

HEAVY PRECIPITATION IN A CASE OF SEVERE CONVECTION

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Abstract: Precipitation amounts recorded on 6 August 2009 over only a few hours and related to a Central Wallachia dynamic thermal convection, easily reached and topped the climatologic norms for the entire August. Therefore, this case was detailed from a synoptic scale down to the inner physical process of convective organization. Once again, as regards the extra-Carpathian region, orography played an important part in local scale circulation. Since these motions and their interference on convergence lines have been studied by several distinguished Romanian meteorologists, my intention was to put together in this paper standard as well as new forecasting elements in order to provide forecasters with a short-range forecasting methodology wherein the initial state of the atmosphere should have a special importance for the further understanding of such phenomena. In the evening of 6 August 2009, every basic ingredient that initializes and develops convection was present: high humidity in the low level layers, a vertical stratification of the atmosphere that allows a positive buoyancy and forcing mechanisms for the mesoscale ascending motion (ground-level convergence line and gust front) that lifts air particles to the level of free convection (LFC). The upward and downward velocities were clearly influenced by a super-adiabatic gradient in the first 1000 meters and by two mid-troposphere dry areas - When condensation products reached the first dry layer, there occurred a temperature-decreasing evaporation, the difference between particle temperatures on that level and the environment temperature increased, and particle buoyancy got higher – which led to an explosive convection. A mesoscale analysis of the pressure field at two synoptic moments of reference (12 and 18 UTC) was able to capture the local-scale evolution of this phenomenon. Therefore, as regards the nowcasting activity, it is recommendable to establish a methodology whereby the initial state should be analyzed as laboriously as possible in order to understand the evolution of phenomena.

1. INTRODUCTION

From climatological point of view, August is generally a dry month in Romania, hot and dry air masses of tropical origin prevailing. Therefore, precipitation are rather rare and mostly of a torrential type. During August 2009, has been poor in precipitation, but in central and northern Wallachia rainfall amounts exceeded August's multi-annual

means, having been recorded levels above 200 mm in the northern part of the Arges and Prahova Counties. As a particular case, in the evening of 6 August 2009, the monthly mean over the entire month for Bucharest was reached in only a few hours. Given these facts, the first decade of this month brought significant rainfall levels in most Romania, while over 4-7 August 2009 – interval including the analyzed

case - phenomena were very intense and frequent, making the subject of a meteorological warning.

On synoptic scale, there were favorable conditions for interference between warm humid air above the Black Sea and cold air descending along the eastern side of the Eastern Carpathians. Orography also played an important role in the air flow over the extra - Carpathian region of Romania.

The atmospheric dynamics in the area encompassed by the Carpathians and the Balkans has been approached by various Romanian meteorologists such as Ion Bordei (2008), Ion Bordei (2009) and Stan-Sion and Soci (2005).

Together with the previously edited ones, this paper is of peculiar practical importance, as it targets the short-range operational forecasting activity. In comparison to other papers, this one brings together various diagnosis and forecasting elements, among which the initial conditions play a very important role in understanding the further evolution of weather phenomena. The initial state of the atmosphere has been developed using the dataset from SATREP (Satellite and Report). Originally the SATREP is a written report containing information of the Infra Red METEOSAT image in combination with Numerical Weather Prediction-NWP output and observations in terms of Conceptual Models), that combines satellite images with various parameters from the numerical models. Besides those data, the pressure field at mesoscale at two synoptical terms was also analysed. Using the upper-air sounding performed at Bucharest-Afumati, it was possible to establish the way convection was organized on that day and the phenomena expected to occur at ground level.

Details about data and methods used in this paper are presented in Section 2. Initial conditions contributed to the sever

weather phenomena mentioned and detailed analysis on several spatial scales are presented in sections 3 to 6. Conclusions are summarized in section 7.

2. DATA AND METHODS

This study analysis tracked every available meteorological data type, so as to achieve step by step a display as clear and detailed as possible of the phenomenon occurred in the evening of 6 August 2009. Thus, the first stage was to identify the general synoptic frame, using the sea level pressure field, associated with frontal analysis and the absolute topography of 500 hPa.

The following stage consisted in identifying a number of meteorological parameters indicating potentially severe weather for the analysed region, 6 hours ahead of the phenomenon's occurrence. SATREP and ECMWF (European Centre for Medium-Range Weather Forecasts) analysis made it possible to highlight several meteorological parameters that were indicating a high degree of unsettlement - potential temperature at the level of 850 hPa, TFP - the thermal front parameter, CAPE, - the convective available potential energy and the thermal advection at the level of 700 hPa.

Gradually the passage was made from the synoptic scale and the mesoscale to the local scale, which meant detailing the sea level pressure field at the level of Romania - plotting the isobars every mb at the synoptic terms - the first map before the beginning of the phenomenon, at 15:00 L.T. and the second, at 21:00 L.T. as the phenomenon was unfolding. In that same stage, the upper air sounding for Bucharest helped tracking the atmospheric unsettlement degree and the type of convection that was to occur and there were identified: the condensation level, the temperature that had to be reached at ground level for

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convection to initiate, the level of free convection, the equilibrium level and the positive area where the particle was warmer than the environment and had a positive floatability and not lastly the vertical wind shear. Also the low level jet was highlighted with the help of reanalysis data from NCEP-NCAR (National Centers for Environmental Prediction-National Center for Atmospheric Research) and the geopotential field at the level of 850 hPa was subsequently built, which was also made possible by the VAD wind profile (velocity/azimuth display) radar product from Medgidia.

To describe the phenomenon, in the last stage there were used various satellite images RGB¹ Meteosat Second Generation, but also radar products – MOS and ECHOTO, along with the wind field and the precipitation amounts accumulated from radar data.

