Lightning and radar reflectivity signatures in tornadic supercell thunderstorms in Finland

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1. Introduction

The use of real time lightning information as a precursor to severe weather (i.e. large hail, dowbursts, tornadoes) has been a subject of several previous studies, especially in the United States. The main reason for these studies has been to find out if the severe weather events could be nowcast more reliably with the real time lightning information. Usually, the results have been positive, i.e. the more intense is the storm, the more lightning it produces, and the more likely it is to produce severe weather. This is linked to the intensification of the updraft which favors both the electrification of the cloud and the probability of severe weather (e.g. Williams 2001).

The occurrence of a high peak in the flash rate prior to the severe weather event has been observed to be a prominent feature. For example in Florida, Williams et al. (1999) observed abrupt jumps in the total flash rate (i.e. cloud plus ground lightning) 5-20 minutes prior to the severe weather at ground. In a study by Kane (1991) in the USA, in three severe-weather thunderstorms the peak in the 5-minute ground flash rate preceded tornado or large hail by 10-15 minutes. However, at least regarding tornadic storms, there also seem to be cases in the USA which do not follow this pattern. E.g. MacGorman et al. (1989) found no systematic pattern in the ground flash rate in two tornadic thunderstorms, although they reported that the flash rate was highest after the storm had stopped producing tornadoes.

Besides flash rate alone, the prevalence of positive ground flashes has been observed to correlate with severe weather (MacGorman and Nielsen 1991, MacGorman and Burgess 1994, Carey and Rutledge 1998). The most common suggested explanations for this behaviour have been the horizontal tilting of the charge structure due to strong wind shear, the accumulation of a strong positive charge region at the lower levels of the cloud, or the “precipitation unshielding” (i.e. the negative charge is effectively removed from the cloud by heavy precipitation leaving a surplus of positive charge in the cloud). At least the tilting seems to be a logical explanation as it has been widely observed that severe storms favor high-shear environments. Indeed, Reap and MacGorman (1989) and Curran and Rust (1992) suggest that strong shear may be necessary but not sufficient for enhanced positive lightning.

A comprehensive study, containing a data set of a total of 42 tornado-producing (F4, F5) supercells, regarding the ground lightning characteristics in tornadic storms, was made by Perez et al. (1997). The main findings of their study were the occurrence of two different flash rate trends in conjuction with the tornadogenesis: a peak in the flash rate 10-15 minutes prior to the tornado formation, and a relative decrease in the flash rate during the tornado touchdown. They also observed a sudden polarity change of flashes from positive to negative in 14 % of the cases and they stated that intense positive lightning was related especially to the most intense storms (F5) with long damage paths. However, Perez et al. (1997) conclude that because of the large variety of the observed flash rate patterns, lightning information solely may not be enough to indicate storms that will produce a tornado, although lightning data can be very helpful as an additional tool in conjunction with e.g. weather radar data.

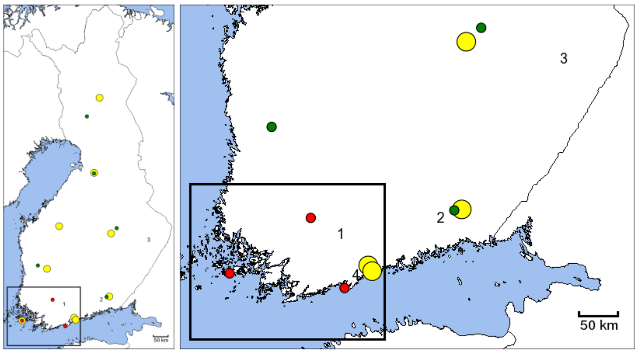

Fig. 1 FMI LLS sensors and weather radars. Red and green dots are the VHF and LF lightning sensors, respectively, Yellow dots are radars (5.3 cm wavelength, 1.0 degree beamwidth). The large rectangle represents the efficient detection area for total lightning. The midpoint locations of the storm tracks of the studied cases are numbered. The sounding station at Jokioinen is located at the same place as the northernmost VHF-sensor.

In this study, the developments of four tornadic supercells in Finland have been studied to understand the relationship between lightning, radar reflectivity and the occurrence of tornadoes. Finnish Meteorological Institute’s (FMI) Doppler radar data were used to produce time-height plots which were combined with the observed vertical temperature sounding profiles and compared to the observed ground and in two cases also to cloud lightning data. The polarity (i.e. negative or positive) of ground flashes is also investigated to determine the role of positive flashes in tornadic storms in Finland. The purpose of this study is to find out if there are common characteristics in lightning preceding the occurrence of tornadoes. This data set provides useful nowcasting information about tornadic supercells in Finland and how the lightning activity corresponds to the tornado touchdown and lifecycle. Our results will also be compared to those obtained in similar studies e.g. in the USA.

