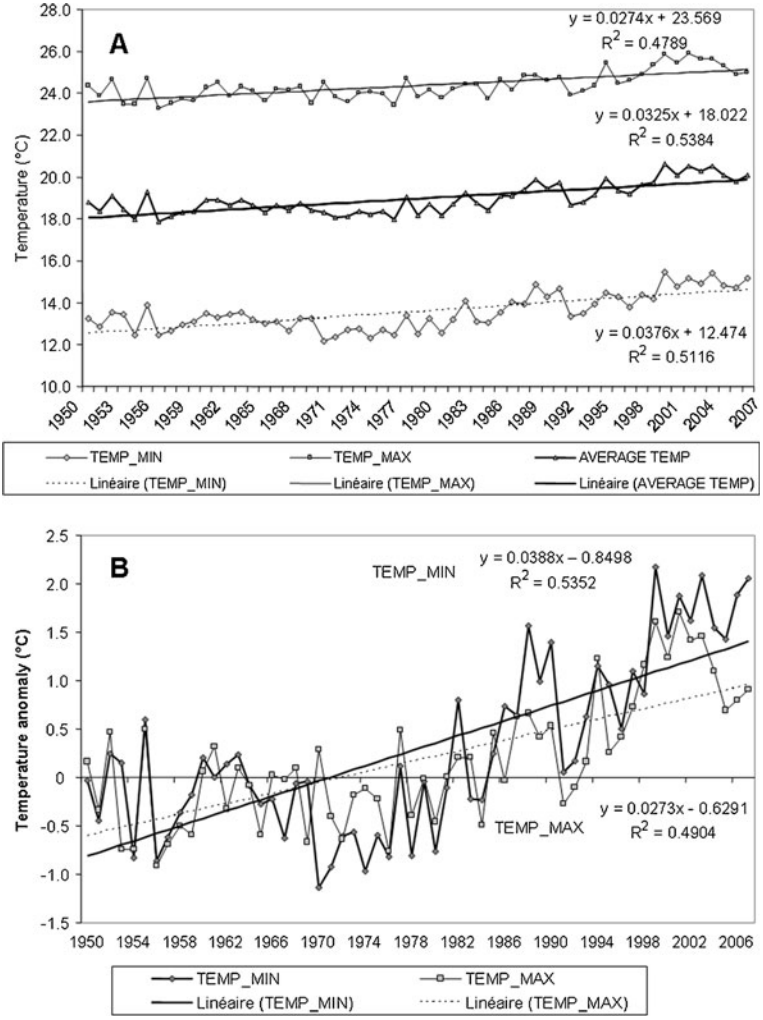


Fig. 2 Annual average and extreme (averaged maximum and minimum temperatures) temperatures values (**a**) and there anomalies (**b**) for the period 1950–2007 (R^2 = *Coefficient* of *determination;* data from National Institute of Meteorology)

reliable for detecting average discontinuities and they also have their specificities. The 'Buishand' (Bois 1986) tests provide a qualitative evaluation of the existence of a discontinuity. It is a parametric test and supposes, under the null hypothesis, that the values of the testing variable are independent and identically normally distributed. Under the alternative hypothesis, it assumes that a step-wise shift in the mean (a break) is present. That of 'Pettitt' searches for an eventual discontinuity and situates it within the record. The null hypothesis is that the data are independent, identically distributed random quantities, and the alternative is that a stepwise shift in the mean is present. The test statistic is related to the Mann–Whitney statistic. The Pettit test is more sensitive to breaks in the middle of a time series (Wijngaard et al. 2003). 'Lee–Heghinian's Bayesian' method is based on the hypothesis that a discontinuity exists and determines the probability of its position within time and 'Hubert's segmentation', looks for different discontinuities and in this way divides the record into homogeneous periods. These methods are based on the hypothesis that the data series' variance is unchanging (Laraque et al. 2001).

We considered the time series 'to be suspicious' if some tests reject the homogeneity, and the station time series were not considered homogeneous. The details of these absolute test methods are explained in Sahin and Cigizoglu (2010).

Meteorological observations could be affected by changes in instrumentation, station dislocation, urban growth or changes in observing practices (different observation times, new observers). This can be checked by the use of metadata files containing station history which should describe all kinds of possible factors affecting the time series.

The correction technique proposed by Caussinus and Mestre (2004) can not be applied using one of the 3 other series mentioned in the global perspective part since no reference series could be considered. In fact, their are several missing data in these stations, and there metadata files show some sensors displacement.

- Trends: Several tests are available for the detection and/or quantification of trend rates. Probably the most common approach is to estimate trends by linear regression (Solow 1987). The trend can be assumed to be linear as in Eq. 1:

$$f(x) = ax + b \tag{1}$$

a denotes the slope, b a constant

The test of significance is based on the assumption that the distribution of the residual values (i.e., the deviations from the regression line) for the dependent variable y follows the normal distribution, and that the variability of the residual values is the same for all values of the independent variable x. In addition, the nonparametric test of Mann–Kendall is used to determine the existence and significance of a trend in the time series of monthly minimum and maximum temperature and annual mean values (Tayanç et al. 1997). When a trend exists, the null hypothesis (H0) is rejected (H0 = the slope of the regression is zero).

