

Observed changes in precipitation in the Danube river lower basin in the context of climate change

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Abstract

The study presents the observed variability and changes in precipitation regime in the Danube river lower basin, which is situated along both sides of the border between Bulgaria and Romania. The research is based on monthly precipitation totals recorded at 22 meteorological stations from Bulgaria and Romania. The investigated period is 1961-2007 out of which two reference periods are considered, the last 30 years (1978-2007) and the usually used WMO reference for the contemporary climate (1961-1990).

The main objective of the study is to give actual information about precipitation variability in the region in the context of global climate change. The results of the work point out on some characteristics of extreme precipitation events in the region – drought and high precipitation, and on the role of natural mechanisms for precipitation variability.

Based on the statistical methods we have used, the results can be summarized as follows:

- Summer precipitation represents 30-35% of annual precipitation total followed by spring precipitation with about 25-28% of annual values. Autumn precipitation is between 22-24% of annual values in most of the stations. Winter precipitation represents about 20% of annual precipitation

- The wet periods have been observed at the end of the 1960's and at the beginning of the 1970's

- The intensive drought from 1983 to 1993 has been confirmed by calculating the precipitation indices like as Rainfall Anomaly Index and Cumulative Anomaly Index. The driest year during the investigated period was 2000.

- Increasing occurrence of extremely wet months has been observed since 2002

Keywords: *precipitation, extreme events, NAO index, Bulgaria, Romania*

Rezumat. Schimbări observate în regimul precipitațiilor atmosferice în bazinul inferior al Dunării în contextul schimbărilor climatice globale

Studiul prezintă variabilitatea și schimbările observate în regimul precipitațiilor sezoniere în bazinul inferior al Dunării, care este situat de-o parte și de alta a frontierei dintre Bulgaria și România. Cercetarea se bazează pe datele lunare de precipitații înregistrate la 22 de stații meteorologice din Bulgaria și România. Perioada de studiu este 1961-2007 din care s-au considerat două perioade de referință, ultimii 30 de ani (1978-2007) și perioada considerată în mod obișnuit de OMM ca referință pentru climatul actual (1961-1990).

Obiectivul principal al studiului este prezentarea unei informație actuale despre variabilitatea precipitațiilor din regiune în contextul schimbărilor climatice globale. Rezultatele studiului evidențiază câteva caracteristici ale evenimentelor cu precipitații extreme în regiune – secetă și precipitații abundente - și asupra rolului mecanismelor naturale în variabilitatea precipitațiilor.

Pe baza metodelor statistice pe care le-am utilizat rezultatele pot fi sintetizate astfel:

- Cantitățile de precipitațiile din timpul verii reprezintă 30-35% din totalul cantităților anuale, cele din primăvară 25-28%, cele din timpul toamnei 22-24%, iar cele din iarnă aproximativ 20% din totalul cantităților anuale.

- Cele mai ploioase perioade s-au înregistrat la sfârșitul deceniului 1960 și la începutul deceniului 1970.

- Seceta intensă din perioada 1983-1993 a fost confirmată atât de Indicele RAI (Indicele Anomaliei de Precipitații) cât și de Indicele CA (Anomalia Cumulată) a precipitațiilor. Anul 2000 a fost cel mai secetos din perioada analizată.

- Începând cu anul 2002 s-a observat o creștere a numărului de luni cu precipitații mult excedentare.

Cuvinte cheie: *precipitații, evenimente extreme, indice NAO, Bulgaria, România*

INTRODUCTION

Warming observed over the past several decades is consistently associated with changes in the hydrological cycle. In this regard, increasing atmospheric water vapor, changes of precipitation characteristics, changes in the

magnitude and the intensity of extreme events, widespread melting of snow and ice and, changes in soil moisture and runoff have been intensively reported. The fourth Assessment Report (AR4) of the IPCC pointed out that the 100-year linear trend (1906–2005) of 0.74°C is larger than the corresponding trend of 0.6°C

(1901–2000) given in the Third Assessment Report (TAR), (IPCC, 2007). The increase in global surface temperature leads to significant melting of snow and ice and reduces the areas covered with snow and ice cover (Brown and Alt, 2001; Goodison et al., 2007).

Studies on precipitation variability show decreasing trend in the Central and Southern Europe and increasing trend in the Northern Europe. The Balkan Peninsula is characterized by a general decreasing trend of precipitation since the beginning of the 1980s (Alexandrov, 2004).

However, heavy rains have been observed in many parts of Bulgaria and Romania. During the flooding events of the last years in Romania (2005 and 2006) and other regions in the central and south-eastern Europe, losses of life and very high economic damages have been experienced. On the other hand, in the southern Europe including the northern part of Bulgaria and the southern part of Romania, it has been observed that in most of the cases, heavy rains occurred during long lasting dry months. These facts illustrate how climate extremes become more frequent and more intense during the last decades.

The aim of this study was to provide detailed information in our region of interest about:

- seasonal variation of precipitation;
- temporal and spatial changes of extreme precipitation months;
- link between precipitation variability and large scale circulation processes, in particularly in relation with North Atlantic Oscillation (NAO).

DATA AND METHODS

The Danube river lower basin, situated on both sides of the border between Bulgaria and Romania is one of the main agricultural areas for Bulgaria and Romania as well.

The present paper present a part of the results obtained in the framework of Bulgaria–Romania Joint Research Project "Observed changes in precipitation regime in the Danube river lower basin in the context of climate change".

We used monthly precipitation data for 22 meteorological stations situated on both sides of Danube river on the territories of Bulgaria and Romania. According to their geographical situation and to the peculiarities of the study area the stations have been grouped into three groups: 1) western part of the study area which includes the stations Tr. Severin, Calafat, Băilești, Bechet, Caracal, Tr. Măgurele, Vidin, Vratsa, Lom, Oryahovo, Kneja and Pleven; 2) central part including the stations Alexandria, Giurgiu, Obraztsov chiflik, Razgrad, București-Băneasa and Călărași and 3) eastern part of the region with the stations Sulina, Tulcea, Galați and Hârșova (Fig. 1).

The main investigated period is 1961-2007. In order to investigate the changes in the variability of precipitation two 30-year reference periods have been used: 1961-1990 and 1978-2007.

In order to avoid the influence of non meteorological factors on climatologic data, homogeneity testing and then homogenization of the initial time series were made by using the AnClim software (Stepanek, 2006 and <http://www.climahom.eu/AnClim.html>).

