Charging and Lightning in Simulations of the 29 June 2000 STEPS Supercell

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Abstract: Numerical simulations of the storms from STEPS (Severe Thunderstorm Electrification and Precipitation Study) can assist the improved understanding of relationships between kinematics, microphysics and electrification. The OU-NSSL three-dimensional dynamic cloud model was used to simulate the first three hours of the life cycle of the 29 June 2000 tornadic supercell from STEPS. This study examines the sensitivity of simulated charge structure and lightning due to changes in the charge separation parameterizations. Comparisons of the simulated electrical structure and lightning characteristics are made with electrical observations from 29 June using balloon-borne electric field soundings and the Lightning Mapping Array (LMA).

Introduction

The model being used for this study is a three-dimensional, non-hydrostatic, fully compressible model with a discreet branched lightning parameterization and explicit treatment of ions as described in Mansell et. al., 2003 (this volume). Three different parameterizations for noninductive graupel-ice charge seperation are being used for comparison: Saunders and Peck (1998), Riming Rate, Takahashi (1978) (all described in Mansell et. al., 2003).

The supercell storm is initiated on a 81 by 81by 20 km domain. Simulations contain one km horizontal resolution with vertical resolution on a stretched grid ranging from 200m at the surface to 500 meters aloft. A warm bubble with randomized thermal perturbations is used to initiate the storm. A modified version of the mobile NCAR CLASS sounding released from Goodland, KS at 2022 UTC containing just over 1200 J/kg CAPE is used to determine the thermodynamic profile. The simulations contain the first three hours of the storm lifetime, including the initial electrification and the development of the multicell storm into a supercell.

This study also looks at the dependence of electrification on storm microphysics, including graupel volume, updraft mass flux, updraft strength, and updraft volume. Correlations between the in-cloud flash rate and the storm parameters are performed to determine which may give the most accurate representation of lightning storm behavior.

Results and Discussion

The 29 June supercell from STEPS first appeared on radar at 2130 UTC and lasted approximately four hours before merging into a MCS later that evening. During the first three hours, it produced large hail and an F1 tornado as well as a profuse amount of lightning (Tessendorf and Rutledge, 2002). As it propagated through the STEPS domain, observations were taken from a multiple-Doppler network, electric-field soundings and the Lightning Mapping Array (LMA). The storm produced a 5 minute flash rate of 100 flashes early in the storm's lifetime and reached a maximum of 520 flashes per five minutes at a time corresponding to the tornado, as determined from LMA data. Approximately 90% of the CG flashes were positive; a total of 140 positive CG flashes and 19 negative CG flashes were counted by the NLDN during the first three hours of the storm (Regina Doyle, personal correspondence).

Saunders and Peck (SP98) creates a generalized inverted tripole charge profile (small lower region of negative charge below a larger positive and followed by an upper negative layer centered at approx 12 km) [Fig. 1a]. The first flashes to occur are IC flashes, which begin approximately 25 minutes into the simulation. The IC flash rate reaches a maximum of 242 flashes min^{-1} at 1.3 hours with other pulses nearing that rate at later times in the simulation. SP98 produces a total of 79 positive CG flashes, the first occurs at approximately 1.5 hours into the simulation and no negative CG flashes occur. The electric field reaches a maximum of 114 kV m^{-1}.

The riming rate (RR) NI charging scheme produces a similar tripole structure to that of SP98, though the lower negative charge region is a higher magnitude with a less intense negative region located at 9 km (not shown). The maximum IC flash rate is 190 flashes min^{-1} occurring at 1 hr 20 min. Again, only positive CG flashes are produced, the first at 81 minutes into the simulation. A total of 59 positive CG flashes are scattered throughout the 3 hours, the majority occurring after 2 hours into the simulation. The electric field for RR also reaches a maximum magnitude of 114 kV m^{-1}.

The Takahashi NI charging scheme generates a charge structure fitting that of the classic tripole profile (lower positive, middle negative, upper positive) [Fig. 1b]. At approximately 3 hours, the storm reaches a maximum IC flash rate of about 180 flashes min^{-1}. This scheme starts producing negative CG flashes at 60 min and continues with only negative CG flashes throughout the 3-hour simulation, generating a total of 83 negative CG flashes throughout the simulation. The maximum electric field reaches a magnitude of 122 kV m^{-1}.

