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THE OCCURRENCE OF A TORNADO IN SERBIA ON 31 MARCH 2013

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Abstract: Tornado occurs very rarely in the territory of Serbia. The occurrence of a tornado above Torda (Vojvodina, Serbia) on 31 March 2013 indicted the importance of monitoring such a dangerous weather phenomenon, knowing its characteristics and forecasting it. This paper analyzes the synoptic conditions and vertical structure of the atmosphere that prevailed during the development of a supercell with a tornado. Changes in temperature and air pressure are presented on mesoscale maps. The analysis was performed by using the Nonhydrostatic Mesoscale Model (NMM). The tornado occurrence was monitored via satellite images and radar characteristics of a supercell. The cause of tornadogenesis has been ascertained. According to the EF scale, the tornado reached F0 intensity. Damages to roofs, power lines, trees and cars caused by the wind (>35ms-1) are also presented.

Key words: tornado, supercell, SRH, CAPE.

Introduction

Tornado is a violently rotating column of air usually visible as a funnel cloud, stretching from the cloud base to the surface of the Earth. A tornado forms when such condensation funnel, composed of water drops, dust and debris, reaches the ground.

The occurrence of a tornado is related to a deep wet convection, the mesocyclone in supercells (Burgess and Lemon, 1990), as well as with the preservation of the angular momentum of rotation.

Tornadogenesis occurs within a "tornado cyclone", which are several kilometers across. The majority of supercells have a low-level tornado cyclone (Lemon and Doswell 1979, Davies-Jones 1982, Davies-Jones and Brooks 1993) which extends to very close to the ground, although in many cases a cyclone does not cause the formation of a tornado. The formation of a tornado in a supercell is followed by the processes of the persistent updraft rotation development, the

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development of a “special” rear flank downdraft with a rotation to aid in the development of the funnel to the ground, and focusing of the low-level rotation through convergence and upward spin up into the updraft (storm relative helicity). All three elements must occur in unison, i.e. simultaneously, in order for a typical tornado to be formed (with F2 or greater intensity). A weaker tornado with shorter duration can occur within a supercell or in a non-supercell environment without the presence of all three elements.

The formation of a tornado occurs in supercells, in dry squall lines, as well as outside of supercells. Supercells occur in the environments exposed to some well-known characteristics such as sufficient moisture in the ground layer, sufficient convective available potential energy (CAPE), deep-layered vertical wind shear and significant forcing mechanism.

Formation of tornados in supercells

The first step is the formation of a vortex. Large vortices or mesocyclones can form with the beginning of a slow, horizontal rotation within a storm cloud.

The second step is the presence of a vertical wind shear creating circular movement around horizontal air, which is then ingested by a strong updraft tilting the air vertically.

The third step is the preservation of angular momentum. Due to the preservation of angular momentum, the rotation must decrease in order for the wind speed to increase. That creates a narrowing column of rotating air, which stretches downward, forming a wall cloud. The wall cloud consists of significantly cooler, still wet air from the cloud base and is thus located below the supercell.

The fourth step is the appearance of a narrow rapidly spinning column of air, known as a cloud funnel. When the cloud funnel touches the ground, it becomes a tornado and that is the fifth step in the tornado formation process.

For the tornadogenesis to occur, there has to exist a persistent, rotating updraft in the low level. The updraft must persist to strengthen storm-relative helicity (SRH) in order to develop rotation. The higher CAPE and SRH are, the faster a mesocyclone forms. The persistence of the updraft is also very important for the development of a rear flank downdraft (RFD) and rotation below it.

Tornado life cycle

The first stage is the dust-whirl stage. Air swirls near the ground and upward, which indicates the tornado's circulation on the ground. A short funnel cloud appears and extends below the storm. The damage caused in this stage is minor.

The second stage is more organized. The tornado increases in intensity. The funnel cloud extends downward. Damage is still very low.

The third stage is the mature stage. The funnel cloud reaches the ground and becomes a tornado. The tornado spreads to its greatest width. Wind speed increases. The damage is most severe. From this stage until the end of its life cycle, tornado normally remains in contact with the ground.

The fourth stage is the shrinking stage. The width of the funnel decreases and the vortex shrinks.

The fifth stage is the decay stage. This is the final phase in which the funnel stretches almost into the shape of a rope.