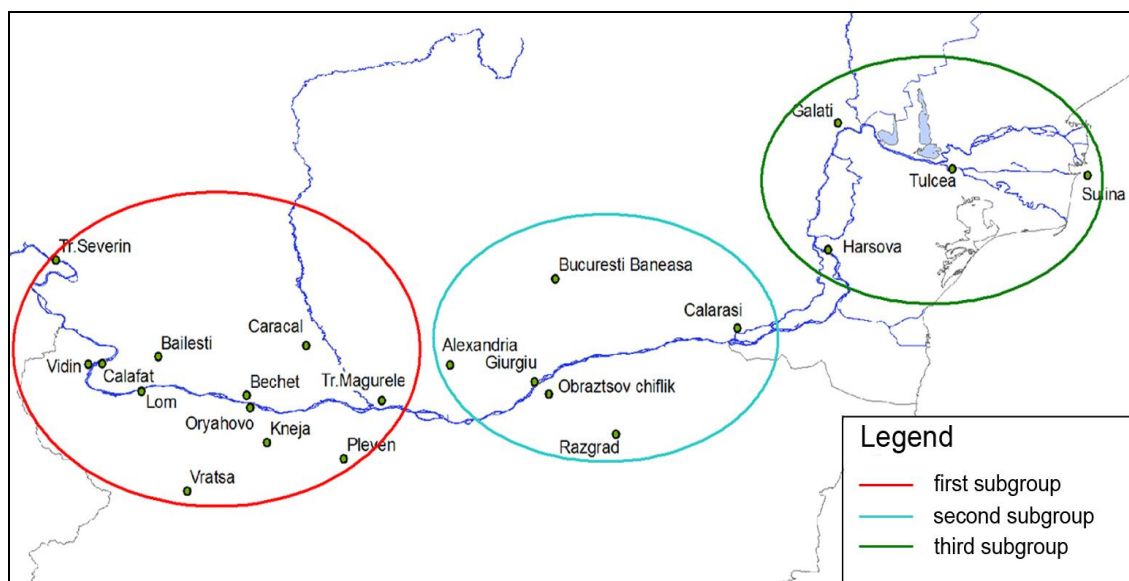


Fig. 1. Meteorological stations used for the research

All time series of monthly precipitation totals, where breakpoints have been detected, were adjusted (Manea et al., 2010). The seasonal precipitation was determined by summing the monthly precipitation totals as follow: winter – December, January, February; spring – March, April, May, summer – June, July, August and autumn – September, October and November.

The link between winter precipitation and atmospheric circulation was examined on the base of gridded sea level pressure (SLP) monthly means extracted for the Atlantic-European domain (30°W-50°E; 30°-80°N) from the NCEP Reanalysis web site at <http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html>. The time series for winter NAO index has been calculated as average of monthly values ((DJF)) of NAO indices available at Climate Research Unit web site <http://www.cru.uea.ac.uk/cru/data/nao/>.

Regional differences in the variability of rainfall and duration of dry and wet periods are determined by Rainfall Anomaly Indices (RAI) and Cumulative precipitation Anomalies (CA). These indices are used by many authors (Keyantash and Dracup, 2002; Hänsel and Matschullat, 2006, etc.) for determining the drought and assess its magnitude expressed as positive and negative anomalies.

Rainfall Anomaly Index is used to calculate annual precipitation anomalies (dry events). It is calculated by

$$RAI = -3 \frac{P_i - \bar{P}}{\bar{E} - \bar{P}},$$

where P_i is annual precipitation total for each year, \bar{P} is the average annual precipitation for the period 1961-1990, and \bar{E} is the average of the ten lowest precipitation totals (the driest 10 years) for the investigated period. Cumulative Precipitation Anomalies (CA) are used in order to determine the duration of drought event. CA are calculated as follow: 1) the differences between seasonal or annual precipitation for each year (P_i) and average values for the period 1961-1990 (\bar{P}) are calculated; 2) those anomalies are cumulated.

$$CA = \sum_{i=1}^n (P_i - \bar{P}),$$

From the graphical representation of this quantity, the negative slopes of the graph indicate the duration of drought event (Hänsel and Matschullat, 2006).

Extreme wet month is defined as a month whose monthly precipitation total is higher than the 90th percentile of the empirical distribution during the reference period 1961-1990. As extreme dry month,

we consider the month with precipitation total lower than the 10th percentile of the empirical distribution.

In order to determine the influence of the large scale mechanisms on precipitation variability, a link between the North Atlantic Oscillation (NAO) and winter precipitation in our region is investigated. The NAO refers to a north-south oscillation in the atmospheric mass with centers of action near Iceland and over the subtropical Atlantic from the Azores across the Iberian Peninsula. NAO occurs in all seasons but during winter it has a dominant role for precipitation variability in the Atlantic European region including our domain. During the months of December through March, the NAO accounts for more than one-third of the total variance of SLP over the North Atlantic (Hurrell, 2000). According to Rimbu and Boroneant (2000), 32% of the total variance of the decadal winter precipitation in Europe is explained by a spatial structure of sea level pressure (SLP) associated to the NAO. During the positive phase of the NAO, negative precipitation anomalies occur over the southern part of Europe (Wibig, 1999). In our study, the time series for winter NAO index has been calculated as an average of monthly values ((DJF)) of the NAO index.

The EOF analysis was used to identify the principal modes of winter variability of sea level pressure and precipitation which are coherently varying. The EOFs were calculated as unitary eigenvectors of the covariance matrix. Each EOF can be regarded as a spatial mode of variability.

DISCUSSIONS

The main contribution to annual precipitation totals comes from summer precipitation. Exceptions are made only for a few stations in the western part of the study area where the spring precipitation is higher or equal to summer precipitation. In general, the summer precipitation accounts for about 30-35% of annual precipitation (Fig. 2). The second contribution comes from spring precipitation which accounts for about 25-28% of annual precipitation. At some stations from the eastern part of study area, autumn precipitation ranks on the second place in annual amount after the summer precipitation but in most of the investigated stations, autumn precipitation follows spring precipitation with 22-24% from annual totals. The winter precipitation represents the lowest contribution to the annual total. In the eastern part of the study area, as well as in the western part, at most of the stations the winter precipitation accounts for about 20% of the annual precipitation total.

