Romanian Reports in Physics **72**, 702 (2020)

OBSERVED CHANGES IN MEAN AND MAXIMUM MONTHLY WIND SPEED OVER ROMANIA SINCE AD 1961

MARIUS-VICTOR BIRSAN[1†], ION-ANDREI NITA[1,2], ALEXANDRA CRACIUN[1,3], LUCIAN SFÎCĂ[2], CRINA RADU[1], RÓBERT SZEP[4,5], ÁGNES KERESZTESI[5,6], MIRUNA MIHAELA MICHEU[7]

[1] Meteo Romania (National Meteorological Administration), Bucharest, Romania
[2] Alexandru Ioan Cuza University of Iași, Faculty of Geography, Iași, Romania
[3] University of Bucharest, Faculty of Physics, Doctoral School, Bucharest, Romania
[4] Institute for R&D in Cinegetics and Mountain Resources, Miercurea Ciuc, Romania
[5] Sapientia Hungarian University of Transylvania, Faculty of Economics, Socio-Human Science and Engineering, Department of Bioengineering, Miercurea Ciuc, Romania
[6] University of Pécs, Faculty of Natural Sciences, Doctoral School of Chemistry, Pécs, Hungary
[7] Clinical Emergency Hospital of Bucharest, Department of Cardiology, Bucharest, Romania
[†] Corresponding author, E-mail: *marius.birsan@gmail.com*

Received October 1, 2019

Abstract. Monthly time series of mean and maximum wind speed over the period 1961–2018 from 104 weather stations evenly distributed over Romania (spatially and elevation-wise) were tested for trends with the Mann-Kendall nonparametric test. The monthly mean wind speed is decreasing at about half of the stations, while increasing trends are between 5% (November) and 28% (September). The maximum wind speed presents decreasing trends in all months at the vast majority of stations – between 75% and 88.5%.

Key words: wind speed, trend analysis, terrestrial stilling, monthly data, East Atlantic Pattern, Scandinavian Pattern, South-Eastern Europe.

1. INTRODUCTION

The study of the long-term changes of terrestrial near-surface wind speed is important for assessing the effects of both anthropogenic activities and natural climatic changes.

Long-term changes in wind speed influence water vapor evaporation and implicitly the hydrological cycle at regional scale [1]. They also have implications in wind energy production, [2], wind erosion, transport of pollen and seeds, pollution spreading and its related impact on health [1, 3]. Multiple studies on regional or global basis found a decreasing trend in wind speed over land referred as stilling [4]. Possible reasons of the terrestrial stilling include the increase in land surface roughness in some areas [5], the increasing water demand for irrigation [6] and increasing aerosol emission [7], which alters the chemical composition of precipitation [8–11].

Climatic changes over Romania are well documented. Recent studies from observational data show increases in rain shower frequency [12, 13], regional warming [14–17] and decreasing snow pack [18, 19]. These changes were proved to affect the natural streamflow regime [20–22], the meteorological and hydrological drought [23, 24], the forest ecosystems [25, 26], and the human comfort [27]. Also, the decrease of thermal contrast between tropical and polar regions as effect of polar amplification process could explain the overall reduction of zonal wind speed in the temperate zone [28].

Previous studies on wind speed have found decreasing trends over 1961–2003 [29] and 1961–2010 [30] at annual and seasonal time scale – for the mean wind speed.

This paper presents an up-to-date, 58-year analysis of monthly trends in mean and maximum wind speed in Romania, using high-quality observational data from 104 weather stations. Linkages with large-scale atmospheric circulation are also investigated.

2. DATA AND PERIOD OF STUDY

The data used in this study belongs to Meteo Romania (National Meteorological Administration). The time series consist in quality-controlled data, most of them presenting continuous records over the period of study (1961–2018). The dataset does not include any reconstructed record – *e.g.*, missing values or extensions that were filled using statistical or stochastic methods. For all stations, all months / seasons / years involved in the analysis have full data records. If a given station had missing value(s) during a month / season / year, the respective record was not taken into account. In order to obtain a better spatial coverage, stations with less than 10% missing data have also been included in the analysis.

We used monthly values of five standardized Northern Hemisphere teleconnection indices provided by National Oceanic and Atmospheric Administration (NOAA) / National Weather Service / Climate Prediction Center (https://www.cpc.ncep.noaa.gov/), namely: North Atlantic Oscillation (NAO), East Atlantic Pattern (EA), East Atlantic / West Russia Pattern (EA/WR), Scandinavia Pattern (SCA), Polar / Eurasia Pattern (POL).

