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Landslide Risks in the Western Balkans Under the Climate Change

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Abstract Under the global warming impact, the Western Balkans region has experienced a mean temperature increase exceeding the global average, of about 1.4°C rise over the last 60 years. Depending on global efforts to reduce greenhouse gasses emissions, further warming of the region could vary from 1.7 to 4°C. Alongside the temperature rise, the Western Balkans countries have seen change in inter-annual and distribution of precipitation, as well as an increase in frequency and severity of the extreme weather and climate events. Changes in climate characteristics are increasing the risks from natural disasters such as floods, droughts, wildfires, and landslides, and emphasize the need for risk assessment of such events in future periods in order to prevent catastrophic consequences and preserve lives and assets. In this study analysed are changes in the precipitation patterns and intensity distribution by the end of the 21st century using the results of an ensemble of eight regional climate models from the EURO-CORDEX database, under the RCP4.5 and RCP8.5 IPCC scenarios. The results showed increase in the average number of days with heavy precipitation events, especially in the mountains and hilly parts of the region. Besides, more frequent, longer, and severe drought events and heatwaves, and the changes in vegetation and land use, further diminish the natural capacity to mitigate landslide risks, intensifying the overall vulnerability across the region. Projected increase of landslides risks indicates the need to incorporate future climate change impact assessments into the risk management strategies, land-use planning, and infrastructure development across the Western Balkans region.

Keywords climate change, landslides, risk assessment, precipitation, natural disasters

Introduction

Although human activities such as urbanisation and infrastructure development, deforestation, and in general land degradation is considered as the important factor of the land disturbance (Jakob, 2022) these natural disasters are further intensified by the changed patterns and increased intensity of precipitation caused by the climate change. The Western Balkans (WB) region, characterised by its diverse topography, is prone to landslides that may pose a significant risk to human lives, infrastructure, and the environment. At the same time, WB is recognised as a region where temperature increases at the rate above the global average (Vukovic and Vujadinovic Mandic, 2018), bringing quicker and more intensive changes than in many other parts of the world.

Over the last two decades WB has experienced a large number of extreme weather events (TNC SRB 2024, TNC MNE 2020, FNC BIH 2021, FNC MKD 2023, FNC ALB 2022), including intensive rainfall, floods and flash floods, and prolonged droughts, which all may contribute to the intensifying slope instability and increasing frequency and magnitude of landslides in the region.

According to the IPCC Assessment Report 6 (IPCC, 2021) further warming, precipitation changes and intensification of extreme weather events is expected to continue, if not worsen, in the forthcoming decades. Therefore, there is a need for further strengthening of knowledge on the link between climate characteristics and landslides in the region in order to assess and map future vulnerabilities and risks, develop effective early warning systems, and adaptation measures and strategies in order to mitigate the adverse impacts.

This study aims to assess the changes in precipitation patterns and intensity over WB by the end of the century in order to estimate changes in future levels of landslide risks in the region.

Methods and materials

An ensemble of high-resolution regional climate models (RCMs) was used for assessment of future climate change in WB. Data on daily temperature and precipitation were taken from eight RCMs from the EURO-CORDEX database (Jacob et al. 2014), which were proven to be able to reproduce past climate feature across the region. The names of selected RCMs and their driving global climate models (GCMs) are given in the Tab. 1.

Table 1 Global (GCM) and regional (RCM) climate models used in the ensemble.

GCM	RCM
ICHEC-EC-EARTH	CLM-CCLM4-8-17
ICHEC-EC-EARTH	DMI-HIRHAM5
ICHEC-EC-EARTH	KNMI-RACMO22E
MOHC-HadGEM2-ES	CLM-CCLM4-8-17
MOHC-HadGEM2-ES	KNMI-RACMO22E
MPI-M-MPI-ESM-LR	CLM-CCLM4-8-17
MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009_r1
MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009_r2

Climate change is assessed under the two most commonly used Relative Concentration Pathways (RCP) scenarios of greenhouse gas (GHG) emissions, RCP4.5 and RCP8.5. Scenario RCP4.5 predicts peak of GHG emissions around the year 2040 and gradually decline afterwards, while RCP8.5 foresees continuous increase of the emissions by the end of the century (van Vuuren et al. 2011). Projected climate conditions of two future periods, the mid-century (2046-2065) and end-of-century (2081-2100), are compared to the climate conditions of the referent period (1986-2005).

