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Analysis of annual and seasonal temperature trends using the Mann-Kendall test in Vojvodina, Serbia

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Abstract—The annual and seasonal trends of mean, maximum, and minimum temperatures were analyzed on the territory of Vojvodina, north Serbia. We used observed, quality controlled, homogenized, and spatially averaged data from 9 meteorological stations during two periods: 1949–2013 and 1979–2013. Positive trends were found in 29 out of the 30 analyzed time series using a linear tendency (trend) equation, while negative trends were found in only 1 case. After the application of the classical Mann-Kendall (MK) test, statistically significant positive trends were confirmed in 15 series, while in remaining cases, statistically significant trends were not confirmed. After applying the modified MK test, positive trends were found in 26 series, and 4 cases were with no trend. We find that significant positive trends are dominated during the year, spring and summer; and they are most numerous in the time series of monthly mean temperatures. In accordance with the behavior of analyzed trends, the increase of temperatures is dominant in Vojvodina.

Key-words: annual and seasonal temperature trends, Mann-Kendall test, Vojvodina

1. Introduction

According to the *IPCC* (2007) report, the average global surface temperature of the world has increased by 0.74 °C in the past 100 years. This increase in the global temperature is not homogeneously distributed over the Earth's surface. It varies among regions and locations. The seasonal and annual Central European series of the mean temperature exhibited an increasing trend during the period 1951–1990 in most regions (*Brázdil et al.*, 1996). Using data recorded daily from 168 stations across Europe, *Klein Tank et al.* (2002) showed that trends in mean temperature have increased during the period from 1946 to 1999.

Analysis of the surface air temperature observed at stations located in all regions of the Mediterranean basin indicated a cooling during the period 1955–1975, and a strong warming during the 1980s and the first half of the 1990s (*Piervitali et al.*, 1997). Warming trends in the Mediterranean region (*Böhm et al.*, 2001; *Alcamo et al.*, 2007) occurred largely during the summer season, thereby intensifying summertime drought and irrigation problems. *Brunetti et al.* (2004) noted that the temperature trend in Italy was positive for each season in the south, and for autumn and winter in the north. *Feidas et al.* (2004) examined trends of annual and seasonal surface air temperature time series for 20 stations in Greece for the period 1955–2001. They found that Greece, in general, exhibits a cooling trend in winter, whereas in summer it exhibits an overall warming trend. The significant increase in average temperature over the Iberian Peninsula in recent decades was found by *Brunet et al.* (2007).

In Serbia, the mean summer temperature increased in Belgrade after 1975 (*Unkašević et al.*, 2005). 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 (*Unkašević* and *Tošić*, 2013). In addition to these results, the climate in Serbia was studied in other recent papers (*Đorđević*, 2008; *Unkašević* and *Tošić*, 2009a; *Gavrilov et al.*, 2010; *Pavlović Berdon*, 2012). Also, the weather and climate of Vojvodina were investigated in several papers (*Gavrilov et al.*, 2011; *Hrnjak et al.*, 2014; *Tošić et al.*, 2014; *Gavrilov et al.*, 2015).

In this study, we focus on analyzing the recent trends in the annual and seasonal temperatures over Vojvodina, Serbia. We find that the period from 1949 to 2013 contains more than two 30-year climatic cycles and, therefore, the results could be a good indicator for recent climate interpretations. Our paper is organized as following: Section 2 presents a description of the research region and data; methodology is described in detail in Section 3; the obtained results are presented in Section 4; and discussion and conclusions are given in Sections 5 and 6.

2. Data

2.1. Region

Vojvodina is a region in northern Serbia, located in the southeastern part of the Carpathian (Pannonian) Basin, encompassing the confluence area of the Danube, Sava, and Tisa rivers (*Fig. 1*). More than 60 % of this lowland area is covered by loess and loess-like sediments (*Marković et al.*, 2008). The most distinctive landforms of the Vojvodina region are two mountains: Fruška Gora Mountain, which is situated between the Danube and Sava rivers, and Vršac Mountain, which is located in the southeastern part of the region. In addition to these physical features of the region, there are sandy and lower areas-alluvial plains.

The climate of Vojvodina is moderate continental with cold winters and hot and humid summers, and with a large range of extreme temperatures featuring inconsistent amounts of rainfall over the course of months. The average annual air temperature was 11.1 °C and annual amount of precipitation (*Tošić et al.*, 2014) was 606 mm between 1949 and 2006.

