Ground- and Space-based Observations of Horizontally-extensive Lightning Flashes

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Abstract

Horizontally-extensive lightning flashes occur frequently in association with mature and late phases of multicellular thunderstorms, both in trailing stratiform regions and horizontally-extensive anvils. The spatial relationship between these flashes and the parent cloud volume is of importance for space launch operational decision making, and is of broader scientific interest. Before this question can be accurately addressed, there is a need to understand the degree to which current lightning observation systems can depict the spatial extent of these long flashes. In this ongoing work, we will intercompare the depiction of horizontally-extensive flashes using several ground-based lightning locating systems (LLSs) located at Kennedy Space Center (KSC) with space-based observations observed by the recently-launched Geostationary Lightning Mapper (GLM) onboard the GOES-16 satellite. Ground-based datasets include the KSC Lightning Mapping Array (KSCLMA), the operational narrow-band digital interferometer network MERLIN, and the combined cloud-to-ground and cloud lightning dataset produced by the U.S. National Lightning Detection Network (NLDN). The KSCLMA system is a network of VHF time-of-arrival sensors that preferentially report breakdown processes, and MERLIN is a network of VHF interferometers that point to the discharges in the horizontal plane. Observations to date indicate that MERLIN and the KSCSLMA provide similar overall descriptions of the spatial and temporal extent of these flashes, while the NLDN does not provide adequate spatial mapping of these flashes. The KSC LMA system has much better location accuracy, and provides excellent 3-dimensional representation within ˜100 km of KSC. It also has sufficient sensitivity to provide 2-dimensional flash mapping within ˜250 km of KSC. The MERLIN system provides a more-detailed representation of fast leader propagation (in 2 dimensions) with ˜100 km of KSC. Earlier work during the CHUVA campaign in Brazil with similar systems and the (orbital) Lightning Imaging System (LIS) has shown that the interferometric data correlated much better in space and time with the LIS optical observations. We are currently investigating this relationship at KSC, where both the LMA and interferometer perform much better than the systems used during CHUVA.

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Introduction

Horizontally-extensive lightning flashes occur frequently in association with mature and late phases of multicellular thunderstorms. The spatial relationship between these flashes and the parent cloud volume is of importance for space launch operational decision making, and is of broader scientific interest. Our campaign aims at looking at how well both ground- and space-based lightning measurements perform in detecting these horizontally-extensive flashes.

Two severe thunderstorms at the Kennedy Space Center (KSC) during 2017 summer were studied. For nearby flashes (centered within 40 Nm of KSC), flash parameters including flash length, flash extent, and flash area were determined from the convex hull of the plan projection area of the VHF sources that comprised the flash.

Lightning Datasets

Ground-based networks:

- **Lightning Mapping Array (LMA)** at KSC: uses VHF time-of-arrival that preferentially detects breakdown sources. Used as **ground-truth** for this study.
- **The Mesoscale Eastern Range Lightning Information Network (MERLIN)**: uses VHF interferometry to preferentially detect fast leader processes.
- **National Lightning Detection Network (NLDN)**: uses VLF/LF time of arrival and direction finding techniques to detect both return strokes and cloud pulses.

Satellite-based sensor:

- **Geostationary Lightning Mapper (GLM)**: detects the optical emissions from return strokes, k-changes, etc.

Preliminary Findings

Out of 67 flashes studied:

- 10 exhibited a good spatial match between GLM and LMA (< 3 single pixel differences);
- 32 had LMA channel(s) extending more than 12 km (~1.5 GLM pixel size) beyond GLM;
- 4 had more than 3 GLM pixels (~8x8 km²) extending beyond any LMA sources;
- 27 showed high-energy GLM burst(s) lasting >50 ms;
- 37 exhibited initial breakdown sources that were not detected by GLM;
- 0 had GLM illumination before the first LMA source;
- 0 had GLM illumination after the last LMA source.

References

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- Bruning, E.C. and Thomas, R.J., 2015. Lightning channel length and flash energy determined from moments of the flash area distribution. *Journal of Geophysical Research: Atmospheres*, 120(17), pp.8925-8940.
- Smith, T.M., V. Lakshmanan, G.J. Stumpf, K.L. Ortega, K. Hondl, K. Cooper, K.M. Calhoun, D.M. Kingfield, K.L. Manross, R. Toomey (2016), Multi-Radar Multi-Sensor (MRMS) Severe Weather And Aviation Products Initial Operating Capabilities, *BAMS*, 97 (9), DOI: 10.1175/BAMS-D-14-00173.1
- Kingfield, D., K. Calhoun, K. de Beurs, and G. Henebry, 2017: Effects of City Size on Thunderstorm Evolution Revealed through a Multi-Radar Climatology of the Central United States. *J. Appl. Meteor. Climatol.* doi:10.1175/JAMC-D-16-0341.1, in press.

