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J. Geogr. Inst. Cvijic. 65(3) (281–296)

Original scientific paper

UDC: 911.2:551.58(497.11)
DOI: 10.2298/IJGI1503281P

STORM ON JUNE 22, 2013 IN INDJIJA (SERBIA) — A CONSEQUENCE OF HEAT WAVE

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Received: October 27, 2015; Reviewed: November 12, 2015; Accepted: November 19, 2015

Abstract: In the period between 16 and 22 June 2013, Europe was hit by a heat wave. At the end of the period characterized by extremely high temperatures, the development of storm along with supercell HP convection cell took place in Serbia, producing tennis ball-sized hailstones and wind with speed exceeding 35 m/s. This paper analyzes the underlying conditions that led to development of this storm using synoptic charts, vertical atmosphere characteristics as well satellite and radar images. The development of strong convective clouds was enabled by exceptional thermal instability of the atmosphere above the Pannonian Plain and the Balkans and warm subtropical air. The analysis of the vertical structure of atmosphere indicates that the separate convective cells could produce large amounts of precipitation and hailstones up to 8 cm in diameter. Cloudy zone, of the supercell type in development, of 12–16 km width, reached to 20 km height (cloud penetrated tropopause) and indicating extremely great energy instability. Furthermore, this analysis is supplemented with results of nonhydrostatic mesoscale NMM model. Big hailstones from this storm took life of 31 persons in addition to great material damage it caused.
Key words: heat wave, HP supercell, CAPE, hail, stormy wind

Introduction

In this work, the development of supercell in convective day during summer 2013 is shown, as a consequence of heat wave above the portions of southeastern Europe. The environmental condition for severe weather potential over Vojvodina (Serbia) has been analysed. A high precipitation supercell type (HP) is determined on 22 June 2013 in Indjija.

Appreciably strong low pressure in the upper layers of troposphere located above the southern Spain forced the high pressure ridge to centre above Eastern Europe (blocking of cut off type). Heavy precipitation events in the western Mediterranean region typically occur downstream of a significant cyclone aloft

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(often, but not always, exhibiting “cut off” cyclone characteristics), but important.

structural and evolutionary differences are found among these cases (Doswell III, Ramis, Romero, & Alonso, 1998). Low pressure at high altitudes was situated above Spain and France most part of the observed period (from 16-22 June 2013) allowing the ridge to strengthen, producing heat wave above the portions of southeastern Europe (Figure 1). This episode is due to the incursion of Saharan air into middle Europe.

Atmospheric blocking leads to stagnation in weather patterns. In case of blocking, the same pattern reoccurs, that is, persists for several days even weeks resulting in floods, droughts, extremely high or low temperatures and other weather extremes.

Extreme heat can cause illnesses such as heat cramps, heat stroke, and even death. A 2003 heat wave in Europe caused about 50,000 deaths, and a 1995 heat wave in Chicago caused more than 600 deaths.

Schär et al. (2004) propose that a regime with an increased variability of temperatures (in addition to increases in mean temperature) may be able to account for summer 2003. To test this proposal, they simulate possible future European climate with a regional climate model in a scenario with increased atmospheric greenhouse-gas concentrations, and find that temperature variability increases by up to 100%, with maximum changes in central and Eastern Europe.

Patz, Campbell-Lendrum, Holloway, and Foley (2005) review the growing evidence that climate–health relationships pose increasing health risks under future projections of climate change and that the warming trend over recent decades has already contributed to increased morbidity and mortality in many regions of the world.

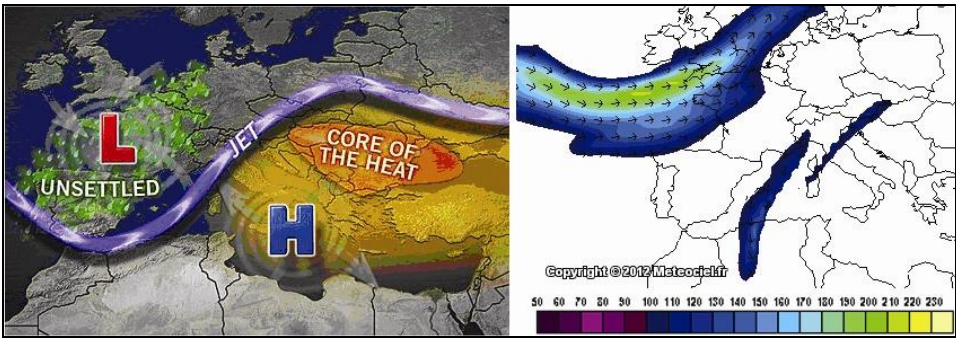


Figure 1. Blocking in the period between 16–22 June (left) and jet stream (right) for 22 June 2013 at 18, 00 UTC (Source: http://www.accuweather.com/en/weather-news/heat-wave-for-eastern-europe/14266535, by Eric Leister)

