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TORNADO OCCURRENCE NEARBY VALJEVO ON 27 MAY 2014 – ANALYSIS OF WEATHER SITUATION

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Abstract: This study shows the case of a tornado on 27 May 2014 in the vicinity of Valjevo. According to its characteristics and considering that this is a mesocyclonic severe weather event, accompanied with heavy rain, violent wind, hail and thunderstorm, it belongs to extraordinary dangerous meteorological events. The aim of this study is to determine and examine the cause of tornado occurrence in this area using the methods of synoptic and mesoscale analysis, as well as radar analysis. That could contribute to better understanding of this phenomenon in Serbia as well as to improving the forecast methods and models. Contrary to the previous researches, the capacities of the meteorological radar MRL – 5 have been presented in this study.

Key words: tornado, supercell, beaver tail cloud, BWER, MRL – 5

Introduction

A great number of researchers studied the occurrence of landspouts, i.e. tornadoes, in Serbia from meteorological and geographical aspects or in the context of astrophysical predispositions (Maksimović, 1987; Ducić, Tanasijević, 1993; Radovanović, 2009; Mihajlović et al., 2013; Pavlovic-Berdon et al., 2013). This type of air vorticity can occur in Serbia every three years (Andjelković, 2009).

About 20% of tornadoes are related to the non – supercell convection, that is, to squall lines and/or towering cumulus clouds (TCu). Tornadoes of *EF*2 – *EF*5[2] intensity are related to the supercell thunderstorms (Trapp et al., 2005). Supercell thunderstorms are characterized by a deep, persistent mesocyclone (Doswell & Burgess, 1993). Mesocyclone[3] is a cyclonically rotating vortex,

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[2] Enhanced Fujita Scale (*EF* – scale) is an updated version of *F* – scale, implemented on the 1st of February, 2007 in the United States.
[3] http://glossary.ametsoc.org/wiki/Main_Page

around 2–10 km in diameter, in a convective storm. The vorticity associated with a mesocyclone is often on the order of 10^{-2} s^{-1} or greater.

The aim of this research is to determine and examine the causes of the tornado occurrence in the vicinity of Valjevo by using the methods of synoptic and mesoscale analysis, as well as radar analysis. The object of this research is the supercell tornado event of 27.5.2014. This paper tries to contribute to better understanding of this complex atmospheric phenomenon.

Database and research methodology

A strong supercell cloud together with a violent wind, small hail, heavy rainfall and a tornado hit Valjevo (44° 16′ 27″ N, 19° 53′ 28″ E, 185 m AMSL) and nearby villages - Kotešica (44° 20′ 27″ N, 19° 50′ 28″ E, 296 m AMSL) and Gola Glava (44° 23′ 33″ N, 19° 51′ 19″ E, 227 m AMSL) at 15:30 CET.

The database consists of synoptic maps and complex synoptic charts available at the web page http://www.wetter3.de, and the radar cloud images from the Republic Hydrometeorological Service of Serbia (http://www.hidmet.gov.rs).

Figure 1. Geographical map with terrain topography and marked spots where supercell thunderstorm occurred, i.e. a possible tornado location (The map was made by an online tool - GPS Visualizer (http://www.gpsvisualizer.com))

Fujita and Enhanced Fujita Scale (*F* – scale, *EF* – scale) were used to estimate the damage.

Synoptic maps are products of Global Forecast System (GFS), and they are available four times a day: at 00, 06, 12 and 18 UTC. Two software were used for processing radar cloud images – Rainbow and ASU - MRL 2012. Cloud and radar images were processed by two software packages – PhotoScape and PhotoFiltre Studio X.

Synoptic analysis: surface and upper – level structure of atmosphere

In order to get a clear picture of surface and upper – level structure of the atmosphere on 27 May 2014, isobaric surfaces of 1013, 850 and 500 mb were used in this analysis in the following synoptic time terms: 00, 06, 12 and 18 UTC.

