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SPATIAL-TEMPORAL VARIABILITY OF AIR TEMPERATURES IN SERBIA IN THE PERIOD 1961–2010

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Abstract: The aim of this paper is to examine the spatial and temporal variability of the average monthly, seasonal and annual air temperatures in Serbia. Therefore, data from 64 climatologic stations were analyzed in the period from 1961 to 2010. Based on the data, on the position of the stations (their latitude, longitude, altitude), and the characteristics of the terrain in their vicinity (inclination and terrain exposure in a radius of 10 km around the station), a regression model was constructed based on which air temperatures are interpolated for the territory of Serbia. The root-mean-square error (RMSE) of the regression model ranged from 0.2 ºC in January, February and November to 1.1 ºC in August. Spatial distribution of air temperatures is shown (maps of mean monthly, mean seasonal and mean annual air temperatures are made), and the Sen's procedure was used to calculate trends of air temperatures (maps of average monthly, mean seasonal and mean annual trends of air temperatures). The Mann-Kendall test was used to test the significance of air temperature trends. Apart from the southeast, the whole territory of Serbia has practically experienced a statistically significant rise in the average annual air temperature, with the highest increase in the summer and winter months.

Keywords: air temperature, trend, Sen's slope estimation, Mann-Kendall test, Serbia

Introduction

Air temperature is one of the fundamental climatic elements largely determining the climatic type of a place or area (Ducić & Anđelković, 2004). Because of the impact it has on many spheres of human life, it is difficult to overestimate the importance of obtaining reliable information about the spatial and temporal variability of this climatic element. Since air temperature data (as well as other climate elements) exist most often for a limited number of stations, it is necessary to make some sort of interpolation in order to obtain a full spatial coverage. According to Luo, Taylor, and Parker (2008), the quality and reliability of the interpolated values, in addition to the nature of the interpolated

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climatic element (e.g. wind velocity has greater spatial variability than air temperature) are also affected by the accuracy of observations, the density and distribution of stations, and variability of the climatic factors in a certain area. Similarly, Li and Heap (2011), who analyzed 72 methods or submethods of interpolation, found that an increase in data variability fundamentally influences the accuracy of interpolation methods where the magnitude according to which the accuracy decreases depends on the method used.

For the area of Serbia, Milovanović, Ducić, Radovanović, and Milivojević (2017a) and Bajat et al. (2013) dealt with the problem of selecting the appropriate methods of interpolation and the accuracy of models based on which the interpolation of certain climatic elements was performed.

When it comes to the analysis of air temperature in Serbia, the paper written by Bajat, Blagojević, Kilibarda, Luković, and Tošić (2015) comprises a benchmark. The authors use the least squares method and examine in detail the spatial distribution of seasonal air temperature trends in the period 1961–2010 based on data from 64 stations. With respect to the fact that the data were processed from the same number of stations and for the same period, compared to Bajat et al. (2014), in our research, a multiple regression model was applied, a different way of calculating the slope of a trend line and testing the significance of the trend, and, in addition to the annual and seasonal air temperatures, the focus was also placed on the spatial distribution of monthly air temperatures and their trends. In this paper we aim at answering three research questions:

1. How to interpolate air temperature values on the basis of indirect spatial data such as altitude, latitude, longitude, and relief around meteorological stations?
2. How accurate are the interpolated spatial air temperature fields?
3. What is the temporal and spatial variability of air temperature in Serbia?

Study area

Serbia is located in the northern temperate climate zone at latitudes 41°46' to 46°11'. Due to this position, during the year it is under the influence of air masses of very different origin such as arctic, polar, and tropical (continental or maritime). Although relatively small in size (88,443 km^2), Serbia has a very dissected relief in which the flat and low terrain prevails in the north (Pannonian plain with its periphery) while the hilly and mountainous terrains are dominant in the central and southern part of the country (highest peak Djeravica of 2,656 m above sea level) around the valleys of the great rivers (Zapadna Morava, Južna Morava, Velika Morava, Timok) (Figure 1). In climatic terms, the Dinaric mountain range in the west and southwest of the country is very important, because it represents a natural barrier to the penetration of humid air masses from the west (Ducić & Radovanović, 2005). According to Milovanović et al. (2017a), Cfa, Cfb, Dfb, Dfc and Efc climate types are represented in Serbia according to the Koppen climate classification (Kotteki, Grieser, Beck, Rudolf, & Rubel, 2006) Except for the extreme south and southwest (Metohija and smaller parts of Kosovo) and smaller areas in the north-east of central Serbia, the continental pluviometric regime with the major part of precipitation falling during the summer season is present everywhere.

Data and methods used

In this study we analyze data on mean monthly, mean seasonal and mean annual air temperatures from 64 climate stations that are relatively evenly distributed throughout Serbia (Figure 1). A weaker coverage of stations is apparent in Kosovo and Metohija where there are data from only 5 stations. However, measurements have not been carried out since 1999 at these stations with the exception of the station at Prizren where weather was monitored between 2003 and 2006, and Dragaš where monitoring was continued until 2010. These data series were used to interpolate the missing data at other stations in this area. The interpolation of missing data was done using a procedure similar to Milovanović, Radovanović, Stanojević, Pecelj, and Nikolić, (2017b): If at any station A air temperature data for a particular month (Ta) in a given year were missing the average value of the data series for that month ($\overline{T}a$) was calculated. The mean value ($\overline{T}b$) for that month was calculated using the data collected at station B thereby serving as data source for the interpolation in the station A data. In this case air temperature data (Tb) is available for the month for which the same data are missing at station A. In the following step the difference of the mean values for this particular month at stations A and B was calculated: $\Delta T=\overline{T}b-\overline{T}a$. The air temperature at station A for a given month in a given year was calculated using the formula: $Ta = Tb-\Delta T$.