Blocking above the great regions is usually driven by high pressure extending over enormous spatial area, with the tendency to transfer more slowly than the low pressure.

Methodology and Data

The data for analysis of this supercell are: synoptic maps, forecast weather from European Storm Forecast Experiment (ESTOFEX), Belgrade sounding and hodograph, meteorological measurements and radar images from RHS, and satellite image from EUmeTrain. The Nonhydrostatic Meso-Scale Modelling (NMM) model, using the boundary conditions from the European Center for Medium range Weather Forecasting (ECMWF) model, was run in the mesoscale domain. The comparison of a conceptual HP supercell model with the radar characteristics of the observed supercell, was performed. Consequences of storm damage are shown across damage from the wind and hail.

The basic concept of this paper is the methodology of analysis of extreme weather conditions. This methodology uses all available data from macro to micro scale. The starting point is the analysis of the dominant weather patterns before the storms, and ends with its consequences.

Analysis of the Synoptic Situation above Europe and the Balkan Peninsula for 22 June 2013

The territory of Serbia and the Balkans was under the prevalence of sunny and notably warm weather with maximum daily air temperatures ranging from 30°C to 36°C, at most places with tropical nights observed as well. Weak southerly wind prevailed.

On 22 June 2013, in the afternoon hours, southwestern Serbia was under the dominance of convective clouds and the approach of weakened frontal zone along with the increasing air humidity led to intensification of strong convective development in Šumadija and Vojovdina. Instability line in the warm air mass (Figure 2) moved northeastward from west and southwest causing severe thunderstorms in Pocerina, Podunavlje, Srem, Bačka, Banat and Belgrade accompanied by showers, storm and hail.

