P1.26 EVALUATION OF SIMULATED CLIMATE TRENDS OF THE CARPATHIAN BASIN USING PRECIS OUTPUTS FOR 2071-2100

Judit Bartholy*, Rita Pongrácz, Ildikó Pieczka
Eötvös Loránd University, Budapest, Hungary

1. INTRODUCTION

The results from coarse resolution global climate models (GCM) can only be considered as a first-guess of regional climate change consequences of global warming. Regional climate models (RCM) nested in GCMs may lead to better estimations of future climate conditions in the European subregions since the horizontal resolution of these RCMs is much finer than the GCMs' (IPCC, 2007). Expected regional climate change focused to the Carpathian basin (located in Central/Eastern Europe) is modelled by four different RCMs (Szepszo et al., 2008). Two of them (RegCM and PRECIS) are run by the Department of Meteorology, Eötvös Loránd University, Budapest (Bartholy et al., 2006; Torma et al., 2008). The other two RCMs are run by the Hungarian Meteorological Service (Csima and Horanyi, 2008, Szepszo and Horanyi, 2008): ALADIN (developed by the Meteo-France) and REMO (developed by the Max Planck Institute, Hamburg).

The present paper discusses the results from the regional climate modeling experiments using PRECIS. First, model PRECIS is introduced, which is then used to analyze the simulated temperature and precipitation change for 2071-2100 for Hungary. Besides the evaluation of mean climate changes, extreme conditions are also discussed. Finally, the main conclusions are summarized in the last section.

2. REGIONAL CLIMATE MODEL PRECIS

The installation and the adaptation of the regional climate model PRECIS at the Department of Meteorology, Eötvös Loránd University (Budapest, Hungary) has started in 2004 (Bartholy et al., 2006). At the beginning of our studies, version 1.3 was used but the results presented in this paper are from an updated model version (1.4.8). The PRECIS is a high resolution limited area model with both atmospheric and land surface modules. The model was developed at the Hadley Climate Centre of the UK Met Office (Wilson et al., 2005), and it can be used over any part of the globe (e.g., Hudson and Jones, 2002, Rupa Kumar et al., 2006, Taylor et al., 2007, Akhtar et al., 2008). The PRECIS regional climate model is based on the atmospheric component of HadCM3 (Gordon et al., 2000) with substantial modifications to the model physics (Jones et al., 2004). The atmospheric component of PRECIS is a hydrostatic version of the full primitive equations, and it applies a regular latitude-longitude grid in the horizontal and a hybrid vertical coordinate. The horizontal resolution can be set to 0.44°×0.44° or 0.22°×0.22°, which gives a resolution of ~50 km or ~25 km, respectively, at the equator of the rotated grid (Jones et al., 2004). In our studies, we used 25 km horizontal resolution for modeling the Central European climate. Hence, the target region contains 123x96 grid points (Fig. 1). There are 19 vertical levels in the model, the lowest at ~50 m and the highest at 0.5 hPa (Cullen, 1993) with terrain-following σ-coordinates (σ = pressure/surface pressure) used for the bottom four levels, pressure coordinates used for the top three levels, and a combination in between (Simmons and Burridge, 1981). The model equations are solved in spherical polar coordinates and the latitude-longitude grid is rotated so that the equator lies inside the region of interest in order to obtain quasi-uniform grid box area throughout the region. An Arakawa B grid (Arakawa and Lamb, 1977) is used for horizontal discretization to improve the accuracy of the split-explicit finite difference scheme. Due to its fine resolution, the model requires a time step of 5 minutes to maintain numerical stability (Jones et al., 2004). In the post processing of the RCM outputs, daily mean values are used.

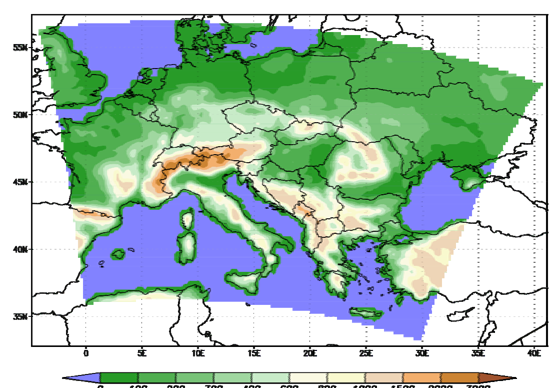

Fig. 1. Topography of the selected Central European integration domain used in model PRECIS.