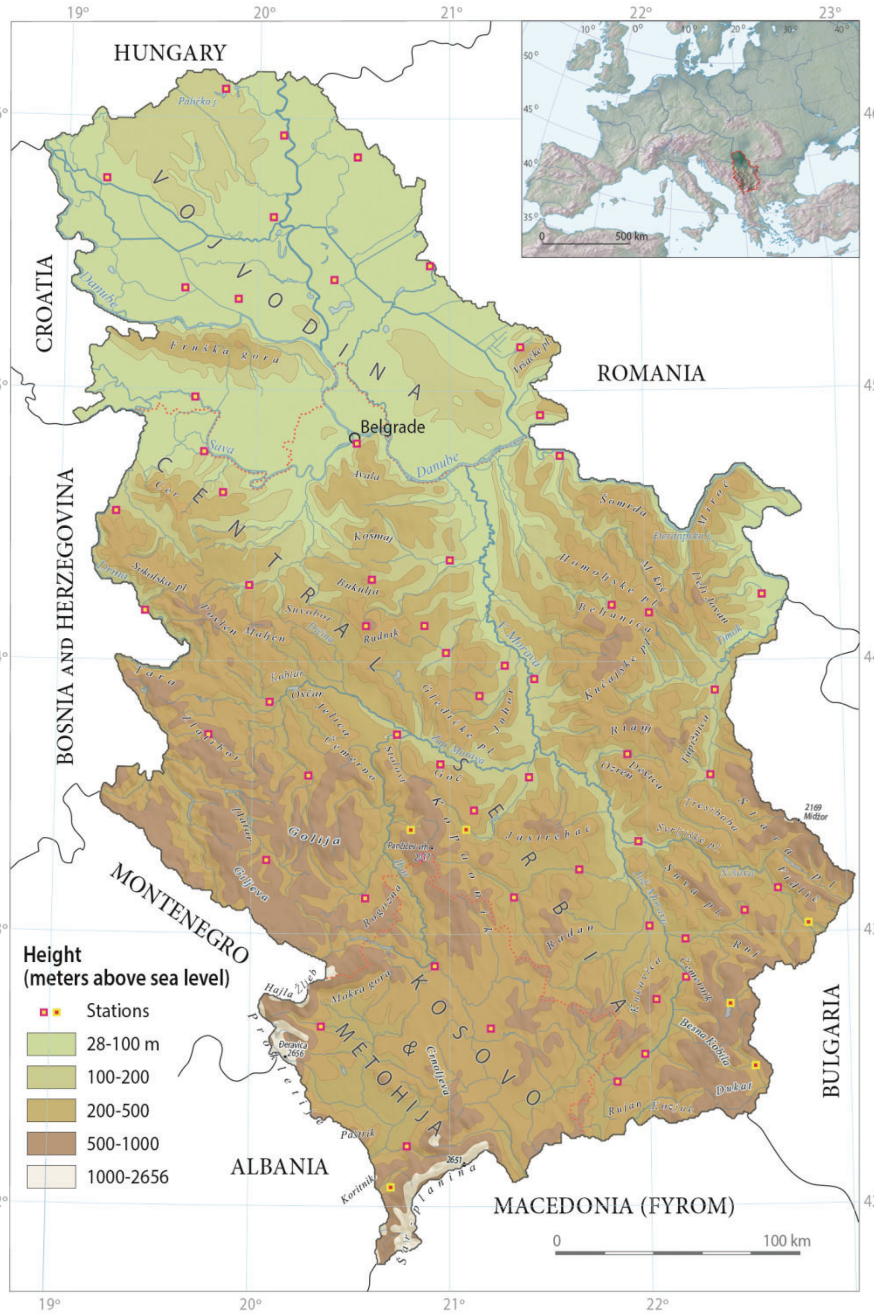

Figure 1. Distribution of stations from which the data were used (stations marked with yellow have no statistically significant trend of mean annual air temperatures)

Regarding the distribution by altitude most climate stations are located in the belt up to 500 m above sea level, 51 stations that represent approximately 61% of Serbia. There are 7 stations from 500 m to 1,000 m covering about 28% of Serbia. However, there are no stations in the belt 700–800 m above sea level and 900–1,000 m above sea level while there are 6 stations at altitudes above 1,000 m above sea level (about 11.2% of Serbia) (Table 1).

Table 1. Distribution of climate stations in Serbia by altitude[1]

Altitude range (m a.s.l.)	Number of stations	Surface area (km^2) (Ćalić et al. 2017)	Percentage of area of Serbia
28–100	14	20,898	23.6
101–200	12	11,592	13.1
201–300	11	8,181	9.2
301–400	7	6,839	7.7
401–500	7	6,660	7.5
501–600	4	6,747	7.6
601–700	1	5,791	6.5
701–800	/	4,744	5.4
801–900	2	3,874	4.4
901–1,000	/	3,171	3.6
1,001–1,100	3	2,620	3.0
1,101–2,656	3	7,328	8.2

In this study we follow the expectation that the use of a large number of predictors will result in more accurate information on the criterion variable, in our case on air temperature To obtain more information on altitude, slope and aspect, data of the SRTM (Shuttle Radar Topography Mission) digital elevation model (DEM) were used at a resolution of 30 x 30 m. Additionally, two extra spatial layers in the form of grids were formed for testing the impact of longitude and latitude on air temperature similar to the approach followed by Milovanović et al. (2017b).

In order to get information on the local factors (slope and aspect of the terrain around the station) circular "buffer" zones with a radius of 10 km around each climate station were selected. The mean values and standard deviations of the variables were calculated for each station's "buffer" from the DEM. This created a set of seven predictor variables (latitude, longitude, altitude of station, mean values and standard deviations of slope and aspect of the "buffer" zones around climate stations).

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1 For the purpose of this study, the surface area values are rounded. In the original text, the surface area values were rounded to two decimal places.

The variables were selected as predictors due to their explaining power for the spatial distribution of air temperature according to direct linear correlations. The combined influence of the predictors according to the best fitting statistical model was subtracted from the observations. Residuals were interpolated using simple kriging. Using the inverse of this procedure a raster of the values of air temperature at each grid point was created. In other words, by adding the interpolated residual at each grid point to the modelled influence of altitude and latitude, air temperature was obtained for any grid point of the study area.