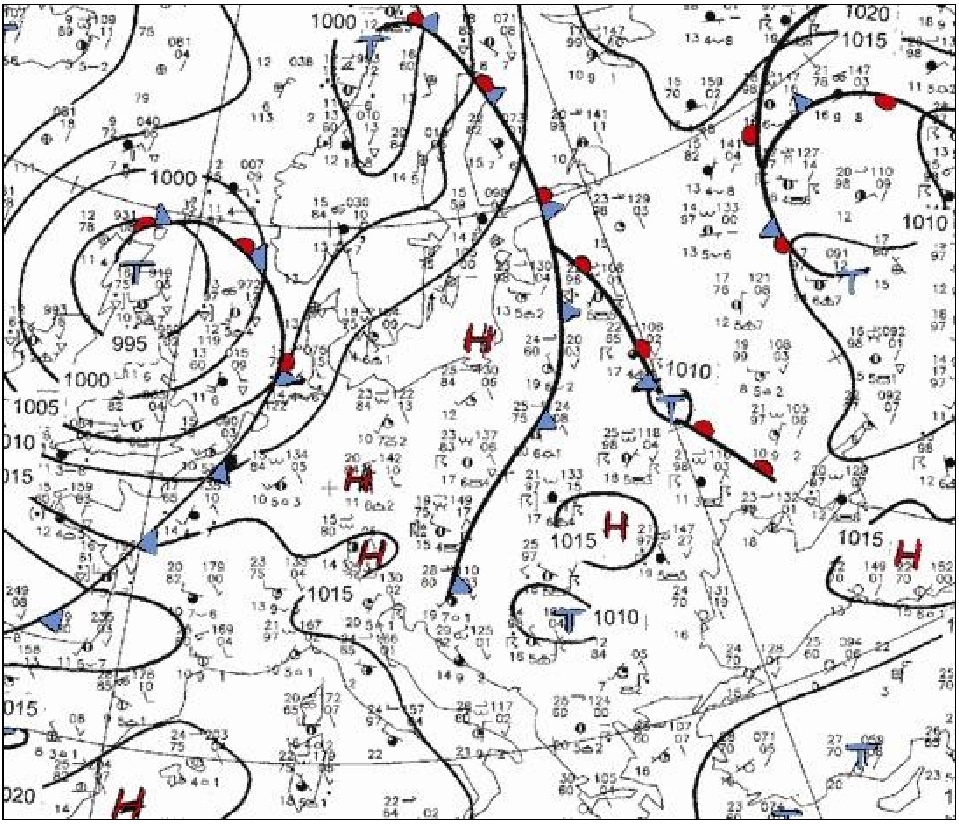


Figure 2. Europe synoptic analysis chart (surface) 22.06.2013. 18:00 UTC (Source: Republic Hydrometeorological Service of Serbia)

The development of strong convective clouds was enabled by exceptional thermal instability of the atmosphere above the Pannonian Plain and the Balkans (CAPE from 3,000–5,000 J/kg) and warm subtropical air (T_{850} was above 20°C, 2–3 standard deviations above the normal — in other words, anomalous). Southwesterly upper air wind brought wet air from the Atlantic and Mediterranean (Figure 3) and during the course of its movement toward Serbia it changed direction southward creating conditions for the strengthening of potential vorticity. The forecasted CAPE in the most unstable troposphere layer – ML CAPE amounted to 3,500 J/kg. Instability in energy is rapidly changing and for a short period of time it can decrease or increase, which was the case that day. More intense wind shear in the layer between 0–6 km was expected as well as in the part where CAPE was increased, which indicated the possible development of supercell or mesoconvective system in which the possible development of some supercell may occur.

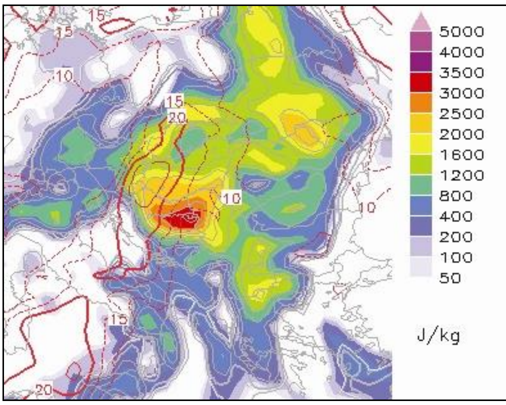


Figure 3. ML CAPE and wind shear 0-6 km (Source: http://www.estofex.org)

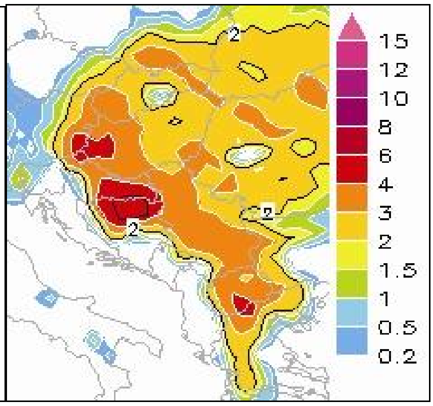
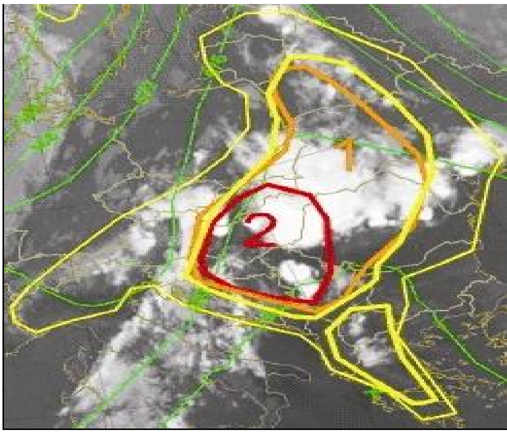


Figure 4. Hail parameter (Source: http://www.estofex.org)

Lifted index indicated the instability above Vojvodina and Sumadija (values from -1 to -3). Hail parameter is shown in the Figure 4.

Satellite Image and ESTOFEX Forecast at 18 UTC

For the territory of Serbia, Romania and Hungary for 22 June 2013, ESTOFEX forecasted second level warning of severe thunderstorm, hail accompanied by stormy wind gusts and heavy rainfall (Figure 5) entirely corresponding to the development of the upcoming weather situation.