The assessment is performed on a high-resolution grid (about 12 km regular latitude/longitude grid) over the WB region, i.e. Albania (ALB), Bosnia and Herzegovina (BIH), Montenegro (MNE), North Macedonia (MKD) and Serbia (SRB).

Results and discussion

Change in temperature

Mean annual temperature averaged across WB is expected to continuously increase by the end of the century, according to both considered scenarios. Under the RCP4.5 median value of the mean annual temperature will increase by 1.6°C by the mid-century (min/max range of change from 0.4 to 2.6°C) and by 2°C by the end of the century (min/max range of change from 0.8 to 3.1°C), compared to the referent period. Warming under the RCP8.5 is more pronounced, and it will reach 2.1°C (min/max range of change from 1.1 to 3.5°C) by the middle and 4.4°C (min/max range of change from 3.3 to 5.5°C) by the end of the century. Ranges of projected changes under the two scenarios mostly overlap until the 2080's, when they begin to diverge and complete diverge by the end of the century, when the minimum warming estimate according to RCP8.5 exceeds the maximum estimate according to RCP4.5. Spatial distribution of the median value of mean annual temperature anomaly is given in Fig. 1.

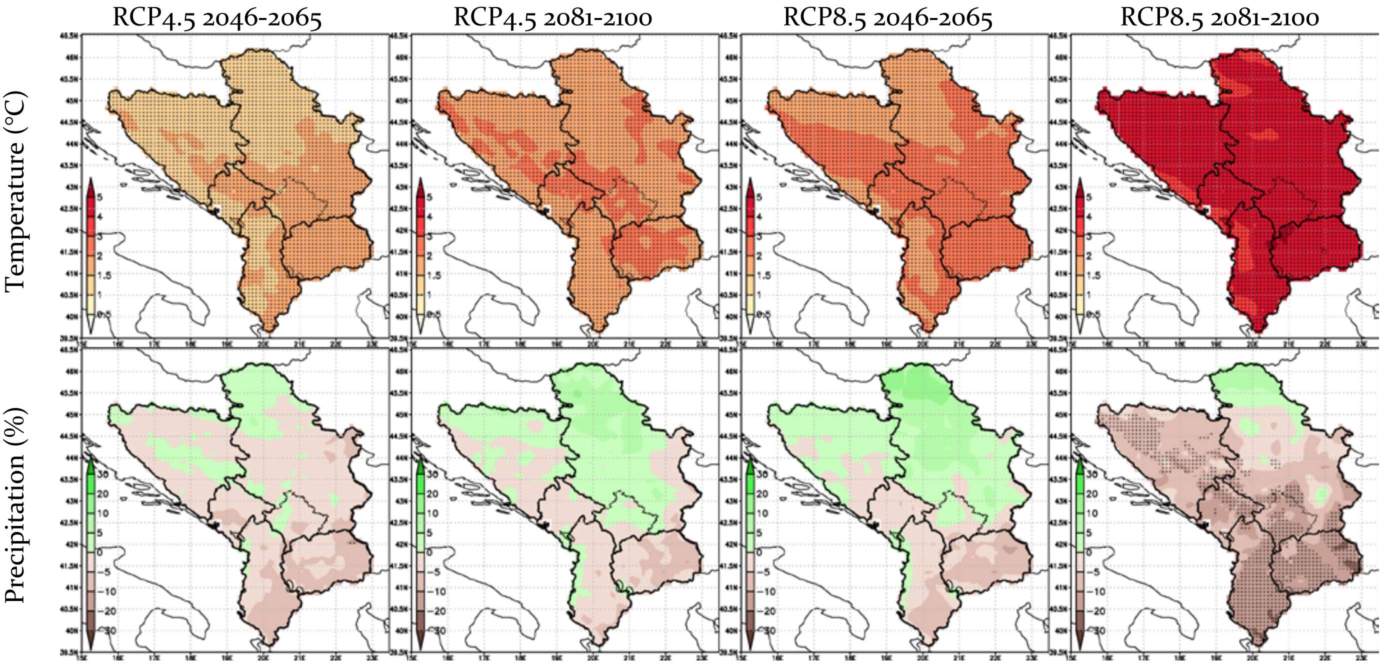

Figure 1 Mean annual temperature and precipitation anomalies for mid-century (2046-2065) and end-of-the-century (2081-2100) periods, under RCP4.5 and RCP8.5 scenarios, compared to referent period (1986-2005). Black dots denotate statistically significant change.

Seasonal changes of the median value of the mean temperature show that spring (MAM, March-April-May) warms the least, followed by winter (DJF, December-January-February) and autumn (SON, September-October-November), while summer (JJA, Jun-July-August) warms the most in both periods and under both scenarios. The least winter worming is found along the coast. Mean maximum temperatures increase more than mean minimum temperatures. Ranges of median values of the mean seasonal changes across the region are shown in Tab. 2, while spatial distribution of summer change is presented in Fig 2.

