72 MULTI-MODEL APPROACH FOR PROJECTING EXTREMES RELATED TO THE LACK AND EXCESS OF PRECIPITATION IN CENTRAL/EASTERN EUROPE

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1. INTRODUCTION

Frequent hot weather in summer and overall increasing warm regional climatic conditions are quite straightforward local-scale consequences of global warming. Regional warming induced effects on precipitation are less clear than on temperature because of the higher spatial and temporal variabilities, which often hide changing signals and clear statistical trends. Nevertheless, precipitation is one of the key meteorological elements since it considerably affects natural ecosystems and cultivated vegetation as well, as most of human activities.

Extreme precipitation events – either excessive, intense rain/snowfalls or severe droughts – may result in several environmental, agricultural, and even economical disasters. In order to avoid or at least reduce the effects of these precipitation-related natural hazards, national and local communities need to develop regional adaptation strategies, and then, act according to them. For this purpose, analyzing future precipitation projections is essential, for which results of global climate model (GCM) simulations must be downscaled to regional and local scales, hence better serving end-users' needs.

2. DATA AND METHODS

In order to analyze the estimated trends of precipitation- and drought-related climate indices we used a multi-model (MM) approach taking into account 11 regional climate model (RCM) simulations from the ENSEMBLES project (van der Linden and Mitchell, 2009) with 25 km horizontal resolution using the emission scenario A1B (Nakicenovic and Swart, 2000). Validation analysis completed by Pongrácz et al. (2011) for the Central/Eastern European region showed that simulated precipitation values significantly underestimate the observations in summer and overestimate them in the rest of the year. Therefore, we applied quantile matching bias correction technique (Pongrácz et al., 2014) to eliminate these systematic errors. Thus, the monthly empirical distribution functions of each grid cell for each RCM simulation were fitted to the observed distributions using reference data (Table I) from E-OBS (Haylock et al., 2008) and CarpatClim (Szalai et al., 2013); then, the calculated multiplicative bias correcting factors are applied to the raw outputs of individual RCM experiments for the entire simulation period (1951–2100). After the correction, we analyzed several precipitation-related climate indices (Karl et al., 1999) both on seasonal and annual scales.

Table I: The reference databases used in the analysis

Database	E-OBS	CarpatClim
Reference	Haylock et al., 2008	Szalai et al., 2013
Time period	1951–2000	1961–2010
Area	Central/Eastern Europe (43.625–50.625 °N, 13.875–26.375 °E)	Carpathian Region (44–50 °N, 17–27 °E)
Horizontal resolution	0.25°	0.1°
Number of gridcells	1441	5895
Subregions	SE-CZ, E-AT, SK, SW-UK, SI, HU, RO, CR, N-SR	SK/C, UA/C, HU/C, RO/C, SR/C

In Fig.1 monthly precipitation totals are compared to the reference (upper panel: CarpatClim, lower panel: E-OBS) for three 30-year-long time slices for three selected subregions within the Carpathian Region, namely, for Slovakia, Hungary, and Romania. In 1961–1990 the annual distributions of precipitation are similar in all the selected subregions: the wettest and the driest seasons are summer and winter, respectively. The differences between the wettest and the driest months are projected to decrease substantially by the end of the 21st century since precipitation is estimated to decrease in the summer months (and also in May), whereas winter (as well, as autumn and early spring) months tend to become wetter than previously. The largest average increasing change (+11%) is estimated for Slovakia in February. The most pronounced decreasing trend (–32% on average) is estimated for Romania in July. The uncertainty of the MM ensemble is low in the 1961–1990 reference period due to the applied bias correction method. However, in the future time periods the intervals of the spatial averages of simulated values from the MM ensemble are quite large, especially, in the summer months.

CarpatClim better represents the regional climate than E-OBS due to its finer resolution, the applied statistical homogenization, and because of more stations involved in the interpolation. Therefore, in the detailed analyses we considered those bias-corrected RCM outputs, for which the CarpatClim database served as a reference. Our earlier results, using only E-OBS as a reference database can be found in Pongrácz et al. (2013, 2014) and Bartholy et al. (2015).

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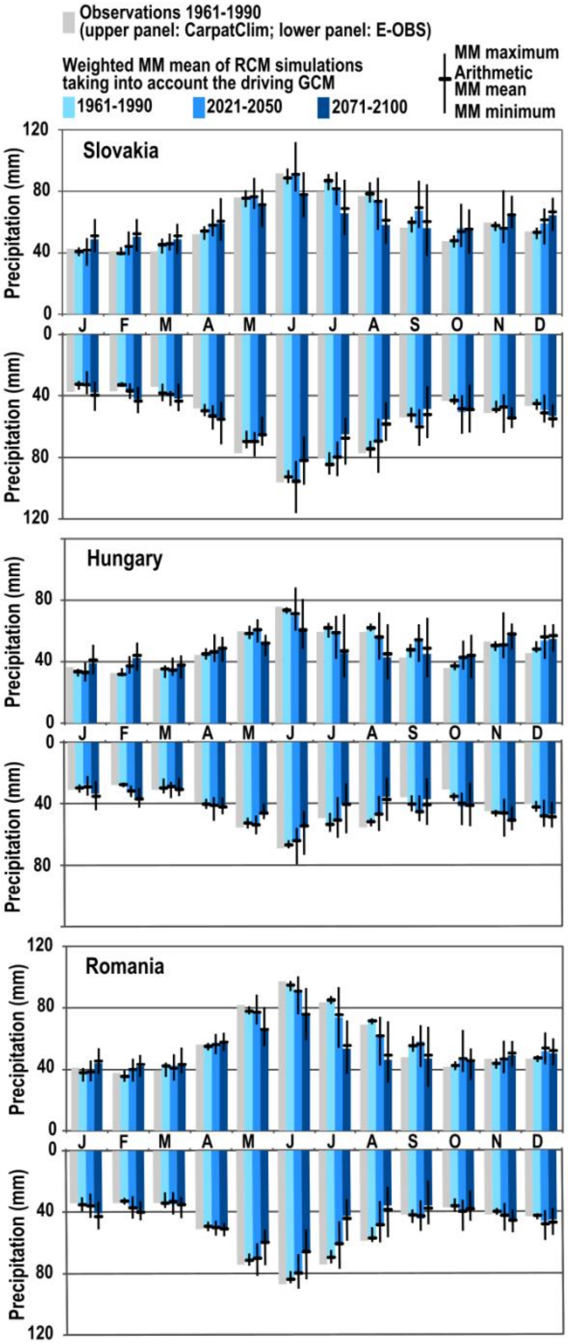

