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RESEARCH

Long-term air temperature trends in North Cyprus

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Abstract

The Eastern Mediterranean region is a major climate change hotspot. The island of Cyprus is likely to face increases in the frequency and intensity of hotter weather conditions and heatwaves in the near future. Studies conducted on the long-term temperature changes in Cyprus are very limited. Here, we present an updated and most detailed assessment of the maximum, minimum, mean and diurnal temperature series in North Cyprus for the period 1975–2021. Data obtained from the meterological stations of North Cyprus have been analysed using Mann–Kendal (MK) test and Theil–Sen slope estimator. Overall the mean minimum temperature trend (T_{min}) showed the highest warming rate 0.61 ($0.24 \leq T_{\mathrm{min}} \leq 0.99$)°C decade^{-1} followed by the mean temperature trend (T_{mean}) 0.38 ($0.29 \leq T_{\mathrm{mean}} \leq 0.50$) °C decade^{-1} and the mean maximum temperature trend (T_{max}) 0.28 ($0 \leq T_{\mathrm{max}} \leq 0.50$) °C decade^{-1}. The magnitude of the warming trend observed in the overall mean minimum temperature of North Cyprus 0.61 °C decade^{-1}, is one of the fastest warming trends reported in the literature. A negative association was detected between the direction of prevailing winds of North Cyprus and the magnitude of increase in the mean temperature trends of the locations with coastal Mediterranean climate, which has pointed out the importance of prevailing winds regarding their cooling effect in coastal areas. The diurnal temperature range trend of North Cyprus indicates an apparent decrease (− 0.33 °C decade^{-1}). The warming impact of urban heat island effect was detected in temperature trends of Nicosia in the Mesaoria plain. The information provided here is invaluable to consider in any climate assessment and adaptation plan in Cyprus. If the current warming trend persists into the future, it will devastatingly impact all sectors and natural systems in the region.

1 Introduction

The average global surface temperature on Earth has increased by at least 1.1° C since 1880 due to the enhanced greenhouse effect, as a result of the increasing concentrations of carbon dioxide and other greenhouse gases in the atmosphere (Nasa, 2021). However, warming has not been uniform across the planet. Land warming varies across the continents and countries (Odnoletkova and Patzek 2021). Due to geographically specific climate feedback mechanisms, some regions warm more rapidly than the global mean. One such climate change hotspot is the Eastern Mediterranean and Middle East (EMME) region (Zittis et al. 2022). Yosef et al. (2019) reported ~ 0.55 °C/decade increase in daily minimum and daily maximum temperature in Israel between the years 1950–2017. In another study, ~ 0.52° C increase in mean average temperatures per decade was found in Saudi Arabia between the years 1979 and 2019 (Odnoletkova and Patzek 2021). Ghasemi (2015) also showed an increase in the mean annual minimum and maximum temperature records in Iran (0.34 °C and 0.15 °C respectively per decade). In Egypt, between the years 1950 to 2017, daily maximal and minimal temperatures have increased by 1.3 ± 0.1 and 1.3 ± 0.3 °C respectively (Mostafa et al. 2019). The increasing annual average temperature trend of 0.88 °C century^{-1} was also reported in Turkey between the years 1901–2014 (Hadi and Tombul 2018). Finally, for the period 1901 to 2001, Lelieveld et al. (2012) has revealed increasing monthly mean temperature anomalies of capital cities in the Eastern Mediterranean and the Middle East (EMME) between ranges 0.33 °C per decade to 0.46 °C per decade,

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all pointing out the fact that there is a general fast warming trend in the EMME.

Cyprus is likely to face increases in the frequency and intensity of hot weather conditions in the near future (Zittis et al. 2022). Since the region is a primary climate change "hot spot", there is concern about the future state of the environment and societal consequences (IPCC 2007). Studies conducted on the long term temperature changes in Cyprus are very limited. The previous studies only representing the few locations of Cyprus with short-time periods. Moreover, very little is known about the seasonal change and diurnal temperature of the island. In a study conducted by Price et al., (1999) at Limassol and Nicosia between periods 1900 to 2000 has revealed that the strongest warming trends occurred in annual mean minimum temperatures at both Limassol and Nicosia (3 °C century^{-1} and 1.3 °C century^{-1} respectively). Türkeş and Sarış (2007) investigated the seasonal temperature series of Kyrenia and Nicosia between periods 1975 to 2003. Strongest warming trend showed up in summer minimum temperatures at both Kyrenia and Nicosia (1.63 °C per decade and 1.15 °C per decade respectively). Between the period 1982 to 2011, for the Nicosia centre station, Theophilou and Serghides (2015) has showed 0.42 °C and 0.55 °C per decade increase in the mean yearly maximum and mean yearly minimum temperatures respectively. However, the number of locations and the time periods used in these studies do not represent the majority of the island. Therefore, the actual state of the historic changes in long term temperature trends in Cyprus do not exist. Given the importance of the long-term temperature changes for the preparation of climate adaptation strategies, in this study, we present the most detailed and the longest gauge observation trend study using monthly mean (averages of daily means), monthly mean maximum and minimum (averages of daily maximum and minimum) temperatures in North Cyprus on a continental level. Seasonal air temperature trends and annual diurnal temperature ranges (DTR) trends were also investigated accordingly.