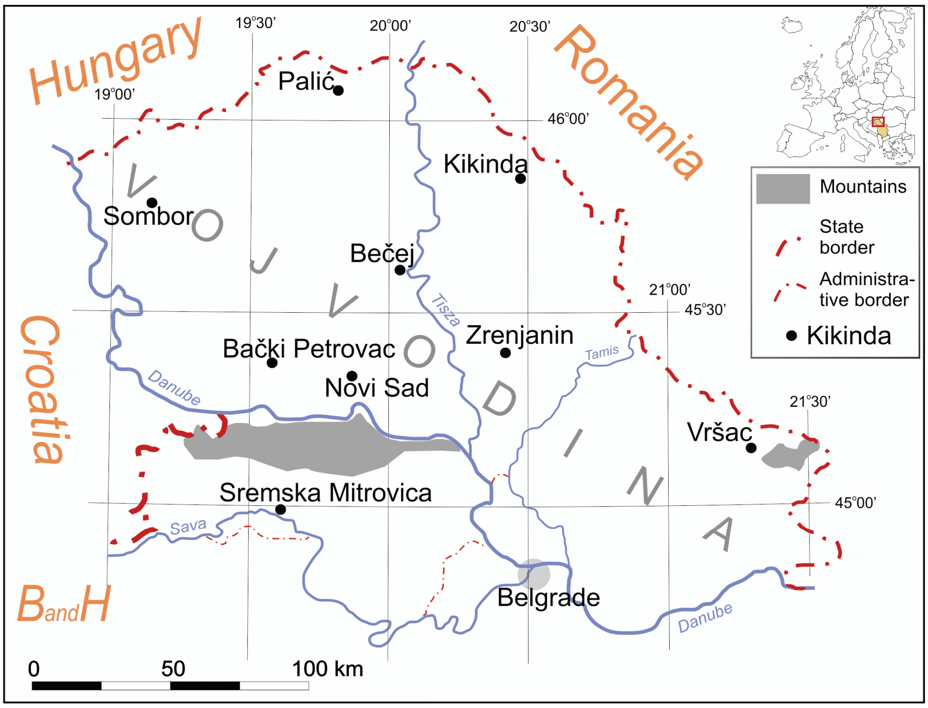

Fig. 1. The region of Vojvodina and position of meteorological stations.

2.2. Data used

In this work, an analysis of surface air temperature trends in Vojvodina from 9 meteorological stations was performed. The locations of stations are presented in *Fig. 1* and their geographical coordinates and altitudes are given in *Table 1* in accordance with the *Republic Hydrometeorological Service of Serbia* (2014). All stations have relatively similar altitudes, varying between 75 m and 102 m. Only stations that have almost continuous raw data sets of temperatures for the period between 1949 and 2013 were selected. The selected period is the longest of all observation periods in Vojvodina with standardized measurements and controlled data (*WMO*, 2012) on a large number of meteorological stations. Thus, it can be considered that these selected data and period are the most representative for the region of Vojvodina.

Table 1. List of meteorological stations, their geographical parameters and missing data for the period 1949–2013

Meteorological stations	**Geographical parameters**			**Missing data (%)**		
	Latitude (°)	**Longitude (°)**	**Altitude (m)**	T	T_x	T_n
Bački Petrovac	45.37	19.57	85	0.05	0.05	0.05
Bečej	45.63	20.03	75	0.54	1.57	1.54
Kikinda	45.85	20.47	81	0.0	0.0	0.0
Novi Sad	45.33	19.85	86	0.0	0.0	0.0
Palić	46.10	19.77	102	0.76	0.38	0.38
Sombor	45.77	19.15	87	1.54	1.54	1.54
Sremska Mitrovica	45.00	19.55	82	0.0	0.0	0.0
Vršac	45.15	21.32	83	0.0	0.0	0.0
Zrenjanin	45.37	20.42	80	0.0	0.0	0.0

Three used raw data sets of surface air temperatures are: monthly mean temperatures, T, monthly maximum temperatures, T_x, and monthly minimum temperatures, T_n. Monthly mean temperatures are obtained as the average of the daily mean temperatures, while monthly maximum/minimum temperatures are the maximum/minimum values of daily temperatures in corresponding month. As shown in *Table 1*, raw data were complete at five stations, while at four stations missing data were varied from 0.05 % to 1.57 %. We used the method/software MASH (*Szentimrey*, 1999) for data homogenization and filling in the missing raw data in accordance with the *CarpatClim project* (2014).

Of these three homogenized data sets, new data sets were created: average of stations over the territory of Vojvodina annual and seasonal mean, maximum, and minimum temperatures, T, T_x, T_n, respectively. The standard seasons definitions are used: winter (DJF), spring (MAM), summer (JJA), and autumn

(SON) during two periods: 1949–2013 (*P*1), and 1979–2013 (*P*2). We expect from the data processing in the first period to give the state of surface air temperature trends for longest continuous observation period (65 years) in Vojvodina. We also expect the second period to show the temperature trends during the last 35 years (5 years more than one 30-year climate standard), when global warming became the most intense (*Hardy*, 2006).