Fig. 1: Monthly precipitation totals for 1961–1990, 2021–2050 and 2071–2100 in Slovakia, Hungary, and Romania calculated from the E-OBS, the CarpatClim, and the MM ensemble of 11 bias-corrected RCM simulations. The MM minimum and maximum values (lower and upper end of the vertical black line, respectively), and both the GCM-weighted (colored column) and the arithmetic MM means (horizontal black line) of the spatial averages of individual bias-corrected RCM outputs are shown.

3. RESULTS

In this section some of our results are presented and discussed, namely, the estimated changes of mean dry spell (MDS), the highest five-day precipitation amount (RX5), and the high percentile values of daily precipitation (e.g., R95p, R99p) for three subregions (SK/C, HU/C, and RO/C, which are the groups of gridcells representing Slovakia, Hungary, and Romania, respectively, within the area covered by the CarpatClim data) along the northwestern-southeastern axis of the Carpathian domain.

3.1. *Projected changes of mean dry spell*

First, estimated changes of the mean dry spell are presented. This climate index is related to the lack of precipitation, and it indicates how long (i.e., for how many days) dry periods (when the daily precipitation sum is continuously less than 1 mm) last on average. This average length of dry periods has considerable effects on agricultural activity.

The projected changes and also the uncertainty of the model simulations are generally larger in the late century period (2071–2100) compared to the middle of the 21st century (2021–2050) in all seasons and subregions. The largest changes are estimated for summer in all the selected subregions (Fig. 2). The MM average changes by 2071–2100 are +32%, +47%, and +44% in Slovakia, Hungary, and Romania, respectively. Specifically, this means for instance in Hungary that in the reference period MDS lasted 6 days on average, which is projected to increase remarkably by the end of the 21st century, so it is very likely that dry periods will last for 9 days on average. Smaller but still increasing trend (by about 10% by the late-century) is very likely to occur in spring and autumn, whereas decreasing tendency is projected for winter, especially, in the northern parts of the domain.

Besides the estimated seasonal average MDS index values, the entire frequency distribution of MDS is evaluated for each gridcell for all the four seasons. Here, results for only three selected gridcells (i.e., representing Bratislava (SK/C): 48.125°N; 17.125°E; Szolnok (HU/C): 47.125°N; 20.125°E; and Bucharest (RO/C): 44.375°N; 26.125°E) located along the northwestern-southeastern axis of the Carpathian domain are shown for summer (Fig. 3). The empirical frequency distributions of simulated past and future MDS values in summer are compared using the RACMO/ECHAM experiment from the MM ensemble.

The largest distribution changes are projected in the southern-most located gridcell, representing Bucharest. The estimated past and future frequency distributions are clearly different at 0.05 level of significance in all the selected gridcells in the summer season according to the Kolmogorov-Smirnov test.

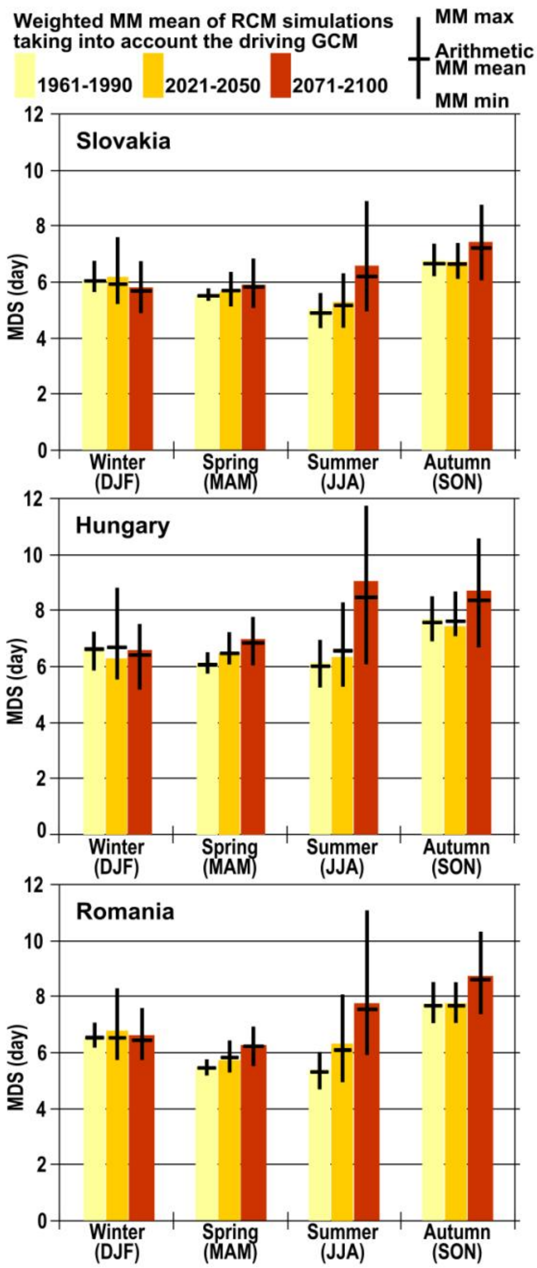

Fig. 2: Estimated MDS values using the MM ensemble of 11 bias-corrected RCM simulations for 1961–1990, 2021–2050, and 2071–2100 in Slovakia, Hungary, and Romania (spatial averages are shown for each subregion).

