

Case study of two splitting hailstorms over Bulgaria on 20 May 2013

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1 Introduction.

The paper is focused on two successive thunderstorm developments, which show specific splitting behavior in the same track over Bulgaria with time difference of 5 hours and have produced severe weather (hail and wind gusts). Each one of these cases (storm A and storm B) developed in two individual cells: Left and Right – in valley regions north and south of Balkan mountain correspondingly, and show opposite characteristics regarding the severity of each individual splitting cell.

Splitting thunderstorms have been investigated first by Fujita and Grandoso (1968). They described process by which a single convective cell splits into two convective cells, one dominated by cyclonic rotation and the other by anticyclonic rotation, their paths then deviating substantially from each other. Occasionally storms splits several times and authors called this process multiple splitting. In their work a mechanism of echo split is explained and a numerical cloud model with included cloud rotation was proposed. Further Klemp and Wilhelmson (1978) and Routuno (1981) using a three-dimensional numerical cloud model simulated self-sustaining right and left-moving storms which arise through splitting of the original storm. By altering the direction of the environmental shear at low and middle levels, either the right- or the left- moving storm can be selectively enhanced. Specifically, if the wind hodograph turns clockwise with height, a single right-moving storm evolves from the splitting process. Conversely, counterclockwise turning of hodograph favors development of left-moving storm. Waisman and Klemp (1982) investigated dependence of convective storm structure on environmental vertical wind shear and buoyancy. They found that weak wind shear produces short-lived single cells, low-to-moderate shears lead to multicell process and moderate-to-high shear produce supercells. The relationship between wind shear and buoyancy is expressed in terms of nondimensional convective parameter Bulk Richardson Number (BRCH). Optimal conditions for development of supercell storms are when BRCH is between 10 and 45, when BRCH >40 – ordinary or multicell process is likely to develop.

The two successive convective cases on 20 May 2013 over Bulgaria developed in same environmental wind shear conditions, but the splitting behavior of these storms was different. The paper analyzes additional factors (besides wind shear), which govern the splitting behavior and lead to differences in development of the individual cells of storm A (developed in time frame 12-17 UTC) and storm B (between 16:30 and 21:00 UTC). The pre-convection environment is studied by NWP fields, upper level sounding, synoptic observation at different altitudes and satellite information for land surface state. Satellite imagery and advanced products are used for inferring atmospheric instability and low-level moisture. Images of Meteosat water vapour channels are considered for analysis of specific double jet-stream configuration directly connected with the splitting process of the convective storms.

Soil moisture influences a number of processes in land-atmosphere interactions on different spatial and temporal scales. Some of these processes concern the initiation of convection and the subsequent possibility of convective precipitation, such as the influence on the surface temperature and the availability of moisture in the planetary boundary layer (Hohenegger et al., 2009). In our study convective storm initiation and development is considered in parallel with land surface moistening conditions (Section 2.1.4). Moistening of vegetation and soil are assessed on the bases of land surface skin temperature according to LSA SAF LST product (<http://landsaf.meteo.pt/>) on the bases of Meteosat data (Stoyanova et al., 2012).

The study shows specific features of the convective developments as seen on time-synchronized radar and satellite pictures showing different splitting behavior and strength of the thunderstorms.

2 Analysis of storm A and storm B.

2.1 Pre-convective environment.

2.1.1 Synoptic situation:

At upper and mid levels cut off low is present above Central and Western Europe. At its southern flank, a specific double jet-stream configuration travels across the central Mediterranean and Balkan Peninsula (fig.1 and fig.2). Ahead of a cut of low, warm air masses are advected across eastern Europe. Frontal boundary extends from Poland to Greece and slowly moves eastward; around 12:00 UTC it is located around west border of Bulgaria. A tongue of rich low-level moisture exceeding 8 g/kg mixing ratio is present along the equatorward side of the frontal boundary. This moisture overlaps with steep mid-level lapse rates, which are present from the southern Baltic Sea to the Aegean Sea.

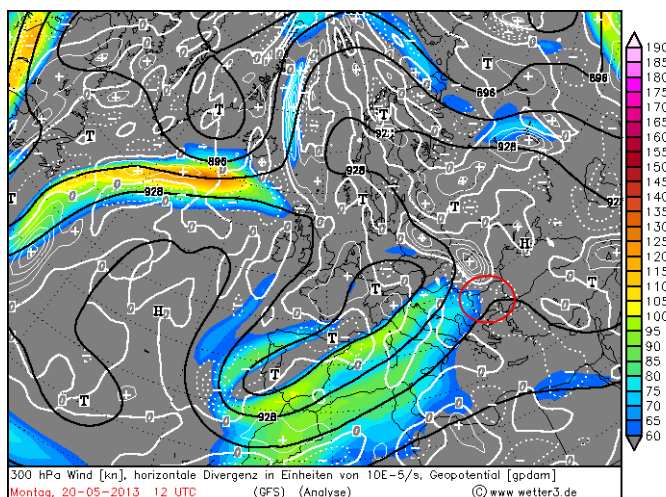


Figure 1: 12:00UTC GFS 300hPa wind and geopotential
(source: <http://www.wetter3.de/Archiv/>)

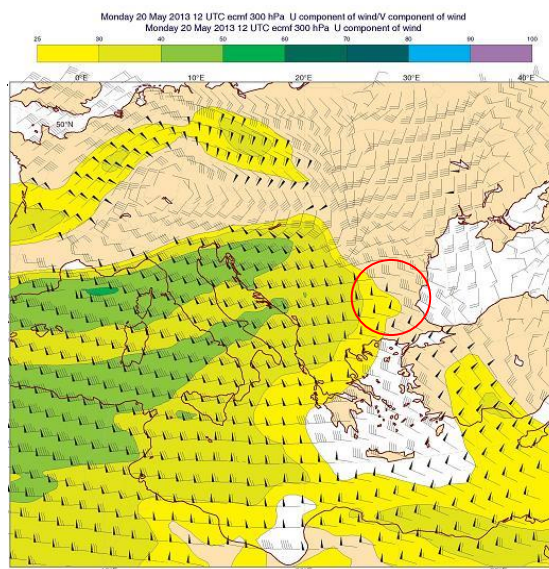


Figure 2: 12:00UTC ECMWF 300hPa wind

Bulgaria is in red circle.

