Romanian Journal of Meteorology, vol. 9, no.1-2, 2007 ISSN 1223-1118

SPATIAL AND TEMPORAL VARIABILITY OF EXTREME DAILY PRECIPITATION AMOUNTS IN ROMANIA

Liana CAZACIOC

National Meteorological Adminstration
Sos. Bucuresti-Ploiesti 97, 0136786 Bucharest, Romania,
e.mail: liana.cazacioc@meteoromania.ro

Abstract. The aim of this study is to analyze the maximum daily precipitation amounts in Romania for the period 1961-1996. The data were collected from 96 meteorological stations distributed over the entire Romanian territory. The annual maximum of daily precipitation amounts for successive years over the period 1961-1996 and the absolute maximum of the maximum daily precipitation amounts for the period 1961-1996 were determined for each station. A statistical analysis of the annual values of maximum daily precipitation amounts was performed in order to provide their spatial and temporal variability. Various statistical characteristics of maximum daily precipitation amounts during the whole period analyzed, like the annual mean, the standard deviation and the coefficient of linear trend were mapped over Romania. The annual maximum of the daily precipitation amounts series shows mostly a decreasing trend during the analyzed period, but statistically significant trends were found only at a few stations in Romania. The temporal variability and linear trends of maximum daily precipitation amounts were presented for selected Romanian stations. The influence of the atmospheric circulation on the extreme daily precipitation was analyzed by using the large-scale pattern classification expressed by Hess-Brezowsky weather types. The highest daily precipitation amounts occur usually during circulation types with cyclonic centre or cyclonic trough over south-eastern Europe. However, heavy rainfalls may occur over Romania during other situations including those with high pressure.

1. INTRODUCTION

Extreme weather events, among which the heavy precipitation during one day, represent a major risk for the population and economy, therefore it is very important to study their variations and trends.Analyses of trends in extreme precipitation events in Europe have generally been limited to national studies, making it difficult to provide a continent-wide overview of changes in precipitation intensities (IPCC Third Assessment Report 2001). Regional scale studies on extreme precipitation have been based on different periods of data availability, as follows. The analysis of long term series (1880-1996) of maximum daily precipitation in Nordic countries (Denmark, Faeroe Islands, Finland, Greenland, Iceland, Norway and Sweden) referred to the geographical distribution of absolute values or to some of their basic statistics, like the mean annual and standard deviation, long-term trends and weather situations favourable for high 1-day precipitation amounts (Forland *et al*., 1998).

A study of the annual maximum daily precipitation in Norway 1900-2004 shows an increasing tendency during the 20th century. The frequency of extreme precipitation values was highest in the 1920's-1930's and in the 1980's-1990's (Alfnes and Forland, 2006). Extreme daily precipitation in Sweden for the years 1961-2000 were analyzed with respect to spatial scale, regional variations and associated weather types (Hellström and Malmgren, 2004). Daily precipitation intensities over the UK have increased in winter during the recent decades (Osborn *et al*., 1999), at the same time as a marked decrease in the frequency of cold winter days in the UK (Jones *et al.*, 1999). The storminess over the northeast Atlantic has increased in recent decades, but storm intensities are no higher than they were early in the 20th century (WASA, 1998).

An analysis of extreme rainfalls over Poland, including the mean, the standard deviation and the coefficient of trend of maximum daily precipitation was performed by Bogucka (1998) on the background of daily precipitation totals from 56 synoptic stations for the period 1966-1995. The maximum daily precipitation series have a very slight growing tendency in the northern part of Poland and falling tendency in southern Poland. Ustrnul and Czekierda (2001) studied the influence of atmospheric circulation on precipitation totals and especially upon their extreme daily values in Poland. They used the precipitation data collected from over 50 meteorological stations for the period of 1951-1999, as well as the classification of circulation types known as "Grosswetterlagen" patterns (Gerstengarbe *et al.*, 1999).

The extreme precipitation totals for various durations (from 1, to 5-days) for the 1901-2000 period have been analysed in Slovakia in connection with global warming (Gaál and Lapin, 2002).

There were realized also studies relating to extreme precipitation on the entire Europe (Goodess *et al.*, 2006 or Haylock and Goodess, 2004).

Trends in highest 1-day rainfall in Canada were analyzed by Vincent and Mekis (2006) for the period 1950-2003. Around 95% of stations do not show any significant changes in the highest 1-day rain amount in this period. The analysis of precipitation data from fourteen South and West African countries indicates statistically significant increasing trend for the maximum annual 1-day rainfall over the period 1961-2000 (New *et al.*, 2006).

The study of extreme precipitation is also important and necessary for Romania. The present study covers a period of 36 years and includes an assessment of the spatial and temporal variability of greatest daily precipitation amounts in Romania, suggesting also some connections between the extreme precipitation and the large-scale atmospheric circulation associated to them. Thus, the existent information at European level is completed as regards this category of extreme events with data concerning our country.

2. DATA AND METHODS

The precipitation data from 96 meteorological stations evenly distributed on Romania's territory were used for the 1961-1996 period. The greatest daily precipitation amounts in consecutive years of this period (the absolute value for each year) and the absolute value in 36 years were established for each station. The analysis of the annual maximum of daily precipitation amounts series (96 series with 36 maximum daily amounts each) was achieved by using the following methodologies:

- mean and standard deviation for the period 1961-1996
- simple linear regression applied at each station for modelling the series values as a linear function of time.

