Romanian Journal of Meteorology, Vol. 9, No. 1-2, 2007 ISSN 1223-1118

SUMMER ANOMALIES IN 2007 IN THE CONTEXT OF EXTREMELY HOT AND DRY SUMMERS IN ROMANIA

Aristita Busuioc, Alexandru Dumitrescu, Elena Soare and Alina Orzan

National Meteorological Administration, Romania
Sos. Bucuresti-Ploiesti 97, 013686 Bucharest, Romania,
e.mail: busuioc@meteoromania.ro

Abstract: Summer 2007 was among the hottest summers in Romania over the entire observational period 1901-2007. This paper presents a detailed analysis of the surface air temperature and precipitation anomalies recorded during the summer 2007 in comparison with the corresponding values of the first three hottest summers recorded in Romania, in order to understand the mechanisms controlling these events and, more generally, the summer temperature variability in Romania. In order to reach this objective, the time series of the mean air temperature and total precipitation for two observational periods were analyzed: a longer period for 14 stations (1901-2007) and a shorter one (1961-2007) for a complete higher spatial density data set (94 stations for temperature and 104 for precipitation). Non-parametric tests (Mann-Kendall and Pettitt) and empirical orthogonal function analysis were used as statistical tools to identify the main temporal characteristics of regional climate variability (trends and shifts). It was found that, in terms of spatial average over the country, the summer 2007 was similar with that of 1946, considered so far the hottest one over the period 1901-2006. In order to understand the large-scale mechanisms responsible for these extreme events, the corresponding anomalies of the possible dynamic factors (sea level pressure and geopotential heights at 500 hPa) and thermodynamic factors (specific humidity and temperature at 850 hPa), from the NCEP reanalysis for the period 1961-2007, were analyzed. The obtained results showed that a persistent anticyclonic structure over Romania, associated with very large positive temperature anomalies at 850 hPa, were the main reasons of the very hot summers in Romania. When these large-scale anomalies were additionally associated with a persistent dry air mass at 850 hPa, prolonged and intense droughts were recorded in Romania. A strong agreement between the temporal variability of the summer temperature anomalies in Romania and upper large-scale geopotential and temperature anomalies over the period 1961-2007 was found as well. The signal extracted from the sea level pressure field was not so significant for the analyzed summer extreme events in Romania.

1. INTRODUCTION

The global warming is unequivocally accepted by the scientific community, being already identified in the observed data set, as it has been presented in the Fourth IPCC Assessment Report (AR4) (IPCC, 2007). Instrumental observations over the past 157 years show that temperatures at the surface have risen globally, with important regional variations. For the global average, warming in the last century has occurred in two phases, from the 1910s to the 1940s and more strongly from the 1970s to the present. An increased warming rate occurred over the last 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years (Trenberth et al., 2007).

In addition to global warming, on regional scale, several other factors may shape future climate change such as variation in atmospheric circulation and topography (Christensen et al., 2007). Variations in atmospheric circulation influence the climate over large areas both on interannual and longer time scales while the topography modifies the effects of atmospheric circulation at fine geographical scales (Bojariu and Giorgi, 2003). As an example, for Europe, a severe heat wave was recorded during the summer 2003 (Fink et al., 2004), which was characterised by a long period of anticyclonic weather. Luterbacher et al. (2004), using the multi-proxy reconstructions of monthly and seasonal surface temperature fields for Europe back to 1500, showed that the late 20th- and early 21st-century European climate is very likely (>95% confidence level) warmer than that of any time during the past 500 years and 2003 was by far the hottest summer. Other example includes the strong warming of the 1960-1990 winters in northern Europe, which was affected by an upward trend toward a more positive phase of the North Atlantic Oscillation (NAO) (Hurrell and van Loon, 1997; Scaife et al., 2005).

In Romania, various studies pointed out certain changes observed in the surface air temperature and precipitation regime (mean state and extremes) and their connection with changes in the large-scale circulation patterns. Winter precipitation variability (including extreme events) in Romania is mainly controlled by variation in atmospheric circulation, the south-westerly circulation having the dominant role, modulated by the Carpathian topography (Busuioc and von Storch, 1996; Busuioc, 2001; Busuioc et al., 2003). Bojariu and Matei (2001) found a significant connection between NAO phases and Romanian temperature variability in winter. 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.

Since 2000, extreme hot and dry summers were quite frequent over Romania and 2007 was among the hottest ones. The objective of the present study is to analyse in detail the temperature and precipitation anomalies recorded during summer 2007, in comparison with similar events recorded since 2000 (mainly 2000 and 2003) as well as with the summer 1946, which was so far the warmest one over the entire instrumental observation period from 1901 to 2006. Data and methods used in this study are presented in Section 2. Characteristics of the long term summer temperature variability over the period 1901-2007 are also analyzed to see if there is a long term trend associated to the global warming or other natural reasons. All these results are presented in Section 3. In order to understand the mechanisms responsible for the long term behaviour of the summer temperature and precipitation variability in Romania and especially for the extreme events mentioned above, the corresponding surface (sea level pressure-MSLP) and upper (geopotential heights at 500 hPa-H500, specific humidity-SH850 and air temperature at 850 hPa-T850) large-scale anomalies are analysed in section 4. Unfortunately, these fields (MSLP and H500 excepted) were not available for the year 1946. The conclusions are presented in Section 5.

2. DATA AND METHODS

Two types of instrumental observation data sets were used to describe the temperature and precipitation anomalies in Romania in this paper (see Figure 1). Firstly, long time series at 14 stations over the period 1901-2007 were considered, in order to underlay the observed long-term behaviour (linear trends and shifts). Secondly, a complete high density temperature and precipitation data set (94 stations for temperature and 104 for precipitation) over the period 1961-2007, was simultaneously analyzed with various large scale fields of surface (sea level pressure-SLP, surface air temperature-TAS) and upper levels (geopotential heights at 500 hPa-H500, air temperature-T850 and specific humidity-SH850 at 850 hPa), in order to understand the possible mechanisms controlling the

