USING BALLOON MEASUREMENTS TO VERIFY AND QUANTIFY RADAR AND LMA INFERENCES ABOUT THUNDERSTORMS

Thomas C. Marshall, Maribeth Stolzenburg, Leonidas M. Coleman
Department of Physics and Astronomy, University of Mississippi, University, MS, USA.
Paul R. Krehbiel, William Rison, Ronald J. Thomas
Geophysical Research Center, New Mexico Institute of Mining and Technology, Socorro, NM, USA.

INTRODUCTION

During the summer of 1999 we flew instrumented balloons into mountain thunderstorms that developed over the Langmuir Laboratory for Atmospheric Research in central New Mexico. In addition to the in situ balloon data, we made remote measurements of the storms with the New Mexico Tech dual polarization radar and Lightning Mapping Array (LMA). In this presentation we compare the electric field and thermodynamic soundings with parameters measured or inferred from the radar and lightning data. The goal is to verify interpretations of the remote measurements by comparing them to data from the balloons. With the same comparisons we also attempt to place quantitative bounds on parameters inferred from remote measurements.

1. USING ZDR AND K_{DP} TO INFER UPDRAFT REGIONS OF STORMS

Figure 1 shows sounding data from a balloon launched on July 31, 1999, into a developing thunderstorm cell. By comparing the balloon's ascent rate to its still-air rise rate of approximately 5 m s^{-1}, we infer that the balloon entered the storm's updraft at 4.3 km altitude (when the ascent rate exceeded 5 m s^{-1}). Between 4.3 and 6.4 km altitude, the updraft speed indicated by the balloon increased to a maximum value of about 15 m s^{-1}. At 8.9 km altitude, the balloon exited the updraft.

Figure 2 shows an RHI scan from the dual polarization radar through the center of the developing cell and along the balloon's path. At this time reflectivities were less than 40 dBZ along the balloon's path. The strong 'couplet' of opposite polarity values in the rate of change of the phase difference (K_{dp}, lower left panel of Figure 2) associated with a maximum in differential reflectivity (ZDR, upper right panel) indicates the presence of a substantial updraft associated with the cell's growth [e.g. *Scott et al.,* 2001]. At this time the balloon was located within the K_{dp} couplet, so the balloon ascent rate can provide direct verification of the interpretation presented in *Scott et al.* [2001]. From the balloon data (Figure 1), we estimate that the updraft speed at the balloon's location (4.9 km altitude) was about 5 m s^{-1}.

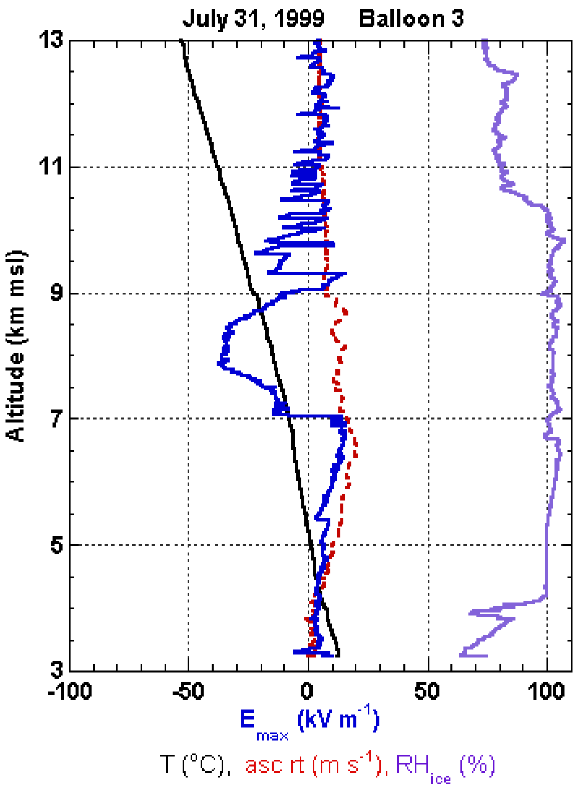
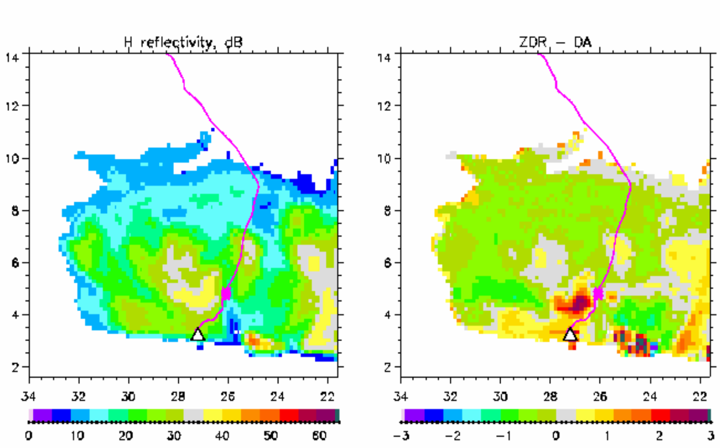