Variability of seasonal precipitation

According to the *Rainfall Anomaly Index (RAI)* calculated for the three groups of stations, the driest

winters have been observed in the eastern part of the Danube river lower basin since 1971 (Fig. 3)

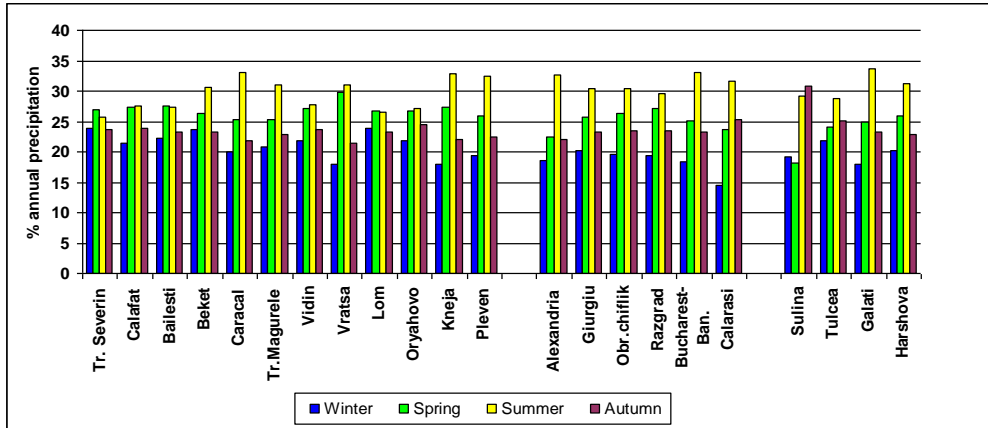


Fig. 2. Distribution of seasonal precipitation as % of annual precipitation total for the period 1961-2007

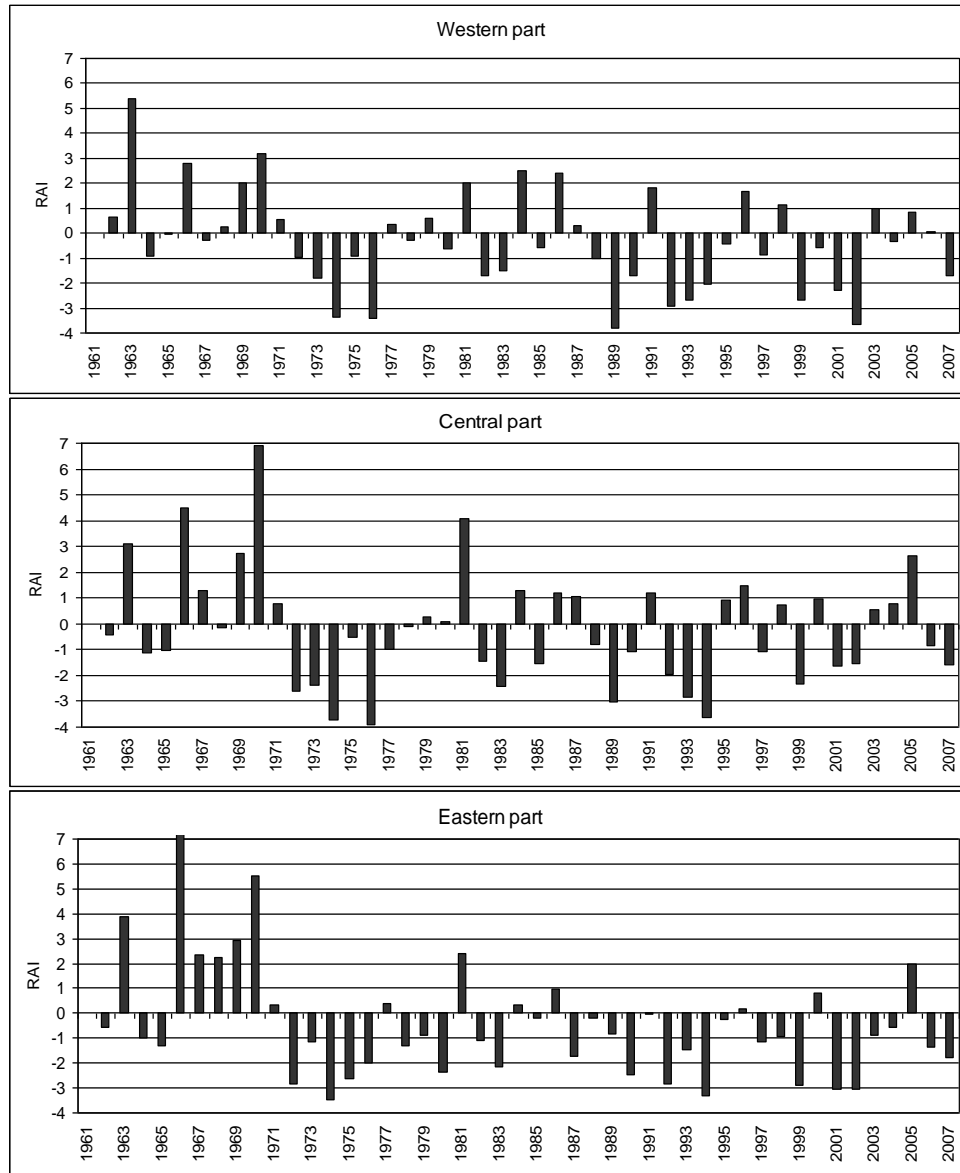


Fig. 3. RAI for winter precipitation

The values of RAI show that the winters have been wet from 1962 to 1970 at all stations but most pronounced at the eastern group of stations. According to RAI the highest winter precipitation for the period 1961–2007 has been observed in 1970 for the central group of stations, in 1966 for the eastern group and 1963 for the western group of stations, respectively. Since 1971 the winter

precipitation has shifted to dry characteristic at most of the stations in the region. However, during that period, in the western and central group of stations several wet years have been observed.

According to RAI, the spring precipitation is characterized by an interannual variability that not clearly shows any dominant trend (Fig. 4). The spring drought is well expressed in 1968, 1983, 1986, 2000, 2003 and 2007.

