Radar signatures of Three Body Scatter Spike (TBSS) detected in Bulgaria

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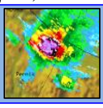

INTRODUCTION

The Three Body Scatter Spike (TBSS) is an artifact echo witch can be seen on the radar display. The TBSS is a mid-level radar signature generally a 10-30 km long. It is aligned radially downrange from an echo region with a high reflectivity (>60 dBZ). The radar artifact as first explain by Zrnić (1987) is caused by non-Rayleigh scattering of the electromagnetic waves from a region with large hydrometeors most likely wet hail. Zrnić (1987), Wilson and Reum (1988) attributed the TBSS at S-band radar is a result of multiple (three-body) triple reflections (Fig.1):

1) scattering of electromagnetic waves by a large hydrometeors to the ground;
2) backscattering by the ground to the hydrometeors;
3) scattering back to the antenna of the weather radar.

Zrnić (1987) explained that the backscatter power decreases with r^{-3} times. Depending on the height of the area with strong reflecting targets, the TBSS will occur in different location from the hail core. Hail spike appearance depends from the height of hail core (C). The TBSS begins along the radial downrange of the core at a point R+h, where h is the smallest distance between hail core and ground ($\theta r=90^{o}$). The radar artifact may not be detected if the radar elevation scan beam is near the ground. Although the presence of hail spike is sufficient but not necessary indication for very large hail it is often used by operational forecasters.

Bulgaria is country with high frequency of hail storms. The present research is the first study of TBSS registered in Bulgaria and it is directed to answer the question how to use the radar data of this artifact as a new tool for nowcasting of severe hail in Bulgaria.

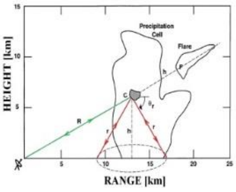

Fig. 1 Schematic of the radar signal path responsible for the TBSS

DATA AND METHODOLOGY

Fig. 2 Radar network of Hail suppression agency

The Bulgarian Hail Suppression Agency has an operating network of three S-band Doppler radars, equipped with the Interactive Radar Information System (IRIS) software from Vaisala (Fig. 2). The radar data is obtained by automatic volumetric scanning at 14 elevation angles. The elevation of each scan increases from 0.2° to 85° with an irregular step. The rotation of the antenna beam is through 360□ of azimuth. An individual full-volume scan takes 4 minutes and covers a range of 150 km.

In the study, 20 severe hail cells (5 - in Southern Bulgaria and 15 - in Northern Bulgaria) producing TBSS during the years 2010-2015, were analyzed (Fig.3). The radar characteristics maximum radar reflectivity (Zmax), vertically integrated liquid water (VIL) and Doppler radial velocities were analyzed. Data of VIL are obtained for 3 layers (0.5 km – 17 km; -10ºC÷-40ºC; 0. 5 km - 0ºC). The radar threshold of visualization of VIL is 65.5 mm. The criterion used for cases selection was the hail spike to be observed more than 8 minutes (2 full-volume scans). During the lifetime of the cells, hailstones with different sizes on the ground in various duration and intensity were detected. As additional information for the type, size and duration of the hail, it was used data from 200 rocket sites located in 10-12 km distance from each other in the protected area.

Fig. 3 Map of Bulgaria with marked places of TBSS detection

SUPERCELL – MONTANA JULY 08, 2014

The presented case was observed in distance of 50 km from the radar located in Bardarski Geran (Northern Bulgaria). The first registration of the Montana supercell was at 13:00 UTC between height of 5 and 10 km with maximum reflectivity of 35 dBZ [all heights are above mean see level (AMSL)]. The storm increased in intensity and height rapidly and after 31 minutes the first appearance of the hail spike (Fig. 4a) was seen at elevation scan 4.5°, 20 minutes before the registration of hail on the ground and 44 minutes before hailstones with size greater than 2 cm (in diameter). According to radar data at 13:31 UTC the storm core had Zmax=63 dBZ at ~ 6 km height. The most obvious and striking was the hail spike signature observed during 14:14-14:18 UTC. In that period, hailstones ≥6 cm were registered on the ground. The maximum TBSS length 41.3 km at 7.0° (elevation angle) and Zmax=73.5 dBZ at ~ 6.4 km (Fig. 4b).

Based on theory of hail spike appearance, a relationship between maximum length of TBSS and Zmax and maximum width of area with Z=60 dBZ was analyzed. At Fig. 5 is seen that the hail spike length rapidly increased when the area of 60 dBZ expened and Zmax rised up to 73.5 DBZ. These futures were observed during the hail registration on the ground (13:51-13:59 UTC – hail stone size 1.5 cm and 14:14-14:26 UTC - hail stone size > 2 cm).

