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ANALYSIS OF SIMULATED MEAN AND EXTREME CLIMATE TRENDS FOR THE EASTERN/CENTRAL EUROPEAN REGION BASED ON REGCM OUTPUTS USING A1B SCENARIO

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1. INTRODUCTION

Fine-scale features of the expected regional climate change can be analyzed and evaluated using regional climate model (RCM) experiments, which are nested in large-scale global climate models. One of the available RCMs, namely, model RegCM is applied to assess the 21st century climatic trends for the Carpathian basin (located in Eastern/Central Europe) and its vicinity. Projected regional climate change is evaluated using simulations for 1961-1990 (as the reference period), 2021-2050 and 2071-2100 (as the target periods). The RegCM experiments consider A1B scenario, which projects the global population to reach 9 billion within a few decades, and then, to decrease to about 7 billion by the end of the 21st century (Nakicenovic and Swart, 2000). According to the A1B scenario fast economical and technological growths are projected, and the increase of CO_2 concentration is slowing down by 2100, when the projected CO_2 concentration level may exceed 715 ppm.

2. REGIONAL CLIMATE MODEL REGCM

Model RegCM was originally developed by Giorgi et al. (1993a, 1993b) and then modified, improved and discussed by Giorgi and Mearns (1999) and Pal et al. (2000). The RegCM model (version 3.1) is available from the Abdus Salam International Centre for Theoretical Physics (ICTP). The dynamical core of the RegCM3 is fundamentally equivalent to the hydrostatic version of the NCAR/Pennsylvania State University mesoscale model MM5 (Grell et al., 1994). Surface processes are represented in the model using the Biosphere-Atmosphere Transfer Scheme, BATS (Dickinson et al., 1993). The non-local vertical diffusion scheme of Holtslag et al. (1990) is used to calculate the boundary layer physics. In addition, the physical parametrization is mostly based on the comprehensive radiative transfer package of the NCAR Community Climate Model, CCM3 (Kiehl et al., 1996). The mass flux cumulus cloud scheme of Grell (1993) is used to represent the convective precipitation with two possible closures: Arakawa and Schubert (1974) and Fristch and Chappell (1980).

Model RegCM can use initial and lateral boundary conditions from global analysis dataset, the output of a GCM or the output of a previous RegCM simulation. In our experiments these driving datasets are compiled from the Centre for Medium-range Weather Forecasts (ECMWF) ERA-40 reanalysis database (Uppala et al., 2005) using 1° horizontal resolution, and in case of scenario runs (for 3 time slices: 1961-1990, 2021-2050, and 2071-2100) the ECHAM5 GCM using 1.25° spatial resolution (Roeckner et al., 2006). The selected model domain covers Central/Eastern Europe centering at 47.5°N, 18.5°E and contains 120x100 grid points with 10 km grid spacing and 18 vertical levels (Fig. 1). The target region is the Carpathian Basin with the 45.15°N, 13.35°E southwestern corner and 49.75°N, 23.55°E northeastern corner (Torma et al., 2008).

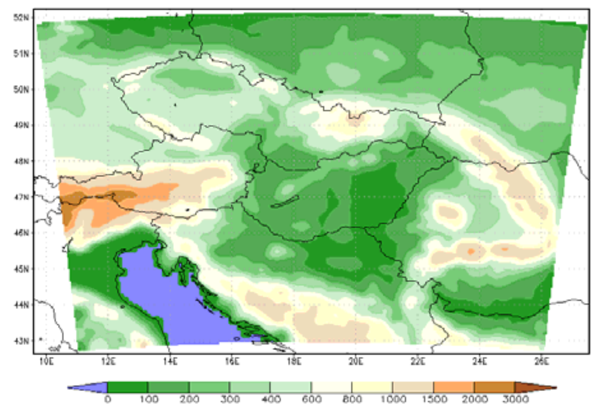

Fig. 1. Model domain and topography (m) at a grid spacing of 10 km covering the Carpathian basin and its vicinity.