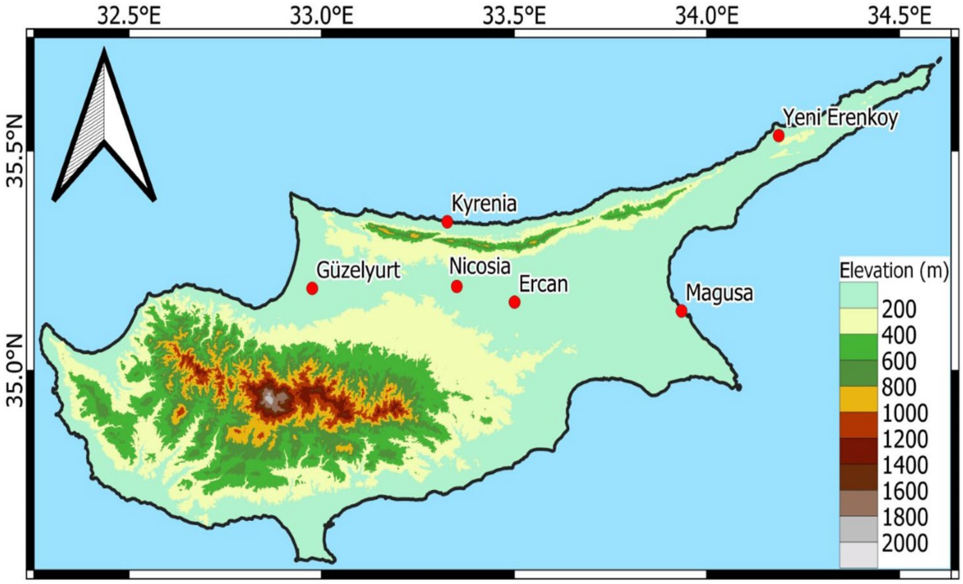
2 Description of study area

The island of Cyprus is located in the eastern part of the Mediterranean Basin. The island is situate between latitudes circles 34° and 36°N and meridians 32° and 35°E (Lingis and Michaelides 2009). Cyprus has a typical eastern Mediterranean climate: cool-to-mild wet winters and long, warm-to-hot dry summers (Lingis and Michaelides 2009). From a geomorphological point of view, the island can be divided into four main physical geographical morphological regions: (a) The mountain complex of Troodos mountains (with peaks about 1.951 m) at the south centre of Cyprus, (b) the mountain range of the Pentadaktylos (with peaks of about 1.000 m) at the northern part, (c) the central plain of Mesaoria and (d) the coastal plains (Hadjimitsis et al. 2013). These morphological features create their own microclimatic effects in different locations. Therefore, it is important to consider these features while evaluating the long-term temperature trends in Cyprus.

3 Methods and data processing

The database of the present study consists of monthly minimum, monthly mean and monthly maximum temperature values of six locations in Cyprus (Fig. 1). Data set

Fig. 1 Spatial distribution of stations used in the study



for Kyrenia (North part of pentadaktylos along the coastal plain), Yeni Ereköy (Northeastern part of Cyprus along the coastal plain at the peninsula region of the island), Nicosia (centre of Mesaoria plain), Ercan (centre of Mesaoria plain), Magusa (southeast of Mesaoria plain along the coastal plain) and Güzelyurt (west of mesaoria plain along the coastal plain) were obtained from North Cyprus Meteorological Administration based on records from 1975 to 2021. Monthly data were obtained from consistent number of daily data. The data are quality controlled by North Cyprus Meteorological Administration. The data were converted to average annual minimum, mean and maximum temperature. The graphical representation of long-term climatic trends of the average annual minimum, mean, maximum temperatures for each of the sites and the overall general trend for North Cyprus were represented with the line of best fit on a scatter plot using Matlab R2020a. Seasonal variability of the long-term temperature trends was also studied. The annual mean DTR values were calculated by subtracting mean monthly maximum and mean monthly minimum temperatures (Thorne et al. 2016). The monthly DTR values were then converted to annual DTR values. To determine the statistical trends significance and the magnitude of trends, the Mann – Kendall test and the Theil – Sen slope estimator were applied for all data series. All tests were performed by using statistical package XLSTAT.

3.1 Mann – Kendall test

The Mann – Kendall test was first created by Mann (1945) to be used for testing the significance of long-term monotonic non-linear trends by testing the significance of Kendall's (1938) tau. It has since become the most widely used non-parametric test for several applications and especially for meteorological applications.

