JP1.15 DETECTED TRENDS IN EXTREME TEMPERATURE AND PRECIPITATION INDICES IN THE CENTRAL/EASTERN EUROPEAN REGION

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1. INTRODUCTION

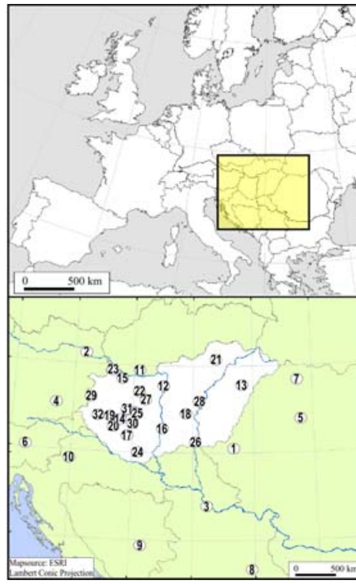
Drought events in a particular region often occur in case of long-term lack of precipitation coinciding with hot weather. Global climate change implies increasing global mean temperature (IPCC, 2001), which may occur due to the increasing average and the modified frequency distribution of temperature values. The main objective of our research is to detect the possible changes of intensity and frequency of the extreme events associated with precipitation and temperature. In this paper, several climate extreme indices have been analysed and compared for the Carpathian Basin (located in Central/Eastern Europe) based on the guidelines suggested by the joint WMO-CCl/CLIVAR Working Group on climate change detection (Karl et al., 1999; Peterson et al., 2002). One of the task groups of this Working Group aimed to identify the climate extreme indices and completed a climate extreme analysis on all part of the world where appropriate data was available (Frich et al., 2002).

The next section of this paper presents the definition of the extreme climate indices. Similarly to the global and the European (Klein Tank and Können, 2003) analyses, 13 extreme temperature indices and 12 extreme precipitation indices are evaluated for the Carpathian Basin in Sections 3 and 4, respectively. Finally, Section 5 summarizes the main conclusions of the paper.

2. DEFINITION OF EXTREME INDICES

The climate extreme indices are determined on the base of daily maximum, minimum and mean temperature observations and daily precipitation amounts. Because of the lack of century-long meteorological time series, the analysis was accomplished mainly for the second half of the 20th century. However, the analysis was extended for the entire century in case of some stations, where sufficient data was available.

For the evaluation of recent trend of temperature and precipitation extremes in the Carpathian Basin, 13 and 31 meteorological stations were used (Fig. 1), respectively. Datasets for the 21 Hungarian stations were available from the Hungarian Meteorological Service (HMS), while datasets for the 11 stations located in the neighbouring countries are freely available via Internet (Klein Tank, 2003) from the European Climate Assessment Dataset (ECAD).



Station	N.lat.	E.long.	m
Stations located in neighbouring countries			
1 Arad	46°08'	21°21'	117
2 Vienna	48°14'	16°21'	199
3 Beograd	44°48'	20°28'	132
4 Graz	47°05'	15°27'	366
5 Cluj Napoca	46°47'	23°34'	410
6 Ljubljana	46°04'	14°31'	299
7 Baia Mare	47°40'	23°30'	216
8 Nis	43°20'	21°54'	202
9 Sarajevo	52°30'	22°30'	211
10 Zagreb	45°49'	15°59'	157
11 Hurbanovo	47°53'	18°12'	115
Stations located in Hungary			
12 Budapest	47°31'	19°02'	118
13 Debrecen	47°33'	21°37'	123
14 Fonyód	46°44'	17°33'	166
15 Győr	47°41'	17°38'	119
16 Kalocsa	46°31'	18°59'	92
17 Kaposvár	46°22'	17°50'	152
18 Kecskemét	46°54'	19°46'	114
19 Keszthely	46°45'	17°15'	115
20 Marcali	46°35'	17°25'	128
21 Miskolc	48°08'	20°48'	118
22 Mór	47°23'	18°12'	203
23 Mosonmagyaróvár	47°53'	17°16'	121
24 Pécs	46°00'	18°14'	202
25 Siófok	46°55'	18°02'	108
26 Szeged	46°15'	20°06'	82
27 Székesfehérvár	47°12'	18°25'	111
28 Szolnok	47°10'	20°12'	90
29 Szombathely	47°15'	16°38'	218
30 Tab	46°44'	18°01'	177
31 Tihany	46°55'	17°54'	150
32 Zalaegerszeg	46°50'	16°51'	162

