A Lightning Mapping Array for West Texas: Deployment and Research Plans

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1. Introduction

Texas Tech University (TTU) will be deploying a VHF Lightning Mapping Array (Krehbiel et al. 2000; Thomas et al. 2004) during 2011. Initial site survey work was carried out during fall 2010. Site surveys and infrastructure work are ongoing and final deployment is planned for mid-to-late summer 2010. The network, which will be called the West Texas LMA (WTLMA), and its research objectives are described herein.

2. Network location and hardware

The 11-station WTLMA network will be centered on Lubbock County, and will provide 3D mapping within a 150 km diameter circle. 2D mapping of all flashes in thunderstorms will extend to 400 km. The western edge of the 2D detection network will reach past the New Mexico border. To the east, coverage will touch the southwest corner of Oklahoma, and will link up with a planned Oklahoma network expansion near Altus, OK (Fig. 1). This extensive network, with a combined 800 km x 400 km 2D domain will provide a unique opportunity to fully map extensive mesoscale convective systems and long-track supercells. It is expected that co-processing data from the combined Oklahoma and West Texas networks will also provide an extensive, contiguous area of 3D mapping. Such coverage will be ideal for storm electrification studies and will also broaden the number of possible targets for field campaigns seeking lightning measurements in supercell storms. The new LMA will complement existing observation resources at TTU including the West Texas Mesonet (Schroeder et al. 2005) and TTU Ka-band mobile doppler radars (Weiss et al. 2009).

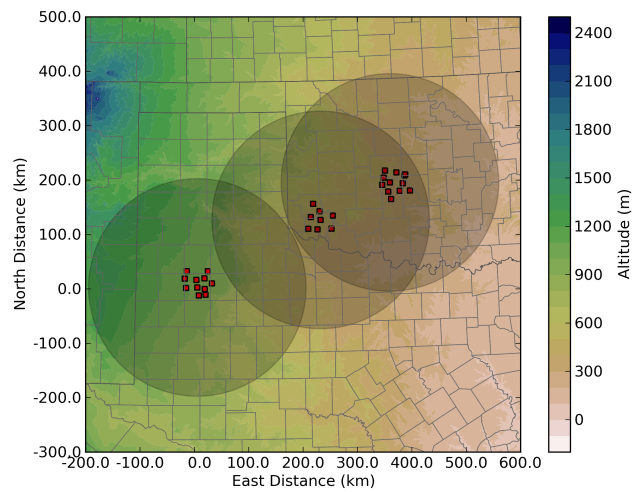

Figure 1: Flash size spectrum (curved line) and $\kappa^{-5/3}$ line, plotted relative to flash width κ for 10 June 2009 over Oklahoma.

LMA station electronics will be of the latest design

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from New Mexico Tech (Rison et al. 2011). The stations will use a redesigned, radio-frequency-sealed electronics enclosure and contain electronics further optimized for low power consumption, nominally 10 W for standalone operation. One of the major power savings was due to the elimination of active cooling. Such low power consumption allows use of direct-current solar power. The greatly reduced RF noise produced by the electronics greatly simplifies deployment, such that a single tripod-type mount can be used for the antenna, electronics, solar panel, and batteries.

The network will be operated in real-time mode, similar to networks in OK (MacGorman et al. 2008), Washington, DC (Krehbiel 2008), and Northern AL (Goodman et al. 2005). As with the DC network, preferred locations for the stations will be with partner schools that can provide internet for reliable transmission of data to the central processing facility at TTU. The present strategy for field installations is to use a 5.4 GHz wireless modem link to transmit data from the LMA antenna no more than one mile away in an adjacent field (isolated from buildings and other VHF noise sources) to the wired internet link. This short-range link should be more robust than past wireless links, and is designed with the needs of real-time users in mind. Data will be processed and delivered to the local National Weather Service Forecast Office in real-time with target latency of 1 min or less. The data will also be provided to the GOES-R Proving Ground (Goodman et al. 2009) and the GOES-R Geostationary Lighting Mapper algorithm team, and other testbeds (e.g. Kuhlman et al. 2010) for use in operational trials and algorithm development and validation.

As of January, 2011, five sites with very good to excellent VHF noise characteristics have been identified. Two others are satisfactory, but it should be possible to work with adjacent landowners to further lower the noise floor at these sites. Four other sites are yet to be surveyed.

