Reverse Geolocation of Imagery Taken from the ISS Utilizing Lightning Datasets

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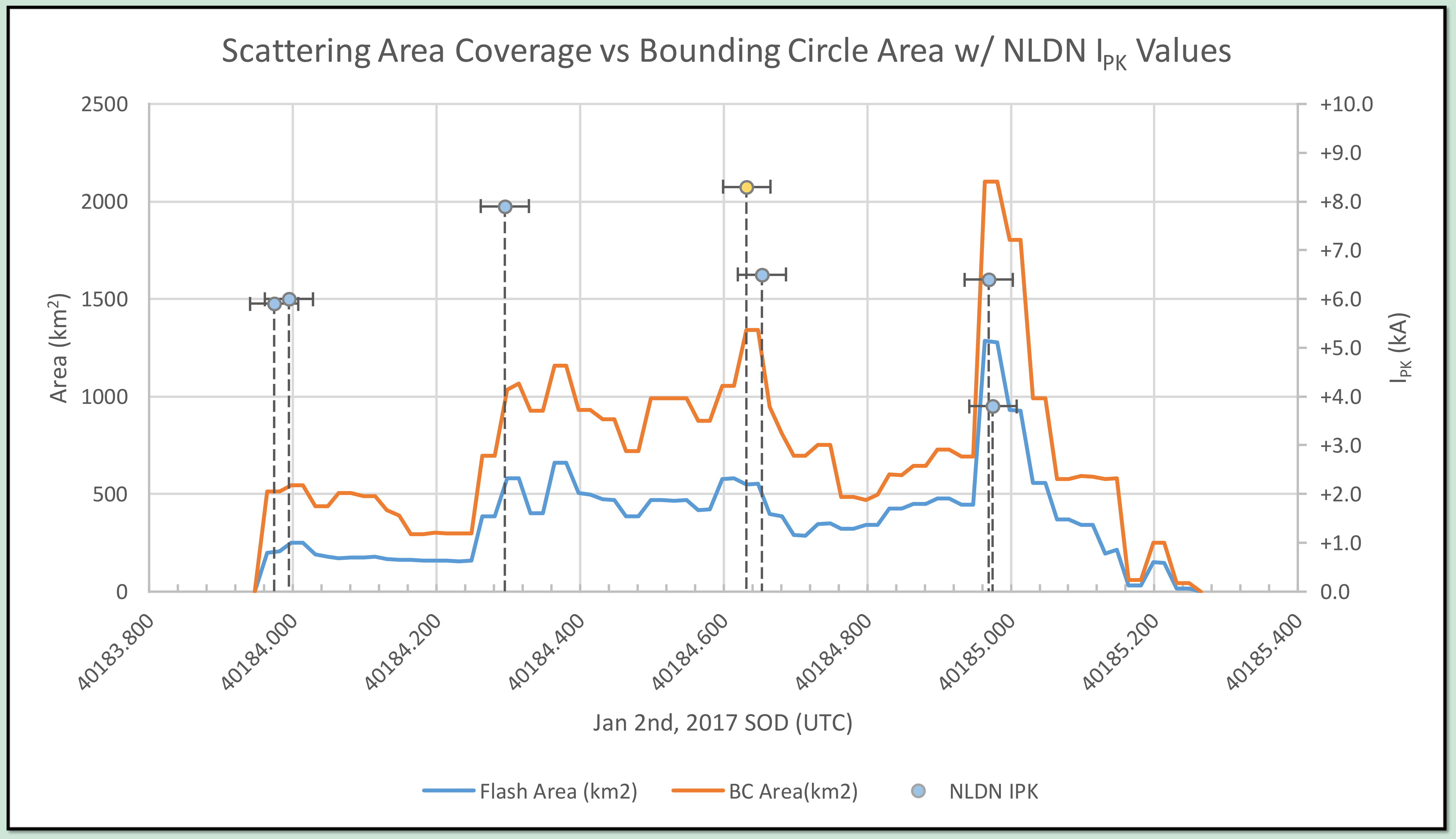
Introduction

