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Trend analysis of long-lasting air temperature and precipitation time series in a mountainous fir forest in central Greece. Implications for nitrogen uptake by plants

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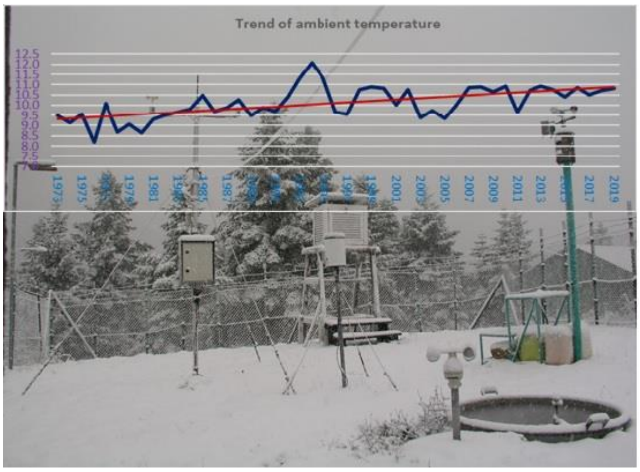
Graphical abstract



Abstract

In the present work meteorological data, concerning temperature and precipitation in a mountainous Bulgarian fir (*Abies borisii-regis* Mattf.) forest, was analyzed in order to find trends for the period 1973-2019. The results showed that temperature values on annual and seasonal base, especially in summers, showed a significant increasing trend. In addition, the number of days with particularly high temperatures increased together with the daily temperature range. With regard to the rain height an increasing trend was found significant at the 0.1 probability level. The nitrogen concentration in current year needles of the Bulgarian fir measured in the period 1997-2019 showed an increasing trend. This fact could be a sign of increased mineralization rates of organic matter as a response to the temperature increase.

Keywords: fir forest**,** trends, temperature, precipitation, Mann-Kendall Test, nitrogen uptake

1. Introduction

In the last decade, there has been a widespread concern on climate change. In 1988, the World Meteorological Organization launched the (Intergovernmental Panel on Climate Change - IPCC) under the auspices of the United Nations. The IPCC has issued five reports (1994, 2001, 2007, 2013, 2014) regarding the observed climate changes and their possible impact on the environment. In the last decades, the research on climate trends has expanded considerably especially in terms of precipitation and temperature (Sun *et al*. 2010; Croitoru *et al.,* 2012; Shrestha *et al.,* 2016; Mekonen *et al.*, 2020).

The rise of temperature is considered a world phenomenon (Todisco and Vergni, 2008; Ahmadi *et al*. 2018). The IPCC (2001) reported an average 0.6 ± 0.2 °C temperature increase in the 20th century together with an increase of precipitation height in the middle and high latitudes of the northern hemisphere (Watson, 2001). It should be mentioned, however, that the observed increasing trends in temperature are not uniform and there are areas where decreasing trends were also observed (Giles and Flocas, 1984; Makrogiannis *et al*., 1998; Gadgil and Dhorde, 2005).

So far, the available data have showed a temperature increase in the earth and oceans' surfaces of 0.85 (0.65 – 1.06 °C) in the period 1880-2012 (IPCC, 2013). In the eastern Mediterranean area, a temperature decrease of -0.6 °C in the 60s and 70s was reported, whereas after the 80s there was a new rising trend (Repapis and Philandras, 1988; Philandras, 1994). In Greece, a significant rise of temperature was observed in urban areas compared to other land uses (Founda *et al*., 2004). The agricultural and forested areas present a higher variation as there is no influence from the uniformity of big cities (Proedrou *et al.,* 1997; Philandras *et al.,* 1999).

Rainfall in the Eastern Mediterranean decreased, with significant differences between regions and strong variability from year to year, depending on the topography and transit routes of the low barometric. The decrease (of precipitation) since 1900 in coastal areas reached an average of 5% and it kept going down in the period 1960-1990 (Kandylis *et al.,* 1989; Hatzioannou *et al.*, 1998; Paz *et al.,* 1998). Subsequently, there was an increasing trend in the 90s (Palutikof *et al.,* 1996;

Piervitali, 1997). Decreasing trends in precipitation in mountainous and semi mountain areas were reported by Proutsos *et al.,* 2011; Stathis *et al.,* 2015 and Zerefos *et al.,* 2010 used statistical models and concluded that the precipitation height would be reduced in the eastern and southern parts of the Mediterranean zone in the future, mainly in the time space of October to May.

The IPCC in their fourth report (Alcamo *et al*., 2007) concluded that climate change would have an adverse impact on many ecosystem functions. In a review, Solomou *et al.,* 2017, argued that the climate change would bring about great reductions on biodiversity in the Mediterranean zone.

Mountainous areas are fragile environments (Diaz *et al.*, 2003). At the same time, they constitute a biodiversity sink and offer great services with regard to water quality and other ecosystem functions (Körner, 2004) while their beneficial influence transcends the mountainous borders. For this reason, a particular emphasis was given on the effects of climate change on the mountainous ecosystems (Price, 1995; Nogues-Bravo *et al.,* 2007; Coll *et al.*, 2013). Also, a recent IPCC report (2018) considered mountain biodiversity hotspots as a "cause for concern" due to climate change.

More specifically, the mountain forests have been identified as particularly sensitive and vulnerable to climate change (Grabherr *et al.*, 2000; Kozyr 2014). In addition, they are vulnerable due to climate change and various other issues, including anthropogenic disturbances (Wan *et al.*, 2018; Negi *et al.*, 2019). Climate change has also caused increasing tree mortality, changes in fire regimes, species relocation and migration, insect outbreaks, pathogen attacks, alien species invasion and declining productivity (Buotte *et al.*, 2019; Dupire *et al.*, 2019 and Fremout *et al.*, 2020)

The topography in Greece affects all climatic parameters, particularly the rainfall height, the average value of which is 800 mm (BANK OF GREECE, 2011). However, the rainfall height has a high variation from 2,000 mm in the western Greece to 400 mm (e.g. Athens) in the eastern part. Likewise, the air temperature is modified by mountains.

