SOME ASPECTS OF THE RELATIONSHIP BETWEEN SYNOPTIC-SCALE WIND AND CONVECTIVE CELLS' MOTION GENERATING HEAVY RAINS IN THE NORTH-WESTERN ROMANIA

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ABSTRACT. - Some aspects of the relationship between synoptic-scale wind and convective cells' motion generating heavy rains in the north-west of Romania. The paper examines some aspects of the relationship between synoptic-scale wind parameters and those of convective cells that generate heavy rainstorms. In this respect, torrential rains from 14 weather stations in the north-western Romania were analyzed, torrential characteristic being determined based on the Hellman criteria. Analyzing radar information, we determined a number of dynamic parameters of convective cells (direction and speed), taking into account synoptic scale conditions.
Analysis of the results reveals a number of features of the dynamics of convective cells by synoptic-scale circulation of each case, being a starting point in forecasting the spatial development of such nuclei generating convective rains.

Keywords: convective cells, heavy rains, north-western Romania

1. INTRODUCTION

Torrential rains are extreme rainfall events with negative environmental and social effects. Large amounts of water fallen in a short or long period of time are generating flash floods in the first case, or soil saturation in water and excess precipitation accumulation on the soil, in the second case. The knowledge of the environment conditions in which they occur it's essential in the forecast process of these events. Synoptic conditions favorable to the emergence and development of convective systems are generated by the pronounced instability of air masses and the existence of a flow of moisture. The instability of an air mass occurs in the following conditions: daytime heating of the active surface and the heat transfer into the upper atmosphere through convection, generating ascending turbulent currents (instability generated by thermal convection); forced ascent of air masses along the lines of instability (fronts), as a result of dynamic processes near the ground surface (frontal instability), and the instability associated with "cut off" cyclones (lows), which occurs due to the formation of cold cyclones in the middle and lower layers of the atmosphere as a result of cold air advection in the middle

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troposphere. Once generated, convective systems trajectories are influenced by three factors: the flow in the middle and lower troposphere (main flow), the features of the surface above they occur and the physical processes that take place within the convective systems.

There are various methods for determining the main flow of an atmospheric layer. In this regard, Merritt and Fritsch (1984) led to a poor correlation between cell movement and wind parameters at different troposphere levels. Corfidi and coauthors (2003), determined the speed and direction of wind vector as an average of 850, 700, 500 and 300 hPa atmospheric levels.

This paper analyzes the features of the convective systems moving environment in which they occur (type of instability) and the flow of medium and lower troposphere (or main flow). In this respect, several methods were analyzed to determine the main flow and the comparison with the actual movement of the convective cells that have generated torrential rains in the studied area.

2. DATA AND METHODS

The analysis was performed by using data of torrential rains from 14 weather stations in northwestern Romania, located at altitudes between 123 m and 1836 m (Satu Mare - 123 m, Supuru de Jos - 159 m, Baia Mare - 216 m, Sighetu Marmaţiei - 275 m, Ocna Şugatag - 503 m, Huedin - 560 m, Cluj-Napoca - 410 m, Dej - 232 m, Turda - 424 m, Zalău - 295 m, Bistriţa - 366 m, Băişoara - 1384 m, Vlădeasa 1800 - 1836 m and Iezer - 1785 m). For this purpose, for each heavy rain event produced at any weather stations in the studied area in the warm season (April-October) of 2004-2009 period, rain with the same feature have been identified at the hydrometric stations from north-west Romania, based on the warnings issued by those stations. It has been taken into account the spatial extent of the torrential rains depending on the synoptic and mesoscale context of their occurrence, as well as the features of their manifestation in the analyzed area.

Regarding the methodology, the first step was to identify the torrential character of rainfall events, based on Hellman criteria. Using thematic maps of the low and medium troposphere (geopotential height, temperature, relative humidity, atmospheric pressure) and sea level pressure maps provided by the electronic archive of www.noaa.gov and by www.wetterzentrale.de, it was identified the structure of synoptic type that has generated each torrential event, determining the type of atmospheric instability. Finally, for each class of instability has been made an average structure of the atmospheric fields in which it occurs and for each heavy rain event, the convective cells that caused it has been identified, analyzing their movement parameters (direction and speed).