As regards the methodology, the author attempted to combine classical forecasting elements (like the European sea-pressure level map, together with the frontal analysis, the sea-level pressure analysed at mesoscale and absolute topography data) with new ones (the synoptic forcing was highlighted with the omega equation – ascending speeds, instability indices, equivalent and equivalent potential temperatures), so that this become a working model for the nowcaster.

3. GENERAL SYNOPTIC BACKGROUND

On 6 August 2008, the synoptic overview for Europe looked as follows: the Scandinavian High extended throughout the northern and central regions, the belt together with the Azores Anticyclone

were interrupted in the western part, and the Azores High was located in its place of origin; the Icelandic Low, which was fully developed in its place of origin, affected through its related fronts the western part of Europe and transported a warm air mass to the central-west and north regions – a fact that was also indicated by the presence of a mid-troposphere thermal ridge - up to the northern parts of the Scandinavian Peninsula. In the front part of the Scandinavian High, air moved in from the north so that the air masses descending to the southern latitudes brought about an increased thermal contrast over the Russian Plain. Herein, the low pressure area grew deeper, the cold air circulating in the rear reached higher speeds and the main cold front descended to the northern parts of the Black Sea and Moldavia in the afternoon of August 6 (Fig. 1) South – east Europe together with Romania was placed inside a low-pressure area, the air mass was of tropical origin and the warm ridge remained over Turkey and the Black Sea.

So over the European continent was this a typical blocking structure, with a well developed and stable Scandinavian High, supported by a warm ridge in the mid-troposphere. Therefore, we can speak of a prevailing meridian circulation; the air was transported from south in the western regions and from north in the eastern ones. A new break through of Arctic Ocean cold air came to the front part of this ridge drawing near the northern regions of our country and bringing fresh air on this level (Fig.2). Weak circulation in mid-troposphere above Romania and from the Black Sea, an eastern circulation of warm, humid air was present from ground level to 3000 meters.

¹ technique to allocate a color for each spectral channel – red, green, blue.

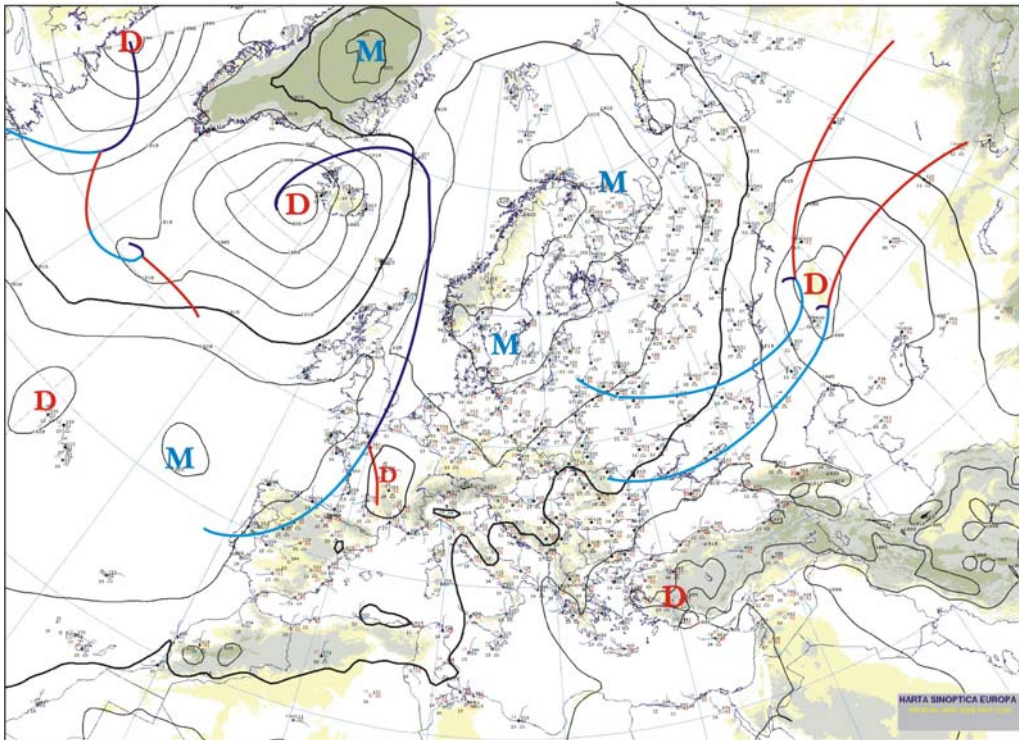


Fig 1. Sea level pressure and frontal analysis - 06 August 2009, 12⁰⁰UTC
ARPEGE analysis –NEXREAP

