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CONTRIBUTIONS TO THE STUDY OF THE EXTREME METEOROLOGICAL EVENTS IN ROMANIA

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1. Introduction

In the last years, Romania was affected by extreme meteorological events like drought, heat waves, etc. that have a direct impact on socio-economic sectors. From the analysis of the climate models is expected that some extreme events to become more frequent, more intense and more persistent due to the anthropogenic influences of the climate system [1, 2].

The PhD thesis presents original contributions to the identification of the physical mechanisms responsible for the extreme meteorological events in Romania based on air circulations. In order to achieve this important objective, the doctoral research was dedicated to: (i) the identification of the optimal spatial domain for analysis of the climate parameters temperature and precipitation; (ii) the investigation of the relationship between temperature and precipitation and air circulation; (iii) the analysis of trends and change points of the air circulation patterns; (iv) determination of the air circulation types responsible for the heat waves and droughts occurrence in Romania; (v) the development of a statistical downscaling model based on the multiple linear regression approach for the very warm days seasonal frequency estimation, using as a predictor the air circulation types.

The thesis includes, after an introduction with the state of the art of the subject and presentation of the useful concepts, the methods and data used in study (section 2 in this abstract) and chapters covering the issues (i), (ii), (iii), physical mechanism for each extreme meteorological event and a Multiple Linear Regression Model (MLRM) to find relationship between the large-scale atmospheric circulation and occurence frequency of very warm days (sections in the chapter 3, Results and discussions, of this abstract).

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2. Data and methods

For the determination of the atmospheric circulation types using the two catalogues developed within COST733 Action [3] namely Grosswettertypes (GWT) and WetterLagenKlassifikation (WLK) described below, 2.5° by 2.5° gridded daily mean of sea level pressure (SLP), geopotential high at 925 and 500 hPa, U and V wind component at 700 hPa and precipitable water for the entire atmosphere column were used. These data sets were extracted for the period from 1961 to 2010, from the NCEP/NCAR reanalysis data archive [4]. Temperature and precipitation data sets recorded at Romanian synoptic station have been also used and were obtained from Romanian National Meteorological Administration (NMA).

The GWT catalogue is based on the idea of characterizing the atmospheric circulation by the coefficients of zonality (Z), meridionality (M) and vorticity (V) of the sea level pressure (SLP) field [5, 6]. The Z, M and V coefficients are determined as spatial correlation coefficients between SLP field and three prototype patterns representing idealized west-east, south-north, and central low-pressure isobars over the region of interest. In more detail, the GWT Catalogue is presented in the work of Beck et al. in 2014 [7].

The WLK Catalogue is based on the Objektive Wetterlagenklassifikation classification of the weather types developed by Dittmann et al. in 1995 [8]. This catalogue uses information from three basic tropospheric levels: 925, 700 and 500 hPa, and information on the precipitable water content over the entire atmosphere column. Geopotential fields at 925hPa and 500hPa are used for establishing the cyclonicity (C) or anticyclonicity (A), while the U and V components of wind at 700hPa for establishing the dominant direction of flow. Precipitable water content is used to determine dry (D) or wet (W) conditions of air mass.

Table 1. GWT circulation types (west-W, southwest-SW, northwest-NW, north-N, northeast-NE, east-E, southeast-SE, south-S, cyclone-C, anticyclone-A) and WLK circulation types where 00-undefined, 01-northeast (NE), 01-southeast (SE), 03-southwest (SW), 04-northwest (NW), cyclonicity-C, anticyclonicity-A, dry-D, wet-W)