The test statistic S is calculated using:

$$S = \sum_{i<j} y_{ij} \tag{1}$$

where

$$y_{ij} = sign\left(x_j - x_i\right) = sign\left(R_j - R_i\right) = \left\{ \begin{array}{l} 1 \; x_j < x_i \\ 0 \; x_j = x_i \\ -1 \; x_j > x_i \end{array} \right\} \tag{2}$$

here R_i and R_j are the ranks of the x_i and x_j observations of the time series.

According to Kendall (1975), the mean and variance of S are:

$$E(S) = 0 \tag{3}$$

$$\mathrm{V}_0(S) = n(n-1)(2n+5)/18 \tag{4}$$

where n is the number of observations.

$$Z_{\mathrm{MK}} = \begin{cases} \frac{S-1}{\sqrt{\mathrm{V}_0(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\mathrm{V}_0(S)}} & S < 0 \end{cases} \tag{5}$$

The standardized Mann – Kendall variable Z_{MK} is calculated using:

The significance of the test is determined by comparing the standardized variable Z_{MK} with the standard normal distribution quantile at the desired significance level.

3.2 Theil–Sen slope estimator

The Theil–Sen slope estimator (Theil 1950; Sen 1968) is a non-parametric test for fitting a robust line to a set of points. The test identifies the median of the lines' slopes between every pair of points in the sample. It has been widely used for estimation of change in meteorological data (Salman et al. 2017; Lu et al. 2016; Thomas and Prasannakumar 2016).

The slopes are estimated using:

$$Q_i = \frac{y_j - y_k}{t_j - t_k} \text{ for} i = 1, 2, 3 \ldots, N \tag{6}$$

where y_j and y_k are observations at times t_j and t_k for all $t_j > t_k$, and where there is only one data point at every time point:

$$N = n(n-1)/2 \tag{7}$$

where n is the number of time points. The N values of the slopes Q_i are ranked by $Q_1 \le Q_2 \le Q_3 \le \ldots \le Q_N$ for the Sen estimator $\widehat{\beta}_1$, estimated using:

$$\widehat{\beta}_1 = \begin{cases} Q_{(N+1)/2} & \text{if } N \text{ is odd} \\ \frac{1}{2}\left(Q_{(N+1)/2} + Q_{(N+2)/2}\right) & \text{if } N \text{ is even} \end{cases} \tag{8}$$

4 Results and discussion

4.1 Trends and changes in the mean temperature

The mean annual temperature trends indicate an apparent positive trend in all locations (Fig. 2). At the coastal plains, the greatest increase in mean annual temperature was observed in Kyrenia (0.50 °C decade^{-1}), secondly in Magusa (0.43 °C decade^{-1}), thirdly in Yeni Erenköy (0.37 °C decade^{-1}) and fourthly in Güzelyurt (0.29 °C decade^{-1}). The magnitude of warming trend at the coastal plains showed negative association with the direction of prevailing winds of

