Spring and autumn frosts in the Pannonian Basin in Serbia

SLAVICA MALINOVIĆ-MILIĆEVIĆ[1], MILAN M. RADOVANOVIĆ[2,3]

[1] University of Novi Sad, ACIMSI, University Center for Meteorology and Environmental Modelling, Novi Sad, Serbia; e-mail: slawica@sbb.rs
[2] Serbian Academy of Sciences and Arts, Geographical Institute "Jovan Cvijic", Belgrade, Serbia
[3] South Ural State University, Institute of Sports, Tourism and Service, 60, Russia

ABSTRACT The study analyzes the number of light, moderate and severe spring and autumn frosts and occurrence of the last spring and the first autumn frost in the Pannonian Basin in Serbia, over the period 1961–2010. Only the average number of light and severe spring frosts decreased significantly over the investigated period, while the number of spring and autumn frosts of all intensities decreased at the majority of stations since 1990. Since 1990, the last light and moderate spring frosts have had a tendency to occur earlier, while autumn frosts have shown the tendency to occur later. In the urban station of Belgrade the last spring frosts appeared on average 17 days earlier relative to rural stations, while first autumn frosts appeared 17 days later. The lengthening of the period without light frosts since 1990 was the result of an earlier ending of spring frosts, while the lengthening of the period without moderate and severe frosts is caused by the later start of autumn frosts.

KEY WORDS frost – minimum temperature – linear trends – Pannonian Basin – Serbia

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1. Introduction

One of the main conclusions of the Fifth Report of the Intergovernmental Panel on Climate Change (IPCC) was that the impact of human society on the climate system is undeniable. This influence is reflected in the increase in the concentration of greenhouse gases and global temperature. Mean global temperature has risen by about 0.85 °C (0.65 to 1.06 °C) since the beginning of the last century, while two-thirds of this increase was observed since 1980 (IPCC 2013). Warming was the most intense over lands and over the northern hemisphere, while warming intensity increases with latitude. Pronounced upward trend in air temperature is present in the whole territory of Serbia. In the period 1960–2012 a significant increase in mean daily temperature has been. The mean temperature rise was about 0.3 °C per decade, which is more than the global rise (CEKOR 2014). According to data for the period 1951–2007, the most intense positive trend in air temperature is in the north of Serbia, in the area of Loznica, in the wider area of Belgrade and at Negotinska krajina (Popović 2007).

Besides changes in mean temperatures, there are very significant changes in extreme temperatures. Recent studies have shown small differences of the global mean trends after 1980 between mean daily minimum temperatures (T_{min}) and mean daily maximum temperatures (T_{max}; Thorne et al. 2016). The frequency of extreme cold events generally declines, while the frequency of the extreme warm events increases (IPCC 2013). The frequency of extreme cold events has more significant long-term trends than the extreme warm events in some large regions of the world (Finkel, Katz 2017). However, in several parts of Europe, including Serbia, the increase in the frequency of extreme warm events is the most intense. Daily T_{max} increases faster than T_{min} in western Germany (Hundecha, Bardossy 2005), the Pannonian Basin in central/eastern Europe (Bartholy, Pongracz 2007), extra-Carpathian regions of Romania (Croitoru, Piticar 2013) and northeastern Spain (El Kenawy, López-Moreno, Vicente-Serrano 2011). Such trends in extreme temperatures may indicate that these parts of Europe have a slower decline in the number of frost days than the rest of Europe, and consequently higher potential damage from frosts ($T_{min} < 0$ °C).

According to CEKOR (2014), in Serbia the positive trend in daily T_{max} is larger (0.35 °C per decade), than the trend in daily T_{min} (0.25 °C per decade). These temperature trends indicate that in Serbia the potential frost risk decreases slower compared to other regions. Bearing in mind the facts that the Serbian agricultural area is mainly located in the Pannonian Basin, where mean temperature increases fastest, and daily T_{min} increases slowest in Serbia (Popović 2007), the number of frost days and dates of frost occurrences in the Pannonian Basin need to be analyzed. Previous studies showed negative trends in the number of frost days during winter and spring and positive trends for autumn (Unkasevic, Tosic 2013, Knezevic et al. 2014). However, the extent of the damage to agricultural crops depends not only on the occurrence of frost, but also on frost severity and timing. Therefore, the most harmful frost events from agricultural point of view, i.e. spring and autumn frosts, need to be examined regarding their severity and the time of occurrence. In this study a comprehensive analysis was done on the spatio-temporal variability of the number of spring and autumn frost days, the last spring frost dates, the first autumn frost dates and the frost free periods, all classified in three severity categories. Additionally, the frost risk characteristics, i.e. the probabilities, of the first and last occurrences of frosts were calculated. Although the frost-related risk levels for particular crop species are not analyzed in this study, the results are potentially useful for agricultural planning and agricultural adaptation to the climate change.

