CHARACTERIZATION OF THE GLM PERFORMANCE
(FOCUS ON SHORT-PERIOD ASSESSMENT)

- OR –

ON THE USE OF GROUND-BASED LLS NETWORKS TO CHARACTERIZE LIGHTNING OBSERVATIONS FROM SPACE

Ken Cummins

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THE UNIVERSITY OF ARIZONA®

SCOPE OF THIS PRESENTATION

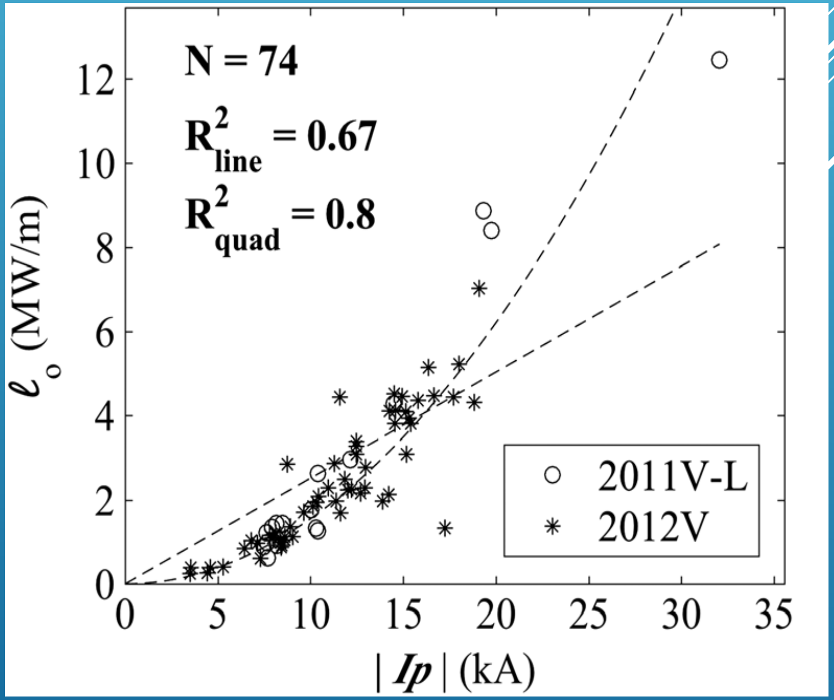
- Key Points from decades of doing this kind of work
- Illustrative examples of short-term on-orbit assessments
- Illustrative example of longer-term assessment using LMA
- (time-permitting): Quantifying GLM detection:
  first-principles modeling and observations

KEY POINT #1

The common physical parameter relating ground-based systems measuring low-frequency E-M fields, and space-based optical lightning observations is (roughly):

"sub-flash optical energy *produced* by lightning is **Charge-transfer x Channel-length**"

Long Discharge Source Optical Energy $\approx \iint_{l=0;t=0}^{L;T} I^{\beta}(l,t) \cdot dldt$

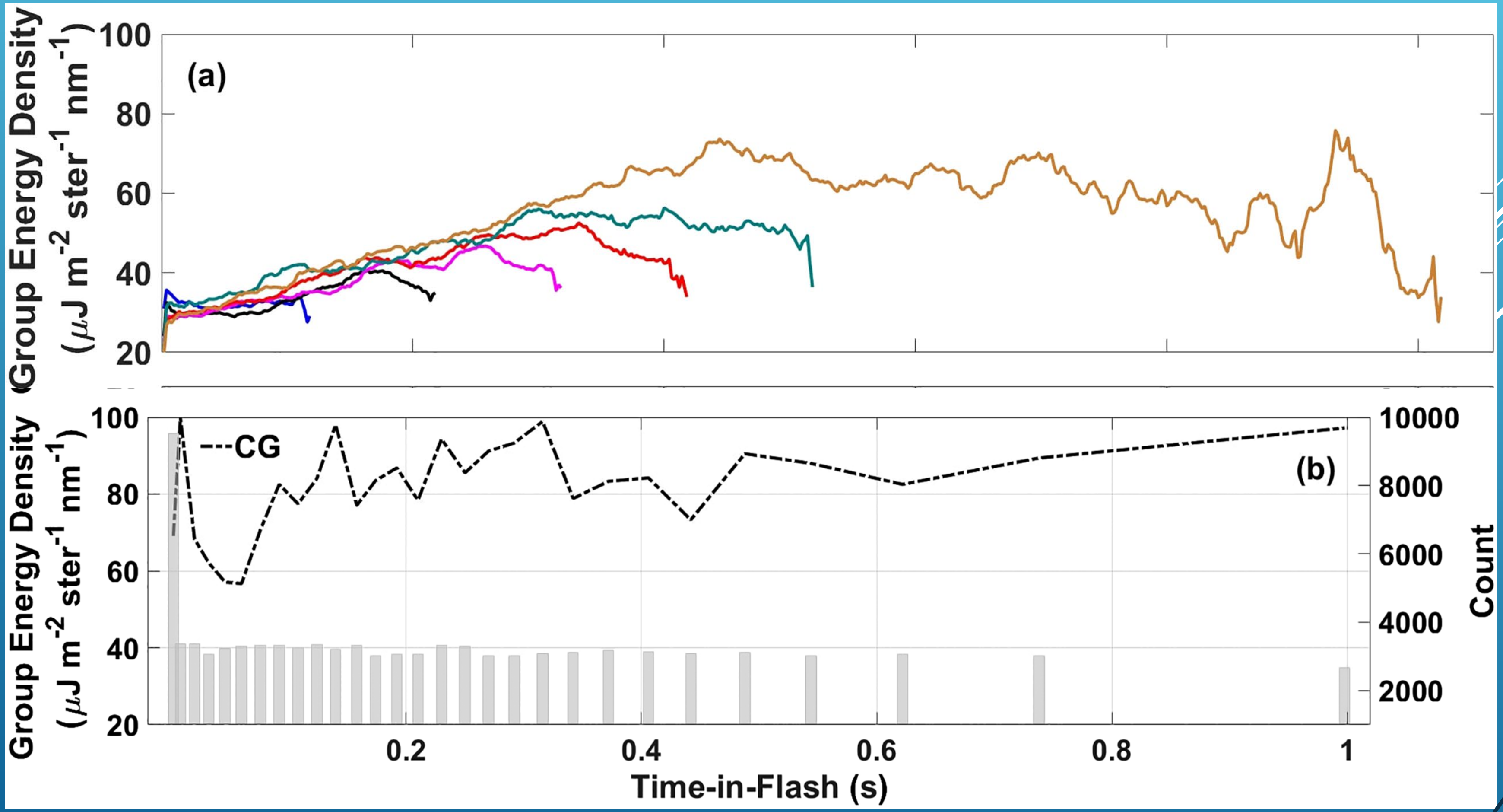


Optical power per unit length ➔
Quick and Krider, JGR 2017

KEY POINT #1 (evidence for "charge x length")

TRMM-LIS optical energy density and source area increase as a function of time-in-flash; therefore, channel length *(Zhang and Cummins, JGR2020)*

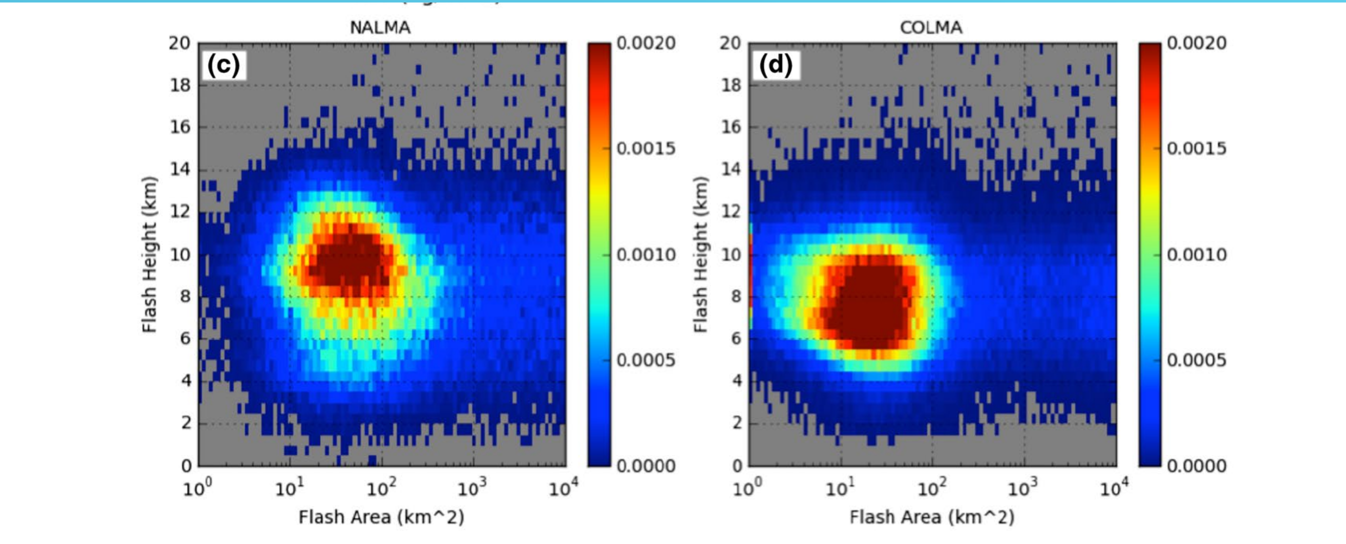
Cloud-to-ground flashes behave differently, possibly because higher-current strokes have shorter breakdown-to-ground-contact intervals *(Nag and Cummins, GRL 2017)*



KEY POINT #1 ½ (the cloud path also matters!)

Regional (and storm specific) difference in *cloud optical depth*, *vertical gradient of scattering particles*, and *channel height* have a strong influence on cloud-top optical energy *(Rutledge et al., JGR2020; Brunner & Bitzer GRL 2020)*

Regional GLM Threshold differences play a significant role, too (more later!)



Lower channel heights (relative to cloud top - above) & dependence of scattering on cloud-top water path (right) results in lower DE In Colorado vs. Alabama

(Rutledge et al. JGR2020)

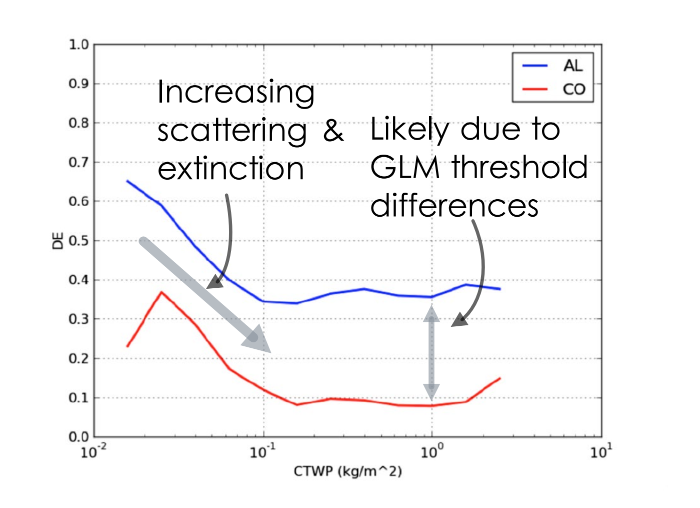


Figure 12. The detection efficiency versus CWP for Alabama (blue) and Colorado (red).

