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Faculty of Geography

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PhD. Thesis

~ abstract ~

Genetic characteristics and spatiotemporal manifestations of heavy rains and annual maximum intensity rainfalls in northwestern Romania

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PhD thesys summary

PhD abstract summary

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INTRODUCTION

The main objective of the research topic is the knowledge of spatial and temporal distribution of high intensity rainfalls, to determine the aero synoptic and mesoscale conditions and to contribute to the improvement of high intensity rainfall forecasting, by determining its dynamic parameters (direction and speed). Spatial and temporal distribution of precipitations sets the context and limits of rainfalls occurrence and provides an overview of the defining elements of the analyzed phenomenon (intensity, duration, quantity etc.); the synoptic scale and mesoscale conditions are determining elements of genesis and of occurrence in a certain area of the atmospheric precipitations, which influence the rainfall parameters like the quantity of fallen water, the rain intensity and duration etc.; the motion parameters of convective systems represent supplementary elements useful to anticipate the time and place of the rain events, by determining the connection between mesoscale and synoptic scale.

The importance of the topic is given by the effects of the annual maximum intensity rainfalls and heavy rains have in the actual context of climatic changes. The mentioned rain events generate, most frequently, flash floods, especially in small water basins areas and in urban areas, with immediate effects on the environment. The chosen topic is meant to be contributing to the determination of the rainfall triggering factors and of the elements that influence the spatial evolution of the cloud formations responsible for these categories of rainfalls.

The numerous approaches in the meteorological literature emphasize the relevance of the issue at the national or international level. The most notable recent studies at the national level are ones of Popovici, Dragotă and Niculescu (1999) that follow the statistical analysis of torrential rain parameters; Bogdan and Niculescu (1999), who consider that the most powerful downpours take place in the most arid regions of Romania; Dragotă (2006), who observes the inhomogeneous territorial distribution of rains; Tudose and Moldovan (2009 and 2010), Şerban (2010). At international level, it can be distinguished the studies of Brooks and Stensrud (2000), that are interested in monthly frequency and spatial distribution of heavy rains; Sun and coauthors (2001), who approaches the thermal convection clouds frequency issue; Nesbitt and Zisper (2003), studying the Mesoscale Convective Systems and the precipitations they generate; Dairaku and coauthors (2004), interested in some correlations between the torrential rains parameters and altitude; Endo and coauthors (2005) who analyze the precipitation quantities tendency.

The aim of this analysis is to find the synoptic context in which the torrential rains and the annual maximum intensity rainfalls occur, to determine a series of particularities, as well as to increase forecast accuracy of these precipitations. In the scientific literature, the extreme rainfall events issue has been approached from different points of view, quantitative and qualitative, spatial and temporal, as well as in connection with different weather events. This paper brings a series of new elements regarding the spatial and temporal distribution of these extreme events in an area which has been less analyzed from this perspective, by using an extended database (35 years) and a series of correlations with meteorological radar-measured products (radar reflectivity, vertical integrated liquid, direction and motion speed of clouds formations etc.). It also establishes a quick way to determine the movement of mesoscale structures with high potential to generate heavy rains.

The database

For the present analysis, cartographical and numerical data has been used. The cartographical database contains the synoptic maps of the European continent, of the North Atlantic Ocean and of the western side of Asia, for the 1975-2012 period, as well as maps of the sea pressure level, of the geopotential and temperature level-standard (925. 850, 700, 500, 400 and 300 hPa) and maps of humidity field for the 700 hPa level. These were used to determine the characteristics of air masses that affect the study area (thermal and humidity characteristics), of associated fronts (warm, cold, occluded) and of synoptic-scale pressure structures (cyclones, anticyclones, ridges, troughs, cut-off lows). At the storm scale (mesoscale), the most recent data starting with 2004, regarding storms has been used. These include thematic images representing the radar reflectivity, one and three hours precipitations estimation, speed motion of the convective storms, vertical integrated liquid, cloud masses height etc. These were used in order to determine the direction and motion speed of the convective storms, as well as to estimate the solid and liquid water content of the storm clouds, the height of convective system and to determine the types of the convective systems (single cell, multicells, supercells). All these thematic materials have helped to outline the atmospheric fields' structure at a certain time, structures that facilitate, generate and intensify the convective systems.

The numerical database contains: *rain data* (rainfall duration, water quantity, medium and maximum intensity, maximum intensity duration, the starting hour of the rainfall and of the time maximum intensity); *data regarding the water quantities*, based on meteorological, rain and hydrometric stations warnings; *data regarding meteorological parameters from the atmospheric sounding* (air and dew point temperature, wind speed and direction).

There have been analyzed 14 meteorological stations located on different landforms: in the plains, valleys or depressions area the Satu Mare, Supuru de Jos, Baia Mare, Sighetu Marmaţiei, Ocna Şugatag, Zalău, Cluj-Napoca, Huedin, Turda, Dej and Bistriţa stations has been used and from mountain area, Băişoara, Vlădeasa 1800 and Iezer has been under study, to which rainfall and hydrometric stations were added.

Research methods

In the case of duration, frequency and rain intensity parameters as well as in order to determine the atmospheric stability indices and to establish the convective cells direction and motion speed, the method of statistical analysis has been used and for the annual maximum intensity rainfalls, the method of frequency analysis. There have been computed frequencies and probabilities (in the third and fourth Chapters), and synoptic configurations, specific to each instability type, based on *www.esrl.noaa.gov* site facilities (Chapter 4) have been built.

The convective cells direction and speed motion determination, from Chapter 5, required a more laborious work, consisting in the transformation of inverse polar coordinates (azimuth and distance) into cartesian coordinates, considering the site of the two radars (Oradea and Bobohalma) as origin, afterwards, the results being compared with the considered main air flow. For the statistical analysis, the facilities of Excel, XlStat, Curve Expert and Hyfran programs has been used.