2. Materials and Methods

2.1. Location and climate

The Serbian part of the Pannonian Basin includes the Pannonian Plain and a narrow band south of the Danube River and the Sava River. Geographically it belongs to the southeastern part of the Pannonian Plain, the largest plain of central Europe, whose total area is more than 100,000 km^2 (Fig. 1a). In Serbia, the area of the Pannonian Basin is 24,448 km^2, which is 27.5% of the total territory of the country. The Serbian part of the Pannonian Basin is limited by the administrative border with Romania, Hungary, Croatia and Bosnia and Herzegovina, while the southern boundary is natural. In the direction from the west to the east, the southern border of the basin comprises the lower course of the Drina River in town Loznica. The natural southern border continues along the western and northern edge of Pocerina region, comprises the lower course of the Kolubara River, and flows along the Sava River and the Danube River at town Smederevo. Further to the east, the border encompasses the lower flows of the Velika Morava River and the Mlava River, ending at the border with Romania close to village Ram. Excluding the Mountains Fruska Gora and Vrsacke Planine, the elevations of topographic surface range from 68.5 to 155 m (Calic et al. 2012).

Daily series of minimum temperatures were analyzed from the weather station network of the Republic Hydrometeorological Service of Serbia (RHMSS) for the period 1961–2010. The position of the stations is shown in Figure 1b and Table 1. Except station BG, all other stations are located in the rural area. Meteorological station Belgrade is located in the middle of urban area and consequently it is not included in the estimation of the regional frequency and the date of frost occurrence. However, Belgrade data have been compared with rural stations in order

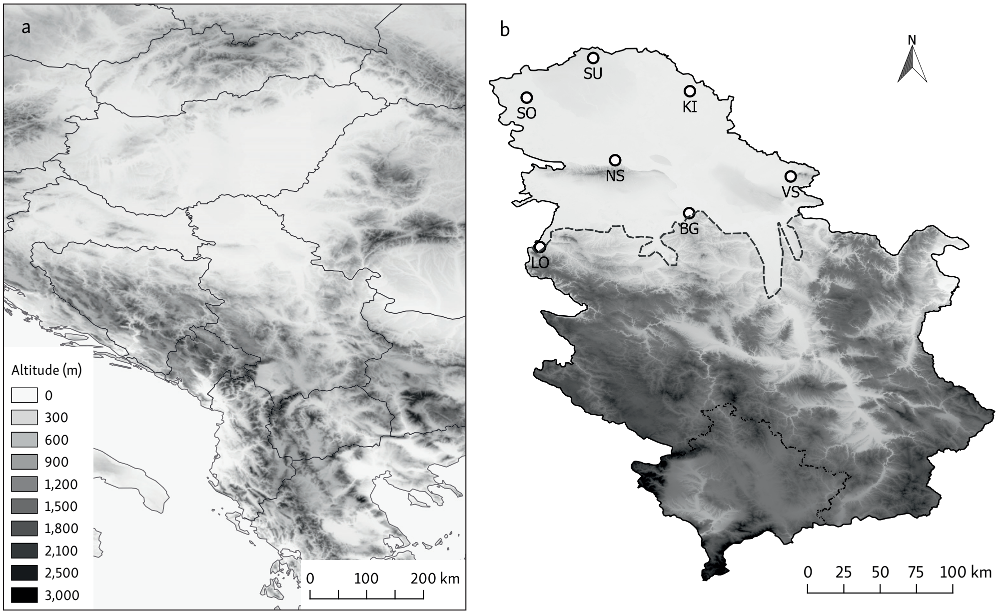

Fig. 1 – Location of Pannonian Plain in Europe (a) and in Serbia with meteorological stations used in this study (b)

to evaluate the effects of urbanization on the number of frost days and the time of occurrence of spring and autumn frosts.

