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THE BLACK SEA INFLUENCE IN CONVECTIVE STORMS INITIATION IN SOUTH EASTERN ROMANIA

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1. INTRODUCTION

Thunderstorms in Romania can be severe and cause significant damage and loss of life. Forecasters have difficulty forecasting their initiation, severity and associated weather. Conceptual models, based on radar, satellite and synoptic observations have been developed for convective storm initiation. These have provided invaluable guidance for forecasters.
This paper presents both common and uncommon forms of convective storm initiation in Romania. Mechanisms like the Black Sea breeze, lakes and mountains breezes, gust fronts, convective rolls, convergence zones and lines, and boundary intersections are presented, together with associated conceptual models. Special attention is given to the Black Sea breeze, highlighting situations when it has a major role in convective initiation.

Analyses are based on Doppler radar data archives since 2002, complemented by satellite, ground station data and NWP.

The conceptual models are specific for the Romanian topography and mesoscale circulations and are included in the operational forecasting decision process.

In 2002 the Romanian Weather Service commenced installation of a Doppler radar network, which become fully operational in 2004. The eight Doppler radars, five of which are WSR-98Ds, a clone version of the WSR-88D used by the U.S. National Weather Service (Fig. 1), cover not only the Romanian territory, but also well beyond the frontiers, making possible a good surveillance of mesoscale systems that approach on different circulations. The radar observations are supplemented by satellite information (METEOSAT Second Generation) every 15-30 minutes and with real-time total electrical activity detection provided by the 8 detectors of the Romanian SAPHIRE network.

Romanian forecasters faced challenges during the implementation of the new meteorological systems. In the first years the major problem was interpreting Doppler radar data because convective storms in Romania (as in all East European countries) had never before been observed with Doppler radar. Second, there was a general lack in understanding atmospheric convection and especially the specific local features of convective development in Romania, a country with a territory dominated by the presence of the Carpathians Mountains and the Black Sea.

Although there had been some studies of local circulations and their impact on the climatological structures of the dominant winds in low levels and precipitation distribution (Bordei-Ion, N., 1988), a systematic approach on how these features could impact on convective developments and how they could be assimilated in the forecasting process, was difficult to achieve prior to the "Doppler era".

Since 2002 in Romania, the underlying principle of operational nowcasting is the "ingredients method", where deep moist convection is a result of three ingredients: lift, instability, and moisture (Johns and Doswell 1992). Thus, intense convection will occur provided that large convective available potential energy (CAPE) is present in the air column and provided that the typical negative area (CIN, or convective inhibition) below the level of free convection for surface air is removed or reduced to a small value that can be overcome, through a mesoscale or synoptic scale mechanism.

After more than five years of observations, several attributes of severe storm development have been documented. Questions such as: what is the prevalent circulation type that causes severe weather and where severe weather happens more often are beginning to have answers. Storm initiation received special attention in order to provide severe weather warnings as early as possible. Lifting mechanisms in regions with anticipated instability and moisture soon became new “targets” for the forecasters. Terms like “convergence lines”, “low level jets”, “updrafts and downdrafts”, “outflows and inflows”, now have frequent use in the forecasting room.

***Fig. 1**: a) Upper image: geography of Romania and the main topography of the region; the yellow dot line follows the S-shape of the Carpathian Mountains.*
b) Bottom image: The Romanian National Radar Network integrates: 5 WSR-98D S-band radars and 3 C-band radars (2 from EEC - DWSR-2500C type and 1 from Gematronik - METEOR 500C type).

Finally, the forecasters started to apply Romanian conceptual models for convective initiation.

Romanian forecasters are challenged to recognize environmental mesoscale factors that favour the onset of supercellular thunderstorms, mainly in south-eastern Romania where the environment tends to be more conducive to severe convection than in other parts of the country (Stan-Sion and Antonescu, 2006).

Observations of storms whose buoyant updraft air originated in the boundary layer shows that they are initiated along or near surface airstream boundaries, especially in the south-eastern Romanian Plain.

An airstream boundary is defined as a line of discontinuity or a narrow zone separating air having different meteorological properties (e.g., Cohen and Kreitzberg 1997; Markowski et al. 1998; Cohen and Schultz 2005). Mesoscale lift along such surface boundaries can decrease the convective inhibition, increase the convective available potential energy, and moisten the air column (e.g., Wilson and Schreiber 1986).