The analysis was conducted over the period 1961–2018, on monthly and annual basis.

3. METHODOLOGY

The trend significance was analysed with the nonparametric Mann-Kendall (MK) test for the monthly mean and maximum wind speed. The MK test is a rank-based procedure, particularly suitable for non-normally distributed data, data containing outliers and non-linear trends [31]. The null and the alternative hypothesis of the MK test for trend in the random variable x are:

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

The MK statistic S is calculated as:

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

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:

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

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

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

The standard deviation of S from Equation (4) includes a correction for tied values, t_i denoting the number of ties of extent i. Then, for hypothesis testing, the standard normal variate Z_S is used.

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

The null hypothesis is rejected at significance level α if $|Z| > Z_{\alpha/2}$ (non-directional test), where $Z_{\alpha/2}$ is the value of the standard normal distribution with an exceedance probability α/2. In the present analysis we fixed the trend significance level at 90%, *i.e.*, p-value < 0.1 (two-tailed).

The trend magnitude was calculated with the nonparametric Theil–Sen estimator (also known as Sen's slope estimator or Kendall–Theil robust line), which is suitable for quasi-linear trends in the variable x and is less affected by non-normal data and outliers [32]. The slope is computed between all pairs i of the variable x:

$$\beta_i = \frac{x_j - x_k}{j - k}, \text{ cu } j > k; \quad j = 2,\ldots, n; \quad k = 1,\ldots,n - 1, \tag{6}$$

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

The correlations with large-scale atmospheric circulation were investigated with Pearson's r – also known as the linear correlation coefficient, which is the most widely-used measure of the linear association between two variables [32].

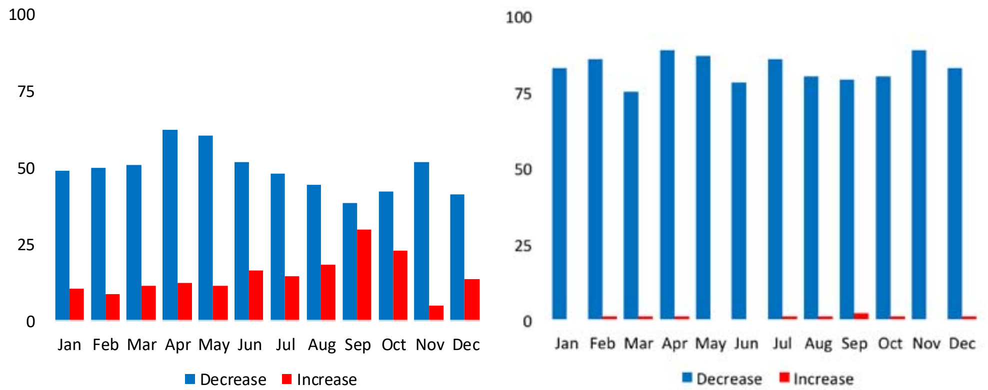
4. RESULTS AND DISCUSSION

The Mann-Kendall trend test applied to monthly data series revealed considerable changes in both mean and maximum wind speed. The monthly mean wind speed is decreasing at about half of the stations, while increasing trends are between 5% in November and 28% in September (Fig. 1). The maximum wind speed presents decreasing trends at the vast majority of stations (75–88.5%). It is worth mentioning that the highest decreases are recorded in April, which is the month with the highest wind speed in Romania, and November, which record normally a secondary peak in annual run of mean wind speed. As well, the most pronounced increase is observed for the months with the lowest wind speed at annual level (August–October). The combined effect of increasing and decreasing trend should lead toward a levelling of annual run of wind speed.

The spatial distribution of trends in mean annual wind speed is shown in Fig. 2 – together with the trend magnitude. 71% of stations present downward trends, most of them significant at 99% level (p-value < 0.01). The median decrease in wind speed (computed with Theil–Sen method) is of –0.187 m/s per decade.

The trends in average monthly wind speed (Fig. 3) present similar spatial patterns for all months. Compared to the results reported for the 1961–2010 period [30], the present study also shows upward trends; they are most present in September and October, in particular in more orographic sheltered area within the intra-Carpathian area and over the western part of the Romanian Plain. Recent studies indicate changes in wind speed trends in the past few years [33], highlighting increases in surface wind speeds in regions of Asia [34, 35].