According to Milovanović et al. (2017), the Koppen's Cfb climate is most dominated, while Cfa climate is present in the lower flow of the Velika Morava River, in the area of Belgrade and middle and southern Banat and Srem (*C* = mild temperate / mesothermal climate; *f* = significant precipitation during all seasons; *b* = warmest month's average temperature is < 22 °C (but there are at least 4 month averaging > 10 °C); a = temperature of warmest month is ≥ 22 °C). The data on the annual, spring, autumn and growing season temperatures (mean, minimum and

Table 1 – List of stations with their abbreviations, latitudes, longitudes and altitudes

Abbreviation	Station	Latitude	Longitude	Altitude (m)
SU	Subotica	46°06'	19°46'	102
SO	Sombor	45°46'	19°09'	88
KI	Kikinda	45°51'	20°28'	81
NS	Novi Sad	45°20'	19°51'	86
VS	Vrsac	45°09'	21°19'	84
BG	Belgrade	44°48'	20°28'	132
LO	Loznica	44°33'	19°14'	121

Table 2 – Mean seasonal and annual temperatures and precipitations in Southeastern Pannonian Basin for the period 1961–2010 and for the period 1991–2010

	1961–2010				1991–2010			
	T_{mean}	T_{max}	T_{min}	Prec	T_{mean}	T_{max}	T_{min}	Prec
				Spring				
Mean	11.8	17.3	6.5	155.0	12.2	17.8	6.8	148.9
Maximum	13.8	19.8	8.0	282.2	13.8	19.8	8.0	226.1
Minimum	8.9	13.8	4.1	54.2	10.4	15.6	4.9	54.2
				Autumn				
Mean	11.8	17.4	7.0	150.6	12.1	17.5	7.4	176.1
Maximum	14.3	20.5	9.2	284.3	14.3	20.5	9.2	284.3
Minimum	9.6	14.1	4.7	53.0	10.3	15.2	6.0	71.5
				Growing season				
Mean	15.8	21.6	10.2	488.6	16.1	21.9	10.6	524.6
Maximum	17.5	23.6	11.4	780.4	17.5	23.6	11.3	780.4
Minimum	14.1	19.6	8.9	229.6	14.9	20.8	9.4	229.6
				Annual				
Mean	11.5	16.7	6.6	650.3	12.0	17.2	7.1	684.2
Maximum	13.3	19.1	8.0	971.5	13.3	19.1	8.0	971.5
Minimum	10.1	14.8	5.4	322.8	10.7	15.4	6.0	322.8

maximum) and precipitation are averaged spatially and are presented in Table 2. Because it includes urban station *BG*, climate regionally averages in Table 2 may have a very slight urban effect. The mean annual (T_{mean}), T_{max} and T_{min} in the Pannonian Basin in Serbia are higher compared with the temperatures in the country (11.5 °C vs. 11.2 °C, 16.7 °C vs. 16.4 °C and 6.6 °C vs. 6.2 °C, respectively). Temperatures during the growing season are about 4 °C higher than the mean annual temperatures. During the growing season T_{mean} and T_{min} were highest in urban station BG, while the lowest values of T_{min}, (10.0 °C and lower) were concentrated in the western part of the Basin (*SO* and *LO*). Considering T_{min} and T_{max}, autumn is warmer than spring. The average temperatures for the last two decades (mean, minimum and maximum) are higher than those for the whole investigated period, with up to 0.5 °C. The mean annual precipitation total is 650.3 mm in the period 1961–2010, which is lower than the mean precipitation amount for the entire territory of Serbia (686.3 mm). The majority of precipitation falls during the growing season (75% of annual totals), mostly in summer. The annual amount of precipitation is very variable, particularly in the last two decades. Excessive amount of precipitation during certain years can lead to floods (such as in 2010, with 971.5 mm), while the lack of precipitation can contribute to extreme drought (e.g., in 2000, 322.8 mm).

2.2. Methodology

The subject of research is spring and autumn frosts. The following parameters are defined for each station and each year: the number of frost days during spring and autumn (FD), the last spring frost day (LSF), the first autumn frost day (FAF) and the length of the frost-free period (FFP). The LSF is defined as the last date in a year before June 30th when frost occurred, while FAF is defined as the first date in a year starting on July 1st on which frost occurred. The FFP is the number of days between the last day with $T_{min} < 0.0$ °C in spring and the first day with $T_{min} < 0.0$ °C in autumn. In terms of severity, we examined three categories of frosts defined in Table 3. The classification is based on the extent of the damage of the majority of agricultural crops at mid-latitudes. Air temperatures between −2.0 °C and −4.0 °C result in partial damage to flowers and leaves of most plants, while temperatures below −4.0 °C result in a complete freezing of these parts of plants (Otorepec 1980).

To detect significant trends in FD, frost dates, FFPs and T_{min}, the non-parametric Mann–Kendall test was used on data series smoothed by 11-year moving average. The magnitude of the trend was assessed by Sen's slope estimator (Sen 1968). A suitable statistical distribution for each station and for each frost variable (FAF and LSF) was used to analyze the risk of the occurrences of frosts. It was done by using EasyFit 5.6 computer software (Mathwave 2017) that computes parameters of more than fifty frequency distributions and selects the best model. For every supported distribution, EasyFit implements one of the following parameter estimation methods: the method of moments (MOM), maximum likelihood (ML), least squares estimates (LSE) and the method of L-moments. We assessed the goodness of fit with the Kolmogorov-Smirnov statistic test that is based on the largest vertical difference between the theoretical and empirical cumulative distribution function. The best-fitted distribution is used to analyze the probabilities of the first and last occurrences of frosts.