In case of the control period (1961-1990), the initial and the lateral boundary conditions for the regional model are taken from (i) the ERA-40 reanalysis database (Uppala et al., 2005) using 1° horizontal resolution, compiled by the European Centre for Medium-range Weather Forecasts (ECMWF), and (ii)

* *Corresponding author address*: Judit Bartholy, Eötvös Loránd University, Dept. of Meteorology, Pf. 32. Budapest, Hungary, H-1518; e-mail: bari@ludens.elte.hu

the HadCM3 ocean-atmosphere coupled GCM using ~150 km as a horizontal resolution. For the validation of the PRECIS results CRU TS 1.2 (Mitchell and Jones, 2005) datasets are used.

According to the simulation outputs, PRECIS is able to sufficiently reconstruct the climate of the reference period in the Carpathian Basin (Bartholy et al., 2009a, 2009b). The temperature bias (i.e., difference between simulated and observed annual and seasonal mean temperature) is found mostly within (-1 °C;+1 °C). The largest bias values are found in summer, when the average overestimation of PRECIS over Hungary is 2.2 °C.

Both spatial and temporal variability of precipitation is much larger than temperature variability. The spatially averaged precipitation is overestimated in the entire model domain, especially, in spring and winter (by 22% and 15%, respectively). The precipitation of the high-elevated regions is overestimated (by more than 30 mm in each season), while the overestimation of the seasonal precipitation occurring in the plain regions is much less in spring than in the mountains (Bartholy et al., 2009c). The summer and autumn mean precipitation amounts are underestimated in the lowlands. The underestimation is larger in the southern subregions than in the northern part of the domain. Inside the area of Hungary the seasonal means are slightly underestimated (by less than 10% on average), except spring. In spring, the precipitation in Hungary is overestimated by 35% on average, and bias values are significantly large (in 99% of all the gridpoints located inside the Hungarian borders).

Temperature and precipitation bias fields of the PRECIS simulations can be considered acceptable if compared to other European RCM simulations (Jacob et al., 2007, Bartholy et al., 2007). Therefore, model PRECIS can be used to estimate future climatic change of the Carpathian Basin. For the future (2071-2100), two experiments were completed so far, namely, considering A2 and B2 global emission scenarios (Nakicenovic and Swart, 2000). A2 scenario is less optimistic than B2, which is indicated by the CO_2 concentration level projected by 2100 (856 ppm and 621 ppm, respectively). Results for the expected change of temperature and precipitation (compared to 1961-1990) are discussed below.

3. ANALYSIS OF FUTURE REGIONAL TEMPERATURE TRENDS

For 2071-2100, both A2 and B2 scenario runs are completed. Since A2 is associated with higher CO_2 concentration than B2, it is not surprising that this scenario projects higher temperature values in the Carpathian Basin (due to the high dependence of temperature on CO_2 concentration). The expected annual and seasonal mean temperature change for Hungary is shown in Table I. The largest warming is expected for summer (the spatial average of the expected change is 6 °C for B2, and 8 °C for A2). The amplitude of the projected change is larger in case of A2 than B2 scenario in each season. The mean temperature in autumn is likely to increase more than in spring, thus autumn may become warmer than spring due to the robust warming at late summer/early autumn (Bartholy et al., 2009c). The simulated change is significant at 0.05 level in all the four seasons for each grid point (Pieczka et al., 2010).

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

	B2	A2
Annual	4.0	5.4
Winter	3.2	4.2
Spring	3.1	4.2
Summer	6.0	8.0
Autumn	3.9	5.2

The year-to-year variation of seasonal mean temperature for Hungary is presented in Fig. 2. It shows remarkable warming for each season and for both scenarios. The year-to-year variation in the transient seasons is also likely to increase up to 1.5-2 times of their current value in case of A2, which is highlighted by the standard deviation values shown in Table II. Standard deviation of winter mean temperature is projected to slightly decrease in case of both scenarios. According to the simulations, the presently quite large standard deviation in summer is likely to decrease slightly for B2, and increase slightly for A2 scenario.