The aim of this work was to find the averages, ranges as well as the trends in air temperature and precipitation in a mountainous forested area with Bulgarian fir as the main forest species in central Greece. The data was derived from the meteorological station installed in the area and covered a period of 47 years (1973-2019). It was also decided to check for significant trends in the nitrogen (N) concentrations in current's year needles of fir trees in the period 1997-2019 as *Abies* species, especially silver fir (*Abies alba* Mill.), Greek fir (*Abies cephalonica* Loudon) and Bulgarian fir (*Abies borisii*-regis Mattf), are sensitive to environmental changes (Potocic *et al.*, 2005). Tree populations found at the limit of the species geographical distribution may be responding more dramatically to climate change than those at the core of the range (Brubaker, 1986). In higher altitudes, the increase in temperature can enhance the mineralization of organic matter and consequently organic N. The forest stand under consideration was surveyed for the N content in needles in the past (Michopoulos *et al.*, 2015) because of the high N content in soils.

2. Materials and methods

2.1. Site description

The meteorological station was installed in a fir forest opening near the village of Agios Nikolaos, Evrytania central Greece at an altitude of 1,120 m (Figure 1). The coordinates are 38°53′20′′(N) and 21°52′07′′(E). The main forest species is a Bulgarian fir (*Abies borisii-regis* Mattf.) The ground vegetation consists mainly of ferns (*Pteridium aquilinum* L.), shrubs (*Rubus hirtus* W. & K.), herbs (*Sanicula europaea* L., *Geranium lucidum* L., *Geranium rotundifolium* L.*, Luzula forsteri* Sm.) and plants from the family *Gramineae* such as *Melica uniflora* R. and *Brachypodium sylvaticum* H.

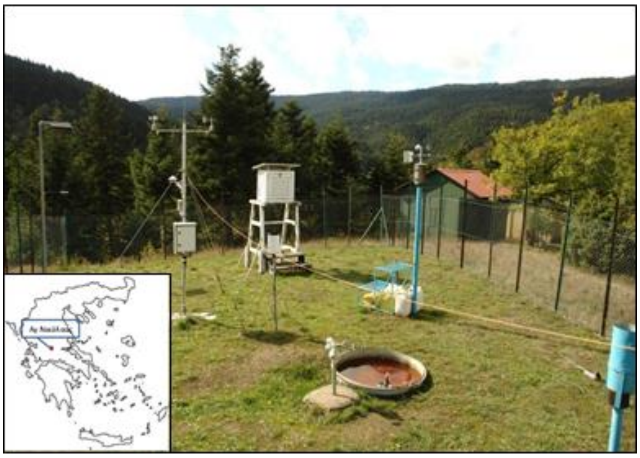


Figure 1. The forest meteorological station in Agios Nikolaos Evritanias.

The soil was developed on sandy flysch, it is deep and classified as Cambisol (FAO, 1988). It is worth pointing that the land use of the area has remained unchanged since the start of meteorological observations (1972) so any impact of anthropogenic activities can be considered negligible. The forest stand is part of the Intensive Monitoring Survey of the ICP Forests network (UN-ICP-Forests, 2020).

The ombrothermic diagram according to the Bagnouls and Gaussen, 1953, for the station showed a very short xerothermic period of 1.5-2 months, which began in mid-June and ended in mid-August (Figure 2).

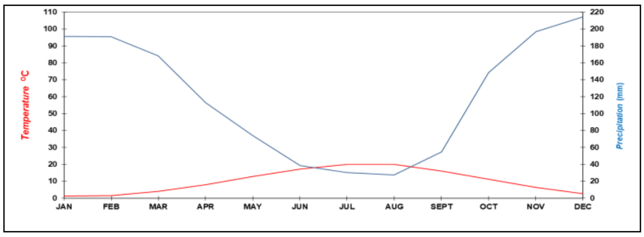


Figure 2. Pluviothermic diagram (Bagnouls and Gaussen 1957) of Agios Nikolaos Evritanias meteorological station.

Based on the above and according to the climatic classification Köppen W., 1884, which gives the picture of the climate that prevails in a specific geographical area, the climate of the area is classified as part of the type Csb (Csb = Coastal Mediterranean. Mild winters, dry short and hot summer).

2.2. Field measurements

The air temperature in Greece has a minimum in January and February and a maximum in the end of July and August. The meteorological data of air temperature and precipitation concern the data for the period 1973 to 2019 (47 years). This time spell comprises more than 30 years of continuous monitoring representing a normal climatic period as defined by the World Meteorological Organization – WMO (WMO, 2017). Moreover, the data missing is very little (30 days for a 47 years' period). For these reasons, reliable results concerning temperature and precipitation trends can be given. The parameters monitored and the types of instruments are given in Table 1.

Table 1. Meteorological parameters and types of instruments/sensors used at the station of Agios Nikolaos

Meteorological instruments and sensors		
Parameter	**Instruments of conventional station (1972-2009)**	**Sensors of automatic station (2003-2019)**
Precipitation	BELFORT Cat. No. 5-780 Rain and Snow Recording Gage	BELFORT Cat. No. 5-780 Rain and Snow Recording Gage
Air temperature and moisture	LAMBREHT Typ. 252	MP101A

From July 1972 to October 2003, the data monitoring was carried out by conventional instruments. Later on, the monitoring was done automatically (Campbell CR10X-2M). The automatic monitoring uses a 10 sec scanning and stores average values every hour. The Pearson correlation between the daily values taken by the automatic and conventional stations (2003-2009) was very good. The correlation R^2 was 99.2 %.

2.3. Collection of current year needles

Samples of current year needles of the Bulgarian fir were collected every two years in winter (dormant period) from the upper part of the crown from five dominant trees and formed a pooled sample. The collection always took place from the same trees. The needles were dried at 80 °C for 48 hours and then ground in a special mill for analysis. The data covers the period 1995-2019. The nitrogen (N) concentrations were determined by the Kjeldahl method.

2.4. Data handling and statistics

In the present work, the daily, monthly, seasonal and annual values were calculated for the period 1973-2019 with regard to a) average temperature, b) average maximum temperature, c) average minimum temperature, d) precipitation height. In addition, the daily and annual thermometric ranges were also estimated.

Before the data processing, there was a data validation with regard to wrong entries and missing daily values. If three hours were missing from a 24 hours per day, there was no calculation. After the data validation, the monthly values were calculated. If five days were missing from a month, there was no calculation. In any case there was no month exclusion from the data.