Validation of RegCM for the selected domain is discussed by Bartholy et al. (2009). Precipitation is overestimated by 35% in winter, 25% in spring, 5% in summer, and 3% in autumn (on average for the whole domain). Persistent drying bias occurred in the southern part of the Alps. For Hungary, the seasonal bias values are acceptable and less than 23% (except in spring, when it's 29%). The annual bias is +16% for the Hungarian grid points. Temperature is over-estimated in winter (by 1.1 °C), and underestimated in the other seasons (by 0.3 °C, 0.2 °C, and 0.1 °C in spring, summer, and autumn, respectively). The largest bias values are identified in the high mountainous regions (Alps, southern part of the Carpathians). For Hungary, the seasonal bias values are +1.3 °C, -0.5 °C, -0.5 °C, and -0.2 °C for DJF, MAM, JJA, SON, respectively. The annual bias is less than 0.05 °C for the Hungarian grid points.

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3. ANALYSIS OF FUTURE REGIONAL TEMPERATURE TRENDS

The simulation results suggest that temperature change in the simulated regional climate is evident in all season for both future time slices. Warming is expected in all regions (Fig. 2), the spatially averaged seasonal changes (for the entire domain) are projected as follows: +1.8 °C in winter, +1.6 °C in spring, +0.6 °C in summer, and +0.8 °C in fall by 2021-2050, and +1.8 °C in winter, +1.6 °C in spring, +0.6 °C in summer and +0.8 °C in fall by 2071-2100 (relative to the 1961-1990 reference period).

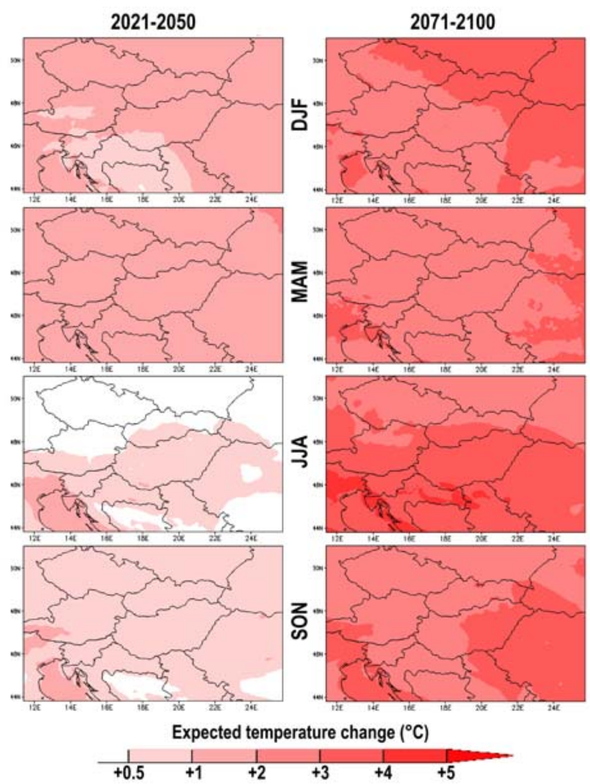

Fig. 2: Projected seasonal temperature change for the selected domain using A1B scenario (reference period: 1961-1990)

Table I: Projected annual and seasonal mean temperature change (°C) for Hungary for 2021-2050 and 2071-2100 (reference period: 1961-1990)

	2021-2050	2071-2100
Annual	1.1	3.1
Winter (DJF)	1.1	2.9
Spring (MAM)	1.6	2.8
Summer (JJA)	0.7	3.5
Fall (SON)	0.8	3.0

The projected warming for the Hungarian grid points are summarized in Table I. The annual temperature increase in Hungary is projected to exceed 1 °C and 3 °C on average by 2021-2050 and 2071-2100, respectively. The largest seasonal warming is projected for spring (1.6 °C) by the middle of the 21st century, and for summer (3.5 °C) by the end of the 21st century. Overall, the seasonal warming rate for Hungary is about 0.3 °C/decade (Fig. 3), the largest increase rate is projected in summer (0.31 °C/decade), the smallest in autumn (0.26 °C/decade).

