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Observed changes of temperature extremes in Serbia over the period 1961 – 2010

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ABSTRACT

The analysis of spatiotemporal changes of temperature extremes in Serbia, based on 18 ETCCDI indices, was performed using daily minimum and maximum temperature observations from 26 meteorological stations over the period 1961–2010. The observation period was divided into two sub-periods (1961–1980 and 1981–2010) according to the results of the sequential Mann–Kendall test. Temporal trends were evaluated by a least-squares linear regression method. The average annual minimum temperature displayed a mixed pattern of increasing, decreasing, and no trends over 1961–1980 and a significant increasing trend over 1981–2010 across the whole country, with a regionally averaged rate of 0.48 °C per decade. The average annual maximum temperature showed a decreasing trend during 1961–1980 and a significant increasing trend at all stations during 1981–2010, with a regionally averaged rate of 0.56 °C per decade. Hot indices exhibited a general cooling tendency until 1980 and a warming tendency afterwards, with the most pronounced trends in the number of summer and tropical days during the first period and in the frequency of warm days and nights in the second. Cold indices displayed a mostly warming tendency over the entire period, with the most remarkable increase in the lowest annual maximum temperature and the number of ice days during the first period and in the frequency of cool nights during the second. At most stations, the diurnal temperature range showed a decrease until 1980 and no change or a slight increase afterwards. The lengthening of the growing season was much more pronounced in the later period. The computed correlation coefficient between the annual temperature indices and large-scale circulation features revealed that the East Atlantic pattern displayed much stronger association with examined indices than the North Atlantic Oscillation and East Atlantic/West Russia pattern.

1. Introduction

Climate change is manifested not only by changes in average conditions, but also by changes in the occurrence of climate extremes (IPCC, 2013). The connection between the incidence of extremes and global warming may be nonlinear (Coumou and Rahmstorf, 2012) and relatively small changes in the mean temperature could produce substantial changes in the temperature extremes (Mearns et al., 1984; Hansen et al., 1988). The results of the recent study of Fischer and Knutti (2015) suggest that about 75% of the moderate daily heat extremes occurring over land worldwide are attributable to the observed warming, which is primarily human-induced. According to the IPCC's Fifth Assessment Report, the globally averaged surface air temperature increased by 0.85 °C over the 1880–2012 period (IPCC, 2013). The rate of warming was especially high from 1951 to 2012 (0.12 °C decade^{-1}).

Changes in the frequency, intensity, duration, and timing of extreme climate events are of particular importance due to the risk they pose to human and natural systems as highlighted in the IPCC Special Report on Extreme Events (SREX) of the Intergovernmental Panel on Climate Change (IPCC, 2012). Extreme weather events are among the most destructive natural disasters that may severely impact many sectors of society, such as agriculture, forestry, the energy sector, water resource management, urban planning, human health, tourism. Therefore, besides climatologists, many other researchers and end-users have been increasingly interested in information about the historical and future changes in the frequency, intensity, and duration of extreme weather and climate events, as well as about the driving mechanisms underlying these trends.

A large number of indices have been defined and applied in studying climate extremes, but the difference in methodologies used limits the scope of direct comparison between studies. The World Meteorological Organization's Expert Team on Climate Change Detection and Indices (ETCCDI) recommended a suite of 27 core indices, which provides a

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common framework for assessing the frequency, duration, or severity of extreme temperature and precipitation worldwide (Zhang et al., 2011). User-friendly software was developed for standardised calculation of these indices and made available for public use. The suggested extreme indices describe so-called “moderate” or “soft” extreme events, with the annual number of occurrences sufficiently large to allow meaningful trend analysis within the typical length of daily meteorological data of 50 years.

The ETCCDI indices have been widely used to investigate changes in temperature and precipitation extremes across the world on different spatial scales, both in historical data and climate projections (e.g. Orlowsky and Seneviratne, 2012; Sillmann et al., 2013; Thibeault and Seth, 2014). The ETCCDI regional workshops held worldwide resulted in many papers describing changes in climate extremes in various parts of the world, such as in Central and South Asia (Klein Tank et al., 2006), the western Indian Ocean (Vincent et al., 2011), the Indo-Pacific region (Caesar et al., 2011), parts of Africa (Aguilar et al., 2009), the Middle East (Zhang et al., 2005), the Arab region (Donat et al., 2013b), South America (Skansi et al., 2013), and the Caribbean region (Stephenson et al., 2014). At a national level, numerous studies have been conducted, such as in Canada (Zhang et al., 2000), Georgia (Keggenhoff et al., 2014), Iran (Rahimzadeh et al., 2009), New Zealand (Salinger and Griffiths, 2001), and Saudi Arabia (Athar, 2014). Observed changes in climate extremes in Europe at the continental level were studied by Klein Tank and Können (2003) and Moberg et al. (2006). National trends were examined for Austria (Nemec et al., 2013), Greece (Kioutsioukis et al., 2010), Italy (Fioravanti et al., 2016), the extra-Carpathians regions of Romania (Croitoru and Piticar, 2013), Spain (Brunet et al., 2007), and some other countries or their parts.

