GLOBAL WARMING IMPACT ON CLIMATE CHANGE IN SERBIA FOR THE PERIOD 1961-2100

by

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Serbia is situated at Balkan Peninsula, and currently majority of the territory is under warm temperate – fully humid climate type with warm summers (Cfb type, according to Koppen-Geiger Climate Classification). Observed changes in climate conditions since 1961 until present time show significant increase in temperature change and change in precipitation patterns. Disturbances in heat conditions, which are recorded to affect human health, agricultural production and forest ecosystem, are priority in climate change analysis and application in adaptation planning. Future change analysis show accelerated increase of temperature by the end of the 21st century, which proves the needs for immediate measures for mitigation of negative impacts. Temperature increase averaged over the territory of Serbia is 1.2 °C for the period 1996-2015 with respect to the period 1961-1980, with highest increase of maximum daily temperature during the summer season, 2.2 °C. Using high resolution multi-model ensemble approach for analysis of the future changes with respect to the base period 1986-2005, in compliance with Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5), it is estimated that temperature may increase by 1.9 °C according to Representative Concentration Pathway 4.5 (RCP4.5) scenario and by 4.4 °C according to RCP8.5 by the end of the century. Spatial distribution of temperature increase, intensification of high precipitation events and decrease of summer precipitation, show intrusion of subtropical climate over the Serbia and increase of high temperature and high precipitation risks. Results presented in this paper, using high-resolution multi-model ensemble approach, provide climate change information for short term to long term planning in different sectors of economy and preservation of human health and environment.

Key words: *climate change, IPCC, Serbia, temperature, precipitation*

Introduction

Accelerated global warming induced increased climate change signals in all parts of the Earth, with variety of recorded weather extremes as well as signals of change in slowly evolving systems [1]. According to latest National Oceanic and Atmospheric Administration

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(NOAA, USA, https://www.ncdc.noaa.gov/cag/global/time-series) analysis of global temperature anomaly for the last decade (2008-2017), with respect to the 20th century average, is 0.7 °C. Because of the different methodologies applied in the analysis of the averaged global surface temperature change over land and ocean, in order to have higher confidence in obtained results, it is desirable to have multi data-sets comparison. Several different observational data-sets (Hadley Centre of the UK Met Office and Climatic Research Unit version 4 data set – HadCRUT4, European Centre for Medium-Range Weather Forecasts Re-Analysis data set – ERAInterim; Goddard Institute for Space Studies Surface Temperature Analysis data set – GISSTEMP and NOAA data set) show that increase of global temperature during the 2007-2016 is 0.87-0.92 °C compared to the preindustrial period climate [2]. Warmest year on record is 2016, with anomaly 1.1 °C. More pronounced surface temperature warming is detected over land, and thereby the heating over the northern hemisphere is higher than over southern hemisphere. Average temperature anomaly over Europe for the last decade is about 1.6 °C higher than during the pre-industrial period. Temperature extremes, which indicate severe warming, especially during the summer months, are one of the most pronounced signals of global warming impact over this region [2-4]. Future increase of global temperature is estimated most likely to be 1.4 °C according to RCP4.5 and 1.8 °C according to RCP8.5 scenario for the period 2046-2065 with respect to the 1986-2005, and for the period 2081-2100 is estimated to be 2.0 °C and 4.4 °C according to same scenarios [1].

Serbia, which is in south-east part of the Europe at Balkan Peninsula, is experiencing warming trend [5] with accelerated temperature increase, and evident signal in trend of increase since 1980-ties [6]. Negative impacts of temperature increase, especially in combination with precipitation inter-annual re-distribution toward extended drought periods and more extreme precipitation events, are recorded as increase in frequency and intensity of heat waves [7], floods, forest fires, and disturbance in food production and general ecosystem health, which is also predicted to continue, accelerate and intensify in the future [8].

Since Republic of Serbia has signed and ratified Paris agreement, and thereby has responsibility to report on climate change impacts, mitigation and adaptation planning and implementation, and on success of undertaken measures for reducing negative impacts, it is of high importance to have climate change analysis with high confidence in information derived from observations and future projections. Complexity of terrain and high dependence of citizens safety and life quality, and economical sustainability on weather conditions justify the need for high resolution multi-model approach in analysis presented in this paper, because small scale features of climate impacts are significant on national level. Here are presented results obtained for change of temperature and precipitation and example of future change for several indices, which reflect significant risks over the territory of Serbia. Observed temperature change analysis is done using E-OBS gridded daily data set, for the period 1961-2015 [9]. For gridding of daily temperature and precipitation over Serbia, 28 stations were used in E-OBS data set. Independent verification of E-OBS data, using 46 stations over Serbia showed that correlation coefficient for daily and monthly temperature between E-OBS and observations on meteorological stations are 0.99 and 1, respectively, and for precipitation, correlation coefficients for daily and monthly values are 0.85 and 0.98, respectively, [10]. Future changes with impact analysis are estimated for the period 2016-2100 with respect to reference period 1986-2005, using EURO-CORDEX datasets for nine different models [11, 12] and two Representative Concentration Pathway (RCP) scenarios of GHG emissions: RCP4.5 – stabilization scenario, with GHG emissions peak around 2040 and decline afterwards [13] and RCP8.5 – constant increase scenario [14]. This selection of methodology in future change analysis is in compliance with IPCC AR5, and enables comparison of results with other regions, which contribute in assessing cross-border priorities and motivate international collaboration in combating negative impacts of rapid changing climate.

