

The variability of winter high temperature extremes in Romania and its relationship with large-scale atmospheric circulation

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Abstract The frequency variability of extreme high winter temperature as recorded at 85 meteorological stations from Romania during 1962–2010 period and its relationship with large-scale atmospheric circulation was investigated. An Empirical Orthogonal Function analysis reveals that large part of the extreme temperature frequency variability is common to all stations suggesting a strong influence of large-scale circulation anomalies. The North Atlantic Oscillation, West Pacific, East Atlantic, and Scandinavian patterns are related with extreme temperature frequency variability. We show that the East Atlantic Oscillation controls a significant part of interannual extreme high temperature variability over Romania via advection of warm air from the west. In addition, a strong relationship between blocking activity and frequency of extreme high temperature events in Romania was found. High blocking activity in the (20°W–70°E) sector is related with relatively strong advection of cold air over the country during winter. On the other hand, low blocking activity in the same sector is related with weak advection of relatively cold air in the region. Moreover, the blocking frequency in this sector is modulated mainly by the East Atlantic Oscillation.

1 Introduction

In recent decades, Europe has experienced unprecedented increase in the frequency of extreme phenomena (Klein

Tank et al. 2002) and part of these changes is related to atmospheric circulation patterns (e.g., Knežević et al. 2013). The relationship between the extreme phenomena variability and large-scale atmospheric circulation anomalies depends on the geographical position and other characteristics of the region under investigation (e.g., Unkašević and Tošić 2013).

In this study, we investigate the variability of extreme high temperatures in Romania and its relationship with large-scale atmospheric circulation anomalies, in particular with Northern Hemisphere atmospheric teleconnection patterns. Romania is situated in the southeastern part of Europe (Fig. 1) and has a temperate continental climate. The climate characteristics are strongly influenced by orography. An important role is played by the Carpathian Mountains which divides the country into parts with various climates (National Meteorological Administration 2008). Because of this, the western and central part of the country is influenced by the Atlantic air masses being characterized by milder winters and heavier rainfalls than the rest of the country. The mountains also act as a barrier for continental climate influences from the north. In the east and south east of the country, the climate is influenced by the Black Sea.

Romania has been experiencing also strong extreme events over the last decades. In particular, the frequency of extreme temperature events in Romania increased significantly during the last decades (Busuioc et al. 2007). Croitoru and Piticar (2012) identified significant trends in maximum and minimum temperatures in the extra-Carpathians regions of Romania. Other studies analyzed extreme temperature changes related to cold and heat waves (Busuioc et al. 2010).

In Romania, various studies pointed out that certain changes in observed surface air temperature and precipitation regime (mean state and extremes) are connected with changes in the large-scale atmospheric circulation patterns. Atmospheric teleconnection patterns characterize low-frequency

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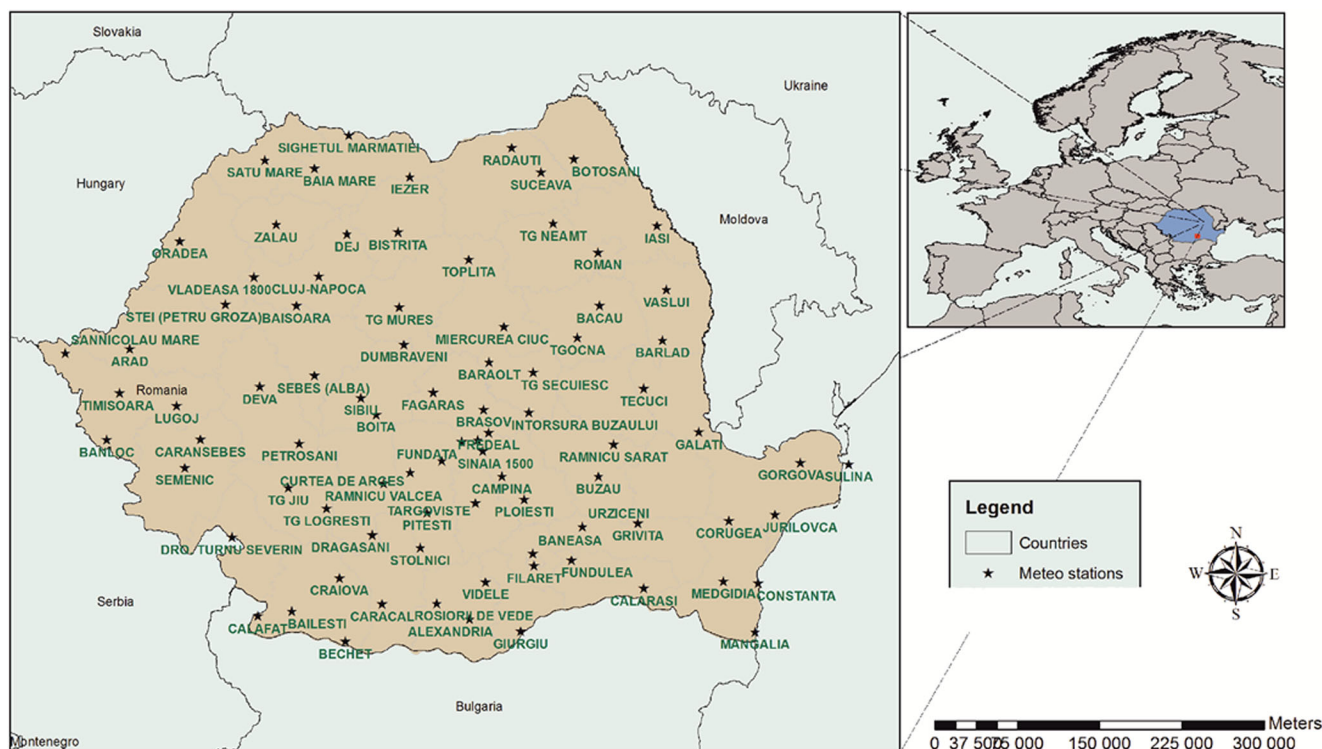


Fig. 1 Synoptic meteorological stations from Romania used in this study and the map of Europe with the Romanian territory *highlighted*

atmospheric variability on regional and hemispheric scales. In the Atlantic-European sector, the North Atlantic Oscillation (NAO), the East Atlantic (EA), the East Atlantic/Western Russia (EA/WR), and Scandinavian (SCA) patterns are the leading modes of low-frequency atmospheric variability. Other atmospheric teleconnection patterns are the Pacific North American (PNA), West Pacific (WP), East Pacific-North Pacific (EP/NP) and Tropical-Northern Hemisphere (TNH) (e.g., Rimbu et al. 2011). Tomozeiu et al. (2002) analyzed the connection between seasonal mean of maximum air temperature in Romania and various large-scale circulation indices, highlighting the seasonal dependence of this connection. Significant relationships between the NAO and winter temperature variability were identified by Bojariu and Paliu (2001). A large part of temperature variability in central part of Romania is related with EA/WR (Rimbu et al. 2011). The Atlantic Multidecadal Oscillation (AMO) influences also the temperature variability in Romania through modulation of the frequency of daily atmospheric circulation patterns (Ionita et al. 2013).