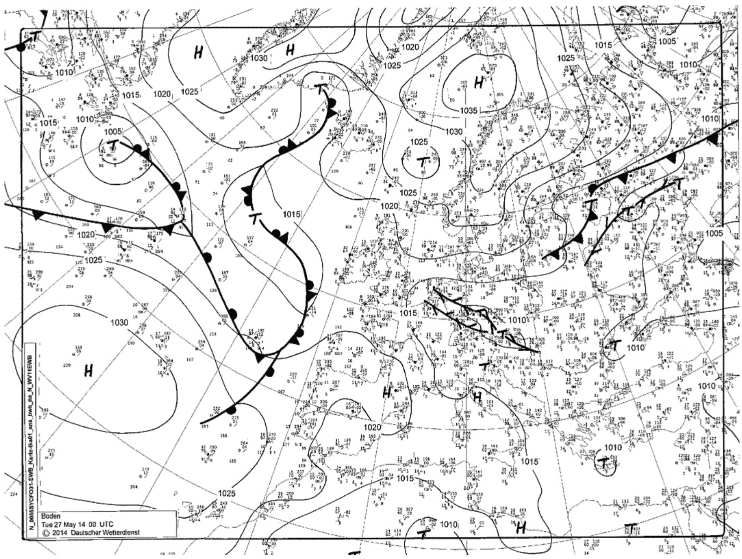

Figure 2. Surface pressure map at 00 UTC, 27 May 2014 (Source: http://www.wetter3.de)

Surface synoptic situation (Figure 2,3,4 and 5) begins with an occluded system of low pressure, which spreads from Greenland to the Iberian Peninsula, and the ridge of an anticyclone over Scandinavia and Finland. These two systems lead to an advection of moist and unstable air in the region of the Baltic Sea. The ridge of high pressure spreads from primary strong and vast anticyclone whose centre is over the Bay of Biscay and across the Iberian Peninsula, western Mediterranean and western parts of the Apennine Peninsula to the Atlas region and ends in the Gulf of Sidra. The strengthening convergence line spreads from the coastline of the North Sea, i.e. Netherlands and Belgium, to the Pannonian Plain and marks the existence of a continuous low pressure channel.

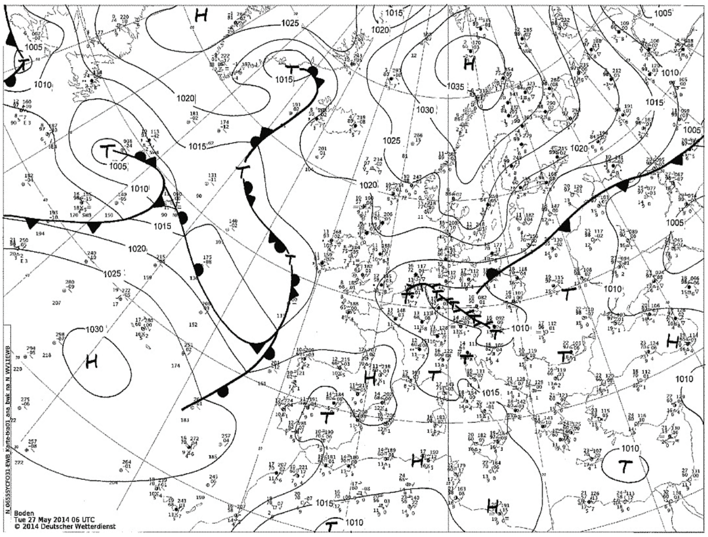

Figure 3. Surface pressure map at 06 UTC, 27 May 2014 (Source: http://www.wetter3.de)

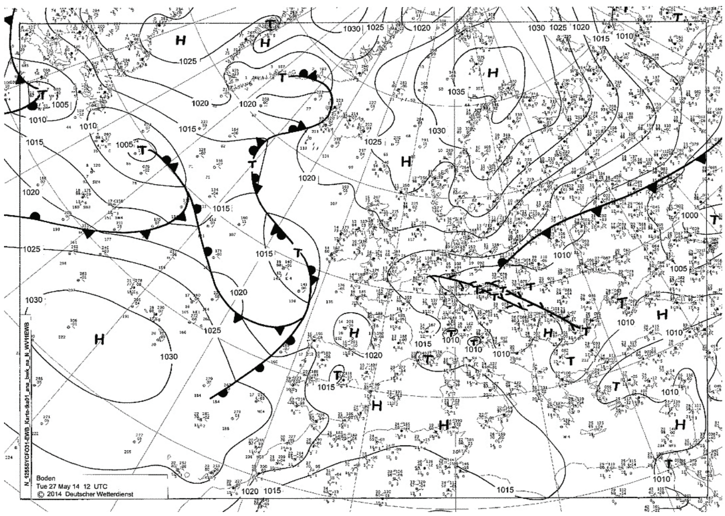

Figure 4. Surface pressure map at 12 UTC, 27 May 2014 (Source: http://www.wetter3.de)