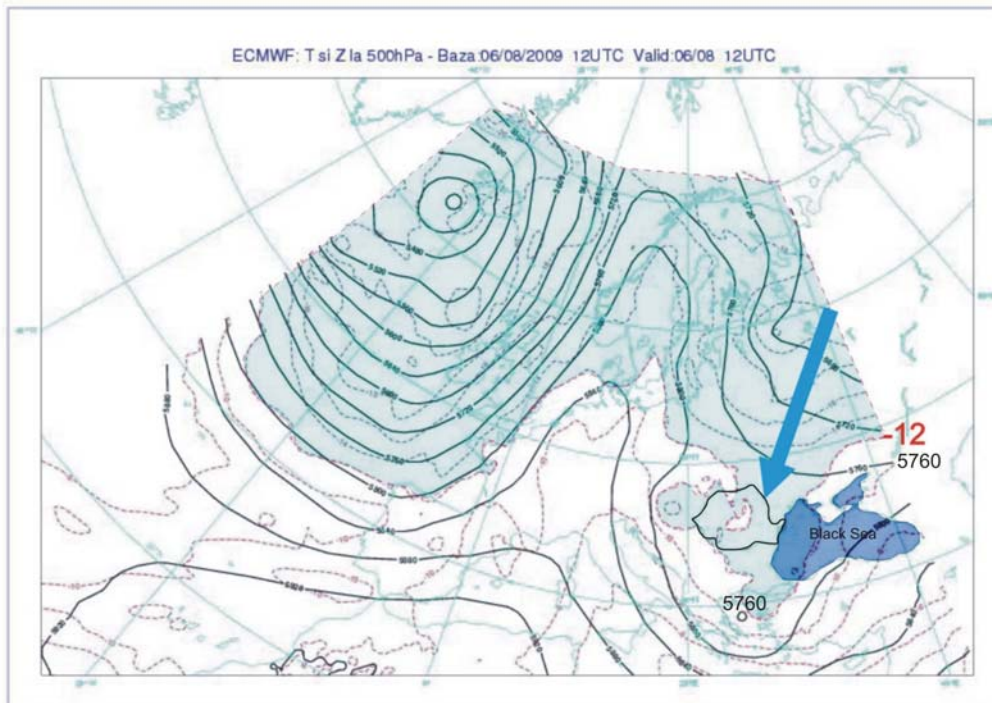


Fig 2. 500 hPa geopotential height (black lines) and temperatures (⁰C, dashed red lines) -
ECMWF analysis, August 6, 12 UTC (intranet - <http://192.168.5.18/>)

4. CONVECTION – TRIGGERING CONDITIONS: ANALYSIS – 12 UTC

Those conditions were assessed as of 12:00 UTC (15:00 LT), three hours before convection initiated in Bucharest and in the surroundings.

For this investigation concerning the moment 6 August, 12 UTC that preceded the phenomena of interest, a number of concluding parameters (ECMWF and NWP analyses) and satellite images (MSG 2) were studied. According to the satellite images, better organized convective structures were already present in the Eastern Carpathians (warm air forced to ascend by the cold air descending near the external side of the mountains), western Dobrudja and northern Moldavia.

The *convective potential* CAPE was very high in south-eastern Romania and

NWP analysis. Those high values of the potential convective energy can be explained through the moisture increase in the lower layer of the troposphere (moisture coming from over the Black Sea) but also from cold air penetration in the mid-troposphere (Fig. 3).

The advection of warm, moist air in the low troposphere is also obvious through the increase of *potential temperature at the level of 850 hPa*, especially in south-eastern Romania, where the highest values occur.

At the level of 700 hPa also, a warm air pulsation is remarkable, especially over Dobrudja and *vertical speeds* were high in the central part of Wallachia.

The cold front associated to the depression situated over the Russian Plain was at that time in the northern part of Moldavia, in Ukraine and in the

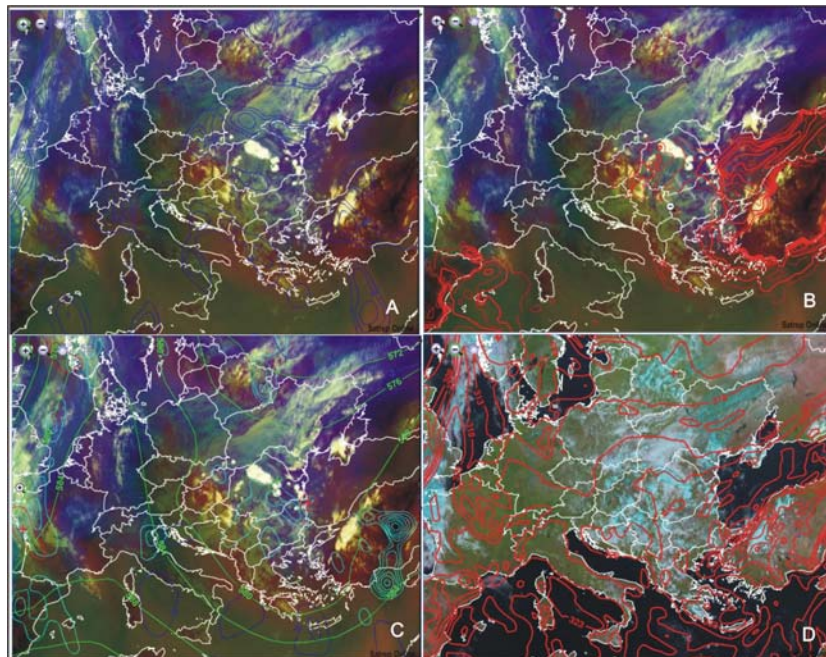


Fig. 3. Analysis: ECMWF, NWP, Meteosat Second Generation , August 6, 12 UTC: A) Air mass RGB, TFP – frontal parameter; B) Air mass RGB, CAPE; C) Air mass RGB, red/blue – thermal advection at 700 hPa, green hgt 500 hPa, turquoise – vertical speeds at 700 hPa; d) Natural colour RGB, ThetaE850 – potential temperature at 850 hPa.

in the west of the Black Sea, as results from this image also, the ECMWF and

Republic of Moldova. As you will see, the cold, dense air found favourable

conditions to infiltrate rapidly by the eastern side of the Eastern Carpathians, down towards the Romanian Plain.

5. AEROSYNOPTIC AND MESOSCALE ANALYSIS

For the same moment, there were assessed the synoptic conditions, however at a local scale, for the extra-Carpathian Romanian areas, but the aerosynoptic ones also, as extracted from the Bucharest upper-air sounding.

Thus, at 12:00 UTC (15:00 LT), an east peri-Carpathian anticyclonic lobe that detached from the Scandinavian High stood out mostly on the eastern side of the Eastern Carpathians, with high

meteorologists in previous studies (for example, Ion Bordei, 2008).

