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Atmospheric Research 51 (1999) 85–98

ATMOSPHERIC
RESEARCH

Long term changes in diurnal temperature range in Cyprus

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Received 5 November 1998; accepted 10 March 1999

Abstract

Long term temperature data from two stations on the island of Cyprus have been analysed. Increasing trends of approximately 1°C/100 years in the annual mean temperatures are found at both stations. However, the minimum daily temperatures have generally increased at a larger rate than the maximum daily temperatures, resulting in a decrease in the long-term diurnal temperature range. This decrease ranges from −0.5°C/100 years to −3.5°C/100 years, depending on the location. The reduction in the diurnal temperature range is consistent with observations from other parts of the globe, and may indicate that the climate in this region of the globe is part of a larger global climate change that has been occurring over the last century. It is possible that long term changes in greenhouse gas concentrations in the atmosphere are responsible for the long-term annual mean temperature increase. Furthermore, the changes in the diurnal temperature range can possibly be explained by increases in cloud cover and/or tropospheric aerosols. It is possible that part of these changes is caused by local land-use changes, primarily by the increasing urbanization of Cyprus. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Climate change; Diurnal temperature range; Temperature trends; Cyprus

1. Introduction

There is increasing evidence that the earth's climate is changing as a result of anthropogenic activity (IPCC, 1996). Measurements of surface temperature, primarily over land regions, show an approximate 0.6°C warming of global temperatures over the

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PII: S0169-8095(99)00022-8

last century (Jones et al., 1991). It is still difficult to state what part of this global warming is due to natural climate variability, and what part is due to increases in the concentration of greenhouse gases in the atmosphere. However, one of the characteristics of this warming is that in many locations around the globe the difference between the minimum and maximum daily temperatures is decreasing (Karl et al., 1993). Since 1950 the amplitude of the diurnal cycle has decreased by approximately 0.5°C on a global scale.

In the eastern Mediterranean, Turkes et al. (1996) have shown significant decreases in the diurnal temperature range (DTR) in Turkey due to significant increases in minimum temperature since 1930. Cohen and Stanhill (1996) showed a significant reduction of the DTR at three stations in the Jordan Valley, although at all stations a decrease in the maximum temperature was observed, while the minimum temperature increased at only one of the stations in the dry southern regions of the valley. A more comprehensive study of 40 meteorological stations in Israel has recently shown a slight regional decrease in the diurnal temperature range over the past 30–50 years (Ben-Gai et al., 1999). Although a decrease in the diurnal cycle is observed throughout the year, the summer temperatures (both minimum and maximum) show significant increases over the same period, while the winter temperatures show significant decreases over this period, resulting in an increase in the annual temperature range in this region during the recent decades.

There are a few possible causes for these decreases in diurnal temperature range. It is possible that these changes are to a certain extent the result of local anthropogenic land-use modification such as urbanization, occasionally coupled with changes in irrigation. The heat island effect tends to be stronger in the nighttime hours than during the daytime hours (Landsberg, 1981), and is also dependent on season (Wang et al., 1990). The difference in energy consumption during the year is primarily determined by winter heating and summer cooling. In the summer months solar heating of the surface is at its maximum, while energy consumption continues to be high, if not higher than in the winter months, mainly as a result of energy use for air conditioning. This is especially true in Mediterranean countries like Cyprus, where temperatures in the winter are relatively mild. One would therefore expect that the heat island effect in Cyprus would be larger in the summer months. Nevertheless, Karl et al. (1988) have shown that even after correcting for the urbanization effect, the diurnal range trends remain basically unchanged. Increases in irrigation have the effect of reducing the daytime temperature relative to the nighttime temperature. This is a result of the sensible heat being converted into latent heat through the process of enhanced evaporation. However, no connection has been found between large changes in diurnal temperature range and increased irrigation (Karl et al., 1995). In fact, many of the regions with the smallest increase in irrigation are also the regions with the largest decrease in diurnal temperature range. Although the regions around the observation sites presented here have been systematically urbanized over time, the major crops in the agricultural areas lost in this way were primarily cereals, which are not irrigated.

In addition to the local effects, there are explanations for this decrease in diurnal temperature range that can be related to long term climate change. Increasing the cloud cover in a region would have different effects during the day and night (Ramanathan et al., 1989). During the day, increased cloud cover would tend to backscatter more incoming solar radiation, a negative feedback that would diminish any daytime surface warming. During the night, these same clouds absorb the terrestrial infrared radiation emitted from the surface, resulting in a positive feedback that would enhance any nighttime warming. Hence, by simply increasing the amount of cloud cover in a region, the diurnal temperature range would decrease (Hansen et al., 1995; Hansen et al., 1997). Observations show that in regions where long term cloud cover data are available, the decreasing diurnal cycle is positively correlated to increasing cloud cover (Plantico et al., 1990; Dessens and Bucher, 1995; Karl et al., 1995; Rebetez and Beniston, 1998). There also appears to be a general increase of cloudiness on a global scale (Henderson-Sellers, 1986, 1989; Jones and Henderson-Sellers, 1992).

