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Lightning behavior during the lifetime of severe hail-producing thunderstorms

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Abstract– Results from an analysis of total lightning (cloud-to-ground and intracloud) behavior during the lifetime of severe hail-producing thunderstorms are presented. The analysis was carried out for different types of storms: multicell, supercell, and multicell which evolved into supercell storms. The study reveals: (1) There is a positive time lag between the jumps of both multiplicity and flash rate and the beginning of large hail in the three analyzed thunderstorms. (2) The mean and maximum values of total flash rate, as well as the multiplicity of negative total strokes in the multicell and supercell storms are remarkably lower than for the multicell that became supercell storm. (3) Significant numbers of positive total strokes are detected in both supercell and multicell which evolved into supercell storms. The highest percentage of positive strokes is observed during the period of large hail falls on the ground. (4) The jump of lightning density is observed before large hail fall in the three storms, following a dramatic decrease of the lightning rate during the beginning of the hail fall. In the supercell storm the lightning "hole" occurred, associated with an existence of bounded weak-echo region of the cell.

Key-words: total lightning; flash rate; multiplicity; lightning density; hail; radar reflectivity

1. Introduction

The relationship between lightning and thunderstorm severity (large hail, heavy rain leading to flash flooding, strong wind, and tornado) has been subject of studies for more than 50 years. One of the purposes of these studies has been to evaluate whether lightning characteristics could be used to improve nowcasting of severe thunderstorm events. However, the results related to lightning characteristics during the lifetime of severe thunderstorms are often contradictory in the numerous studies.

In previous studies it is noted that severe storms are characterized by higher total flash rates than ordinary non-severe storms. The more intense the storm the more lightning is produced (*Maier* and *Krider*, 1982; *Taylor*, 1973; *Turman* and *Tettelbach*, 1980). *Williams* (1985) explained this link with the intensification of the updrafts. The correlation between updraft and flash rate is also established by *Deierling* and *Petersen* (2008), *Goodman et al.* (2005), and *Wiens et al.* (2005).

However, there are severe storms that are characterized by low cloud-to-ground flash rates. Low CG flash rates are observed when hail was produced in two thunderstorms studied by *Lang et al.* (2000). In both studied storms, radar reflectivity and the production of hail were anti-correlated with the production of significant negative cloud-to-ground lightning. The authors explained this with the elevation charge hypothesis (*MacGorman et al.*, 1989) and suggested that low production of negative CGs can be explained by the production of significant quantities of hail, high IC flash rates, and strong updrafts. In hail -bearing storms, studied by *Soula et al.* (2004), the CG rate does not exceed 2 min^{-1} when the cells produce hail, while it can reach up to 12 min^{-1} for heavy precipitating storms.

According to some studies, the cloud-to-ground (CG) lightning frequency decreases when hail forms in the cloud (*Lang et al.*, 2000; *Soula et al.*, 2004). *Williams et al.* (1999) found that peak flash rate precedes severe weather at the ground by 5–20 min. Their analysis showed that "A distinguished feature of severe storms is the presence of lightning "jumps"– abrupt increases in flash rate in advance of the maximum rate for the storm". *Kane* (1991) obtained similar results – tornadoes and large hail occurred about 10–15 min after the peak of the 5-min cloud-to-ground lightning rate.

Additionally, a change in the polarity ratio is apparent in cases of severe weather: positive CGs are more prevalent than negative ones, resulting in a decrease of negative CG lightning frequency. Some authors (e.g., *Carey* and *Rutledge*, 1998; *Lang et al.*, 2004; *Reap* and *MacGorman*, 1989; *Seimon*, 1993; *Stolzenburg*, 1994; *Wiens et al.*, 2005) reported a relationship between large hail and positive CG lightning. They showed that hailstorms usually produce large hailstones in the active period of positive CG flashes. For example, *MacGorman* and *Burgess* (1994) analyzed the characteristics of CG flashes in 15 severe storms with large hailstones or tornadoes and found that the large hail occurred during the period when positive ground flashes dominated. In 11 tornadic storms, tornadoes occurred either during or after the period when positive ground flashes dominated. The strongest tornado usually begins after the positive ground flash rate decreases from its maximum value. *Montanya et al.* (2007, 2009) and *Soula et al.* (2004) revealed a reversal of the dominant polarity of the CG flashes from negative to positive during the period when cells produced hail.

Other studies showed that severe weather often occurs without dominating positive strokes. *Bluestein* and *MacGorman* (1998) and *Curran* and *Rust* (1992) reported that within the hailstorms they had studied, the negative cloud-to-ground flashes dominated.

Carey et al. (2003) analyzed severe storms for a period of 10 years (1989–1998) and came to the conclusion that there was a significant regional variability in the percentage of positive CG lightning produced by severe storms during the warm season. It is assumed that the geographical preference of positive storms is linked to specific meteorological conditions of the region. For this reason, some authors (*Gilmore* and *Wicker*, 2002; *MacGorman* and *Burgess*, 1994; *Smith et al., 2000*; *Williams et al.*, 2005) explored the relationships between the environmental conditions and CG lightning. Based on the hypothesis that mesoscale environment indirectly influences lightning polarity of the storms by directly controlling storm structure, dynamics, and microphysics which in turn control storm electrification, the analysis of *Carey* and *Buffalo* (2007) demonstrated significant and systematic differences in environmental conditions of positive and negative storms.

Lang and *Rutledge* (2002) analyzing 11 thunderstorms came to the conclusion that "The only significant differences between intense storms that produced predominately positive cloud-to-ground (CG) lightning for a significant portion of their lifetimes (PPCG storms) and intense storms that produced little CG lightning of any polarity (low-CG storms) was that PPCG storms featured much larger volumes of significant updrafts and produced greater amounts of precipitation (both rain and hail)".

Different authors reported various values of multiplicity. For example: *Soula et al.* (2004) obtained values from 1.9 to 2.6 for the negative CG flashes and from 1.0 to 1.2 for the positive ones, while *Carey et al.* (2003) obtained similar values of mean positive and negative CG multiplicity (1.2 and 1.1, respectively) for the analyzed supercell.