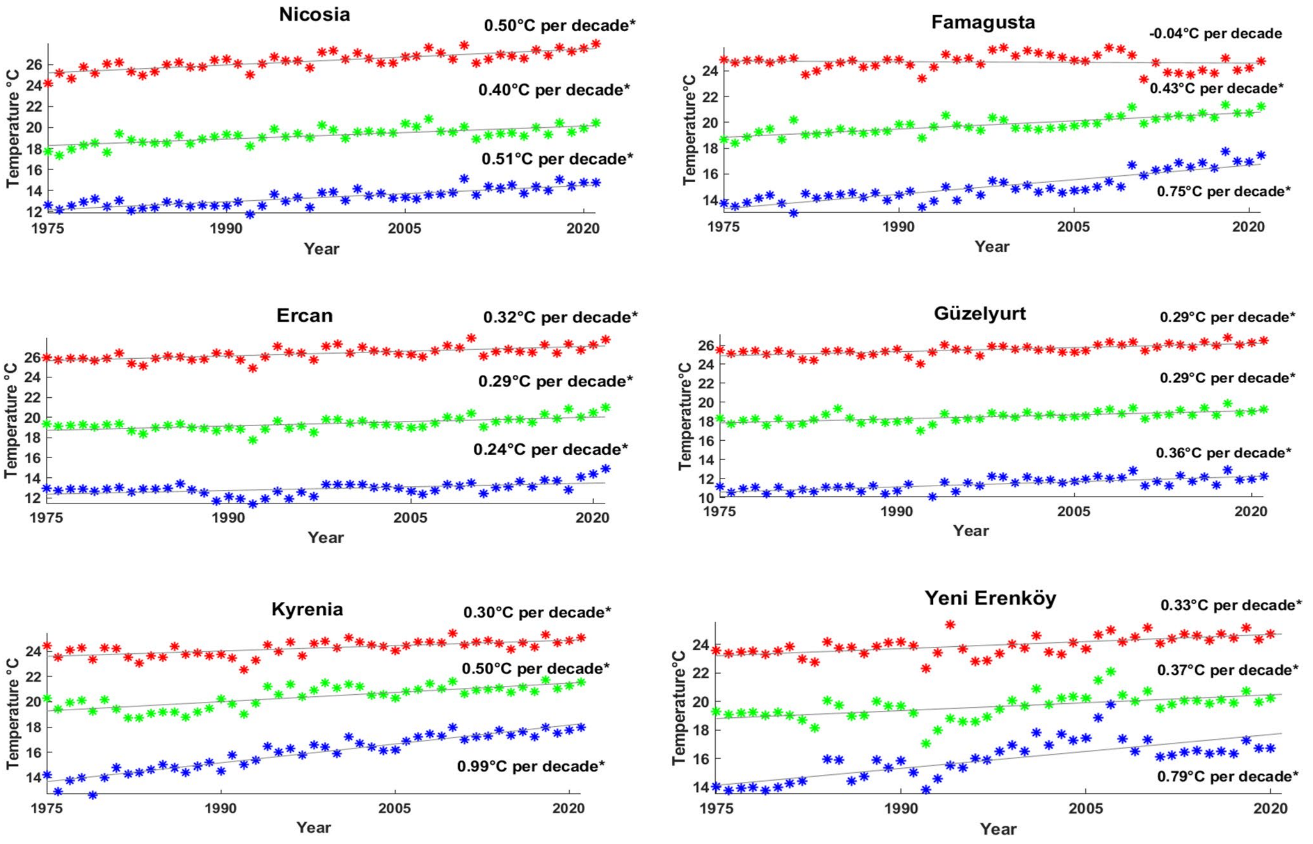


Fig. 2 Long-term trends and year to year variations in time series of mean minimum air temperature (blue dots), mean temperature (green dots), and mean maximum air temperature (red dots) of each station. (*) indicates the statistically significant trends at the 0.05 significance level ($p < 0.05$). "C° per decade" values indicate the magnitude of trends (Theil–Sen slope estimator)

North Cyprus. These results are not necessarily surprising. Prevailing winds can impact cooling power of sea breeze on coastal areas and its inland penetration (Zhou et al. 2021). Majority of the prevailing winds of North Cyprus is from west (22.2%), and the lowest increase in the mean annual temperature was observed in this area (Güzelyurt). The lowest percentage of the prevailing winds of North Cyprus is from North (7.1%), and the highest increase in the mean annual temperature was observed in this area (Kyrenia). Magusa from the southeast region of North Cyprus showed lower increase in the mean annual temperature trend than Kyrenia. This again could be explained by the fact that the percentage of prevailing winds received from the southeast (11.4%) is higher than the North. Only Yeni Erenköy region which is at north-eastern part of the island does not fit into this concept. North-eastern part receives lower percentage of prevailing winds (7.9%) than south-eastern part (11.4%). Though, Yeni Erenköy still displayed lower increase in the mean annual temperature than Magusa. This could be explained by the fact that Yeni Erenköy is at the peninsula region of the island and may resulted in this exception. Information provided above about the prevailing winds of North Cyprus can be found from (North Cyprus Meteorological Administration (NCMA) 2022). The cooling effect of wind circulation patterns on temperature trends were also reported in the most south-eastern Mediterranean region of Turkey which is very close to Cyprus (Türkeş and Sümer 2004). In the future climate change could change the direction, frequency and the speed of prevailing winds (Katopodis et al. 2021). If our results are indicative of the impact of prevailing winds on the mean temperature trends, climate change could also change the future mean temperature trends indirectly by changing the wind patterns.

Locations in Mesaoria plain that has inland (non-coastal) climatic conditions; Nicosia and Ercan (Fig. 2), also showed an apparent positive trend in the mean annual temperature trends (0.40 °C and 0.29 °C per decade respectively). The higher warming trend in Nicosia compared to Ercan could be explained as the result of "the Urban Heat Island Effect" (Kim and Brown 2021) in Nicosia. Nicosia is an urban area (city centre), whereas Ercan is a suburban area. Given the fact that the urban heat island effect has a serious impact on energy needs of the buildings, urban air quality and human health (Santamouris 2015), mitigation to minimize the urban heat island effect in Nicosia should be investigated. For Nicosia, similar increase in the mean temperature trend (~ 0.38 °C per decade) was observed between the years 1983 and 2011 (Theophilou and Serghides 2015). However, for the time period 1900–2000, Price et al. (1999) reported much lower increase in Nicosia for the mean temperature trend (0.10 °C decade^{-1}) compared our study. This difference in the magnitude of trend may indicate that the recent warming is faster than the past. Our results support the findings by Yosef et al. (2019), as they also reported faster warming trends in Israel between the years 1988 and 2017 compared to the period 1950–2017. Therefore, supporting the idea that the recent warming might be faster than the past.