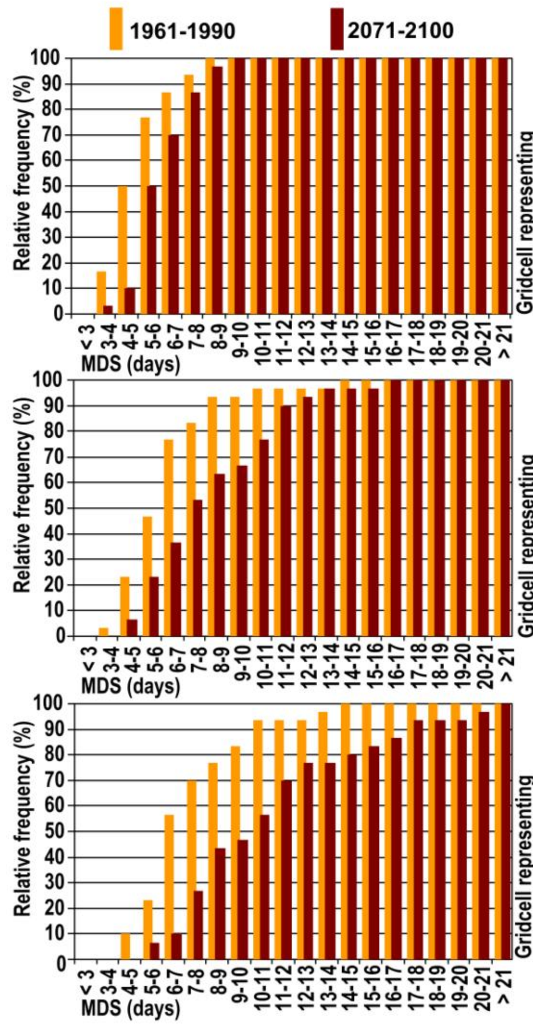

Fig. 3: Comparison of empirical frequency distributions of simulated past and future MDS values in summer using the bias-corrected RACMO/ECHAM simulation in a representative gridcell for each subregion.

The spatial distributions of seasonal MM mean changes of MDS values are presented in Fig. 4. The composite maps clearly suggest that drier climatic conditions are estimated for the future, except for the northern subregions in winter. The largest relative changes (exceeding +40%) are projected for summer, for most of Hungary, western and southern Romania, Serbia, and Croatia. For spring and autumn also increasing trends of MDS are estimated, which is more pronounced (+15–20%) in the southern parts of the domain.

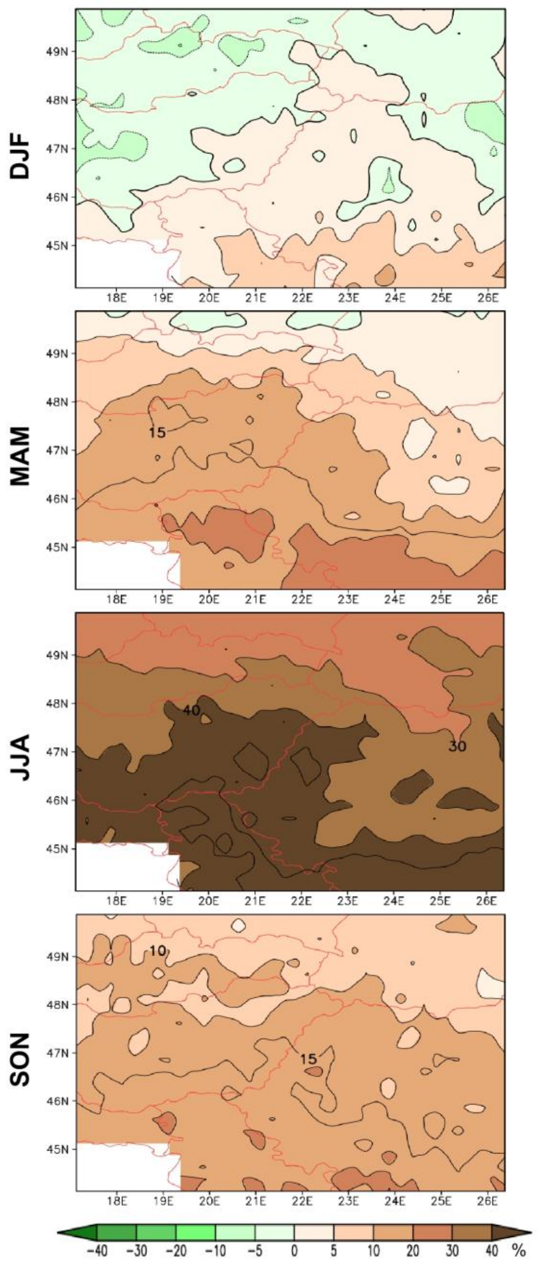

Fig. 4: MM composite maps of the relative seasonal mean changes of MDS using the 11 bias-corrected RCM simulations for 2071–2100 (reference period: 1961–1990).