The interesting feature of lightning behavior during the lifetime of a severe storm is the presence of a lightning "hole" (areas of week or even zero total lightning density surrounded by larger values). The existence of a hole is reported by many authors (*Goodman et al.*, 2005; *Lang et al.*, 2004; *MacGorman et al.*, 2005; *McKinney et al.*, 2008; *Murphy* and *Demetriades*, 2005; *Steiger et al.*, 2007; *Wiens et al.*, 2005). *Lang et al.* (2004) found that the lightning hole is associated with extremely strong updrafts in the bounded weak echo region of the supercell. This hypothesis is supported by different observations (for example, *Goodman et al.*, 2005; *Steiger et al.*, 2007). However, *Murphy* and *Demetriades* (2005) analyzing two hail-producing supercells reported that the lightning "hole" was not linked to the bounded weak echo region but rather was a manifestation of a more complicated radar structure.

It is clear that conclusions based on the investigations conducted in different geographical regions are often contradictory, because the variability of lightning parameters is linked to several factors, especially latitude, season, location, and climatic conditions (e.g., *Orville*, 2002; *Sheridan*, 1997; *Soriano et al.*, 2001; *Soula et al.*, 2004;). Different types of thunderstorms were studied by *Lang et al.* (2000) and *Ray et al.* (1987) in order to analyze the reasons for the differences in lightning behavior.

Bulgaria is situated in southeast Europe. Within a relatively small area (111 000 km^2), the Bulgarian landscape exhibits a striking topographic variety – large plains and lowlands, valleys and gorges, low and high mountains (up to 2–3 km). The mountains are important factor for the intensification of convection.

From April to September the frequency of thunderstorms in Bulgaria is high. In more than 60% of the days there are thunderstorms and half of them produce hail.

The analyses in *Dimitrova et al.*, (2009) revealed that most of lightning features of the studied severe and non-severe thunderstorms developed over Bulgaria were similar to those in other geographical regions. However, there are some differences in lightning behavior in severe storms that stimulated the analysis of lightning characteristics in different types of severe storms.

The goal of the present paper is to study the lightning behavior in three different types of severe storms produced large hail (diameter more than 2 cm) over Bulgaria. The evolution of lightning characteristics of a multicell, a supercell, and a multicell that evolved into a supercell storm is analyzed together with the radar characteristics.

2. Data

The lightning and volume radar data over the territory of Bulgaria have been available since 2008. Lightning data are taken from the LINET network (*Betz et al.*, 2008). Radar information is obtained from radar network of Hail Suppression Agency in Bulgaria.

The main information about the hail precipitation is regularly obtained using data from the rain gauge network with distance between the gauges of about 10–12 km. Additional information is given by voluntary observers in towns and villages situated between the rain gauges.

2.1. Radar data

Data from two S-band Doppler radars were used (*Fig. 1*). The one is in North Bulgaria (Bardarski geran village, Vratsa district) and the other is in South Bulgaria (Golyam Chardak village, Plovdiv district).

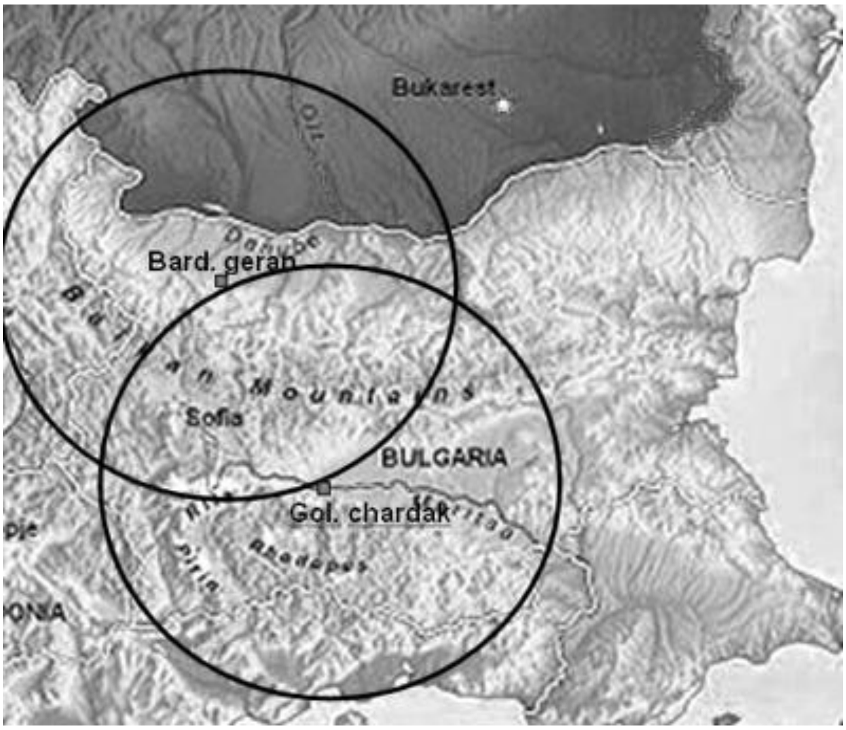

Fig. 1. Range of radar observation. Both radar stations (in Bardarski geran village – North Bulgaria and Golyam Chardak – South Bulgaria) are part of radar network of Hail Suppression Agency in Bulgaria.

Radar data were used to produce horizontal and vertical cross sections of thunderstorm cell structures. These profiles are estimated from volumetric data generated by an automatic scanning at 14 elevation angles. The elevation of the successive scan was increased from 0.2^o to 85^o with an irregular step while spinning around 360^o of azimuth. The full volume scan was performed for 4 minutes in a range of 150 km. IRIS (Interactive Radar Information System) generates products based on this volume scan.

Data for the vertical profile of reflectivity for the storms' cells - maximum reflectivity, height of maximum reflectivity, Hzmax, maximum heights of 15 dBZ, and 45 dBZ contour (H15 and H45 respectively) were analyzed to investigate storm's structure and evolutions.

2.2. Lightning data

The analyzed information for lightning characteristics was taken from the European LINET (Betz et al., 2008).

LINET is a VLF/LF lightning detection network developed at the University of Munich, which provides continuous data for both research and operational purposes. During international co-operations, LINET has been deployed in four continents. LINET covers a wide area approximately from a longitude of –10^o to 25^o and from latitude of 35^o to 66^o (*Betz et al.*, 2009). The LINET data set provides information on stroke time, geographical location, height of intra-cloud (IC) events, peak current (PC), and polarity. The discrimination between CG and IC lightning in LINET relies on a TOA (times of arrival) analysis. The corresponding differences in travel time from high- and low-lying emission centers are exploited within the TOA locating algorithm (*Betz et al.*, 2004; *Betz at al.*, 2009). This 3D discrimination method is reliable when the sensor baseline does not exceed ~250 km. Thus, while the sensor geometry in the central part of the network allows locating very weak lightning events with the inclusion of large numbers of IC and reliable discrimination between CG and IC, in the surrounding areas the network reports predominantly the stronger events, which are mainly return strokes (CG) (*Betz et al.*, 2009). Bulgaria is in the edge of the LINET network geometry. To avoid inaccuracies in the separation of IC and CG strokes, total lightning is studied in the present paper.