2. Data

The radar data used in the time-height plots are from the FMI’s Doppler radars (Fig. 1). For each case, the data from the closest radar was used to obtain the time-height distribution of radar reflectivity (Fig. 2-5). For all radars, complete volume scans were available at 15-minute intervals

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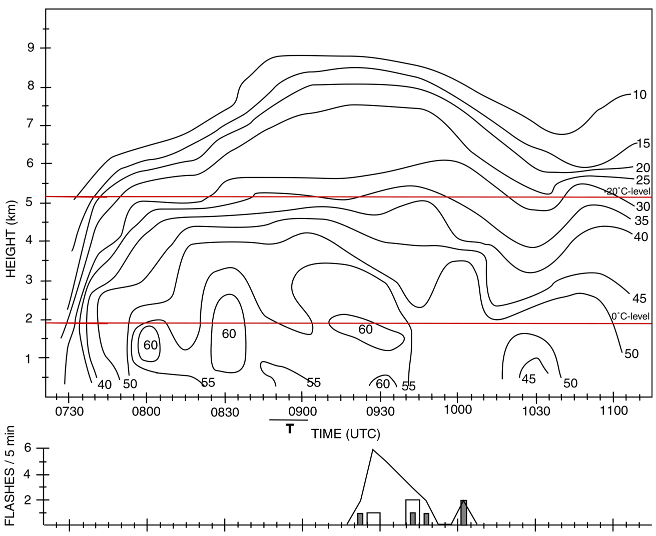

Fig. 2 Time-height representation of data for the storm on 26 June 2002, with contours of reflectivity dBZ. Tornado time is denoted by T. In the histogram below, ground flash rate is indicated as white (negative flashes) and gray (positive) bars, solid line is the cloud flash rate. Red lines represent the 0˚C and -20˚C temperature levels.

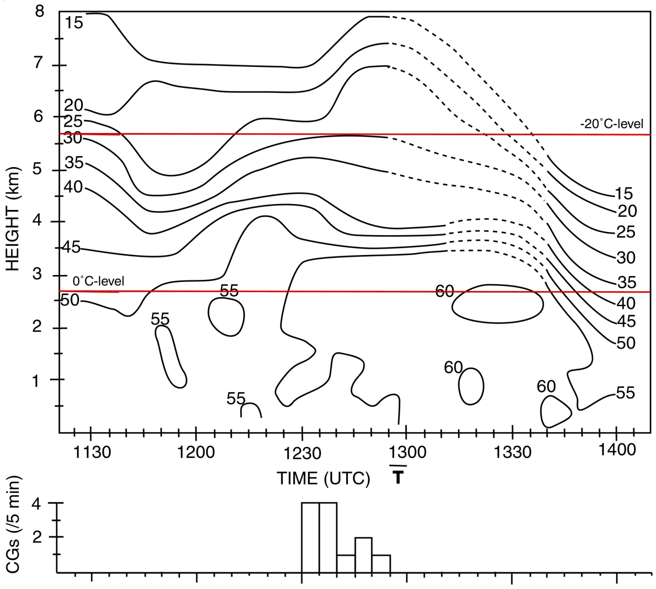

Fig. 3 Same as Fig. 2 but for the storm on 18 August 2004. Dashed lines are the assumed isolines when the storm was close to the radar.

and additional scans at the lowest four elevation angles were available at 5-minute intervals. The evolution of each tornadic storm was studied in detail to identify storm types, splits and mergers (not shown). For vertical temperature profile, the observed rawinsonde soundings from Jokioinen were used.

Ground lightning information is obtained from the Nordic Lightning Information System (NORDLIS) which is composed of about 30 IMPACT-type sensors (e.g. Cummins et al. 1998) located in Finland, Sweden, and Norway (Fig 1; only FMI's sensors and radars are shown). One similar sensor in Estonia is also connected to the FMI's central processor. For cloud lightning detection FMI has three SAFIR-type sensors (e.g. Richard et al. 1986) but due to the small number of sensors (and the frequency band) the detection area of cloud flashes is rather small. Because of this reason total lightning data were available only for two cases; ground flash data were available for all of the cases.

In all four events, the tornado damage tracks and intensities were confirmed by damage surveys, and the exact time of tornadoes by the emergency call information (received by Emergency Response Centres) and by passage of a hook echo over the damage path.

