Development of the Langmuir Electric Field Array (LEFA) – AE43B-0265

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Science Goals

- To use multi-station data to measure charge transport for IC and CG flashes independent from a Lightning Mapping Array (LMA)
- To use multi-station ΔE data constrained by LMA data to see time and space dependence of charge transport along different lightning channels in a single flash.
- To observe and detail positive breakdowns that are poorly visible to radio techniques

Instrument Capabilities

Dynamic Range: Twenty million to one

Measurement Range: Useful measurements on lightning flashes up to 150 km away

Sample Rate: 50 kS/sec sustained on 4 channels at 16-bits/sample (24 MBytes/minute)

Power: 17 Watt/station, Solar-powered

Sites: Six stations currently operational. Twelve are planned.

Network: Wireless 802.11g server separate from instrument. Allows remote control of instrument power

Software Post-Trigger: Continuous data collection in storms. Fair-weather periods used to discard uninteresting data.

Software: Instruments run Debian Linux, C, and Python allowing analysis in the field, remote data collection, rapid reporting of decimated data.

Figure 1: View of station #6, looking North. Shown left to right: WiFi antenna for network. Solar panels, controller and marine deep-discharge batteries for power. White enclosure at center of picture provides summer shade for data-acquisition module. Data acquisition module is placed close to instrument to minimize cable runs. A GPS is used for time synchronization; it is the small black speck on the cement brick on top of data-acquisition enclosure. ΔE instrument sits atop a 6 foot by 6 foot metal mesh so that ground plane is consistent and independent of soil moisture. Barbed wire fence protects against cattle.

Simultaneous Sampling at three Sensitivities

Instrument simultaneously digitizes three channels at increasing sensitivity:

Insensitive - I: Flashes closer than $\simeq 1\ km$ where $0.01 < \Delta E < 100\ \frac{kV}{m}$

Medium - M: For relatively nearby flashes $0.08 < \Delta E < 800\ \frac{V}{m}$

Sensitive - S: For flashes beyond 10 km where $0.001 < \Delta E < 10\ \frac{V}{m}$

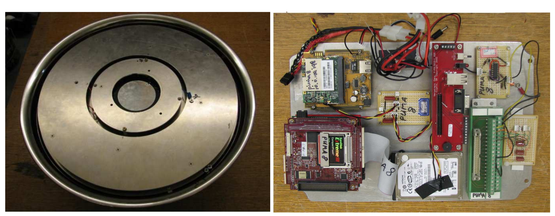

Figure 2 [left]: The three ΔE sensors are arranged concentrically. The outermost has area $A_S = 0.1\ m^2$. The middle sensor-ring has $A_M = 0.02\ m^2$. The innermost sensor ($A_I = 0.005\ m^2$) is built onto the circuit board which contains three independent charge amplifiers.

[right] Data acquisition unit. In the *lower-left corner* is a Pentium-class PC-104 single-board computer (Versalogic Puma) stacked with two data acquisition (DAQ) boards. The fast-DAQ (Apex STX-104) samples 4 channels in parallel at 50 kHz/channel. The four data streams are time from the GPS and the three E-sensors. The slow-DAQ (Technologic TS-9700) samples < 10Hz. It is for temperature and battery status and (in the future) for a field mill. In the *upper-left corner* is a Wiligear WBD-111 with WMR-400 radio. This small Linux appliance keeps the network running and can power-cycle all other systems via remote commands. The hard-drive holds 100 hours of continuous data. Other boards are for interfacing and signal conditioning.

Siting the Array: The need for Calibration

In an initial test before field deployment, four stations were collocated on the flats between Socorro and Magdalena, NM in July of 2009. Despite being only 10 m apart, and having circuit boards calibrated to within 0.1% in the laboratory, instruments were found to vary in relative sensitivity by 20%. Further, we have deployed stations in mountainous as well as flat terrain. Local topography leads to sensitivity variations. For high precision charge models to be realized, the relative gains of the stations must be known as well as possible. Thus, field calibration is essential. Fortunately, it can be done using distant flashes of lightning.

