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# JUNE 29, 2000 STEPS SUPERCELL STORM: RELATIONSHIPS BETWEEN KINEMATICS, MICROPHYSICS, AND LIGHTNING

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## 1. INTRODUCTION

One of the primary goals of the Severe Thunderstorm Electrification and Precipitation Study (STEPS) is to document and understand the relationships between severe weather and anomalous lightning behavior. In pursuit of this goal, Tessendorf and Rutledge (2002, this volume) describe the co-evolving kinematic and microphysical structure of the supercell storm that occurred on June 29, 2000 in northwest Kansas. Here, we supplement their results by also investigating the electrical evolution of this storm.

In general, we find very close associations between updraft volume, graupel echo volume and total flash rate. In addition, we find that +CGs are closely associated with formation and descent of hail.

## 2. DATA AND METHODOLOGY

The CSU-CHILL, NCAR S-Pol, and NWS (Goodland) radars provide the radar data for this study. See Tessendorf and Rutledge (2002, this volume) for a description of our methodology.

The National Lightning Detection Network (NLDN) provides the cloud to ground (CG) lightning data.

New Mexico Institute of Mining and Technology provides the Lightning Mapping Array (LMA) data (Krehbiel et. al., 2000). At full duty cycle, the LMA can detect lightning discharge events every $100\mu s$, giving a maximum of 10,000 events each second. For statistical studies, like flash rate counts, we use data that is decimated by roughly 90% yielding a maximum resolution of roughly 1000 events per second. However, for inspection of individual flashes, we use the full-rate data to see more of the structure of the discharge path.

The LMA preferentially maps the positive charge region because the negative breakdown component of the discharge through this region is noisier at the VHF frequencies used by the LMA (Krehbiel et. al., 2000, Shao and Krehbiel, 1996). This preferential mapping often allows us to identify the polarity charge regions, as positive charge regions tend to have many more LMA points than do negative regions. Horizontally stratified regions of charge (especially positive ones) mapped by the LMA, give additional indication of the polarity of the regions.

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To arrive at flash counts, we sort each successive 10 minutes of LMA data into isolated groups of points which are separated by less than 0.15 seconds in time and 3 kilometers in radial distance. Each of these groups is deemed a "flash", even if there is only one point in the group. For severe storm cases, we have found that this sorting algorithm produces enormous flash rates dominated by "flashes" consisting of only a few points. These sparse point "flashes" may well be genuine isolated discharges, but may also be noise. To set aside these sparse point flashes, *we add an additional category to count only those flashes which have at least 10 points*. This value of 10 is somewhat arbitrary but seems large enough to ensure that the flashes in this separate category are not noise.

We also compute the maximum (minimum) altitude of flashes by taking the mean of the maximum (minimum) altitude of all flashes each minute. These maximum and minimum altitudes represent the mean vertical extent of the flashes each minute.

All altitudes are referenced to mean sea level (MSL) and all times are UTC. Local ground level is approximately 1.1 km MSL and local time lags UTC by 6 hours.

## 3. OBSERVATIONS

Fig. 1 shows time series of the lightning activity in this storm in terms of flash rates and altitude of the flashes. The lightning is totally dominated by IC flashes with rates up to hundreds of flashes per minute. The flash rates increase and decrease in noticeable bursts, the largest of which occurs near the time of tornado touchdown (23:28) and onset of frequent +CGs. These frequent +CG flashes begin at 23:25 (a full two hours after the first IC flash in the storm) and $\approx 90\%$ of them are positive.

Fig. 2 shows time series of the total volume of updrafts and downdrafts exceeding $\pm 5$, 10 and $20 ms^{-1}$. Fig. 3 shows the time series of the graupel echo volume above the $0°C$ isotherm along with time-height contours of this volume. Fig. 4 shows time-height contours of hail echo volume above the $0°C$ isotherm along with the time series of various precipitation volumes below the $0°C$ isotherm. The heights of the overlaid isotherms were taken from a balloon sounding through the storm at 00:04 (June 30).

As is evident in these time series, increased updraft volume is followed closely by increased graupel and hail volume, which is in turn followed by (or coincident with) increased flash rates. In addition, the trends in +CG rate closely follow the trends in hail volume. Carey and Rutledge (1998) noted similar correlations in their studies of severe hailstorms in eastern Colorado. We now look at these trends more closely.