2. Surface boundaries in south-eastern Romania

Initiation of storms in southern Romania occurs in the vicinity of three types of low-level boundaries: synoptic, mesoscale, and convective boundaries (Stan-Sion and Soci, 2005).

Synoptic boundaries consist of fronts or the interaction of the synoptic flow with orography. The interaction of the synoptic flow with the curved shape of the Carpathian Mountains results in a convergence zone between the eastward and westward circulations (Bordei-Ion, 1988), discussed further in section 2a.

Mesoscale boundaries consist of drylines, discontinuity lines produced by differential heating, convergence lines produced in the lee of a mountain chain, enhanced convergence at the exit of a canyon, sea-breeze fronts and mountain-breeze circulations. Examples of such circulations are presented in sections 2b and 2c.

The last category, outflow boundaries, are the most difficult to predict as they are produced by the convection itself. Radar is the most appropriate tool to monitor the behaviour of the convectively generated cold pool and its associated gust front. Predicting the initiation of convective storms along an outflow boundary or its intersection with a previous boundary, such as the sea-breeze or the convergence line along a roll cloud, before the onset of the parent storm, is difficult, if not impossible.

2a. Wallachian back-building squall line conceptual model and the convergence zone in southern Romania

Romanian topography is dominated by the S-shape of the Carpathian Mountains (Fig. 1a), deflecting the flow from the general western circulation into two branches that converge in the Southern plain of Romania. (Fig. 2a).

The fingerprint of this pattern on the low-level wind is the so-called Romanian Plain Convergence Zone that often forms in southern Romania.

The convergence is also enhanced by the presence of two natural canyons on the river Olt and Danube (small blue arrows in Fig. 2 – bottom image, represent the flow through these canyons). Low level warm and moist advection from the Mediterranean Sea provides good conditions for storms initiations in the region of the convergence zone.

If the Northern flow prevails, then there are conditions for the development of a back-building convective line over the hills with Southern exposure to the sun. The new cells repeatedly form towards the west, where the warm and moist air is lifted by the gust front, producing a backward propagation of the system.

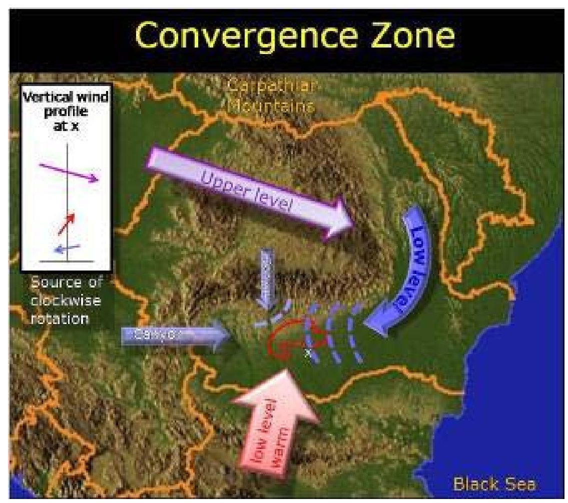


Fig. 2: The „Romanian Plain Convergence Zone": Arrows depict the pericarpathian flows that converge in the middle of the Romanian Plain when a western high pressure system approaches the Carpathian Curvature. a) Upper image: the pink dashed region represents the convergence where convection is often initiated, also known as Wallachia region. B) Bottom image: the thin dashed line, oriented from North to South, or later from West to East (Fig.3a), represents secondary "cold fronts" that can form at the leading edge of the Northern flow.

The convergence line that often develops near the river Olt may intersect other boundaries, like the outflows from the storms, or enhanced flow from the canyon. These intersections can generate new initiation.

This convergence zone is produced by the pericarpathic flow when a high-pressure system approaches from the west. The flow splits into branches (one with a northerly direction of the flow and the other one with south-westerly flow, Fig.2a) around the obstacle and the convergence region of these two flows can shift to the east or to the west, depending on which branch is more intense.