These are the stages of a strong tornado; if a tornado is weak, it may skip the mature stage and continue directly to the dissipating stage, or just proceed from the organizing stage.

Methodology and data

Synoptic maps, satellite images and sounding data for Belgrade for 12:00 UTC, specifically data on the vertical structure of the atmosphere and the wind parameters, were used to present the conditions which prevailed during the development of the supercell with a tornado. The non-hydrostatic NMM model, using the boundary conditions from the ECMWF model, was run in the mesoscale domain. Changes in temperature and air pressure at the moment of tornado formation are presented on the maps of Serbia. The comparison of a conceptual tornado model with the radar characteristics of the observed supercell was performed.

Data on temperature and air pressure, as well as radar data from the RHSS observation system (the MRL-5 is dual-wavelength radar) were used. The Surfer 10 graphic software was used for graphical representation. The damages were categorized in accordance with the Extended Fujita Scale.

Analysis and results

In the previous two days above the western Mediterranean area a cyclonic field prevailed in the surface layer, along with the leading part of an upper-level trough (Figure 1). The western areas of Croatia and Bosnia received large amounts of precipitation (40 to 100 mm). After that, on 30 and 31 March 2013, cold Arctic air penetrated in northern Italy through the Alps, which additionally deepened the cyclonic field above the northern Adriatic, and conditioned the strengthening of the southwestern high-level stream over the eastern and central part of the Balkan Peninsula. The southwestern wind speed of 30-45 m/s for 300 hPa created favorable kinematic conditions for an organized convection in the warm area of the eastern parts of the Pannonia plain.

In addition to the synoptic situation, Figure 1 also shows a conceptual model characteristic of tornado development.

ESTOFEX issued a level 1 warning for some parts of Hungary, Romania and Serbia, mostly indicating a high possibility of hail, tornadoes and dangerous isolated convective developments.

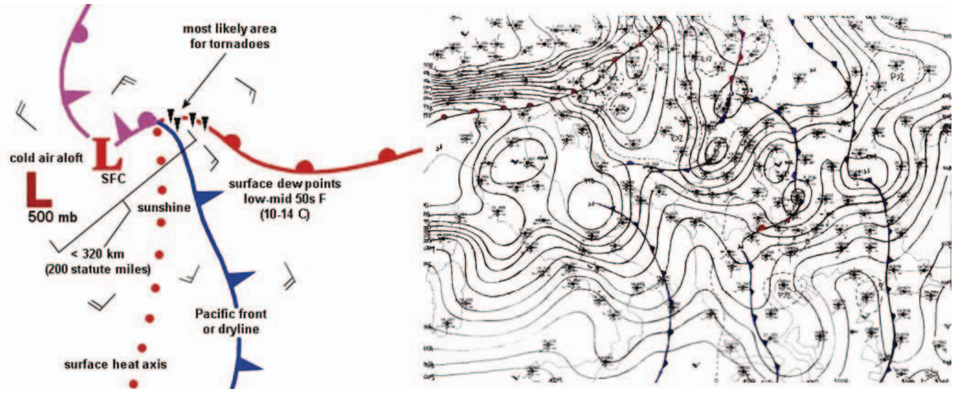

Figure. 1 Conceptual model and synoptic situation (surface data) on 31 March 2013, at 15:00 UTC

The convective regime was expected to be mostly linear, considering the convection conditions, but supercells with large hail were also possible. The hodograph forecasts were rather straight-lined, and wind shear in the 0-6 km layer was around 25 m/s. In the 0-1 km layer, wind shear could have reached 15 m/s, supporting the development of a tornado. There existed a real possibility of a strong wind, which should have represented the leading mechanism in the case of a linear system; however, buoyancy was the limiting factor.

