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A TORRENTIAL PRECIPITATION EVENT IN THE EASTERN PART OF ROMANIA–A CASE STUDY[*]

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Abstract. The case study is focused on the flash flood from 5 September 2007, a (235 mm of rain in 12 hours) occurred in the city of Tecuci (eastern Romania), causing fatalities and numerous properties damage. It was generated by a back-building mesoscale convective system developed in an area with strong warm advection at low levels and diffluent southerly flow at upper levels. Analyses of conventional weather station, radar and high resolution visible satellite imagery, together with ALADIN model analysis, are used to describe the synoptic and mesoscale weather patterns associated with the flash flood. Surface analysis and high resolution visible satellite imagery identified a convergence line that acted to focus thunderstorm development in a limited area. Radar reflectivity indicated that rapid cell generation occurred where the convergent line existed, just north of Tecuci. A strong southerly low level jet focused the most active convection over the same area during several hours. The aim of this paper is to identify the different mesoscale processes leading to continuous regeneration of convection in the same area that contributes to the heavy rain accumulation in a short period of time in the small watershed located in the eastern part of Romania.

Key words: heavy rain, mesoscale convective system, flash flood.

1. INTRODUCTION

Heavy precipitation events in the Romanian territory can be attributed to either convective or non convective processes, or a combination of both. Large amounts of precipitation can accumulate over several day-long periods when one or several frontal perturbations associated with Mediterranean cyclones are slowed down and enhanced by the Carpathian Mountains. These situations are very well known and documented in the specialized literatures [1, 5, 8]. Alternatively, when a Mesoscale Convective System stays over the same area for several hours, significant rainfall totals can be recorded in less than a day. The combination between high rainfall totals and the short period of time can cause severe flash

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flooding. Flash floods produced by mesoscale convective systems are distinguished from floods produced by synoptic-scale cyclones because flash floods tend to evolve on the same time and spatial scale as the intense precipitation, leading to short warning and response time [6]. Forecasting severe convection and flash flooding can be a considerable challenge because flash floods are associated with different storm types and, additionally, are a function of storm location and movement within the hydrological basin.

2. DATA AND METHODOLOGY

The present study evaluates a particular extreme case of long-lived quasi-stationary convective system over eastern Romania. The convective activity started around 0500 UTC, 05 September 2007 over the Carpathian Corner hills, progressed north-eastward while strengthening, and remained near stationary during 12 hours over the southern part of Moldova region. Rainfall in 12 h exceeded 230 mm, caused devastating flash floods in Tecuci city and other localities from Bacau, Vrancea, Galati and Vaslui counties, which result in 7 fatalities and important property damage. This flash flood is the most severe convective flash flood related in the recent history of Moldova. Our goals in this study are, firstly, to identify synoptic and mesoscale processes leading to deep convection producing heavy rain development and, secondly, to find also mesoscale and convective scale factors that take part in making a MCS stationary. The quasi-stationary behavior of convective cells can be explained using the Chappel [2] conceptual scheme in which, convective cells are forced to repeatedly trigger over a given area and are generally transported downstream by the mean tropospheric flow. If new convective cells can regenerate at a rate compensating the advective speed of the older cells, the quasi-stationarity of the mesoscale convective system occurs. Diagnosing deep moist convection producing rain, on the other side, includes an evaluation of basic processes and their possible contribution and interactions (ingredients-based methodology) [6]. This processes go from synoptic scale, which has to produce the favorable environment, to mesoscale, which provides the lifting mechanisms for low-level parcels. A broad range of processes on the synoptic scale (areas of upward motion associated with troughs or upper level jets) to the mesoscale (fronts, convergent lines, sea breeze fronts, upslope winds) and the scale of the convection itself (gust fronts) can create that lift. Synoptic scale and mesoscale processes are evaluated using numerical model parameters from ECMWF and ALADIN data, Doppler radar products, high resolution visible satellite imagery and conventional weather station. The ECMWF (The European Centre for Medium Range Weather Forecasts) is a general circulation model that consists of a dynamical component, a physical component and a coupled ocean wave component. A spectral method is used for the representation of upper-air fields and the computation of the horizontal derivatives. It is based on a spherical harmonic representation, triangularly truncated at total wave number 799. This roughly corresponds to a grid length of about 25 km. For the representation at the surface and for the model physics a grid point system is used instead of a spectral formulation. The ALADIN (Aire Limitee Adaptation dynamique Developpement InterNational) is a limited geographic areas model coupled with model ARPEGE (Action de Recherche Petit Echelle Grande Echelle). Both models use the spectral technique for the horizontal representation of fields. The ALADIN model works with small domains and high spatial resolution (10 km); the important meteorological events at these fine scales (local winds, breezes, thunderstorms lines, etc) are mainly the result of a so-called “dynamical” adaptation to the characteristics of the earth's surface. Since 2002, the operational network of five WSR-98 D (Weather Surveillance Radar) and two EEC-DWSR-2500C Doppler radars is in place. These radar network system contains numerous algorithms that use Doppler radar base data (reflectivity (dBZ) and velocity (m s^{-1})) as input to produce meteorological and hydrological analysis. The WSR-98 D is an important tool in detecting and forecasting severe storms, tornadoes, flash floods and other than those directly associated with severe storms (convergence lines, land/sea breeze fronts, gust fronts). Convective scale processes are identified using radar conceptual models.