1. THE CURRENT INTERNATIONAL AND NATIONAL STATUS OF RESEARCH OF THE PRESENT THEME

On international level, the diurnal variation of rains has been studied by Hann (1901); the diurnal variation frequency and the hourly intensity of rains has been a base of study for McDonald (1929); the diurnal frequency of precipitation occurrence represented high interest for Howard (1942) and Wallace (1975). The duration, frequency and intensity of rainfalls has been approached by Fassig (1923); the rains frequency and intensity recorded with the pluviograph was studied by Counts (1933); the diurnal variation of precipitations quantity and the convective or stratiform genesis of rainfalls represented a research subject for Nesbitt and Zipser (2003) and for Dairaku and coauthors (2004); and also Brooks and Stensrud (2000) studied the torrential rainfalls frequency. Humphreys (1919) classified the rain characteristics according to the recorded water quantity, establishing the raindrops falling speed and the height of clouds base; Zawadzki and Ro (1978) analyzed the correlation between the maximum rate of precipitation and mesoscale parameters; Sun and coauthors (2001) observed the increasing frequency of nebulosity generated by the convective clouds during the summer season etc.

Other remarkable studies that analyze the rainfalls parameters, as follows: Drufuca and Zawadzki (1975) took into consideration a series of statistical parameters, such as duration, medium and maximum intensity, the standard deviation, variance, autocorrelation function and the quantity of rainfalls during the warm season; Sharrat (2001) studied the precipitation frequency north of Corn Belt (USA); Dai (2001), follows the diurnal variation of the precipitations and storms frequency; Tank and Kőnnen (2003) approached the study of the tendency of some indexes of extreme precipitations tendency in Europe; Endo and coauthors (2005) studied the quantity of precipitations tendency and the number of rainy days and torrential rainfalls during the summer season in China, for the period of 1961-2000.

In Romania, the studies refer to significant quantities of precipitations recorded during the last century, or on single events, occurred due to severe weather conditions, but also to the high quantity precipitations regime in some specific periods (seasons or years), as well as to the determination of rainfalls parameters methodologies. To these studies can be added a series of synthesis which regard the spatial and temporal distribution of important quantities of precipitations. Further, there are mentioned some approaches concerning the rainfall parameters analysis (intensity, duration, quantity), including heavy rains: Predescu (1973), Crăciun (1956), Platagea (1959), Cristodor and Darie (1963), Stoenescu and coauthors (1965), Buzea and Ghiţă (1968), Ţîştea and Miha (1978), Popovici and coauthors (1998), Bogdan and Niculescu (1999), Dragotă (2006), Tudose and Moldovan (2009 and 2010), Şerban (2010). Some other important studies at national level usually make a theme of the Annual Session of Scientific Communications of National Administration of Meteorology, that include the „Weather Forecast" section, where the case studies about severe weather events have a large share.

Some authors propose the use of statistical and mathematical methods to analyze the climatic events, especially those that may frequently become risk phenomena (Haidu, 2002). Thereby, in the annual maximum intensity rainfalls case, the probability distribution function used varies according to analyzed area and period: in Australia, Eastern Africa and in the United Kingdom, the Generalized Extreme Value distribution (GEV) has been widely used while in the United States, the Gumbel distribution fits better. Koutsoyiannis and coauthors (1998) used the Gumbel, Gamma, GEV, Log Pearson III and Log Normal Exponential functions; Trefry and coauthors (2000) used the maximum probability method to determine the probability distribution of maximum annual values of the precipitations intensity from Michigan; Trefry and coauthors (2005) used the frequency analysis for the planning management of pluvial water from the US state of Michigan; Rayford and coauthors (2007) used the normal probability density, normal Log, GEV, Pearson type III and Log Pearson type III functions in order to analyze the annual maximum precipitations, the best results being obtained by using the Khi^2 test; and El-Sayed (2011) discovers, by using the Hyfran software, that most of the annual maximum intensity series of the precipitations used for projecting the IDF curves in the Sinai Peninsula present a Log Normal and Log-Pearson type III distribution.

2. PHYSICO-GEOGRAPHICAL CHARACTERISTICS OF THE STUDIED AREA

The North-Western part of Romania, as it was considered in this paper, refers to the area delimited by the territories of the five counties located in the North-Western part of Romania: Satu Mare, Maramureş, Sălaj, Cluj and Bistriţa-Năsăud, with a total surface of 26.615 sqkm, representing 11,2 % out of Romania's surface. Thus defined, the analyzed territorial unit stretches, from an administrative point of view, from the Hungarian border (in North-West), Ukrainian border (to North), the Suceava county in East through the Mureş and Alba counties in South, and Bihor county (in South-West).

The area is highly heterogeneous, containing all the landforms (mountains, plateaus, hills and plains) on various proportions (Figure 2.1). Because of this fact and of certain geographic literature opinions regarding the placement of certain relief units in one category or another, a unitary presentation of landform characteristics was fairly difficult, so it has been resorted to the analysis on levels of relief. Thereby, in the mountain level it has been included the mountain frame and the related depression areas, situated in the Northern and Eastern part of the analyzed unit, as well as the South-Western part of the region, to which was added the „Intracarpathian yoke", as it is considered being part of this category because of its lithologic structure. The more complex hilly and plateaus level has been subdivided between the following categories: the hills, the depressions and corridors that delimit Transylvanian Plain, Silvano-Someşene Hills, the Almaş-Agrij Depression and the Someşan Plateau. In the plain area, there have been included two major landform units: the Transylvanian Plain and the Someşului Plain.

