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ORIGINAL PAPER

Recent climatic changes in Romania from observational data (1961–2013)

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Abstract The paper presents a country-wide trend analysis in seasonal air temperature, precipitation, sunshine hours and wind speed over the 1961–2013 period. Changes in annual temperature and precipitation extremes are also investigated by means of 14 indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI). The air temperature and the number of sunshine hours present significant increasing trends in winter, spring and summer; the precipitation amount is rather stable, with increasing trends in autumn and decreasing trends in the other seasons, at few locations. The wind speed shows downward trends in all seasons, in agreement with the tendency of the terrestrial stilling. The annual thermal extremes show decreasing trends for the cold-related indices and increasing trends for the warm-related ones, with the warming signal being consistent over the region. The most striking results concern the number of summer days which is increasing at 95 % of the stations and the duration of warm spells increasing at 83 % of the stations. The annual precipitation extremes show mixed signals in all eight indices, with the majority of the stations presenting no significant trends. Our findings are in good agreement with recent studies on climatic variability in the region.

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1 Introduction

The analysis of long-term seasonal climate change is important both scientifically and practically. Detailed regional studies are essential for the assessment of the impacts of climate variability and change in a given area and necessary for planning adaptation strategies (e.g. Viviroli et al. 2011).

Romania is the largest country in south-eastern Europe, covering an area of 238,391 km^2. It has a transitional climate between temperate and continental with four distinct seasons, and with various climatic influences: oceanic in the western area, Mediterranean in the south-west, Baltic in the northern region, semi-arid in the east and Pontic in the south-east. Climatic variations are modulated by geographical elements, the position of the main mountain chain, elevation, the location of the Black Sea, etc. The agricultural land covers 62 % of Romania, whilst forested areas occupy about one third of the country (e.g. Balteanu et al. 2010). The average annual temperature varies from 8 °C in the north to 11 °C in the south, with around 2.6 °C in the mountains and 11.7 °C in the plains. The mean annual cumulated precipitation varies between 300 and 1200 mm.

Several previous studies have dealt with hydroclimatic variability in Romania. Decreasing trends in winter precipitation, most significantly in extra-Carpathian regions, were found by Busuioc and von Storch (1996) and Tomozeiu et al. (2005). Significant increases in mean air temperature during 1960–1998 were found for both winter and summer by Tomozeiu et al. (2002). By means of empirical orthogonal function techniques (EOF), Rimbu et al. (2014) revealed a dominant pattern of extreme high temperature in winter, with a monopolar structure influenced mainly by the East Atlantic Oscillation. Summer temperature variability was found to present pronounced multidecadal variations with a new warming period since 1990 (Ionita-Scholz et al. 2013). A study on minimum and maximum temperatures at 14 weather stations in the extra-Carpathian region found evidence of important warming in the area (Croitoru and Piticar 2013). The temperature increase led to a decrease in winter snow depth, more obvious in the Western Romanian Carpathians and in north-eastern Romania during 1961–2000 (Bojariu and Dinu 2007). Micu (2009) and Birsan and Dumitrescu (2014) had similar findings for the 1961–2003 and the 1961–2010 periods, respectively. These aforementioned changes proved to affect drought (e.g., Cheval et al. 2014a), and toalter the natural streamflow regime in Romania (e.g. Birsan et al. 2012, 2014a), leading to increases in winter and autumn flow since 1961 and to a decrease in summer flow, especially since 1975.

The purpose of this paper is to present a unified and up-to-date country-wide study of seasonal trends in air temperature, precipitation, sunshine hours and wind speed, using good-quality data series (i.e. following the standards recommended by the World Meteorological Organization concerning both the data measurement and the weather station conditions) from all available stations with continuous record over 1961–2013 and which were subject to an additional quality control by means of statistical tests. Changes in annual temperature and precipitation extremes are also investigated by means of 14 indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI).