Other data used in this study were the daily weather types over the1961-1996 period, determined according to the atmospheric circulation classification proposed by P. Hess and H. Brezowsky and revised by Gerstengarbe *et al.* (1999). They have subjectively-defined 29 atmospheric circulation patterns and one undefined circulation pattern over Europe and eastern North Atlantic Ocean, each of them consisting of the sea level pressure and the 500 hPa geopotential height distributions. The 29 circulation pattern categories (table 1) describe cyclonic, anticyclonic or neutral weather types over Central Europe.

Table 1. Names and labels of the Hess-Brezowsky weather types (HB)

Class	*No.*	*Abbreviation*	*Circulation pattern*
Zonal	1	WA	Westerly anticyclonic
	2	WZ	Westerly cyclonic
	3	WS	South westerly
	4	WW	Westerly
Mixed	5	SWA	South-westerly anticyclonic
	6	SWZ	South-westerly cyclonic
	7	NWA	North-westerly anticyclonic
	8	NWZ	North-westerly cyclonic
	9	TM	Central European Low
	10	HM	Central European High
	11	BM	Central European Ridge
Meridional	12	TRM	Central European Trough
	13	NA	Northerly anticyclonic
	14	NZ	Northerly cyclonic
	15	HB	British Isles High
	16	HNA	Norwegian Sea-Iceland high, anticyclonic
	17	HNZ	Norwegian Sea-Iceland high, cyclonic
	18	NEA	North-easterly anticyclonic
	19	NEZ	North-easterly cyclonic
	20	HFA	Fennoscandian high anticyclonic
	21	HFZ	Fennoscandian high cyclonic
	22	HNFA	Norwegian Sea-Fennoscandian high anticyclonic
	23	HNFZ	Norwegian Sea-Fennoscandian high cyclonic
	24	SEA	South-easterly anticyclonic
	25	SEZ	South-easterly cyclonic
	26	SA	Southerly anticyclonic
	27	SZ	Southerly cyclonic
	28	TB	British Isles Low
	29	TRW	Western European Trough
		U	Unclassified

The horizontal scale of the classification is much larger than the scale of cyclones and anticyclones at mid-latitudes, and since the process of classifying begins in the middle of the area, it does not work for peripheries (Romania is situated at the eastern border of the analyzed region, and therefore the circulation-type name is not suggestive for Romanian territory). A Hess-Brezowsky weather type generally persists at least 3 days, during which the weather characteristics remain constant. The transition to the following type takes place rapidly. The abbreviations in table 1 originate from the German names of the Hess-Brezowsky weather types.

The atmospheric circulation patterns over Europe according to Hess and Brezowsky have been used in Europe for several regional synoptic meteorology or climatology studies of temperature, wind speed, thunderstorms and drought.

3. RESULTS

3.1 Annual maximum of daily precipitation in Romania

3.1.1 Absolute maximum of daily precipitation

The absolute maxima of precipitation amounts recorded in one day at Romanian meteorological stations over the whole period 1961-1996, are shown in Table 2. It can be observed that they vary between 53.6 mm at Sebes (25.06.1975) in the central part of Romania and 204.2 mm at Cuntu (19.07.1970), in the mountainous region of western Romania.

The spatial distribution of the absolute maxima of daily precipitation shows a large variability over the whole Romanian territory. However, precipitation was heavier mostly in eastern and southern regions, in comparison to the rest. Thus, the values of absolute maximum of daily precipitation amounts generally range between 50 and 120 mm in north-western, western and central Romania, while in southern and eastern areas it usually exceeds 60 mm, up to 137 mm.

The great inhomogeneous distribution over Romania of the absolute maximum of daily precipitation is connected with the main atmospheric processes producing precipitation in south-eastern Europe. Usually, extremely large daily precipitation may be generated either by frontal-systems covering large areas, by local convective cells or induced by orography. Still, heavy precipitation does not occur on the same day at neighbouring stations, with few exceptions. Thus, the analysis of the above-mentioned period highlights the date of 2.07.75 when the maximum daily amount of precipitation was recorded at eight stations, and 25.08.1977, when the maximum daily amount of precipitation was recorded at five stations (table 2). In both cases, the referring stations were located in central and southern regions of Romania.

The atmospheric circulation patterns in 2.07.1975 (figure 1) and 25.08.1977 (figure 2) classified as North-East Cyclonic (NEZ) and, West-European Trough (TRW) circulation types respectively, in Hess-Brezowsky classification (table 1), generated heavy precipitation at several stations, as mentioned above. The two synoptic situations were characterized by an upper-level trough associated with a surface one over Western Europe and by a ridge lying over Central Europe. In the meantime, a deep low associated to a sea level pressure minimum over south-eastern Europe caused a return of the very wet easterly flow from the Black Sea towards the southern and central regions of Romania. Such synoptic situations combined with the Carpathian mountainous barrier are most frequently connected with heavy precipitation over Romania.