Furthermore, a student test had been applied to the (a) slope with 0.05 significant level. In fact, several authors (e.g. Peterson et al. 1998; Tuomenvirta 2001) use Student's t-tests to determine whether the sample of estimated/adjusted temperature values is significantly different from the original data (Table 1).

We use the homogeneity and Student's tests as a first approach because they assume an unchanging variance.

– Multivariate statistics: Principal Component Analysis (PCA) involves a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components (Jolliffe 2002). In this paper, the PCA is used only for detecting the relation between temperature and regional circulation parameters at annual scale for the period 1950–2007. Precisely, it allows us to visualize and determine the existing correlations between seven variables: minimum and maximum temperatures, southern and western wind direction and speed and atmospheric oscillation indexes (OM: Mediterranean Oscillation and NAO: North Atlantic Oscillation). We use Pearson's correlation. The result is shown in the correlation matrix (Table 2).
– Clustering: Hierarchical Clustering (AHC) is subdivided into agglomerative methods, which proceed by series of fusions of the N objects into groups, and divisive methods which separate N objects successively into finer groupings. In this paper, similarity index is given by the Euclidean distance and Ward's method is selected as aggregation criterion. Our aim is to create homogeneous clusters of years based on the temperature

Table 1 Monthly extreme temperature trend in Sfax between 1950 and 2007

Months	Minimum temperature					Maximum temperature				
	a (°C)	Standard error of (a)	sign	R^2	H0	a (°C)	Standard error of (a)	sign	R^2	H0
1	0.03	0.009	S	**0.16**	Rejected	0.021	0.009	S	**0.087**	rejected
2	0.023	0.008	S	**0.139**	Rejected	0.008	0.013	NS	0.007	unable to reject null hypothesis
3	0.027	0.008	S	**0.154**	Rejected	0.016	0.011	NS	**0.038**	unable to reject null hypothesis
4	0.029	0.008	S	**0.191**	Rejected	0.028	0.008	S	**0.185**	Rejected
5	0.042	0.009	S	**0.287**	Rejected	0.030	0.009	S	**0.162**	Rejected
6	0.035	0.008	S	**0.249**	Rejected	0.027	0.009	S	**0.147**	Rejected
7	0.056	0.009	S	**0.378**	Rejected	0.029	0.010	S	**0.135**	Rejected
8	0.056	0.008	S	**0.479**	Rejected	0.037	0.008	S	**0.291**	Rejected
9	0.029	0.008	S	**0.197**	Rejected	0.018	0.008	S	**0.081**	Rejected
10	0.046	0.011	S	**0.213**	Rejected	0.050	0.011	S	**0.266**	Rejected
11	0.033	0.012	S	**0.128**	Rejected	0.0315	0.009	S	**0.167**	Rejected
12	0.027	0.009	S	**0.144**	Rejected	0.020	0.010	NS	0.063	unable to reject null hypothesis

In bold. Significant values at the level of Significance alpha = 0.050 (two-tailed test)

a: Trend of temperature per year in °C

H0: There is no trend at the 0.05 significance level using Mann-Kendall test

S: . Significant values of trend (a) at the level of significance alpha = 0.050 using student test

NS: Non significant values of trend (a) at the level of significance alpha=0.050 using student test

data available to us. Both minimum and maximum yearly temperatures are used, thus 2 component vectors are classified. The objective is to separate the relatively warm years from those relatively cold. The result to look at is the levels bar chart, the centroïds of the obtained classification as well as the dendrogram. It represents how the algorithm works to group the observations, then, the sub groups of observations.

We selected the automatic truncation; it is based on the entropy and tries to create homogeneous groups. The levels bar chart reveals a great deal about the structure of the data. When the increase in dissimilarity level is strong, we have reached a level where we are grouping groups that are already homogenous. Automatic truncation uses this criterion to decide when to stop aggregating observations.

Table 2 Correlation matrix between circulation variables and extreme temperatures (obtained using Principal Component Analysis (PCA) method) (data from National Institute of Meteorology)

	S	W	OM	NAO	Wind speed	TEMP-min	TEMP-max
TEMP-min	**0.703**	**−0.508**	**0.272**	−0.032	**0.611**	1	**0.845**
TEMP-max	**0.576**	**−0.718**	0.126	0.017	**0.809**	**0.845**	1

In bold. significant values at the level of Sificance alpha = 0.050 (two-tailed test) (S: South; W: West; OM: Mediterranean Oscillation; NAO: North Atlantic Oscillation)

3 Homogeneity

3.1 Testing

For the 1950–2007 period, the Buishand's test, nonparametric Pettitt's method and Lee and Heghinian's Bayesian method reject the absence of break at the significance level of 0.01%. A sudden increase in the maximum and minimum temperatures is detected from early 1980s onward. The main break point was recorded in 1984 according to the majority of tests. It separates two homogeneous periods (1950–1984) and (1985–2007) with a respectively drop in minimum and maximum temperature of 1.4 and 0.9 between the first and the second period.