Table 3 – Classification of spring and autumn frost severity (Schnelle 1965)

Light	Moderate	Severe
−0.1 °C ≥ T_{min} ≥ −2.0 °C	−2.1 °C ≥ T_{min} ≥ −4.0 °C	T_{min} ≤ −4.1 °C

2.3. Data quality control and homogenization

The data quality control was carried out using different control tests similar to those described by Peterson et al. (1998) and Dunn et al. (2012): the existence of gaps in data series, occurrences of physically impossible values, long consecutive occurrences of the same value and extreme outliers. We found that only station Subotica has short data gap from May 19 to July 25 in 1999. However, since the missing data do not influence the analysis of frost occurrence, the station was not discarded from the analysis. We did not find inconsistent and physically impossible values, consecutive occurrences of the same value and outliers. The homogeneity test procedure has been carried out with ACMANT homogenization software (Domonkos 2014) which is recommended homogenization method by COST ES0601 for its high efficiency (Venema et al. 2012).

3. Results and discussion

3.1. Linear trends in the number of frost days

On average 11 spring FD and 10 autumn FD were recorded between 1961 and 2010 in the Pannonian Basin in Serbia. The spring FD varied from 0 (BG in 2006 and 2007, SU in 1989, KI in 2007) to 28 (VS in 1997), while autumn FD varied from 0 (BG in 1974, 1986, 2000, 2009, 2010 and 2007) to 34 days (SU in 1973).

Figure 2 shows the number of spring and autumn frosts, as well as their severity distribution. It can be noticed that spring frosts were slightly more numerous than autumn frosts, and also more severe. Urban station BG has a lower risk both of spring and autumn frosts due to lower intensity and frequency. Regarding frequency, the highest risk of spring and autumn frosts was at the northwestern station (SO), while regarding intensity at the easternmost station (VS). On average, in spring the most frequent were light frosts (50.4%), then moderate and severe frosts (24.8% each). In autumn, the most frequent were light frosts (55.0%), then moderate frosts (27.2%), while the least frequent were severe frosts (17.8%).

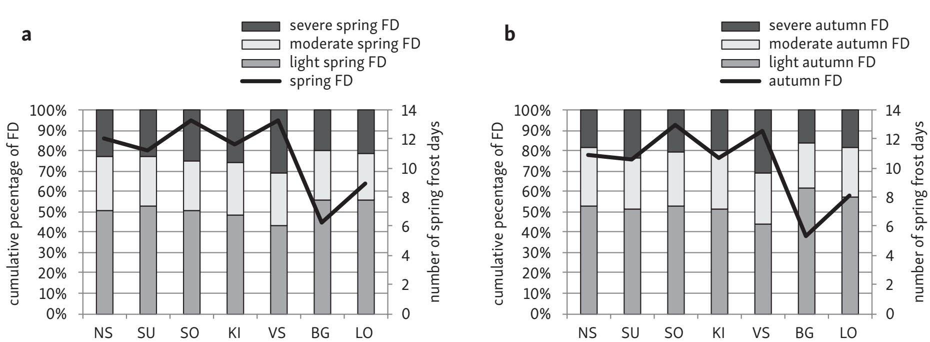

Fig. 2 – The number and severity distribution of spring (a) and autumn (b) frosts in Pannonian Basin in Serbia over the period 1961–2010

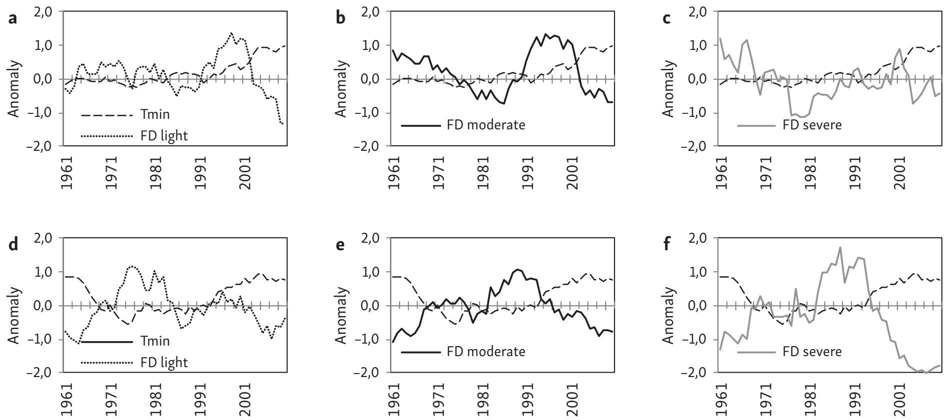

Fig. 3 – Interannual variations in the light, moderate and severe anomaly of FD and T_{min} in rural stations in spring (a, b, c) and autumn (d, e, f). The anomalies are calculated relative to the normal of 1961–1990 (horizontal gray line). The values are smoothed by 11-year centered moving average.

