THE ANALYSIS OF TEMPERATURE TRENDS IN VOJVODINA (SERBIA) FROM 1949 TO 2006

by

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The annual and seasonal trends of surface air temperatures were analyzed on the territory of Vojvodina, north Serbia, using observed data from 10 meteorological stations during 1949-2006. Of the 15 analyzed time series statistically significant positive trends were found in only 2 series. In the remaining 13 series were found trends with reduced statistical confidence. In general, the behavior of temperature could be considered rather non-changeable, than changeable. Quasi-changeable temperatures from 1949 to 2006 are surprisingly similar to the last glacial July paleo-temperatures. It seems that Vojvodina is a territory with more stable climate parameters than other regions.

Key word: *temperature trends, Mann-Kendall test, climate change, Vojvodina region (Serbia)*

Introduction

According to the [1], the mean global temperature of the world has increased by 0.74 °C in the last 100 years. This increase in the global temperature is not homogeneously distributed over the Earth's surface, varying among regions and locations. Using data recorded daily from 168 stations across Europe [2], showed that trends in mean temperature have increased during the period from 1946 to 1999.

In Serbia, the mean summer temperature increased in Belgrade after 1975 [3]. Analyzing the temperature data from 1949 to 2007, [4] found that the slow decrease of the annual summer temperatures until 1975 was followed by a temperature increase that lasted until 2007 in Belgrade. Using the extreme temperatures at 15 meteorological stations during the period 1949-2009, an analysis of the extreme temperature indices suggested that the Serbian climate has become warmer over the last 61 years [5]. In addition to these results, the climate in Serbia was studied in other recent papers [6, 7]. Also, the weather and climate of Vojvodina were investigated in a series of papers [8-10].This study focuses on an analysis of the recent trends in the annual and seasonal temperature over Vojvodina from 1949 to 2006.

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Area and data

Area

Vojvodina is a region in northern Serbia, located in the southeastern part of the Carpathian (Pannonian) Basin (fig. 1). More than 60% of this lowland area is covered by loess and loess-like sediments. The loess-paleosol sequences situated in the Vojvodina region exhibit the most detailed archive of climatic and environmental fluctuations during the Middle and Late Pleistocene on European continent [11, 12]. The most distinctive gemorphological units of the Vojvodina region are two mountains: Fruska Gora and Vrsac Hill.

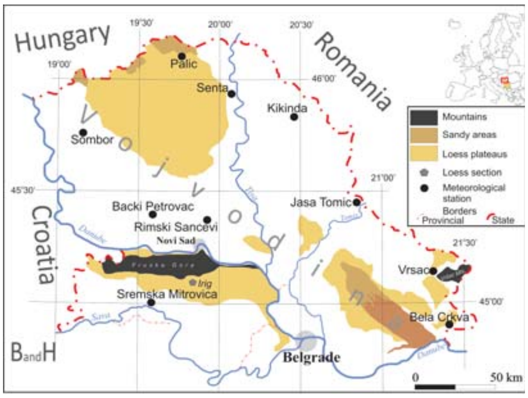


Figure 1. The Vojvodina region with geographical position of analized meteorological stations and Irig loess section

The climate of Vojvodina is moderate continental with cold winters and hot and humid summers, and with a huge range of extreme temperatures featuring inconsistent amounts of rainfall over the course of months. The mean annual air temperature was 11.1 °C and annual amount of precipitation was 606 mm between 1949 and 2006 [10].

Data

In this work, an analysis of surface air temperature trends in Vojvodina from 1949 to 2006 from 10 meteorological stations was performed. The locations of stations are presented in fig. 1 and their geographical co-ordinates and altitudes above mean sea level (AMSL) are given in tab. 1 in accordance with [13]. Only stations that have continuous raw data sets of temperatures for the period between 1949 and 2006 were selected. This means that the raw data were completed at all stations and missing data were not there. The selected period is the longest of all observation periods in Vojvodina with standardized measurements and controlled data [14] on a maximum number of meteorological stations. Thus, it can be considered that these selected data and period are very representative for the region of Vojvodina.