The methodology for calculating Mann-Kendall statistics based on which the decision is made to accept or reject the zero hypothesis on the statistical significance of the trend, as well as the Sen's slope estimation of trend line are detailed in Salmi, Määttä, Anttila, Airola, and Amnell (2002), Sutapa and Galib (2016), Milovanović et al. (2017a). For interpolation of Sen's slope estimation of trends the method of radial basis function was used (Di Piazza, Lo Conti, Viola, Eccel, & Noto, 2015) whereby their possible dependence on the characteristics of the terrain (position and altitude of the stations, slope and orientation of the terrain in their surrounding) was not investigated. We use the same interpolation procedure both for temperature itself and temperature trends.

All data processing and statistical computing concerning multiple linear regression and trend analysis have been done using R (R Development Core Team 2008). For interpolation, spatial analysis and mapping ArcGIS by Esri (Esri 2011) and open-source QGIS (QGIS Development Team 2015) were used.

Results and Discussion

Based on the set of the seven predictor variables the regression model explaining the largest proportion of the air temperature variances was chosen. It turned out that in all cases, at the level of monthly, seasonal, and annual air temperature the statistically most significant model is the one using only the predictor altitude and latitude. The value of the coefficient of determination in the regression models from these two predictors ranged from $R^2 = 0.75$ in January to $R^2 = 0.93$ in May. At the annual level, the determination coefficient is $R^2 = 0.89$. Observed by seasons, the coefficient of determination is highest in spring and lowest in the winter (Table 2). The effect of other predictors was not statistically significant or only marginally contributed to the explained variance of air temperature (< 1%). In the next step the set of data was divided into a subset of test data (10% of all stations, 6 randomly selected stations) and a subset for modelling (the remaining 90%, 58 stations).

Table 2. Parameters of regression model for air temperatures

Month or season	Significance of the predictor (t value / p level)		Customized determination coefficient (R^2)
	Altitude	Latitude	
January	–13.2 / 0.01	–4. 6 / 0.01	0.75
February	–18.6 / 0.01	–6.4 / 0.01	0.86
March	–22.1 / 0.01	–6.4 / 0.01	0.90
April	–27.1 / 0.01	–5.2 / 0.01	0.93
May	–25.8 / 0.01	–2.7 / 0.01	0.93
June	–23.9 / 0.02	–3.4 / 0.01	0.92
July	–19.6 / 0.01	–3.5 / 0.01	0.88
August	–18.0 / 0.01	–3.9 / 0.01	0.86
September	–17.7 / 0.01	–4.0 / 0.01	0.85
October	–15.5 / 0.01	–3.8 / 0.01	0.81
November	–14.8 / 0.01	–4.3 / 0.01	0.80
December	–14.0 / 0.01	–4.4 / 0.01	0.77
Spring	–26.4 / 0.01	–5.3 / 0.01	0.93
Summer	–20.9 / 0.01	–4.0 / 0.01	0.89
Autumn	–17.2 / 0.01	–4.6 / 0.01	0.84
Winter	–16.3 / 0.01	–5.8 / 0.01	0.82
Annually	–20.8 / 0.01	–4.8 / 0.01	0.89

Willmott and Matsuura (2005) state that in climate studies as an estimate of model performance three types of errors are used which are defined as differences between predicted and observed values of specific climatic element. These are: mean absolute error (MAE), root-mean-square error (RMSE) and mean bias error (MBE).

However, there are disagreements in the literature which of these measures is more appropriate for evaluating a model. Willmott and Matsuura (2005) state that with respect to the calculation method RMSE shows a great dependence on variance of errors and becomes much larger than MAE as the variability of the errors and the number of errors observed increase. On the other hand, Chai and Draxler (2014) state that RMSE is suitable for assessing the model when its errors have normal distribution which usually is the case for air temperature. In this paper the accuracy of the applied approach is checked by comparing the values of air temperatures from the stations from the evaluation subset and the values of the pixels in which the stations are located by calculating both MAE and RMSE. The errors are lowest during January and February and highest in August (Table 3). The difference between the MAE and RMSE does not exceed 0.3 °C in any month or season which indicates that the model is suitable to reproduce air temperatures at high spatial resolution. Further, there is no large temporal variability regarding the errors of the model.

Table 3. Monthly, seasonal and annual values of the root-mean-square error and the mean absolute error of the applied model

	RMSE (°C)	MAE (°C)
January	0.2	0.2
February	0.2	0.2
March	0.5	0.4
April	0.5	0.4
May	0.6	0.4
June	0.4	0.3
July	0.6	0.4
August	1.1	0.8
September	0.8	0.5
October	0.6	0.5
November	0.2	0.1
December	0.4	0.3
Annual	1.0	0.7
Fall	0.2	0.2
Spring	0.4	0.2
Summer	0.7	0.6
Winter	0.6	0.5

Spatial distribution of air temperatures in Serbia

The total of 34 maps (17 maps of the average monthly, average seasonal and mean annual air temperatures and 17 maps of the average monthly, mean seasonal and mean annual trends of air temperatures) were formed by the described methodology. Given that it is not possible to show and describe here all obtained results, only the characteristics of mean annual temperatures and air temperatures during the coldest (January) and the hottest month (July) will be shown. All spatial data produced in this study can be downloaded as geo-coded GIS raster data from a website hosted at Humboldt University, Berlin (https://www.geographie.hu-berlin.de/en/professorships/climate_geography/climate _serbia/).

Average annual air temperatures above 11 °C characterize Vojvodina (except Fruška gora, Vršačke planine and the north of Bačka), Posavina, and the lower terrains of north-western Serbia, part of Metohija, Veliko Pomoravlje, Negotinska krajina, and Ključ, mountainous terrains in Šumadija and Zapadno Pomoravlje and Južno Pomoravlje (Figure 2). Exceptions are the stations of Prizren (located at 401 m above sea level — mean annual air temperature 12.1) and Belgrade (Figure 2) where the mean annual temperature is 12.3 °C and the effect of the urban heat island is present (Milovanović et al., 2017b; Anđelković, 2005). The mean annual temperature below 3 °C is represented only in the highest parts of the mountains of south-western and south-eastern Serbia (terrains above 1,800 m above sea level).