3. ANALYSIS OF THE FLASH FLOOD EVENT

3.1. ANALYSIS OF SYNOPTIC SCALE CONDITIONS

The 500-hPa analysis, as derived by the operational ECMWF model is shown six hours before the event began (Fig. 1a) and during the event. At 0000 UTC (Fig. 1a) a large-size trough with cut-off low at 5520-gpm height was reaching the west of Romania, while a large upper ridge was situated over Eastern Europe. The 1200 UTC situation (Fig. 1b) showed a tilting of the trough associated with a rapid decreasing of geopotential values over the Romania and with strong upper level cold advection. Between these both large-scale structures, prevailed an intense upper level southerly flow.

The frontal analysis for 0600 UTC 05 September 2007 is represented in Fig. 2, illustrating the mean sea level presure field and 850-hPa temperature isolines from ECMWF analysis (Fig. 2a) and mean sea level pressure field and wind barbs at 10 m from ALADIN analysis (Fig. 2b). The Azore 1030-hPa ridge has moved into west Europe, while in east Europe was a low with Mediteraneean origins. The warm front associated with this low was situated over the south-weaster part of Romania, and the cold front was advancing rapidlly towards south-east Europe. The ALADIN model revealed presence of two surface lows, one in the south of Romania and second in central part of Romania (Fig. 2b). These lows drove southeasterly flows into eastern part of the country and the frontal analysis was made according with these mesoscale circulations.

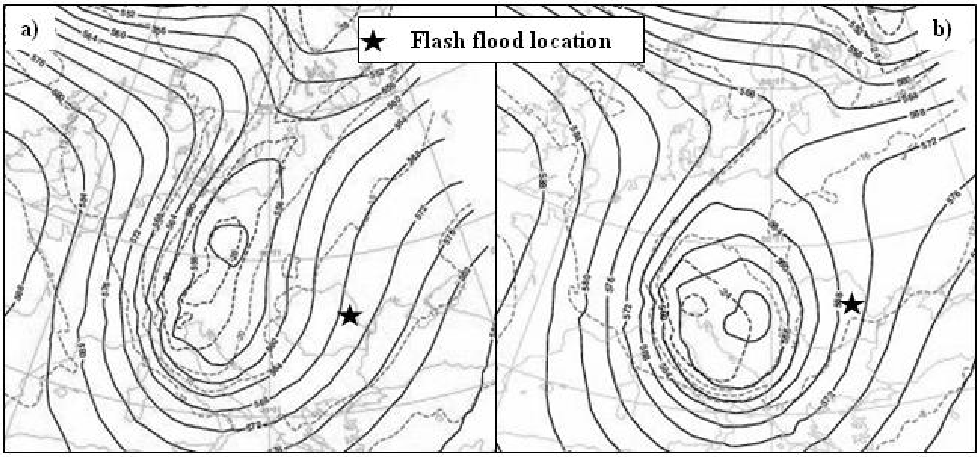

Fig.1 – 500 hPa surface geopotential contours (thick lines at 4 gpm interval) and temperature contours (dashed lines at 4^0C interval) at 0000UTC (a) and 1200 UTC (b) 05 September 2007 from ECMWF model analysis. The flood location in marked with a black star.