The air temperature and precipitation data were checked for the criterion of normality with the Kolmogorov-Smirnov test. The trend analysis was done for temperature and precipitation. It concerned monthly, seasonal and annual values. Seasonal values were derived from the averages of the monthly values as follows: Winter: 1st December of previous year until the 28th February, Spring: 1st of March until the 30th of May, Summer: 1st of June until the 30th of August and Autumn 1st of September until the 30th of November.

The significance of trends was assessed with the non-parametric Mann–Kendall test (Mann, 1945; Kendall, 1975), which reliably assesses monotonic linear and non-linear trends in non-normal data sets with outliers (Helsel and Hirsch, 1992). The choice of the non-parametric test was made because the Kolmogorov-Smirnov test showed that there was not a clear normal distribution for the available data. The slope Q of each trend was identified by the method of Sen, 1968. The probability levels for which the trends were considered significant were those of a=0.001, a=0.01, a=0.05 and a=0.1 (Burns *et al.*, 2007).

The Mann-Kendall method is widely used in environmental research (Chen *et al.*, 2007; Tigkas, 2008; Proutsos *et al.*, 2010; Karpouzos *et al.*, 2010; Proutsos *et al.*, 2011 and Kaoukis *et al.,* 2015).

The Mann-Kendall calculations were made with the use of the excel software by means of macro-instructions of Visual Basic, MAKESENS 1.0 (Salmi *et al.*, 2002).

The Mann–Kendall method was also used to determine trends for the N concentrations in the fir needles for the time 1995-2019. The number of values (13) was not sufficiently high to apply for parametric tests, so the Mann-Kendall was the most suitable.

3. Results

3.1. Climate type

From the analysis of the above climatic data (47 years) it was estimated that: the average annual temperature of the area was 10.11 °C (± 0.79 °C), the seasonal variation 1.85 °C (± 1.10 °C) in winter and 19.09 °C (± 1.22 °C) in summer.

The average maximum temperature of the year was found 14.12 °C (± 0.97 °C) and the average minimum one 6.01 °C

(± 0.66 °C). In addition, the average daily thermometric range on an annual basis reached 8.04 °C (± 0.46 °C), while the annual thermometric range had an average value of 18.71 °C with a standard deviation of 2.03 (Table 2). The monthly, seasonal and annual average values and fluctuations of temperatures and precipitation for the region, as shown by the analysis of the monthly values of the period 1973-2019, are presented in Table 2, while the daily temperature fluctuations, as well as the days of total frost throughout the period, are shown in Figures 3 and 4, respectively.

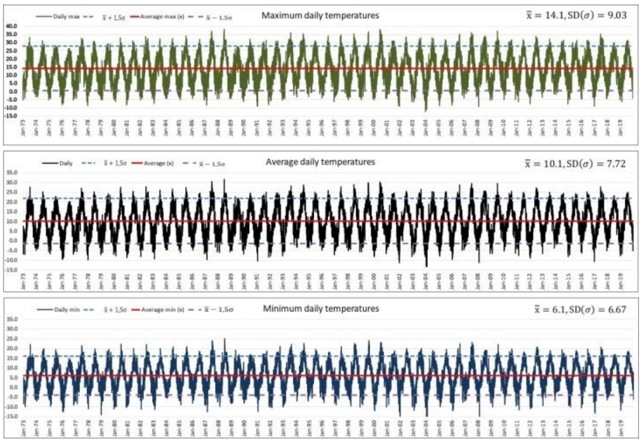


Figure 3. Daily values of maximum (up), mean (center) and minimum (down) temperature for the time period 1973-2019, recorded from the forest meteorological station in Agios Nikolaos Evritanias. The solid red lines show the average $\overline{x}$ of all daily values and the dashed lines present the limits $\overline{x}$ ±1.5σ.

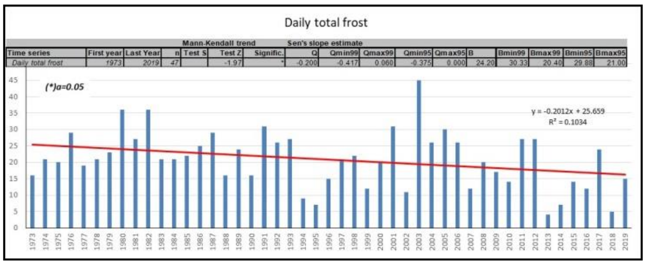


Figure 4. Number of days of total frost during the period 1973-2019 recorded in the forest meteorological station of Agios Nikolaos. The red line shows the trend line which has a relatively small R2, but the downward trend is confirmed at the significance level a = 0.05.

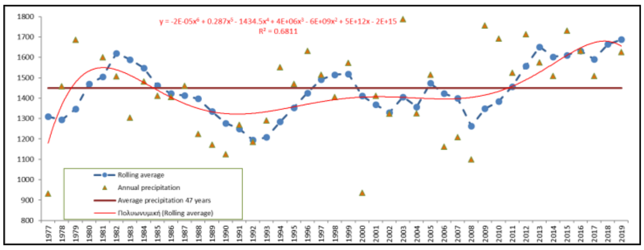


Figure 5. Annual precipitation (blue points) & average annual precipitation (green line) in Agios Nikolaos Evritanias for the time period 1973-2019. Also presented are the 7-year moving average (blue dashed line) and the 6th degree polynomial equation (red line) referring to the points of the moving average line with time.

For the study period, the average annual precipitation was 1449 mm (± 225 mm), while it is important to note that there were strong variations from year to year, which showed a periodicity of about 14 years, as evidenced by the relatively high correlation coefficient. (R^2 = 0.68) of the rolling averages of the annual values over time (Figure 5).