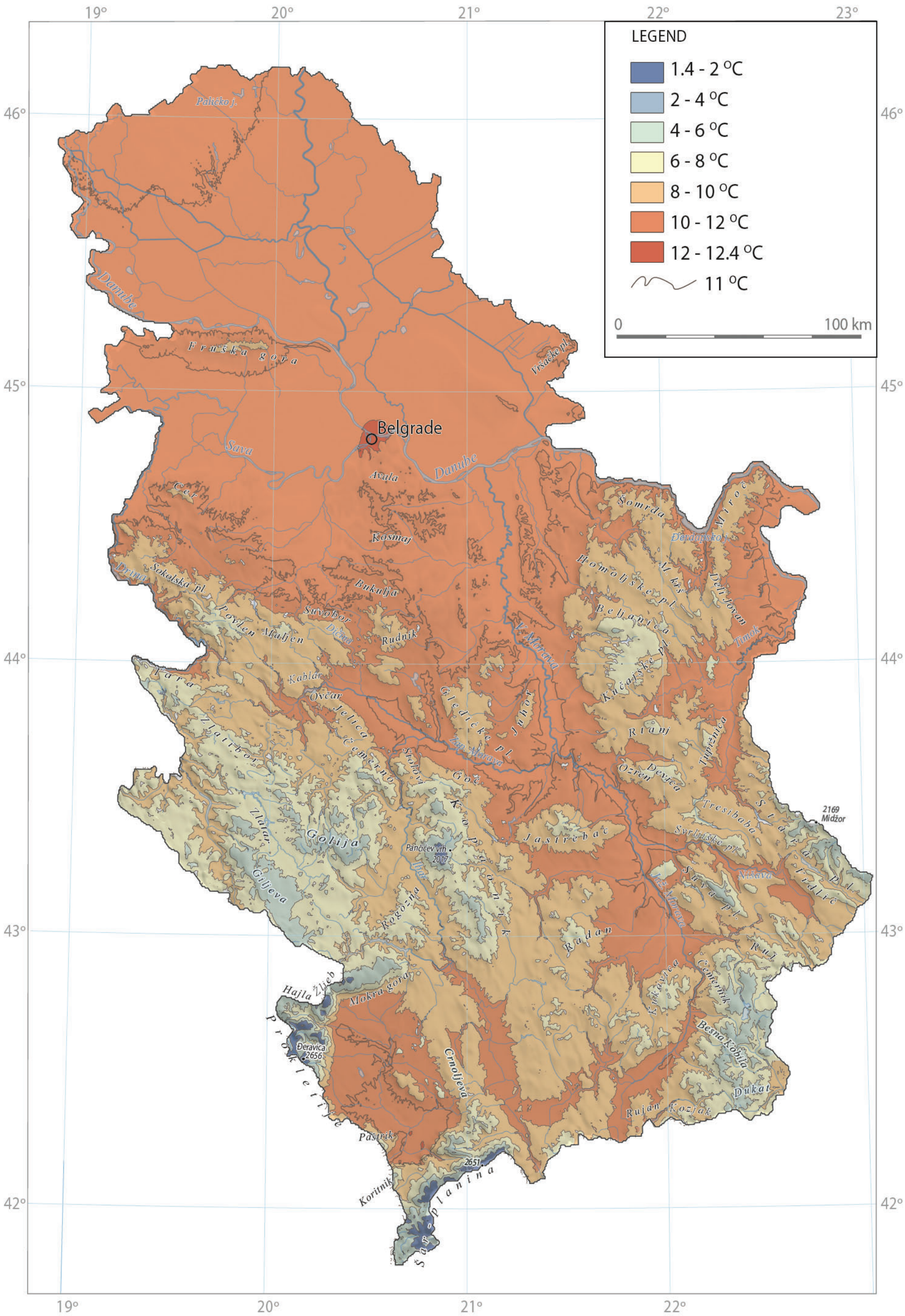

Figure 2. Average annual air temperatures in Serbia in the period 1961–2010

There are different opinions in the literature on the height of the 10° C-isotherm in Serbia. Bajat et al. (2014), analyzing data on the mean annual air temperature in the period 1961–2010, state that terrains with this or lower average annual temperature generally extend above 600 m above sea level. However, for some parts of Serbia they can be found at much lower altitudes. Similarly, Ducić and Radovanović (2005), based on data for the period 1961–1990, indicate that the limit of this isotherm would be at 500–550 m above sea level. An analysis of the digital height model for an isotherm with this value indicates that the highest pixel frequency is in the class of 450–500 m above sea level (Figure 3). The average altitude for this mean temperature is 464 m. The standard deviation is 120 meters which means that in about 95% of cases, the mean annual air temperature of 10 °C would be at altitudes between 220 and 700 m.