Vantage points from Low Earth Orbit (LEO) and Geostationary Orbit (GEO) provide unique opportunities for imaging high flash rate storms. These events produce lightning phenomena, such as red sprites- electrical discharge into the ionosphere triggered by thunderstorms, and continuing current lightning- where a discharge lasts on the order of tens of milliseconds compared to the typical ~1ms [1]. Efforts between NASA's Marshall Space Flight Center and Johnson Space Center aim to use hardware already in orbit, primarily aboard the International Space Station (ISS), to image high flash rate storms.

Nadir imagery is captured utilizing standard DSLR cameras. Video footage is provided curtesy of Chiba University METEOR Camera team from their instrument aboard the ISS. The timeframes under study by the METEOR team happen to coincide with optimal viewing of lightning from LEO. The tools under development for analysis and classification of this data aim to provide quick and accurate means of classification regardless of camera parameters by instead relying on direct image analysis.



Time series of the perceived coverage of a lightning flash over the course of 80 consecutive METEOR frames. NLDN Flash data closely correlates with the peak coverage values, intermittent peaks correspond to intracloud flashes not detected by NLDN. The minimum bounding circle can be used to approximate leader speed. This particular event occurred over Austin, TX, January 2nd, 2017. It lasted over 1400ms with 14 observed flashes, 7 of which registered as unique NLDN flash events with a multiplicity of one.

Methodology

Imagery can be reverse geolocated provided one of the following conditions is met:

- **Camera angles are known**
- **Precise time of image capture is known**

The unknown condition can be solved with

- guess-and-check approach for near nadir camera pointing angles
- temporal alignment to an auxiliary dataset

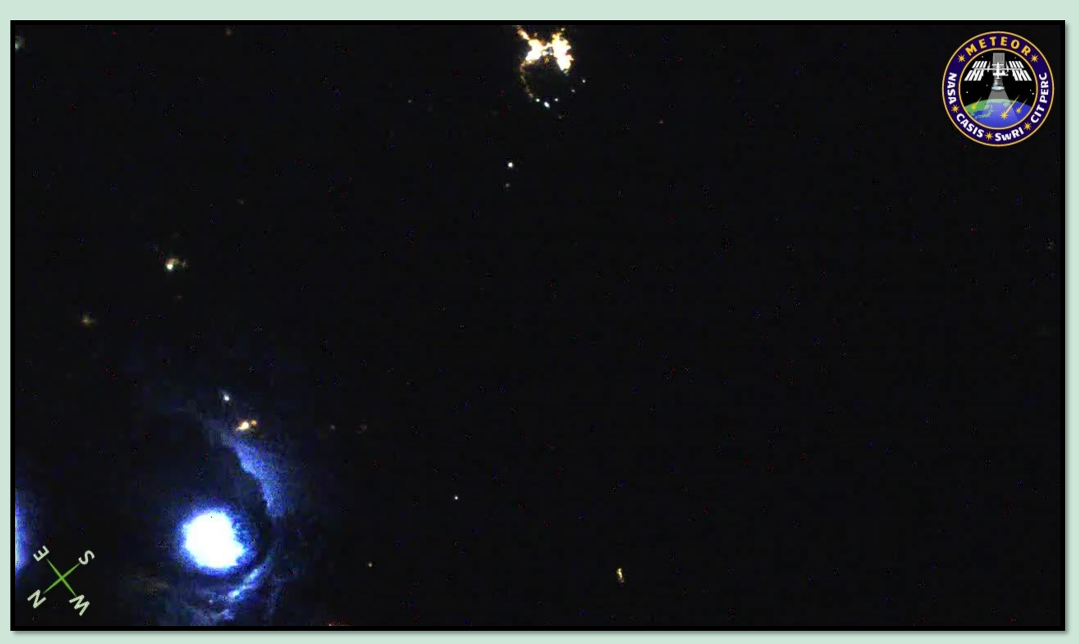
A least squared approach on temporal error can be applied to find precise timing across a range of sequential images of which the time between images is known (i.e. frame rate).