2.1.2 Atmospheric Instability:

The nearest upper level sounding release point to the location of these convective developments is at station in Sofia and we accept data from it as reliable for assessing convective instability. As additional information we use other near stations – Bucharest (storms approaching it) and Belgrade (storms moving away of it). They show (fig.3): significant low level moisture with levels of mixing ratio around 10 g/kg (Sofia, Bucharest), right hodographs in all three station (fig.4), wind veering and causes warm advection, favors development of right-moving storm in splitting proses (Klemp and Wilhelmson, 1978 and Routuno, 1981) , CAPE around 600-700 J/kg and LI below minus 2°C (Sofia, Bucharest), BRCH in Sofia is 20.12 – value favourable for development of supercell storms (Waisman and Klemp, 1982), low moisture zone in mid-altitude known as “dry punch”, which is favourable for convection if the lower layer is buoyant (Georgiev, 2003), steep lapse rates in layer between 850hPa and 500hPa- around 7-8°/km. (Sofia, Bucharest fig.3). All these factors are favourable for deep moist convection according to the ingredients-based forecast methodology (Doswell et al., 1996).

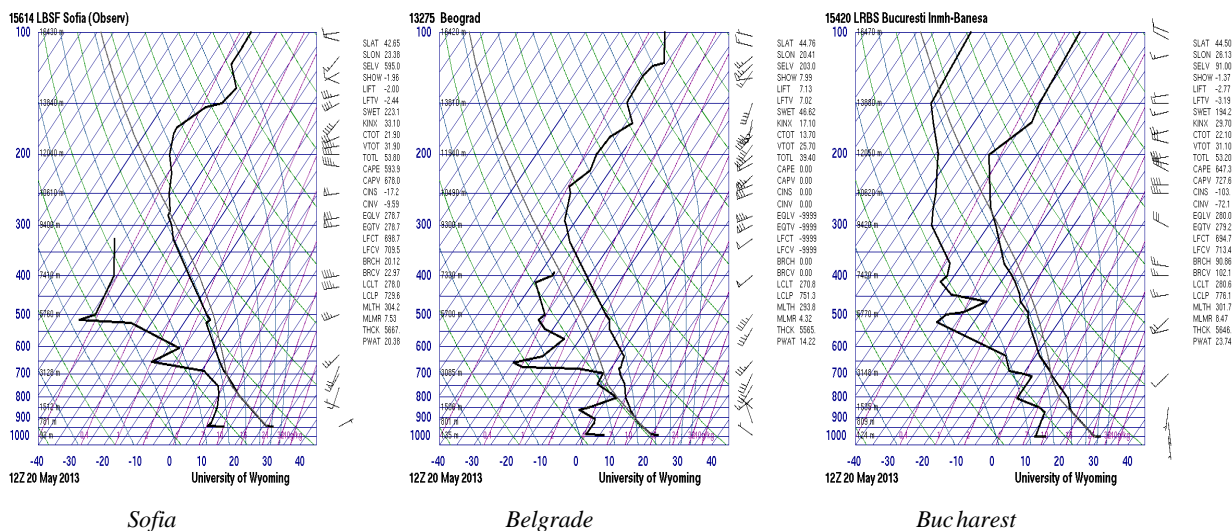


Figure 3: Upper level soundings at 12:00 UTC at nearest release points to location of the convective developments.

(source: <http://weather.uwyo.edu/upperair/sounding.html>)

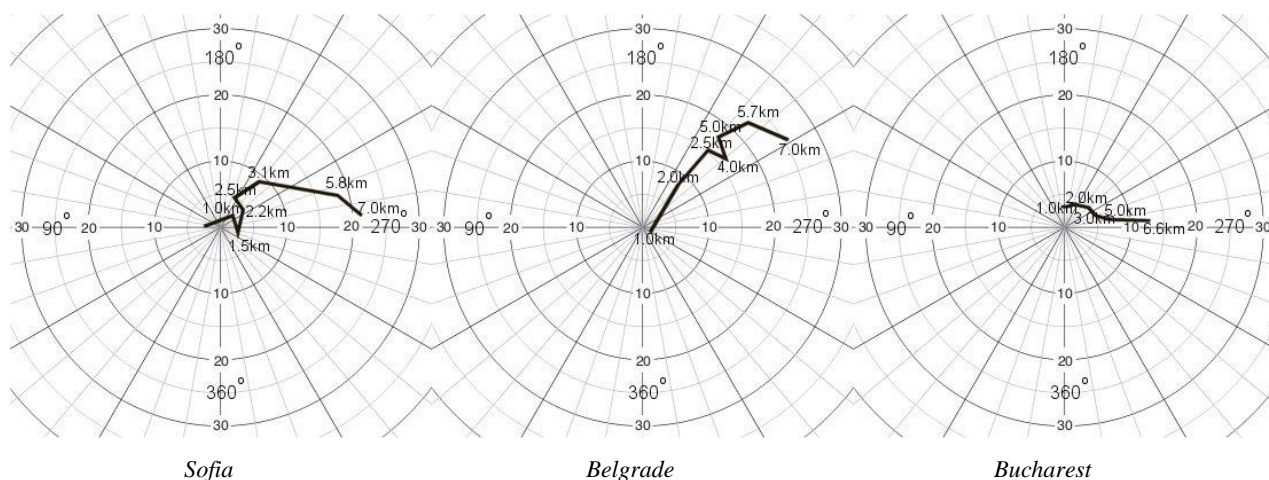


Figure 4: Hodographs from upper level soundings at 12:00 UTC at nearest release points to location of convective development.