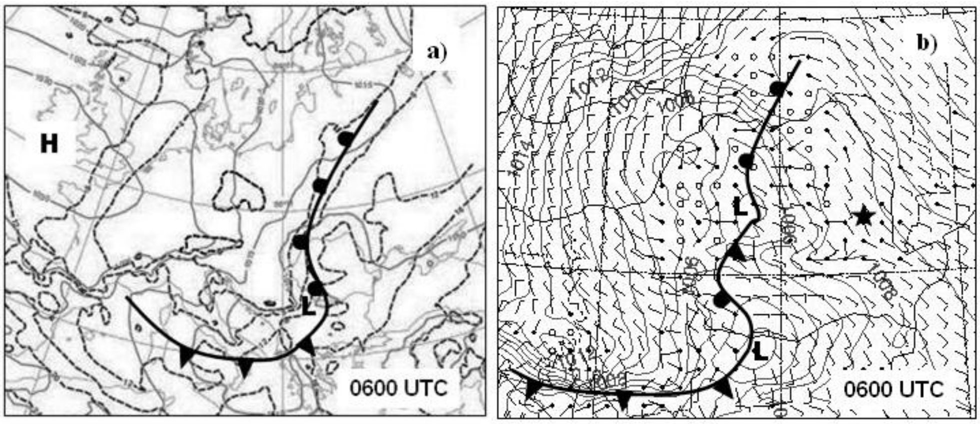

Fig. 2 – The frontal analysis for 0600 UTC 05 September 2007: a) the mean sea level presure field and 850-hPa temperature isolines from ECMWF analysis; b) the mean sea level pressure field and wind barbs at 10 m from ALADIN analysis. Frontal drawing are convectional. The Azore 1030-hPa high is depicted with "H" and Romania lows with Mediteraneean origins are depicted with "L". The flood location in marked with a black star.

The maximum wind speed analysis from ECMWF model at 300 hPa and 500 hPa levels for 12 UTC (not shown), revealed a jet down to 500 hPa with jet streaks reaching 60 ms^{-1} at 300 hPa level and 40 ms^{-1} at 500 hPa level. The eastern part of the country was situated in the exit region of the upper level jet. The roles of tropospheric jet streaks to enhance upper level divergence associated with convergence at lower levels are summarized by Keyser and Shapiro [7]. Consequently, upper level and low level jets, under suitable conditions are coupled through their vertical circulations and related to the organization of an environment conductive to the initiation and organization of severe convective storms.

Persistence of a mid-to-upper level ridge increased the amplitude of the upper level trough that, in turn, may have acted to increase upper-level divergence over the eastern part of Romania. In this context, a large scale source of upward vertical motion at large scale, was present.

3.2. ATMOSPHERIC INSTABILITY AND DEEP CONVECTION CONDITIONS

Because eastern Romania was situated in the warm sector, the 00.00 UTC and 1200 UTC 5 September 2007 soundings at Bucharest were representative for the advected flow. They showed the presence of the intense moist southerly flow, both in the night and the daytime. The low level wind velocities were more intense in the night with values about 10 m·s^{-1}, and mean mixed layer mixing ratio was about 10 g·kg^{-1}. In the 0000 UTC sounding the winds also veered from the east to the south until 500 hPa and were south-south west above this level, indicating the presence of warm advection (not shown). The 1200 UTC sounding from Bucharest showed strong southerly winds (20–30 m·s^{-1}) above 500 hPa, associated with a dry layer revealing the existence of an upper level jet (not shown). Over the night, CAPE (Convective Available Potential Energy) was 111 J·kg^{-1} and CIN (Convective Inhibition) was 231 J·kg^{-1} as a consequence of a strong inversion close to the ground. During the day, CAPE was 295 J·kg^{-1} and CIN (Convective Inhibition) was 65 J·kg^{-1}. Stability indexes exhibited some probability of convection since the Lifted index (LI) was -1.14, the K index (KI) was 24.9 and the Total Total's index (TT) was 45.

