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Analyses of temperature extremes in the Carpathian Region in the period 1961–2010

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Abstract―The harmonized data derived in CARPATCLIM project has enabled the presentation of the most comprehensive picture of trends of extreme temperatures in the Carpathian Region. A set of climate change indicators derived from daily temperature data, focusing on extreme events, was computed and analyzed in this study. Annual extreme indices for the period 1961–2010 were examined. Trends in the gridded fields were calculated, mapped, and tested for statistical significance. Results showed significant changes mainly in temperature extremes associated with warming. A large part of the region showed a significant decrease in the annual occurrence of cold nights and an increase in the annual occurrence of warm nights. The growing season starts earlier in more than third part of the region. The trend and proportion of the area that sign significant change of warm extremes strengthen the obvious warming in the Carpathian Region.

Key-words: CARPATCLIM, Carpathian Region, climate indices, temperature extremes

1. Introduction

The impacts of climate change on society come forward mainly through extreme weather and climate events, such as heat waves, droughts, heavy rainfall, and storms. The climate change evokes increasing frequency of climate extremes

(*Easterling et al.*, 2000; *Moberg et al*, 2006; *Alexander et al.*, 2006; *Seneviratne et al.,* 2012; *Donat et al*, 2013, *IPCC*, 2014).

Climate change is expected to result in significant changes in the Carpathian Region to affect ecosystems and human activities (*UNEP,* 2007). To describe the changes of extremes, a sort of climate indices is used in general as prevailing indicators of changes in extremes. The European Climate Assessment and Dataset (ECA&D) (*Klein Tank* and *Konnen*, 2003) contains climate indices from countries across Europe located in the Carpathian Region amongst them.

The purpose of the current study is to analyze the trends of temperature extremes in the Carpathian Region by means of a high-quality and high-resolution ($0.1^{\circ} \times 0.1^{\circ}$) daily gridded dataset constructed in the framework of the CARPATCLIM Project (www.carpatclim-eu.org). A set of indices follows the definitions recommended by the WMO CCl/CLIVAR Expert Team on Climate Change Detection and Indices (ETCCDI) was computed and analyzed in this paper. The CARPATCLIM dataset currently represents the most comprehensive, homogenized, and harmonized gridded dataset of daily in-situ data available for the Carpathian Region. It has been used to climate variability and trend studies (*Spinoni et al.,* 2015a) and drought investigations (*Spinoni et al.,* 2013) for instance. The Carpathian Region are subjected to climate change and also to weather-related extremes such extreme temperatures and heavy rainfall based on CARPATCLIM dataset (*Lakatos et al.,* 2013*, Spinoni et al.,* 2015b).

In the next sections, we describe the dataset and the method to derive grids of the different extremes indices and the analysis of this dataset over the Carpathian Region. After the introduction, the data and the definition of climate indicators are set up. Then, after the description of the trend estimation and the results showed on graphs and maps, a brief summary concludes the paper.

2. Data

Studying the spatio-temporal changes of climate extremes can be implemented through the analysis of observations reliable both in time and space. In this paper we used the CARPATCLIM (Climate of Carpathian Region & Digital Atlas of the Region) dataset for calculation of trends of several climate indicators to detect changes in temperature extremes in the Carpathian Region. As result of a Hungarian initiative on creation high quality dataset over the Carpathian Basin, the European Commission financed the CARPATCLIM project to supply the data demand of Joint Research Center (JRC) Desert Action activity (*JRC*, 2010). The consortium led by the Hungarian Meteorological Service together with 10 partner organizations from 9 countries in the Carpathian Region with the JRC created a multi-variable, gridded daily dataset.

The outcome of the CARPATCLIM project are 0.1°(~10 km×10 km) resolution homogenized, gridded daily time series of various meteorological parameters from January 1, 1961 to December 31, 2010. The target area is partly includes the territory of the Czech Republic, Slovakia, Poland, Ukraine, Romania, Serbia, Croatia, Austria, and Hungary (*Fig. 1*).

