10.5 LIGHTNING CHARACTERISTICS OF TWO STORMS OBSERVED DURING STEPS

Andrew G. Detwiler*, John H. Helsdon, Donna V. Kliche, Qixu Mo, and Tom A. Warner
South Dakota School of Mines & Technology, Rapid City, South Dakota

1. Introduction

Storms observed in the west central U.S. High Plains during the Severe Thunderstorm Electrification/Precipitation Study (STEPS) in 2000 produced cloud-to-ground lightning with various predominant polarities, some positive and some negative. Here, we compare the microphysical and lightning characteristics of two STEPS storms. One was a hail-bearing asymmetric MCS, the southern portions of which produced predominantly negative, and northern portions predominantly positive, cloud-to-ground lightning during its mature phase. The other was a much more vigorous tornadic single-cell storm that produced intracloud lightning for almost an hour before producing a tornado, hail, and predominantly positive cloud-to-ground lightning thereafter. Both produced hail with peak sizes between 2 and 3 cm. The microphysical and charge structures differ between the two storms in complex ways that are discussed below.

Data from four key STEPS observing systems form the basis for this study. Observations of lightning ground strike locations and polarity are available from the National Lightning Detection Network (NLDN), operated by Global Atmospherics, Inc. (http://www.lightningstorm.com/ls2/guide/index.jsp). Locations of the breakdown processes associated with the leader phase of lightning events, both intracloud and cloud-to-ground, are available from the Lightning Mapping Array (LMA) deployed by the New Mexico Institute of Mining and Technology. This system is described by Rison *et al.* (1999) and at http://ibis.nmt.edu/nmt_lms/ . This system basically maps lightning leader channels as they are forming. A third key system in STEPS was a triangle of 10 cm Doppler radars, including the polarimetric CSU-CHILL (http://chill.colostate.edu/CSU-CHILL.html) and NCAR Spol (http://www.atd.ucar.edu/rsf/STEPS/) radars, and the WSR-88D radar associated with the Goodland office of the National Weather Service (http://www.crh.noaa.gov/gld/) . This radar network mapped the distribution of winds and hydrometeors within storms traveling across the STEPS domain. The final key system involved in our discussion is the armored T-28 operated by the South Dakota School of Mines and Technology (http://www.ias.sdsmt.edu/institute/t28/index.htm) . In situ observations of hydrometeors, electric fields, and standard meteorological parameters are available from storm penetrations typically around the –10 C (6 km MSL) level. More information on these and other observing systems deployed for STEPS can be found at http://www.mmm.ucar.edu/community/steps.html .

* *Corresponding author address:* Andrew Detwiler, Institute of Atmospheric Sciences, South Dakota School of Mines & Technology, Rapid City, SD 57701-3995; email: Andrew.Detwiler@sdsmt.edu

2. Thunderstorm Electrification

MacGorman and Rust (1998) and Williams (2002) recently reviewed the electrification of thunderstorms, including severe ones. There are many processes by which charge is exchanged between particles and redistributed within thunderstorms. Most important among those processes that appear to determine the pattern of initial electrification of storms is non-inductive charge separation resulting from collisions between riming graupel and smaller cloud ice particles. When smaller ice particles collide momentarily with larger graupel particles that are riming, one sign of charge is preferentially left on the larger graupel and the other on the smaller rebounding ice particle. Gravitational sorting leads then to the vertical separation of charge within the storm. This separation can occur in the absence of any ambient electric field, and is therefore called “noninductive”.

As a result of laboratory experiments (reviewed in detail in the above references) it is known that the sense of charge separation by this collision process depends on ambient temperature, cloud liquid water concentration, cloud droplet sizes, and several other factors. An example of results synthesized from one set of experiments is shown in Figure 1. The tendency for the most extensive charge regions within mature thunderstorms to be arranged in a qualitative positive over negative dipole is often attributed to the fact that graupel in most storms tends to be growing in environmental conditions represented by the negative (shaded) region in Figure 1. The fact that the lowest main charge region in most thunderstorms appears to be a region of negative charge is thought to be consistent with the observation that most thunderstorm cloud-to-ground lightning lowers negative charge to ground.

