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Recent Temperature Trends over Mountainous Greece

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Abstract: This study aims to investigate (minimum, mean and maximum) temperature trends at high altitudes in Greece. The temperature variations can affect plant phenological behaviour and growth. The dates of growth initiation or the length of the growing period are defined mostly by minimum temperature. On the other hand, maximum and mean temperatures have a direct effect on water availability, affecting growth and development rates of rain fed ecosystems, especially during the water-stressed summer period. Data from 9 meteorological stations at altitudes 520-1310 m, covering the time period 1960-2006, are analyzed for temperature variability. The stations are located in agricultural and forest environments with no significant land use changes over the study period. Trends of temperature are calculated on a monthly, seasonal as well as an annual basis under different levels of confidence.

Generally, significant yearly decreases of mean temperature were observed. Averaged for all sites, the annual mean temperature decrease rate is – 0.015 ^{o}C y^{-1}. In all months and seasons, the average trends of mean temperature are also negative, with November becoming coolest (– 0.061 ^{o}C y^{-1}) and autumn showing the greatest temperature decrease (– 0.032 ^{o}C y^{-1}). In comparison with mean temperature, an even greater decreasing rate is observed for minimum temperature (– 0.027 ^{o}C y^{-1}). Monthly minimum temperature trends are similar to those of mean temperature. On a seasonal basis, however, it is in spring that minimum temperature shows maximum negative trend (– 0.038 ^{o}C y^{-1}). On the contrary, maximum temperature slope has a positive annual trend, with a site-average of + 0.011 ^{o}C y^{-1}. The greatest increasing rate (+ 0.037 ^{o}C y^{-1}) is observed in summer with July becoming warmest. In some months, even maximum temperature becomes cooler with November, again, becoming coolest (– 0.045 ^{o}C y^{-1}). Conclusively, high altitude sites in Greece generally become cooler, with reference even to maximum temperature in some cases.

Keywords: Mann Kendall, Sen slopes, temperature, trends

1. INTRODUCTION

Temperature increase and global warming is considered to be a universal phenomenon (Keim et al. 2003, Trombulak and Wolfson 2004, Chmielewski et al. 2004, Todisco and Vergni 2008) although there are cases where on opposite variation is recorded (Gadgil and Dhorde 2005, Giles and Flocas 1984, Makroyannis et al. 1998). According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001), the global average surface temperature has increased by about 0.6 ± 0.2 ^{o}C over the 20th century, when rainfall appears to decrease in the Northern Hemisphere. Climate change as an impact of urbanization and population growth (Jones et al. 1990, Fujibe 1995, Karaca et al. 1995) is more intense in major cities (Wigley and Farmer 1982, Colacino and Rovely 1983, Karaca and Aslan 1993, Founda et al. 2004). In Greece such increasing rates of temperature is confined in rural developed areas (Founda et al. 2004). In natural ecosystems and agricultural regions, climate change appears to differ, being affected less by urbanization and land use changes (Proedrou et al. 1997, Philandras et al. 1999).

In this work a study of temperature data from 9 high altitude (higher than 500 m) agricultural and forest meteorological stations is attempted, by statistically analyzing their trends. Average minimum, maximum and mean values of temperature play a significant role in vegetation development and therefore their changes can affect the species populations in plant societies, along with their spatial and temporal distribution.

2. MATERIALS AND METHODS

Common meteorological data were used in this study. The monthly average values of temperature, mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}), from 9 meteorological stations at different altitudes (520-1310 m) in Greece, were analyzed on a monthly, seasonal (winter: December-February, spring: March-May, summer: June-August and autumn: September-November) and annual basis. The time series cover the period 1960-2006. Where data gaps existed, no seasonal or annual averages were extracted. The geographical characteristics of the stations, along with their vegetation coverage, are presented in Table 1, whereas the average climatic conditions for each site in Figure 1. All stations, either forest or agricultural, are located away from highly populated cities, where significant urbanization and land use changes have occurred since 1960.

Table 1. Meteorological stations geographical characteristics and their vegetation coverage. The stations are operated either by the National Agricultural Research Foundation[1] or by the National Meteorological Service of Greece[2].