September is the month with highest number of stations showing increasing trends for both maximum (although for few stations) and mean monthly wind speed, while for downward trends, late spring months (April and May) and November prove highest frequencies.



(a) (b)

Fig. 1 – Relative frequency [%] of stations showing statistically significant trends in mean (a) and maximum (b) monthly wind speed.

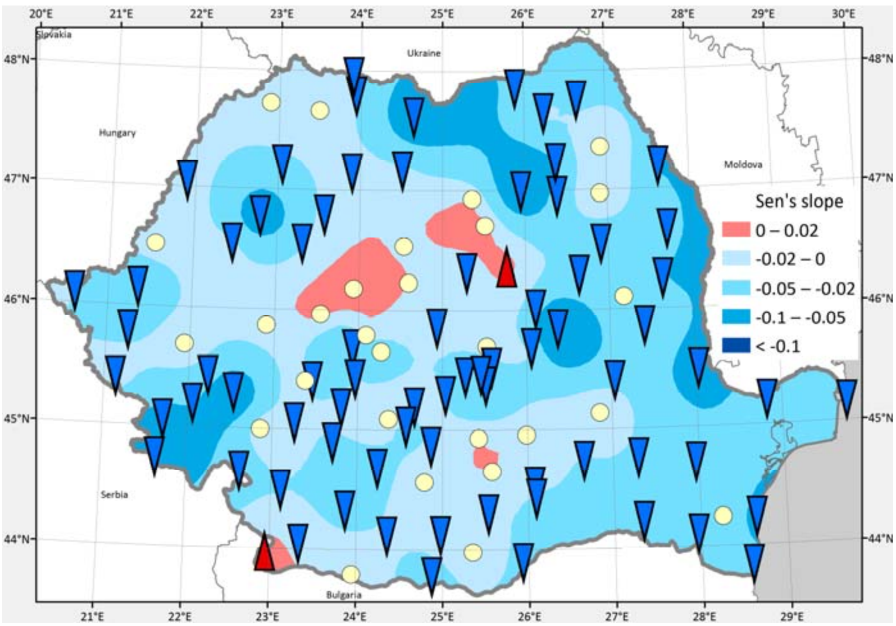


Fig. 2 – Trends in mean annual wind speed. The statistical significance level is 10% (two-tail test). Downward blue triangles denote decreasing trends, upward red triangles symbolize increasing trends; circles represent stations with no trend.

The majority of stations in the Carpathians show decreasing trends in all months. This may indicate a height dependency of wind speed trends. However, faster decrease in wind speed was observed at higher elevations [36], which should be put in relation with the hemispheric decrease of wind speed in altitude [28]. As well, this observed decrease of wind speed in altitude could indicate that the decrease of wind speed in Romania is not a residual effect of the recent sub-urbanization of weather stations position. Furthermore, it seems that most stations in the eastern and south-eastern parts of the country (Dobrogea and the Moldavian Plateau) show a downward trend, both areas being of high interest for wind energy production in Romania. For such purposes, a decrease in low wind speeds may prove even more problematic than the decrease in maximum values [37].