The cold air over Moldavia took a laminar flow by the eastern flank of the Eastern Carpathians, whereas in the curvature area its flow was oriented westwards through the dynamic cavitation effect. On the other hand, an isobaric circulation from Oltenia induced a weaker cold air flux. In the low troposphere, but also at ground level in south-eastern Romania the air circulation has mainly easterly, with a contribution of moisture from over the Black Sea (Fig. 6).

Interferences in air circulation brought about a convergence line in central-south Wallachia.

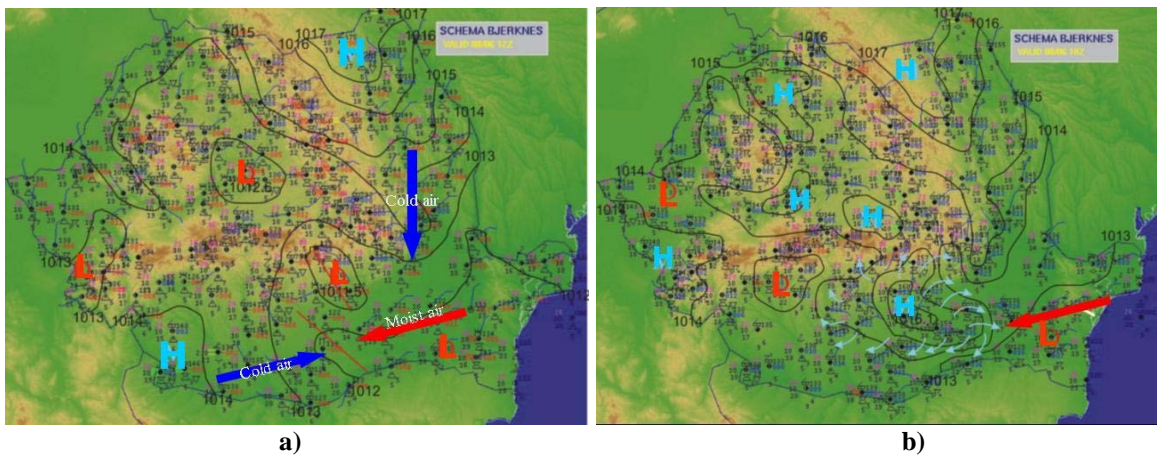


Fig 4 . Mesoscale sea level pressures (hPa) at 12UTC (a) and 18 UTC (b)
Source: maps SIMIN – COF

pressures in north Moldavia, while a second pressure high, related to a pre-existing cold air mass, was present over western Oltenia. Low pressures were recorded in the rest of the territory, the lowest values being seen in Wallachia, where a close nucleus of dynamic cavitation was noticed (Fig. 4a).

Given these initial conditions, the local air dynamics in peri-Carpathian regions could be easily inferred, just like it was also described by other Romanian

This local convergence lasted almost five hours during which the pre-existing warm air mass was gradually dislocated in a vertical direction, while convection showed a pulsating pattern more or less over the same areas. At the same time, amounts cumulated over this interval reached high values.

When reanalysing the sea level pressure at mesoscale level, at 18 UTC 21:00 LT, high pressure area is noticeable in central Wallachia

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(Fig. 4b), associated to a descent of the cold, dense air from the upper tropospheric layers.

A simple analysis would have normally shown conditions for the air column to stabilize (cold air at ground

(Fig. 5) and fresh convective cells with westwards propagation were incorporated into the main system. Thus the system had a pulsating evolution in the same area, given that circulation was weak in the mid-troposphere (Fig 6).

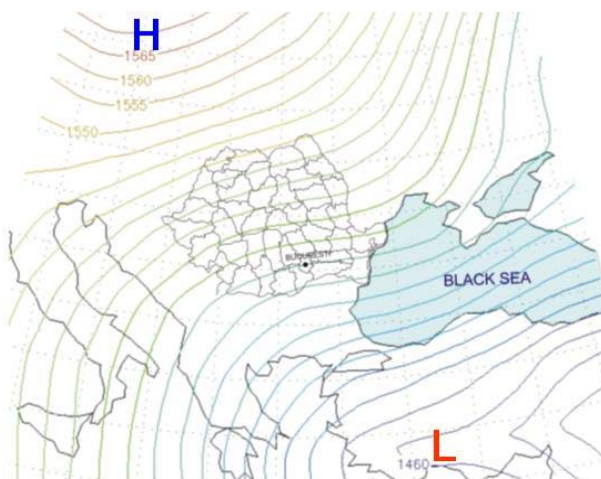


Fig. 5 Relatively intense easterly circulation, from the Black Sea, at the level of 850 hPa – low tropospheric jet, August 6, 12UTC

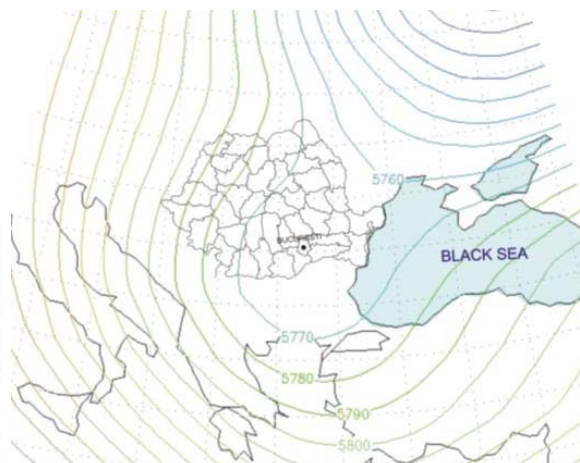


Fig. 6 Weak circulation in mid-troposphere (500 hPa) – favourable to quasi-stationary convective structures that generate flash floods, August 6, 12UTC

level and warm air in the altitude). However, the cold air accumulated in that area spread all around acting like a true gust front. Eastwards, in Baragan area, it encountered the low tropospheric jet