In the continuation of this research, the data base was formed by year (Y), four seasons (DJF, MAM, JJA, and SON), three types of temperatures (T, T_x, and T_n), and two periods (*P*1 and *P*2). The total number of series was 30 that were used for the trend calculation. Each of these 30 cases is marked with the acronym consisting of the abbreviation for the year/seasons, period, and type of temperature (*Table 2*).

Table 2. List of 30 time series to calculate surface air temperature trends in Vojvodina

	Year	**Winter**	**Spring**	**Summer**	**Autumn**
T	Y-T-P1	DJF-T-P1	MAM-T-P1	JJA-T-P1	SON-T-P1
	Y-T-P2	DJF-T-P2	MAM-T-P2	JJA-T-P2	SON-T-P2
T_x	Y-T_x-P1	DJF-T_x-P1	MAM-T_x-P1	JJA-T_x-P1	SON-T_x-P1
	Y-T_x-P2	DJF-T_x-P2	MAM-T_x-P2	JJA-T_x-P2	SON-T_x-P2
T_n	Y-T_n-P1	DJF-T_n-P1	MAM-T_n-P1	JJA-T_n-P1	SON-T_n-P1
	Y-T_n-P2	DJF-T_n-P2	MAM-T_n-P2	JJA-T_n-P2	SON-T_n-P2

3. Methodology

Three statistical approaches were used to analyze the temperature trends in 30 time series. First, the tendency (linear trend) equation (e.g., *Draper* and *Smith*, 1966) was calculated for each time series. Second, in all cases, the trend magnitude was calculated from the trend equation. Finally, in the third approach, all trends were assessed using the Mann-Kendall (MK) test, completely independent of the first approach (*Mann*, 1945; *Kendall*, 1975; *Gilbert*, 1987).

3.1. The trend equation

The first statistical approach was to calculate the trend equation of temperature using linear regression (e.g., *Draper and Smith*, 1966), as

$$y = ax + b, \qquad (1)$$

where y is the temperature in °C, a is the slope, x is the time in years, and b is the temperature at the beginning of the period.

This approach has been long utilized in this type of research (e.g., *Wibig* and *Glowicki*, 2002; *Feidas et al*., 2004), because it gives results which are simple to interpret; both graphically and analytically on the basis of the shape and parameters of the trend equation. For instance, the sign of the temperature trend depends on the value of the slope. In this kind of interpretation when the slope 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.

3.2. The trend magnitude

In the second statistical approach, the trend magnitude was defined, as the difference in temperature between the beginning and the end of the period, which was obtained from the linear trend equation (*Gavrilov et al*., 2015), or which is calculated as follows,

$$\Delta y = y(P_b) - y(P_e), \tag{2}$$

where Δy is the trend magnitude in °C. Values $y(P_b)$ and $y(P_e)$ represent temperatures from the trend equation in the beginning, P_b, and at the end period, P_e. Recall that two periods $P1$ and $P2$ have two beginning: $P_b = 1949, 1979$; and common end: $P_e = 2013$, with the exception of winter, where the periods were shorter for one year at the beginning and the end.

For a better understanding of the trend magnitude, we note the following. First, 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*.

The trend equation, trend magnitude, linear trend line, and annual course of temperature were computed and plotted for each time series using MATLAB scripts.

3.3. The Mann-Kendall test

In the third statistical approach, the MK test was applied to assess the significance of temperature trends. This test is widely used in the analysis of the climatological time series, for example: temperature and precipitation in earlier researches (e.g., *Gan*, 1995), as well as in recent researches (e.g., *Mavromatis* and *Stathis*, 2011; *Karmeshu*, 2012); extreme temperatures (e.g., *Serra et al*., 2001; *Wibig* and *Glowicki*, 2002); hail (e.g., *Gavrilov et al*., 2010, 2013); aridity (e.g., *Hrnjak*, *et al*., 2014); evapotranspiration (e.g., *Tabari et al*., 2011); and atmospheric deposition (e.g., *Drapela* and *Drapelova,* 2011); then in the hydrological time series (e.g., *Yue* and *Wang*, 2004); and other geophysical time series, such as: freeze and thaw soil (e.g., *Sinha* and *Cherkauer*, 2008); because 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, H0, that *there is no trend* in the time series; and the alternative hypothesis, Ha, that *there is a significant trend* in the series, for a given α significance level (e.g., *Onoz* and *Bayazit*, 2003). Probability, p, in percent was calculated (e.g., *Karmeshu*, 2012; *Gavrilov et al*., 2017) to determine the level of confidence in the hypothesis. If the computed value p is lower than the chosen significance level α (e.g., α=5 %), the H0 (*there is no trend*) should be rejected, and the Ha (*there is a significant trend*) should be accepted. In case p is greater than the significance level α, the H0 (*there is no trend*) cannot be rejected. We used XLSTAT software (http://www.xlstat.com/en/) for calculating the probability, p, and hypothesis testing.