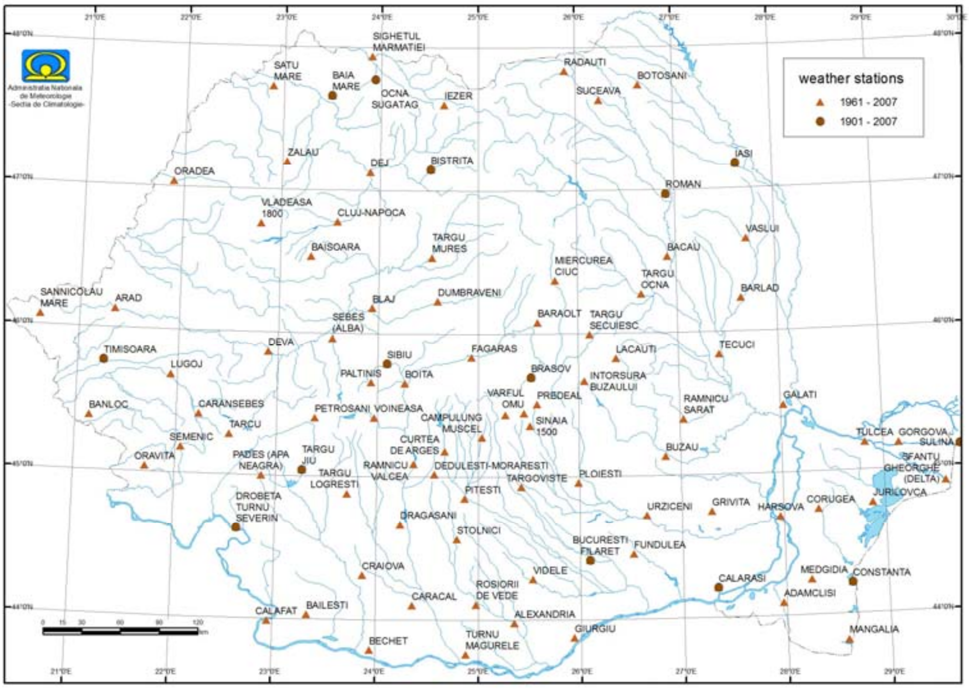


Figure 1. Positions of the stations used in this study. The stations with longer (1901-2007) or shorter (1961-2007) data sets are marked.

summer temperature and precipitation variability in Romania, with special focus on the extreme events of the years 2000, 2003 and 2007. The large-scale data sets were provided by the NCEP reanalysis (Kalnay et al., 1996) with the spatial resolution of 2.5^{o} x 2.5^{o} latitude x longitude over the following areas: 20E-30E and 40N-50N (T850 and SH850), 45W-50E and 30N-60N (MSLP, H500 and TAS). Anomalies related to the 1961 to1990 mean were considered in this paper, in order to quantify the magnitude of extreme temperature and precipitation events. Every Romanian data set is quality controlled.

Empirical Orthogonal Function (EOF) (Barnett, 1981) analysis has been used to extract the climate signal from the data sets analysed in this paper. The EOF analysis is used to identify the spatial and temporal characteristics of regional and large-scale variability. The main spatial features of the climate variability in the analysed data set are given by the first few EOF patterns, the first EOF pattern being the most important one that explains the largest part of the variance in the analysed data set. The EOF coefficient time series describes the dominant time variability in the data set, the largest part of the signal being captured by the coefficient time series associated with the first EOF pattern. The time series associated to the first EOF patterns of local temperature and large-scale anomalies presented above were analysed in this paper with regard to trends and shifts in the mean in order to identify the changes in their variability regime. Non-parametric tests were used for this purpose. Testing of the significance of a linear trend against the null hypothesis of "no trend" is made with the non-parametric *Mann-Kendall's test* (Sneyers, 1975). The change points are detected by using the Pettitt's test (Pettitt, 1979). Besides the general trend, the identification of "change points" in the mean of the climatological series is important for many reasons. First, it is important to know the time when certain changes in the regional climate regime take place and then to analyse their cause (for details see Busuioc and von Storch, 1996; Busuioc et al., 2001).

3. OBSERVED EXTREME HOT AND DRY SUMMERS IN ROMANIA

After the summer 1946, considered the hottest and one of the driest in Romania over the entire observational period 1901-2006, a couple of similar extreme events were recorded over the recent period 2000-2007. This period was characterised by intense temperature and precipitation anomalies, which by intensity, duration and spatial extension were between the most pronounced ones in Romania over the entire observational period.

3.1. Temperature anomalies

In order to see if there is a significant long-term trend in the summer mean temperature in Romania, the longest available observational time series at 14 stations (1901-2007), uniformly distributed over the Romanian territory, were analysed (see Figure 1). The spatial average of the summer mean temperature anomalies (related to 1961-1990) derived from the corresponded values recorded at these stations is presented in Figure 2.

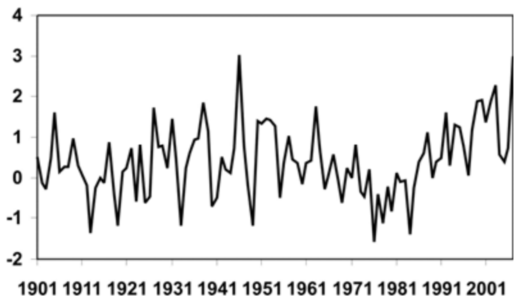


Figure 2. 1961-1990 Summer anomalies (^{o}C) of the mean air temperature spatially averaged over Romania, derived from the values recorded at 14 meteorological stations over the period 1901-2007. Positions of these stations are presented in figure 1.

The corresponding values at the 94 stations over a shorter period (1961-2007) are almost identical (root-mean squared error equal to 0.1), meaning that the 14 stations are representative for the summer temperature regime in Romania. Therefore, the conclusions based on the analysis of temperature time series at these stations are robust.

A statistically significant long-term warming trend of Romanian summers over the last 107 years (1901-2007) was identified (0.6^{o}C on spatial average) but this characteristic is not linear, two statistically significant changes in the mean summer temperatures being objectively noted: a primary upward shift around 1985, marking an increasing warming rate over the last decades and a secondary downward shift around 1964, interrupting the warming trend over the first half of the 20th century by a colder (but stable) regime between 1965 and 1985. Similar features are found at all the 14 stations (not shown) using the Pettitt's test, meaning that a large-scale mechanism is responsible for this behaviour, which will be discussed in Section 4.

Figure 3 shows the spatial distribution of the linear trend over 1961-2007 for the 94 stations. It can be seen a warming trend of about 1.6-2 ^{o}C over most of the country, which is statistically significant at the 5% level. Figure 2 shows that the summers of 1946 and 2007 are the highest peaks of same magnitude of anomaly with respect to the 1961 to 1990 mean (3^{o}C) over the two sub-periods, being followed by the summers 2003, 2000, 2002 and 1999. Temperature anomalies of the first 6 warmest summers in Romania derived from the two data sets are presented in Table 1.