Unfortunately atmospheric soundings have time and space limitations and do not always are representative for specific area like Balkan mountains regions, where convective developments occurred on 20 May 2013. To avoid these limitation and compare atmospheric conditions before initiation of storm A (12:00UTC) and storm B (16:30UTC), we use Meteosat satellite imagery and advanced products for inferring atmospheric instability and low-level moisture as well as 3-hourly measurements in synoptic stations at different altitude near to location of storm development in order to assess low level wind shear (table 1).

Meteosat MPEF GII-Lifted index can be used for assessing atmospheric instability, it is generated by EUMETSAT every 15 minutes in cloudless areas and represents the temperature difference between an air parcel lifted adiabatically at 500 hPa and the temperature of the environment at this level.

Convective instability before storm A is higher compared with same in storm B (fig.5, fig.6- blue circles).

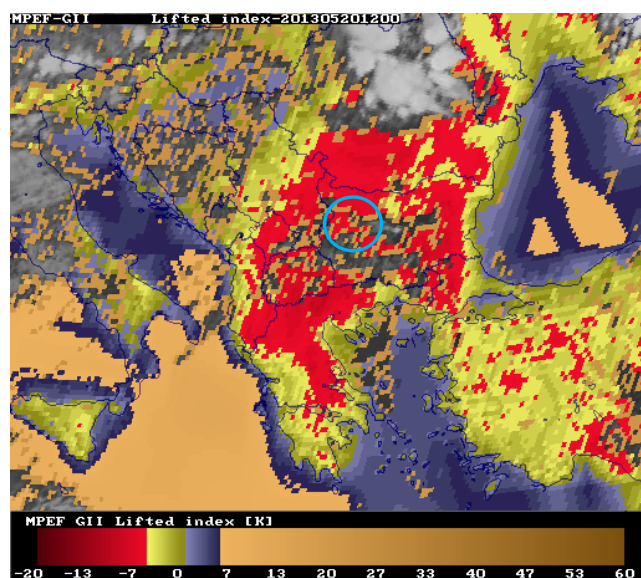


Figure 5: 12:00UTC MPEF GII-Lifted index

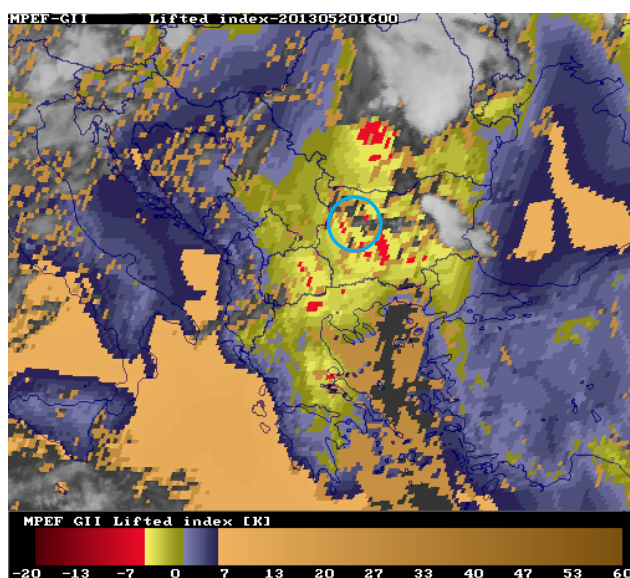


Figure 6: 16:00 UTC MPEF GII-Lifted index

Meteosat RGB Dust can be used for assessing low-level moisture. More moist regions appear in more bluish shades, while dryer regions appear in pinkish colors. Both storm initiates in comparatively moist air at low levels. Storm A initiates in slightly more moist low level conditions compared with storm B (fig.7, fig.8 – red circles).

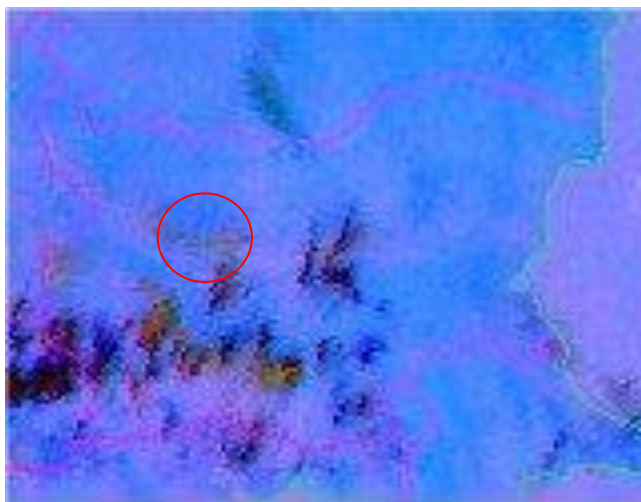


Figure 7: RGB Dust 11:00UTC

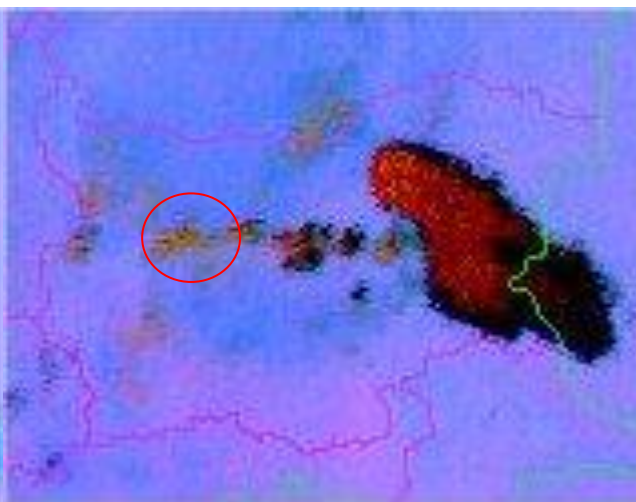


Figure 8: RGB DUST 16:00UTC

2.1.3 Low level wind shear:

Analysis of data from synoptic stations shows that wind shear conditions before storm A and storm B are almost same. (table1). Prevailing low-level wind in North Bulgaria is from north, but in South Bulgaria it is from south, so near Balkan mountain (around location of convective development) there is a convergence zone. Above 2000 m wind is from south with speed around 8-10 m/s, winds in valley regions of North Bulgaria is from north with speed 1-3 m/s, so in this regions at low levels (0-3 km) there is strong directional wind shear.