Similar relationships between large-scale atmospheric circulation patterns and variability of extreme temperatures in other countries from the region were identified (e.g., Knežević et al. 2013). Unkašević and Tošić (2013) found that EA pattern and NAO dominate the variability of winter and summer temperature in Serbia. Changes in extreme temperatures were detected in the entire Carpathian basin (Bartholy and

Pongracz 2007) or over the entire European continent (Moberg et al. 2006).

Besides changes in climatic modes, like the NAO (Bojariu and Paliu 2001) or AMO (Ionita et al. 2013), another possible candidate to explain these variations is the atmospheric blocking (Andrei and Roman 2012). Andrei and Roman (2012) shown that blocking activity in the Euro-Atlantic region is responsible for extreme weather conditions in the southern part of Romania. However, blocking activity and the low-frequency atmospheric circulation patterns are not independent each other (e.g., Shabbar et al. 2001).

The aim of this study is to investigate the dominant large-scale patterns that control extreme high temperature variability in Romania during winter. The focus is on the teleconnection patterns and on the atmospheric blocking. It is important to investigate such connections because of the possibility of translation large-scale circulation anomalies, accurately predicted by climate models, into regional context.

The paper is organized as follows. In Section 2, data and methods are presented. The relationship between the extreme high temperature variability in Romania and relevant Northern Hemisphere atmospheric teleconnection patterns are presented in Section 3.1. The relationship of atmospheric blocking and extreme temperature variability is presented in Section 3.2. The main conclusions follow in Section 4.

2 Data and methods

The temporal variability of extreme temperature events is typically evaluated based on the analysis of a set of indicators defining variation and extreme conditions. In our study, we have used the TX90p index (e.g., Klein and Können 2003). The TX90p is a threshold-based index that corresponds to the number of days in winter (DJF) with maximum temperature above the long-term 90th percentile. TX90p index is also commonly referred to as the number of occurrences of warm days (e.g., Andrade et al. 2012).

In our study, the TX90p indices over the period 1962–2010 were calculated at the 85 meteorological stations (Fig. 1) covering the entire Romanian territory. The daily maximum temperature (TX) data set was provided by the National Meteorological Administration (NMA), Bucharest, Romania. These data were a priori quality controlled using the MASH software (Szentimrey 1997). The geographical position (latitude and longitude) as well as the height of most of these stations are presented in Birsan and Dumitrescu (2014).

The dominant pattern of the interannual to decadal variability of these indices is derived using Empirical Orthogonal Function (EOF) analysis (von Storch and Zwiers 1999). The first TX90p anomalies against the 1962–2010 means were calculated. These anomaly time series were then normalized with the corresponding standard deviation. The normalization helps to avoid the distortion in data patterns due to large differences of the time series variance. The EOFs and the corresponding principal components (PCs) were calculated from the correlation matrix of the 85 normalized anomaly time series of the TX90p indices.

Because our study is focused on interannual to decadal time scales, the linear trend was removed from the data prior to the analysis. The trends in the data as well as their statistical significance were calculated using the nonparametric Mann–Kendall (M-K) test (WMO 1966). In this study, we used the Pearson's correlation coefficient as a measure of the degree of linear relationship between extreme temperature and atmospheric circulation indices. The significance of the correlations are calculated using simple t test distribution (e.g., Wilks 2006) with $N-2$ degrees of freedom, where N is the number of observations.

The large-scale anomaly circulation patterns associated with high and low frequency of extreme temperature events in Romania are derived using the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) (hereafter NCEP/NCAR) reanalysis data. The NCEP/NCAR data are based on a state-of-the-art analysis/forecast system that performs data assimilation using past data from 1948 (Kalnay et al. 1996; Kistler et al. 2001). Monthly 500 hPa geopotential height field (Z500) were downloaded from the NCEP/NCAR reanalysis data base (available at [http://www.esrl.noaa.gov/psd/data/gridded/data.](http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html)

[ncep.reanalysis.html](http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html)). Using monthly fields, we have calculated the winter Z500 fields by averaging the Z500 corresponding to the December, January, and February (DJF) months. We have used also winter means of eight atmospheric teleconnection pattern indices, the NAO, EA, WP, EP/NP, PNA, EA/WR, SCA, and TNH, calculated also from NCEP/NCAR data.

Atmospheric blocking can be identified using a large variety of objective and subjective procedures. Most common blocking indicators are based on calculation of the meridional Z500 gradients (e.g., Tibaldi and Molteni 1990) or on detection of Z500 anomaly maxima (Scherrer et al. 2006). In our study, we have used the one-dimensional (1-D) blocking index as defined by Tibaldi and Molteni (1990) (TM). The TM index is calculated using the daily Z500 maps downloaded from NCEP/NCAR reanalysis database (Kalnay et al. 1996; Kistler et al. 2001). In our study, a longitude is considered to be blocked if the TM conditions, that is the southern gradient is higher than zero and the northern gradient is less than -10 m/(° lat.), are satisfied for at least one based latitudes (based latitudes are 55°N, 60°N and 65°N) and for at least five consecutive days. A longitudinal sector is considered to be blocked if at least five consecutive longitudes (resolution is 2.5° longitude) are blocked for at least five consecutive days.