Station	Latitude	Longitude	Altitude	*Vegetation coverage*
Arnea[1]	40° 29' 35''	23° 36' 09''	520 m	*Querqus frainetto, Fagus sylvatica*
Artemisia[1]	37° 05' 49''	22° 14' 04''	710 m	*Pinus nigra* ssp *nigra*
Krania[1]	39° 53' 51''	21° 17' 02''	930 m	*Pinus nigra* ssp *nigra*
Vamvakou[1]	37° 14' 42''	22° 33' 17''	970 m	*Abies cefalonica*
Fournas[1]	39° 03' 25''	21° 53' 16''	1100 m	*Abies borisii-regis*
Metsovo[1]	39° 47' 07''	21° 09' 34''	1310 m	*Pinus nigra ssp nigra*
Aspropotamos[1]	*39° 38' 57''*	*21° 20' 25''*	*1200 m*	Abies borisii-regis
Tripolis[2]	*37° 32' 05''*	*22° 24' 19''*	*652 m*	Agricultural crops
Kalavrita[2]	*38° 02' 05''*	*22° 06' 10''*	*731 m*	Agricultural crops

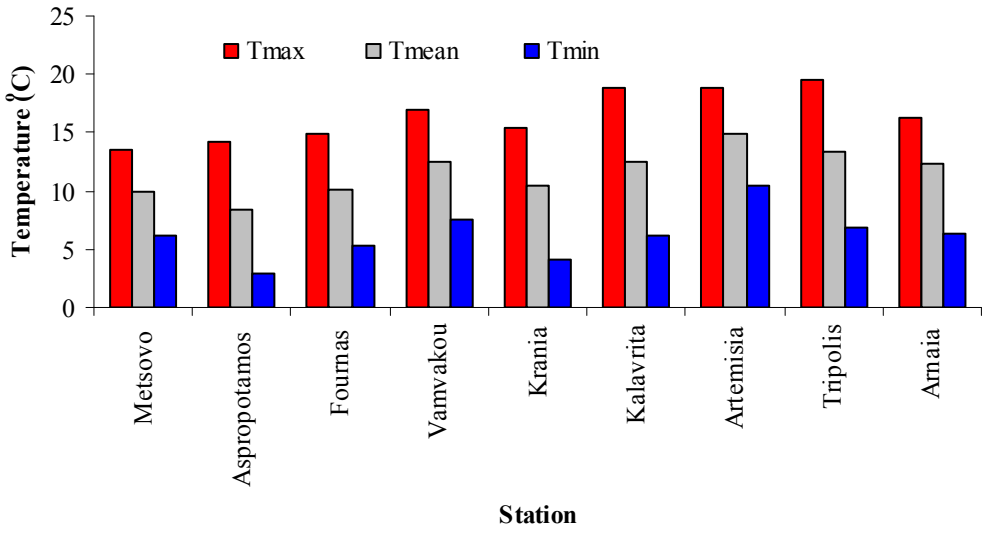

Figure 1. Annual average temperatures (minimum, mean and maximum) at 9 high altitude (520-1310 m) meteorological sites of Greece.

In order to define trends for each parameter the non parametric Mann-Kendall test (Mann 1945, Kendall 1975) under different confidence levels (α=0.001, 0.01, 0.05 and 0.1) is used. This test is widely used for climatic and environmental time series trends evaluation (Chen et al. 2007, Proutsos et al. 2008, Tigkas 2008, Karpouzos et al. 2010), because as a non-parametric method requires only data independence and is tolerant to outliers. It is a reliable method to identify monotonic linear and non-linear trends in non-normal data sets (Helsel and Hirsch, 1992). The slope of each trend evaluated from the climatic data, is identified by the Sen method (here referred as Q Sen slope), as a

median of all possible slopes (Sen 1968, Helsel and Hirsch 1992). The variability of trends and slopes with altitude is also examined and a further investigation is conducted through the categorization of the stations as north (Arnea, Krania, Fournas, Metsovo and Aspropotamos) and south (Artemisia, Vamvakou, Tripolis and Kalavrita).

3. RESULTS AND DISCUSSION

3.1 Annual and seasonal variations of temperature

On an annual basis, analysis shows generally negative trends in T_{min} and T_{mean} with site-average slopes – 0.026 and – 0.015 $^{o}C\ y^{-1}$, respectively. On the other hand, T_{max} slopes appear to be positive (+ 0.014 $^{o}C\ y^{-1}$). Specifically, according to the geographical site position, in Northern Greece the T_{mean} and T_{min} slopes have much greater negative values than the ones in Southern Greece (Figures 2 and 3). Though the T_{max} slope averaged for Northern Greece is slightly negative (– 0.013 $^{o}C\ y^{-1}$), positive trend is recorded in Southern Greece (+ 0.047 $^{o}C\ y^{-1}$).