2 Data

The data series used in this study were extracted from the climatic database of the Romanian National Meteorological Administration. The related weather stations are located at elevations ranging from 1 to 2506 m.a.s.l. and have a good spatial coverage across the country, as well as a fair altitudinal distribution (Fig. 1). All stations with continuous data record as well as data with up to 30 % missing values were considered. The quality control, homogenisation and data filling of the missing records were realised with the software Multiple Analysis of Series for Homogenization (MASH) v3.03, developed by Szentimrey (1999) at the Hungarian Meteorological Service. MASH is a state-of-the-art relative homogenisation method which makes no a priori assumption regarding the data homogeneity and uses an exhaustive searching scheme to detect the most probable break and shift points in the data series from each station. The data completion and quality control are performed automatically, and corrections are applied to the inhomogeneous series until no break is found. The homogenisation of daily data uses the parameterisation results obtained from monthly data homogenisation (Szentimrey 2008, 2011). Costa and Soares (2009) and Venema et al. (2012) found the MASH method to be one of the most comprehensive and efficient procedures for homogenisation.

The analysis was conducted for the period 1961–2013, for the standard meteorological seasons (winter—DJF; spring—MAM; summer—JJA; autumn—SON). The following parameters have been considered:

(1) Mean daily temperature (average of the four measurements of the day, at 0, 6, 12 and 18 h Coordinated Universal Time (UTC))
(2) Daily precipitation amount (for the *i*th day=the cumulated precipitation between 18 h of the previous day and 18 h of the day *i*)
(3) Daily number of sunshine hours (calendar day)
(4) Daily wind speed (average of the four measurements of the day, at 0, 6, 12 and 18 h UTC)

Additionally, 14 indices of annual extremes defined by ETCCDI (Karl et al. 1999; Peterson et al. 2001) were also computed from daily records of minimum and maximum temperatures (calendar day) and cumulated precipitation; they are described in Table 1.

3 Methods

The local significance of trends has been analysed with the nonparametric Mann-Kendall (MK) test (Mann 1945; Kendall 1975) on a seasonal basis for mean air temperature, precipitation, sunshine hours and wind speed and on annual basis for the thermal indices of extremes. The MK test is a rank-based procedure, especially suitable for nonnormally distributed data, data containing outliers and nonlinear trends (e.g. Salas 1993; Helsel and Hirsch 1992). Beyond its robustness, the MK test has become extremely popular in assessing trends in environmental data, which allows a fair comparison of trend results between regions. The null and the alternative hypotheses of the MK test for trend in the random variable x are

$$\begin{cases} H_0 : \Pr(x_j > x_i) = 0.5, & j > i \\ H_A : \Pr(x_j < x_i) \neq 0.5, & \text{(two-sided test)} \end{cases} \quad (1)$$

The MK statistic S is calculated as

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad (2)$$

where x_j and x_k are the data values in years j and k, respectively, with $j>k$; n is the total number of years; and