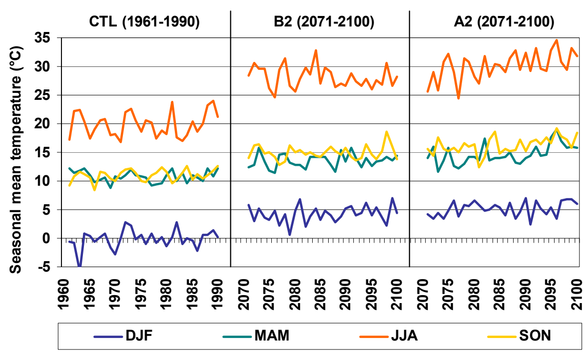

Fig. 2: Year-to-year variation of seasonal mean temperature (°C) for Hungary

Table II: Temporal standard deviation of simulated annual and seasonal mean temperature (°C) for the periods of 1961-1990 (CTL) and 2071-2100 (A2 and B2 scenario) for Hungary

	CTL	B2	A2
Annual	1	0.8	1.3
Winter	1.7	1.4	1.3
Spring	0.9	1.2	1.7
Summer	2.2	1.9	2.4
Autumn	1	1.2	1.5

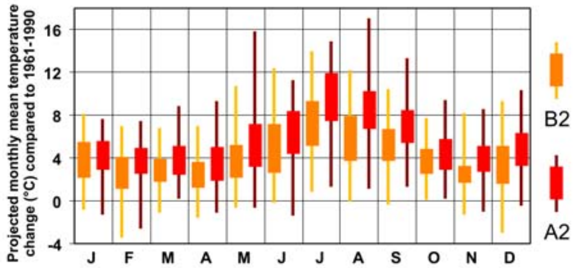

Fig. 3: Distribution of expected monthly temperature change (°C) in the gridpoints located within Hungary for 2071-2100 (reference period: 1961-1990)

In Fig. 3 Box-Whisker diagrams calculated from the simulated values of monthly temperature anomaly for 2071-2100 (relative to the 1961-1990 monthly mean values) in all the gridpoints located within Hungary, are shown for both scenarios. The small rectangles represent the lower and the upper quantiles, and the vertical lines indicate the minimum and the maximum of the sample (the size of the entire sample is 6,870=229×30). The lower quantile values are always positive (and mostly in summer and autumn the minimum also), which underlines the expected warming trend. The middle 50% of the sample is represented by the boxes: the larger the size, the larger the variance of the sample. In case of the two different scenarios, the total ranges of the middle-half of the monthly anomalies are similar (around 2-5 °C), the largest ranges are projected in the summer months. Negative anomalies compared to the mean of 1961-1990 are likely to occur by 2071-2100 only in a few cases, mainly in the winter months (especially in February).

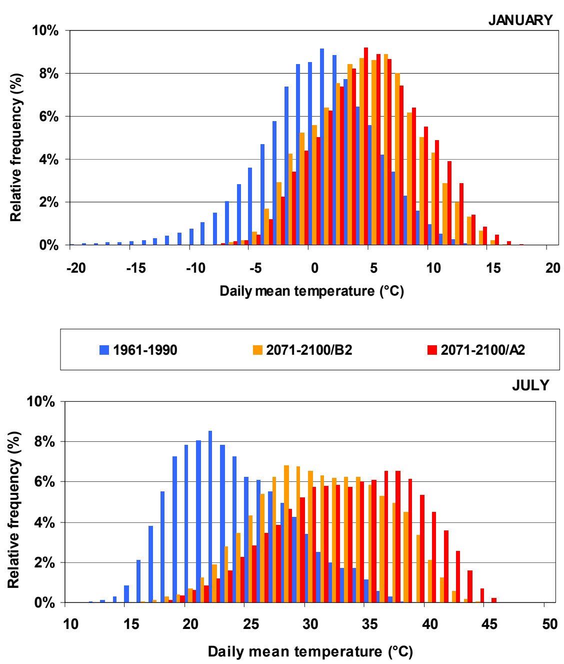

Fig. 4: Distribution change of simulated daily mean temperature in January (top) and July (bottom)

The distribution change of simulated daily mean temperature is also analyzed. The results for January and July (being the coldest and warmest months in Central Europe) can be seen in Fig. 4. In January the distribution is projected to shift towards the larger temperature values (the expected monthly mean change is about +3.8 °C and +4.3 °C in case of B2 and A2 scenario, respectively), which implies less cold and more warm and record warm periods in winter. In July (shown in the lower panel) not only a shift, but also a shape-change of the empirical distribution can be recognized. The relative frequency values of different temperature intervals are likely to change remarkably (the expected monthly mean temperature increase is +7.2 °C and +9.4 °C in case of B2 and A2 scenario, respectively). The simulations imply less cool and more hot periods, and larger record hot conditions in the last three decades of the 21st century than in the reference period. This frequency shift is projected to become larger when considering A2 scenario than for B2 scenario.