Temperature data series are divided into three temporal segmentations by Hubert method. It shows that minimum air temperatures increased from 13°C between 1950 and 1984 to 14.1°C between 1985 and 1997 to 15.1°C between 1998 and 2007. During the same periods maximum air temperatures averages were respectively 24°C, 24.6°C and 25.4°C (Table 3).

3.2 Possible explanations

3.2.1 Metadata

Metadata files are considered as a source of complementary information for evaluating possible heterogeneities of the series. In our case, the equipment, as well as the position of the thermometric gauge has not been changed since 1948. Thus, it is reasonable to assume that heterogeneities do not result from instrumental equipment.

3.2.2 Large scale circulation (MOI and NAO)

The temperature increase in the Mediterranean region has been greater than the global average increase (Maheras and Kutiel 1999). Thus, the warming tendency detected for the central-western Mediterranean could be in agreement with the present results obtained for Sfax station.

Besides, links between circulation patterns and surface climatic variables have been of great interest for many researchers. For instance, Bartzokas and Metaxas (1991) established that recent trends in surface temperature across the Mediterranean region are due to changes in atmospheric circulation. Since then, many researchers have examined the relationship between the 'Mediterranean oscillation Index' (MOI, barometric contrast between the western and eastern Mediterranean) and temperature (Kutiel and Maheras 1998; Maheras

Table 3 Comparison of discontinuity years from 4 statistical tests: Buishand range test Pettitt's method. Lee and Heghinian's Bayesian method and Hubert's segmentation

	Bayesian method of Lee	Pettitt's method	Buishand range	Hubert's segmentation
TEMP-min	1985	1984	Existence of discontinuity	1950–1984
				1985–1998
				1999–2007
TEMP-max	1984	1984	Existence of discontinuity	1950–1984
				1985–1997
				1998–2007

and Kutiel 1999). The correlation between the T-850 hPa and the MOI, empirically defined by Conte et al. (1989), is equal to r=0.60. In this paper, referring to the matrix showing the significance levels for Pearson's correlation, the correlation between annual maximum (resp. minimum) air temperatures and MOI, in Sfax, is given by r=0.27 (resp. 0.12), it is significant only for the first ones. We did not detect any statistically significant relation between air temperature and NAO index.

According to several studies, meridional circulation is responsible for either high (S circulation) and low temperatures (N circulation) on the monthly or seasonal scale (Maheras 1983, 1989). A better relationship can be found between the temperature changes and wind speed and direction in Sfax. This can be noted from the correlation matrix (Table. 2). The Western Mediterranean will be affected by high temperatures when a high pressure is centred over the region between the Balearic Islands and Sardinia (Hénia 1980). This will cause a strong southern flow originating in the Sahara desert (Dahech et al. 2007). During the studied period, the correlation between maximum and minimum air temperatures and southern wind direction are respectively given by r=0.7 and 0.58. For instance, the highest temperatures observed in 1982 are due to some warm months, especially June and July, when southern wind is very frequent: winds coming from SE, SSE, S and SSW represent 50% of the three hourly wind directions while they do not exceed 23% in average in 1950–2007.

3.2.3 UHI effect

UHI is most pronounced on clear, calm nights; and there are often cool islands in parks and less-developed areas (Gaffin et al. 2008). In Sfax, sunny days are more frequent particularly during summer due to the installation of the Azores anticyclone (Dahech 2007).

The survey route running from east to west passes through different land uses, like industrial areas, residential areas, urban park and olive fields. The results are illustrated in Fig. 3 and show temperature differences in various city regions against Medina (historic downtown) temperature. It is clear from the map that all the urban or built-up areas have a relatively high temperature. The temperature difference between the historic downtown and the rural area ranges from 4.5°C to 7.5°C. The industrial areas and the downtown have less green areas compared with other land uses. Therefore, the heat absorbed by massive hard surfaces during daytime are re-emitted at night. This is the reason why higher temperatures are observed in these areas during the night survey. Lower temperatures were detectable in residential areas because plants can cool the surroundings and generate a lower ambient temperature.

"Suburban sites continue to warm relative to nearby rural areas until local urbanization is complete, as shown for London's Heathrow airport" (Jones and Lister 2009). It is the same case for Sfax airport where we observe a clear increasing trend of air temperature, especially the minimum one. Local urban heat island effect can influence air temperature principally the minimum ones because this phenomenon is strongest at night (Oke 1976). Dense neighbourhoods like El Bahri and El Khadra, founded at the beginning of the 1980s, knew a notable vertical and horizontal extension during the 1990s (Fig. 4). The emission of heat by human activities such as transport and air conditioning of buildings contribute to some urban heat islands. In addition, the diminution of vegetation cover can reduce moisture availability near the airport. This can increase the sensible heat and reduce the fraction of solar energy converted into latent heat. Figure 4 presents a comparison between urban fabric and surface temperature in January 1982 and in March 2007. It shows that in areas surrounding the meteorological station (Sfax-el-Maou) (2 km distance), we observe an expansion of the