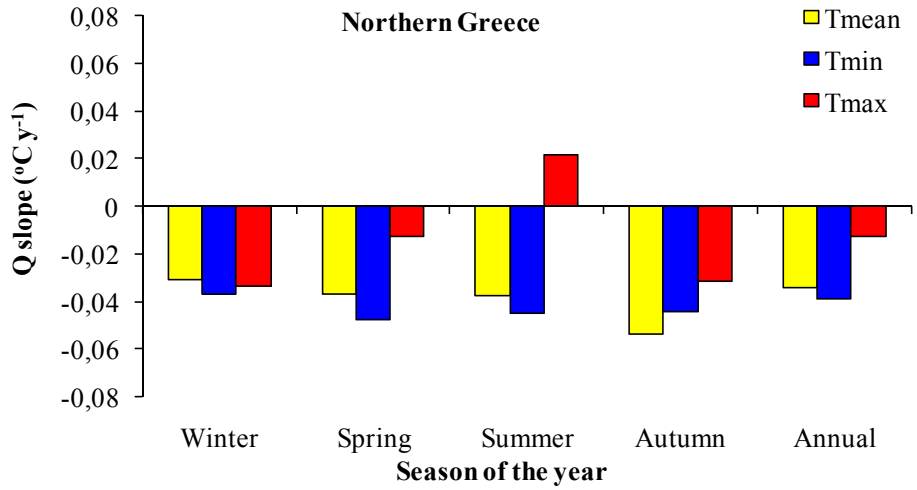

Figure 2. Average seasonal and annual variation of Sen slopes (Q) of temperature, mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}), from 5 meteorological stations in Northern Greece.

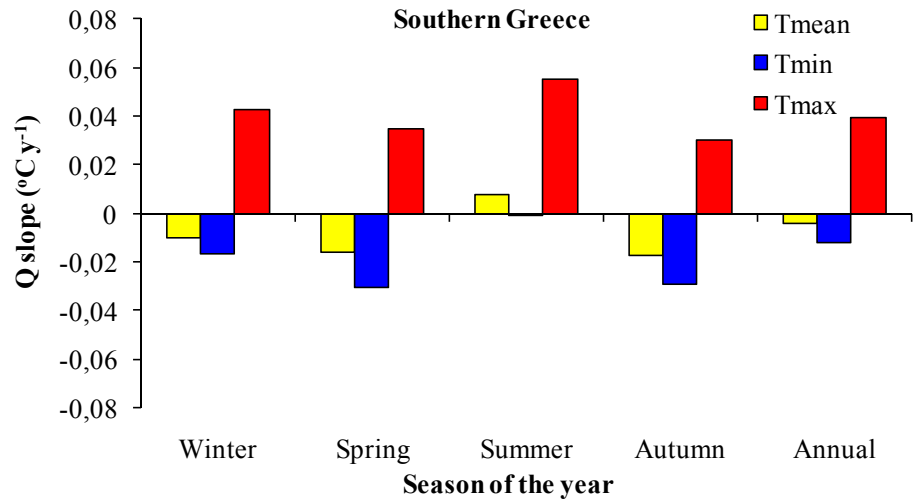

Figure 3. Average seasonal and annual variation of Sen slopes (Q) of temperature, mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}), from 4 meteorological stations in Southern Greece.

T_{min} and T_{mean} trends (Table 2) aregenerally negative. On an annual basis and specifically for T_{min}, negative slopes characterize six stations, three of which are statistically significant, even at a level of confidence greater than $\alpha = 0.001$. Similarly, for T_{mean}, negative slopes were also calculated for six stations and in fact significantly ($\alpha = 0.05$) for four of them. T_{max} trends, on the contrary, were positive in five stations, in three of which significantly ($\alpha = 0.01$).

Table 2. Seasonal positive (+), negative (-) and non (0) trends of minimum (T_{min}), mean (T_{mean}) and maximum (T_{max}) temperatures in 9 forest-agricultural meteorological stations, at different significant levels (a= 0.001, 0.01, 0.05 and 0.10). The 0 trend refers to absolute slopes less than 0.009 °C y^{-1}.

