WEATHER RADAR VELOCITY FIELD CONFIGURATIONS ASSOCIATED WITH SEVERE WEATHER SITUATIONS THAT OCCUR IN SOUTH-EASTERN ROMANIA

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Abstract. In the present study, the analysis of the Doppler radial velocity field obtained with the weather radar operational at Medgidia (SE Romania) is performed. This was made in order to characterize the severe weather situations that occurred during the convective seasons (May–September) of the years 2003–2007. The radial velocities were measured at 3.4° elevation of the radar antenna. The measurements at this particular elevation were chosen because they highlight better the tropospheric flow. An average over 24 hours of the velocity field for the days with severe convection was performed, emphasizing the vertical wind shear and the tropospheric jets. Averaged Doppler velocity fields were divided into classes (configurations) depending on the direction of tropospheric flow and on the vertical shear. For each configuration, a characteristic velocity field that reveals the intensity of the tropospheric flow was emphasized. Each configuration of velocity field is associated to various characteristics of severe convective cells.

Key words: Doppler velocity, directional shear, convection, tropospheric flow.

1. INTRODUCTION

Severe weather phenomena associated with summer convection (i.e., supercells) \cite{1, 2} in the south-eastern part of Romania present a particular interest both in terms of their characteristic dynamic behavior and very short-term forecast (nowcasting) \cite{3–6}. Highlighting and analyzing certain features associated with convective cells, and meso-alpha or synoptic scale features of the environment in which they evolve, have an important role in the nowcasting process. With the introduction of Doppler weather radar network in S-band (10 cm wavelength) through SIMIN project \cite{7}, mesoscale phenomena could be traced and studied at sufficient temporal (6 min.) and spatial resolution (1km\textsuperscript{2}) to highlight some
dynamic characteristics related to severe convective cells (e.g., rotational structure (mesocyclone)) [8]. Besides these characteristics, other features of meso-alfa and sinoptic dynamics, represented by vertical wind shear and the presence of upper tropospheric jet could be observed with Doppler weather radars. These meteorological scales can be considered as a dynamic base state [9] in which the severe convective cells evolve, a base state which is intrinsically linked to the severity and persistence of convective phenomena. The study highlights the main types of dynamic configuration (tropospheric jets, vertical wind shear) associated with severe convective developments during the years 2003–2007, in the South-Eastern part of Romania [10]. Meso-synoptic dynamic configurations were identified according to air circulation in altitude and directional shear in the troposphere. The base Doppler velocity field at the 3.4° elevation was used, the Doppler velocity measurements at different elevation angles being the only weather radar product that can be used to observe the tropospheric flow intensity and its direction on different layers. This can be achieved with the weather radar running at a convenient temporal resolution (e.g., 6 min.), and when cloud systems are present within the radar range [11, 12].

The paper is structured in three sections. Section 2 presents the data and methods used to highlight the different meso-synoptic structures in which severe convective cells developed. In Section 3, the discussions on numerical distribution of severe convective cells and temporal distributions (life time associated to severe convective cells) for each meso-synoptic configuration are presented. Discussions on the features of the Doppler velocity field at 3.4 degrees elevation associated with each meso-synoptic configuration are also presented within this section. The conclusions of the study end the paper.

2. DATA AND METHODS

The analysis was performed using radar data sampled during the convective season (May–September), from 2003 to 2007, using the S-band Doppler weather radar system (10 cm wavelength) operational at Medgidia (Fig. 1).