3. Lightning research objectives

Underlying the infrastructure and data provision goals described above are a number of scientific objectives for the WTLMA. The following questions are simple and fundamental, and of direct application in interpreting total lightning mapping data:

1. Where does lightning start?

2. Where does lightning go?

3. How do the above factors relate to “large” charge transfers and optical flashing?

Question 3 above is essential in making a connection between VHF LMA data (which maps less-bright leader development, but is available over relatively large time-and-space domains) and the very bright, large charge transfers that create an optical signal detectable from space, as proven with the present TRMM LIS and future GOES-R GLM sensors. Proper emulation of these optical processes using LMA data alone has proven challenging. This question is not addressed further in this study, but could potentially be solved with simultaneous detection of lower-frequency electromagnetic signals also produced by lightning.

Questions 1 and 2 have seen significant advancement in the past decade with the advent of VHF lightning mapping arrays (LMAs), which map all lightning channels in the cloud, with sufficient time resolution and spatial precision to locate their origin and propagation throughout storms. Charge structures inferred from LMAs have been essential in confirming conditions that support both positive and negative ground strikes, and the storm-relative locations in which those flashes happen. Furthermore, the unprecedented time and space scale of LMA data makes it trivial to correlate individual flashes to storm-relative locations indicated by satellite and radar data.

A number of papers have been published (e.g. Carey et al. 2005; Tessendorf et al. 2005; Wiens et al. 2005; Tessendorf et al. 2007; Ely et al. 2008; Bruning et al. 2007, 2010) that relate VHF lightning mapping data to precipitation trajectories in mesoscale convective systems, supercells, and ordinary “airmass” thunderstorms. A close correspondence has been found between deep convective cells and high flash rates, with lower flash rates in advected ice clouds downshear from the convective cores; these principles underly the McCaul et al. (2009) lightning parameterization. Many of these authors have noted that flashes near deep convective updrafts are generally smaller in size, while flashes in stratiform regions tend to have large extents.

The meteorological idea of frontogenesis, which is the time rate of change of the gradient of a scalar may be generalized to apply to turbulent conditions (Kraus 1992), and is a helpful conceptual framework for understanding how the electrification metrics that control flash origin (electric field maxima; Maggio et al. 2005; Marshall et al. 2005; Stolzenburg et al. 2007) and extent (potential wells; Coleman et al. 2003), would be stirred by turbulent deep convection, forming relatively larger or smaller pools of charge that set up more or less frequent flash initiations and more or less extensive flash propagation. Electric potential frontogenesis is the time rate of change of the electric field, and electric field "frontogenesis" is the time rate of change of charge. The flow dynamics under mass conservation contain deformation, tilting, confluence, and local source terms. These processes may represent a theoretical/conceptual link to tie together turbulent, large-eddy flow geometry and flash morphology as represented by initiation location and rate, and flash channel extent. Such flash morphologies are readily retrievable from LMA systems, which have the advantage of resolving the channel structure in great detail.

Comparison of LMA data with high-resolution, rapidly-updating vertical scans of thunderstorms with Ka-band mobile Doppler radars is a high priority. Radial velocity scans with these radars show contrasting regions of highly turbulent flow in and near deep convective updrafts, and relatively laminar-appearing flow regimes outside further away from overturning deep convection (Fig. 2)

