Lightning behaviour during the lifetime of severe thunderstorms

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I. INTRODUCTION

Several studies (Kane et al., 1991, Williams et al., 1999, Lang et al., 2000, Soula et al., 2004, etc.) established a relation between lightning characteristics and severe events such as tornado and large hail. The conclusions based on the investigations are often contradictory. Sorriano et al., 2001, Soula et al., 2004 assumed that the variability of lightning parameters is linked to several factors, especially the latitude, the season, and the climatic conditions. There is only a limited number of studies (Dimitrova et al., 2009, Mitzeva et al., 2011) concerning lightning activity of thunderstorms developed over Bulgaria. They showed that there is a significant difference between lightning characteristics in thunderstorms, producing hail, heavy and weak rain.

The goal of the present work is to study the lightning behaviour during the lifetime of different types of severe hail producing thunderstorms developed over Bulgaria during the summer.

II. PRESENTATION OF RESEARCH

Lightning data are taken from the LINET network [Betz et al., 2009]. Radar information is obtained by S-band Doppler radar MRL5-IRIS from the Hail Suppression Agency in Bulgaria. The flash rate is calculated per 4 minutes in accordance with the period of the radar volume scan.

Three severe thunderstorms developed over Bulgaria during the summer of 2009 and 2010 have been analysed concerning flash rate (FR), peak current (PC), multiplicity (Mn), and polarity of total lightning (intra-cloud and cloud-to-ground), and several radar parameters, namely height for maximum radar reflectivity (Hzmax), maximum height of 15 dBZ (H15) and 45 dBZ (H45).

The genesis of the studied thunderstorms was different. One of them was a multi-cellular storm (MC) which developed on 8 August 2010. The other one occurred on 30 May 2009 and was an isolated developed supercell (SC), while the third one was multi-cellular and evolved into a supercell storm (MSC) on 6 August 2010. The lifetimes of the thunderstorms were longer than 2 hours. There is a significant difference in the duration of large hail falling on the ground from the three thunderstorms – 60 min from MC, 15 min from SC and 26 min from MSC. The MC and SC thunderstorms produced hailstones with diameter up to 3 cm and MSC up to 6 cm.

III. RESULTS

In Figure 1 the flash rate, FR, and the radar characteristics are presented for MC (Fig.1a), for SC (Fig.1b) and for MSC (Fig.1c). The maximum radar reflectivity reached 60-65 dBZ (marked by dots on the curve of Hzmax in Fig.1a,b,c) in the studied three thunderstorms and their radar cloud tops (see H15 in Fig.1a,b,c) rose above 16 km. The duration of existence of radar reflectivity $Z \geq 60$ dBZ above zero isotherm, H0, in MC and in SC was ≈3 times longer than for MSC.

There is one well pronounced pulse in the vertical development of MC and two in MSC. These pulses are associated with a sharp increase of the heights of 15 and 45 dBZ centered around 14:16 UTC in the MC storm and around 12:34 UTC and 13:06 UTC in the MCS. The more detailed analysis reveals that the second jump in MSC starts after the transformation of a multi-cell into a supercell MSC storm (≈ 13:00 UTC).

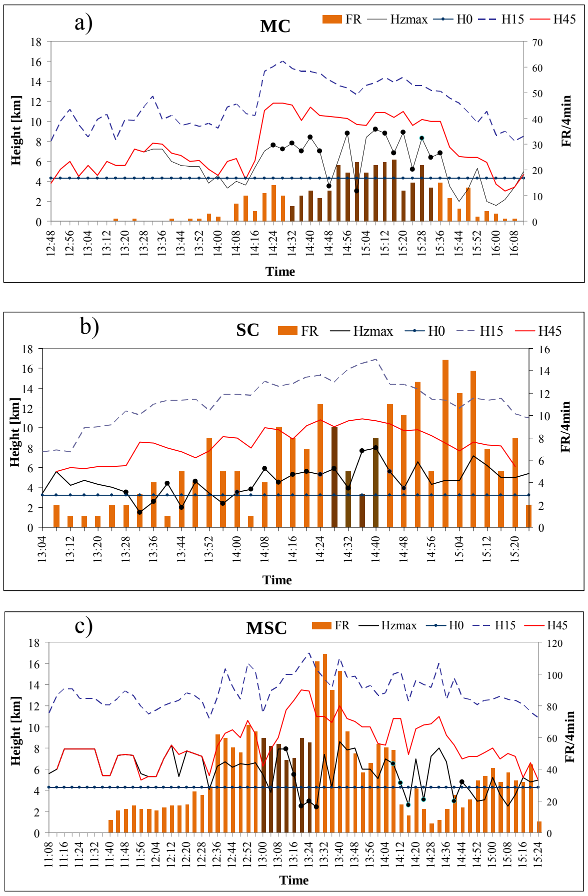

FIG.1: Number of flashes per 4 minutes, FR, and radar information as a function of time. The FR during the period of intensive large hail on the ground is denoted by darker columns