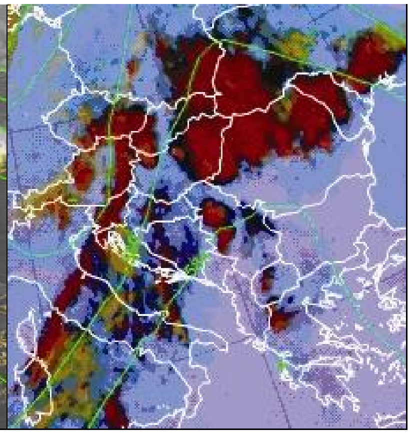


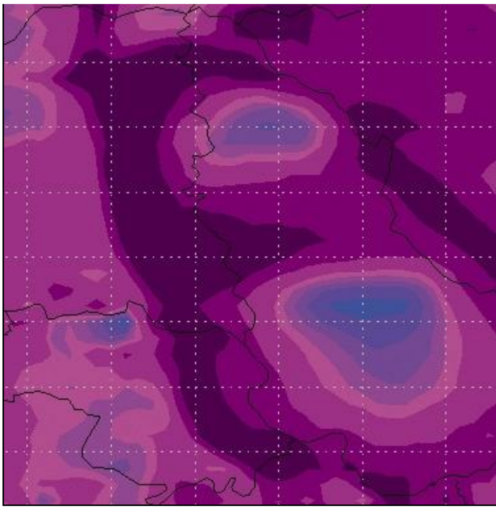
Figure 5. ESTOFEX forecast for 22 June 2013 (Source: http://www.estofex.org)

Figure 6. Dust RGB combination+AT500 hPa (Source: http://www eumetrain.org)

Satellite image RGB combination for 22 June 2013 at 18:00 UTC (Figure 6) depicts developed cumulonimbus above the territory of Serbia, Romania and Hungary. High ice clouds of great thickness are presented in red colour, cirrus are shown in black while violet indicates the wet air mass.

Analysis of the NMM model results

Figures 7 and 8 depict results of the nonhydrostatical mesoscale model of RHS Serbia, 4km resolution and input data 22 June 2013 from 12:00 UTC and boundary conditions from the global model ECMWF. For the period 19–20 UTC, extreme CAPE (3,500–5,000 J/kg) above the territory of Srem and Belgrade was forecasted (Figure 10) and total amount of cloudy ice ranging from 4-8 g/kg (Figure 8).



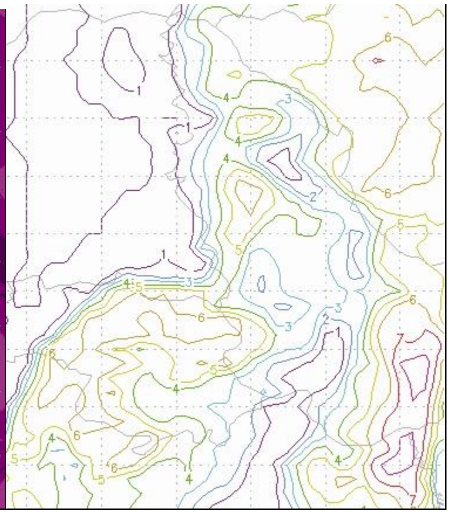


Figure 7. CAPE (J/kg) from NMM 22 June 2013 Figure 8. Cloudy ice (g/m^2) from NMM 22 06 at 20 UTC (Source: Republic Hydrometeorological Service of Serbia)

Overall, NMM model has forecasted substantially weaker convection compared to the one that actually occurred.

Analysis of the Sounding Data and Wind Parameters for 22 June 2013 in Belgrade

Table 1 shows criteria for the developement of hazardous convective storms with the occurrence of hail.

