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# ANALYSIS OF EXPECTED CHANGE OF EXTREME CLIMATE INDICES IN THE CARPATHIAN BASIN BY 2071-2100

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## 1. INTRODUCTION

According to the Fourth Assessment Report of IPCC (2007), global warming has manifested in several consequent climatic changes in different regions of the world. These include both mean climate shifts and distribution changes of various climatic elements resulting in more frequent or more intense extreme climate events related to precipitation, drought, and warm conditions. In order to analyze these extremes, a joint WMO-CCl (World Meteorological Organization Commission for Climatology) / CLIVAR (a project of the World Climate Research Programme addressing Climate Variability and Predictability) Working Group formed in 1998 on climate change detection (Karl et al., 1999); and one of its task groups aimed to identify climate extreme indices (Peterson et al., 2002) and completed a climate extreme analysis on all parts of the world where appropriate data were available (Frich et al., 2002; Alexander et al., 2006). Klein Tank and Können (2003) analyzed extreme climate indices on continental scale for Europe (86 and 151 stations were used in case of temperature and precipitation time series, respectively) for the second half of the 20th century. Extreme climate analysis results for the Carpathian Basin (located in Central/Eastern Europe) using 32 stations for the 20th century are discussed in Bartholy and Pongracz (2007) and Pongracz and Bartholy (2007).

For the future, Kharin et al. (2007) used global climate model outputs to analyze the expected changes of extreme climatic conditions in the whole world. According to their results cold extremes are projected to warm faster by about 30-40% on global average than warm extremes. Furthermore, the returning period of extreme precipitation events are very likely to become reduced in the future.

In this paper, simulated trends of extreme temperature and precipitation indices is discussed for the Carpathian Basin for the last three decades of the 21st century using outputs of several regional climate model simulations with 50 km horizontal resolution. The next section presents the daily temperature and precipitation simulated datasets used in our study. Then, expected changes of extreme temperature indices are discussed for the Carpathian Basin followed by a similar analysis for the precipitation indices. Finally, the last section summarizes the main findings of this paper.

## 2. DATA

In order to analyze the expected trends of the extreme climate indices for the Carpathian basin, simulated daily mean, maximum, and minimum temperature, and precipitation amounts are obtained from the regional climate model (RCM) outputs of the Danish Meteorological Institute (DMI) in the frame of the completed EU-project PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects). Results of the project PRUDENCE (Christensen, 2005) are disseminated widely via Internet (http://prudence.dmi.dk/). The primary objective of PRUDENCE was to provide high resolution (50 km × 50 km) climate change scenarios for Europe for 2071-2100 (Christensen and Christensen, 2007) using dynamical downscaling methods with RCMs (using the reference period 1961-1990). Extreme index analysis of the RCM simulation outputs are discussed in Frei et al. (2006) for four regions of Europe, i.e., the Alpine region, Central Europe (which is mainly Germany only), southern Scandinavia, and the Iberian peninsula.

DMI used the HIRHAM4 RCM (Christensen et al., 1996) with 50 km horizontal resolution (the RCM has been developed jointly by DMI and the Max-Planck Institute in Hamburg), for which the boundary conditions were provided by the HadAM3H/HadCM3 (Rowell, 2005) global climate model of the UK Met Office. The simulations were accomplished for present day conditions using the reference period 1961-1990 (the model performance of HIRHAM4 is analyzed by Jacob et al., 2007) and for the future conditions in 2071-2100 using scenario A2 and B2 scenarios (Nakicenovic and Swart, 2000). The $CO_2$ concentration under the A2 scenario is projected to reach about 850 ppm by the end of the 21st century (IPCC, 2007), which is about triple of the pre-industrial concentration level (280 ppm). The $CO_2$ concentration under the B2 scenario is projected to exceed 600 ppm (IPCC, 2007), which is somewhat larger than a double concentration level relative to the pre-industrial $CO_2$ conditions. B2 scenario can be considered optimistic among the global emission scenarios while A2 is one of the most pessimistic ones (Nakicenovic and Swart, 2000).

## 3. ANALYSIS OF TEMPERATURE INDICES

In order to compare the past and future extreme temperature indices, Table 1 lists the annual mean

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index values for the reference period (1961-1990) and the last three decades of the 21st century determined from the daily temperature outputs of the HIRHAM4 experiments of DMI. The annual values are calculated as a spatial average of all the grid points located in Hungary. It can be seen that cold extremes are expected to decrease for both A2 and B2 scenarios, while warm extremes tend to increase significantly. Both changes imply further regional warming in the Carpathian Basin. The largest increase due to this warming trend can be expected in case of extremely hot days (Tx35GE), hot nights (Tn20GT), hot days (Tx30GE), and warm nights (Tn90) by more than 100%. The expected changes are larger in case of the more pessimistic A2 global scenario than in case of B2, the ratio is about 1.3-1.7. These expected warming trends of all the temperature indices are completely consistent with the detected trend in the 1961-2001 period (Pongracz and Bartholy, 2007). The simulated changes are illustrated in Fig. 1.