In order to evaluate the projected distribution change from a spatial aspect, a special method has been developed. The main aim of this method is to quantify the empirical probability of temperature or precipitation anomalies exceeding given thresholds using model simulation outputs, and then, to compare to the occurrence determined from observational datasets (such as the gridded data of the Climatic Research Unit (CRU) at the University of East Anglia (Mitchell and Jones, 2005)). The comparison enables us to provide a clear message to the impact modellers on the distribution shift of the given climatic variable.

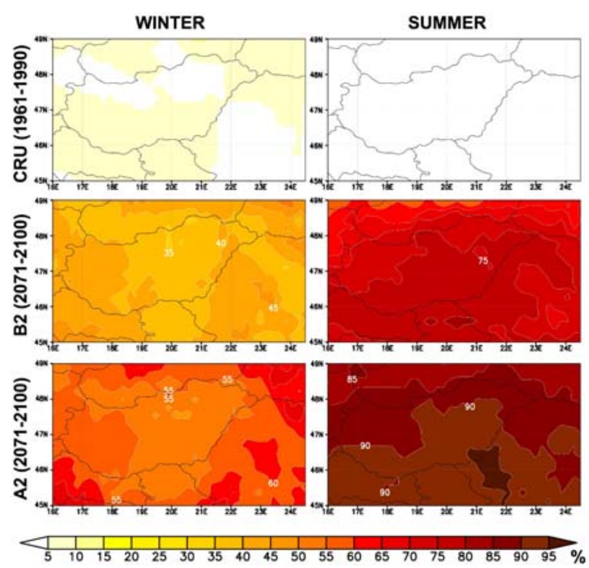

Fig. 5: Seasonal empirical probability (%) of monthly temperature anomaly exceeding 4 °C (relative to the 1961-1990 monthly mean values)

Fig. 5 shows the empirical probability of temperature anomaly exceeding 4 °C in winter and summer for the reference period (1961-1990) and the target period (2071-2100) for both scenarios. For the end-users these maps may provide useful spatial information about the probability of threshold exceedance. In the past climatic conditions monthly temperature anomaly exceeding 4 °C occurred in about 5-10% of all the winter months, and it hardly ever happened in the other seasons. According to the PRECIS simulations, it is very likely to change in the future: by the end of the 21st century the monthly temperature anomaly (e.g., the difference from the mean of 1961-1990) exceeding 4 °C will become quite frequent (B2: 35-45% in winter, 30-35% in spring, 70-80% in summer, and 40-50% in autumn; A2: 50-60% in winter, 40-50% in spring, 85-95% in summer, and 65-70% in autumn). The smallest and the largest probability values can be expected in spring and in summer, respectively. The spatial structure of the empirical probability fields are similar for the two scenarios, only the values differ, namely, probability values for A2 are larger than for B2 in each season. In winter, the largest change is projected in the Transdanubium, which is located at the western part of Hungary. In summer the largest probability values are projected in the eastern/southern part of Hungary.

4. ANALYSIS OF FUTURE REGIONAL PRECIPITATION TRENDS

The model predicts about 20% annual precipitation decrease on average for Hungary by the end of the 21st century in case of both scenarios. The largest change is expected for summer, when the model projects significant drying for the whole country (the simulated precipitation decrease is 43% in case of B2, and 58% in case of A2 in spatial average). For spring and autumn the expected trend is also negative (Table III), however, it is much smaller than in summer and not significant at 0.05 level. In winter, a slight increase is projected (in spatial average about 14%), which is significant in case of A2 in the Transdanubium, where the simulated winter precipitation change may exceed 30-40% (Pieczka et al., 2010).

Table III: Projected annual and seasonal mean precipitation change (%) for Hungary for 2071-2100 (reference period: 1961-1990)

	B2	A2
Annual	-21	-22
Winter	-6	14
Spring	-8	-13
Summer	-43	-58
Autumn	-18	-8

Precipitation is highly variable both in space and time. According to the PRECIS simulations the year-to-year variation in Hungary will remarkably change in the future (Fig. 6). The results suggest a major annual redistribution of precipitation, a significant decrease in summer precipitation, as well as in interannual variation of summer precipitation, and increase of the interannual variation in spring and winter (Table IV). In summer both the sum and the temporal standard deviation is likely to decrease dramatically, by about 50% in case of both scenarios. The largest decrease of the standard deviation is expected in June, July, and September, in the rest of the year the simulated changes are less pronounced. However, the simulated year-to-year variation increase of monthly precipitation in spring is quite large, especially, in May when considering A2 scenario.