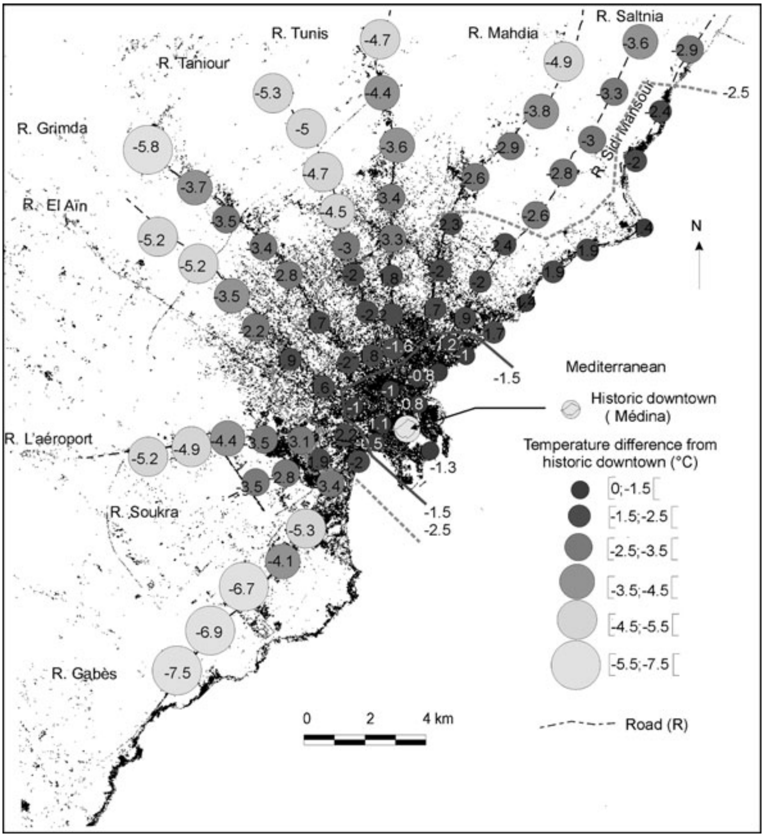


Fig. 3 Urban heat island morphology in Sfax agglomeration during clear nights (The circles show the temperature difference from the historic downtown (Medina); car survey realised in 12/04/03. 20/04/03. 9/08/04. 23/01/05 and 21/07/05 at night between 2 am and 3 am)

continuous urban fabric particularly in the northern and the western part of the sensors. NOAA-AVHRR images show the existence of a nocturnal urban heat island (mean ΔT_{u-r}=7°C) during clear nights. The temperature increase potentially due to this effect in the airport area is about 2 ° C (Fig. 4).

4 Trends

4.1 Annual air temperature changes

Temperatures in Sfax exhibit a marked warming trend. It is significant at the significance level of 0.01. Trend rates per decade are 0.38°C for minimal temperature and 0.27°C for the maximum (Fig. 2a).

Annual average temperatures are computed using minimum and maximum temperatures. The annual temperature anomalies are computed while referring to the averaged temperature values that were calculated for the period 1950–2007 (Fig. 2b). After 1984, annual temperature anomalies become positive except for 1991–1993 period. They prove, on the one hand,