Table 1. Comparison of extreme temperature indices in the reference period (1961-1990) and in case of A2 and B2 scenario (2071-2100) based on the daily outputs of the RCM of DMI. All units are days/year, percentage values in parentheses indicate the expected change.

| Temperature index | 1961-1990 | 2071-2100 | |
|---|---|---|---|
| | Reference period | A2 scenario | B2 scenario |
| Tx90: Warm days ($T_{max} > T_{max,90\%,1961-90}$) | 36 | 80 (+123%) | 68 (+88%) |
| Tn90: Warm nights ($T_{min} > T_{min,90\%,1961-90}$) | 36 | 88 (+143%) | 75 (+108%) |
| SU: Summer days ($T_{max}$ > 25 °C) | 80 | 122 (+54%) | 109 (+37%) |
| Tx30GE: Hot days ($T_{max} \geq$ 30 °C) | 30 | 74 (+156%) | 61 (+109%) |
| Tx35GE: Extremely hot days ($T_{max} \geq$ 35 °C) | 4 | 33 (>+300%) | 20 (>+300%) |
| Tn20GT: Hot nights ($T_{min}$ > 20 °C) | 24 | 75 (+229%) | 62 (+169%) |
| Tx10: Cold days ($T_{max} < T_{max,10\%,1961-90}$) | 36 | 10 (-73%) | 20 (-46%) |
| Tn10: Cold nights ($T_{min} < T_{min,10\%,1961-90}$) | 36 | 9 (-75%) | 17 (-52%) |
| FD: Frost days ($T_{min}$ < 0 °C) | 73 | 27 (-64%) | 46 (-37%) |
| Tx0LT: Winter days ($T_{max}$ < 0 °C) | 18 | 3 (-82%) | 6 (-65%) |
| Tn-10LT: Severe cold days ($T_{min}$ < -10 °C) | 6 | <1 (-95%) | 1 (-87%) |

Among the extreme temperature indices, the number of winter days (Tx0LT, as an example of cold extremes) and the number of hot days (Tx30GE, as an example of warm extremes) are selected to illustrate the spatial distribution of the projected change of the index values between 1961-1990 and 2071-2100. Figs. 2 and 3 show the projected changes of the mean annual numbers of Tx0LT and Tx30GE, respectively.

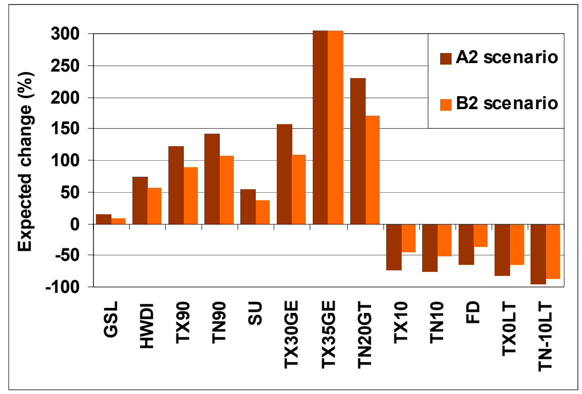


Fig. 1. Expected change of extreme temperature indices in case of A2 and B2 scenario (2071-2100) based on the daily outputs of the regional climate model of DMI. Reference period: 1961-1990.

The results (Fig. 2) suggest that in the higher elevated mountainous areas (in the range of the Carpathians and in the eastern foothills of the Alps), the simulated changes of Tx0LT is smaller (less than 70% and 50% in case of A2 and B2, respectively) than in the plain subregions inside Hungary where the decrease is projected to exceed 100% (60%) in most of the gridpoints considering A2 (B2) scenario.

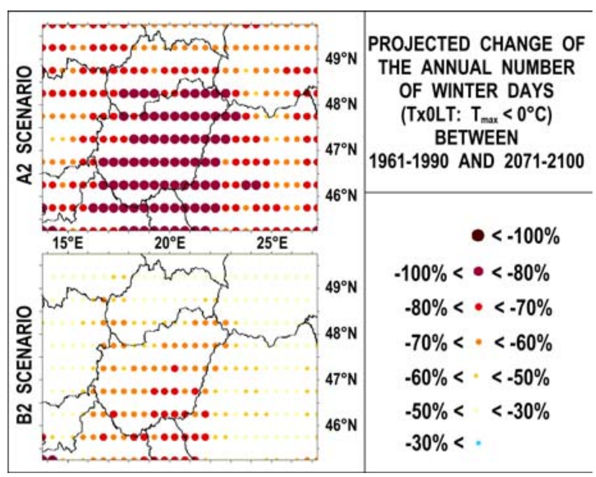


Fig. 2. Expected change of annual number of winter days (Tx0LT) in case of the A2 and B2 scenarios by 2071-2100. Reference period: 1961-1990.