Table 2. Absolute maximum of daily precipitation at Romanian meteorological stations (1961-1996)

region	station	altitude (m)	total (mm)	date	circulation pattern	region	station	altitude (m)	total (mm)	date	circulation pattern
North-West	Baia Mare	216	121.4	13.05.70	TM		Bucuresti Baneasa	92	85.1	25.08.77	TRW
	Ocna Sugatag	503	60.5	29.06.65	NWA		Bucuresti Filaret	82	78.4	4.11.62	SA
	Satu Mare	123	69.4	9.06.71	HNZ		Buzau	96	90.5	22.05.76	HFZ
	Iezeru	1785	83.5	20.10.91	TRM		Calarasi	19	84	25.05.67	WS
West	Oradea	137	62.4	30.06.86	HNA		Cimpina	461	112.1	2.07.75	NEZ
	Arad	117	59.4	2.06.88	WZ		Dedulesti	548	87.6	4.10.72	HFA
	Timisoara	86	76.4	29.05.82	HM		Faurei	54	72.6	2.07.71	NEA
	Lugoj	123	78.5	22.08.82	WZ		Fetesti	58	118.4	16.07.94	BM
	Zalau	295	66.6	4.07.67	WA		Fundulea	67	88.8	27.06.69	HNFZ
	Caransebes	241	91.7	8.06.90	WZ		Giurgiu	24	78.7	17.08.79	HFZ
	Banloc	83	98.6	22.06.79	BM		Grivita	51	104.8	9.06.91	WZ
	Oravita	308	78.8	21.08.66	HNZ		Pitesti	306	84.7	5.07.70	NWZ
	Semenic	1432	122.6	12.08.74	WZ		Ploiesti	177	102.4	22.06.79	BM
	Cuntu	1500	204.2	19.07.70	TRM		Rimnicu Sarat	152	95.2	28.06.82	WS
	Virfu Tarcu	2180	126	2.01.66	WZ		Rosiori De Vede	102	82.6	11.07.94	HM
	Vladeasa	1838	88.2	21.06.75	NEZ		Sinaia 1500	1500	106	2.07.75	NEZ
	Sinnicolau Mare	84	62.1	30.06.74	WS		Tirgoviste	296	130.3	2.07.75	NEZ
Centre	Baisoara	1384	65.2	22.06.79	BM		Turnu Magurele	31	132.4	5.07.70	NWZ
	Baraolt	509	96	2.07.75	NEZ		Urziceni	55	95	27.05.71	WW
	Bistrita	366	72.3	13.05.70	TM		Videle	108	85.6	9.06.69	NEA
	Blaj	334	55	15.09.81	WZ		Virfu Omu	2507	102.4	22.06.79	BM
	Boita	517	93.7	25.08.77	TRW		Predeal	1090	122.1	19.06.81	NZ
	Brasov	534	74.9	25.08.77	TRW	South-East	Adamclisi	158	70.8	12.08.79	HFA
	Cluj	410	81.6	29.07.69	HFZ		Constanta	13	77.8	22.08.87	SWA
	Deva	230	65.3	10.05.73	WZ		Corugea	219	86.8	12.08.66	SWA
	Fagaras	428	75.8	2.07.75	NEZ		Gorgova	3	108.4	4.06.86	TM
	Fundata	1383	97.6	27.07.81	NWZ		Hirsova	38	96.7	2.09.71	WA
	Intorsura Buzaului	701	81.4	6.06.94	WZ		Jurilovca	38	79.9	5.08.72	SWA
	Miercurea Ciuc	661	76	2.07.75	NEZ		Mangalia	6	127.7	18.09.95	HNFZ
	Paltinis	1454	94.6	25.08.77	TRW		Medgidia	64	84.6	31.08.74	WW
	Petrosani	607	86.4	10.05.73	WZ		Sfintu Gheorghe	2	97.6	22.08.87	SWA
	Piclisa	260	83.7	30.07.71	HNFZ		Tulcea	41	62.1	22.09.72	BM
	Sebes	253	53.6	25.06.75	NWA	North-East	Avrameni	240	77.9	18.06.85	WS
	Sibiu	443	69.9	10.05.73	WZ		Bacau	184	94.7	6.09.89	BM
	Tirgu Mures	308	67.8	2.07.75	NEZ		Birlad	172	86.4	20.08.68	HM
	Toplita	687	65	5.07.67	WA		Botosani	161	80.4	18.08.69	NEZ
	Tirgu Secuiesc	569	64.9	13.08.79	HFA		Cimpulung Moldovenesc	659	79	21.07.86	WA
	Lacauti	1776	115.4	12.07.69	NWZ		Galati	71	126.2	25.08.77	TRW
South-West	Calafat	66	84.8	1.10.81	TRW		Iasi	102	136.7	25.08.70	NA
	Caracal	112	118.2	8.07.70	WA		Tirgu Neamt	387	111.3	6.09.89	BM
	Craiova	105	84.8	27.07.72	HNZ		Poiana Stampei	387	59.4	31.05.84	TM
	Drobeta Turnu Severin	70	171.7	30.07.69	HFZ		Radauti	389	77.3	28.06.78	WZ
	Polovragi	531	110.4	12.08.79	HFA		Rarau	1536	110.6	29.06.78	WZ
	Tirgu Jiu	203	93.6	6.09.68	HFZ		Roman	216	95.6	29.07.91	HFA
	Voineasa	583	86.8	19.08.68	HM		Suceava	350	85.8	18.07.67	HFA
	Titesti	548	107.8	10.05.73	WZ		Tecuci	57	76.1	11.10.72	SEA
South	Alexandria	75	110.5	27.07.64	BM		Vaslui	116	91.1	22.07.80	HM
	Curtea de Arges	448	97.8	2.07.75	NEZ		Ceahlau-Sat	552	79.2	12.06.74	U

