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Coordinated LMA, Balloon-borne Electric Field, and Polarimetric Radar Observations of a Triggered Lightning Flash at Camp Blanding, FL

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Abstract— **In an 18-day period of July – August 2013, coordinated observations were attempted with a balloon-borne electric field meter, a balloon-borne particle imager, the 5-cm wavelength polarimetric Shared Mobile Atmospheric Research and Teaching Radar (SMART-R), a small-baseline VHF Lightning Mapping Array (LMA), and the extensive observing facilities for triggered lightning at the International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, Florida. This experiment was the first to provide vertical profiles of the electric field relative to radar data in Florida storms. Furthermore, mapped three-dimensional lightning structure, surface measurements of lightning current, and multiple-station electric fields and electric field derivatives were provided by the ICLRT for triggered flashes. Balloon soundings provided the first vertical profiles of electric fields and inferred charge in Florida storms. On 1 August, an electric field meter was flown during a period in which 3 flashes were triggered and confirmed the hypothesis that the turn to horizontal lightning structure just above the melting level occurred in a layer of negative charge.**

Keywords—triggered lightning, electric field, charge

I. Introduction

Based on previous studies that showed much of the horizontal structure of a cloud-to-ground lightning flash tends to be within charge regions (e.g., MacGorman et al. 1981, 2001; Coleman et al. 2003), one suggestion was that the horizontal channels typically just above the melting level of storms typically were within negative charge (Hill et al. 2013, Pilke et al. 2013). However, microphysical effects on lightning propagation also were considered possible. One goal of the present effort to measure vertical profiles of the electric field was to determine which hypothesis is correct.

II. Observations

On 1 August, strong convection reaching up to 14 km MSL occurred over the ICLRT. Radar data showed that the storm was weakening as the balloon carrying an electric field meter was launched at 1912 UTC. Four attempts were made to trigger lightning in this storm just before and during the balloon flight. A natural flash apparently interfered with the first trigger attempt, made approximately 1 minute before the balloon was launched. The last three attempts were successful and were mapped by the local 7-station lightning mapping array. Only six stations were available on 1 August, and data from only five were available for the third triggered flash, so the mapped structure of the third flash is noisier. The structure of the first two triggered flashes turned from predominantly vertical to predominantly horizontal at an altitude of 4–5 km MSL (Fig. 1). The larger reflectivities at roughly 4 km MSL were caused by the increase in reflectivity as ice particles melted. Thus, as noted in previous cases, the horizontal channels occurred at or just above the melting level of the storm.