Table 1. List of meteorological stations, and their geographical co-ordinates and altitudes

Number	Meteorological station	Latitude [°]	Longitude [°]	Altitude AMSL [m]
1	Backi Petrovac	45.37	19.57	85
2	Bela Crkva	44.90	21.42	90
3	Jasa Tomic	45.45	20.85	80
4	Kikinda	45.85	20.47	81
5	Palic	46.10	19.77	102
6	Rimski Sancevi	45.33	19.85	86
7	Senta	45.93	20.08	80
8	Sombor	45.77	19.15	87
9	Sremska Mitrovica	45.00	19.55	82
10	Vrsac	45.15	21.32	83

Three data sets of surface air temperatures: monthly mean temperatures, monthly maximum temperatures, and monthly minimum temperatures, all in °C, were used. Monthly mean temperatures are obtained as the average of the daily mean temperatures, while monthly maximum and minimum temperatures are the maximum and minimum values of daily temperatures in corresponding month. Of these three data sets, new data sets were created: mean annual and seasonal; temperatures (T), maximum temperatures (T_x), and minimum temperatures (T_n) over the territory of Vojvodina during 1949-2006, respectively. Seasons definitions are used: winter (W), spring (Sp), summer (Su), and autumn (A), which are arranged in triplets of the months: January, February, and March; April, May, and June; July, August, and September; and October, November, and December [9], respectively.

In the continuation of this research, the data base was formed by year (Y), four seasons (W, Sp, Su, A), and three types of temperatures (T, T_x, and T_n). The total was 15 (5 × 3) time series that were used for the trend calculation. Each of these 15 cases is marked with the acronym consisting of the abbreviation for the year/seasons and type of temperature (tab. 2). The homogeneity analysis according to the [15] showed that the time series of the data for all stations are homogeneous.

Table 2. List of 15 time series to calculate surface air temperature trends in Vojvodina

	Year (Y)	Winter (W)	Spring (Sp)	Summer (Su)	Autumn (A)
T	YT	WT	SpT	SuT	AT
T_x	YT_x	WT_x	SpT_x	SuT_x	AT_x
T_n	YT_n	YT_n	SpT_n	SuT_n	AT_n

Methodology

Three statistical approaches were used to analyze the temperature trends in 15 time series. First, the tendency (trend) equation [16] was calculated for each time series. Second, completely independent of the first approach, all trends were assessed using the Mann-Kendall test [17]. Third, in all cases the trend magnitude was calculated from the trend equation [18].

The trend equation

The first statistical approach was to calculate the trend equation of temperature using linear interpolation of the mean annual and seasonal temperatures [19]. This approach is very easy for the interpretation of results. When the coefficient direction of the trend equation is greater than zero, less than zero or equal to zero, the sign of the *trend is positive* (increase), *negative* (decrease) or *there is no trend* (no change), respectively.

The Mann-Kendall test

In the second statistical approach, the Mann-Kendall (MK) test was applied to assess the significance of temperature trends. This test is widely used in the climatological time series [20]. The MK test is simple and robust, it can cope with missing values and values below the detection limit.

According to the MK test, two hypotheses were tested: the null hypothesis, H_0, that *there is no trend* in the time series; and the alternative hypothesis, H_a, that *there is a significant trend* in the series, for a given significance level. Probability, p, was calculated to determine the level of confidence in the hypothesis.

For the study that follows, the brief mathematical procedure for the hypotheses test and assessment of the significance of the temperature trends will be described. A key step in the application of MK test is the computation of the MK statistics, which is calculated as [20]:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(T_j - T_i) \tag{1}$$

where

$$\operatorname{sgn}(T_j - T_i) = \begin{cases} 1 & \text{if} \quad T_j - T_i > 0 \\ 0 & \text{if} \quad T_j - T_i = 0 \\ -1 & \text{if} \quad T_j - T_i < 0 \end{cases} \tag{2}$$

Here, T_j and T_i are the time series of the annual and/or seasonal values of the temperatures in years $j = i + 1, i + 2, i + 3, \ldots, n$ and $i = 1, 2, 3, \ldots, n-1$, where $j > i$, and n is the last year in the time series.