The lightning characteristics – flash rate (FR), peak current (PC), multiplicity (number of strokes in one flash) Mn, and polarity of total lightning (intra-cloud and cloud-to-ground) were analyzed. The flash rate was calculated per 4 minutes in accordance with the period of radar volume scan.

3. Case studies

Three severe thunderstorms with a different development were studied. One of them was a multi-cellular storm (MC) which developed on August 8, 2010 (*Fig. 2a*). The other one occurred on May 30, 2009 and was an isolated developed supercell (SC) (*Fig. 2c*), while the third one, developed on August 6, 2010, was multicellular and evolved into a supercell storm (MSC) (*Fig. 2b*).

Maximum values of some radar characteristics together with the corresponding temperature given in *Table 1* show that the three thunderstorms had a strong vertical development (the top echo, H15 of thunderstorms reached at altitude of 16–17 km) and intense radar reflectivity echo – 60–65 dBZ. The other similarity between the studied thunderstorms is the long life time (longer than 2 hours) and the registration of large hail (diameter larger than 2 cm) at the ground.

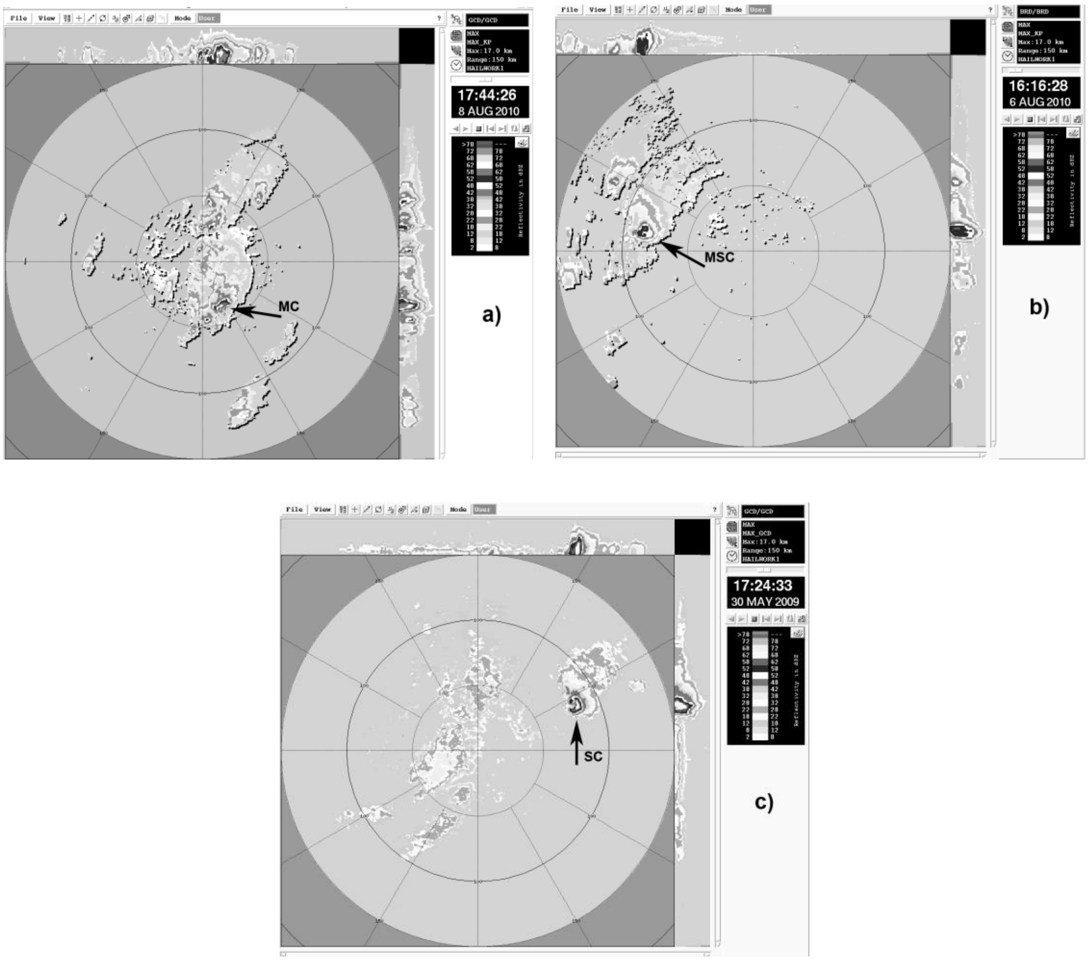

Fig. 2. Radar display of the maximum radar reflectivity [dBZ] obtained by S-band radar in the moment of maximum development of: a) multicell thunderstorm, MC on August 8, 2010 at 1444 UTC (1744 local time); b) multicell evolving into a supercell thunderstorm, MSC on August 6, 2010 at 1316 UTC (16:16 local time); c) supercell storm, SC on May 30, 2009 at 1424 UTC (1724 local time). The range markers identify 50 km separations.

Table 1. Maximum values of some radar characteristics and corresponding temperature in the three studied thunderstorms: multicell thunderstorm, MC; evolved from multicell into supercell thunderstorm, MSC; supercell storm, SC

Max values	**MC**	**MSC**	**SC**
H15 [km]	16.1	16.5	16.9
T_{H15} [°C]	–60.7	–59.2	–60.1
H45 [km]	11.8	13.5	10.9
T_{H45} [°C]	–42.2	–51.0	–54.3
Zmax [dBZ]	65.0	60.0	63.5
Hzmax [km]	8.8	7.9	8.0
T_{Hzmax} [°C]	–28.4	–24.6	–33.1

However, the studied storms had differences in the development and radar structure. From the beginning the SC storm developed as an individual super cell with a rapid vertical development. In 10 minutes the height of 15 dBZ radar echo increased from 7.6 km to 10 km and the maximum reflectivity increased from 35 dBZ to 53.5 dBZ. In the next 10 minutes the maximum reflectivity reached 60 dBZ keeping up these high values (60–65 dBZ) during the next 90 min.

Unlike this storm, both MSC and MC storms started as ordinary non-severe multicell storms. MSC storm underwent a transition from a weak multicellular storm into an intense supercellular storm in the period 1236 UTC – 1300 UTC. The development of MC storm intensified after 1416 UTC. The maximum measured radar reflectivity in MSC storm was 60 dBZ and in MC storm – 65 dBZ.