Table 1. Criteria for the development of hazardous convective storms from sonde

Convection parameters	Value	Interpretation
CAPE (Jkg^{-1})	> 2,300	Potential for very strong storms
LI	< -5	Potential for very strong storms
TT	52	Isolated and numerous hazardous storms
K-index	> 35	Numerous storms
DCAPE (Jkg^{-1})	> 1000.00	Strong downdraft
SRH (m^2/s^2)	12	

Source: Brooks & Doswell III (1993); Doswell III (2001)

Great values of available potential energy (CAPE) allow development of mighty convective storms, relative vorticity (SRH) indicates the development of mesocyclone that supports long life of supercells and the occurrence of hail and strong upper air jet stream. DCAPE talks about the strength of the downdraft contributing to strong wind gusts below cumulonimbus, long life of mesocyclone and heavy rainfall. Given the fact that instability in the atmosphere and the possibility of development of strong convection was observed 20 hours prior to its occurrence (emagram Belgrade at 00:00 UTC and emagram at 12:00 UTC), the Table 1 shows the convection and wind parameters as well as convective indices for both times.

Table 2. Sounding parameters for 22 June 2013 in Belgrade at 00:00 and 12:00UTC

Convection paramaters	Values at 00,00 UTC	Values at 12,00 UTC	Interpretation
Convective T (°C)	34.25	31.74	
Lift indeks (°C)	-6.8	-12.82	Stormy weather expected
CAPE (J/kg)	262.79	4,949.50	Stormy weather expected
CIN (J/kg)	227.02	0.00	
CAPE Virt (J/kg)	2,844.75	5,321.26	Stormy weather expected
DCAPE(LFS=566mH) (J/kg)	1,138.19	859.07	
Grad (SHIP)	1.19	1.98	Large hail is possible
Max hailstone size (cm)	5.69	8.62	
Convective height (km)	11.07	11.62	
LCL	772.31	1,136.29	
Convective indices			
Shovalter index (°C)	-2.11	-5.67	Stormy weather expected
Modif. Tomson index (°C)	25.76	42.13	Stormy weather expected
Total Totals index (°C)	51.40	56.40	Stormy weather expected
KO index	-25.33	-35.93	Supercells expected
Craven SigSvr / 1000 (m^3/s^3)	3.66	1.45	Supercells expected
SCP LM	0.74	0.14	
SWISS 12 Index	-4.27	-11.33	Supercells expected
Wind parameters			
Share 9-11 km (m/s)		9.41	HP supercells expected
Bulk-Richardson number	171.36	616.69	Multicell developments expected
MAX 3km SRH (m^2/s^2)		1,957.00	
3km potential worticity (m/s^2)		0.02	Supercells not expected

Source: Republic Hydrometeorological Service of Serbia and http://62.202.7.134

The analysis of the emagram for Belgrade on 22 June 2103 at 00:00 and 12:00 UTC (Table 2) indicates that the developments of separate convective cells HP type (supercells with great amount of rainfall) were expected along with multicell developments, possibly containing supercells.

Emagram of radiosound Belgrade 22 June 2013 for 12:00 UTC, points to the possibility of strong convective developments with the great precipitation amount. One can notice extremely high available energy instability CAPE (5,071 J/kg) (Figures 3 and 12), most likely the greatest in the last 60 years for this area.

The content of water vapour in the vertical column was high as well (33.7mm). Convective condensation level (LCL) was at 1,500 m (869 hPa), and equilibrium level at 13,500 m, (172 hPa) (height at the upper troposphere, where the saturated air becomes colder compared to the environment and continues to move upward). Index of instability (LI −14, Shovalter −6, SWT 489, Total Totals 56) indicates the development of supercell and severe weather.

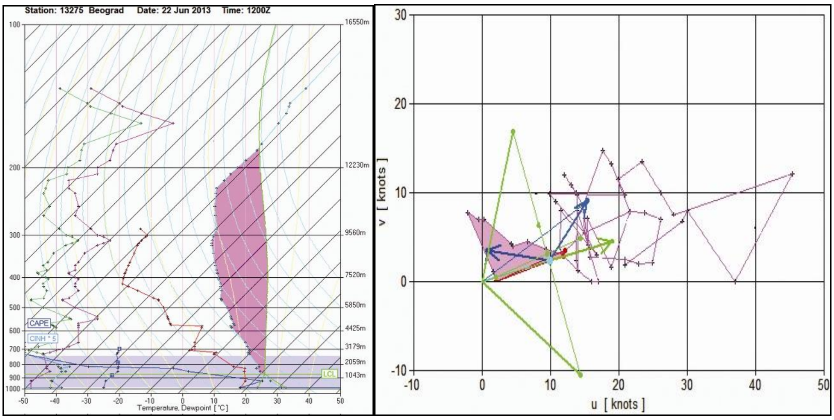


Figure 9. Emagram (left) and hodograph (right) for wind for Belgrade 22.06.2013 at 12 UTC (Source: Republic Hydrometeorological Service of Serbia, and http://62.202.7.134)