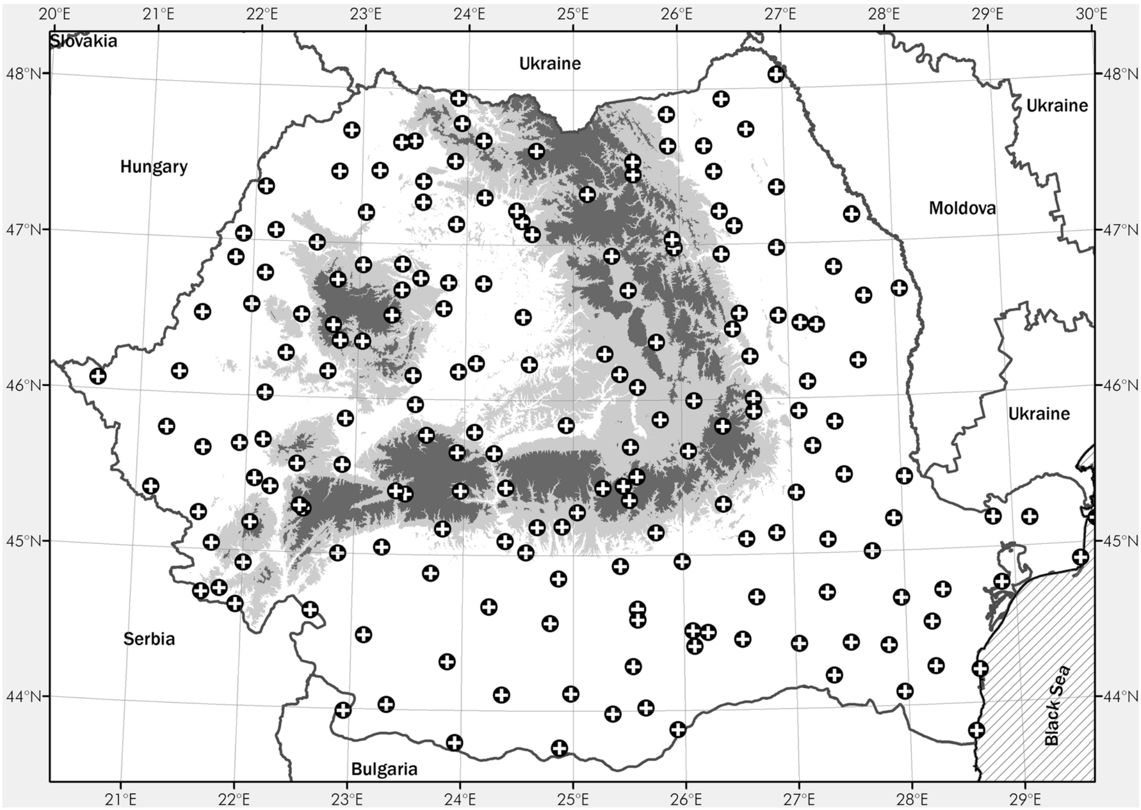

Fig. 1 The meteorological stations used in the present study. *Light grey* areas mark elevations between 500 and 1000 m.a.s.l., whilst elevations above 1000 m.a.s.l. are marked in *dark grey*

sgn() is the sign function:

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1, & \text{if } x_j - x_k > 0 \\ 0, & \text{if } x_j - x_k = 0 \\ -1, & \text{if } x_j - x_k < 0 \end{cases} \tag{3}$$

For large n, the distribution of S can be well approximated by a normal distribution with mean zero and standard deviation given by

$$\sigma_S = \sqrt{\frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18}} \tag{4}$$

Equation (4) gives the standard deviation of S with the correction for ties in data, with t_i denoting the number of ties of extent i. The standard normal variate Z_S is then used for hypothesis testing.

$$Z_S = \begin{cases} \frac{S-1}{\sigma_S} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma_S} & \text{if } S < 0 \end{cases} \tag{5}$$

The null hypothesis is rejected at significance level α if $|Z| > Z_{\alpha/2}$ (two-tail test), where $Z_{\alpha/2}$ is the value of the standard normal distribution with an exceedance probability $\alpha/2$. In the present analysis, the significance level was fixed at 10 % (two-tail test).

4 Results and discussion

The trend analysis based on the nonparametric MK test was applied on seasonal data series for the period 1961–2013 at 90 % level (two-tail test). The results highlight significant climatic changes in all seasons and are discussed in the following paragraphs, for each variable.

The mean air temperature presents exclusively upward trends (Fig. 2), statistically significant over almost the entire country during spring and summer; winter trends are also increasing in the north-eastern and central regions of Romania, but the percentage of stations with significant trends is smaller than previous findings for the 1961–2010 interval (e.g. Birsan and Dumitrescu (2014)). Autumn is the only stable season with respect to long-term changes in mean air temperature, having no station with statistically significant trends.

The seasonal precipitation amount (Fig. 3) presents predominantly downward trends in winter, spring and summer.

Table 1 The annual indices of extremes used in the present study

CSDI	Cold spell duration index: the annual count of days with at least 6 consecutive days with daily minimum temperature <10th percentile
WSDI	Warm spell duration index: the annual count of days with at least 6 consecutive days with daily maximum temperature >90th percentile
FD	Number of frost days: the annual count of days with daily minimum temperature below 0 °C
ID	Number of icing days: the annual count of days with daily maximum temperature below 0 °C
SU	Number of summer days: annual count of days with daily maximum temperature above 25 °C
TR	Number of tropical nights: annual count of days with daily minimum temperature above 20 °C
CDD	Annual maximum length of dry spell, in days (dry spells are defined as consecutive days with less than 1 mm of precipitation per day)
CWD	Annual maximum length of wet spell, in days (wet spells are defined as consecutive days with daily precipitation of at least 1 mm per day)
R10MM	Annual count of days with daily precipitation above 10 mm
R20MM	Annual count of days with daily precipitation above 20 mm
R95PTOT	Annual precipitation amount extracted from days with daily precipitation above the 95th percentile of the daily precipitation during 1961–2013
R99PTOT	Annual precipitation amount extracted from days with daily precipitation above the 99th percentile of the daily precipitation during 1961–2013
PRCPTOT	Annual sum of precipitation computed from the days with at least 1 mm of precipitation
SDII	Simple precipitation intensity index: the sum of precipitation in wet days (days with precipitation over 1 mm) during the year, divided by the number of wet days in the year