In our study, we have used also the two-dimensional (2-D) blocking indicator defined by Scherrer et al. (2006). The Z500 gradients are evaluated in each grid point using a latitudinal interval of 15° instead of 20° like in the case of the 1-D TM index described above. A certain grid point is considered to be blocked if the TM conditions are satisfied for at least five consecutive days (5-day persistent criteria). These characteristics typically correspond to persistent quasi-stationary high-pressure systems (Scherrer et al. 2006). Using Z500 data north of 20°N, the frequency of blocked grid points from 35°N to 75°N can be calculated.

To understand how large-scale atmospheric circulation is related to the dominant pattern of the extreme temperature frequency in Romania, we calculate the average of Northern Hemisphere Z500 anomalies for winters characterized by high ($PC1 > 0.75$ of standard deviation) and low ($PC1 < -0.75$ of standard deviation) values of normalized and linear detrended PC1. A similar procedure was used to calculate the corresponding 1-D and 2-D blocking anomaly patterns as well as the Z500 anomaly patterns associated to a blocking index.

3 Results and discussion

Extreme temperature anomalies in Europe are controlled by large-scale atmospheric circulation patterns (e.g.,

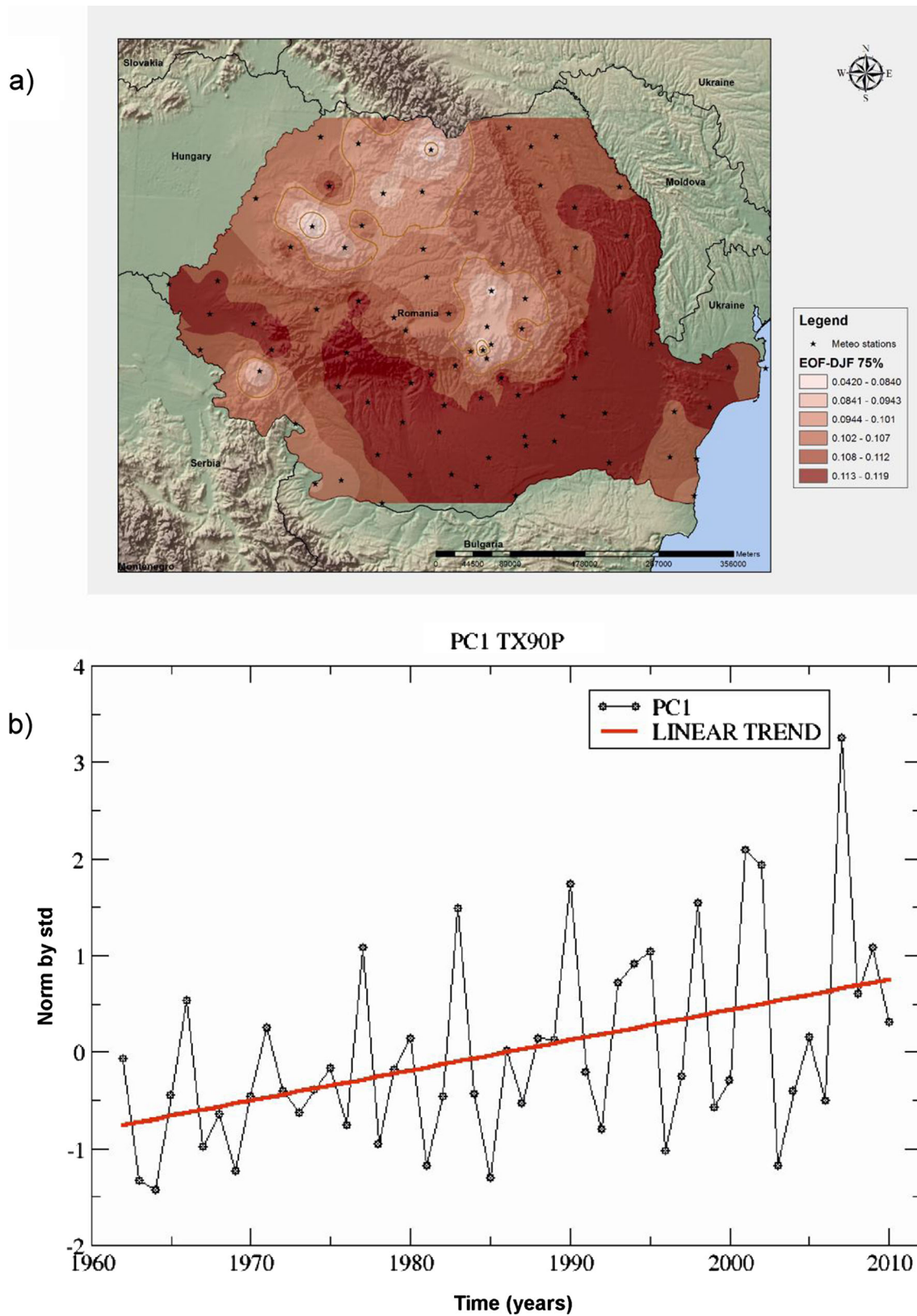


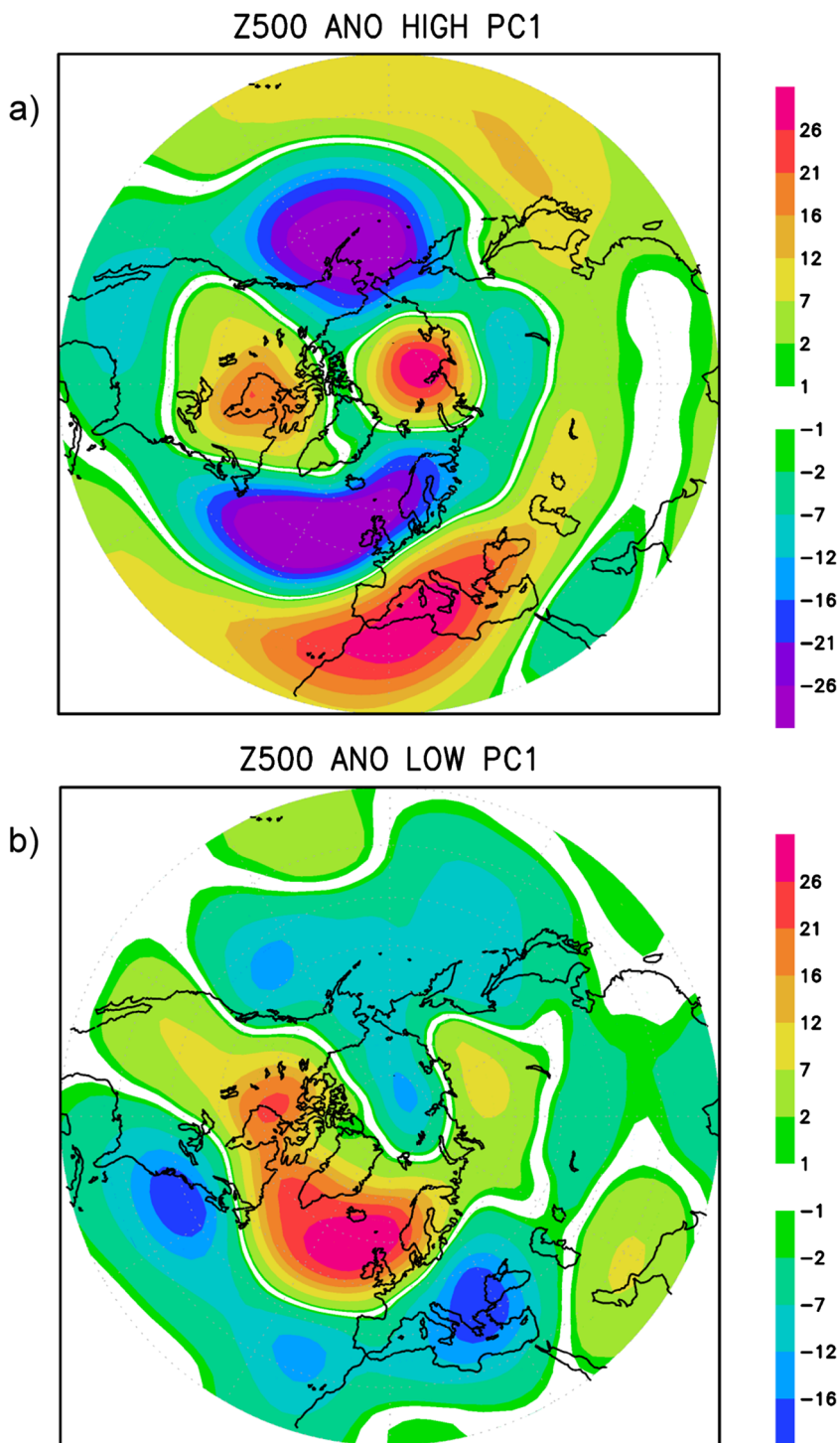
Fig. 2 **a** The dominant pattern (EOF1 explaining 75 % of variance) of winter TX90p indices variability. The TX90p anomalies were normalized prior to EOF analysis. The units are arbitrary. **b** The corresponding principal components (PC1) (black line) and its linear trend (red line). The PC1 time series was normalized by its standard deviation

Wanner et al. 2001). Part of this influence is related with modulation of the blocking activity by these patterns. Thus, we further investigate the dominant large-scale patterns influencing the winter (DJF) extreme high temperatures in Romania and the role of blocking in connecting them.

3.1 Atmospheric circulation anomalies associated to dominant pattern of high temperature extremes in Romania

First, the TX90p indices were analyzed to assess changes in the linear trends of temperature extremes. The 84 out of the 85 weather stations TX90p indices show positive trends over the

