The Status of our Search for Inverted-Polarity Electrical Structures in Thunderstorms

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ABSTRACT: Additional evidence for the existence of inverted-polarity electrical structures in thunderstorms has been obtained from the Severe Thunderstorm Electrification and Precipitation Study (STEPS) in 2000. Electrical structure is found using Gauss’s Law, vector plots of the electric field with altitude, and lightning structure. Not every method shows all the charge regions, but the evidence points to the possibility of inverted-polarity electrical structure, including the entire storm.

INTRODUCTION

During the Severe Thunderstorm Electrification and Precipitation Study (STEPS) in the area of Goodland, Kansas, in 2000, we made balloon-borne soundings of the electric field in coordination with observations from a three-dimensional, total lightning mapping system, and polarimetric radars (see http://www.mmm.ucar.edu/community/steps.html).

The lightning mapping array observed a number of storms in which the cloud flashes were inverted in polarity, namely between midlevel positive charge and upper level negative charge. We are searching for a correspondence between the inverted-polarity cloud flashes and the charge structure in the storm as inferred from the electric field profile. It is the storms with possibly inverted-polarity electrical structures we focus on here.

OBSERVATIONS OF INVERTED-POLARITY STORM CHARGE AND LIGHTNING

By inverted-polarity storm (more specifically, inverted-polarity electrical structure) we mean that the normal polarities of charge in two or more vertically separated regions of a storm are reversed. Because looking for inverted structures in these data requires knowledge of typical (i.e., noninverted) thunderstorm structures, we summarize present knowledge of typical, noninverted structures. Based largely on profiles of the vertical component of the electric field, $E_z$, estimated from corona current by Simpson and Robinson (1941), the classic view of the gross electrical structure of a thunderstorm has been that it is a ‘tripole’: a main positive charge above a main negative charge above a smaller lower positive charge. Lightning mapping data have now confirmed that cloud flashes in storms with an apparently normal charge distribution typically occur between the upper positive region and the midlevel negative region below it. Ground flashes are typically between the midlevel negative region and ground.

Strong evidence that the polarity of cloud flashes in the upper part of storms can be inverted from normal was obtained with the lightning mapping system in central Oklahoma in 1998. Many additional storms producing inverted-polarity lightning were observed in STEPS, providing increased evidence for inverted charge distributions from the lightning mapping array (Krehbiel et al. 2000). The inverted-polarity discharges are characterized by downward rather than upward initial development in the located radiation sources and have a bilevel structure indicative of breakdown between upper negative and midlevel positive charge regions, rather than the other way around.

Previous electric field evidence that the gross electrical structure of a storm can be inverted was shown by Marshall et al. (1995). More evidence is from the electric field profiles such as the example in Figure 1 (left panel) to which Rust and MacGorman (2002) applied a one-dimensional approximation of Gauss’s law to infer the vertical sequence of
charges shown in the figure. Part of what we are attempting is to extract more information from the electric field profile. To do this, we are comparing the charge structure from Gauss’s law with that inferred in plots of the electric field vector along the balloon’s track. We are working on ways to plot and interpret these data relative to lightning structure and radar-derived storm parameters. For example, Figure 2 shows the vector electric field in a vertical cross section of the same storm as in Figure 1. The vectors suggest that most of the charge is to the right of the balloon track and indicate a layer of positive charge near 7.5 km MSL and layers of negative charge above and below that. This analysis does not yield the highest charge region inferred by applying Gauss’s law. We interpret the charge distributions inferred from both analyses to show possibly inverted-polarity electrical structure of this storm.

Figure 1. Sounding in an isolated storm during STEPS. (Left) The inferred charge layers are the vertical bars, Q, to the right of the sounding plot. (Right) The dots on the radar RHI show 4 min of lightning mapping data. The dashed lines depict the approximate center of the lightning. The lightning data suggest the upper charge is negative and the lower charge positive. The horizontal arrows indicate the heights of these two charge regions relative to the inferred charge from Ez. The balloon track is the nearly vertical line to the left of the radar core until it goes over the core at about 12 km.

Further evidence that inverted-polarity electrical structures exist is found in a second storm from STEPS. The partial profile of electric field from this storm (Figure 3) does not alone provide conclusive evidence of an inverted-polarity structure. However, when coupled with the lightning mapping array data and the vector electric field, the electric field structure can be better understood. The flash shown in Figure 3 was chosen as a representative flash for this storm. According to the lightning mapping array data, the flash initiates between 9 and 10 km MSL with the initial downward development of the radiation sources to 6 km MSL followed by a lower density of sources at 12 km MSL. This initial downward development and lower density of sources in the radiation sources is consistent with an inverted-polarity
cloud discharge. Analysis of all the electric field vectors also indicates a layer of negative

Figure 2. Representative electric field vectors and balloon track overlaid on RHIs of radar reflectivity. (Left) Balloon ascended to about 10 km through the storm’s updraft. (Right) The balloon continued to rise and then move across through the top of the storm. Vector-inferred charges are shown, with the lowest negative charge at 94 km range on the left. The vector-inferred charges correspond in altitude with those from $E_z$ shown in Figure 1.

Figure 3. Sounding and lightning flash in convective region of storm. (Left) There are no E data from middle of storm. The apparent two lowest and two highest charges in storm are inferred from Gauss’s law. (Right) Balloon track and E vectors shown with dots mapping the flash. The electric field vectors, shown in blue along the track, point from the balloon track along the direction positive charge would move. The LMA and E vectors confirm the polarity and altitude of two of the inferred charge regions (blue and red lines with arrows).

charge coincident with the upper layer of sources at 12 km MSL and a layer of positive charge coincident with the lower layer of sources near 6 km MSL. This concurs with the charge
structure obtained from Gauss’s law. The presence of many flashes with this structure leads us to believe that the overall electrical structure of this storm is inverted-polarity.

The electric field profiles presented in the figures indicate more charge layers than are indicated by the lightning data. Other balloon soundings during the last two decades (e.g., Stolzenburg et al. 1998) and modeling studies (e.g., Ziegler and MacGorman 1994) indicate that the vertical structure is often more complex than the traditional tripole view. Lightning is not always coincident with all of these layers. These differences in lightning- and electric field-inferred charge regions could arise from horizontal nonuniformity or the space-time nature of the sounding measurements. The analysis is a complex task that is still in progress.

CONCLUDING REMARKS

We continue to test the hypothesis that inverted-polarity electrical structures exist in thunderstorms and to analyze storms to look for relationships between lightning-inferred charge structure, radar derived storm structure, and charge from the electric field profiles. The results shown above of the apparent link between the inverted-polarity flashes and storm electrical structure adds to the credence that such exists. Furthermore, the newest version of the electric field meter just completed has high resolution pointing information that substantially increases the directional accuracy of the electric field vectors. We will obtain additional soundings using these improved field meters in field programs in May and June, 2003 and 2004. We are continuing to address the questions about inverted-polarity electrical structures in storms, e.g., what causes them, and do they occur only in some regions?

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REFERENCES