However, the number of stations with statistically significant trends in these seasons is quite low, considering the significance level of 10 %, which implies that there is a 10 % possibility that changes would occur by chance alone. Significant upward trends in autumn precipitation were found at 14 % of the stations located mostly in the intra-Carpathian region. Overall, the long-term evolution of the precipitation amount seems rather stable, suggesting that the climate change signal is still dominated by the natural variability when the evolution of seasonal amounts is analysed for the last 53 years. It is worth mentioning that the inter-decadal component of natural variability is particularly strong for precipitation (e.g. Rîmbu et al. 2002).

The seasonal number of sunshine hours (Fig. 4) is significantly increasing over large areas of Romania during winter, in particular in the southern part of the country. Like air temperature, the signal of increase in sunshine duration is present over the entire country in spring and summer; significant downward trends are found at 10 % of the locations during autumn. Sunshine duration is directly related to global radiation and can be used to evaluate the impact of solar dimming on temperature (e.g. Spinoni et al. 2012). For the Carpathian Mountains region, which covers about three quarters of Romania, Spinoni et al. (2014) found that the dimming period (1964 to 1981) had negligible effect on temperature increase, whilst during the brightening period (since 1987),

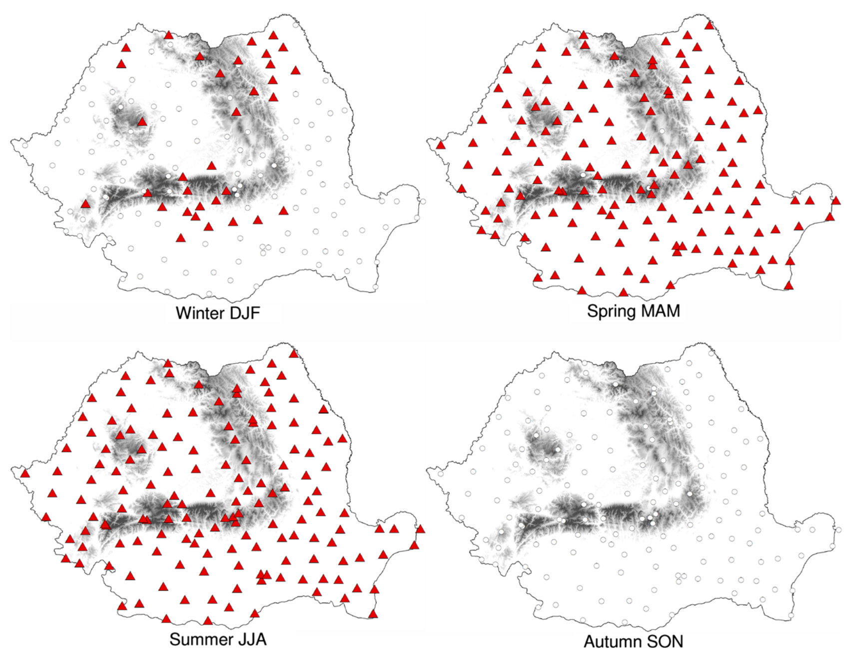

Fig. 2 Seasonal trends in mean air temperature at 150 meteorological stations in the period 1961–2013. Significant increasing trends are represented by *upward (red) triangles*; *circles* denote stations with no significant trend