Effective wind shear between the soil and 6 km was not great (around 11 m/s) as well as SRH (Storm-Relative Helicity — the measure of potential rotation of 57 m^2/s^2) indicate that the formation of slow-moving supercell which owing to the absence of jet air may stretch high above the troposphere (H_{trop} =11,510 m, T_{trop}= −52.7°C) into stratosphere.

The analysis of the vertical structure of atmosphere indicates that the separate convective cells could produce large amounts of precipitation and hailstones up to 8cm in diameter.

Analysis of Radar Characteristics of Supercell Cloud

On the territory of Fruška Gora, an area between Irig and Maradik, at approximately 19:45 UTC, the formation of the thunderstorm cloud took place — cumulonimbus with maximum radar reflectivity of 55 dBZ at the 7 km height. When maximum radar reflectivity exceeds the value of 45 dBZ, and the cell is being formed at height, this evidently leads to hailstone formation. In a very short period of time, the strengthening of cumulonimbus occurred (radar reflectivity of maximum radar reflection increased to 70 dBZ in a zone between 4 and 8 km height) moving slowly (15–20 km/h) toward Indjija. Cloudy zone, of the supercell type in development, of 12–16 km width, reached to 20 km height (cloud penetrated tropopause, indicating great energy instability, H_{trop} = 11.51 km). Rainfall became much more intense causing strengthening of the downdraft and stormy wind gusts reaching up to 35 m/s. The storm lasted for nearly half an hour causing great material damage.

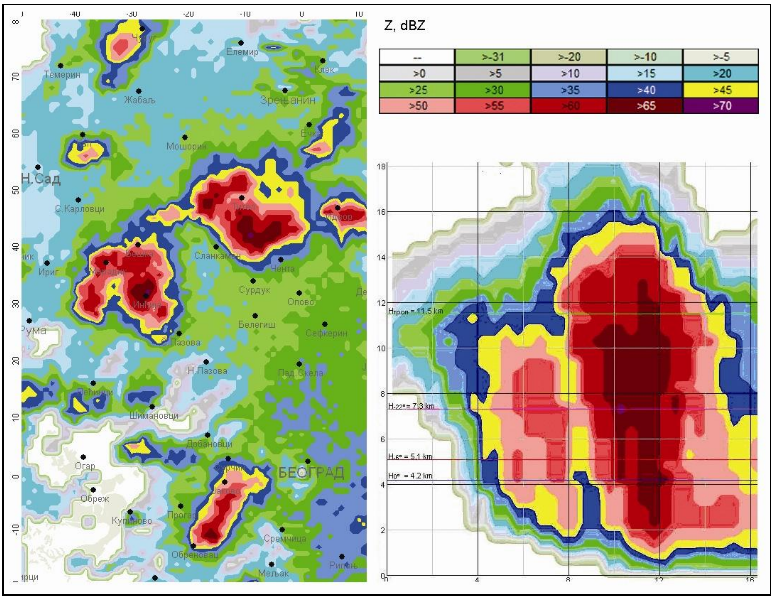


Figure 10. Radar reflectivity and vertical cross section of the cloud 22.06.2013 at 20:17 UTC (Source: Republic Hydrometeorological Service of Serbia)

Supercells with the large precipitation amount (HP) are the biggest of all supercells. They are very effective producers of precipitation often producing strong downdrafts and strong wind gusts (Doswell III, 2011; EUMeTrain). Large precipitation sums are available and wrapped around mesocyclone, producing big, high reflective hook (Doswell III, 2001). Occasionally, backside of downdraft creates gust front associated with the hook (Doswell III & Burgess, 1993), intensifying it sufficiently to form strong convection along the leading supercell edge (Figure 10, right side). At the right side the Figure 11 shows conceptual model of supercell (Source: http://www.aopa.org).