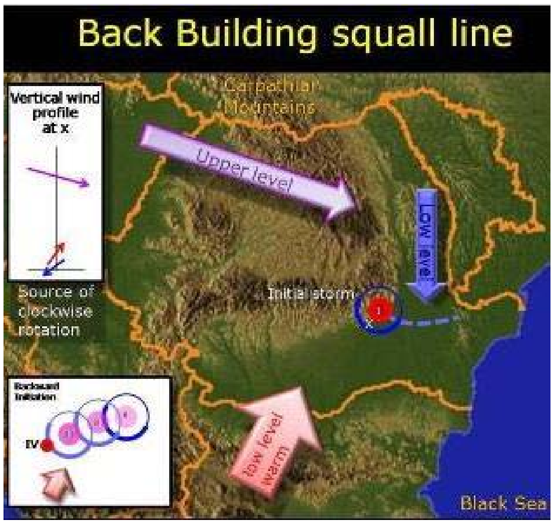
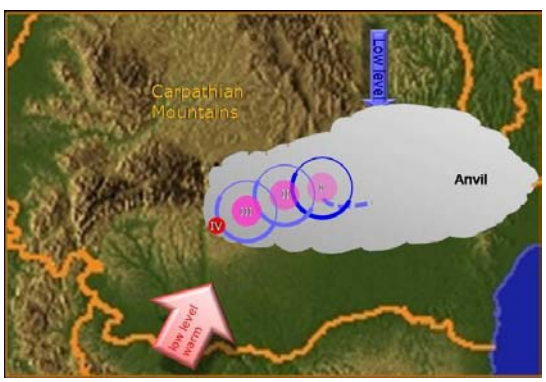
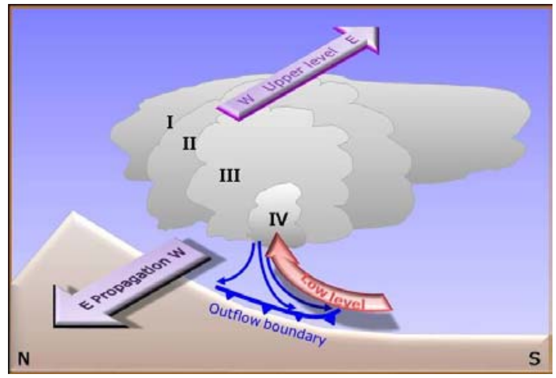


Fig. 3*.a) Initiation of convection on the side that receives the SW flow. The rectangle in the left lower corner represents the propagation of the storms toward the source of moisture and instability.*



b) The generation of different cells, that propagate backward in respect to the flow in the altitude, following the low level jet.



c*). Vertical crosssection through the back building squallline.*

This convergence zone is similar to other mesoscale convergence zones produced by flow around complex topography such as the Puget Sound Convergence Zone (e.g., Mass and Dempsey 1985) and the Snake River Convergence Zone (e.g., Andretta and Hazen 1998). The Romanian Plain Convergence Zone (RPCZ) interacts, in appropriate synoptic conditions, with a southerly low-level jet or can intersect with other boundaries. In these conditions, severe convection is initiated near the RPCZ.

This is the case of a back-building squall line with zonal orientation that often forms on the southern slopes of the Meridional Carpathian Mountains. The first convective cells form on a zonally oriented, secondary, strong, cold front, perpendicular to a northerly flow on the eastward branch of the pericarpathic flow over Moldavia (fine dashed line in Fig. 2).

If there is a southerly warm, moist, low-level jet (shown by the pink arrow in Fig. 3a), intensified also by the daytime mountain breeze on a sunny day, then the propagation of the convective system, or the direction in which the new cells will form in respect to the general westerly flow, will be oriented toward the west. This is termed a backward-propagating or backbuilding convective system (e.g., Bader et al. 1995, pp. 418–421; Schumacher and Johnson 2005).

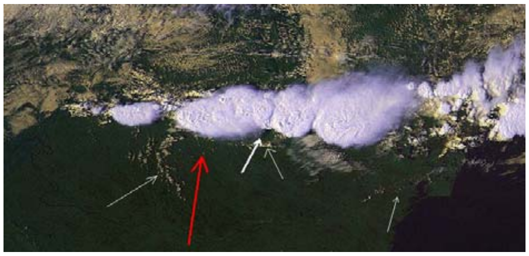


***Fig. 4 a**: NOAA satellite image 21 August 1991, 13:21 UTC. The image shows a back-building squall-line zonally oriented. Arrows indicate the shallow cumulus produced by (from left to right) the convergence zone, the differential heating by the anvil shadow, the outlow boundary and the Black Sea breeze. (Courtesy Martin Setvak)*

***Fig. 4 b**: NOAA satellite image from 21th of August 1991, 15:12 UTC. Arrow indicates severe convection initiation in the intersection region of two previous boundaries. (Courtesy: Martin Setvak)*

This was the case on 21 August 1999. The satellite image (Fig. 4a), shows the squall line in its mature stage and concurrent surface boundaries. The convective cells developed from the east to the west although the dominant upper flow was in the opposite direction.