As seen in (1) and (2), if the temperature from the later year is higher than the temperature from the earlier year, S is incremented by 1. On the other hand, if the temperature from the later year is lower than the temperature of the earlier year, S is decremented by 1. The net result of all such increments and decrements yields the final value S. Statistics S can serve for evaluation of the temperature trend, because a very high positive value of S is an indicator of an increasing trend, and a very low negative value of S indicates a decreasing trend. However, to statistically quantify the significance of the trend, it is necessary to compute the probability associated with S and the number of years, n.

Now, the procedure to compute this probability will be described. For this purpose, the normalized/standard test statistic Z is calculated as:

$$Z = \begin{cases} \dfrac{S-1}{\sigma} & \text{for} \quad S > 0 \\ 0 & \text{for} \quad S = 0 \\ \dfrac{S+1}{\sigma} & \text{for} \quad S < 0 \end{cases} \tag{3}$$

where σ^2 is variance for the approximately normally distributed statistics S for $n \geq 10$. Finally, for measure of significance of the temperature trend, the probability p is computed as:

$$p = [1 - f(Z)] \cdot 100 \tag{4}$$

Here, $f(Z)$, as the probability density function for a normal distribution with a mean of 0 and a standard deviation of 1, is given by the following equation:

$$f(Z) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{Z^2}{2} \right) \tag{5}$$

As seen in eq. (4), the probability p takes values between 0 and 100 in %. In fact, p is used to test the level of confidence in the hypothesis [7]. If the computed value p is lower than the chosen significance level, α (*e. g.* $\alpha = 5\%$), the H_0 (*there is no trend*) should be rejected, and the H_a (*there is a significant trend*) should be accepted; and if p is greater than the significance level, the H_0 cannot be rejected. We used XLSTAT software [21] for calculating the probability, p, and hypothesis testing.

It is considered that accepting the H_a indicates that a trend is statistically significant. On the other hand, acceptance of the H_0 implies that there is no trend (no change), while often in practice, the trend equation indicates the opposite, *i. e.*, there is a trend. Therefore, to reduce the contradiction in analyzing the temperature trends between two independent statistical approaches, trend equation and applying the previous or classical interpretation of the MK test, the modified interpretation of the MK test will be used [18].

It is quite clear that with decreasing the probability p, statistical confidence in the H_0 is decreasing and confidence in the H_a is increasing, and *vice versa*. For the purposes of this study in modified MK test with four levels of confidence was declared. Based on the computed probability p, these four levels of confidence are:
(a) less or equal than 5%, *there is a significant positive/negative trend*,
(b) greater than 5%, and less or equal than 30% *there is a moderately positive/negative trend*,
(c) greater than 30%, and less or equal than 50% *there is a slightly positive/negative trend*, and
(d) greater than 50% *there is no trend*.

As can be seen, in cases (a) and (d) both interpretations of the MK tests have the same meaning. Differences occur in cases (b) and (c), where the classical MK test claims there is no trend, and the modified MK test allows trend with reduced levels of confidence. It is clear that modified interpretation is more subtle, and it enables obtaining diverse assessments.

The trend magnitude

In the third statistical approach, the trend magnitude was calculated as:

$$\Delta y = y(1949) - y(2006) \tag{6}$$

where Δy is the trend magnitude in °C, $y(1949)$ and $y(2006)$ are temperatures from the trend equation in the beginning, 1949, and at the end period, 2006, both in °C. When Δy is greater than zero, less than zero or equal to zero, the sign of the trend is *negative* (decrease), *positive* (increase) or *no trend* (no change), respectively. Second, when Δy is less than or equal to the standard error of the temperature measurement, certainly *there is no trend*.