The centre of the shallow cyclone is over the north-western part of the Balkan Peninsula. An occluded front develops within this cyclone, on its north periphery. The cyclone feeds on unstable (moist and cold) air from northwest which causes its slow deepening and wind strengthening. The inflow of warm air from the south causes the strengthening of the warm sector in the front part of the cyclone. In the southeast, over the eastern part of Romania, there is poorly developed anticyclone which slowly shifts across the northern part of the Black Sea. Within the upper – level trough there is a secondary depression over the Ligurian Sea, which shifts with it across the northern Italy and northern Adriatic, farther to the east. In the early morning hours, within the upper – level west – southwest stream, the cold air mass from the northwest penetrates over the north-western and western parts of the Balkan Peninsula.

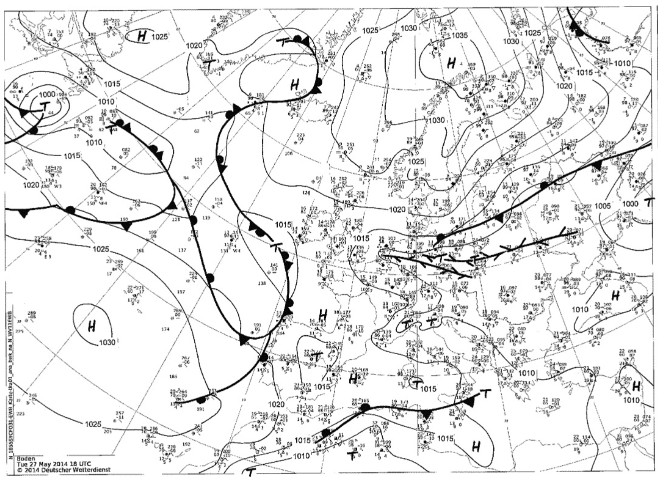

Figure 5. Surface pressure map at 18 UTC, 27 May 2014 (Source: http://www.wetter3.de)

In the fields of the geopotential and temperature, on 850 mb isobaric surface for selected synoptic terms, the stationary trough, which spreads from Ireland and the Bay of Biscay, across France, northern Italy to eastern parts of BiH and western Serbia, can be seen. The channel of low geopotential heights marks the negative temperature advection from the north-eastern parts of Europe, that is, the intrusion of cold air in these regions. The structure of the atmosphere on the 500 mb isobaric surface (Figure 6,7,8 and 9) is similar to that on 850 mb surface. The stationary trough spreads from Ireland and the Bay of Biscay across France and the northern Italy to the western parts of our country. The cold upper – level core within this baric creation shifts across the Iberian Peninsula and western Mediterranean causing unstable weather in this part of Europe. The channel of low geopotential heights is formed in the northeast – southwest direction. At the same time, the upper – level anticyclone with the centre of 572 hPa over Belorussia weakens and shifts to the south as another upper – level trough shifts across Scandinavia, farther to the south.

Analysis of radar images

The supercell cloudiness, which caused the tornado occurrence in the vicinity of Valjevo, has been observed by the meteorological radars GEMATRONIK (radar centres Jastrebac and Fruška Gora) and MRL – 5 (radar centre Košutnjak). The most significant details of the cloudiness are shown in the composite radar images CAPPI (the horizontal cross–section of the cloudiness on the desired height) (Figure 10,11,12 and 13) in time terms from 13:30 – 15:30 UTC, from 10 cm wavelength radar Gematronik in the Rainbow software. The observed data of the supercell cloudiness have been formed by the meteorological radar MRL – 5 and shown on the layer maps: maximum reflectivity map (ZMAX) on 10 cm and map of severe meteorological events on 10 cm, as well as vertical cross–section of the cells in any direction. The radar images have been made in the software ASU - MRL 2012, for time terms 14:02 – 14:14 UTC. The capacities of MRL – 5 radar are reflected in receiving and processing the radar meteorological information simultaneously on two radar channels (λ_1= 3.2 cm and λ_2= 10 cm), as well as the information from Doppler radars (λ_3= 5.3 cm). This type of radar can be used for short–term weather forecast.