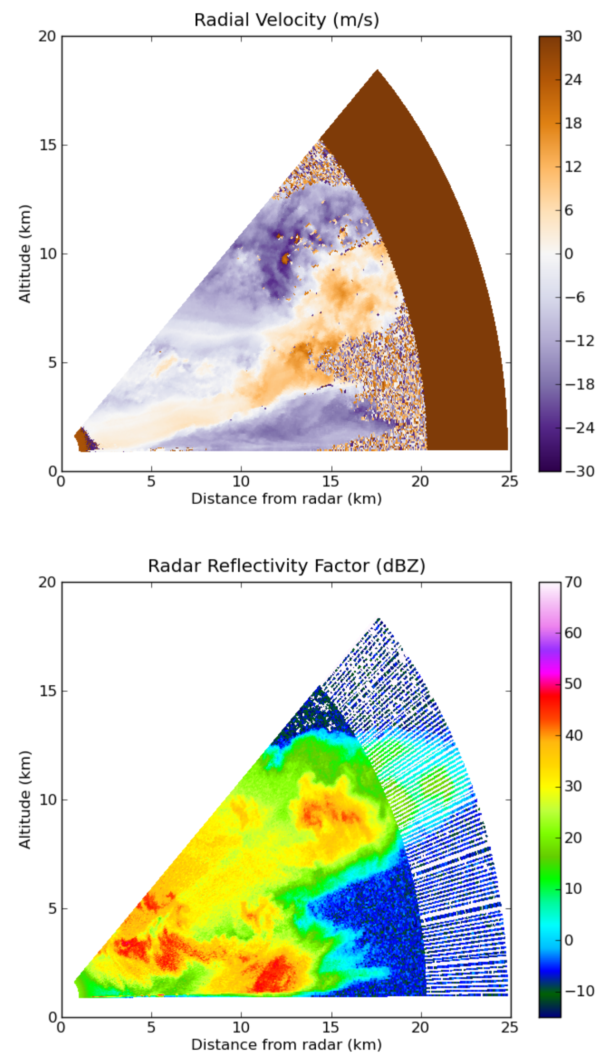

Figure 2: Radar reflectivity and radial velocity data in a vertical (RHI) section through a squall line on 22 October 2010 at 0020:55 UTC near Lubbock, TX. Note that the radar signal attenuates in these images at longer ranges. Inflow rises over a cold pool advancing toward the radar and turns upward into a deep convective plume at 15 km range, while relatively laminar / stratified flow can be seen at 6-7 km altitude between 5-10 km range.

4. Flash sizes and storm kinetic energy spectra

Fig. 3 shows the flash size spectrum for a mixed squall-line and cellular convection case from 10 June 2009 over Oklahoma, for several hours of data. LMA source data were sorted using the McCaul et al. (2009) algorithm into flashes using a time and space criteria of 0.15 s and 3 km, respectively. Flash footprints were calculated as the area of the convex hull of (x,y) event coordinates, and all LMA sources and flash metadata were recorded in an HDF5 file for easy query with PyTables (Alted et al. 2002–). A flexible data processing pipeline written in the Python language for counting and gridding of any parameter in any map projection was developed; source code is available at https://bitbucket.org/deeplycloudy/lmatools/src.

Flash width was calculated as the square root of the flash footprint area, and the total number of flashes in each footprint bin size were counted. The maximum number of flashes is at about 4 km width. A few very large flashes with widths much larger than 10 km were observed. Perhaps most interestingly, the slope of the spectrum at flash widths on the order of 1 km or smaller scales in a quasi-linear fashion in log-log space. Motivated by the previous discussion of turbulence, Fig. 3 also shows the -5/3 power-law relationship for wavelength, which Kolmogorov (1941) proposed to explain the downscale transfer of kinetic energy. The flash size spectra here are similar in shape to plots of kinetic energy spectra taken from the large-eddy resolving squall line simulations of Bryan et al. (2003), including a possible -5/3 scaling region and a maximum in kinetic energy at about 4 km scale. This similarity between eddy-resolving kinetic energy spectra and flash size suggests that, as hypothesized, the turbulent eddy structure of storms may be controlling the flash size.

Flash size spectra are similarly-shaped for other cases, including supercells, but the spectral shapes show some variation, especially for small flash extents. Further investigation of the flash counts at small sizes, including sensitivity to flash algorithm parameters, is planned to test the appropriateness of applying the Kolmogorov (1941) argument to flash size spectra.

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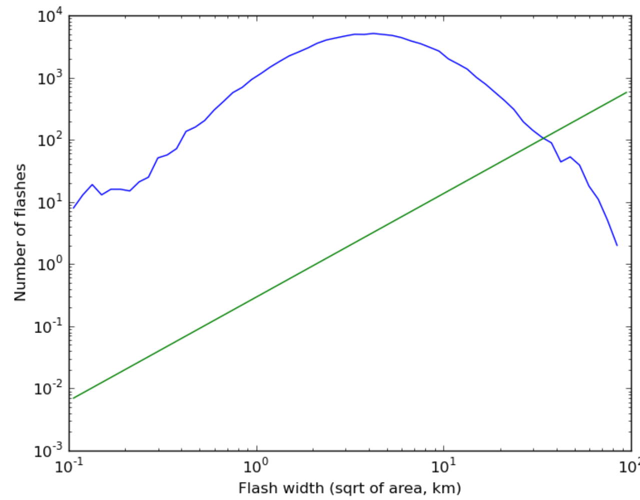

Figure 3: Flash size spectrum (curved line) and $\kappa^{-5/3}$ line, plotted relative to flash width κ for 10 June 2009 over Oklahoma.

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