GWT18		WLK40			
01-W(C)	10-SW(A)	01-00AAD	11-00ACD	21-00CAD	31-00CCD
02-SW(C)	11-NW(A)	02-01AAD	12-01ACD	22-01CAD	32-01CCD
03-NW(C)	12-N(A)	03-02AAD	13-02ACD	23-02CAD	33-02CCD
04-N(C)	13-NE(A)	04-03AAD	14-03ACD	24-03CAD	34-03CCD
05-NE(C)	14-E(A)	05-04AAD	15-04ACD	25-04CAD	35-04CCD
06-E(C)	15-SE(A)	06-00AAW	16-00ACW	26-00CAW	36-00CCW
07-SE(C)	16-S(A)	07-01AAW	17-01ACW	27-01CAW	37-01CCW
08-S(C)	17-nedef(C)	08-02AAW	18-02ACW	28-02CAW	38-02CCW
09-W(A)	18-nedef(A)	09-03AAW	19-03ACW	29-03CAW	39-03CCW
		10-04AAW	20-04ACW	30-04CAW	40-04CCW

For the present study the GWT catalogue with 18 circulation types and WLK catalogue with 40 circulation types were used. Table 1 presents the GWT and WLK circulation types abreviation.

For the investigation of the relationship between very warm days in Romania and large-scale air circulation the Multiple Linear Regression Model (MLRM) was employed. MLRM is a statistical method that is used to model the relationship between a dependent variable (predictand) and one or more independent variables (predictors) by assuming a linear dependence between predictand and predictors [9]. Thus, the estimation procedure assumes the use of an analytical expression of linear type between dependent and independent variables.

Therefore, the predictand y(t) is estimated from the predictors $\{x_i(t)\}_{i=1,2,\ldots,n}$ by the following relationship [10]:

$$y(t) = \beta_0 + \beta_1 x_1(t) + \beta_2 x_2(t) + \cdots + \beta_n x_n(t) \quad (1)$$

where β_0 is the regression constant, $\beta_1 \ldots \beta_n$ are the regression coefficients.

The following statistics were used to quantify the MLRM performance: *multiple correlation coefficient* (R – is a measure of correlation between predictand and predictors), s*quared multiple correlation coefficient* (R^2 – quantifies the proportion of variance of the predictand that is explained by the predictors), *F-Test* (it is a global test of significance of the ensemble of coefficients), *p-value* – characterizes the significance level so that the null hypothesis to be rejected or accepted against the alternative hypothesis, and s*um squared residuals* (SSR – indicate the deviation between the estimated values by the MLRM and the observed values).

3. Results and discussions

3.1. Selection of the optimal spatial domain for air circulation types in correlation with climate parameters

Eight spatial domains of varying size, centered over Romania (Table 2) are used with increasing extension from domain 1 (the smallest one) with 25 grid points to domain 7 (the largest ones) with 289 grid points, were tested for the circulation types ability to capture the precipitation and temperature characteristics.

In order to investigate the domain size dependence of precipitation and temperature, the Explained Variance (EV) has been used. The EV determines the relation between the variance among circulation types and the total variance of the variable under consideration [10].

This method quantifies the discriminatory power of a classification, and can be calculated as follows:

$$EV = \frac{\sum_{k=1}^{K} N_k (\bar{a}_k - \bar{a})^2}{\sum_{i=1}^{N} (a_i - \bar{a}_i)^2} \qquad (2)$$

where ***N*** is the number of cases, ***K*** is the number of circulation types, $\boldsymbol{a_i}$ is the value of the target variable for case ***i***, ***a*** is the overall mean value and $\boldsymbol{a_k}$ is the type-specific mean value.

Table 2. The coordinates of the spatial domains of varying size used for circulation type classification

Domeniul	Coordonate geografice	Nr. puncte de grila
0	05.0º,45.0ºE ; 35.0º,55.0ºN	153
1	20.0º,30.0ºE ; 40.0º,50.0ºN	25
2	17.5º,32.5ºE ; 37.5º,52.5ºN	49
3	15.0º,35.0ºE ; 35.0º,55.0ºN	81
4	12.5º,37.5ºE ; 32.5º,57.5ºN	121
5	10.0º,40.0ºE ; 30.0º,60.0ºN	169
6	07.5º,42.5ºE ; 27.5º,62.5ºN	225
7	05.0º,45.0ºE ; 25.0º,65.0ºN	289

The best discriminatory power of a classification for the analyzed variable is for higher values of EV.