Table 1: Synoptic station around location of convective development. Station numbers: 1 and 2 are in North Bulgaria, 3 and 4 are peaks in Balkan mountain, 5 is peak in mountain Vitosha near Sofia, 6 and 7 are in South Bulgaria

№	Name location	Altitude (m)	0900UTC		1200UTC		1500UTC		1800UTC	
			Wind		Wind		Wind		Wind	
			Speed (m/s)	Direc tion	Speed (m/s)	Direc tion	Speed (m/s)	Direc tion	Speed (m/s)	Direc tion
1	Lovech	220	2	W- NW	3	N	1	N-NE	1	E-NE
	24.72°E									
2	43.13°N Vratsa	308	2	N	2	NW	3	NE	0	quiet
	23.55°E									
3	43.2°N Murgash	1687	0	quiet	2	W- NW	4	N- NW	4	N
	23.67°E									
4	42.83°N Botev	2384	4	SW	8	S	10	S	10	S
	24.92°E									
5	42.72°N Cherni vrah	2286	6	S	6	S	8	S	8	S
	23.28°E									
	42.56°N									

	Sofia	586	0	quiet	2	E-NE	4	S	3	E
6	23.32°E									
	42.70°N									
	Sliven	257	0	quiet	3	SW	1	SW	0	quiet
7	26.33°E									
	42.68°N									

We can conclude that pre-convective environment before storm A and storm B is almost same. Slightly more moist and unstable are atmospheric conditions before storm A.

2.1.4 Land surface effects:

The influence of soil moisture in mesoscale convective systems was suggested by many studies, several field programs have been undertaken with a focus on the land surface-atmosphere interactions (e.g. Betts and Beljaars, 1993). Soil moisture maintains a control over land-atmosphere interactions, which affects the features of deep convection through the regional energy and water cycles.

In the current study surface soil moisture dynamics at the presence of grassland cover accompanying initiation and development of the convective storm over the country on 20 May 2013 is studied. For that purpose radiation temperature on the land surface (as one of the key parameters in the physics of land surface processes on regional and global scales) derived through the LSA SAF LST product is used as an indicator of energy and water exchange on the land surface over Bulgaria. As approximation of land surface moistening conditions, the temperature difference between land surface skin temperature derived by Meteosat information (digital values at MSG pixel resolution) and air temperature measured at synoptic stations over the country is applied. The reliability of this approach has been confirmed for 'dry' anomalies' in land cover state (Stoyanova et al., 2012) by comparisons with site-scale assessment of soil moisture from operational run of a Bulgarian 1D site-scale Soil-Vegetation-Atmosphere-Transfer 'SVAT_bg' model (Stoyanova and Georgiev, 2013), where the vegetation cover is parameterized by one layer at two levels of soil moistening. The convective process on 20 May is developed at 'dry' soil moisture anomalies according to the 'SVAT_bg' assessments.

The temperature difference is constructed between the 5x5 pixels mean MSG LST values for the pixels containing corresponding synoptic station and air temperature (T_{air}) measured at this site. The course of this cloud free pixels temperature difference during the storm and a day before at three stations in the environment of the storms is shown on fig. 9.

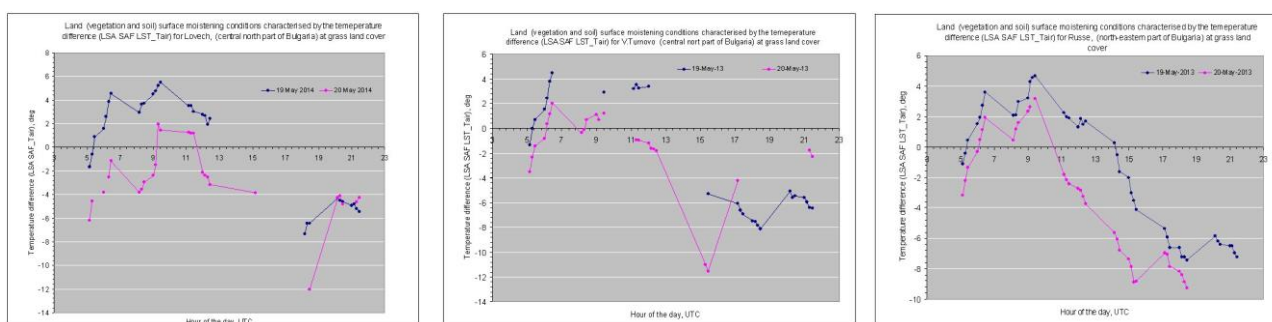


Figure 9: Land surface moistening conditions derived by the temperature difference between MSG LST and air temperature at synoptic stations over Bulgaria close to the convective storm on 20 May 2011: a) Lovech is representative for initial stage; b) V. Turnovo is representative for 'mature' stage; c) Russe is representative for the pre-convective environment of left member of storm B.

In all cases temperature difference is lower on 20 May (magenta line) compared to the day before (blue line) convective storm indicating for increased moistening conditions. For storm A (developed in time frame 12-17 UTC) this temperature difference becomes lowest at about 15:30 UTC (fig. 9b) when some rain quantities (of 11 mm) are detected at station V. Turnovo. With the development and movement of the convective cells to east, except the first temperature minimum at around 15:15 UTC (station Lovech), the second phase of convective process is very clear detected at 18:45 UTC when the temperature difference reaches 12.04 deg (fig. 9a). A very pronounced declined trend with a minimum of temperature difference at about 1845 UTC during development of the second storm B (between 16:30 and 21:00 UTC) in north-eastern part of Bulgaria (station Russe) is also observed (fig. 9c). The increased land surface moistening conditions (fig. 9) corresponds to comparatively moist air at low levels as seen by the Meteosat RGB (fig. 7, fig. 8) that is a result of the interaction between the Earth's surface and the atmosphere associated with the convective processes.