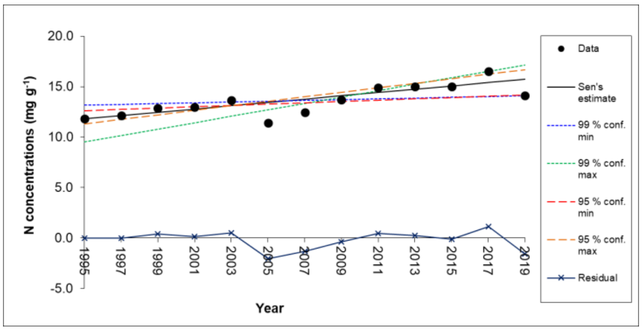


Figure 6. Nitrogen (N) concentrations (mg g^{-1}) in current year needles of fir trees in time

Table 2. Monthly, seasonal and annual averages and standard deviationς of mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}) temperatures, diurnal temperature range (DTR), precipitation and annual thermometric range (ATR) in Agios Nikolaos Evritanias during the period 1973-2019

Time period	T_{mean} (°C)	SD_{mean}	T_{max} (°C)	SD_{max}	T_{min} (°C)	SD_{min}	DTR(°C)	SD_{DTR}	Precipitation (mm)	SD (mm)	ATR (°C)	SD_{ATR}
January	1.3	1.7	4.0	1.9	-1.4	1.7	5.5	1.1	191.4	111.5		
February	1.6	2.2	4.6	2.6	-1.3	2.0	5.9	1.4	191.2	80.9		
March	4.1	1.9	7.6	2.4	0.6	1.6	7.0	1.4	168.2	63.4		
April	8.1	1.9	12.3	2.3	3.8	1.5	8.5	1.1	113.2	51.0		
May	12.8	1.5	17.5	1.8	8.1	1.2	9.5	0.9	74.2	38.1		
June	17.3	1.3	22.5	1.6	12.1	1.1	10.5	0.8	38.8	36.9		
July	20.0	1.4	25.5	1.8	14.6	1.2	10.9	0.9	30.4	29.9		
August	19.9	1.7	25.3	2.0	14.6	1.4	10.7	0.8	27.5	30.7		
September	16.0	1.5	20.7	1.8	11.2	1.3	9.3	1.1	54.7	38.6		
October	11.1	1.8	14.7	2.2	7.5	1.5	7.1	1.1	148.3	80.1		
November	6.4	1.8	9.4	2.0	3.4	1.6	6.1	1.0	196.9	68.3		
December	2.6	1.7	5.3	1.9	-0.1	1.5	5.5	1.2	214.5	90.7		
Winter	1.9	1.1	4.6	1.3	-0.9	1.0	5.7	0.8	597.1	155.3		
Spring	8.3	1.2	12.5	1.6	4.2	1.0	8.4	0.8	355.6	90.0		
Summer	19.1	1.2	24.4	1.5	13.8	1.0	10.7	0.6	96.7	65.0		
Autumn	11.2	1.1	15.0	1.3	7.4	1.0	7.5	0.6	399.9	89.1		
Year	10.1	0.8	14.1	1.0	6.1	0.7	8.0	0.5	1449.3	225.3	18.7	2.0

From the processing of the data to estimate the trends of the temperature parameters and the precipitations with the Mann-Kendall method, the Table 3 was made. It shows the values of parameter Z, the statistically significant trends at significance levels a = 0.001, a = 0.01, a = 0.05 and a = 0.1, as well as the slope Q by Sen for each trend line in monthly, seasonal and annual basis. From all the above the following conclusions were drawn. In addition, the Table 3 shows the changing trends along with the averages and standard deviations of the monthly numbers of days with specific temperature characteristics. At the end of the table there are the trends of the Annual Thermometric Range (ATR) and the concentrations of N (mg g^{-1}) in the needles of the current year in the fir trees in time.

In this work, the characterization of extreme values was carried out for those ones within the range of $\overline{x} \pm 1{,}5\sigma$. The choice of this range was made because the 89% of the total number of values is found. We did not want to increase the range because a large number of values would be left out.

3.2. Average temperature

It showed a statistically significant increasing trend (a = 0.001), resulting in an average growth rate of 0.032 °C yr^{-1}. In terms of the seasons of the year we had an increasing trend in summer by 0.042 °C yr^{-1}, in spring by 0.044 °C yr^{-1} at a (a=0.01) and in autumn by 0.028 °C yr^{-1} (a=0.05).

The assessment of the monthly variation of the average temperature showed that August and November recorded the highest growth trends with 0.01 °C yr^{-1} and 0.058 °C yr^{-1}, respectively (a = 0.01). The months of April, June and July also showed increasing trends (a<0.05) and March the lowest level of significance (a = 0.1), while the rest did not show significant changes with regard to the average temperature.

The number of days of the year with high average temperatures {greater than 21.8 °C ($\overline{x} + 1{,}5\sigma$)} showed a significant increase (a = 0.05) with an average rate of 0.29 day yr^{-1}, while no statistical trend was found for the extremely low average temperatures (Table 3).

Table 3. Mann Kendall test Z values and Sen-slope Q values (in °C yr^{-1} or in mm yr^{-1}), for the trends evaluation of monthly mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}) temperatures, diurnal temperature range (ΔT) and precipitation in the mountain forested area of Agios Nikolaos Evritanias for a 44 years period (1973-2019). The statistically significant trends are also presented: (***) a=0.001, (**) a=0.01, (*) a=0.05 and (+) a=0.10.

Detection of trends with the Mann Kendall test and determination of Q slopes by Sen															
Time period	T_{max}			T_{mean}			T_{min}			DTR			Precipitation		
	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q
January	1.33		0.027	0.89		0.019	0.75		0.015	1.76	+	0.022	1.21		1.488
February	1.98	*	0.041	1.74	+	0.037	1.09		0.026	2.51	*	0.043	0.17		0.211
March	2.53	*	0.073	2.42	*	0.053	1.71	+	0.027	2.60	**	0.039	2.40	*	1.641
April	2.52	*	0.067	2.43	*	0.052	2.29	*	0.037	2.58	**	0.033	-2.20	*	-1.269
May	1.87	+	0.033	1.78	+	0.025	1.47		0.021	2.53	*	0.027	0.70		0.350
June	1.89	+	0.038	2.27	*	0.034	2.53	*	0.032	1.58		0.014	0.88		0.259
July	2.49	*	0.047	2.42	*	0.036	2.39	*	0.025	2.07	*	0.021	1.44		0.365
August	3.03	**	0.070	3.06	**	0.061	3.02	**	0.044	1.71	+	0.018	0.96		0.200
September	0.95		0.017	0.62		0.009	0.37		0.006	-0.79		-0.011	3.30	***	1.405
October	1.63		0.032	1.49		0.024	1.34		0.024	0.84		0.012	-0.29		-0.286
November	3.17	**	0.063	3.01	**	0.058	3.03	**	0.053	1.38		0.016	-0.58		-0.385
December	0.75		0.018	0.53		0.009	0.22		0.003	2.57	*	0.033	-0.08		-0.120
Year	**4.49**	***	**0.044**	**4.16**	***	**0.032**	**3.52**	***	**0.026**	**4.11**	***	**0.022**	**1.87**	+	**4.338**
Winter	1.93	+	0.027	1.56		0.019	1.36		0.012	3.45	***	0.029	0.84		1.531
Spring	3.41	***	0.062	3.21	**	0.044	2.77	**	0.029	3.26	**	0.033	0.64		0.784
Summer	3.19	**	0.050	3.19	**	0.042	3.10	**	0.033	2.16	*	0.018	1.95	+	1.018
Autumn	2.62	**	0.035	2.54	*	0.028	2.00	*	0.023	0.18		0.001	0.81		0.821