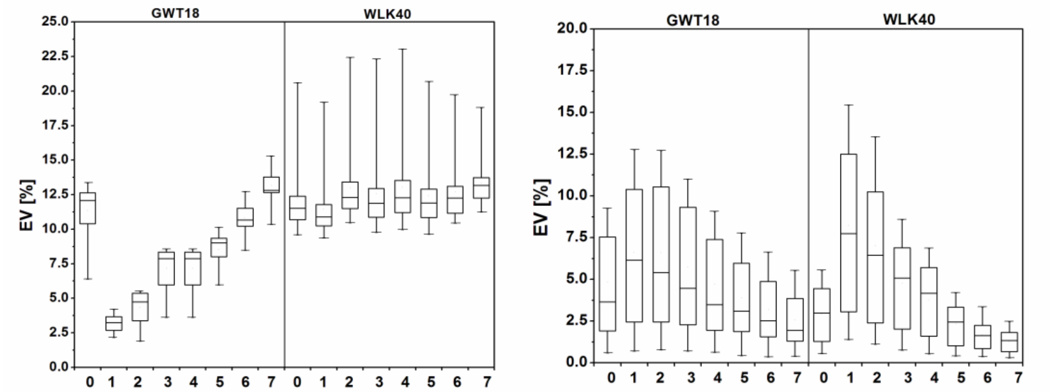

Fig. 1. Boxplot of EV estimated for yearly time scale for precipitation (left side) and temperature (right side) for all stations grouped according to the domain size used for the circulation types classification. The EV have been determined separately for each of the eight domains for GWT and WLK catalogues. Upper and lower whiskers represent minimum and maximum value of EV. On the X-axis threa are the all eight domaines (from 0 to 7).

Figure 1 presents EV for both catalogues and for all stations grouped according to the spatial domain related to precipitation (left side) and temperature (right side) for yearly time scale. The domain with the highest value of EV for both GWT and WLK circulation types related to the daily amount of precipitation is the domain 1. EV for daily amount of precipitation decreases in the same time with domain increase for both catalogues.

For temperature there is an increasing of EV at the same time with the domain increase. The domain 7 (the largest ones) appears to be the most suitable for the circulation types classification related to temperature for both, GWT and WLK catalogues. From this analysis we can conclude that the optimal spatial domain for temperature is domain 0 and for precipitations is domain 1, domains that were used in the present study.

3.2. Study of the relationship between climate parameters and atmospheric circulation

In order to quantify the relationship between large-scale air circulation types and temperature and precipitation Pearson correlation coefficient was used. From the analysis of the above mentioned correlation coefficient values can be note that Southwestern anticyclonic (SW[A]), northwestern anticyclonic (NW(A]) and undefined cyclonic (Nedef [C]) circulation types presents good correlation with winter temperature variability.