In case of the summer mean changes, projections from the individual bias-corrected RCM outputs are shown in Figs. 5, 6, and 7. The largest increase of MDS for the entire domain (+73%) is estimated by CLM/HadCM. Spatial averages of the estimated mean summer changes for the entire Carpathian domain and the three subregions are summarized in Table II.

Table II: Spatial mean estimated relative changes of MDS (%) for summer by 2071–2100 relative to the reference period 1961–1990

Area	Carpathian domain	Slovakia	Hungary	Romania
ALADIN/A	63.5	59.0	69.1	57.3
HIRHAM/A	47.3	32.4	51.7	53.9
HIRHAM/E	15.2	0.5	9.0	28.5
Racmo/E	32.5	26.2	35.8	35.5
RegCM/E	17.1	13.7	15.9	21.5
REMO/E	27.5	23.8	25.3	31.2
RCA/E	25.5	18.8	26.2	27.8
RCA/H	25.2	16.7	21.4	36.2
RCA3/H	19.1	11.5	7.3	30.7
CLM/H	73.3	52.2	79.1	86.5
HadRM/H	46.8	41.0	69.1	35.7

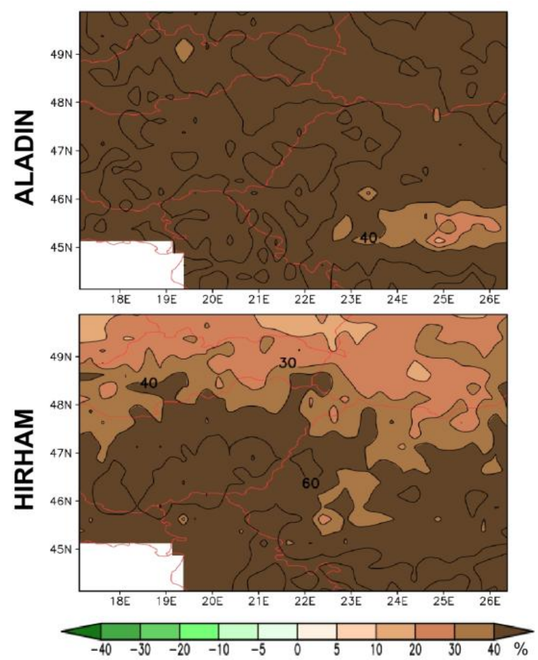

Fig. 5: Maps of the relative summer mean changes of MDS using the ARPEGE-driven RCM simulations for 2071–2100 (reference period: 1961–1990).

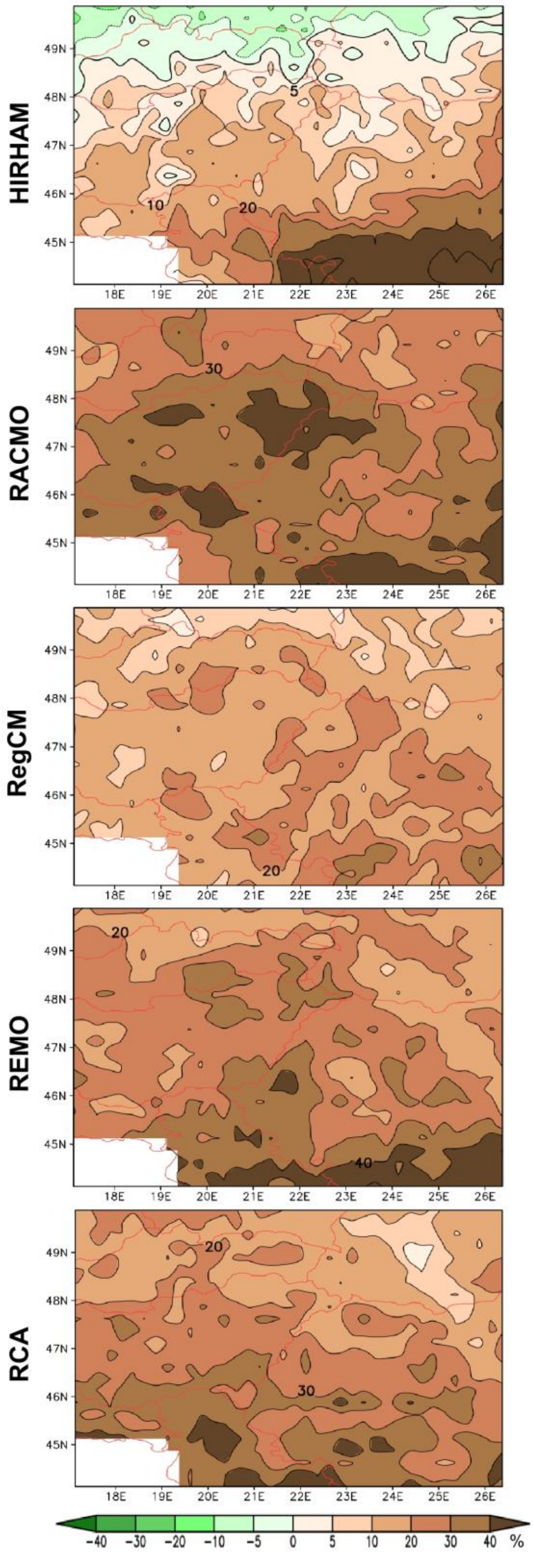

Fig. 6: Maps of the relative summer mean changes of MDS using the ECHAM-driven RCM simulations for 2071–2100 (reference period: 1961–1990).