For the next 50 years, the projections evaluated with gridded dataset for Cyprus in the mean temperature trends indicate ~ 0.36 °C decade^{-1} increase (with respect to control reference period 1981–2010) under business-as-usual pathway (Zittis et al. 2020). Our observations between the years 1975 and 2021 for the overall mean temperature trend of North Cyprus, indicate almost the same increase with a rate 0.38 °C decade^{-1} (Fig. 3). Between the years 1988 and 2017, Yosef et al. (2019) reported higher increase (0.53 °C per decade) in Israel. Almazroui et al. (2012) also reported faster warming trend (0.60 °C per decade) in Saudi Arabia for the period 1978–2009. Whereas, Toreti and Desiato (2008), Ghasemi (2015), and Galdies (2012) reported lower warming trends in Italy (0.22 °C per decade), in Iran (~ 0.25 °C per decade) and in Malta (0.28 °C per decade) for the time periods 1961–2004, 1961–2010, and 1951–2010 respectively. Therefore, depending on the location and the time periods used in the studies, lower and higher mean temperature trends were observed compared to our study.

In our study, majority of seasonal trends also showed an apparent increasing trend in most of the locations (Table 1). Most of the greatest increase in the seasonal temperature trends of the mean temperatures were observed in summer and autumn times. Between the time period 1975 and 2003, Türkeş and Sarış (2007) also reported the greatest increase in the mean annual temperature for Kyrenia in winter time (0.74 °C decade^{-1}) and for Nicosia in summer time (0.12 °C decade^{-1}). The greatest warming magnitudes in summer and winter times also reported in Turkey (Hadi and Tombul 2018) and Saudi Arabia (Odnoletkova and Patzek 2021). However, in contrast to our results, between years 1961 and 2010, Ghasemi (2015) reported the most significant increase in the mean seasonal temperature trends in summer and spring time for Iran.

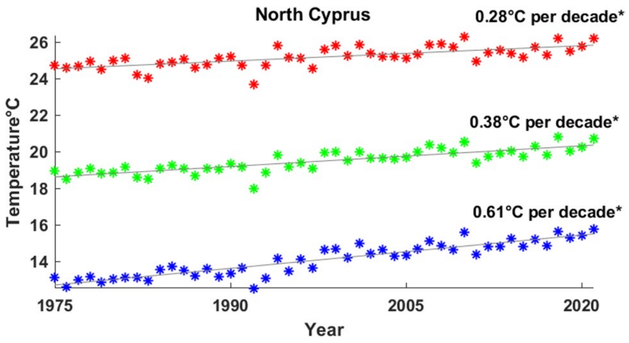


Fig. 3 Long-term trends and year to year variations in time series of mean minimum air temperature (blue dots), mean temperature (green dots) and mean maximum air temperature (red dots) of North Cyprus. (*) indicates the statistically significant trends at the 0.05 significance level ($p < 0.05$). "C° per decade" values indicate the magnitude of trends (Theil–Sen slope estimator)

4.2 Trends and changes in the mean maximum temperature

Between the years 1975 and 2021, overall mean maximum temperature trend of North Cyprus indicates 0.28 °C decade^{-1} increase (Fig. 3). In our study, most of the greatest increase in the seasonal temperature trends of the mean maximum temperatures were observed in Spring and Autumn times (Table 1). Between period 1961 and 2010, Ghasemi (2015) reported lower increase in the mean maximum temperature trend (0.15 °C decade^{-1}) in Iran. Whereas, Almazroui et al. (2012), observed higher mean maximum temperature trend (0.71 °C decade^{-1}) in Saudi Arabia between the years 1978 and 2009. Therefore, depending on the location and the time periods used in the studies, lower and higher mean temperature trends were observed compared to our study.

The mean maximum annual temperature trends indicate an apparent positive trend in majority of the locations (Fig. 2). The highest trend value was observed in Nicosia (0.50 °C decade^{-1}) that has inland (non-coastal) climatic conditions. In Turkey, most of the highest values in the mean maximum temperature trends were also recorded in areas dominated with non-coastal climatic conditions (Central Anatolia and South-eastern Anatolia; Türkeş and Sümer 2004). Our findings in Nicosia are like those found by Theophilou and Serghides (2015), which have shown 0.42 °C decade^{-1} increase in the mean maximum temperature trend between years 1983 and 2011. It is interesting to note that the trend difference between Nicosia and Ercan is higher in the mean maximum temperature than the mean temperature. Again, emphasizing the possible impacts of the urban heat island effect on temperature trends.