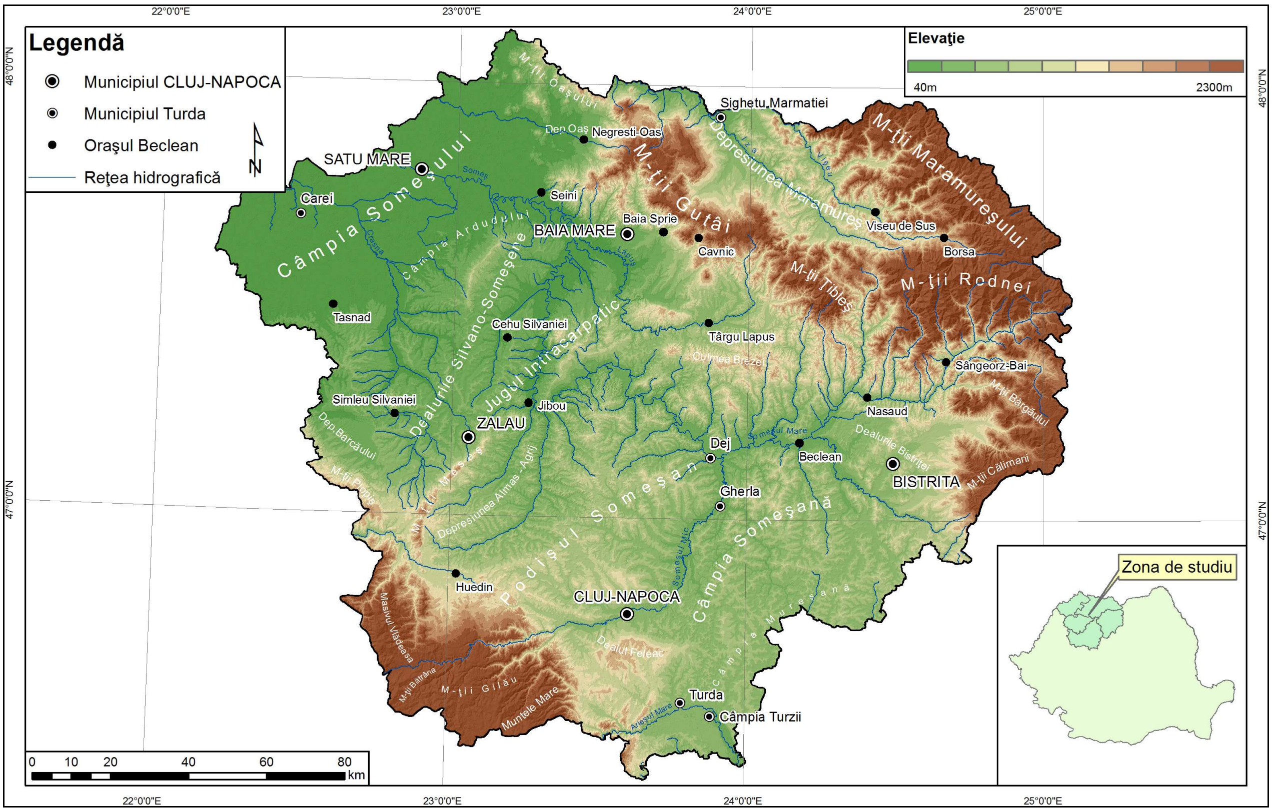

Fig. 2.1. Elements of geographic location of the study area

3. DIURNAL VARIATION, DURATION AND INTENSITY OF HEAVY RAINS AND ANNUAL MAXIMUM INTENSITY RAINFALLS

Analysis of liquid precipitation parameters such as diurnal variation, intensity, duration etc, takes into account the spatial and temporal manifestations from statistical perspective, achieving an overview of their structure in a certain area.

In the studied area, heavy rains and annual maximum intensity rainfalls were analyzed during 1975-2009, being identified a total of 271 heavy rains (0.89% of all significant rainfall) and 490 cases of annual maximum intensity rainfalls. Further, the statistical analysis of multiple parameters such as frequency, diurnal variability and intensity was made in order to find similar manifestations in the area.

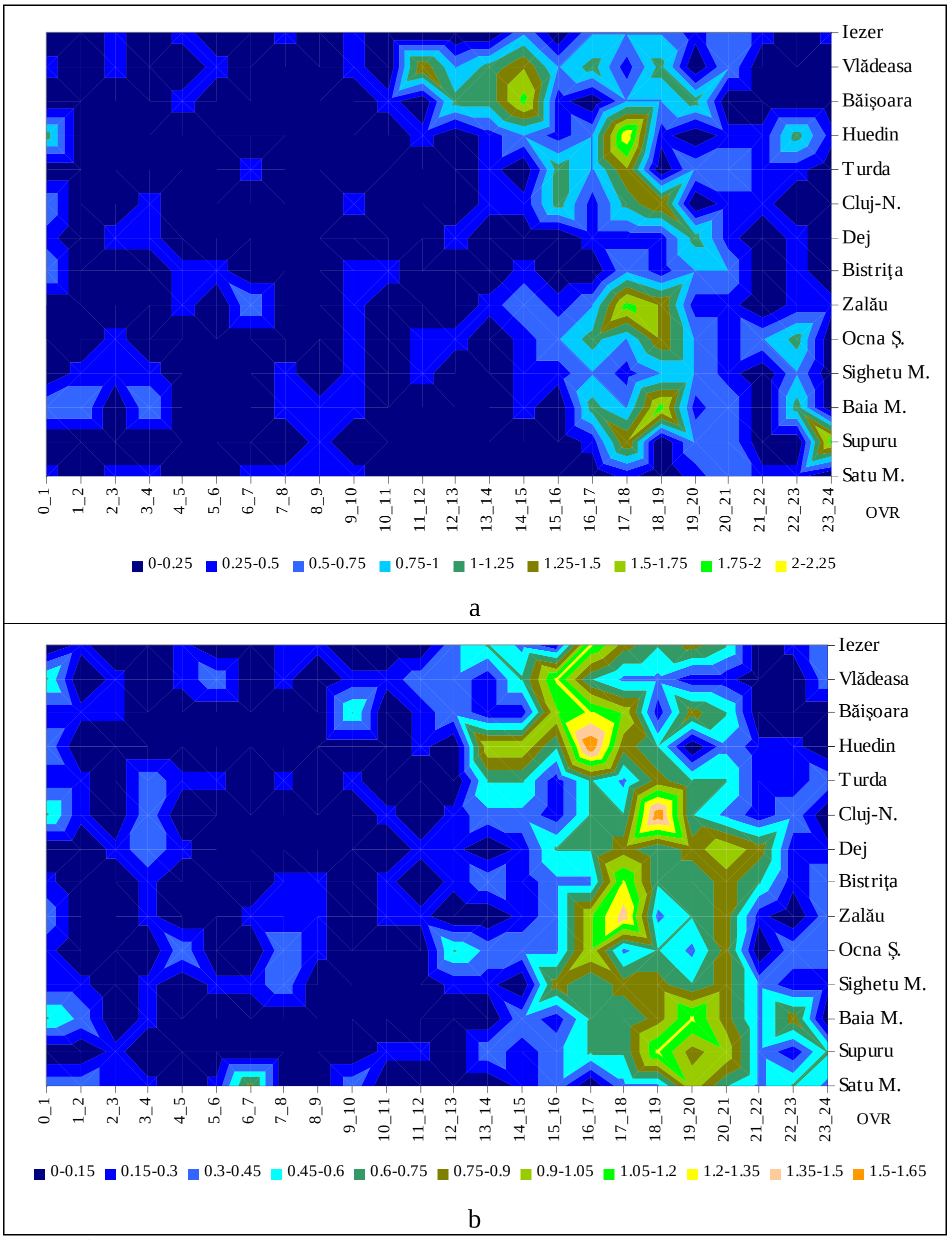

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Fig. 3.1. Diurnal variation in the frequency of heavy rains (a) and annual maximum intensity rainfalls (b)