However, the summer 2007 is distinguished by a high persistence of dog days (daily maximum temperature greater or equal to 35^{o}C) and a record-breaking

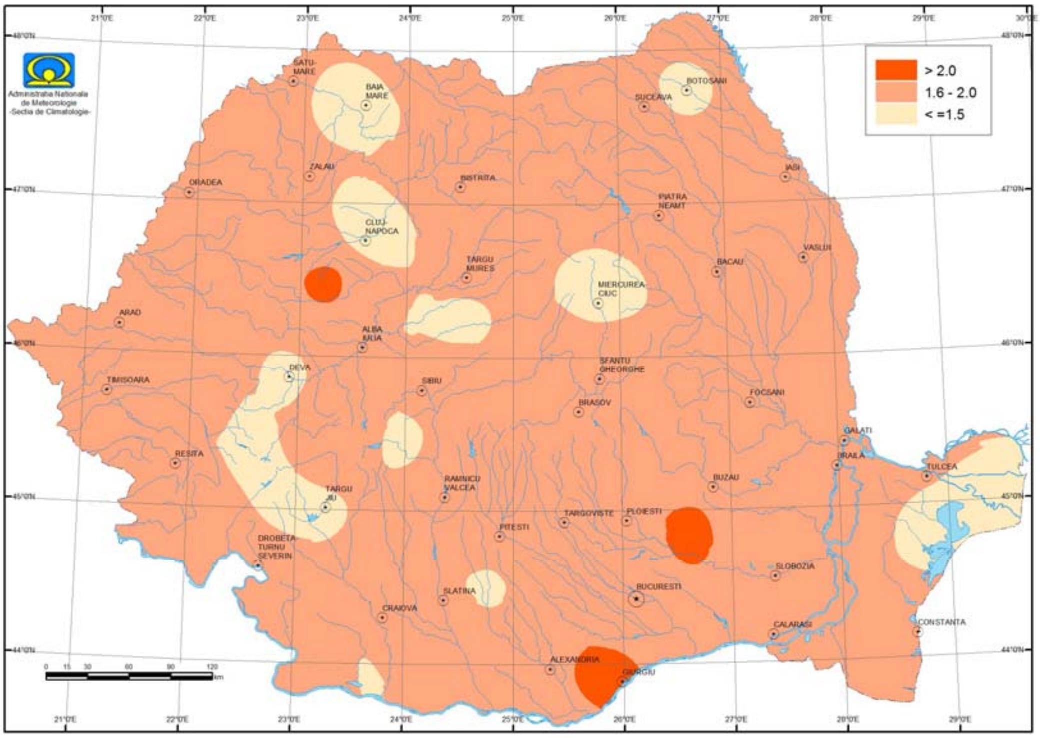


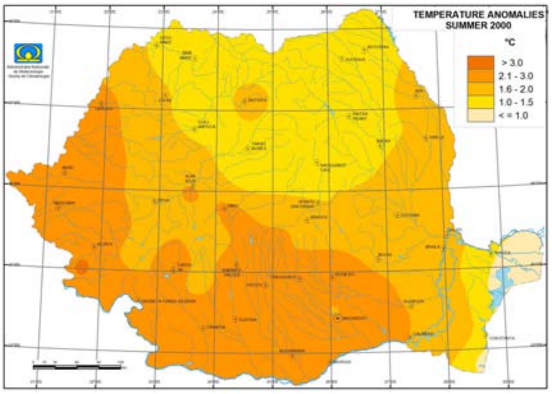
Figure 3. Linear trend (°C/47 years) of summer mean air temperature at 94 Romanian stations over the period 1961-2007. All values are statistically significant at the 5% level.

Table 1. Spatial average of temperature anomalies of the first 6 warmest summers in Romania derived from the two data sets: 94 stations over the period 1961-2007 and 14 stations over the period 1901-2007

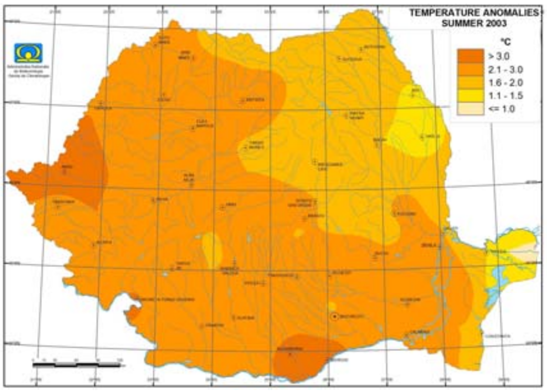
94 stations (1961-2007)		14 stations (1901-2007)	
2007	3.0	1946	3.0
2003	2.3	2007	3.0
2000	1.9	2003	2.3
1999	1.8	2000	1.9
2002	1.7	2002	1.9
1963	1.7	1999	1.9

number of days with maximum temperature greater than or equal to 40°C: 148 cases (not shown). On monthly scale, there are some differences: June and July 2007 were warmer than in 1946, while August 1946 was much warmer. On a spatial average over the entire country, July 2007 was the hottest one since 1901, while for August, 1946 was the warmest year. During summer 2007, for all three months, temperature anomalies exceeding 2°C, similar to summer 1946, were recorded. The difference between the summers 2007 and 1946 is that, in 2007 two consecutive months (June, July) recorded spatial average temperature anomalies exceeding 3°C. The highest seasonal temperature anomalies were recorded over the south-eastern regions with values between 3 °C and 4 °C over large areas. Spatial distribution of the summer temperature anomalies for the years 2000, 2003 and 2007 is presented in Figure 4, using the common data set of the

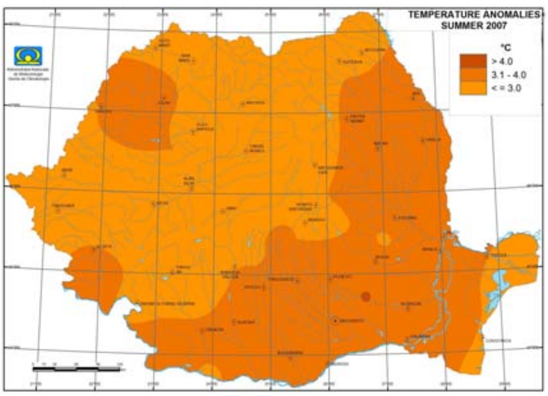
94 stations. It can be seen that the largest anomalies were recorded over the south-eastern area in 2007 and over the south and western areas in 2003 and 2000. The physical reasons for this behaviour are explained in Section 4.



a) 2000



b) 2003



c) 2007

Figure 4. Summer temperature anomalies (^{o}C) relative to the period 1961-1990 for the years 2000, 2003 and 2007.