4.3 Trends and changes in the mean minimum temperature

Between the years 1975 and 2021, overall mean minimum temperature trend of North Cyprus indicates 0.61 °C decade^{-1} increase (Fig. 3). Between period 1961 and 2010,

Table 1 The resultant test statistics from the Mann–Kendall test and the Theil–Sen slope estimator of seasonal temperature trends of all clusters and of annual diurnal temperature trends for each location. (*) indicates statistically significant trends at the 0.05 significance level ($p<0.05$). Bold values indicate trends that are not significant. "C° per decade" values indicate the magnitude of trends (Theil–Sen slope estimator)

		Mean maximum temperature	Mean temperature	Mean minimum temperature	Diurnal temperature range
Location	Season	Slope (°C 10 year^{-1})	Slope (°C 10 year^{-1})	Slope (°C 10 year^{-1})	Slope (°C 10 year^{-1})
Nicosia	Spring	0.62*	0.40*	0.47*	**0.15**
	Summer	0.51*	0.62*	0.61*	**–0.10**
	Autumn	0.50*	0.42*	0.63*	**–0.13**
	Winter	0.36*	0.14*	0.34*	**0.02**
Kyrenia	Spring	0.30*	0.43*	0.97*	–0.67*
	Summer	0.17*	0.44*	1.04*	–0.87*
	Autumn	0.33*	0.64*	1.18*	–0.85*
	Winter	0.33*	0.47*	0.79*	–0.49*
Magusa	Spring	**–0.035**	0.69*	0.70*	–0.74*
	Summer	–0.28*	0.81*	0.81*	–1.09*
	Autumn	**–0.11**	0.90*	0.90*	–1.01*
	Winter	0.16*	0.59*	0.60*	–0.44*
Güzelyurt	Spring	0.33*	**0.18**	0.27*	**0.06**
	Summer	0.18*	0.52*	0.58*	–0.40*
	Autumn	0.29*	0.43*	0.46*	**–0.17**
	Winter	0.19*	**0**	**0.12**	**0.07**
Ercan	Spring	0.34*	0.25*	**0.13**	0.21*
	Summer	0.24*	0.27*	0.29*	**–0.05**
	Autumn	0.34*	0.31*	0.30*	**0.04**
	Winter	0.20*	**0.13**	**0.01**	**0.19**
Yeni Erenköy	Spring	0.43*	0.42*	0.80*	–0.37*
	Summer	0.32*	0.19*	0.73*	–0.41*
	Autumn	0.39*	0.37*	0.86*	–0.47*
	Winter	**0.09**	0.28*	0.65*	–0.56*

Ghasemi (2015) reported lower increase in the mean minimum temperature trend (0.34 °C decade^{-1}) in Iran. Almazroui et al. (2012) also found lower increase in the mean minimum temperature trend (0.48 °C decade^{-1}) in Saudi Arabia between the years 1978 and 2009. Trend analysis conducted by Toreti and Desiato (2008) for the north, centre and south of Italy also showed lower increase in the minimum temperature trend compared to our study (0.53 °C decade^{-1}, 0.38 °C decade^{-1}, and 0.28 °C decade^{-1} respectively). In Bangladesh, between the years 1961 and 2008, Shahid (2012) also found lower increase (0.15 °C decade^{-1}) in the mean minimum temperature. Last but not least, for the periods 1894 to 2010 and 1974 to 2010, Koutsias et al. (2012) also reported a slower increase in the mean minimum temperature series in Greece (0.10 °C decade^{-1} and 0.50 °C decade^{-1} respectively) compared to our study. As far as we are aware, the trend value observed in this study is one of the highest mean minimum temperature trends (0.61 °C decade^{-1}) reported in the literature on a continental level obtained with data from meteorological stations.

The mean minimum temperature trends indicate an apparent positive trend in all locations (Fig. 2). The greatest increase in the mean minimum annual temperature was observed in locations that have coastal climatic conditions. Kyrenia with trend 0.99 °C decade^{-1} had the highest increase. Most of the greatest increase in the seasonal temperature trends of the mean minimum temperatures were observed in Autumn and summer times (Table 1). In Iran, between years 1961 and 2010, Ghasemi (2015) also reported the most significant increase the mean minimum seasonal temperature trends in summer time. Our findings in Nicosia (0.51 °C increase per decade) are similar to those found by Theophilou and Serghides (2015), which have shown 0.55 °C per decade increase in the mean minimum temperature trend between the years 1983 and 2011. It should be pointed out that the magnitude of trend difference between Nicosia and Ercan is higher in the mean minimum temperature than the mean maximum and the mean temperature trend. This indicates that in Mesaoria plain, the highest impact of urban heat island effect on temperature trends was on mean minimum temperature trends. Higher ambient air urban temperatures result in higher use of air conditioning and a considerable increase in electricity consumption (Pyrgou and Santamouris 2022). In Europe, Cyprus is already the second highest energy consumer in space cooling (Eurostat 2020). In the future, climate change and urbanisation in the island will add further pressure in energy demand for cooling.