A small fraction of thunderstorms produce predominantly positive cloud-to-ground lightning (lightning lowering positive charge to ground). It has been noted that if a large thunderstorm is producing mostly positive cloud-to-ground lightning, it is very likely to be producing large hail (e.g. Carey and Rutledge, 1998). The STEPS was motivated by a desire to understand the origin of this relationship. Several hypotheses have been advanced to explain this relationship. These include (a) development of an inverted (negative-over-positive) main electrical dipole in the storm, possibly resulting from graupel and hail growth in a region conducive to acquiring positive charge; (b) tilting of the updraft/precipitation region so that a normal positive-over-negative dipole has its upper positive region exposed directly to the ground; and (c) the precipitation of the initially-formed main negative region in a “normal” positive-over-negative dipole, leaving the upper positive region as the remaining dominant charge region in the storm and also the closest to the ground.

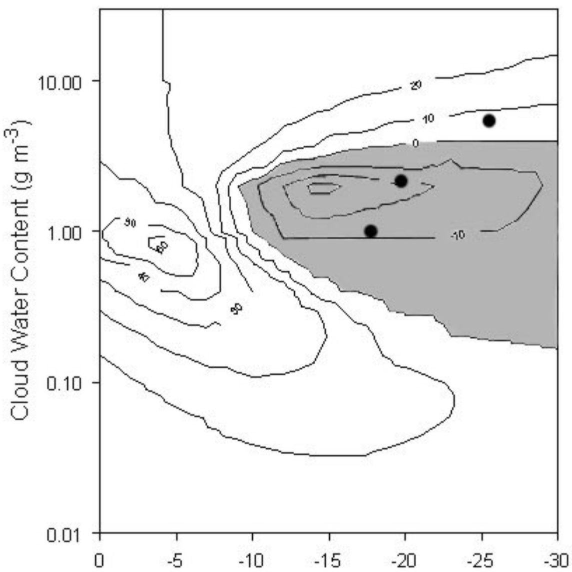


Figure 1a) Summary of rimer charging characteristics observed by Takahashi (1978) during laboratory experiments, as a function of temperature and cloud liquid water concentration. Contours are in units of fC acquired per collision. Shaded are represents negative rimer charging. Dots represent estimated conditions in precipitation growth zones in three STEPS storms discussed below. Adapted from Helsdon *et al.* 2001.

We show here observations from two storms on two different days, a single cell storm which produced mostly positive lightning along with large hail and an F1 tornado, and an asymmetric mesoscale convective system (MCS) which produced mostly negative lightning from some cells and mostly positive lightning from others. The positive lightning appears to results from different processes in the two storms. Brief comparison is made to a third very small thunderstorm occurring on a third day that made only negative lightning.

3. Single-cell severe storm

On 29 June a large thunderstorm developed just northwest of the Spol radar and tracked eastward and southeastward through the core of the STEPS observing region. For most of an hour it made almost exclusively intracloud lightning, with the first lightning coming to ground at about the time the tornado spun up. The armored T-28 encountered updraft speeds of 35 m s^{-1} at 6 km MSL while an electrical sounding balloon launched into the updraft demonstrated that the updraft reached 50 m s^{-1} at 8 km MSL. Hail up to 2 cm and an F1 tornado were observed from the ground. The evolution of this storm is discussed in more detail at http://radarmet.atmos.colostate.edu/~saraht/29June_paper.html .