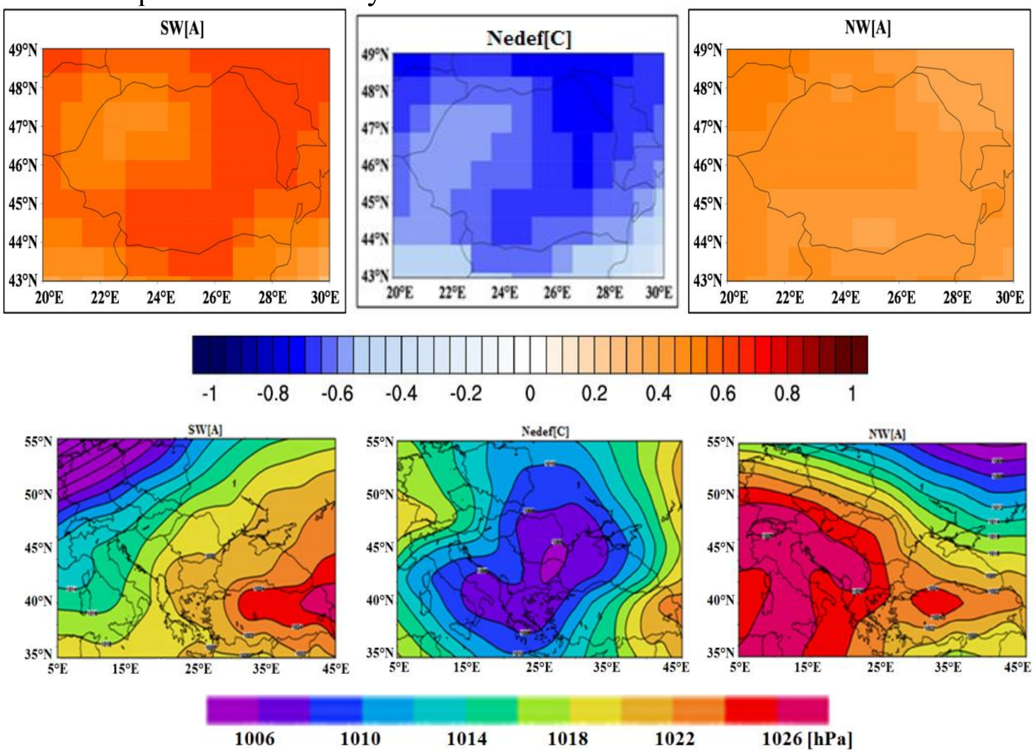

Fig. 2. Correlation coefficients (upper pannel) and associated circulation patterns (lower pannel).

From the spatial distribution analysis of correlation coefficient values (Figure 2) it is observed that the highest values are obtained for the extra-Carpathian region for the SW[A] circulation type. Analyzing the SW[A] circulation pattern it is noticed that an anticyclone is located in the Arabian Peninsula, and favors the warmer mass advection from southern latitudes. Due to the presence and orientation of the Carpathian Mountains, this warm air advection is limited to the extra-Carpathian regions.

The NW[A] circulation type influences more pronounced mean temperature variability in intra-Carpathian regions. This circulation type is determined by the presence of an anticyclone in the Mediterranean area – over Italian Peninsula. The undefined cyclonic circulation type (negative correlation) significantly influences the temperature variability in the extra-Carpathian region, and is characterized by the presence of a cyclone over Romania.

3.3. Changes in the large-scale air circulation types

The aim of this sub-chapter is to investigate the trends and shifts of the circulation types over Romania for 50-year period (1961-2010) on seasonal basis. Daily circulation types were grouped according to the cyclonicity and anticyclonicity and were used to calculate the seasonal occurrence frequency of cyclonic and anticyclonic types.

From Fig. 2 it can be seen that for the GWT circulation types, the occurrence frequency of anticyclonic circulations is higher than that of the cyclonic ones for all seasons, except of winter season when cyclonic circulations were more frequent (around 58%). It is well known that during summer the anticyclonic activity is pronounced and in winter the cyclonic activity is more frequent**.** In the transition seasons (spring and autumn), since the generation of baroclinic instabilities determines the rapid succession of baric systems related to a decrease of meridional temperature gradient reduces the persistence of the atmospheric circulation [11] and leads to small differences between the occurrence frequency of cyclonic and anticyclonic circulation types.