The analyses of the indices from different parts of the world showed the widespread significant changes in temperature extremes in the recent past, especially in the last few decades. According to the majority of studies, minimum temperature extremes were warming faster than maximum temperature extremes on the global scale (Alexander et al., 2006; Donat et al., 2013a) or on a regional or national scale (e.g. Hundecha and Brádossy, 2005 – western Germany; Jones, 2005 – western United States; Moberg and Jones, 2005 – central and western Europe; El Kenawy et al., 2011 – northeast Spain; Stephenson et al., 2014 – the Caribbean region; Ghasemi, 2015 – Iran). However, Klein Tank and Können (2003) found that the pronounced warming between 1976 and 1999 in Europe was rather associated with an increasing trend in warm extremes than with a decreasing trend in cold extremes. Additionally, in several studies for the Mediterranean region (Kostopoulou and Jones, 2005; Efthymiadis et al., 2011; Burić et al., 2014; Fioravanti et al., 2016), stronger warming trends for hot rather than for cold extremes was detected.

Most of the previous studies on observed temperature changes in Serbia were focused either on the mean temperature (Bajat et al., 2015) or on a few extreme temperature indices and a relatively small number of meteorological stations (Unkašević and Tošić, 2009a; Unkašević and Tošić, 2009b; Unkašević and Tošić, 2013; Knežević et al., 2014; Malinovic-Milicevic et al., 2015). Since a comprehensive analysis of changes in temperature extremes for Serbia is still lacking, the objective of this study was to investigate the trend characteristics and the variability of temperature extremes using the complete set of the core ETCCDI temperature indices, calculated for 26 meteorological stations with high-quality daily data over the period 1961–2010. In order to identify driving mechanisms contributing to the observed changes in temperature extremes, the relationship between the indices and large-scale circulation patterns (North Atlantic Oscillation (NAO), East Atlantic Pattern (EA), and East Atlantic/West Russia Pattern (EA/WR)) was examined.

2. Data and methods

2.1. Study area and data

Serbia is located on the Balkan Peninsula (Fig. 1), in the southern part of the temperate zone, between latitudes 41°50′ and 46°10′ N. The northern part of the country is situated in the Pannonian plane, while the rest of the territory has a complex topography comprised of hills, low and medium-high mountains, and valleys.

The temperature data, consisting of daily observations of maximum (TX) and minimum (TN) air temperature, were provided by the Republic Hydrometeorological Service of Serbia (RHMSS). A total of 26 meteorological stations selected for analysis are fairly uniformly distributed over the entire Serbian territory. Recent data were not available for the Autonomous Province of Kosovo and Metohija, located in southwest of Serbia (Fig. 1), because this area has not been covered by the RHMSS since the late 1990s. Complete records were available for 19 stations, while 7 stations had 2% of values missing at most. The acronym, name, geographical coordinates, altitude, and percentage of missing data are presented for each station in Table 1.

2.2. Temperature indices

To ensure straightforward comparison with results of other studies, standardised software packages developed and maintained by ETCCDI were used. A total of 18 ETCDDI indices (Table 2), 16 from a core set and two user-defined, were calculated on an annual basis using the R-based software package RClimDex, which is freely available from the ETCDDI website (http://etccdi.pacificclimate.org/). The indices, which describe different characteristics of warm and hot extremes, such as intensity, frequency, and duration, are defined as absolute or threshold indices (for definition see Table 2). Absolute indices include the hottest and coldest day, the hottest and coldest night, and diurnal temperature range. Threshold or ‘day-count’ indices are based on fixed or percentile-based thresholds. Fixed-threshold indices (summer, tropical, and hot days, frost and ice days, tropical nights, and growing season length) are less suitable for spatial comparisons than percentile-based (warm and cool days, warm and cool nights, warm and cold spell duration indicators), because they sample different parts of the temperature distribution at different sites. On the other hand, fixed-threshold indices are more relevant for impact assessments, as well as absolute indices, which are also often related to observed impacts.

Two additional user-defined indices, based on fixed thresholds of 30 and 35 °C for TX, were included in the study, because these temperatures are not rare and have biological significance in the studied region. The baseline period of 1971–2000 was used for the estimation of threshold values for the percentile-based indices. The percentile indices were modified from the original ETCCDI definition (Zhang et al., 2011) and expressed as the number of days instead of as a percentage.

2.3. Quality control and homogeneity test

Prior to indices calculation, a quality control and homogeneity test of the data were done for each station. Even though the RHMSS performed technical and critical controls of the measurements, quality control was applied as the first step in the analysis procedures of the station data in the RClimDex. Temporal homogeneity of the monthly series of TN and TX was assessed by the RHtestV4 software package, based on the penalised maximal t-test (Wang et al., 2007) and the penalised maximal F-test (Wang, 2008a) set in a recursive algorithm (Wang, 2008b). Software and documentation are available at http://etccdi.pacificclimate.org/. The goal of climatic data homogenisation is to adjust observations, if necessary, so that the temporal changes in the adjusted data are caused solely by variation in climate, not by some non-climatic factors. Non-climatic factors may include changes in station location, environment, instrumentation, or observing methodologies, and may mask or strengthen real trends in data.

The RClimDex-based quality control did not reveal physically implausible values in the temperature time series. The results of the homogeneity test are given in Table 1. Altogether, eight step changes were detected, six in the mean monthly TN time series and two in the mean monthly TX time series. All detected steps were marked with ? in the