Increases in anthropogenic aerosols such as sulfate and dust particles can also lead to a decrease in the diurnal temperature range. Tropospheric aerosols can have a direct effect by scattering incoming solar radiation (Taylor and Penner, 1994), and an indirect effect by increasing the cloud droplet concentrations, resulting in clouds having higher albedos during the day (Charlson et al., 1987). If the albedo increases without increasing the areal coverage of the clouds, then both of these effects are additional negative feedbacks that are active only during daylight hours. The possible causes of the observed diurnal temperature range changes are summarized in Table 1.

In this paper we present a new long term temperature data set from Cyprus (Fig. 1) which adds to the large pool of evidence that the global diurnal temperature range is decreasing over time. It should be noted that this is perhaps the first such a study of changes in the DTR to be carried out on an island.

Cyprus has an intense Mediterranean climate with the typical seasonal rhythm marked by hot dry summers from June to September and rainy changeable winters from November to March, separated by short autumn and spring seasons of rapid change in

Table 1
Possible causes of long-term decreases in diurnal temperature range (DTR)

Possible cause of decrease in DTR	Effect on minimum temperature	Effect on maximum temperature	Effect on DTR	References
Increased Irrigation	Minimal Effect[a]	Decrease	Decrease	Karl et al., 1995
Increased Urbanization	Large Increase	Small Increase	Decrease	Landsberg, 1981; Karl et al., 1988
Increased Aerosols	Minimal Effect[b]	Decrease	Decrease	Charlson et al., 1987; Charlson et al., 1992; Taylor and Penner, 1994
Increased Cloud Cover	Large Increase	Decrease	Decrease	Ramanathan et al., 1989; Plantico et al., 1990; Dessens and Bucher, 1995; Hansen et al., 1995; Hansen et al., 1997; Rebetez and Beniston, 1998

[a] Possible slight increase in minimum temperature due to increased water vapor.
[b] Possible infra-red absorption by particles will increase minimum temperature.

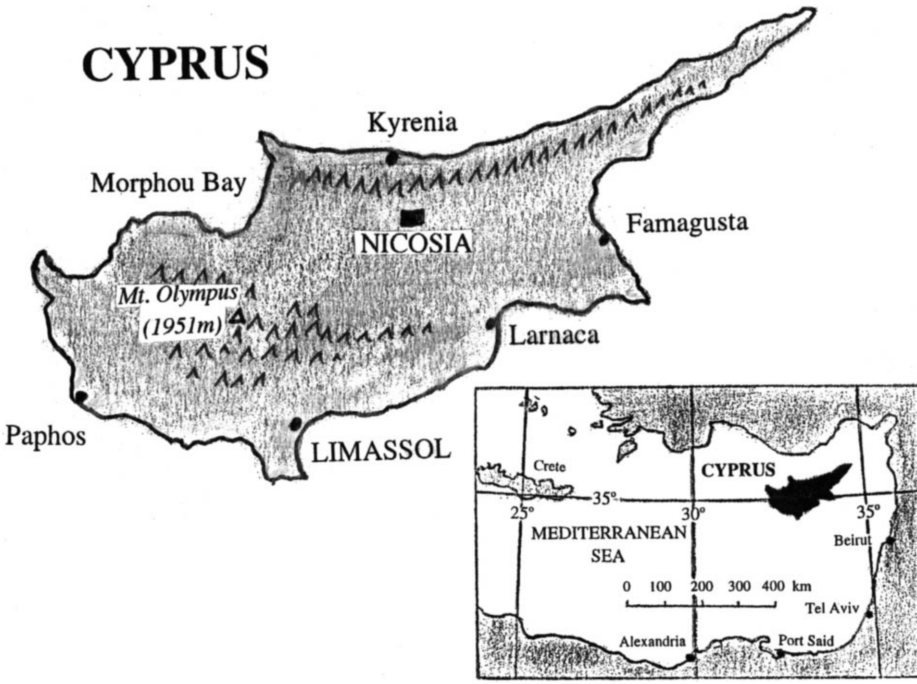

Fig. 1. Map of the location of Cyprus in the eastern Mediterranean, showing the two sites used in the analysis.

October, April and May. In summer the island is mainly under the influence of a shallow trough of low pressure extending from the great continental depression centered over Southwest Asia. It is a season of high temperatures with almost cloudless skies. Rainfall is almost negligible but isolated thunderstorms sometimes occur contributing less than 5% of the total annual rainfall.

In winter, Cyprus is near the track of fairly frequent small depressions which cross the Mediterranean Sea from west to east between the continental anticyclone of Eurasia and the generally low pressure belt of North Africa. These depressions give periods of disturbed weather usually lasting for a day or so and produce most of the annual precipitation. The predominantly clear skies and high sunshine amounts give large seasonal and daily differences between temperatures of the sea and the interior of the island, which also cause considerable local effects especially near the coast. The central Troodos massif, rising to 1951 m and, to a less extent, the long narrow Kyrenia mountain range with peaks of about 1000 m also play an important part in the meteorology of Cyprus.