3.2. Precipitation anomalies

The extreme hot summers presented above were also characterised by intense and prolonged droughts, with different characteristics from one case to another. The country average time series derived from the 14 long time series does not reveal any significant trend over 1901-2007 (see Figure 5), on local scale being identified increases over some regions and decreases over other regions (not shown). A pronounced inter-decadal variability can be noted. On seasonal scale (June to August), 2000 is the driest summer over the last 107 years (precipitation deficit of -48.8%), followed by 2003 (-47.7%) and then by 1990 (-36.7%), 1952 (-36.6%) and 1946 (-36.3%). 2007 is the 53rd driest summer due to the large positive precipitation anomalies recorded in August. As average over April-July, 2007 was the driest one (precipitation deficit of -39.6%), followed by 2000 (-36.9%), 2003 (-31.2%) and 1946 (-24%). Using the data set from 104 stations same hierarchy of the precipitation extreme events are noted.

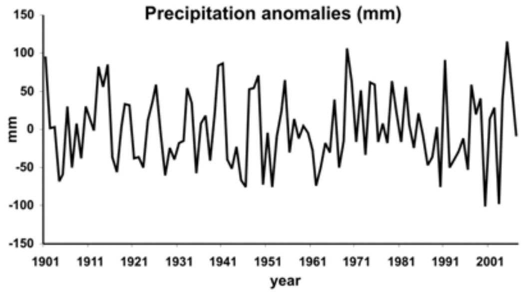
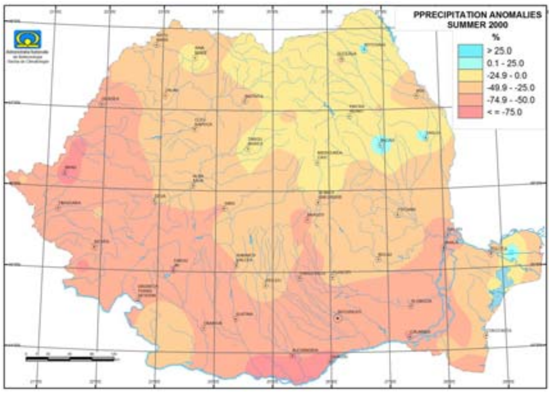
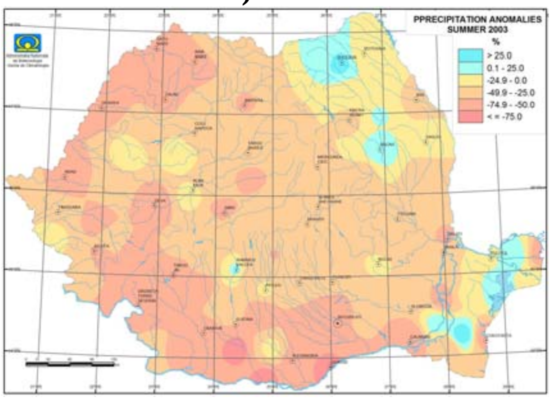


Figure 5. Summer anomalies (mm) of the total precipitation spatially averaged over Romania, relative to the period 1961-1990, derived from the values recorded at 14 meteorological stations over the period 1901-2007. Positions of these stations are presented in figure 1.

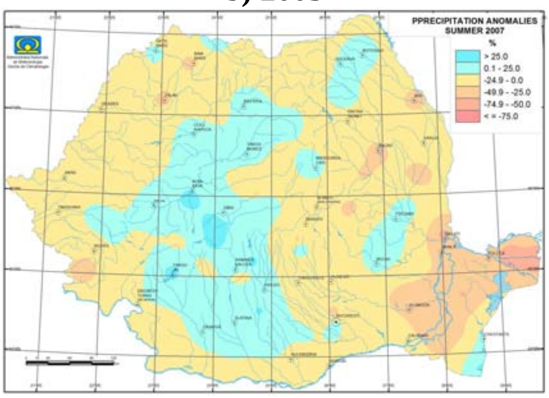
The spatial distribution of summer precipitation anomalies for the years 2000, 2003 and 2007 is presented in figure 6, using a data set from the 104 stations. It can be seen that the precipitation deficit values between -75% and -50% covered large areas over southern and western Romania during the summers 2000 and 2003, while the total precipitation deficit during the summer 2007 was less extended and with lower magnitude, due to the large positive anomalies recorded in August over most of Romania.



a) 2000



b) 2003



c) 2007

Figure 6. Summer precipitation anomalies (mm) relative to the period 1961-1990 for the years 2000, 2003 and 2007.

4. LARGE-SCALE ANOMALIES CONTROLLING THE HOT AND DRY SUMMERS IN ROMANIA

In order to understand the mechanisms responsible for the extreme summer events presented above, the corresponding anomalies of the possible dynamic factors (sea level pressure and geopotential height at 500 hPa) and thermodynamic factors (specific humidity and air temperature at 850 hPa) were analyzed. Figure 7 shows the spatial distribution of the summer SH850 and T850 anomalies. The summer H500 and MSLP anomalies over the Atlantic-European region are presented in figures 8 and 9, respectively.

4.1. Mechanisms controlling the hot summers

From the figures 7 (right) and 8, it can be seen that, in terms of magnitude and spatial distribution, there is a very good agreement between the summer air temperature anomalies in Romania and the large-scale H500 anomalies on the one hand and regional scale T850 anomalies, on the other hand.

During the **summer 2007**, a dipole structure over the Atlantic-European region can be noted, with a nucleus of strong H500 positive anomalies centered over the Black Sea (anticyclonic area) and one of negative H500 anomalies (cyclonic area) centered over the north-western Europe (Figure 8c). Very large positive anomalies of T850 were recorded over Romania with a nucleus of higher vales (greater than 4^{o}C) centered over the Black Sea as well (Figure 7c right). These patterns determined the stabilization of a warmer than normal air mass over Romania by the transport of an upper hot air mass from south-eastern Romania, leading to positive anomalies of surface air temperature over the entire country with higher values across the southern