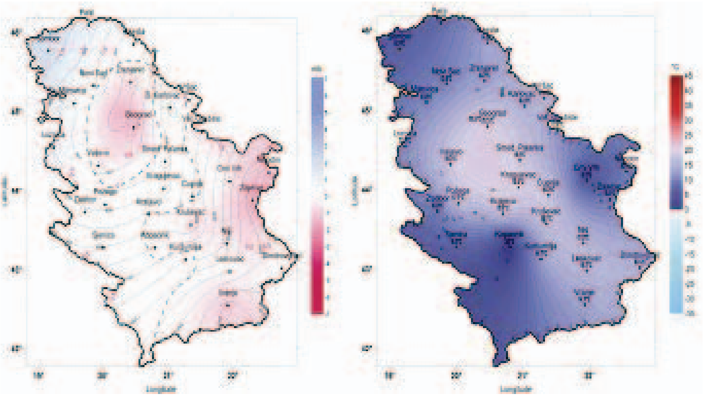

Figure 2. Air pressure field data (left) at 14:00 UTC and air temperature data (right) at 15:00 UTC, recorded at synoptic stations in Serbia

Figure 2 on the left shows the air pressure field with its tendency at 14:00 UTC, and on the right shows the spatial distribution of air temperature at 15:00 UTC, according to the data from automatic stations (AMS) in Serbia. The air pressure tendency was most prominent in the area between Belgrade and Kikinda, while the warm temperature area encompassed the southeastern part of Vojvodina and central Serbia.

Review of satellite images

Images from the geostationary meteorological satellite METEOSAT 10 show that cloudiness was present over Serbia and its vicinity, which was in accordance with the synoptic situation. In Figure 3, in the Dust RGB colour combination, very thick, high-level icy clouds are shown in red, cirrus clouds in black and wet air mass in purple colour.

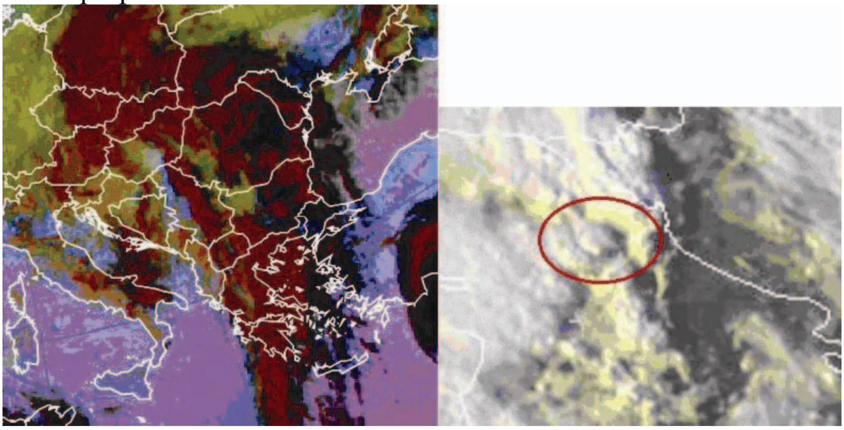

Figure 3. a)Dust RGB,(12:00 UTC,EUMeTrain) and b) MET10, HRV RGB03 312013, (15:00 UTC, EUMETSAT), on 31 Marth 2013

Within the European Severe Weather Database (ESWD), the European Storm Forecast Experiment (ESTOFEX) forecasted a possible occurrence of hail, windstorm and a tornado in its cloud forecast for 31 March 2013, for the area of Serbia, Romania and Hungary.

In Figure 3b, the HRV RGB combination of a visible high-resolution channel (1 km) and an infrared channel 10.8 µm shows an area of enhanced convection. Figure 4 shows a Cb cloud over Torda from which the tornado formed (specific parts of the cloud are indicated).

A wall cloud or pedestal cloud is an isolated cloud lowering attached to the rain-free base of the thunderstorm. The wall cloud is usually located to the rear of the visible precipitation area. A wall cloud that may produce a tornado usually exists for 10–20 minutes before a tornado appears. A wall cloud may also persistently rotate (often visibly), have strong surface winds flowing into it, and may have rapid vertical motion, quickly rising into the rain-free base beneath the cumulonimbus cloud.