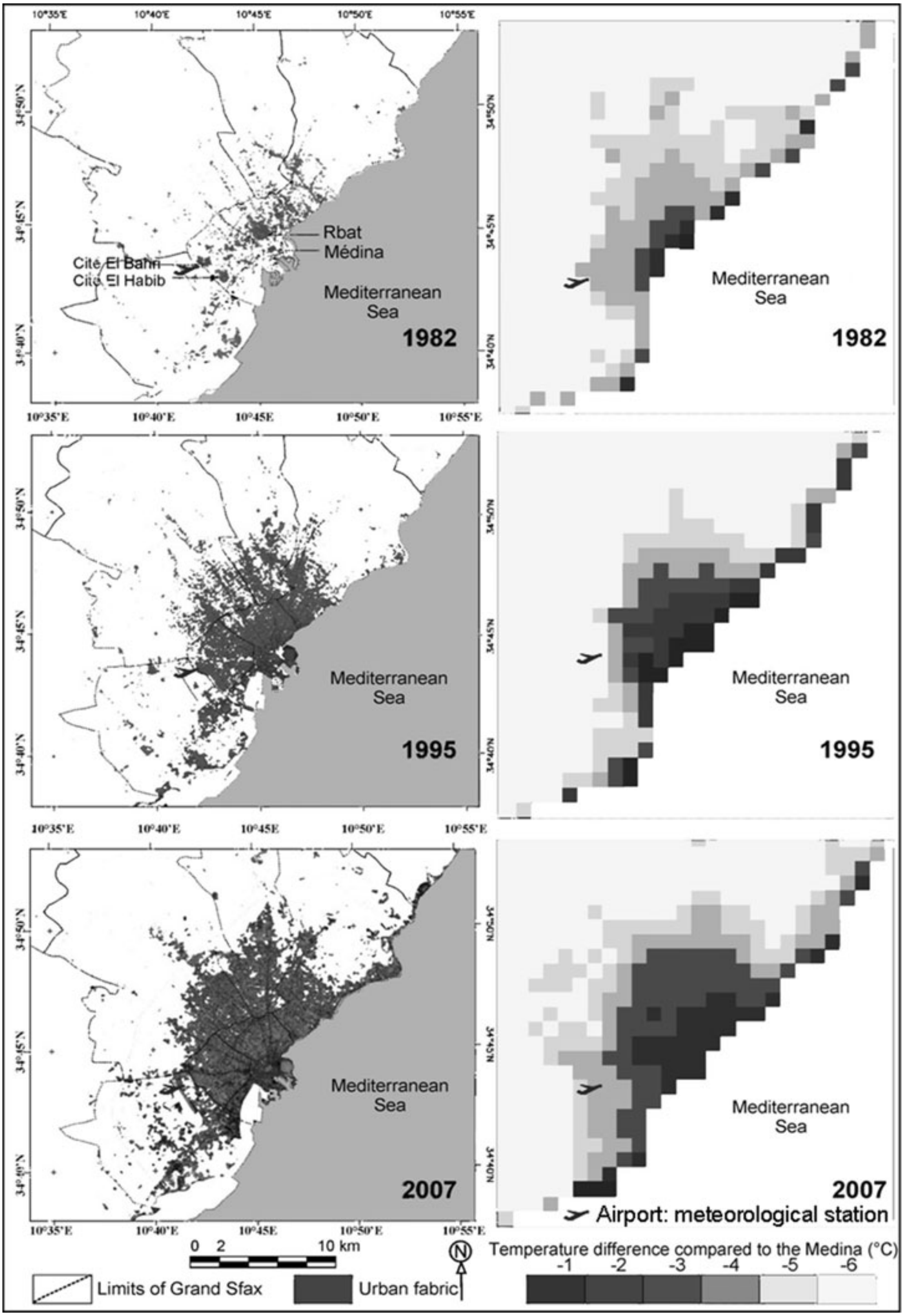


Fig. 4 Urban fabric and UHI extension in Sfax agglomeration for the period 1982–2007 and its impact on surface temperature. Urban fabric obtained from three LANDSAT images. channels 2. 3 and 4. recorded in June 1982. 1995 and 2007. Surface temperature (°C) derived from channels 4 and 5 of 3 NOAA-AVHRR images recorded in June 1982. 1995 and 2007 at midnight

that the five warmest years are, in decreasing order, 1999, 2001, 2003, 2002 and 2007. On the other hand, the coldest years are 1956, 1976, 1954, 1971 and 1957 (Fig. 2). The difference between these both extreme groups exceeds 1.9°C.

The graphic resulting from AHC method, whose aim is the years' classification according to annual minimum and maximum temperatures, shows two groups (Fig. 5). The dotted line represents the automatic truncation, leading to these two groups having different sizes and class centroids. The class centroids of minimum and maximum temperatures are respectively 13.13 and 24.06°C for the first group and 14.8 and 25.2 for the second one. Referring to the class centroids, the first one including the relatively "cold" years. The second, gathering relatively "warm" years (Fig. 5).