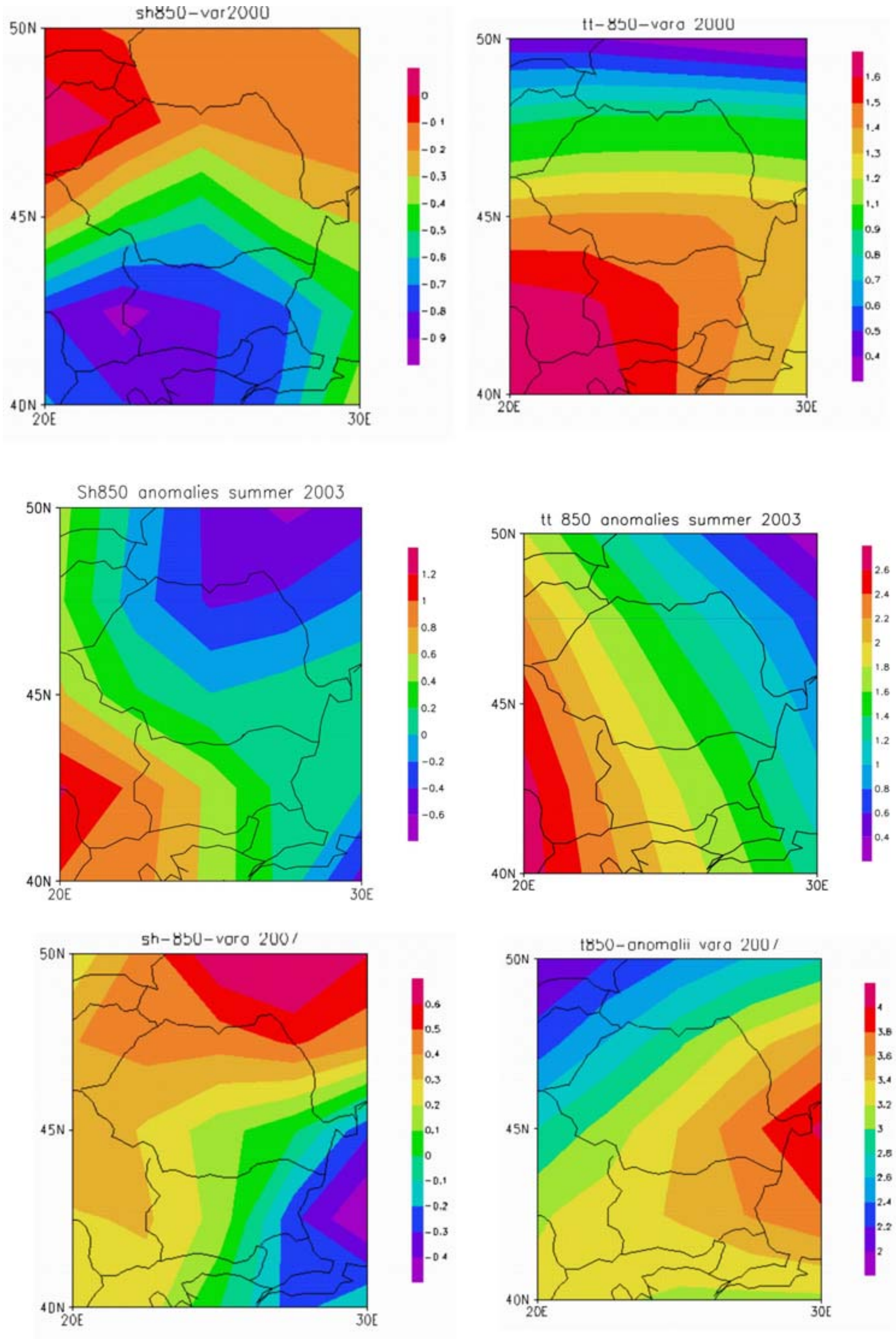


Figure 7. Anomalies of the mean SH850 (left) and T850 (right) for the summers 2000, 2003 and 2007.

and eastern regions. It can be seen that the intensity and position of the nucleus of H500 and T850 anomaly patterns give the characteristics of the summer air temperature anomalies in Romania. These results are in agreement with the conclusions presented by Busuioc (2001), who used the canonical correlation (CCA) technique as an objective tool for analyzing the connection between winter temperature in Romania and large-scale H500 anomalies: positive H500 anomalies covering Romania are optimum correlated with positive air surface temperature

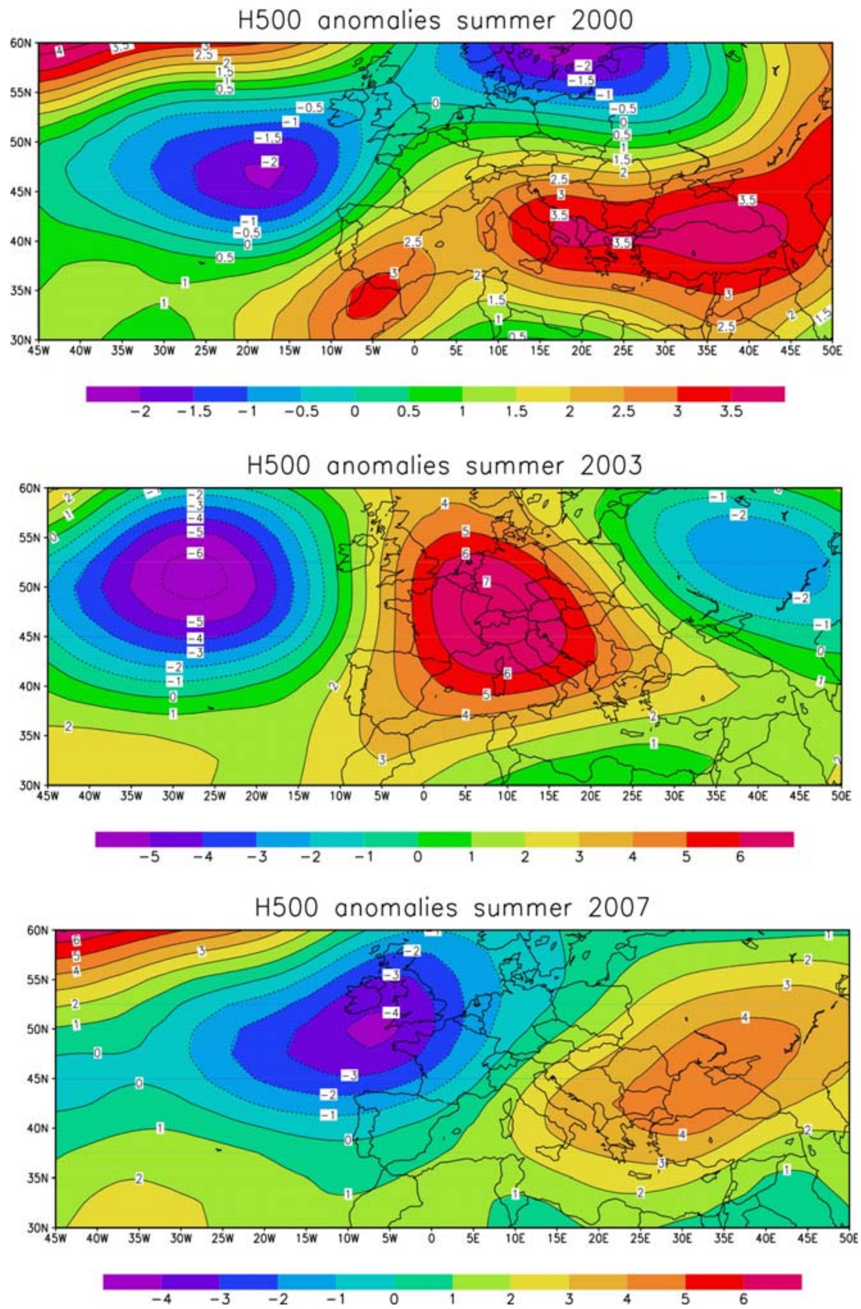


Figure 8. Anomalies of the mean H500 field relative to the period 1961-1990 for the summers 2000, 2003 and 2007.

anomalies. Similar conclusion was found for the summer season as well.