Heavy rains structure show high frequency of occurrence in the depression area of Maramureş and mountain area (over 6.3% for each station), being less frequent in the lowlands. The highest percentage of occurrence is in the summer (87.1%), especially in the mountain area, and the most frequent duration is that of 3-6 hours (37.3%). A similar situation was found by Cristodor and Darie (1963) for Bucureşti-Băneasa airport as well as Brooks and Stensrud (2000) which show that the highest frequency of heavy rains is in July (20% of all), 81 % of them being recorded from April to September. In the case of annual maximum intensity rainfalls, which are more often in the valley corridor areas and depressions, the highest frequency is in July but their occurrence is high at the beginning and the end of warm season, too. Duration analysis shows that one-third of these rainfalls are less than one hour and those less than two hours have a percentage of 63.2.

Diurnal variation shows that heavy rains are more frequent in the afternoon and evening, occurring 3-4 hours earlier in the mountain area than depression one and lowlands (fig. 3.1, a). A secondary maximum occurs at midnight in the depression area of Maramureş and lowlands, caused by rains lasting more than 2 hours. A similar diurnal variation structure is recorded in the case of annual maximum intensity rainfalls (fig. 3.1, b), but their frequency decreases with the increasing of rain maximum intensity and duration.

Table 3.1. The intensity classes frequency of heavy rains and annual maximum intensity rainfalls according to duration (percentage)

Duration	Heavy rains			Annual maximum intensity rainfalls		
	Medium intensity (mm/min)					
	<0.17	**0.17 - 0.41**	**>0.41**	**<0.17**	**0.17-0.41**	**>0.41**
< 1 ore	-	0.7	24.5	4.7	16.3	13.1
1-2 ore	-	14.0	6.3	13.1	15.4	1.2
2-3 ore	-	14.8	0.7	11.5	5.3	-
3-6 ore	26.9	10.3	-	13.5	1.2	-
> 6 ore	1.8	-	-	4.7	-	-
Total	**28.7**	**39.8**	**31.5**	**47.5**	**38.2**	**14.3**

Processed after NMA archive (1975-2009)

In the case of medium intensity, taking into account the fact that heavy rains are determined by a formula which connects their duration and intensity, it can be noted an inverse relationship between the two elements, pointing out, however, relatively high frequency of high intensity (31.5% of them over 0.41 mm/min) (Table 3.1). Duration-medium intensity variation type is logarithmic (R^2 = 0.837). The correlation of the two parameters, determined by Curve Expert 1.3 program, highlights the regression coefficient values for each station of 0.82 to 0.98, correlation type being logarithmic or power. Annual maximum intensity rainfalls present a different medium intensity structure, almost half of them having relatively low values of intensity (47.5% below 0.17 mm/min) (Table 3.1).

Maximum intensity class structure stands, in both cases of pluviometric events, the highest percent of those over 1.0 mm/min (85.2%) (Table 3.2). Duration of maximum intensity of 2 to 5 min threshold it’s over 50 percent in the case of torrential rains (55.4%), followed by the 1 min class (almost 25%), and in the situation of annual maximum intensity rainfalls, maximum intensity duration up to 5 min it’s 96.1% of the total cases.

Table 3.2. The maximum intensity classes frequency of heavy rains and annual maximum intensity rainfalls according to duration (percentage)

Duration	Heavy rains			Annual maximum intensity rainfalls		
	Maximum intensity (mm/min)					
	<0.5	**0.5 - 1.0**	**>1.0**	**<0.5**	**0.5 – 1.0**	**>1.0**
< 1 ore	-	1.5	23.6	0.2	1.7	32.1
1-2 ore	-	1.5	18.8	-	1.2	28.6
2-3 ore	-	1.5	14.0	-	0.4	16.4
3-6 ore	0.4	9.2	27.7	-	0.4	14.3
> 6 ore	-	0.7	1.1	-	0.8	3.9
Total	**0.4**	**14.4**	**85.2**	**0.2**	**4.5**	**95.3**

Processed after NMA archive (1975-2009)

The frequency of annual maximum intensity rainfalls decreases with the increasing value of the maximum intensity duration. Thus, from 45.5% in the case of 1 min duration the frequency drop to 0.6 % for more than 8 min duration. Exponential and Log-normal variations were found to fit best the maximum rainfall intensity in the area under study. Based on them, low values of return periods are specific to minimum rainfall intensities while higher values (15.9 - 120 years) with probabilities of not exceeding more than 93.71 %, were found in case of maximum rainfall intensities. The higher the return period is, the higher absolute maximum intensity gets, with an overall average of 17 %, for the 100 years return period and up to one third, in the case of 1,000 years return period.

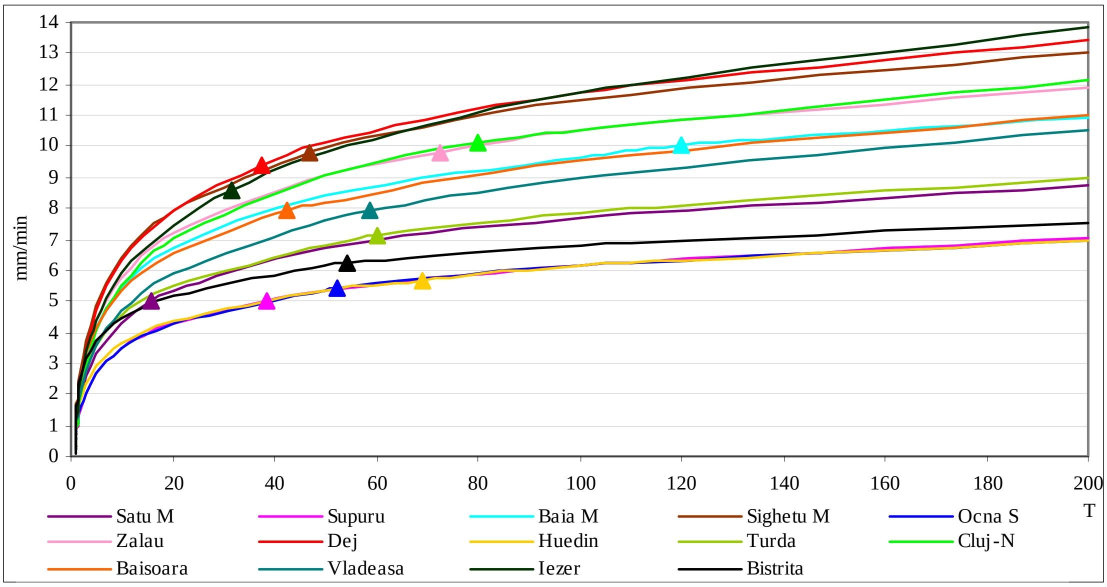

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Fig. 3.2. The return period of maximum intensity of annual maximum intensity rainfalls (▲).