It is considered that accepting the Ha indicates that a trend is statistically significant. On the other hand, acceptance of the H0 implies that there is no trend (no change), while often in practice, the trend equation and the trend magnitude indicates that there is a trend. Therefore, to reduce the doubt in analyzing the temperature trends with two independent statistical approaches, trend equation and applying the previous or classical interpretation of the MK test, the modified interpretation of the MK test (*Gavrilov*, *et al*., 2015; *Gavrilov*, *et al*., 2017) will be used. The difference between these two MK tests is in the number of levels of confidence. The classic MK test has only two levels of confidence: (i) *there is a significant positive/negative trend* and (ii) *there is no trend*. The modified MK test declares four levels of confidence, when p is:

(1) less or equal than 5 %, *there is a significant positive/negative trend*;

(2) greater than 5 %, and less or equal than 30 %, *there is a moderately positive/negative trend*;

(3) greater than 30 %, and less or equal than 50 %, *there is a slightly positive/negative trend*; and

(4) greater than 50 %, *there is no trend*.

As it can be seen, in cases (1) and (4) both interpretations of the MK tests have the same meaning. Differences occur in cases (2) and (3), 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.

4. Results

4.1. Parameters of trend

Figs. 2–4 show annual and seasonal mean, maximum, and minimum temperatures during the period 1949–2013 with two trend equations (Eq. (1): above (1949–2013) and below (1979–2013); and two trend lines: for longer and shorter period, respectively. The trend magnitude, Δy, and the probability of the confidence, p, for each time series over the territory of Vojvodina are shown in *Table 3*, respectively.