In order to analyze the variation in the change in light, moderate and severe FD over time in relation with T_{min} we calculated their time series anomalies from the 1961–1990 normal, and presented them filtered with 11-year centered moving average in Figure 3. Until the mid 1970s the number of all spring FD (light, moderate and severe) in rural stations was higher than the long-term average, while from mid 1970s to the end of the 1980s it was below average. Moderate and severe spring FD varied higher than light FD. During the same period, the mean spring T_{min} was around long-term average and stayed relatively unchanged. Mean spring T_{min} started to rise in 1990s and continue to rise significantly until the end of the analyzed period (0.7 °C per decade). Although it is expected that spring FD decreases with increasing mean spring T_{min} this was not the case. Despite the increase in T_{min}, light and moderate spring FD were above the average in 1990s, while they decreased in the last decade. Figures 3d–e reveal a strong relation between autumn FD and autumn T_{min}. In contrast to the spring FD, all autumn FD were below average until the beginning of the 1970s with a tendency to increase, which was caused by high mean autumn T_{min}. The light autumn FD was above average in 1970s, while moderate and severe autumn FD was above average from mid 1980s to mid 1990s. Moderate and severe autumn FD declined from the beginning of the 1990s, together with an intensive growth of autumn T_{min}. Light autumn FD declined only in the 2000s. Variation in T_{min} and FD anomaly in urban station shows the pattern that is similar to rural regional averages, with few exceptions (not shown). Severe spring FD in urban station follow the rise of T_{min} in the 1990s, being below the average until the end of the observed period, while urban autumn light FD are decreasing since the beginning of the 1990s, a decade before rural average.

The linear trend analysis of FD over the period 1961–2010 has shown that mean number of light and severe spring frosts decreased significantly (–0.14 and –0.12 days per decade, respectively), while the number of autumn frosts did not have statistically significant tendency. To reveal recent changes in the number of light, moderate and severe frosts, in Figure 4 shows the spatial distribution of trends over the period 1991–2010. It can be noticed that FD decreased at the majority of stations in the last two decades, in most cases significantly. The number of spring moderate frosts decreased fastest (up to –1.49 days per decade), while the number of severe frosts decreased slowest. The severe autumn FD decreased rapidly and significantly, up to –2.28 days per decade in the north part of the region. Light and moderate autumn FD decreased slower than severe FD at the majority of stations. Contrary to other stations, the number of light autumn frosts in VR shows statistically significant increase at a rate of 0.25 days per decade, while the number of moderate autumn frosts remained at the same level.