Fig. 3 Composite maps of Z500 anomalies (gpm) for **a** high and **b** low values of PC1. Both PC1 and Z500 anomaly field were linear detrended prior to the composite analysis



period 1962–2010. The highest trend is recorded at Curtea de Arges station (Fig. 1; central part of Romania) with an increase of 13 warm days during the 1962–2010 period. Only the TX90p index from the Vârful Omu mountain station shows a negative trend (of minus two warm days during the 49 years) which is nonsignificant at 95 % level.

The first EOF of the TX90p indices (Fig. 2a), which describes 75 % variance, has a monopolar structure. However, several regional characteristics can be identified on this map. Relatively high EOF1 loadings characterize the southern and eastern part of the country. They are related especially with the influence of the orography, particularly the influence of the Carpathian Mountains on temperature extreme variability. The corresponding principal component (PC1) (Fig. 2b) shows a significant (95 % level) positive trend over the period 1962–2010. This is consistent with positive trends identified in original TX90p time series through linear regression analysis. Pronounced interannual variations are superposed on this positive linear trend. Extremely high value of PC1, that is high frequency of extreme temperature events over entire Romania, is recorded in 2006/2007 winter (Fig. 2b).

The Z500 composite maps associated to the positive (high PC1 values) and negative (low PC1 values) phase of the dominant mode of temperature variability (Fig. 3) show large-scale features. Both PC1 and Z500 anomaly field were linear detrended prior to the composite analysis. The high Z500 anomaly center in the western Mediterranean and southwestern Europe accompanied by the low Z500 anomaly center over central North Atlantic (Fig. 3a) favor the advection of warm air from the southwest towards Romania. These anomalous centers are close to the corresponding anomalous centers associated to the positive phase of the EA as presented by Barnston and Livezey (1987). The atmospheric circulation

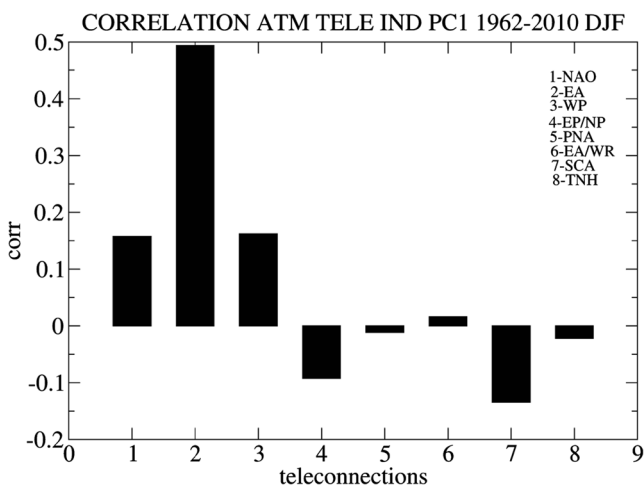


Fig. 4 Correlation coefficients of PC1 with eight atmospheric teleconnection pattern indices for the period 1962 to 2010 (see text for details). Linear trends were removed from the data prior to the correlation