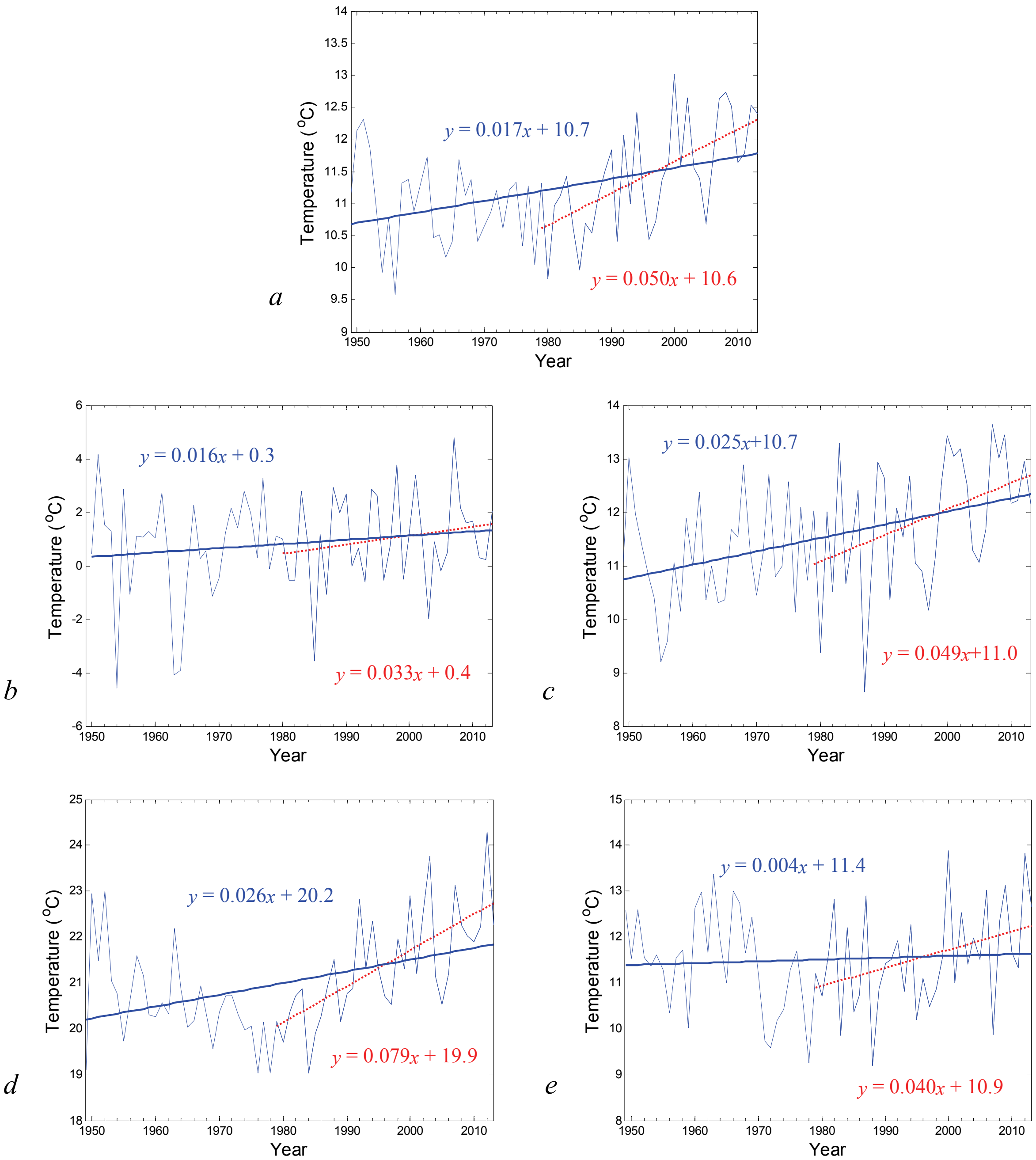

Fig. 2. Average annual and seasonal temperatures, trend equations, and trend lines for couples of time series: Y-*T*-*P*1 and Y-*T*-*P*2; DJF-*T*-*P*1 and DJF-*T*-*P*2; MAM-*T*-*P*1 and MAM-*T*-*P*2; JJA-*T*-*P*1 and JJA-*T*-*P*2; and SON-*T*-*P*1 and SON-*T*-*P*2 on panels a-e, respectively.