Presented study on future climate change is continuation of different studies performed for Serbia, but common for all is the use of the regional models data, *i. e.* dynamical downscaling approach. Some of the initial studies are done using coupled atmospheric–ocean model Eta Belgrade University – Princeton Ocean Model (EBU-POM) with resolution 0.25° of atmospheric part of the model, according to A1B and A2 Special Report on Emissions Scenarios (SRES), [15, 16]. Later, these projections are bias corrected, using quantile mapping approach, and applied for impact assessments [8, 17], and compared with other regional models results obtained from ENSEMBLES project [8] in order to introduce future projections uncertainty in assessment of climate change and its impact in Serbia. After the release of IPCC AR5 with new scenarios on GHG emissions [1], climate change studies in Serbia are updated with high resolution non-hydrostatic multiscale model on B-grid (NMMB) on resolution 0.06°, according to RCP8.5 scenario [18], which is also bias corrected [19] and used in some impact studies giving much more detail spatial assessment of climate change [20, 21]. Finally, this paper represents both, high-resolution and multi-model ensemble approach, in climate change study according to the latest scenarios on GHG emissions, RCP 4.5 and RCP8.5, in order to comprehend uncertainty of future projections and investigate spread of future climate characteristics and its impacts in relation to future human behavior in GHG emissions.

Observed and projected climate change

Study area

Serbia is located on Balkan Peninsula between latitudes 41°-47°N and longitudes 18°-23°E. The northern, low land with flat terrain, part of the country belongs to Pannonian basin. Central and southern parts, which are separated from northern with Sava and Danube rivers, have hilly and mountain configuration intersected with local rivers basins, forming relatively small scale terrain features and rich forest taxa distribution. This shapes food, water and hydropower production, defining local and global agricultural economy, which is highly dependable on weather conditions. Since country's economy and therefore citizens safety issues are affected, Serbia needs high resolution climate change analysis [19-22]. Serbian territory is under warm temperate – fully humid climate type with warm summers, Cfb type acoording to Koppen-Geiger Climate Classification [23], with precipitation maximum during the late spring and early summer, *e. g.* during the June. Figure 1 shows topography of Serbia at resolution that reflects real values, fig. 1(a), and at resolution of data used for the analysis in following text, fig. 1(b).

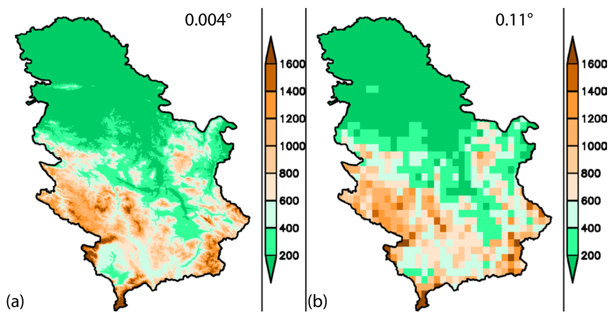

Figure 1. Altitude of the terrain in Serbia at resolution 0.004° (a) and 0.11° (b). Note: maps in this figure and other figures with presented territory of Serbia are displayed using grid analysis and display system
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Observed temperature and precipitation change

Observed temperature and precipitation change analysis is done using E-OBS daily temperature data for