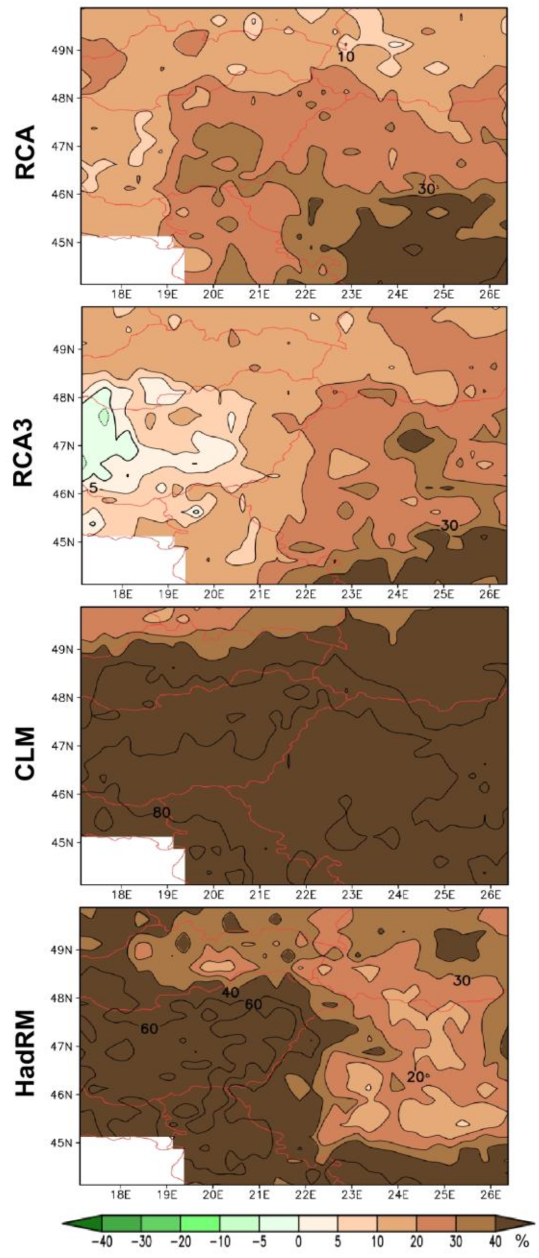

Fig. 7: Maps of the relative summer mean changes of MDS using the HadCM-driven RCM simulations for 2071–2100 (reference period: 1961–1990).

3.2. *Projected changes of the highest five-day precipitation amount*

In this section estimated changes of the highest five-day precipitation amount are analyzed. The climate index RX5 is expressed in mm and it shows the largest precipitation sum in (consecutive) 5-day-long periods. Due to its definition this climate index is associated to both the length and the intensity of precipitation. Since long-lasting, intense precipitation events may induce floods, landslides, or transportation problems, from possible impact point of views it is important to evaluate this index.

By the end of the 21st century the largest changes are projected for winter. The overall average intercentury change of the spatially averaged index values are +23% in Slovakia (from 33 mm in 1961–1990 to 41 mm by 2071–2100), +22% in Hungary (from 30 mm in 1961–1990 to 37 mm by 2071–2100), and +16% in Romania (from 31 mm in 1961–1990 to 36 mm by 2071–2100) on the basis of the MM ensemble of 11 bias-corrected RCM simulations (Fig. 8).

The estimated changes in winter for 2021–2050 are about 10% in all subregions. In the reference period the largest RX5 values occurred in summer (Fig. 8); the average MM mean values are 58 mm, 52 mm, and 61 mm in Slovakia, Hungary, and Romania, respectively. The projected mean changes by the end of the 21st century are –9%, –7%, and –13% from north to south. Similarly to winter, in the equinox seasons increasing trend is likely to occur, which is more emphasized in autumn than in spring.

Empirical frequency distributions of RX5 in winter are compared in Fig. 9 for 1961–1990 and 2071–2100 using the bias-corrected outputs of RACMO/ECHAM simulation. Larger differences between the past and the future distribution functions are estimated in the northern gridcells (near Bratislava and Szolnok) than in the southern gridcell (near Bucharest). In the two northern gridcells the past and future frequency distributions are significantly different at 0.05 level (according to the Kolmogorov-Smirnov test). The slight difference in case of the southern gridcell representing Bucharest is not significant statistically.

The spatial distributions of projected seasonal MM mean changes of RX5 by the late-century relative to the reference period are shown in the composite maps of Fig. 10. Decreasing trend is likely to occur only in summer, which is about 5% in the northern subregions, and 15% in the southern subregions of the Carpathian domain. For the rest of the year, an overall increasing trend is projected, which is generally larger in the northern parts of the selected region than in the southern parts.

The largest increase is estimated for winter, mainly in the northern, northeastern subregions where it can exceed 35%. In autumn also quite remarkable changes (+20%) are likely to occur, especially in northeastern Hungary, the southwestern Czech Republic, and southern Poland.

