Changes in the Large-Scale Atmospheric Circulation over Romania Between 1961 and 2010 on Seasonal Basis

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Abstract

The aim of this paper is to investigate the trends and shifts of the circulation types over Romania for 50-year period (1961-2010) on seasonal basis. In order to achieve this, two objective catalogues, namely GWT and WLK, from COST733 Action were employed. 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. The trend of seasonal time series was investigated by using Mann–Kendall test and the shifts points were determined by using Pettitt test. The results reveal that the occurrence frequency of anticyclonic types increases in summer and winter seasons and the occurrence frequency of cyclonic ones decreases for the summer season (for $\alpha = 0.05$).

Key words: circulation types, GWT, WLK, Mann–Kendall test, Pettitt test.

1. INTRODUCTION

The atmospheric circulation is the principal factor that determines the climate variability in Europe and therefore in Romania. A variety of subjective or objective methodological approaches were applied for atmospheric circulation classification (Huth *et al.* 2008, Philipp *et al.* 2010). The subjective (so-called manual) classification of atmospheric circulations (Hess and Brezowski 1952, Lamb 1972, Perret 1987) has no longer been used for atmospheric circulation classification; however it has not lost its scientific importance (Yarnal *et al.* 2001).

Changes in the atmospheric circulation over the North Atlantic European region have been studied in the last decades by several authors (Bárdossy and Caspary 1990, Jacobeit *et al.* 2001) employing various methods for different periods of time and most of them have noted changes in circulation type frequencies. A few recent studies have reported considerable changes in the 1980s and 1990s in the persistence of air circulation over Europe for zonal circulation in winter (Werner *et al.* 2000) and for all circulation types in summer (Kysely 2002). One important application of circulation type classification is to quantify past, present, and future in the atmospheric circulation in terms of frequency and persistence (Huth *et al.* 2008).

In Romania, Georgescu and Stefan (2010) have investigated the link between cyclonic activity over Romania and air circulation types by using LWT2 catalogue. According to the same study the anticyclonic circulation types seem to be the most frequent and cyclonic activities are correlated to the eastern and southeastern circulation types.

The objective of this study is to analyze the temporal variability of air circulation over Romania on seasonal basis. In order to achieve this, two objective classifications, namely Grosswetter-Types (GWT) and WetterLagen-Klassifikation (WLK) of atmospheric circulation from COST733Action for a domain centered over Romania, were employed. The trend of the circulation types is analyzed by using Mann–Kendall test and the Pettitt test is used to investigate the change point in the mean circulation types.

This paper is organized as follows: In Section 2 the data sets used for determining circulation types and statistical tests are introduced. Relevant results and discussions are presented in Section 3. Section 4 is dedicated to conclusions.

2. DATA AND METHODS

Re-analysis data sets for 50 years period (1961–2010), built up by the NCEP/NCAR (Kalnay *et al.* 1996) were used with a spatial resolution of 2.5° (latitude) by 2.5° (longitude) and consists of daily mean sea level pressure, geopotential high at 925 and 500 hPa, u and v component of the wind vector at 700 hPa and precipitable water content for the entire atmosphere column.

Fig. 1. Spatial domain used to determine the circulation types. Romania is highlighted.

For the large-scale air circulation classification, two objective catalogues, namely GWT and WLK from the COST733Action, were employed. The spatial domain used (Fig. 1) for building up the GWT and WLK catalogues is delimited by 5° E, 35° N and 45° E, 55° N, and includes Romania in its center (Barbu *et al.* 2014).

The GWT Catalogue uses as its input data set the sea level pressure (SLP) field (Beck *et al.* 2007), and it is based on the idea of characterizing the air circulation by the coefficients of zonality (Z), meridionality (M), and vorticity (V).

The WLK catalogue is based on the classification of weather types developed by Dittmann *et al.* (1995) and Bissolli and Dittmann (2004) originally including 40 different types. This catalogue uses information from three basic tropospheric levels: 925, 700, and 500 hPa, and information of the precipitable water content over the entire tropospheric column.

For the present study, we have been used the GWT Catalogue with 18 circulation types and the WLK Catalogue with 40 circulation types.

The trend of air circulations was investigated by using Mann–Kendall (Mann 1945, Kendall 1975) statistical method. Mann–Kendall test is a statistical test widely used for the analysis of trend in climatology (Mavromatis and Stathis 2011). More theoretical details about this test can be found in a lot of studies (*e.g.*, Salarijazi *et al.* 2012, Marin *et al.* 2014).

In this study, the non-parametric approach developed by Pettitt (1979) in order to detect change-points in the circulation types was employed. It is a

rank-based and distribution-free test for detecting a significant change in the mean of a time series and it is particularly useful when no hypothesis is required to be made about the location of the change point. More theoretical details about Pettitt test can be found in the study of Salarijazi *et al.* (2012).

3. RESULTS AND DISCUSSION

For the evaluation of air circulation over Romania, 18 262 cases that correspond to daily circulation types between 1 January 1961 and 31 December 2010, were analyzed. First, the seasonal occurrence frequency of circulation types was computed and thereafter the values obtained were averaged over the entire study period.

Figure 2 presents the occurrence frequency of GWT (left side) and WLK (right side) circulation types grouped by cyclonicity and anticyclonicity for each season over the entire study period. 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 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 (Geng and Sugi 2003) and leads to small differences between the occurrence frequency of cyclonic and anticyclonic circulation types. 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%).

Fig. 2. Occurrence frequency of GWT (left side) and WLK (right side) circulation types for all seasons (winter – DJF, spring – MAM, summer – JJA, and autumn – SON). Please see the text for the explanation circulation type's abbreviation.