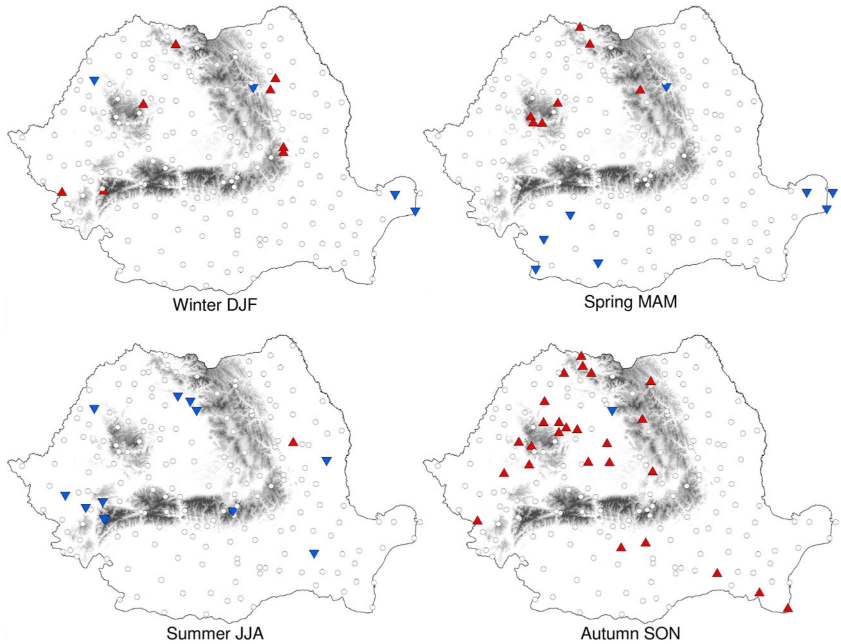

Fig. 3 Seasonal trends of precipitation at 188 meteorological stations in the period 1961–2013. Significant increasing/decreasing trends are represented by *upward (red)/ downward (blue) triangles*; *circles* denote stations with no significant trend

both minimum and maximum temperatures showed a considerable increase.

Wind speed shows decreasing trends (Fig. 5) in the seasonal mean in all seasons, at most of the locations (76 % during winter, 84 % for spring and 69 and 64 % for summer and autumn, respectively). These results are in good agreement with previous findings in the area (e.g. Birsan et al. 2013; Cheval et al. 2014b). Amongst the possible causes of the terrestrial stilling listed by McVicar et al. (2008), there are some that could explain this phenomenon in our study area: first, an increase in surface roughness (e.g. Vautard et al. 2010) due not only to the abandonment of agricultural land (Vuichard et al. 2008) but also to the temperature warming and atmospheric CO_2 concentrations enhancing vegetation growth (Liu et al. 2008); second, an increase in water amount available for irrigation—so that more available energy is partitioned into the latent heat flux and less into the sensible heat flux and associated turbulent transport (Shuttleworth et al. 2009); finally, there is a higher warming rate at the polar latitudes than at the tropical ones (Lorenz and DeWeaver 2007), which causes a weakening of the equatorial-polar thermal differential and is

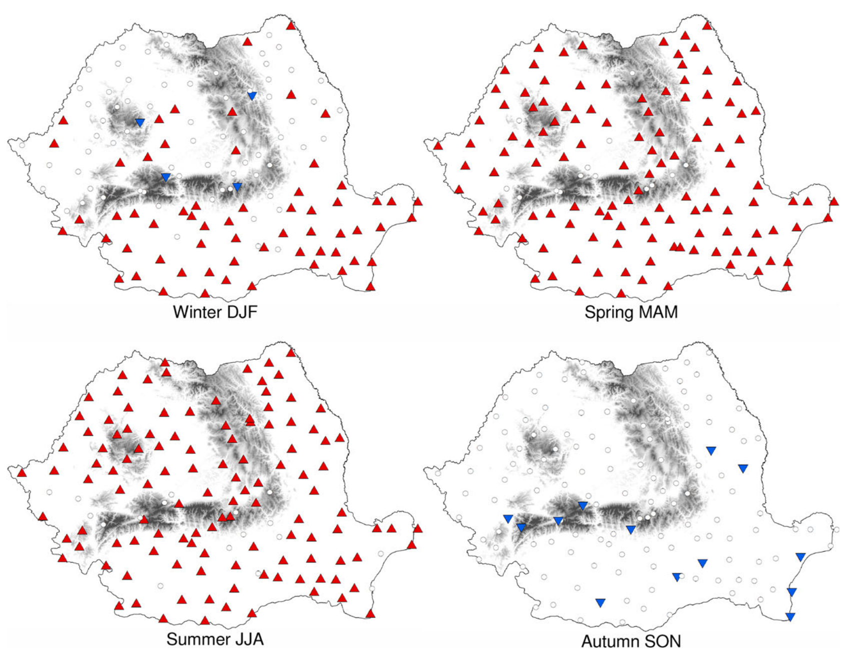

Fig. 4 Seasonal trends of sunshine duration at 135 meteorological stations in the period 1961–2013. Significant increasing/decreasing trends are represented by *upward (red)/ downward (blue) triangles*; *circles* denote stations with no significant trend