	Test Z	Signific.	Q
Annual Thermometric Range (ATR)	-2.99	**	-0.147
N concentrations (mg g^{-1})	3.11	**	0.328

Time period	Aver	SD	Signific.	Z	Q
Summer days with Tmax>27.7 °C (σ = 9.03)	20.100	11.00	*	*2.40*	0.26
Winter days with Tmin<-3.9 °C ((s = 6.67)	19.800	8.40		*-0.62*	-0.07
Days of the year with Tmax>27.7 °C ((σ = 9.03)	21.900	12.30	*	*2.45*	0.29
Days of the year with Tmιn<-3.9 °C ((σ = 6.67)	23.700	10.00		*-1.18*	-0.14
Days of the year with Tmean>21.8 °C ((σ = 7.72)	20.700	12.30	*	*2.44*	0.29
Days of the year with Tmean<-1.4 °C ((σ = 7.72)	23.300	9.60		*-1.08*	-0.13
Days of the year with DTR>13.6 °C ((σ = 3.71)	18.800	9.40	***	*4.16*	0.38
Total frost days <0 °C	20.800	8.50	*	*-1.97*	-0.20
Days of the year with Tmax>35.0 °C	2.600	2.20		*-1.30*	-0.07

3.3. Average maximum temperature

This parameter showed an upward trend (stronger than the corresponding annual average with Z = 4.49), at a significance level a = 0.001. The average rate of change was +0.044 °C yr^{-1} (Table 3) The increasing trend of the average maximum temperature was higher in summer (a = 0.001) followed by spring and autumn (a = 0.01), while in winter they were at a lower level of significance (a = 0.10). Seasonal average rates of change range from +0.028 °C yr^{-1} in winter to +0.062 °C yr^{-1} in summer, with intermediate values in winter and spring.

On a monthly scale, there was an increase in the maximum temperature in August and November, with an average growth rate of + 0.070 °C yr^{-1} and +0,063 °C, respectively (a = 0.01). The upward trends in February, March, April and July were also significant (a = 0.05) with a rate of change of + 0.041 °C yr^{-1}, + 0.073 °C yr^{-1}, + 0.067 °C yr^{-1} and 0.047 °C yr^{-1}, respectively.

The number of days of the year with high maximum temperatures (greater than 27.7 °C) increased significantly (a = 0.05) from year to year (Table 3) with an average rate of 0.26 days yr^{-1}. This fact indicates an increase in extreme maximum temperatures compared to earlier data. These relatively extreme conditions became worse from summer to summer as there were frequent increases in extreme mean maximum temperatures with an average growth rate of 0.26 days yr^{-1} showing a strong growth trend (a = 0.05). However, there was not a significant increase in the number of days with temperatures above 35 °C (heat wave), except in 1987 and 2009.

3.4. Average minimum temperature

The trend of the annual average minimum temperatures also appeared increasing at the level (a = 0.001) with an average growth rate of 0.026 °C yr^{-1}, mainly in summer, spring (a = 0.01) and autumn (a = 0.05), while no trends were observed for winter. The most important trend of the average minimum temperature (a = 0.01) occurred in summer and spring with an average growth rate of 0.033 °C yr^{-1} and 0.029 °C yr^{-1}, respectively. On a monthly basis, a significant increase of the minimum temperatures was recorded in August and November (a= 0.01), with an average growth rate of 0.044 °C yr^{-1} and 0.053 °C yr^{-1} respectively, while a smaller one (Table 3) appeared in the months of April, June, July (a = 0.05) and March (a = 0.1).

3.5. Daily thermometric range and annual thermometric range

The difference between maximum and minimum daily temperatures indicates the daily thermometric range, which is an important parameter for plant life (Chen *et al.*, 2011; Hackl *et al.*, 2012). The difference between the average temperature of the warmest and coldest month of the year is called the Annual Thermometric Range. During the analysis of the temperature data for the area of Agios Nikolaos, an increasing trend of the daily range was found (+ 0.022 °C yr^{-1}), at a significance level a = 0.001. The seasons with the most important growth trends were spring (0.029 °C yr^{-1}) at the level of significance a = 0.001 and summer (0.023 °C yr^{-1}), at the level of significance a = 0.01.

The trends per month, March and April showed an increasing trend of 0.039 and 0.033 °C yr^{-1}, respectively (a=0.01). Growth trends were also observed in February, May and July (a=0.05), while in the remaining months no differences of the daily thermometric range were observed. August was an exception when an upward trend was observed, with a lower level of significance (a = 0. 1).

The number of days with extreme daily thermometric range was higher than 13.6 °C, which indicated strong temperature variations during the day (0.37 days yr^{-1}) for a significance level of 0.001 (Table 3).

Finally, it should be mentioned that the annual thermometric range showed a decreasing trend of -0.147 °C yr^{-1}, at the level of significance a = 0.01 variations from year to year.

3.6. Precipitation

From the analysis of the precipitation data, some changes seem to appear (Table 3). In particular, their annual values show an increasing trend of 4.3mm yr^{-1} but at a low level of significance (a = 0.1). The picture is similar from the analysis of seasonal precipitation, where an increasing trend was observed only in autumn (a = 0.1). On a monthly basis, almost all months show insignificant differences. Exceptions, however, are September where a highly significant increasing trends 1.4 mm yr^{-1} (a = 0.001) appeared and the months March and April which showed a statistically significant increase 1.64 mm yr^{-1} (a = 0.05) and decrease -1,34 mm yr^{-1} (a = 0.05), respectively.