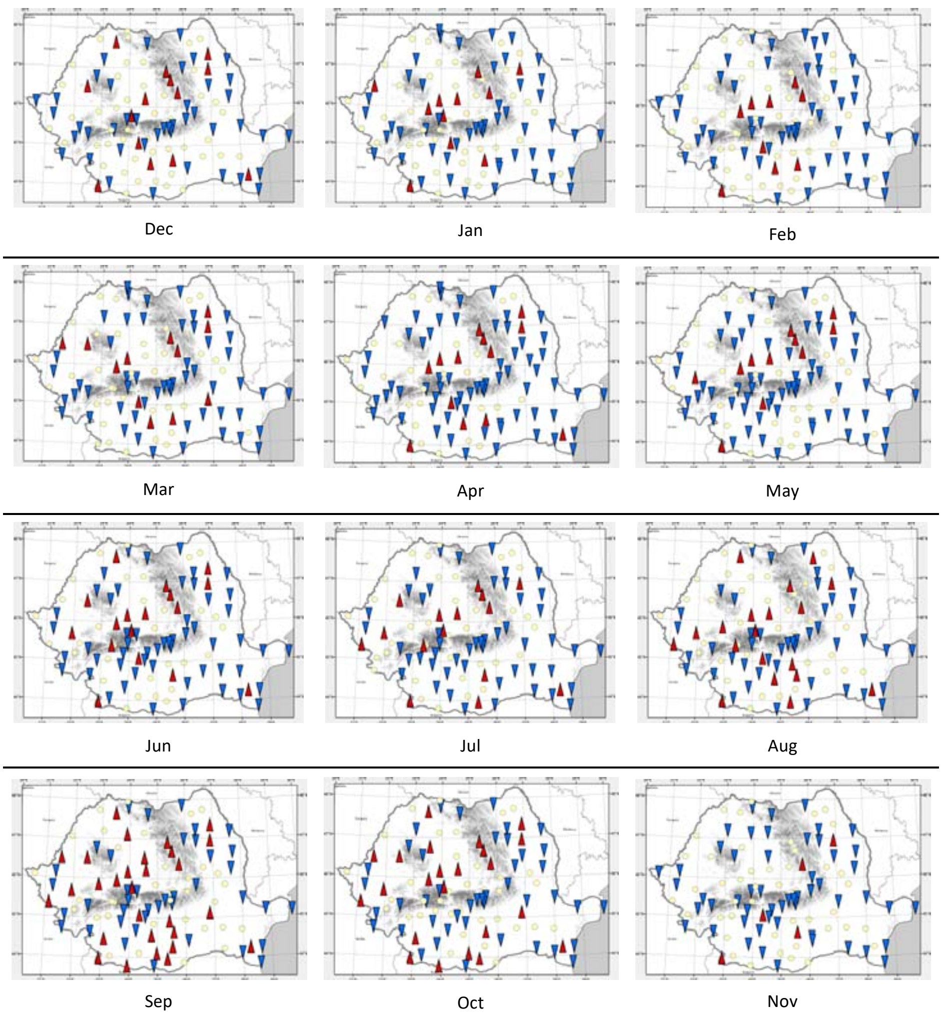


Fig. 3 – Trends in mean monthly wind speed. The statistical significance level is 10% (two-tail test). Downward blue triangles denote decreasing trends, upward red triangles symbolize increasing trends; circles represent stations with no trend.

Regarding the maximum monthly wind speed (Fig. 4), our results indicate a consistent country-wide decrease, which is significant in all months, and more pronounced in extra-Carpathian regions.