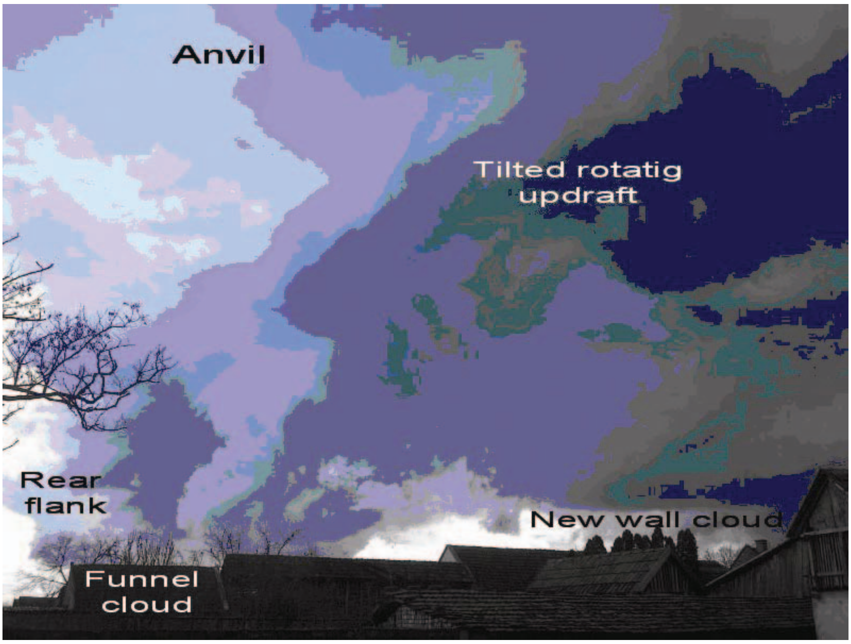

Figure 4. A photograph of cumulonimbus clouds and a tornado in Torda on 31 March 2013, at 15:00 UTC

Analysis of sounding data and wind shear in Belgrade

According to the 12:00 UTC sounding of 31 March 2013 for Belgrade (Figure 5), isolated convective developments of the classic supercell type were expected. The instability parameters (Table 1) show CAPE (625.34 Jkg), DCAPE (365.23 J/kg-1), maximum hailstone size (1.29 cm) and the height of convection of around 8.5 km. The speed of the storm movement of 17ms-1 (33.58 knots) was also forecasted. The possibility of the occurrence of a tornado was also indicated by the SWISS 12 convective index and wind shear in the 4-6 km layer (with the speed of 13 ms).

The effective wind shear up to 6 km from the ground reached 30 ms-1 (58.21 knots). Most parameters and convective indices did not signal the possibility of tornado formation.

Table 1. Sounding parameters for 31 March 2013 at 12:00 UTC for Belgrade

Convection parameters	Value	Interpretation
Convective T (□C)	18.07	
Lift index (□C)	-3.39	Expected storms
CAPE (J/kg)	625.34	Isolated storms
CIN (J/kg)	36.97	
CAPE Virt (J/kg)	682.48	Isolated cells
DCAPE(LFS=678mH) (J/kg)	365.23	
Hail (SHIP)	1.07	
Max hailstone size (cm)	1.29	
Height of convection (km)	8.44	
LCL	568.87	
	Convective indices	
Showalter Index (□C)	2.11	Isolated storms
Modif. Thompson Index (□C)	32.75	Expected supercells
Total Totals index (□C)	51.40	Widespread storms
KO index	-5.99	No storms expected
SCPLM	1.05	Possible supercells
SB STP	0.17	No tornados expected
SWISS 12 Index	-10.14	Expected tornado
Wind parameters		
Wind shear 0-2 km (m/s)	6	Possible supercells
Wind shear 4-6 km (m/s)	13	Possible supercells with a tornado
Wind shear 9-11 km (m/s)	26	Expected classic supercell
Bulk Richardson Number	10.51	Multicellular developments
MAX 3 km SRH (m2/s2)	133.59	Possible supercells
3 km potential vorticity (m/s2)	0.13	No tornados expected
Effective wind shear up to 6 km (m/s)	30	Possible dangerous storms

The stronger and higher the updraft (depending on the convective available potential energy – CAPE) and the ambient storm-relative helicity (SRH), the more likely the updraft can organize into a significant mesocyclone. The updraft then must continue to persist as the rear flank downdraft (RFD) develops, focuses, and concentrates rotation below it. A persistent, rotating updraft creates a dynamic pressure gradient that allows low-level air to be pulled upward into the updraft. This is important, that is, the ability of the updraft to create boundary layer lift below the level where positive parcel buoyancy creates lift. This allows for the ingestion of low-level SRH. Large values of low-level humidity, as evidenced by low lifting condensation levels (LCLs), are more conducive to tornado formation, as strong cold pools are inhibited.