4. SYNOPTIC STRUCTURES OF HEAVY RAINS AND ANNUAL MAXIMUM INTENSITY RAINFALLS

Synoptic analysis is a basic tool in predicting precipitations. According to different studies (classical and modern approach) the most important type of air circulation that determines precipitations in Romania in the warm season, are polar circulation (the largest percentage), western and maritime tropical circulation.

The existences of geopotential trough and cut-off lows are two essential synoptic elements that generate precipitations in the warm season. On the other hand, an important role in the genesis of precipitations is the moisture advection or the preexistence of it and the temperature advection. These conditions are essential in the process of cloud formation, the main type of air circulation that satisfies the most of these requirements are polar circulation, followed by the western and the tropical ones.

Another approach of the conditions of rainfall occurrence is the presence of cyclonic structure, and the most important airflows that generate this type of structure are northwestern and northeastern ones. Overall, northern and northwestern flows are associated with a geopotential trough or cut-off low favorable to cold front instability or thermal convective instability.

Based on these remarks we consider that rainfalls characterized by high values of intensity and water amounts are local events generated by the air instability, a process influenced by two factors: temperature and air moisture. Therefore, rainfall events analysis was conducted from the perspective of air instability types like thermal convection instability, frontal instability and cut-off low instability.

For the study area, heavy rains occurrence is mostly generated by the thermal convection instability, especially in the mountain area, depressions and valley next to it, due to initiation of convection in the mountain area, followed by frontal instability. Diurnal variability shows the occurrence of these rain events in the afternoon and evening, especially in the mountain area where their occurrence is a few hours earlier, having a small duration (generally less than 3 hours). Frontal instability is more often in the north part of the study area and mountain area, being more often in the afternoon and evening, having small and medium intensity. Cut-off instability generates heavy rains characterized by long duration, low medium intensity and high water amounts (25-50 mm in more than ¾ cases). The occurrence frequency is higher in the afternoon and night hours and the spatial distribution is influenced rather by the synoptic scale than the mesoscale.

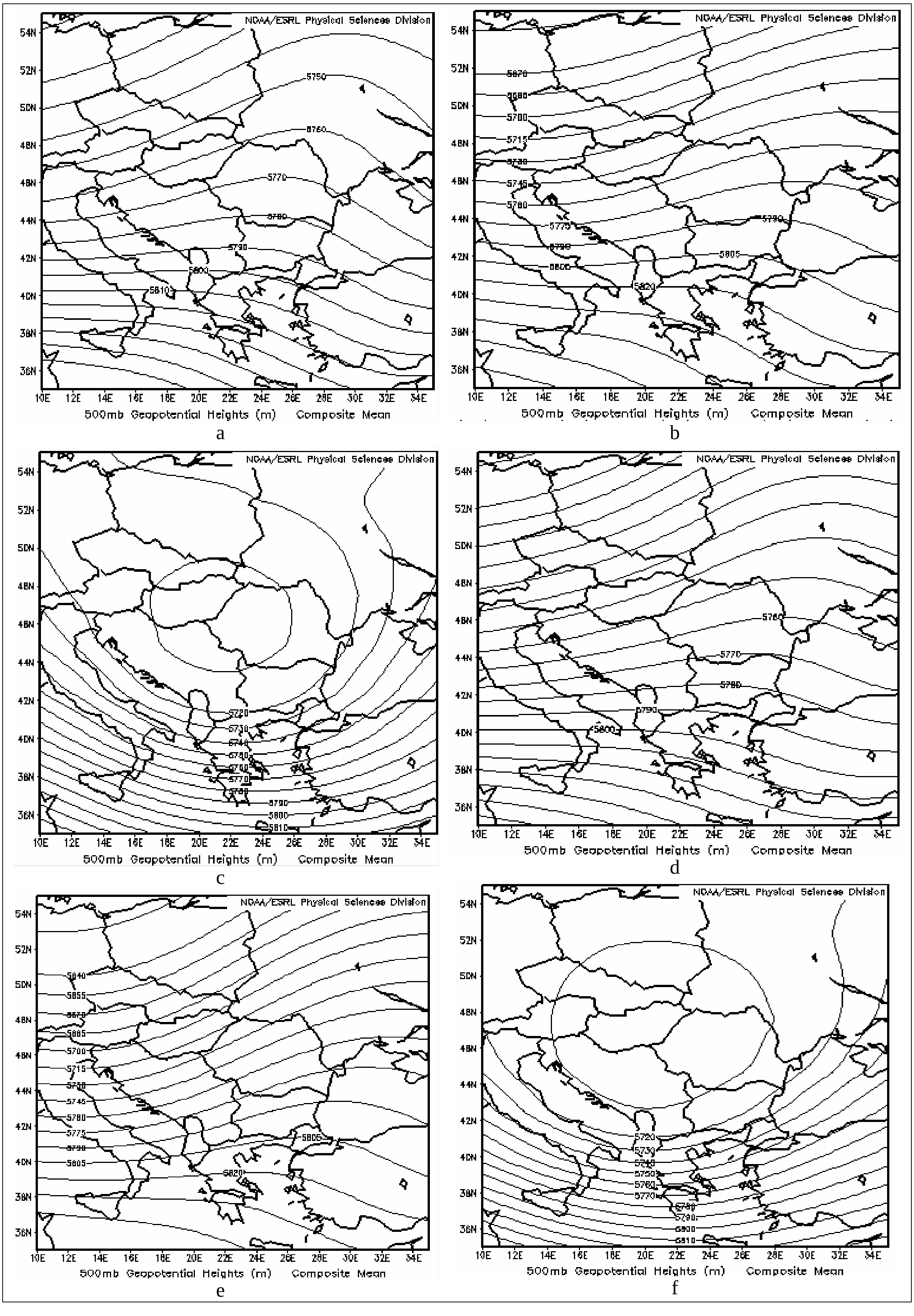

Fig. 4.1 Geopotential height (gpm) at 500 hPa for heavy rains generated by thermal convection (a), atmospheric fronts (b), cut-off lows (c) and annual maximum intensity rainfalls generated by thermal convection (d), atmospheric fronts (e), cut-off lows (f) (processed by www.esrl.noaa.gov)