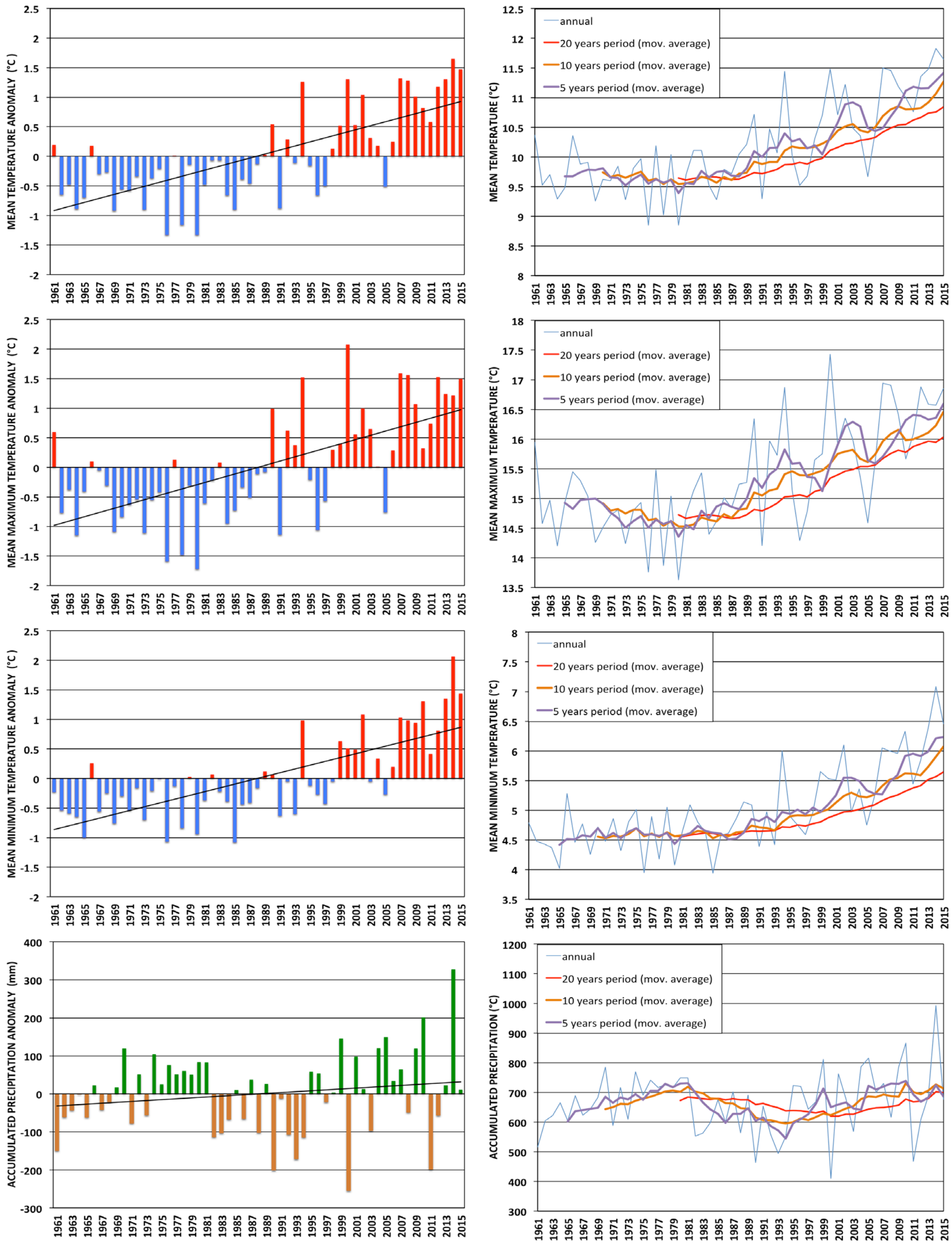

Figure 2. Anomaly of mean annual values of mean, maximum and minimum temperature, and of annual accumulated precipitation with respect to the mean values for the period 1961-2015 (left panels), and annual values with moving average values for 5, 10, and 20 years period assigned to the last year of the period, for the same climatological parameters (right panels); values are averaged for the territory of Serbia (*for color image see journal web site*)

the period 1961-2015, originally available on regular latitudes-longitudes grid with resolution 0.25°. In the analysis presented here, daily data are re-gridded on 0.11° resolution, to match resolution and grid configuration of the future climate projections. Interpolation of daily data is done using method of successive corrections [24], which is usual in numerical weather forecast for creating initial fields for forecast runs. This method is used for interpolation of daily data used for climate analysis in viticulture zoning of Serbia [25].

Figure 2 shows anomalies with respect to the mean values for the whole period 1961-2015 (left panels) and moving averages (right panels) of annual values for temperature (mean, mean maximum, and mean minimum) and for annual accumulated precipitation, averaged for the territory of Serbia. In Anomalies of temperature and precipitation for two selected periods 1986-2005 (the reference period for future climate change analysis) and 1996-2015 (as present climate period), with respect to the climatological period 1961-1980 are presented in tab. 1. The main conclusions derived from presented results are that temperature is increasing with accelerated rate, with more pronounced increase of maximum temperatures, especially during the summer. According to the used data the hottest year for the territory of Serbia is 2014, and from 10 hottest years, 9 happened since year 2000. Highest average maximum temperature over Serbia was in 2000, and minimum in 2014, which had hottest winter months. Hottest summer was during 2012. Since the end of the 1980's variability in mean annual temperature increased and is much more pronounced in mean annual maximum temperature than in mean annual minimum temperature. Mean annual temperature for the period 1996-2015 increased by 1.2 °C with respect to the 1961-1980. Highest increase, of 1.8 °C, is recorded for the summer season. Mean maximum temperature increased by 1.3 °C, and during the summer by 2.2 °C. Mean minimum temperature increased by 1.1 °C, and in summer by 1.5 °C. Season with second highest increase of temperatures is winter.

Annual precipitation averaged over Serbia shows more complex variability during the period 1961-2015. During the 1980's and first half of 1990's precipitation over Serbia was decreasing, and started increasing from mid 1990's, but with higher variability in values and intercepted with significantly dry years. Highest annual precipitation averaged over Serbia is

Table 1. Annual (ANN) and seasonal December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), September-October-November (SON) values for area averaged mean temperature (T_{mean}), mean maximum (T_{max}) and minimum (T_{min}) temperature, and mean accumulated precipitation (RR) for the period 1961-1980 and difference for these parameters (ΔT_{mean}, ΔT_{max}, ΔT_{min}, ΔRR) for the periods 1986-2005 and 1996-2015 with respect to the 1961-1980

Parameter	Period	ANN	DJF	MAM	JJA	SON
T_{mean} [°C]	1961-1980	9.6	–0.4	9.7	18.5	10.6
ΔT_{mean} [°C]	1986-2005	0.7	0.8	0.4	1.2	0.2
ΔT_{mean} [°C]	1996-2015	1.2	1.3	0.9	1.8	0.7
T_{max} [°C]	1961-1980	14.7	3.1	15.0	24.6	16.0
ΔT_{max} [°C]	1986-2005	0.8	1.1	0.6	1.5	0.1
ΔT_{max} [°C]	1996-2015	1.3	1.4	1.2	2.2	0.5
T_{min} [°C]	1961-1980	4.6	–4.0	4.3	12.5	5.3
ΔT_{min} [°C]	1986-2005	0.5	0.5	0.2	1.0	0.3
ΔT_{min} [°C]	1996-2015	1.1	1.2	0.7	1.5	0.9
RR [mm]	1961-1980	673.0	144.4	174.9	197.8	155.8
ΔRR [mm (%)]	1986-2005	–29.6 (–4.4)	–11.5 (–8.0)	–13.6 (–7.7)	–16.6 (–8.4)	12.1 (7.7)
ΔRR [mm (%)]	1996-2015	26.8 (4.4)	6.1 (4.2)	5.0 (2.9)	–18.1 (–9.2)	33.8 (21.7)