The first twenty minutes of lightning in this storm consisted entirely of infrequent (only 1 or 2 per minute) IC flashes between a negative charge region centered at 7.5 km ($T \approx -10°C$) and a positive region centered at 5 km ($T \approx 0°C$). The lower positive charge is a persistent feature of this storm and is somewhat of an anomaly. Initial IC flashes in most storms tend to extend from negative charge upward into positive charge. The lower positive charge generally develops later as precipitation grows and descends. Nevertheless, the *vertical positions* of the negative and lower positive charge regions at the early stage of this June 29 storm are still consistent with past observations (see, for example, Table 3 of Williams, 1989).

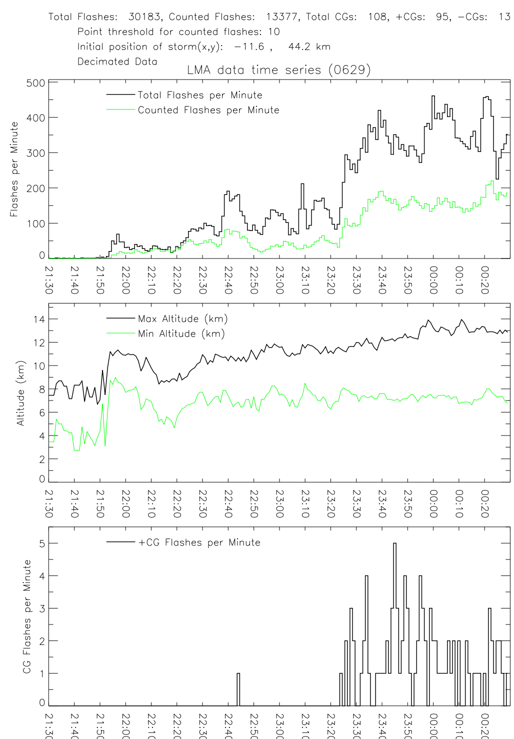


**Figure 1.** Time series of lightning statistics. Top: total flashes and counted flashes each minute. Middle: mean of the maximum and minimum flash altitudes. Bottom: positive cloud to ground flashes each minute. Time axis gives UTC time in 10-minute increments. Flash totals and other information are listed above the plots.

Prior to 21:45, there is very little updraft exceeding 5 $ms^{-1}$, and very little graupel volume aloft. Furthermore, there is almost no graupel volume above the $-10°C$ isotherm. This is consistent with laboratory observations of the non-inductive charging mechanism. As summarized in Williams (1989), collisions between riming graupel and ice crystals at $T > -10°C$ typically grant positive charge to the rimer, regardless of liquid water content. Thus, it appears that the bulk of the graupel defines the positive charge region. Presumably, ice crystals and/or smaller graupel lofted past the charge reversal level constitute the negative charge at 7.5 $km$.

Just after 21:45, there is a sharp increase in the 5 $ms^{-1}$ updraft volume and corresponding increase in the graupel volume aloft. This graupel extends vertically to > 10 km. Subsequently, at 21:51:30, the storm produces its first upper level IC flash between a negative region at 11 km and a positive region at 9.5 km. Following this upper level flash there are 3 more flashes between the negative layer at 7.5 km and the lower positive layer. From 21:55 to 22:10, the lightning consists of a mixture of IC flashes, some extending downward from 7.5 km, but much more often from 10-12 km downward to 9.5 km. The histogram of the LMA sources during this time (not shown) has well-defined peaks at 9.5 and 5.0 km. The structure of individual flashes indicate that these two peaks are positive charge regions. These two positive regions, along with a negative charge region in between, give the typical tripole structure (Williams, 1989). There is also concentrated activity between adjacent negative and positive regions at 11 and 13 km, respectively. The two upper level flash regions (above 9 km) dominate and bring the flash rate up to tens of flashes per minute.