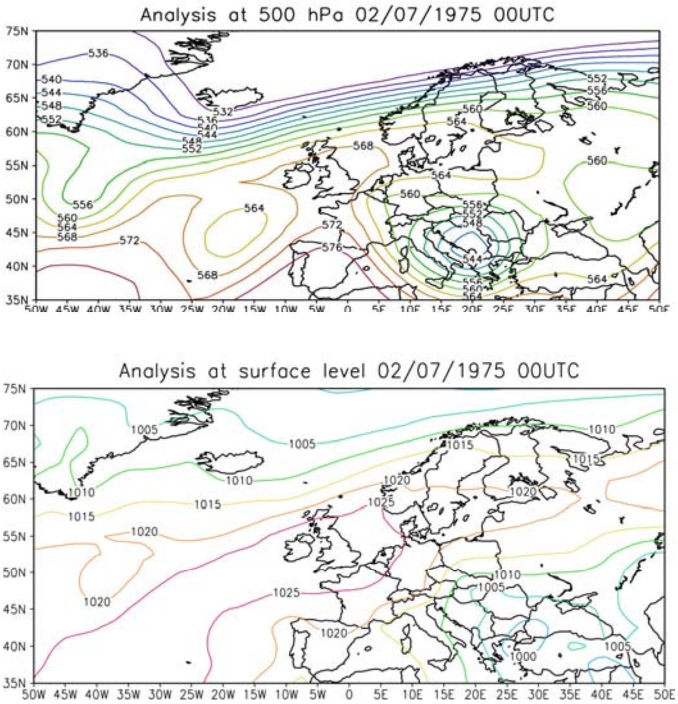


Figure 1. 2 July 1975, 00:00 UTC, analysis at 500 hPa, geopotential (in damgp) and surface analysis, sea level pressure (in mb) from the ECMWF reanalysis

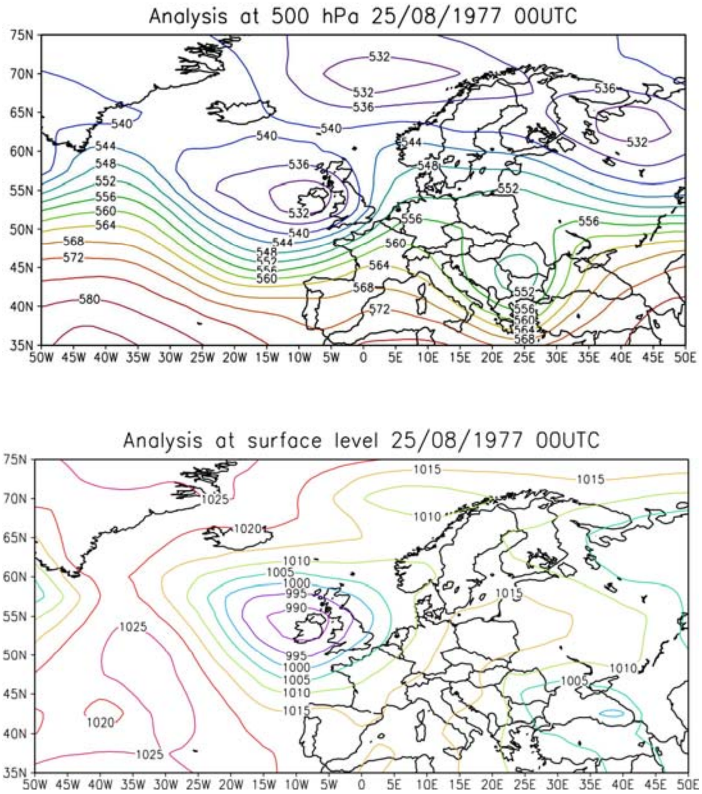


Figure 2. 25 August, 1977 00:00 UTC, analysis at 500 hPa, geopotential (in damgp) and surface analysis, sea level pressure (in mb) from the ECMWF reanalysis

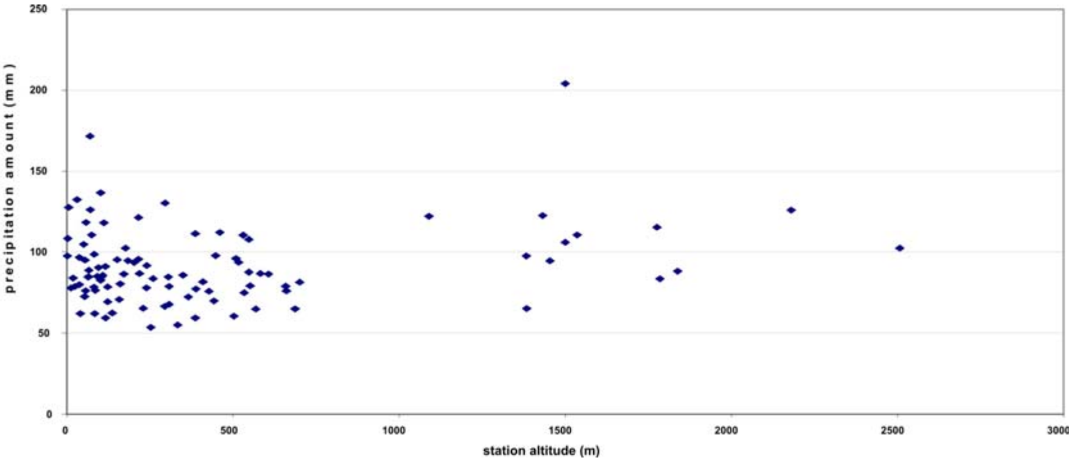


Figure 3. The dependency of the absolute maximum of daily precipitation amounts on station altitude