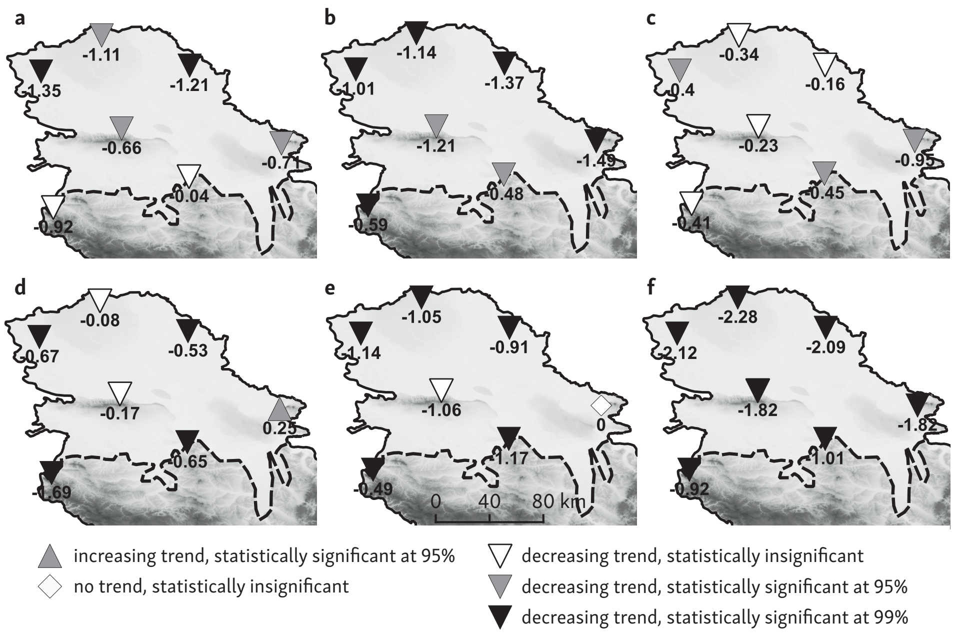

Fig. 4 – Spatial distribution of linear trends (per decade) in light (a, d), moderate (b, e) and severe (c, f) frost days in spring (above) and autumn (below) for the period 1991–2010.

3.2. Linear trends in the last spring frost, the first autumn frost, and the length of the frost-free period

Averages for the period 1961–2010 show that in the Pannonian Basin in Serbia FFP started on 3 Apr and ended on 28 Oct. The earliest LSF and the latest FAF are recorded in urban station BG (19 Mar and 11 Nov, respectively), while the latest LSF and the earliest FAF are recorded in the eastern part of the area, at station VR (15 Apr and 18 Oct, respectively). The FFP lasts between 185–236 days, i.e. on average from middle April to the end of October. The longest T_{min} above 0 °C was in the largest urban area in the Pannonian Basin in Serbia (BG, 236 days), while the shortest was in the eastern part (VR, 185 days). The LSF and FAF dates are characterized by large fluctuations from year to year. The standard deviation of the averaged LSF during the investigated period ranges from 13 to 16 days, while the standard deviation of FAF is similar, between 12 and 15 days. Fluctuation of threshold dates of severe frosts occurrences was higher than the fluctuation of light and moderate frosts.

The long-term variability of the mean dates of light, moderate and severe spring and autumn frosts, as well as, that of the FFPs in rural stations is shown in Figure 5. It can be seen that all the LSF (light, moderate and severe) in rural stations had tendencies to occur earlier, while all the FAF had tendencies to occur later. The linear trends in LSF and FAF are reflected in the lengthening of FFP. The last light spring frosts show statistically significant tendency to occur earlier (on average –1.64 days per decade), and as a consequence, the lengthening of the period without light frosts was also statistically significant (3.08 days per decade). Approximately uniform variations of the last moderate and last severe spring frosts are noticeable over the entire period with slight tendency to earlier occurrences in the last decade. On average, the last light spring frosts tend to occur earlier since mid 1990s, and are shifted from the first decade of April to the last decade of March. Moderate and severe autumn frosts had tendency to occur

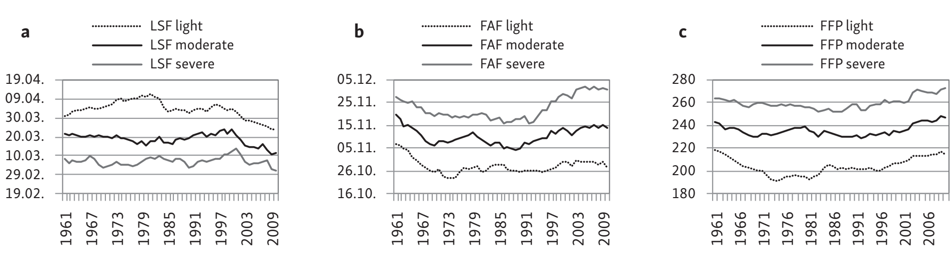

Fig. 5 – Interannual variations in the average (a) date of the last spring frost, (b) date of the first fall frost, and (c) length of the frost-free period in rural stations over the period 1961–2010, presented as 11-year centered moving average.