A total of 413 severe convective cells associated with convective activity were identified in 139 days. In order to identify the convective cells associated with severe convection, the radar reflectivity fields at the 0.5°, 1.5° and 2.4° elevation were used. The reflectivity field was compared with the Doppler velocity field calculated relative to the storm at the same elevation (Fig. 2). The goal was to identify a cyclonic or anticyclonic rotation in the relative Doppler velocity field, at least at one elevation angle (Fig. 2). If during the life time of a convective cell rotation was identified, then the convective cell was identified as severe and classified as an event. Time of existence of a severe convective cell was associated with the persistence time of rotation at least at one elevation angle.
Fig. 1 – The coverage area (230 km radius) of the Medgidia weather radar. Range rings are at 50 km apart.
The Doppler velocity field at 3.4° elevation was used for the mesoscale configuration analysis of days with convective events (Fig. 3). As the radar beam propagates further, the altitude of the beam increases with distance from radar, therefore one can not measure velocities at a constant height from the ground. Thus, the Doppler velocity field at 3.4° is actually the Doppler velocity field obtained from the surface of a cone described by the radar beam for a full scan in azimuth [12]. At this elevation angle, the Doppler velocities are measured on all tropospheric layers (from 100 m to 10 km). Fig. 3 (left) illustrates the base Doppler velocity field at 3.4° elevation for tropospheric flow in the SE–NW direction (towards radar (−), away from radar (+)). In the right panel of Fig. 3 we present an anticyclonic rotation of horizontal velocity vector with height. Negative Doppler velocities (dark gray) have (−) sign, and the positive (gray) (+) sign. To view the tropospheric flow in the base Doppler velocity field, the zero isodop curve is used (thickened white line). At the corresponding heights, along the zero isodop, the base Doppler velocities are null because the atmospheric fluid velocity vectors are perpendicular to the radar beam. Using this property, to find out the actual speeds of the flow at a certain altitude we can join a point on the isodop curve, located at a certain height above the ground, with the radar location point. At this point velocity vector is oriented from (−) to areas with (+), and the magnitude is obtained following the circle of constant elevation containing the point on the isodop and noting the maximum Doppler velocity. In Fig. 3, the constant altitude circles are highlighted at 10.5 km, 6.7 km and 3.2 km.
Vertical shearing flow equivalent to the Doppler velocity field is shown in Fig. 3 (right), and was obtained with Velocity Azimuth Display (VAD) algorithm. Vectors $A_1, A_2$ are real speeds at about the same height but at different positions from the radar, as the other pairs of vectors $(B_1, B_2), (C_1, C_2), (D_1, D_2)$. In addition to vertical velocity profile, one can observe a horizontal gradient of velocity.

If the vectors $A_1$ and $A_2$ vectors were parallel, then the upper level flow would have the same direction (translational component), but notice that there is a change in direction (angle between $A_1$ and $A_2$ is non zero) which is equivalent to the presence of diffluent flow to the SE–NW direction. This property was used in the analysis of Doppler velocity fields.

For each day in which we have identified severe convective cells, we have constructed the daily mean Doppler velocities field at the 3.4° elevation angle (Fig. 4). The average has been calculated taking into account the frequency of detection over a certain radar bin. The 24 hours average velocity field within a radar bin was made by summing all the values (positive and negative), and the sum was divided by the number of measurements within the respective bin. This weighted average was done to highlight the vertical structure of tropospheric flow (vertical shear and the presence of tropospheric jets). In altitude, nonzero Doppler velocities are measured with the passage of various mesoscale cloud systems. These base Doppler velocities are associated with the movement of the air fluid imposed by
the flow at high altitudes. As the lifetime of the cloud systems during the summer is just a few hours long, the Doppler velocities are not continuously measured (Fig. 4 – up). This discontinuity in the measurements increases with altitude. Resulting 24 hour weighted average of Doppler field has homogeneous structure, and this is equivalent to a 24 hours mean if we had continuous measurements in each bin.

When constructing the weighted average of the Doppler velocity field at 3.4° elevation, the scale of the weather phenomena was taken into account. As the height above the ground increases (free atmosphere, above the boundary layer), the horizontal flow is governed by various atmospheric barocline disturbances. The horizontal velocity vector variation has a time scale comparable to the inertial or the barocline oscillations [9]. Thus, even if only few velocity measurements are made within a few hours in a bin, they are representative for fluid dynamics. Further, a separation in classes called „configurations” was made depending on certain factors essential in mesoscale dynamics and in short-term forecast (nowcasting). Therefore, the mesoscale configurations from the days with severe
convective cells were grouped by circulation in altitude and by the directional shear (of the wind vector at upper and lower levels) in the troposphere. Both horizontal circulation in altitude and directional shear are modulated by barocline perturbations and represent the fundamental elements associated with severe weather. Doppler velocity fields at 3.4° averaged over 24 hours were divided into classes representing different meso-synoptic configurations. The Doppler velocity fields measured during the days associated with different meso-synoptic configuration (Day 1, ..., Day n), a weighted average was made and an average dynamic configuration was obtained (Fig. 4).

3. RESULTS AND DISCUSSION

From the analysis of Doppler velocity fields at the 3.4° elevation, averaged over 24 hours in every day with severe weather phenomena, the following configurations resulted: NW-1 (North-West cyclonic), NW-2 (North-West anticyclonic), W-1 (West cyclonic), W-2 (West anticyclonic), SW-1 (South-West cyclonic), SW-2 (South-West anticyclonic), SE-1 (South-East cyclonic), SE-2 (South-East anticyclonic), SE-3 (South-East anticyclonic with low-level jet), NE-1 (North-East cyclonic), NE-2 (North-East anticyclonic).