The outflow boundary of the cell situated in the middle of the line was intensified by the thermal boundary produced by the shadow of a stationary anvil. The sun was situated to the west of the cell, so the anvil shadow has superposed with the outflow boundary (the bold white arrow in Figure 4a). The intersection region of these two types of surface boundaries, at the northern edge of the convergence line, became the place where a strong convective cell later developed (Fig. 4b). An important role was also played by the Olt river canyon, enhancing the convergence in that part of the line.

At that time, no Doppler capabilities were installed. Hail 10-cm in diameter and 120 mm of rain in one hour were reported in the town of Curtea de Arges. Strong winds destroyed the roofs of many houses and electricity poles were seriously damaged, but no tornado was reported.

The ALADIN model (not shown here) depicted the onset of the mountain breeze, the RPCZ and the secondary cold front. The model also accurately depicts low level flow in the wind field.

Another factor that can enhance the southerly low level jet (LLJ) during the general zonal circulation in middle and upper levels, is the negative anomaly in the pressure field and the colocated positive thermal anomaly generated by the flow over a mountain obstacle (Bluestein 1993, p. 39-41). The CAPE field provided by ALADIN indicated high values up to 5500 J/Kg.

2b. Surface-boundary interactions with sea and mountain breezes

When the northern branch prevails (Fig. 5), the convergence line may interact with a boundary produced by the sea breeze (situated east of the boundary) or with a LLJ associated with the mountain breeze (west of the boundary). Severe convection may be initiated at this interaction zone.

The middle and upper flows are zonal and induce two major low level pressure anomalies: positive inside the Carpathian Arc and negative in southwest Romania.

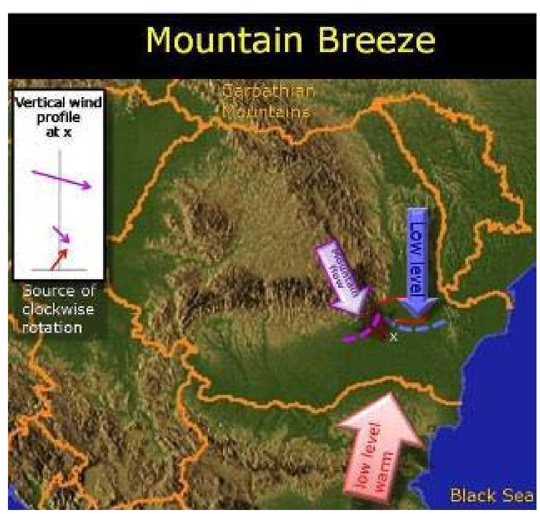


Fig. 5: The conceptual model of storm initiation in Southeastern Romania when the Nordic branch of the pericarpathian low level circulation is prevailing (blue big arrow).

Such a situation happened during the afternoon of 17 August 2005 when the surface boundary ahead of a northerly low level flow (synoptic boundary) intersected the intense southerly LLJ (CAPE values of 4500 J/Kg) to the west, and also a new boundary produced by a convective outflow. Although the sea breeze was also active, the instability there was not as high as in the western air mass (Fig.6).

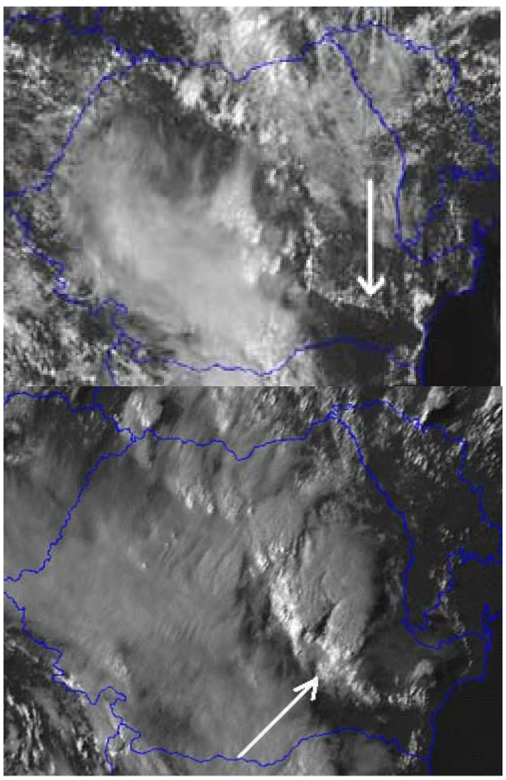


***Fig. 6**: **Upper image**: METEOSAT7 satellite VIS image, 17 August 2005, 1200 UTC. The white arrow indicates the surface boundary of the pericarpathic northern flow. **Lower image**: METEOSAT7 satellite VIS image, 17th of August 2005, 1445 UTC. The white arrow points toward the overshooting of an intense updraft that developed at the intersection with an intense LLJ and outflow boundary.*