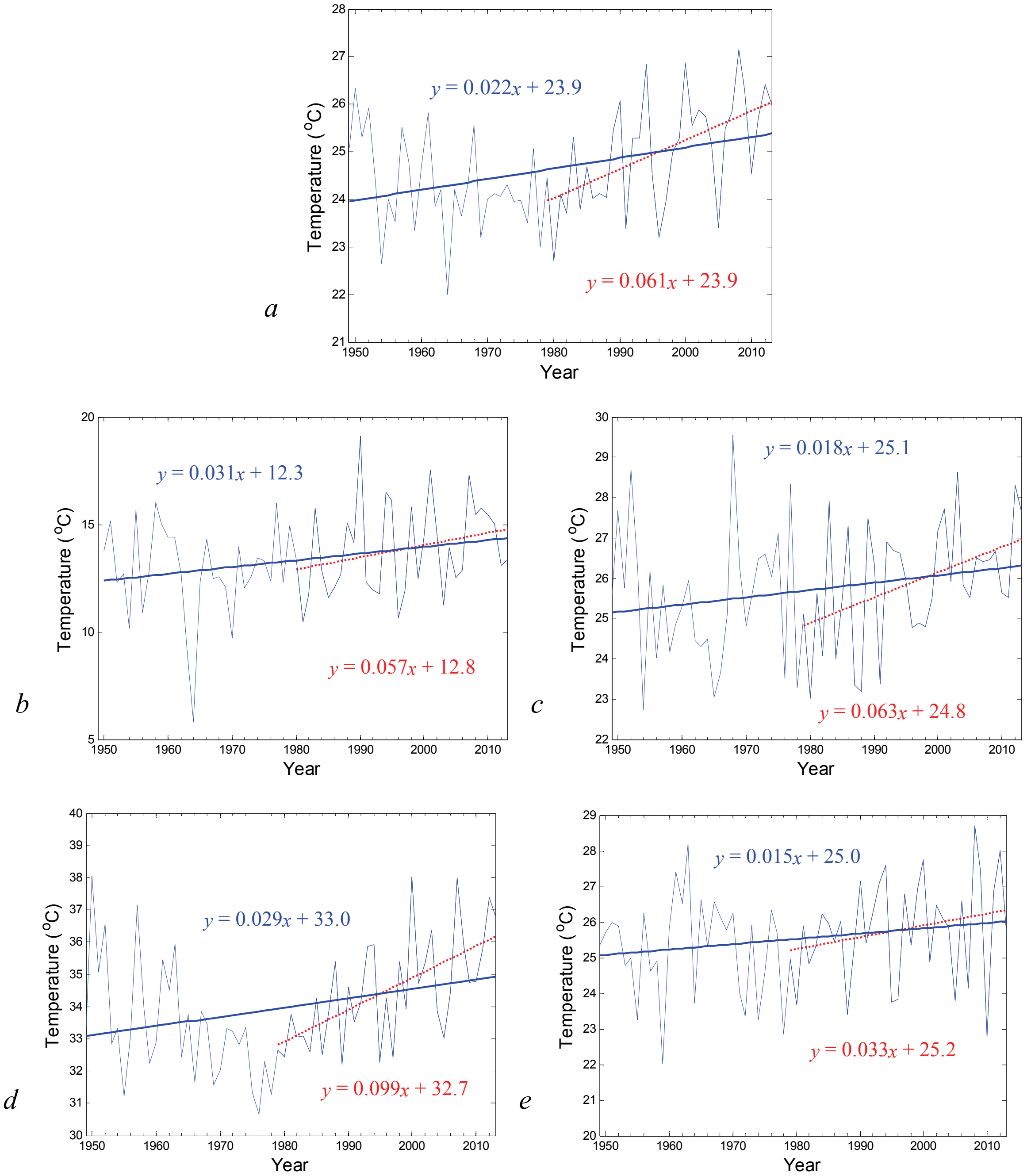

Fig. 3. As in *Fig. 2* but for T_x.

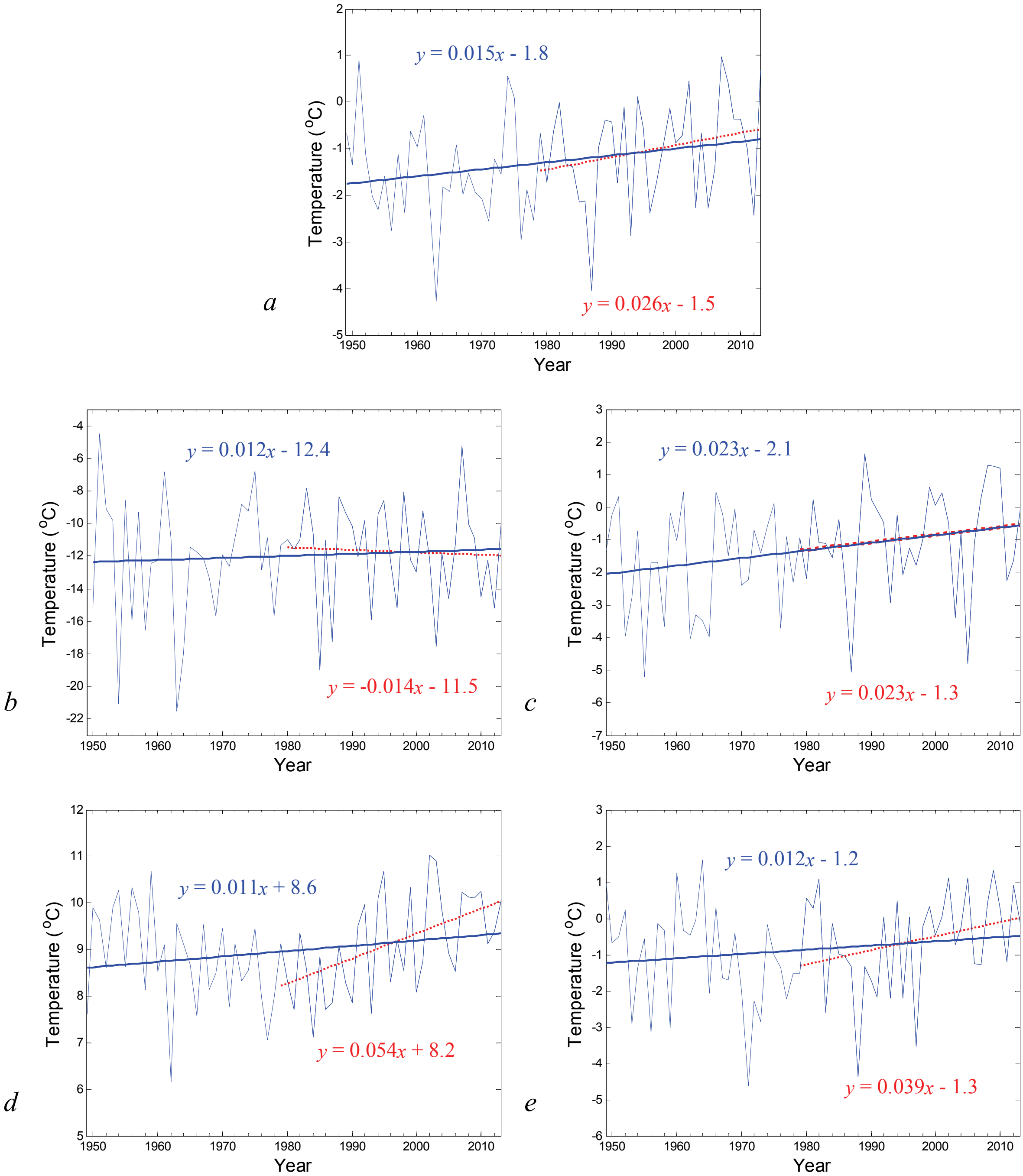

Fig. 4. As in *Fig. 2* but for T_n.