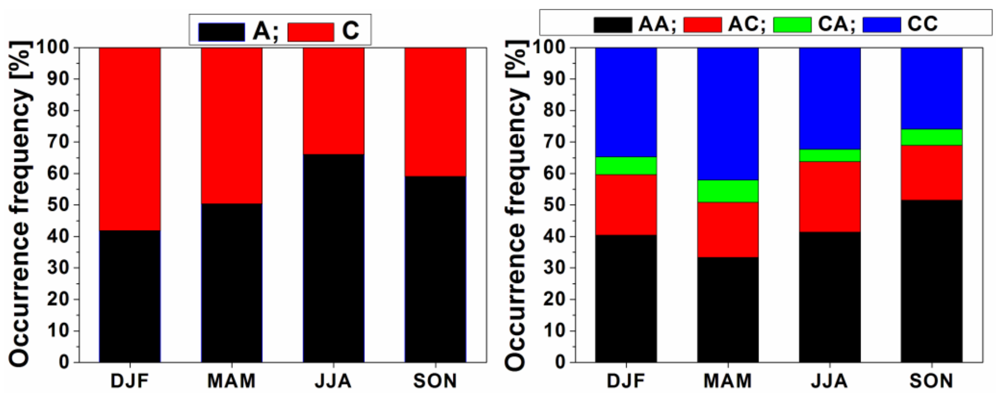

Fig. 3. GWT18 (left side) and WLK40 (right side) circulation types occurence frequency grouped by cyclonic (C) and anticyclonic (A) type of flow.

For the WLK circulation types the highest occurrence frequency of cyclonic types was obtained for spring (around 45%) and the highest occurrence frequency of anticyclonic types was obtained for autumn (around 50%).

The trend of seasonal time series was investigated by using Mann-Kendall test and the shifts points were determined by using Pettitt test. From Mann-Kendall statistics of the time series grouped by cyclonicity (C) or anticyclonicity (A) at 925 and 500 hPa it can be noted that the anticyclonic regime increases for 925 and 500 hPa levels in summer (JJA) and winter (DJF), while cyclonic regime decreases for the same geopotential levels in summer (JJA). This result is in agreement with those obtained by Wang *et al.* in 2013 [12]. According to this study, the occurrence frequency of cyclones increases in the high latitude North Atlantic in cold seasons, with decreases in the mid-latitude North Atlantic-southern Europe.

Increasing frequency of anticyclonic types found in this study can be linked to increasing frequency of regional climate extremes. For example, concerning the study conducted by Birsan *et al.* in 2014 [13] related to climate change in Romania, the upward trend found for summer mean temperature can be linked to the increasing frequency of anticyclonic types. According to Barbu *et al.* (2014) [14] Azores Ridge and North-African Ridge are the main synoptic patterns that produce prolonged and very warm days in Romania.

3.4. Study of the heat waves

The heat waves are generally associated with high pressure synoptic systems and tropical air mass advection. The study of the main causes and effects of these particular situations and their subsequent impacts focuses on the analysis of connections between heat waves and large-scale circulation.

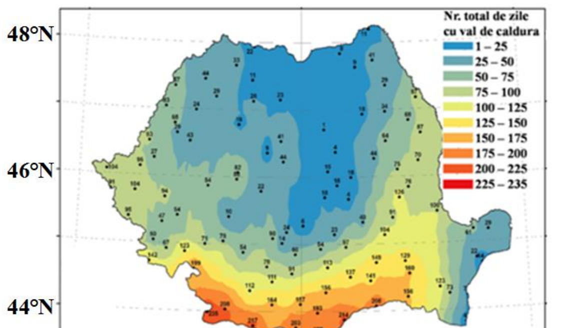

Fig. 4. Spatial distribution of the total number of days with heat waves for the period 2000-2012.

The spatial distribution of heat wavse is depicted in Fig. 4. The results show that the southern part of Romania presents the highest number of heat wave days.

Calafat weather station presents the greatest number of heat wave days, 238 days, also at this station was registeret the highest Romanian maxima temperature, 44.3 °C in 2007.