The new boundary (Fig. 7) produced by convective outflow intersected the synoptic boundary and a strong updraft developed; an overshooting could be seen on the satellite VIS image. The WSR-98D S-band radar installed at Medgidia (southeast Romania) detected also the outflow boundary (Fig. 7, lower image).

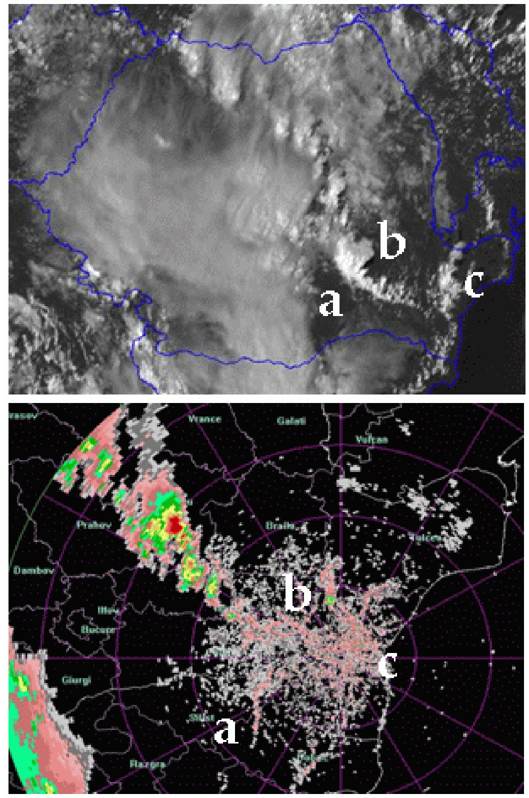


***Fig. 7 Upper part** : Meteosat VIS image, 17 August 2005, 1507 UTC. **Lower part**: WSR-98D Medgidia, reflectivity, first tilt, same time. (a): outflow boundary, (b): synoptic boundary, (c): sea breeze*

A strong supercell developed near the intersection of these boundaries and a persistent mesocyclone was identified in the radial velocities. Some villages in Buzau County affected by the supercell reported large hail, strong winds and up to 75 mm of rain in one hour. A funnel cloud was also reported.

The “mirror” situation, with convective development on the opposite side of the boundary, occurs when the high values of CAPE encourage the convective development at the eastward point of intersection with the sea breeze front (Fig. 8).

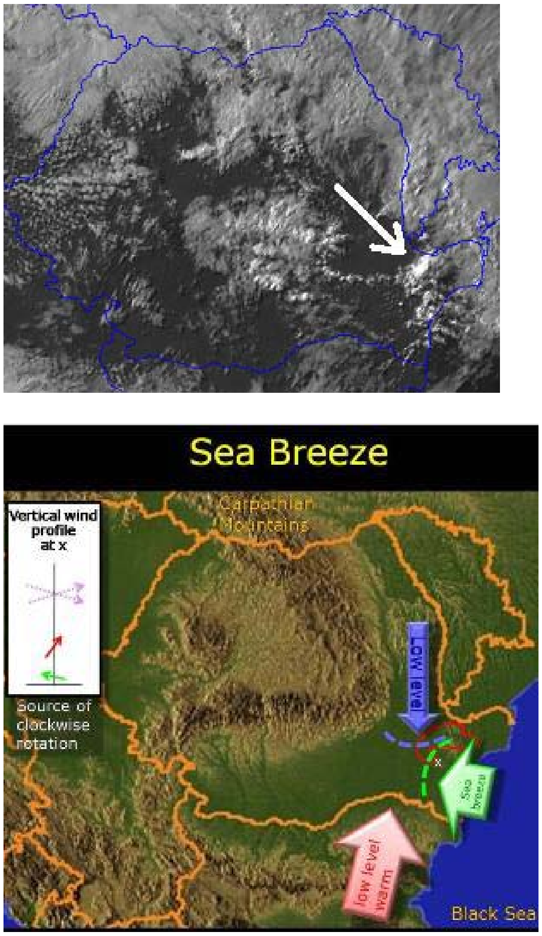


***Fig. 8: Upper image**: Meteosat7 satellite VIS image, 6th July 2005, 1445 UTC. The white arrow points toward the intersection between two surface boundaries where severe convection developed and a tornado was reported. **Bottom image**: the conceptual model for storm initiation at the intersection of the Northern flow with the sea breeze.*

