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AN OVERVIEW OF ANNUAL CLIMATIC CHANGES IN ROMANIA: TRENDS IN AIR TEMPERATURE, PRECIPITATION, SUNSHINE HOURS, CLOUD COVER, RELATIVE HUMIDITY AND WIND SPEED DURING THE 1961–2013 PERIOD

Lenuta MARIN[1,2]*, Marius-Victor BIRSAN[1], Roxana BOJARIU[1], Alexandru DUMITRESCU[1], Dana Magdalena MICU[3] & Ancuta MANEA[1]

[1]*Meteo Romania (National Meteorological Administration), Department of Climatology*
Şos. Bucureşti-Ploieşti N° 97, 013686 Bucharest - Romania
[2]*University of Bucharest, Faculty of Physics, Doctoral School in Earth and Atmospheric Physics. P.O.BOX MG-11 Bucharest-Măgurele.*
[3]*Institute of Geography, Romanian Academy. Str. Dimitrie Racovita N° 12, Bucharest, Romania.*
**Corresponding author: Lenuta Marin. E-mail: marinlenuta00@gmail.com; lenuta.marin@meteoromania.ro*

Abstract: Six meteorological variables from all available Romanian weather stations were tested for trends at annual scale over the 1961-2013 period. Changes in annual air temperature, precipitation, sunshine hours, nebulosity, relative humidity and wind speed were investigated. The Mann-Kendall nonparametric trend test was used in order to find statistically-significant trends, whilst the magnitude of trends was estimated using the Kendall-Theil method. The results point to significant climatic changes at annual scale in Romania. The most drastic change regards the air temperature, which is increasing at all stations. The number of sunshine hours follows a similar pattern, increasing at most stations – except in the mountainous regions of Meridional and Curvature Carpathians. The wind speed presents a significant decreasing signal at the majority of the locations, in agreement with the overall tendency of terrestrial stilling. The annual precipitation amount is rather stable, with increasing trends North-Western Romania and decreasing trends in the Danube Delta (South-East). Cloud cover is generally decreasing, and the relative humidity shows mixed trends. Our findings are in good agreement with previous studies on climatic variability in Romania.

Keywords: air temperature; precipitation; sunshine hours; cloud cover; relative humidity; wind speed; annual trends; Mann-Kendall; climate change; Romania.

1. INTRODUCTION

The analysis of long-term trends is essential for the assessment of the impacts of climate variability and change in a given area, and necessary for planning adaptation strategies.

Romania covers an area of 238 391 km², being the largest country in South-Eastern Europe. The terrain is fairly equally distributed between mountainous (Carpathians), hilly and lowland territories (e.g., Bălteanu et al., 2010). The climate is transitional temperate-continental, with oceanic influences from the West, Mediterranean modulations from the South-West and excessive continental effects from the North-East. Climatic variations are modulated by geographical elements, like the Carpathian Mountains chain and the position to the Black Sea.

There are several studies dealing with hydroclimatic variability in Romania, regarding winter precipitation (Busuioc & von Storch, 1996; Tomozeiu et al., 2005), precipitation extremes (Stefanescu et al., 2013) temperature extremes (Tomozeiu et al., 2002; Croitoru & Piticar, 2012; Ionita et al., 2013; Rimbu et al., 2014), natural streamflow regime (Birsan et al., 2012, 2014a), snow (Bojariu & Dinu, 2007; Micu, 2009; Birsan & Dumitrescu, 2014), evapotranspiration (Croitoru et al., 2013) or drought (Stefan et al., 2004; Cheval et al., 2014a).

The purpose of this paper is to provide a brief overview of annual climatic change in Romania, by means of trend analysis in six meteorological parameters – air temperature, precipitation, sunshine hours, nebulosity (cloud cover), relative humidity and wind speed –, using good quality, homogenized data series from all available stations with continuous record over the period 1961-2013.

2. DATA

The time series used hereby were extracted from the climatic database of the Romanian National Meteorological Administration. The weather stations have a good spatial coverage across the country, as well as a fair altitudinal distribution, ranging from 1 to 2506 m above sea level.

All stations with continuous data record were involved in the analysis. For a better spatial coverage, additional time series with up to 30% missing values were also considered. The quality control, homogenization and data filling of the missing records (where necessary) were realised with the software MASH (Multiple Analysis of Series for Homogenization), version 3.03, formulated and developed by Szentimrey (1999, 2008, 2011) at the Hungarian Meteorological Service. MASH is a state-of-the-art relative homogenization procedure which makes no *a priori* assumption regarding the data homogeneity, and it uses an exhaustive searching scheme to detect the most probable break and shift points in the data series from each weather station. The good performance of MASH was demonstrated Costa & Soares (2009) and Venema et al., (2012).