After alignment of the image to a latitude/longitude coordinate system, analysis on individual flashes can be performed. Approximations on spatial flash parameters can be achieved with sufficient temporal resolution. The ~18ms between frames of METEOR video has proved to be near the minimum temporal resolution due to the inability to capture the optical emission from flash initiation, this makes analysis of some flash parameters, such as leader speed, difficult or impossible to quantify.

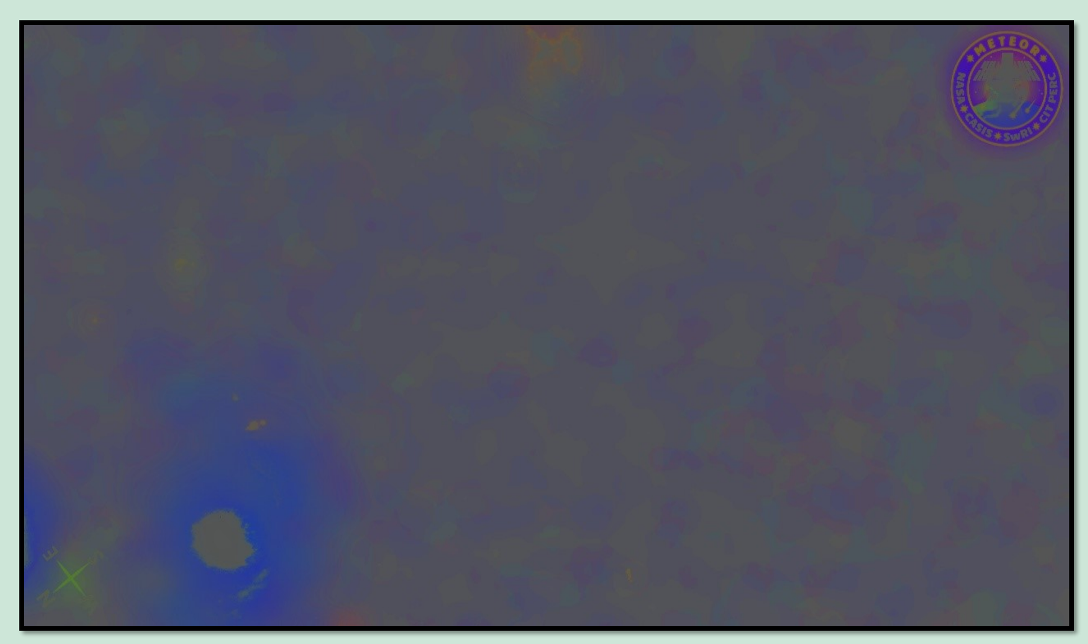
Instrumentation

In practice, no Lightning Locating System (LLS) achieves total detection efficiency due to each type of LLS detecting a different subprocess of a flash[2]. These processes include:

- Detection of very-high-frequency/high-frequency signals that pinpoint radiation emitted from electrical breakdown of air
- Detection of very-low-frequency/low-frequency electromagnetic waves associated with the return stroke process of a flash
- Detection of optical discharge from LEO/GEO