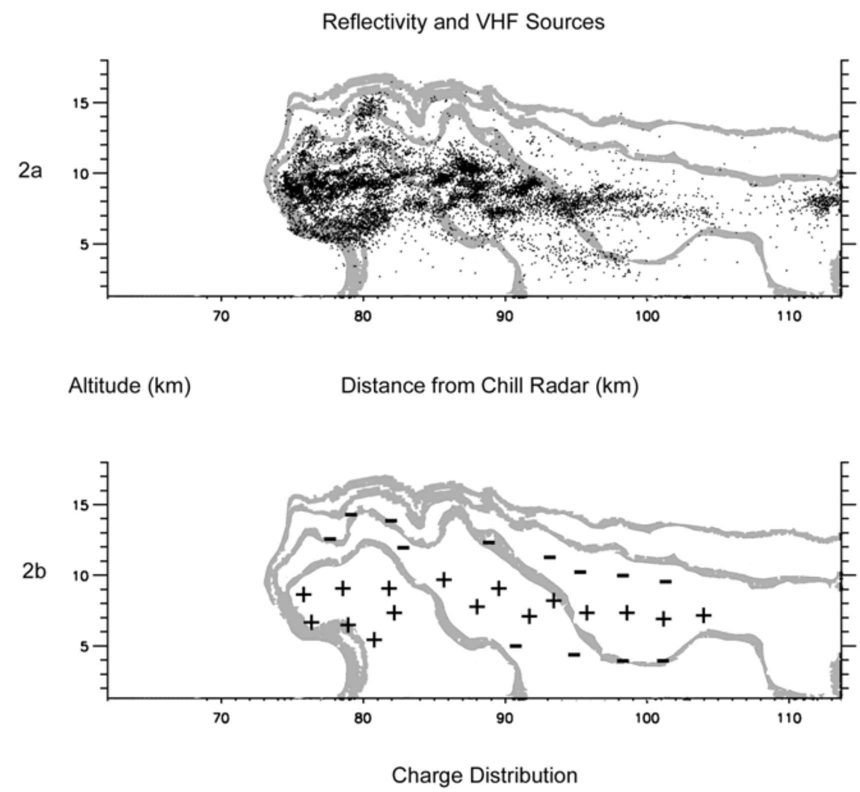
A radar reflectivity RHI of the storm in its mature stage is shown in Figure 2a, with VHF source locations detected by the LMA during a short time interval superimposed. The leader propagation process producing these sources shows characteristic differences in source density between the situations of negative leader propagating into positive charge, and positive leader propagating into negative charge. Replay of the data in slow motion allows one to distinguish these differences by watching individual leaders propagate upward or downward, and thus infer locations of positive and negative charge regions in the storm. (See Rison *et al.*, 1999) Our analysis by this method leads us to depict the charge structure of the storm at this time as shown in Figure 2b. The storm appears to be electrically inverted, with a main positive charge region starting at 8 km MSL just downshear of the updraft, and descending with further distance downshear (eastward). There is a region of negative charge above this positive charge. The cloud-to-ground lightning is almost 100% positive and coming to ground to the rear (east) of the main precipitation shaft.

4. Asymmetric MCS

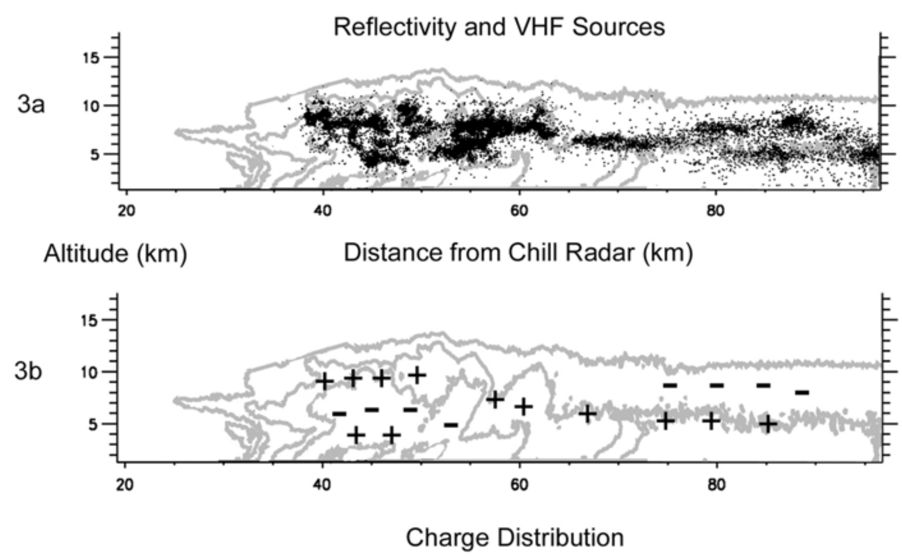
On 11 June an asymmetric MCS developed on the western edge of the STEPS observing region and propagated eastward across it, intensifying as it went. Initially most cells were producing predominantly negative lightning, but around 2200 UT the northern end of the complex began to produce mostly positive lightning. Observations of hail approaching 2.5 cm were obtained from the armored T-28 and from the ground. A reflectivity RHI through this northern region is shown in Figure 3a, with LMA VHF source locations for a short time interval superimposed. The charge structure deduced from study of the time sequence of VHF sources is depicted in Figure 3b. The main convective region of the storm appears to be electrically "normal", with a positive-over-negative dipole. The inference of a "normal" dipole in the convective region is supported by electric field observations from the armored T-28 as it transited this region. The negative region ends at the transition between convective and stratiform regions, and the upper positive charge region descends to the rear (west) throughthe trailing stratiform region. At this time, the positive cloud-to-ground lightning is coming to ground predominantly under the trailing stratiform region.