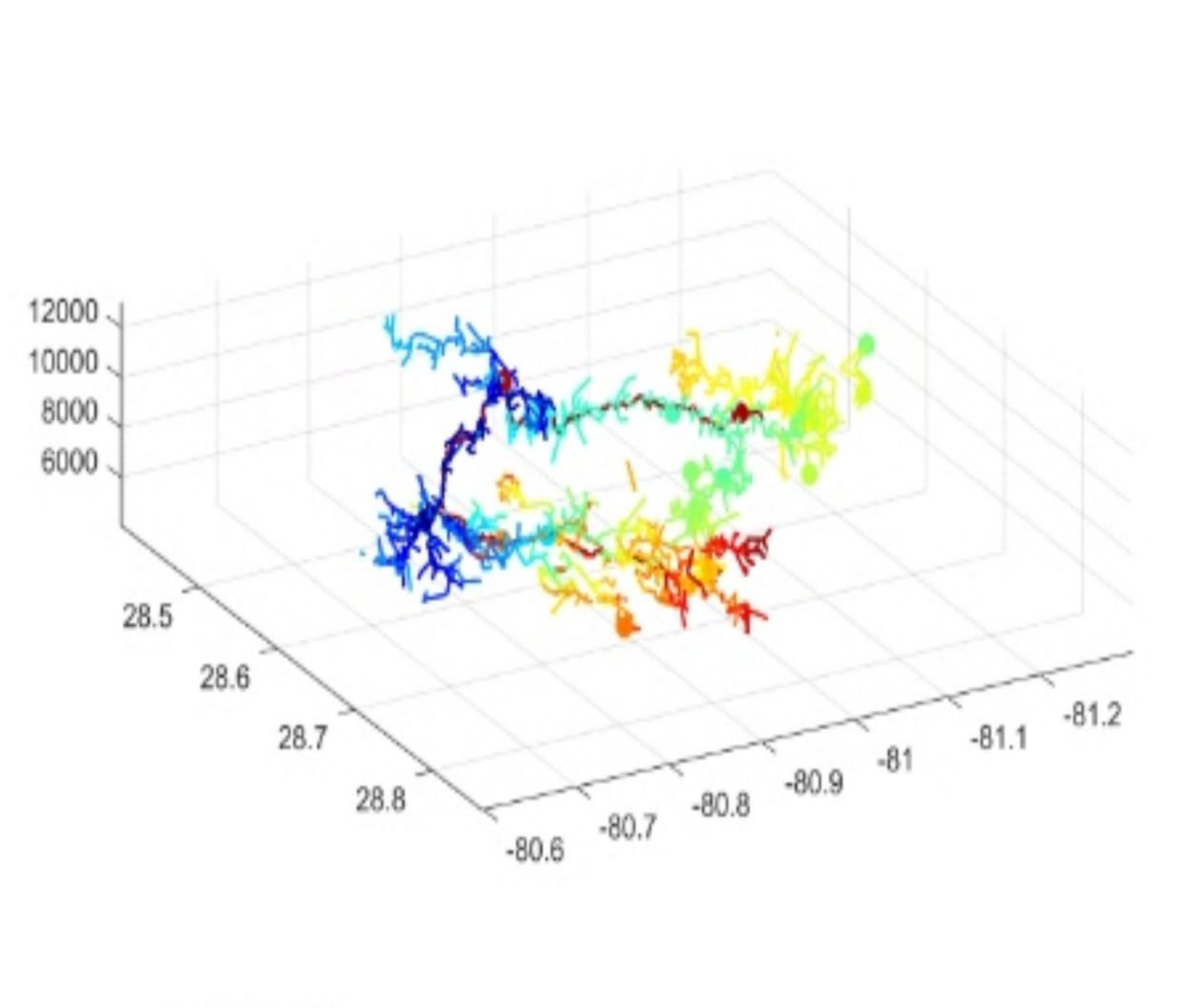
KEY POINT # 2

Networks of ground-based electromagnetic sensors see different lightning processes depending on their operating frequencies.

a. **VLF/LF**: charge transfer over distance and time (current)

b. ***VHF***: breakdown-related processes

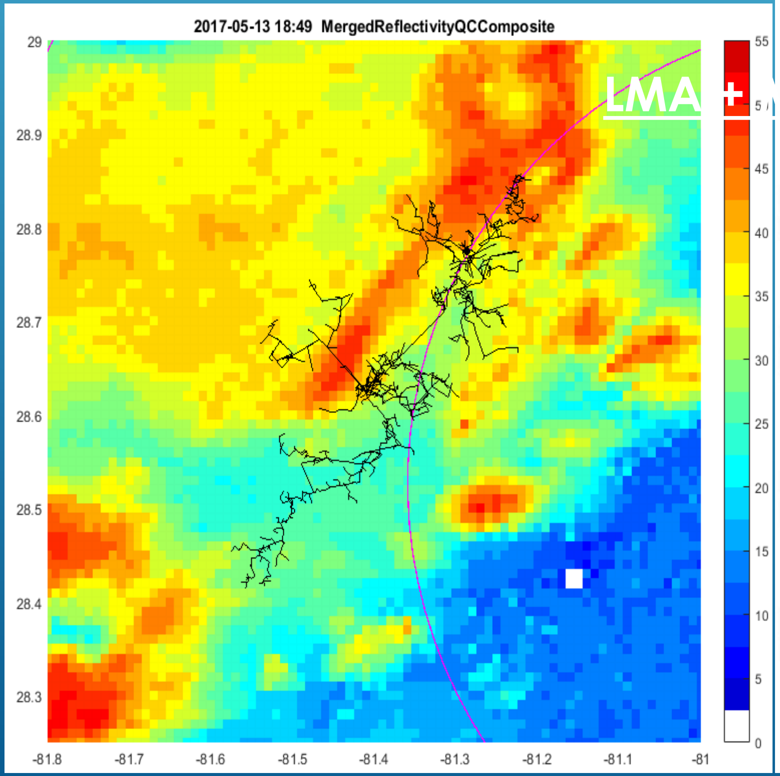
(the two “meet” at k-changes!)



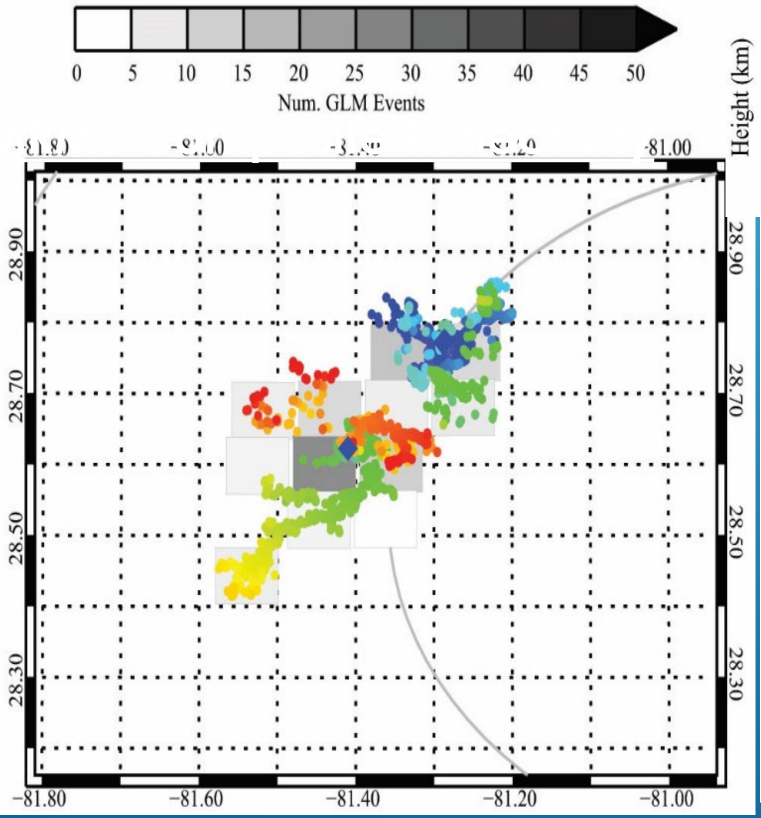
KEY POINT # 2 (examples of simultaneous observations)