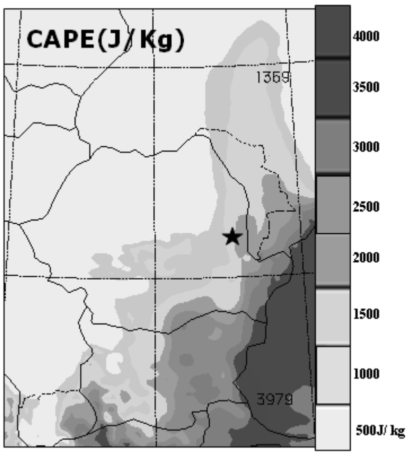

Fig. 3 – Spatial distribution of CAPE (Convective Available Potential Energy) at 0600 UTC 05 September 2007 from ALADIN model analysis. The flood location in marked with a black star.

Spatial distribution of CAPE from ALADIN model analysis at 06 UTC (Fig. 3) showed values from 1000 and 4000 J·kg^{-1} over the south and eastern part of the country with greater values in the extremities of this region. The analysis of the radiosonde data from Bucharest, together with the ALADIN model, reveals that the air mass towards the south and eastern part of Romania was conditionaly unstable and could support the convection development.

Another diagnosis for vertical motion can be deduced by looking for a source of lift at mesoscale. If mesoscale lifting mechanisms for convective initiation are present, associated with warm air mass, mesoscale processes can further increase the convective available potential energy and vertical wind shear locally. Over eastern Romania surface convergence lines are the main source of mesoscale lift. An area with surface convergence was clearly visible at the 0300 UTC associated with wind directions reported by the ground meteorological stations situated in the south of Moldova region and north of Muntenia region (Fig. 4a). In the south-east of Romania south-eastern flow blowing toward the Carpathian Curvature is forced to separate in two main directions: to the north into south Moldova region and to the west into eastern Muntenia. This created a convergent flow between meteorological stations situated in the hilly part of the Carpathian Curvature and Moldova region and for those situated in the plain.

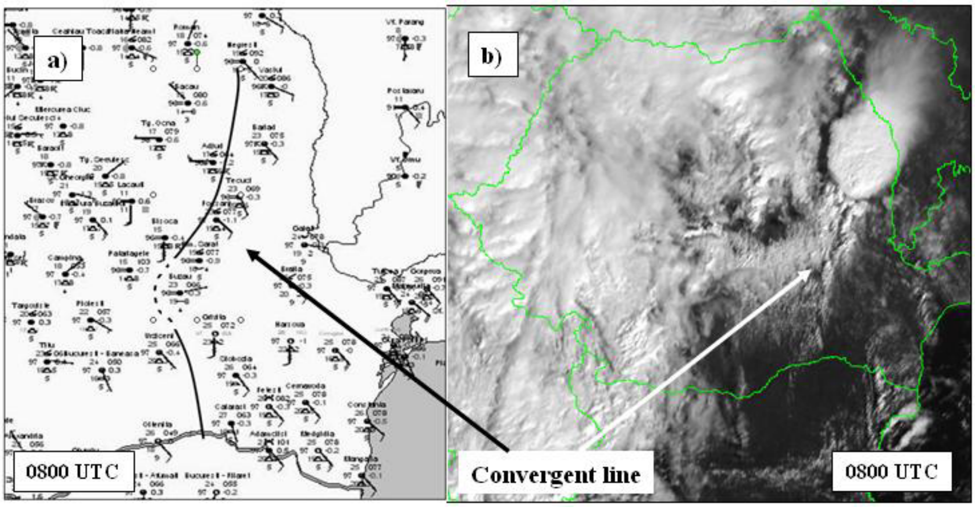

Fig. 4 – Convergence line at 0800 UTC 05 September 2007: a) in the wind directions at 10 m reported by the ground meteorological stations. b) in METEOSAT high resolution visible satellite image. Observation plots are conventional.

The Meteosat Second Generation high resolution visible satellite image revealed initiation and development of the convection at 0800 UTC (Fig. 4b) directly in this convergence area.