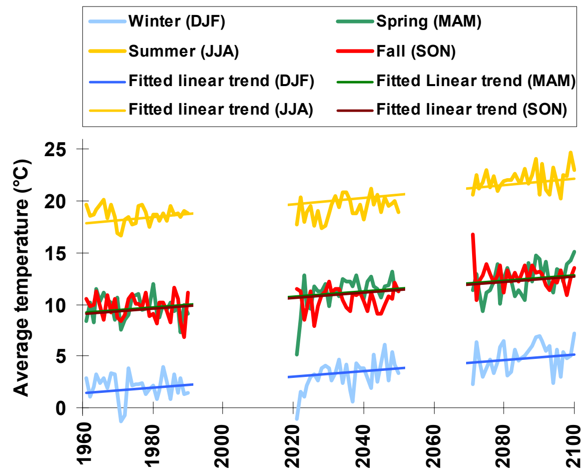

Fig. 3: Spatial average of seasonal mean simulated temperature taking into account all the grid points located in Hungary, 1961-2100

4. ANALYSIS OF FUTURE REGIONAL PRECIPITATION TRENDS

Precipitation seasonal changes in the simulated climate are naturally far more variable in space than temperature. For Hungary, in general, drier climate is projected for 2021-2050 (on annual scale by 7% on average), especially, in the eastern and southern parts of the country (left panel of Fig. 4). The spatially averaged expected seasonal changes for Hungary are as follows: -9% in winter, -10% in spring, -2% in summer, and -4% in fall. The largest precipitation decrease is expected close to southern edges of the Alps, which can be caused by the shadowing effect of the mountain, the weakening of the uplifting force. In the southeastern part of the domain (outside of Hungary) a large precipitation increase is expected in every season, which can be related to stronger low level easterlies in future climate. If we look at the end of the century (right panel of Fig. 4), for Hungary, in general, winter and fall are expected to become wetter than in the reference period (by 8% and 5% on spatial average), especially, in the northern part of the country. Drier summers (by 18%) and slightly drier springs (by 5%) are projected for 2071-2100 compared to 1961-1990. On annual scale, a slight decrease (by about 2%) is projected in Hungary, which is not significant.

For the entire domain summer is expected to become drier in general, however, the southeastern part of the domain is projected to become wetter by 2071-2100 as well, as by 2021-2050.

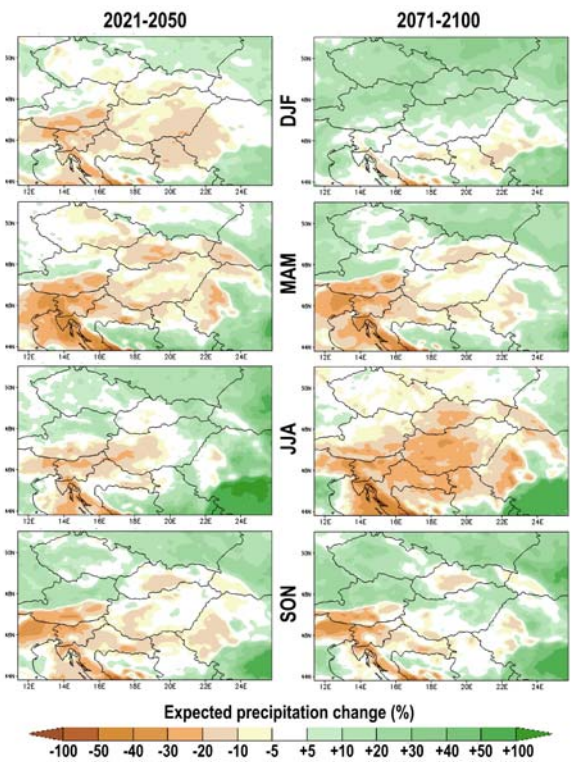

Fig. 4: Projected seasonal precipitation change for the selected domain using A1B scenario (reference period: 1961-1990)