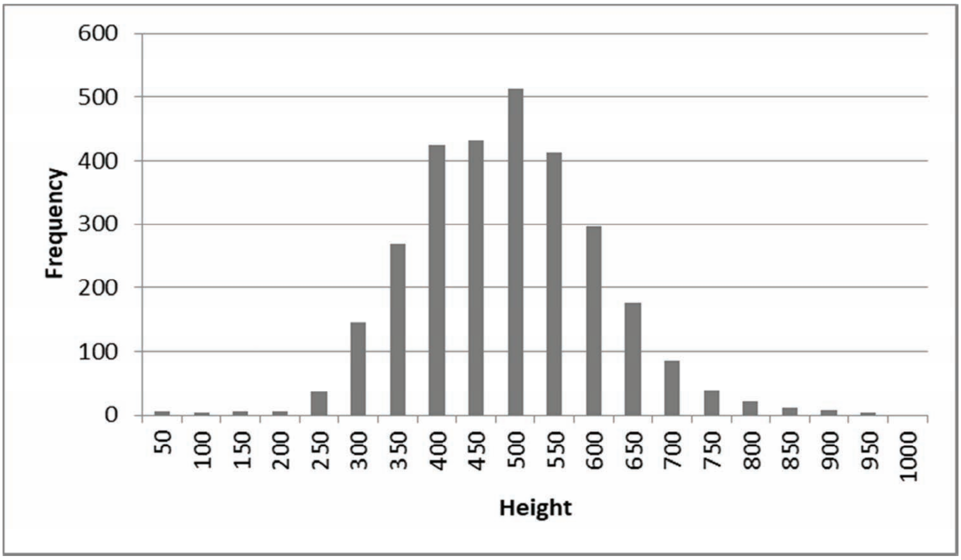

Figure 3. Distribution of altitudes of the 10 °C isotherm

The lowest average January air temperatures below –4 °C are represented in the highest parts of Prokletije, Šar planina, Kopaonik, Stara planina and the mountains of south-western and south-eastern Serbia (Figure 4). Such low January temperatures are also present on the Pešterska visoravan which although at a relatively small altitude of 1,150 m is one of the most prominent cold poles in Serbia. The average January temperatures close to 0 °C are represented in the southern parts of Srem and Banat and parts of Šumadija, Južno Pomoravlje, Zapadno Pomoravlje and Veliko Pomoravlje. Positive mean January air temperatures characterize Metohija (Prizren 0.5 °C) and Belgrade (0.9 °C).

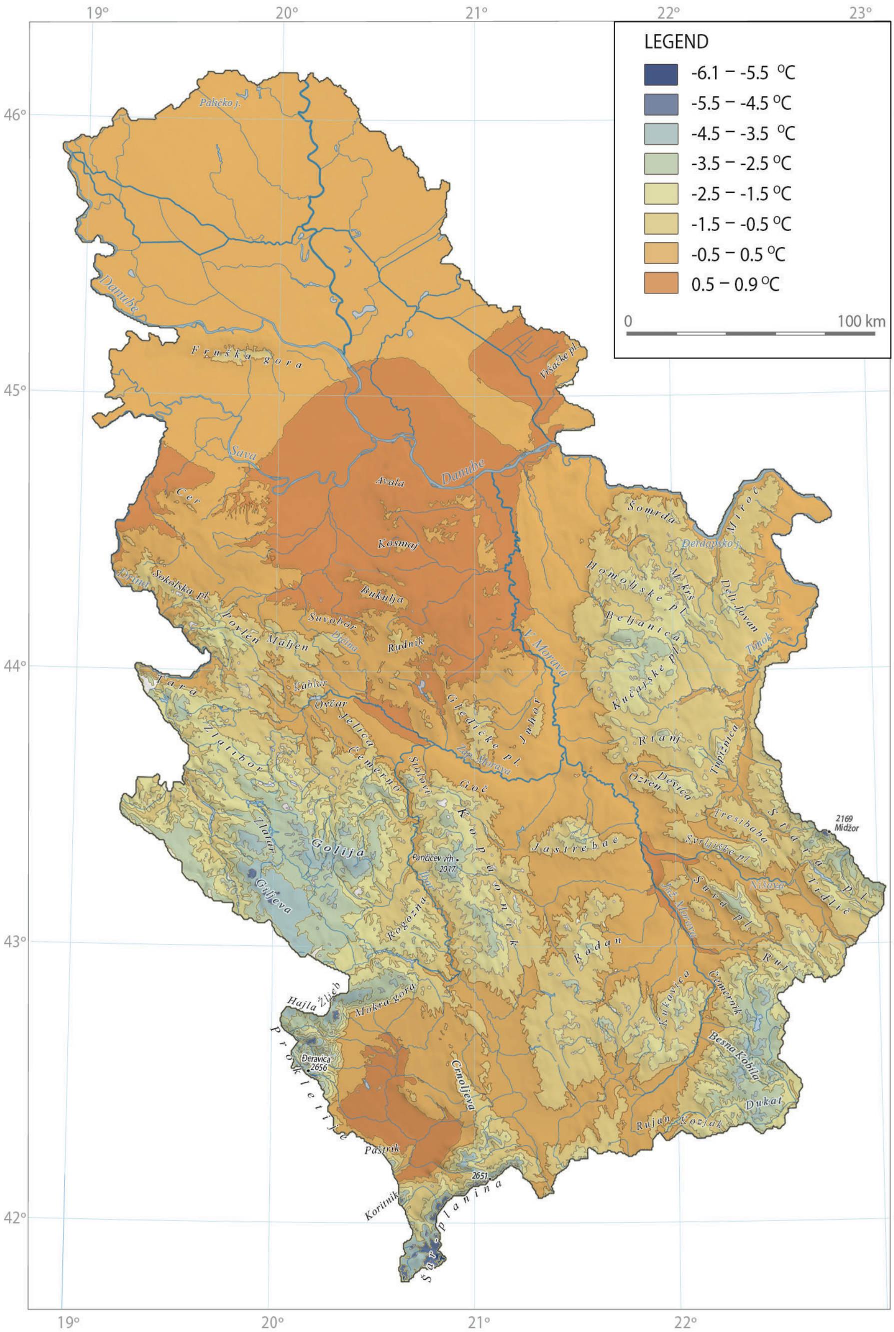

Figure 4. Average January air temperatures in Serbia in the period 1961–2010

The highest July air temperatures are in Negotinska krajina, Belgrade and part of Metohija where they exceed 22 °C (Figure 5). Values close to this characterize parts of Veliko Pomoravlje and Južno Pomoravlje. Mean July air temperatures below 10 °C are represented only on the highest mountain terrains (Figure 5).