This was the case during the afternoon of the 6 July 2005 (Fig.8 the satellite image), where a tornado was reported in the village of Topolog and a forest nearby was damaged.

The sea breeze has an important role in enhancing convection. Even more important is the intersection of the sea breeze with other small-scale structures, such as convective rolls. Fig.9a depicts the sea breeze convergence line, oriented from NE to SW, parallel to the shore and, to the west, many roll clouds. One of the roll clouds was stationary for many hours. A storm subsequently developed at the intersection of this roll cloud with the sea breeze and a convective outflow (Fig.9b). We have noticed that near the moment of convective initiation, the orientation of the rolls in regard to the sea breeze changes, becoming more perpendicular to it.

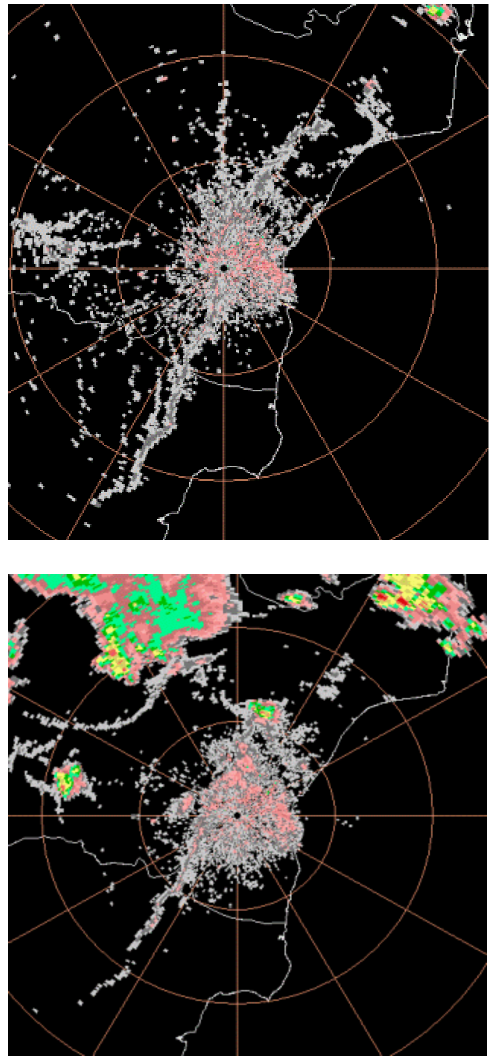


***Fig. 9: Upper image**: radar reflectivity, WSR-98D Medgidia, first tilt, 24 June 2008, 14.20 UTC. **Lower image**: the same as above but at 16.16 UTC.*