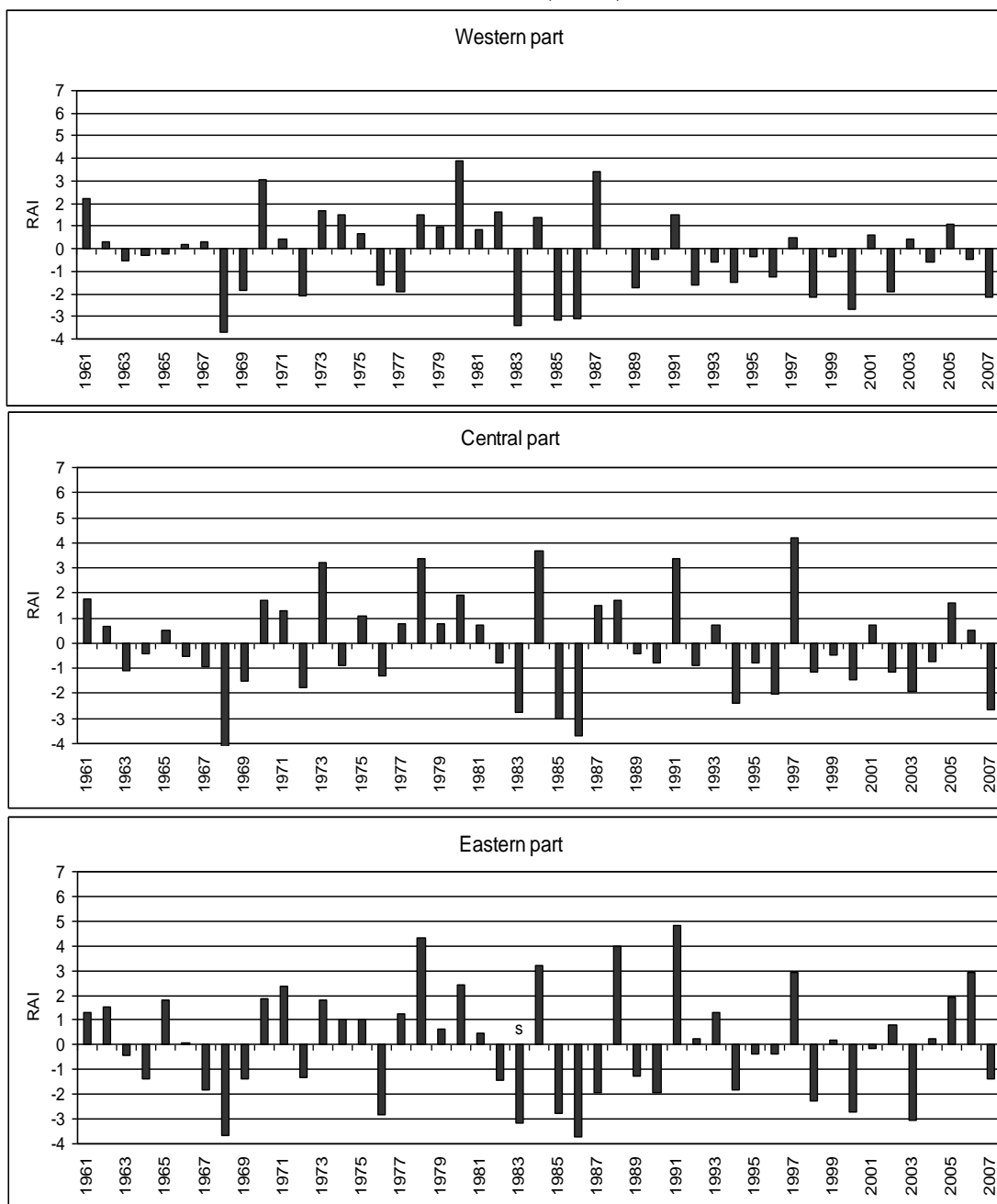


Fig. 4. RAI for spring precipitation

Unlike the spring, during summer, according to RAI, since 1961 till 1965 a dry period has been detected at most of the analyzed stations and then a wetter period followed (1966-1976). Starting with 1977 till 2007 the summer precipitation has shifted

to dry. However, during that generally dry period at most of the stations, extremely wet years have been recorded such as 1997 in the eastern group of stations and 2005 in the central and western group of stations (Fig. 5). It is worth to note that these

were the years when heavy precipitation gave rise to severe floods in Romania.

During 1961-1980, the autumn precipitation is characterized by successive wet and dry years at most of the stations. The wettest year was 1972 at

all the stations. That period was followed by dry years till the mid of 1990's when a shift to wetter period was shown in the RAI at all stations. The wettest years have been recorded at the central group of stations (Fig. 6).