Distant Flashes

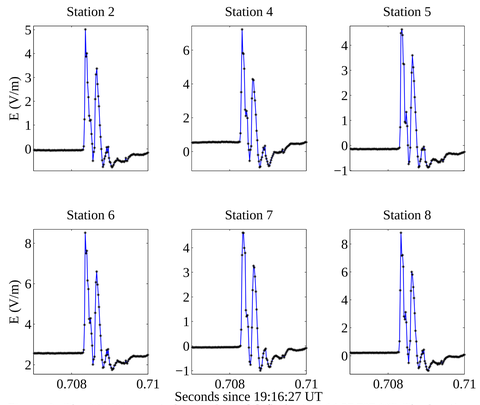

Figure 3: The NLDN reported a 228 kA +CG flash at 19:16:27.707 UT. The location was 101 km north and 105 km west of LEFA station #2. These six waveforms correspond to that event. The time of the peak shown in all six plots is 19:16:27.70835 UT. Note that all waveforms are identical except for amplitude. This allows the use of distant flashes like this to calibrate the instrument in-situ. For example, station #7 on the mountain is roughly 2.5 times as sensitive as station #6 on a flat plain.

Note these flashes produce no step change in E-field. Given the lack of step-change and the well-known result [Uman75] that lightning E-fields proportional to the current attenuate at $1/r^2$ whereas electrostatic fields proportional to the charge transferred fall as $1/r^3$, it is likely that these are primarily current effects. The large positive spike would be consistent with the expected shape of a return-stroke current wave-form for a positive CG flash. Three subsequent peaks of decreasing amplitude occur at a $300\mu s$ interval. Perhaps these are time-delayed reflections off the ionosphere and the ground. In calibrating the instrument at a distance, ionospheric image charges must also be accounted for. [Ross08]

October 20, 2009 frontal storm

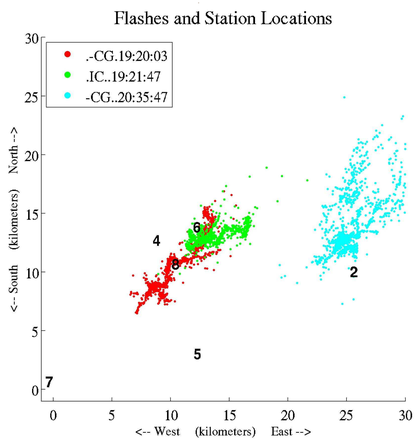

Figure 4: Several flashes of the 10/20/2009 storm were within 2 km of some station of the array. Three of those flashes are shown in this planview of LMA sources. Station #s in black indicate the location of each of the six stations participating in the measurement. The zero of our coordinate system is located at the Langmuir Laboratory annex. Station 7 is at the balloon hangar on the mountain. Station 2 is atop the physics building in Socorro, NM. The same colors used to represent each flash in Figure 4 are used to show the E-field data for that flash in columns 3 and 4 of this poster.

Acknowledgments

We thank Steve Cummer of Duke University and Vaisala for providing NLDN data in connection with collaborative work on the large CG flashes shown here.

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19:20:03 UT, CG Flash

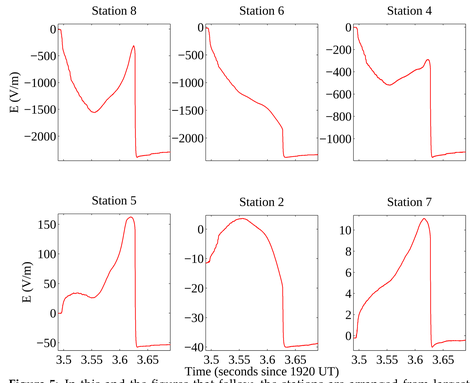

Figure 5: In this and the figures that follow, the stations are arranged from largest ΔE to smallest. A negative CG flash with a single return stroke occurred over the center of the array. Note that all stations show a negative step in E-field at 19:20:03.63 UT. However, the IC activity preceeding the return stroke is dramatically different between the stations; thus explaining it should give a lot of detail about the charge structure of the flash. Note also that all E-field data presented has only been scaled and dedrooped. The only filter applied is a custom narrow notch filter to remove 60 Hz noise-pickup from power lines.