Figure 1. Sounding of E, temperature, ascent rate (dashed curve), and relative humidity over ice from a balloon ascending in a storm's updraft.

2. USING ZDR TO INFER HAIL OR GRAUPEL REGIONS

Information about the elevated region of precipitation in the same thunderstorm cell can be inferred from the ZDR data shown in Figures 2 and 3. Early in the growth of the cell (Figure 2), the ZDR values at upper levels were zero or slightly positive, which indicates the precipitation at those levels was frozen. Precipitation growth in the cell increased substantially in the next few minutes. Figure 3 shows an RHI near the end of this rapid growth phase. The slightly negative ZDR values (0 to –0.75) observed in the elevated core of largest



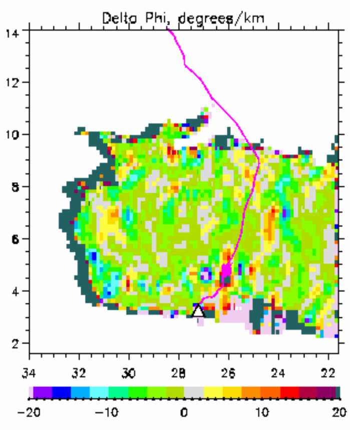


Figure 2. Radar range-height scan at 2242:32 UT on July 31, 1999, through the track of Balloon 3 that ascended in the storm's updraft. Location of the balloon at the time of the scan is indicated by the wider portion of the curve; it is within the K_{dp} couplet (lower left panel) that is associated with the maximum in ZDR.

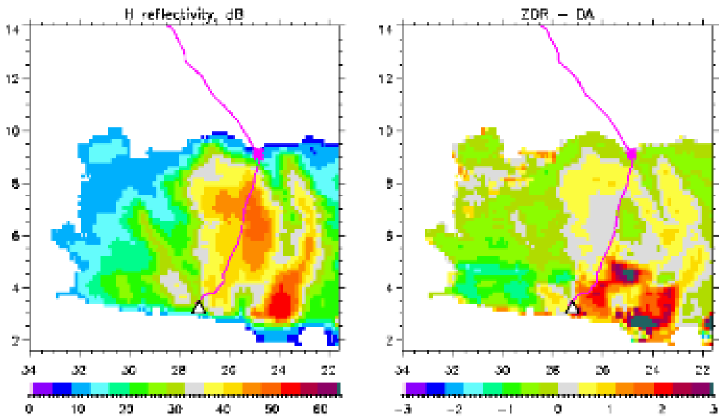


Figure 3. RHI scan at 2247:46 UT on July 31, 1999, through the track of Balloon 3. The center of the elevated reflectivity core is located along the balloon track, below the balloon's position at this time. The core has grown significantly in the 5 min between this scan and that shown in Figure 2, and the ZDR values are slightly negative within the core.

reflectivity suggest the presence of small hail or graupel particles that were elongated vertically [e.g., *Bringi et al.,* 1984; *Scott et al.,* 2001]. When the balloon was at the altitude of the center of this core (6.7 km, reached by the balloon about 3 min earlier than the time of the Figure 3 scan), the balloon ascent rate was 20 m s^{-1}, indicating the presence of strong updraft. This updraft would produce large liquid water contents to 'fuel' the growth of hail or graupel. The strong positive ZDR values below 5 km altitude are indicative of liquid precipitation, in good agreement with the altitude of the 0˚C level, 5.3 km, in the balloon sounding.