The method and software used for data quality control, homogenization, data completion, and data harmonization was the Multiple Analysis of Series for Homogenization software (MASH version 3.03; *Szentimrey* 1999, 2008, 2011). Interpolation of the homogenized time series were carried out by applying the MISH (Meteorological Interpolation Based on Surface Homogenized Data Basis version 1.03; *Szentimrey* and *Bihari*, 2007) method. The complete procedure is described in details in the project deliverables which can be found on the website of the project: www.carpatclim-eu.org/pages/deliverables/ and *Spinoni et al.* (2015a).

The final outcome of the CARPATCLIM are quality controlled, homogenized, in-situ daily time series and gridded fields along with metadata catalogue containing the documentation of the datasets. The daily grids with the metadata are freely accessible for scientific purposes on the website of the project: www.carpatclim-eu.org.

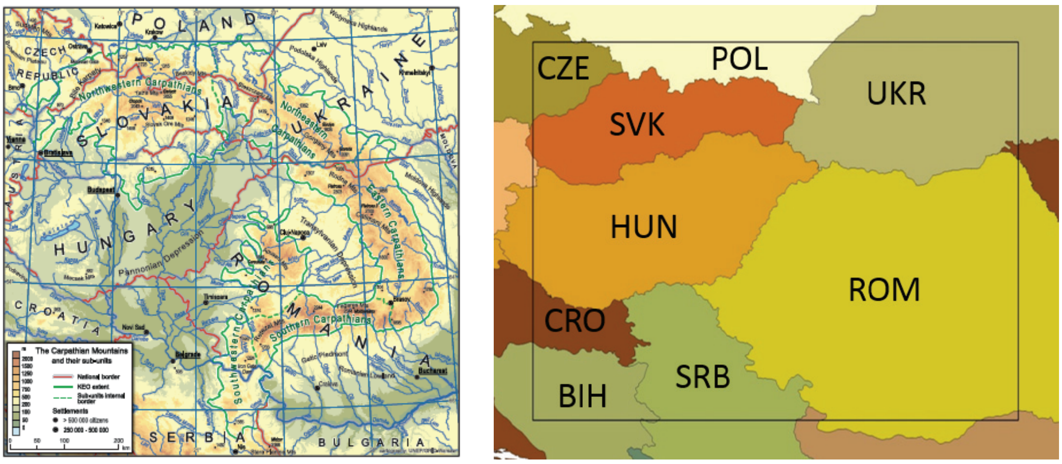

Fig. 1. The target area of the CARPATCLIM between latitudes 50°N and 44°N, and longitudes 17°E and 27°E approximately (left), and the political boundaries (right). (HUN: Hungary, SVK: Slovakia, CRO: Croatia, SRB: Serbia, ROM: Romania, UKR: Ukraine, BIH: Bosnia Hercegovina is not included in the project)

The preliminary analysis of the changes indicates that the temperature trend is variable in space in the Carpathian Region (*Spinoni et al.*, 2015a; *Lakatos et al.*, 2013). To do a further investigation into the spatio-temporal temperature trends in the Carpathian Region, we analyzed the trends of extreme temperature related indicators. Results are presentedin the next section.

3. Climate indices

The climate change indices (climate indicators) shown in this paper (*Table 1*) were calculated from the homogenized, gridded daily observations of maximum, minimum and daily average temperatures at each grid point of the region in question. We note that the daily average temperatures were derived as arithmetic means of homogenized daily maximum and minimum temperatures according to the CARPATCLIM consortium member's agreement (*CARPATCLIM Deliverable 3.7,* 2013). Percentile required for some of the temperature indices (*Table 1.*) were calculated for the climatological standard period 1961–1990.