According to the European Environment Agency (EEA) report (2017), the area of the whole of Europe has recorded an average annual air temperature increase in the period 1960–2015. The trends range from 0.05 °C/decade in the southern part of Europe (in Greece and parts of Italy) to 0.4 °C/decade in the European part of Russia. An increase of 0.15 to 0.25 °C/decade was calculated for Serbia and the surrounding countries. In northern Montenegro (southwest of Serbia), the increase in air temperature in the period 1951–2008 was 0.12 to 0.15 °C/decade (Burić, Ducić, & Luković, 2011). In eastern Bosnia and in Croatia, to the west of Serbia, the increase was around 0.33 °C/decade (Trbić, Popov, & Gnjato, 2017; Rabi, Nyarko, & Šperac, 2015). A similar amount of changes in mean annual temperatures is found in Hungary (Klapwijk, Csoka, Hirka, & Bjorkman, 2013) and Romania (Marin et al., 2014). These changes are in the same range as the trends found in this study.

In the period 1961–2010 practically the whole territory of Serbia has recorded a statistically significant increase (at a confidence level of 95%) of the average annual air temperatures. The exception is the south-southeast of the country and the area around the three-border with Macedonia and Bulgaria where there was a slight cooling in the observed period. The largest increase was recorded in the north of Vojvodina, in the northwest and southwest of the country (the area between Pešterska visoravan, Kopaonik and the northern part of Kosovo and Metohija) and Negotinska krajina, which exceeds 0.04 °C/year. In the rest of Serbia, the mean annual average air temperature increase falls in the range of 0.01–0.03 °C/year (Figure 6).

An upward trend in air temperature is present throughout Serbia during January. The increase is most prominent west of Kopaonik and in Kosovo and Metohija, exceeding 0.05 °C/year and shows statistical significance. However, it must be kept in mind that data after 1999 in these areas only rely on single stations and the interpolation procedures as described above. In the rest of Serbia, the increase in the mean January air temperatures ranges from 0.03 to 0.05 °C/year (Figure 7).

The largest and statistically significant increase in mean July air temperatures of over 0.05 °C/year was calculated for northern Vojvodina, western Serbia, then Kopaonik and the Timok valley while the smallest increase is in southeast Serbia (Figure 8).