Results

Each figs. 2-4 shows yearly and seasonal temperature during the period 1949-2006, the trend equation, where y is the mean annual and/or seasonal value of the temperature in °C, x is the time in years; and the trend line. The probability confidence, p, and the trend magnitude, Δy, for each time series over the territory of Vojvodina are shown in tab. 3, respectively. In all cases, the significance level was the same, $\alpha = 5\%$ [20].

Table 3. The probability confidences and the trend magnitude for all time series

	T		T_x		T_n	
	p [%]	Δy [°C]	p[%]	Δy [°C]	p[%]	Δy [°C]
Y	11	–0.5	4	–1.0	17	–0.6
W	14	–1.3	11	–2.2	15	–1.8
Sp	15	–0.7	15	–0.7	35	–0.5
Su	26	–0.4	99	0.1	1	–1.5
A	46	0.2	16	–0.9	18	1.4

In strictly formal terms, some trends can be observed in all cases. However, all trends do not have the same sign, probability, and magnitude. To obtain a final evaluation of the temperature trends in Vojvodina, all numerical parameters, the visual representation of trends and, most importantly, the results of both MK tests, were used.

Figures 2-4 and trend equations show that for the time series YT, WT, SpT, SuT, YT_x, WT_x, SpT_x, AT_x, YT_n, WT_n, SpT_n, and SuT_n trends are positive; and in the cases AT, SuT_x, and AT_n the trends are negative. MK testing will prove whether these statements are true.

As the computed values of probability p for the time series YT, WT, SpT, SuT, AT, WT_x, SpT_x, SuT_x, AT_x, YT_n, WT_n, SpT_n, and AT_n are greater than the significance level, $\alpha = 5\%$,