Most of the absolute maxima of daily precipitation have occurred at Romanian meteorological stations in the late 60's and 70's during the summer months, when heavy rainfalls were associated with strong convection of warm and humid air masses coming from the southern sector. The absolute maxima of daily precipitation are also recorded during autumn and early spring at a few stations distributed on the whole Romanian territory.

The greatest daily precipitation amounts are not influenced mainly by altitude, as shown in figure 3. Great amounts of precipitation occurred at stations located in the lowlands from southern and eastern Romania, with altitudes of up to 500 m above sea level. There is no well-defined relationship between the absolute maximum of daily precipitation amounts and altitude, because the altitude of a station is just one of the determining factor in the occurrence of heavy precipitation.

3.1.2 Mean of the annual maximum of daily precipitation

The mean of the annual maximum of daily precipitation is calculated as an average over 36 years (1961-1996) of the highest amounts of precipitation recorded every year. The highest means of annual maximum of daily precipitation amounts are located in the south-western mountain region of Romania (figure 4), reaching 68 mm at Semenic. The lowest mean values occur in central Romania (31 mm at Deva).

The mean of the annual maximum of daily precipitation shows large gradi-ents in the mountainous regions of Romania because of strong orographic precipitation enhancement induced by the shape and massiveness of the Carpathian range. The mean of the annual maximum of daily precipitation increases from the lowlands to the mountainous areas, showing the largest gradients in the southern and north-eastern mountain ranges, as observed in figure 4.

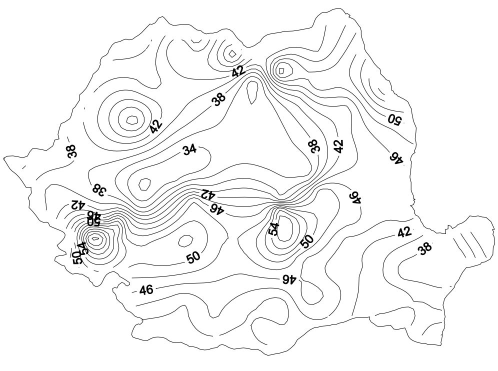


Figure 4. Mean of the annual maximum of daily precipitation amounts (mm) over Romania in the 1961-1996 period

3.1.3 Spatial and temporal variability of the annual maximum of daily precipitation amounts

The maximum amounts of daily precipitation in consecutive years show a large spatial variability over Romania, as observed on the distribution of standard deviation (figure 5): the highest values (up to 37 mm) are recorded in the mountainous region from south-western Romania, but there is a second area in north-eastern Romania, where the standard deviation values are quite large, up to 29 mm. It means that in these regions there were noticed very high differences among the 1-day maximum amounts of precipitation during consecutive years. Small year-to-year variations of the maximum daily precipitation amounts are reflected in small standard deviations between 9 and 15 mm at almost all stations in the central part of Romania, where the means of annual maximum of daily precipitation amounts are the lowest, as shown before. The standard deviation presents a large gradient on the coastal region of Black Sea, where it ranges between 15 and 23 mm. In this region, the synoptic conditions favourable to heavy precipitation are highly influenced by the complex air-sea interaction and therefore large differences between neighbouring stations occur.

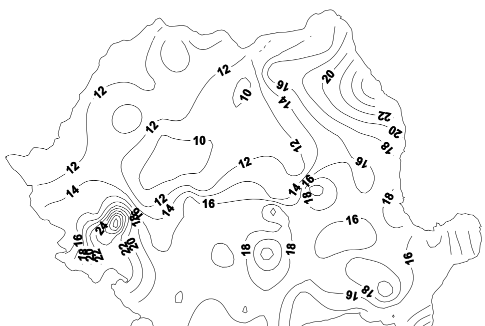


Figure 5. Standard deviation of the annual maximum of daily precipitation amounts (mm) over Romania (1961-1996)

The temporal variability of precipitation amounts can be developed based on the analysis of linear regression of their values during the studied period. By applying the linear regression to the maximum daily precipitation amounts series between 1961 and 1996, the trend coefficient was calculated at each station (Wilks, 1995), represented by the slope in the regression equation. Results show mostly decreasing trends over Romania (figure 6), with the exception of some areas in western and north-eastern Romania, where slight growing linear trends are observed, between 0.1 and 0.4. The most important decreasing trends, up to -1.8, are located in the south-western mountain region. Decreasing trends up to -0.7 were found in some southern plain and eastern hilly areas of Romania.