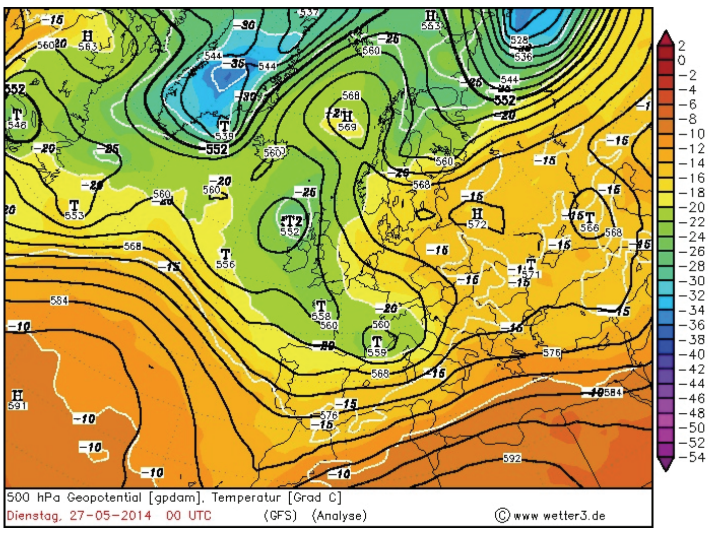

Figure 6. Upper-air map AT 500 mb at 00 UTC, 27 May 2014 (Source: http://www.wetter3.de)

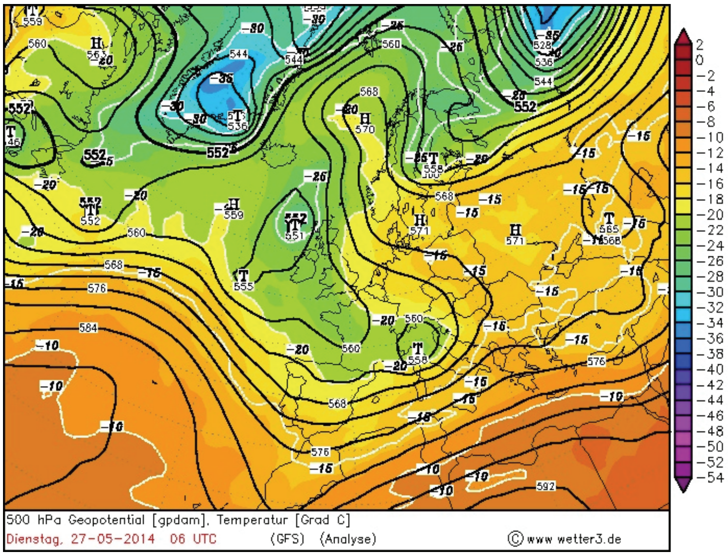

Figure 7. Upper-air map AT 500 mb at 06 UTC, 27 May 2014 (Source: http://www.wetter3.de)

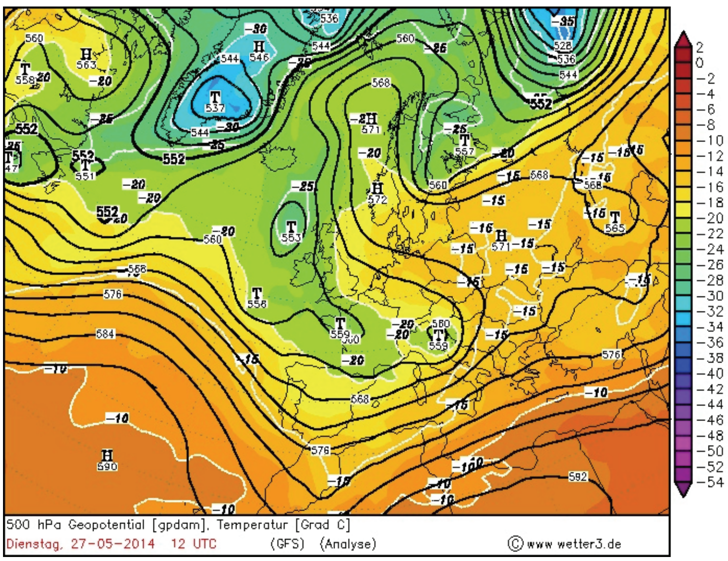

Figure 8. Upper-air map AT 500 mb at 12 UTC, 27 May 2014 (Source: http://www.wetter3.de)