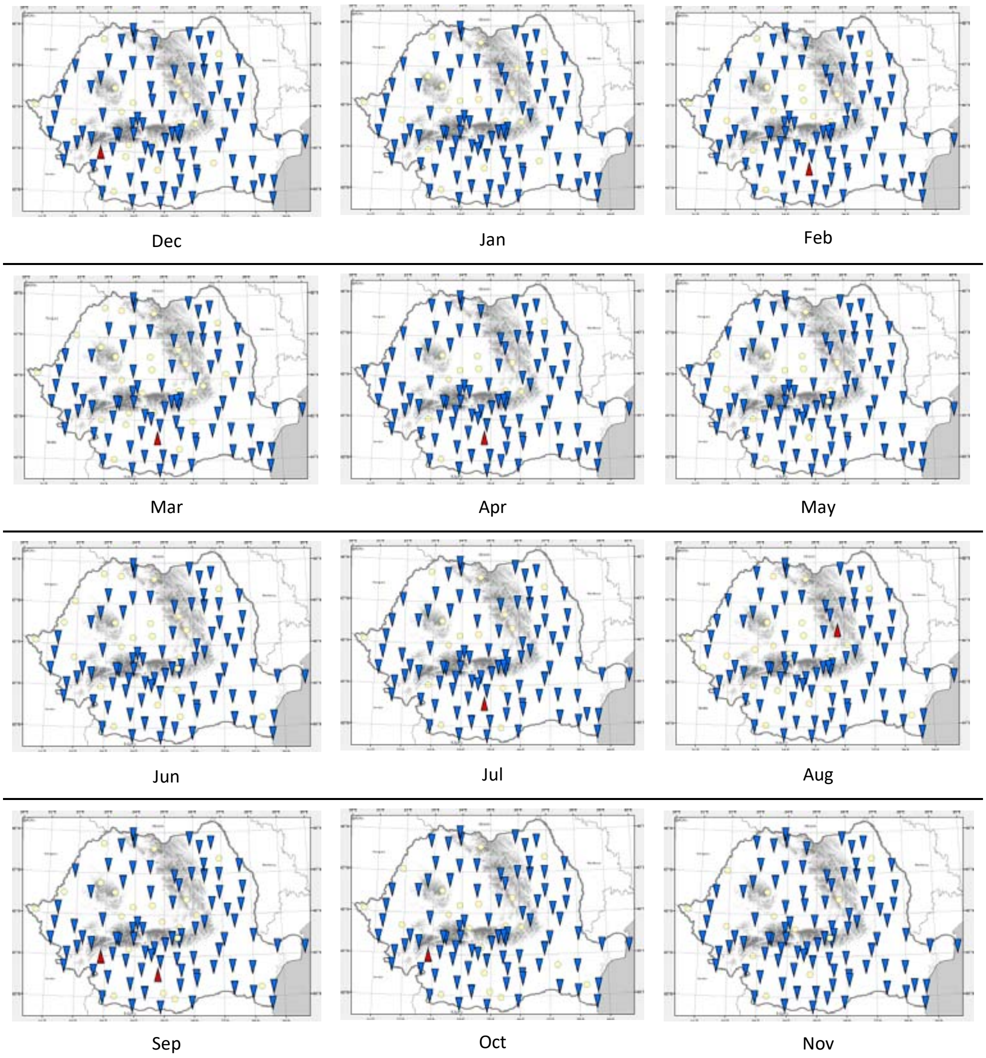


Fig. 4 – Trends in maximum monthly wind speed. The statistical significance level is 10% (two-tail test). Downward blue triangles denote decreasing trends, upward red triangles symbolize increasing trends; circles represent stations with no trend.

Our findings are similar with the vast majority of recent studies on wind speed, which confirm an overall tendency towards terrestrial stilling over Eurasia

[38]. They are also in agreement with recent trends in actual evapotranspiration over Romania [39, 40].

Statistically significant negative correlations (p-value < 0.05) between monthly wind speed and the East Atlantic Pattern (EA) were found at 52% of the weather stations (Fig. 5). EA pattern is the second prominent mode of low-frequency variability over the North Atlantic (appearing as a leading mode in all months), and is structurally similar to NAO: it consists of a North-South dipole of anomaly centers spanning the North Atlantic from East to West. The anomaly centers of the EA pattern are displaced southeastward to the approximate nodal lines of the NAO pattern [41]. Hence, EA could be considered a southward-shifted NAO pattern (source: https://www.cpc.ncep.noaa.gov/data/teledoc/ea.shtml). The negative correlation between the wind speed over Romania and the EA should indicate an increase of high-pressure conditions over the continent, which is a marker of EA's positive phase. On the other hand, large-scale circulation indices are harder to quantify in variability of wind speed over Europe. Still, previous studies show a decrease in the cyclonic circulations in the last decades over central and southern Europe, while an increase in frequency can be observed over Iceland [42].

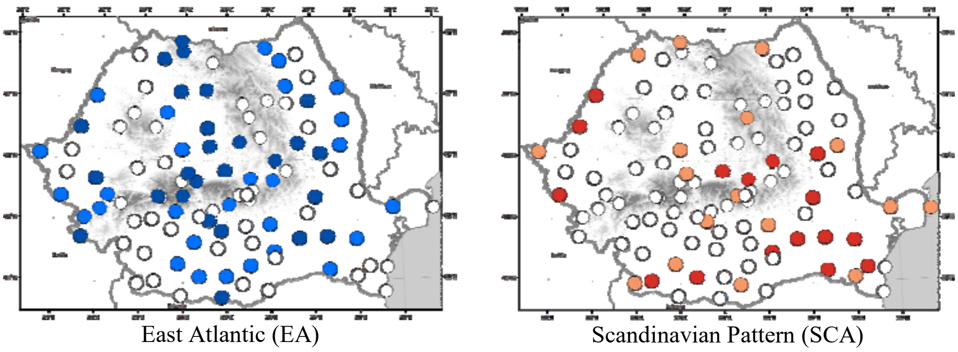


Fig. 5 – Correlation between mean monthly wind speed and EA (left) and SCA (right). Positive (negative) statistically significant correlations are in red (blue). Lighter colors denote a significance level of 95% (p-value < 0.05) and darker colors, of 99% (p-value < 0.01).

Scandinavian Pattern (SCA), another mode of low-frequency variability with an important impact on climate variables in Northern Hemisphere [43] is positively correlated with wind speed in Romania. This indicates that the positive phase of this pattern – characterized by the development of high-pressure centers over Scandinavia – contribute to the occurrence of low wind speed values in Romania.

In fact, both correlations with EA and SCA indicate the same aforementioned large-scale circulation mechanism – consisting in an increase of high-pressure conditions over Europe, which leads toward the observed stilling.