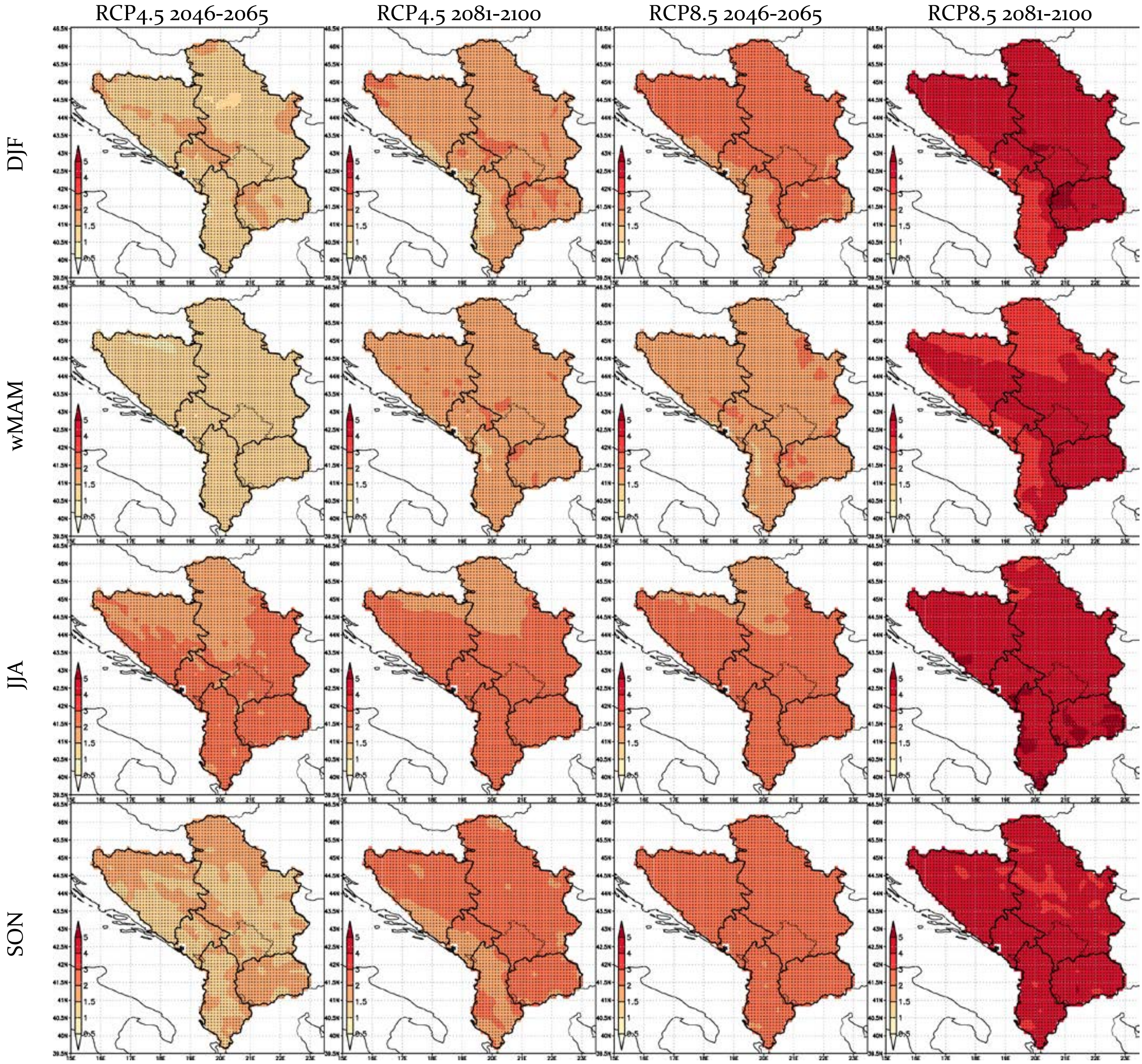

Figure 2 Mean seasonal temperature anomalies (°C) for mid-century (2046-2065) and end-of-the-century (2081-2100) periods, under RCP4.5 and RCP8.5 scenarios, compared to referent period (1986-2005). Black dots denotate statistically significant change.

Table 2 Range of median value of mean seasonal anomaly (°C) across WB, for mid-century and end-of-century periods, under RCP4.5 and RCP8.5, compared to the referent period.

Season	Mid-century		End of century	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5
winter	1-2°C	1.5-3°C	1-3°C	3-6°C
spring	1-1.5°C	1.5-2°C	1.5-2°C	3-5°C
summer	1.5-3°C	1.5-3°C	1.5-3°C	3-6°C
autumn	1.5-2°C	1.5-3°C	1.5-3°C	3-5°C

Change in annual and seasonal precipitation

Unlike the temperature, change in annual precipitation is not uniform across WB. Generally, northern parts of the region could have somewhat more precipitation in average, while southern parts could have a slight decrease on annual level (Fig. 1). These changes are mostly within the range from -10% to +10% comparing to the referent period, and therefore they could be considered as a part of a natural climate variability. However, notable changes are expected in inter-annual distribution of precipitation. Seasonal precipitation changes are presented in Fig. 3.

Increase in winter precipitation is expected across the region in both future periods and under both scenarios. This change is the greatest in northern and central parts of SRB and BIH, northern MNE, and central parts of ALB and MKD. Besides the winter precipitation increase, it is important to note that due to warming of the season there will be less snowfall and shorter snow cover retention, especially in lower altitudes.