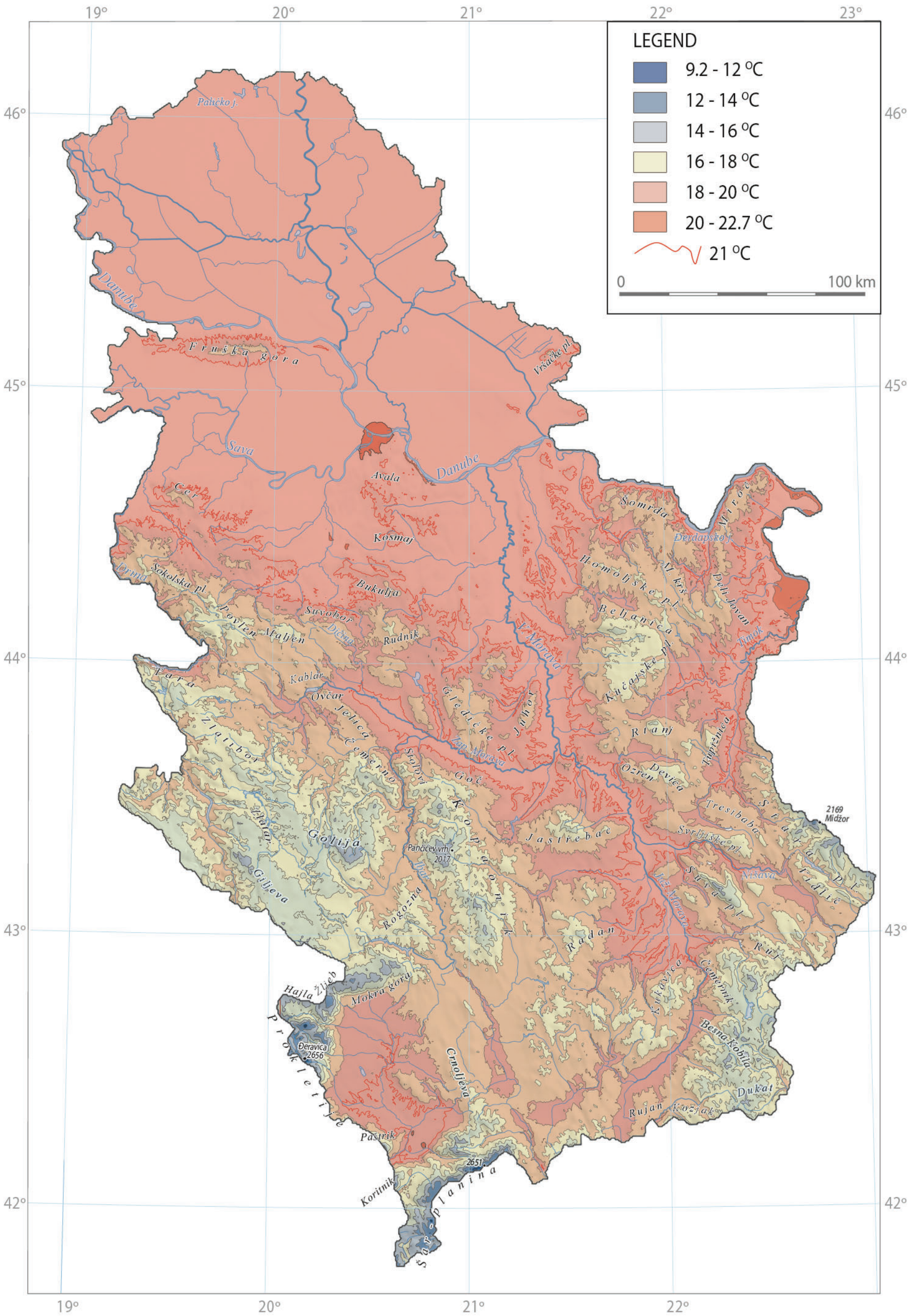

Fig. 5. Average July air temperatures in Serbia in the period 1961–2010

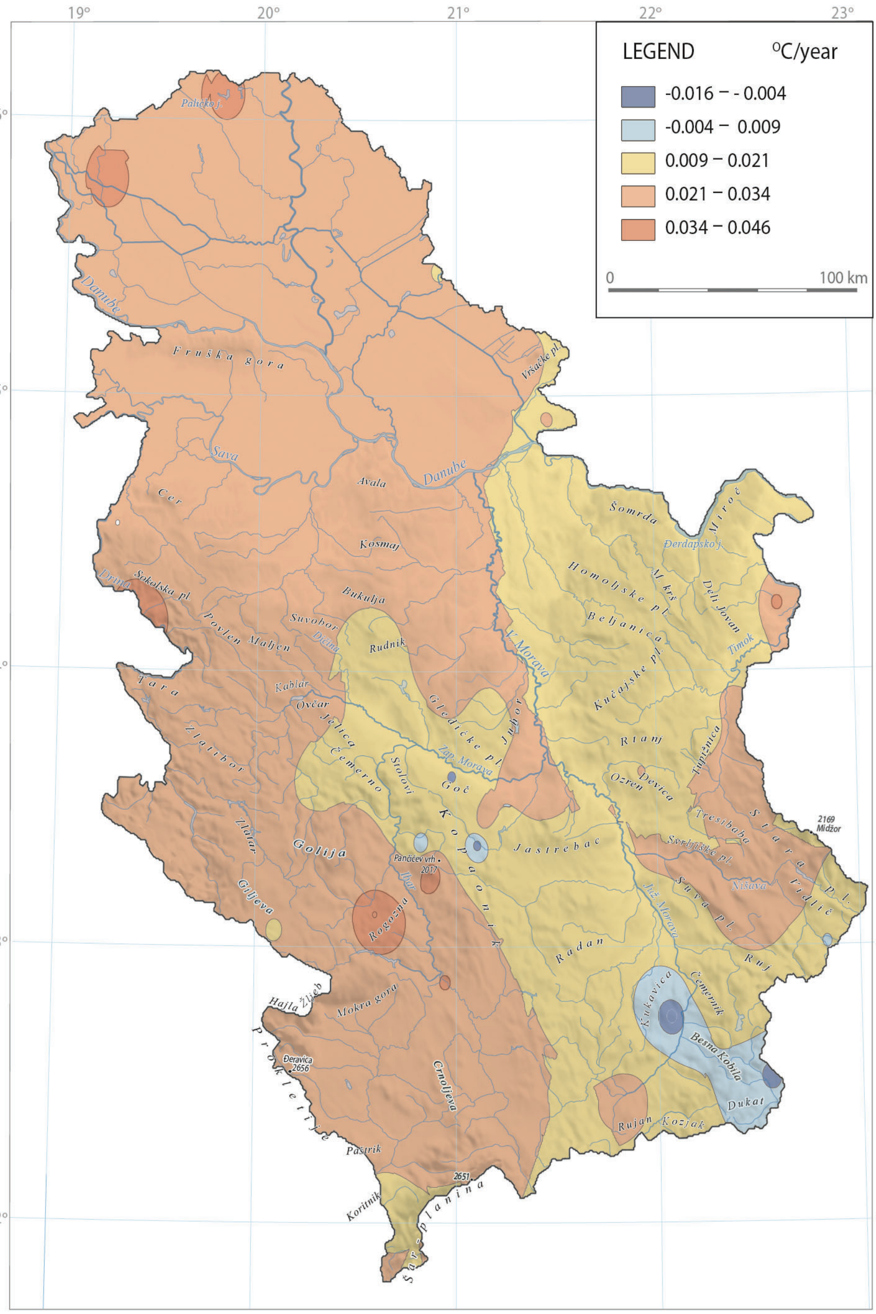

Figure 6. Trend of average annual air temperature in Serbia in the period 1961–2010