Fig. 1. Geographical locations of the meteorological stations used in the present analysis.

Stations were selected on the base of considering the following general criteria used by the global NOAA NCDC datasets (Peterson and Vose, 1997), or the ECAD (Klein Tank et al., 2002b): (i) from the entire 1946-2001 period, data must be available for at least 40 years, (ii) missing data cannot be more than 10%, (iii) missing data from each year cannot exceed 20%, (iv) more than 3 months consecutive missing values are not allowed.

Our statistical trend analysis for the Carpathian Basin includes the evaluation of 25 extreme indices, e.g., the numbers of severe cold days, winter days, frost days, cold days, warm days, summer days, hot days, extremely hot days, cold nights, warm nights, the intra-annual extreme temperature range, the heat wave duration, the growing season length, the number of wet days (using several threshold values defining extremes), the maximum number of consecutive dry days, the highest 1-day precipitation amount, the greatest 5-day rainfall total, the annual fraction due to extreme precipitation events, etc. They are defined as listed in Table 1, furthermore their units and the commonly used abbreviations are summarized.

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Table 1. Definition of the extreme climate indices

Extreme index	Definition [unit]
ETR	Intra-annual extreme temperature range: difference between the observed maximum and minimum temperatures, T_{max}-T_{min} [°C]
HWDI	Heat wave duration index: when for at least 5 consecutive days $T_{max}^{N} \geq T_{max}^{N}$ + 5°C, where T_{max}^{N} is the mean of T_{max} for the baseperiod 1961-90 [day]
Tx10	Number of cold days: when T_{max} < 10th percentile of daily maximum temperature based on the baseperiod 1961-90 [day]
Tx90	Number of warm days: when T_{max} > 90th percentile of daily maximum temperature based on the baseperiod 1961-90 [day]
Tn10	Number of cold nights: when T_{min} < 10th percentile of daily minimum temperature based on the baseperiod 1961-90 [day]
Tn90	Number of warm nights: when T_{min} > 90th percentile of daily minimum temperature based on the baseperiod 1961-90 [day]
FD	Number of frost days: when T_{min} < 0°C [day]
SU	Number of summer days: when T_{max} > 25°C [day]
Tx30GE	Number of hot days: when $T_{max} \geq$ 30°C [day]
Tx35GE	Number of extremely hot days: when $T_{max} \geq$ 35°C [day]
Tn20GT	Number of hot nights: when T_{min} > 20°C [day]
Tx0LT	Number of winter days: when T_{max} < 0°C [day]
Tn-10LT	Number of severe cold days: when T_{min} < -10°C [day]
CDD	Consecutive dry days: maximum number of consecutive dry days when R_{day} < 1 mm [day]
Rx1	Highest 1-day precipitation amount: max. of R_{day} [mm]
Rx5	Greatest 5-day rainfall total: maximum of $\Sigma_5 R_{day}$ [mm]
SDII	Simple daily intensity index: total precipitation sum / total number of days when $R_{day} \geq$ 1mm [mm/day]
R95T	Fraction of annual total rainfall (R_{total}) due to events above the 95th percentile ($R_{95\%}$) of the daily precipitation in the baseperiod 1961-90: ΣR_{day} / R_{total}, where ΣR_{day} is the sum of daily precipitation exceeding $R_{95\%}$ [%]
RR10	Number of heavy precipitation days: when $R_{day} \geq$ 10 mm [day]
RR20	Number of very heavy precipitation days: when $R_{day} \geq$ 20 mm [day]
R75	Number of moderate wet days: when R_{day} > $R_{75\%}$, where $R_{75\%}$ is the upper quartile of the daily precipitation in the baseperiod 1961-90 [day]
R95	Number of very wet days: when R_{day} > $R_{95\%}$, where $R_{95\%}$ is the 95th percentile of the daily precipitation in the baseperiod 1961-90 [day]
RR5	Number of precipitation days exceeding 5 mm: when $R_{day} \geq$ 5 mm [day]
RR1	Number of precipitation days exceeding 1 mm: when $R_{day} \geq$ 1 mm [day]
RR0.1	Number of precipitation days exceeding 0.1 mm: when $R_{day} \geq$ 0.1 mm [day]