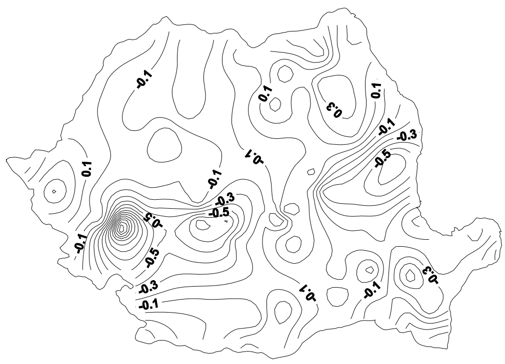
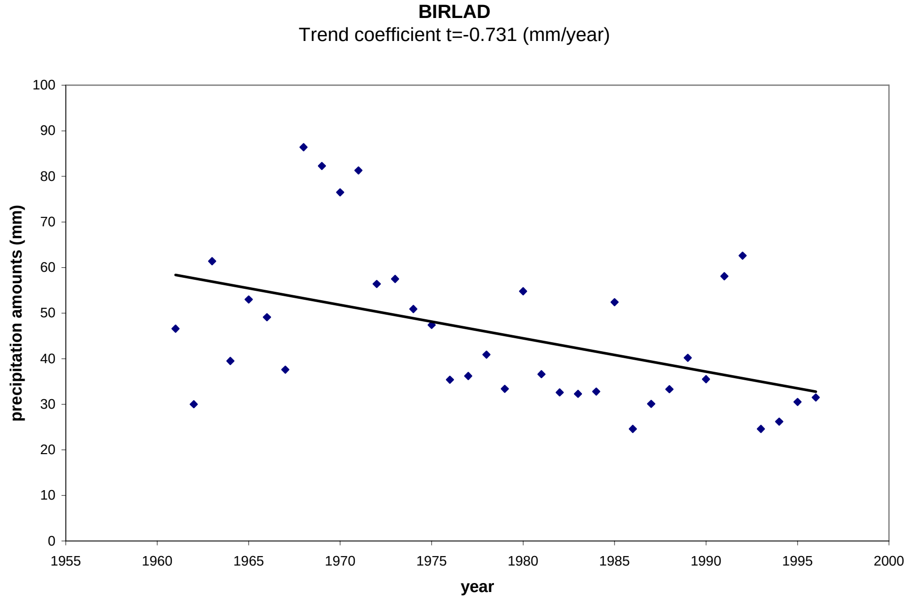


Figure 6. Linear trend coefficient (mm/year) of the annual maximum of daily precipitation amounts over Romania

The statistical significant levels of the linear trend coefficients were determined at each station by using the t-test (Wilks, 1995). Due to the shortness of the data series length, - only 36 values for each station, many of them have trends with low levels of statistical significance. Still, there are some areas where the statistical significance of the linear trend coefficients is very good. Statistically significant decreasing trends were found in south-western mountain region (Virfu Tarcu, Cuntu, Voineasa, Titesti) and locally in eastern (Birlad, Tecuci) and south-eastern (Hirsova) Romania, and significant increasing trends in western Romania (Timisoara) and the north-eastern region (Tirgu Neamt, Avrameni) as shown in figure 7.

4. CONNECTION BETWEEN THE MAXIMUM DAILY PRECIPITATION AND THE ATMOSPHERIC CIRCULATION

The large-scale atmospheric circulation is an important climatic factor influencing the occurrence of precipitation with



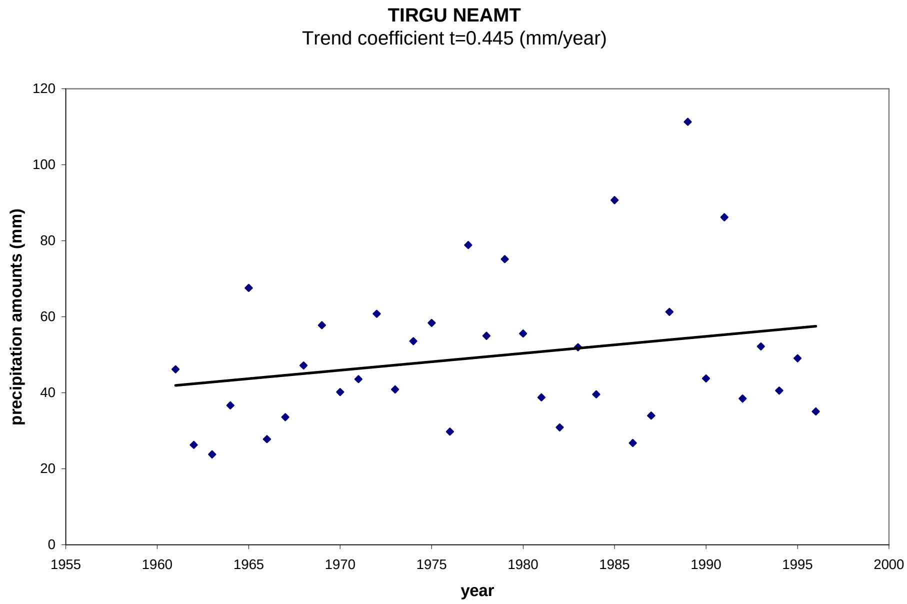


Figure 7. Temporal variability of maximum daily precipitation amounts in selected Romanian stations (1961-1996)

particular respect to extreme values. Many studies on the relation between circulation conditions and precipitation totals for particular regions of Europe are based on the ‘Grosswetterlagen’ (GWL) patterns (Gerstengarbe *et al.*,1999), translated as “catalogue of large-scale weather patterns in Europe”, well known in literature as Hess-Brezowsky weather types. This classification based on both the surface pressure patterns and the 500 hPa height patterns has been extensively used in researches referring to the influence of atmospheric circulation on the precipitation regime because the middle troposphere plays a significant role in the formation of precipitation. The GWL classification is based on a subjective analysis of synoptic scale conditions over Europe, in which each day from 1881 to the present is classified into one of 29 types or as ‘unclassifiable’ (table 1). According to Werner *et al.* (2000) the GWL classification is free of artificial bias or trends therefore it has been used extensively.