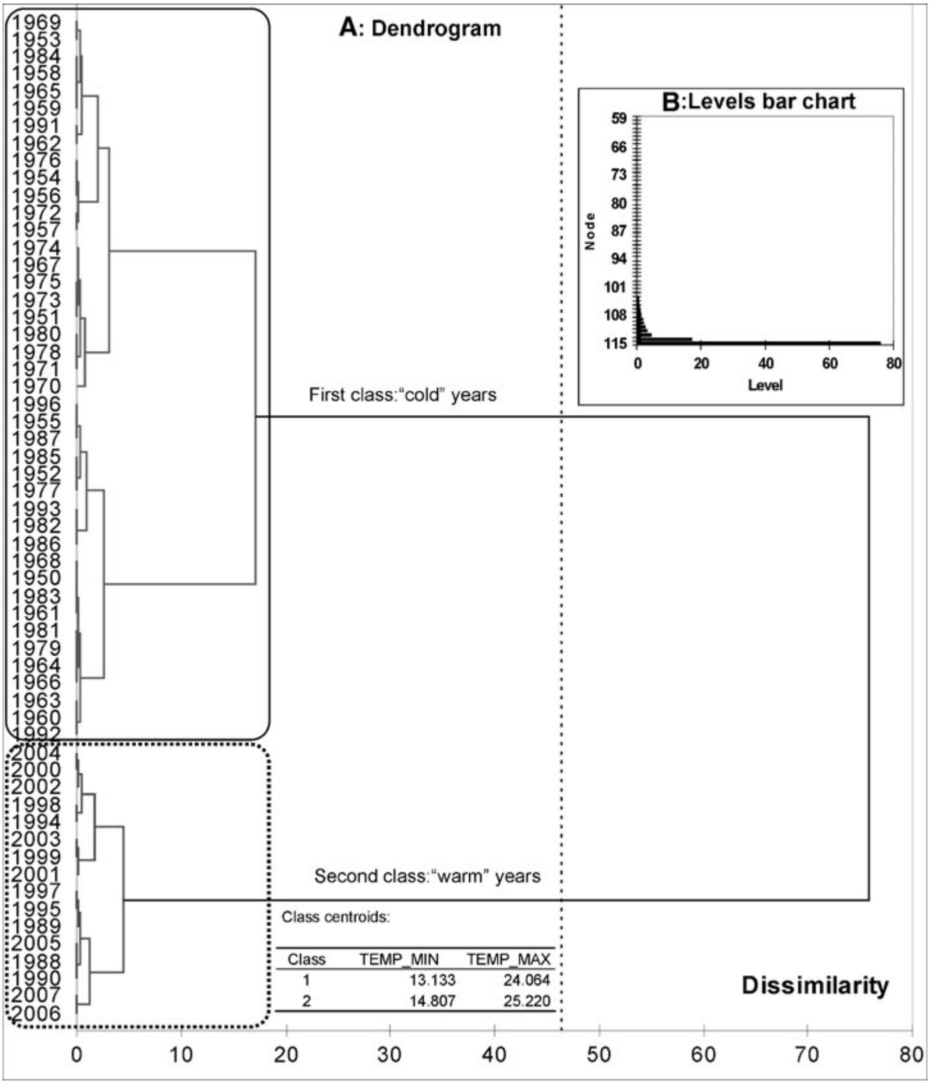


Fig. 5 Annual temperature clustering using the extreme values by means of AHC for the period 1950–2007: dendrogram (**a**) and levels bar chart (**b**). (data from National Institute of Meteorology)

The first group is composed of 42 years principally included in the 1950–1987 period. The second group is composed of 16 years included in the 1988–2007 period except for 1991, 1992, 1993 and 1996. Homegeneity is higher for the second as indicated by its flatter shape on the dendrogram. Within-class variance is higher for the first group (0.43) than for the second one (0.33), which confirms this homogeneity.

4.2 Monthly air temperature changes

The thermal rise is more significant for minimum temperatures. Linear regression indicates a higher trend in minimum temperature, especially in summer and autumn months. The trend rate indicates a significant increase with 0.056, 0.056, 0.046, 0.042 and 0.033°C/year respectively in, July, August, October, May, and November (Table 1; Fig. 6).

Table 1 summarizes the results of the Mann–Kendall test applied to the monthly minimum and maximum temperature recorded between 1950 and 2007 (last column). All data, except maximum temperature recorded in December, February and March, exhibit positive and significant trends at 0.05 significance level. On the other hand, the slope trend (a) obtained for all minimum monthly data are significant as given by the student t test, which

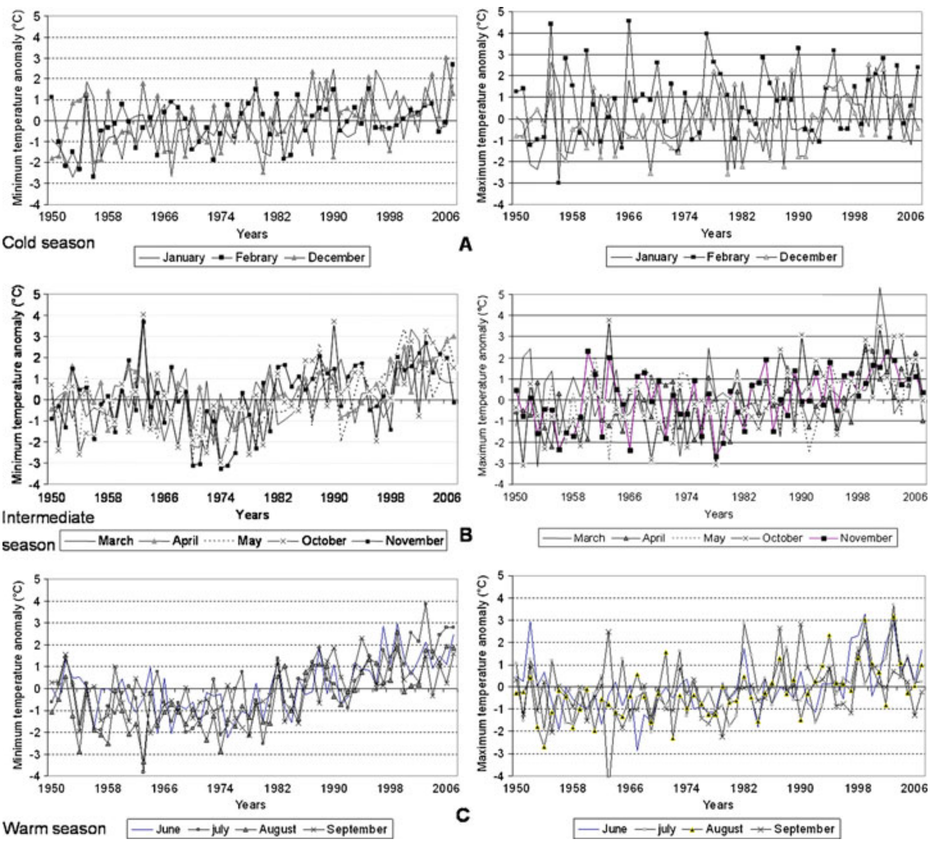


Fig. 6 Averages of monthly extreme temperatures anomalies for the period 1950–2007 (**a**: months of cold season. **b**: months of intermediate season. **c**: months of warm season; data from National Institute of Meteorology)

confirms that the increase mainly affects minimum temperatures. Whilst, for maximum monthly data, the test is not significant for February, March and December. Standard deviations of slope trends (Table 1) have been computed and indicate a high quality regression since all relative values are under 30% of (a) slope particularly during July and August (Table 1).