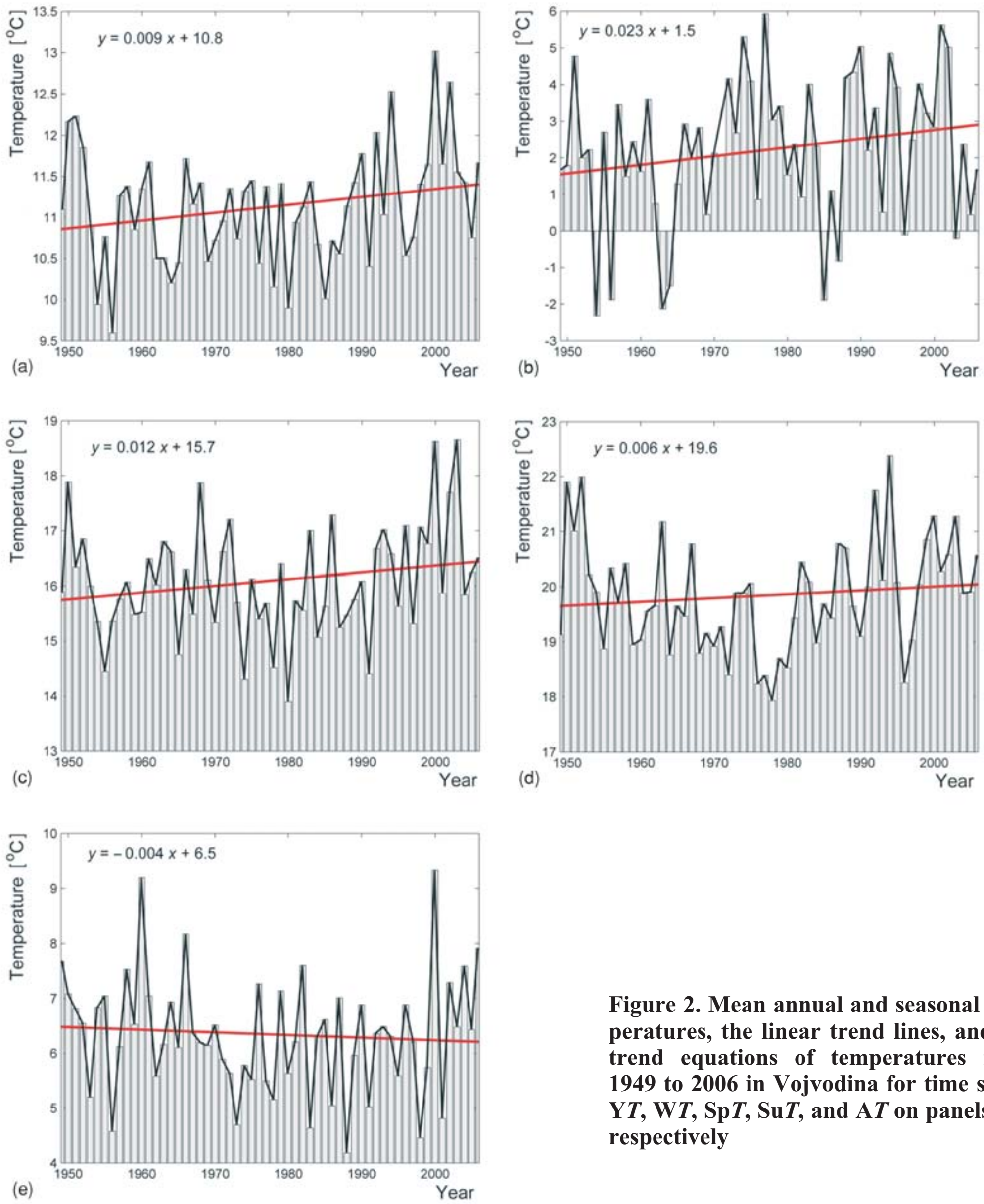
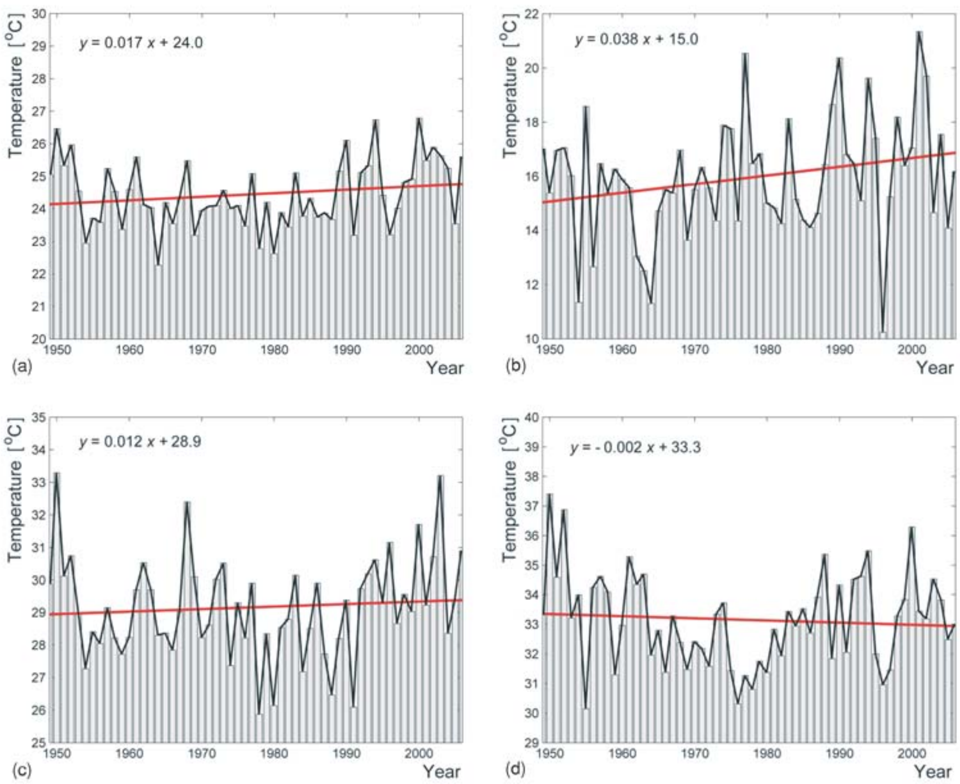