2.2 Development of storms on time-synchronized radar and satellite pictures.

2.2.1 Storm A:

Convection initiates around 12:00 UTC. On radar picture (fig.10) one can see first radio-echo of two cells (right and left) over Balkan mountain, which plays role of triggering mechanism for convection. On satellite picture in IR10.8 μm channel there are two clouds with brightness temperature on top of cloud around -45°C (fig.12- blue pixels). The Meteosat satellite picture in WV 6.2 μm channel (fig.11) shows that upper level wind structure consists of two jet streams close each other, which are separated over Southwest Romania: the northern cyclonic jet structure turns to north and the southern anticyclonic jet feature turns further to southeast. In next hours this double-jet configuration shifts to south towards Bulgaria. Convection over Bulgaria initiates on anticyclonic part of the double-jet steam structure (fig.11-red circle). Till 14:00UTC two cells developed like single cells.



Figure 10:12:00UTC S-band Radar picture CAPPI 2.5 km.

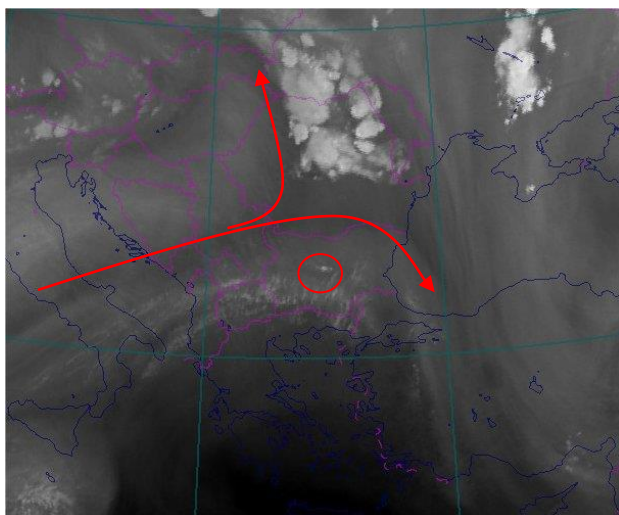


Figure 11:12:00 UTC MSG WV6.2 μm channel

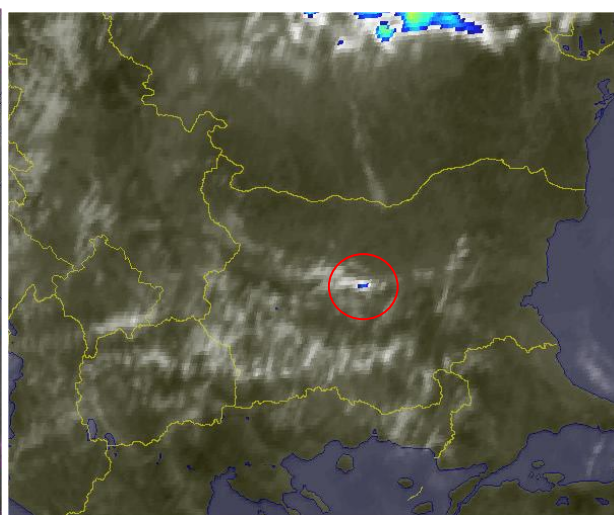


Figure 12: 12:00UTC MSG IR10.8 μm channel-enhanced

After 14:00UTC cells merged and developed like multicell process till 15:00UTC.

After 15:00UTC convective process shows a splitting behavior. Left cell became hailstorm, right cell weakens and dissipates. On radar picture (fig.13) the reflectivity around 55 dBz at the arrow, indicates a zones with formed hail stones. At that time in town Veliko Turnovo (long:25.65°, lat:25.65°) wind gusts above 15 m/s, hail and 11 l/m² precipitation for short period time was registered. On IR10.8 μm satellite picture (fig.15) splitting of the cloud in two cell is seen. On WV 6.2 μm picture (fig.14) it is seen that the convective cells seems to be located close to the right entrance of the upper level jet steam.

This is a factor, which favors an intensification in the southern direction where divergence in upper level leads to upward motions in lower levels.



Figure 13: 15:00UTC S-band Radar picture CAPPI 2.5 km.

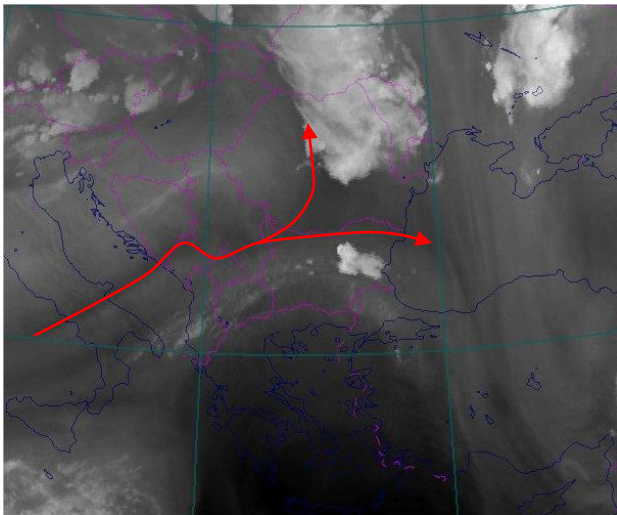


Figure 14: 15:00UTC MSG WV6.2μm channel



Figure 15: 15:00UTC MSG IR10.8μm channel-enhanced

2.2.2 Storm B:

Convection initiates close to 16:30 UTC. On radar picture (fig.16- red circle) one can see zone with reflectivity around 15 dBz over Balkan mountain, which again plays role of triggering mechanism for convection. On satellite picture in IR10.8 μm channel there is one cloud with brightness temperature on top of cloud around -50°C (fig.18- light blue pixels). On satellite picture in WV 6.2μm channel (fig.17) there is more complex upper level dynamics compared with this, before initiation of storm A. Storm B initiates in right entrance of upper level jet streak (fig.17- blue rectangle). In the same time, strengthening and approaching of the southern part of the upper level double-jet stream from south-west occur. In this case we have much more upper level dynamic forcing of convection, compared with case of storm A.