SRH estimates thunderstorm's potential to acquire a rotating updraft given a vertical wind shear profile. There must be local augmentation of SRH to generate tornados.

When it comes to the development of the tornado that occurred in Torda on 31 March 2013, based on the wind shear in the 0-1 km layer (< 10m/s) and the LCL height (LCL = 568.87m), there was no indication of a possible tornado (the probability reached 42%, and for a tornado to form it should be > 70%).

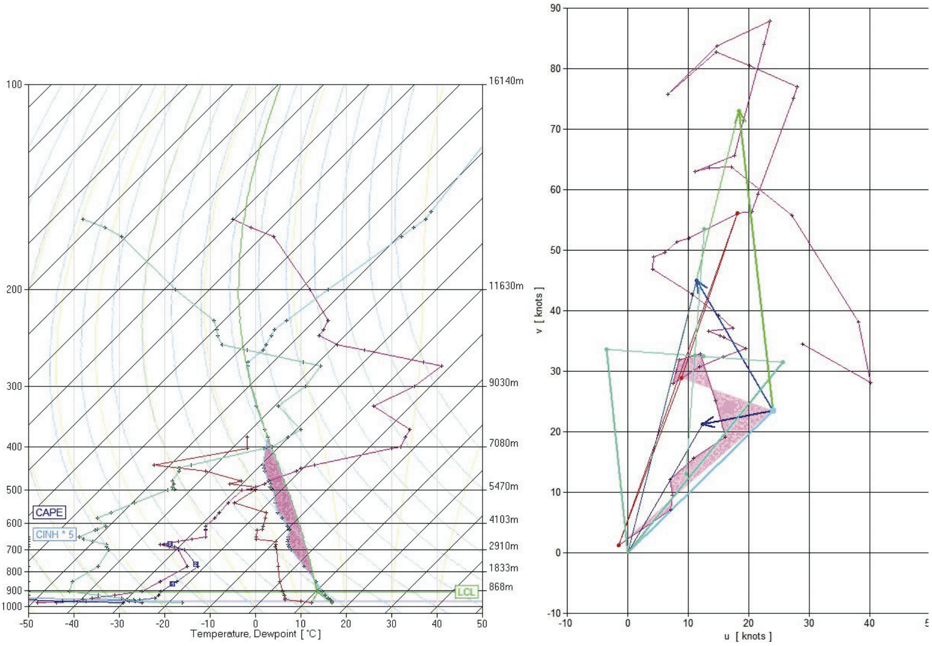

Figure 5. Skew–t plot and hodograph of wind for Belgrade for 31 March 2013 at 12 UTC, with sounding on the left and wind hodograph on the right (taken from http://62.202.7.134)

NMM model results

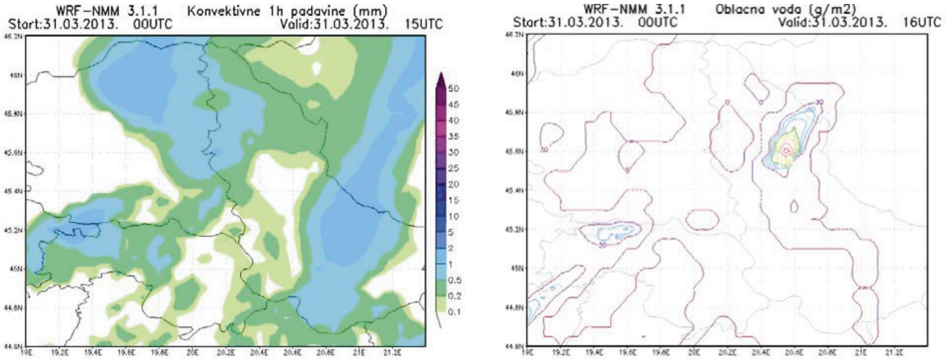

Figure 6. Convective precipitations, (left) and total cloud water amounts (right) at 15:00 UTC, according to the model

The non-hydrostatic mesoscale model (NMM) with 4 km resolution was run for 31 March 2013, and its results can be seen on Figure 6 (left and right) represents convective precipitation over Vojvodina at 15:00 UTC, and Figure 6 on right side shows that cloud water amount is the largest precisely in the part of Vojvodina where the cumulonimbus cloud with the tornado formed.