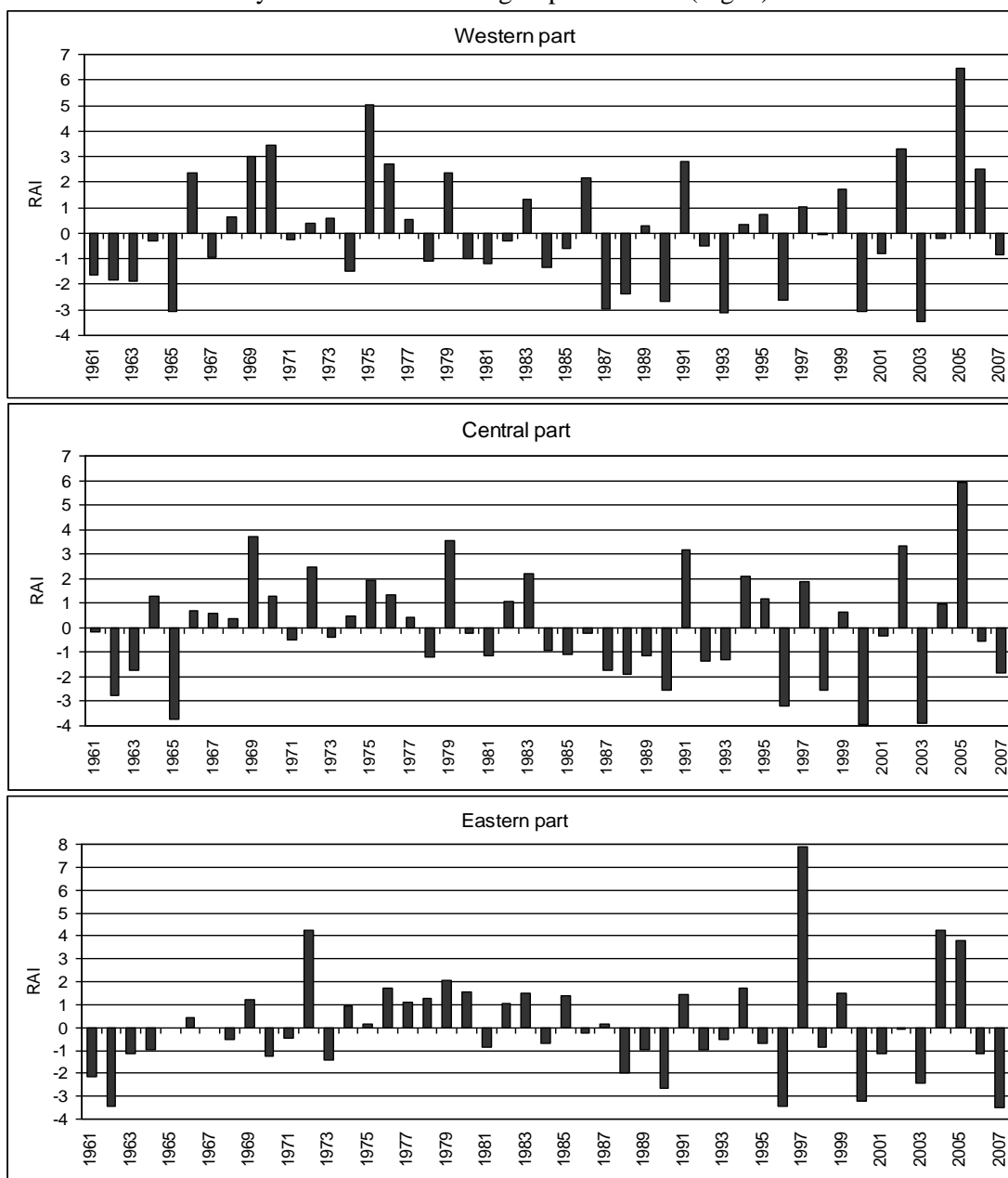


Fig. 5. RAI for summer precipitation

Cumulative anomaly (CA) allows us to determine the periods with positive and negative phases in the time series of seasonal precipitation. The positive phase from 1962 to 1971 is characteristic for winter precipitation. The following negative phase continues until 1976 (1978). During the last 30 years of the investigated period there are one positive phase of winter precipitation (1976/1978–1987/1988) and one negative (1987-2002) as shown in Fig. 7.

There is asynchrony in the occurrence of positive and negative phases in time series of spring precipitation for various stations. The positive phase from 1969 to 1980/1984 is established in most of investigated stations followed by negative phase lasting to 2004.

The beginning of the period is characterized by a negative phase of the summer precipitation, which continued until 1965 (1968). The following is a positive phase lasting from 1965 to 1983 being

observed in the most of stations in the central and eastern part of study area, while for the stations of western part the positive phase is better expressed from 1968 to 1977/1979. The negative phase in summer precipitation is established from 1983 to 2003. For some stations from the first group (western) the negative trend continued from 1979 to

1996. In some of the investigated stations there is a slightly expressed positive phase in the summer precipitation for the period 1993-1999 but it generally remains the negative trend. There is a positive slop in the time series of summer precipitation since 2003 in most of the investigated stations (Fig. 8).

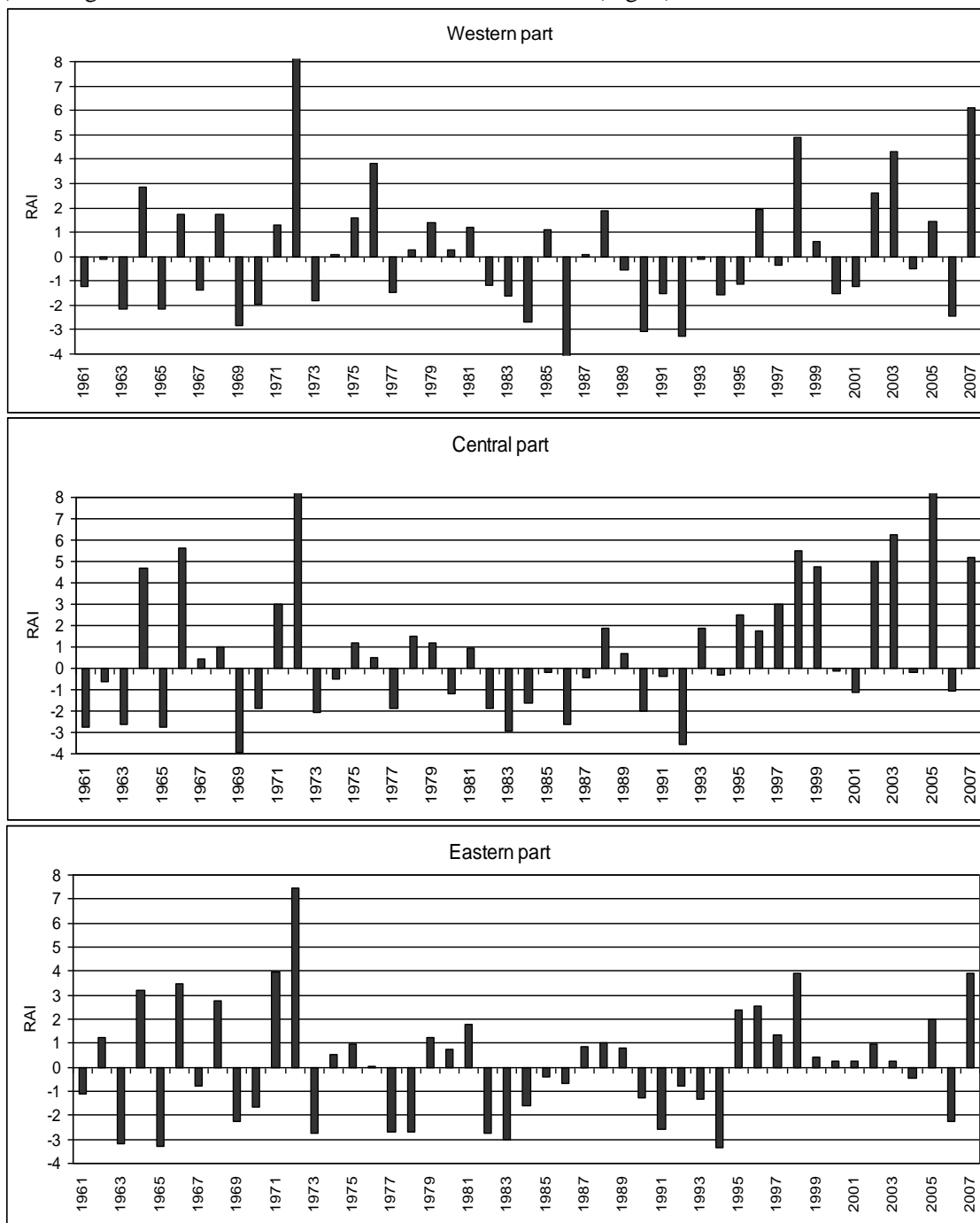


Fig. 6. RAI for autumn precipitation

Unlike summer, in autumn there is not well-defined negative phase at the beginning of the period. The minimum during the autumn precipitation in 1970, expressed in almost all investigated stations

makes impression. The subsequent positive phase lasted until 1981/1982 at the stations located in the western part of the Danube plain of the Bulgarian territory, and in some Romanian stations (Turnu Severin, Calafat, Băilești, Bechet).