In the summers of **2000 and 2003** (Fig. 4), there were similar mechanisms, but the characteristics (spatial extension and intensity) of H500 and T850 anomalies (Figs. 7a,b, 8a,b) determined corresponding positive temperature anomalies over southern and western Romania. Thus, the curve of 4 hPa for H500 anomaly covered the western Romanian regions in 2003 and those of 2.5 hPa covered the southern areas in 2000. Similarly, high positive anomalies of the T850 field, but lower compared to 2007, covered these areas: curves of

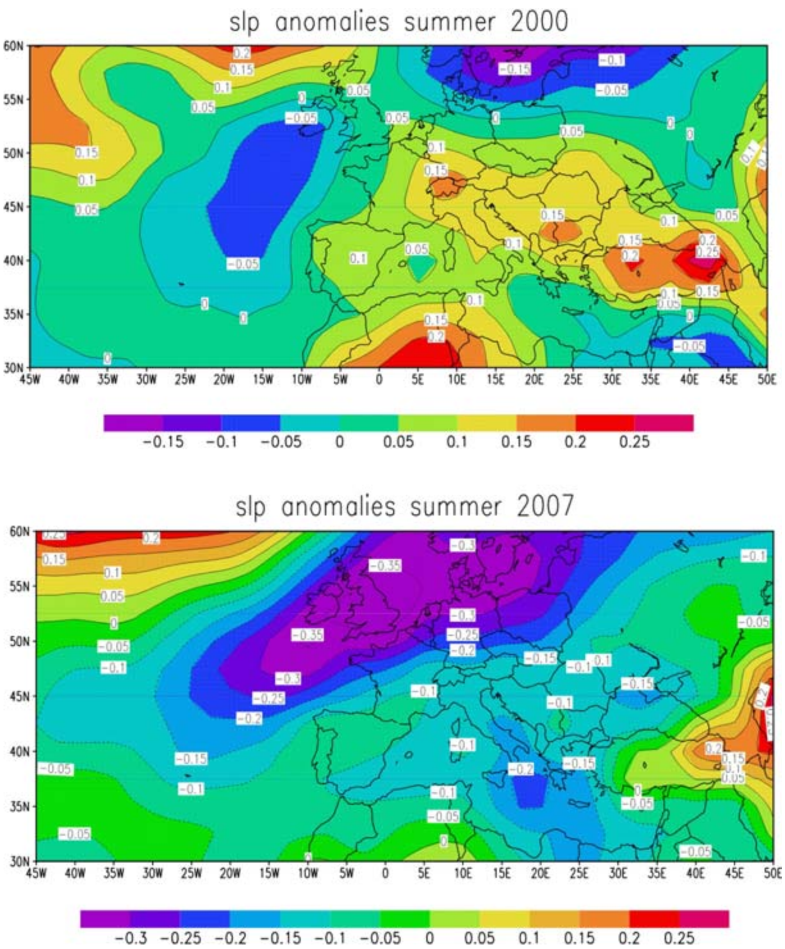


Figure 9. Anomalies of the mean MSLP field relative to the period 1961-1990 for the summers 2000 and 2007.

1.8-2.2 ^{o}C covered the southwestern areas in 2003 and those of 1.3-1.5 ^{o}C covered the southern areas in 2000. It can be noted that, even if H500 anomalies of about same magnitude (4 hPa) covered the respective areas in 2003 and 2007, the higher surface air temperature anomalies recorded over south-eastern Romania in 2007 were determined by higher T850 anomalies. This result could lead to the conclusion that the characteristics of the patterns (intensity and spatial extension) of summer extreme air temperature anomalies in Romania are mainly determined by similar characteristics of the patterns of T850 anomalies.

It should be mentioned that, while the summer 2003 was the hottest one in Western Europe (Luterbacher et al., 2004; Christensen et al., 2007), summer 2007 was the hottest for Romania, as it has been presented in Section 2, and probably also for southeastern Europe as well, as it is presented in Figure 10, which shows the spatial distribution of surface air temperature on the Atlantic-European scale. These events were determined by the persistence of very high T850 and H500 anomalies over the Romanian area in 2007 and over western and central Europe in 2003. The H500 anomalies for summer 2003 reached values of 7 hPa over central Europe. Using the summer 1946 H500 anomalies, a similar mechanism to that presented above for the other summers was found. The high