Table 3. The trend magnitude, Δ*y*, and the probability of the confidences, *p*, for all time series

	T				***T*x**				***T*n**			
	***P*1**		***P*2**		***P*1**		***P*2**		***P*1**		***P*2**	
	Δ*y* (°C)	***p* (%)**	**Δ*y* (°C)**	***p* (%)**	**Δ*y* (°C)**	***p* (%)**	**Δ*y* (°C)**	***p* (%)**	**Δ*y* (°C)**	***p* (%)**	**Δ*y* (°C)**	***p* (%)**
Y	–1.1	0.13	–1.7	<0.01	–1.6	0.47	–2.1	0.04	–1.0	4.45	–0.9	24.65
DJF	–1.0	53.15	–1.1	36.11	–2.0	12.61	–1.9	11.00	–0.8	75.00	0.5	55.63
MAM	–1.6	0.07	–1.7	1.63	–1.2	5.86	–2.1	3.02	–1.5	3.24	–0.8	33.71
JJA	–1.6	0.10	–2.7	<0.01	–1.8	0.69	–3.4	0.01	–0.7	18.34	–1.8	0.27
SON	–0.2	60.64	–3.1	2.07	–1.0	8.84	–1.1	7.83	–0.7	12.92	–1.3	13.59

4.2. Evaluation of trends

In strictly formal terms, some trends can be observed in all cases (see *Figs. 2–4*). However, all trends do not have the same sign, magnitude, and probability. 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.

Figs. 2–4 and *Table 3* show that the trend for 29 time series is *positive*, and it is *negative* only for the case DJF-T_n-$P2$. MK testing proves whether these statements are true.

As the computed probability values *p* for *P*1 cases: Y-*T*, MAM-*T*, JJA-*T*, Y-T_x, JJA-T_x, Y-T_n, and MAM-T_n; and for *P*2 cases: Y-*T*, MAM-*T*, JJA-*T*, SON-*T*, Y-T_x, MAM-T_x, JJA-T_x, and JJA-T_n, are lower than the significance level, *α*, the H0 should be rejected, and the Ha should be accepted for all of these cases. The risks to reject the H0 are lower than 4.45 %. The statement that *there is a significant trend* is correct in these cases with a probability greater than 95.55 % in both MK tests.

As values *p* for *P*1 seasons: DJF-*T*, SON-*T*, DJF-T_x, MAM-T_x, SON-T_x, DJF-T_n, JJA-T_n, and SON-T_n, and for *P*2 time series: DJF-*T*, DJF-T_x, SON-T_x, Y-T_n, DJF-T_n, MAM-T_n, and SON-T_n are greater than *α*, the H0 cannot be rejected. The risks to reject the H0 while it is true are between 5.86 % and 75.00 %. In accordance with the classical MK tests, all cases are declared as *there is no trend*; while the modified MK test declared the first, second, sixth, and thirteenth cases as *there is no trend*, the ninth and fourteenth cases as *there is a slightly positive trend*, and the remaining cases as *there is a moderately positive trend.*

In addition, *Figs. 2–4* show that in P2 the trend lines have greater slope in all time series for *T* and T_x, and in case T_n in 3 out of 5 time series. Only for the case DJF-T_n-*P*1 slope is greater than DJF-T_n-*P*2, while for the time series MAM-T_n-*P*1 and MAM-T_n-*P*2 slopes (*a*=0.023) are equal.

The main results of our analysis of temperature trends in Vojvodina are summarized in *Table 4*. The results are classified according to all time series, temperatures (T, T_x, T_n), and methods (the trend equation, the classical and the modified MK tests).