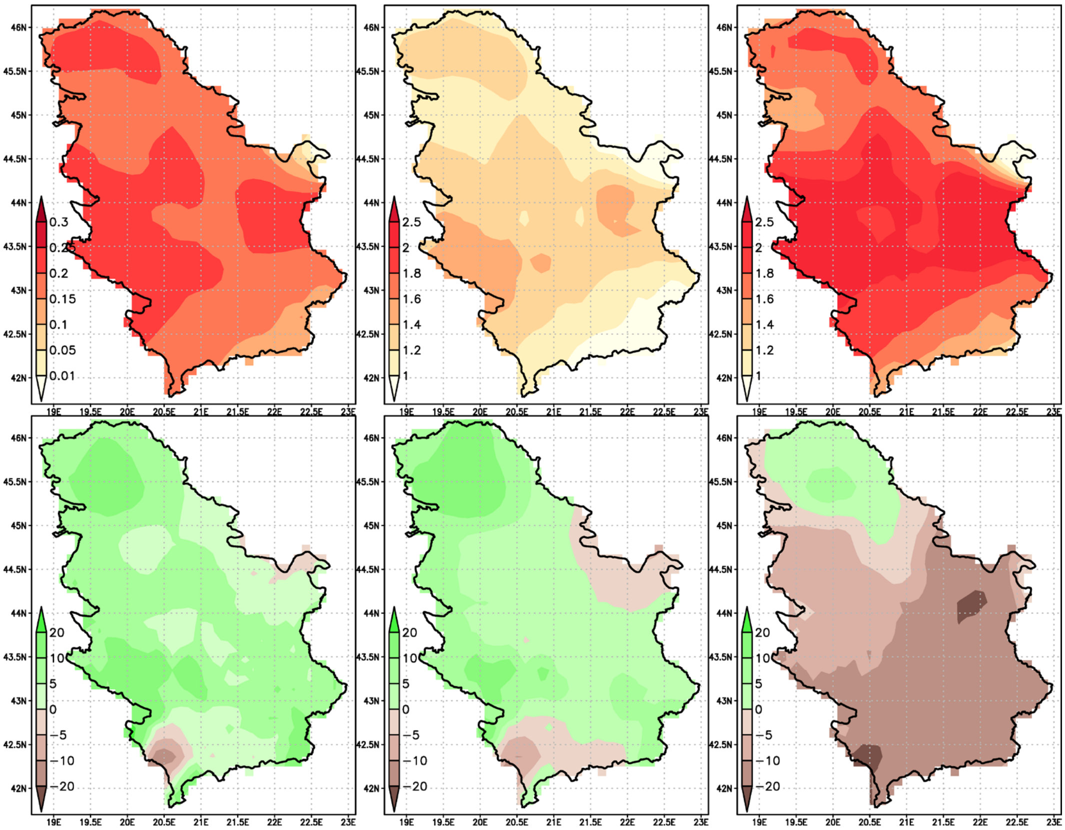

Figure 3. Mean 10 year trend for the period 1961-2015 (left panels) for temperature [°C] and annual accumulated precipitation [mm], mean temperature [v] and annual accumulated precipitation (%) change (middle panels) and the same but for JJA season (right panels) for the period 1996-2015 with respect to the 1961-1980; temperature is presentenced in upper panels and precipitation data in lower panels (*for color image see journal web site*)

recorded for 2014 and lowest for 2000. Mean annual accumulated precipitation over Serbia in the period 1996-2015 increased by 4.4% compared to the period 1961-1980, with highest increase during autumn (21.7%), but with decrease during summer (–9.2%).

Spatial distribution of mean 10 year trends of annual values of temperature and precipitation in the period 1961-2015 (left panels) and differences of mean values for two climatological periods, 1996-2015 and 1961-1980, annual (middle panels) and for summer season (right panels), which is most affected by increase of temperatures and decrease in precipitation, are presented in fig. 3. Central parts of Serbia are most affected by temperature increase, which is between 1.2 °C and 1.6 °C, and during summer even over 2.0 °C. Precipitation increase is most pronounced over northern parts of Serbia, exceeding 10% during the period 1996-2015 with respect to 1961-1980. This part also does not suffer decrease in accumulated summer precipitation, while central and southern parts show summer decrease exceeding 10%.

Future temperature and precipitation change

Analysis of future temperature and precipitation change is done using multi-model ensemble approach, using daily bias corrected temperature and precipitation data from nine different models, tab. 2, on 0.11° horizontal latitudes-longitudes resolution (WGS84 co-ordinate system), and for two scenarios of future GHG emissions: RCP4.5 (stabilization scenario) and RCP8.5 (constant increase scenario). Results are available available from EURO-CORDEX. Bias correction was done following quantile mapping technique [19, 26, 27], for each separate grid cell. More details about this data set can be found in [12]. Assessment of the statistical significance of the selected variables is calculated using the *t-test* for each model and each separate grid cell, which has the purpose to distinguish the change beyond the natural variability range. For each separate grid cell, the ensemble median change is denoted as *significant* if more than 50% of the models in the ensemble have a change that is significant according to *t-test* [27]. Each cell with significant change is marked with dot on figures.