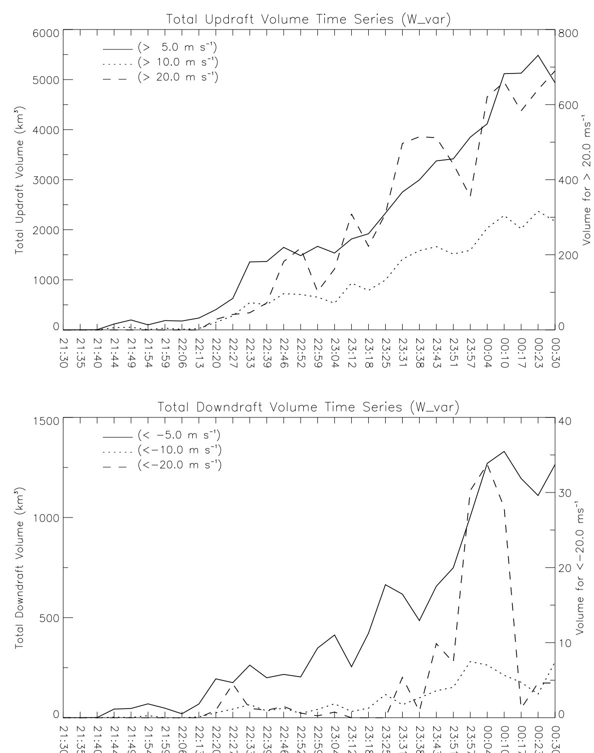


**Figure 2.** Time series of updraft and downdraft volumes. In both plots, the left ordinate gives volume exceeding $\pm 5$ and $\pm 10 ms^{-1}$, while right ordinate gives volume exceeding $\pm 20 ms^{-1}$.

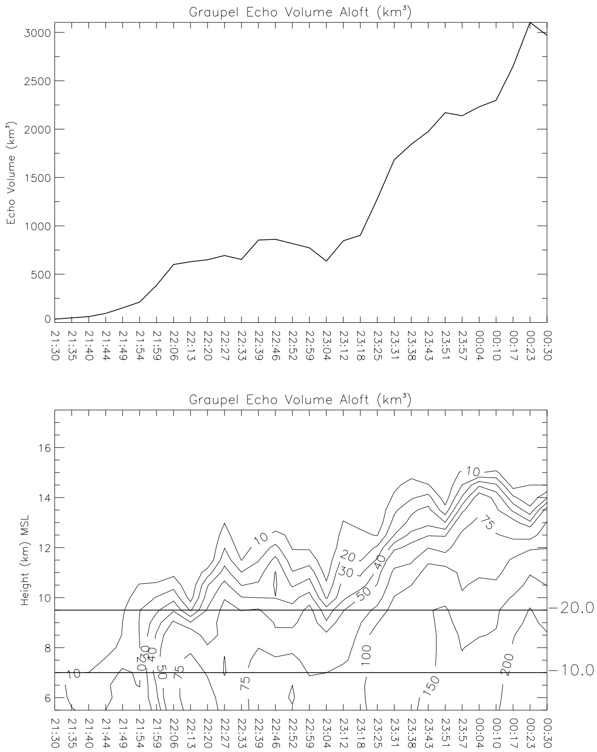


**Figure 3.** Graupel echo volume. Top: time series of total graupel above $0°C$. Bottom: time-height contours of graupel volume above $0°C$. The $-10$ and $-20°C$ isotherms are indicated by horizontal lines at 7 and 9.5 km respectively.

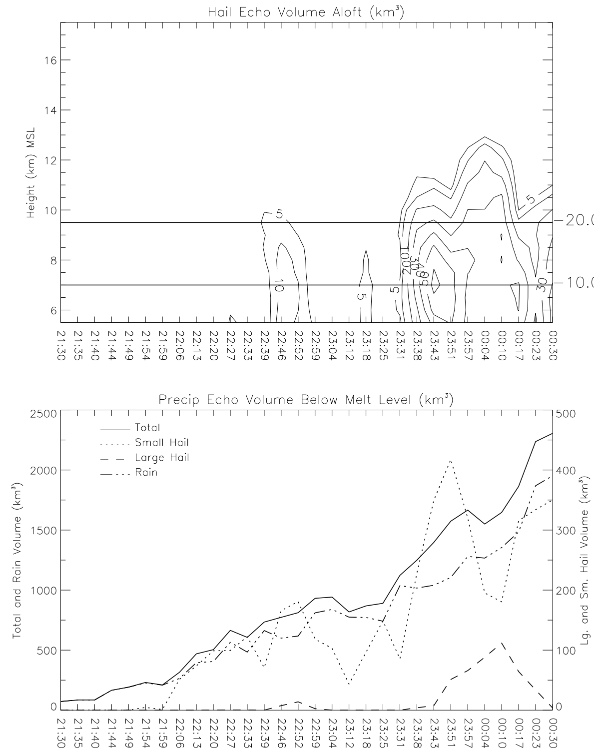


**Figure 4.** Top: time-height contours of hail echo volume above the $0°C$ isotherm. Bottom: echo volume of specific precipitation types below the $0°C$ isotherm. Note the separate ordinate for hail.