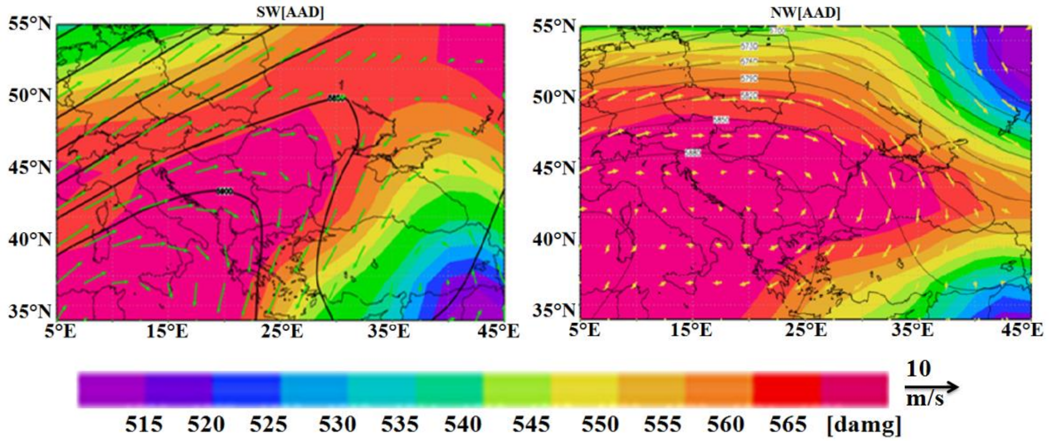

Fig. 5 WLK40 circulation patterns responsible for heat waves occurrence in Romania

From the occurrence frequency of circulation patterns determined for heat wave days was found that southwestern (Fig. 5 – left side) and northwestern (Fig. 5 – right side) anticyclonic dry circulation types are responsible more than two thirds of heat waves occurence in Romania. In the case of the southwestern anticyclonic type, both in the lower and middle troposphere a ridge extends of the Azores Anticyclone, that favors the warm air advection from the North of Africa – a typical situation for heat waves in Romania, while the circulation (as established by the dominant direction of wind at 700hPa) is mostly southwestern.

3.5. Study of the drought

For this study the drought temporal evolution according to its severity for the Barlad basin (eastern Romania) was analysed and the results are presented in Fig. 6. It can be seen the increasing frequency, persistence and severity of the drought since the 80s. This is due to the increasing trend of anticyclonic circulation patterns. Worth to mention that 2009 was the year with the most persistent and severe drought.

In all three cases of drought severity, the dominant circulation types are the anticyclonic ones, with the highest frequency of undefined anticyclonic circulation type. The main baric system that influences the drought severity is the Azores’ ridge. In addition, in the mid-troposphere, the persistence of the Azores’ ridge determines the drought severity in the Barlad basin.