2. Data

The temperature data used in this analysis were obtained from the Cyprus Meteorological service, in Nicosia, Cyprus. Although there were five stations on the island with minimum and maximum daily temperature records, only three had time series extending for periods greater than 50 years. One of these stations (Larnaca) was relocated three times since the start of the data collection in 1933, with these relocations clearly showing up as shifts in the temperature trends. Therefore, only two stations were eventually used in this study.

(1) Limassol (34°40′N, 33°03′E, elevation 5 m) with a record from 1903–1996. Although this station was relocated twice during this period (May 1977 and October 1987) there still remains a continuous long period of 74 years before the first station move, even though little change is observed in the temperature trends after the two station relocations. We consider the time series with and without the data after 1977. This station is a coastal station on the southern shore of Cyprus (Fig. 1). The station was situated in the town during the period 1903–1987 at a distance of about 500 m from the coast and afterwards was moved nearer to the coast.

(2) Nicosia (35°10′N, 33°21′E, elevation 160 m) with a continuous record of 101 years from 1896–1996 at the same station location. This station is located inland, away from the coastline (see Fig. 1). The station is situated at the top of a small hill with an elevation of about 160 m in the center of the town. The station is surrounded by eucalyptus and acacia trees at a distance of approximately 25 m from the screen. The height of the eucalyptus trees ranges from 5 to 10 m.

The climatic conditions of the two stations are quite different due to the location of the stations. Nicosia is located in the center of the island while Limassol is influenced by the sea breezes which give cooler summers and warmer winters for the coastal areas. The seasonal difference between mid-summer and mid-winter temperatures is 18°C in the inland areas and approximately 14°C along the coasts. In July and August the mean daily temperature reaches 29°C on the central plain (Nicosia) and 27°C on the coasts, while in January the mean daily temperature is 10°C on the central plain and about 12°C on the coasts. Seasonal differences between daytime maximum and nighttime minimum temperatures are also quite large, especially in the inland areas during summer. During winter these differences are from 8°C (coasts) to 10°C (lowlands), while in the summer the values increase to 10°C (coasts) and 16°C (central plain).

With respect to humidity Limassol is more humid during the summer. The mean value of relative humidity at mid-day during the summer in Limassol is about 50–55% while in Nicosia it is about 30%. In summers during the afternoons, Nicosia is affected by westerly winds blowing from Morphou Bay reducing the high temperatures remarkably. During the night katabatic dry winds from the Troodos mountains influence the central plain keeping humidity to low levels. As mentioned above most of the annual rainfall falls in the winter months, with the annual average precipitation in Nicosia being 325 mm while at Limassol it is about 425 mm.

The mean monthly maximum and minimum temperatures are derived from the average of the daily maximum and minimum temperatures. The monthly mean DTR is defined as the difference between the mean monthly maximum and minimum temperatures. The annual mean temperatures are calculated by averaging the monthly mean maximum and minimum temperatures over the year. Since the diurnal temperature cycle is not perfectly symmetrical about the minimum and maximum temperatures, the mean temperatures calculated here may not represent the true mean values. However, the bias in the mean will be constant over the time series, not influencing the long-term trends.

It is necessary to point out the difficulty of reaching general conclusions from a small number of local stations. Nevertheless, given the rarity of such long time series in this region, we felt it important to have these results presented in the scientific literature.

3. Results

The two stations analysed both show a significant increase of approximately 1°C in the annual mean temperature over the last century (Fig. 2). The correlation coefficients are calculated using a linear regression model, with the rate of change defined by the slope of the linear regression curves. There has been a slightly larger warming at Limassol (1.3°C/100 years) than at Nicosia (1°C/100 years), with both these trends being statistically significant at the 99.9% level. This local warming is approximately twice the observed globally averaged warming over the last century (IPCC, 1996).

The data presented in Fig. 2 can be separated into the annual mean minimum and maximum temperatures for the two stations (Fig. 3). At Limassol the difference in the maximum and minimum trends over the last century is quite obvious. The annual mean maximum temperature indicates a slight decrease of −0.4°C over the last 100 years. However, the annual mean minimum temperature at this station has increased dramatically by 3°C over the same period. At the Nicosia station (Fig. 3b) both maximum and minimum annual mean temperatures show increases over time, although the annual mean minimum temperature has increased more rapidly (1.3°C/100 years) than the annual mean maximum temperature (0.8°C/100 years). These differences result in the reduction of the diurnal range at both locations. At Limassol the annual mean change in the diurnal cycle is −3.4°C per 100 years, while at Nicosia there is a change of −0.5°C over the same period. The decrease in diurnal temperature range over the past century has been fairly constant at Limassol, while at Nicosia the diurnal temperature range has decreased at a rate of −2.2°C/100 years since 1950, with little change in the first half of the century.