The higher number of weather stations presenting significant increasing / decreasing trends of wind speed than the number of weather stations with significant correlations between wind speed and EA / SCA suggests that the observed trends are just partly explained by large scale circulation mechanisms. Besides this, the local factors should be taken in consideration when trying to explain the observed changes in wind speed.

5. CONCLUSIONS

We presented a 58-year (1961–2018) trend analysis of monthly mean and maximum wind speed in Romania, using high-quality observational data from 104 weather stations. The main conclusions of this study are:

(1) The monthly mean wind speed is decreasing at about half of the stations; the percentage of increasing trends ranges between 5% in November and 28% in September.

(2) The maximum wind speed presents decreasing trends in all months at most of the stations (75%–88.5%). The decrease in more pronounced during the months with the highest wind speed, while the increase characterizes the stillest month (September and October).

(3) The monthly EA pattern is negatively correlated with the mean monthly wind speed at 52% of the locations. According to this finding the decrease of the wind speed in Romania is the effect of the increase in high pressure conditions over the continent.

Our results indicate not only a tendency towards terrestrial stilling over Romania, but also a country-wide decline in variability between months.

Acknowledgements. This study was realized within the framework of the UEFISCDI “Nucleu 2018” program: “Re-evaluating the regions of provenance for forest tree species under climate change, on genetic-ecological basis” (project code: PN 204/2018).

REFERENCES

1. T.R. McVicar et al., *Global review and synthesis of trends in observed terrestrial near-surface wind speeds: Implications for evaporation*, J. Hydrol. **416–417**, 182–205 (2008). doi: 10.1016/j.jhydrol.2011.10.024.
2. Q. Tian, G. Huang, K. Hu, D. Niyogi, *Observed and global climate model based changes in wind power potential over the Northern Hemisphere during 1979–2016*, Energy, **167**, 1224–1235 (2019). doi: 10.1016/j.energy.2018.11.027
3. A. Okubo, S.A. Levin, *A theoretical framework for data-analysis of wind dispersal of seeds and pollen*, Ecology **70**, *2*, 329–338 (1989).
4. M.L. Roderick, L.D. Rotstayn, G.D. Farquhar, M.T. Hobbins, *On the attribution of changing pan evaporation*, Geophys. Res. Lett., **34**, 7403 (2007). doi: 10.1029/2007GL031166
5. R. Vautard, J. Cattiaux, P. Yiou, J.N. Thépaut, P. Ciais, *Northern hemisphere atmospheric stilling partly attributed to increased surface roughness*, Nat. Geosci. **3**, *11*, 756–761 (2010).
6. W.J. Shuttleworth, A. Serrat-Capdevila, M.L. Roderick, R.L. Scott, *On the theory relating changes in area-average and pan evaporation*, Quart. J. Roy. Meteorol. Soc. **135**, *642*, 1230–1247 (2009).