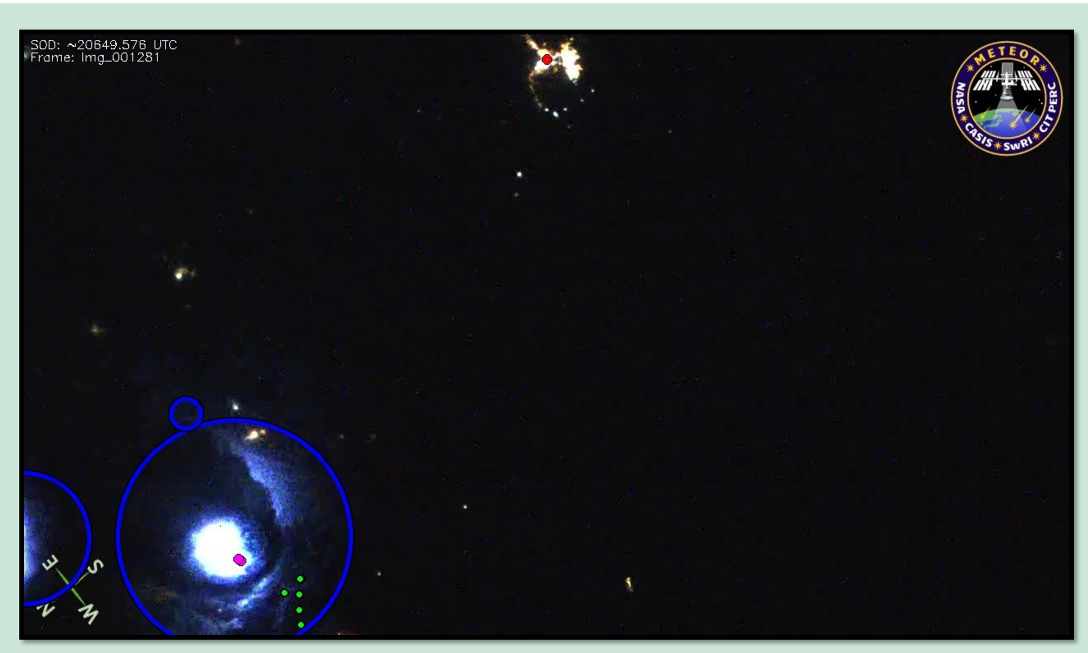
Input image from a METEOR video. Del Rio, TX is located top center. This image was chosen based off of the strong flash geometry used to initially verify timings for this METEOR video. The large amount of light escaping from the side of the cloud lead to some interesting edge case tests on the flash identification algorithm.



Input image after a bilateral blur with a 49x49 kernel size with 0.75 std. dev. for space and color. Standard analysis utilized a 9x9 kernel. The image was then converted to the red green chromaticity color space in order to remove intensity information of pixels for accurate thresholding, especially around city lights.

Reverse geolocated image from METEOR video over Southern Texas, May 17, 2017. This image was located using known pointing angles and precise timing from identified lightning flashes. The image was then plotted on top of a Visible Infrared Imaging Radiometer Suite derived city light map and sensor data overlaid. Courtesy of Tim Lang.

Red Green Chromaticity image after conversion to Hue Saturation Value color space and application of thresholds to find pixels with highest blue values. The resulting image is a binary mask that has underwent one erosion and seven dilations in order to remove high frequency noise and combine fragmented contours.



Final output of algorithm. The blue circles represent the minimum bounding circles around contours meeting a minimum radius of ten pixels. The green dots represent ISS-LIS event data, whereas the fuchsia dots are NLDN flash data. The single red dot is Del Rio, TX. Note the offset between ISS-LIS and NLDN Data.

Conclusion

Reverse geolocation of hand-held DSLR imagery had its benefits; whereas data quality is excellent, pitfalls include:

- Few cases w/ current aux. sensor data
- Images are often taken at oblique angles

Reverse geolocation METEOR video proved to be a far more in-depth process than initially anticipated, these challenges included:

- Over exposure of video for flash analysis
- Video compression artifacts

The resulting algorithms compensate for many of the above issues; offering flexibility, decent performance, and unique analysis by:

- Utilizing generalized approaches in order to accommodate a variety of input formats
- Exploring relatively new areas of flash MS analysis with machine vision

References/Acknowledgments

[1] Bitzer, Phillip M. "Global Distribution and Properties of Continuing Current Lightning". Journal of Geophysical research: Atmospheres, January 2017, accessed July 2017.

[2] Bitzer et al. " A Bayesian Approach to Assess the performance of Lightning Detection Systems", American Meteorological Society, March 2016, accessed July 2017.

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