The highest frequency of annual maximum intensity rainfalls is determined by frontal instability (42.3%), followed by the thermal convection instability (39.5%). Frontal instability generated by fronts especially cold ones, has the highest frequency in the north part of the area and mountain area, and is characterized by 1 to 3 hours duration, low intensities and small amount of water (10 to 25 mm in more than half of the cases). Thermal instability is characterized by short duration rainfalls (less than 3 hours), average intensity between 0.17-0.41 mm/min and small amounts of water (10 to 25 mm in 54.4% of cases). Diurnal variability shows that 72.5% of rain events occur in the afternoon and evening hours (from 13 to 21 RST-Romanian Summer Time), with a peak from 17 to 19 RST, in the mountain area being earlier. Cut-off instability reveals a heterogeneous spatial distribution of rainfalls, similar to heavy rains generated by the same type of instability, and it is characterized by medium and long duration (more than 3 hours), small and medium rain intensities leading to 10 to 25 and 25 to 50 mm of water.

Synoptic configurations generating heavy rains and annual maximum intensity rainfalls are different, depending on genetic criteria of rainfall events. At 500 hPa geopotential height, thermal convection instability is characterized by a ridge retreating eastward, the study area being situated on its upward slope; frontal instability presents a trough located westerly and cut-off low instability is characterized by at least a geopotential low situated in the north-west or north part of the country (Fig. 4.1). The lower layers of the atmosphere (the 700, 850, 925 hPa) present the same shape, and the air pressure at the ground level has values below average and low gradient, allowing instability to develop (in the case of thermal convective and cut-off low instability).

Atmospheric stability indices most useful for the prediction of these kinds of rainfall events are KI, VTI, TTI, CTI and LI. Their importance depends on the type of instability: in the case of thermal convective and the frontal instability the most useful are KI, TTI, VTI and LI, and in the case of cut-off low instability TTI index it’s best suited. It should be noted that the value of atmospheric stability indices it’s higher in the case of heavy rains than those of annual maximum intensity.

5. DIRECTION AND SPEED OF CONVECTIVE SYSTEMS GENERATING HEAVY RAINS

Convective cells' trajectory is an important feature for predicting severe weather events that may occur in areas affected by them. In this respect, Merrit and Fritsch (1984) found a weak correlation between the movement of convective cells and wind at different levels in the troposphere, noting that convective cells' direction usually corresponds to the 300-850 hPa thickness lines. Corfidi and coauthors (1996) studied the movement of meso-beta convective systems belonging to Mesoscale Convective Complexes in the US and concluded that it can be obtained a speed vector by summing wind vectors in the 300 and 850 hPa atmospheric layers, adding the low-level jet, equal but opposite in sign.

The same methodology was applied for convective storms generating heavy rains in the study area, determined by WSR98-D weather radar, for the period 2004-2009. Four atmospheric layers has been used for calculating wind speed and direction (300-850 hPa, 400-850 hPa, 500-850 hPa and 500-700 hPa), using the following formulas:

$$\vec{V}_{med} = u_{med}\,\vec{i} + v_{med}\,\vec{j} \quad \textbf{(5.1)},$$

$$\text{and } u_{med} = \frac{(u_1 + u_2 + ... + u_n)}{n} \text{ şi } v_{med} = \frac{(v_1 + v_2 + ... + v_n)}{n}$$

and

$$V_{CL} = \frac{V_{850} + V_{700} + V_{500} + V_{300}}{4},\ V_{PROP} = (-V_{LLJ})$$

$$V_{MBE}^2 = V_{CL}^2 + (-V_{LLJ})^2 + 2V_{CL} \times |-V_{LLJ}| \times \cos\phi,\ \textbf{(5.2)},$$

$$\text{and } \psi = \arcsin\left(\frac{|-V_{LLJ}|\sin\phi}{V_{MBE}}\right)$$

where: V_{med} – average wind (m/s);

i, j –ox and oy axis unit vector;

u, v – velocity vector projection on ox and oy axis;

n – number of atmospheric layers.

V_{CL} – vector sum of the mean flow in the cloud layer;

V_{850} … V_{300} – wind advection at the standard levels of 850 … 300 hPa;

V_{MBE} – Mezo-beta Convective Cell movement;

V_{PROP} – propagation component;

V_{LLJ} – low-level jet component;

SCM – Mesoscale Convective System; ϕ, ψ – angles.

Table 5.1. Direction deviation of the convective cells' movement to main flow depending on the type of instability (%)

Layer	Thermal convection instability			Cut-off lows instability			Frontal instability		
	Deviation to the main flow (degrees)								
	±45	-90…-45 45…90	< -90 > 90	±45	-90…-45 45…90	< -90 > 90	±45	-90…-45 45…90	< -90 > 90
300-850 hPa	58.6	24.3	17.1	53.8	28.0	18.2	82.5	11.7	5.8
400-850 hPa	64.3	20.0	15.7	57.0	29.0	14.1	84.4	9.8	5.8
500-850 hPa	60.0	24.3	15.7	54.8	29.0	16.2	80.5	11.7	7.8
500-700 hPa	62.9	20.0	17.1	54.8	26.9	18.3	81.2	12.3	6.5

Processed after NMA archive (2004-2009)

Regarding the direction deviation of convective cells' motion to the main flow considered, given the high percent of small deviations and low percent of large deviations, 400-850 hPa layer is most useful for determining the direction of movement of convective cells in the analyzed area, regardless the type of instability in which it occurs (Table 5.1). On the other hand, between the two ways of determining the direction deviation of convective cells' motion (with or without low-level jet), given the best statistical results in the case in which low-level jet was not included, it is recommended to be used.

