Relationship between lightning characteristics and radar estimated parameters during pre-severe and severe stages of hail producing thunderstorms developed over Bulgaria

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I. INTRODUCTION

The relationship between lightning and thunderstorm severity (large hail, heavy rain leading to flash flooding, strong wind, and tornado) has been subject to studies for more than 50 years

Several studies have shown that there is a relationship between lightning activity and radar characteristics of thunderstorms. Some studies search for correlation between radar reflectivity and lightning (e.g.. Changnon, 1992, Mosier et al., 2011, MacGorman, 2012, Seroka et al., 2012, Zipser and Lutz, 1994). Others are directed to establish if there is a relationship between vertically integrated liquid, VIL and flash rate (MacGorman et al., 2007; Metzer and Nuss, 2013; Watson et al., 1995). These studies are motivated by the general consensus that the so-called non-inductive mechanism plays the major role in the electrification of thunderstorms, culminating in lightning. According to this mechanism the magnitude of separated charge is higher at larger sizes of interacting ice particles (graupel and ice crystals) and at higher values of supercooled liquid water content.

There are limited number of studies related to lightning activity in thunderstorms developed over Bulgaria. The results reveal that there is a difference between lightning activity in severe and non–severe thunderstorms (Dimitrova et al, 2009) and in different type of thunderstorms - multicell and supercell (Dimitrova et al, 2011).

The aim of the present work is to analyze the lightning activity during pre-severe and severe stages in hail producing thunderstorms and to search for the relationship between flash rate and various thunderstorm characteristics estimated from the radar.

II. 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.

Data from three S band Doppler radars were used. Radar data are 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 is 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.

LINET is a VLF/LF lightning detection network developed at the University of Munich, which provides continuous data for both research and operational purposes. The LINET data set provides information on stroke time, geographical location, peak current (PC), and polarity. The discrimination between CG and IC lightning in LINET relies on TOA (times of arrival) analysis.

Various radar estimated parameters (e.g. radar cloud top, height of several radar reflectivity factors, volume integrated liquid, VIL, VIL density, VILD) and lightning characteristics (flash rate, FR, multiplicity, Mn, polarity and peak current, PC) are analyzed for 28 severe hail producing thunderstorms, developed over Bulgaria in the period 2010-2012 years.

The studies are performed separately for non-severe (pre-severe) and severe stages of hail producing thunderstorms. The transition from pre-severe to severe stage is determined by the detection of radar reflectivity 55 dBZ above 0°C isotherm and it is assumed that the collapse of the severe stage starts when the height of 55 dBZ decreases below 2 km AGL.

The flash rate is calculated per 4 minutes in accordance with the period of radar volume scan.

III. RESULTS

The analysis is directed to establish:

- If there is a significant difference between flash rate FR (positive and negative) during pre-severe and severe stage.
- If there is a differences between various radar estimated characteristics during pre-severe and severe stages.
- If there is a relationship between lightning activity and radar estimated characteristics?

The analyses shows that the mean values of flash rate FR (positive and negative) as well as the mean values of flash rate of positive (FR+) and negative (FR–) lightning are significantly higher during severe stage of thunderstorms than the corresponding mean values during pre-severe stage of thunderstorms development (Fig.1). However, there is no significant difference in mean values of peak current and multiplicity in the both studied periods.

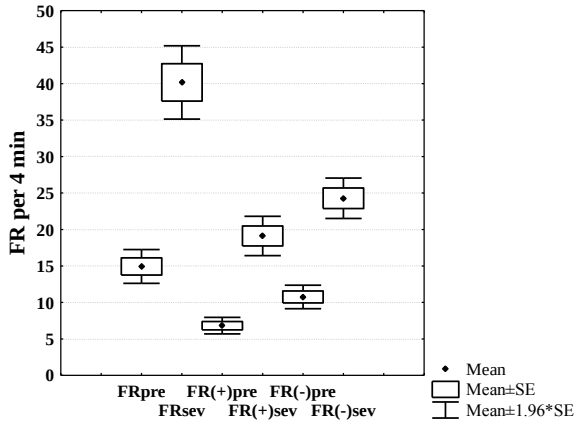

FIG. 1: Box and whiskers plots of total, FR, positive, FR(+) and negative, FR(–) flash rate during the pre-severe (pre) and severe (sev) stages

The statistical analysis (F- and t-test) indicates that the mean values of most of the radar estimated characteristics are significantly higher during the severe stage than during the pre-severe stage. The significant difference is visible in Fig. 2 and Fig.3.