3.7. N concentrations in needles

The Mann Kendall test showed an upward significant trend ($p<0.01$) in the period 1995-2019 for N concentrations in the current year needles of the fir trees (Figure 6 and Table 3).

4. Discussion

4.1. Temperature conditions

The average maximum, the average minimum and the average annual temperature values showed statistically significant upward trends with average rates of 0.044 °C yr^{-1}, 0.026 °C yr^{-1} and 0.032 °C yr^{-1}, respectively. A similar result was found by Proutsos *et al.* (2010) who analyzed the temperature trends in nine agroforestry stations in the period 1960-2006.

Summer was the season when the most significant temperature increase was observed in all temperature components (average, maximum and minimum temperature) for the period 1973-2019. In addition, the number of days of the year and summer with very high temperatures increased in the last 47 years. There was a statistically significant increase in the days of the year and summer with very high maximum temperatures, as well as an increase in the annual number of days with very high average temperature values. An increase in the duration and frequency of thermal stress of natural vegetation, with potential adverse effects in the future was found. The first rise of daily temperature (Tmax> 35 °C) was observed in 1987. The rise reappeared in 1988, 1993, 1994, 1998, 1999, 2000, 2006, 2007, 2009 and 2017. The days of total frost (Figure 4) had a significant decreasing trend. The combination of both findings can be an indication of climate change.

4.2. N in foliar tissues

The increase in ambient temperature can have implications for forests. In higher altitudes, the increase in temperature can enhance the mineralization of organic matter and organic N. The increase of concentrations in the current year needles are probably due to the increase in temperature. At a global scale climate is the best predictor (in comparison with litter chemistry) for the decomposition constants (k-values) of the litter (Aerts, 1997; Guntiňas *et al.*, 2012) found that temperature is more important factor than moisture for the organic matter decomposition under the presupposition that we do not refer to xeric conditions. According to Hoyle *et al.* (2006), the temperature effect results in the increase of net N mineralization.

4.3. Precipitation

Precipitation also showed a slight upward trend on an annual basis as well as in summer, while it is important to mention that declining precipitation trends have been observed in mountainous and semi-mountainous areas of Greece as reported in the works of Stathis, 2005; Mavromatis and Stathis, 2011).

The observed upward trend of precipitation by 4.3 mm yr^{-1}, which were significant (a = 0.1), is not able to balance the corresponding strong tendencies of increase of the average annual temperature (0.032 °C yr^{-1} with a = 0.001), which can create water deficits for the forest vegetation of the area under consideration. This is a suggestion for future research.

5. Conclusions

The days of total frost appeared to be declining compared to the past.

Significant changes were observed in the daily thermometric range compared to the past, with an increasing rate of 0.022 °C yr^{-1} In addition, there was an increase in the number of days when the daily thermometric range showed extreme values (i.e. >13.6 °C) by 0.37 days yr^{-1}.

The Annual Thermometric Range in contrast to the Daily Thermometric Range showed a decreasing trend, at the significance level of 0.01.

There was an increase in temperature in terms of its average annual value, but also in the average maximum and average minimum of the year in spring and summer when the requirements of the plants for water are higher due to their growth activity.

There was no corresponding increase in rainfall in spring, while in summer the observed increase was marginal.

The increase of N concentrations in current year needles was probably the result of increased N mineralization rates, which were related to the increase of ambient air temperature.

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References

Aerts R. (1997), Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship, *Oikos,* **79,** 439–449.

Ahmadi F., Nazeri Tahroudi M., Mirabbasi R., Khalili K., Jhajharia D. (2018) Spatiotemporal trend and abrupt change analysis of temperature in Iran. *Meteorological Applications,* **25**(2), 314–321.

Alcamo J., Moreno J.M., Nováky B., Bindi M., Corobov R., Devoy R.J.N., Giannakopoulos C., Martin E., Olesen J.E. and Shvidenko A. (2007), *Europe. Climate Change 2007*: Impacts, Adaptation and Vulnerability. Contribution of Working Group II *to the Fourth Assessment Reportof the Intergovernmental Panel on Climate Change*, Parry M.L., Canziani O.F., Palutikof J.P., P.J. van der Linden and C.E. Hanson, Eds., *Cambridge University Press, Cambridge*, UK, 541–580.

Bagnouls F. and Gaussen H. (1953), Saison sèche et indice xérothermique. *Documents pour les Cartes des Productions Vegetales*, Tome **III** (1), Toulouse, p 47.

Bank of Greece. (2011). The Environmental, Economic and Social Impacts of Climate Change in Greece, ISBN: 978 - 960 - 7032 - 58 – 4, pp494.

Brubaker L. B. (1986), Responses of tree populations to climatic change, *Vegetatio,* **67**, 119–130.

Buotte P.C., Levis S., Law B.E., Hudiburg T.W., Rupp D.E. and Kent J.J. (2019). Near-future forest vulnerability to drought and fire varies across the western United States. *Global Change Biology*, **25**, 290–303.

Burns D.A., Klaus J., and McHale M.R. (2007). Recent climate trends and implications for water resources in the Catskill Mountain region, New York, USA. J*ournal of Hydrology*, **336**, 155–170.

Chen H., Guo S., Xu C., and Singh V.P. (2007), Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in Hanjiang basin. J*ournal of Hydrology*, **344**, 171–184.

Chen I.C., Hill J.K., Ohlemüller R., Roy D.B., and Thomas C.D. (2011), Rapid range shifts of species associated with high levels of climate warming, *Science,* **333**,1024–1026.

Coll J., Bourke D., Gormally M., Sheehy S.M., and Sweeney J. (2013), Winners and Losers: Climate change impacts on biodiversity in Ireland: Projecting changes and informing adaptation measures. *Environmental Protection Agency (CCRP)*, Report No. **19**.

Croitoru A.E., Holobacal H., Lazar C., Moldovan F. and Imbroane A. (2012), Air temperature trend and the impact on winter wheat phenology in Romania. *Climate Change*, **111**(2), 393–410.

Diaz H.F., Grosjean M., and Graumlich L. (2003), Climate variability and change in high elevation regions: past, present and future., *Climatic Change*, **59**(1), 1–4.