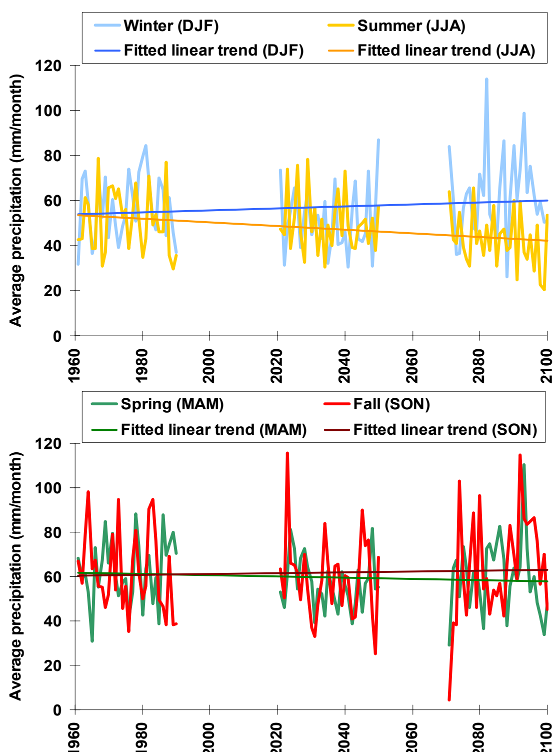

Fig. 5: Spatial average of seasonal mean simulated precipitation taking into account all the grid points located in Hungary, 1961-2100

Simulated time series of spatial average of seasonal precipitation are illustrated in Fig. 5. The spatial average is calculated from all the grid point values, located inside the borderline of Hungary. The upper graph shows the winter and summer trends, which are opposite to each other. The summer decrease rate is about twice as large as the winter increase rate. Furthermore, the interannual variability of winter precipitation is projected to increase significantly by 2071-2100. The lower graph illustrates the simulated time series for spring and autumn. The trends are not significant in either of these seasons, however, the interannual variability of fall precipitation is projected to increase considerably.

5. TREND ANALYSIS OF EXTREME TEMPERATURE CONDITIONS

Simulated winter and summer daily maximum temperature are projected to increase by both future time slices relative to the reference period (1961-1990). In Hungary the projected changes are about 1 °C by the middle of the 21st century, and about 3 °C in winter and 4 °C in summer by the end of the 21st century (Fig. 6). The projected winter warming is larger than the summer warming for the 2021-2050 period, while for the 2071-2100 it is smaller.

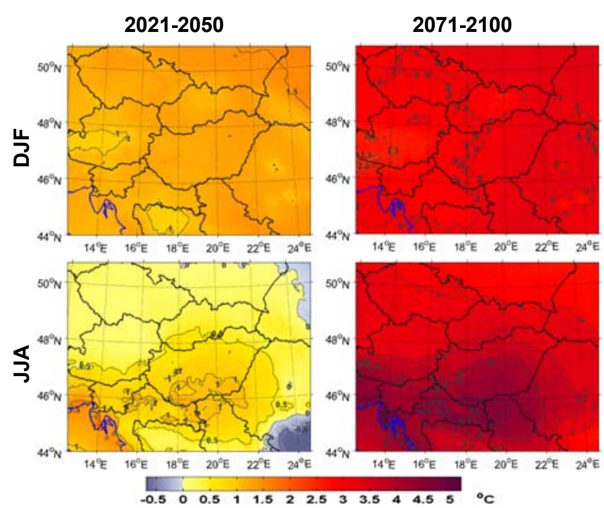

Fig. 6: Projected mean seasonal change of daily maximum temperature for A1B scenario (reference period: 1961-1990)

Summer days (when the T_{max} is larger than 25 °C) may occur mainly in May-September in Hungary. In the reference period 6-20% of the total days are simulated as summer days, which means about 22-73 days in a year. Evidently, in the mountainous subregions (e.g., the Eastern Alps or the Carpathians), less summer days occur than in the lowlands of Hungary. By the near future (2021-2050) it is not likely to change too much in Hungary (the increase is only about 1-3%, which is not exceeding a week). However, by the end of the century (2071-2100) the annual percentage of summer days is likely to increase by about 7-14% in Hungary (left panel of Fig. 7). This implies that the annual number of summer days is projected to exceed 110 days in a year in the southern part of the country, and may even reach as much as 120 days per year.