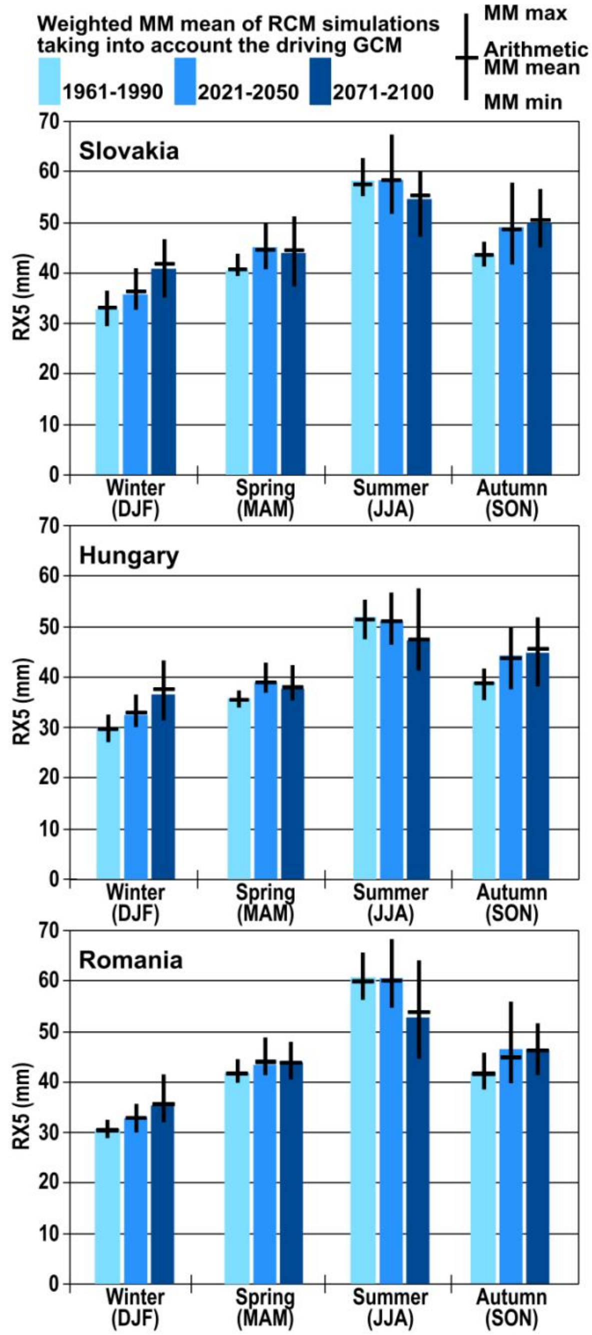

Fig. 8: Estimated RX5 values using the MM ensemble of 11 bias-corrected RCM simulations for 1961–1990, 2021–2050, and 2071–2100 in Slovakia, Hungary, and Romania (spatial averages are shown for each subregion).

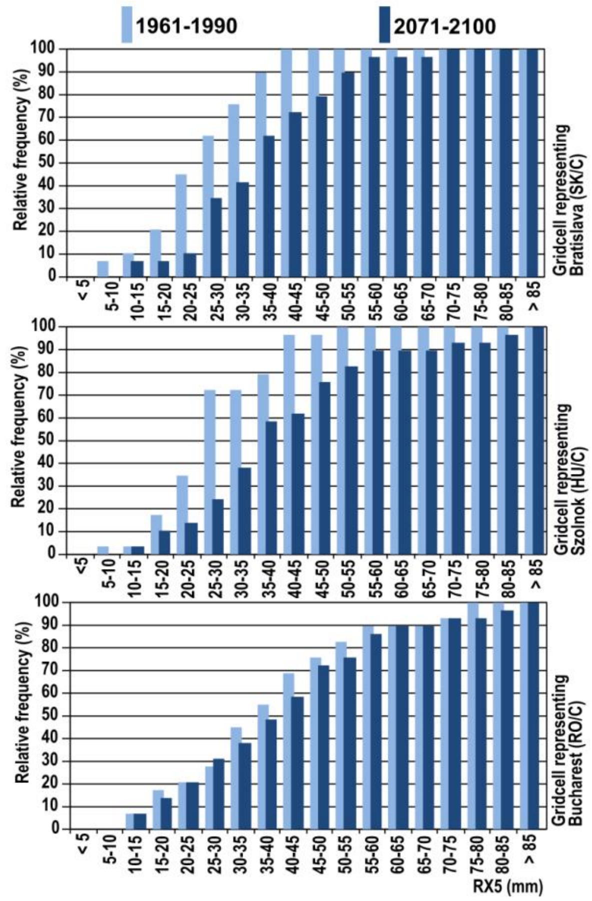

Fig. 9: Comparison of empirical frequency distributions of simulated past and future RX5 values in winter using the bias-corrected RACMO/ECHAM simulation in a representative gridcell for each subregion.

In Table III spatial averages of the estimated mean winter changes for the entire Carpathian domain and the three subregions are summarized. Considering the entire area, the largest spatial mean change (+33%) is projected by HadRM/HadCM. The smallest changes are estimated by the ARPEGE-driven RCMs.

Table III: Spatial mean estimated relative changes of RX5 (%) for winter by 2071–2100 relative to the reference period 1961–1990

Area	Carpathian domain	Slovakia	Hungary	Romania
ALADIN/A	5.6	-3.7	11.8	4.1
HIRHAM/A	7.8	13.3	5.1	4.0
HIRHAM/E	25.0	31.5	29.5	17.3
Racmo/E	21.3	35.7	25.8	27.6
RegCM/E	29.7	31.4	33.7	13.9
REMO/E	24.7	31.5	23.2	23.4
RCA/E	30.5	30.4	28.5	29.9
RCA/H	16.3	18.9	16.9	13.6
RCA3/H	28.3	38.5	50.6	22.5
CLM/H	28.2	29.9	37.5	14.5
HadRM/H	33.4	34.4	29.6	22.4