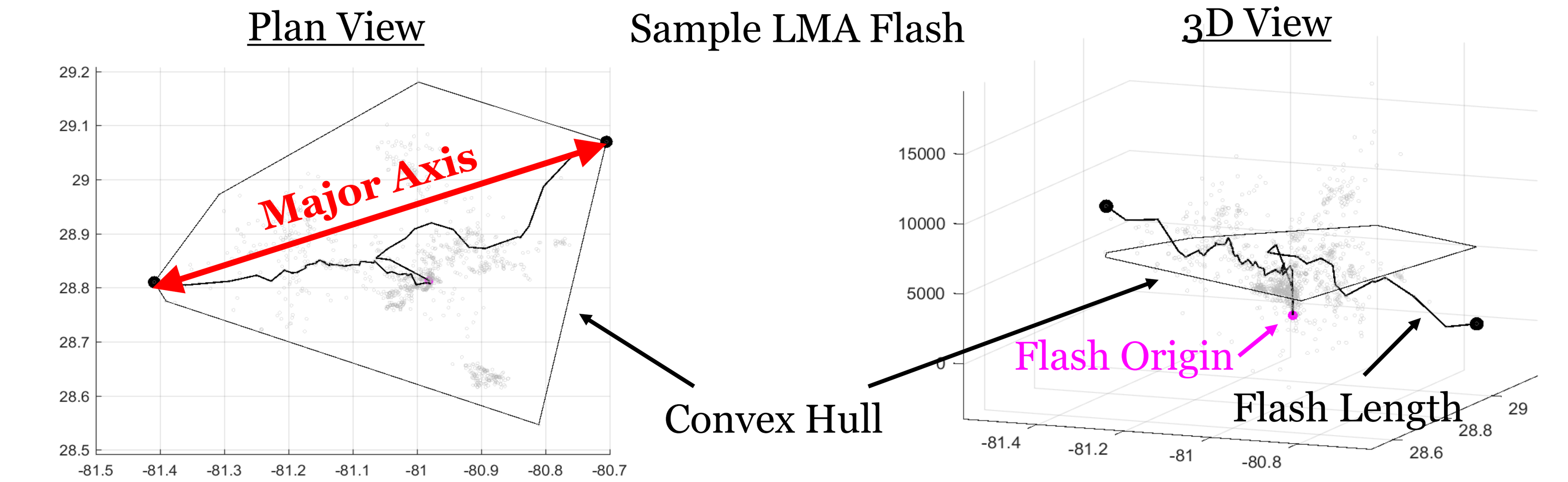
Flash Size Measurement Method

Create **Convex Hull** Flash object (see Bruning and MacGorman (2013); Bruning and Thomas (2015))