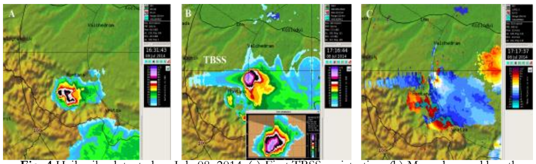

Fig. 4 Hail spike detected on July 08, 2014: (a) First TBSS registration; (b) Max. observed length; (c) Doppler velocities

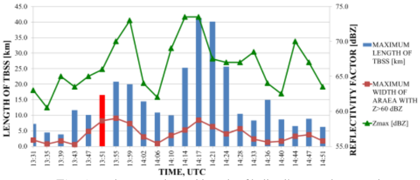

Fig. 5 Maximum registered length of hail spike , maximum radar reflectivity and width of area with Z>60 dBZ. With red color was marked the time when hail reached the ground

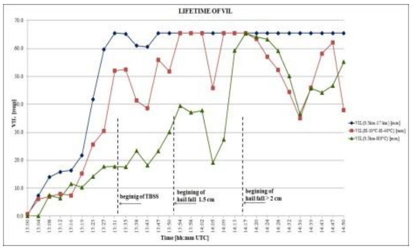

Fig. 6 Data for Integrated Liquid Water (VIL) in three different layers. With dashed lines were marked (from left to right): First registration of TBSS; First detection of hail (1.5 cm) on ground; First detection of hail (>2cm) on ground

An additional analysis between the hail spike existence and VIL is shown in Fig. 6. The first TBSS detection was after strong increase of VIL (0.5 km-17 km) and VIL (-10ºC-H-40ºC). VIL(0.5km-17 km) reached values >60 mm and VIL (-10ºC-H-40ºC) – higher than 50 mm. Hailstones with size >1.5 cm were reported at 13:54 UTC. During the time period 13:54 - 14:10 UTC, width of area with Zmax=60 dBZ and TBSS length decreased. Despite the maximum reflectivity factor decreased, all values were higher than 60 dBZ in that time period.

The maximum reflectivity factor raised up to 73.5 dBZ after 14:10 UTC. The width of area with Z=60 dBZ and TBSS length strongly increased. During the whole TBSS lifetime, VIL (0.5 km-17 km) maintained values higher than 65.5 mm. At the moment of hail fall (max size ≈ 1.5 cm), VIL (-10ºC-H-40ºC) reached values above 50 mm and VIL (0.5 km-17 km) - above 65.5 mm. VIL in all analyzed layers were higher than 65.5 mm at 14:17 UTC when hail size was greater than 2 cm. At the same time, the maximum length of hail spike was registered.

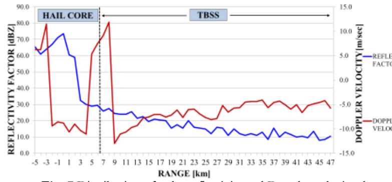

Fig. 7 Distribution of radar reflectivity and Doppler velocity along the TBSS. With dashed line was marked the beginning of TBSS

The analysis of reflectivity factor and Doppler velocity along the TBSS during the maximum length register (Fig. 7) confirmed to the theory of hail spike formation (Zrnić,1987; Wilson and Reum,1988). The reflectivity decreased as moving away from the hail core and the dominant Doppler velocity along the TBSS ware majority negative. The development of the cell accompanied by high updraft velocity was confirmed by the fact that speeds in the centre of the core are close or equal to zero. This conclusion is based on the relationship between the Doppler radial velocities in the TBSS area and the storm core and the vertical velocities associated with hydrometeors (Zrnić, 1987; Carbunaru et al., 2010) and the presence of high positive Doppler velocity in the beginning of TBSS.

SUMMARY OF CASES WITH TBSS IN BULGARIA

The Zmax was higher than 60 DBZ during the periods of TBSS registration in all analyzed cases. The maximum length of TBSS cases was between 5.8 and 46.2 km. A length between 10 ÷ 15.2 km was observed in 40% from all cases. Hail spike with length less than 8 km was registered in 5 cases and longer than 40 km – 2 cases. The maximum length of TBSS was register when Zmax was above 63 dBZ in 90 % from all cases. The hail cores during the maximum length of TBSS registration were found in altitudes between 1.8 and 7.2 km with average value of 4.2 km. Analysis showed (Fig. 8) that the coefficient of correlation between maximum observed length of TBSS and registered Zmax in this moment was 0.65. A correlation between the distance from the radar and hail spike length was not found.

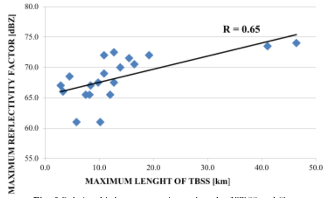

Fig. 8 Relationship between maximum length of TBSS and Zmax

The possible explanation of this results is the presence of strong updrafts, which support the existence of hailstones in the cloud for a long time, which is a precondition for their growth to large sizes leading to reflectivity Z> 60 dBZ from hail core and TBSS appearance respectively. The hailstones (d>2cm) fell to the ground in a later stage when $VIL_{0.5km\text{-}H0^{o}C} \geq 60$ mm were registered and more than 10 minutes after TBSS registration.