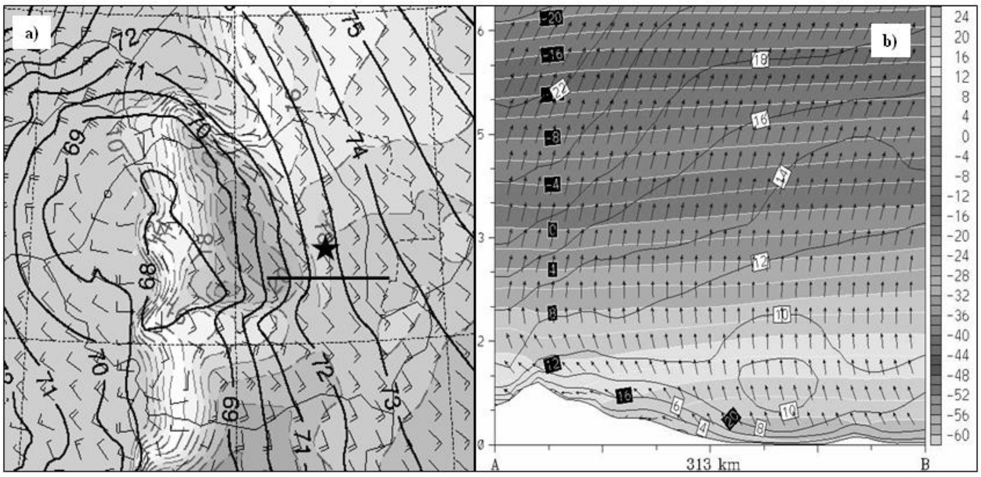

Fig. 5 – a) 925 hPa surface geopotential contours (thick lines), temperature contours and filled (dashed lines) and wind barbs at 0600 UTC 05 September 2007. b) Cross section along line from Fig. 5a (from west to east) at constant latitude situated at south from the flash flood area. The flood location in marked with a black star.

The west-east vertical cross section shows the wind and temperature fields obtained from the ALADIN analysis valid at 0600 UTC 5 September (Fig. 5b). This vertical cross section is taken at a constant latitude crossing an area situated at south from the flash flood area (along line from Fig. 5a). Wind is depicted as isotachs every 5 ms^{-1} and as arrows for velocity and direction. One relative maximum of the wind is located approximately at 1000 m and has values of velocity greater that 10 m/s. (Fig. 5b). This low level jet is associated with a warm sector at 925 hPa-level delimitated very well in the field of temperature (dashed line in Fig. 5a). Also, in vertical cross section (Fig. 5b) the wind veers from south-east at low levels, to south at upper levels, indicating the presence of warm advection.

3.3. EVOLUTION OF THE CONVECTIVE SYSTEM FROM RADAR IMAGES

The mesoscale convective system was observed with METEOSAT high resolution visible satellite system (Fig. 6a) and Barnova (Iasi) S-band WSR-98 D radar system (Fig. 6b). At 1200 UTC 5 September 2007, the Doppler radar system displayed values of reflectivity at 0.5^0 elevation greater than 45 dBZ and at some points reaching 60 dBZ (120 mm·h^{-1}) in the area of Barlad catchment (Fig. 6b). Between 0800 and 1800 UTC mesoscale convective system was roughly linear and south-north oriented along the main axis of the Barlad catchment, with greater values of reflectivity detected in this area. The mesoscale convective system extension was about 120 km and remained active until 2030 UTC, when the cold front passed this region.