3. TREND ANALYSIS OF EXTREME TEMPERATURE INDICES

On the base of our previous study of time series of mean temperature and extreme temperature parameters, a strong warming tendency was detected from the middle of the 1970's (Pongrácz and Bartholy, 2000). Therefore, the entire 1961-2001 period was separated into two subperiods, namely, 1961-1975 and 1976-2001. The trend analysis was accomplished for these subperiods.

Detailed quantitative information on the trend analysis of extreme temperature indices is summarized in Fig. 2. The distributions of the trends are represented by the maximum, the minimum and the quartile values of the determined trend coefficients based on all the stations. These Whisker plot diagrams provide statistical characteristics of the decadal trends for each extreme temperature index, for the two subperiods (1961-1975 and 1976-2001).

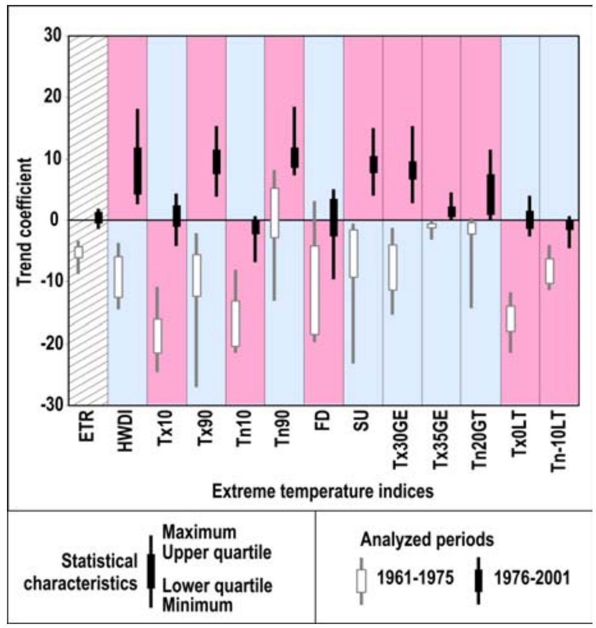

Fig. 2. Summary of the trend analysis of extreme temperature indices for the Carpathian Basin

The sign of the trend coefficients is not directly indicative of a warming or cooling tendency. For instance, negative coefficients of the number of cold days (Tx10) and positive coefficients of the number of hot days (Tx30GE) both indicate warming climate. Therefore, warming trends are shown with pink background color, while cooling trends with blue. In case of the index ETR (intra-annual extreme temperature range), white background is used since the sign of the trend coefficient is not directly connected to warming or cooling tendency.

Based on the trend coefficients of HWDI, Tx90, SU, Tx30GE, Tx35GE, Tn20GT, the cooling climatic trends until the middle of the 1970's are followed by a warming climate in the last quarter of the 20th century. Opposite trends can be detected in case of two indices (Tx10, Tx0LT) using regional scale average. However, these cooling trend coefficients of the last decades are small (the regional means of the decadal trends are 0.39 and 0.36, respectively). Note that four extreme indices (Tn10 – number of cold nights, Tn-10LT – number of severe cold days, FD – number of frost days, Tn90 – number of warm nights) indicate warming tendencies both for the 1961-1975 and 1976-2001 subperiods.