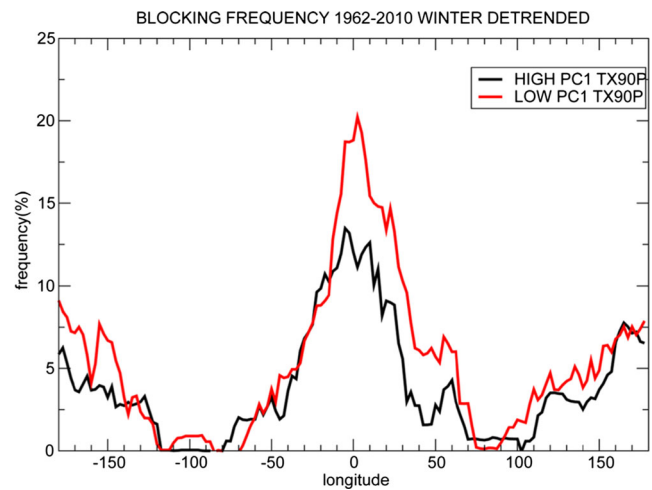


Fig. 5 Blocking frequency for high (black) and low (red) values of PC1 of TX90p indices. Both PC1 and blocking frequency were linear detrended prior to the composite analysis. Units are percentage of blocked days with respect to the total number of winter days

pattern associated to the negative phase of TX90p indices pattern (Fig. 3b) projects well on the negative phase of the EA in the Atlantic European region. Figure 3 also suggests that other Northern Hemisphere teleconnection patterns play a role in modulation extreme temperature variability over Romania but with weaker influence. The correlation coefficients between PC1 of TX90p indices and atmospheric teleconnection pattern indices (Fig. 4) are consistent with the composite maps represented in Fig. 3. The highest correlation coefficient ($r \sim +0.50$) is obtained for the EA. Consistent with the composite maps represented in Fig. 3, significant (90 % level) positive(negative) correlations are obtained also for the NAO and WP (SCA) (Fig. 4).

Andrade et al. (2012) identified three dominant coupled modes of TX90p anomaly field from Europe and Atlantic-

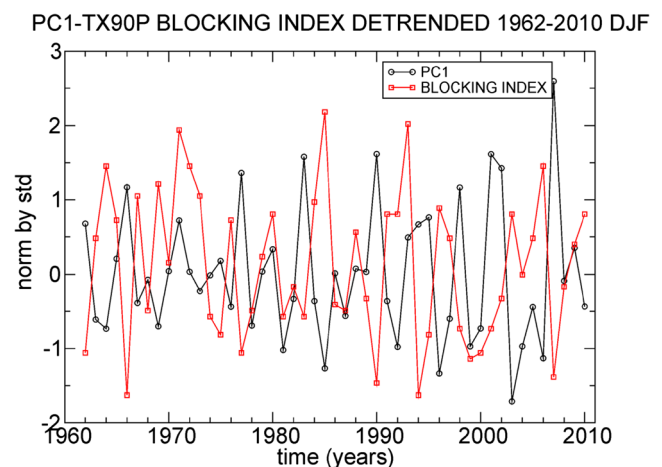
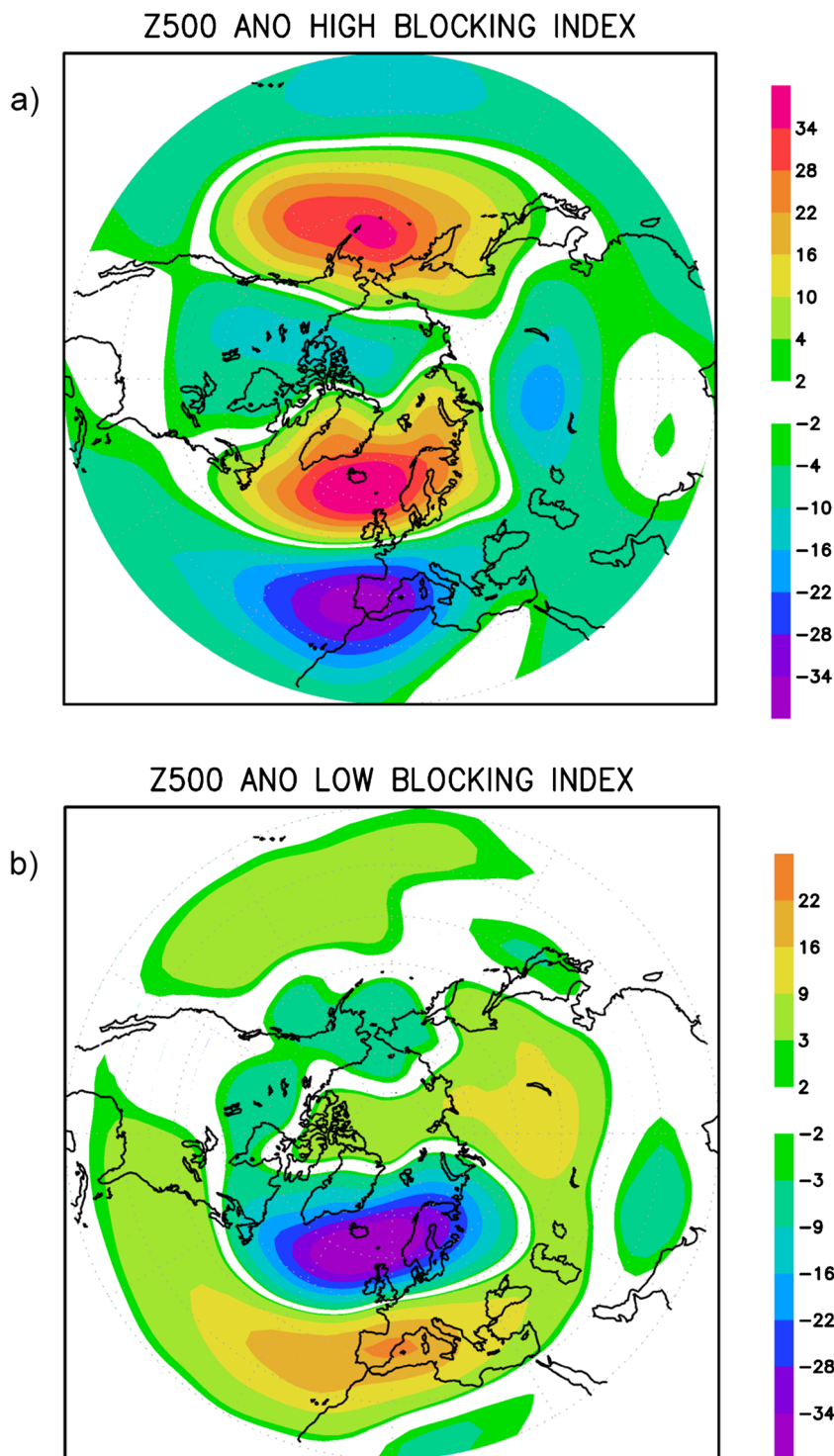