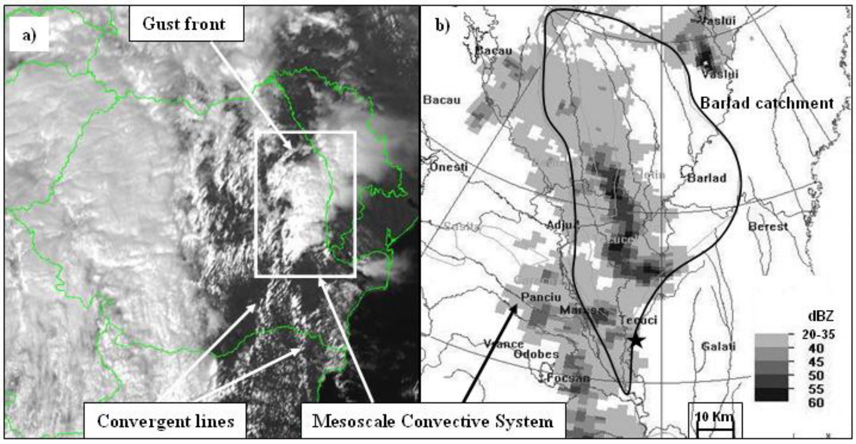

Fig. 6 – Mesoscale convective system from eastern Romania at 1200 UTC 05 September 2007 observed with: a) METEOSAT high resolution visible satellite image (white rectangle) and b) Barnova (Iasi) S-band WSR-98 D radar image. The high resolution visible satellite image detected two convergent lines situated in the eastern part of the country and the gust front north of the convective system. At 1200 UTC, values of radar reflectivity at 0.5^0 elevation were greater than 45 dBZ and at some points reached 60 dBZ (120 $\text{mm}\cdot\text{h}^{-1}$) in the area of Barlad catchment (b). Between 0800 and 1800 UTC the mesoscale convective system was roughly linear and south-north-oriented along the main axis of the Barlad catchment, with greater values of reflectivity detected in this area. The flood location in marked with a black star.

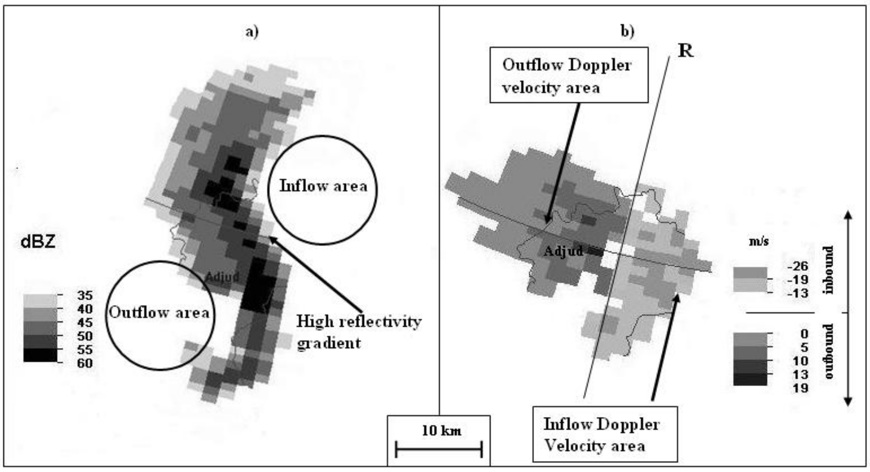

Fig. 7 – WSR-98 D radar data from Barnova (Iasi) at 07.53 UTC 5 September 2007. The radar site is locared 200 km from Adjud city in a north-west direction marked with "R" and line is radar range against which the Doppler radial velocities are interpretated. a) Reflectivity (dBZ) at 0.5^0 elevation showing structure of super cell that affected Adjud city, with inflow, outflow area and high reflectivity gradient associated with inflow area. b) The Doppler radial velocity (m/s, negative values are inbound velocity and positive values are outbound velocity) showing the mesocyclone structure. The inbound values are inflow Doppler radial velocity towards the radar, and outbound values are outflow Doppler radial velocity away from the radar. These circulations suggests the cyclonic rotation associated with a supercell .