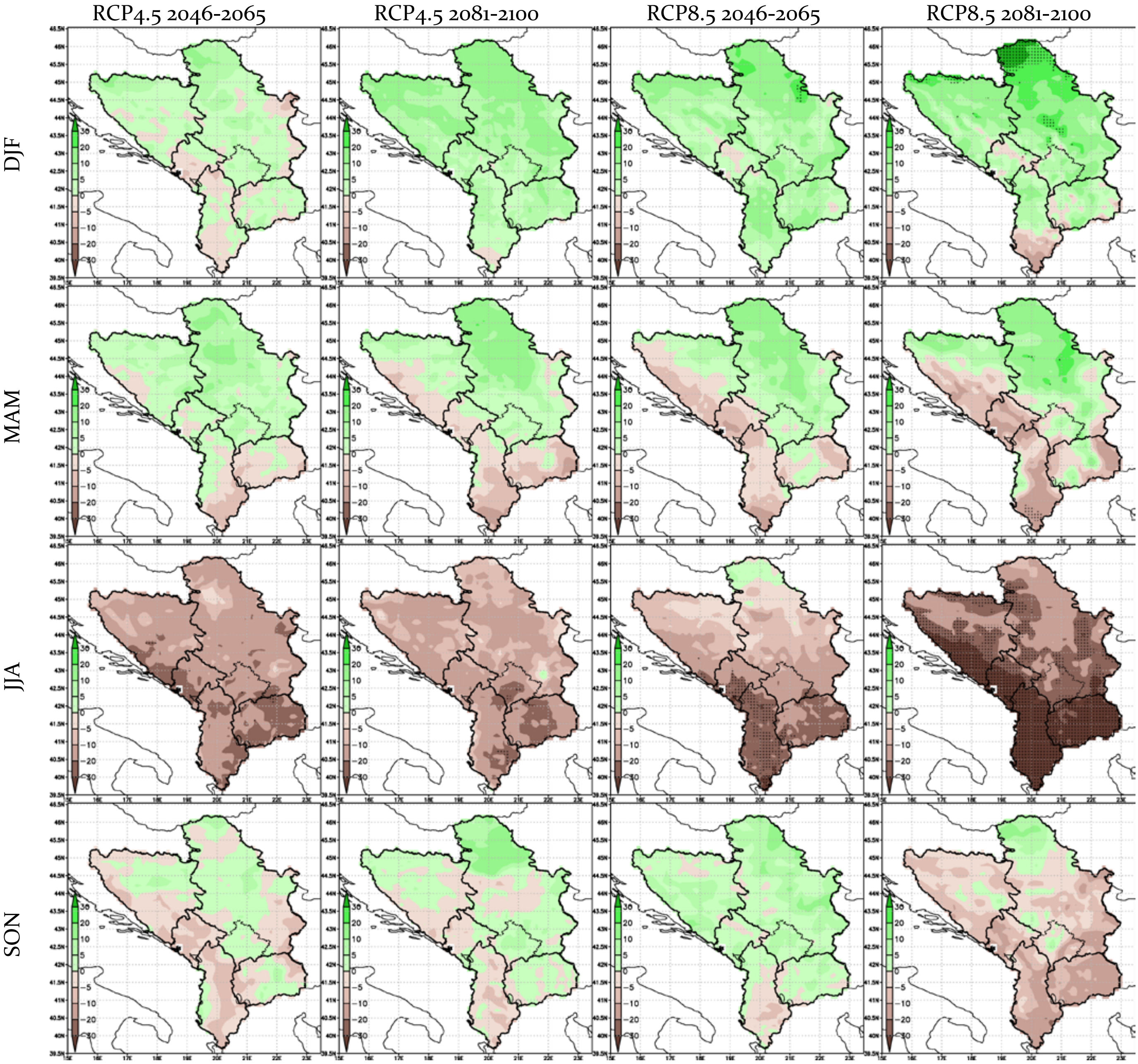

Figure 3 Mean seasonal precipitation anomalies (%) for mid-century (2046-2065) and end-of-the-century (2081-2100) periods, under RCP4.5 and RCP8.5 scenarios, compared to referent period (1986-2005). Black dots denotate statistically significant change.

Spring precipitation is expected to increase over SRB, northern and eastern BIH, coastal ALB, central MKD and northern MNE (only under RCP4.5). Frequent episodes of warm weather may trigger fast snow melting. If such event coincides with high spring rainfall or comes after the high winter rainfall, it could cause saturation of slopes, increase in groundwater levels and increase risk of landslides.

Summer is the season with pronounced precipitation deficit projected all over the region. The expected decrease ranges between 10 and 20%, locally up to 30% in parts of ALB, MKD and the coastline. Under RCP8.5 by the end of the century projected summer precipitation shortfall is the largest and it exceeds 30% in the southern part of WB (ALB, MKD, MNE, and south and southwestern BIH), while in other regions it is mainly between 10 and 20% compared to the referent period. Very high summer temperatures combine with droughts stress vegetation, impacting, among other, root growth which in turn provides less stabilization for slopes. Reduced soil moisture content and/or depletion of groundwater levels weakens cohesion between soil particles, creates cracks and change soil properties influencing its ability to absorb and retain water, which increase surface runoff and erosion. Prolonged droughts and high temperature increase the risk of wildfires which removes vegetation leaving slopes more prone to landslides during later rainfall events.