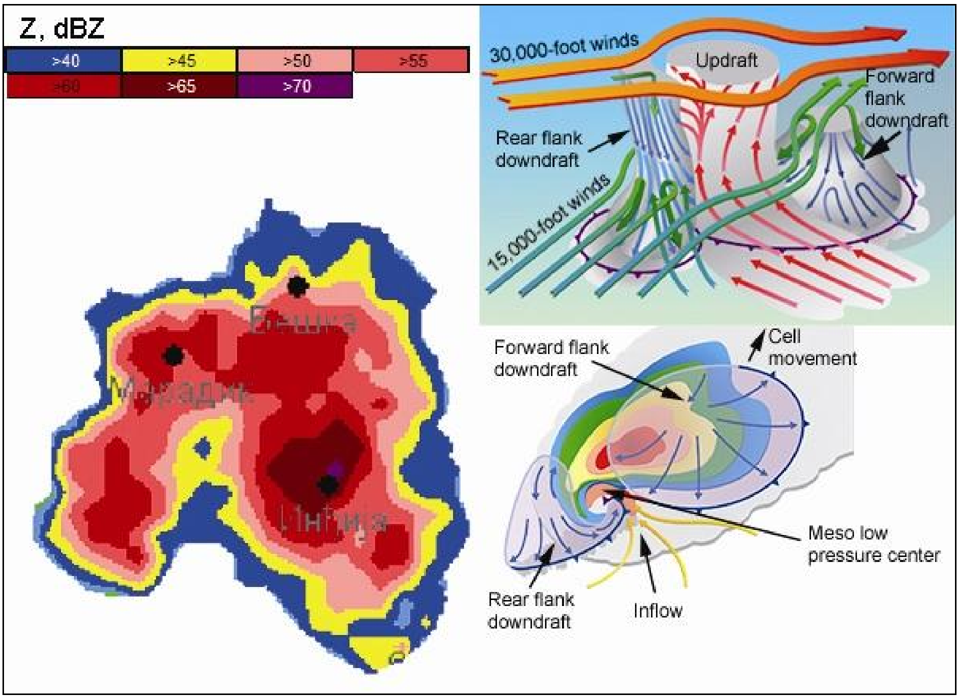


Figure 11. Comparison of radar image observed by HP supercell (Source: Republic Hydrometeorological Service of Serbia) and conceptual model (Source: http://www.aopa.org/News-and-Video/All-News/2010/August/1/Wx-Watch-Super-Storms)

Result of the supercell development is that the strongest core may be placed behind and on the right side of the mesocyclone. Ocassionally, this process leads to development of supercells in the Bow echo. There are number of possibile HP supercell configurations, however they all have characteristics mutual for all supercells — long lived mesocyclone and well-connected with updraft (Berdon, 2009). Mesocyclones are usually well-observed and identified with radar due to high reflectivity in hook-formed radar echo (Pavlović Berdon, Zarić, & Stanković, 2013).

The mechanism of generating the strong winds, in the absence of a well organized low-level mesocyclone, is consistent with the conceptual model of the relationship of low-level mesocyclones to supercell storms proposed by Brooks and Doswell III (1993).

Brooks and Doswell III (1993) have examined four thunderstorm events and they used numerical model. The model used was developed by Wicker and Wilhelmson (1990). Their model builds on the work of Rotunno and Klemp

(1985) and Davies Jones & Brooks (1993), which stressed the importance of baroclinic generation of vorticity in the evaporatively-cooled air in downdrafts of supercells as the source of vorticity at low levels.

The most interesting details of cloudiness are shown on radar images 20:17 UTC, with dual wavelength radar HMS MRL-5 (3.2 and 10 cm).

Figure 10 (left) shows the development of convective cloudiness at 20:00 UTC, above the portions of the territory of Serbia. On different locations isolated cells occurred, out of which several were classified as supercells. Convective cell that encompassed Indjija is shown enlarged on the right side of the Figure 11, in order to enable seeing its structure and compare it with the conceptual model HP supercell. Areas with hail and heavy rain are marked, as well as location of updraft. The Figure clearly shows that radar reflectivity within hail core exceeded 70 dBz on the height ranging from 4–7 km (Figure 10, left).

Damage Caused by Thunderstorm

Severe thunderstorm cloud hit Indjija causing severe weather bringing heavy rain and tennis-sized hailstones.