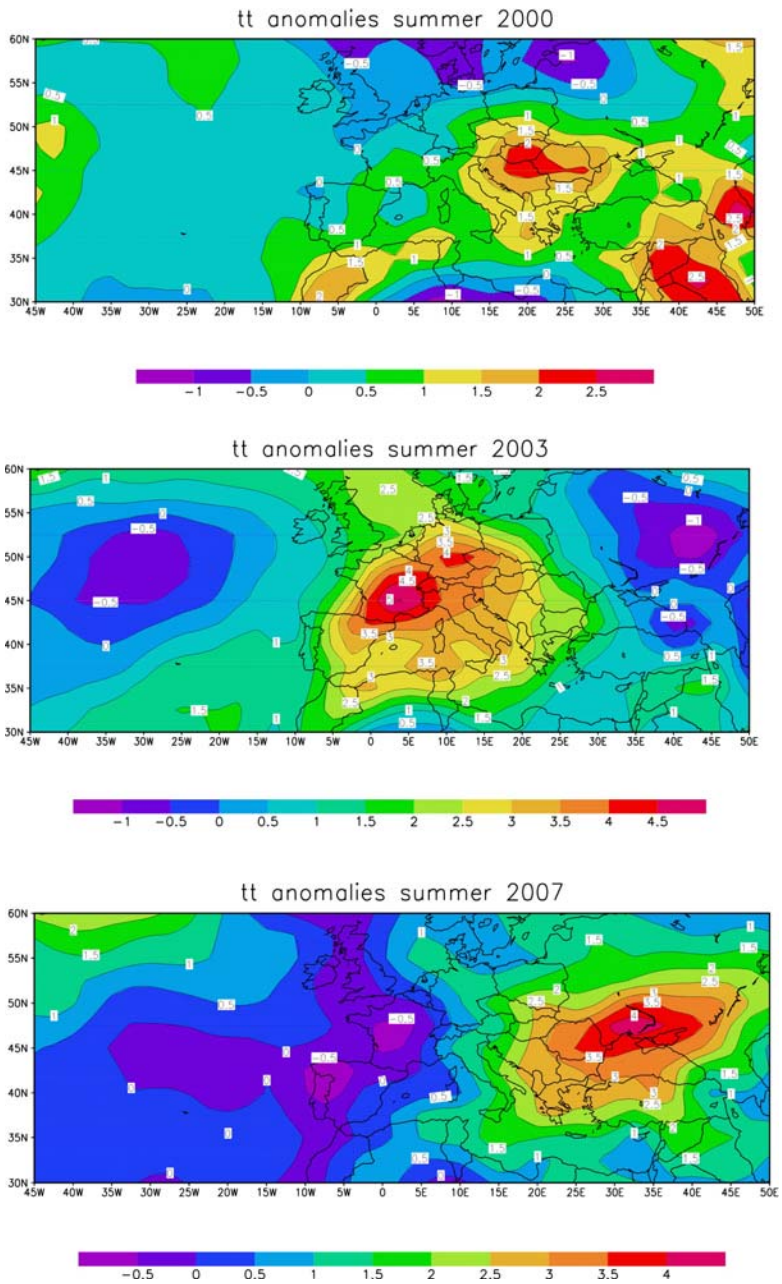


Figure 10. Anomalies of the mean air temperature relative to the period 1961-1990 for the summers 2000, 2003 and 2007.

temperature anomalies in Romania were mainly caused by high H500 anomalies across Romania (not shown).

In order to understand, in general, the mechanisms controlling the characteristics of summer temperature variability in Romania, the time series associated to the first EOF pattern of the summer anomalies related to temperatures at 94 Romanian stations, H500 and T850 across the Romanian area (20^{o}E-30^{o}E and 40^{o}N-50^{o}N) were analysed. These time series include the climate signal (represented in this case by the characteristics of temporal variability) of the three fields as it has been presented in Section 2. Their temporal evolution over the period 1961-2007 is presented in Figure 11.

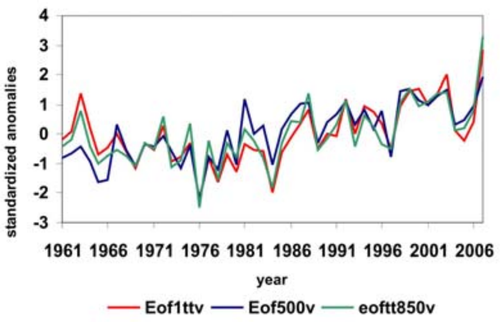


Figure 11. Temporal coefficients associated to the first EOF pattern of the H500 (blue) and T850 (green) anomalies over the Romanian area (20-30E, 40-50N) as well as of the summer temperature anomalies at the 94 stations (red).

It can be seen that there is a very high similarity between the temporal evolutions of these time series, including the extreme events as well. The highest values for all fields were recorded in 2007 together with the highest similarity between Romanian summer air temperature and T850 field covering Romania, as it has also been proved by the above-mentioned analysis of extreme events. This result can be quantitatively proved by the correlation coefficient as well as the temporal structure of the three time series given by the change points, objectively identified by the Mann-Kendall test (see Section 2). The temperature over Romania and T850 time series present a similar upward shift around 1985, while for the H500 time series it was noted around 1981. Finally, it can be concluded that the spatial extension, magnitude and temporal variability of the summer air temperature anomalies in Romania are strongly connected to the same variability characteristics of the H500 and T850 anomalies, and primarily of the T850 ones.

4.2. Mechanisms controlling dry summers

First, it should be noted that, in this paper, dry summers were analyzed only in the context of the above-mentioned extremely hot summers. Drought is a very complex long-term phenomenon and it is not analyzed in detail here. In general terms, drought is a “prolonged absence or marked deficiency of precipitation” that causes a serious hydrological imbalance (IPCC, 2007, Box 3.1). Topor (1964), analyzing the dry and wet years in Romania before 1964, presented in detail the main circulation patterns responsible for producing these events, which are still valid, even if new objective methods are used to identify these patterns. Summer 1946 is mentioned in that study as a hot and excessively dry one.

In this section, a brief analysis of the causes of precipitation deficit during the hot summers of 2000, 2003 and 2007 is presented. To reach this objective, the patterns of large- and regional-scale anomalies of H500, SLP and SH850 fields were analyzed. Busuioc (2001), using the canonical CCA technique as an objective tool for analyzing the connection between winter precipitation in Romania and large-scale H500/SLP anomalies, found that positive H500/SLP anomalies over Romania are optimum correlated with negative precipitation anomalies (deficit of precipitation). A similar conclusion was found for the summer season as well but the link with the SLP field is not as strong as in the winter case.

Considering these results, the negative precipitation anomalies over the **summers of 2000 and 2003** across most of the country but with highest precipitation deficit in southern and western regions (see section 3.2) could be first explained by the positive H500 anomalies over Romania, with highest values in southern areas in 2000 and in southwestern areas in 2003 (Figure 8a, b). Even if higher H500 anomalies were recorded in 2003, the negative precipitation anomalies over Romania had the same magnitude in both years. This result shows that the H500 anomalies alone can not explain the intensity of precipitation deficit. By analyzing the moisture anomalies represented by the SH850 anomalies (Figure 7 left), it can be seen that in summer 2000 a dry air mass at 850 hPa covered the entire Romania, with more pronounced negative anomalies over the southern areas. Summer 2003 was characterized by negative SH850 anomalies over north Romania but the upper north-northwesterly circulation induced by the anticyclonic structure (Figure 8b) transported this dry air mass over Romania. These mechanisms led to about the same intensity of precipitation deficit over Romania in both summers. This result is in agreement with the explanation given by Topor (1964), who showed that the most droughts in Romania are associated with upper air anticyclonic structures maintained by warm and dry air advection in the upper troposphere.