Composite radar reflectivity was over 30 dBz in northeastern Vojvodina, while convective available potential energy was stronger in southern Serbia than in Vojvodina.

It can be concluded that the NMM model predicted significantly weaker convection than observed.

Analysis of radar data

In order for a tornado to form, air masses with different characteristics need to be present (warm air mass from the surface layer, dry air from the middle layer and cold air mass from the upper layers of the troposphere). The conditions for the development of a tornado usually occur at an occluded front.

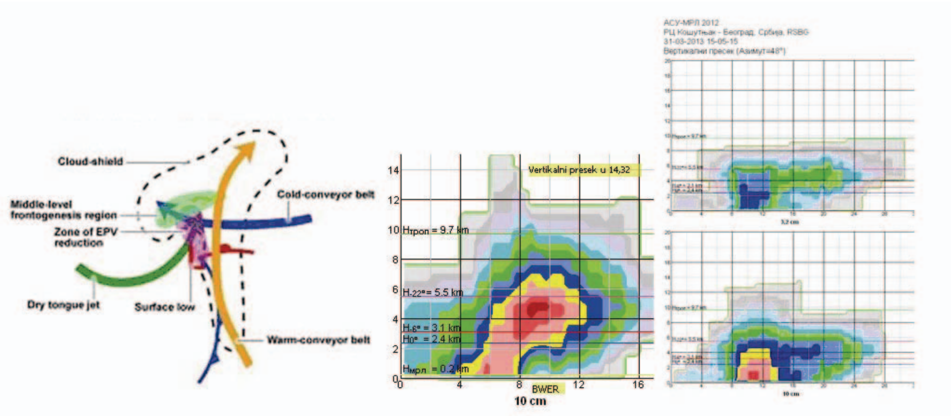

Figure 7. A conceptual tornado model, vertical cross-section of the supercell at 14:32 UTC and radar echo in the form of a hook at 15:05 UTC

When it comes to the tornado that formed over the village of Torda in Vojvodina on 31 March 2013, an already developed cumulonimbus, passing over Melenci, Rusanda thermal lake (with water temperature of 32°C) and nearby lakes Okanj-Mutljaca and Ostrovo, picked up warm, wet air, embracing the air mass which additionally supported the rotation within the cloud (radar image 10 from the RHMSS MRL-5 dual-wavelength radar at 15:00 UTC + 2 hours for local time). Figure 7 (in the middle and on the right) shows BWER (in the form of a hook) with a strong rotation below.

At the height of around 5 km, at 14:45, after only 5 minutes, the core began to extend downwards, and a part of the cloud started to produce precipitation (rain with hail). As the storm intensified, the wind drew in low-level air from several kilometers around. Some low-level air was pulled into the updraft from the rain area. This cooled air was very humid so that it quickly condensed under the rain base to form the wall cloud.

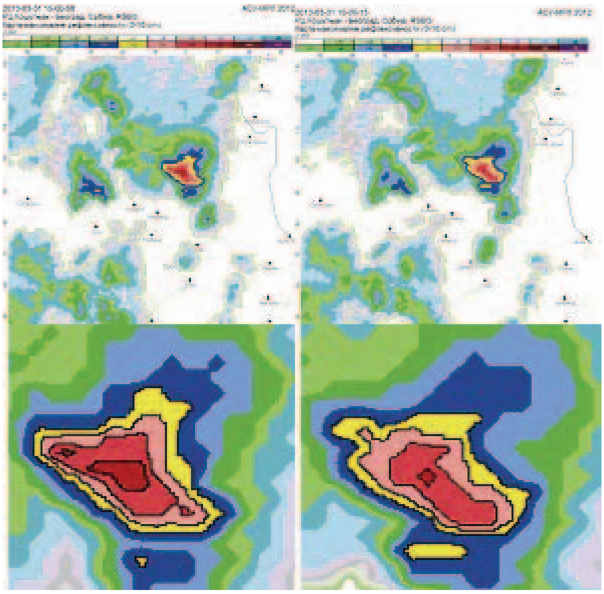

Figure 8. Horizontal cross-section of the supercell at the moment of the tornado formation at 15:00 UTC and its dissipation at 15:05 UTC

The tornadogenesis process traditionally manifests itself on radar as an increase in rotational velocity in the mid- and/or low-levels. The tightening of a region of circulation is common, which often leads to the development of a Tornadic Vortex Signature (TVS) by radar. At low levels, TVS probably represents a part of mesocyclone development inside the wrapping rear flank downdraft – RFD (Figure 9). The RFD axis is usually closely aligned with the axis of the wrapping hook axis (hook echo, Figure 7, vertical cross-section). The low-level flow inside the hook/RFD gradually accelerates with decreasing distance to the circulation center, which can be seen on Doppler radar.