The convective cell was well developed early in the day. Thus, at 07.53 UTC, radar reflectivity and Doppler radial velocity products at 0.5^0 elevation depicted rotational features (Fig. 7). Reflectivity (dBZ) at 0.5^0 elevation shows the structure of a supercell that affected Adjud city, with inflow area, outflow area and high reflectivity gradient associated with inflow area. The inflow and outflow area are associated with updraft and downdraft, respectively and high reflectivity gradient suggest the presence of the low level jet (Fig. 7a). The negative values of the Doppler radial velocity are inflow velocities towards the radar and the positive values are outflow velocity away from the radar (Fig. 7b). These circulations suggests the cyclonic rotation (mesocyclone) associated with a supercell. Combination of the low level jet and rotating updraft can increase the high rainfall rain potential [6]. Several surface stations provided *in situ* observation of this system, confirming the high peak precipitation rates observed also in radar products: 60 mm in 60 min in Adjud city, and 90 mm in 90 min at Podu Turcului village when a second supercell with rotating updraft was detected by WSR-98 D from Barnova at 1038 UTC (not shown). The subsequent effect of the high rainfall rate associated with these two supercells is the cold outflow from downdrafts that create a cold pool along the earth's surface. The periphery of a cold pool, that is the gust front, tends to elongate in the direction of the mean wind [4]. In our case, the preexisting convergent line was parallel with the mean wind, and the gust front from the strong convection could increase the low level convergence along the boundary. In this way the region of lower tropospheric convergence was a combination of mesoscale and storm scale processes. The maximum rain accumulation generated by system was 235 mm in 12 hours at Podu Turcului village (Fig. 8a).

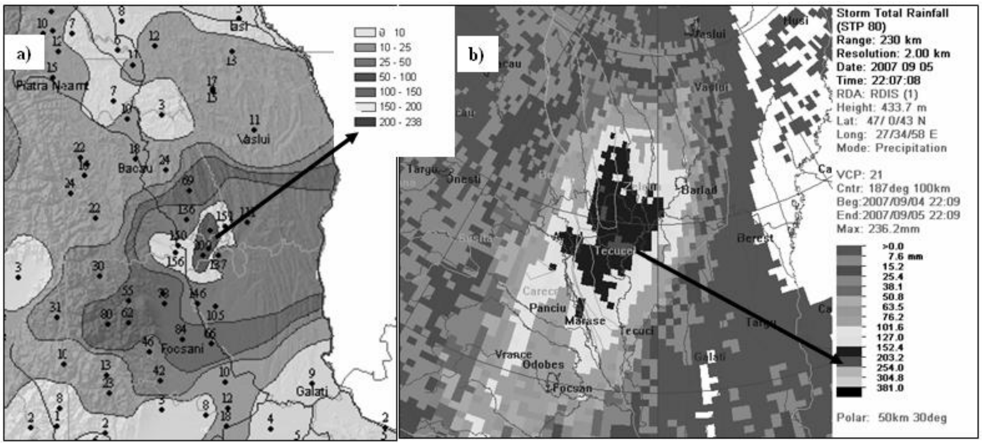

Fig. 8 – Total amount of rainfall accumulation in 24 hours: a) from rain gauge observational stations between 0600 UTC 05-06 September 2007 and b) from Storm Total Rainfall S-band WSR-98 D radar product between 22.09 UTC 04-05 September 2007. Radar accumulation interval was fixed for 24 hours but, in this interval of time the radar algorithm for accumulation only used data from this event.

The 24-h Storm Total Rainfall product from WSR-98 D estimated very well the total amount of precipitation associated with this system, comparing with rain observation at the surface (Fig. 8b), despite the known problem arising from using radar estimate rainfall quantitatively. Radar accumulation was calculated from 22.09 UTC between 04 and 05 September 2005. In this interval of time the radar algorithm for accumulation only used data from this event. Maximum radar rainfall accumulation was 236 mm for 12 hours corresponding with rain accumulation at the surface station that was 235 mm in 12 hours at Podu Turcului village.

The motion of the 5 September 2007 eastern Romania mesoscale convective system was analyzed using the Corfidi empirical technique [3], which considers that the motion of a convective system is the sum of an advective component, given by the mean motion of the cell composing the system, and a propagation component, defined by the rate and location of new cell formation relative to existing cells. Overlapping the direction of the mean wind and low level jet above mesoscale convective system observed with radar at 1200 UTC (Fig. 9, left), we find that the direction of the new cell formation (observed using radar loop) relative to existing cells was rearward in the opposite direction of the low level jet.

The mean wind and low level jet magnitude and direction are approximated using the ALADIN model data. The direction and magnitude of the speed of movement of the system observed with the radar loop was in accord with that obtained using the Corfidi technique (Fig. 9). Decaying cells moved downstream in the direction of mean wind and were replaced by cells reaching their mature stage, behavior that appears in radar data as an unmoving area of high reflectivity.