Convection had a typical pulsating evolution: when cold air masses accumulated over central Wallachia, as it clearly appeared on the 18 UTC mesoscale pressure map, they dispersed

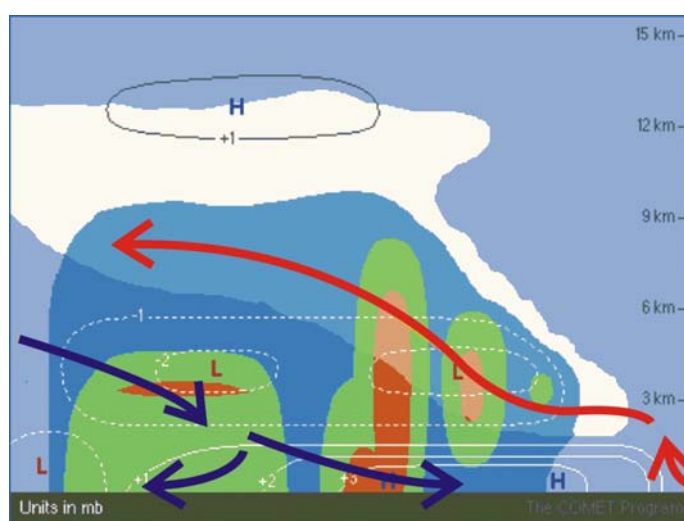


Fig. 7 Vertical section in a mesoscale pulsating convective structure (related phenomena, strong descending currents, maybe tornadoes), structure in its full-grown stage

Source: <http://www.meted.ucar.edu/>

in every direction like a real gust front and met a low troposphere warm, humid air flux over the Baragan Plain, where new westward-moving convective cells appeared. Such new developments were all the time included in the main system (Fig. 7).

The vertical structure of the atmosphere indicated the presence of highly unstable weather conditions. To evaluate them as well as the time when convective developments are triggered, there were identified the characteristic levels and the instability indices for the 12:00 (afternoon) UTC soundings.

Convective temperature is essential to trigger convection. It reached 31°C at Filaret station as early as 13:00 hrs. The level of free convection (LFC) came down from about 2700 m during the night to 2200 m in daytime, while the equilibrium level (up to which air particles have positive buoyancy) maintained above 11000 meters, where on air temperature was -54 °C.

radio sounding was necessary suitable for quite unstable atmosphere with a vertical gradient of 1,2°C/ for 100 m in the first 1000 meters.

The vertical distribution of winds indicated anticyclonic motion, from the east in the lower troposphere to the west in the high troposphere. In the first 3000 meters, there was an easterly circulation of 5-7m/s, a warm, humid air mass that increased the lower-layer humidity and supplied the storm.

This is also ascertained by the wind profile above the Medgidia radar (fig 9), which points at this clockwise (anticyclonic) rotation, but also maxim speeds at the 600 m level of about 14 m/s, that can be associated to a low-level jet. The vertical wind shear along with the moisture contribution made it possible for convective developments to be organized as super cellular structures, the most sever of which- close to Calarasi, where hail was reported, along with wind in excess of 25 m/s.

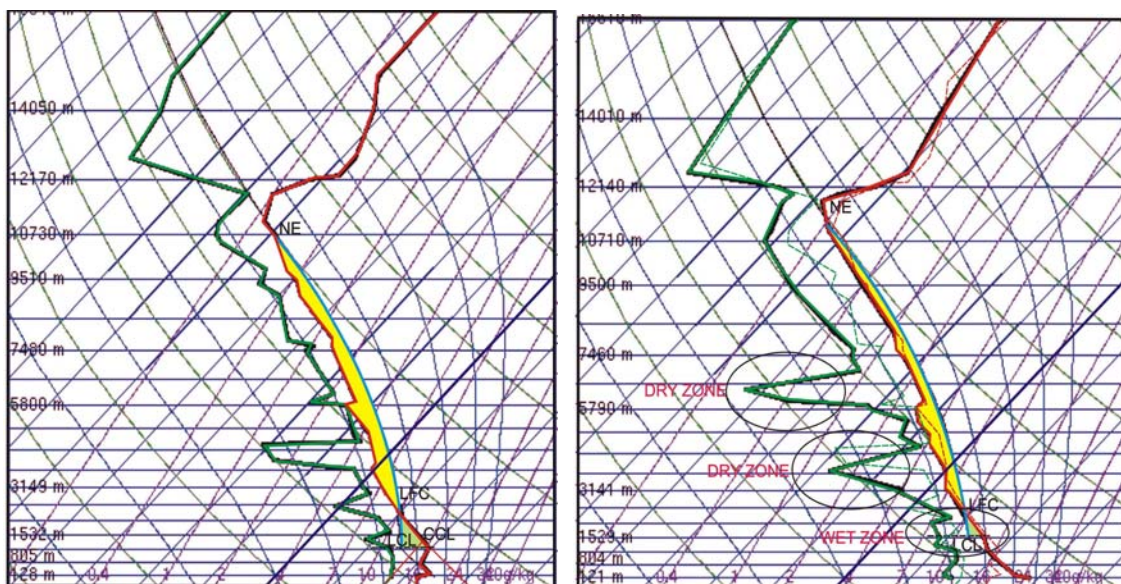


Fig. 8. Upper-air sounding in Bucharest (diagram Skew-t) – 6 August 2009: left at 03 LT (00UTC) and right 15 LT (12 UTC) Source: University of Wyoming

Available potential energy (CAPE) was around 650 J/kg, while inhibition energy reached low values (Fig. 8) A

Specific humidity reached high values (12-13 g/kg), typical of tropical air masses, while dew-point temperature was

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14-17 degrees. Up to 1000 meters, there was a warm, humid layer. It is interesting that, at noontime, two dry areas appeared, at about 3500 m and the second at 6000 m (Fig.8 right), which can explain this afternoon's deep convection.