The analysis was applied on the annual values of the following parameters, for the 1961–2013 interval:

(1) annual mean air temperature (°C);
(2) annual precipitation amount (mm);
(3) annual mean daily sunshine hours (h);
(4) annual mean fraction of cloud cover (scale from 1 to 10);
(5) annual mean relative humidity (%);
(6) annual mean wind speed (m/s).

3. METHODS

The local significance of trends has been analysed with the nonparametric Mann-Kendall (MK) test (Mann 1945; Kendall 1975). The MK test is a rank-based procedure, especially suitable for non-normally distributed data, data containing outliers and non-linear trends (e.g., Salas, 1993). 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 hypothesis 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:

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

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 sgn() is the sign function:

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

The distribution of *S* can be well approximated by a normal distribution for large *n*, with mean zero and standard deviation given by:

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

The above equation (5) 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.

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

The null hypothesis is rejected at significance level α, if $|Z| > Z_{\alpha/2}$ where $Z_{\alpha/2}$ is the value of the standard normal distribution with an exceedance probability $\alpha/2$. Here, the significance level was fixed at 90% (two-tail test).

The linear trends were computed using the Kendall-Theil robust line (also known as Theil-Sen slope estimate), which is suitable for a nearly linear trend in the variable *x*, and is less affected by non-normal data and outliers (e.g., Helsel & Hirsch, 1992). The slope is computed between all pairs *i* of the variable *x*:

$$\beta_i = \frac{x_j - x_k}{j - k} \text{ with } j>k \tag{6}$$

where i=1...N. For n values in the time series x this will result in $N = n(n-1)/2$ values of β. The slope estimate b is the median of β_i, i=1...N.

4. RESULTS AND DISCUSSION

The trend results suggest significant climatic changes at annual time scale (Fig. 1), which are discussed for each variable in the following paragraphs.