There is a well pronounced pulse in the vertical development of MC storm and two pulses in MSC storm. These pulses are associated with a sharp increase of H15 and H45 centered around 1416 UTC in the MC storm and around 1236 UTC and 1304 UTC in the MSC storm. The maximum values of H45 in the three studied storms are significantly different (Table 1). In MSC storm, H45 reached 13.5 km and in SC and MC storms – 10.9 and 11.8 km, respectively. Another significant difference between MSC storm and MC and SC storms is the location of region with high radar reflectivity ≥ 60 dBZ. The duration of an existence of high radar reflectivity above zero isotherm, H0, in MC storm and in SC storm was about 3 times longer than for MSC storm. (*Fig. 3a, b, c*)

The MC and SC thunderstorms produced hailstones with diameter up to 3 cm and MSC storm up to 6 cm. There is also a significant difference in the duration of large hail falling on the ground from the three thunderstorms – 60 min from MC storm (with interruptions due to the multi-cellular development), 15 min from SC storm, and 26 min from MSC storm.

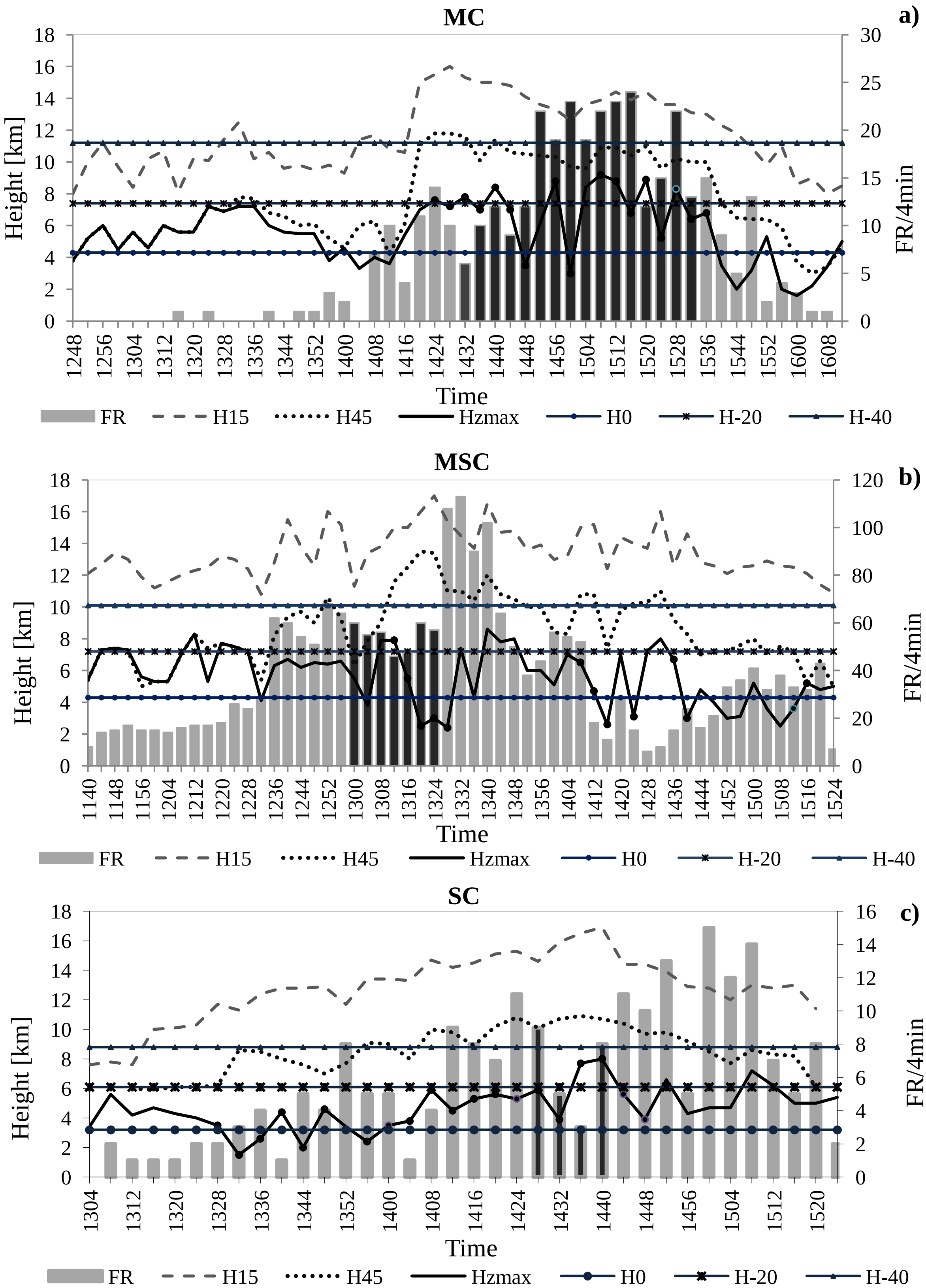

Fig. 3. Number of total flashes per 4 min, FR and radar information, as a function of time for the studied thunderstorms: a) multicell thunderstorm, MC; b) multicell evolving into a supercell thunderstorm, MSC; c) supercell storm, SC

4. Lightning behavior

Evolution of flash rate (FR), polarity, peak current (PC), and multiplicity (Mn), during the lifetime of the three severe storms were analyzed together with radar characteristics of the storms.

The flash rate of total lightning in MSC storm (*Fig. 3b*) is remarkably higher than in MC and SC storms (*Fig. 3a* and *Fig. 3c*, correspondingly). The mean and maximum values of both negative and positive flash rates in the MSC storm are also considerably higher than the corresponding characteristics in MC and SC storms (*Table 2*).

Table 2. Mean and maximum values of flash rate per 4 minutes during the lifetime of studied thunderstorms: multicell thunderstorm, MC; evolved from multicell into supercell thunderstorm, MSC; supercell storm, SC

	Flash rate per 4 minutes					
	Positive		Negative		Total	
	mean	max	mean	max	mean	max
MC	1.2	2	9.9	23	10.1	24
SC	2.1	5	4.9	15	6.0	15
MSC	11.2	38	27.8	80	38.8	113

During the non-severe stage of MC storm (from 1248 UTC till 1412 UTC) and MSC storm (from 1140 UTC till 1232 UTC), the flash rate is significantly lower in comparison with the severe stage (see *Fig. 3a*, *Fig. 3b*). In the non-severe stage, the time duration of H15 and H45 above –40 °C and –20 °C isotherms, respectively, is longer for MSC storm in comparison with MC storm. Thus, the vertical profile of radar reflectivity indicates that MSC storm has a stronger updraft than MC storm. One can speculate (see *Carey* and *Rutledge,* 1996) that the stronger updraft in MSC storm is responsible for the greater number of graupel than in MC storm and thus for higher flash rate via the non-inductive mechanism of thunderstorm electrification (*Saunders et al.*, 1991).