The topography-related spatial structure can be also clearly identified in Fig. 3. However, in case of Tx30GE, large increase is projected in the mountainous areas (exceeding 300% for both scenarios), while in the lower elevated regions the projected increase generally does not exceed 300% and 200% in case of A2 and B2 scenario, respectively.

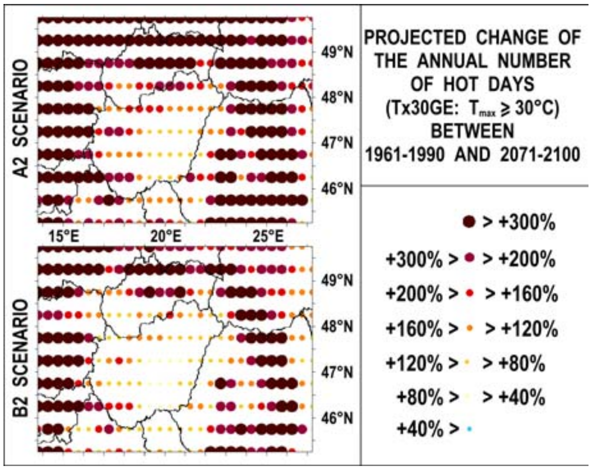


Fig. 3. Expected change of annual number of hot days (Tx30GE) in case of the A2 and B2 scenarios by 2071-2100. Reference period: 1961-1990.

## 4. ANALYSIS OF PRECIPITATION INDICES

Table 2 shows the simulated future changes of extreme precipitation indices determined using the climate simulation of DMI for the 1961-1990 and the 2071-2100 periods (using A2 and B2 scenarios). Similarly to the temperature indices, the presented annual values are calculated as a spatial average of all the grid points located in Hungary.

Expected changes of annual precipitation indices are generally consistent with the detected trends in the last quarter of the 20th century (Pongracz and Bartholy, 2007). However, the projected regional increase or decrease is not likely to exceed 20% in absolute value. Much larger positive and negative changes are projected in January and in July, respectively, on the base of the RCM simulations both in case of the A2 and B2 scenario. These results suggest that the climate tends to be wetter in January and drier in July in the Carpathian Basin. Since the projected increases of the RR20, RR10, and R95 (these indices describe very extreme precipitation events) exceed 50% in January in case of A2 scenario, and the expected increases of RR0.1 or RR1 (these indices are not related to extreme precipitation) is 10% and 21%, respectively, the extreme precipitation events are expected to become more intense and more frequent in January. Similar but smaller changes are expected in case of B2 scenario. Furthermore, precipitation in July is likely to become less common, with a general decrease in the frequency of light and moderate precipitation (i.e., RR5, R75) but a somewhat smaller decrease or even increase in extreme precipitation (e.g., RR20). The largest decrease rates (exceeding 25%) in July are expected in case of the RR5, R75, and R95 for A2 scenario, and RR20, R75, and RR5 for B2 scenario.

Table 2. Comparison of extreme precipitation indices in the reference period (1961-1990) and in case of A2 and B2 scenario (2071-2100) based on the daily outputs of the RCM of DMI. Percentage values in parentheses indicate the expected change of annual, January and July index values.

| Precipitation index [unit] | 1961-1990 | 2071-2100 | |
|---|---|---|---|
| | Reference period | A2 scenario | B2 scenario |
| Rx1 [mm]<br>($R_{max}$) | 21.5 | 25.0<br>(+17%,<br>+33%,<br>+2%) | 25.3<br>(+18%,<br>+20%,<br>-2%) |
| Rx5 [mm]<br>($R_{max,5\ days}$) | 43.5 | 49.6<br>(+15%,<br>+24%,<br>-7%) | 49.9<br>(+15%,<br>+17%,<br>-13%) |
| SDII [mm/day]<br>($R_{year}$/RR1) | 4.6 | 4.9<br>(+7%,<br>+15%,<br>-2%) | 4.9<br>(+8%,<br>+12%,<br>+1%) |
| R95 [days/year]<br>($R_{day} \geq R_{95\%,1961\text{-}90}$) | 18 | 19<br>(+9%,<br>+59%,<br>-28%) | 21<br>(+18%,<br>+41%,<br>-23%) |
| R75 [days/year]<br>($R_{day} \geq R_{75\%,1961\text{-}90}$) | 90 | 85<br>(-6%,<br>+21%,<br>-29%) | 91<br>(+1%,<br>+13%,<br>-26%) |
| RR20 [days/year]<br>($R_{day} \geq$ 20 mm) | <1 | 2<br>(+106%,<br>+271%,<br>+80%) | 2<br>(+105%,<br>+275%,<br>-56%) |
| RR10 [days/year]<br>($R_{day} \geq$ 10 mm) | 9 | 11<br>(+19%,<br>+83%,<br>-18%) | 12<br>(+28%,<br>+59%,<br>-14%) |
| RR5 [days/year]<br>($R_{day} \geq$ 5 mm) | 37 | 37<br>(+2%,<br>+58%,<br>-32%) | 40<br>(+9%,<br>+40%,<br>-25%) |
| RR1 [days/year]<br>($R_{day} \geq$ 1 mm) | 132 | 124<br>(-6%,<br>+21%,<br>-20%) | 130<br>(-1%,<br>+12%,<br>-22%) |
| RR0.1 [days/year]<br>($R_{day} \geq$ 0.1 mm) | 231 | 217<br>(-6%,<br>+10%,<br>-14%) | 226<br>(-2%,<br>+7%,<br>-13%) |