Autumn precipitation changes are nonuniform across the region. Generally, increase could be expected in the largest part of SRB, MKD, coastal ALB, and north and central BIH. At the end of the century under RCP8.5 precipitation decrease is projected in almost all WB, except for northern SRB and locally in eastern BIH and southern and western SRB.

Change in precipitation intensity

With the atmosphere warming, it is expected to have more intensive precipitation events. Such events are associated with high uncertainties within the climate models, since they mainly come from convective processes which have spatial scales bellow the horizontal resolution of RCMs. However, the tendencies of increased number of intensive precipitation events, as well as increase in maximum 1-day and 5-days accumulated precipitation have been observed all over WB.

Number of days with precipitation above 20 mm, which are found to may increase landslide risks in the region, is projected to increase on an annual level all over the region, especially in SRB, BIH, northern MNE, central and western MKD, and coastal and eastern ALB. The largest increase in the accumulated water in such events is expected in the northern and southern SRB, northern and eastern BIH, northern and western MKD and eastern ALB.

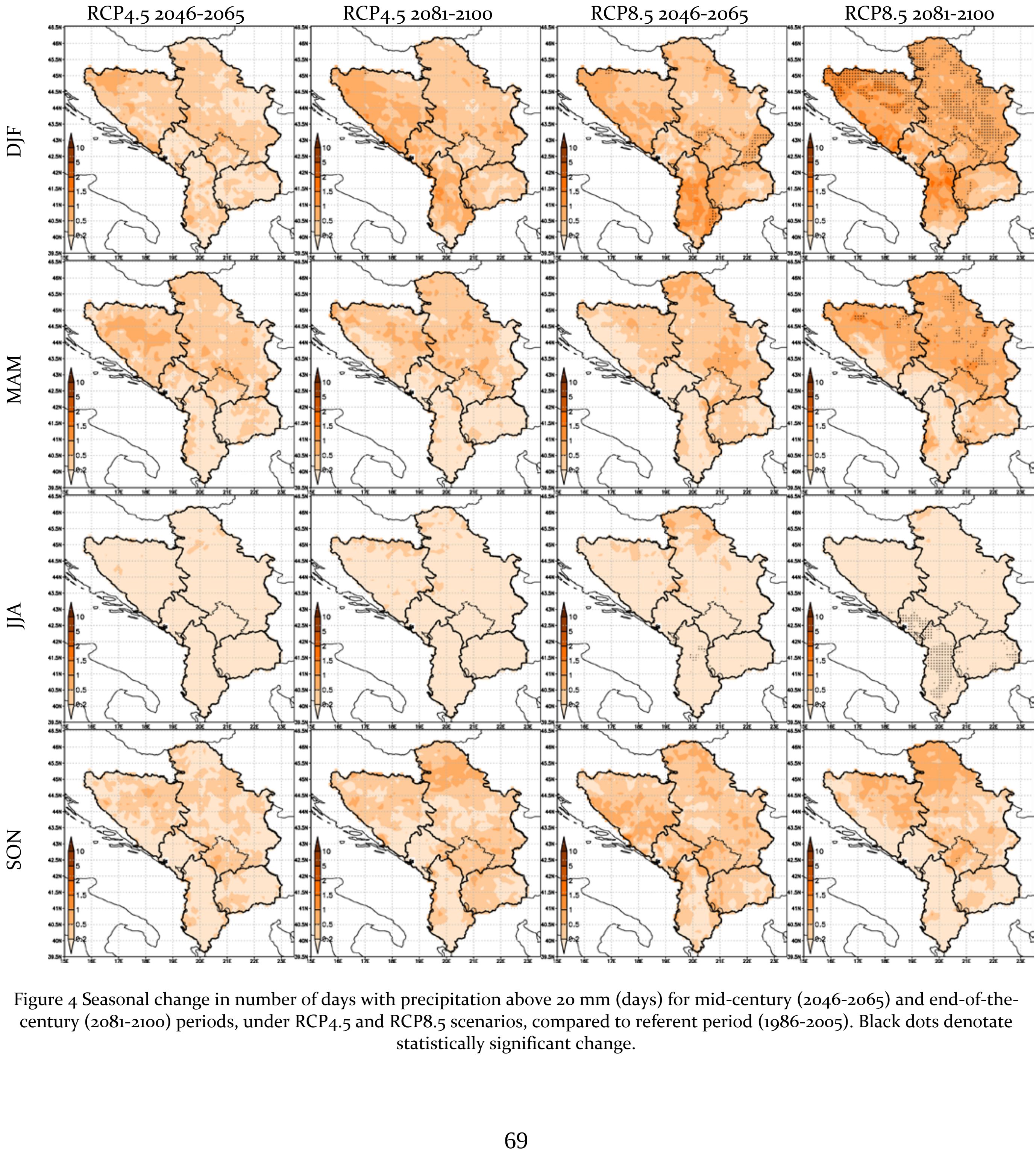