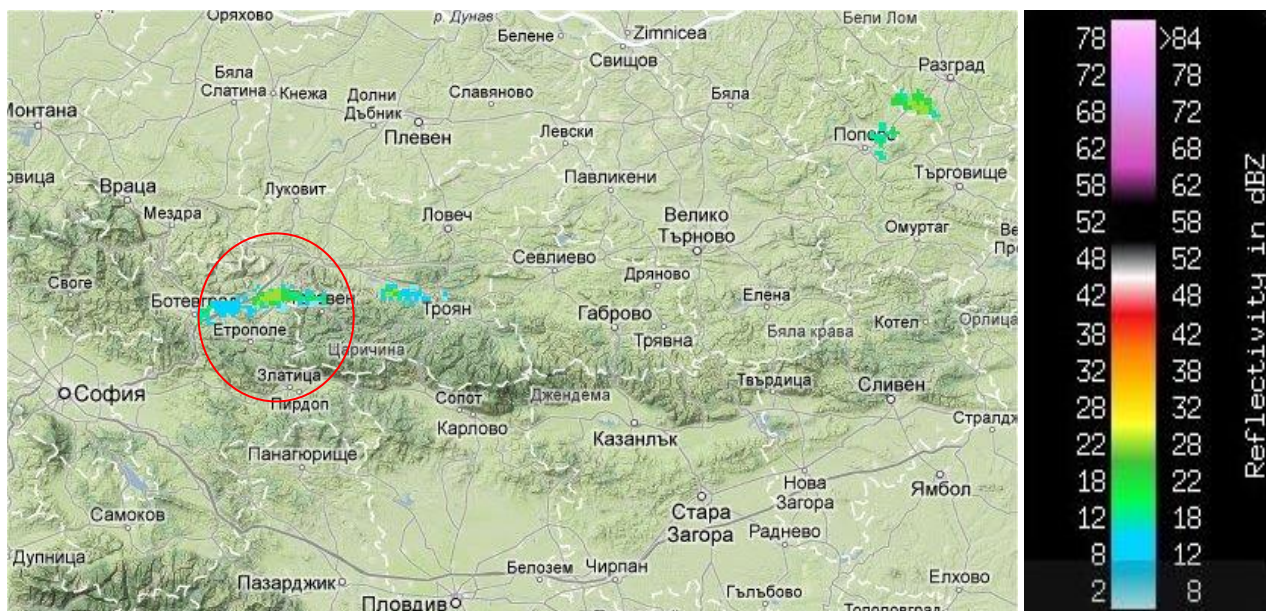


Figure 16: 16:30 UTC S-band Radar picture CAPPI 2.5 km.

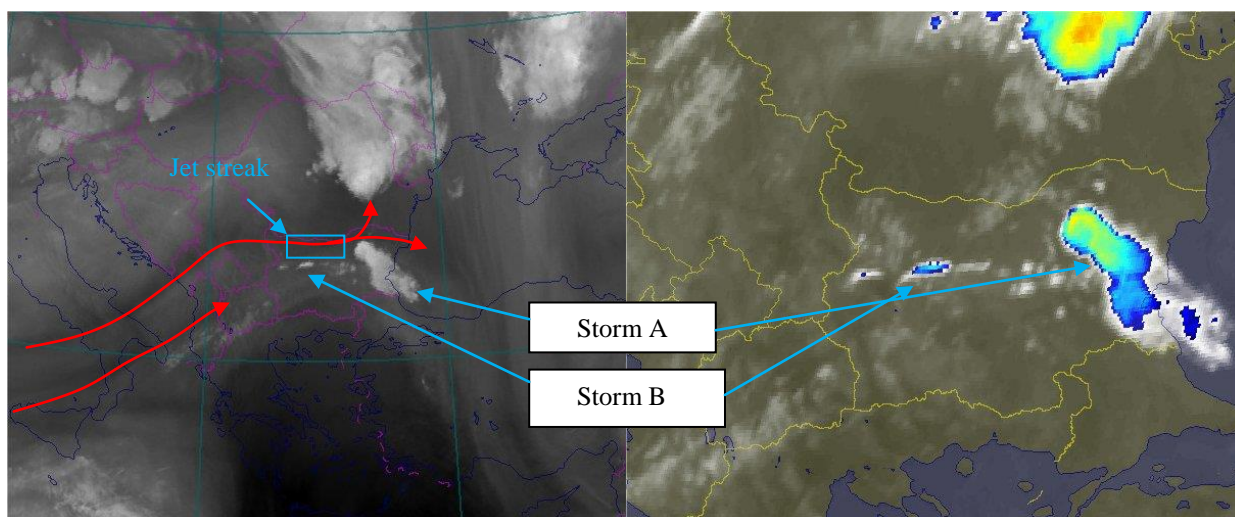


Figure 17: 16:30UTC MSG WV6.2μm channel

Figure 18: 16:30UTC MSG IR10.8μm channel-enhanced

Between 16:30 UTC and 18:30 UTC storm B splits in two storms: Left, which spreads in valley regions of North Bulgaria and Right, which spreads in sub Balkan valleys in South Bulgaria. In this time period both storms developed like multicell processes, but left is stronger with hail reports by its path (fig.19 – reflectivity around 50-55 dBz, fig.21 – overshooting tops with brightness temperature below minus 65° - red arrow – indicates zones with strong updrafts). It can be explained with stronger north part of double-jet stream structure, which intensifies the left storm (fig.20).