It is also interesting to note that the flashes extending downward from the negative region at 7.5 km often extend as low as 3 km through the most intense precipitation. This strongly suggests that this precipitation is carrying positive charge. The NLDN does not associate CGs with these flashes. One interpretation of this is that the persistent lower positive charge is large enough to effectively shield the negative layer from the ground and neutralize the flashes.

From 22:00 to near 22:20, the total graupel volumes increase slowly; however, the graupel volume at higher levels appears to descend, and there is a peak in graupel volume below 8 km. The descent of this graupel is followed by intensification of downdrafts at mid-levels in the storm and rapid increase of small hail below the melt level. The descent of this graupel is closely followed by a dramatic downward shift in the lightning. From 22:10 to 22:20, the previously evident layered charge structure collapses somewhat, with one broad peak centered at 6 km and another at 8.5 km. It is as if the upper charge layers have all descended by a kilometer or so. Again this lowering of the lighting sources seems consistent with the descent of the graupel volume.

The $> 5ms^{-1}$ updraft volume increases sharply at 22:13 and again at 22:27. Volumes with updraft exceeding $20ms^{-1}$ also increase significantly after 22:13. Both of these updraft bursts are followed by increases in the graupel volume at high levels in the storm. In particular, from 22:20 to 22:27 or so, the graupel volume ramps up at higher levels and decreases somewhat at lower levels. Again the lightning seems to follow this graupel transition, with flash rates and flash altitudes increasing noticeably during this time. By 22:30, LMA data show very little activity below 4 km and pronounced peaks of LMA points centered at two levels: one at 10 km and another at 7 km. Typical interpretation of these data would lead us to believe that both of these peaks correspond to positive charge regions; however, a cursory analysis of the individual flashes during this time gives no clear indication of the polarity of these regions. The vertical position of adjacent negative and positive layers seems to be strongly dependent on their position relative to the core of the storm. If indeed the concentration of points at 7 km is a positive charge region, then it would seem that the intense and broad updrafts may have simply lifted all of this positively charged precipitation. However, Williams et. al. (1994) point out that for large liquid water contents, graupel and hail undergoing wet growth can charge positively at temperatures lower than $-10°C$. Hence, this apparent elevation of the positive charge could be the effect of both broad updraft and particle collisions.

Starting at 22:40 there is a series of bursts of updrafts exceeding 20 $ms^{-1}$. As before, each of these bursts is followed by significant increases in graupel volume, vertical extent of graupel volume, flash rate, and vertical extent of the flashes. Furthermore, these bursts are followed by significant increases of hail above then below the melt level. The LMA data show a very pronounced absence of lightning on the western edge of the storm during these bursts. This lightning "hole" is co-located with a bounded weak echo region in the strongest updraft and is most pronounced after 23:20. In addition, there is a well-defined region of lightning extending past 15 km, just above and slightly downwind of this lightning "hole".

After the first such updraft burst, the storm produces its first +CG at 22:45, just as the hail volume below the melt level peaks. This +CG appeared to originate in a region of graupel at 6 km and struck ground in a hail shaft. From 23:25 to 23:30, the storm produces seven more +CGs. These +CGs again closely coincide with the increase of hail below the melt level and strike ground very near the most intense rain and hail. The low level hail and +CGs continue from this point on. The majority of these +CGs struck ground in or near the region of most intense hail and rain. In their study of a severe hail storm, Carey and Rutledge (1998) also found that onset of +CGs closely followed onset of hail but the peaks in +CGs tended to lag the peaks in the hail by several minutes.

## 4. DISCUSSION

Our observations show very good correlations between flash rate, updraft, and hail/graupel echo volume. In particular, the IC flash rate seems to be a very good indicator of the vertical extent of the graupel volume and thus the strength of the storm itself. Furthermore, +CG flashes appear to be strongly associated with the formation and descent of hail.

In the case of this storm, the most extreme increase in flash rates was nearly coincident with large hail and a tornado. However, such high flash rates seem to have some value as a predictor of severe weather at the ground. Further analysis of the LMA data, on a flash-by-flash basis, in the microphysical context provided by polarimetry will lead to a much better understanding of the lightning and electrification processes in this and other storms.

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