5. Charge Distribution and Lightning Polarity

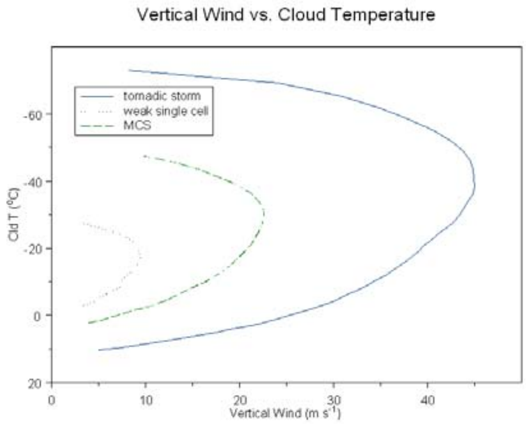
Our analysis of radar, NLDN, and LMA data suggests that these two storms produced mostly positive lightning for different reasons. The tornadic single-cell storm had an elevated and "inverted" electrical structure near its updraft. It produced exclusively intracloud lightning until the main positive region descended closer to the ground and apparently reached a configuration conducive to (positive) cloud-to-ground lightning. The individual convective cells in the MCS, on the other hand, had a "normal" electrical structure. In its mature phase positive lightning came to ground mainly from the transition and trailing stratiform regions where the "upper" positive layer had descended and became exposed directly to the ground because the negative charge below precipitated out within the convective region.

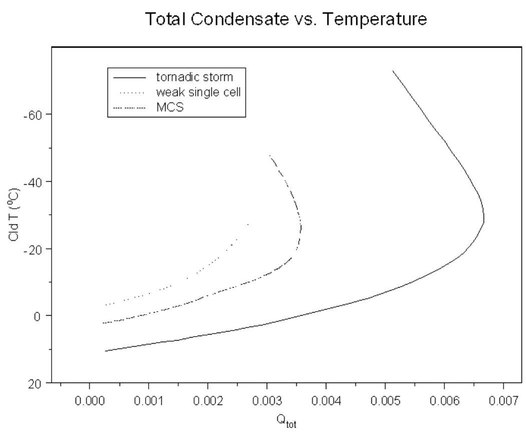


2 a) 29 June 2000 RHI from CHILL radar showing reflectivity contours overlaid by LMA indicated VHF sources. b) Reflectivity contours and charge distribution implied from LMA source locations. Higher density source areas imply negative breakdown propagating through positive charge regions. Lower density source areas imply positive breakdown propagating through negative charge regions. (Rison *et al*. 1999)



3. a) 11 June 2000 RHI from CHILL radar showing reflectivity contours overlaid by LMA indicated VHF sources. b) Reflectivity contours and charge distribution implied from LMA source locations. Higher density source areas imply negative breakdown propagating through positive charge regions. Lower density source areas imply positive breakdown propagating through negative charge regions. (Rison *et al.* 1999)





4. a) Updraft profile predicted by one-dimensional steady-state model from representative inflow soundings for the three storms. b) Condensate profile predicted from the same soundings.

Representative soundings for these two storms were processed using a steady-state one-dimensional cloud model derived from Weinstein (1970). This model is used to infer updraft and cloud condensate profiles in representative updrafts in the two storms, and to estimate at what levels precipitation (graupel) development might have begun. These profiles are shown in Figure 4. Model updraft speed and condensate mixing ratio at the –10 ^{o}C level match closely *in situ* T-28 observations at the same level. The zones in which precipitation initially begins to accumulate, based on model and radar observations, are just below the updraft peaks. These conditions also are represented as dots on Figure 1 for the three different storms. The temperature and liquid water concentrations in these precipitation development zones are consistent with positively charged graupel near the –25 ^{o}C level in the tornadic storm situation, and negative graupel near the –20 ^{o}C level in individual cells within the MCS. Despite the similar temperatures, the cloud liquid condensate mixing ratio in the growth region is almost twice as high in the tornadic storm as in the MCS, accounting for the different inferred charge on the riming graupel and hail in this region. For comparison, corresponding profiles for a weak cell observed on another day in STEPS also are shown in Figure 4. This weak storm produced only negative lightning, and is represented by the lowest point in Figure 1.

6. Conclusions

The dominant polarity of lightning in thunderstorms is determined by complex interactions between storm circulations and microphysical processes. We show two storms with differing electrical structures that both were producing predominantly positive cloud-to-ground lightning. The inferred structures are consistent with observed and inferred microphysics and laboratory observations of non-inductive charge separation resulting from collisions between cloud ice and riming graupel particles. Further explorations of storm electrification processes are underway utilizing a three-dimensional storm electrification model evolved from the two-dimensional model of Helsdon *et al.* (2001).

7. Acknowledgements

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8. References

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