Station	Altitude (m)	Winter			Spring			Summer			Autumn			Annual		
		T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}
Metsovo	1310	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aspropotamos	1200	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-
Fournas	1100	+	-	0	+	-	-	+	-	+	0	-	-	+	-	0
Vamvakou	970	-	-	0	-	0	+	0	0	0	-	-	-	0	0	0
Krania	930	-	-	-	-	-	+	-	-	+	-	-	0	-	-	+
Kalavrita	731	0	0	+	-	-	+	-	0	+	-	-	+	-	-	+
Artemisia	710	0	0	+	+	+	+	+	+	+	+	0	+	+	+	+
Tripolis	652	-	-	0	0	+	+	+	+	+	-	+	+	-	+	+
Arnea	520	-	-	0	-	-	+	0	0	+	-	-	-	-	-	+
		α=0.1			α=0.05			α=0.01						α=0.001		

On a seasonal basis, T_{mean} and T_{min}, since 1960, generally show decreasing rates throughout the year, whereas T_{max} remains almost unvaried in all seasons except summer, when high positive trends indicate warming at an average rate + 0.040 °C y^{-1}. Specifically, in Northern Greece (Figure 2), with regard to T_{mean}, the greatest cooling rates appear in autumn (– 0.054 °C y^{-1}), whereas reference to T_{min} in spring (– 0.047 °C y^{-1}). Finally, the T_{max} slopes indicate greatest cooling in winter (– 0.034 °C y^{-1}) and greatest warming in summer (+ 0.022 °C y^{-1}). In Southern Greece (Figure 3), T_{mean} slopes are negligible or slightly negative in all seasons, except in summer, when positive trends are detected, with an average slope (+ 0.023 °C y^{-1}). Spring has the greatest negative T_{min} slope (– 0.027 °C y^{-1}). T_{max} slopes are positive all year round and highest in summer (+ 0.063 °C y^{-1}).

Also shown in Table 2 are the station-specific trends for each season. Generally, T_{max} positive trends are identified in spring and summer, but negative T_{min} and T_{mean} trends in almost all seasons for most of the sites. All temperature parameters show negative signs for the sites with the highest altitudes (Metsovo, Aspropotamos). On the other side, the south Artemisia and Tripolis show generally positive trends, especially in spring and summer.

3.2 Monthly variations of temperature

The mean monthly slopes of T_{mean}, T_{min} and T_{max} indicate most decreasing rates in November (– 0.061, – 0.060 and – 0.045 °C y^{-1}, respectively). The mean slopes of T_{max} in summer months are positive, with greatest rates in June (+ 0.046 °C y^{-1}) and July (+ 0.047 °C y^{-1}). Northern Greece temperature trends do not differ from the general trend (Figure 4), although in Southern Greece (Figure 5) T_{mean} is decreasing in winter, with the greatest negative slopes in March and November. However, summer months present positive trends, with the greatest slope in May (+ 0.022 °C y^{-1}). Respectively, the mean slopes of T_{min} are negative in most months, being more negative in November (– 0.045 °C y^{-1}). The T_{max} mean slopes are positive in all months and become maximum in June and July (+ 0.073 °C y^{-1}).