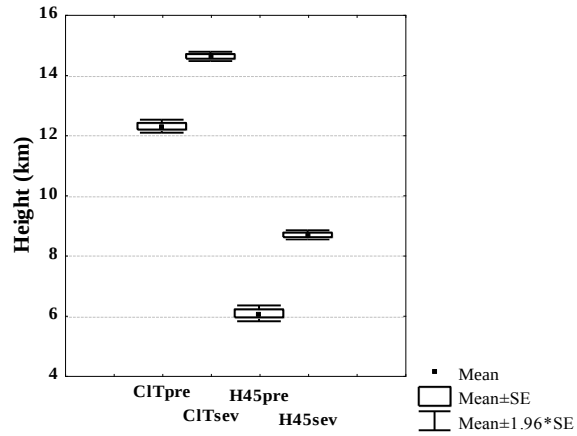

FIG. 2: Box and whiskers plots of cloud top height, ClT and height of 45 dBZ, H45 during the pre-severe (pre) and severe (sev) stage.

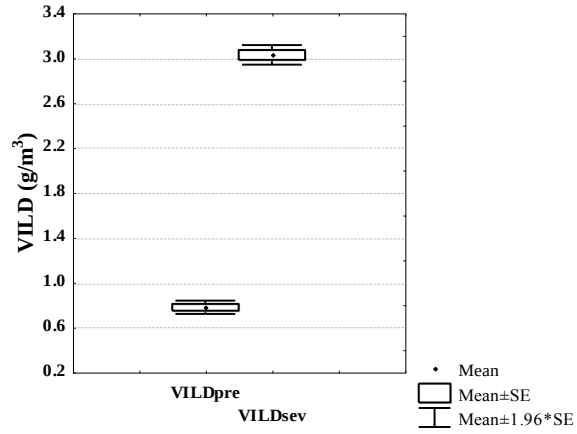

FIG. 3: Box and whiskers plots of VIL density, VILD during the pre-severe (pre) and severe (sev) stage.

Analysis shows that there is no direct correlation between heights of radar reflectivity factors and FR, however there is a correlation (see Table I) between the heights of several radar reflectivity values and FR (averaged in 1 km bin of corresponding heights). The results show that the correlation coefficient between cloud top height (H5dBZ) and FR (averaged in 1 km bin) is more than 0.95 during severe and pre-severe stage. The results presented in Fig. 4 and Fig. 5 reveals that the slope of lines is steeper in the sample of severe stage, than in the sample of pre-severe stage i.e. the increase of flash rate with the increase of cloud top height and H45 is more pronounced during severe stage than before that.

Radar characteristics	Correlation coefficient, R	
	Pre-severe stage	Severe stage
Cloud top (km)	0.95	0.96
H30dBZ (km)	0.94	0.91
H45dBZ (km)	0.80	0.83
VIL (kg/m^2)	0.72	0.68

TABLE I: Correlation coefficient between radar characteristics (cloud top, heights of 30 and 45 dBZ, VIL) and FR averaged in 1 km bin of corresponding heights and 5 kg/m^3 VIL bin during pre-severe and severe stage

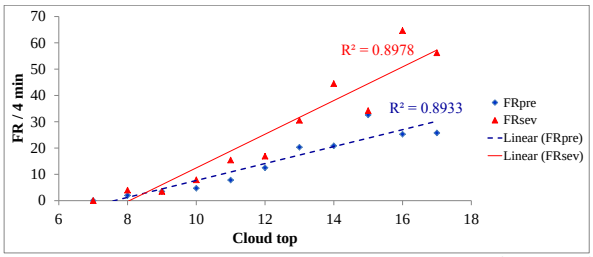

FIG. 4: Flash rate, FR/4 min (averaged in 1 km bin), as a function of cloud top height (km) during pre-severe and severe stages, R^2 – coefficient of determination

Based on the assumption that the radar volume fraction for graupel correlates with the volume of reflectivity 45 dBZ, one can speculate that the high correlation between height of 45 dBZ, H45 and FR averaged in 1 km bin is consistent with the non-inductive charging mechanism (Saunders, 1993), which relies on rebounding collisions between graupel and ice crystals.

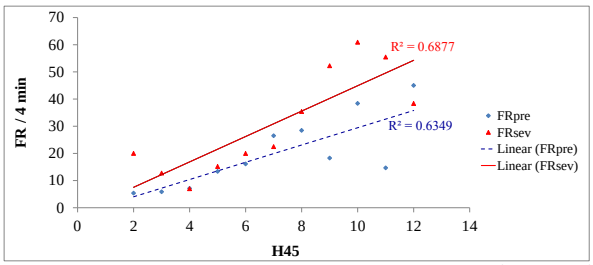

FIG. 5: Flash rate, FR/4 min (averaged in 1 km bin), as a function of height of 45 dBZ, H45 (km) during pre-severe and severe stages, R^2 – coefficient of determination

Additional analysis shows that there is an increase of FR– and FR+, with the increase of maximum radar reflectivity, Zmax up to 55 dBZ and 60 dBZ, correspondingly (Fig. 6). The established decrease of FR at the subsequent increase of Zmax is in accordance with Emersic et al. (2011), who reported that flash rates stopped their rapid increase when reflectivity exceeded 60 dBZ – a signature of wet hail growth regime. (Zrnić, 1987).