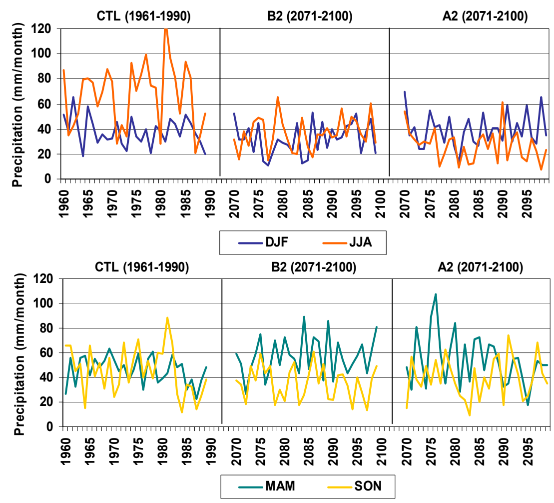

Fig. 6: Year-to-year variation of seasonal mean precipitation (mm/month) for Hungary

Table IV: Temporal standard deviation of simulated annual and seasonal precipitation (mm/month) for the periods of 1961-1990 (CTL) and 2071-2100 (A2 and B2 scenario) for Hungary

	CTL	B2	A2
Annual	11	8	8
Winter	12	14	15
Spring	17	18	22
Summer	26	14	14
Autumn	20	15	18

The expected change in the annual distribution of simulated monthly mean precipitation is shown in Fig. 7. In the recent climate (1961-1990), the wettest months in Hungary are in late spring, early summer (from April to July), when the monthly mean precipitation sum exceeds 60 mm. The driest months are January and February with about 30-35 mm total precipitation on average. The PRECIS simulation outputs suggest that the annual distribution of monthly precipitation is very likely to be restructured by 2071-2100 both in case of A2 and B2 scenario. The driest months are expected to be July and August (A2: with less than 20 mm, B2: with about 25-30 mm on average). The wettest month of the A2 scenario runs is April with about 65-70 mm precipitation on average, while in case of B2, the wettest months are April, May and June with about 60 mm total precipitation on average.

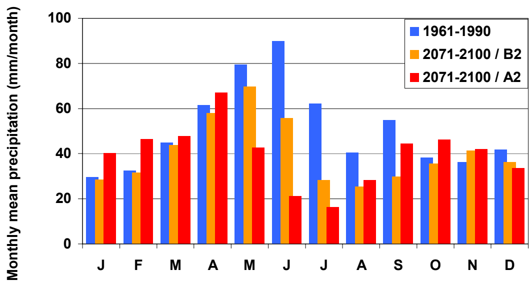

Fig. 7: Annual distribution of simulated monthly mean precipitation (mm/month) in the reference period (1961-1990) and in the target period (2071-2100)

Overall, the model PRECIS predicts a drier future climate in the Carpathian Basin. The empirical probability of negative precipitation anomaly exceeding -20% in the past (1961-1990) climatic conditions occurred in about 35-45% of all the months in the winter and summer seasons (as shown in Fig. 8). According to the PRECIS simulations, a drying tendency is projected by the end of the 21st century, especially, in the summer months (the occurrence of the monthly precipitation anomaly exceeding -20% increases significantly to 70-80% and 80-90% in case of B2 and A2 scenario, respectively). In the other seasons a less pronounced frequency increase is expected (B2: to 40-60% in winter, to 35-55% in spring, and to 50-60% in autumn; A2: to 30-50% in winter, to 40-60% in spring and autumn).