In the three thunderstorms there is a jump in the flash rate before the occurrence of large hail on the ground. The flash rate FR$\geq$1 min^{-1} sharply increases more than 2 times 12 min before the hail fall in MC storm, 20 min in SC storm, and 24 min in the MSC storm (see *Fig.3a, b, c*). The increase is more pronounced in MSC and MC storms. It is just before the transition of non-severe to severe stage of both thunderstorms, when a pulse in the vertical development of the cells (sharp increase of H15 and H45) is abrupt.

The maximum values of flash rate in the three storms are detected after the maximum vertical development of the storms (see *Fig 3*). In MC and MSC storms these values are reached after a second jump of flash rate, which occurs after the lowering of the height of radar reflectivity ≥ 60 dBZ below the 0°C isotherm.

A small decrease of the flash rate is observed in MSC storm during the large hail falls, while the corresponding decrease by a factor of 4 is significant in SC storm. However, the flash rate reached maximum values in MC storm during the occurrence of large hail.

The plot of lightning density (number of strokes for 10 minutes in a grid cell 5 km × 5 km) is shown in *Fig. 4*. The lightning density reached its maximum values before the falling of large hail on the ground and decreased in the beginning of this period in all three thunderstorms. While the lightning density reached its maximum, there was a convective vertical development, when a reflectivity of 45 dBZ extended up to –40°C isotherm and the maximum radar reflectivity (≥60 dBZ) – extended up to the –20 °C isotherm.

During the large hail fall (the period of time is denoted by red color in *Fig. 4*), the decrease of lightning density was observed, although the radar reflectivity was very high. The lower panel in *Fig. 4* shows that a lightning "hole" is observed in SC storm during the hail fall (from 1430 UTC till 1440 UTC). The more detailed analysis revealed that the presence of a lightning "hole" is accompanied by an occurrence of bounded weak-echo region (BWER) of the SC storm (*Fig. 5*).

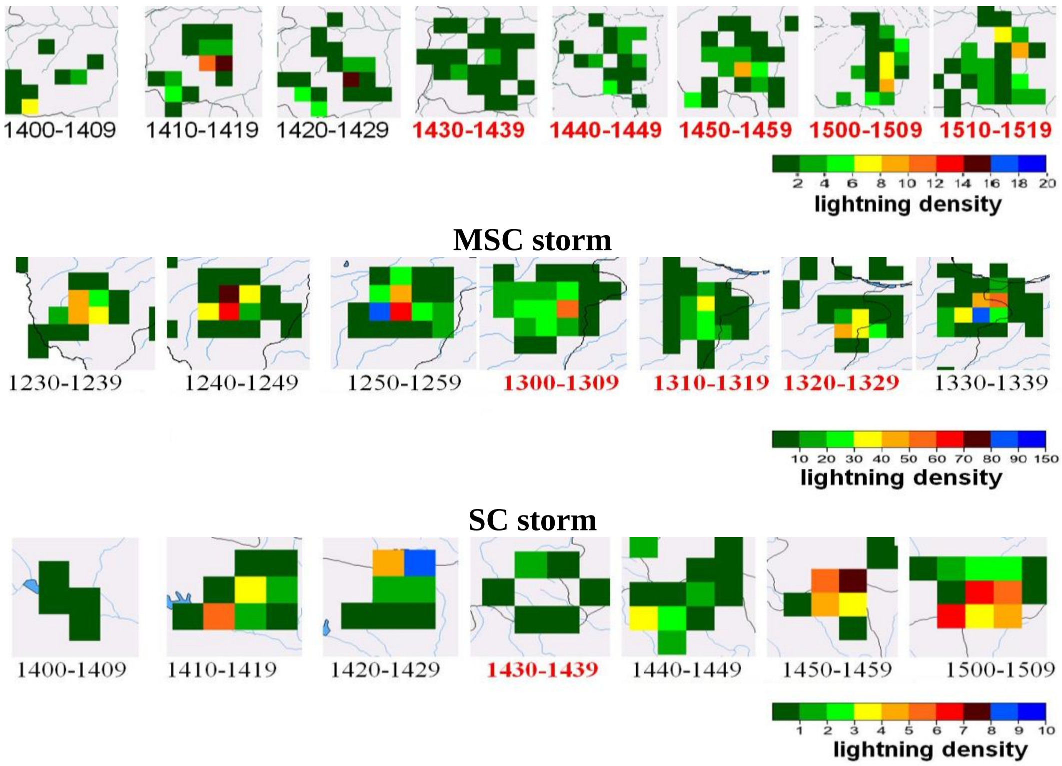

Fig. 4. Lightning density (number of strokes for 10 minutes in a grid cell 5 km x 5 km) during the part of lifetime of a multicell thunderstorm, MC (upper panel); multicell evolving into supercell thunderstorm, MSC (middle panel); a supercell storm, SC (lower panel). The period of large hail is denoted in red.

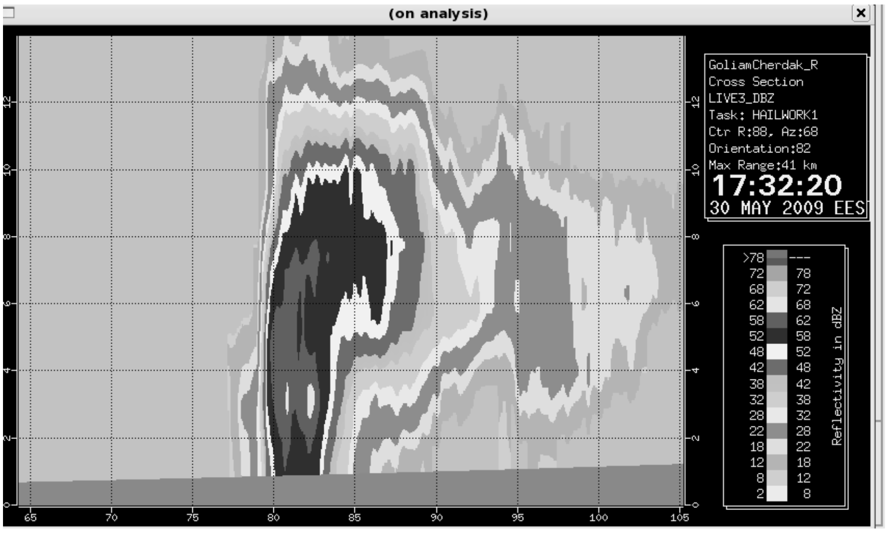

Fig. 5. Vertical cross-section of the supercell storm, SC on May 30, 2009 at 1432 UTC (17:32 in local time).