In the end, different comparisons to the wind structure of various layers of the atmosphere were made, structure determined on survey data at 00 GMT for each day with torrential rains.

3. RESULTS

In the period under review there were a number of 48 days with pronounced atmospheric instability that generated torrential rainfall events. The study of the synoptic situations for each day highlighted the largest percentage of days with heavy rain caused by frontal instability (47.9%), followed by the situations of "cut off" lows (31.3%), and the instability caused by diurnal convection (20.8%). A similar structure was recorded in the case of number of events with torrential rains, 49.5% of them occurring due to frontal instability, 29.6% due to cold nuclei, and 20.9% in the case of thermal convective instability.

The average intensity of heavy rains presents a wide range (0.08-3.13 mm/min), pointing out the largest share of rains with values below 1.0 mm/min (88.3%), and the highest frequency belong to those generated by thermal convection (94.4%).

Quantities of water recorded during these events varies depending on the genetic type of rains, the extreme values being 9.8 and 87 mm, the highest values belonging to the <25 mm class (51%), followed by the 25-50 mm (42.2 %). Frontal instability generates amounts of water less than 25 mm in most cases (fig. 1), while the thermal convection instability and the one with cold nuclei are responsible for greater quantities of water (over 50 mm)(fig. 1).

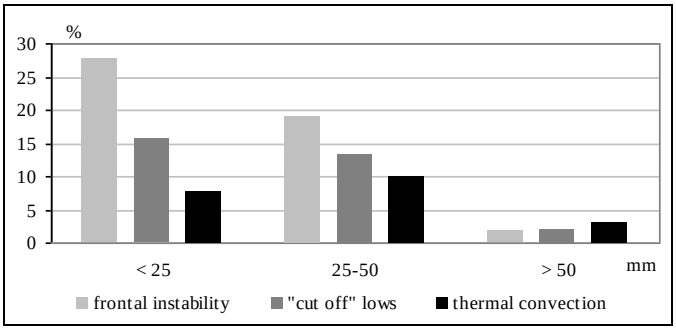

Fig.1. The frequency of heavy rainfall amounts of precipitation depending on the synoptic situation type (%)

Based on the facilities offered by www.esrl.noaa.gov, maps of atmospheric structure in different cases of instability were made (convective heating, front and "cut off" lows). Each map represents the average structure of the thematic field drown as a result of all situations of instability taken in the analysis.

In the case of thermal convection, the structure of the geopotential height at 500 hPa level over the Romania has a slight character of ridge, north-western part of Romania being situated in the back side of the ridge, having a height of 5780-5790 gpm (geopotential meters) (fig. 2 a), the airflow being southwesterly. A similar structure is present at 850 hPa level, pointing out that the area of interest is located on the back side of the ridge axis, in this case the airflow in the studied area being most southern. At sea level, air pressure field is characterized by values of 1012-1013 mb, below the average values, the 1013 mb line having a cyclonic shape (fig. 2 b).