7. A. Bichet, M. Wild, D. Folini, C. Schär, *Causes for decadal variations of wind speed over land: Sensitivity studies with a global climate model*, Geophys. Res. Lett., **39**, L11701 (2012). doi:10.1029/2012GL051685
8. Á. Keresztesi, M.V. Birsan, I. A. Nita, Zs. Bodor, R. Szép, *Assessing the neutralisation, wet deposition and source contributions of the precipitation chemistry over Europe during 2000–2017*, Environ. Sci. Eur. **31**, 50 (2019). doi: 10.1186/s12302-019-0234-9
9. R. Szép, Zs. Bodor, I. Miklóssy, I. A. Nita, O. A. Oprea, Á. Keresztesi, *Influence of peat fires on the rainwater chemistry in intra-mountain basins with specific atmospheric circulations (Eastern Carpathians, Romania)*, Sci. Total Environ. **647**, 275–289 (2019). doi: 10.1016/j.scitotenv. 2018.07.462
10. R. Szép, E. Mateescu, A.C. Nechifor, Á. Keresztesi, *Chemical characteristics and source analysis on ionic composition of rainwater collected in the Carpathians "Cold Pole", Ciuc basin, Eastern Carpathians, Romania*, Environ. Sci. Pollut. Res. **24**, 27288–27302 (2017). doi: 10.1007/s11356-017-0318-2
11. R. Szép, E. Mateescu, I. A. Nita, M.V. Birsan, Zs. Bodor, Á. Keresztesi, *Effects of the Eastern Carpathians on atmospheric circulations and precipitation chemistry from 2006 to 2016 at four monitoring stations (Eastern Carpathians, Romania)*, Atmos. Res. **214**, 311–328 (2018). doi: 10.1016/j.atmosres.2018.08.009
12. A. Busuioc, M.V. Birsan, D. Carbunaru, M. Baciu, A. Orzan, *Changes in the large-scale thermodynamic instability and connection with rain shower frequency over Romania: verification of the Clausius–Clapeyron scaling*, Int. J. Climatol. **36**, 2015–2034 (2016). doi: 10.1002/joc.4477
13. A. Manea, M.V. Birsan, G. Tudorache, F. Cărbunaru, *Changes in the type of precipitation and associated cloud types in Eastern Romania (1961–2008)*, Atmos. Res. **169**, 357–365 (2016). doi: 10.1016/j.atmosres.2015.10.020
14. M.V. Birsan, D.M. Micu, I.A. Nita, E. Mateescu, R. Szép, Á. Keresztesi, *Spatio-temporal changes in annual temperature extremes over Romania (1961–2013)*, Rom. J. Phys. **64**(7–8), 816 (2019).
15. M. Ionita, N. Rimbu, S. Chelcea, S. Patrut, *Multidecadal variability of summer temperature over Romania and its relation with Atlantic Multidecadal Oscillation*, Theor. Appl. Climatol. **113**(1–2), 305–315 (2013). doi: 10.1007/s00704-012-0786-8
16. S. Cheval, M.V. Birsan, A. Dumitrescu, *Climate variability in the Carpathian Mountains Region over 1961–2010*, Global Planet. Change **118**, 85–96 (2014). doi: 10.1016/j.gloplacha.2014.04.005
17. A. Busuioc, A. Dobrinescu, M.V. Birsan, A. Dumitrescu, A. Orzan, *Spatial and temporal variability of climate extremes in Romania and associated large-scale mechanisms*, Int. J. Climatol. **35**(7), 1278–1300 (2015); doi: 10.1002/joc.4054
18. M. V. Birsan, A. Dumitrescu, *Snow variability in Romania in connection to large-scale atmospheric circulation*, Int. J. Climatol. **34**(1), 134–144 (2014). doi: 10.1002/joc.3671
19. D. Micu, *Snow pack in the Romanian Carpathians under changing climatic conditions*, Meteorological and Atmospheric Physics **105**(1), 1–16 (2009); doi: 10.1007/s00703-009-0035-6
20. M.V. Birsan, L. Zaharia, V. Chendes, E. Branescu, *Recent trends in streamflow in Romania (1976–2005)*, Rom. Rep. Phys., **64**, *1*, 275–280 (2012).
21. M.V. Birsan, L. Zaharia, V. Chendes, E. Branescu, *Seasonal trends in Romanian streamflow*, Hydrol. Process. **28**(15), 4496–4505 (2014). doi: 10.1002/hyp.9961
22. M.V. Birsan, *Trends in Monthly Natural Streamflow in Romania and Linkages to Atmospheric Circulation in the North Atlantic*, Water Resour. Manag. **29**(9), 3305–3313 (2015); doi: 10.1007/ s11269-015-0999-6
23. S. Cheval, A. Busuioc, A. Dumitrescu, M.V. Birsan, *Spatiotemporal variability of meteorological drought in Romania using the standardized precipitation index (SPI)*, Clim. Res. **60**, 235–248 (2014). doi: 10.3354/cr01245
24. S. Cheval, A. Dumitrescu, M.V. Birsan, *Variability of the aridity in the South-Eastern Europe over 1961–2050*, Catena **151**, 74–86 (2017). doi: 10.1016/j.catena.2016.11.029