Modeled (SP98) and observed electric field soundings at about 2.5 hours show a remarkably consistent storm structure [Fig. 2]. The simulated soundings reach a maximum updraft of 25 m s^{-1}. The horizontal electric field has relatively the same appearance for each simulation, though there are obvious discrepancies between the vertical electrical fields. SP98 and RR have vertical electrical fields that look almost identical except SP98 has a slightly stronger upper vertical electric field. Takahashi produces a profile almost exactly opposite to that of SP98 and RR. It depicts a lower positive charge at about 7 km and an upper negative at 11 km, each of relatively the same strength. SP98 and RR, however, perform most like that of the actual sounding from 29 June during the intense storm phase at 2.5 hours.

All NI schemes produce levels of electrification and flash rates comparable to that of the real storm, as determined from LMA and electric field meters [Fig 3]. The observed and simulated storms show somewhat similar trends in total flash rate, with a much more drastic jump earlier in the simulations than in the real storm; beginning time is set corresponding to the onset of lightning at approximately 25-30 minutes. Correlations of flash rates for the different simulations with the observed storm range from .67 to .72, RR being the strongest but all simulations behave similarly.

In both the real storm and the simulations, flash rates increase and decrease in obvious bursts, occurring generally with surges in different dynamical and microphysical parameters. There are numerous dynamic and kinematic parameters that could be used as predictors of flash rate. Predictors chosen for this model study are: graupel volume, updraft mass flux, maximum updraft speed, and updraft volume. Correlations show that graupel volume and updraft volume are the best predictors of flash rate, though all show strong correlations [Table 1]. A rapid increase is depicted in both graupel volume and flash rate in the first 60 minutes of the storm, with other pulses evident throughout the three hours of the simulation in both flash rate and graupel volume [Fig 4].

TABLE 1	*SP98*	*RR*	*Takahashi*
Graupel Volume (km**3)	0.899	0.908	0.919
Updraft Mass Flux (T=-20)	0.864	0.881	0.894
W-max	0.736	0.732	0.786
Updraft Volume (>10 m/s)	0.895	0.909	0.906

Conclusions and Future Work

The SP98 and RR noninductive charging schemes produced a charge structure and lightning polarity most like that observed during 29 June. However, all schemes only produce either all positive (SP98, RR) or all negative (Takahashi) ground flashes, while the observed storm produced ground flashes of both polarities. Analysis of lightning-storm relationships has shown strong positive correlations in the IC flash rate and graupel volume and updraft volume as well as moderate correlations between the flash rate and updraft mass flux and maximum updraft speed. In addition to the three schemes shown here, we will be adding the Gardiner et. al. (1985) noninductive charging scheme [as described in Mansell et. al, 2003] for comparison. We will also be testing different microphysical parameters by varying the thermodynamic profile of the initial sounding and using more robust statistical tests with the comparisons of flash rate.

