P12.2

THREE-DIMENSIONAL LIGHTNING MAPPING OBSERVATIONS IN STORMS

P. Krehbiel, W. Rison, R. Thomas, T. Hamlin, J. Harlin, and Y. Zhang[1]
Langmuir Laboratory, New Mexico Tech, Socorro, New Mexico, 87801

A GPS-based system for mapping lightning discharges inside storms has been developed and used to study thunderstorms in central Oklahoma, central New Mexico, and most recently during the Severe Thunderstorm Electrification and Precipitation Study (STEPS) in the high plains area of northwestern Kansas and eastern Colorado. The system is called the Lightning Mapping Array, or LMA, and produces detailed three-dimensional images both of individual lightning discharges and of the total lightning activity inside electrically active storms. The discharges are imaged by locating the sources of impulsive radio signals ('sferics') in an unused VHF television channel (60-66 MHz, U.S. Channel 3). The radiation events are located by measuring their time of arrival at a county-wide network of measurement stations. The LMA was patterned after the Lightning Detection and Ranging (LDAR) system developed at NASA's Kennedy Space Center by Carl Lennon and Launa Maier (Maier et al., 1995).

In the STEPS project, 13 measurement stations were deployed over an area about 80 km in diameter. Each station utilized GPS timing to measure the arrival times of radiation events with $\simeq$50 ns accuracy. This enabled the radiation sources to be located to within about 50–100 m over or near the network, and with gradually decreasing accuracy out to the maximum range of the instrument. The maximum range was limited by the radio horizon to an area 400-500 km in diameter. High-speed wireless communications linked the stations to an operations center where sampled data could be processed and displayed in real time. Each station detected the peak radiation event in successive 100 μs time intervals, corresponding to a maximum data rate of 10,000 s^{-1}. Typically several hundred to several thousand sources can be located per lightning flash, which show both the structure and development of the discharges inside the cloud.

For further description of the measurement approach and examples of the results, see www.lightning.nmt.edu. The system operates extremely well, providing detailed pictures both of individual lightning discharges and of the total lightning activity in a storm, and monitors the overall lightning activity over a large geographic area. Some highlights of the results are as follows:

• Lightning is essentially continuous and volume-filling in the large and often severe storms of the U.S. central great plains (Krehbiel et al., 2000). Of particular interest has been the discovery of lightning-free regions or 'holes' in tornadic and supercell storms that appear to be associated with strong rotating updrafts. In several cases, tornadoes formed on the western edge of the lightning holes. Also discovered is the occurrence of frequent, short duration (sub-millisecond) discharges within the overshooting convective tops of large storms. The discharges rise up above the other lightning activity in the storm over a time span of 3–4 minutes, reaching a maximum altitude of 16 to 19 km and indicating a strong convective surge in the storm.

• The LMA observations have been found to be a good indicator of storm intensity and development. Plan views of the density of radiation sources are similar to PPI scans of radar reflectivity in that they show the convective cores of storm systems as well as the overall extent of the electrically active parts of a storm. Vertical projections show the the vertical extent and growth of the storm. Time animations of the observations show the motion and convective 'pulsations' of the storm.

• The lightning observations are useful both for studying the electrical structure of storms as well as the lightning discharge types and processes themselves. For example, a primary goal of STEPS was to study convective storms in which the cloud-to-ground (CG) lightning is predominantly of positive polarity, namely it lowers positive charge to ground. Normal storms in their convective stages produce predominantly negative CG lightning. Numerous +CG storms were observed in STEPS. The intracloud (IC) lightning in these storms was also observed to be inverted in polarity from normal storms, namely to be between upper negative and lower positive charge. (In normal storms IC discharges tend to occur between a mid-level negative and upper positive charge regions.) This indicates that the storms are somehow 'inverted' in polarity, and raises important questions about the electrification processes (see Paper P12.1 by Rust et al.).

• A number of anomalous or inverted polarity storms were observed that produced substantial intracloud lightning but no cloud-to-ground discharges, either over their entire lifetime or for substantial periods in their initial stages. For example, the tornadic storm of June 29, 2000 produced large numbers of IC discharges during the first 90 minutes of its existence, but only one CG discharge (a +CG). During this time the storm gradually intensfied to the tornadic stage, whereupon it started

[1]Visiting from the Plateau Institute of Atmospheric Physics, Chinese Academy of Sciences, Lanzhou, People's Republic of China.

producing relatively large numbers of +CG discharges (1–4 per minute). The lack of CG activity in anomalous storms suggests that there is no 'lower' charge in the storm to initiate such discharges.

• The LMA observations provide considerable information about the lightning discharge processes themselves. For example, the polarity of a discharge can be determined from its direction of development; impulsive RF events are produced primarily by negative polarity breakdown into positive charge regions, fewer events are produced by positive polarity breakdown into negative charge regions. Since the location of each radiation source is known it is possible to estimate the total VHF power radiated by the source. The results show that negative polarity breakdown produces stronger impulsive radiation than positive polarity breakdown (Thomas et al., 2001).

• Additional phenomena of interest are the occurrence of numerous short-duration (single source, less than 100μs duration) RF events, both randomly in the upper part of a storm and in overshooting convective tops, and as precursors of normal, large scale discharges. Some of the short-duration events are highly energetic, radiating VHF source powers of several hundred kilowatts. These are referred to as 'positive bipolar' events because of the shape of their fast electric field change, and are undoubtedly the source of energetic Trans Ionospheric Pulse Pairs (TIPPs) observed to emanate from the earth at VHF by satellites (Smith et al., 1999; Rison et al., 2000, Thomas et al., 2001)

• The STEPS program also provided excellent observations of the multiple +CG discharges that propagate over 50-100 km distances through the trailing stratiform regions of storms (Thomas et al., 2000a). These included discharges that initiated sprites at high altitudes in the atmosphere above the storms (Lyons et al., 2000).

• The ground-based VHF lightning mapping observations have been compared with optical images of lightning obtained by NASA's Lightning Imaging Sensor (LIS) on the TRMM satellite (Thomas et al., 2000b). Intracloud lightning discharges were readily detected by the LIS and cloud-to-ground discharges were less-well detected in the large storm system of the study.

The mapping system has proven to be highly useful for studying thunderstorms and for the regional monitoring of lightning activity. Second generation versions of the mapping system are currently being set up by NASA in northern Alabama and by the University of Oklahoma near Oklahoma City. A commercial version of the mapping system has been developed by Global Atmospherics, Inc., of Tucson, Arizona; an initial system is being operated in Dallas-Fort Worth for monitoring thunderstorms around large metropolitan areas and airports.

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