25. G. Mihai, M.V. Birsan, A. Dumitrescu, A. Alexandru, I. Mirancea, P. Ivanov, E. Stuparu, M. Teodosiu, M. Daia, *Adaptive genetic potential of European silver fir in Romania in the context of climate change*, Ann. Forest Res. **61**, *1*, 95–108 (2018). doi: 10.15287/afr.2018.1021
26. G. Mihai, I. Mirancea, M.V. Birsan, A. Dumitrescu, *Patterns of genetic variation in bud flushing of Abies alba populations*, iForest **11**, *2*, 284–290 (2018). doi: 10.3832/ifor2314-011
27. A. Dobrinescu, A. Busuioc, M.V. Birsan, A. Dumitrescu, *Changes in thermal discomfort indices in Romania and responsible large-scale mechanisms*, Clim. Res., **64**, *3*, 213–226 (2015). doi: 10.3354/cr01312
28. J.A. Francis, S.J. Vaavrus, *Evidence for a wavier jet stream in response to rapid Arctic warming*, Environ. Res. Lett. **10**, 014005 (2015). doi: 10.1088/1748-9326/10/1/014005
29. A. Vespremeanu-Stroe, S. Cheval, F. Tătui, *The wind regime of Romania – Characteristics, trends and North Atlantic Oscillation influences*, Forum geografic **XI**, *2*, 118–126 (2012). doi: 10.5775/fg.2067-4635.2012.003.d
30. M.V. Birsan, L. Marin, A. Dumitrescu, *Seasonal changes in wind speed in Romania*, Rom. Rep. Phys. **65**, *4*, 1479–1484 (2013).
31. J.D. Salas, *Analysis and modeling of hydrologic time series* (Chapter 19), in D.R. Maidment (Ed.), *Handbook of Hydrology*, McGraw-Hill, New York, 19.1–19.72.
32. D.R. Helsel, R.M. Hirsch, *Statistical Methods in Water Resources. Techniques of Water Resources Investigations*, Book 4 (Chapter A3), U.S. Geological Survey, 2002.
33. C. Azorin-Molina, R.J.H. Dunn, C.A. Mears, P. Berrisford, T.R. McVicar, *Global Climate: Surface winds* (Ch. 2.e.2), in J. Blunden, D.S. Arndt and G. Hartfield (Eds.): *State of the Climate in 2017*, B. Am. Meteorol. Soc. **99**, *8*, S41–S42 (2018). doi:10.1175/2018BAMSStateoftheClimate.1
34. C. Lin, K. Yang, J. Qin, R. Fu, *Observed coherent trends of surface and upper-air wind speed over China since 1960*, J. Climate **26**(9), 2891–2903 (2013). doi: 10.1175/JCLI-D-12-00093.1
35. Y. Li, Y. Chen, Z. Li, G. Fang, *Recent recovery of surface wind speed in northwest China*, Int. J. Climatol. **38**, *12*, 4445–4458 (2018). doi: 10.1002/joc.5679
36. T.R. McVicar, T.G. van Niel, M.L. Roderick, L.T. Li, X.G. Mo, N.E. Zimmermann, D.R. Schmatz, *Observational evidence from two mountainous regions that near-surface wind speeds are declining more rapidly at higher elevations than lower elevations: 1960–2006*, Geophys. Res. Lett. **37**, 06402 (2010). doi:10.1029/2009GL042255.
37. R. Stull, *Practical meteorology: an algebra based survey of atmospheric science*, version 1.02b. Ch. 17: Regional Winds, University of British Columbia, 2017.
38. J. Wu, J. Zha, D. Zhao, Q. Yang, *Changes in terrestrial near-surface wind speed and their possible causes: an overview*, Clim. Dyn. **51**, 2039–2078 (2018). doi: 10.1007/s00382-017-3997-y
39. A.E. Croitoru, A. Piticar, C.S. Dragotă, D. C. Burada, *Recent changes in reference evapotranspiration in Romania*, Global Planet. Change **111**, 127–136 (2013). doi: 10.1016/j.gloplacha.2013.09.004
40. R. Prăvălie, A. Piticar, B. Roșca, L. Sfîcă, G. Bandoc, A. Tiscovschi, C. Patriche, *Spatio-temporal changes of the climatic water balance in Romania as a response to precipitation and reference evapotranspiration trends during 1961–2013*, Catena **172**, 295–312 (2019). doi: 10.1016/j.catena. 2018.08.028
41. A.G. Barnston, R.E. Livezey, *Classification, seasonality and persistence of low-frequency atmospheric circulation patterns*, Mon. Wea. Rev. **115**, 1083–1126 (1987).
42. M. Cahynová, R. Huth, *Atmospheric circulation influence on climatic trends in Europe: an analysis of circulation type classifications from the COST733 catalogue*, Int. J. Climatol. **36**, 2743–2760 (2016). doi: 10.1002/joc.4003
43. L. Sfîcă, M. Voiculescu, *Possible effects of atmospheric teleconnections and solar variability on tropospheric and stratospheric temperatures in the Northern Hemisphere*, J. Atmos. Sol-Terr Phys. **109**, 7–14 (2014). doi: 10.1016/j.jastp.2013.12.021