Table 2. Multi-model ensemble members, consisting of results from listed regional climate models (RCM), which use initial and boundary conditions from global climate models (GCM)

RCM	GCM
CCLM4-8-17	CNRM-CERFACS-CNRM-CM5
CCLM4-8-17	ICHEC-EC-EARTH
CCLM4-8-17	MOHC-HadGEM2-ES.rcp85
CCLM4-8-17	MPI-M-MPI-ESM-LR
HIRHAM5	ICHEC-EC-EARTH
RACMO22E	ICHEC-EC-EARTH
RACMO22E	MOHC-HadGEM2-ES
REMO2009	MPI-M-MPI-ESM-LR
REMO2009	MPI-M-MPI-ESM-LR

Results for anomalies of area averaged mean annual and seasonal temperatures (mean, maximum, and minimum) and accumulated precipitation, is presented in tab. 3. Presented anomalies are ensemble median and ensemble average values, and show the difference between values obtained for three future periods (2016-2035 as near future period, 2046-2065 as mid-century period and 2081-2100 as end of century period) and values for the reference period 1986-2005. Periods are selected according to IPCC AR5. Representative results from ensemble of data are median values, but average ensemble values are given to show variability of ensemble members. If median and average values do not much differ it means that models results are well distributed in some interval of values between ensemble minimum and maximum value, and if they do differ significantly it means that results of some model or models much overestimate or underestimate values compared to other ensemble members.

During the near future period (2016-2035) mean temperature increase is expected to be up to 1.0 °C in average over Serbia according to RCP8.5 and somewhat lesser according to RCP4.5, with larger differences in summer than in autumn. Similar increase is projected also for mean minimum and mean maximum temperature. Change of accumulated precipitation averaged over Serbia does not show significant change, but decrease in precipitation is present during the summer according to both scenarios.

During the mid-century period (2046-2065) increase of mean temperature is expected to be 1.5 °C with higher increase during summer, according to RCP4.5, and 2.1 °C with higher increase during colder part of year, according to RCP8.5. Again, mean minimum and maximum temperature change show similar behavior. Annual accumulated precipitation over Serbia may increase up to 4.4% according to RCP8.5, and according to both scenarios decrease is expected during summer, more pronounced according to RCP4.5 (5.1%).

During the end of century period (2081-2100) according to RCP4.5 mean temperature will be higher by 1.9 °C than during 1986-2005 according to RCP4.5, but higher by 4.4 °C according to RCP8.5, with highest increase during summer and somewhat higher increase of maximum than minimum temperature, according to both scenarios. Annual accumulated precipitation over territory of Serbia in total will be higher by 3.5% and 6.8%, but with decrease during summer by 3.2% and 4.5%, according to RCP4.5 and RCP8.5, respectively.

Table 3. Anomalies of annual (ANN) and seasonal (DJF, MAM, JJA, SON) values for area averaged mean temperature (T_{mean}), mean maximum (T_{max}), and minimum (T_{min}) temperature, and mean accumulated precipitation (RR) for the periods 2016-2035, 2046-2065, and 2081-2100, with respect to the reference period 1986-2005, according to RCP4.5 and RCP8.5 scenarios; results are given for models ensemble median and average values

Parameter	Period	Ens. valus	RCP4.5					RCP8.5				
			ANN	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON
ΔT_{mean} [°C]	2016-2035	median	0.6	0.6	0.9	0.9	1.1	1.0	0.8	0.7	1.1	1.0
		average	0.8	0.7	0.8	0.9	1.0	1.0	0.8	0.9	1.1	1.2
	2046-2065	median	1.5	1.3	1.3	2.0	1.5	2.1	2.3	1.8	2.1	2.3
		average	1.6	1.7	1.3	1.9	1.7	2.2	2.1	1.9	2.3	2.5
	2081-2100	median	1.9	1.8	1.9	2.0	2.1	4.4	4.4	4.1	4.5	4.1
		average	2.1	2.1	1.8	2.2	2.3	4.6	4.7	4.1	4.8	4.5
ΔT_{min} [°C]	2016-2035	median	0.6	0.5	0.7	0.8	1.1	1.0	0.7	0.7	1.0	1.0
		average	0.8	0.7	0.7	0.8	0.9	1.0	0.8	0.9	1.0	1.1
	2046-2065	median	1.4	1.3	1.3	1.8	1.4	2.0	2.2	1.8	2.1	2.3
		average	1.6	1.6	1.3	1.8	1.6	2.2	2.1	1.9	2.2	2.4
	2081-2100	median	1.9	1.8	1.8	1.9	2.1	4.3	4.2	4.1	4.4	4.2
		average	2.0	2.0	1.8	2.1	2.2	4.3	4.4	3.9	4.6	4.4
ΔT_{max} [°C]	2016-2035	median	0.6	0.6	1.0	0.9	1.0	1.0	0.3	0.7	1.2	1.0
		average	0.9	0.8	0.8	0.9	1.0	1.0	0.8	1.0	1.2	1.2
	2046-2065	median	1.5	1.4	1.3	2.2	1.6	2.1	2.5	1.9	2.3	2.4
		average	1.7	1.8	1.3	2.0	1.7	2.2	2.2	1.9	2.3	2.5
	2081-2100	median	2.0	2.0	1.9	2.2	2.2	4.5	4.8	4.2	4.9	4.3
		average	2.2	2.2	1.8	2.3	2.3	4.7	5.0	4.1	5.0	4.6
ΔRR [mm]	2016-2035	median	0.3	0.3	1.3	–1.7	0.8	–1.4	0.6	1.0	–1.0	1.6
		average	0.6	0.9	1.0	–1.3	0.0	–0.7	0.2	0.5	–1.7	0.2
	2046-2065	median	–1.5	0.4	1.2	–5.1	–0.5	4.4	1.7	1.6	–1.6	1.4
		average	0.6	0.6	1.2	–3.6	0.1	1.8	2.6	1.1	–3.1	1.2
	2081-2100	median	3.5	2.3	1.5	–3.2	0.6	6.8	2.7	1.8	–4.5	–0.1
		average	1.5	1.9	1.3	–3.0	1.2	5.8	3.1	1.3	–7.4	–0.6

Results presented in tab. 3 are obtained as models ensemble median and mean values for anomalies of area averaged values (difference between area average value for the future period and area average value for the reference period). Values obtained in this way could differ from results obtained by calculating first ensemble median and average values for anomalies for each model grid point separately, and than averaging for the territory of Serbia. This difference may be very notable in values of precipitation anomalies.