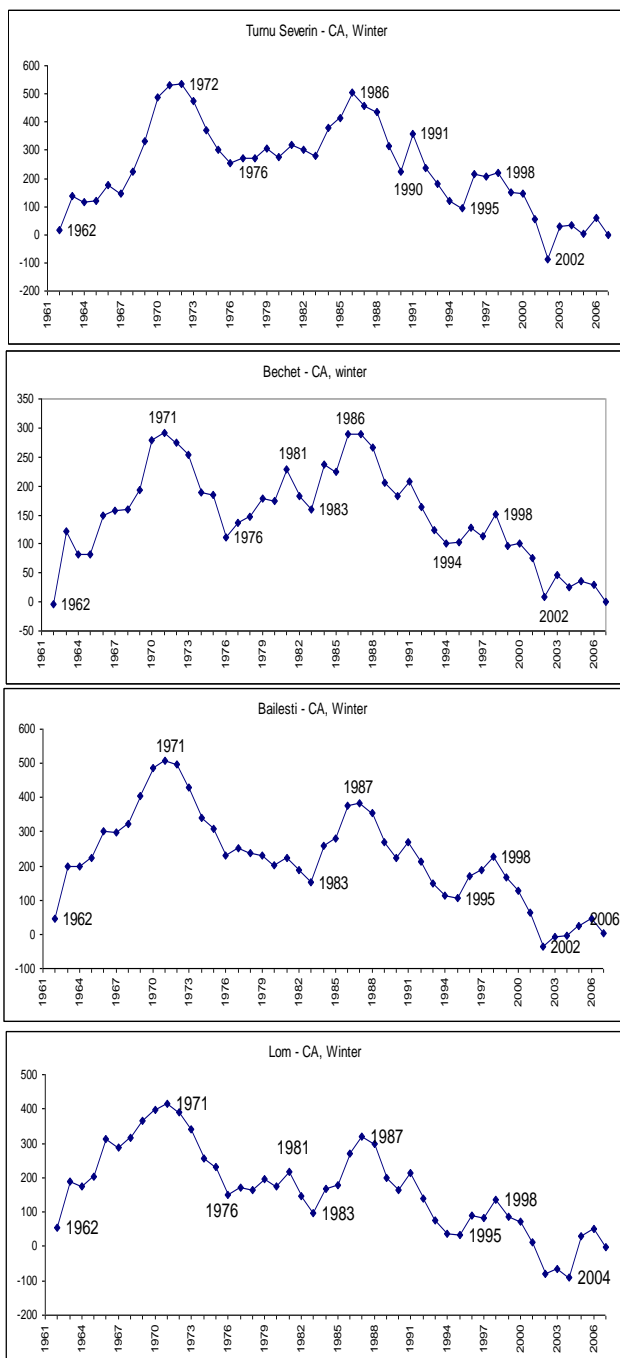


Fig. 7. Cumulative anomalies (CA) of winter precipitation

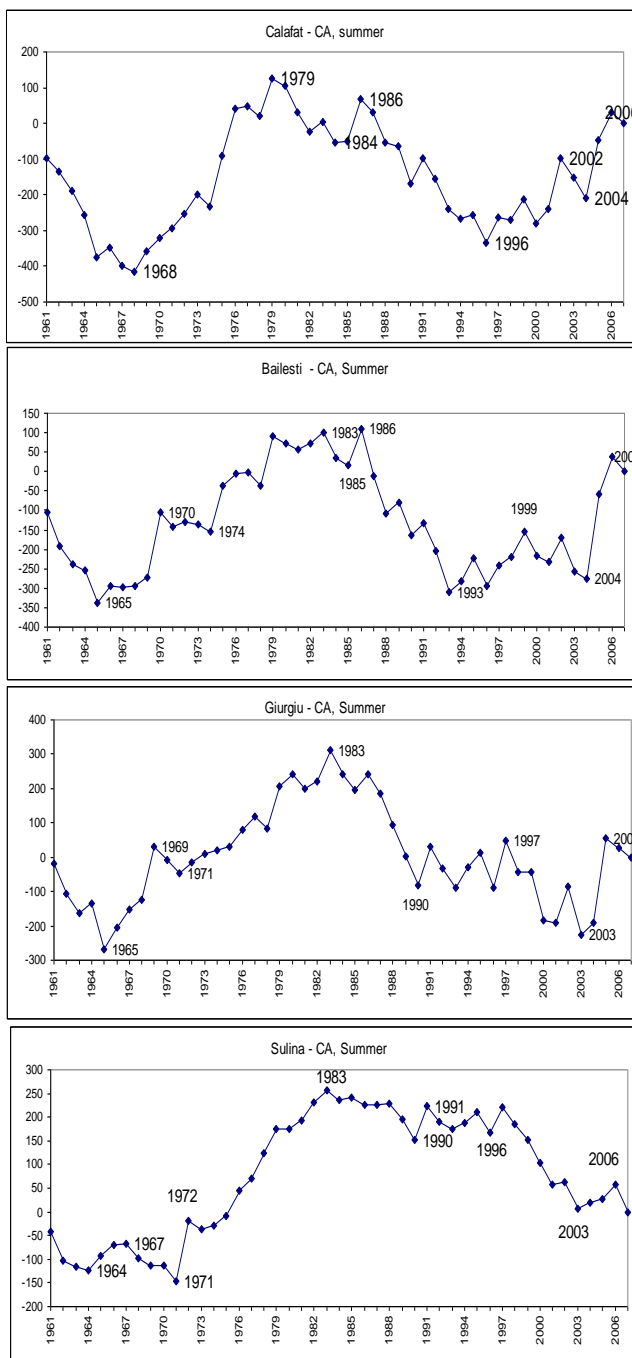


Fig. 8. Cumulative anomalies (CA) of summer precipitation

The eastern part of study area is characterized by negative phase in autumn precipitation with duration from 1972 to 1994. From 1994/1995 until the end of the investigated period in all stations, the positive phase of the autumn precipitation is established.