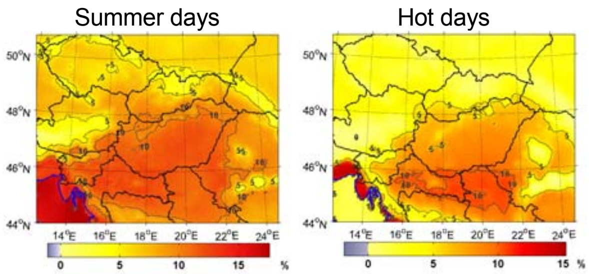

Fig. 7: Projected mean change of annual percentage of summer and hot days by 2071-2100 using A1B scenario (reference period: 1961-1990)

Hot days (when the T_{max} is larger than 30 °C) may occur mainly in June-August in Hungary. In the reference period less than 8% of the total days are simulated within the country as hot days, which means less than 30 days/year on average. Similarly to the percentage of summer days, the simulated changes by 2071-2100 in Hungary are much larger than the changes by 2021-2050 (4-12% and 1-3%, respectively). Also similarly to the summer days, the large frequency changes are projected to occur in the southern part of the country (right panel of Fig. 7) where according to the RegCM simulations about 62 days will be considered hot days yearly.

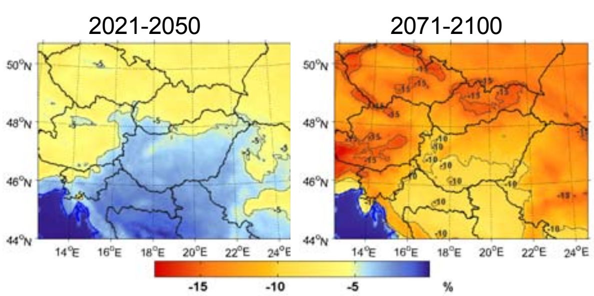

Fig. 8: Projected mean change of annual percentage of frost days by 2021-2050 and 2071-2100 using A1B scenario (reference period: 1961-1990)

Unlike the previous temperature parameters, the occurrence of frost days (when $T_{min} < 0$ °C) is mainly in the winter half-year. According to the RegCM climate simulations 55-128 days can be considered as frost days in Hungary in the reference period (1961-1990): in the lowlands (below 200 m above the sea level) less than 70 days/year, in the higher elevated subregions (i.e., the northern/northeastern part of the country) frost days are more frequent, exceeding 100 days/year. In the future, the frequency of frost days is likely to decrease, by about 3-8% and 8-14% in Hungary by 2021-2050 and 2071-2100, respectively. Thus, by the end of the 21st century, the annual number of frost days is projected not to exceed 55 days, and even smaller in the lowlands of the country, less than 25 days. The decrease is evidently larger in mountainous regions where frost days occurred more frequently in the past.