The regional climate of the Carpathian Basin can be characterized by a general warming trend for most of the indices when the entire 41 years are considered (except HWDI – heat wave duration index).

As an example for the spatially detailed trend analysis, two indices (Tn90 – number of warm nights, Tx90 – number of warm days) are presented for the 1976-2001 subperiod in Fig. 3. Circles of the upper maps represent decadal trend coefficients of the meteorological stations (using the baseperiod 1961-1990). Red and blue circles indicate increasing and decreasing tendencies, respectively, while circle size depends on the intensity of these positive or negative trends. No decreasing tendency can be identified in these maps. The positive trend coefficients detected in the last 26 years are significant at 95% level of confidence for both indices.

The lower graphs of Fig. 3 show the anomaly from the 1961-1990 average values of the regional mean index. The fitted linear trends are clearly increasing in the last quarter of the 20th century in case of both indices.

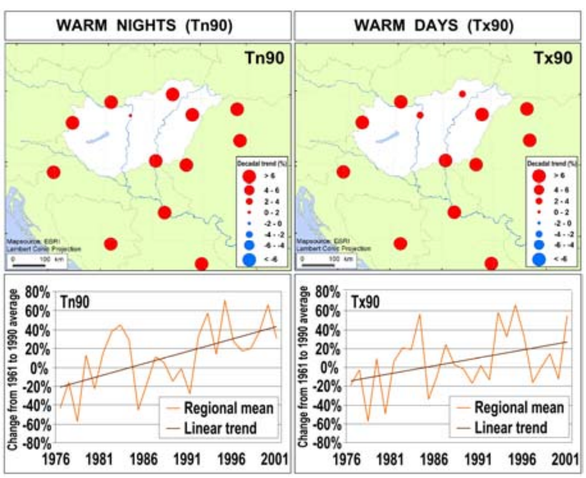

Fig. 3. Increasing trends of warm nights (Tn90) and warm days (Tx90) in the last quarter of the 20th century. Trend coefficients greater than 0.4 in absolute value are significant at 95% level of confidence

Similarly to the global and European trends (Frich et al., 2002; Klein Tank et al., 2002a), analysis of the extreme temperature indices suggests that the regional climate of the Carpathian Basin tended to get warmer in the last 41 years. Based on the results presented in this section, and also in Bartholy and Pongrácz (2006), the frequency of extreme temperature values increased considerably in the Carpathian Basin. Furthermore, the trend coefficients, determined in case of the 13 extreme temperature indices, for the 13 stations included in the selected database of our analysis, are mostly significant at 95% level (except the index Tn20GT, number of hot nights).

3. TREND ANALYSIS OF EXTREME PRECIPITATION INDICES

In case of the trend analysis of precipitation indices, two subperiods were defined, namely, 1946-2001 and 1976-2001. Results of the trend analysis are summarized in Table 2 for these two subperiods. When similar changes are detected for all stations, only one "+" or "–" sign indicates the tendency. In case of different trends of the western and eastern parts of the selected region, "– +" or "+ –" signs can be found in the table. The detected regional mean trend coefficients for the 1976-2001 subperiod are significant at 95% level, except indices SDII and RR5. In case of the entire 1946-2001 period, only 4 precipitation indices exhibit significant regional mean tendency, namely, CDD, Rx5, RR1, and RR0.1. Parentheses indicate not significant regional tendency. In addition, the number of stations, where the decadal trend coefficients are not significant at 95% level, are shown in the left columns for both periods. Note that the numbers of stations used in the trend analysis are different in case of periods 1946-2001 and 1976-2001 (26 and 31, respectively). Based on the analysis of tendency maps (Bartholy and Pongrácz, 2005), only some of the extreme indices can be characterized by homogeneous positive or negative trends for both periods. Most of the extreme precipitation indices increased considerably in the Carpathian Basin by the end of the 20th century. Positive trends were detected mostly in the last 26 years. The strongest increasing tendencies appear in case of extreme indices indicating very intense or large precipitation (i.e., R95T, RR20, R75, R95).