As mentioned in the introduction, there appears to be only two possibilities for explaining the change in the diurnal cycle at these two sites: urbanization resulting in a heat island effect, or climate change resulting from more aerosols and cloud cover, possibly connected to the 20th century global warming trends. Since the heat island effect in Cyprus is likely to be larger in the summer months than in the winter, the trends in minimum and maximum temperature were divided into the winter and summer seasons, the former comprising the months December, January and February (DJF), and the latter comprising the months of June, July and August (JJA) (Figs. 4–6). Comparing Figs. 4a and 5a for Limassol, it is clearly seen that the maximum temperature decrease shown in Fig. 3 is dominated by the summertime cooling of the maximum temperature. If the heat island effect was significant in Limassol then an increase in both minimum and maximum temperatures should be seen in the summer. A decrease in the summer time maximum temperatures points to a small heat island effect on the daytime temperatures. If the heat island effect is small in the summer daytime, it must be even smaller in the winter daytime at Limassol, which indicates a rise of 0.8°C for the maximum winter daytime temperature. A decrease in the summer daytime maximum

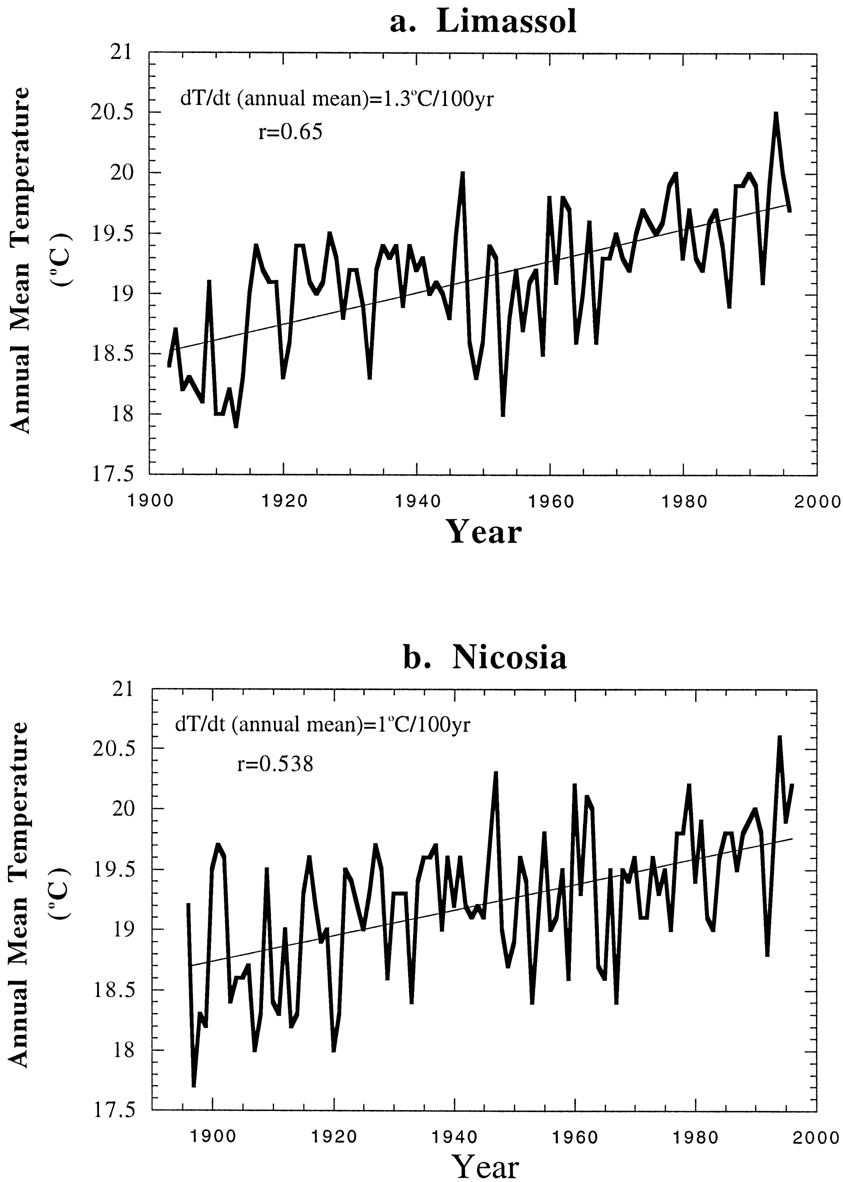

Fig. 2. The long term change in the annual mean temperature at (a) Limassol and (b) Nicosia on the island of Cyprus in the eastern Mediterranean.

with an increase in the winter daytime maximum also implies a negative feedback in the daytime summer months that is less significant in the daytime winter months. This can be explained by an increase in both clouds and tropospheric aerosols, both of which would have a larger negative feedback in the summer months than in the winter months