The expected changes of R95 (number of very wet days) are illustrated in Fig. 4 using annual and monthly (January and July) changes of gridpoint values of the extreme climate indices for A2 (left maps) and B2 (right maps) scenario. Blue circles in the maps indicate expected increase, while yellow and red circles imply expected decrease. The size of the circles corresponds to the magnitude of the expected changes. In case of the annual change, the expected increasing rate between 2071-2100 and 1961-1990 in Hungary is about 9% and 18% on average using the A2 and B2 emission scenarios, respectively. Much larger changes are projected in January, namely, +59% and +41% for the country. Opposite changes can be expected in July, the average decrease is expected about 28% (A2) and 23% (B2) for the gridpoints located in Hungary

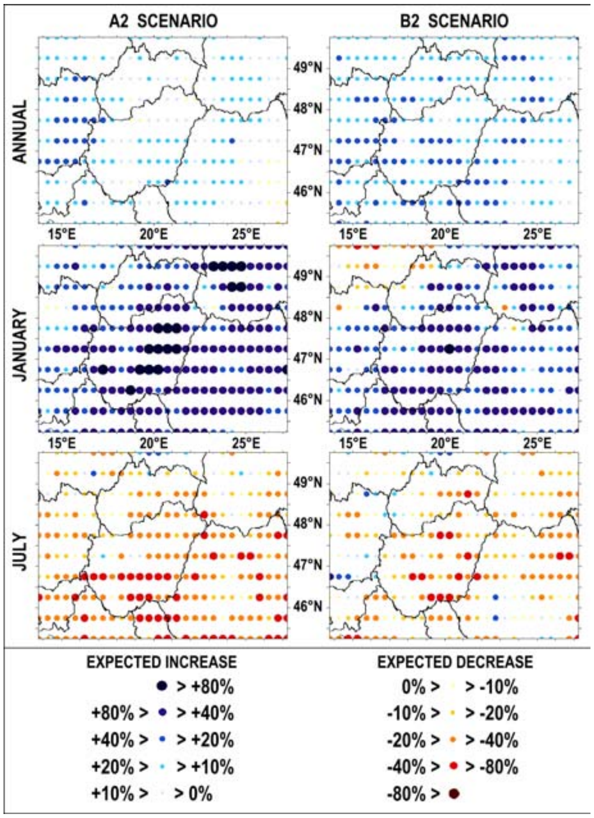


Fig. 4. Expected change of annual and monthly number of very wet days (R95) in case of the A2 and B2 scenarios by 2071-2100. Reference period: 1961-1990.

## 5. CONCLUSIONS

Analysis of extreme temperature and precipitation indices (according to the suggestions of the WMO-CCl/CLIVAR Working Group) is presented in this paper for the last three decades of the 21st century (using A2 and B2 scenario). Based on the results the following conclusions can be drawn for the Carpathian basin located in Central/Eastern Europe.

1. Analysis of simulated daily temperature datasets suggests that the detected regional warming is expected to continue in the Carpathian Basin by 2071-2100. The cold extremes are projected to decrease (more intensely in the low-elevated regions) while warm extremes tend to increase significantly (more intensely in the mountainous regions). The expected changes of the extreme temperature indices are larger in case of the A2 scenario than in case of the B2 scenario.

2. Expected changes (for 2071-2100) of annual precipitation indices are small, but generally consistent with the detected trends in 1976-2001. The projected changes in winter and in summer are opposite to each other, which means that large positive and negative changes of monthly precipitation indices are projected in January and July, respectively. Projected increase of very extreme precipitation events exceeds 50% in January, while the expected increases of not extreme precipitation indices do not reach 15%. These results imply that the extreme precipitation events are expected to become more intense and more frequent in January. Furthermore, precipitation in July is likely to become less common, with a general decrease in the frequency of light and moderate precipitation.

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