The presence of Zmax>60 dBZ is necessary but not sufficient condition for subsequent registration of large hailstones on the ground. Therefore, it was searched relation between the time of the first registration of a radar spike and VIL in layer between -10ºC and -40ºC ($VIL_{H\text{-}10^{o}C\text{-}H\text{-}40^{o}C}$), where the hailstones growth, and VIL in layer below freezing level ($VIL_{0.5km\text{-}H0^{o}C}$). Analysis showed that: $VIL_{0.5km\text{-}H0^{o}C}$ higher than 60 mm and duration more than 10 minutes is associated with hailstones with size > 2 cm; $VIL_{0.5km\text{-}H0^{o}C}$ between 20÷60 mm is associated with hailstones with size < 2 cm. Based on these results, an analysis of relationship between the time of existence, Δt_{VIL}, of high values of $VIL_{0.5km\text{-}H0^{o}C}$ (> 60 mm or closed to the registered maximum in the cases with values < 60 mm) and the interval, $\Delta t_{VIL\text{-}TBSS}$, between the moments of first registrations of TBSS and these values of $VIL_{0.5km\text{-}H0^{o}C}$ was made (Fig. 9). In all case when $VIL_{0.5km\text{-}H0^{o}C} \geq 60$ mm, these values were kept for more than 10 minutes. On Fig. 9 can be seen that if $VIL_{0.5km\text{-}H0^{o}C} \geq 60$ mm is registered after more than 10 minutes from TBSS appearance, there is a possibility for duration of severe hail on the ground over 10 minutes and vice versa. There is correlation (Fig. 10) between the time of existence of TBSS and $\Delta t_{VIL\text{-}TBSS}$ (R=0.85).

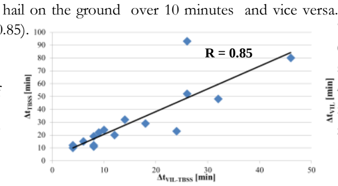

Fig. 10 Relationship between time of existence of TBSS and the interval $\Delta t_{VIL\text{-}TBSS}$, between the moment of first TBSS registration and first moment of high values of $VIL_{0.5km\text{-}H0^{o}C}$ (> 60 mm or closed to the registered maximum in the cases with values < 60 mm) registration

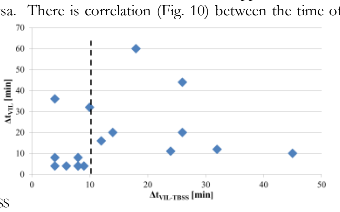

Fig. 9 Relationship between the time of existence of high values of $VIL_{0.5km\text{-}H0^{o}C}$ (> 60 mm or closed to the registered maximum in the cases with values < 60 mm) and the interval, $\Delta t_{VIL\text{-}TBSS}$, the moment of first TBSS registration and first moment of high values of $VIL_{0.5km\text{-}H0^{o}C}$ (> 60 mm or closed to the registered maximum in the cases with values < 60 mm) registration

In 13 of analysed cases, TBSS is observed when $VIL_{H\text{-}10^{o}C\text{-}H\text{-}40^{o}C} > 40$mm. In 10 of them, $VIL_{0.5km\text{-}H0^{o}C} \geq 60$ mm (hailstones with d>2cm on the ground). In 5 of the cases, TBSS appeared when $VIL_{H\text{-}10^{o}C\text{-}H\text{-}40^{o}C} < 40$ mm. The hailstones fall started less than 10 minutes after TBSS registration and the maximum hailstones size is < 2 cm.

CONCLUSIONS

- The results confirm conclusions of other authors (Lemon, 1998, Wilson and Reum,1988; Zrnić, 1987) that it would be prudent for operational forecaster to interpret the TBSS as indicator of severe hail.
- TBSS was register at Zmax ≥ 60 dBZ and the values of Zmax ware bigger than 63 dBZ at registration of maximum length of the spike in 90 % from all cases.
- The reflectivity factor in TBSS was between 28 and 5 dBZ and decreased as moving along the TBSS.
- TBSS was observed after registration of $VIL_{H\text{-}10^{o}C \div H\text{-}40^{o}C} > 40$ mm in 72% of the cases. In 77% of them, the hailstones had sizes larger than 2 cm with duration more than 10 minutes.
- There is a correlation (R=0.85) between the time of existence of high values of $VIL_{0.5km\text{-}H0^{o}C}$ (> 60 mm or closed to the registered maximum in the cases with values < 60 mm) and the interval between the first registrations of TBSS and these values of $VIL_{0.5km\text{-}H0^{o}C}$. The later $VIL_{0.5km\text{-}H0^{o}C} \geq 60$ mm is registered compare to the TBSS appearance, the longer $VIL_{0.5km\text{-}H0^{o}C} \geq 60$ mm (severe hail on the ground) will exist.
- Despite of the limited number of the analysed cases, the results encourage that TBSS in combination with VIL in layers -10ºC÷-40ºC and under the freezing level could be used for nowcasting of severe hail.

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