There is no direct correlation between flash rate, FR, and radar characteristics. However, a statistically significant (α=0.05) correlation is established between H45 and FR averaged in 1 km bin (see *Fig. 6*). Based on the assumption that the radar volume fraction for graupel correlates with the volume with reflectivity of 45 dBZ, one can speculate that these results are consistent with the non-inductive charging mechanism (*Saunders et al.*, 1991; *Sanders*, 1993), which relies on the rebounding collisions between graupel and ice crystals in the presence of the super-cooled liquid water.

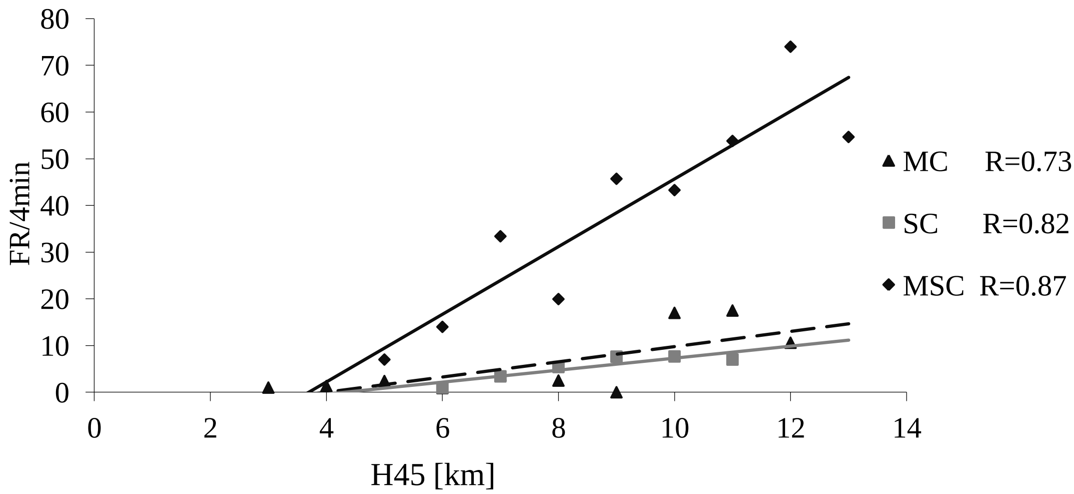

Fig. 6. Flash rate FR (averaged in 1 km bin), as a function of H45.

The analysis of strokes polarity showed that positive strokes were detected in all three studied cases (*Fig. 7*). However, the percentage in MC storm is very low (≈1%), while in SC and MSC storms it is approximately 20%. The number of positive strokes is highest during the period of large hail detected on the ground (*Fig. 8*). In SC storm, the FR of positive flashes predominated and was 2.5 times higher than FR of negative ones 8 minutes before large hail on the ground (*Fig. 7c*).