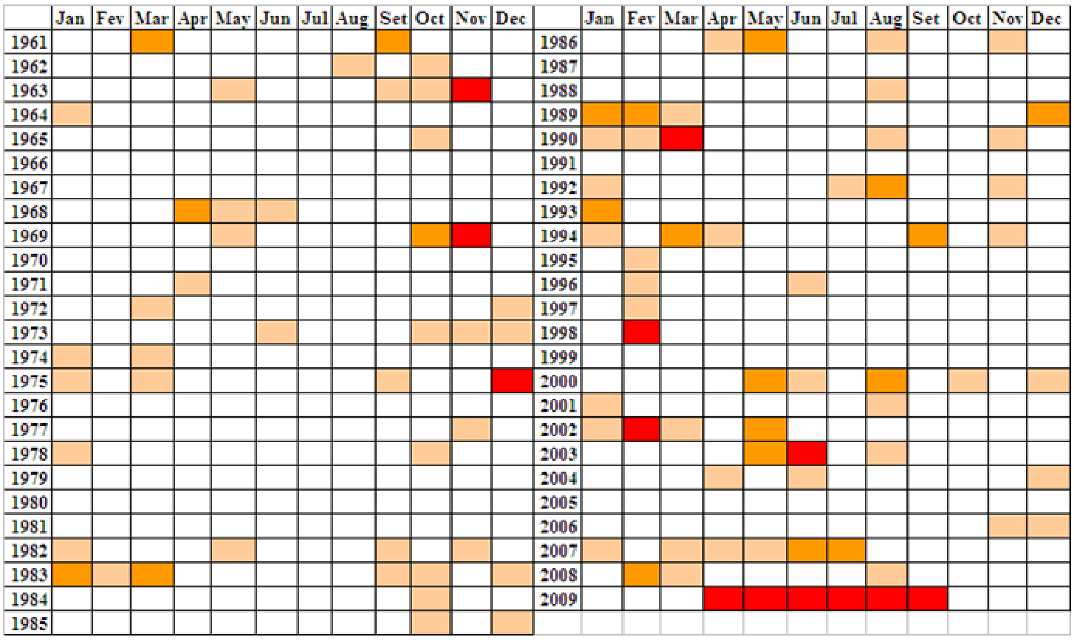

Fig. 6. Temporal variability of drought taking into account its severity (light orange – moderate drought, orange – severe drought, red – extreme drought).

3.6. Investigation of the relationship between the very hot days frequency and air circulation using multiple regression approach

The relationship between the large-scale atmospheric circulation and occurence frequency of very warm days was investigated by the using multiple linear regression approach.

The Multiple R values (not shown) range between 0.45 and 0.87 in winter and 0.41 and 0.82 in summer. This points to the fact that the influence of the large-scale atmospheric circulation on very warm days is most pronounced in winter. The R^2 values (Fig. 7) vary between 0.2 and 0.75 in winter (upper panel) and 0.17 and 0.66 in summer (lower panel).

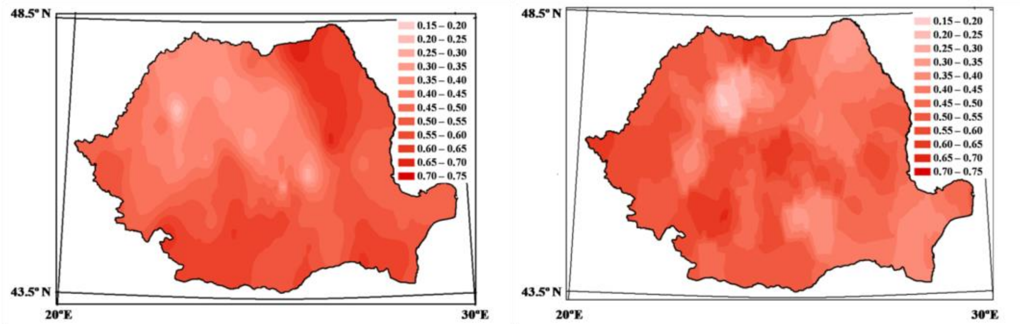

Fig. 7. Explained variance ot MLRM for winter (left side) and summer (right side).

The performance of the MLRM, in terms of explained variance, is greater than 50% for 55 (64.7%) synoptic stations in winter and for 40 (47.1%) stations in summer.
Starting with the fact that Multiple R (not sown) and R^2 present a similar behaviour over the country for both winter and summer, by analysing the spatial variation in R^2 for winter (Figure 7 – left side), a pronounced decrease in skill can be stated with the elevation of the stations, the correlation coefficient between R^2 and elevations of all synoptic station being -0.41. This decrease in skill is not visible in summer (Figure 7 – right side) when the correlation coefficient between R^2 and elevation is 0.11. This result shows that the large-scale circulation influence is more visible in winter (compared to summer) for higher elevations compared to lowlands. For winter, the local factors, represented by the orography and the vicinity of the Black Sea, which strongly influences and modifies the atmospheric circulation patterns, are more important because the air mass advection given by the surface circulation is an important factor compared to summer when the mid-troposphere air mass advection is of great importance as well.