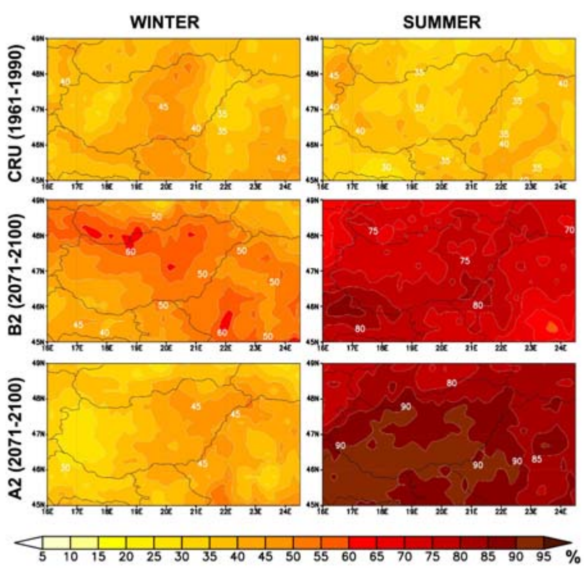

Fig. 8: Seasonal empirical probability (%) of monthly precipitation anomaly exceeding -20% (relative to the 1961-1990 monthly mean values)

The empirical probability of positive precipitation anomaly exceeding 20% in the past climatic conditions occurred about 25-30% of all the months throughout the year. A major decrease is expected for summer months: the probability of wet conditions decreases to 0-20% in case of B2, and to 0-10% in case of A2 (Fig. 9).

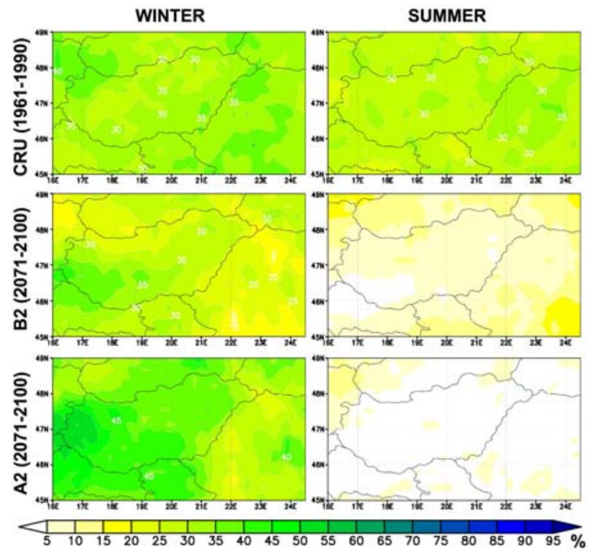

Fig. 9: Seasonal empirical probability (%) of monthly precipitation anomaly exceeding +20% (relative to the 1961-1990 monthly mean values)

Based on these maps (Figs. 8 and 9) it can be clearly seen that in case of the A2 scenario the amplitude of the summer changes are likely to be larger than in case of B2. For winter the changes are less pronounced, however, for A2 a major increase is projected in the Transdanubium (from 25-30% to 45-55%). In winter, in case of A2 the wetter periods will become more frequent in the whole country, while the dry periods will become less frequent mainly in the area of Transdanubium. For the transient seasons only small, not remarkable changes can be expected (Pieczka et al., 2010).

5. CONCLUSIONS

The climate conditions of the 1961-1990 (reference) and 2071-2100 (target) periods have been simulated using the PRECIS regional climate model. In the present paper the expected temperature and precipitation changes for the Carpathian Basin for the end of the 21st century (compared to the mean of 1961-1990) have been analyzed. The following main conclusions can be drawn.

(i) The sign of the simulated temperature change is the same for A2 and B2 scenarios, but the amplitude of the projected warming is larger in case of A2 (expected annual temperature change: 5.4 °C, while 4.0 °C in case of B2).

(ii) In all the four seasons significant warming is projected at 0.05 level for both scenarios, the largest warming can be expected in summer (for Hungary the spatial average warming by the end of the 21st century is likely to reach 6 °C for B2, and 8 °C for A2).

(iii) Not only the mean climatic conditions will change, but also the distribution of the daily mean temperature implying more frequent warm and hot periods and larger record hot conditions than in the

1961-1990 reference period.

(iv) By the end of the century the annual precipitation in the Carpathian Basin is likely to decrease by about 20% for both A2 and B2 scenarios.

(v) Significant drying is projected in the region, especially, in summer (the seasonal precipitation is expected to decrease by 43% and 58% on spatial average in Hungary in case of B2 and A2, respectively) while the winter precipitation is expected to increase in the region of Transdanubium.

(vi) According to the PRECIS simulations the annual distribution of monthly mean precipitation is also expected to change. In the 1961-1990 reference period the wettest months in Hungary occurred from April to July, and the driest months were January and February. In the 2071-2100 future period, the driest months are projected to be July and August, while the wettest April, May and June.

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