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

Time series	The trend equation	The classical MK test	The modified MK test
T			
Y-T-P1	*positive trend*	*positive significant trend*	*positive significant trend*
Y-T-P2	*positive trend*	*positive significant trend*	*positive significant trend*
DJF-T-P1	*positive trend*	*no trend*	*no trend*
DJF-T-P2	*positive trend*	*no trend*	*positive slightly trend*
MAM-T-P1	*positive trend*	*positive significant trend*	*positive significant trend*
MAM-T-P2	*positive trend*	*positive significant trend*	*positive significant trend*
JJA-T-P1	*positive trend*	*positive significant trend*	*positive significant trend*
JJA-T-P2	*positive trend*	*positive significant trend*	*positive significant trend*
SON-T-P1	*positive trend*	*no trend*	*no trend*
SON-T-P2	*positive trend*	*positive significant trend*	*positive significant trend*
$\boldsymbol{T_x}$			
Y-T_x-P1	*positive trend*	*positive significant trend*	*positive significant trend*
Y-T_x-P2	*positive trend*	*positive significant trend*	*positive significant trend*
DJF-T_x-P1	*positive trend*	*no trend*	*positive moderate trend*
DJF-T_x-P2	*positive trend*	*no trend*	*positive moderate trend*
MAM-T_x-P1	*positive trend*	*no trend*	*positive moderate trend*
MAM-T_x-P2	*positive trend*	*positive significant trend*	*positive significant trend*
JJA-T_x-P1	*positive trend*	*positive significant trend*	*positive significant trend*
JJA-T_x-P2	*positive trend*	*positive significant trend*	*positive significant trend*
SON-T_x-P1	*positive trend*	*no trend*	*positive moderate trend*
SON-T_x-P2	*positive trend*	*no trend*	*positive moderate trend*
$\boldsymbol{T_n}$			
Y-T_n-P1	*positive trend*	*positive significant trend*	*positive significant trend*
Y-T_n-P2	*positive trend*	*no trend*	*positive moderate trend*
DJF-T_n-P1	*positive trend*	*no trend*	*no trend*
DJF-T_n-P2	*negative trend*	*no trend*	*no trend*
MAM-T_n-P1	*positive trend*	*positive significant trend*	*positive significant trend*
MAM-T_n-P2	*positive trend*	*no trend*	*positive slight trend*
JJA-T_n-P1	*positive trend*	*no trend*	*positive moderate trend*
JJA-T_n-P2	*positive trend*	*positive significant trend*	*positive significant trend*
SON-T_n-P1	*positive trend*	*no trend*	*positive moderate trend*
SON-T_n-P2	*positive trend*	*no trend*	*positive moderate trend*

5. Discussion

It is difficult to find identical results in neighboring areas, but there are similarities. For example, greater increase of the absolute maximum temperature (0.16 °C/year) than the absolute minimum temperature (0.12 °C/year) obtained *Unkašević et al.* (2005) for Belgrade during the period 1975–2003. Similarly to our results, *Brázdil et al*. (1996) concluded that in ten countries in Central and Southeast Europe between 1951 and 1990, there had been an increase in both annual maximum and minimum temperatures. *Brunetti et al*. (2004) found that trends in the annual temperature series ranged from 0.4 °C/(100 years) for the north to 0.7 °C/(100 years) for the south of Italy. These conclusions are in agreement with the *IPCC* report (2007), in which the increase in the global temperature is not homogeneously distributed on the Earth surface.

In *Fig. 2a* we show three characteristic time intervals in the behavior of the annual mean temperature. The higher temperatures are at the beginning and the end of the $P1$ period, and the lower temperatures are in the middle of the period from 1970s until the mid 1980s. Our results are in accordance with the results of *Unkašević* and *Tošić* (2009b). Analyzing the temperature data from 1949 to 2007, they found that the slow decrease of summer temperatures until 1975 was followed by a temperature increase that lasted until 2007 in Belgrade (Serbia). Obtained temperature changes in Vojvodina are very similar to the behavior of global temperature during the same period (*Hardy*, 2006), where the increase of the temperature was started in the mid-1980s. It seems that there is a coincidence of regional temperature changes in Vojvodina and global temperature change.

6. Conclusions

An analysis of annual and seasonal trends of mean, maximum, and minimum surface air temperatures in Vojvodina for two periods: 1949–2013 and 1979–2013 was performed. Temperature trends in 30 time series were analyzed using (i) the trend equation, (ii) the trend magnitude calculated from the trend equation, and (iii) the MK test in the classical and modified declaration. The main conclusion can be summarized as follows:

(a) In accordance with the trend equations, positive trends were found in 29 out of 30 time series, and negative trend was found in only one case.

(b) Using the classical MK test, significant positive trends were found in 15 series; 8 in the shorter period, and 7 in the longer period; and no trend was found in 15 cases. The significant positive trends are dominated during the year, spring, and summer, where it was found in 14 out of 18 cases. From the three types of temperatures, T, T_x, and T_n, significant positive trends were found 7, 5, and 3 times, respectively.

(c) Based on the modified MK test, positive (significant, moderate, and slight) trends were confirmed in 26 (15, 9, and 2, respectively) series.

(d) The increase of the temperature was found in 29 time series in a wide range of values from 0.2 °C to 2.0 °C for the longer period and from 0.8 °C to 3.4 °C for the shorter period. The decrease of the temperature was found only for the minimum temperatures during the winter for the shorter period. The increase of temperatures was higher for the shorter period, than for the longer period.

As shown, the positive temperature trends and the increase of temperatures are dominant in Vojvodina. This behavior of the temperature resembles the warming in the Northern Hemisphere (e.g., *CRU*, 2003).

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