Figure 2. Mean annual and seasonal temperatures, the linear trend lines, and the trend equations of temperatures from 1949 to 2006 in Vojvodina for time series Y*T*, W*T*, Sp*T*, Su*T*, and A*T* on panels a-e, respectively



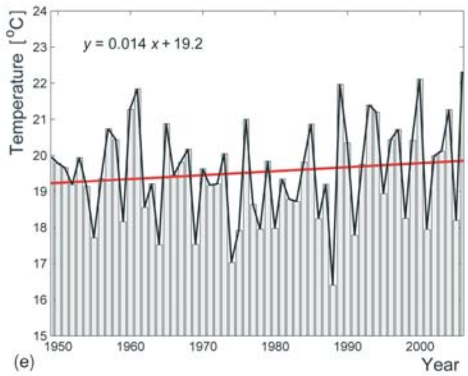


Figure 3. Mean annual and seasonal temperatures, the linear trend lines, and the trend equations of temperatures from 1949 to 2006 in Vojvodina for time series YT_x, WT_x, SpT_x, SuT_x, and AT_x on panels a-e, respectively

the H_0 cannot be rejected in all cases. The risks to reject the null hypothesis while it is true are 11, 14, 15, 26, 46, 11, 15, 99, 16, 17, 15, 35, and 18 (all in %) for all time series, respectively. In accordance with the classical MK tests, all cases are declared as there is no trend; while the modified MK test declared: first, second, third, fourth, sixth, seventh, ninth, tenth, eleventh, and thirteenth cases as *there is a moderately positive trend*, fifth, and twelfth cases as *there is a slightly negative trend*, and eighth case as *there is no trend*.

As the computed probability value p for the time series YT_x and SuT_n are lower than the significance level, α, the H_0 should be rejected, and the H_a should be accepted for both time series. The risks to reject the null hypothesis are lower than 4% and 1%. The statement that there is a significant trend is correct with probabilities greater than 96% and 99% in both MK tests.