During the three last decades, a notable increasing tendency is observed more precisely between 1985 and 2007. Average minimum and maximum temperature anomalies during this last period are illustrated in Fig. 7 from which we deduce that the highest temperature rise is recorded during October, the summer and the other intermediate months. An intensification and extension of the warm season can be noticed.

Figure 8 shows how 10-day average temperature is varying over the annual cycle and over the 1950 to 2007 period in Sfax; it also confirms the extension of the warm season after 1984.

How can we explain warming after 1984 and justify the exceptional cooling in 1991, 1992 and 1993?

4.3 Global perspective

In Sfax city, the years 1991, 1992 and 1993 are characterized by a drop of around 0.3°C and 1°C below temperature values recorded respectively for the periods 1950–2007 and 1984–1990. This cooling is observed in the majority of stations in low and middle latitudes (see Fig. 2b of Parker et al. 1996). It was caused by natural variability and/or probably the result of the eruption of Mt. Pinatubo in the Philippines. Indeed, the June 1991 eruptions of Pinatubo had near-global effects on weather and climate via the introduction of sulfur dioxide and aerosols into the atmosphere, which reduces the net radiation (Angell 1993). Satellite observations, made 2 years later, show that this aerosol layer still existed, and that many parts of the world experienced a drop in average temperature of approximately 0.5°C in 1992 compared to the 30-year average (Delfin et al. 1992).

The time evolution of the annual average maximum and minimum temperature shows a notable increasing trend observed since the beginning of the 1980s (Fig. 2). The sharp variation in temperatures after 1980 is also corroborated on the global scale by analysing combined air temperatures recorded on continental and oceanic surfaces for the Northern and Southern Hemisphere and the whole Earth (Jones and Moberg 2003). These changes result from, at least in part, rising concentrations of atmospheric greenhouse gas which are largely due to the burning of fossil fuels (IPCC 2007; Ahrens 2008).

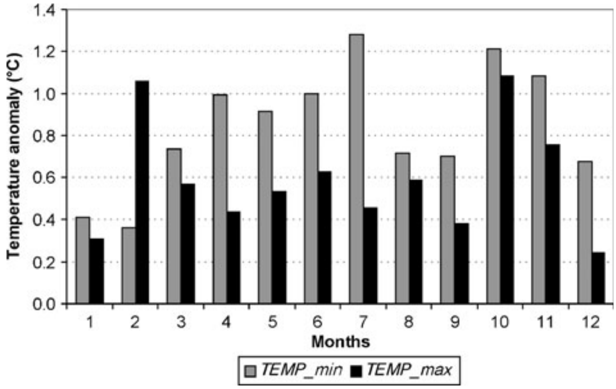


Fig. 7 Averages of monthly extreme temperature anomalies the period 1985–2007 (data from National Institute of Meteorology)