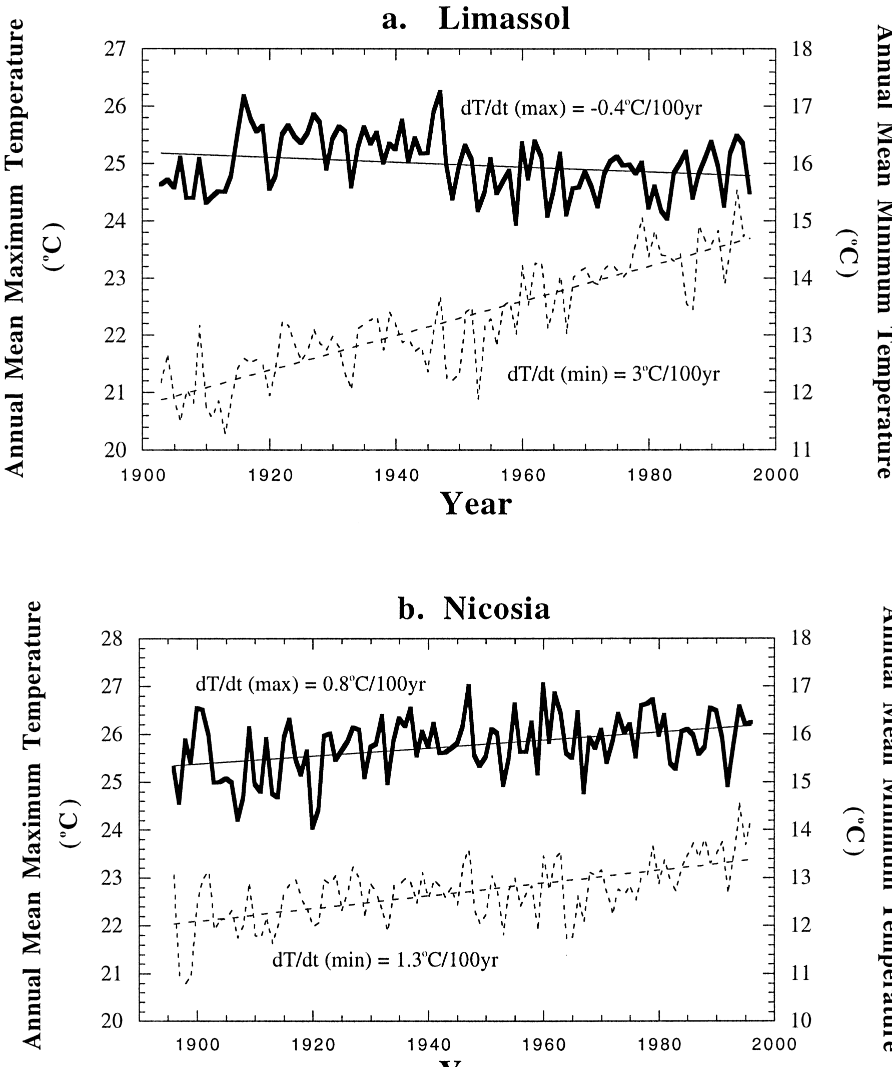

Fig. 3. The long term change in the annual mean minimum and maximum temperature at (a) Limassol and (b) Nicosia.

(Hansen et al., 1995). In the eastern Mediterranean, the period with the greatest dust and aerosol loading is during the summer months (Moulin et al., 1997).

The winter and summer nighttime temperatures at Limassol show significant increases over the last 100 years, with the winter minimum temperatures increasing 1.6°C and the summer nighttime temperatures increasing 4.5°C over this period. The diurnal temperature range during summer and winter for this station is shown in Fig. 5a. A huge decrease of −5.3°C during this century is seen for the summer months, while a smaller