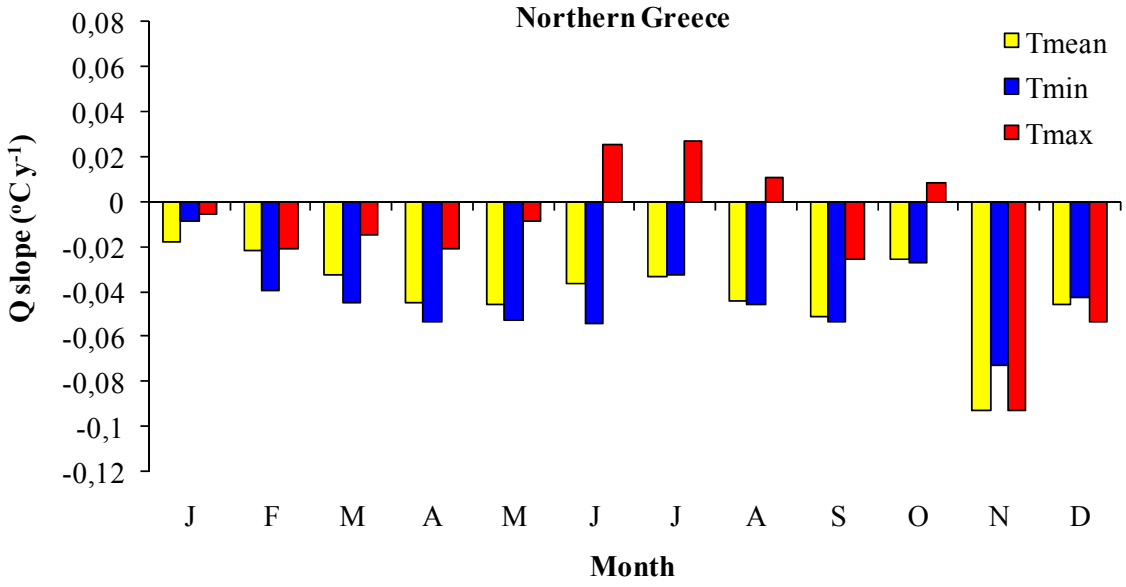

Figure 4. Average monthly variation of Sen slopes (Q) of temperature, mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}), from 5 meteorological stations in Northern Greece.

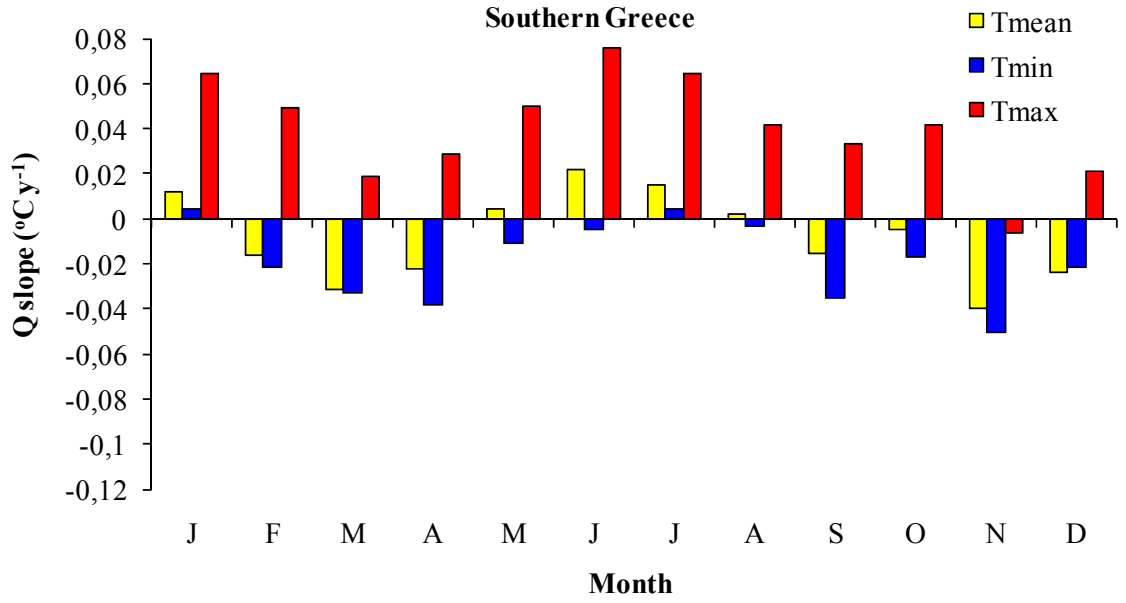

Figure 5. Average monthly variation of Sen slopes (Q) of temperature, mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}), from 4 meteorological stations in Southern Greece.

Trends of T_{mean}, T_{min} and T_{max} for each station at different levels of confidence are presented in Tables 3, 4 and 5, respectively. The most significant (α = 0.001) trends for T_{mean} were detected in November in four of the five N-stations and were all negative. T_{min} monthly trends at a high significant level (α=0.001) appear seven months of the year in Metsovo (1310 m), indicating a gross minimum temperature decrease in the region since 1960. A T_{max} increase is detected for almost all months in Artemisia (the southest site), and is most significant (α = 0.05) during the water stressed period (May to October), leading to continuously dryer conditions since 1960 (Proutsos et al. 2008). Almost same results were detected for Tripolis and Arnea (relatively low altitude stations in Southern and Northern Greece, respectively).