4.4 Trends and changes in the diurnal temperature

The overall diurnal temperature range trend of North Cyprus indicates – 0.33 °C decade^{-1} decrease (Fig. 4). The greatest decrease in the diurnal temperature range trends was observed in summer and autumn seasons (Table 1). In the USA, between the years 1900 and 2010, Qu et al. (2014) also reported the highest decrease in the DTR trends in summer and autumn times. In North Cyprus, most of the locations that have coastal climatic conditions showed decreasing trend in the diurnal temperature range (Fig. 5). However, Nicosia and Ercan with inland (non-coastal) climatic conditions did not show a significant change in the DTR trend. In a study conducted by Abbasnia and Toros (2020) in Turkey, similar pattern was observed. An increasing trend or no change in the diurnal temperature range is mostly located in central, eastern, and northern parts of Turkey (non-coastal). However, the diurnal temperature range has significantly decreased in the Mediterranean coastal regions, including the western and southern coasts. This kind of opposite behaviour of the coastal stations compared to non-coastal locations might depend on the content of atmospheric humidity and along with the local geographical factors of these areas (Pal and Eltahir 2016). Land has a lower heat capacity than water, during the day the land surface (non-coastal areas) warms up faster than the sea surface (Papanastasiou et al. 2010). In the evening, land cools faster than the sea (Papanastasiou et al. 2010). Therefore, the fast-warming properties of Nicosia and Ercan could explain the high warming trends observed in the mean maximum temperature. At the same time, the fast-cooling properties of these regions could explain the slower warming trends in the mean minimum temperature which resulted in no significant change in the diurnal temperature range trends of these locations (Figs. 2 and 5).

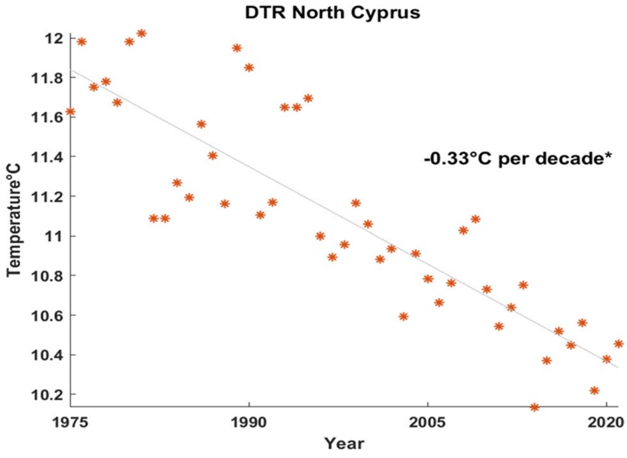


Fig. 4 Long-term trends and year to year variations in time series of DTR trends of North Cyprus. (*) indicates the statistically significant trends at the 0.05 significance level ($p < 0.05$). "C° per decade" values indicate the magnitude of trends (Theil–Sen slope estimator)

In contrast to this, the climate characteristics of coastal climate regions keeping high temperatures stable from day to night (slow cooling property), which could explain the high warming trends observed in the mean minimum temperature. At the same time, the slow-warming properties of coastal climate regions could explain the slower warming trends in the mean maximum temperature (Fig. 2), therefore, resulting in the observed trends in the diurnal temperature range depending on the location (Fig. 5). Türkeş and Sümer (2004) also confirms the effects of factors such as continentality, topography, exposure duration to sunlight and atmospheric features on DTR series in Turkey. The changes in DTR trends can also be attributed to the changes in factors such the amount of cloud and/or aerosols, and humidity (Pyrgou et al. 2019; Albrecht 1989; Hansen et al. 1995; Dessens and Bücher 1995). Therefore, associating long term trends of these factors in Cyprus with observed DTR trends require investigation.

The overall decline in the diurnal temperature range trend of North Cyprus could be attributed to the fact that Cyprus is a small island in the middle of eastern Mediterranean Sea. Although there are few areas with inland climatic conditions, most of the island is dominated with coastal climatic conditions, which could explain the declining trend in the diurnal temperature range. Two meteorological stations used by Price et al. (1999) also confirm the declining DTR trends in Cyprus. However, a study evaluated with gridded dataset for Cyprus indicates an increase in DTR trends (mean maximum temperature trend increasing faster than the mean minimum temperature) both for the past reference period (1981–2010) and for the future projection (Zittis et al. 2020). This reveals an important difference between gridded data from a model output vs. station-based air temperature observations.

It is important to note that some previously published studies related to changes in temperature trends compared their results by only mentioning "°C decade^{-1}" increase or decrease in other countries without mentioning the time periods of the data used in those studies that they referenced. Given the fact that the most of the warming trends are higher in recent past years since 1975 (Nasa, 2021), it will not be possible to understand which regions of our planet is warming faster or slower without mentioning the time periods of the data compared. Moreover, after analysing certain type