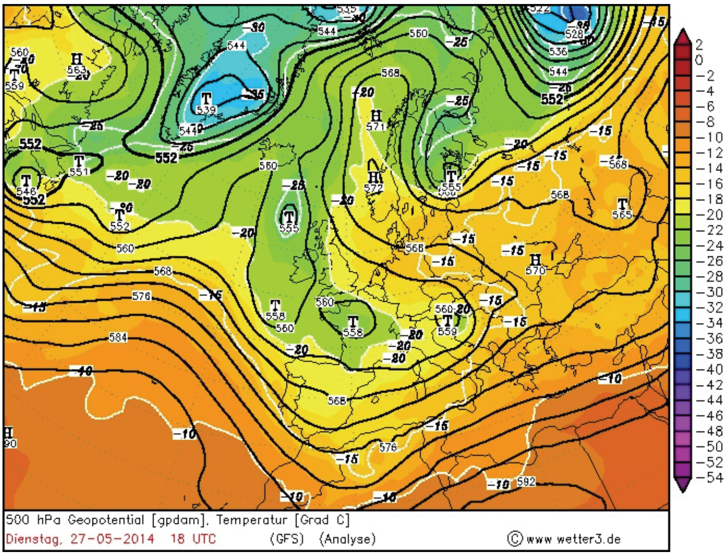

Figure 9. Upper-air map AT 500 mb at 18 UTC, 27 May 2014 (Source: http://www.wetter3.de)

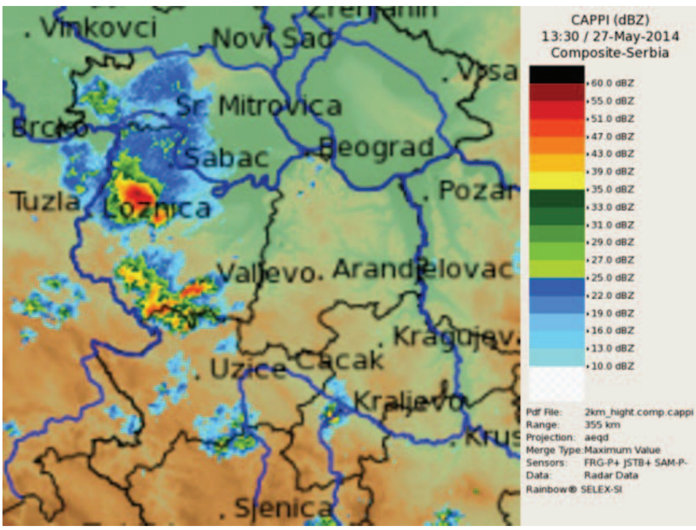

Figure 10. Composite radar image CAPPI (dBz) 10 cm wavelength, at 13:30 UTC, 27 May 2014 (Source: http://www.hidmet.gov.rs)

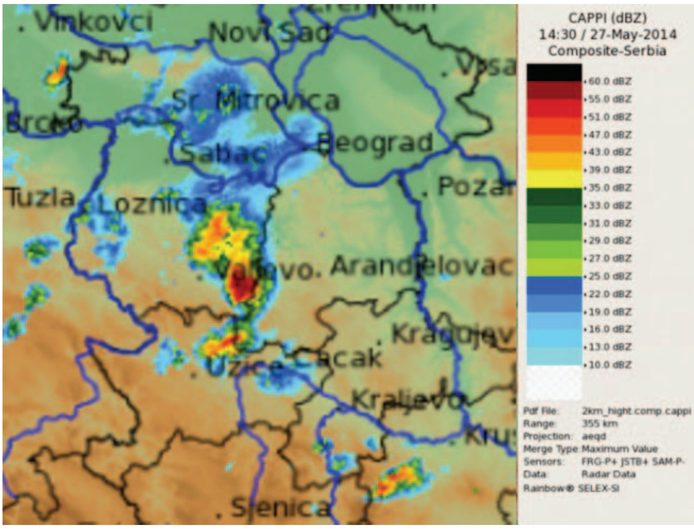

Figure 11. Composite radar image CAPPI (dBz) 10 cm wavelength, at 14:30 UTC, 27 May 2014 (Source: http://www.hidmet.gov.rs)