The Hess-Brezowsky classification was chosen so as to point out the weather types which cause the highest 1-day precipitation totals recorded in the whole analyzed period (1961-1996) at Romanian meteorological stations. Table 2 presents the circulation patterns associated with the absolute maximum 1-day precipitation at the particular stations used in this study. They occur during different synoptic situations but most frequently during cyclonic situations (WZ, NWZ, NEZ, HFZ, HNFZ, TRW) with air advection from the sector W-NW-N-NE over south-eastern Europe. Among these types, the WZ situation was responsible for most of cases (14), followed by the NEZ situation (10 cases). The cyclonic trough over Western Europe (TRW) situation produced maximum precipitation in 6 cases. There are also some anticyclonic synoptic situations, like BM (9 cases), HM (5 cases), HFA (6 cases), SWA (4 cases) causing the absolute maximum 1-day precipitation mostly in southern and eastern Romania, when the air flows from the NW-N. Northern anticyclonic advection combined with the orographic barrier of the Carpathian mountain range forces strong condensation of water vapour, usually in tropical pre-existing air masses. Thus, heavy rainfalls and thunderstorms can occur in the southern and eastern regions of Romania.

It should be noted that the absolute maximum 1-day precipitation amounts have occurred in different synoptic situations, as seen in table 2. Thus, north-western, western, south-western and central parts of Romania have been mostly influenced by cyclonic patterns, while the anticyclonic patterns generated extreme precipitation in the south-eastern and north-eastern Romanian territories. In southern Romania, the highest 1-day precipitation amount was produced in most cases by cyclonic circulations, but it can be also caused by some anticyclonic circulation types, like the BM and HM patterns. In these situations, continuous precipitation is associated with the existence of a stationary front over the southern region of Romania. This front is generated by a higher thermal contrast between the unusually cool air brought by the northern circulation and the pre-existing warmer air mass, having great moisture content. Stationary fronts are more active in summer time, therefore exceptional precipitation amounts have been recorded in June and July in both the plain and mountain areas of southern Romania.

The WZ situation is connected to the absolute maximum precipitation in many areas of the western and central Romanian regions. According to the surface chart of this pattern, westerly cyclonic airflow prevails over northern

Europe, while the south-eastern part is influenced by a low pressure zone, with air advection from the northern sector. The WZ patterns determine high totals of precipitation most frequently in western, north-western and central Romania because of the Carpathian mountain range, which forms an orographic barrier for the westerly air masses.

Although the absolute maximum 1-day precipitation amounts are exceptional events, one can distinguish some prevailing circulation patterns causing them in the western and eastern regions of Romania

5. CONCLUSIONS

The maximum daily amount of precipitation is one of the extreme climate index with potentially strong and dangerous hydrological consequences in the Romanian regions. The absolute maximum of daily precipitation amounts shows a large variability over the entire Romanian territory. The great inhomogeneous distribution over Romania of the absolute maximum of daily precipitation amounts is connected with the main atmospheric processes creating precipitation i.e. the frontal activity, the convection and the effect of orography. However, heavier precipitations are generally found in the eastern and southern regions, rather than in the other regions. Most of the absolute maxima of daily precipitation occurred in the late 60’s and the 70’s, during the summer months when heavy rainfalls were associated with the strong convection specific for the warm season. Absolute maxima of daily precipitation amounts were also recorded during autumn and early spring at a few stations distributed on the whole Romanian territory. There is no direct relation between the greatest amounts of daily precipitation and the altitude of the station.

The analysis of the climatic variability of the annual maximum of daily precipitation amounts recorded at Romanian meteorological stations over the whole period 1961-1996 pointed out regional differentiations of their basic characteristics like the annual mean, the standard deviation and the linear trend.

The greatest means of annual maximum of daily precipitation amounts are found in the south-western mountain region of Romania, and the lowest mean values occur in central Romania. There are large gradients of the mean of annual maximum of daily precipitation distribution, especially in the southern and north-eastern Carpathian mountain range.

The inter-annual variability of the maximum daily precipitation amounts, expressed by standard deviation, is more important in the south-western and north-eastern regions than in the rest of Romania. Small standard deviations have been observed at almost all stations of the central part of Romania. Large local gradients of standard deviation distribution are observed on the Black Sea coastline. In this area, the synoptic conditions causing heavy precipitation are highly influenced by the complex air-sea interaction and therefore large differences occur between neighbouring stations.

The analysis of the temporal variability of the maximum daily precipitation amounts between 1961 and 1996 reveals mainly decreasing trends over Romania except for some limited areas in western and north-eastern Romania, where slight growing linear trends up to 0.4 are observed. The most important decreasing trends up to -1.8 are located in the south-western mountain region. Decreasing trends up to -0.7 were found also at some stations in southern plain and eastern hill of Romania. In spite of the shortness of data series length, there are statistical significant trends at a few stations in above-mentioned areas.