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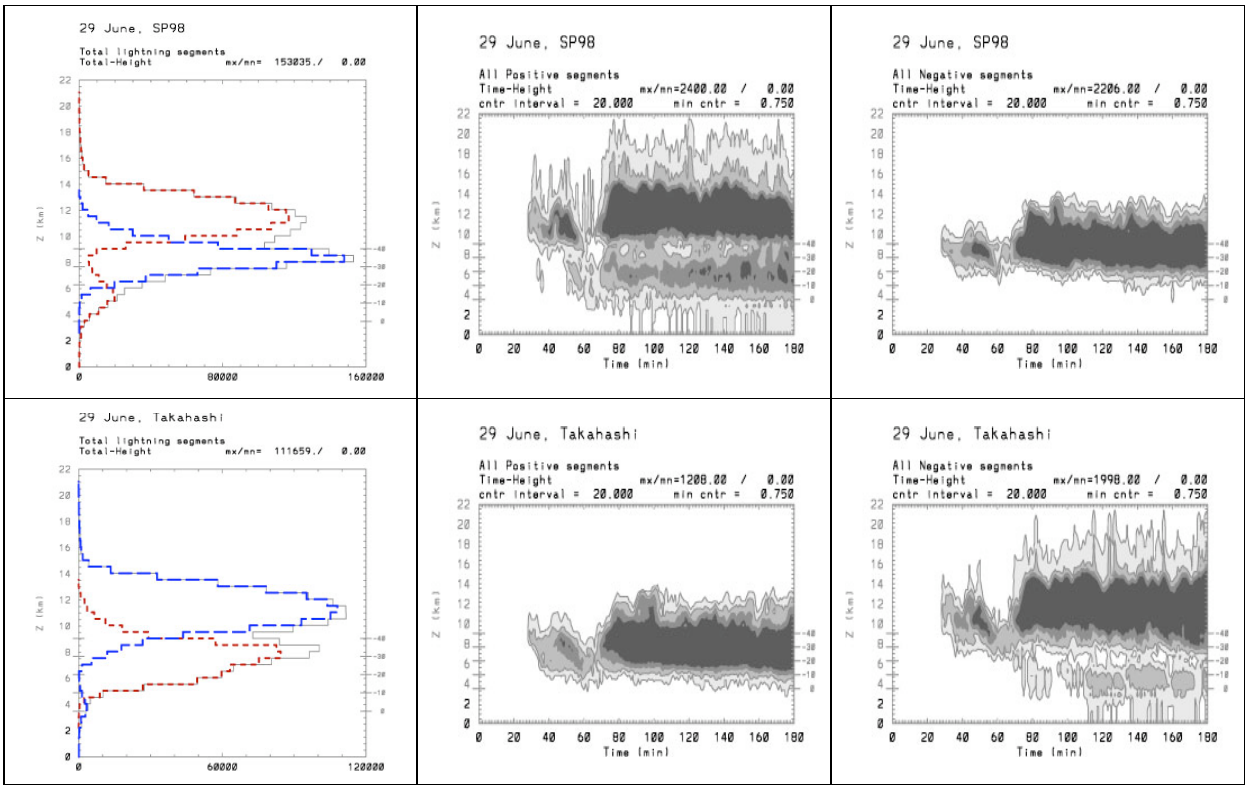

Figure 1: histogram of lightning height with polarity (long dash (blue): negative leaders, short dash (red): positive leaders) and contour plots of the positive and negative channel segments (a) Saunders and Peck NI scheme, top row (b) Takahashi NI scheme, bottom row