Fig. 6 PC1 of TX90p indices (black) and a blocking index (red). Both time series were linear detrended and normalized by the corresponding standard deviation

European region during winter. The first coupled mode, a NAO-like pattern in the sea level pressure (SLP) field and north–south dipolar pattern in the TX90p field (their Fig. 4a, d), shows relatively weak positive TX90p anomalies over Romania during positive NAO phase consistent with our results. The second coupled mode of TX90p and SLP (their Fig. 4b, e) captures mainly the signature of the EA on extreme

temperatures in Europe and shows positive anomalies over Southern Europe, including Romania. This is consistent with positive and highly significant correlation between the dominant mode of TX90p indices over Romania and EA index reported in this study. A similar relationship between EA and extreme winter temperatures from Serbia was reported recently (Unkašević and Tošić 2013).

Fig. 7 Composite maps of Z500 anomalies (gpm) for **a** high and **b** low values of the blocking index. Linear trends were removed from the data prior to the composite analysis.



3.2 Relationship with atmospheric blocking

First, we examine the distribution of 1-D blocking frequency during high and low values of PC1 for the whole Northern Hemisphere. Figure 5 shows the 1-D spatial distribution of blocking activity, measured as the number of days when a given longitude was blocked by the presence of a blocking event lasting at least 5 days. Both distributions show that blocking is most frequent in the North Atlantic/Europe and the North Pacific consistent with Northern Hemisphere blocking distribution during winter (e.g., Shabbar et al. 2001). However the frequency of 1-D blocking during winters characterized by low values of PC1 is significantly (90 % level) higher than the blocking frequency during the winters characterized by high values of PC1 in the Atlantic-European region (from about 20°W to 70°E) (Fig. 5). Outside this longitudinal band, the differences in the blocking frequency corresponding to high and low values of PC1 are not significant.

Based on 1-D blocking pattern associated to high and low values of PC1 (Fig. 5), we defined a blocking index taken into account both temporal persistency and spatial extension. The index is the frequency of cases when the sector 20°W–70°E is blocked, that is at least five consecutive longitudes within the sector are blocked for at least five consecutive days. The resulting index is significantly (95 % level) negatively correlated ($r=-0.50$) with PC1 (Fig. 6).

To identify the patterns associated to blocking variability in the 20°W–70°E sector, we construct the composite maps of Z500 anomalies corresponding to high and respectively low values of the blocking index. High blocking activity in this sector is related to relatively strong advection of cold air from the northeast over Romania favoring relative low frequency of extreme high temperature events during winter (Fig. 7a). In contrast, during low values of blocking index, the advection of

warm air from the west toward Romania is enhanced favoring the occurrence of extreme high temperatures in the region (Fig. 7b).

The mean of the 2-D blocking index over 1962–2010 (Fig. 8), indicating the occurrence of blocking in the North Atlantic-European region, shows more complex spatial pattern which are not captured by the 1-D TM index. Relatively high frequency of blocking is recorded in a region from Davis Strait/Labrador Sea to Scandinavia. A strip of high values of blocking frequency develops from the British Isles southwestward to Florida at very low latitudes. Local maxima are found over southeastern Greenland, Northern Sea, and Ural Mountains region (Fig. 8). Rimbu and Lohmann (2011) found the same high frequency blocking centers using the same blocking indicator for a different time interval. Scherrer et al. (2006) obtained a similar 2-D blocking climatology based on 2-D potential vorticity blocking indicators.

The 2-D blocking frequency anomalies relative to the climatology represented in Fig. 8 for high and low PC1 are shown in Fig. 9. During winters characterized by high values of PC1, blocking activity is reduced over northwestern Europe and a high blocking activity center appears in the Black Sea region (Fig. 9a). Relatively high blocking activity is recorded in a band stretching from Greenland to Scandinavia during winters characterized low values of PC1, indicating low frequency of extreme high temperature events over Romania (Fig. 9b). The 2-D blocking anomaly patterns (Fig. 9) are consistent with the corresponding 1-D blocking patterns (Fig. 5).

4 Conclusions

The variability of high extreme temperature in winter from Romania in connection with large-scale atmospheric

Fig. 8 Two-dimensional blocking climatology of the Atlantic European region. Units are percentage of blocked days to total number of days per winter. Note that 1 % blocking frequency corresponds to about one blocked day per winter