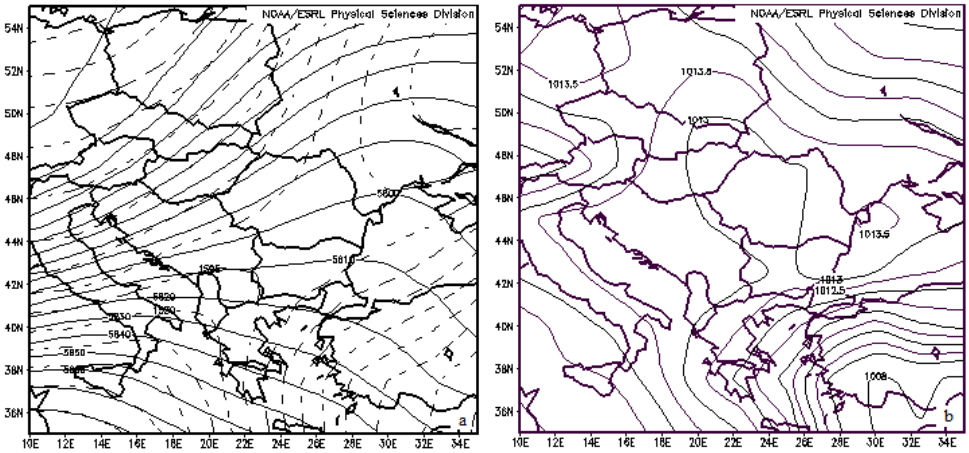

Fig. 2. The medium structure of geopotential field (gpm) of 500 hPa (solid line) and 850 hPa (dashed line) levels (a) and sea pressure level (mb)(b), in the case of heavy rains caused by thermal convection (processed by www.esrl.noaa.gov)

For frontal instability, the 500 hPa geopotential field presents a wide trough, with mean values of the geopotential height between 5760 and 5775 gpm (fig. 3a), the airflow in north-west part of Romania being from west-south-west; a similar structure is present at the 850 hPa level, the trough presenting a sharper form, being located north-west of the analyzed area (fig. 3 a). The sea level pressure is characterized by low values (1012-1013 mb), due to the existence of a low corridor extended from Scandinavian Peninsula to the eastern Mediterranean basin (Fig. 3 b).

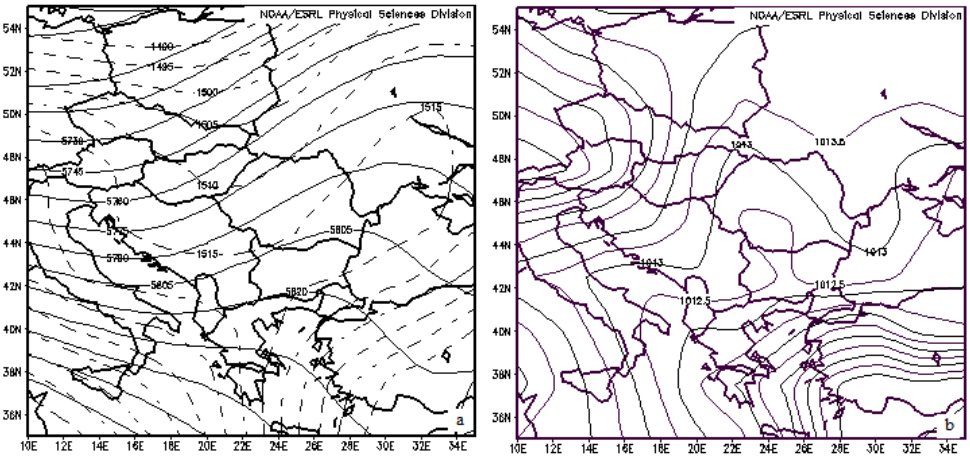

Fig. 3. The medium structure of geopotential field (gpm) of 500 hPa (solid line) and 850 hPa (dashed line) levels (a) and sea pressure level (mb)(b), in the case of heavy rains caused by frontal instability (processed by www.esrl.noaa.gov)

In the case of instability generated by the “cut off” lows, the 500 hPa field structure is characterized by a core above the western half of Romania, the average values being 5710-5720 gpm (fig. 4 a), pointing out the existence of core structure in the lower layers of the atmosphere (850 hPa, fig 4 a). As it can be seen, in both cases the airflow is from south-east and east, providing a flow of moisture from the Black Sea area. At sea level pressure, the north-east part of the continent is under the influence of the Azores anticyclone ridge, extended to northern Scandinavian Peninsula and western Russian Plain, the south-east part of Europe being in a low pressure field (1011-1011.5 hPa) (fig. 4 b).