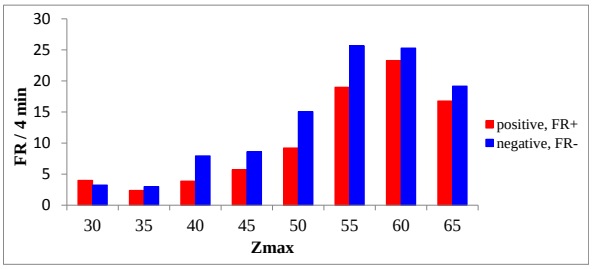

FIG. 6 Positive (FR+) and negative (FR–) flash rate (averaged in 5 dBZ bin of Zmax) as a function of maximum radar reflectivity, Zmax (dBZ)

More detailed analysis of FR averaged in 1 km bin of H55 reveals a sharp increase of FR when H55 surpasses 7 km (T<–20°C). However our results show (Fig. 7) that FR decreases when the depth of region with 55 dBZ above –20°C isotherm increases. One possible explanation is the decrease of separated charge in the regions with T<-20°C due to the wet growth of hail.

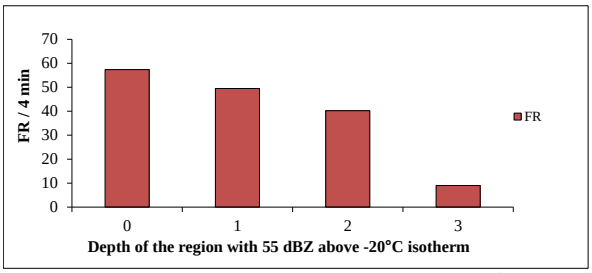

FIG. 7 Flash rate FR/4 min (averaged in 1 km bin), as a function of depth of the region with 55 dBZ above –20°C isotherm (km)

The highest values of FR averaged in 1 g/m^3 bin of VILD are reached when VIL density is between 3 and 4 g/m^3. The further increase of VILD above 5 g/m^3 leads to FR decrease (Fig. 8). The VILD values greater than 3 g/m^3 are determined as threshold of severe hail (Amburn and Wolf, 1997; Stumpf et al., 2004). Our analysis demonstrates that the maximum values of FR (averaged in 1 g/m^3 bin of VILD) in the studied thunderstorms are at the beginning of severe stage of their developments, which is an indication that the determined thresholds of VILD > 3 g/m^3 is also appropriate indicator for the transition into severe stage of thunderstorms developed over Bulgaria. One possible reason for the decrease of FR at higher values of VILD can be the decrease of separated charge at the wet growth regime of hail.

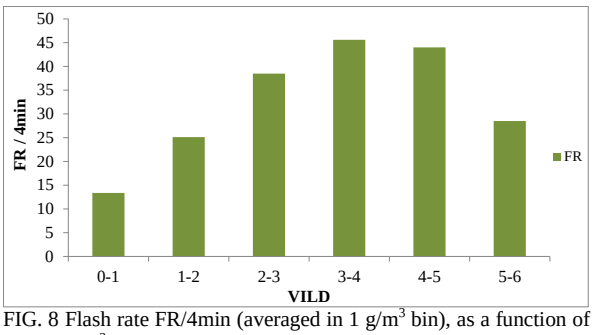

FIG. 8 Flash rate FR/4min (averaged in 1 g/m^3 bin), as a function of VILD (g/m^3)

IV. CONCLUSIONS

An analysis of relationship between lightning characteristics and radar estimated parameters during the pre-severe and severe stages of hail producing thunderstorms developed over Bulgaria was carried out. The main results are:

1. The mean value of flash rate is significantly higher during the severe stage than during the pre-severe stage.
2. There is no significant difference in peak current and multiplicity of lightning during the pre-severe and severe stages.
3. Most of the mean values of radar estimated characteristics are significantly higher during the severe stage than during the pre-severe stage.
4. There is no direct correlation between FR and radar estimated characteristics. However there is a significant correlation between several radar characteristics and FR, averaged in corresponding bins.
5. The results indicate that the established for other geographical regions threshold of VIL density (VILD > 3 g/m^3) for transition into severe stage is appropriate value for Bulgaria.

V. ACKNOWLEDGMENTS

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