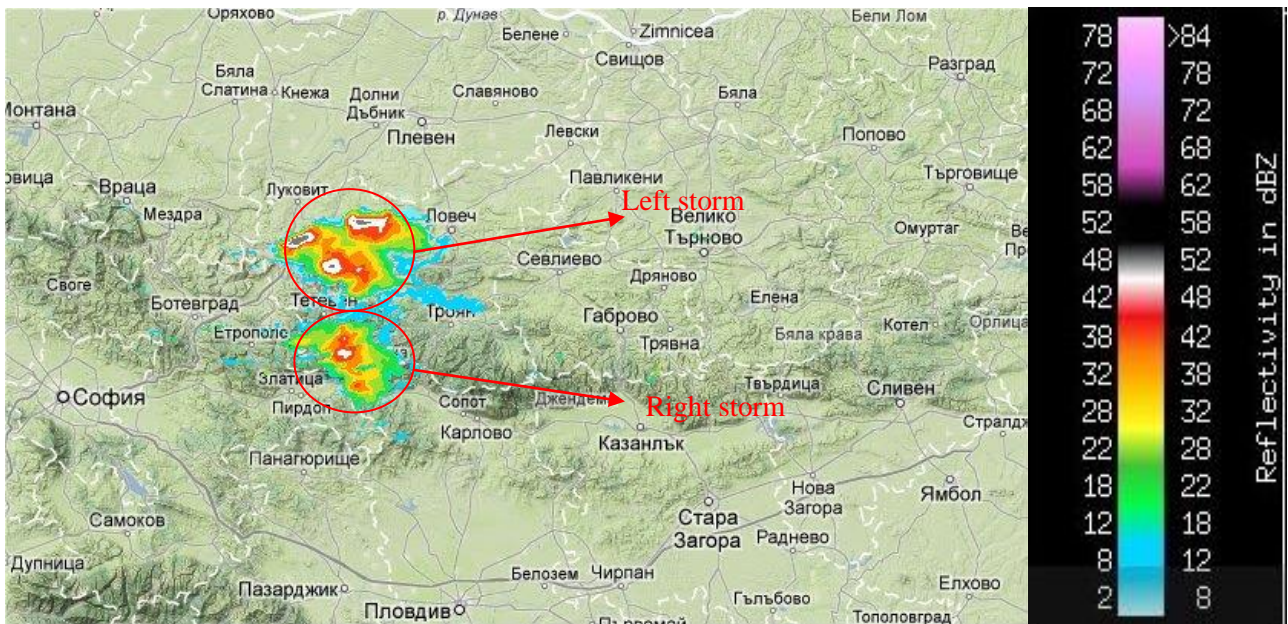


Figure 19: 18:00UTC S-band Radar picture CAPPI 2.5 km.

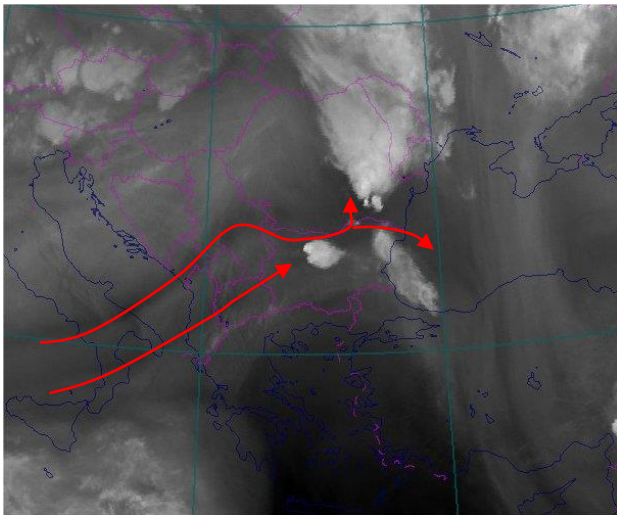


Figure 20: 18:00UTC MSG WV6.2μm channel

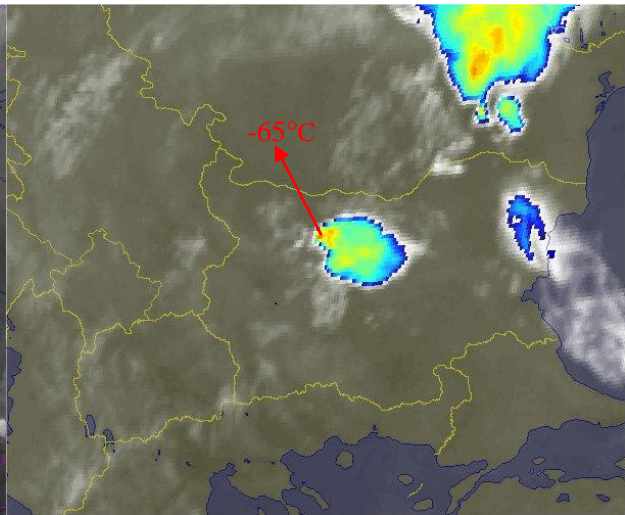


Figure 21: 18:00UTC MSG IR10.8μm channel-enhanced

After 18:30 UTC Left storm developed like squall line in same time Right storm became stronger and developed like supercell. At 19:30UTC on fig.22-south part of picture, can be seen specific radar features of supercell, like weak echo regions (WER)–indicate zones with strong updrafts, reflectivity above 60 dBZ–indicates zones with formed big hailstones (reported diameter of hailstones on ground was around 5 sm.). Also there is a specific radar configuration of squall line in north part of picture (throughout path of squall line from Balkan mountain to river Danube there are many hail reports). On fig. 24 with arrow is marked area of cold U/V shape form and brightness temperature below -65°C – satellite indicators of severity of storm. Thunderstorms with enhanced-V anvil thermal couplet (ATC) frequently produce hazardous weather at the earth's surface such as heavy rainfall, damaging winds, large hail, and tornadoes (Brunner et al. 2007).

