Multi-mode Observations of Cloud-to-Ground Lightning Strokes

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Introduction

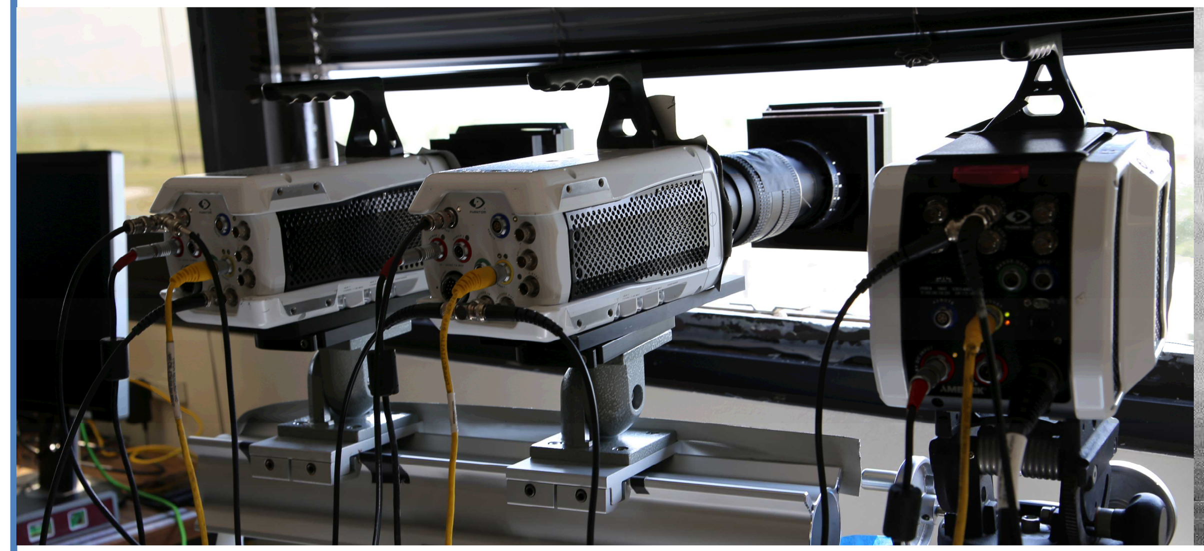
The ability to identify and characterize lightning discharges observed from the ground or from space is an area of significant interest for both geophysics and remote sensing. During the summer of 2015 personnel from Sandia National Laboratories (SNL) set up a suite of high speed sensors on the southern edge of Albuquerque, NM and collected data over a period of six weeks during the summer thunderstorm season. The sensor suite included an imager and a pair of slit-less spectrometers with different spectral resolutions. This poster highlights some of our results. A companion poster describe a lightning model that is being developed at SNL, and compares measured and modeled spectra.

References

1. “A High-Speed Time-Resolved Spectroscopic Study of the Lightning Return Stroke: Part I. A Qualitative Analysis”, R. E. Orville, Journal of the Atmospheric Sciences, **25**, 827-838 (1968)
2. “Daylight Spectra of Individual lightning Flashes in the 370-690 nm Region”, R. E. Orville, Journal of Applied Meteorology, **19**, 470-473 (1980)
3. “Spectral (600-1050 nm) time exposures (99.6 µs) of a lightning stepped leader”, T. A. Warner, R. E. Orville, J. L. Marshall, and K. Huggins, Journal of Geophysical Research, **116**, D12210 (2011)

Methods: Sensor Suite

Slit-less spectrometers (left) and imaging camera (right).



Central portion of scene as recorded by imaging camera.