Table 2. Summary of tendency analyses of extreme precipitation indices for the Carpathian Basin for the 1946-2001 (based on 26 stations) and for the 1976-2001 (based on 31 stations) periods. Signs in parentheses indicate regional mean coefficients being not significant at 95% level.

Extreme index	1946-2001		1976-2001	
	Mean trend	Number of stations with not significant trends	Mean trend	Number of stations with not significant trends
CDD	**+**	4	**–**	3
Rx1	**(– +)**	4	**–**	4
Rx5	**–**	5	**+ –**	3
SDII	**(+)**	24	**(+)**	23
R95T	**(+)**	5	**+**	3
RR10	**(– +)**	7	**+**	8
RR20	**(– +)**	17	**+**	5
R75	**(–)**	11	**+**	6
R95	**(– +)**	22	**+**	11
RR5	**(–)**	10	**(–)**	8
RR1	**–**	1	**–**	2
RR0.1	**–**	4	**–**	1

In this paper, three indices of Table 2 are presented in details. The Carpathian tendencies of annual number RR20 of heavy precipitation days (when daily precipitation is greater than 20 mm) are shown for the last quarter of the 20th century in Fig. 4. Based on the tendency analysis of the entire European continent (Klein Tank et al., 2002a), heavy precipitation days occurred more often in the last 2-3 decades in northern stations, while they became less frequent in the Mediterranean region. The Carpathian Basin is located in-between, however, our detailed regional analysis (Fig. 6) suggests that except for a few southern stations, the annual number of heavy precipitation days (RR20) increased during the last 26 years. The entire Carpathian Basin can be characterized by a strong positive trend. Considering only the Hungarian stations, the annual number of wet days exceeding 20 mm increased more in Transdanubia (the western part of the country) than in the Great Plains (the eastern part of the country).

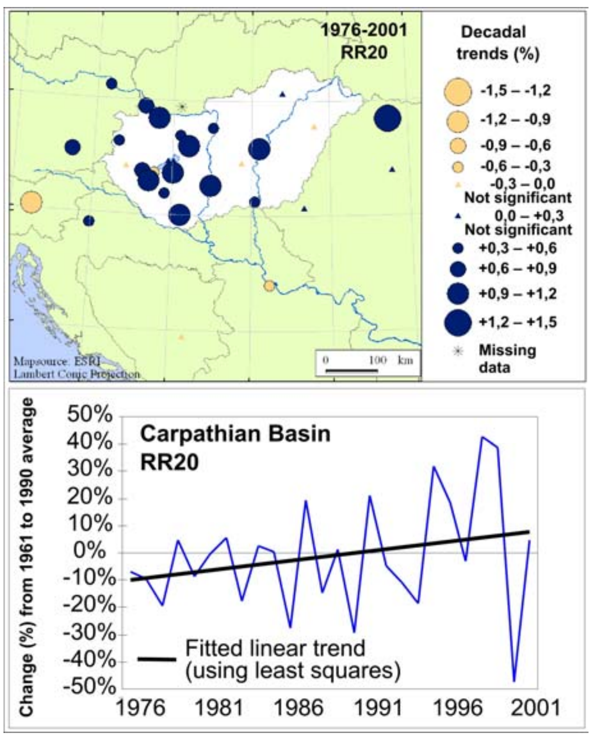

Fig. 4. Trend of the annual number of very heavy precipitation days exceeding 20 mm (RR20) in the last quarter of the 20th century.