The analysis of direction deviation of convective cells' motion to the main flow shows the dominance of positive values of deviations in thermal convection and frontal instability cases and the negative one in cut-off lows instability and from the air circulation perspective, the most important air flows are from south, west and south-west. South and south-west air flows are more often in the case of thermal convective instability, east and south-east flows have higher frequency in the situation of cut-off lows instability, depending on the spatial position of geopotential lows, and south-west, west and north-west flows are more often recorded in the case of frontal instability (Fig. 5.1).

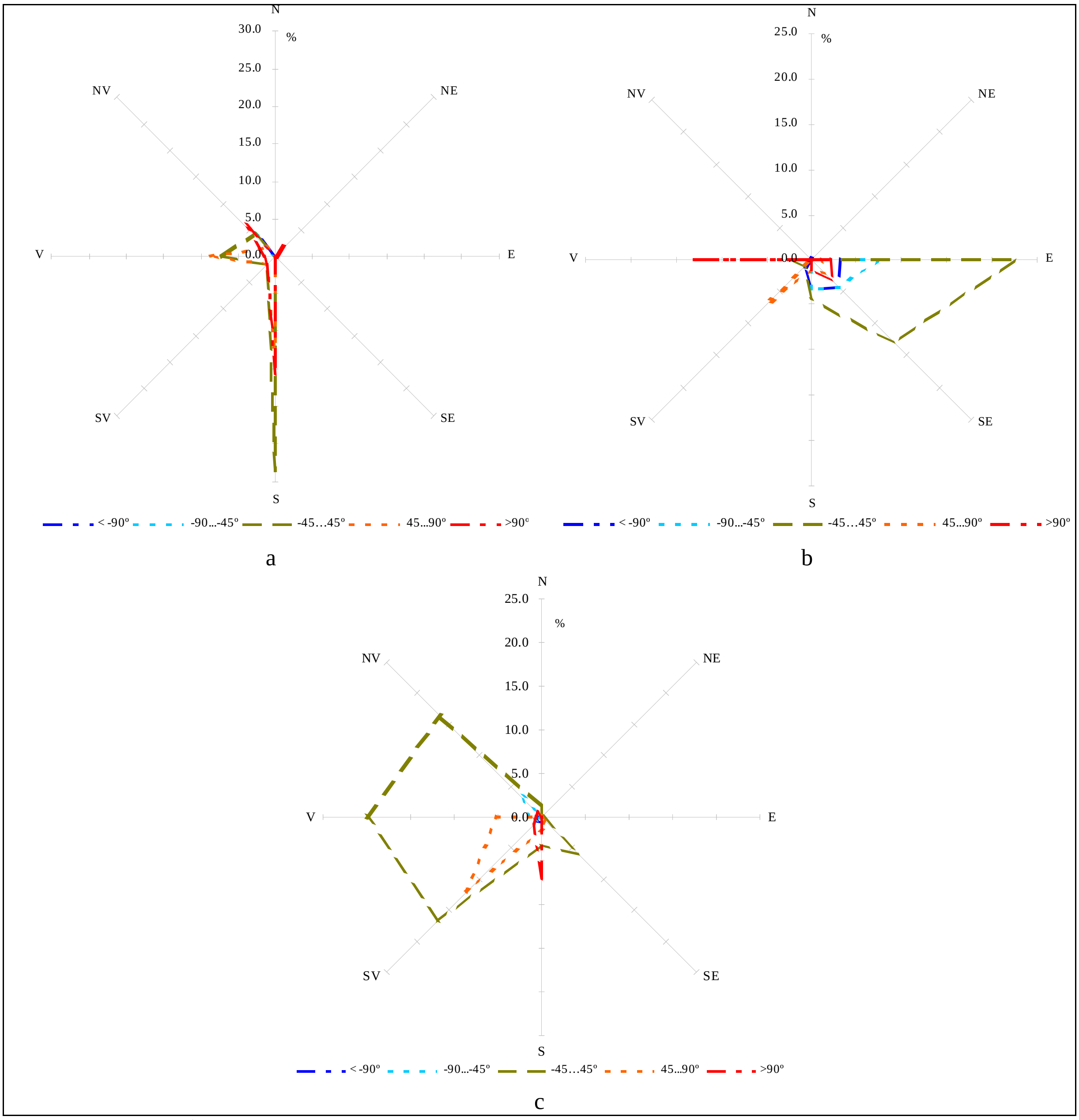

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Fig. 5.1. Direction deviation level of the convective cells' motion to main flow (%), depending on flow direction, in the case of thermal convection instability (a), cut-off lows instability (b), and frontal instability (c)

It can be noted an inverse relationship between cells' speed and deviation degree of convective cells' direction, deviation degree increasing with reducing speed of convective cells, the situation being more obvious in the case of large deviations (Fig. 5.2). In the case of small deviations of convective cells (up to ±45º), there is a high frequency of 5-10 m/s speed threshold, while medium and large deviations are characterized by small speed of convective cells (under 5 m/s).

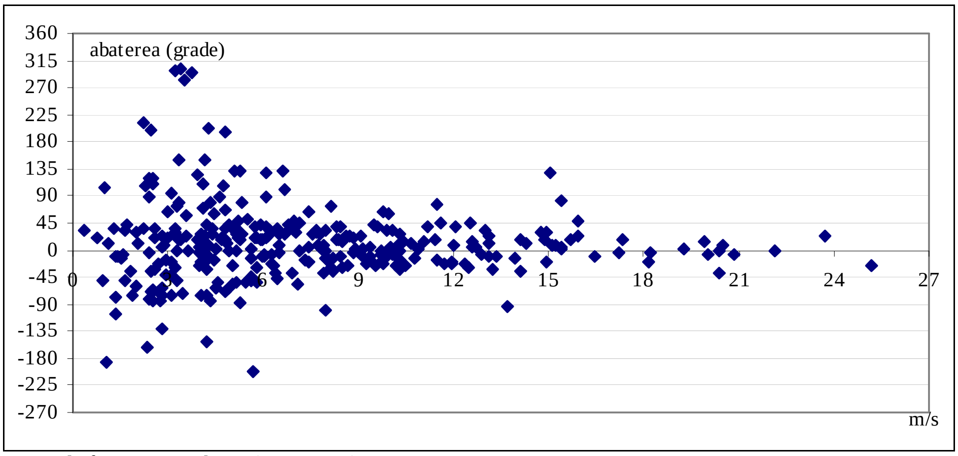

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Fig. 5.2. Cells' direction deviation degree to the 400-850 hPa atmospheric flow, depending on their speed (m/s)

Depending on the synoptic structure, an important finding is that convective cells tend to move within the structure or to join the airflow line concavity of each individual type of structure.