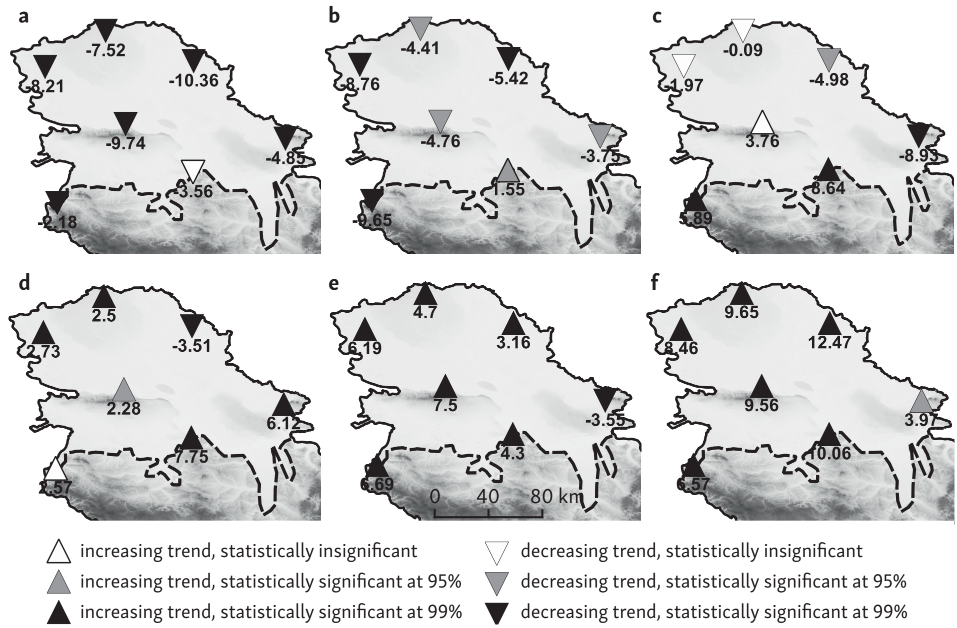

Fig. 6 – Spatial distribution of trends in LSF for light (a), moderate (b) and severe (c) frosts and FAF for light (d), moderate (e) and severe (f) frosts, for the period 1991–2010.

later from mid 1990s. The onset of severe autumn frosts was postponed most, from the second decade of November to the first decade of December. According to Figure 5c, the lengthening of the average period without light frost since the 1990s in rural area was primarily result of earlier ending of the spring frost. However, the lengthening of the average period without moderate and severe frost is primarily caused by the later starting of the autumn frosts. Compared to rural stations, at the urban station BG the last spring frosts on average appeared 17 days earlier, while first autumn frosts appeared 17 days later. The FFP analysis in urban station shows the lengthening of the average period without light frost from the beginning of the 2000s. The length of the period without the frosts of higher intensity in urban station was not significantly altered, which is caused by unexpected and statistically significant later occurrence of severe and moderate spring frosts in the last 20 years.

To reveal recent changes in the last occurrence of all spring frosts and the onset of autumn frosts (light, moderate and severe), Figure 6 shows the spatial distribution of linear trends in the period 1991–2010. The last light and the last moderate spring frosts had significant trends to occur earlier in the last two decades at the majority of stations. Severe spring frosts had significant trends to occur earlier only in the east of region, while at urban station BG there was strong significant tendency to occur later. At most of the stations autumn frosts tend to occur significantly later in the last two decades. The strongest shift forward is recorded in severe frosts (up to 12.47 days per decade). However, light autumn frosts in KI and moderate autumn frosts in VR had significant trends to occur later with about 3.5 days per decade.

3.3. Frost risk

Table 4 shows the dates of occurrence of the last spring frost events for the stations in the Pannonian Basin in Serbia. The dates for probabilities 5%, 10%, 20% and 50% present the risks that the last spring frost occurs on the date shown in Table 4 or later. According to the results of Table 3, there is a 50% chance that the last light spring frost in NS occurs on 5 April or later. As we are going toward the second half of spring, the risk that the last light spring frost is occurring on or after a given date becomes lower. According to the same table, there is a 10% chance that the last spring frost in NS occurs on25 April or later, and only 5% chance that it occurs on 30 April or later. On average, the last light spring frost occurs before 15 April in 4 years out of 5, and in 1 year out of 5 on 15 April or later.

The first autumn frost dates, for the stations in the Pannonian Basin in Serbia are presented in Table 5. The probabilities 5%, 10%, 20% and 50% present the risks that the first autumn frost occurs on the date shown in Table 5 or earlier. Table 5 shows that the chance of the occurrence of the first autumn frost increases as autumn progresses. As an example, according to Table 5 there is a 5% chance (1 in 20 years) that the first light autumn frost in SU occurs on 10 October or earlier and 20% chance (1 in 5 years) that it occurs on 18 October or earlier. The first severe and moderate autumn frosts occur closer to winter, after the light frosts.

4. Summary and conclusions

Many studies confirm the climate warming during the last decades in Serbia. Contrary to the global trend, the positive trend in daily maximum temperature is larger than trend in daily minimum temperature which indicates that in Serbia the potential frost risk decreases slower compared to other regions. In the main agricultural area in Serbia, Pannonian Basin, daily T_{min} increases slowest. Therefore, changes in the number of spring and autumn frosts, earlier occurrence of the last spring frosts and later onset of first autumn frosts, as well as longer frost-free periods are presumed and the true changes are analyzed in this study.