In most analyzed cases, the presence of such dry areas helped the dry, low-

to the Calarasi and Ialomita Counties like a well-organized linear system and also as a supercell structure nearby Calarasi. (Fig. 11) Wind gusts, electrical discharges, hail falls and torrential rainfalls were more intense and more frequent. Winds reached 20 m/s at Slobozia and 25 m/s at Călărași, where

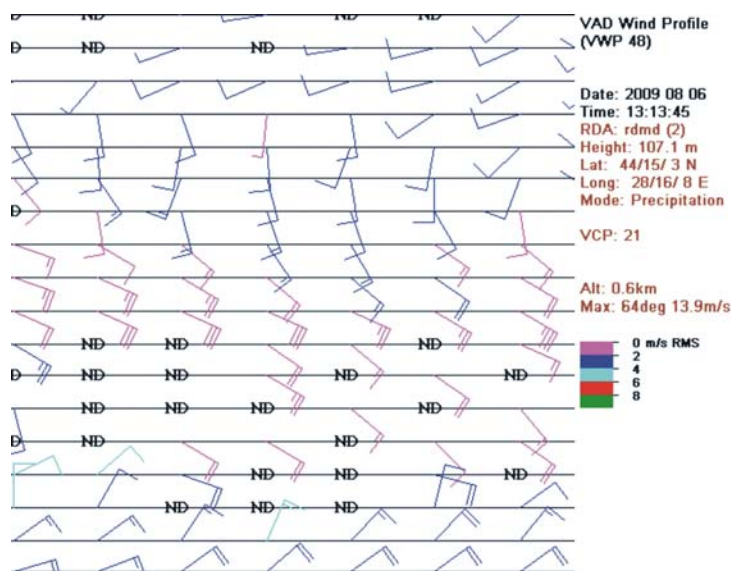


Fig. 9. Wind profile above the Medgidia radar – clockwise (anticyclonic) rotation – maximum speeds of about 14m/s at an altitude of 600 m (2000 feet), August 6, 13 UTC

laying, moisture-rich air (wet microburst) get into a forced descent, which caused squall-like winds at ground level and sometimes, when the 0°C isotherm was low, severe hail falls.

6. EVOLUTION OF PHENOMENA AND THE ORGANIZATION OF CONVECTION

During the first part of the day, fine weather and clear skies prevailed in south-east Romania, which favored an increase in diurnal temperatures up to 32...33 degrees and led to a higher vertical thermal gradient and to the convective temperature being reached. First convective developments showed up right after noontime in western Dobrudja and the mountain area of the counties Prahova and Buzau.

The west Dobrudja convective cells grew rapidly (Fig.10) and moved slightly

hail falls and torrential rain were seen from 16:30 to 17:30 and cumulated precipitation reached 41 mm.

At the same time, convective developments appeared on the convergence line, west and north-west of Bucharest. Those from the mountain area extended westward and southward to the Dâmbovița County, merging with the above-mentioned ones. From 16:45 to 17:45, cumulated precipitation reached 50 mm at Colacu (Dâmbovița County) and gale-like winds were recorded at Videle (Teleorman County).

Detached from the east Wallachia convective structures, the gust front dislodged the warm air and generated a new linear convective system in the western part of the Ialomita and Călărași area. It merged with the west, north-west of Bucharest one around 18:00 hrs (local time).

Given these conditions, the new

convective system had a marked development related to a forced upward motion of warm air on the ground-level convergence line. It extended also over the largest area, including the counties Dâmbovița, Prahova, Giugiu, and Ilfov, the western part of Teleorman County and the city of Bucharest. The clouds extended rapidly up to 12-13 km in altitude (Fig.12) – above tropopause (- 60° RGB 20) – and reflectivity reached a high of 45-50 dBZ (radar mosaic) over Bucharest. In the above-mentioned counties, highly unstable weather

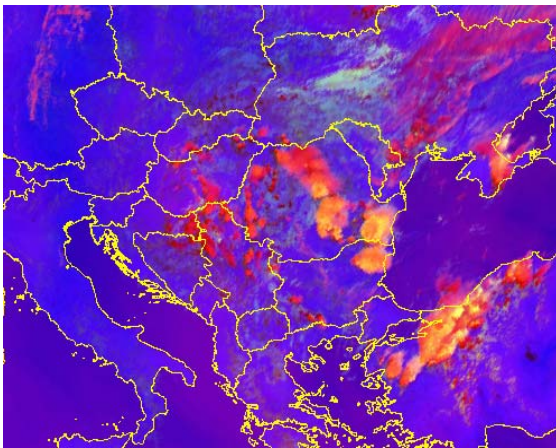


Fig. 10. Severe storm RGB, August 6, 13 UTC

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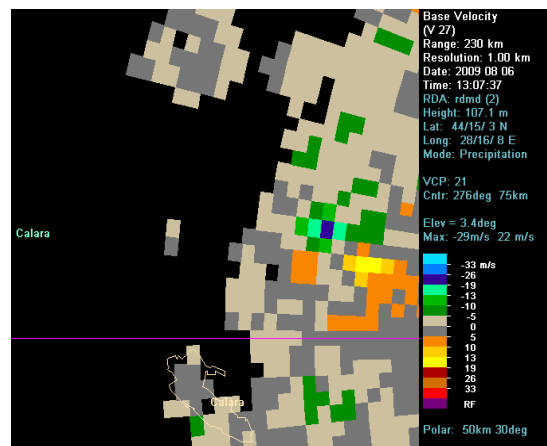


Fig. 11. Supercell structure nearby Calarasi, August 6, 13 UTC

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In the first phase, Bucharest saw an intense storm, wind gusts caused by

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humid air downbursts and a visual phenomenon – areas where clouds descended under their unusual level, which was mistaken for a tornado. Shortly, before 18:00 a heavy rain started. 10 mm were already reached at 18:10, 21 mm at 18:30 and 26 mm at 18:40 in less than one hour at the Filaret station, which issued a warning.