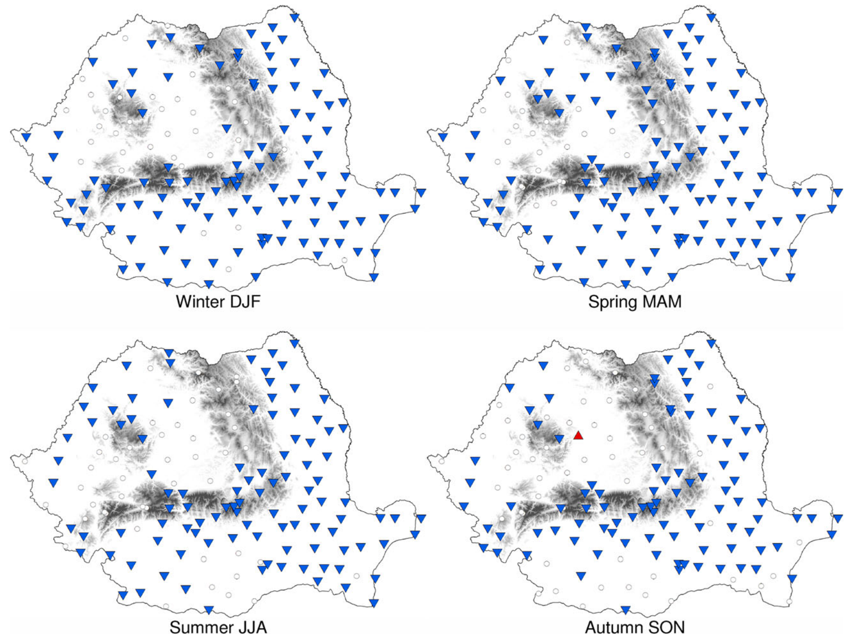

Fig. 5 Seasonal trends in mean wind speed at 149 meteorological stations in the period 1961–2013. Significant increasing/decreasing trends are represented by *upward (red)/downward (blue) triangles*; *circles* denote stations with no significant trend

expected to result in decreased equatorial and mid-latitude wind speed (Ren 2010).

The spatial distribution of significant trends in annual thermal extremes is presented in Fig. 6. The results show