Table 1. List of extreme temperature indices calculated and analyzed. Indices in bold represents those that are publically available in the CARPATCLIM dataset

Indicator name	Indicator definitions	Units
Cool nights TN10p	Cool nights when daily min temperature<10th percentile	days
Cool days TX10p	Cool days when daily max temperature<10th percentile %	days
Warm nights TN90p	Warm nights when daily min temperature>90th percentile %	days
Warm days TX90p	Warm days when daily max temperature>90th percentile %	days
Growing season length (5degree) GS5L*	**Annual count between first span of at least 6 days with TG>5 °C and first span after July 1 of 6 days with TG<5 °C (where TG is daily mean temperature)**	days
Growing season start (5degree) GS5Start	Daynumber at the end of the first span of at least 6 days with TG>5 °C (where TG is daily mean temperature)	daynumber
Growing season end (5degree) GS5End	Daynumber for the end of the last span of at least 6 days with TG>5 °C (where TG is daily mean temperature)	daynumber
Ice days ID	Annual count when daily maximum temperature<0°C	days
Severe cold days ECD	**Annual count when daily minimum temperature <–10 °C**	**days**
Frost days FD	**Annual count when daily minimum temperature <0 °C**	**days**
Summer days SU	**Annual count when daily max temperature >25 °C**	**days**
Hot days HD	**Hot days Annual count when daily max temperature >30 °C**	**days**
Extremely hot days EHD	**Annual count when daily max temperature >35 °C**	**days**
Warm spell duration WSDI	Annual count when at least six consecutive days of max temperature >90th percentile	days
Cold spell duration CSDI	Annual count when at least six consecutive days of min temperature <10th percentile	days

*Indices bolded are available on monthly and yearly scale in CARPATCLIM, except growing season length as it is available yearly

4. Trend estimation and results

The focus of this paper is to assess detailed regional changes of extreme temperatures in the Carpathian Region. The spatial high resolution of the gridded data can clearly highlight the regional trends. Linear trend was fitted to the indices series at each grid point, as it is widely used measure for presenting the changes. Although it is not certainly the best fit to the indices series, the results are comparable to other studies focusing on areas surrounding the Carpathian Region. Decadal changes of indices are shown on maps represent the 50 years period. The test of significance is based on student test (*Szentimrey*, 1989). Dots on maps indicates grid points where trends are significant at 5% significance level.

In this section the trend analysis for annual temperature indices are presented. The trends with their significance are featured on maps in some cases and in tables in other cases for space constraints, because all the indices were analyzed (*Table 1*). The time series plot of the indices supplemented occasionally by the 21-point smoothing functions (*Davis*, 1973) enables to demonstrate the decadal variations of the observed temperature extremes since the 1960’s.

5. Annual indices

The temperature-related indices show significant warming trends widely in the Carpathian Region. Warming trends are generally stronger for indices derived from daily minimum temperature than for those derived from daily maximum temperature. This finding is in agreement with global studies, e.g., *Alexander et al.,* 2006 and *Donat et al.,* 2013.

For example, the frequency of cool nights (TN10p) (*Fig. 2a*) based on daily minimum temperatures is shown to have significantly decreased more than three-quarter to the region during the past 50 years from 1961 to 2010. The greatest magnitudes of the trends up to 8 days per decade are found over the bordering region of Ukraine and Romania, Poland, and fewer regions in Serbia. Regionally averaged the frequency of cool nights in the Carpathian Region has decreased by about a third (17 days) between the 1960s and the first decade of the 21st century (the average annual frequency during the 1961–1990 base period is by definition 53.3 days).

Correspondingly, the frequency of warm nights (TN90p) (*Fig. 2b*) in all grid points increased significantly. Regionally averaged, the frequency of warm nights has increased by about one and a half month (44 days) during the examined period (the average annual frequency during the base period is by definition 54.4 days). The strongest change occurred in the annual occurrence of warm nights (TN90p) among the temperature indices. The largest increasing is detected in wide regions in the territory of Serbia.

Examining daytime temperature extremes, the changes in cool days (TX10p) (*Fig. 2c*) and warm days (TX90p) (*Fig. 2d*) resulted in smaller variations compared to the cool and warm nights frequency changes. The trends of cool days are significant in the half of the Carpathian Region. The decrease is the highest between 4 and 5.3 days per decade, respectively, in the mid-Transdanubian regions and in the northern edge Hungary. Negative but non-significant change appears in the regions of the Pannonian Plain, the mountainous region in Romania, and the Romanian Plain. The warming trend results in more frequent warm days everywhere in the area. The warm days increasingly grow from northeast to southwest, by 40 days on average in the Carpathian Region.