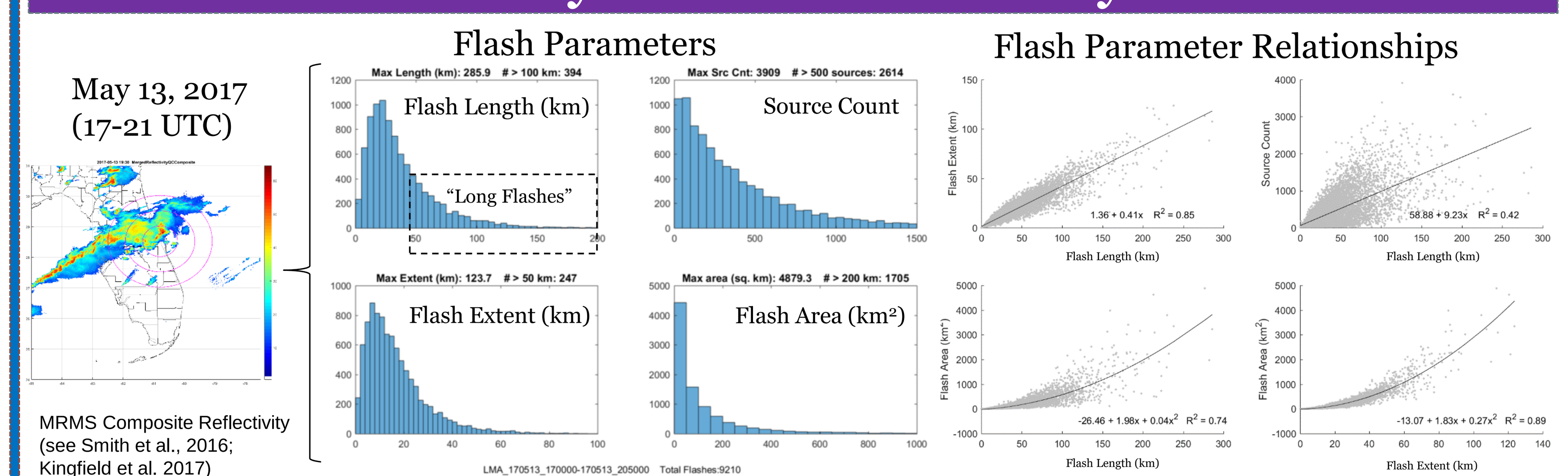
Flash Area: defined as hull area

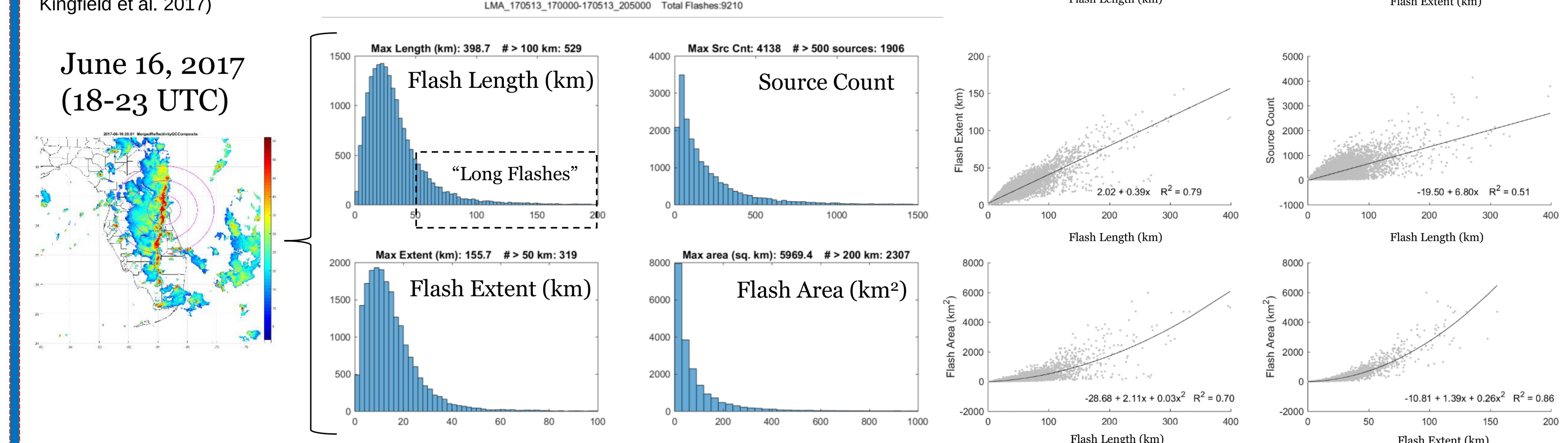
Flash Extent: defined as major axis length

Flash Length: defined as total path length of connected LMA sources from major and minor axis limits back to flash origin



Daily Flash Size Summary

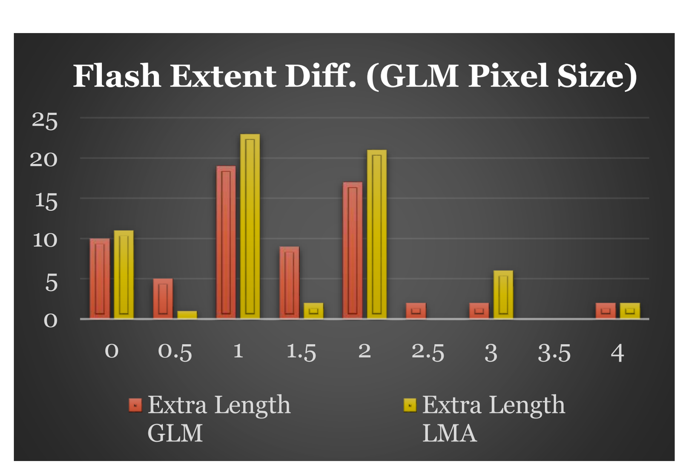




GLM Flash Feature Statistics

GLM Flash Detection Features:

- No GLM pixel illuminated **before** the first LMA source
- No GLM pixel illuminated **after** the last LMA source



Basic GLM Features :

F1: Spatial Match with LMA (<3 single pixel differences)

F2: Missed LMA long channels (>1.5 GLM pixel)

F3: Had larger spatial extent (>=3 GLM pixels)

F4: Had high-energy Burst(s) (>50 ms)

F5: Detected initial breakdown/stroke (first 100 ms)

	F1	F2	F3	F4	F5
Yes	14.9% (10/67)	47.8% (32/67)	6.0% (4/67)	40.3% (27/67)	46.3% (31/67)
No	85.1% (57/67)	52.2% (35/67)	94.1% (63/67)	59.7% (40/67)	53.7% (36/67)

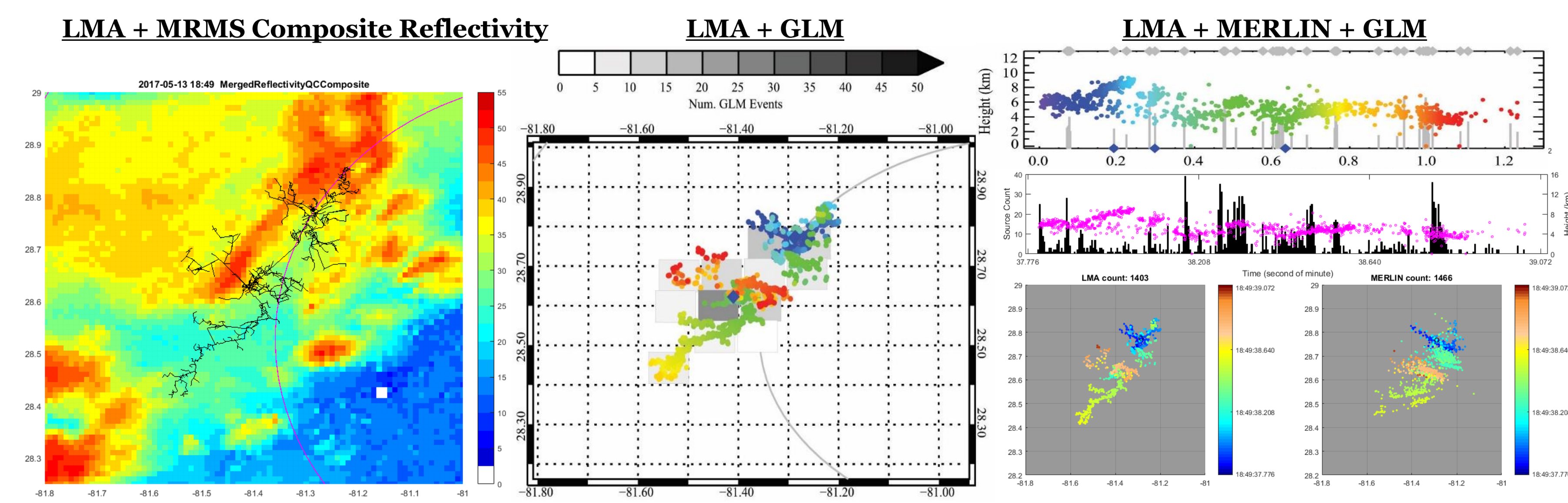
Flash Case Study

Flash Summary (IC flash):

- May 13, 2017 18:49 UTC
- The flash originated at higher reflectivity (35 dBZ), propagating to lower reflectivity (25 dBZ)

Features:

- GLM and LMA spatially matched well
- Both GLM and MERLIN reported the LMA extensive channel
- No GLM high-energy burst
- MERLIN and GLM correlated well