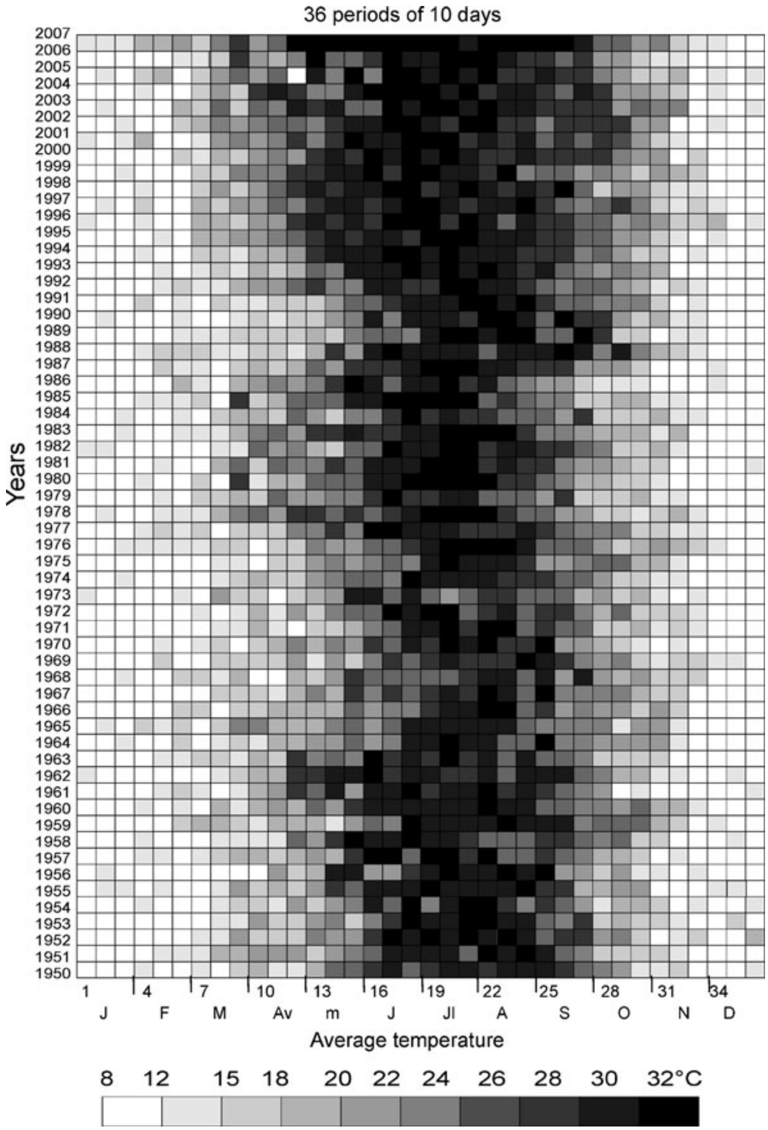


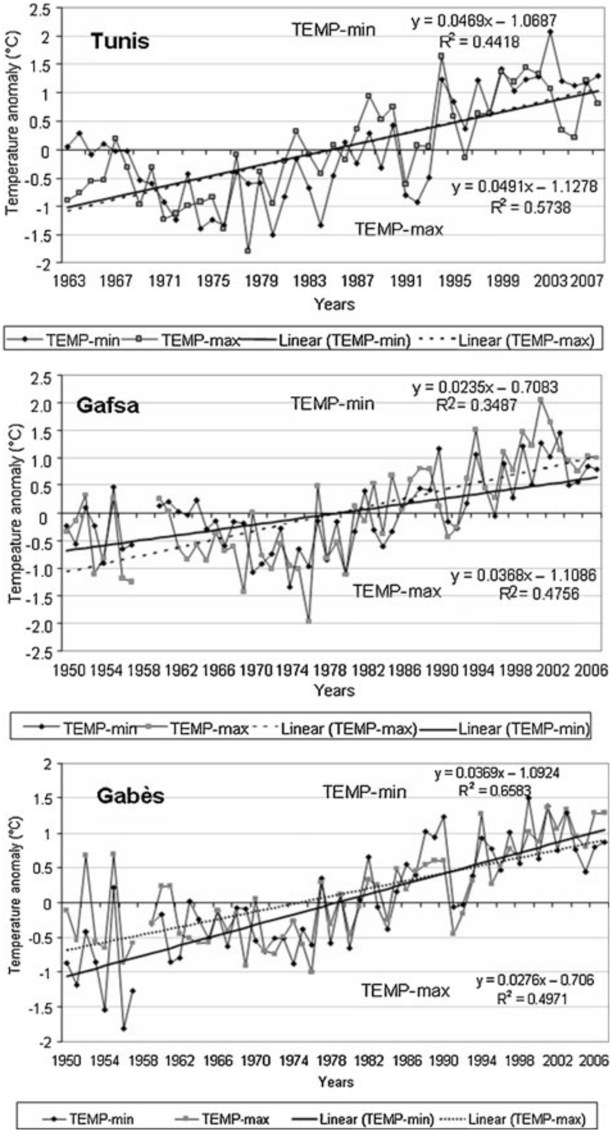
Fig. 8 10-day average temperature varying over the annual cycle over the 1950 to 2007 period. (data from National Institute of Meteorology)

When we compared the results with other Tunisian stations like Tunis-Carthage in the north, Gafsa in the South-west and Gabès in the south-east, we found similar results. A warming trend is observed at all the three stations (Fig. 9).

5 Conclusion

The time evolution of the annual average of daily maximum and minimum temperatures shows a significant increasing trend since the earlier 1980s, especially for minimum values

Fig. 9 Averages of annual temperature anomalies for the period 1950–2007 in Tunis (Tunis-Carthage station). Gafsa and Gabès (data from National Institute of Meteorology)



and during warm season. It can be concluded that this variation was caused, on the one hand, by climatic factors (volcanic activity and earth global warming) because the same increase was observed on global and regional scale and on the other hand by urban heat island effect on meso-scale.

This study confirms that land use has major impacts on land surface temperature. With the warmer area becoming larger, the extent of UHI increased and the spatial pattern changed from 1982 to 2007, which indicated a clear spatial relationship between urbanization and the spatial-temporal trends in UHI change.

Examining the relationship between regional or local scale climate change and land use helped in understanding that the heat and energy transfer varied with land surface physical properties. The UHI pattern derived here is also useful for urban planning and building design strategies. For future development, it would be judicious to create more green areas that can reduce UHI. However, in order that the findings can serve as a useful guide for urban planners and landscape architects, it is essential that more quantifiable data be established.

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