Changes in percentile based indices seem to have occurred around the mid-1980s (*Fig. 3*). It denotes one decade lag to the mid-1970s, when the mean global temperature rise is reported (*Folland et al*, 2001).

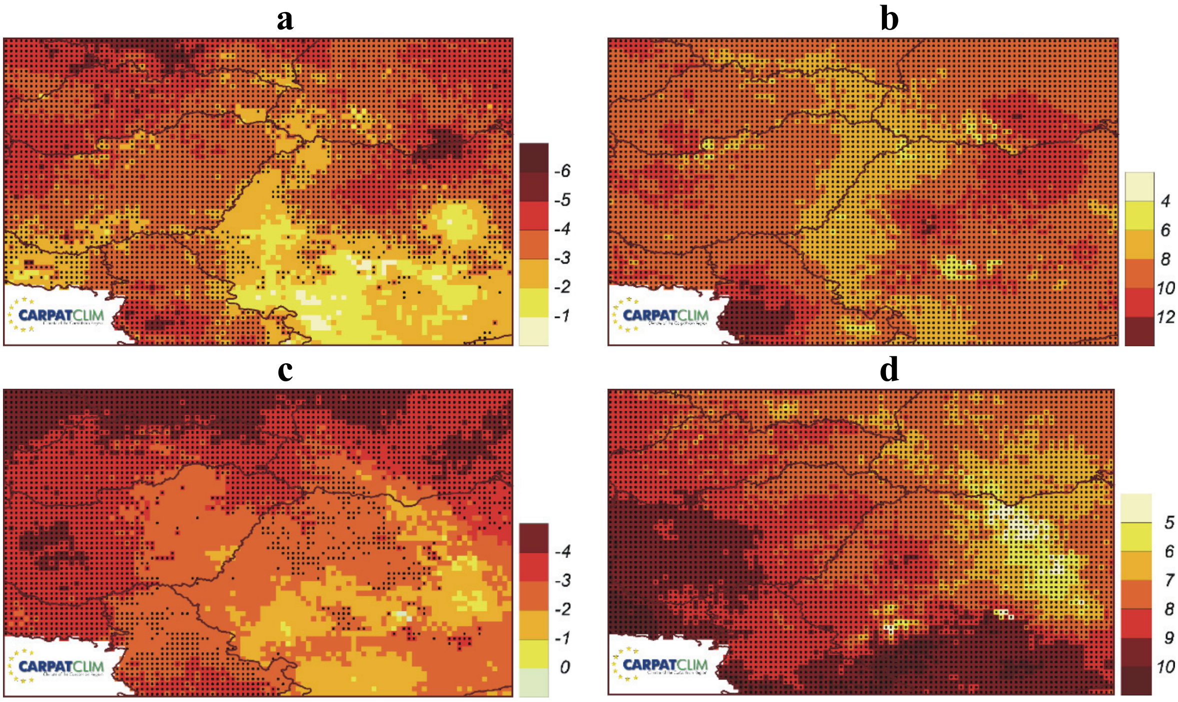

Fig. 2. Trends (in annual days per decade shown on maps) for annual series of percentile temperature indices for 1961–2010. (a) cool nights (TN10p), (b) warm nights (TN90p), (c) cool days (TX10p), (d) warm days (TX90p). Dots indicates regions where trends are significant at the 5% level.

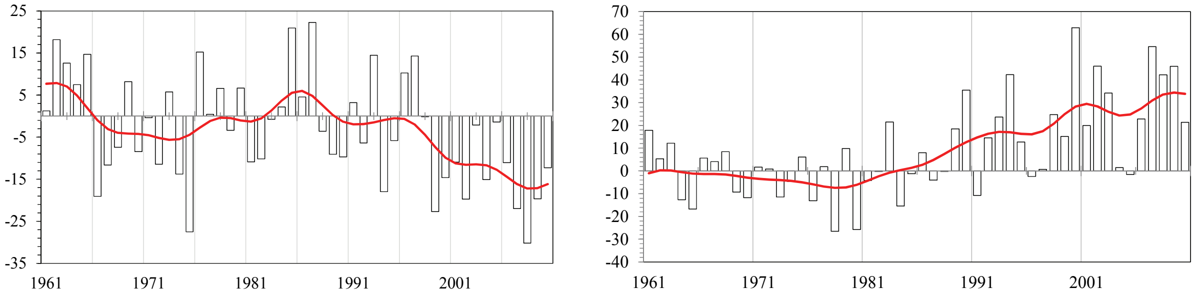

Fig. 3. The time series (columns) show the regional average annual values (in days per year) for cool nights (TN10p) (left) and warm days (TX90p) (right) as anomalies relative to the 1961–1990 mean values. The red line shows the 21-point Gaussian filtered data.