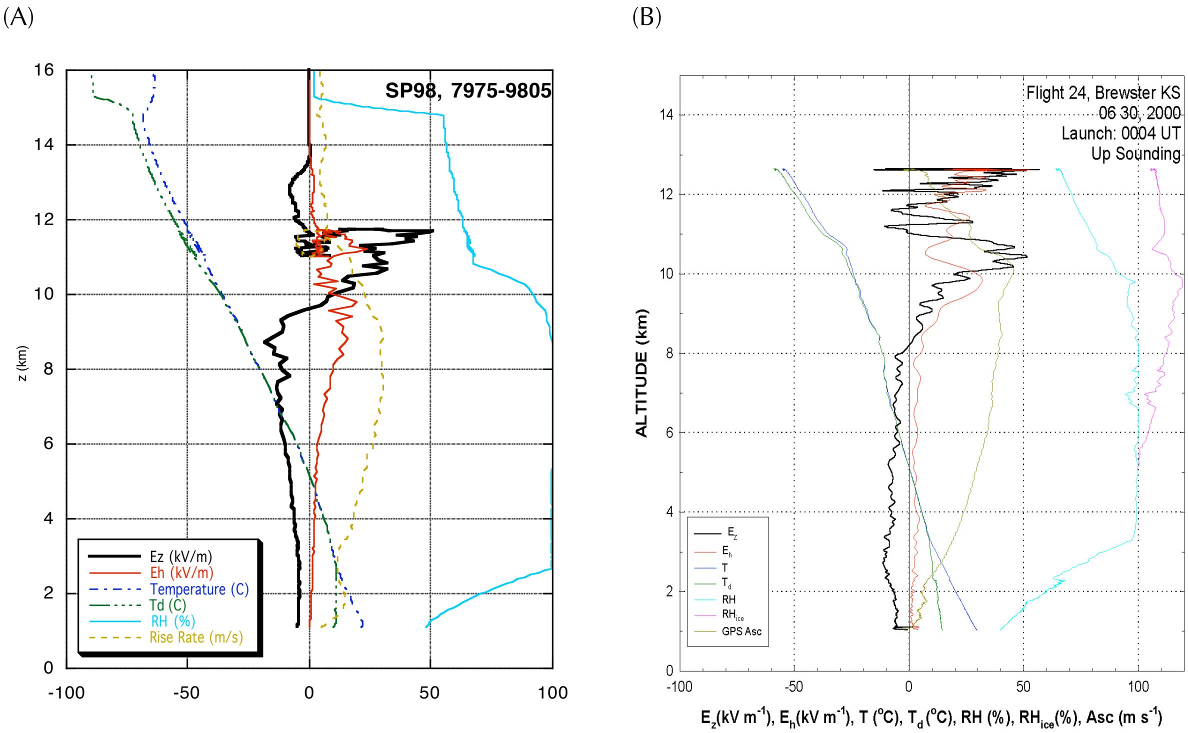

Figure 2: (A) Simulated sounding using Saunders and Peck NI scheme. The simulated soundings are "released" at approximately 2.25 hours and reach the top of the storm at 2.75 hours. (B) Observed sounding from 29 June released at 0004 UT, approximately 2.5 hours into the storms duration

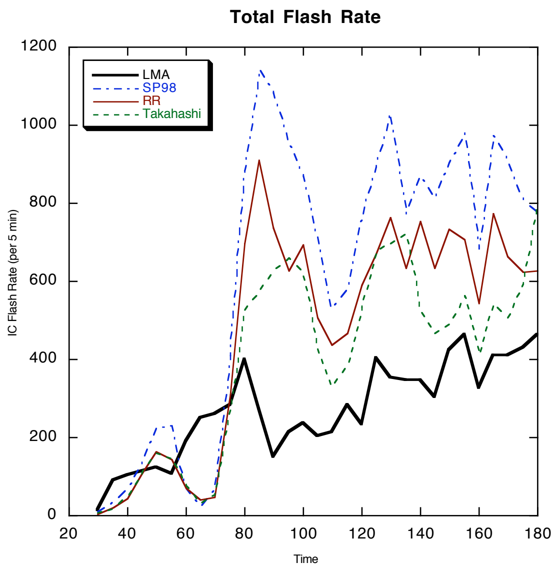

Figure 3: Time series of 5 minute flash rate from the observed storm (solid black) and the three simulated storms

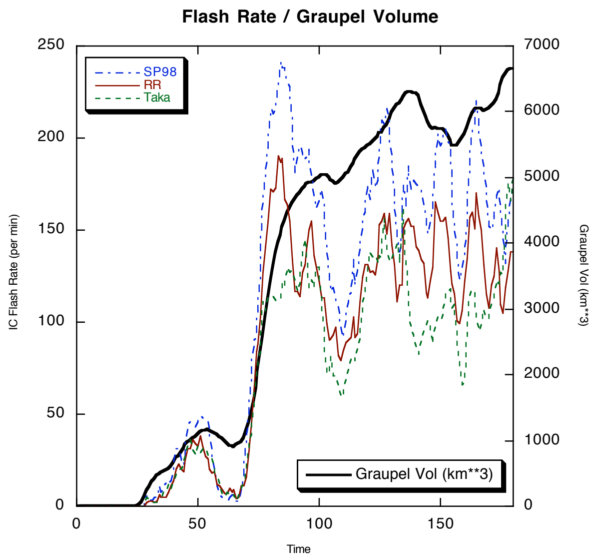

Figure 4: Time series of flash rate corresponding to simulated graupel volume (on secondary y-axis)