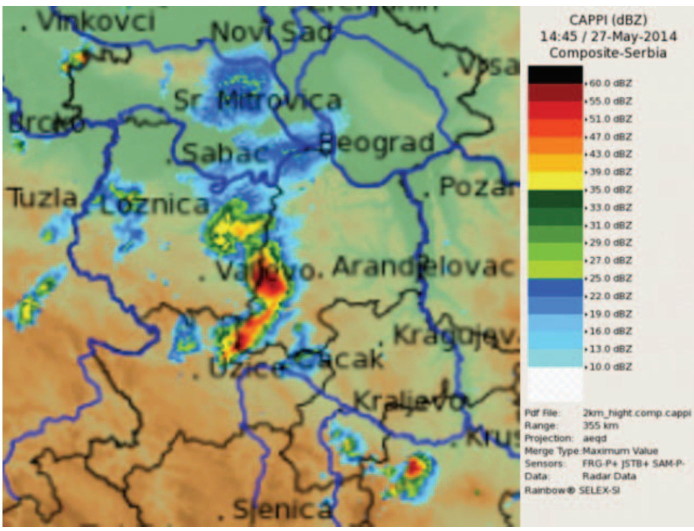

Figure 12. Composite radar image CAPPI (dBz) 10 cm wavelength, at 14:45 UTC, 27 May 2014 (Source: http://www.hidmet.gov.rs)

At 14:30 UTC, an echo with maximum radar reflectivity from 51 to 60 dBz, with characteristic notch shape or hook (hook echo) has been noticed on the composite radar image (CAPPI, dBz) (Figure 11) in the vicinity of Valjevo. This is a specific characteristic of the supercell cloud. On the very next radar image

(Figure 12), the development of bow echo cloudiness can be seen. With the influence of a well – pronounced, large scale rear stream, this cloudiness has been separated into two cells. “V shape“ on the rear side (Rear Inflow Notches) implies the existence of a strong wind on the rear side of the cloud system.

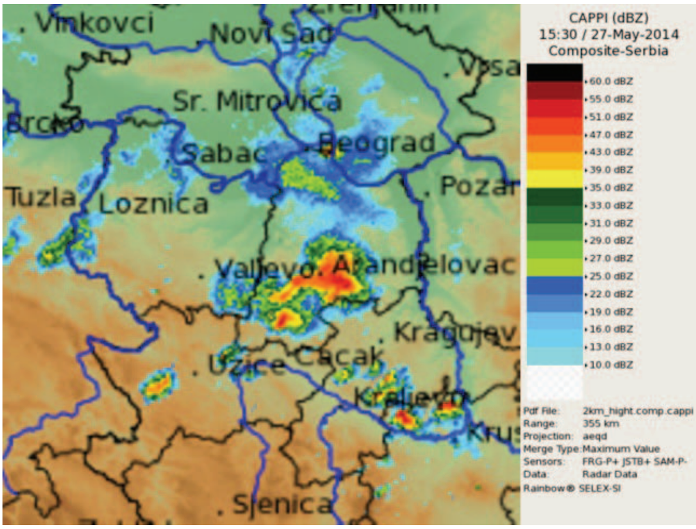

Figure 13. Composite radar image CAPPI (dBz) 10 cm wavelength, at 15:30 UTC, 27 May 2014 (Source: http://www.hidmet.gov.rs)

On the maximum reflectivity map (10 cm) for time term 14:02 UTC (Figure 14. A), the vertical cross–section of the cell with the azimuth of 47^0 has been made for the area where the tornado was registered according to the newspaper reports. The maximum reflectivity of the cloudiness varies from 55 to above 60 dBz. The map of severe meteorological events for the same time term has registered small to moderate hail with the pronounced thunderstorm processes (70–90 %) (Figure 14. E). The vertical cross–section reveals the zone of maximum radar reflectivity (60 dBz) which extends to the height of 4.4 km (the altitude of zero isotherm is H_0= 3.3 km). The cloud zone with the maximum echo and hook shaped BWER, with the horizontal width of 8 km, was extending from cloud base up to the height of 18 km (the cloud penetrated the tropopause H_{TROP}= 10.7 km). The region with the weak echo reflectivity, surrounded by stronger reflectivity (BWER) with the pronounced and strong rotation below it, can be noticed in the front part of this cloud. The direction of cloud movement is towards the west from the main upper – level stream of SW – NE direction. On the vertical cross–section of the cloud, in the rear part of the supercell (Figure 14. A), a clear and pronounced border between strong (60 dBz) and weak echo

(30–40 dBz) can be noticed. It is exactly the spot where the mesocyclone has been formed and the tornado which developed from it.