The effects of climate change clearly appear in agriculture and forestry in the region (*UNEP*, 2007). Production of these sectors is strongly influenced by the length of the growing season of the different species. Start date, end date, and the length of the vegetation period of the cold-tolerant (5 degree) species are investigated in this paper. *Fig. 4* shows that the growing season starts earlier, except for some sparsely located regions in higher elevation with statistically non-significant trend. Regions out of the Carpathians in Ukraine and Romania indicate either more than one month shift ahead. In the Transdanubian region in Hungary, in territory of Croatia and Serbia, the rowing season starts earlier, by 3 weeks in general.

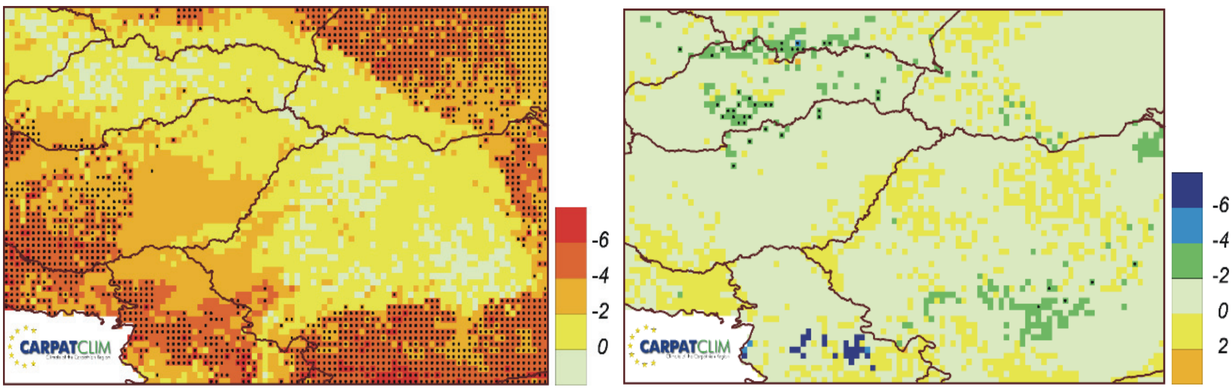

Fig. 4. Trends (in annual days per decade shown on maps) for annual series of growing season (5degree) start (GS5Start) (left) and growing season (5degree) end (GS5End) (right) for 1961–2010. Dots indicates regions where trends are significant at the 5% level.

The time series of the regionally averaged annual anomalies of growing season (5degree) start (GS5Start) show strong year by year variability (*Fig. 5*) of the starting date of the vegetation period. After tending towards to the earlier date to nighties, a slight increasing appear in the course. The years in the last decade of the 20th century put in the highest positive and negative anomalies.