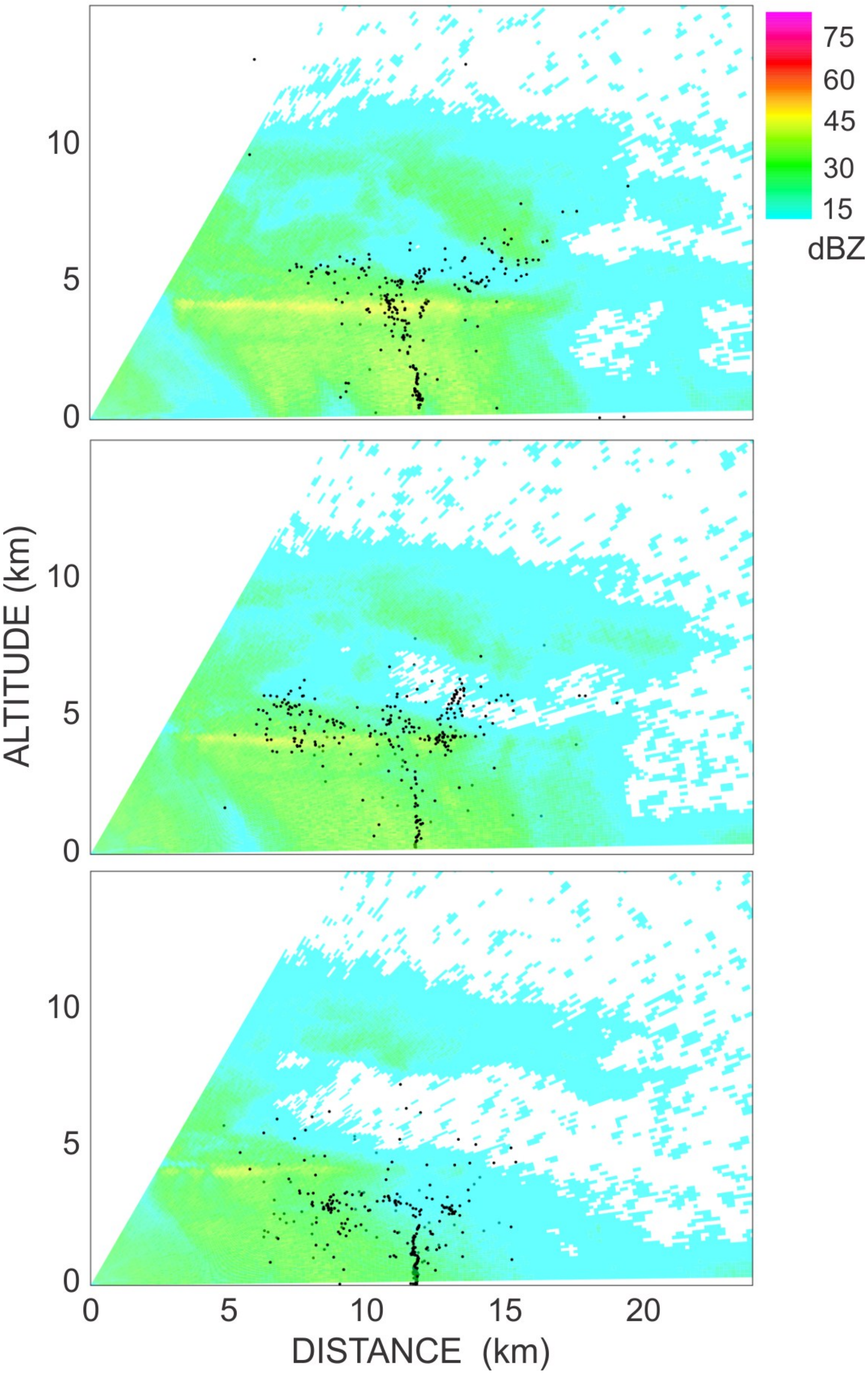

Figure 1. VHF source points for three triggered flashes relative to reflectivity (in dBZ) from the 5-cm wavelength SMART-R radar. The vertical projection is along the 9.6° azimuth from the radar through the flash. Note the bright band (yellow shading) near 4 km MSL, which indicates melting particles. Values of ρ_{hv} (not shown) indicate mixed-phase particles consistent with melting in roughly the same region. Triggered flash at (top) 1919 UTC, (middle) 1925 UTC, and (bottom) 1934 UTC. Data were available from six stations for the first two flashes, but from only five stations for the third flash.

The first triggered flash, at 1919 UTC, produced a relatively long (571 ms) initial stage (IS) discharge followed by a single leader/return stroke and 6 ms of continuing current. The second triggered flash, at 1925 UTC, produced a 532 ms IS discharge followed by 5 leader/return strokes, consistent with the somewhat greater horizontal extent of its channels (the difference in extent was even greater in other planes). Continuing current ranging from 10 ms to >40 ms followed return strokes 1, 4 and 5.

The third triggered flash, which occurred when the electric field meter was near the melting level, produced a relatively short IS (205 ms) and no subsequent return strokes. While the plot of lightning structure is noisier due to the availability of fewer LMA stations, it appears that extensive horizontal channels formed at roughly 2.5 km MSL, approximately half as high as for the two previous flashes. This is consistent with the shorter duration of the IS.

Electric field data from the balloon flight launched at approximately 1912 UTC is shown in Fig. 2. Just above the melting level, the vertical component of the in situ electric field had a large negative gradient with height spanning the mapped horizontal channel structure of the first and second triggered flashes. The 1-dimensional approximation of Gauss's Law, consistent with the relatively stratified structure of the weakening storm, indicates that the large negative gradient in the vertical component of the electric field was caused by a region of negative charge just above the melting layer. Thus, it appears that the horizontal structure of the first two triggered flashes did propagate through a negative charge layer at and just above the melting layer, as hypothesized by previous studies.