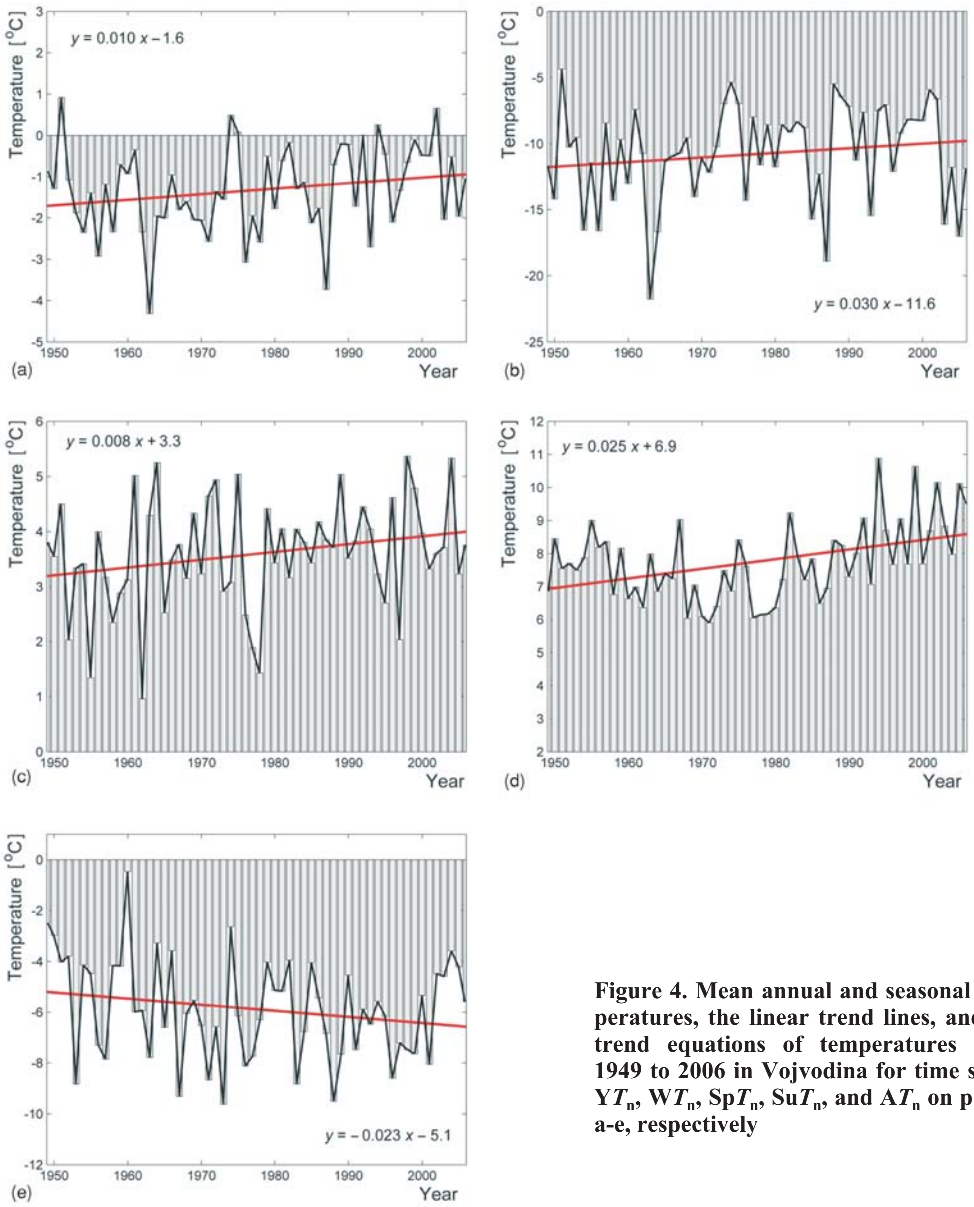


Figure 4. Mean annual and seasonal temperatures, the linear trend lines, and the trend equations of temperatures from 1949 to 2006 in Vojvodina for time series YT_n, WT_n, SpT_n, SuT_n, and AT_n on panels a-e, respectively

Discussion and conclusions

The main result of our analysis of temperature trends in Vojvodina is given in tab. 4. It seems that the positive temperature trends are dominant.

In accordance with the trend equations, positive trends were found in 12 time series, and negative trends were found in 3 time series. After applying the classical MK test, only 2 positive trends were statistically significant and the remaining cases there were no trends. Also, after applying the modified MK test (I) significant positive trends were confirmed in 2 time series; and in the remaining cases the trends were declared as: (II) moderately and slightly positive in 10 series; (III) moderately and slightly negative in 2 cases; and (IV) there was no trend in 1 case.

For all temperatures, T, T_x, and T_n, the annual trends were declared as moderately positive, significantly positive, and moderately positive, respectively. All winter trends were declared as moderately positive. The spring trends were declared as moderately positive twice, and slightly positive. Summer and autumn trends were the most diverse and declared as moderately positive, no trend, significantly positive, slightly negative, moderately positive, and moderately negative, respectively.

From the above discussion it can be concluded that the increase of the temperature is dominant in Vojvodina. Based on the trend magnitude in tab. 3, the increase in the temperatures was in a wide range of values from 0.4 °C to 1.8 °C. This behavior of the temperature in Vojvodina resembles the warming in the northern hemisphere [22]. It is difficult to find identical results in neighboring areas. For example, [23] concluded that in ten counties in Central and Southeast Europe between 1951 and 1990, there had been an increase in both annual maximum and minimum temperatures.