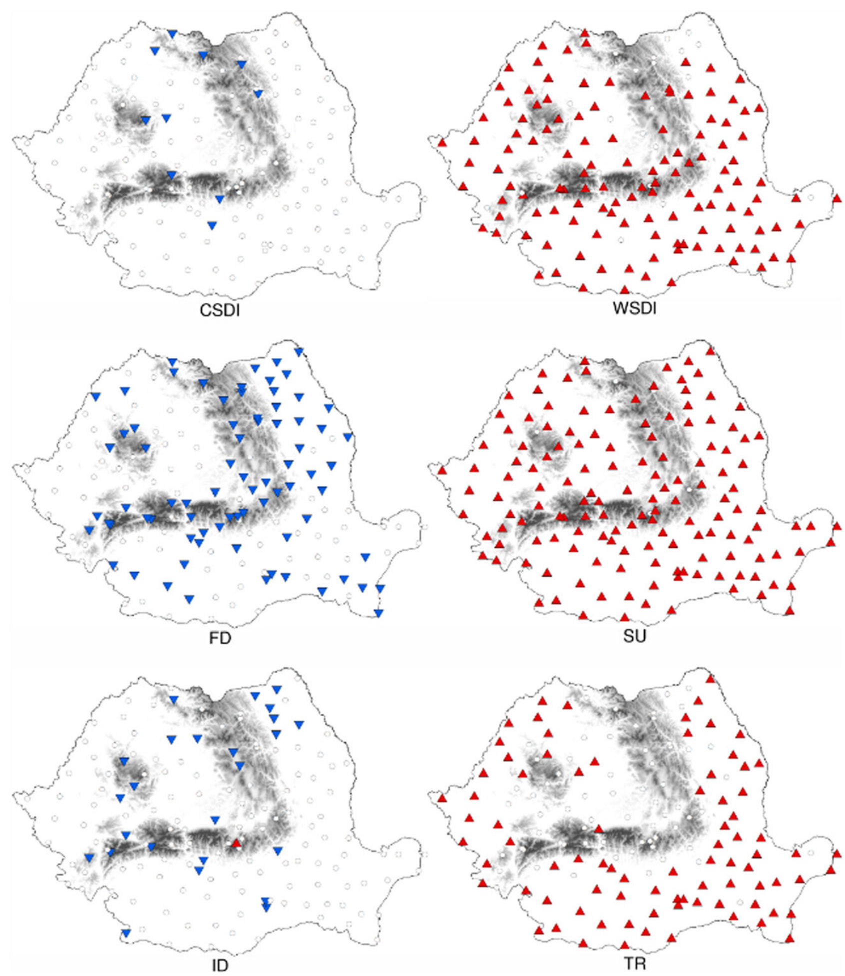

Fig. 6 Trends in annual thermal extremes at 150 meteorological stations in the period 1961–2013. Significant increasing/decreasing trends are represented by *upward (red)/downward (blue) triangles*; *circles* denote stations with no significant trend