LMA=>VHF TOA **GLM**=>Satellite Optical **MERLIN**=>VHF ITF **NLDN**=>VLF/LF TOA

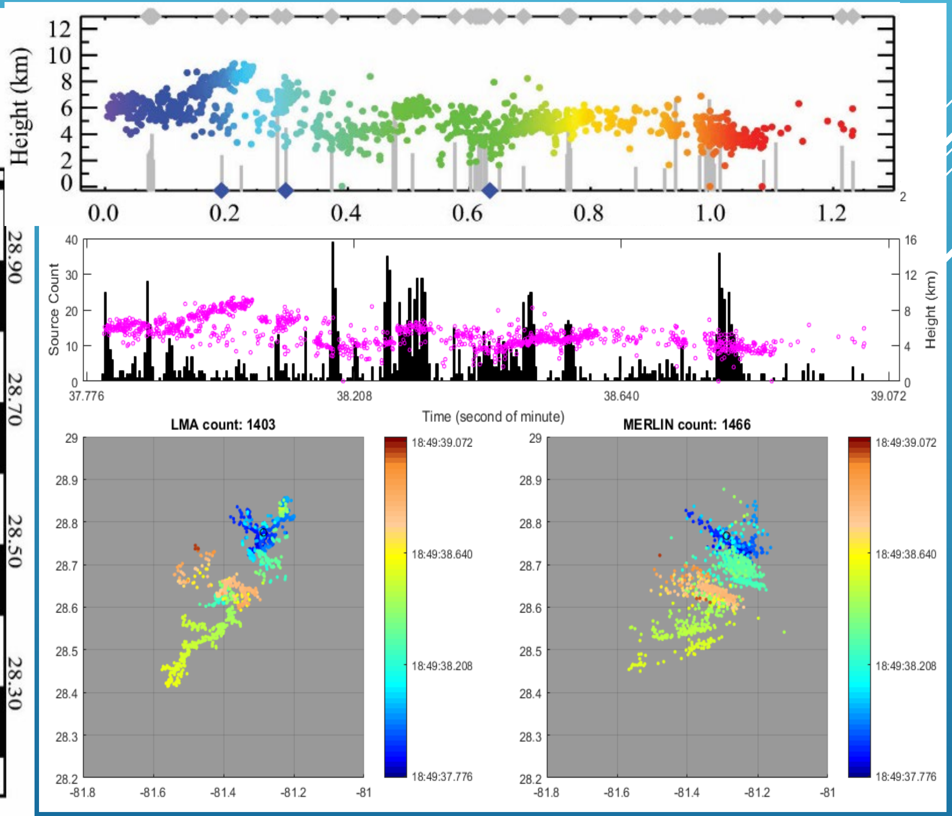
LMA + MRMS Composite Reflectivity



LMA + GLM + NLDN



LMA + MERLIN + GLM + NLDN

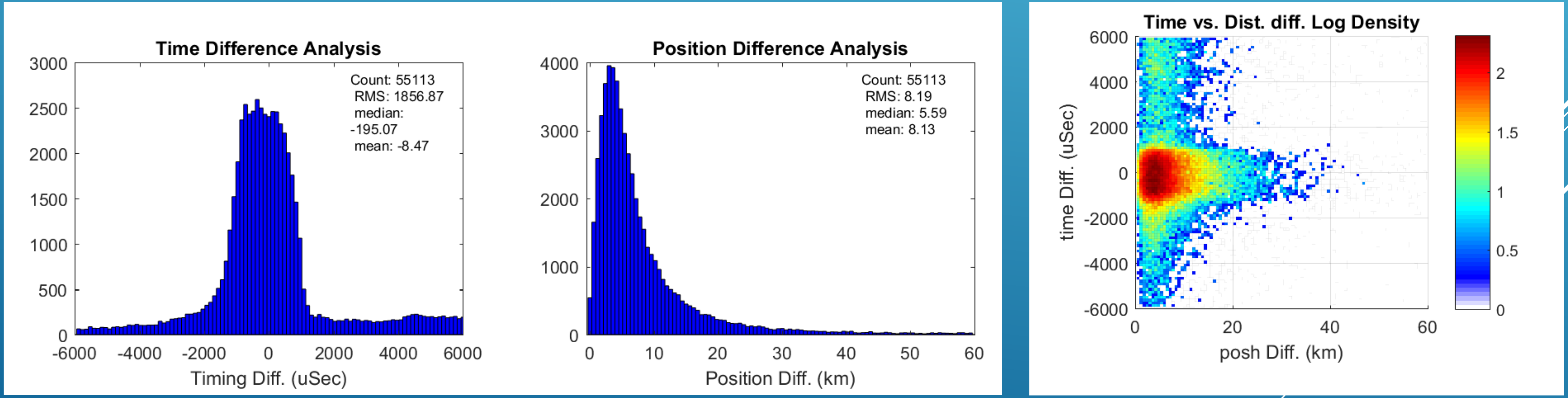


KEY POINT # 3

Practical/useful comparisons require an understanding of the spatial and temporal coherence of the datasets to be compared.

The tighter the space:time coherence, the more you can learn

(Process-level matching for sub-flash location and timing)



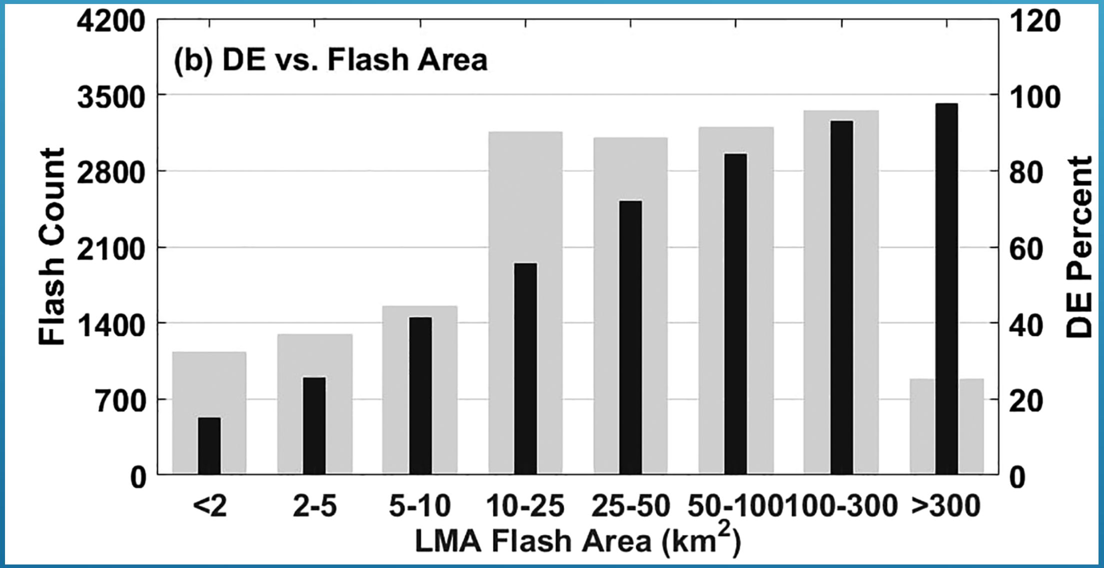
GLD360 space:time matching with GLM during early validation:
(fits with GLM space:time resolution (8-15 km ; 2 msec)

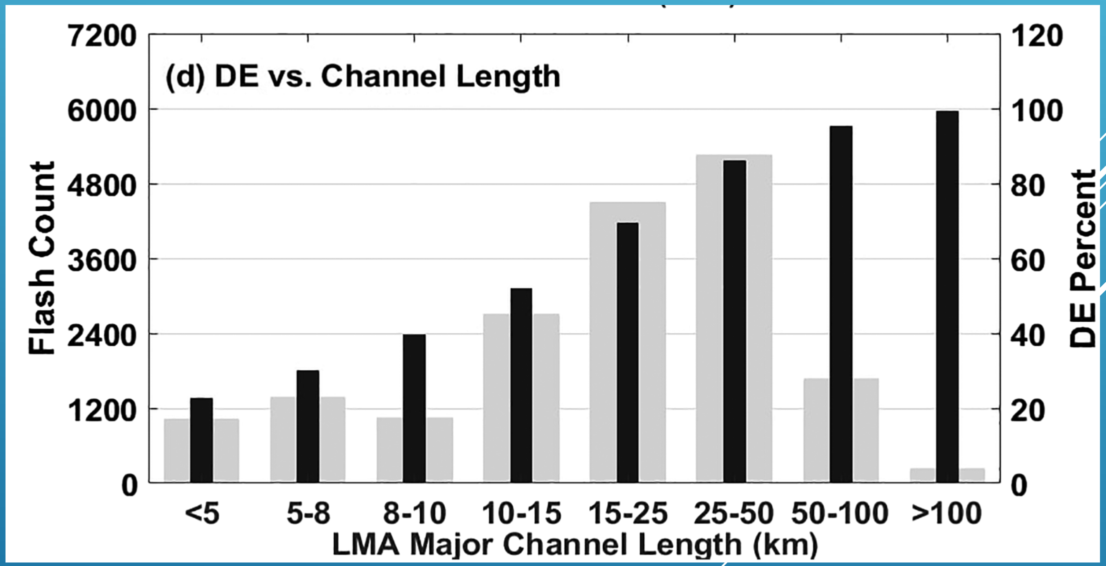
KEY POINT # 3 (crude space:time coherence)

Practical/useful comparisons require an understanding of the spatial and temporal coherence of the datasets to be compared.

coherence only at the flash level is still be very helpful!

(Trade process-level matching for flash parameter information)



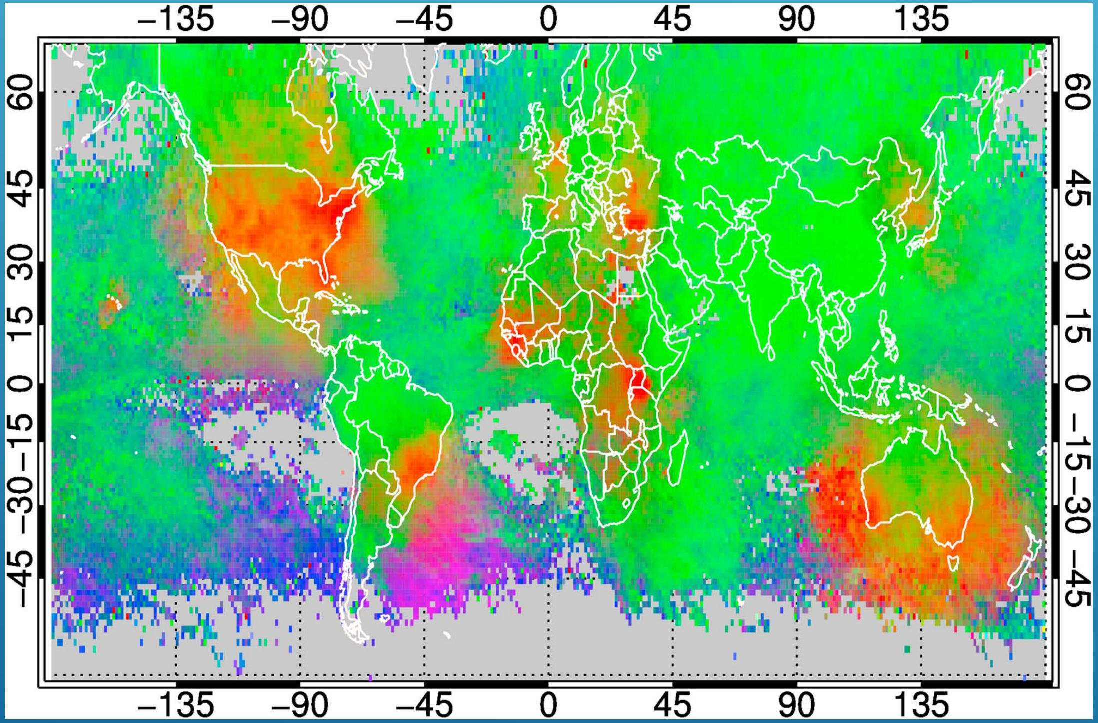


GLM Flash DE vs. LMA near Kennedy Space Center, Florida as a function of flash area and Major channel length *(Zhang and Cummins, JGR2020)*

KEY POINT # 4

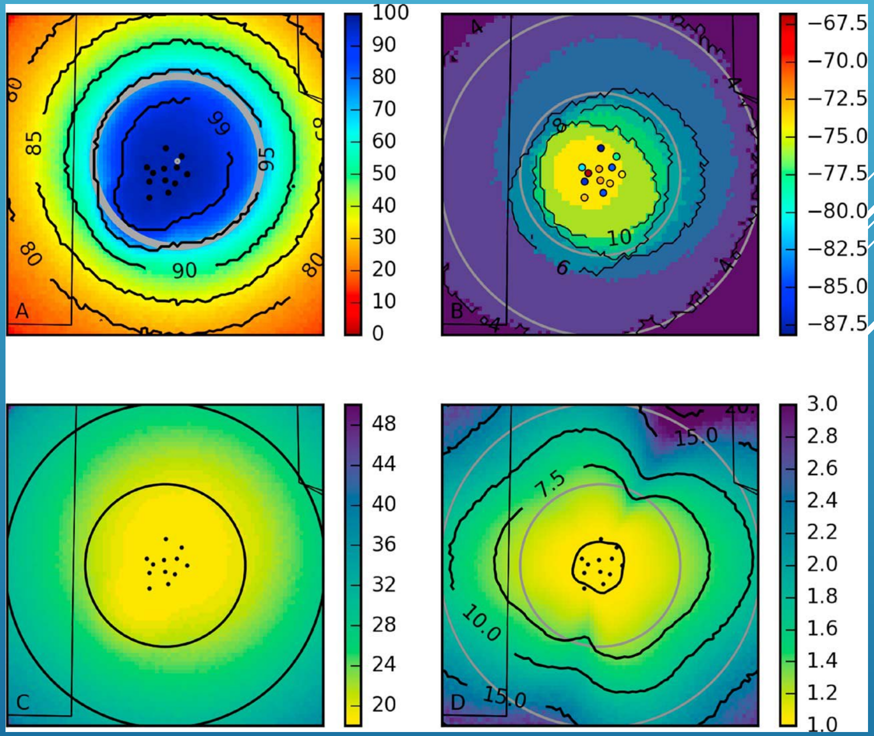
No single LLS reports every flash, let alone every process in every flash

Short-baseline mapping systems (both VHF and LF) come the closest, but they have a limited spatial domain and strong spatial performance gradients.