Rainfalls continued and another 15 mm accumulated by 19:30. After 20:00 hrs, rain fell intermittently until midnight,

matter of fact, this idea is also suggested by the very clear radar image (Fig. 13) (mos and echotop) of a mesoscale cyclonic vortex.

The mesoscale cyclonic vortex was caused by a release of latent heat of condensation and an implicit increase in isentrope gradient³. As an effect, potential vorticity advection led to the mesoscale cyclonic circulation.

Finally we can speak about a mesoscale convective system; a classical

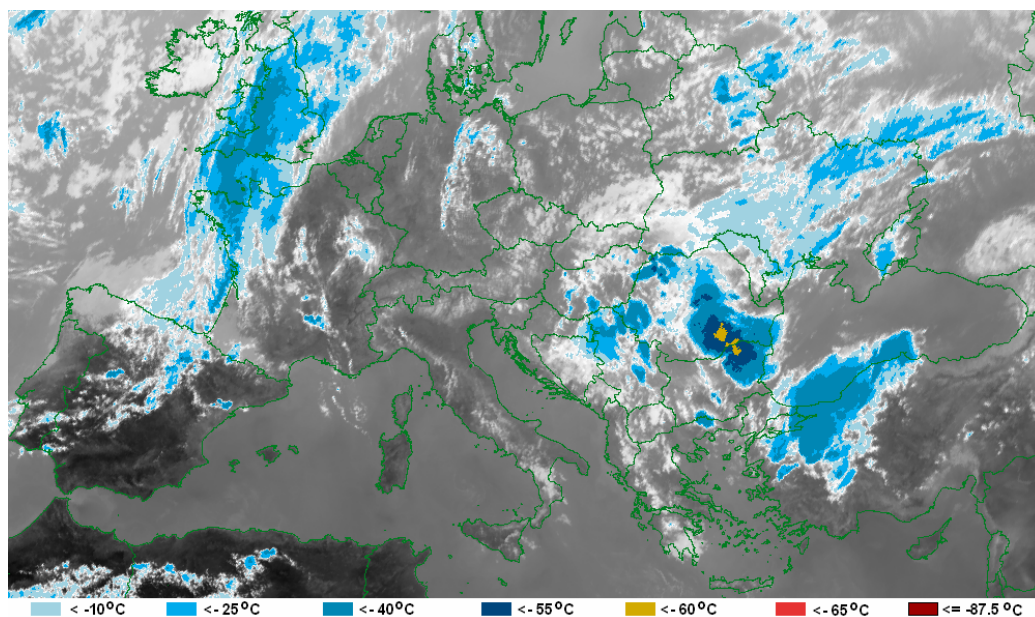


Fig. 12. Infrared satellite image (RGB 20), August 6, 15:30 UTC

but with lower intensity, around 4-5 mm/hour. Under these circumstances, the National Meteorological Administration issued a nowcasting warning of dangerous phenomena for Bucharest and the Ilfov County, regarding heavy showers, storm-like wind gusts and cumulated water amounts topping locally 20-25 mm and scarcely 30 mm.

As regards the convective event over central Wallachia, its duration and pulsating evolution can be connected to a mesoscale convective structure². As a

² *Mesoscale convective systems* – an ensemble of convective clouds whose ascending currents are continually supplied by mesoscale circulations

structure within which severe phenomena occurred over wide areas and the mesoscale circulation favoured continuous supply to the ascending currents that favour the storm.

Mesoscale convective structure. The occurrence and evolution of a convective event on a convergence line lasting almost five hours, a continuous flux of warm, humid air in lower atmosphere and

and which cause ground-level severe phenomena over areas larger than 100 km².

³ *Isentrope* = a line of constant potential temperature – temperature that would be reached by an air particle if it were adiabatically compressed or expanded to a standard pressure

the release of latent heat of condensation in high troposphere all led to the storm having ceaselessly been supplied with energy and to a mesoscale circulation with a Coriolis force that could not be neglected. As the convective event was organized into multi-cell structures within the main convective system and since it was a bow echo convective system that appeared in the end, we can maintain that we were dealing with a classic mesoscale convective system (MCS).

This phenomenon lasted till after midnight, rain still falling, but lighter. The highest levels of 8-hour cumulated precipitation reached 114 mm at Cornu

(Dâmbovița County), 74 mm in Prahova County, 69 mm in Giurgiu and 61 mm in Bucharest - Filaret. station (Fig. 14).