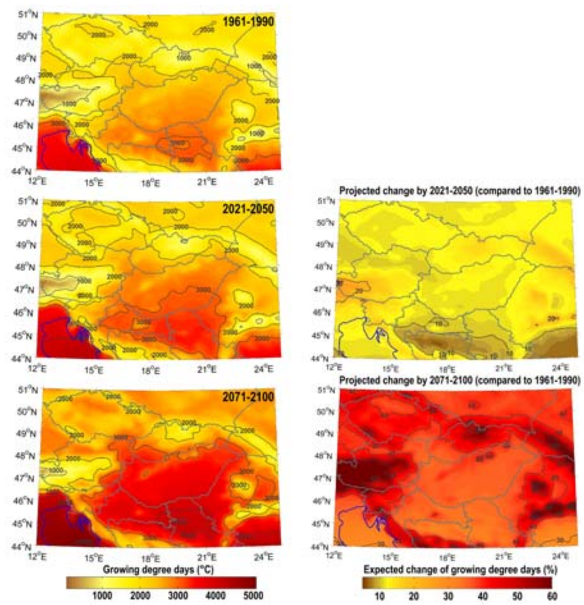

Fig. 9: Growing degree days (Sum of (T_{mean} – 4 °C) for all days with T_{mean} > 4 °C) based on simulated daily mean temperature

Among the temperature related extreme indices, one more example is selected, which has a strong influence on agriculture. Growing degree days (Fig. 9) are defined as the annual sum of the daily mean temperature values (T_{mean}) decreased by 4 °C when T_{mean} is larger than 4 °C. According to the simulated results, in the entire domain an evident increase of the growing degree days is expected for both future time slices compared to the reference period (1961-1990). Projected changes are larger for 2071-2100 than for 2021-2050 (in Hungary, the growing degree days are projected to increase by about 38% and 12% on average, respectively)

6. TREND ANALYSIS OF PRECIPITATION-RELATED EXTREME CLIMATE CONDITIONS

Simulated winter wet-day mean precipitation is projected mostly to decrease in eastern Hungary and increase in western Hungary by 2021-2050 (Fig. 10). In summer, large portion of the country (especially in east) may expect an increase of mean wet-day precipitation amount, decrease is projected only around the lake Balaton. The RegCM simulations show similar changing pattern by the end of the century for summer. In winter, the wet-day mean precipitation is projected to increase in the entire country (Table II). The largest increase is about 30% in the northern mountainous region of Hungary.

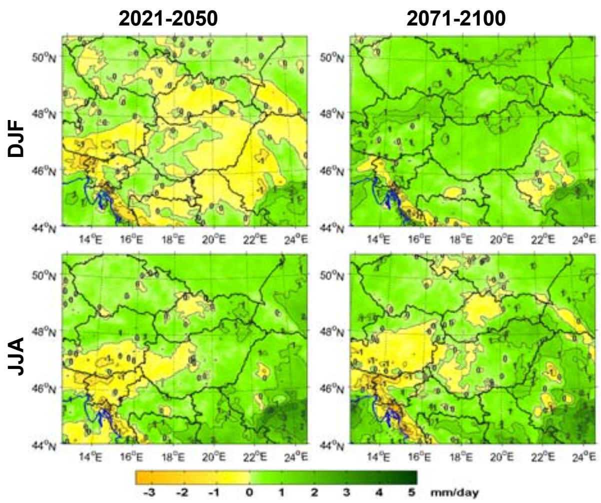

Fig. 10: Projected mean seasonal change of mean wet-day precipitation for A1B scenario (reference period: 1961-1990)

Table II: Projected mean seasonal change of wet-day precipitation for Hungary for 2021-2050 and 2071-2100 (reference period: 1961-1990)

Season	2021-2050	2071-2100
Winter (DJF)	(-0.5; +0.5) mm/day (-10%; +10%)	(0; 1.2) mm/day (0%; +20%)
Summer (JJA)	(-1; +1.2) mm/day (-10%; +22%)	(-0.5; +2) mm/day (-7%; +30%)

The percentage of wet days is projected to decrease for both winter and summer, and for both future time slices in Hungary. The simulated changes are larger by 2071-2100 than 2021-2050 (Fig. 11). The largest changes are projected for summer by the end of the 21st century, when the percentage is likely to decrease by as much as 10% in the country, which means about 9 days less wet day in a season (Table III).