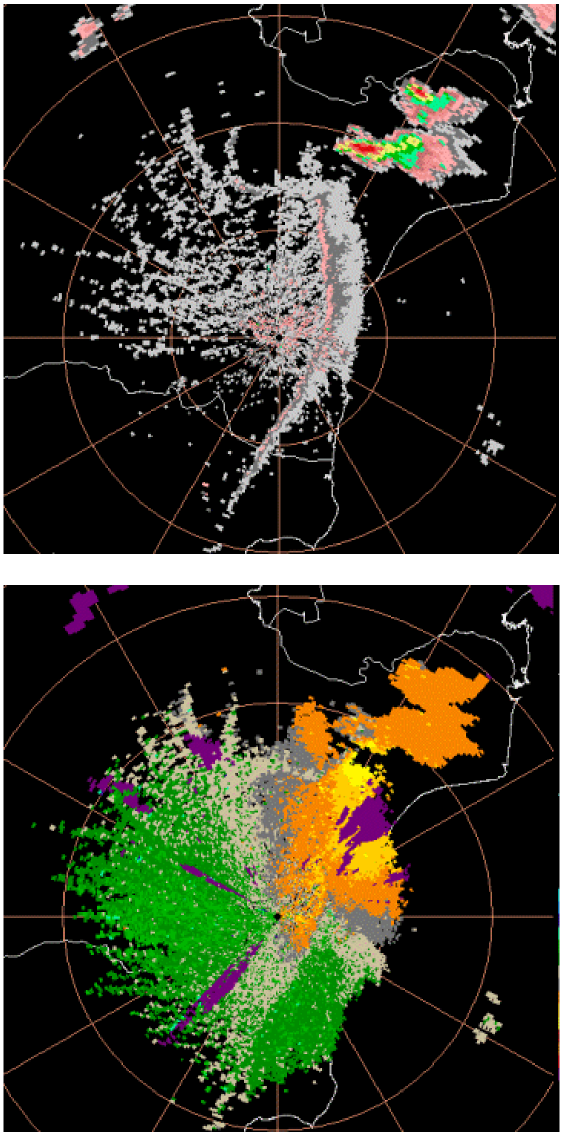


***Fig. 10: Upper image**: radar reflectivity, WSR-98D Medgidia, first tilt, 18 June 2008, 18.13 UTC. Lower image: the same as above but the radial velocity field.*

2c. Southern convergent flow

The first tornado observed in Romania using Doppler radar was at Facaeni in 2002 (Lemon et al. 2003). Now that the tornado threat in Romania has been recognized, an average of 10 tornadoes per year are observed and sometimes even video recorded (Oprea and Bell, 2009).

The most severe cases were associated with the presence of a southerly flow toward a low pressure situated in the eastern part of the country. This flow was advecting moisture from the Black Sea and developed a strong convergence line in the vicinity of the Danube River (Fig.11a – dashed white line). Three of the tornadic supercells that formed in this type of circulation had a movement along this convergence line. We call this line the Lower Danube convergence line. It often extends further to the north, following the lowest orography. The flows at 10m above the ground have been simulated very well by the ALADIN model (Fig.11b). Two similar cases developed on 22 April 2008 (Fig.12) and 25 June 2009 (Fig. 13). Both were tornadic, from strong supercells.

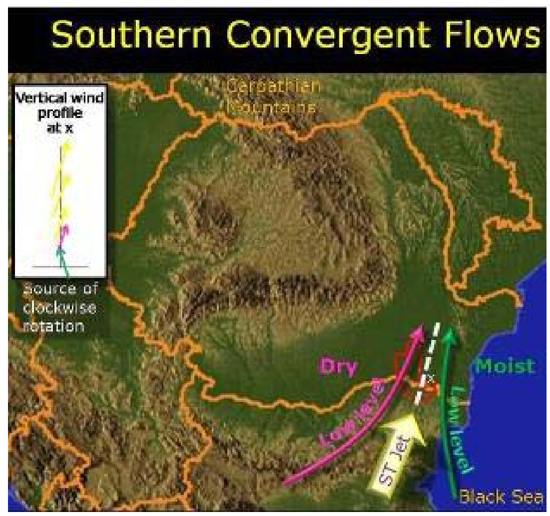


***Fig. 11: a) upper image**, the conceptual model of the Lower Danube convergence line*

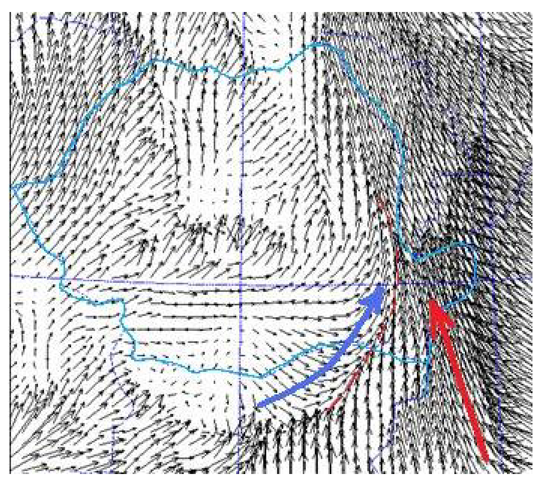


***Fig. 11:.b) middle image**, wind at 10m, ALADIN model for 12 August 2002, 14 UTC*

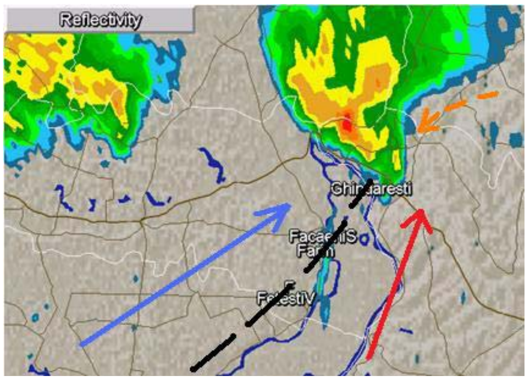


Fig. 11 c) lower image, *the tornadic supercell that moved along the convergence line.*