Table 3. Monthly positive (+), negative (-) and non (0) trends of mean temperature in 9 forest-agricultural meteorological stations, at different significant levels (a= 0.001, 0.01, 0.05 and 0.10). The 0 trend refers to absolute slopes less than 0.009 $^{o}C\ y^{-1}$.

Station	Altitude (m)	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
Metsovo	1310	-	-	-	-	-	-	-	-	-	-	-	-
Aspropotamos	1200	-	-	-	-	-	-	-	-	-	-	-	-
Fournas	1100	0	0	-	-	-	-	-	-	-	-	-	-
Vamvakou	970	0	-	0	-	-	0	+	-	-	-	-	-
Krania	930	-	-	-	-	-	-	0	-	-	0	-	-
Kalavrita	731	+	-	-	-	-	+	0	+	-	-	0	0
Artemisia	710	0	0	0	-	+	+	+	+	+	+	-	-
Tripolis	652	-	-	+	+	+	+	+	+	+	+	+	-
Arnea	520	0	-	0	-	-	-	-	0	-	-	-	-
		α=0.1			α=0.05			α=0.01			α=0.001		

Table 4. Monthly positive (+), negative (-) and non (0) trends of minimum temperature in 9 forest-agricultural meteorological stations, at different significant levels (a= 0.001, 0.01, 0.05 and 0.10). The 0 trend refers to absolute slopes less than 0.009 $^{o}C\ y^{-1}$.

Station	Altitude (m)	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
Metsovo	1310	-	-	-	-	-	-	-	-	-	-	-	-
Aspropotamos	1200	-	-	-	-	-	-	-	-	-	-	-	-
Fournas	1100	+	+	+	+	0	0	+	-	+	0	-	-
Vamvakou	970	-	-	-	-	0	0	+	0	0	+	-	-
Krania	930	-	-	-	-	-	-	-	-	-	-	-	-
Kalavrita	731	+	-	-	-	-	-	-	-	-	-	-	0
Artemisia	710	+	+	+	0	+	+	+	+	+	+	-	0
Tripolis	652	-	-	-	0	+	+	+	+	-	-	-	-
Arnea	520	0	-	-	-	-	0	0	+	-	0	-	-
		α=0.1			α=0.05			α=0.01			α=0.001		

Table 5. Monthly positive (+), negative (-) and non (0) trends of maximum temperature in 9 forest-agricultural meteorological stations, at different significant levels (a= 0.001, 0.01, 0.05 and 0.10). The 0 trend refers to absolute slopes less than 0.009 $^{o}C\ y^{-1}$.

Station	Altitude (m)	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
Metsovo	1310	-	-	-	-	-	-	-	-	-	-	-	-
Aspropotamos	1200	-	-	-	-	0	0	+	-	-	0	-	-
Fournas	1100	+	0	-	0	-	+	+	0	+	0	-	-
Vamvakou	970	+	-	+	+	0	+	+	-	-	0	-	0
Krania	930	0	0	+	0	+	+	+	+	0	+	-	-
Kalavrita	731	+	+	0	+	+	+	+	+	+	+	+	+
Artemisia	710	+	+	+	+	+	+	+	+	+	+	-	+
Tripolis	652	+	+	+	+	+	+	+	+	0	+	+	-
Arnea	520	+	+	+	-	0	+	+	+	-	+	-	-
		α=0.1			α=0.05			α=0.01			α=0.001		

3.3 Altitudinal variation of mean temperature slopes

Temperature Q-slopes, especially of T_{mean}, can be well correlated with altitude (Table 6). Generally, temperature during the last 50 years changed to much cooler at altitudes higher than 700m and warmer bellow. On an annual basis, T_{mean} and T_{max} Q-slopes altitude changes (Q/100m) have correlation coefficients (R^2) greater than 0.50, indicating significant decreasing trends with

altitude, at average rates – 0.008 and – 0.012 ^{o}C y^{-1}/(100m), respectively. However, T_{min} Q-slope changes are not correlated with altitude (R^2=017). T_{mean} Q changes with altitude appear to be greater and better correlated in autumn and summer, whereas T_{max} Q changes are greater and better correlated in spring and summer. In these seasons, T_{mean} and T_{max} Q-values are much higher, indicating much cooler conditions at altitudes above 700m and much warmer lower, than 50 years ago.