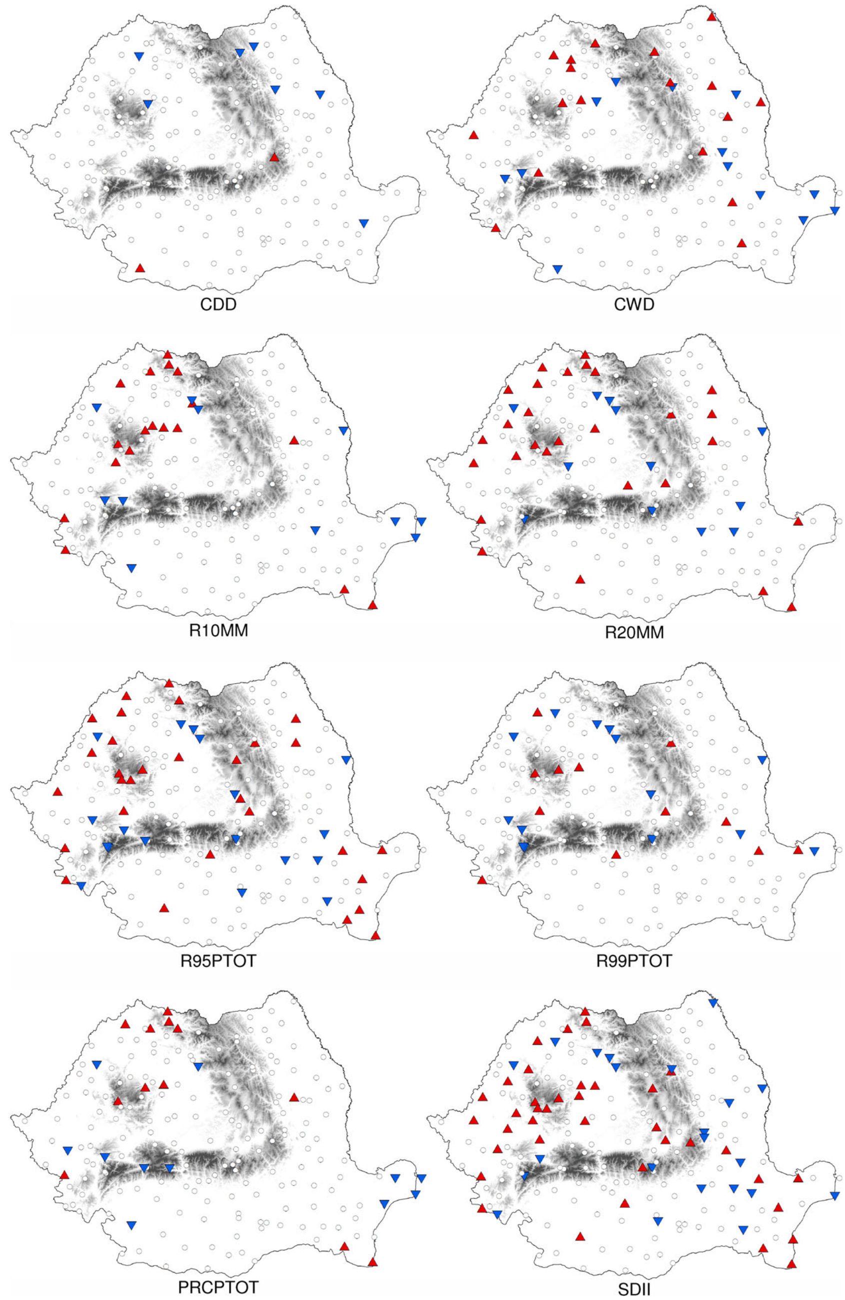

Fig. 7 Trends in annual precipitation extremes at 188 meteorological stations for the interval 1961–2013. Significant increasing/decreasing trends are represented by *red/blue triangles*; *circles* denote stations with no significant trend

decreasing trends in cold-related indices and—to a larger extent—increasing trends in warm-related ones.

The duration of cold spells (CSDI) is significantly decreasing only over limited areas in the central part of Romania, being a rather stable index (only 7 % of the stations present a significant downward trend). The number of icing days (ID) is decreasing at 17 % of the stations. Out of the three cold-related thermal indices of annual extremes, the number of frost days (FD) presents the highest percentage of downward trends, at 51 % of the stations.

The number of summer days (SU) is increasing over the entire country—regardless of the elevation—with 95 % of the stations showing statistically significant trends. The frequency of warm spells (WSDI) is also significantly increasing over large regions (at 85 % of the stations), except the central part of the country. Increases in the frequency of tropical nights (TR) are significant only in the low-elevation areas (below 750 m), generally located outside the Romanian Carpathians, for 55 % of the weather stations. These results are in agreement with those of Busuioc et al. (2014), who found significant increasing trends in seasonal temperature extremes during winter, spring and summer.

The annual precipitation extremes (Fig. 7) show mixed signals in all eight indices, with the majority of the stations presenting no significant trends. Increases in the number of days with precipitation above 10 and 20 mm can be found in the intra-Carpathian region of Romania. About one third of the stations have significant trends in SDII (20 % increasing and 12 % decreasing). However, there are no widespread significant changes in annual precipitation extremes.

The analysis of trends in annual temperature and precipitation indices of extremes managed to provide regional patterns of change which were not obvious at all in previous studies at European scale (e.g. Klein Tank and Können 2003).

Finally, linear trend analysis could provide indications on robust signals in the data, but only the identification of associated mechanisms acting behind the statistics enables us to have confidence in the identified features and their attribution to climate change. Also, even if most of the found trends can be well described as linear, including trends in annual extremes (as previously found by Birsan et al. (2014b) for the Carpathian region), we are aware that in some cases, the linear trend is a simplified representation of time series and one has to admit that nonlinearity is a usual behaviour in the climate system. However, the upward thermal trends in spring and summer which are robust observed signals are very likely related to climate change. Also, the trends in thermal-related indices of extreme episodes are likely to represent manifestations of the changing climate.

5 Conclusions

We presented a trend analysis in seasonal air temperature, precipitation, sunshine hours and wind speed and in 14 indices of annual temperature and precipitation extremes (defined by ETCCDI) over the 1961–2013 interval. The main findings of the study are summarised below.

(1) There is a general warming signal over Romania, with the air temperature and the number of sunshine hours presenting significantly increasing trends in winter, spring and summer. The warming signal is confirmed by the trends in annual thermal extremes and is more evident in the warm-related indices.
(2) The number of summer days is significantly increasing over the entire country, whilst the number of tropical nights presents significant trends only at low elevations.
(3) The precipitation amount is rather stable, with few stations presenting increasing trends in autumn and decreasing trends in the other seasons.
(4) The wind speed shows downward trends in all seasons, in agreement with the general tendency of the terrestrial stilling observed in the last half century.

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