The rear flank downdraft (RFD) is a downward rush of air on the back side of the storm that descends along with the tornado. The RFD looks like a “clear slot” or “bright slot” just to the rear (southwest) of the wall cloud. It can also look like curtains of rain wrapping around the cloud base circulation. The RFD causes gusty surface winds that occasionally have embedded downbursts. The rear flank downdraft is the motion in the storm that causes a characteristic hook clearly visible on radar (radar reflectivity).

Rear flank downdrafts in tornadic supercells seem to have an unusual character compared to non-tornadic supercells and thunderstorm downdrafts in general.

The RFD helps translate rotation to the ground. Upon reaching the ground, some of the RFD air wraps around and flows into the low-level updraft vortex, while other air flows away from the vortex. A condensation funnel is made up of water droplets and extends downward from the convective cloud base.

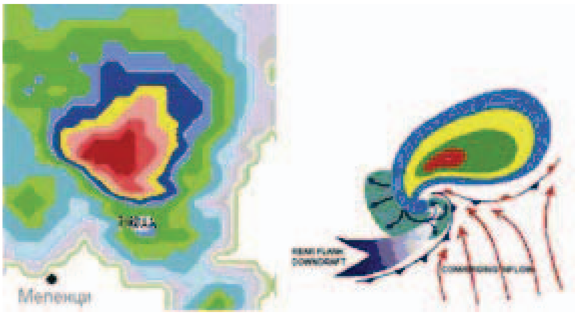

Figure 9. An isolated convective supercell recorded over Torda on 31 March 2013 and a conceptual model of a tornado

Damage caused by the tornado

The most common and practical way to determine the strength of a tornado is to look at the damage it caused. From the damage, we can estimate the wind speeds. An "Enhanced Fujita Scale" was implemented by the National Weather Service (USA) in 2007 to rate tornadoes in a more consistent and accurate manner. The EF-Scale takes into account more variables than the original Fujita Scale (F-Scale) when assigning a wind speed rating to a tornado, incorporating damage indicators such as building type, infrastructure and trees. Tornado wind speeds range from 17.9 to 32.2 m/s for F0 category (weakest) tornadoes. Wind speed in Torda during the tornado is estimated to be around 30.0 m/s.

F0 tornadoes cause damage to chimneys and roof tiles, break branches off of trees and topple shallow-rooted trees.

Figure 10. Damage caused by the tornado in Torda on 31 March 2013

Figures 10 show some buildings damaged by the tornado in Torda. The tornado damaged more than 100 houses, destroyed roofs and fences, toppled trees and power lines, etc. The total damage is estimated at around 6 million euros.

Conclusion

An F0 intensity tornado developed above Torda (Vojvodina, Serbia) on 31 March 2013 at around 15:00 UTC. The tornado developed within a classic supercell that moved across Vojvodina from the southwest towards the northeast. On its path, around 10 kilometers outside Torda, moving over Rusanda thermal lake (Melenci) and other nearby lakes, the cumulonimbus cloud drew in additional warmth and moisture, which was the key factor for the initiation of tornadogenesis. With the exception of the SWISS 12 convective index and wind shear in the 4-6 km layer (speed of 13 m/s), neither the atmospheric instability indices for that date (sounding for Belgrade at 12:00 UTC) nor the wind parameters did indicate the development of a tornado. Neither did the NMM model predict the intense convective development. ESTOFEX issued a level 1 warning for some parts of Hungary, Romania and Serbia, that indicated the possibility of hail, tornadoes and dangerous isolated convective developments.

The tornado lasted for several minutes (from 15:00 to 15:05 UTC), damaging more than 100 houses. Wind speed was over 30 m/s. In addition to the strong wind, nut-sized hailstones and heavy rain also damaged roofs, trees and power installations.

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