7. CONCLUSIONS

The event presented in this study was analysed because the mathematical models, both at global scale and regional scale did not forecast the large water amounts recorded in Bucharest and in the surroundings. An approach as the one described in this paper may thus bring in the future better results 6 or 12 hours before the phenomenon occurs. Therefore, this paper attempts to settle the grounds for a work methodology

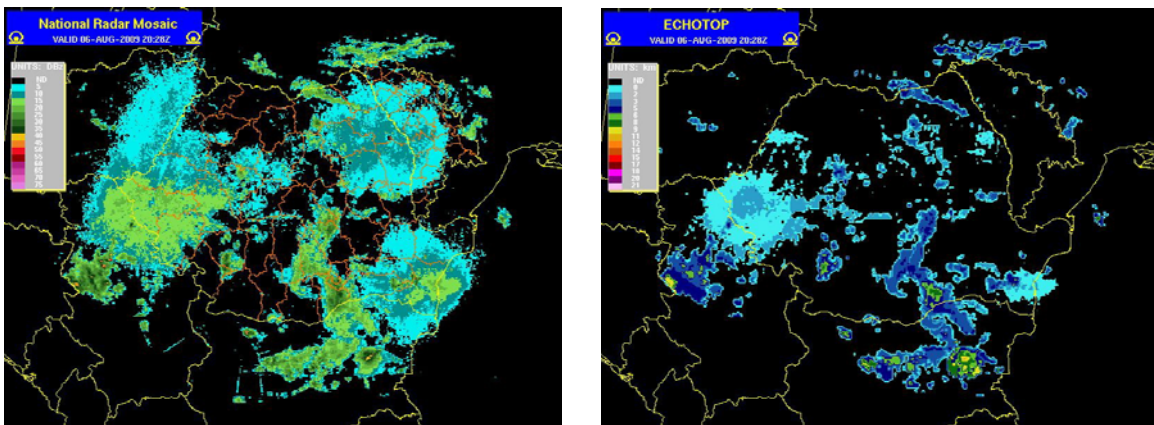


Fig. 13. Radar mosaic: mesoscale cyclonic vortex (bow-echo structure): mos (left) and echotop (right).

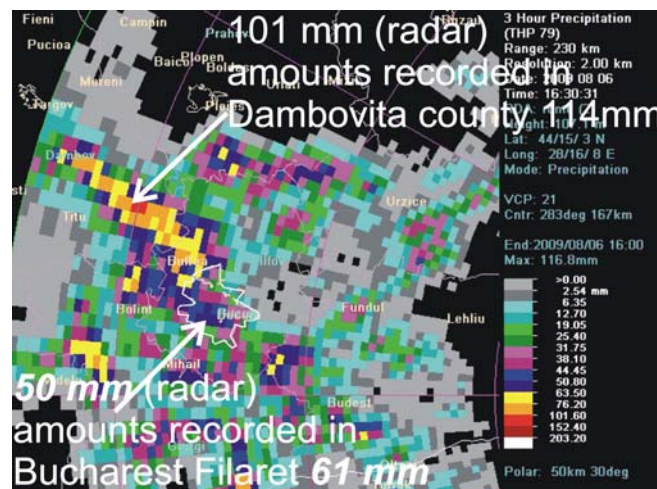


Fig. 14. Accumulated precipitation estimation by radar Medgidia, August 6, 16.30 UTC

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related to the short-range forecast in situations like the investigated one.

On a synoptic scale, there were favorable conditions for interference between warm, humid air above the Black Sea and cold air descending along the eastern side of the Eastern Carpathians. Orography also played an important role in the air flow over the extra-Carpathian regions of Romania.

In the evening of 6 August 2009, every basic ingredient that initializes and develops convection was present: high humidity in the low level layers, a vertical stratification of the atmosphere that allows a positive buoyancy and forcing mechanisms for the mesoscale ascending motion (ground-level convergence line and gust front) that lifts air particles to the level of free convection (LFC). The upward and downward velocities were clearly influenced by a super-adiabatic gradient in the first 1000 meters and by two mid-troposphere dry areas - When condensation products reached the first dry layer, there occurred a temperature-decreasing through evaporation, the difference between particle temperatures on that level and the environment temperature increased, and particle buoyancy got higher – which led to an explosive convection.

A mesoscale analysis of the pressure field at two synoptic moments of reference (12 and 18 UTC) was able to capture the local-scale evolution of this phenomenon. Therefore, as regards the nowcasting activity, it is recommendable to establish a methodology whereby the initial state should be analyzed as laboriously as possible in order to understand the evolution of phenomena.

Another instrument of great importance in studying the evolution and organization of a convective event as well as the expected ground-level phenomena was the 12 UTC sounding. It pointed out that dry air was present in medium-level layers and humid air was in lower layers, which indicated a great risk of wind gusts and hail.

The results presented in this paper are of peculiar practical importance, since they target the short-range operational forecasting activity. In comparison to other papers, this study brings together various elements belonging to diagnosis and forecasting respectively, among which the initial conditions play a very important role in understanding the future evolution of weather phenomena. Therefore, this paper attempts to become basic to a work methodology for the short-range forecasting activity in such situations.

REFERENCES

- Ion Bordei E, (2009)
Role of the Alpine-Carpathian chain in the evolution of the Mediterranean cyclones – second edition, Printech publishing house, Bucharest., 92-106 (in Romanian).
- Ion Bordei N., 2008,
Meteoclimatic phenomena induced in the Romanian Plain by the configuration of the Carpathians, Romanian Academy publishing house Ed., 57-100 (in Romanian).
- Holton J., 2000
An introduction to dynamic meteorology (in Romanian, translation from English), Technical publishing house, Bucharest.
- Stefan Sabina 2004,
Atmospheric physics, weather and climate – publishing house of the University of Bucharest, 130-140;
- James T. Moore, 1999,
Tropopause Undulations and Tropopause Folds. COMET COMAP.
- Stan-Sion A. and C. Soci (2005)
Supercell environment in Southeastern Romania. Preprints, 5th Annual Meeting of the European Meteorological Society EMS), 7th European Conference on Applications of Meteorology (ECAM), Utrecht, Netherlands, 12-16 September 2005.
*** Manual of Synoptic Satellite Meteorology, Version 6.0, ZAMG, Convection and Instability.

<http://www.zamg.ac.at/eumetrain/index.htm>

<http://www.comet.ucar.edu/>

<http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html>

<http://weather.uwyo.edu/upperair/sounding.html>