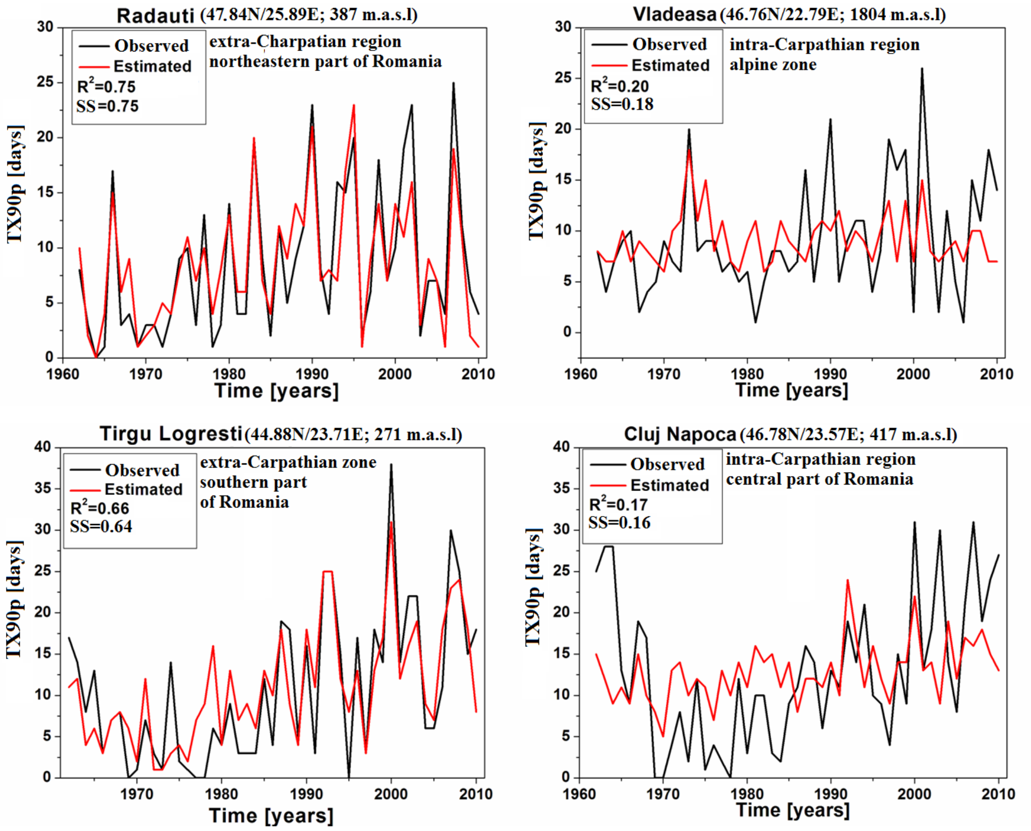

Fig. 8. Registered (black) and extimated (red) values of very warm days frequency for winter (upper panel) and summer (lower panel).

Figure 8 presents, as an example, the observed and estimated time series of the stations with the highest (left) and lowest (right) MLRM performance based on SSR and R^2 for winter (upper panel) and summer (lower panel). The main finding from Figure 6 is the fact that for the best performing model for both, winter and summer the MLRM estimates quite well not only the amplitude but also the trend of the time series. Differences in the MLRM performance at the stations shown in Fig. 8 are caused by the different geographic conditions at the synoptic stations location.

Conclusions

1. It is important to use the optimal domain size to investigate the link between large-scale circulation and local climate parameters. It is found that smaller domains work best for precipitation and larger domains work best for temperature [15].

2. Changes in the occurrence frequency of the circulation types over Romania were investigated. The most important changes in the occurrence frequency of the anticyclonic (increasing trend) and cyclonic (decreasing trend) types were noted for summer, autumn, and winter seasons [16].

3. Heat waves were analyzed in correlation with large-scale atmospheric circulation and main circulation patterns responsible from heat waves in Romania were identified. The main baric system responsible for the onset of heat waves in Romania is the ridge of the Azores Anticyclone [14].

4. Temporal variability of drought reveals that after ‘80s its occurrence frequency, intensity and persistence present an increasing trend due to the increasing tendency of the anticyclonic circulation types occurrence frequency [17].

5. The performances of the MLRM are quite good for both analyzed seasons. We have shown that the large-scale circulation defined by the two catalogues (GWT and WLK) controls the extreme temperature variability over a large part of the country. The MLRM is a skillful tool for the investigation of the relationship between climate parameters and the atmospheric circulation types [17].

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