Figure 12. Tennis size hailstones (6.7 cm) observed in Indjija (https://www.youtube.com/watch?v=8mpyHt3URqA)

Large hailstones (Figures 12 and 13) caused tremendous damage to roof tiles, windows, car windows and crop (Figure 13). Moreover, stormy wind and severe thunderstorms have caused damage to trees and electrical installation, injuring all together 31 people.

Figure 13. Large hailstones breaking car windows and killing several birds (Source: Milenko Pehar)

Hailstones generally begin forming on embryos of rimelike structure (graupels) or frozen droplets, or insects and dust particles, outside the updraft. Certain graupels are pushed back to updraft carried by strong wind, growing fast by circulating up and down several times and stay in the weaker part of updraft that is, in the area of hailstone growth (Figure 14 right).

Wet growth regime occurs when rain drops pour hailstone releasing latent heat of melting, which heats up the surface of the hailstone causing growth of surface temperature of the stone above 0°C, enabling water to expand over the hailstone surface, creating smooth transparent surface (transparent layer).

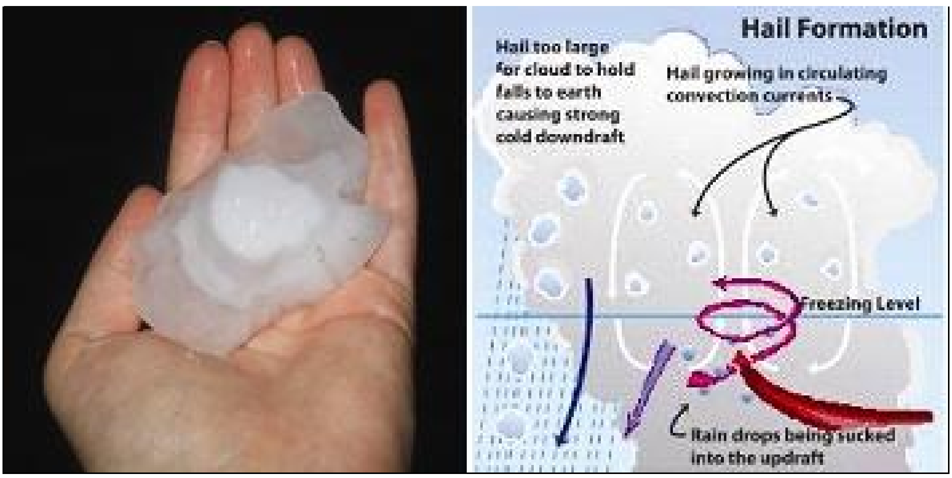


Figure 14. Structure of the hailstone (Photo: Dijana Savić) and the formation process (Source: http://scijinks.jpl.nasa.gov/rain/)

Dry regime produces milky structure and it occurs when there are several collisions with frozen droplets, latent heat is low and the surface temperature of the stone remains below zero. Freezing occurs rapidly, creating milky layer, in which trapped bubbles of air can be observed. Different rings indicate how many times hailstone underwent dry and wet growth. The Figure 14 (hailstone in Indjija) depicts 2 wet and 2 dry growths of hailstone. To form the golf-ball size hailstones it requires over 10 billion supercooled droplets and they must remain in the cloud for at least 5 to 10 minutes, at the updraft speed of 24.4 m/s.

Conclusion

The period between 16 and 22 June 2013 was marked by formation of heat wave above the portions of south-eastern Europe. This episode of high heat is due to the incursion of Saharan air into Middle Europe.

Heat waves usually have the effect of increased mortality of the population, due to long-term action of high temperature (heat wave in Europe in 2003). However, strong storms with supercells or tornado may occur as a result of heat wave.

On this day, 22 June 2013 above Indjija (Vojvodina, Serbia) at around 22:15 UTC high precipitation supercell caused severe weather accompanied by heavy rain, stormy wind as well as hail. Index of instability in the atmosphere on that day (sounding data at Belgrade for 12:00 UTC) along with wind parameters indicated the development and formation of severe thunderstorms and the occurrence of hail. ESTOFEX forecast issued second level warning for the Pannonian plain and most part of Serbia with the high chance of hail, tornado and hazardous convective developments.

The storm lasted for about half an hour causing adverse damage to houses, fruits, electrical installations and cars. Wind reached the speed of 35 m/s, which is characteristic for that type of supercell, unusual for our territory.

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