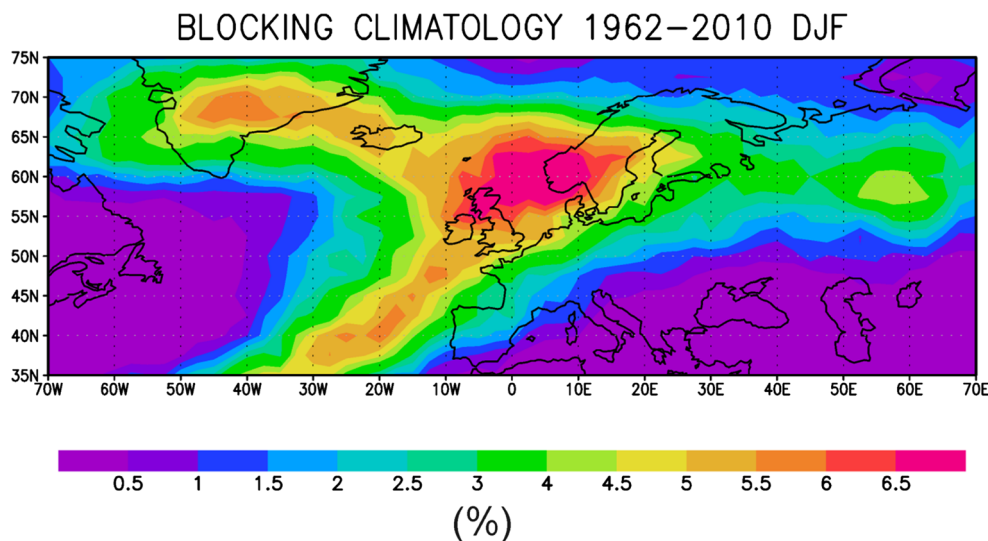
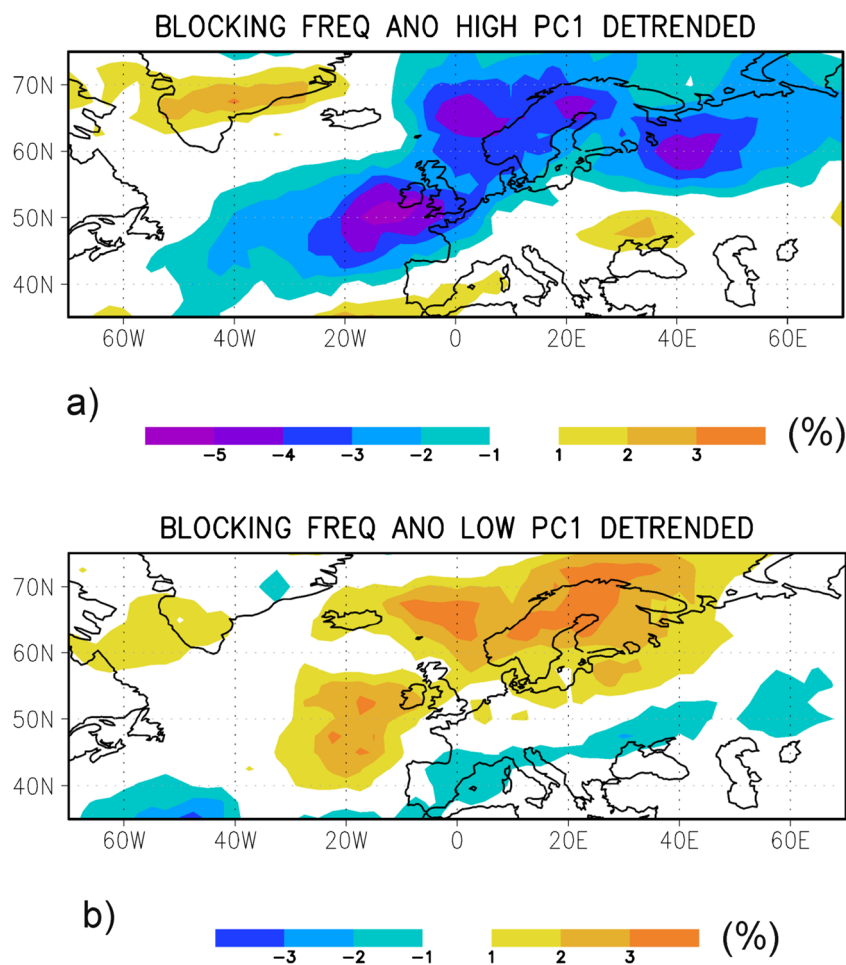


Fig. 9 Two-dimensional blocking frequency anomalies for **a** high and **b** low values of PC1 of TX90p indices. Data were detrended prior to the composite analysis. Units are percentage of blocked days to total number of days per winter. Note that 1 % blocking frequency corresponds to about one blocked day per winter



circulation patterns with focus on the role of the Northern Hemisphere atmospheric teleconnection patterns and blocking frequency in the Atlantic-European region was investigated.

The atmospheric circulation patterns associated to the positive and negative phase of the dominant pattern of extreme high temperature over Romania, which has a monopolar structure, are the superposition of several teleconnection patterns in which the EA plays a dominant role. We argued that the westerly flow over Romania associated to the EA leads to anomalously high occurrences of warm days. This is consistent with more general picture of the EA impact on the extreme temperatures at regional (Unkašević and Tošić 2013) and European scale (Andrade et al. 2012). However, the dominant pattern of TX90p indices from Romania also showed weak connection with the NAO, SCA, and WP. This is not so surprisingly, especially in the context of recent findings of Comas-Bru and McDermott (2013), which show that NAO centers of action are influenced by the phase of the EA and SCA patterns.

High blocking activity in the 20°W–70°E longitudinal band is accompanied by low frequency of extreme temperature events in Romania. The blocking index defined in this study emphasized that activity within the sector 20°W–70°E strongly

modulate the frequency of winter extreme high temperatures over Romania.

In this study, we have shown that large-scale atmospheric circulation influences significantly the extreme temperature variability over Romania. However, an important part of variability remains to be explained by other phenomena. Local factors, like snow and cloud cover, which can influence the local surface temperature during the winter (e.g., Birsan and Dumitrescu 2014) should be considered to explain entire variability of extreme winter temperature in Romania.

The results presented in this paper are helpful to identify regional characteristics of extreme phenomena in future climate using the large-scale anomaly patterns predicted by climate models.