Spatial variability of mean annual temperature and annual accumulated precipitation change over Serbia are presented in figs. 4 and 5, according to RCP4.5 and RCP8.5, respectively. As discussed in observed changes of these parameters, central and southern parts of Serbia will suffer more pronounced increase of temperature and lesser water availability from precipitation, than northern parts. Spatial change results are also presented for summer season, figs. 6 and 7, because this part of the year is most vulnerable to climate change. Results show that Serbia will continue to suffer from increase of summer temperatures and decrease of precipitation during the period which produced highest accumulated precipitation during the past climate.

Comparing results for precipitation anomalies obtained in tab. 3, figs. 4 and 5, it is evident that more severe reduction of precipitation is obtained according to second approach –

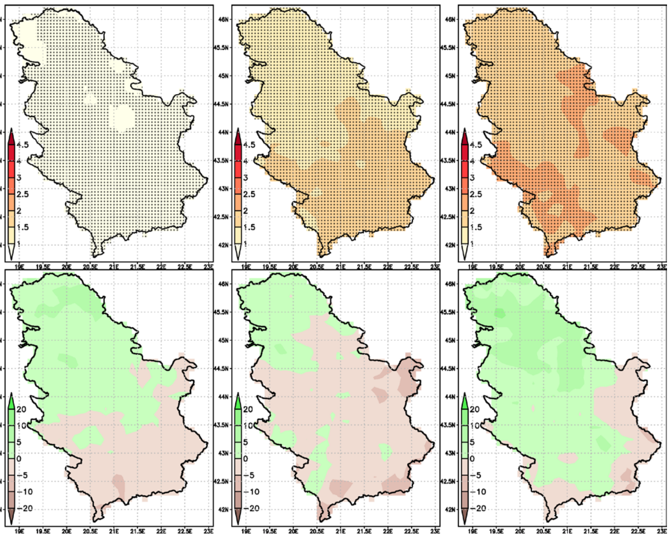

Figure 4. Mean temperature (°C, upper panels) and annual accumulated precipitation (%, lower panels) anomaly for the periods 2016-2035 (left), 2046-2065 (middle) and 2081-2100 (right) with respect to the 1986-2005, according to RCP4.5; regions with dots mark statistically significant change
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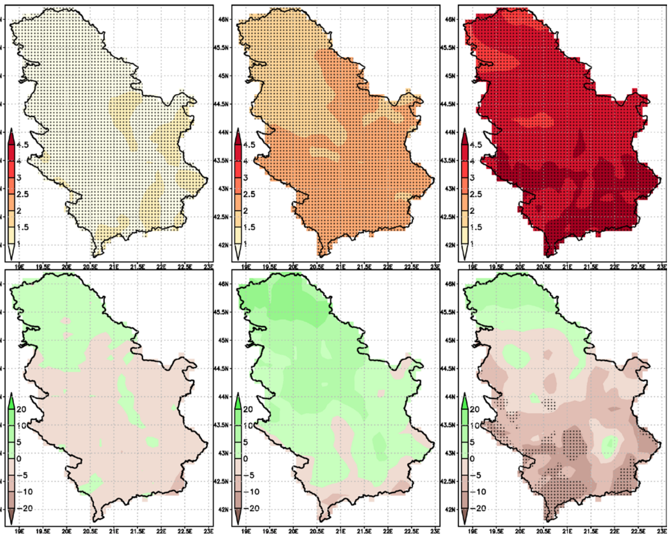

Figure 5. Mean temperature (°C, upper panels) and annual accumulated precipitation (%, lower panels) anomaly for the periods 2016-2035 (left), 2046-2065 (middle) and 2081-2100 (right) with respect to the 1986-2005, according to RCP8.5; regions with dots mark statistically significant change
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calculating anomalies for each model point separately. For example, in this way, reduction of summer precipitation over the Serbia is larger than 10% and in some parts larger than 20% for the period 2081-2100 according to RCP8.5. The methodology applied for calculation of values in tab. 3 produce results that show the change of total amount of precipitation accumulated over the whole territory of Serbia, and figures show change of precipitation accumulated in specific points in Serbia. Comparing results obtained with these two approaches, authors would like to raise attention how much information can differ and may lead to false conclusions.

Examples of climate change risk assessment

Application of multi-model ensemble in calculation of specific indices related to different sectors (agriculture, forestry, health, *etc.*) provide risk assessment, mapping of vulnerable regions and contribute to prioritization of measures for adaptation and mitigation of negative impacts.