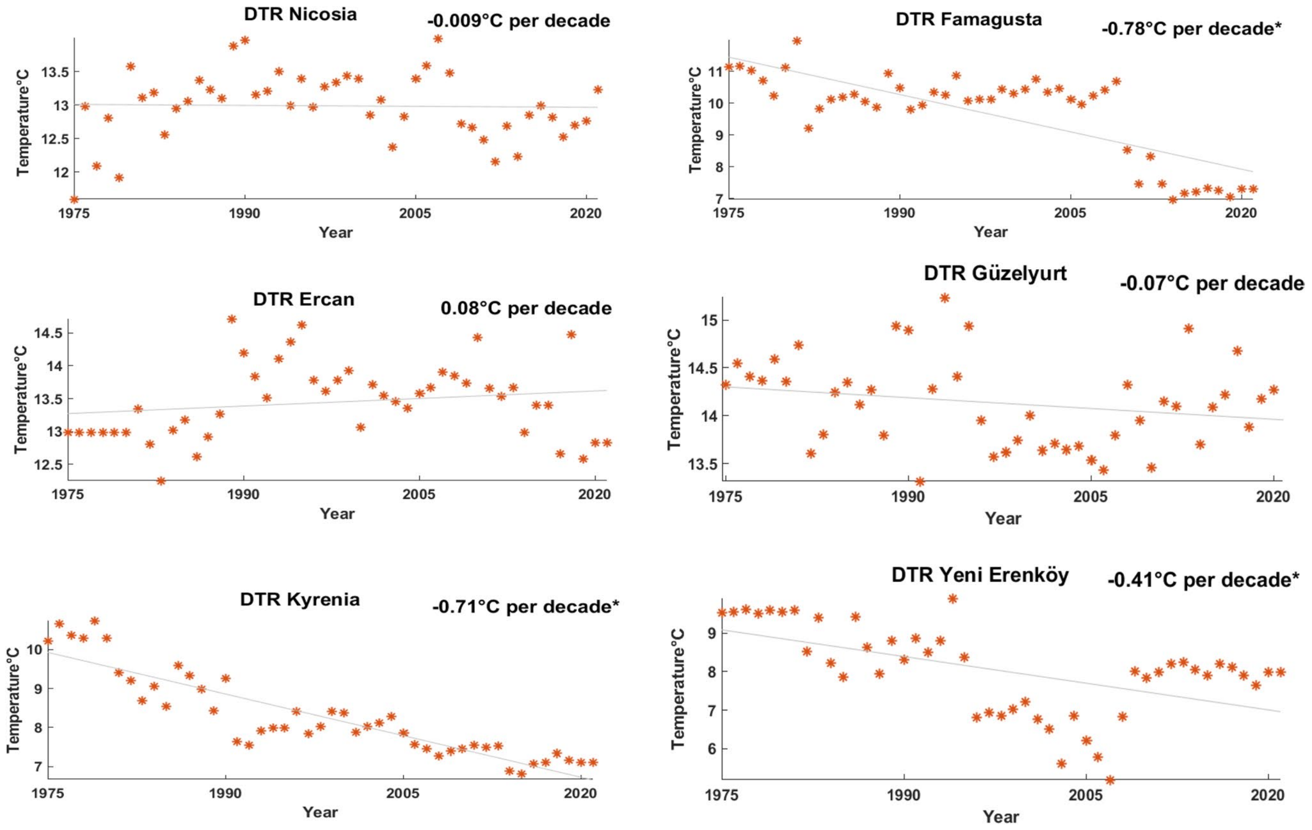


Fig. 5 Long-term trends and year to year variations in time series of DTR trends of each station. (*) indicates the statistically significant trends at the 0.05 significance level ($p < 0.05$). "C° per decade" values indicate the magnitude of trends (Theil–Sen slope estimator)

of temperature trends of different locations in a country, an overall average trend of a country should also be calculated. Lastly, our results showed the importance of working on the changes in all temperature clusters (mean maximum, mean, and mean minimum temperatures), diurnal temperature trends, geographical morphology, and urban–rural features of study areas all together. All these will allow for a proper comparison with future studies.

5 Conclusions

A significant warming trend is evident in all surface air temperature clusters in North Cyprus. Mean minimum air temperatures showed the highest warming rate followed by the mean air temperatures and lastly the mean maximum air temperatures. The magnitude of the mean minimum air temperature trend (0.61 °C decade^{-1}) indicates the evident fast warming of the Eastern Mediterranean and EMME region. A negative association was observed between the direction of prevailing winds of North Cyprus and the magnitude of the mean temperature trends of the locations with coastal climate, emphasizing the cooling effect of prevailing winds in coastal areas. In Nicosia, the impact of urban heat island effect on all temperature clusters, especially on the mean minimum temperature trend, was apparent. Mitigations to limit the urban heat island effect in Nicosia and possibly in other locations should be investigated to minimize additional warming from this effect. The diurnal temperature trends indicate an apparent decreasing trend in majority of locations in North Cyprus. Locations with inland (non-coastal) climatic conditions did not show a significant change in diurnal temperature trends. Both climate model simulations and the observation-based evaluations indicate the Mediterranean region will warm much more strongly than the global mean. Adaptation strategies to minimize the energy needs of the buildings for cooling should be prioritized in Cyprus. Otherwise in the future, climate change will put intense pressure on the energy demand for space cooling.

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Data availability The authors confirm that the data supporting the findings of the study available upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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