Dupire S., Curt T., Bigot S. and Fréjaville T. (2019). Vulnerability of forest ecosystems to fire in the French Alps. *European Journal of Forest Research*, **138**, 813–830. 10.1007/s10342-019-01206-1.

FAO-Unesco 1988. *Soil map of the world. FAO*, Unesco, Rome. 119 p. file:///C:/Users/kk/Downloads/CCRP_19_Biodiversity Published_Sept2013.pdf

Founda D., Papadopoulos K.H., Petrakis M., Giannakopoulos C., and Good P. (2004), Analysis of mean, maximum and minimum temperature in Athens from 1897 to 2001 with emphasis on the last decade trends, warm events, and cold events. *Global and Planetary Change*, **44**, 27–38.

Fremout T., Thomas E., Gaisberger H., Van Meerbeek. K., Muenchow, J., Briers, S., Gutierrez-Miranda, C., Marcelo-Peña, J.L., Kindt, R., Atkinson, R., Cabrera, O., Espinosa, I. C., Aguirre-Mendoza, Z., and Muys, B. (2020), Mapping tree species vulnerability to multiple threats as a guide to restoration and conservation of tropical dry forests. *Global Change Biology*, **26** (2020), 3552–3568.

Gadgil A. and Dhorde A. (2005), Temperature trends in twentieth century at Pune, India. *Atmospheric Environment*, **39**, 6550–6556.

Giles B.D. and Flocas A.A. (1984), Air temperature variations in Greece. Part I. Persistence, Trend, And Fluctuations, *International Journal of Climatology,* **4***, 531–539*.

Grabherr G., Gottfried M., and Pauli H. (2000), GLORIA: a global observation research initiative in alpine environments**.** *Mountain Research and Development*, **20**(2000), 190–191.

Guntiňas M.E., Leirós M.C., Trasar-Cepeda C., and Gil-Sotres F. (2012), Effects of moisture and temperature on net soil nitrogen mineralization: A laboratory study. *European Journal of Soil Biology*, **48**, 73–80.

Hackl H., Baresel J.P., Mistele B., Hu Y., and Schmidhalter U. (2012), A comparison of plant temperatures as measured by thermal imaging and infrared thermometry. *Journal of Agronomy and Crop Science*, **198(6)**, 415–429.

Hatzioannou L., Retalis, D., Pasiardis S., Nikolakis D., Asimakopoulos D.N. and Lourantos N. (1998), Study of the precipitation time series in SE Greece and Cyprus, *Proc. 4th Conf. on Meteorology-Climatology-Atmospheric Physics*, Athens, pp. 279–284.

Helsel D.R., and Hirsch, R.M. (1992), Statistical methods in water resources, New York, *Elsevier*, **49**, 1st edition, 522p.

Hoyle F.C., Murphy D.V., and Fillery I.R.P. (2006), Temperature and stubble management influence microbial CO2 -C evolution and gross N transformation rates., *Soil Biol Biochem*, **38,** 71–80. https://library.wmo.int/doc_num.php?explnum_id=4166.

IPCC. (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the IPCC. Houghton J. T., Ding Y., Griggs D. J., Noguer M., van der Linden P. J., Dai X., Maskell K., and Johnson C. A. (eds.). Cambridge University Press, *Cambridge, UK, and New York.* 881 pp.

IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. and Miller H.L. (eds.)]. *Cambridge University Press, Cambridge, United Kingdom and New York*, NY, USA.

IPCC. (2013)., 'Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change'. Stocker, TF, Qin, D, Plattner, G-K, Tignor, M, Allen, SK, Boschung, J, Nauels, A, Xia, Y, Bex, V and Midgley, PM (Eds.), *Cambridge University Press*, pp.1535. http://www.climatechange2013.org/

IPCC. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel On Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (2014), p. 1132. [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]

IPCC. (2018). Global Warming of 1.5 °C. An IPCC Special Report On the Impacts of Global Warming of 1.5 °C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission pathways, in the Context of Strengthening the Global Response to the Threat of Climate change, Sustainable development, and Efforts to Eradicate Poverty, Masson-Delmotte V., Zhai P., Pörtner H.-O., Roberts D., Skea J., Shukla P. R., et al. (Eds.), Geneva, Switzerland: IPCC (2018).

Kandylis F., Repapis C. and Kotini-Zambaka S. (1989). Climatic Changes During Last 100 Years in Eastern Mediterranean, *1st Greek Conference in Geography, Athens*, 1989.

Kaoukis K., Proutsos N., Bourletsikas At., Tsagari C., Karetsos G., and Baloutsos G. (2015). Temperature and Precipitation Trends in a Maqui Forest in Varetada Amfilohias (1973–2013). (In Greek with an English Abstract) *Proceedings of the 17th Panhellenic Forestry Conference, Hellenic Forestry Society*, Kefalonia, 4–7/10/2015, 432–444.

Karpouzos D.K., Kavalieratou S., and Babajimopoulos C. (2010). Trend analysis of precipitation data in Pieria Region (Greece). *European Water*, **30**, 31–40.

Kendall M.G. (1975). Rank correlation methods. London. *Charles Grifin*.

Köppen W. (1884). Die Wärmezonen der Erde, nach der Dauer der heissen, gemässigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet. *Meteorologische Zeitschrift*, **1**(21), 5–226.

Körner C. (2004). Mountain biodiversity, its causes and function. *Ambio,* **13**, 11–17

Kozyr I.V. (2014), Forest vegetation dynamics along an altitudinal gradient in relation to the climate change in Southern Transbaikalia, Russia. *Achievements in the Life Sciences,* **8**(2014), 23–28.

Makrogiannis, T., Bora-Senta, E., and Philandras, C.M. (1998), Analysis of the air – temperature time series in Thessaloniki – application of the ARIMA (p, d, q) models, *Proceedings of the 2nd Hellenic Conference on Meteorology, Climatology and Physics of the Atmosphere*, Athens, September 22–25, 219–224.

Mann H.B. (1945), Non-parametric test against trend. *Econometrica*, **13**, 245–259.

Mavromatis T., and Stathis D. (2011), Response of the water balance in Greece to temperature and precipitation trends. *Theoretical and Applied Climatology*, **104**, 13–24.

Mekonen A.A., and Berlie A.B. (2020). Spatiotemporal variability and trends of rainfall and temperature in the Northeastern Highlands of Ethiopia. *Model Earth System Environment.* **6,** 285–300. https://doi.org/10.1007/s40808-019-00678-9.