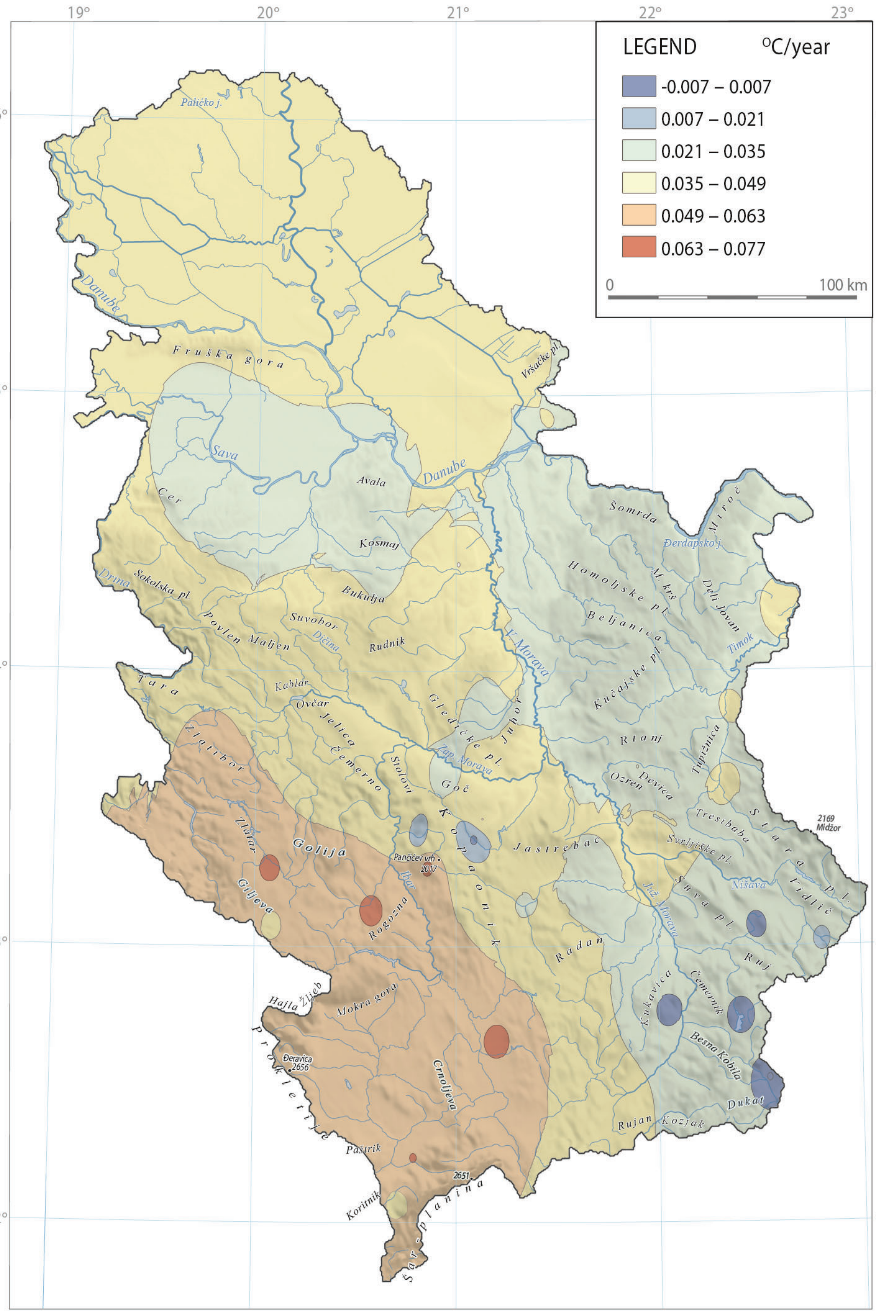

Figure 7. Trend of average January air temperature in Serbia in the period 1961–2010

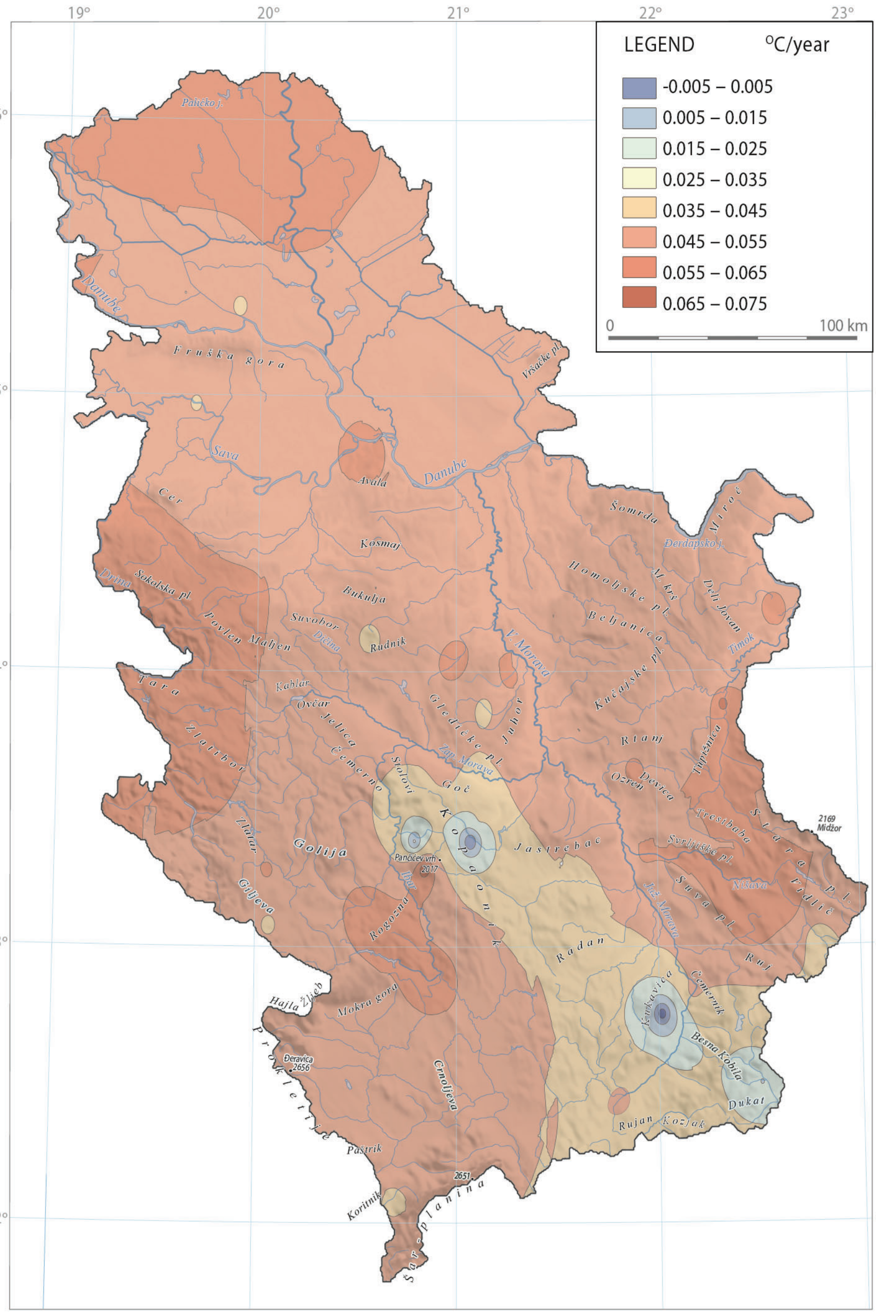

Figure 8. Trend of average July air temperature in Serbia in the period 1961–2010

Conclusion

The basic conclusions of this paper are related to the calculation methodology and spatial-temporal representation of air temperature distribution in Serbia It has been shown that the regression model in which altitude and latitude are used as predictors provides good estimates of air temperature with an acceptable RMSE. Depending on the month, they vary from 0.2 °C to 1.1 °C and MAE ranges from 0.1 °C to 0.8 °C. It has further been shown that the mean annual air temperature in Serbia is below 3 °C on terrains above 1,800 m above sea level, and up to over 12 °C in the part of Metohija and in Belgrade. Except for the extreme southeast of the country where a slight downward trend is present, a statistically significant increase in mean annual air temperature has occurred in practically all of Serbia. The calculated values of air temperature trends in Serbia are in line with those in surrounding countries.

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