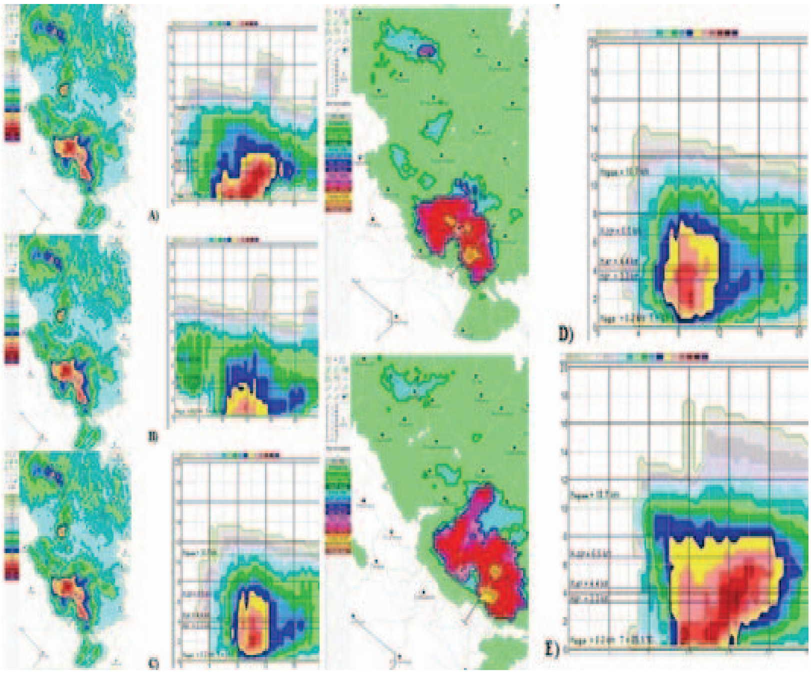

Figure 14. Maximum reflectivity map (A, B, C) and the map of severe meteorological events (D, E) on 10 cm (left) and the vertical cross – sections of the cloud in desired direction (A, B, C, D, E) (right), 27 May 2014 for selected time terms

In the photograph above (Figure 16), the beaver tail cloud is noticed. It develops on the border of the updrafts and downdrafts of the supercell storm, i.e., it is often noticed near the gust front or "pseudo - warm front". It is located on a rain free part of a supercell. In the storm's downdraft (FFD), the heavy and rain-cooled air is spreading laterally, while at the same time warmer and moist air is being lifted. As this warm air is getting saturated, it undergoes the process of condensation and becomes visible as the beaver tail cloud (Spellman, 2012;http://ww2010.atmos.uiuc.edu/;http://mattbrode.wordpress.com/tag/beaver-tail-cloud/).

Damage estimates according to the *EF* – scale

Severe weather event, which hit Valjevo and nearby places on 27 May 2014 around 15:30 CET, followed by the heavy rain (around 20 mm of rainfall), small hail, thunderstorm and tornado, was caused by the supercell cloud which was moving across the town within the upper – level southwest stream. The tornado, which developed within this cloud system, swept the villages of Valjevo – Kotešica and Gola Glava, blew the tiles away and damaged the roofs. Damage from hail was not registered because the anti – hail defence station “Blizonjski vis” fired about a hundred anti-hail rockets. The cloudburst caused the flooding and traffic jams in the town streets.