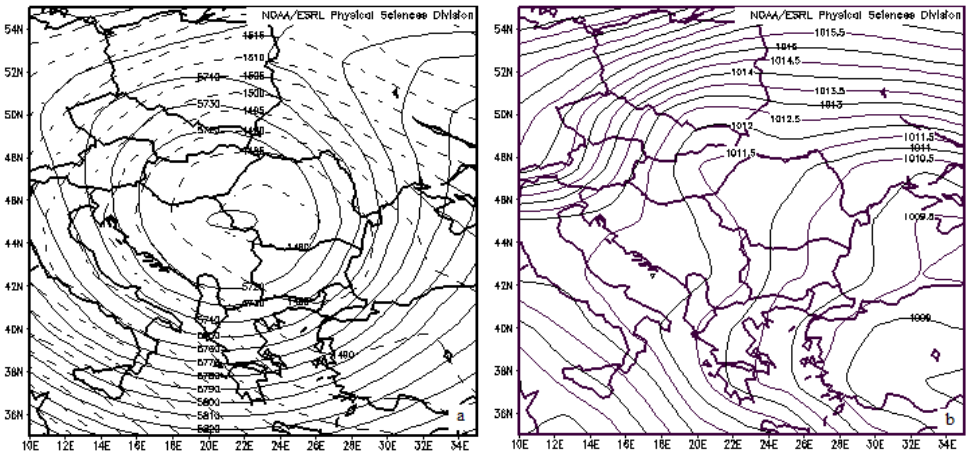

Fig. 4. The medium structure of geopotential field (gpm) of 500 hPa (solid line) and 850 hPa (dashed line) levels (a) and sea pressure level (mb)(b), in the case of heavy rains caused by “cut off” lows (processed by www.esrl.noaa.gov)

In order to emphasize certain features of spatial-temporal event of heavy rains in the studied area, we have looked at the information on rainfall recorded throughout the unit. Thus, for each situation in which torrential rains were recorded at the weather stations, data of water amounts fallen at hydrological stations were analyzed in order to determine the spatial extension of heavy rains. It has been taken into analysis warning messages issued by hydrological stations, since those contain information about the starting and ending time of rains, and the amount of water collected. Based on this information, the radar archives has been used for each time interval in which there were heavy rains, in order to get data on direction and speed of the convective systems that were responsible for those rains, ultimately making the comparison with the direction and speed of the main flow.

In determining the main flow, more layers of the atmosphere were considered in order to establish which one is more close to that of convective cells’ speed and direction. In this respect, the wind direction and speed of three layers were calculated: 300-850 hPa layer (~ 9500-1500 m), 400-850 hPa layer (~ 7400-

1500 m) and 500-850 hPa layer (~ 5500-1500 m), knowing that the great mass of convective systems is confined within these layers.

$$\vec{V}_{med} = u_{med}\vec{i} + v_{med}\vec{j} \text{ and,}$$

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

where: V_{med} – medium speed;

i, j - unit vector of ox and oy axis

u, v - velocity vector projection on ox and oy axis

n - number of atmospheric levels considered for one layer

Tabel. 1. Direction deviation of the convective cells' movement to main flow depending on the type of instability (%).

Layer	Thermal convection			„Cut off" lows			Frontal instability		
	Deviation to main flow (degrees)								
	±45	-90…-45 and 45…90	< -90 and > 90	±45	-90…-45 and 45…90	< -90 and > 90	±45	-90…-45 and 45…90	< -90 and > 90
300-850 hPa	61.2	21.2	17.6	52.5	27.5	20.0	78.6	16.4	5.0
400-850 hPa	64.7	18.8	16.5	54.2	29.2	16.6	80.1	14.9	5.0
500-850 hPa	60.0	24.7	15.3	53.3	28.3	18.4	77.1	15.4	7.5