"RGB weighted detection for three "global" LLS networks (Bitzer et al. GRL2016)

West Texas LMA Modeled Performance



Chmielewski and Bruning, JGR2016

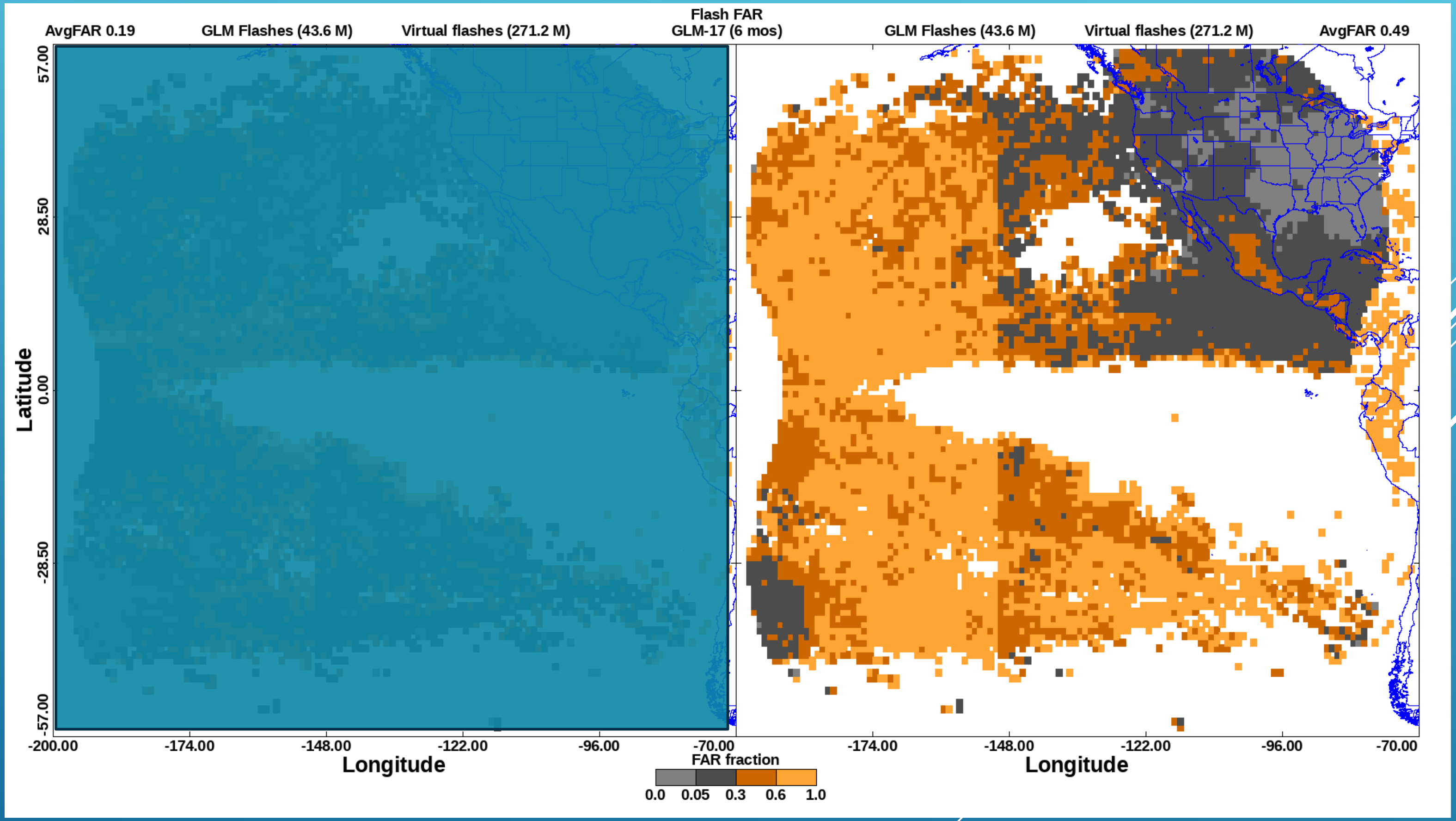
KEY POINT # 4 (even bigger issue over ocean)

Identifying False Flashes

*<u>Question</u>: Are isolated (space:time) GLM flash reports false reports, **-or-** do they reflect poor detection by the reference LLS networks?*

Must use "storm period coincidence" (± 10-minute on this case) to get a useful estimate of false report rate (may still be too high)

± 10-minute coincience ±1 one second coincdence



False-alarm-rate (FAR) for GLM relative to a "virtual network" composed of WWLLN, ENTLN, GLD360, and NLDN (Bateman et al., JGR2020)

GLM ASSESSMENT EXAMPLES:
FULL FIELD-OF-VIEW USING GLD360

(SAMPLES FROM PREVIOUS GLM VALIDATION REPORTS)

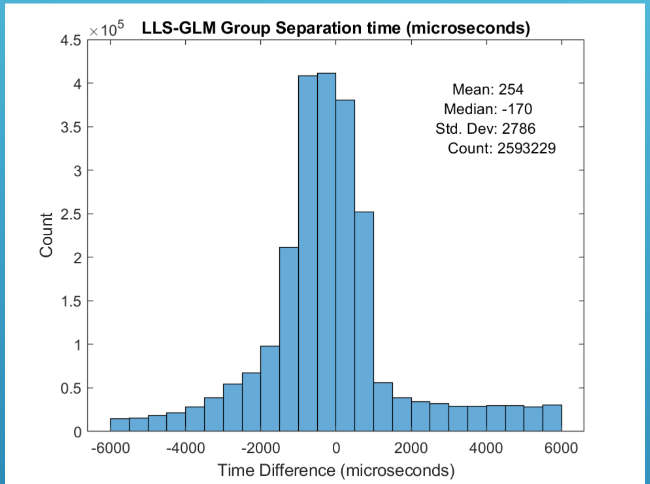
OVERALL TIMING AND DISTANCE SEPARATION FOR MATCHED GROUPS

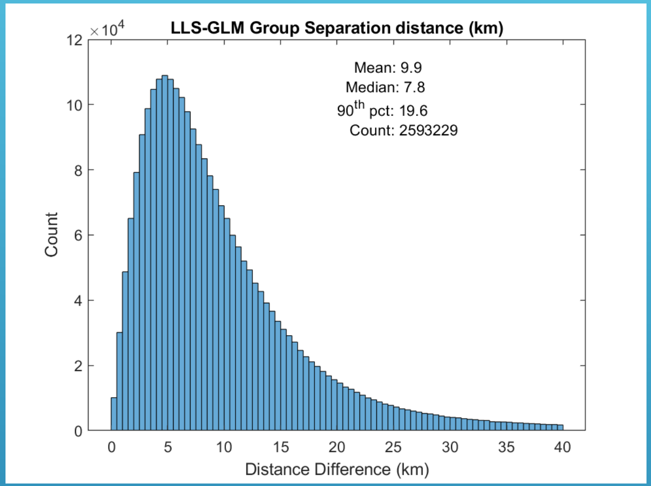
Comments

- *Nearly identical timing differences*
- *G17 has more location differences in the 5-20 km range ("fatter" distribution), possibly due to larger GLD360 location errors*

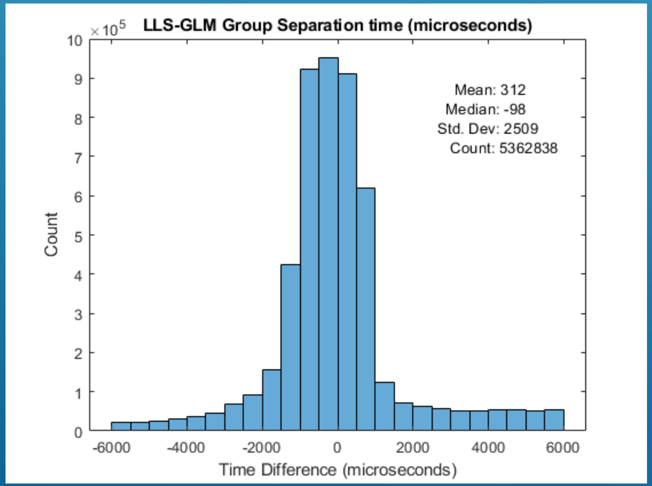
Timing Difference (ms)

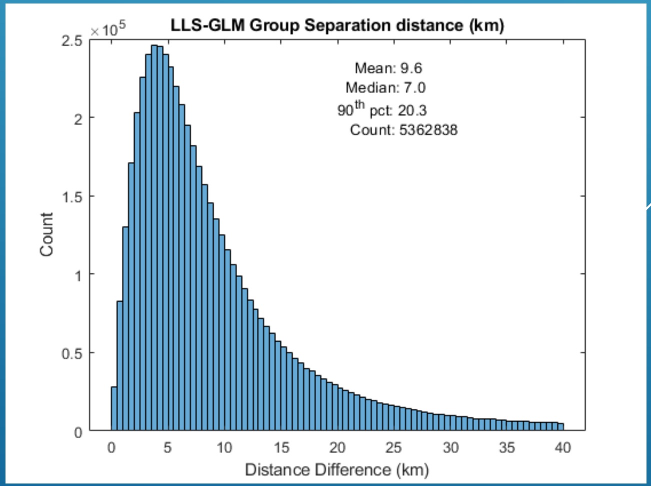
Location Difference (km)