Over the period 1961–2010, the number of spring and autumn frost days in rural stations generally had tendency to decrease. Only the number of light and severe

Table 4 – The dates of the last spring frost for probabilities 5%, 10%, 20 and 50% in the meteorological stations in the Pannonian Basin in Serbia, based on the observed data between 1961–2010

	Probability	SU	SO	KI	NS	VS	BG	LO
Light	5%	13 May	6 May	3 May	30 Apr	8 May	10 Apr	30 Apr
	10%	1 May	27 Apr	25 Apr	25 Apr	2 May	5 Apr	20 Apr
	20%	21 Apr	22 Apr	19 Apr	15 Apr	25 Apr	31 Mar	12 Apr
	50%	3 Apr	9 Apr	5 Apr	5 Apr	14 Apr	18 Mar	29 Mar
Moderate	5%	16 Apr	18 Apr	18 Apr	8 Apr	23 Apr	25 Mar	4 Apr
	10%	4 Apr	12 Apr	6 Apr	2 Apr	17 Apr	20 Mar	29 Mar
	20%	28 Mar	5 Apr	29 Mar	28 Mar	10 Apr	15 Mar	24 Mar
	50%	16 Mar	23 Mar	17 Mar	18 Mar	28 Mar	2 Mar	13 Mar
Severe	5%	2 Apr	2 Apr	5 Apr	6 Apr	16 Apr	21 Mar	25 Mar
	10%	21 Mar	30 Mar	27 Mar	28 Mar	9 Apr	16 Mar	21 Mar
	20%	14 Mar	22 Mar	25 Mar	19 Mar	2 Apr	11 Mar	14 Mar
	50%	2 Mar	10 Mar	10 Mar	7 Mar	20 Mar	27 Feb	29 Feb

Table 5 – The dates of the first autumn frost for probabilities 5%, 10%, 20% and 50% in the meteorological stations in the Pannonian Basin in Serbia, based on the observed data between 1961–2010

	Probability	SU	SO	KI	NS	VS	BG	LO
Light	5%	10 Oct	5 Oct	7 Oct	11 Oct	2 Oct	17 Oct	7 Oct
	10%	13 Oct	11 Oct	12 Oct	14 Oct	4 Oct	20 Oct	13 Oct
	20%	18 Oct	15 Oct	18 Oct	19 Oct	9 Oct	24 Oct	17 Oct
	50%	28 Oct	24 Oct	28 Oct	29 Oct	19 Oct	12 Nov	31 Oct
Moderate	5%	21 Oct	13 Oct	19 Oct	21 Oct	7 Oct	28 Oct	19 Oct
	10%	23 Oct	17 Oct	23 Oct	23 Oct	10 Oct	8 Nov	24 Oct
	20%	27 Oct	21 Oct	25 Oct	27 Oct	14 Oct	18 Nov	7 Nov
	50%	12 Nov	3 Nov	9 Nov	10 Nov	28 Oct	1 Dec	23 Nov
Severe	5%	25 Oct	24 Oct	25 Oct	23 Oct	12 Oct	4 Nov	4 Nov
	10%	1 Nov	27 Oct	31 Oct	31 Oct	18 Oct	19 Nov	9 Nov
	20%	9 Nov	3 Nov	9 Nov	12 Nov	25 Oct	26 Nov	18 Nov
	50%	24 Nov	20 Nov	25 Nov	28 Nov	10 Nov	10 Dec	30 Nov

spring frosts decreased significantly (–0.14 and –0.12 days per decade, respectively), while the decreasing trend in the number of autumn frosts was not statistically significant. However, in the last two decades all spring and autumn FD decreased at the majority of the stations, in most cases significantly. Considering the last spring frost dates and the first autumn frost dates, over the entire investigated period only the light spring frosts had statistically significant tendency to occur earlier (–1.64 days per decade), while all the first autumn frosts had tendencies to occur later. The last two decades were marked by significant shifts in all first autumn frost dates and last spring frost dates. In spring, the last light and the last moderate spring frosts had significantly trends to occur earlier at the majority of stations. Severe spring frosts had a significant tendency to occur earlier only in the east of the region, while at urban station (BG) and at station in the southwestern part of the region (LO) they had strong significant tendency to occur later. At the majority of the stations, the first autumn frosts occurred significantly later in the last two decades than in the earlier part of the study period.

Our analysis shows that the lengthening of the average period without light frost since the 1990s in rural area was primarily the result of the earlier ending of the spring frosts, while the lengthening of the average period without moderate and severe frost is caused by the later starting of the autumn frosts. The frost-free period analysis in urban station shows the lengthening of the average period without light frost from the beginning of the 2000s, while the length of the period without the frosts of higher intensity was not significantly altered.

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