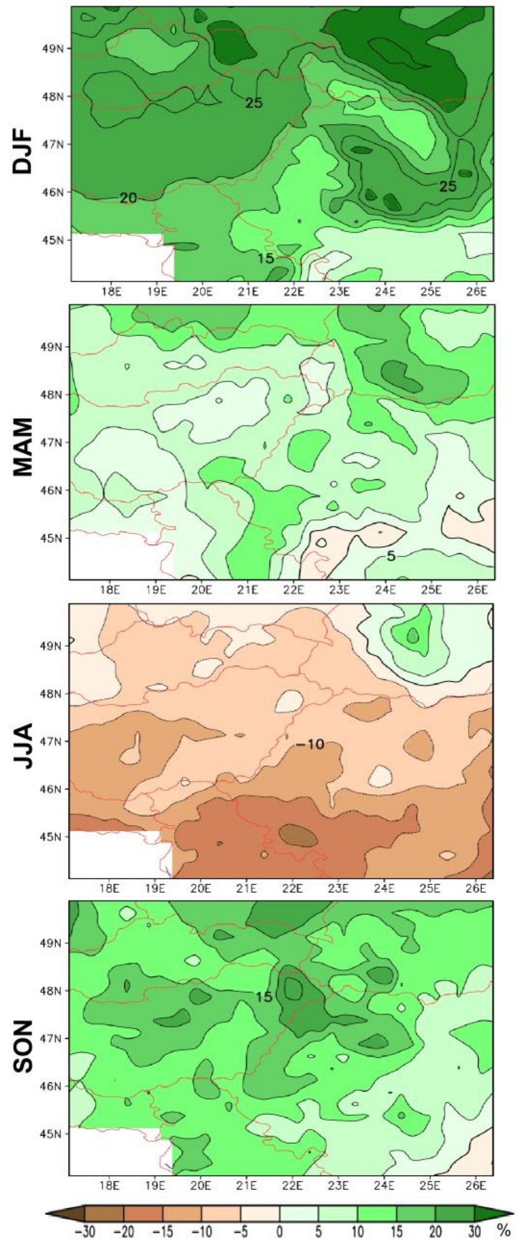

Fig. 10: MM composite maps of the relative seasonal mean changes of RX5 using the 11 bias-corrected RCM simulations for 2071–2100 (reference period: 1961–1990).

3.3. *Projected changes of high percentile values of daily precipitation*

Finally, the estimated changes of high percentile values of precipitation are presented. These indices indicate extreme precipitation events, defined by relative thresholds (i.e., different percentiles of the frequency distribution) instead of absolute value thresholds (e.g, 10 mm, 20 mm).

The 99^{th} percentile of daily precipitation (R99p) is likely to increase in all seasons, except in summer (Fig. 11). The relative MM mean changes by 2071–2100 are +26%, +21%, +18% in winter in Slovakia, Hungary, and Romania, respectively. Estimated MM mean increases of R99p in autumn are also substantial for all the three subregions: +20% (SK/C), +19% (HU/C), and +13% (RO/C),. The largest increasing trend is projected for Slovakia for winter: the MM mean spatial average value of R99p is 15 mm in the reference period, whereas it can reach 19 mm by the end of the 21^{st} century. The largest decrease (6%) is estimated for the summer season, for Romania.

Fig. 12 shows the spatial structure of the projected seasonal MM mean changes of R99p by the end of the 21^{st} century. Increasing trend by more than 20% is estimated for winter in the northern areas, for autumn in the middle part of the domain, and for spring in the northeastern Carpathian mountains. Slight decreasing trend is projected only for summer, which is likely to exceed 10% in th southern part of the Carpathian domain.

Considering the 95^{th} percentile of daily precipitation similar conclusions can be drawn than for R99p. Larger increasing tendencies are estimated for winter (generally +20% on average) and autumn (generally +10% on average), especially, in the northern regions (Slovakia and Hungary). In the summer season decreasing trend is likely to occur, which is more pronounced in case of R95p than R99p. The MM mean of the spatial average change is –13%, –18%, and –23% in Slovakia, Hungary, and Romania, respectively, which implies a general zonal structure in the estimated MM change. In Romania MM mean value of summer average R95p is 14 mm in the reference period, bias-corrected RCM outputs suggest a substantial decrease in the future to 10 mm by the late-century.

In addition to the R95p and R99p percentile values themselves, the fraction of total precipitation above the 95^{th} and 99^{th} percentile values were also calculated (R95pGT and R99pGT, respectively). Our results suggest increasing trends for all seasons and for all the selected subregions.

Overall, the larger the percentile, the larger the projected change. The largest relative MM average change (+57–58%) is projected for Slovakia and Hungary, for autumn in case of R99p. Specifically, this means for instance in Slovakia that the MM mean fraction of total precipitation above the 99^{th} percentile is 14% in 1961–1990, and it can reach 22% in 2071–2100. The MM mean increases of fraction of total precipitation above the 95^{th} percentile are about 20% in winter and 15% in autumn.