3. USING PHI TO SHOW ELECTRICAL ALIGNMENT OF CLOUD ICE CRYSTALS

Ice crystals present in the upper portion of a thunderstorm can be aligned parallel to one another if there is a strong enough electric field (*E*). These aligned crystals contribute to a difference in phase between the horizontal and vertical polarization components of the radar beam. The phase difference, Phi, increases with distance traveled through the region of aligned particles. Figure 4 shows radar data of Phi before and after a lightning flash and Figure 5 shows the corresponding *E* data from a balloon near the lightning flash and near the plane of the radar scans. The strong electrical alignment signature in the Phi data corresponds to a measured electric field of 103 kV m^{-1} within the alignment region. After the flash, the Phi signature is reduced substantially in magnitude, and the in situ *E* is reduced to 62 kV m^{-1}.

4. USING INITIAL RADIATION SOURCES TO INFER LARGE *E* MAGNITUDES

Lightning flashes initiate when a spark occurs in a large electric field. From the LMA data collected for each lightning flash, one can locate the initial lightning radiation source and determine the direction of propagation of the negative polarity breakdown immediately after flash initiation. These quantities should tell the locations of a large *E* and the orientation of the *E* vector. Figure 6 shows an example of sounding data taken during a cloud-to-ground lightning flash that initiated close to the balloon. The positive polarity of E_z measured by the balloon agrees with the polarity inferred from the downward motion of the initial negative polarity breakdown in the LMA data (not shown). More significantly, the magnitude of E, 176 kV m^{-1}, slightly exceeded the value calculated by *Phelps and Griffiths* [1976] as needed for streamer propagation at the altitude of the initial source.

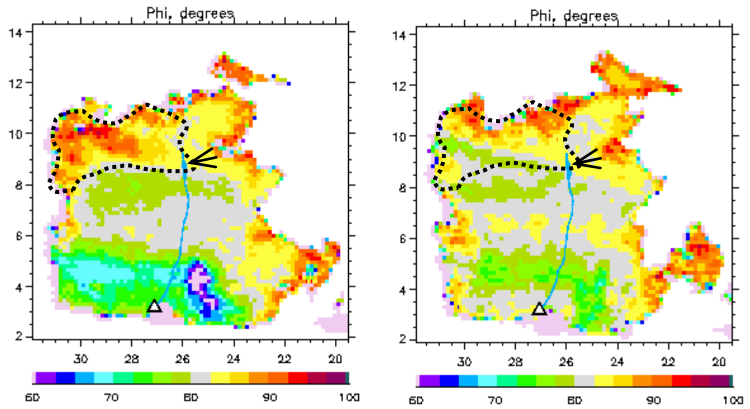


Figure 4. RHI scans showing Phi data a few seconds before (left) and after (right) a lightning flash that occurred partly within the scan plane. The dashed outline shows the extent of the apparent alignment region before the flash. The arrow along the balloon track curve indicates the balloon location at the time of the flash (2142:55 UT; August 2, 1999).