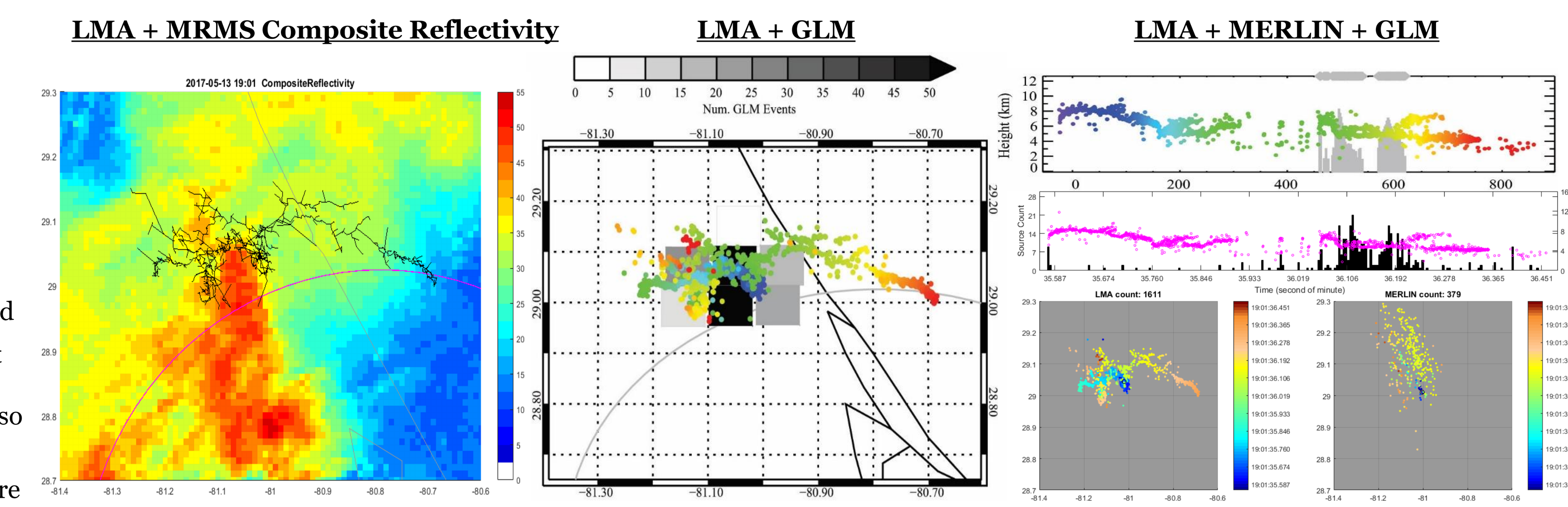


Flash Summary (IC flash):

- May 13, 2017 19:01 UTC
- The flash originated near high reflectivity boundary, and stopped at reflectivity < 15 dBZ

Features:

- GLM did not report the initial breakdown sources , but MERLIN did
- GLM reported sources over land, but did not report sources (extensive channel) over the ocean. MERLIN also failed to report this channel
- The two GLM high-energy bursts were also seen by MERLIN