G17 Period: Jan. 2020

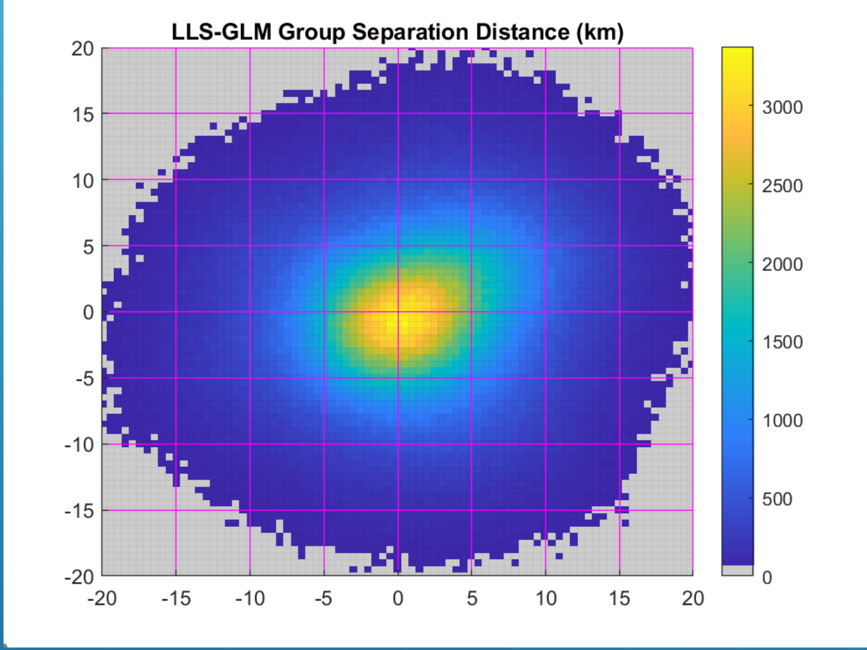




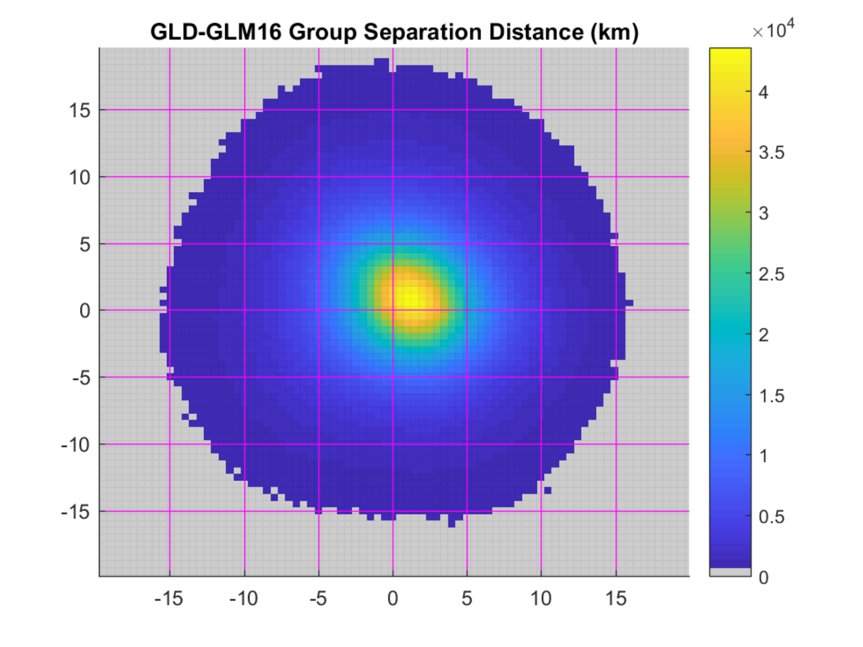
G16 Period: Sep 26 – Oct 2 2018

OVERALL SPATIAL OFFSET FOR MATCHED GROUPS

G17: January 2020



G16: Sep 26 – Oct 2, 2018



Comments

- *Possibly small mean offset for G17*
- *G17 has more location differences in the 5-20 km range ("fatter" distribution) with greater radial variation, possibly due to larger GLD360 location errors*

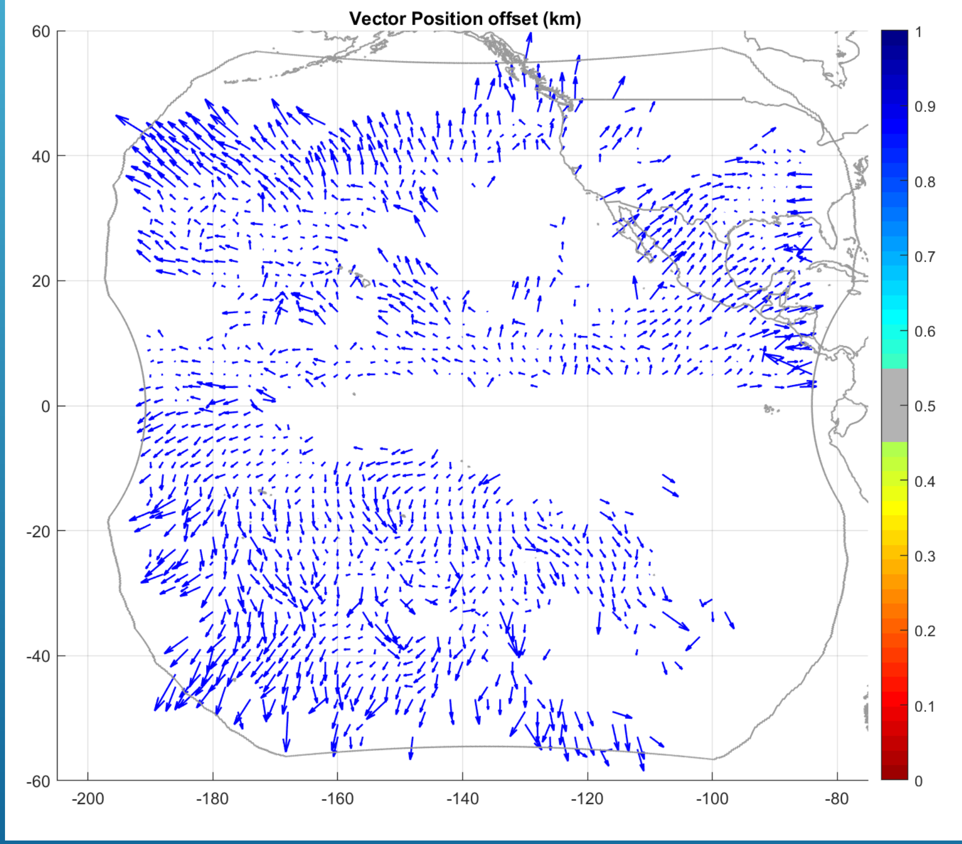
SPATIAL LOCATION DIFFERENCE VECTORS

Comments

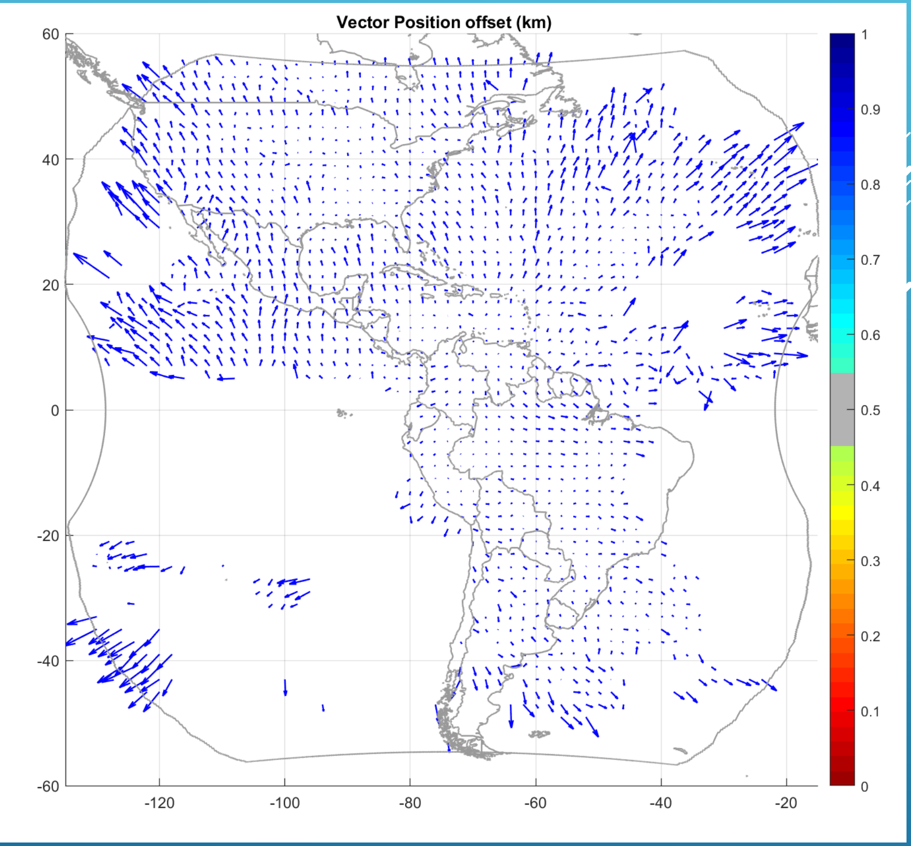
- *Mean differences generally less than 7.5 km near the center of the Field-of-view*

- *Both instruments exhibit their largest mean (bias) error near the edges of the Field-of-view*

G17: January 2020

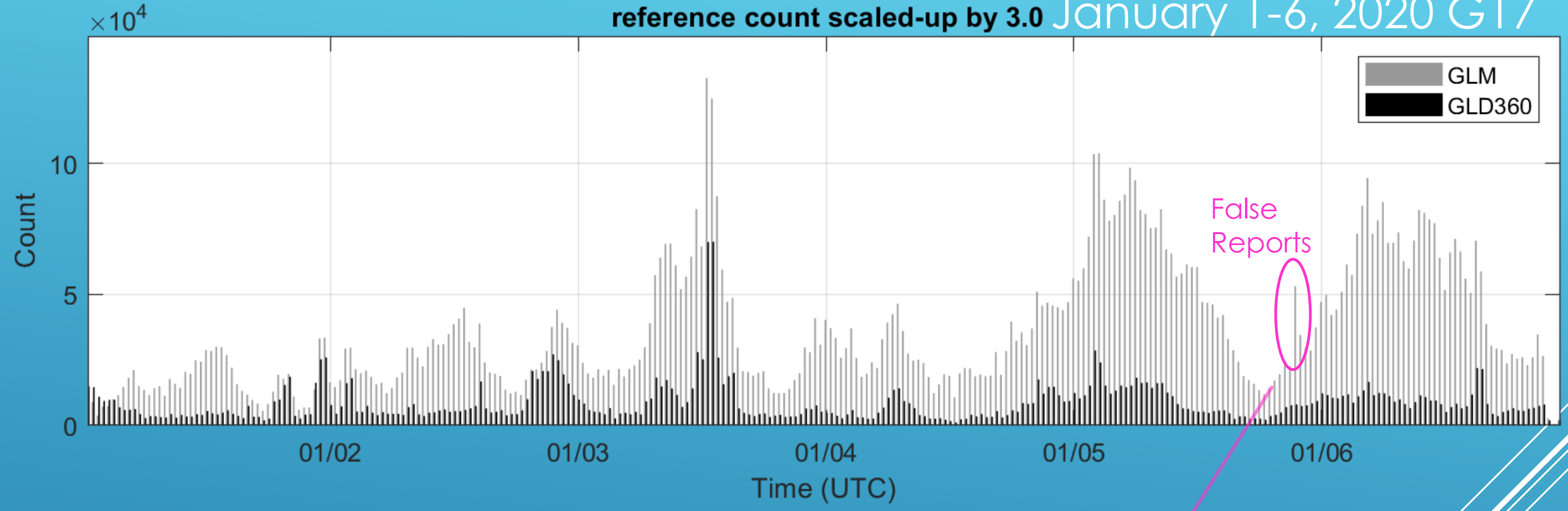


G16:July 20 – Oct 2, 2018



SPATIAL AND TEMPORAL FALSE REPORTS

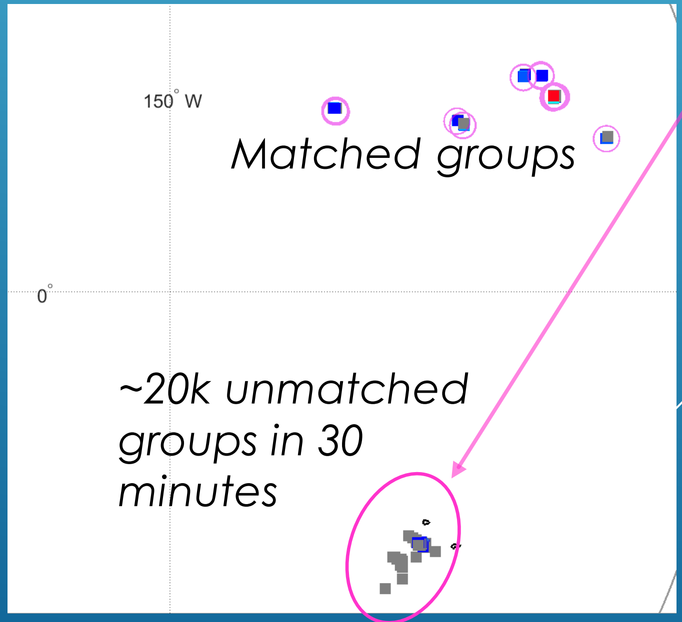
January 1-6, 2020 G17



Comments:

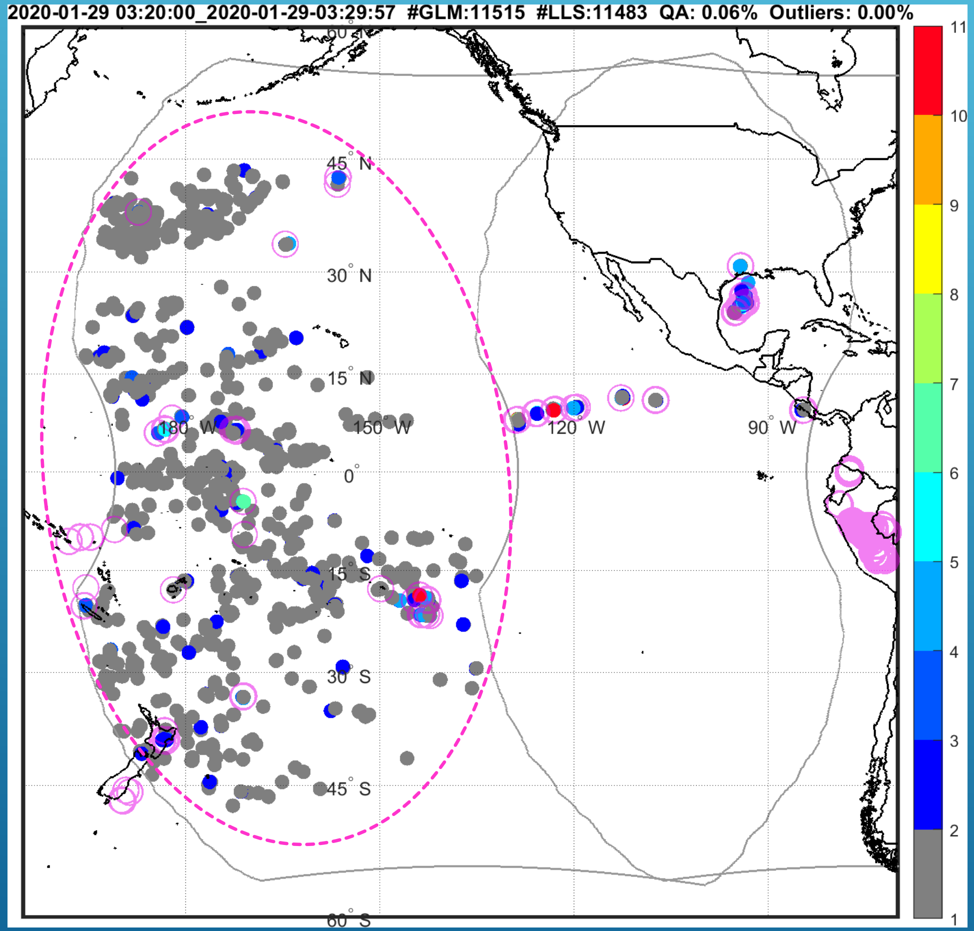
- **CRITICAL Early Analysis!**
- *Visual inspection of 32 days of group data using 10-minute spatial maps & 30-minute time- series plots*
- ***Only found three clear cases** of false reports*
  - *Almost all of the false reports had good QA flag (0)*

21:50 to
22:20 UTC

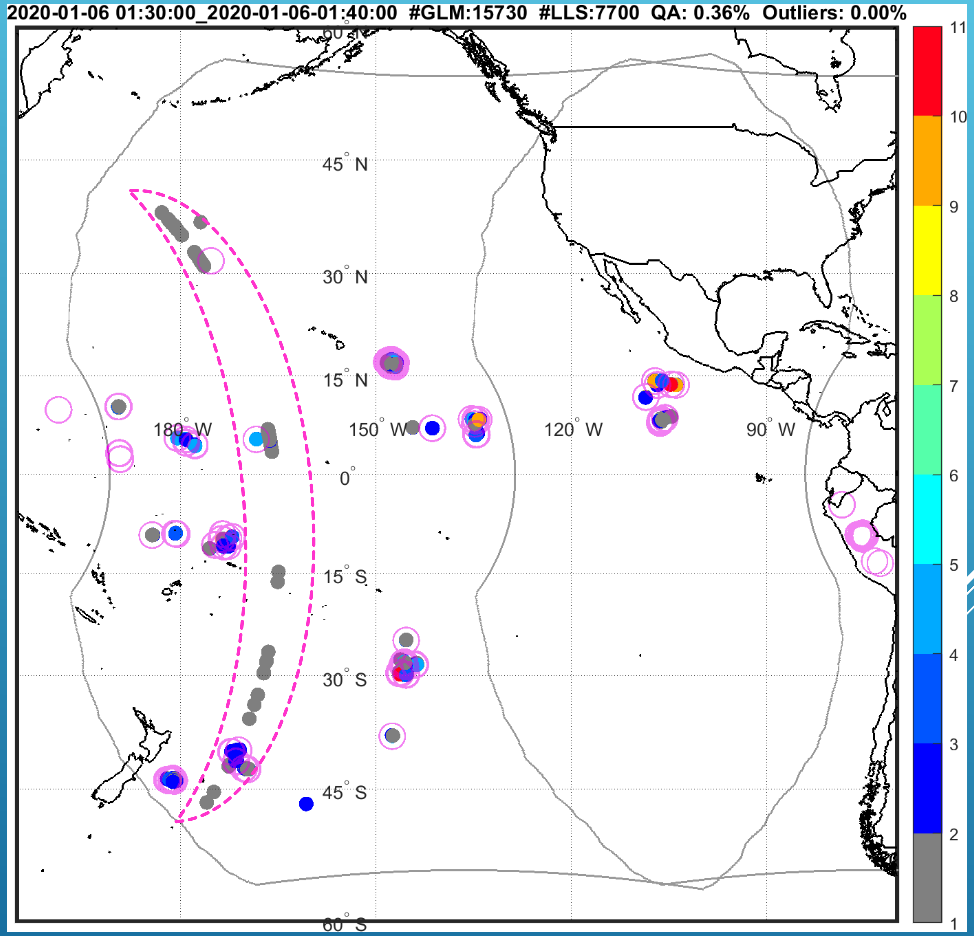


SPATIAL AND TEMPORAL FALSE REPORTS

~4,000 unmatched groups in <10 minutes



~1,000 unmatched groups in <10 minutes

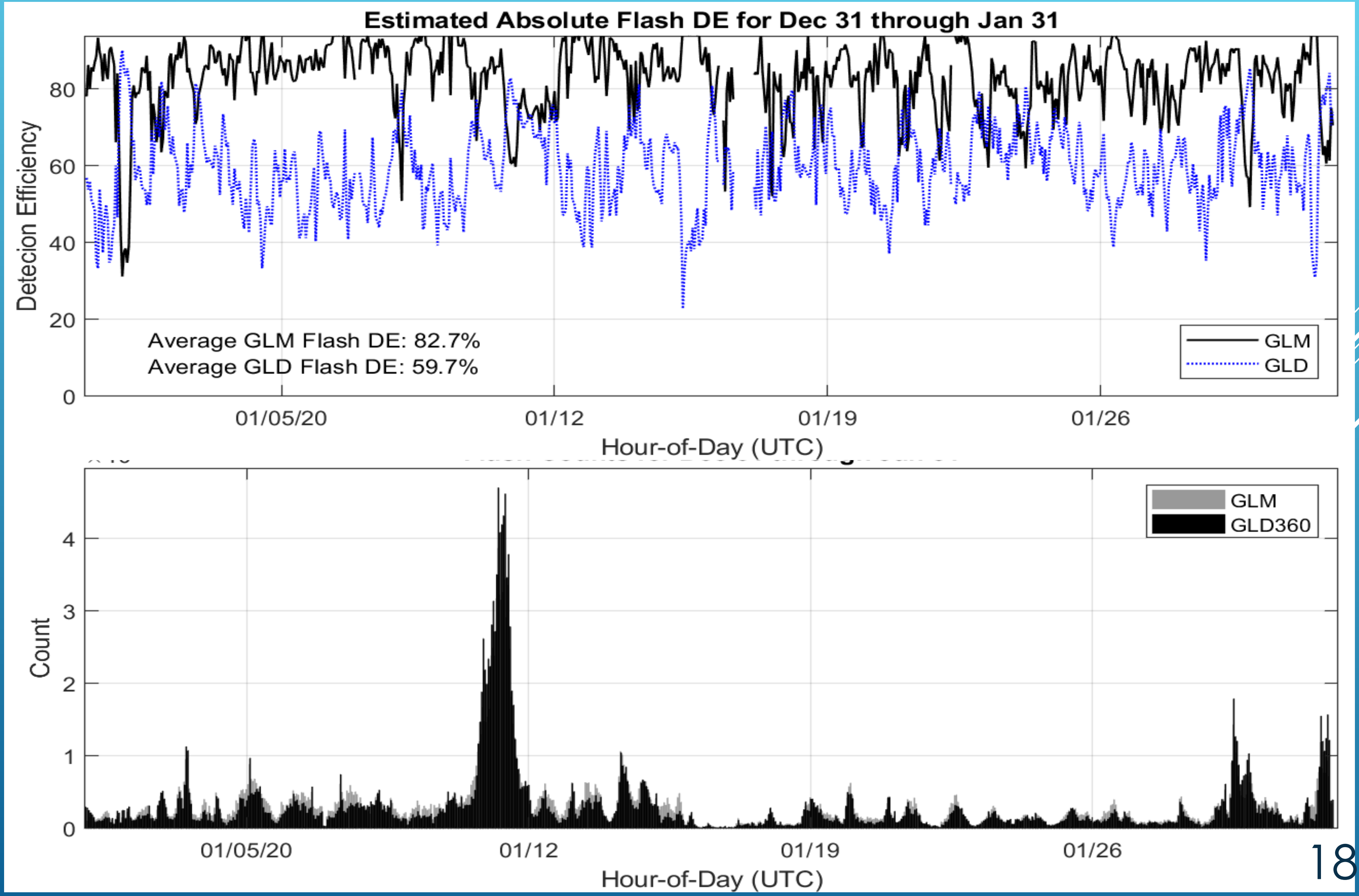


GLM (G17) & GLD360 HOURLY "ABSOLUTE" FLASH DETECTION EFFICIENCY

Comments

- *"Absolute" (Bitzer et al. GRL2016) flash DE is the best emulation of actual flash DE, but it over-estimates DE unless the combined systems see every flash*