Figure 4 Seasonal change in number of days with precipitation above 20 mm (days) for mid-century (2046-2065) and end-of-the-century (2081-2100) periods, under RCP4.5 and RCP8.5 scenarios, compared to referent period (1986-2005). Black dots denotate statistically significant change.

Seasonally, the highest increase in number of days with precipitation above 20 mm is expected in winter across the mountain region of BIH, SRB, MNE and ALB. In spring and autumn, the largest increase in number of such days across SRB, northern and eastern BIH, coastal ALB and western MKD. In summer, increase of such days is smallest, with less than 1 additional day per season, in average. Seasonal changes in number of days with precipitation above 20 mm are presented in Fig. 4.

The expected increase of water amount accumulated in events with precipitation above 20 mm is the largest (above 30%) in winter across SRB, BIH, MKD, northern MNE and eastern and western ALB. In spring, affected are the same region, but within slightly smaller areas compared to winter. In autumn the largest increase is expected in northern BIH, northern and southern SRB, central MKD, and northern MNE. In summer season, decrease in amount of accumulated water in heavy precipitation events is expected in most parts of the region, while the increase is projected in the northern parts of SRB and BIH, and locally in eastern, central and western SRB. Seasonal changes in water accumulated in events with precipitation above 20 mm are presented in Fig. 5.