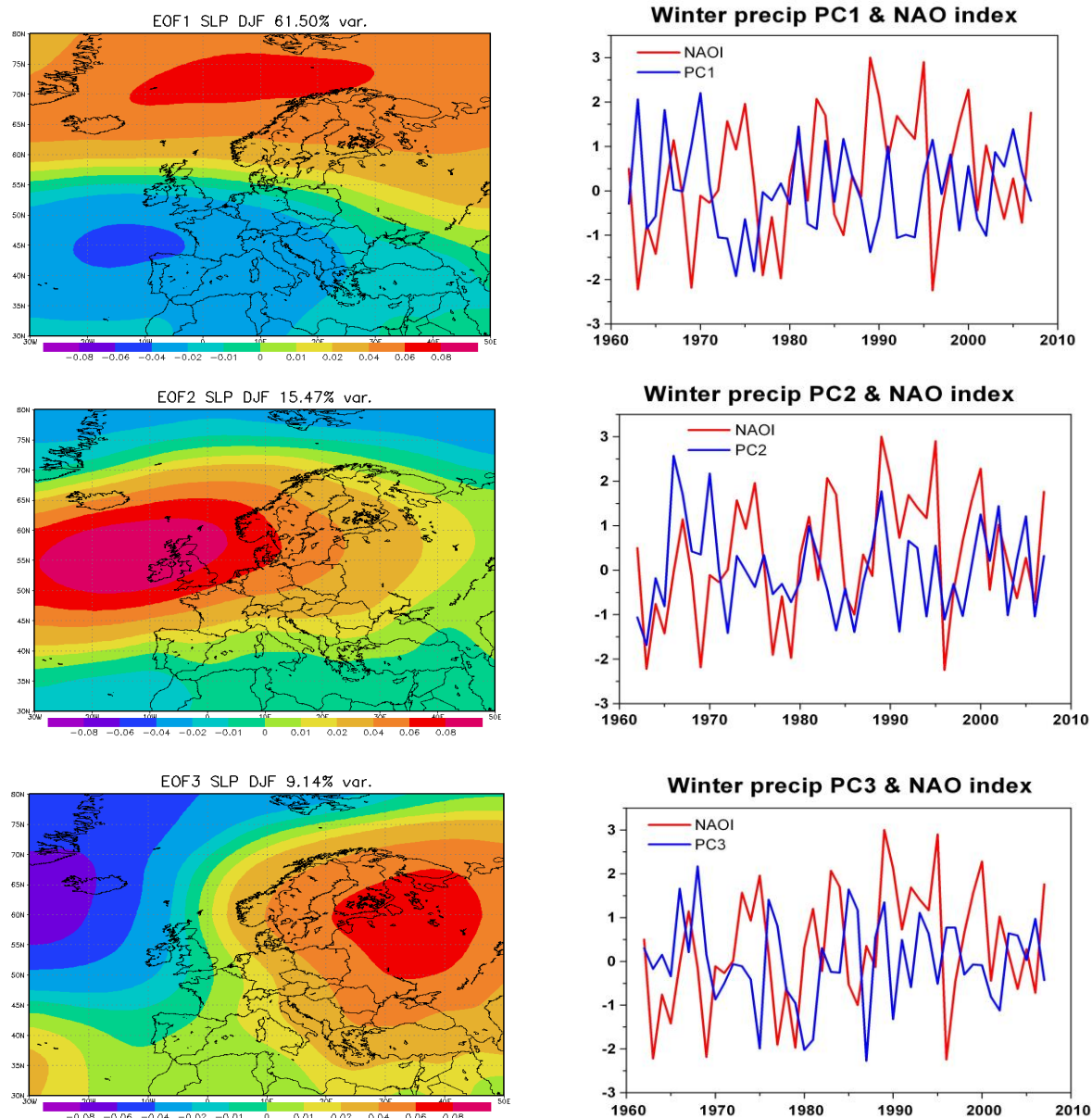
Link between winter precipitation and atmospheric circulation. The dynamics of the atmosphere is an important internal factor for the genesis of climate and its variability. It is characterized by global atmospheric circulation,

which represents all major air currents at a large spatial scale. In order to establish a connection between seasonal precipitation and atmospheric circulation, the indices of the North Atlantic Oscillation (NAOI) are used. In most of the cases, the correlation between seasonal precipitation and NAOI is negative but a statistically significant correlation is established only for winter season. This is explained by the activation of NAO during this period of the year. The most well-defined

correlation is established at the stations from the western half of the study area.

The EOF analysis was performed to detect the main patterns of variability for the SLP in the Atlantic-European sector. The results show that

SLP is one of the main factors influencing precipitation variability in the region. The main characteristics of spatial distribution of the winter SLP can be summarized as follows (Fig. 9a):



a) **b)**
Fig. 9 Relationship between sea level pressure (SLP) variability and winter precipitation: a) spatial configurations of the main leading EOFs and the explained variances and, b) relationship between the series of PC coefficients associated to the main leading EOFs (PC1, PC2 and PC3) of precipitation variability in the Danube river lower basin and the series of NAO index during winter

- EOF1 shows the principal pattern of SLP variability which actually corresponds to the NAO pattern. This mode explains 61.50% of the total variance of winter SLP.
- the EOF2 pattern shows a mono-polar like structure of SLP, centered over the North Atlantic

and the Great Britain. This mode of SLP variability accounts for 15.47% of the variance.

- the EOF3 pattern accounts for 9.14% of total SLP variance and characterizes the blocking situations over the Europe.

The analysis of the series of PC1 coefficients associated to EOF1 of winter precipitation and the

time series of NAO indices show that the winter precipitation variability is in opposite phase with the NAO. This means that during the positive phase of the NAO the winter precipitation anomalies are negative at the stations in Danube river lower basin and, vice versa (Fig. 9b, upper panel).

Spatial and temporal variability in extreme precipitation months in lower part of the Danube river basin during the period 1961-2007.

Analyzing the occurrence of the three driest and the three wettest months during a year allows us to determine dry and wet periods. According to this criterion, 1983-2003 represents the driest period out of the analyzed period 1961-2007. 2000 appeared as the driest year at 64% of investigated stations and it is the driest year during the period 1961-2007, followed by 1992 and 1990. According to the same criterion, extremely wet months were more often recorded during the period 1966-1980 and the wettest year was 1969 which ranked with three and even more wet months at 55% of the investigated stations, followed by 1972 and 1966. During the last years of the investigated period 1961-2007 3 and more extremely wet months have been observed at 40% of the stations during 2005 (Fig. 10). In most

of the years, three and more than three extremely precipitation months have been observed in less than 20% of the investigated stations.