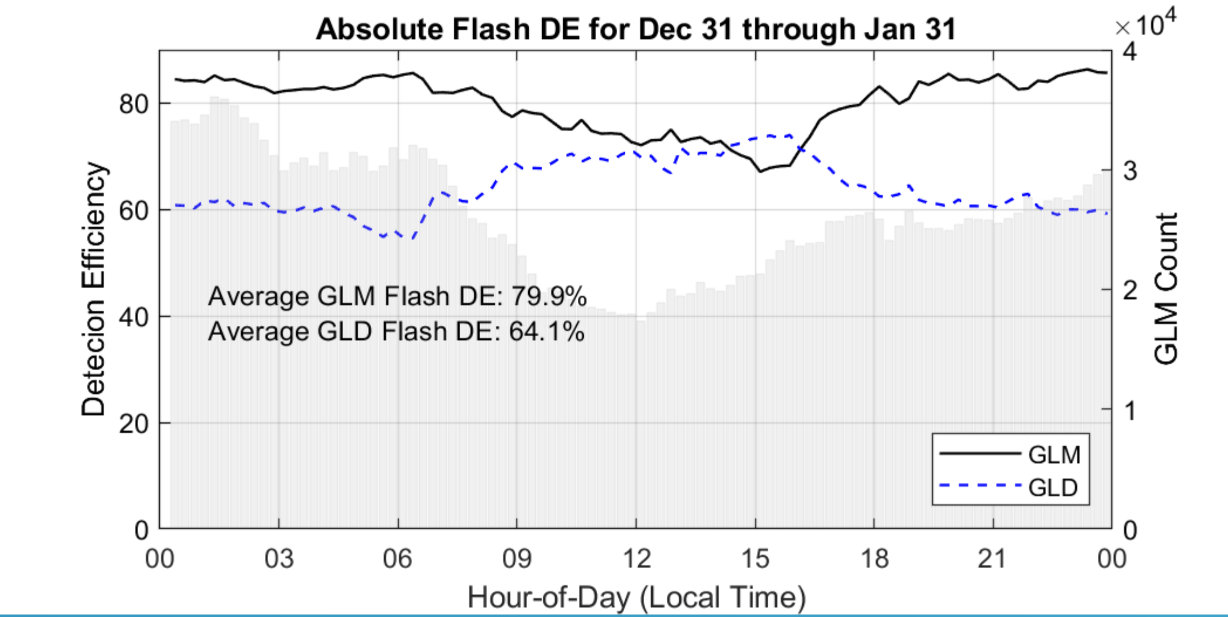
- *GLM absolute flash DE is <u>nearly perfect</u> during certain times of some days (over-estimated due to limited GLD360 DE in parts of the region)*

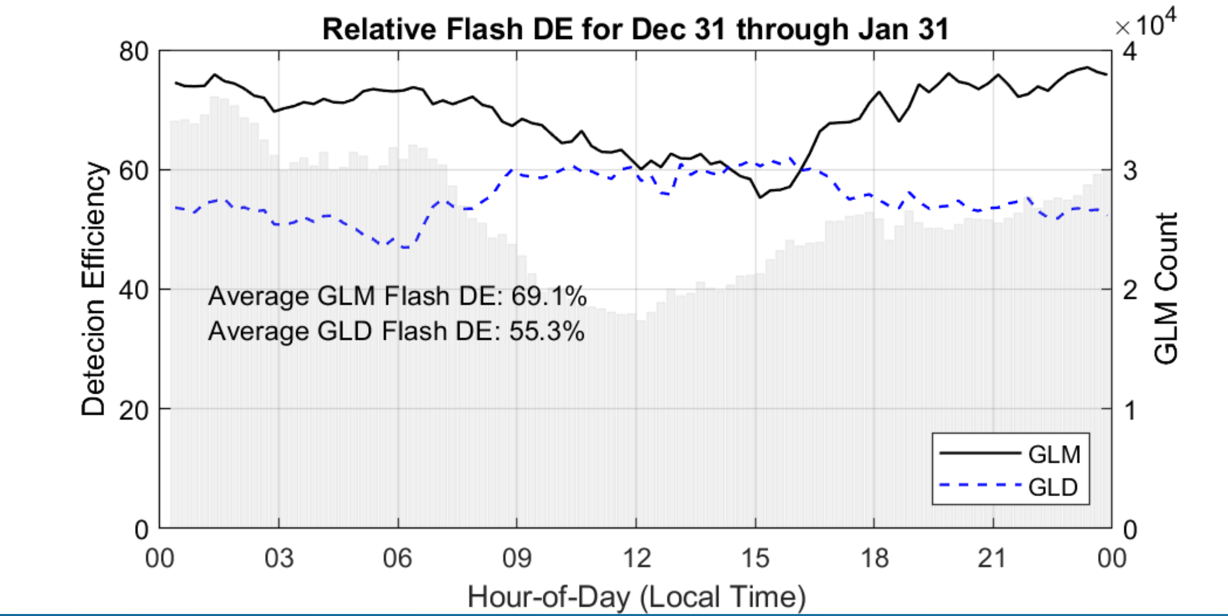


GLM (G17) AND GLD DIURNAL FLASH DE

Comments

- *GLM absolute flash DE is about 90% at night, reducing to about 70% during the day (20% variation)*
- *GLM overall average absolute DE is 79.9% during the day*
- *Both relative flash DE values are lower their associated absolute DEs, indicating that there are large number of flashes reported by each system that are not seen in-common*



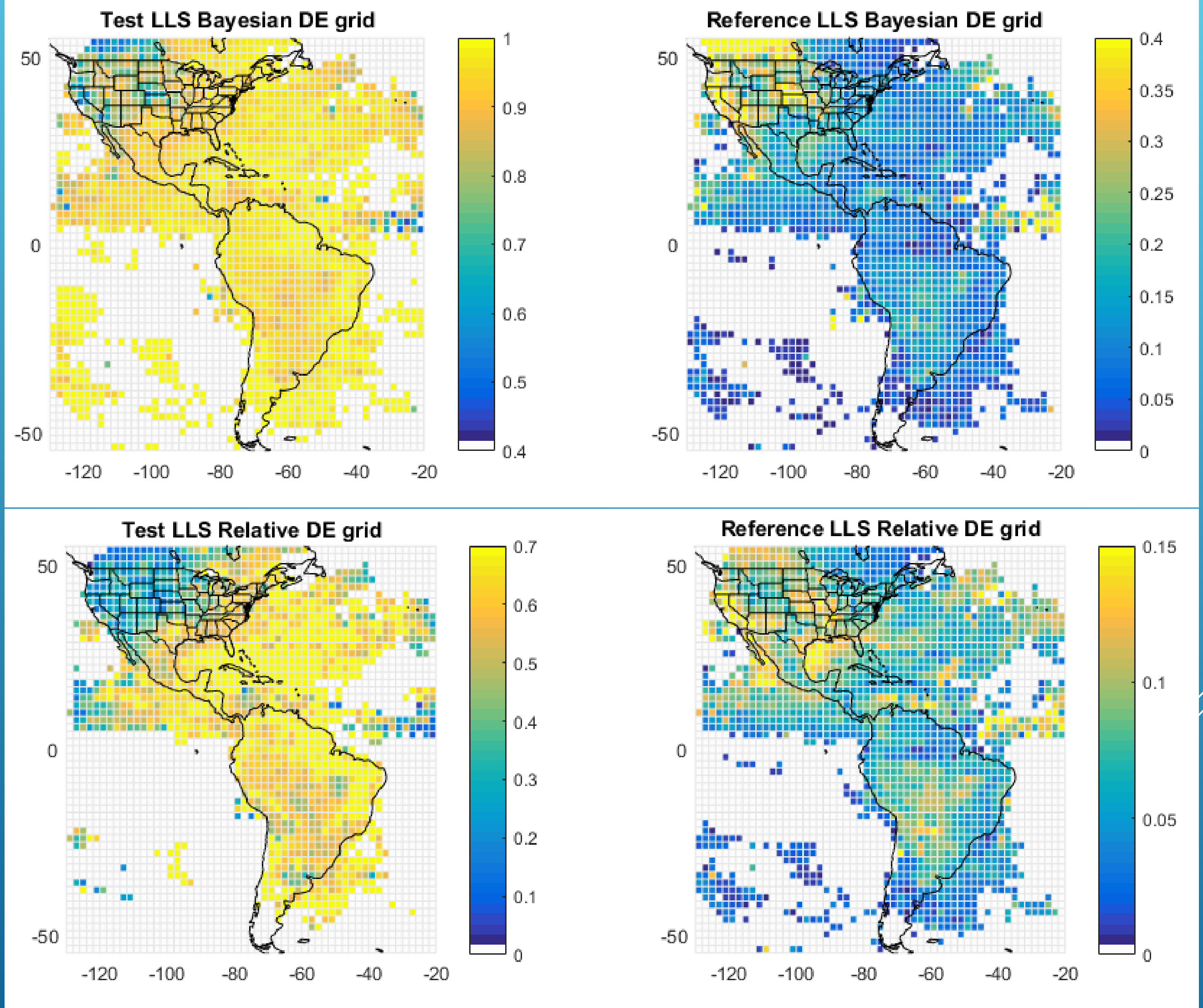


GLM AND GLD360 "RELATIVE" GROUP DETECTION EFFICIENCY (GLM=TEST; GLD=REFERENCE)