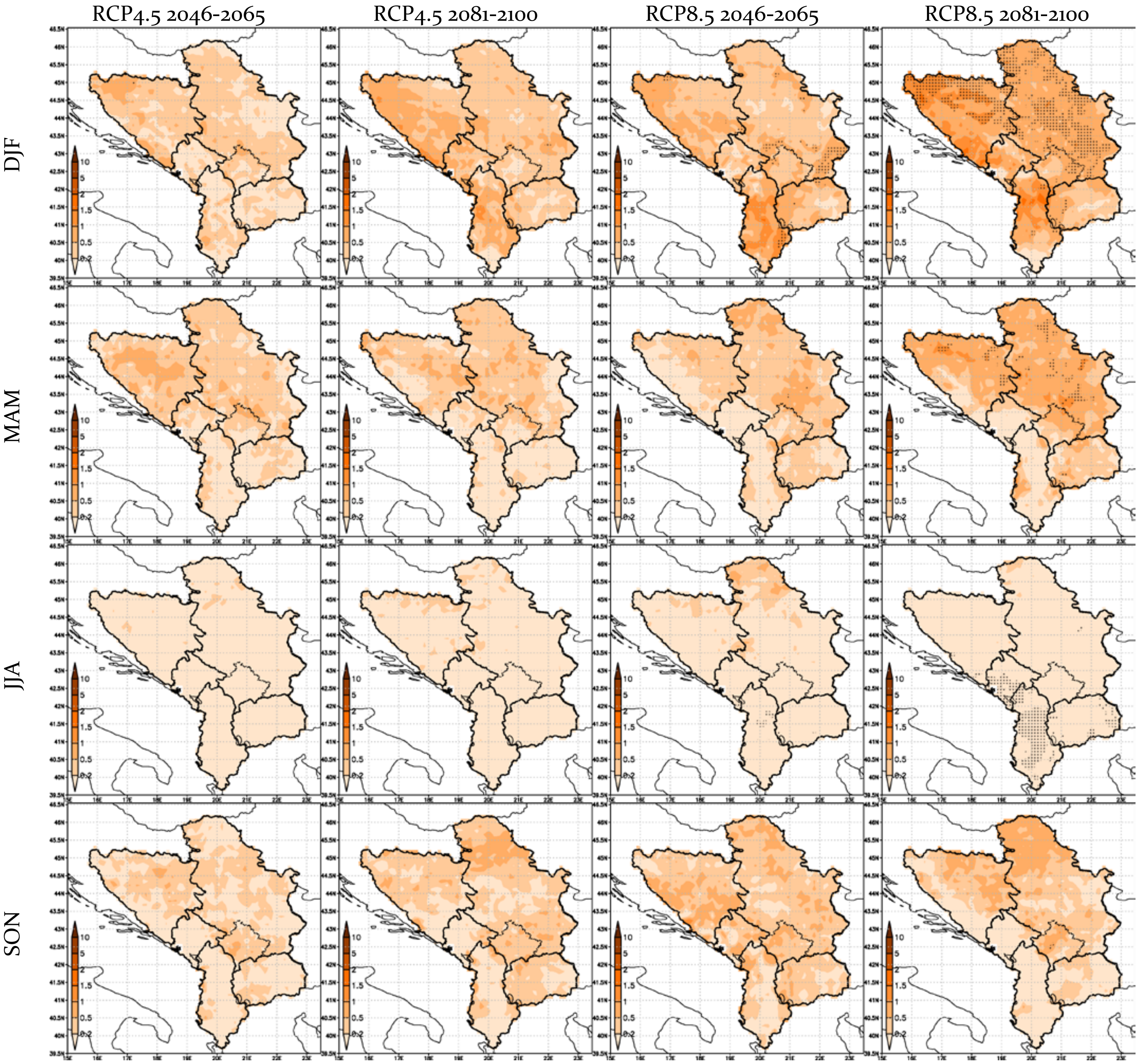

Figure 5 Seasonal change in water accumulated in events with precipitation above 20 mm (%) for mid-century (2046-2065) and end-of-the-century (2081-2100) periods, under RCP4.5 and RCP8.5 scenarios, compared to referent period (1986-2005). Black dots denotate statistically significant change.

Conclusions

Temperature rise, change in seasonal precipitation patterns, intensification of heavy precipitation events, and overall increased climate variability, will increase risks in the landslides-prone areas across the WB region. Beside the direct effect of increased intensive precipitation events and amount of water in such events, other climate-related factors, such as summer droughts, high temperature, wildfires, land degradation, overlap of snowmelt and increased spring precipitation periods could also expand the risk across the areas that are currently not susceptible to landslides. Rate of the expected changes depends on the success of mitigation efforts implemented on a global level, while the direction of the changes is unequivocal.

In addition to the climate changes impacts, shifts of vegetation dynamics and land use practices may influence region's natural capacity to mitigate landslide risks and increase overall vulnerability.

Assessment of the future climate change impacts needs to be systematically integrated into risks management strategies within the region, land-use planning and infrastructure development, and used as basis for developing and prioritizing adaptation measures. Such measures could include, among other, development or strengthening of early warning systems (providing timely alerts and increasing preparedness), increasing infrastructure resilience (both in planning and maintenance) and vegetation management (restore or maintain vegetation cover to enhance slope stability and mitigate erosion), which will all increase readiness of citizens and authorities and contribute to the development of a climate resilient society, environment and infrastructure.

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