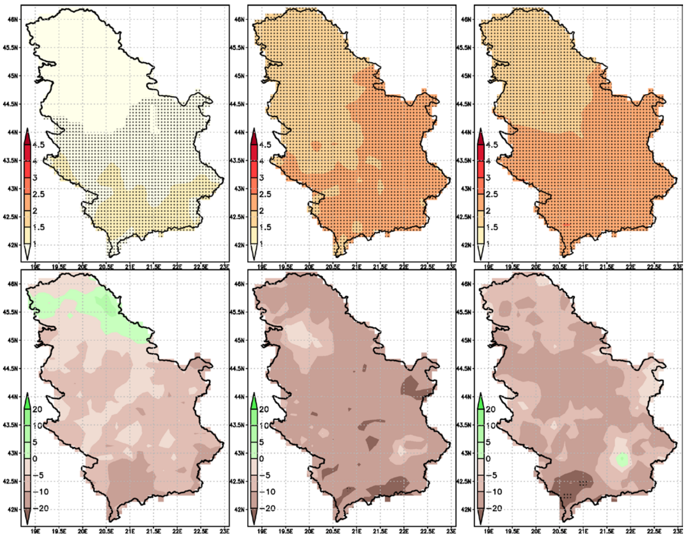

Figure 6. The JJA mean temperature (°C, upper panels) and accumulated precipitation (%, lower panels) anomaly for the periods 2016-2035 (left), 2046-2065 (middle) and 2081-2100 (right) with respect to the 1986-2005, according to RCP4.5; regions with dots mark statistically significant change (*for color image see journal web site*)

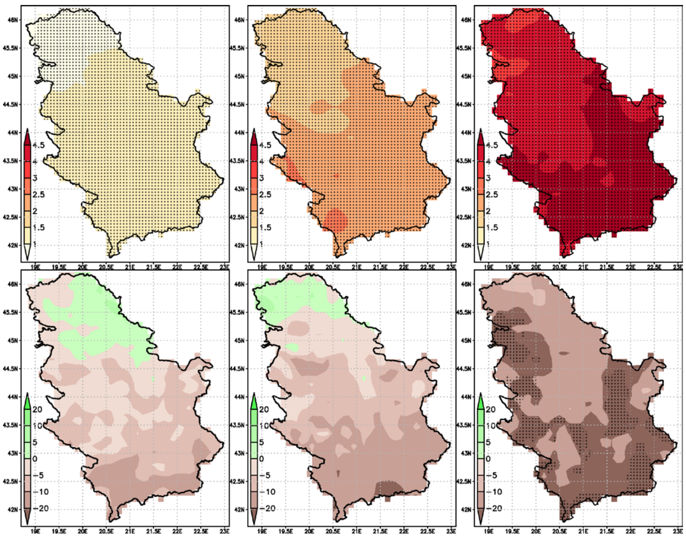

Figure 7. The JJA mean temperature (°C, upper panels) and accumulated precipitation (%, lower panels) anomaly for the periods 2016-2035 (left), 2046-2065 (middle) and 2081-2100 (right) with respect to the 1986-2005, according to RCP4.5; regions with dots mark statistically significant change (*for color image see journal web site*)

Besides conclusions that can be derived from already presented results, we add here some selected examples of results obtained according to both, RCP4.5 and RCP8.5 scenarios, for some specific indices, figs. 8 and 9. Growing season extension (defining beginning and end of growing season as first day after five consecutive days above 10 °C since the beginning of the year and after five consecutive days below 10 °C during the second half of the year), number of very hot days ($T_{\max} > 35$ °C) and change of total precipitation accumulated in days with very heavy precipitation (days with RR > 20 mm).

Most important results related to changes relevant for agriculture show that growing season extension will be about and over 10 days in the near future, over 20-30 days in the mid-century and 30-50 days by the end of the century, taking into consideration both scenarios. Having in mind increase of temperatures, with increase of very hot temperatures during summer, precipitation redistribution between seasons, with increase of high precipitation events,

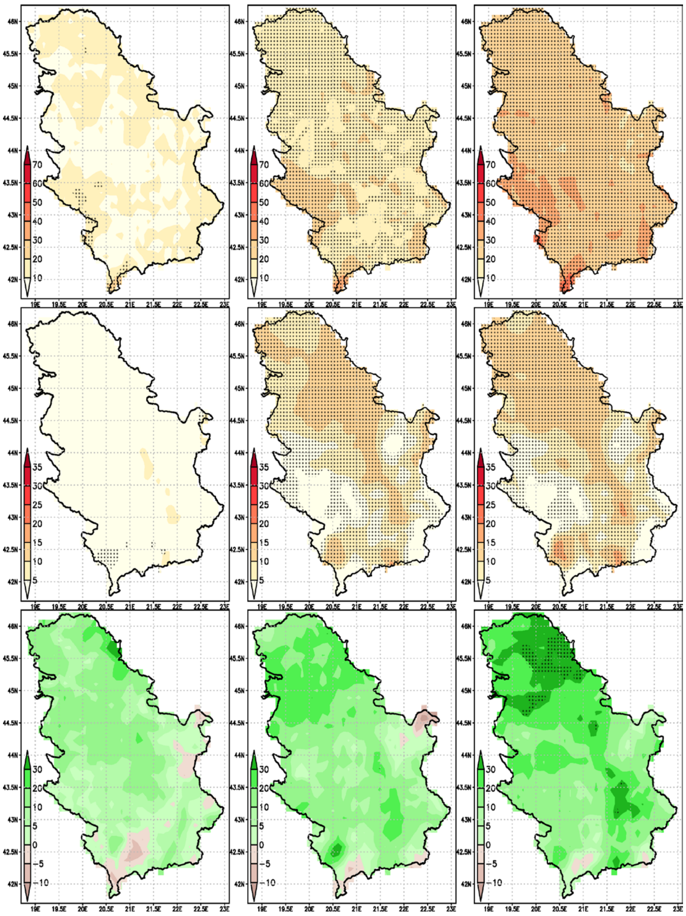

Figure 8. Change of the growing season duration (in days; upper panels), of number of very hot days – T_{max} > 35 °C (in days; middle panels) and of total precipitation accumulated in days with very heavy precipitation (in %; lower panels) for the periods 2016-2035 (left), 2046-2065 (middle) and 2081-2100 (right) with respect to the 1986-2005, according to RCP4.5; regions with dots mark statistically significant change (*for color image see journal web site*)

higher risk of summer draughts, and higher variability of temperatures between years, Serbia has entered the period of highly variable weather conditions within one climate period, potentially unsuitable for traditional cultivation. Immediate measures for advanced planning of agro-technical measures are needed, from short term planning for the upcoming season in combating the draught, high temperatures and hail damage, and consequently risks from pests and diseases, to long term planning in varieties displacement and change of varieties selection, which indicate needs for significant transformation of agricultural production in service for its sustainable development.