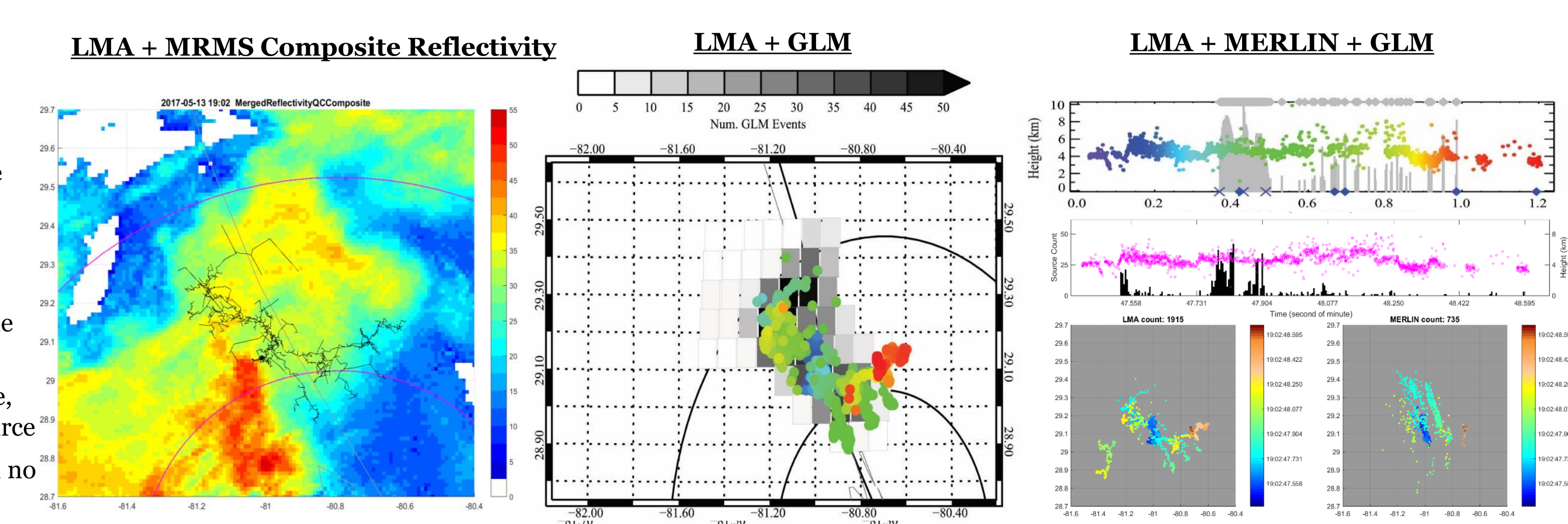


Flash Summary (CG flash):

- May 13, 2017 19:02 UTC
- The flash originated at a high reflectivity boundary, propagated in two directions, and stayed within the >15 dBZ region

Features:

- GLM did not report the LMA initial breakdown sources, nor the tips of the extensive channels
- GLM burst began with first CG stroke, about 400 ms after the first LMA source
- GLM reported a fairly large area with no LMA sources

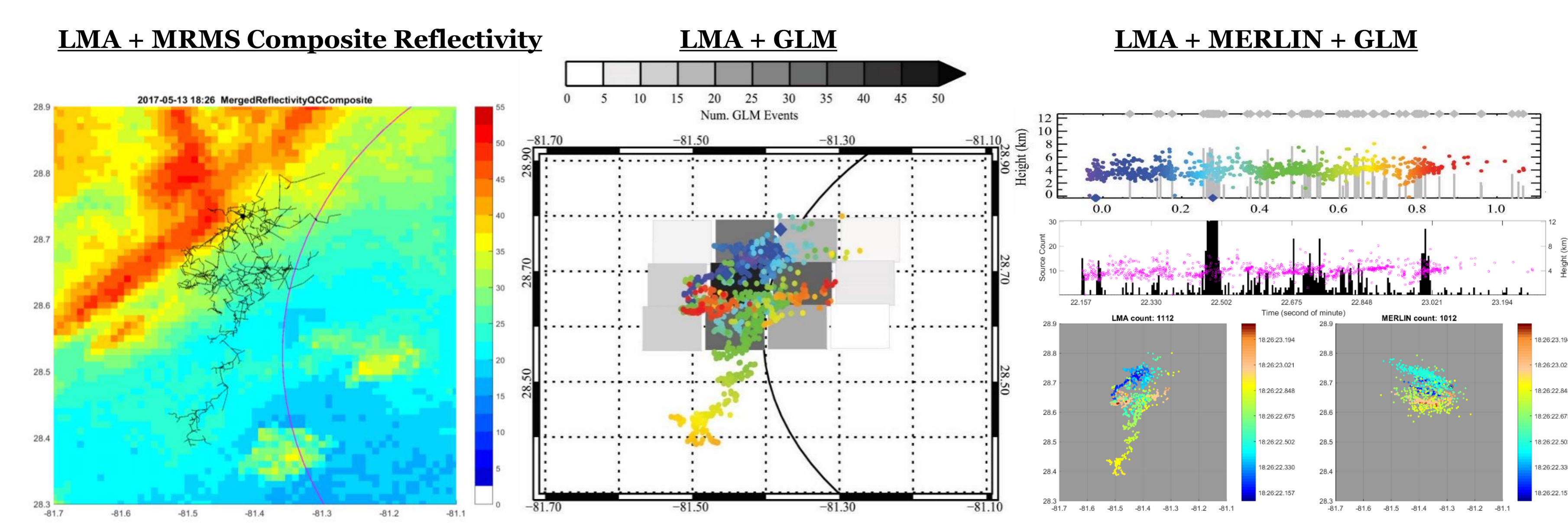


Flash Summary (IC flash):

- May 13, 2017 18:26 UTC
- LMA sources started at a high reflectivity boundary (35 dBz) and propagated to lower reflectivity (>20 dBz)

Features:

- Neither GLM nor MERLIN reported the LMA extensive channel
- GLM did not report the initial breakdown processes



Note that GLM and MERLIN exhibited similar spatial and temporal "burst" patterns, except that MERLIN reported flash initial breakdown

(see presenter about viewing animations of other "cool flashes" ☺)