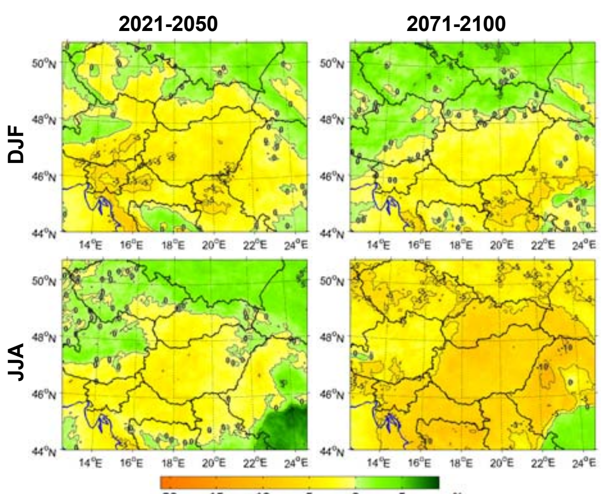

Fig. 11: Projected mean seasonal change of percentage of wet days for A1B scenario (reference period: 1961-1990)

Table III: Simulated mean seasonal percentage of wet days for Hungary for 1961-1990 (reference period), 2021-2050, and 2071-2100

Season	1961-1990	2021-2050	2071-2100
DJF ratio Simulated change	25-43% -	22-45% (-5%; 0%)	25-45% (-3%; 0%)
JJA ratio Simulated change	25-40% -	20-40% (-5%; +2%)	15-30% (-10%; -5%)

The simulated greatest 1-day total rainfall is projected to increase in Hungary by 2071-2100 in winter, the largest changes are expected in the northern mountainous region where it may increase as much as by 40% compared to the reference period (Fig. 12). Similar changes are projected in summer for the eastern part of the country, while for the western part the greatest 1-day total rainfall a decrease is expected on the base of the RegCM simulations. The seasonal mean daily maximum precipitation values determined from the RegCM outputs of the grid points located in Hungary for the three time slices and the corresponding projected changes relative to the reference period are shown in Table IV for winter and summer.

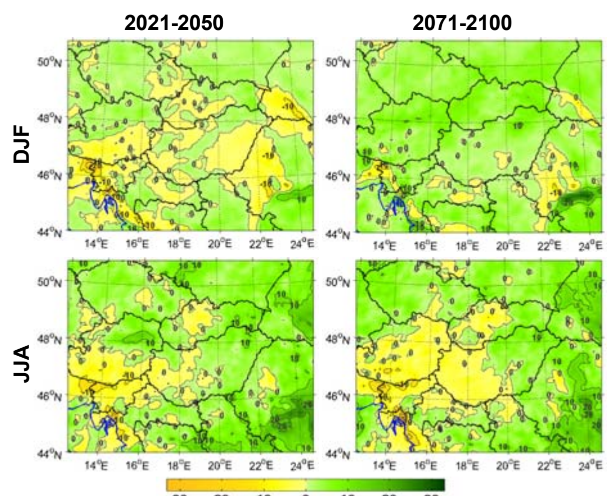

Fig. 12: Projected mean seasonal change of the greatest 1-day total rainfall for A1B scenario (reference period: 1961-1990)

Table IV: The simulated mean seasonal greatest 1-day total rainfall for Hungary for 1961-1990 (reference period), 2021-2050, and 2071-2100

Season	1961-1990	2021-2050	2071-2100
DJF Simulat. change	15-30 mm -	15-35 mm (-5 mm; +5 mm) (-20%; +25%)	18-40 mm (0 mm; +10 mm) (0%; +40%)
JJA Simulat. change	20-30 mm -	30-40 mm (-5 mm; +10 mm) (-20%; +50%)	20-30 mm (-5 mm; +10 mm) (-25%; +50%)

Similarly to the greatest 1-day total rainfall, the simulated greatest 5-day total rainfall is projected to increase in Hungary by 2071-2100 in winter, and in the northern and eastern regions of the country in summer (Fig. 13). This parameter is likely to decrease in the western and central parts of Hungary. By 2021-2050 the pattern of the winter simulated change in Hungary is very different from that of the 2071-2100, namely, the greatest 5-day total rainfall is projected to decrease in Hungary. The pattern of the summer simulated change in Hungary by 2021-2050 is similar to that of the 2071-2100 change, but the decreasing trend is projected for less area in the country. The seasonal mean 5-day maximum precipitation amounts determined from the RegCM outputs of the grid points located in Hungary for the three time slices and the corresponding projected changes relative to the reference period are shown in Table V for winter and summer.