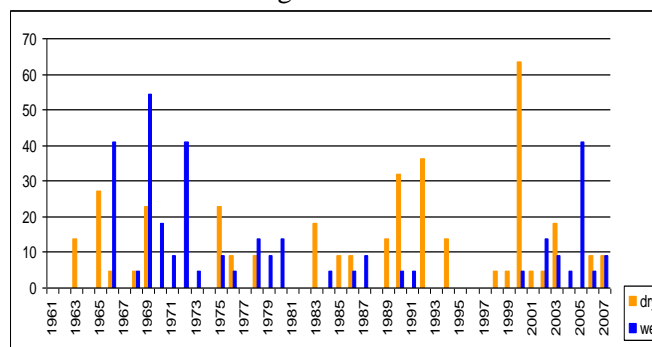


Fig. 10. Percentage of the stations with 3 or more than 3 extremely precipitation months

The general tendency of the climate of the lower Danube river basin during the period 1961-2007 shows lightly predominance of wet months over dry months (Fig. 11a). Nevertheless, for the period 1978-2007 in the most of the investigated stations, the dry months have been observed more often than wet months (Fig. 11b).

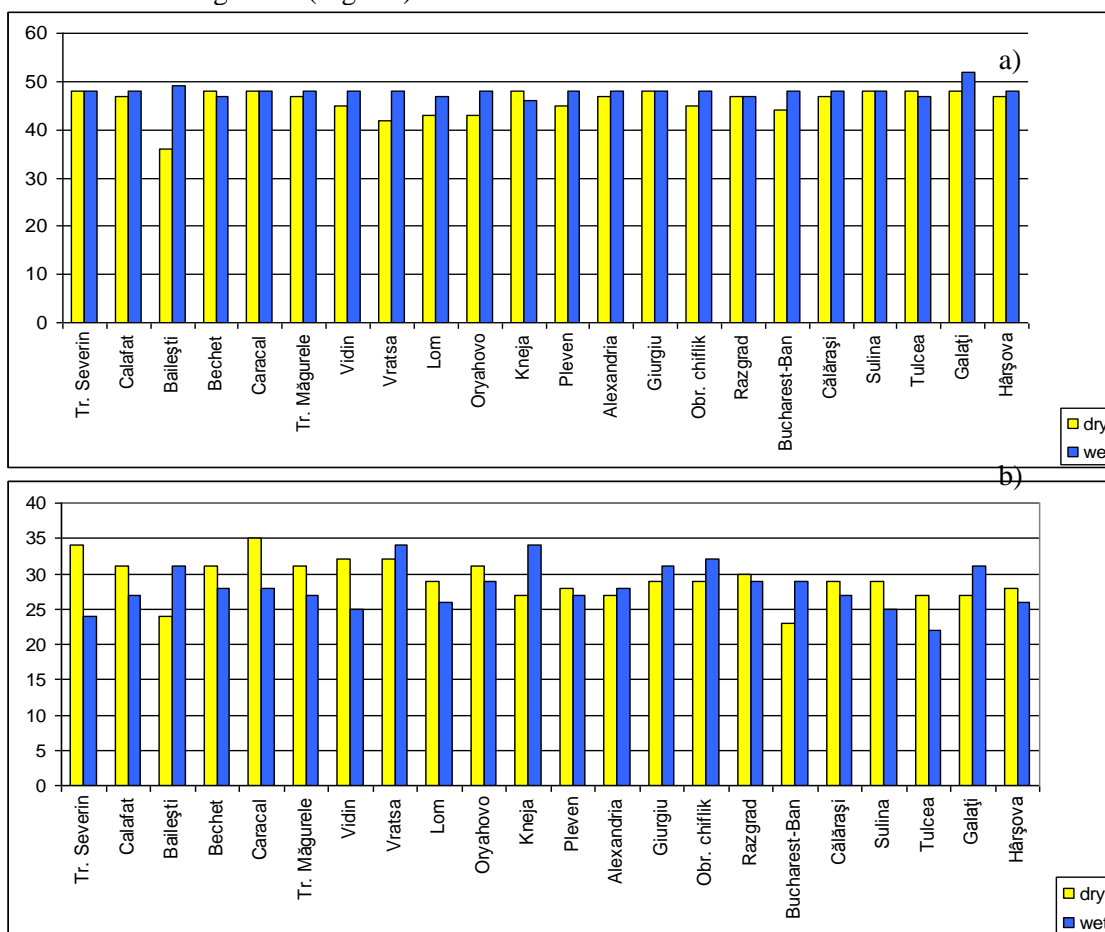


Fig. 11. Number of extreme precipitation months for the periods: a) 1961-2007; b) 1978-2007

The correlation coefficients between the average data for the number of extreme precipitation months and the NAOI show that the relation is better for recent periods (Table 1)

Table 1.

Correlation coefficients between the average number of extreme precipitation months and the NAOI

	1961-2007	1978-2007	1961-1990
Dry months	0.34*	0.53*	0.24
Wet months	-0.19	-0.30*	-0.15

* marked coefficients are statistically significant at $p < 0.05$

CONCLUSION

- According to the RAI in the most of years winters have been dry. The wet years have been observed mainly in the first part of the investigated period. In spring and summer the occurrence of wet years increases but the magnitude of dry events is bigger than that of wet events. The wet autumns are characteristic mainly for the last decades of the investigated period.
- CA clearly show positive phases of seasonal precipitation during the first part of investigated period as the negative are observed mainly since the beginning of 1980's.
- The extremely wet months are more frequent from the beginning of the investigated period to 1972. That wet period is characteristic mainly for winter and summer precipitation. The drought is well expressed during the 1980's.
- During the last years, the occurrence of extreme events has increased. Heavy rainfalls have been observed in many parts of Bulgaria and Romania. On the background of a general tendency of drought, the precipitation totals have been maximal during the summer of 2005. The driest years during the period 1961-2007 are 2000, 1992, 1990 and 1965.
- The main factor for precipitation variability in the Danube river lower basin is the variability of SLP. The relation between NAOI and precipitation is better determined for winter period.
- The results of the research are important for better understanding the relationship between precipitation and related physical processes. The knowledge on spatial and temporal occurrences of extremely dry and wet months will help for further developments of various strategies for mitigation and adaptation to climate change and for effectively tackling environmental problems.

- The results can be further used for impact studies on climate change impacts in agriculture, water resources, energy supply and tourism in both countries in the Danube river lower basin.

ACKNOWLEDGEMENTS

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