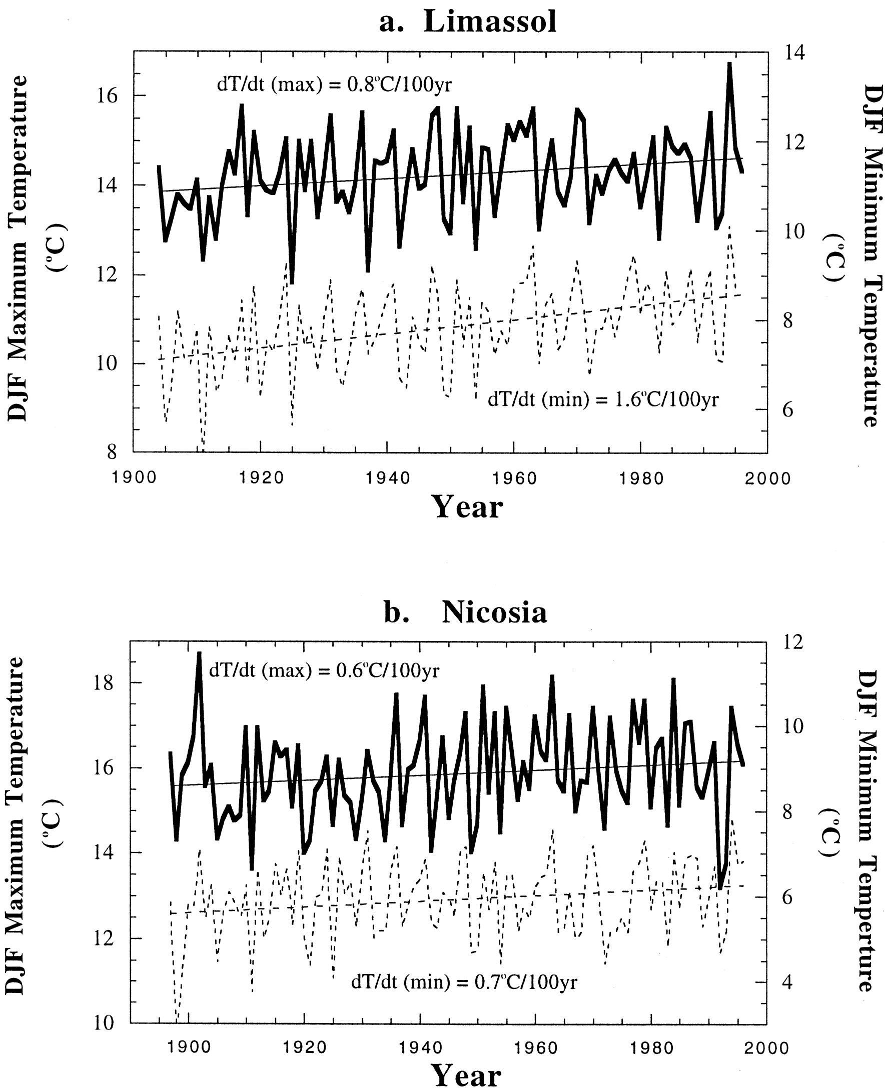

Fig. 4. The long-term change in the December, January, February (DJF) mean minimum and maximum temperature at (a) Limassol and (b) Nicosia.

decrease of −1.4°C is found in the winter months. As mentioned earlier, the location of the Limassol station was moved twice after 1977. If we ignore the data after 1977, we still observe a −5.1°C/100 years change in the summer diurnal range, while in the winter months the change is −1.1°C/100 years. Part of this nighttime warming may be due to the enhanced heat island effect at nighttime, but due to the small heat island effect during the day, it is likely that the majority of this nighttime warming is due to regional or global climatic changes. Jones et al. (1990) estimated that the heat island

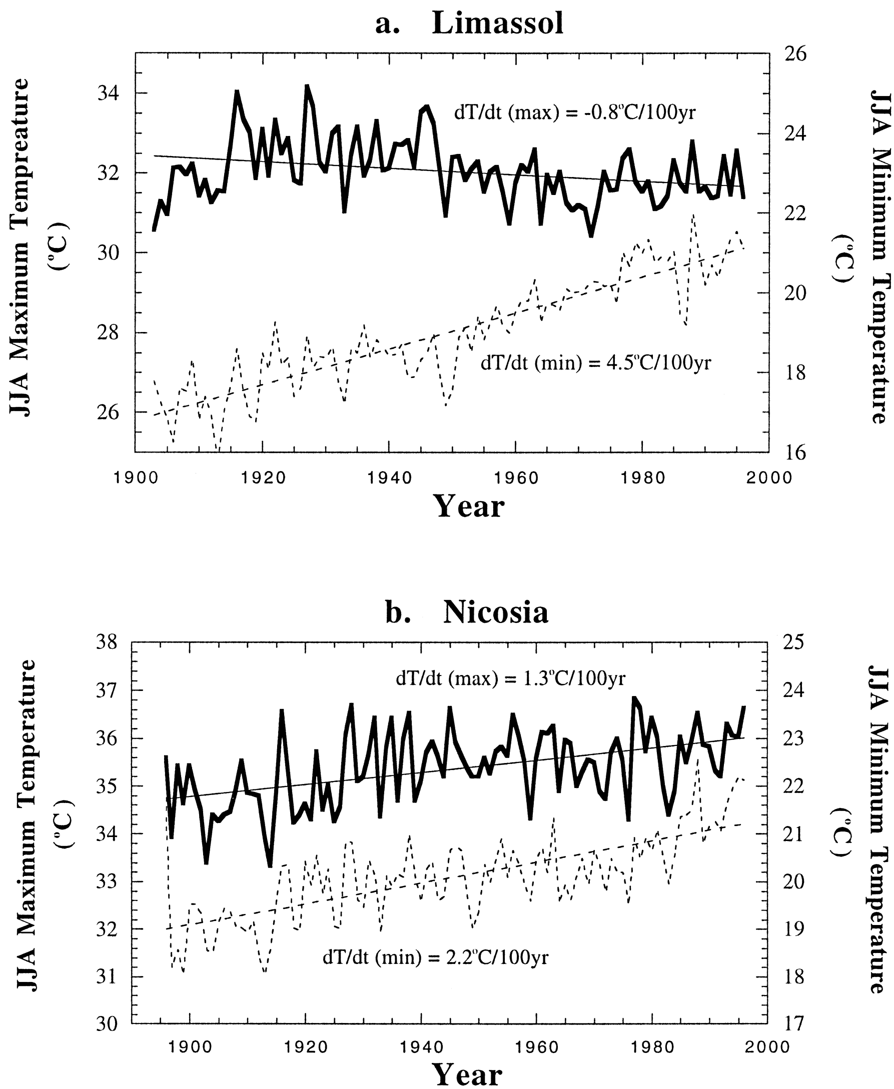

Fig. 5. The long-term change in the June, July, August (JJA) mean minimum and maximum temperature at (a) Limassol and (b) Nicosia.