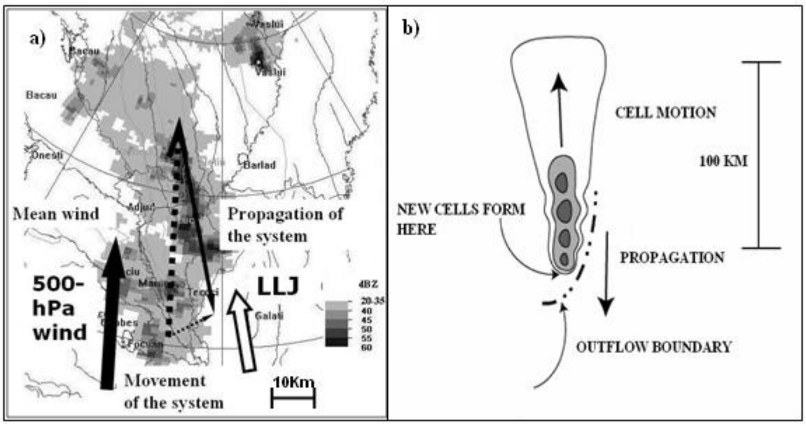

Fig. 9 – a) Schematic drawing of the mesoscale convective system motion as the vector sum overlaid on radar reflectivity image at 1200 UTC. The movement of the convective system (thin dotted arrow) is the sum of an advective component, given by the mean wind (thick dotted arrow), and a propagation component (thin arrow) in the opposite direction of the low level jet (white arrow). The vector that represent cell advection by the mean wind is taken to be the direction and magnitude of the 500-hPa level. b) Back-building mesoscale convective system conceptual model from Schumacher and Johnson [9]. Contours and shadings represent approximate radar reflectivity values (20,40 and 50 dBZ), arrows represent cell motion and cell propagation component of the movement of the system and dashed line represents outflow boundary.

The motion of the 5 September 2007 eastern Romania mesoscale convective system was in accord with the back-building propagating mesoscale convective system conceptual model described by Schumacher and Johnson [9] and presented in Fig. 9. The only difference is the Schumacher and Johnson [9] conceptual model was rotated 90^0 compared with the typical west flow pattern in the United States.

4. SUMMARY AND CONCLUSIONS

A description of a deep moist convective event which produced flash flood over eastern Romania has been presented. The meteorological synoptic-scale and mesoscale context were analyzed and the evolution in which the mesoscale convective system was embedded was described. At the synoptic scale, the meteorological pattern for this case was characterized by a deep cyclonic circulation generating a strong diffluent southerly flow over the eastern part of the country. This upper-level trough with cut-off low moved slowly to the west of Romania due to the blocking ridge located over eastern Europe. The surface pattern revealed a low pressure area situated in the western part of the country while the eastern part was situated in an area with strong warm advection. These low-level synoptic patterns induced an intense south-easterly low-level jet which favored a strong low level moisture transport and significant conditional convective instability over the flooded area. For this torrential precipitation event the basic processes for a flash-flood producing system, as pointed out by Doswell [6], were present: a conditionally unstable atmosphere and moist low levels in the presence of large scale forcing and mesoscale lifting mechanism provided by low level convergence. Even though synoptic-scale processes provided necessary conditions for the convective activity, factors at mesoscale and storm scale contributed to continuously focus the activity over the same region. The movement of the mesoscale convective system was modulated by the low level jet. The south-south-east low level jet oriented approximately parallel with the convergence line, determined the development of convective cells in the rear part of system, and the new cells repeated the movement along the convergence line. This pattern was in accord with back-building or quasi-stationary propagating mesoscale convective system conceptual model described by Schumacher and Johnson [9]. Quasi-stationary mesoscale convective system are particulary efficient in term of rain production due to their high intensities and their spatial stationarity [2]. This type of organization of the convective system has created high rainfall accumulation in a short period of time (236 mm in 12 hours in the are of Barlad catchments), but the magnitude and orientation of the hydrological basin was the factor that marked the differences between a torrential precipitation rainfall and a flash flood event. The location of the Barlad catchments with the mean axis south-north orientated, parallel with the linear convective systems, increased the impact of the high rainfall accumulation and contributed to the flash flood potential.

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