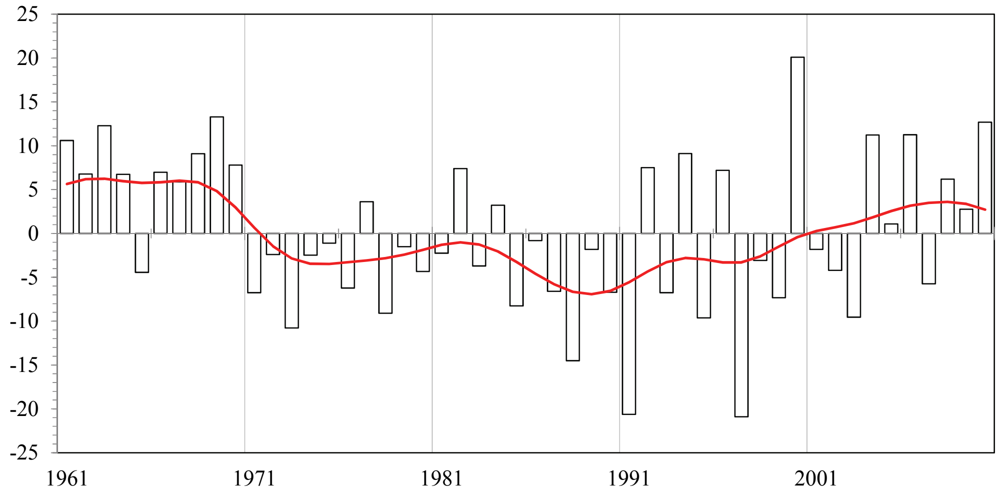

Fig 5. The time series (columns) show the regional average annual values (in days per year) for growing season (5degree) start (GS5Start) as anomalies relative to the 1961–1990 mean values. The red line shows the 21-point Gaussian filtered data.

The end of the 5°C vegetation period is not affected clearly by the warming tendency in the Carpathian Region (*Table 2*). The advanced start indicates longer growing season in the same but narrowed region as the GS5 significantly decreased (*Table 2*).

From the trend maps shown above, it can be seen that a wider area shows significant change in indices derived from minima than maxima. *Table 2* contains the areal average of the trend and the proportion of the area where the changes are significant by indices. The significantly increasing in warm nights and warm days show unanimously warming trend in the region. Significantly fewer cool days cases appear in more than a half part of the area, and less than a third part of the area non-significant change in cool nights cases. The growing season starts earlier in more than a third part of the region. The trend and proportion of the area that sign significant change of warm extremes strengthen the obvious warming in the Carpathian Region.

Table 2. Trends (in annual days per decade) for each index along with the percentage of grid points show either significant increase or decrease at the 5% level during the 1961–2010 period in the Carpathian Region

Indicator name	**Trend**	**Significant increase [%]**	**Significant decrease [%]**
Cool nights TN10p	–3.4	0	77.1
Cool days TX10p	–3.0	0	57.3
Warm nights TN90p	9.0	100	0
Warm days TX90p	8.1	100	0
Growing season length (5degree) GS5L	1.8	10.3	0
Growing season start (5degree) GS5Start	–2.5	0	30.3
Growing season end (5degree) GS5End	–0.7	0	0.7
Ice days ID	–1.8	0	16.7
Severe cold days ECD	–1.4	0	22.0
Frost days FD	–2.5	0	38.7
Summer days SU	3.7	97.9	0
Hot days HD	2.5	89.6	0
Extremely hot days EHD	1.4	40.0	0
Warm spell duration WSDI	4.1	96.1	0
Cold spell duration CSDI	–3.6	0	9.9

6. Conclusion

The focus of this paper was to assess detailed regional changes of extreme temperatures in the Carpathian Region. The CARPATCLIM dataset currently represents the most harmonized and comprehensive gridded dataset of several climate variables based on in situ observations in the Carpathian Region. A 15 pieces set of indices follows the definitions recommended by the WMO CCl/CLIVAR Expert Team on Climate Change Detection and Indices (ETCCDI) was computed and analyzed in this paper. Decadal changes and significance of indices are shown on maps represent the 50 years period, from 1961 to 2010.

According to our analyses, changes in cool nights and warm days have occurred around the mid-1980s according to the time series of areal averages of the indices. The significant increase in warm nights and warm days show unanimously warming trend in the region. Significantly fewer cool days cases appear in more than a half part of the area, and less than a third part of the area shows non-significant change in cool nights cases. The growing season starts earlier in more than third part of the region. In general, trends are stronger for indices derived from daily minimum temperature than for those derived from daily maximum temperature. The trends of the annual extreme temperature indices strengthened that the warming signal is obvious over the Carpathian Region. This type of study dealing with the investigation of climate extremes, observed trends, changes in frequency and intensity could contribute to the establishment of the adaptation strategies in the region. The seasonal changes of the temperature extremes and precipitations are also affect the natural ecosystems, agriculture, and the human health in the region. Our futher analyses will focus on those aspects.

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