Indices listed in Tables 1 and 2, include a few precipitation-related parameters which do not indicate extreme conditions. They belong to the index type annual number of precipitation days exceeding a given threshold; for instance, RR1 is one of them. Decadal trend of the annual number of wet days with daily precipitation exceeding 1 mm (RR1) is analyzed for the second half of the 20th century (Fig. 5). Similarly to Fig. 4, the upper map provides the spatial distribution of decadal trends for the Carpathian Basin, while the lower graph shows the regional mean time series of the RR1 anomalies (using the baseperiod 1961-1990) for the Carpathian Basin. Decadal tendency of RR1 is strongly negative in the last 56 years in most of the stations, as well, as in case of the regional mean anomaly.

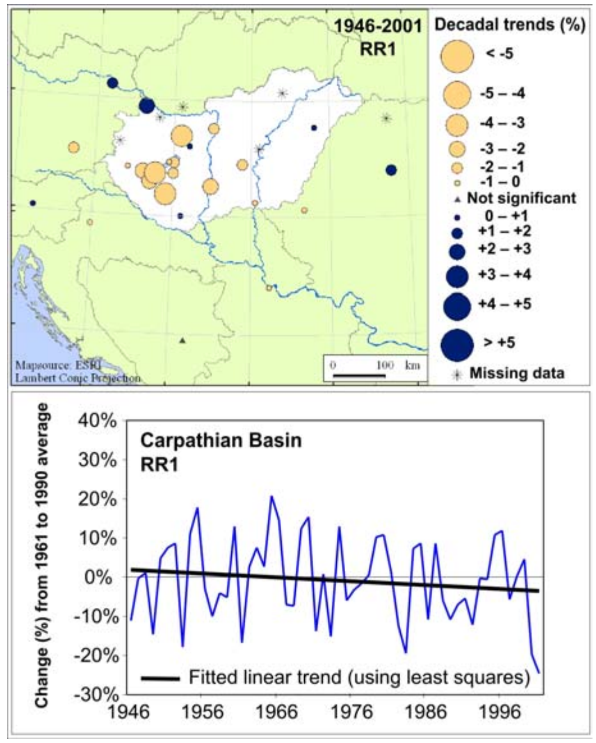

Fig. 5. Trend of the annual number of precipitation days exceeding 1 mm (RR1) in the second half of the 20th century. Trend coefficients greater than 0.3 in absolute value are significant at 95% level of confidence.

Fig. 6 compares the tendency of annual rainfall fraction due to very wet days (R95T) during the second half and the last quarter of the 20th century. Slight decreasing tendencies can be detected in the Transdanubian stations (located in the western part of Hungary) during 1946-2001, while intermediate positive trends appear in other stations of the region on the upper map of the figure. Furthermore, very strong positive trends were found during the last 26 years (shown on the lower map) indicating that the annual fraction of total rainfall (R_{total}) due to events above the 95th percentile ($R_{95\%}$) of daily precipitation in the baseperiod 1961-1990, increased significantly between 1976 and 2001.

Summarizing the results presented in Figs. 4-6, although in general, precipitation occurred more rarely in the Carpathian Basin, the ratio of heavy or extreme precipitation days increased considerably by the end of the 20th century.