Most weight is on the radar signatures for which an exhaustive task was made when collecting the height of the maximum radar reflectivity for every 5/15 minute period from the tornadic cells during their life cycle, but also the temperature profile and the 5-minute lightning flash rate have been included into the time-height plots.

3. Case studies

3.1 Case 1

In the first case (Fig. 2), the F1-tornado formed on 26 June 2002 within a mini-supercell thunderstorm. The storm had radar-identified supercell features only just before and during the F1-tornado. The tornado formed at the end of the storm's updraft growth stage, after the storm had reached its maximum height. During the updraft growth stage the 30 dBZ reflectivity reached the -20˚C level already 20 minutes before the tornado, but no lightning was observed.

The lightning activity started 10 minutes after the tornado and was existent during the time 35 dBZ reflectivity reached above -20˚C level. The peak 5-minute cloud flash rate (1.2 min^{-1}) preceded the peak ground flash rate (0.6 min^{-1}) about 15 minutes and they were observed 15 and 30 min after the tornado, respectively. Five out of eight detected ground flashes were positive and they occurred mainly during the descending of the high reflectivity core.

3.2 Case 2

On 18 August 2004 a F1-tornado (Fig. 3) occurred in south-eastern Finland (Teittinen et al. 2006). This mini-supercell thunderstorm produced a total of 12 negative ground flashes which occurred during 25 minutes before the tornado. The peak 5-minute ground flash rate (0.8 min^{-1}) coincided with the updraft growth stage, just before the storm reached its maximum height. At the same time the 55 dBZ reflectivity core was near 0˚C level, but not reaching the ground. No flashes were detected during the F1-tornado or after it when the high reflectivity core reached the ground. Cloud flash data were not available.

3.3 Case 3

The third case (Fig. 4) was a classic supercell storm on 20 August 2004 which produced two successive tornadoes and 245 ground flashes (219 negative and 26 positive). This case was the most vigorous in lightning of the four studied. The lightning was continuous only during the time the 40 dBZ reflectivity reached above -20˚C level. The parent storm split twice into right and left moving supercells before the second right mover, a classic supercell thunderstorm, formed and produced intense but almost constant negative ground flash rate as the storm 55 dBZ reflectivity core grew in height and reached -20˚C level.

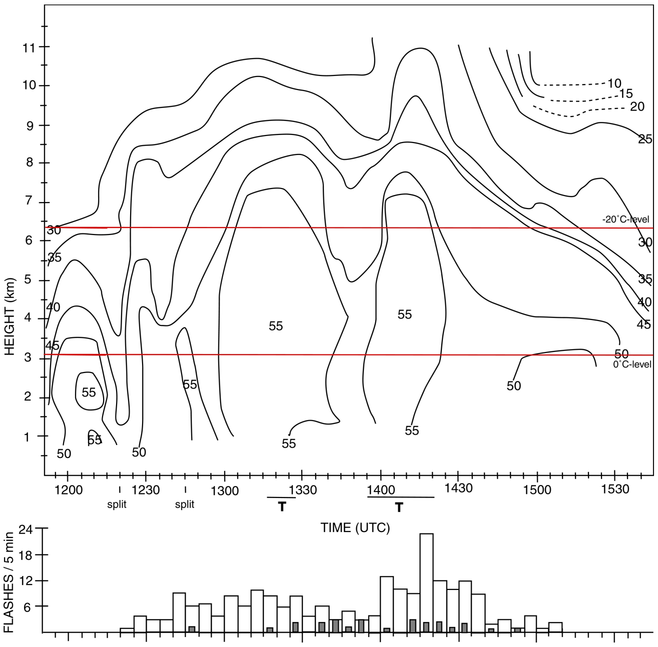

Fig. 4 Same as Fig. 2, but for the storm on 20 August 2004.