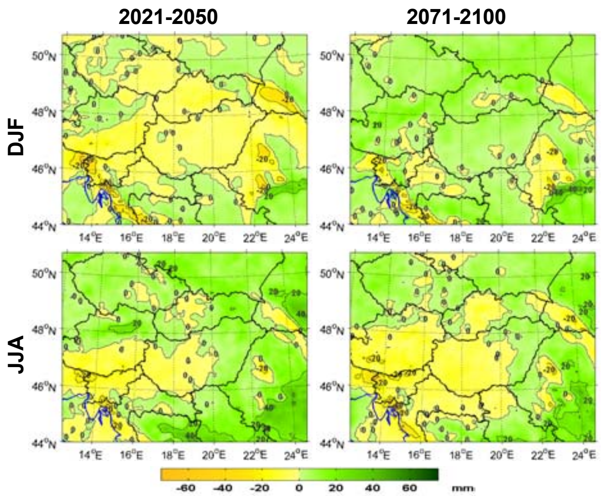

Fig. 13: Projected mean seasonal change of the greatest 5-day total rainfall for A1B scenario (reference period: 1961-1990)

Table V: The simulated mean seasonal greatest 5-day total rainfall for Hungary for 1961-1990 (reference period), 2021-2050, and 2071-2100

Season	1961-1990	2021-2050	2071-2100
DJF Simulat. change	30-50 mm -	30-50 mm (-10 mm; +5 mm) (-15%; +10%)	30-60 mm (0 mm; +15 mm) (-5%; +25%)
JJA Simulat. change	30-55 mm -	30-60 mm (-10 mm; +15 mm) (-20%; +30%)	30-55 mm (-15 mm; +10 mm) (-30%; +30%)

Among the precipitation related extreme indices, one example is selected, which reflects the drought conditions. Annual maximum number of consecutive dry days are shown in Fig. 14 calculated from the simulated daily precipitation amount time series. The results suggest that in general, an increase is projected for the southern part of the domain, and a decrease for the northern part. Expected changes in absolute value are larger for 2071-2100 than for 2021-2050. In Hungary for both periods, consecutive dry days are projected to increase, thus, resulting in more severe drought, especially by the end of the 21st century (in some places the projected increase may exceed 5 days, which means 25% of the current climatic conditions).

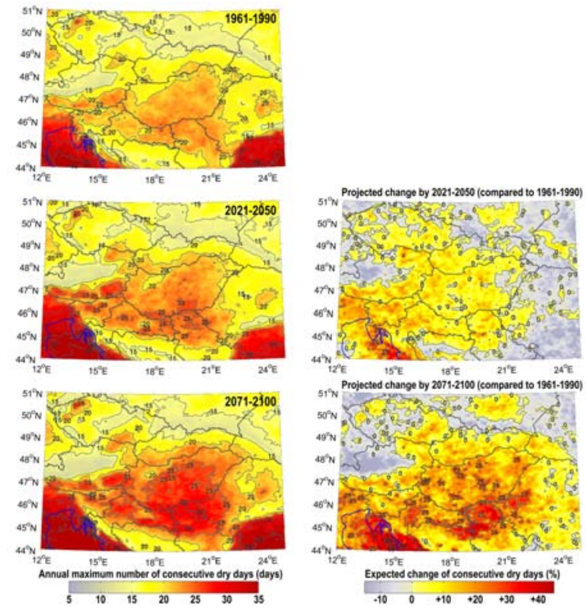

Fig. 14: Maximum number of consecutive dry days based on simulated daily precipitation amounts.

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