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References

- Andrade C, Leite S, Santos JA (2012) Temperature extremes in Europe: overview of their driving atmospheric patterns. *Nat Hazards Earth Syst Sci* 12:1671–1691. doi:10.5194/nhess-12-1671-2012
- Andrei S, Roman I (2012) Severe weather phenomena in southern Romania in association with blocking circulation over Euro-Atlantic area during the cold season. *Rom Rep Phys* 64(1):246–262
- Barnston AG, Livezey RE (1987) Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Mon Weather Rev* 115:1083–1126
- Bartholy J, Pongracz R (2007) Regional analysis of extreme temperature and precipitation indices for the Carpathian Basin from 1946 to 2001. *Global Planet Chang* 57:83–95
- Birsan MV, Dumitrescu A (2014) Snow variability in Romania in connection to large-scale atmospheric circulation. *Int J Climatol* 34:134–144. doi:10.1002/joc.3671
- Bojariu R, Paliu D (2001) North Atlantic Oscillation projection on Romanian climate fluctuations in the cold season. In: Brunet M, Lopez D (eds) *Detecting and modelling regional climate change and associated impacts*. Springer, Berlin, pp 345–356
- Busuioc A, Dumitrescu A, Soare E, Orzan A (2007) Summer anomalies in 2007 in the context of extremely hot and dry summers in Romania. *Rom J Meteorol* 9:1–2
- Busuioc A, Caian M, Cheval S, Bojariu R, Boroneant C, Baci M, Dumitrescu A (2010) Variability and climate change in Romania (in Romanian). *Pro Universitaria*, Bucharest
- Comas-Bru L, McDermott F (2013) Impacts of the EA and SCA patterns on the European twentieth century NAO—winter climate relationship. *Quart J Roy Meteorol Soc* 140(679B):354–363. doi:10.1002/qj2158
- Croitoru AE, Piticar A (2012) Changes in daily extreme temperatures in the extra-Carpathians regions of Romania. *Int J Climatol* 33:1987–2001. doi:10.1002/joc.3567
- Ionita M, Rimbu N, Chelcea S, Patrut S (2013) Multidecadal variability of summer temperature over Romania and its relation with Atlantic Multidecadal Oscillation. *Theor Appl Climatol* 113:305–315. doi:10.1007/s00704-012-0786-8
- Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Iredell M, Saha S, White G, Woollen J, Zhu Y, Leetmaa A, Reynolds R, Chelliah M, Ebisuzaki W, Higgins W, Janowiak J, Mo KC, Ropelewski C, Wang J, Jenne R, Joseph D (1996) The NCEP/NCAR 40-year reanalysis project. *Bull Am Meteorol Soc* 77:437–470
- Kistler R, Kalnay E, Collins W, Saha S, White G, Woollen J, Chelliah M, Ebisuzaki W, Kanamitsu M, Kousky V, van den Dool H, Jenne R, Fiorino M (2001) The NCEP-NCAR 50-year reanalysis: monthly means CD-ROM and documentation. *Bull Am Meteorol Soc* 82:247–267
- Klein Tank AMG, Können GP (2003) Trends in indices of daily temperature and precipitation extremes in Europe, 1946–99. *J Clim* 16(22):3665–3680. doi:10.1175/1520-0442(2003)016<3665:TIIODT>2.0.CO;2
- Klein Tank AMG, Wijngaard JB, Können GP, Böhm R, Demarée G, Gocheva A, Mileta M, Pashiardis S, Hejkrlik L, Kern-Hansen C, Heino R, Bessemoulin P, Müller-Westermeier G, Tzanakou M, Szalai S, Pálsdóttir T, Fitzgerald D, Rubin S, Capaldo M, Maugeri M et al (2002) Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *Int J Climatol* 22(12):1441–1453
- Knežević S, Tošić I, Pejanović G (2013) The influence of the East Atlantic Oscillation to climate indices based on daily minimum temperatures in Serbia. *Theor Appl Climatol*. doi:10.1007/s00704-013-0959-0
- Moberg A, Jones PD, Lister D, Walther A, Brunet M, Jacobeit J, Alexander KV, Della-Marta PM, Luterbacher J, Yiou P, Chen D, Klein Tank AMG, Saladié O, Sigró J, Aguilar E, Alexandersson H, Almaraz C, Auer I, Barriendos M, Begert M, Bergström H, Böhm R, Butler CJ, Caesar J, Drebs A, Founda D, Gerstengarbe F-W, Micela G, Maugeri M, Österle H, Pandzic K, Petrakis M, Smec L, Tolasz R, Tuomenvirta H, Werner PC, Linderholm H, Philipp A, Wanner H, Xoplaki E (2006) Indices for daily temperature and precipitation extremes in Europe analyzed for the period 1901–2000. *J Geophys Res* 111(D22), D22106. doi:10.1029/2006J007103
- National Meteorological Administration (2008) *Climate of Romania* (in Romanian). Romanian Academy, Bucharest
- Rimbu N, Lohmann G (2011) Winter and summer blocking variability in the North Atlantic region: evidence from long-term observational and proxy data from southwestern Greenland. *Clim Past* 7:543–555. doi:10.5194/cp-7-543-2011
- Rimbu N, Onac BP, Racovita G (2011) Large scale anomaly patterns associated to temperature variability inside Scarisoara Ice Cave. *Int J Climatol* 32(10):1495–1502. doi:10.1002/joc.2369
- Scherrer SC, Croci-Maspoli M, Schwierz C, Appenzeller C (2006) Two dimensional indices of atmospheric blocking and their statistical relationship with winter climate patterns in the Euro-Atlantic Region. *Int J Climatol* 26(2):233–249
- Shabbar A, Huang J, Higuchi K (2001) The relationship between the wintertime North Atlantic oscillation and blocking episodes in the North Atlantic. *Int J Climatol* 21:355–369. doi:10.1002/joc.612
- Szentimrey T (1997) Statistical procedure for joint homogenization of climatic time series. In *Proceedings for the Seminar for Homogenization of Surface Climatological Data*, Hungarian Meteorological service, Budapest pp 47–62
- Tibaldi S, Molteni F (1990) On the operational predictability of blocking. *Tellus* 42A:343–365
- Tomozeiu R, Busuioc A, Stefan S (2002) Changes in seasonal mean of maximum air temperature in Romania and their connection with large-scale circulation. *Int J Climatol* 22:1181–1196
- Unkašević M, Tošić I (2013) Trends in temperature indices over Serbia: relationships to large-scale circulation patterns. *Int J Climatol* 33:3152–3161. doi:10.1002/joc.3652
- von Storch H, Zwiers FW (1999) *Statistical analysis in climate research*. Cambridge University Press, London
- Wanner H, Broennimann S, Casty C, Gyalistras D, Schmutz C, Stephenson D, Xoplaki E (2001) North Atlantic Oscillation—concepts and studies. *Surv Geophys* 22(4):321–381
- Wilks DS (2006) *Statistical methods in the atmospheric sciences*. Academic, Amsterdam
- WMO (1966) *Climatic change*. Tech Note No 79. WMO, Geneva