The results of this study show a good relation between the precipitation regime and atmospheric circulation. In Romania the absolute maximum of daily precipitation amounts occur during different synoptic situations, but the most often during cyclonic circulation types with air advection from the W-NW-N-NE sectors over south-eastern Europe. However, especially in southern and eastern Romanian regions, the greatest daily precipitation amounts can be observed also during anticyclonic situations e.g. BM and HM patterns with incoming air flow from the NW-N. Circulation is only one of the factors causing high daily precipitation. Other factors with considerable influence on extreme precipitation, e.g. orographic conditions, convection and humidity of the air masses lead to very varied precipitation conditions at neighbouring stations. Still, heavy precipitation occurred on the same day at a few stations located in central and southern regions of Romania in specific synoptic situations (NEZ, TRW) characterized by meridional circulation over Central and Eastern Europe. Therefore, more attention should be paid to the forecasting of precipitation during these circulation patterns.

Acknowledgements: The author would like to thank the German Weather Service (DWD) for providing the revised dataset of Hess-Brezowsky Grosswetterlagen. Thanks also to two anonymous reviewers for their useful comments to the first version of the paper.

REFERENCES

Alfnes, E., and E.J. Forland, 2006: Trends in extreme precipitation and return values in Norway 1900-2004. *Norwegian Meteorological Institute - Report 2/2006*, 40 pp.

Bogucka Magdalena, 1998: Extreme rainfalls in Poland in the last 30 years. Proceedings of the 2nd European Conference on Applied Climatology,"*Österreichsche Beiträge zu Meteorologie und Geodynamik (ZAMG)*, Viena, Austria, Publ.384.

Forland, E.J., H. Alexandersson, A. Drebs, I. Hanssen-Bauer, H. Vedin and O.E. Tveito, 1998: Trends in maximum 1-day precipitation in the Nordic region. *DNMI - Report 14/98 KLIMA*, 55 pp.

Gaál, L. and M. Lapin, 2002: Extreme several day precipitation totals at the Hurbanovo observatory (Slovakia) during the 20th century. *Contributions to Geophysics and Geodesy*, vol.**32/3**.

Gerstengarbe, F.-W., P.C. Werner and U. Rüge, 1999: Katalog der Grosswetterlagen Europas (1881-1998) nach Paul Hess und Helmuth Brezowsky. *Deutscher Wetterdienst, Offenbach a. Main,* 138 pp.

Goodess, C.M., Anagnostopoulou, C., Bárdossy, A., Frei, C., Harpham, C., Haylock, M.R., Hundecha, Y., Maheras, P., Ribalaygua, J., Schmidli, J., Schmith, T., Tolika, K., 2006: An intercomparison of statistical downscaling methods for Europe and European regions – assessing their performance with respect to extreme temperature and precipitation events, *Climatic Change*.

Haylock, M.R. and C. M. Goodess, 2004: Interannual variability of European extreme winter rainfall and links with mean large-scale circulation. *International Journal of Climatology*, **24**, no.6, 759 – 776.

Hellström, C. and B.A. Malmgren, 2004: Spatial analysis of extreme precipitation in Sweden 1961-2000. AMBIO: *A Journal of the Human Environment*, **33**, no.4, 187-192.

IPCC [Intergovernmental Panel on Climate Change] Climate Change 2001: Impacts, Adaptation and Vulnerability. *The Third Assessment Report of the Intergovernmental Panel on Climate Change*, http://www.grida.no/climate/ipcc_tar/wg2/index.htm

Jones, P.D., E.B. Horton, C.K. Folland, M. Hulme, D.E. Parker, and T.A. Basnett, 1999: The use of indices to identify changes in climatic extremes. *Climatic Change*, **42**, 131-149.

New. M., B. Hewitson, D.B. Stephenson, A. Tsiga, A. Kruger, A. Manhique, B. Gomez, C.A.S. Coelho, D.N. Masisi, E. Kululanga, E. Mbambalala, F. Adesina, H. Saleh, J. Kanyanga, J. Adosi, L. Bulane, L. Fortunata, M.L. Mdoka and R. Lajoie, 2006: Evidence of trends in daily climate extremes over Southern and West Africa. *Journal of Geophysical Research – Atmospheres*, **111**.

Osborn, T.J., M. Hulme, P.D. Jones, and T. Basnett, 1999: Observed trends in the daily intensity of United Kingdom precipitation. *International Journal of Climatology*, **20**, 347-364.

Ustrnul, Z. and D.Czekierda, 2001: Circulation background of the atmospheric precipitation in Cantral Europe (based on the Polish example). *Meteorologische Zeitschrift*, **10**, no.2, 103-111.

Werner, P.C., F.W. Gerstengarbe, K. Fraedrich and H. Oesterle, 2000: Recent climate change in the North Atlantic/European sector. *International Journal of Climatology*, **20**, 463-471.

Vincent, L. and É. Mekis, 2006. Changes in indices of daily temperature and precipitation extremes for Canada over the 20th century. *Atmosphere-Ocean*, **44(2)**, 177-193.

WASA, 1998: Changing waves and storms in the northeast Atlantic. *Bulletin of the American Meteorological Society*, **79,** 741–760.

Wilks, D.S., 1995: Statistical Methods in the Atmospheric Sciences. Renata Dmowskaand James R.Holton Eds. *Academic Press.* 160-188.