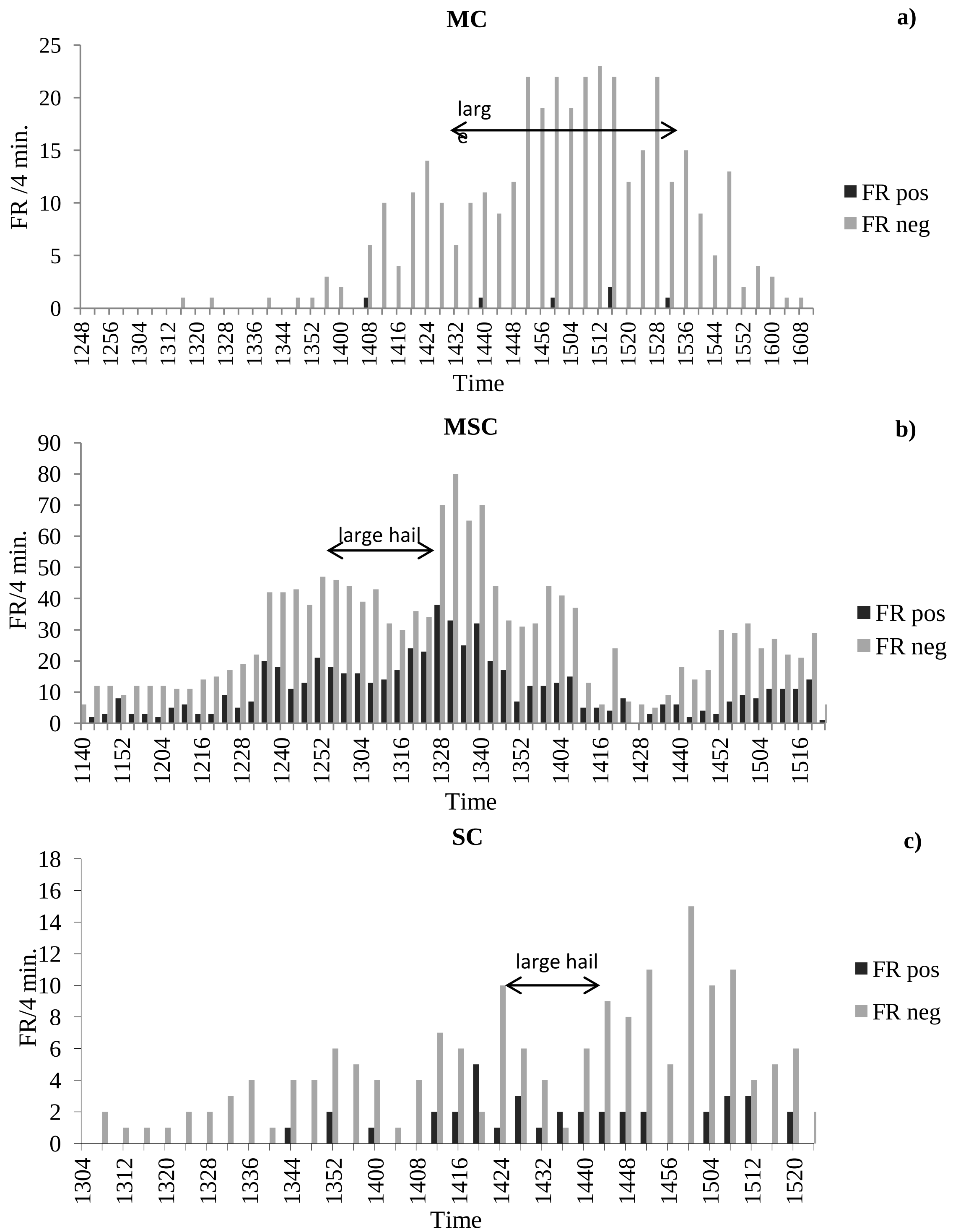

Fig. 7. Number of total negative and positive flashes per 4 min. as a function of time for the studied thunderstorms: a) multicell thunderstorm, MC; b) multicell that evolved into a supercell thunderstorm, MSC; c) supercell storm, SC.

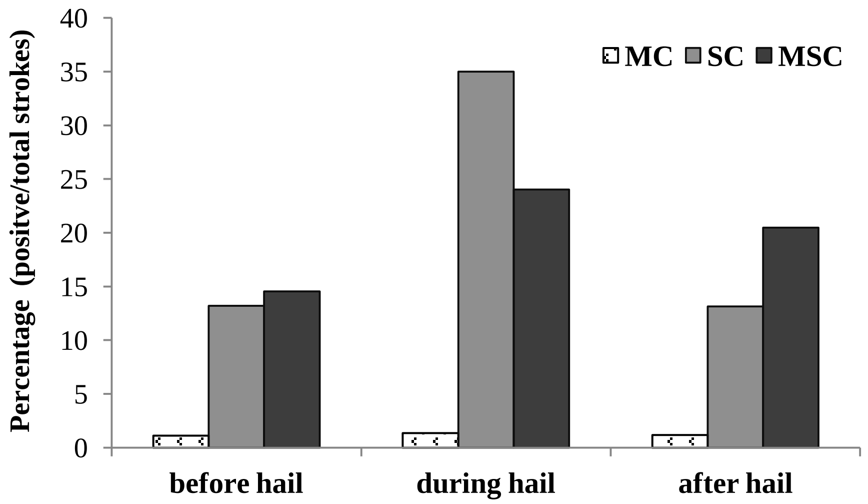

Fig. 8. Percentage of positive strokes before, during, and after large hail falling on the ground.

The mean and maximum values of multiplicity of negative flashes in MC and SC storms are similar (*Table 3*). Their maximum values are significantly lower than the ones in MSC storm.The maximum values of multiplicity in the three storms were before the falling of large hail on the ground (*Table 4*).The highest value of 16 is registered in MSC storm, while maximum values in MC and SC storms are 6 and 7, respectively. 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 storm, 8 min in SC storm, and 68 min in MSC storm (*Fig. 9 a, b, c*).

Table 3. Mean and maximum values of multiplicity and peak current (absolute value), PC, of the studied thunderstorms

	Multiplicity				**PC**			
	Positive		**Negative**		**Positive**		**Negative (absolute values)**	
	mean	**max**	**mean**	**max**	**mean**	**max**	**mean**	**max**
MC	1.0	1.0	1.2	6.0	22.8	48.2	21.4	67.6
SC	1.0	1.0	1.3	7.0	21.2	70.3	17.4	64.5
MSC	1.1	3.0	1.8	16.0	10.8	37.3	16.4	104.7

Table 4. Mean and max values of multiplicity, Mn during different periods of the studied thunderstorms development: before the first severe hail fall on the ground; during a severe hail fall on the ground; after the last registration of severe hail on the ground

	MC				**MSC**				**SC**			
	mean		**max**		**mean**		**max**		**mean**		**max**	
	Neg	**Pos**	**Neg**	**Pos**	**Neg**	**Pos**	**Neg**	**Pos**	**Neg**	**Pos**	**Neg**	**Pos**
before	1.4	1.0	6.0	1.0	2.3	1.1	16	2.0	1.3	1.0	7.0	1.0
during	1.2	1.0	4.0	1.0	2.0	1.1	11	2.0	1.1	1.0	2.0	1.0
after	1.2	1.0	3.0	1.0	1.5	1.1	10	3.0	1.3	1.0	5.0	1.0