Our first analysis of the vertical electric field profile had indicated a region of relatively small positive charge density just below the negative layer and another region of even smaller positive charge density at roughly 2.5 km MSL. What controls continued propagation of lightning is the difference in electric potential between the local ambient environment and the end of the lightning channel. It seems likely that positive charge near 2.5 km MSL reduced the electric potential experienced by the upper IS tip enough to prevent the channel propagating higher. (This may also be related to the lack of return strokes for this flash.) Thus, although one electric field meter could not sample well enough in time and space to determine definitively why the turn to horizontal structure occurred higher for the two previous flashes, it seems likely that either the potential experienced by their channels due to the lowest positive charge was smaller in magnitude or the potential due to the negative charge layer was larger than experienced by the third triggered flash at roughly 2.5 km MSL.

Electric field meters also were launched into two other weakening storms in Florida on different days. In all three observed cases, the vertical structure of the inferred charge consisted of a vertical stack of alternating charge polarities, with the lowest region of large charge density ($|\rho| \geqslant 0.5$ nC m-3) being a negative layer near or just above the melting layer. This is similar to the layer of charge found near the melting layer in stratiform precipitation regions, but that charge can be of either polarity and is often positive (Stolzenburg et al. 1998; MacGorman et al. 2008). Thus, it appears that the melting process may well produce the charge typically observed there, but what controls the polarity of that charging is uncertain. Shepherd et al. (1996) suggested that the charge

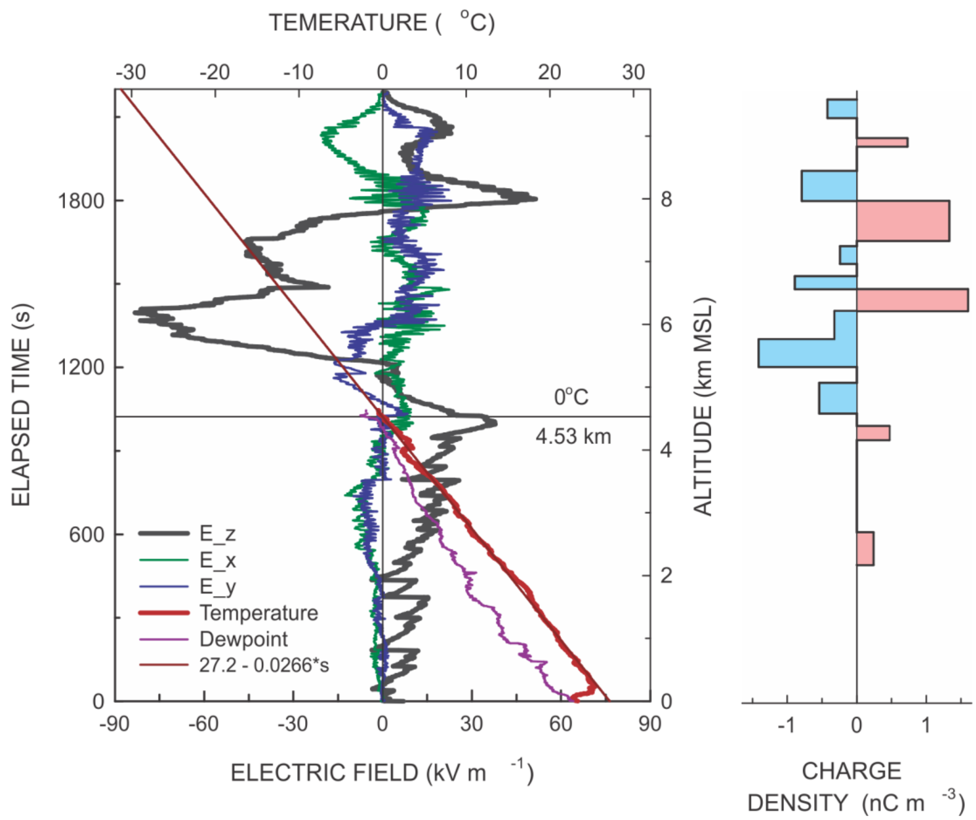

Figure 2. Electric field as a function of height and elapsed time from launch at approximately 1912 UTC. Radiosonde data were lost just above the 0°C isotherm, but the electric field meter continued operating. Heights and temperatures at later times were extrapolated by assuming the rate of change was the same as a linear fit to the change at lower altitudes..

could be produced by inductive processes, in which case the polarity would be controlled by the pre-existing electric field, or by noninductive processes, in which case microphysical properties of melting itself would be responsible.

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