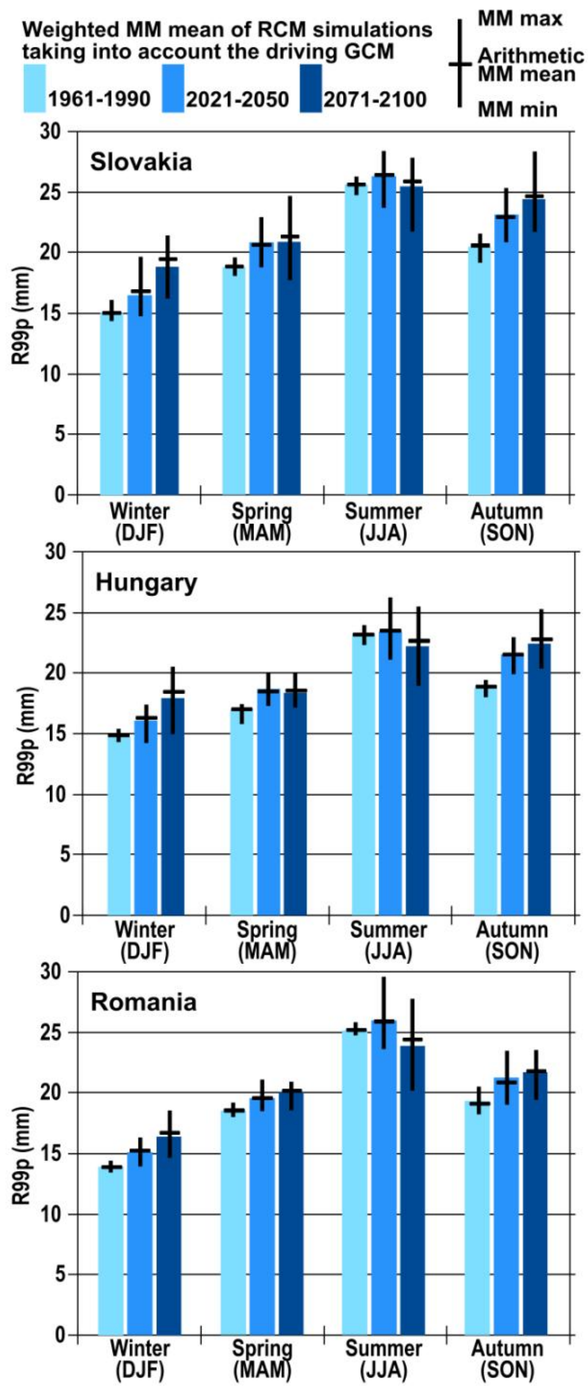

Fig. 11: Estimated R99p values using the MM ensemble of 11 bias-corrected RCM simulations for 1961–1990, 2021–2050, and 2071–2100 in Slovakia, Hungary, and Romania (spatial averages are shown for each subregion).

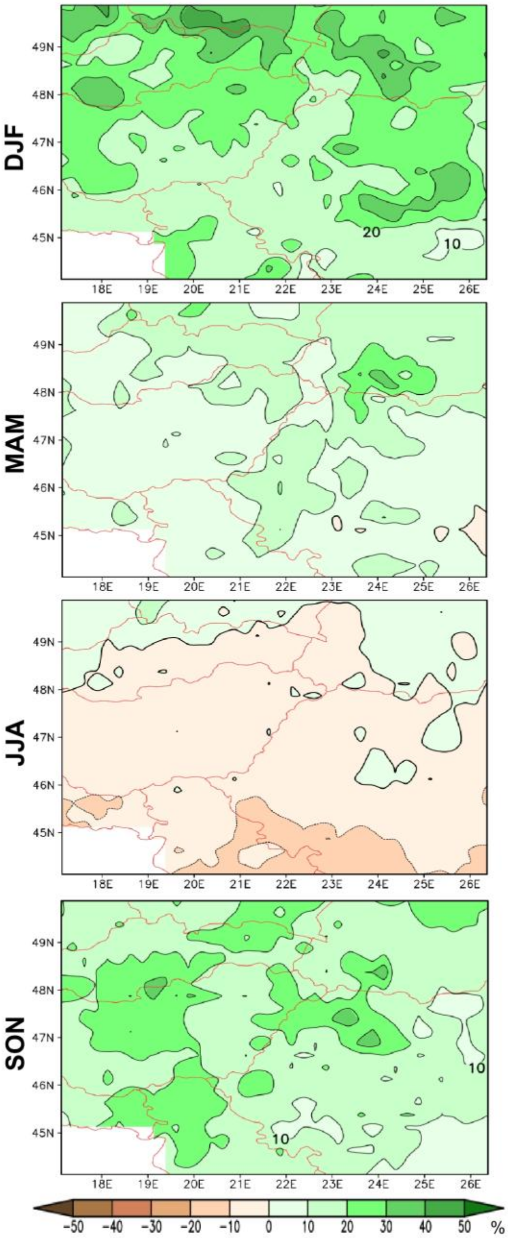

Fig. 12: MM composite maps of the relative seasonal mean changes of R99p using the 11 bias-corrected RCM simulations for 2071–2100 (reference period: 1961–1990).

4. CONCLUSIONS

Estimated seasonal changes of extremes related to the lack or the excess of precipitation using bias-corrected daily outputs of 11 RCM simulations have been presented for the Carpathian region in this paper. According to our results, regional climate change results in more intense and more frequent precipitation extremes in Central/Eastern Europe. For instance, in case of the mean dry spell ~40% increase is estimated for summer, hence substantially drier climatic conditions are projected for the future (Pongrácz et al., 2013, 2014) – especially, in the southern parts of the region. In winter and autumn more intense precipitation are very likely to occur in the 21st century (Bartholy et al., 2015), which has been clearly illustrated by the highest five-day precipitation amount and the high percentile values. All the three indices discussed here (RX5, R95p, R99p) are projected to increase in winter and autumn. Overall, due to the consequences and local impacts of global warming, the Central/Eastern European region should be prepared both for more frequent large floods and more frequent, more severe droughts in the future.

Acknowledgements. Research leading to this paper has been supported by the following sources: the Hungarian Scientific Research Fund under grants K-78125, K-83909, and K109109, the European Union and the European Social Fund through project FuturICT.hu (TÁMOP-4.2.2.C-11/1/KONV-2012-0013), and the AGRÁRKLIMA2 project (VKSZ_12-1-2013-0001). The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged. Furthermore, we acknowledge the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com), and the data providers in the ECA&D project (http://eca.knmi.nl). We also acknowledge the CARPATCLIM Database © European Commission - JRC, 2013.

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