The flash rate of total lightning in MSC is remarkably higher than in MC and SC (compare Fig.1c with Fig.1a and Fig. 1b). The mean and maximum values of both negative and positive flash rates in the MSC are also significantly higher than the corresponding MC and SC characteristics (Table 1).

TABLE 1: Mean and maximum values of flash rate

	Flash rate per 4minutes					
	positive		negative		total	
	mean	max	mean	max	mean	max
MC	1.20	2	9.89	23	10.05	24
SC	2.11	5	4.94	15	6.03	15
MSC	11.20	38	27.82	80	38.82	113

In the three thunderstorms there is a jump in the flash rate before the falling of large hail on the ground. The flash rate sharply increases more than 2 times 24 min before the hail fall in MC, 34 min in SC and 24 min in MSC (see Fig.1a,b,c). The analysis reveals that similar to Carey et al. (2003) the jump of FR in MC and MSC is accompanied by a sharp increase of H15 and H45. During the large hail falls, the FR decreases in MSC and SC but reached maximum values in MC. The maximum values of FR in MSC and SC are detected after this observed event when H15 and H45 start to decrease.

The analysis shows that there is no direct correlation between FR and radar characteristics. However, the correlation is established between H45 and FR averaged in 1 km bin (see Fig. 2). Based on the assumption that the radar volume fraction for graupel correlates with the volume of reflectivity 45 dBZ, one can speculate that these results are consistent with the non-inductive charging mechanism (Saunders, 1993), which relies on rebounding collisions between graupel and ice crystals in the presence of the super-cooled liquid water.

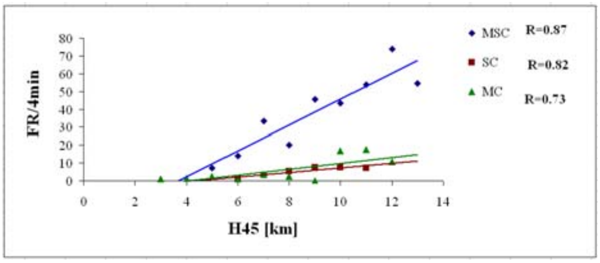

FIG.2: Flash rate FR (averaged in 1 km bin), as a function of H45

In the frame of the present study the reason for the dramatically higher values of FR in MSC in comparison with FR in MC and SC is not clear. One can speculate that factors such as dynamics and microphysics, responsible for the 2 times larger hailstones from MSC in comparison with MC and SC, caused the very high FR in MSC.

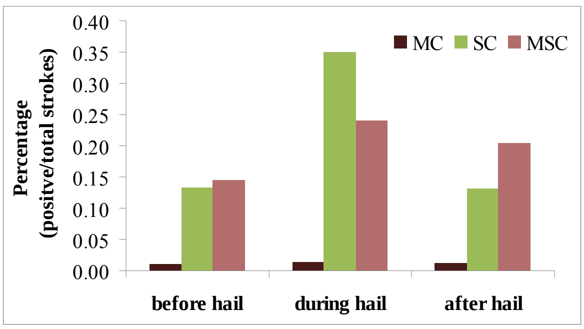

FIG.3: Percentage of positive strokes before, during and after large hail falling on the ground

Positive strokes were detected in all three thunderstorms, however the percentage in MC is very low (≈1%), while in SC and MSC it is approximately 20%. The percentage of positive strokes is highest during the period of large hail detected on the ground (Fig.3).

The analysis of negative peak current shows that there are no significant differences in their mean absolute values for the three storms and the highest absolute value of 104.7 kA is registered in MSC (Table2). The mean values of positive peak current in MC and SC are 2 times higher than in MSC and the highest value of 70.3 kA is registered in SC.

The mean and maximum values of multiplicity of negative flashes in MC and SC are similar. Their values are significantly lower than the ones in MSC (Table 2).