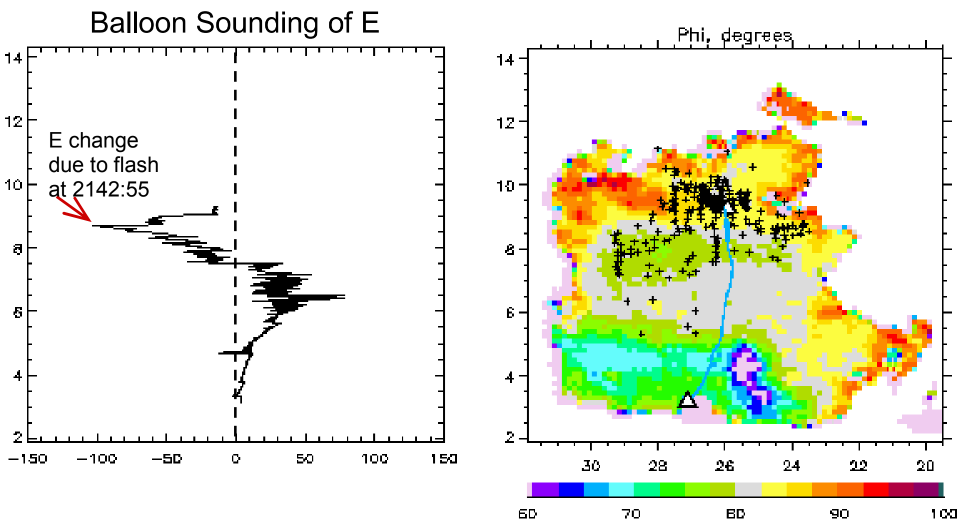


Figure 5. Electric field vs altitude measured before and after a lightning flash (left), and the LMA source locations overlaid on the RHI scan of Phi before the flash (right panel). The balloon was 0.8 km below and 1.0 km south of the first detected radiation source of the flash.

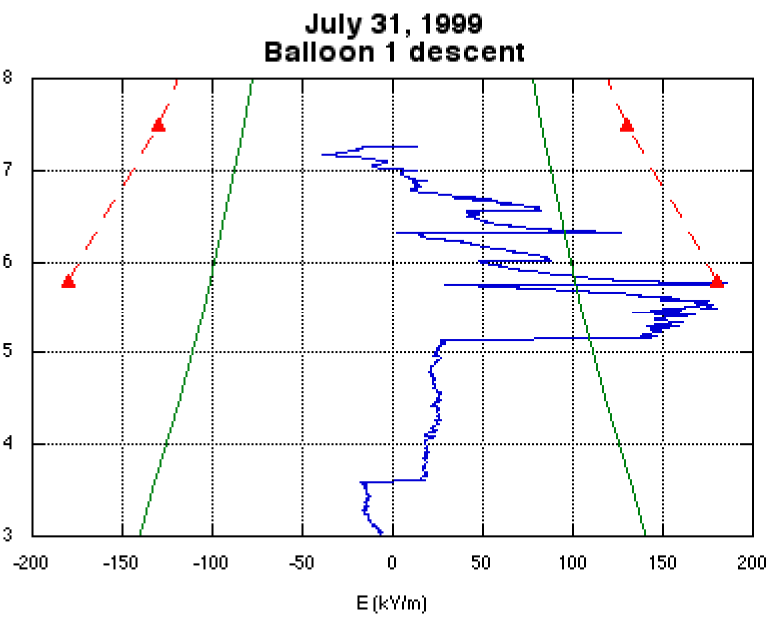


Figure 6. Sounding of electric field acquired during descent of a balloon, along with *Phelps and Griffiths* [1976] data for streamer propagation (triangles, connected with dashed curve) and the calculated breakeven E (solid curve). At 5.8 km altitude, the measured E slightly exceeds the *Phelps and Griffiths* value for a few seconds before a lightning flash initiates less than 1 km away from the balloon. The E immediately after the flash is 28 kV m^{-1}.

SUMMARY

This presentation is a progress report on a project to develop new ways of using remote sensing tools to determine the electrical, dynamical, and microphysical state of thunderstorms. The project also aims to verify earlier remote sensing techniques that have been used to determine thunderstorm parameters. Much remains to be done. However, comparisons 1 and 2 above should help us to use remote measurements to infer more about the microphysical and dynamical environment within storms. Comparisons 3 and 4, especially when used together, should allow remote measurements to infer much information about the electrical structure within a storm. These electrical inferences, based on remote data, will have a much higher time resolution than has been possible with ballooning measurements.

REFERENCES

Bringi, V., T. Seliga, and K. Aydin, Hail detection with a differential reflectivity radar, *Science, 225*, 1145, 1984.

Phelps, C. T., and R. F. Griffiths, Dependence of positive corona streamer propagation on air pressure and water vapor content, *J. Appl. Phys., 47*, 2929, 1976.

Scott, R., P. Krehbiel, and W. Rison, The use of simultaneous horizontal and vertical transmissions for dual-polarization radar meteorological observations, *J. Atmos. Oceanic Tech. 18,* 629, 2001.