3.1. CONVECTIVE CELLS DISTRIBUTION **VERSUS** MESO-SYNOPTIC CONFIGURATIONS

Distribution of convective cells based on the flow direction and on the velocity vector rotation with height (directional shear) is represented in Fig. 5. For the NW-1 and NW-2 configuration flow, the convective cells that have developed in cyclonic shear configurations represent about 13% of total, and have a 11% higher occurrence than those that have developed in the same direction but had anticyclonic shear. On the Western flow (W-1 and W-2 configuration), cyclonic and anticyclonic circulation cell percentage is below 5%. The South-West flow configuration (SW-1, SW-2) has the highest number of total cells, over 20% both in cyclonic and anticyclonic shear. On the SE-1, SE-2 and SE-3 configuration flow the maximum number of cells is on anticyclonic shear with low-level jet (15% of total), cyclonic shear and that with no low-level jet is less than 5% of total. On the NE-1 and NE-2 flow configuration the maximum number of cells was recorded on anticyclonic shear configurations (7% of total). The maximum number of convective cells (over 10% of total in each configuration) is on SW-2, SW-1, SE-3 and NW-1 configurations.
3.2. TEMPORAL DISTRIBUTIONS OF CONVECTIVE CELLS

To illustrate the lifetime of the convective cells associated with each mesoscale configuration in Fig. 6, histograms representing the number of cells with certain duration were plotted.

Table 1

Maximum lifetime of convective cells observed in various configurations

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<th>Cell lifetime (hours)</th>
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The time resolution of the histograms is 30 minutes, this representing the time needed for an air particle to be raised in a simple convective cell [2] by the upward current associated with convection. The particle would be raised until near the tropopause, after that getting a downward movement to the ground. One can observe from Fig. 6 that most severe convective cells are grouped around the period of 1–1.5 hours.

![Fig. 6 – Temporal distribution of the convective cells (percent) for each mesoscale configuration, according to their associated lifetime.](image)

However, the left side of distribution is not symmetrical with the right side, where the convective cells can live up to 6 hours (Table 1).

As convective cell number and severity (maximum duration of life) stands out clearly three mesoscale configurations, namely: SW-1, SW-2 and SE-3.

Configurations in which the convective cells exceeded 3 hours of life time are: W-2, SE-1, NE-1, NE-2, SE-2. The NW-1, NW-2 and W-1 configurations do not contain convective cells that exceed 3 hours of life time. Even if some configurations (SE-2, W-2, SE-1, NE-1) do not have a large percentage of total convective cells detected, they can dynamically support severe convective cells with long lifetime.
3.3. ANALYSIS OF MEAN DOPPLER VELOCITY FIELD AT 3.4° ELEVATION

The analysis of Doppler velocity field associated to each meso-synoptic configuration was performed using the procedure described in Section 2. The wind vectors over layer on Doppler velocities have been constructed taking into account the zero isodop and the maximum intensity of the Doppler field at 3400 m and 7300 m (first and second range ring represented in each figure). The number of velocity vectors below 3400 m varies depending on the flow complexity.

3.3.1. NW-1 and NW-2 configuration

Analysis of Doppler velocity field at 3.4° elevation angle associated to NW-2 configuration shows an upper tropospheric jet in the NW–SE direction (Fig. 7). It also shows a diffusent flow in the upper and lower layers (Fig. 7a).

NW-1 configuration shows a higher tropospheric jet in the NW–SE direction much larger on vertical than in the NW-2 configuration (maximum speed is reached at a lower altitude). Greater vertical shear is highlighted through the higher Doppler velocity gradient near the radar (Fig. 7b). The upper layers diffusent flow is also more pronounced (higher angle between velocity vectors at the same level). Both configurations are compatible with the output of the upper tropospheric jet, and with the existence of a cyclone to the north-east of the country.

3.3.2. W-1 and W-2 configuration

These configurations represent different barocline perturbations superimposed on the western zonal flow. To obtain the Doppler velocity field from Fig. 8a, 8b, barocline waves must have a big wavelength (nearly zonal flow), or cyclone in the north and an anticyclone in the south of the country must exist. This
type of flow is highlighted by the zero isodop which is almost parallel to the meridian of the location. Upper tropospheric jet is more pronounced than in previous configurations, and the Doppler velocity gradient near the radar is much higher. Both in W-1 (Fig. 8b) and W-2 (Fig. 8a) configurations the flow in altitude is diffuent (exit from the jet). Nevertheless, the diffuent flow is more pronounced in the W-1 configuration.