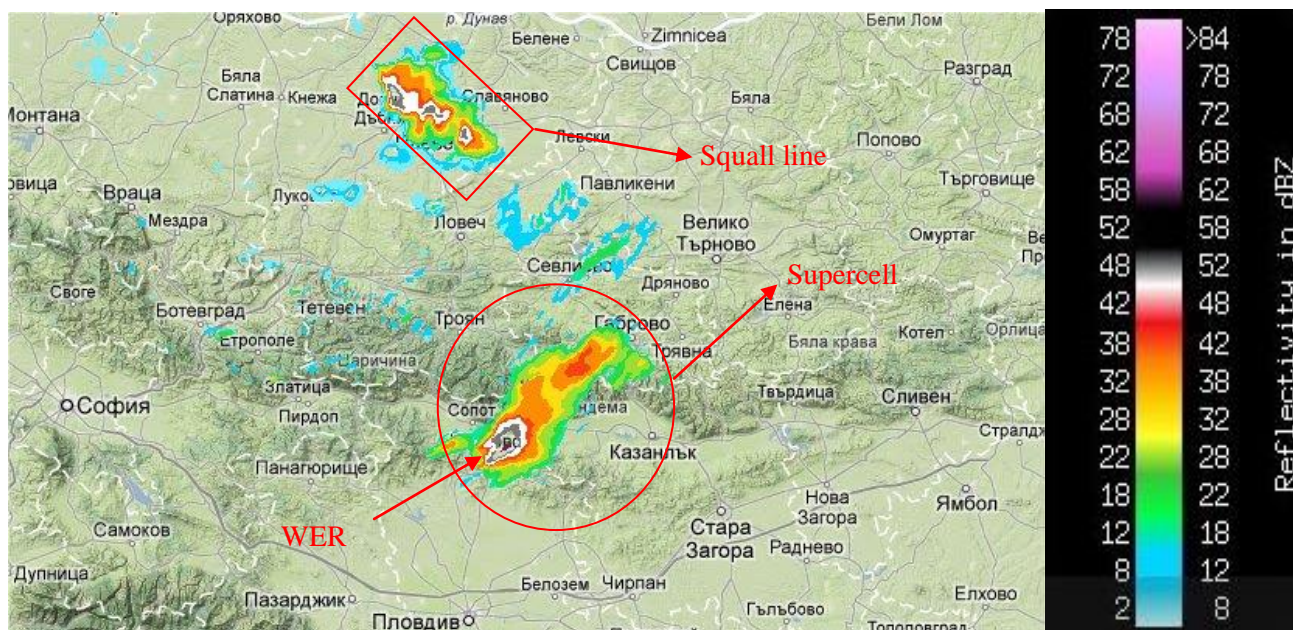


Figure 22 :19:30 UTC S-band Radar picture CAPPI 2.5 km.

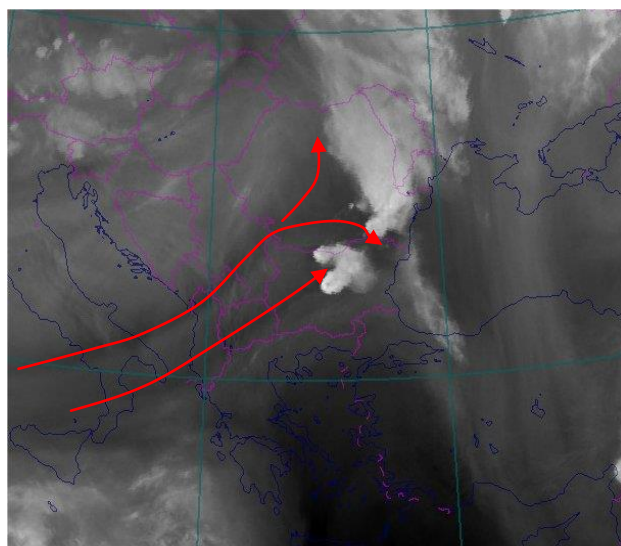


Figure 23: 19:30UTC MSG WV6.2 μ m channel

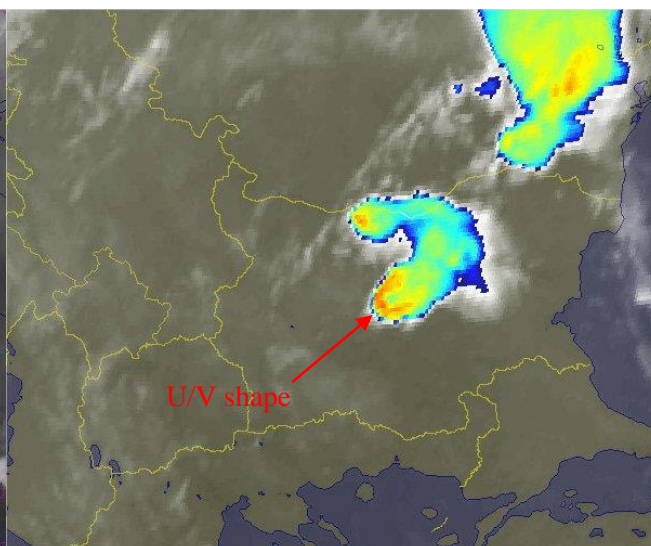


Figure 24: 19:30UTC MSG IR10.8 μ m channel-enhanced

After 20:00 UTC storm B decays, storm A decays after 21:00 UTC in Romania.

3 Conclusions:

This study was aimed to shed some light in understanding of splitting behavior of thunderstorms over complex terrain in Bulgaria. Analysis of pre convective environment was performed with taking into account a synoptic situation, atmospheric instability, wind shear at different levels and some land surface effects. On time-synchronized radar and satellite pictures specific features for severe thunderstorms and particularly for splitting storms was shown.

With storm A, two cells initiated and developed firstly like single cells. At a later stage, under the influence of a double-jet configuration in the upper-level flow, they merged in a multicell process, showing then a splitting behavior with an intensification in the southern direction where divergence of the large-scale upper-level flow leads to upward motions in lower levels.

In the second storm B, besides wind shear conditions, that favor right member in splitting process, we can add upper level forcing from sharpening the south feature of the double-jet stream configuration which enters between left and right storm, while northern part of the double-jet stream structure is moved to north and does not affect the storm developments (fig.23).

An attempt to analyze land surface state conditions related to storm and pre-storm environment for the case 20 May 2013 on the basis of Meteostat information is performed. Using the temperature difference between LSA SAF LST and air temperature (at 2 m high) as an index of near-surface moisture conditions it can be seen that the convective process developed in an environment of decreased temperature difference implying increased potential of moist convection.

This study shows that the upper-level flow pattern and the orography can play an important role in determining the splitting behavior of convective storms in addition to the considerations of Waisman and Klemp (1982) regarding the role of environmental vertical wind shear and buoyancy.

Acknowledgements:

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