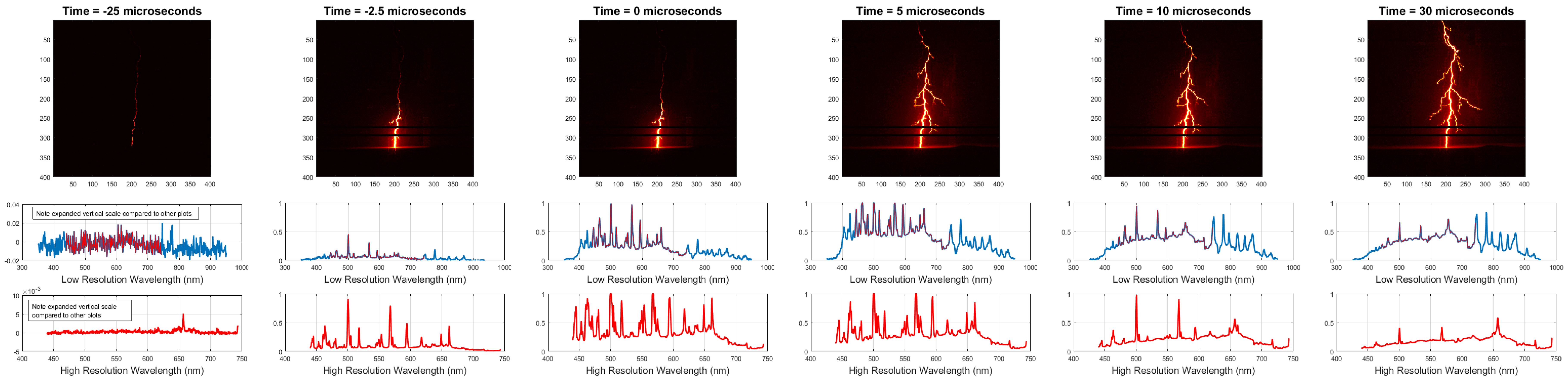
	11 July 2015 to 21 July 2015	22 July 2015 to 22 August 2015
Low Resolution Spectrometer	Dispersion = 0.79 nm/pixel, FWHM = 1.2 nm Frame rate = 400 k/s, Exposure = 1.0 – 1.7 µs	Dispersion = 1.10 nm/pixel, FWHM = 2.5 nm Frame rate = 400k/s, Exposure = 0.5 – 0.6 µs
High Resolution Spectrometer	Dispersion = 0.17 nm/pixel, FWHM = 0.38 nm Frame rate = 350 – 400 k/s, Exposure = 2.0 – 2.4 µs	Dispersion = 0.24 nm/pixel, FWHM = 0.66 nm Frame rate = 250 – 275 k/s, Exposure = 3.0 – 3.3 µs
Imager	Frame rate = 25 – 50 k/s, Exposure = 10.0 µs	Frame rate = 12.5 – 50 k/s, Exposure = 7.0 – 10.0 µs

Methods: Calibration

Spectral Calibration Performed:
- Calibrate spectrometer dispersion with argon lamp
- Use low resolution data that show 0th and 1st order spectra and the corresponding images to calculate the offset between image pixels and location of 0th order light in low resolution channel
- Use results from these two steps to calculate an approximate wavelength scale for each strike
- Up sample low resolution spectra and correlate to known lines in lightning spectra to refine results
- Correlate the high resolution spectra to the fully calibrated, up sampled low resolution spectra

Radiometric Calibration Plans:
- Calibrate the absolute end-to-end radiometric response of each sensor as a function of wavelength
- Use results to find irradiance arriving at sensor
- Identify exact location of strike using NLDN data
- Find distance from sensor to strike
- Calculate atmospheric transmission along path
- Use results to calculate radiance at the source

Results: Sample Sequence of Lightning Images and Spectra



The sequence above shows data that was collected at night on August 17, 2015. The dark bands in the images show the approximate extent of the vertical field of view of the two spectrometers. The spectral range of the high resolution data is highlighted in red in the plots of the low resolution data. T = 0 is defined as the time at which the integrated output of the high resolution spectrometer peaked. For these collects the low resolution spectrometer was running at 400k fps, the high resolution spectrometer was running at 250k fps, and the imager was running at 50k fps. Multiple spectra were therefore collected for each image. Spectral calibration has been carried out, but the data have not been radiometrically calibrated. A few interesting trends stand out. A faint leader channel, as shown in the left most panel, could be discerned for a significant period of time prior to the bright illumination produced by the return stroke. Emission from the H_α line at $\lambda = 656.3$ nm dominates the leader emission, and persists out to the longest time shown. Line emission increases dramatically in the first several microseconds of the return stroke (from -2.5 us to 5 us). Emission at wavelengths less than 700 nm then shifts to primarily continuum emission, although the N II lines at 500 nm and 568 nm are fairly persistent. The emission at wavelengths longer than 700 nm remains structured for a longer period of time than the emission at shorter wavelengths. Presumably this is due to the fact that emission from neutral species ($\lambda > 700$ nm) is more persistent than emission from ions ($\lambda < 700$ nm), which revert rapidly to neutral species.

Summary and Conclusions

During the summer of 2015 personnel from Sandia National Laboratories (SNL) observed lightning in central New Mexico with a high speed imager and a pair of high speed slit-less spectrometers. We collected data on about 65 lightning strikes. All events were captured by the imager. Spectral coverage was not as consistent due to intermittent camera noise issues.

Preliminary data analysis reveals several interesting features. Emission from the H_α line at $\lambda = 656.3$ nm dominates the leader emission, and persists for a long time during the return stroke. Line emission in general increases during the first several µs of the return stroke. Emission at wavelengths less than 700 nm then shifts to primarily continuum emission. Emission at wavelengths longer than 700 nm (which is dominated by neutral species) remains structured for a longer period of time than the emission at shorter wavelengths (which is dominated by emission from ions). This data will be used to validate a lightning model that is being developed at SNL.

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