effect can explain only 0.1°C of the 20th century global warming trends, although this differs from region to region. However, even in the regions of the largest heat islands, such as Hong Kong, the mean annual minimum temperature has only increased approximately 0.5°C since the beginning of the century (Stanhill and Kalma, 1995). The urban heat island regions of the two Cyprus stations are obviously a lot smaller than Hong Kong in size and volume. Nevertheless, at the beginning of the century the population of the urban area of Nicosia was about 20,000. This grew to approximately

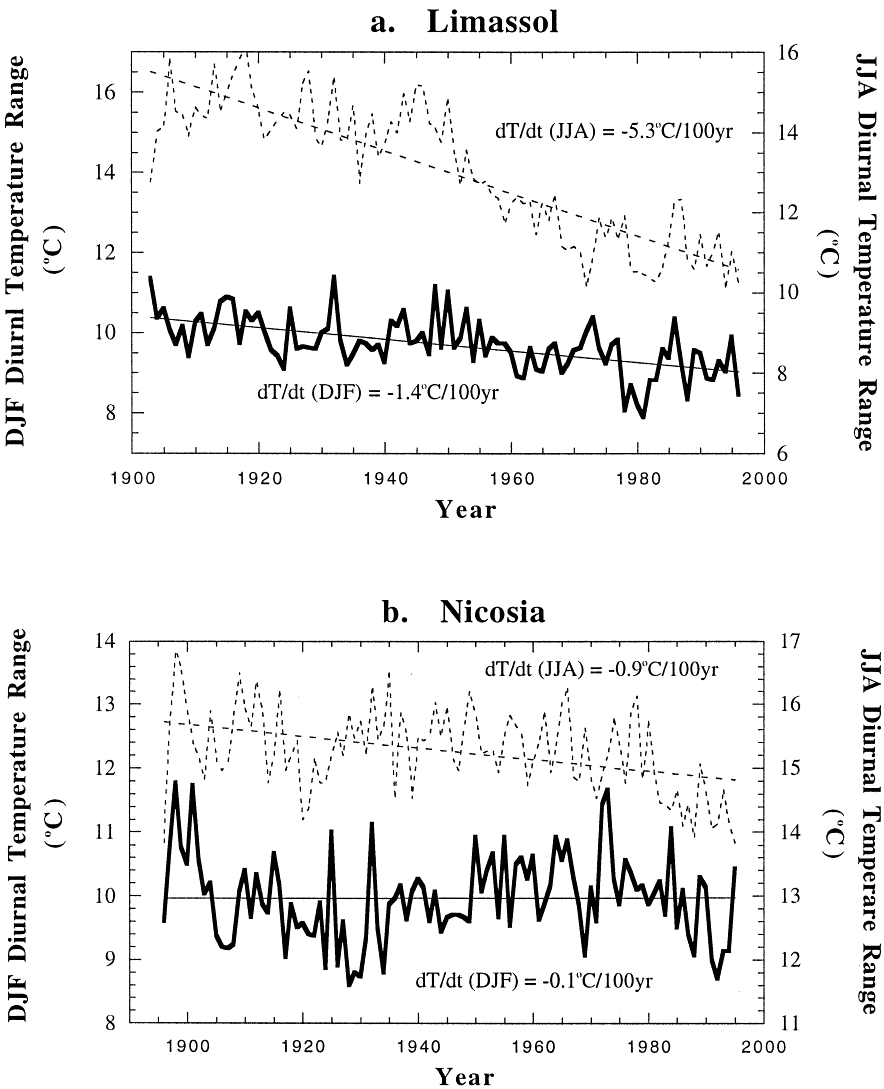

Fig. 6. The long-term change in the DJF and JJA diurnal temperature range (DTR) at (a) Limassol and (b) Nicosia.

230,000 in 1996, representing an increase of more than 10-fold. For Limassol the population at the beginning of this century from a mere 8000, and grew approximately 20-fold to 153,000 in 1996 (Department of Statistics and Research, 1996).

At Nicosia the maximum temperature increases during both winter and summer, with the summer maximum temperature increasing at twice the rate (1.3°C/100 years) of the winter maximum temperatures (0.6°C/100 years). In the winter months (Fig. 4b) the minimum temperature increases at a similar rate to the maximum temperature, resulting in a near zero change in the diurnal temperature range in the winter (Fig. 6b). This suggests that during the winter months, the warming of approximately 0.65°C over the last century is most likely due to large scale climatic changes, whether natural or anthropogenic in origin. At Nicosia, during the summer months, the nighttime temperatures increase more rapidly (2.2°C/100 years) than the daytime temperatures, with the diurnal range decreasing by 0.9°C over the last century (Fig. 6b). In this case it is likely that both the heat island effect as well as large-scale climatic change influence the changing summertime DTR. However, it is difficult to decipher which factor is more dominant in this case.