TABLE 2: Mean and maximum values of peak current and multiplicity

	PC				Multiplicity			
	negative (abs.values)		positive		negative		positive	
	mean	max	mean	max	mean	max	mean	max
MC	21.4	67.6	22.8	48.2	1.2	6	1.0	1
SC	17.4	64.5	21.2	70.3	1.3	7	1.0	1
MSC	16.4	104.7	10.8	37.8	1.8	16	1.1	3

The maximum values of multiplicity in the three storms are before the falling large hail on the ground. The highest value of 16 is registered in MSC (Fig.4c) while maximum values in MC and SC are 6 and 7, respectively (Fig.4a, b).

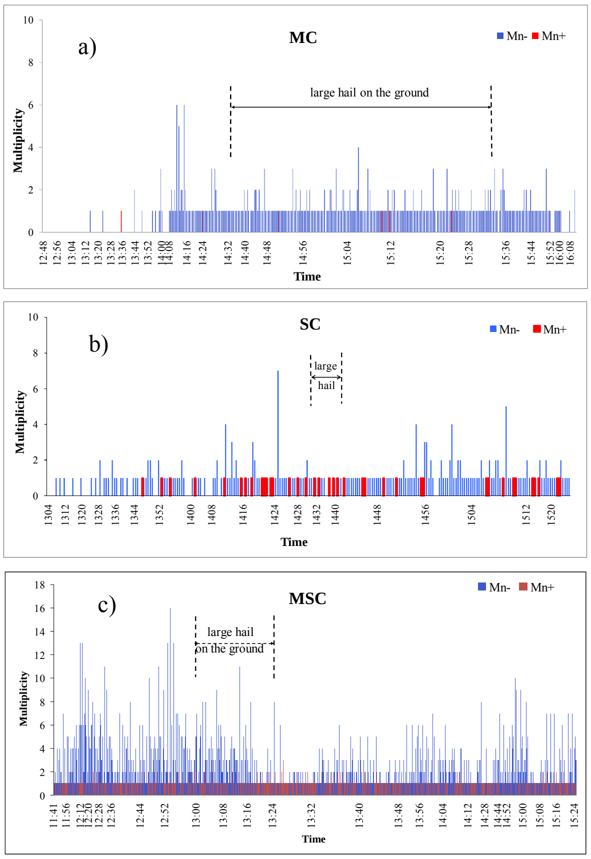

FIG.4: Multiplicity of positive flashes, Mn+ and negative flashes, Mn– as a function of time

In the three thunderstorms, there is a pronounced jump in multiplicity before the time of detection of large hail on the ground – 18 min in MC, 8 min in SC and 68 min in MSC, and the multiplicity of negative flashes is above 6 (Fig.4a, b, c).

IV. CONCLUSIONS

An analysis of lightning behaviour during the lifetime of different types of severe thunderstorms producing large hail over Bulgaria was carried out. The main results are:

- Significant numbers of positive strokes are detected in both supercells of SC and MSC. The highest percentage of positive strokes is observed during the period of large hail falls on the ground.
- There is a positive time lag between the jumps of both multiplicity and flash rate and large hail falls in the three analysed thunderstorms.
- The highest lightning activity (flash rate and multiplicity) is observed during the lifetime of the evolved from a multi-cell into a supercell thunderstorm. The mean and maximum values of FR, as well as the multiplicity of negative strokes in MC and SC are remarkably lower than in MSC.

The established jump in the flash rate before large hail fall is in accordance with the results reported by Soula et al. (2004), Kane (1991), and Williams et al.(1999). The detected significant numbers of positive strokes in both supercells correspond to the results obtained by other authors (e.g. MacGorman and Burgess, 1994; Stolzenburg, 1994; Carey and Rutledge; 1998, Lang et al., 2004; Wiens et al., 2005) and according to MacGorman and Burgess (1994) this can be explained by the structure of supercell storms. One can speculate that the significant difference in flash rate in MSC, SC and MC thunderstorms supports the conclusion by Fehr et al. (2005) that the convective organization plays a crucial role in the lightning development. To answer the question if there is a relationship between an extremely high flash rate in MSC (FR>100 per 4 min) and extremely large hail (greater than 6 cm), more hail producing thunderstorms developed over Bulgaria have to be analyzed.

The present study reveals that most of the lightning signatures in the studied severe thunderstorms developed over Bulgaria are similar to those in other geographical regions, and the results are promising that lightning activity information can be used as an indicator for the occurrence of large hail on the ground over Bulgaria. For firm conclusions the analysis of lightning characteristics of several severe thunderstorms producing damaging hail has to be carried out in order to establish a broader statistical basis.

V. ACKNOWLEDGMENTS

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