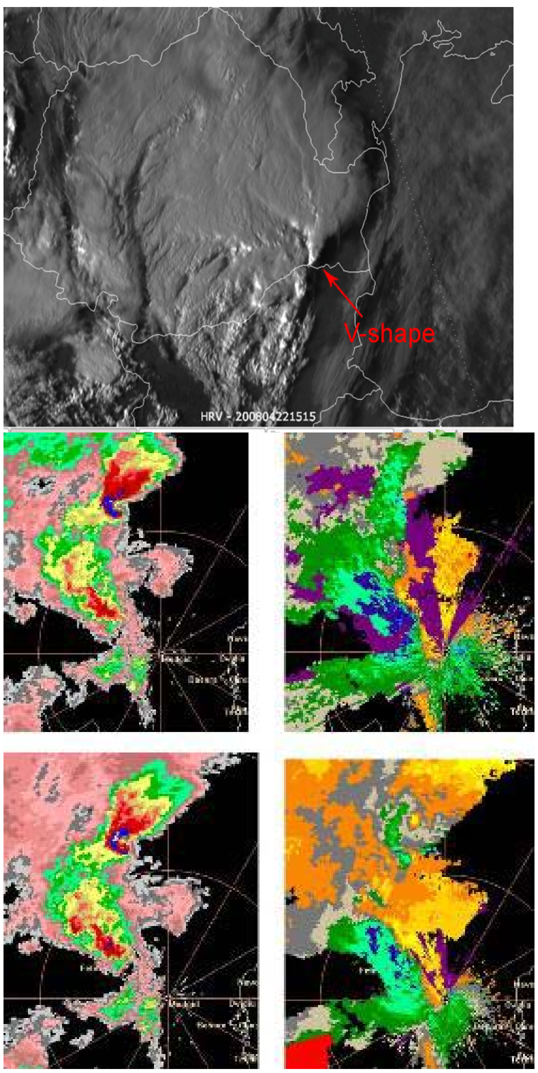


Fig.12 Upper image*: Satellite HRV channel, EUMETSAT MSG, 22 April 2008;*
Lower image*: WSR98D- Medgidia, first tilt, reflectivity and radial velocity, of the same supercell case.*

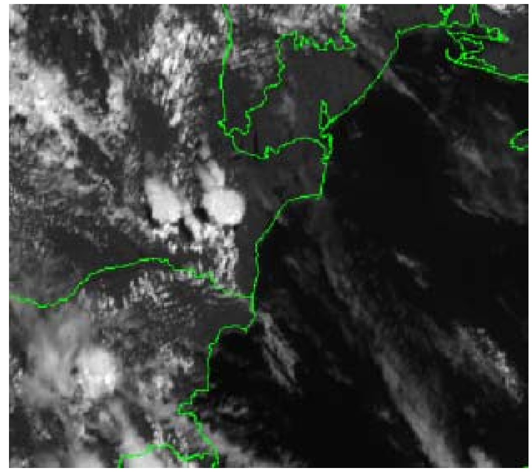


Fig.13*. 25 June 2009, EUMETSAT MSG HRV, 11.30 UTC. Southern Romania, the Lower Danube convergence line and the tornadic supercell.*

3. CONCLUSIONS

Three different types of surface boundaries that precede some severe convective episodes in south-eastern Romania are presented. The boundaries are related to local topographic circulations and the general synoptic flow. They include: convergence lines induced by the S shape of the Carpathian Mountains in south Romania; the Black Sea breeze convergence lines; and interactions between convective outflow boundaries and differential heating boundaries. The conceptual models presented in this paper provide valuable guidance to assist the nowcaster in assessing the environmental conditions that favour severe weather. Two of them, the Wallachian Back Building squall line and the Lower Danube Convergence line, represent specific patterns for severe convection initiation in Southern Romania.

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