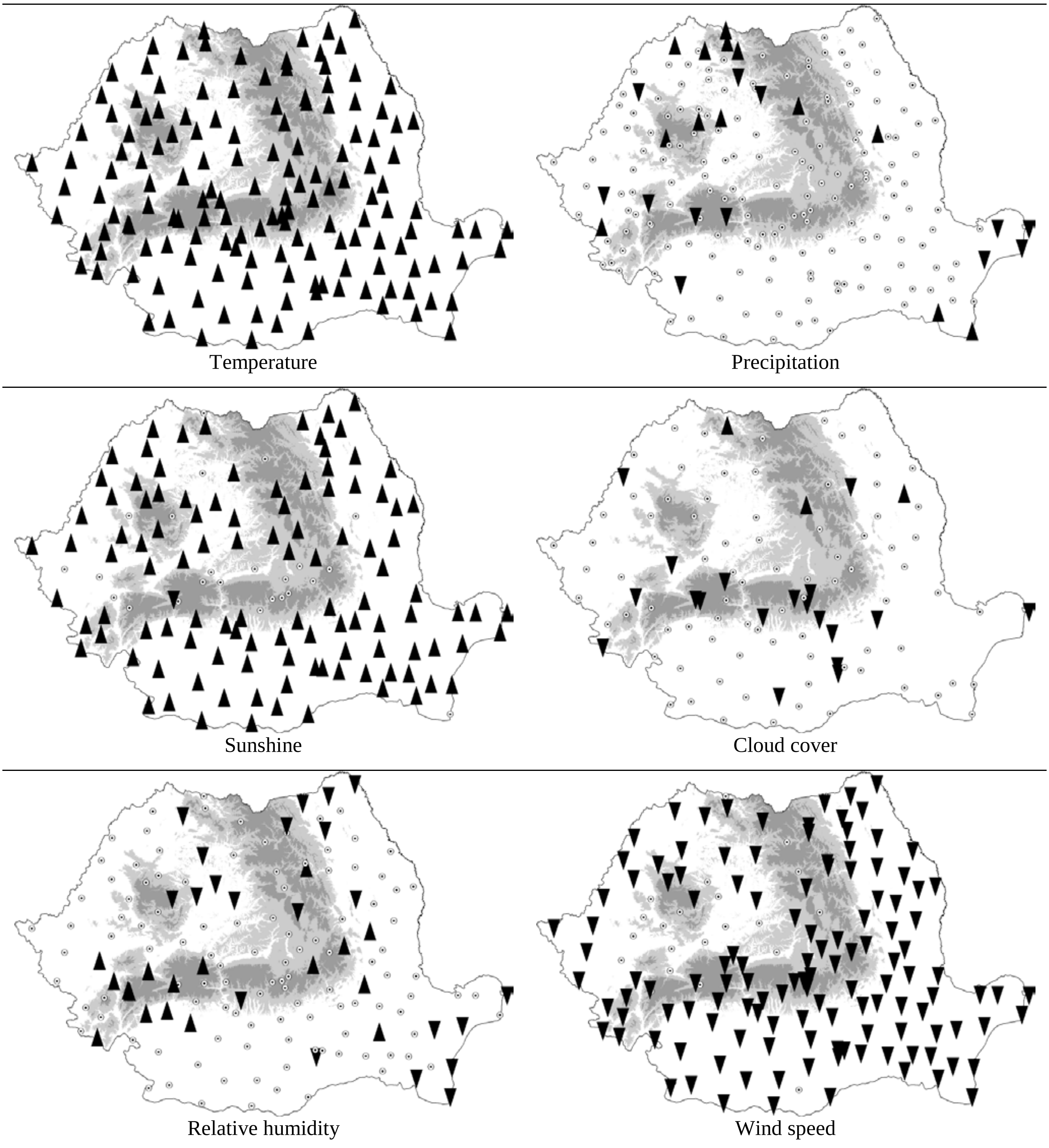

Figure 1. Annual trends (1961-2013) in mean air temperature, precipitation, sunshine hours, nebulosity, relative humidity and wind speed in Romania. Increasing (decreasing) statistically significant trends are marked with upward (downward) triangles. Circles denote no significant trend.

The *mean air temperature* presents exclusively upward trends, statistically significant over the entire country, mainly due to increases in spring and summer (Dumitrescu et al., 2014). The temperature increase is consistent with several previous regional studies (e.g., Hobai, 2009; Piticar & Ristoiu, 2012).

The annual *precipitation* amount presents mixed trends, the number of stations with statistically significant trends being rather low. Busuioc et al., (2014) found significant increasing trends over large areas in the frequency of very wet days and maximum daily amount during autumn, and in the maximum duration of dry spells during summer, but these changes tend to compensate each other, and the long-term evolution of annual precipitation looks rather stable at annual time scale.

The *number of sunshine hours* is significantly increasing over large areas of Romania, except in the mountainous regions of Meridional and Curvature Carpathians.

The annual mean fraction of *cloud cover* has significant downward trends mainly in Meridional and South of Occidental Carpathians and just for three weather stations from the North and Central Oriental Carpathians significant upward trends were registered. Most of the regions of Romania remain relatively steady, with no significant trend during the last 53 years.

The *relative humidity* reveals mixed trends, significant all over the Carpathian Mountains (increasing in the Southern part and decreasing in North) and in southeast – Dobrogea Plateau (only decreasing trends). In the remaining areas of the country, at most of the locations, this parameter shows no significant trend.

Wind speed shows decreasing trends in the seasonal mean at 86% of the weather stations, similar to previous findings for the 1961-2010 period (Birsan et al., 2013). However, in the last three years, the wind speed decrease has extended, the only remaining areas with no trend being the southern Transylvanian Depression and the western Hills.

For the variables showing a consistent signal, statistically significant over a big amount of stations, we looked at the magnitude of the linear trend (Table 1).

The temperature has increasing with 0.14°C to 0.3°C per decade, with a median slope of 0.23°C, pointing to a general warming over the entire region.

For the majority of the stations, the number of sunshine hours has increasing with 0.08 to 0.13 h per decade, and the wind speed is decreasing with 0.06 to 0.16 m/s per decade. In both cases, there are very few stations where the slope has an opposite sign to the general signal; however, these locations present non-significant trends.

Our results confirm the recent studies on climatic variability in the Carpathian Mountains region, evaluated at monthly (Cheval et al., 2014b), seasonal (Spinoni et al., 2014), and annual (Birsan et al., 2014b) time scales.

Table 1. Trend magnitude (%) of air temperature, sunshine and wind speed over 1961-2013. Median values are in bold.

	Air temperature	Sunshine hours	Wind speed
Maximum slope	3.0	2.1	0.2
Upper Quartile	2.5	1.3	-0.6
Median slope	**2.3**	**1.1**	**-1.1**
Lower Quartile	2.2	0.8	-1.6
Minimum slope	1.4	-0.5	-4.0

5. CONCLUSIONS

We presented a trend analysis in annual air temperature, precipitation, sunshine hours, cloud cover, relative humidity and wind speed over 1961-2013. The main conclusions are as follows.

- There is a general warming signal over Romania, with the air temperature and the number of sunshine hours presenting significant increasing trends. The temperature increase is statistically significant at all weather stations.
- The precipitation amount is rather stable, with few stations presenting increasing trends in northwestern Romania and decreasing trends in the Danube Delta (eastern-most area).
- While cloud cover shows predominantly decreasing trends at few locations, the relative humidity shows mixed trends (decreasing in the northern and southeastern regions, and increasing over southwestern Carpathians).
- The wind speed shows downward trends at most of the stations, in agreement with the general tendency of the terrestrial stilling observed in the last half century.

The results are in agreement with several previous findings on climatic changes in Romania.

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