20:35:49 UT, CG Flash

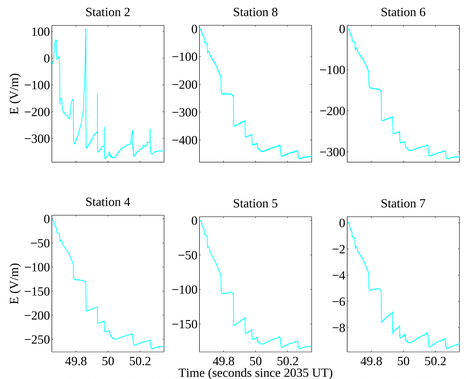

Figure 6: The first stroke of this negative CG flash occurred 20:35:49.8 UT. The multiplicity of this flash was six. The weak seventh feature straddling 50.0 seconds is some IC activity.

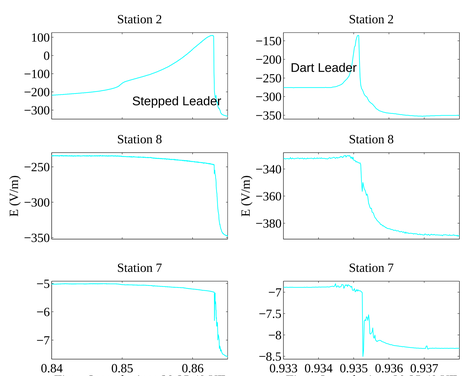

Figure 7: Higher resolution views of the 2nd and 3rd return strokes at the closest and furthest station and at one in between. The 2nd stroke has an ordinary stepped leader, while the dart leader for the 3rd return stroke is clearly resolved. A negative E-field spike at 49.9353 seconds is not visible at station 2 and becomes more visible with increasing distance from the flash. It is assumed to show the current spike in the return stroke. (The same effect observed in Figure 3 for the distant flash.) The current effect is also visible at station 7 for the return stroke of the first flash.

19:21:47 UT, IC Flash

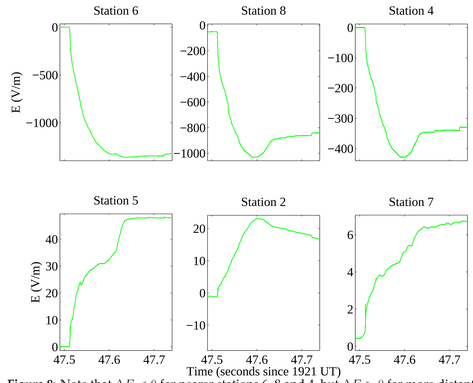

Figure 8: Note that $\Delta E < 0$ for nearer stations 6, 8 and 4, but $\Delta E > 0$ for more distant stations 2, 5 and 7. This field reversal is expected if one considers an IC flash to be a dipole in the sky.

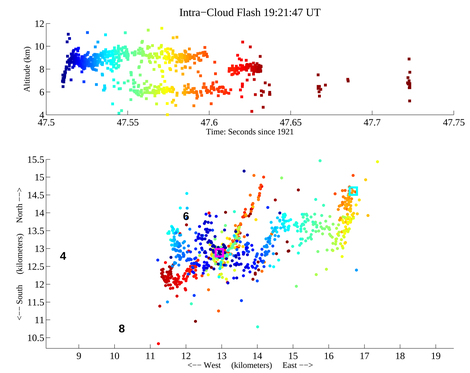

Figure 9: The magenta box at coords (13,13) marks where the flash began. The position of the three nearby stations are marked with their station numbers. The cyan box at (17,14) indicates the end of a long negative leader which stops growing at 47.6 seconds, exactly when the E-field at station 2 peaks. Measurements at stations 2, 4, 6, and 8 are consistent with a growing dipole which points from the magenta to the cyan box. We hope to learn the detailed charge transport of this flash by applying one of the models recently developed for Esondes [Hager09],[Lu10].

Conclusions

The following classical results obtained in a brief analysis of a single storm convince us that the newly constructed LEFA array is working as designed:

- Distant flashes are useful look identical to all stations apart from a constant factor. They provide useful ongoing information allowing cross-calibration between stations.
- For distant IC flashes, current effects dominate charge effects.
- Nearby CG flashes show stepped and dart leaders that reverse in sign at larger distances.
- The gross E-field changes observed in nearby IC flashes are consistent with a model in which every LMA point gets and keeps a constant charge, and charge is conserved.

The array will continue to be built out, and detailed modeling studies can begin on already obtained data.

References

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[Uman75] M. Uman, D. McClain & E. Krider, *The Electromagnetic Radiation from a Finite Antenna* , Am. J. Phys., V43, pp.33-38, (1975).