![Fig. 8 - Mean Doppler velocity field associated with W-2 configuration (a) and with W-1 configuration (b).](image)

### 3.3.3. SW-1 and SW-2 configurations

Within these configurations of the tropospheric flow, the most convective cells have initiated and developed (Fig. 5). The Doppler radar field in Fig. 11 and Fig. 12 describes different barocline waves evolving from west to east, with a wavelength smaller than in previous configurations and higher amplitude. In this case also, the main dynamic element is represented by the upper tropospheric jet. Its intensity is lower than in W-1, W-2 configurations but higher than in NW-1, NW-2 configurations.

The diffuent flow is preserved and it is compatible with the exit of the jet, and the diffuent flow from altitude is approximately equal for both dynamic configurations.

Directional cyclonic shear in the lower layers (Fig. 9a) is given by various front passages in their evolution from west to east, as the flow behind the front NW–SE, being more pronounced, has a higher weight in the averaged Doppler velocity field than the SE–NE flow (in front of the front).

Anticyclonic shear (Fig. 9b) is present in the warm sector of the barocline waves which has a stationary character in the South-Eastern Romania. This configuration can be associated with a cyclone located west of the country.
3.3.4. SE-1, SE-2 and SE-3 configuration

For SE-2 configuration, in Fig. 10a one can observe an anticyclonic shear with increasing height and the presence of upper tropospheric jet. Unlike the western and south-west flow configuration, in this case the flow in altitude is confluent. This confluent flow may be associated with the inflow region in the upper tropospheric jet. Vertical shear and upper tropospheric jet intensity are lower than for the SW-1 SW-2, W-1 W-2 configurations, and are comparable to that of NW-1 and NW-2 configurations. The inflow flow from the Black Sea in the lower layers of the atmosphere may be associated with moisture advection.

SE-1 configuration has a strong cyclonic shear layer (Fig. 10b), wind vector making a rotation around 270 degrees in the lower troposphere. We can observe the presence of an upper tropospheric jet in SE–NE direction. Wind vectors at the
upper levels are nearly parallel, meaning that confluent or diffluent flows are not present. In SE-3 configuration (Fig. 10c), in addition to the upper level jet one can observe a low level jet (the closed contours near the radar) that can be associated with a strong moisture advection from the Black Sea. Directional anticyclonic shear is most important in the first half of the troposphere. In this case the tropospheric flow is nearly parallel, a strong confluence of fluid being present in the lower layers (Fig. 10c). The main features of these configurations are the presence of the low-level jet and the confluent flow from altitude in SE-2 configuration.

3.3.5. NE-1 and NE-2 configuration

For the last two dynamic configurations NE-1 and NE-2 (Fig. 11a and Fig. 11b) we can observe the presence of an upper tropospheric jet and a confluent flow in altitude.
Stronger vertical shear (module) is seen for the NE-1 (Fig.11a), where there is a higher velocity gradient near the radar. In the case of NE-2 configuration, the confluent flow is powerful throughout the troposphere, because the shear is mainly directional (anticyclonic) in the lower layers. These two configurations can be associated with the presence of retrograde cyclone over the Black Sea, the areas where the convection is initiated being associated with the entrance in the high tropospheric jet.

4. CONCLUSIONS

In all the configurations resulting from the analysis of mean Doppler velocity field at 3.4° elevation the presence of the troposferic jet is revealed for severe convective cells.

Strong module shear in the first layers of the troposphere, associated with a higher intensity of upper tropospheric jet, was observed for W-1, W-2, SW-1, SW-2 and NW-1 configurations.

For NE-1, NE-2, W-1, W-2, SW-1, SW-2 configurations, the upper level flow is diffuent and it is associated with the exit from the tropospheric jet.

For SE-2, NE-1, NE-2 configurations, the upper level flow is confluent and it is associated with the entrance in the tropospheric jet.

For SE-3 and SE-1 the upper level flow is parallel. Low-level jet was present in SE-3 configuration, and can be associated with a strong moisture advection from the Black Sea.

Anticyclonic shear configurations (NW-2, W-2, SW-2, SE-2, SE-3, NE-2) can be associated with a stationary synoptic configuration in time: barocline wave warm sector or a retrograde cyclone is stationary in the South-East of the country.

Cyclonic shear configurations (NW-1, W-1, SW-1, SE-1, NE-1) can be associated with different frontal passages (the biggest weight in averaging the Doppler field, in the lower layers, is attributed to the winds behind the atmospheric fronts).

Configurations that support most of the convective development, some of which having a duration of 3 hours are: SE-3, SW-2, SW-1, and NW-1.

Long life time of the convective developments (over 3 hours), but with a small percentage of occurrence, are typical for SE-2, NE-1, SE-1, and W-2 configurations.

REFERENCES