With respect to monthly variability, Q-slope changes indicate significant decreases of T_{mean}, especially in the period from June to December, with Q/100m rates varying from – 0.007 to – 0.017 ^{o}C y^{-1}/(100m) and greatest negative value in August. Also in August, all temperature parameters (T_{mean}, T_{min} and T_{max}) have Q-slopes well correlated with altitude (R^2>0.55) indicating greater decreases or increases of T_{mean}, T_{min} and T_{max} respectively, at heights above 700m and lower (bellow 700m) altitudes. T_{max} Q-slopes have greater R^2 in March, May, July and August with Q/100m values varying from – 0.011 to – 0.016 ^{o}C y^{-1}/(100m), being lowest in August and indicating increased possibility for summer hot events at altitudes lower than 700m.

Table 6. Average Sen slopes variations per 100m altitude increase (Q/100m), of temperature, mean (T_{mean}), minimum (T_{min}) and maximum (T_{max}), along with the correlation coefficients R^2 of Q with altitude on a monthly, seasonal and annual basis. (R^2 greater than 0.50 are indicated in bold).

	T_{mean}		T_{min}		T_{max}	
MONTH	**Q/100m** [^{o}C y^{-1}/(100m)]	**R^2**	**Q/100m** [^{o}C y^{-1}/(100m)]	**R^2**	**Q/100m** [^{o}C y^{-1}/(100m)]	**R^2**
J	-0,005	0,27	-0,004	0,04	-0,015	0,31
F	-0,003	0,17	-0,003	0,05	-0,016	0,35
M	-0,005	0,11	-0,002	0,02	-0,011	**0,74**
A	-0,006	0,24	-0,007	0,12	-0,008	0,42
M	-0,014	0,35	-0,014	0,35	-0,014	**0,54**
J	-0,013	**0,62**	-0,015	0,40	-0,011	0,45
J	-0,011	**0,57**	-0,011	0,26	-0,011	**0,55**
A	-0,017	**0,71**	-0,015	**0,55**	-0,016	**0,64**
S	-0,010	**0,58**	-0,005	0,05	-0,012	0,37
O	-0,008	0,45	-0,007	0,24	-0,009	0,41
N	-0,013	**0,51**	-0,005	0,22	-0,015	0,28
D	-0,007	**0,61**	-0,004	0,16	-0,014	0,39
SEASON						
Winter	-0,005	0,49	-0,003	0,06	-0,014	0,30
Spring	-0,008	0,21	-0,007	0,11	-0,012	**0,64**
Summer	-0,013	**0,66**	-0,014	0,41	-0,012	**0,62**
Autumn	-0,010	**0,69**	-0,006	0,21	-0,012	0,41
ANNUAL	-0,008	**0,50**	-0,007	0,17	-0,012	**0,54**

4. CONCLUSIONS

The following general conclusions can be drawn for the temperature behavior during the latest half century at high-altitude regions of Greece:

- On an annual basis, T_{mean} and T_{min} were decreasing and T_{max} increasing, leading to a less mild climate. With respect to space variability, in Northern Greece, T_{mean} and T_{min} decreased and T_{max} stayed almost unvaried. In Southern Greece, the T_{mean} and T_{min} slopes have not significantly changed but T_{max} appeared to increase.
- On seasonal basis, T_{mean} and T_{min} decreased in all seasons at most stations, but T_{max} remained rather constant, except in summer, when it increased. In Northern Greece, T_{mean} and T_{min} were decreasing throughout the year, whereas T_{max} was increasing in summer and decreasing in all other seasons, especially in winter. However, in Southern Greece, T_{max} increased in all seasons, especially in summer. T_{mean} stayed almost unvaried in all seasons, except in summer, when it increased. T_{min} decreased except in summer, when it remained rather stable.

- On a monthly basis, the most decreasing rates of temperature were recorded in November. In Northern Greece, T_{min} and T_{mean} decreased all year round, but T_{max} showed positive trends, greatest in June and July. In Southern Greece, T_{mean} from May to August and T_{max} all year round were also increasing.
- The T_{mean} Sen-slopes are well correlated with altitude, diminishing as altitude increases and showing that climate became cooler, compared to 50 years ago, at sites higher than 700m. Lower it generally became warmer. High correlations of T_{mean} Sen-slopes with altitude were found for June, July, August, September, November and December, affecting the summer and autumn seasonal correlation coefficients as well as their annual values.

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