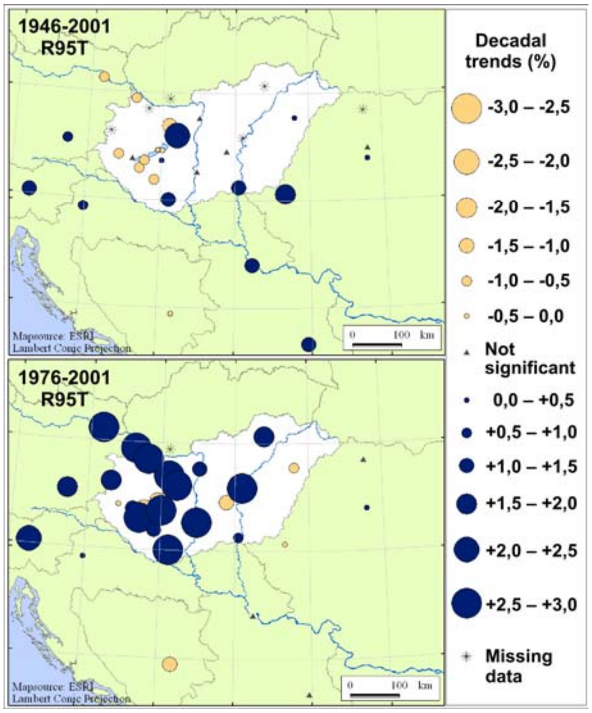

Fig. 6. Trend of the fraction of total annual rainfall due to very wet days (R95T) in the second half of the 20th century. Trend coefficients greater than 0.3 and 0.4 in absolute value are significant at 95% level of confidence on the upper and lower map, respectively.

5. CONCLUSIONS

Global (Frich et al., 2002) and European (Klein Tank and Können, 2003) scale studies on extreme climate indices indicated that trends of the temperature related indices are consistent with the global warming. In this paper, a spatially more detailed analysis for the Carpathian Basin illustrates similar warming tendencies for the 1961-2001 period. In case of extreme precipitation indices, trends are spatially less coherent than in case of temperature. Opposite tendencies can be observed in the northern (towards wetter conditions) and southern (towards drier conditions) parts of Europe (Klein Tank and Können, 2003). The Carpathian Basin is located in the boundary area of these two large regions, which justifies why it is necessary to accomplish a detailed regional analysis using data of more stations from this particular region. Based on the analysis of the extreme temperature and precipitation indices (according to the suggestions of the WMO-CCl/CLIVAR Working Group) for the second half of the 20th century, presented in this paper, the following conclusions can be drawn.

1. Results of the analysis of the extreme temperature indices determined for 13 stations located in the Carpathian Basin:

(i) Significant warming tendencies are dominant during the entire 1961-2001 period.

(ii) In case of most of the indices (e.g., HWDI – heat wave duration, Tx90 – number of warm days, SU – number of summer days, Tx30GE – number of hot days, Tx35GE – number of extremely hot days, Tn20GT – number of hot nights), the entire 41 years can be separated into a cooling period until the middle of the 1970's, and then a warming period in the last quarter of the 20th century.

(iii) The largest trend coefficients (more than 6 days per decade) were detected in case of the following indices: Tn90 (number of warm nights), Tx90 (number of warm days), SU (number of summer days), Tx30GE (number of hot days), HWDI (heat wave duration index).

2. Results of the analysis of the extreme precipitation indices determined for 31 stations located in the Carpathian Basin:

(i) Strong positive trends were detected in most of the extreme precipitation indices (e.g., R95T – annual fraction due to extreme precipitation events, RR20 – number of very heavy precipitation days, R75 – number of moderate wet days, R95 – number of very wet days) for the last quarter of the 20th century indicating increasing precipitation extremity in the Carpathian Basin.

(ii) Significant negative trends dominate the region in case of the non-extreme parameters (i.e., RR5, RR1, and RR0.1 – numbers of precipitation days exceeding 5 mm, 1 mm, and 0.1 mm, respectively) during the second half of the 20th century.

(iii) In general, precipitation occurred less frequently in the Carpathian Basin, however, the ratio of heavy or extreme precipitation days increased considerably by the end of the 20th century.

Acknowledgements. Research leading to this paper has been supported by the Hungarian National Science Research Foundation (OTKA) under grants T-049824, T-034867, and T-038423, also by the CECILIA project of the European Union Nr. 6 program, the Hungarian National Research Development Program under grant NKFP-3A/0006/2002, NKFP-3A/082/2004, and NKFP-6/079/2005, and VAHAVA project of the Hungarian Academy of Sciences and the Ministry of Environment and Water. ESRI software has been used to create maps.

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