The seasonal trends differ from those found in Israel over the last 40–50 years by Ben-Gai et al. (1999), although there is agreement for a few isolated stations. In Israel, 500–1000 km southeast from Cyprus, both minimum and maximum temperatures exhibit decreasing trends during the winter months, while increasing trends are observed during the summer months. It is unclear why such significant differences should occur over relatively small distances (Fig. 1). However, it is possible that climate changes in Israel are also related to its position bordering on a desert region. Segal et al. (1994) have shown that under $2 \times CO_2$ conditions the desert climate propagates northward, resulting in a decrease in cloudiness in this region as climate changes. A decrease in cloudiness in the winter months in arid regions could result in the increase of radiative cooling during both the day and night, which could possibly explain the recent cooling of the winter temperatures in Israel.

4. Conclusions

Long term temperature records from Cyprus were collected and analysed to investigate the long-term changes in the diurnal temperature cycle. Only two of the stations (Limassol and Nicosia) had long enough records, with no major relocation problems, for this analysis. The results are summarized in Table 2.

At both stations similar annual mean temperature changes are observed. A warming of approximately 1–1.5°C has occurred over the last 100 years, approximately twice the global increase observed in the same period (IPCC, 1996). Although the annual mean temperature at both locations increases at a similar rate, the minimum and maximum

Table 2
Temperature trends for the annual mean, annual maximum/minimum, annual DTR, winter (DJF) maximum/minimum, winter DTR, summer (JJA) maximum/minimum, and summer DTR

	Annual mean	Annual max.	Annual min.	Annual range	Max. DJF	Min. DJF	Range DJF	Max. JJA	Min. JJA	Range JJA
Limassol	1.3**	−0.4*	3.0**	−3.4**	0.8*	1.6**	−1.4**	−0.8*	4.5**	−5.3**
Nicosia	1.0**	0.8**	1.3**	−0.5**	0.6	0.7*	−0.1	1.3**	2.2**	−0.9**

All values are in units of degrees Celsius per century.
Trends that are statistically significant at the 95% level are indicated by a single asterisk (*), while those trends significant at the 99.9% level are shown by two asterisks (**).
The time intervals used for these trends are identical to those shown in the Figures.

annual mean temperatures tell a very different story. At Limassol, a coastal station on the south shore of Cyprus, all of the warming has resulted from the increase in the minimum temperature. In fact, there has been a decrease in the maximum temperature during this century. This is very similar to some of the coastal stations from southern Israel that show warming of the minimum temperature, but cooling of the maxima temperature (Ben-Gai et al., 1999). At Nicosia, an inland station in the northern part of Cyprus, the maximum and minimum temperatures have both increased during the century, although the minimum temperatures have increased at a faster rate. Therefore, both locations show significant decreases in the annual mean diurnal temperature range, with the decrease at Limassol (−3.5°C/100 years) being much more pronounced than the decrease at Nicosia over the past century (−0.5°C/100 years). However, since 1950 the decrease in the diurnal temperature range at the Nicosia station has become much more pronounced (−2.2°C/100 years).

There are two main possible causes of these changes in the diurnal temperature range during the 20th century. The first is related to the increased urbanization of Cyprus, which can produce an enhanced heat island effect during nighttime hours relative to daytime hours. The second deals with regional or global climate changes, such as increased cloud cover and atmospheric aerosols, both of which reduce the daytime temperatures, while increasing the nighttime temperatures.

Since the heat island effect is stronger in the summer months than in the winter months, the temperature data were divided into seasons. The heat island effect influences both minimum and maximum temperature, although it has a larger effect on the minimum temperature. In Limassol, the observations show a decrease in the daytime maximum temperature over the past 100 years, and not an increase. We conclude that the change in diurnal temperature range in Limassol is most likely due to long term regional or global climate changes. In Nicosia, the maximum and minimum temperatures both increase during the summer months, with the summer temperatures increasing more than the winter temperatures. This, at first, appears to point to the urban heat island effect as a likely cause for the decreasing diurnal range. However, since 1950 the diurnal range has decreased dramatically, from close to zero change before 1950, to a rate of −2.2°C/100 years since 1950. Once again, the urban heat island effect can probably explain a small fraction of this decreasing trend, however, since 1950 it appears that climatic factors have also contributed to the changes in the diurnal temperature cycle at Nicosia. Unfortunately, cloud cover data is not available over this long time series for these stations. Therefore, it was not possible to check the validity of this hypothesis.

These results add to the global observations that the diurnal temperature range is decreasing over time. Whether these changes are truly a result of regional or global climate change, or due to local effects such as urbanization and changes in soil moisture, has to be determined by further investigation.

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