The summer 2007 precipitation anomalies are less pronounced than those recorded in 2000 and 2003 (see Section 3.2), with only limited areas of negative anomalies over south-eastern areas and positive anomalies over extended areas, due to high positive precipitation anomalies recorded over most of the country in August. This seems to be in agreement with the spatial distribution of the SH850 anomalies, which display only slightly negative values over a limited south-eastern area (see Figure 7 left), probably due to a compensation between positive anomalies in August and negative anomalies in June-July. The MSLP anomaly distribution (Figure 9) shows values around normal over the entire Romania, which could be explained by the same compensation mentioned above. A detailed analysis of July 2007 (not shown) was carried out, because within this month a high precipitation deficit was recorded over a large south-eastern area. It was found that pronounced negative SH850 anomalies were recorded over these regions (not shown) while MSLP anomalies were again not significant (not shown). This result shows that summer precipitation variability in Romania is very complex, the moisture field having an important role, compared with the winter season when the circulation factor (given by the MSLP variability) is the most important (Busuioc and von Storch, 1996; Busuioc, 2001). Intense summer droughts in Romania could be explained by intense positive H500 and negative SH850 anomalies.

In order to draw a more general conclusion about the connection between summer precipitation variability in Romania and H500/SH850 variability, the time series associated to the first EOF pattern of summer anomalies related to precipitation totals at the 104 Romanian stations, H500 and SH850 across the Romanian area (20°E-30°E and 40°N-50°N) were analyzed. Their temporal evolution over the period 1961-2007 is presented in Figure 12.

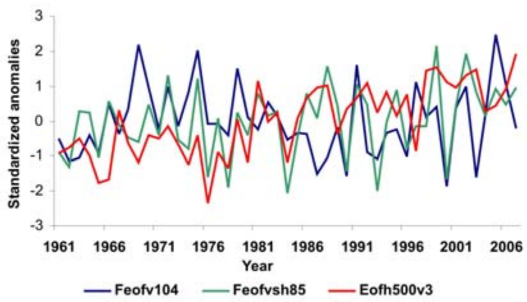


Figure 12. Temporal coefficients associated to the first EOF pattern of the H500 (red), and SH850 (green) over the Romanian area (20-30E, 40-50N) as well as of the summer precipitation anomalies at the104 stations (blue).

It can be seen that, generally, the pronounced negative values of the precipitation time series are associated to pronounced negative values of the SH850 time series and/or positive values of the

H500 time series. The correlation between the corresponding time series is higher for SH850 (correlation coefficient of 0.42, 1% significance level) and lower for H500 (correlation coefficient of -0.23, about 10% significance level). Since the H500 and SH850 time series have a pronounced upward linear trend, which strongly influences the real correlations between two data sets, the linear trend was removed before the calculation of these correlation coefficients. This result shows that summer precipitation variability over Romania is very complex and it is not entirely explained by the variability of time series associated to the principal variability modes of the two parameters, as it was presented above for temperature. Special regional patterns of these parameters (also including other parameters) could be responsible for summer precipitation variability in Romania, which could be selected by the CCA technique (Busuioc and von Storch, 1996; Busuioc 2001).

It is known that, during the summer season, over Romania, convection is one of the most important factors controlling precipitation variability. A test of using a seasonal instability index (see Busuioc et al., 2008) was carried out but the results were not so significant. One reason could be that the monthly or seasonal average of this index loses the signal, which is produced on a shorter temporal scale.

5. CONCLUSIONS AND DISCUSSIONS

The summer 2007 has been analyzed in the context of extremely hot and dry summers in Romania over the 20th and early 21st century, in order to understand the mechanisms controlling these events and, more generally, the summer temperature variability in Romania. To reach this objective, the time series of mean air temperature and total precipitation for two observational periods were analyzed: a longer period for 14 stations (1901-2007) and a shorter one (1961-2007) for a complete high spatial density data set (94 stations for temperature and 104 for precipitation). Non-parametric tests (Mann-Kendall and Pettitt) and EOF analysis were used as statistical tools to identify the main temporal characteristics of regional climate variability (trends and shifts).

It was found that the 14 stations are representative for the summer temperature regime in Romania and therefore, the conclusions based on the analysis of temperature time series at these stations are robust. A significant long-term warming trend of Romanian summers over the last 107 years (1901-2007) was identified (0.6^{o}C on spatial average) but this characteristic is not linear, two statistically significant changes in the mean summer temperatures being objectively noted: a primary upward shift around 1985, marking the increasing rate of warming over the last decades (1.6-2.0^{o} C), and a secondary downward shift around 1964, interrupting the warming trend over the first half of the 20th century by a slightly colder (but stable) regime between 1965-1985. The summers of 1946 and 2007 are the highest peaks of anomaly (same magnitude) regarding the 1961 to 1990 mean (3^{o}C) over the two sub-periods, being followed by the summers of 2003, 2000, 2002 and 1999 with about the same anomaly magnitude (1.8-1.9 ^{o}C). However, the summer 2007 distinguished by a high persistence of dog days. In addition, the result that 5 of the 6 warmest summers over the past 107 years occurred in the last 8 years (2000-2007), is in agreement with the IPCC AR4 (IPCC, 2007) findings that show a rapid warming over the last decades, attributed mainly to anthropogenic reasons.

The precipitation average over Romania (derived from the 14 long-time series) does not reveal any significant trend, being identified local-scale increases over some small regions and decreases over other regions. A pronounced inter-decadal variability can be noted. On seasonal scale (June to August), 2000 had the driest summer over the last 107 years, followed by 2003 and then by 1990, 1952 and 1946. 2007 recorded the 53rd driest summer due to large positive precipitation anomalies occurred in August. As an average over April-July, 2007 was the driest year (deficit of -40%), followed by 2000 (-37%), 2003 (-31%) and 1946 (-24%).

By analyzing the reasons that determined temperature anomalies in the first three hottest summers in Romania, similar mechanisms were found, mainly the persistent patterns of very high positive H500 and T850 anomalies over Romania, given by an anticyclonic structure that conveyed the hot air mass, the T850 anomalies being the primary factor. The spatial extension and magnitude of the summer temperature anomalies in Romania are given by similar pattern characteristics of the H500 and T850 anomalies. When these anomalies are associated with a persistent dry air mass at 850 mb, prolonged and intense droughts are recorded in Romania, meaning that the SH850 anomalies are the primary factor controlling summer droughts in Romania. The consistency of this conclusion is proven by analyzing the coherency of year to year variability over a long period (47 years) between summer temperature and precipitation anomalies in Romania and large /regional scale anomalies of dynamic and thermodynamic parameters.

From the similarity of mechanisms controlling the extremely hot summers in Romania over long periods, it could be concluded that, in the future climate further perturbed by the increasing amount of greenhouse gases, these mechanisms will not be changed but the frequency of occurrence and the magnitude/spatial extension of large /regional scale patterns related to these mechanisms will.

Acknowledgements**:** The large-scale reanalysis data sets were taken from the NCEP/NCAR archive. Dr. Doina Banciu, Dr. Rodica Tomozeiu and an anonymous reviewer are acknowledged for their useful comments.

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