Michopoulos P., Bourletsikas A., Kaoukis K., Karetsos G., Tsagari C., and Daskalakou E. (2015), Assessment of the risk of nitrogen saturation in a mountainous fir stand. *Fresenius Environmental Bulletin,* **24**, 1456–1462.

Negi V.S., Pathak R., Rawal R.S., Bhatt I.D., and Sharma, S. (2019). Long-term ecological monitoring on forest ecosystems in Indian Himalayan Region: criteria and indicator approach, *Ecological Indicators*, **102**, 374–381.

Nogues-Bravo D., Araújo M.B., Errea M.P., and Martinez-Rica J.P. (2007), Exposure of global mountain systems to climate warming during the 21st century. *Global Environmental Change*, **17**, 420–428.

Palutikof J.P., Trigo R.M., and Adcock S.T. (1996), Scenarios of future rainfall over the Mediterranean: is the region drying? in: *Proceedings Mediterranean Desertification, Research Results and Policy Implications*, Crete, Greece.

Paz S., Kutiel H., and Steinberger E. (1998). Variations in rainfall patterns along the Eastern Mediterranean coast. *Proceedings of the 4th Greek Scientific Conference in Meteorology-Climatology-Atmospheric Physics*. September 22–25, Athens, Greece, **2**, 299–304.

Philandras C.M. (1994). Climatic trends and fluctuations of the air temperature regime in Europe and Mediterranean Sea during the last 100 years, PhD Thesis, Faculty of Geology and Geoenvironment, University of Athens, Greece.

Philandras C.M., Metaxas D.A., and Nastos P.T. (1999), Climate variability and urbanization in Athens. *Theoretical and Applied Climatology,* **63**, 65–72.

Piervitali E., Colacino M., and Conte M. (1997), Signals of climatic change in the Central-Western Mediterranean basin, *Theoretical and Applied Climatology*, **58**, 211–219.

Potocic N., Cosic T., and Pilas I. (2005). The influence of climate and soil properties on calcium nutrition and vitality of silver fir (Abies alba Mill.). *Environmental Pollution*, **137**, 596–602.

Price M.F. (1995) Climate change in mountain regions: a marginal issue? *Environmentalist*, **15**, 272–280.

Proedrou M., Theoharatos G., and Cartalis C. (1997), Variations and trends in annual and seasonal air temperature in Greece determined from ground and satellite measurements, *Theoretical and Applied Climatology*, **57**, 65–78.

Proutsos N., Tsagari, C., Karetsos G., Liakatas A., and Kritikos Th. (2010), Recent temperature trends over mountainous Greece. *European Water*, **32**, 15–23.

Proutsos N., Tsagari C., and Karetsos G. (2011), Precipitation variations over the last half of the century in Greece. Conf. Proc. VI European Water Resources Association International symposium: Water Engineering and Management in a Changing Environment. (electronic edition). Abstracts p. 27 (eds. Cancelliere A. and G. Rossi), III Serie vol.6, ISSN:2038-5854. Catania, Sicily-Italy, June 29th–July 2nd 2011.

Repapis C.C., and Philandras C.M. (1988). A note on the air temperature trends of the last 100 years, as evidenced in the Eastern Mediterranean time series, *Theoretical and Applied Climatology,* **39**, 93–107.

Salmi T., Maatta A., Anttila P., Ruoho-Airola T. and Amnell T. (2002). Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Slope Estimates – The Excel Template Application MAKESENS, *Publications on Air Quality* No **31**, Finnish Meteorological Institute, Helsinki, Finland, 35pp.

Sen P.K. (1968). Estimates of the regression coefficient based on Kendall-tau, *Journal of the American Statistical Association*, **63**, 1379–1389.

Shrestha A.B., Bajracharya S.R., Sharma A.R., Duo C., and Kulkarni A. (2016). Observed trends and changes in daily temperature and precipitation extremes over the Koshi river basin 1975–2010. *International Journal of Climatology*, **37**, 1066–1083.

Solomou A.D., Proutsos N.D., Karetsos G., and Tsagari K. (2017), Effects of Climate Change on Vegetation in Mediterranean Forests: A review. *International Journal of Environment Agriculture and Biotechnology* (ISSN: 2456-1878), **2**(1), 240–247.

Stathis D. (2005). Weather, climate and water in 21st Century (In Greek with an English Abstract): *Proceedings of the 12th Panhellenic Forestry Conference. Hellenic Forestry Society*. Drama, 2–5/10/2005, 101–111.

Stathis D., Stathis Efth., Myronidis D., and Sapountzis, M. (2015). Climatic Changes in our Country in the 20th Century. (In Greek with an English Abstract), *Proceedings of the 17th Panhellenic Forestry Conference. Hellenic Forestry Society*. Kefalonia, 4–7/10/2015, 452–460.

Sun H., Chen Y., Li W., Li F., Chen Y., Hao X., and Yang Y. (2010), Variation and abrupt change of climate in Ili River Basin, Xinjiang. *Journal of Geographical Sciences,* **20**(5), 652–666.

Tigkas D. (2008). Drought characterisation and monitoring in regions of Greece. *European Water*, **23/24**, 29–39.

Todisco F. and Vergni L. (2008). Climatic changes in central Italy and their potential effects on corn water consumption, *Agricultural and Forest Meteorology*, **148**, 1–11.

UN-ICP-Forests 2020. International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests operating under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP). Available at: http://icp-forests.net/.

Wan, J.-Z., Wang, C.-J., Qu, H., Zhang, Z.-X. (2018), Vulnerability of forest vegetation to anthropogenic climate change in China, *Science of The Total Environment,* **621** pp. 1633–1641.

Watson R.T. (Ed.). (2001), Climate Change 2001: Synthesis Report. Contribution of Working Group I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

World Meteorological Organization (WMO). (2017), Guidelines on the Calculation of Climate Normals (WMO-No. 1203, ISBN 978-92-63-11212-5).

Zerefos, C., Philandras K., Douvis C., Kapsomenakis I., Tselioudis G. and Eleftheratos K. (2010), Long term changes of precipitation in Greece, *12th Plinious Conference on Mediterranean Storms*, MedCLIVAR session, Corfu, September 3.