Overall, it is noted that the direction deviation of convective cell's movement to the main flow of the three cases taken into analysis is less frequent with increasing deviation angle. Thus, in the case of ± 45° deviation, between 66.5 and 69.2% of the convective cells have this characteristic, percentage values are decreasing for deviations of -90 ...- 45° and 45 ... 90 ° (less than 20%), and respectively when the deviation is higher than 90° and less than -90 ° (10-12%). There are some differences depending on the type of instability that generates the convective cells and the atmospheric layers considered for determining the main flow. In the case of instability generated by thermal convection, it can be notice the largest share of small deviations (± 45°) for 400-850 hPa layer, and in case of deviation of -90 ...- 45°/45 ... 90°, the 500-850 hPa layer, deviations up to ± 90° cumulating 83.5 to 84.7% for the two mentioned layers (table 1). A similar situation is encountered in the case of atmospheric instability due to the existence of "cut off" lows, deviations up to ± 45° having the highest frequencies in the case of 400-850 and 500-850 hPa layers (54.2-53.3%). The difference between the two layers is low, but the percentage of deviations lower than -90º and higher than 90º is smaller in the case of 400-850 and 500-850 hPa layers than the 300-850 hPa layer (table 1).

Frontal instability has a smaller deviation angle of convective cells in relation to the main flow (300-850 and 400-850 hPa layers), the values of deviation

percentage up to ± 45° having 77.1 to 80.1% and of up to ± 90° deviations, 95% of convective cells (table 1).

In addition to direction, speed of convective cells is an important element both in forecasting and especially in the effects that can produce over the areas they move. Typically, high-speed movement of cells is associated with reduced amounts of precipitation and low speeds or stationary, with flash floods or large hail, according to the physical environment in which the convective cells grow. In this respect, for the 3 layers analyzed it has been determined the percentage of the speed of convective cells movement in relation to main flow. For analyzing this parameter two elements were taken into account: a higher percentage of deviations up to 100% of the main flow and the percentage of high deviations (over 200% of the main flow) to be smaller.

Tabel. 2. Share of the convective cells' speed deviation to the main flow depending on the type of instability (%)

Layer	**Thermal convection**				**„Cut off" lows**				**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	32.9	47.1	15.3	4.7	40.0	46.7	10.0	2.5	24.4	39.3	33.8	2.5
400-850 hPa	37.6	41.2	14.1	7.1	33.3	50	12.5	4.2	21.9	40.8	34.3	3.0
500-850 hPa	27.1	45.9	22.3	4.7	26.7	35.8	27.5	10.0	15.4	38.3	41.8	4.5

Analyzed situations show that the speed threshold of 50-100% deviation of the main flow has the highest frequencies, regardless of the analyzed layer (39.2 to 43.6%), followed by 0-50% threshold (for 300 - 850 and 400-850 hPa layers) and 100-200% threshold, for 500-850 hPa layer. In the case of instability caused by thermal convection, the highest percentage rates of convective cells' speed deviation to the main flow (up to 100%) belong to the 300-850 hPa layer (80.0%), followed by the 400-850 hPa layer (78.8%), values higher than 200% having the lowest percentage is the case of 300-850 hPa layer, similar to the case of instability generated by the "cut off" lows and the frontal ones (table 2). The highest difference between types of instability is present in the 0-50% and 100-200% threshold due to the main flow speed of the synoptic situations which generate these types of instability (table 2).

4. CONCLUSIONS

Statistical analysis of the direction of convective cells generating heavy rains in the studied area in relation to the main flow notes that the 400-850 hPa layer is more useful in forecasting the direction of convective cells in the case of instability produced by thermal convection and by "cut off" lows. For frontal instability, 300-850 and 400-850 hPa layers are more suited to determine the direction of movement of convective systems.

In the case of small and medium values of convective cells' deviation of direction to main flow (up to 90°) it can be notice some differences between the percentage values of different atmospheric instability. It can be concluded that in the frontal case of instability smaller frequency deviation (up to ± 45°) has higher percentage than in the case of "cut off" lows as a result of extent of movement of the atmospheric fluid according to the synoptic situation, the movement being higher in the frontal cases (especially cold), than in the case of "cut off" lows.

The ratio of the velocity of convective cells' movement to the main flow noted that 300-850 hPa and 400-850 hPa layers have the lowest deviations regardless of the type of instability in which convective cells develop. Also, these layers are characterized by low threshold values of the speed deviation of the convective cells to the main flow of over 200%, with the prevalence of 300-850 hPa level.

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