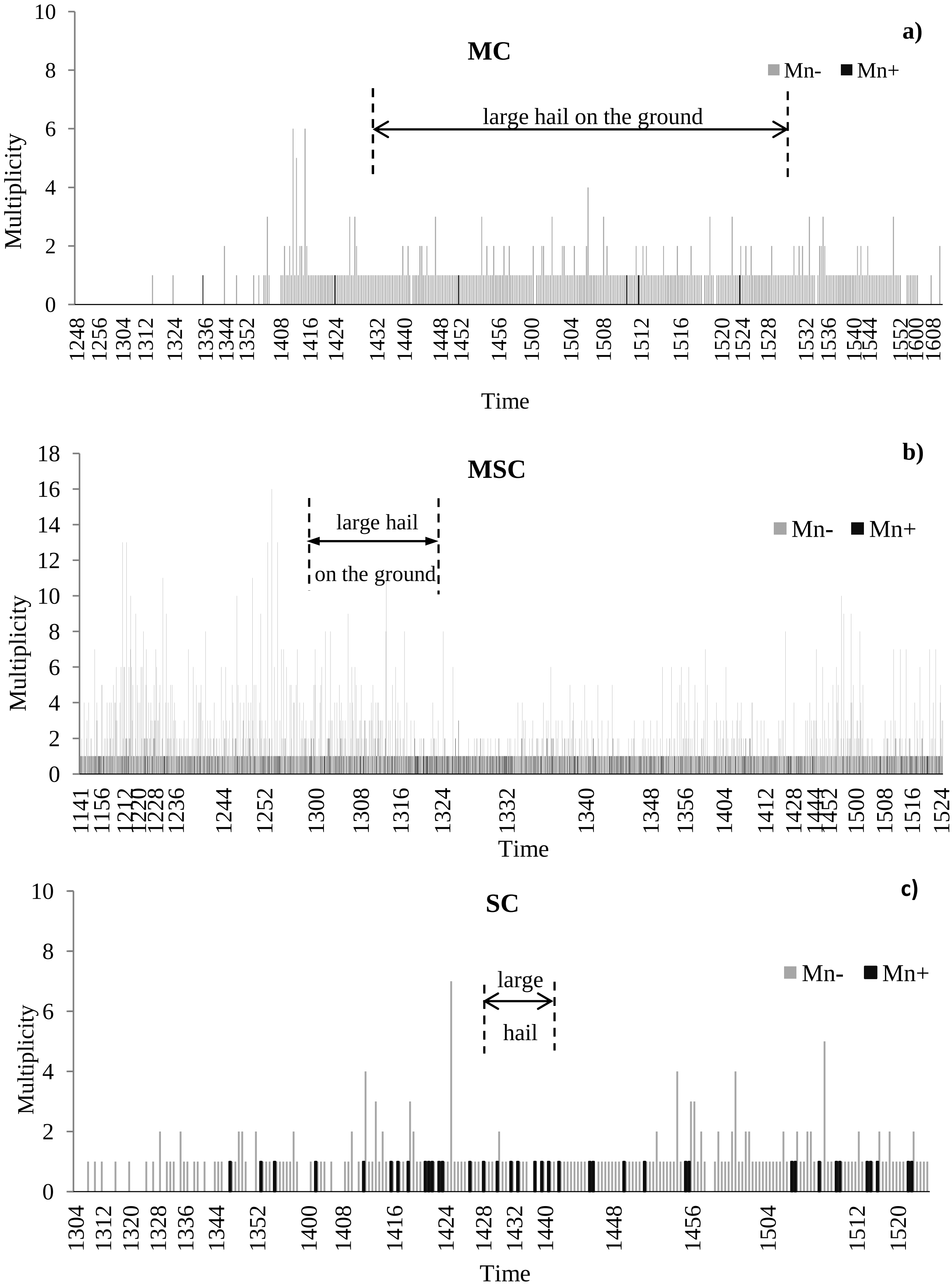

Fig. 9. Multiplicity of positive flashes, Mn+ and negative flashes, Mn−, as a function of time for a) multicell thunderstorm, MC; b) multicell that evolved into a supercell thunderstorm, MSC; c) supercell storm, SC.

The analysis of negative peak current shows that there are no significant differences in their mean absolute values for the three storms (*Table 3*). The mean values of positive peak current in MC and SC storms are 2 times higher than in MSC storm, and the highest value of 70.3 kA was registered in SC, while the highest absolute values of negative peak current was detected in MSC (105 kA). Additional analyses showed that in MC and SC storms all detected strokes had absolute values of peak current above 10 kA, and in MSC storms there was a great number of strokes (14% for negative and 46% for positive) with absolute values of peak currents less than 10 kA.

5. Discussion and conclusion

An analysis was carried out on total lightning behavior during the lifetime of different types of severe thunderstorms (a multicell, a supercell, and a multicell that evolved into a supercell) producing large hail over Bulgaria.

Significant number of positive strokes was detected in both supercell SC and MSC storms with the highest percentage during the period of large hail falls on the ground. In the supercell of the SC storm, the positive strokes even dominated over negative ones 8 minutes before the beginning of large hail fall. The detected significant number of positive strokes is in agreement with the results obtained by other authors (e.g., *Carey* and *Rutledge*, 1998; *Lang et al.*, 2004; *MacGorman* and *Burgess*, 1994; *Stolzenburg*, 1994; *Wiens et al.*, 2005). There are two "main" hypotheses for explaining the large number of positive CG lightning in some thunderstorms – the tilted-dipole charge structure or the formation of inverted dipole (*MacGorman* and *Nielsen*, 1991, *MacGorman* and *Burgess*, 1994). Since a high number of negative flashes together with the positive ones were detected in SC and MSC, one can assume that tilted dipole structure of supercell storm can explain the high number of positive CG flashed. The analyses reveal that the top of the updraft core in SC and MSC is displaced sufficiently far horizontally from the reflectivity core, which supports the assumption that the tilted dipole structure is responsible for the large positive flashes in SC and MSC.

The jump of lightning density is observed before large hail fall in the three thunderstorms, associated with a dramatic decrease in the beginning of the hail fall. There is a positive time lag between the jumps of both multiplicity and flash rate and start of large hail falls in the three studied thunderstorms. The established jump in the flash rate before the large hail fall corresponds to the results reported by *Kane* (1991), *Soula et al.* (2004), and *Williams et al.* (1999). Laboratory results in *Brooks et al.*, 1997 show that the magnitude of separated charge is higher at higher liquid water content and velocity of interacting particles. Based on that one can assume that the flash rate increases sharply at the increase of supercooled water and updraft velocity which also lead to the growth of large hail. Thus, an increase in the CG lightning rate may consider as an indication of the subsequent falling of damage hail on the grounds. One possible reason for the decrease of flash rate at the beginning of intensive hail fall is the diminution of charge density due to the fall out of charged particles from thunderstorm cloud.

The mean and maximum values of total flash rate, as well as of the multiplicity of negative strokes in MC and SC storms are remarkably lower than in MSC storm. In the frame of the present study, the reason for the dramatically higher values of flash rates in MSC storm in comparison to those for MC and SC storms is not clear. One can speculate that this results from the more intensive vertical development during the severe stage of MC and SC storms in comparison with MSC storm. *Lang et al.*, 2000, obtained similar results and suggested that a possible explanation could be the elevation charge hypothesis (*MacGorman et al.*, 1989), namely that strong updraft prevents the formation of dipole structure due to the elevation of interacting ice particles (ice crystals and graupel) at higher level. In the supercell storm, SC, the lightning "hole" in the flash density is observed. The hole is associated with a bounded weak-echo region (BWER) of the cell, respectively with a strong updraft in this region (*Lang et al.*, 2000, *MacGorman et al.*, 2005, 2008, *Wiens*, 2005). We supposed that two processes are responsible for the lack of lightning in this region – the elevation of the interacting ice particles by very strong updraft (*MacGorman et al.*, 2005, 2008) and reduction of the amount of charge separation by rebounding collisions of ice particles in regions where hail is in a regime of wet growth (*MacGorman* et al., 2012; *Murphy* and *Demetriades*, 2005).

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. One can speculate that the significant difference in some lightning characteristics of the three types of thunderstorms supports the conclusion by *Fehr et al*. (2005) that the convective organization plays a crucial role in lightning development. Due to the limited number of the studied cases, the results presented here have to be considered only as a first step to the study of lightning behavior from severe thunderstorms over Bulgaria. For firm conclusions, the analysis of lightning characteristics of more severe thunderstorms producing damaging hail has to be carried out in order to establish a broader statistical basis.

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