Table 4. The main results of the analysis of temperature trends in Vojvodina

Time series	Trend equation	The classical KM test	The modified MK test
YT	*positive trend*	no trend	positive moderate trend
WT	*positive trend*	no trend	positive moderate trend
SpT	*positive trend*	no trend	positive moderate trend
SuT	*positive trend*	no trend	positive moderate trend
AT	negative trend	no trend	negative slight trend
YT_x	*positive trend*	positive significant trend	positive significant trend
WT_x	*positive trend*	no trend	positive moderate trend
SpT_x	*positive trend*	no trend	positive moderate trend
SuT_x	negative tend	no trend	no trend
AT_x	*positive trend*	no trend	positive moderate trend
YT_n	*positive trend*	no trend	positive moderate trend
WT_n	*positive trend*	no trend	positive moderate trend
SpT_n	*positive trend*	no trend	positive slight trend
SuT_n	*positive trend*	positive significant trend	positive significant trend
AT_n	negative tend	no trend	negative moderate tend

On the other hand, it can be summarized that in Vojvodina there was no statistically significant change in the temperature during 1949-2006, so it could be said that temperature was rather non-changeable/quasi-changeable, than changeable. It is possible to find similarities in the behavior of some other climatic parameters in the territory of Vojvodina in the recent and paleo periods, with the results obtained here. For example, [9] showed that there were no annual trends in aridity indices in Vojvodina during the same period, using the same data as here. It seems that there is no significant change in present climatic parameters (temperature and aridity) in Vojvodina in this more recent period from 1949 to 2006.

It is interesting to see what we know about the paleoclimate in the Vojvodina region during the last approximately 130,000 years. Similar to the presented recent climate results, relatively stable, paleoclimate trends are also recorded in the loess-paleosol sequences over the last glacial-interglacial cycle in the northern Serbian region. Generally, the Late Pleistocene climate in the investigated region was drier and considerably warmer compared to other European loess provinces [24]. Evidence of abrupt high frequency fluctuations during the last glacial period appears in loess throughout much of Europe [25], and is linked with the cooling events in the north Atlantic Ocean and associated with the cold phases of Dansgaard/Oeschger cycles recorded in Greenland ice [26], although not clearly expressed in the last glacial loess of the Vojvodina region. The stability of the last glacial climate recorded at Irig loess-paleosol sequence (fig. 1) can be illustrated with variations of July paleo-temperatures estimated using the malaco-paleothermometer method of [27]. Reconstructed July paleo-temperatures ranged from about 17 °C to 21 °C during periods of loess accumulation and the interstadial soil formation of the last glacial period [28]. Generally, the summer conditions of the whole last glacial period were similar to the present July mean temperature of 21.6 °C.

Finally, all these conclusions are in agreement with the [1], in which the increase in the global temperature is not homogeneously distributed on the Earth surface, but is instead varies regionally. In support of such a stance is the conclusion in [20]. From nine examined states in the Northeastern United States, two states do not indicate statistically significant temperature trends. A similar non-homogeneity in the distribution of temperature trends can be found in the work of [29]. Their study identified the general increasing trends in annual, winter, and spring mean air temperatures, particularly over the southern regions of Turkey, and decreasing trends of mean temperatures in autumn over continental central and northern regions of Turkey between 1929 and 1999. Similar non-homogeneity behavior of temperature trends exists in Greece. Greece exhibited a negative trend in winter temperatures and a positive trend in summer temperatures between 1955 and 2001, statistically significant only at a small number of stations [19]. It seems that Vojvodina is a region where temperature changes are less pronounced and it contributes to the conservation and values of other climate parameters.

Acknowledgments

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Nomenclature

Alphabet

f – probability density function, [–]
S – Mann-Kendall statistics, [–]
T, T_x, T_n – surface air mean annual and seasonal; temperatures, maximum, and minimum temperatures, [°C]
T_j, T_i – time series of temperatures, [°C]
Z – normalized/standard test statistic, [–]

Greek symbols

π – Ludolph's number, [–]
σ^2 – variance for S, [–]

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