Increase of very hot days, besides their negative impacts on food production, endangers human health and safety, and impacts higher energy consumption during summer months. Serbia is already affected by this negative impact of high temperatures, as well as prolonged summer draughts, and requires immediate assessment of energy and water availability during summer season and planning of their optimal consumption.

Redistribution of accumulated precipitation during the year and its redistribution towards higher intensity, show increased risk of erosion leading to suitable conditions for vegetation cover decrease and wind erosion, and increased risk from erosion in cases of extreme precipitation events and consequently flash floods. Accelerated increase of temperature and increased risk from forest fires related to very high temperatures and drought endangers forest

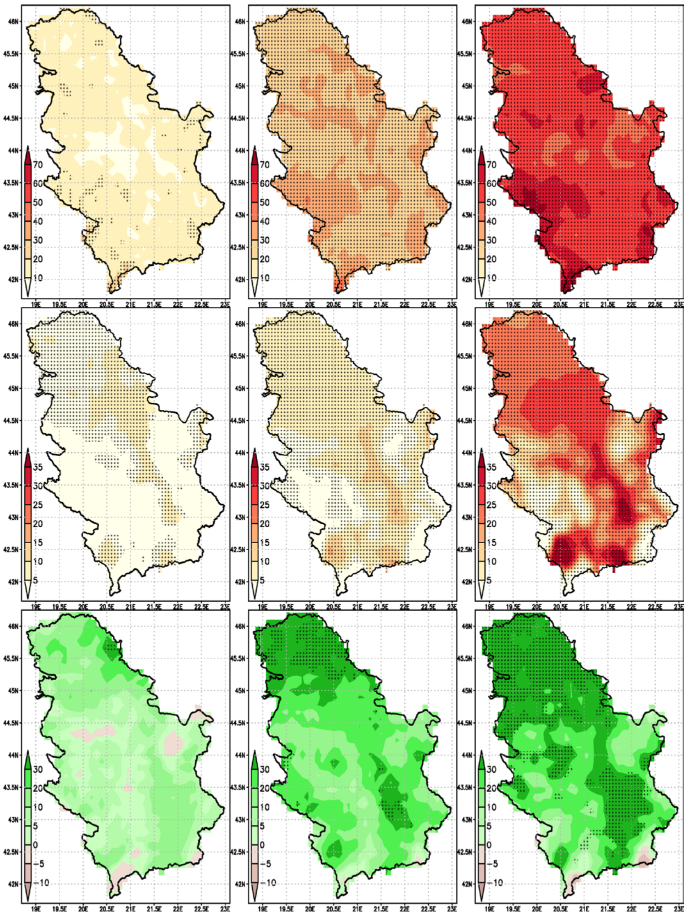

Figure 9. Change of the growing season duration (in days; upper panels), of number of very hot days – T_{max} > 35 °C (in days; middle panels) and of total precipitation accumulated in days with very heavy precipitation (in %; lower panels) for the periods 2016-2035 (left), 2046-2065 (middle) and 2081-2100 (right) with respect to the 1986-2005, according to RCP8.5; regions with dots mark statistically significant change
(*for color image see journal web site*)

ecosystems in Serbia. Slower natural migration than climate spatial shifts, and additional risk of diseases provoked by changing climate, combined with future increase of extreme precipitation and thereby increased risk from erosion, show the need for advanced planning of long term measures in forestry that require immediate actions, considering intensity of future climate change.

It is important to notice that observed change of mean temperature by 0.5 °C between 1996-2015 and 1986-2005 (tab. 1), almost reaches value projected for the near future period 2016-2035 according to RCP4.5 (tab. 3). This means that tipping point for RCP4.5 is possible to be overrun, and the future is more likely to follow more extreme scenarios.

Conclusions

Summary of the results derived from observed data and future climate projections analysis shows that during the period 1961-2100 global warming in Serbia will cause increase of mean temperature over 2.5 °C according to stabilization scenario RCP4.5, and over 5 °C according to constant increase scenario RCP8.5, with reduction of summer precipitation and precipitation increase in intensity, while total annual values do not show significant changes. Values of temperature increase are near global temperature increase according to RCP4.5, but according to RCP8.5 warming will accelerate over Serbia, especially during second half of the century, and by the end of century will be higher by 0.6 °C than global temperature increase. Central and southern parts of Serbia will suffer reduction of water availability and more pronounced temperature increase. Obtained results signals for immediate planning in adaptation and mitigation measures in sectors of economy, planning of optimal water consumption and preservation of natural ecosystems. Since obtained results rely on quality of EOBS and EURO-CORDEX data, it is recommended to create high resolution gridded database of daily data using data from all observation sites is Serbia with recorded values from 1961 for future planning. For local impact and risk assessment, and sustainable development planning resolution should be higher than presented here. Further improvement of future projections reliability and reduction of uncertainty of ensemble results may be obtained with models bias reduction using all available measurements in Serbia, and selection of model ensemble members that reproduced well observed climate change over Serbia well. This is of higher importance in precipitation change analysis since models variability show greater uncertainty, and border that crosses over Serbia, which divides future increase of precipitation at north and decrease at south, differs much among models.

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