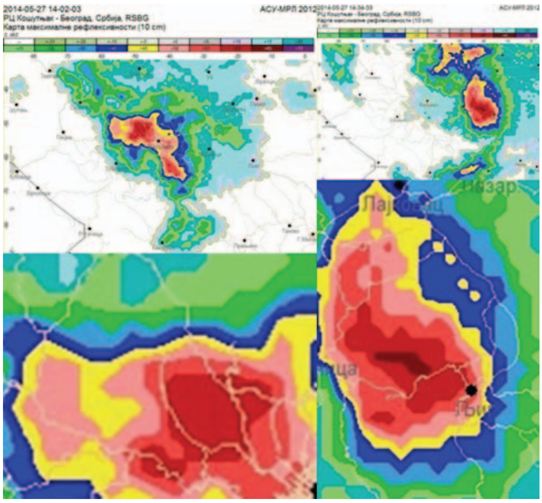

Figure 15. Maximum reflectivity map (10 cm) and enlarged horizontal cross–section of the cells with the strongest echoes, 27 May 2014 for selected time terms

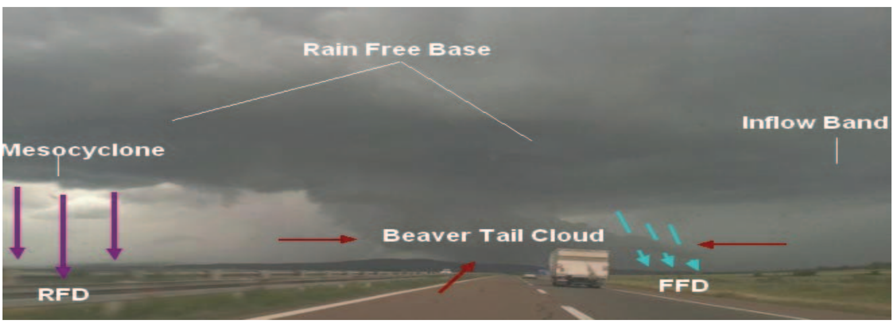

Figure 16. Modified photograph of the beaver tail cloud with marked most significant visible elements of the supercell thunderstorm nearby Valjevo, 27 May 2014 (the photograph taken from: http://bihacity.ba/novosti/valjevo-pogodio-pljusak-grad-i-mini-tornado#sthash.non8soFN.dpuf)

As it is practically impossible to make direct measurements of the tornado speed, the best way to do it is to use the Fujita Scale (*F* – scale), that is, the Enhanced Fujita Scale (*EF* – scale), which is based on the damage estimates caused by tornado and which uses 28 different indicators. According to the analysis, and using this method, it can be concluded that the tornado nearby Valjevo was *F0* (*EF0*) category, i.e. the weakest tornado. According to the radar criteria, and considering the cloud height (18 km), this cloudiness can produce wind gusts greater than 30 m/s, which is in accordance with the strength estimation on the Enhanced Fujita Scale (for *F0* tornado category, wind speeds are expected up to 32 m/s).

Conclusion

On 27 May 2014, a supercell cloud developed over the wide area of Valjevo (nearby villages Kotešica and Gola Glava) and was moving across this area from 13:30 to 15:30 UTC. Upper – level southwest stream caused the development of a bow – shaped cloud system and then, under the influence of a well pronounced large scale rear stream and the separation of this cloud system into two cells, a new supercell developed over Mionica. The supercell cloud, which moved over the villages of Kotešica and Gola Glava, caused the development of *EF*0 tornado at the moment of maximum radar echo. This cloudiness caused severe weather, followed by high precipitation, gust winds, thunderstorms and hail. Gust wind reached the speed of 25–30 m/s.

Synoptic and mesoscale analysis have been performed using surface and upper – air (500 mb) synoptic maps, which are products of the GFS model. The results of the analysis suggest that the baric relief over the Balkan Peninsula and our country was very complex. The centre of the shallow cyclone was over the north-western part of the Balkan Peninsula while the upper – level west – southwest stream had a crucial influence on the development of the supercell over Valjevo within which there was an intrusion of a cold air mass from the northwest (the cold advection) to the western parts of the peninsula. The results of the performed synoptic analysis show that more precise data related to a certain mesoscale situation and tornado development are needed to make the forecast of this type of a strong local storm successful.

The radar analysis showed the vertical cross–section of the supercell cloud at the moment of maximum radar echo (60 dBz), with a pronounced BWER and a hook shape, which both indicate a strong rotation at the surface and the development of a mesocyclone which produced tornado. The cloud penetrated the tropopause and reached the height of 18 km, which is shown on the photograph of beaver tail cloud.

Acknowledgements
The authors want to thank Mr. Dušan Ristić from the Republic Hydrometeorological Service of Serbia for providing radar data from MRL – 5 radar.

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