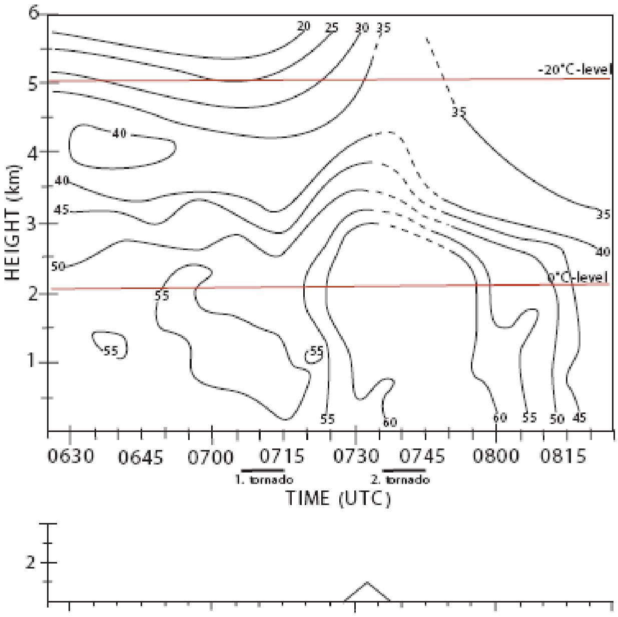

Fig. 5 Same as Fig. 2, but for the storm on 28 August 2005.

The first F1-tornado formed at the end of the intensification of the reflectivity core. As another faster moving storm merged with the tornadic storm, the second, F2-tornado, formed and simultaneously the reflectivity core reached its maximum. At the same time the 5-minute negative ground flash rate intensified, peaking (5.0 min^{-1}) during the end of the second tornado as the reflectivity core collapsed. Positive flash rate was low during the whole life cycle of the cell (peak 0.6 min^{-1}) and they were mainly observed just in the end of the intensification of the reflectivity core and after its collapse. No clear intensification of the flash rate prior to the tornadogenesis was observed. Cloud flash data were not available.

3.4 Case 4

In the fourth case (Fig. 5) on 28 August 2005 (Outinen and Teittinen 2008), a mini-supercell produced two F1 tornadoes, but only one cloud flash. Before the first tornado, there was no lightning, even though 40 dBZ reflectivities extended up to -10 ˚C height. Just before the second tornado, the storm intensified and 60 dBZ extended up to 3 km (-7˚C) height. During the same time, as the echo core reached its maximum height, the only flash occurred just before the second tornado. Intense lightning and higher radar reflectivities were observed within other storms behind this tornadic mini-supercell.

4. Discussion

The lightning characteristics of four tornadic supercell thunderstorms in Finland were studied. The motivation of this study was to find out whether there are similarities between the four cases in the occurrence of lightning before the tornadogenesis: the possible common lightning signatures would be helpful in the tornado nowcasting. Furthermore, our results provide information about the structure of these tornadic storms as indicated by time-height plots of radar reflectivity.

The primary finding was that all of the studied storms had very different lightning characteristics: only one contained intense lightning while the other were moderate or produced lightning barely at all, and only in one case positive flashes outnumbered negative ones (yet flash rate being quite small). No similarities were found in the behaviour of lightning preceding the occurrence of a tornado which could be used when assessing tornado warnings. These findings suggest that tornadoes in Finland cannot be predicted with enough certainty solely with lightning information. However, there was similarity in all three cases that had ground lightning: ground flash occurrence correlated with the 30-35 dBZ reflectivity core reaching certain (about -20°C) temperature level.

The occurrence of positive ground flashes was also investigated as their preponderance or abrupt reversals in the flash polarity (from positive to negative or negative to positive) have been observed to have correlations with severe weather in several studies (see section 1). In this study, positive flashes occurred only in two cases and they seemed to occur mainly at the end of the intensification of a high reflectivity core and during and after its collapse. No clear patterns were observed in the flash rate between the cases: in one case the majority of ground flashes were positive but their number (5) during the storm was so small that it is difficult to estimate their possible connection to the tornado.

Cloud lightning information was available for two cases (due to the limited coverage area of cloud lightning detection): in one case the only located flash in the tornadic cell was a cloud flash, and in the other case cloud lightning was the dominant flash type (cloud flash rate peaking about ten minutes before the peak in the ground flash rate) but the peak 5-minute total flash rate still being only moderate (1.4 min^{-1}).

Although our results do not encourage the use of lightning data as a basis for tornado warnings in Finland, slight indication, however, of a peak in the five minute flash rate prior, coincident or after the tornado touchdown is visible which could indicate a connection between tornadogenesis and lightning. Of course, the data set should be larger to provide more comprehensive results. Similar studies made e.g. in the U.S. have given better results, but also there the large diversity of results suggest that from the severe weather events, tornadoes might not have the best correlation with lightning. We should also note that the studies made e.g. in the USA have been focused usually on more intense tornados (F4, F5) while our study consisted of weaker ones (F1, F2). Furthermore, it would be interesting to make a similar study using data from a dual polarization radar; this could give more detailed information about what kind of processes occur in the tornadic cell which favor both the tornadogenesis and electrification.

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