Fig. 3. Time series of absolute frequency of GWT circulation types grouped due to the cyclonicity (C – left side) and anticyclonicity (A – right side) for spring (MAM – green), summer (JJA – red), autumn (SON – orange), and winter (DJF – blue).

In order to investigate the temporal variations for each season, the circulation types of GWT Catalogue were grouped by cyclonicity (Fig. 3 left side) and anticyclonicity (Fig. 3 right side) thereby resulting in two time series. After that, the Mann–Kendall trend test and Pettitt change point test are applied to these two time series. The results of both tests are not statistically significant, at 0.05 significance level. Also, the Pettitt test indicates that there is no shift in both time series.

For the investigation of temporal variations of WLK Catalogue, circulation types were grouped by cyclonicity (C) and anticyclonicity (A) at 925 and 500 hPa, thereby resulting in four time series as follows: AA – anticyclone at 925 and 500 hPa; AC – anticyclone at 925 hPa, and cyclone at 500 hPa; CA – cyclone at 925 hPa, and anticyclone at 500 hPa; CC – cyclone at 925 and 500 hPa. In Figure 4, the absolute frequency of these four circulation types mentioned above, for seasonal time scales are presented.

The trend of the time series was determined by using the Mann–Kendall test and Pettitt test was applied in order to detect shifts in the time series. In Table 1 the Mann–Kendall statistics of the time series grouped by cyclonicity (C) or anticyclonicity (A) at 925 and 500 hPa that are statistically significant at the 0.05 level are presented (the up arrow indicates upward trend and the down arrow indicates downward trend). From Table 1 it can be seen 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.* (2013). 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.

Fig. 4. Time series of absolute frequency of WLK circulation types grouped by cyclonicity (C – left side) and anticyclonicity (A – right side) at 925 and 500 hPa levels for spring (left upper panel), summer (right upper panel), autumn (left lower panel), and winter (right lower panel). Please see the text for the explanation circulation type’s abbreviation.

Table 1

The trend of the time series grouped by cyclonicity (C) or anticyclonicity (A) at 925 and 500 hPa

Type	MAM	JJA	SON	DJF
AA	—	↑	—	↑
AC	↑	↑	—	—
CA	↓	—	—	↓
CC	—	↓	—	—

Explanations: the up arrow indicates upward trend, and the down arrow indicates downward trend; only the results that are significant at 0.05 level are presented.

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 and Dumitrescu (2014) 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) Azores Ridge and North-African Ridge are the main synoptic patterns that produce prolonged and very warm days in Romania.

Table 2

The shifts in the time series grouped
by cyclonicity (C) or anticyclonicity (A) at 925 and 500 hPa

Type	MAM	JJA	SON	DJF
AA	–	1981↑	1992↑	1987↑
AC	1977↑	1976↑	–	–
CA	1980↓	–	1964↓	1979↓
CC	–	1978↓	1995↓	1987↓

Note: only the results that are significant at 0.05 level are presented.

In Table 2 the shift in the time series grouped by the cyclonicity (C) or anticyclonicity (A) at 925 and 500 hPa that are statistically significant at the 0.05 level are presented (the number represents the year of change point, the up arrow indicates an upward shift, and the down arrow indicates a downward shift). In order to find a plausible explanation for the shift in the time series in '80s, we have taken a look of the North Atlantic Oscillation (NAO – station based) time series (Hurrell and Deser 2010). By applying Pettitt test to the annual NAO was found an upward shift (significant for $\alpha = 0.1$) around 1982, and this may be the reason for the increasing frequency of anticyclonic types over Romania, compensated by decreasing frequency of cyclonic ones.

4. SUMMARY AND CONCLUDING REMARKS

In this study, we presented a statistical analysis of daily air circulation types over Romania during the period 1961–2010 for the lower and middle troposphere. From our knowledge, this is the first study of the temporal variations of air circulation types at the synoptic scale over Romania using objective methods. The study of the circulation types for lower and middle troposphere is useful because, on the one hand, in the lower troposphere the trajectory of air masses is modified by the orography, in our case the Carpathians, which are very important for Romanian's climate, and, on the other hand, for the mid-troposphere the orography no longer influences the air flow direction from this level. We have investigated the trend of the time series of both, GWT (with 18 circulation types) and WLK (with 40 circulation types) catalogues, using Mann–Kendall test and shifts in the time series

using Pettitt test. Both above-mentioned tests were applied to the circulation types grouped by cyclonicity (C) or anticyclonicity (A) for the entire 50 year period of the study, during 1961-2010.

The most important changes in the occurrence frequency of the anticyclonic and cyclonic types were noted for summer, autumn, and winter seasons. For these seasons, according to the WLK Catalogue, a positive trend was found for the anticyclonic types and negative trends for the cyclonic ones. These results are consistent with those previously reported that highlights that the occurrence frequency of anticyclonic types at mid-latitudes increases (Kysely 2002, Jacobeit *et al.* 2003). The general negative trend of the cyclonic types is due to the decrease in mid-latitude cyclone frequency and increase in high-latitude cyclone frequency (McCabe *et al.* 2001). In the context of climate change, the Mediterranean cyclones have a decreasing trend of occurrence frequency (Nissen *et al.* 2014). The extension of the Hadley cell under global warming (Kang and Lu 2012) may cause a northern shift of storm tracks over North Hemisphere mid-latitude (Paciorek *et al.* 2002, Zhang *et al.* 2004).

The present study is very important due to the changes in occurrence frequency of circulation types that can be linked to the increasing of climatic extreme events (*e.g.*, heat waves, droughts, blizzards, floods, and flash floods).

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