Table 5.2. Share of the convective cells' speed deviation to the main flow depending on the type of instability (%)

Layer	**Thermal convection instability**				**Cut-off lows instability**				**Frontal instability**			
	Share of speed deviation to main flow (%)											
	0-50	**50-100**	**100-200**	**>200**	**0-50**	**50-100**	**100-200**	**>200**	**0-50**	**50-100**	**100-200**	**>200**
300-850 hPa	35.7	47.1	15.7	1.4	41.9	46.2	9.7	2.2	22.7	41.6	33.8	1.9
400-850 hPa	40.0	42.9	14.3	2.9	34.4	49.5	11.8	4.3	20.1	42.9	34.4	2.6
500-850 hPa	31.4	45.7	21.4	1.4	25.8	38.7	25.8	9.7	14.9	39.6	40.3	5.2
500-700 hPa	40.0	47.1	11.4	1.4	34.4	44.1	18.3	3.2	25.3	38.3	33.1	3.2

Processed after NMA archive (2004-2009)

Statistical analysis of the methods for determining convective cells' speed motion (with or without low-level jet) notes that the best results were obtained in the case in which the low-level jet was not included, considering the large percentage values of small deviations (Table 5.2). It must be noted that to accurately determine this parameter is difficult, given the variety of factors that can interfere (physical-geographical factors, type of mesoscale structure etc) so speed results do not recommend the use of this method widely.

6. APPLICATIONS AND CASE STUDIES

Applications for the 2010-2012 period

The chapter analyzes the diurnal variation, rainfall intensity, synoptic configurations, atmospheric stability indices of heavy rains and convective cells' speed and direction to the main atmospheric flow for a period of 3 years, to see if it fits the results found in the chapters above. In this respect, 136 rainfall measurement stations has been used, consisting of 15 meteorological stations and hydrometric and rainfall stations from the northwestern Romania. It has been analyzed the situations where the rainfall measurement stations issued warnings messages of torrential rains in the warm season (April to October) of 2010-2012 period, warnings containing data about rain duration and the amount of water fallen. The aim of this application is to see the spatial extension of heavy rains in the synoptic and mesoscale situation in witch they occur, some features of their manifestation in the area and if it the results confirm the findings in the 3rd, 4th and 5th Chapter of the paper.

For this, the following elements were analyzed:

- convective cells' speed and direction for each torrential rainfall event recorded in the area, based on radar products from SRPV Cluj, achieving comparisons with the wind parameters at different layers of the atmosphere. The wind parameters was considered based on the atmospheric sounding of Cluj-Napoca, 00 GMT survey, only for the situations in which heavy rains occurred;

- air advection type from the lower and middle layers of the atmosphere in each torrential rain case;

- stability indices calculated on the atmospheric sounding mentioned.

In the study area, for the period under consideration, a total of 86 days with 444 torrential rainfall events took place, high frequency and number of days of torrential events recorded being in June (47.3%) and July (26.6%), regardless the year considered.

Synoptic study of each heavy rain event revealed a number of features of thermal and air pressure structure of the atmosphere, as it follows:

- low geopotential values associated to a trough or a cut-off low structure;

- low sea level pressure values, usually under 1013 hPa;

- the presence of a thermal trough or a cold cyclone at the low and medium levels of the atmosphere.

The main remarks of the cases of heavy rains analyzed are:

* 400-850 atmospheric layer is more useful for establishing convective cells' direction, given the high percentage values of small deviations and low percentage of large deviations. On the other hand, the increase of convective cells' speed is associated with low deviation of cells to the main atmospheric flow.

* the present analyses reveal the utility of 500-700 atmospheric layer for establishing convective cells' speed, but this method should be used with caution given the variety of factors that can interfere (physical-geographical factors, type of mesoscale structure etc). More than that, the results obtained in Chapter 5 shows the utility of 500-700 atmospheric layer for thermal convection instability and 300-850 hPa layer for frontal and cut-off lows instability, so using this method has to take into account the type of atmospheric instability.

* hodograph is useful for determining type of atmospheric instability. The present study based on hodograph analysis remarks the importance of warm air advection in the lower atmosphere and cold advection at the middle levels for developing convective cells.

* the most useful atmospheric stability indices are those that are calculated based on the moisture from the lower part of the atmosphere (K_{mod} and TT_{mod}), next to CT, VTI, and LI. In addition, their calculation based on daytime values would be more useful.

These applications confirm the results obtained in the analysis carried out in Chapters 3, 4 and 5. This justifies the methods used for the analyses of heavy rains cases in the study area, as well as determining movement directions of Convective Systems.

CONCLUSIONS AND PERSONAL CONTRIBUTIONS

The main objectives of the research topic was to identify quantitative characteristics and determine some methods of forecasting heavy rains and annual maximum intensity rainfalls in the north-west part of Romania. In this regard, it has been studied the spatial and temporal distribution of the two types of rainfall events, synoptic and mesoscale conditions that generates them in order to identify favorable atmospheric conditions of genesis of the Convective Systems and to establish a correlation between convective cell's motion and main atmospheric flow.

Briefly, the contributions resulting from this paper include diurnal variability, duration and intensity of heavy rains and annual maximum intensity rainfalls; a particular correlation type between duration and intensity of heavy rains; Exponential and Log-Normal types of variations of annual maximum intensity rainfalls. More than that, it has been identified three types of atmospheric instability and synoptic structure pattern that generates the two types of rainfall events; the utility of 400-850 hPa atmospheric layer for determining the convective cells' direction of motion and the inverse ratio between convective cells' direction deviation and their speed.

The results obtained from the analysis of the two types of rainfall events will contribute both to quickly identify more accurate the situations generating such events and for a better forecast of the time and place of their occurrence.

The evaluation of the facts presented in the paper and verified in Chapter 6 shows that the main objectives of the present study were achieved. However, less positive results were obtained in the case of convective cells' speed, pointing out a weak correlation with the average wind speed in the atmospheric layers considered.

Future research objectives include identification of the elements that influence convective cells' speed that generates high values of rainfall intensity and the role of physical-geographical factors like orientation of ridges and slopes, terrain altitude, etc, in generating new convective cells. These aspects will complete the results obtained in the case of heavy rains annual maximum intensity rainfalls.

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