G16 - 18 days spread throughout January through October, 2018

Group DE is worthwhile, as it is very sensitive to small variations in detection

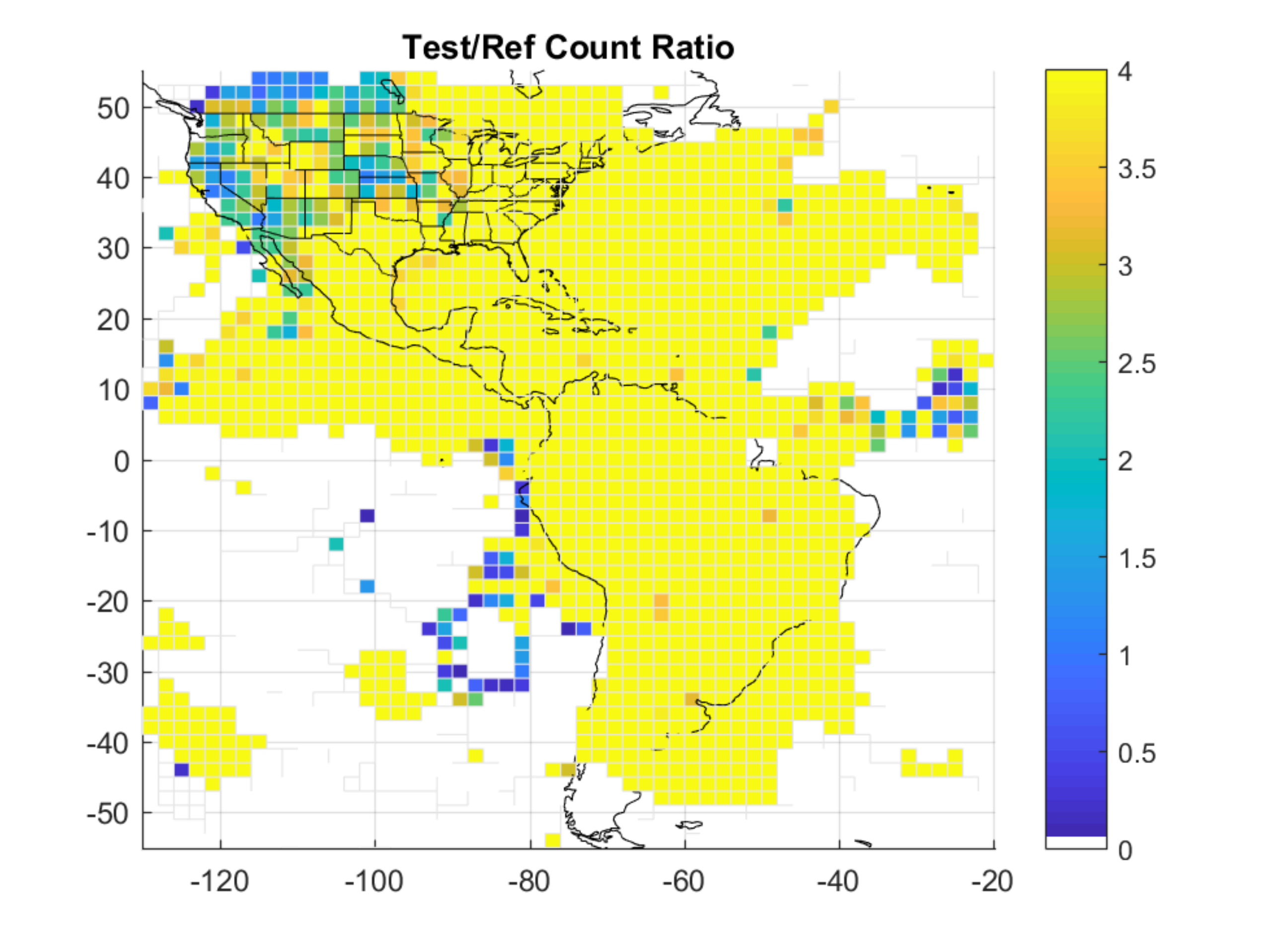
As with the "absolute" (Bayesian) DE, the group "relative" DE for GLM in NW CONUS is also low, suggesting the GLM is not seeming as large a fraction of GLD360 (reference) "strokes" in this area



RATIO OF GLM GROUP COUNTS TO GLD360 COUNTS (GLM/GLD)

GLM is simply reporting fewer "groups per stroke" in the north-central and north-western U.S, and western Canada

There are odd behaviors off the west coast of South America, but it might be low counts.



Specific value of *<u>long-baseline VLF data</u>* (GLD360 in this study)

- Good time and location of high-current sub-flash processes seen by the satellite (better than satellite data)

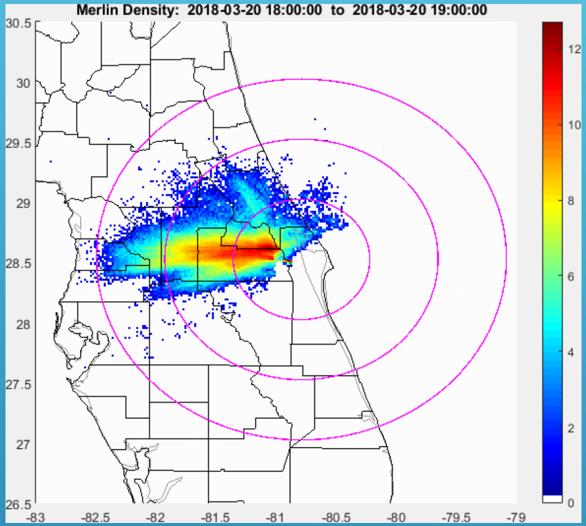
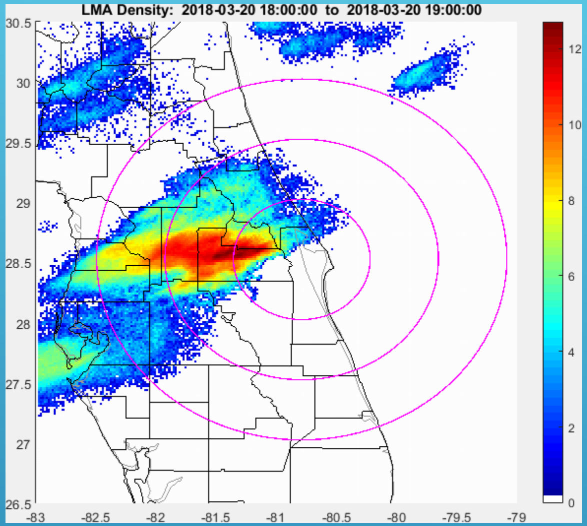
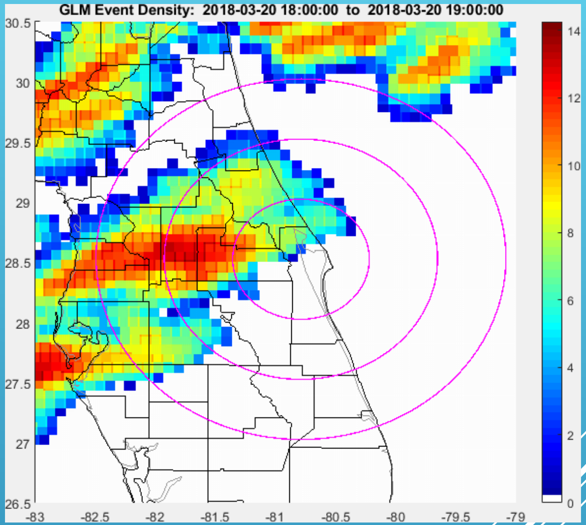
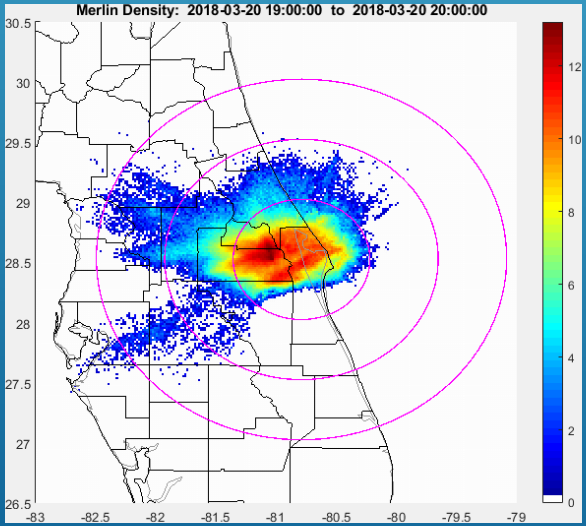
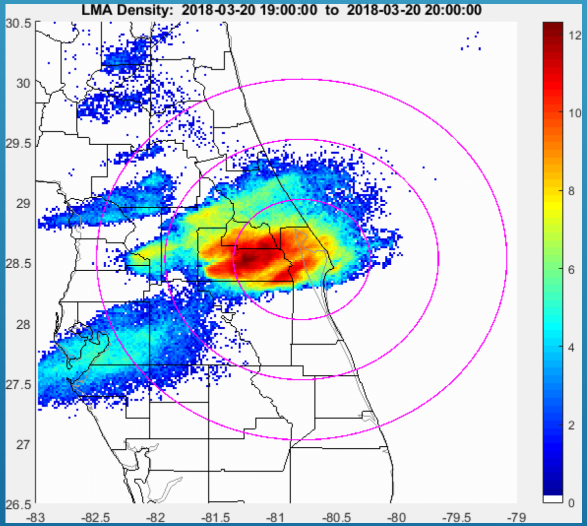
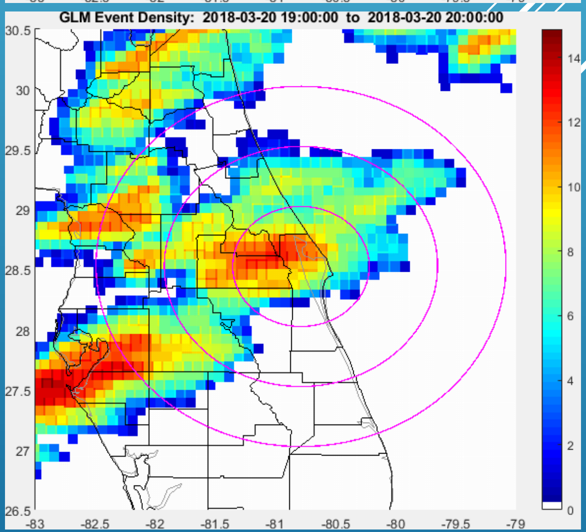
- Useful but imperfect detection over full domain (poorer than satellite in many/most regions
  - can supplement with additional LLS networks
  - shows less diurnal variation than satellite

- Useful for identifying false reports by the satellite
  - solar intrusion
  - “hot” pixels
  - “cold” pixels

GLM LONG-TERM ASSESSMENT EXAMPLE: REGIONAL, USING LMA

Work done in collaboration
with Daile Zhang & Phillip Bitzer

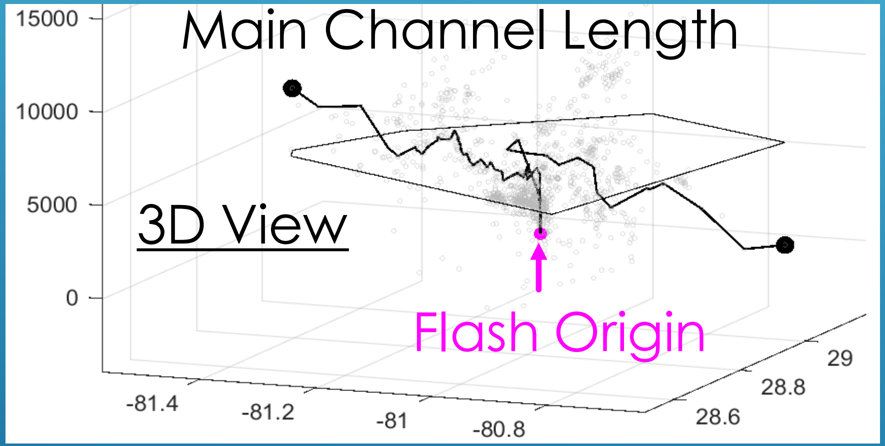
LIGHTNING MAPPING COVERAGE FOR GLM, MERLIN, AND LMA

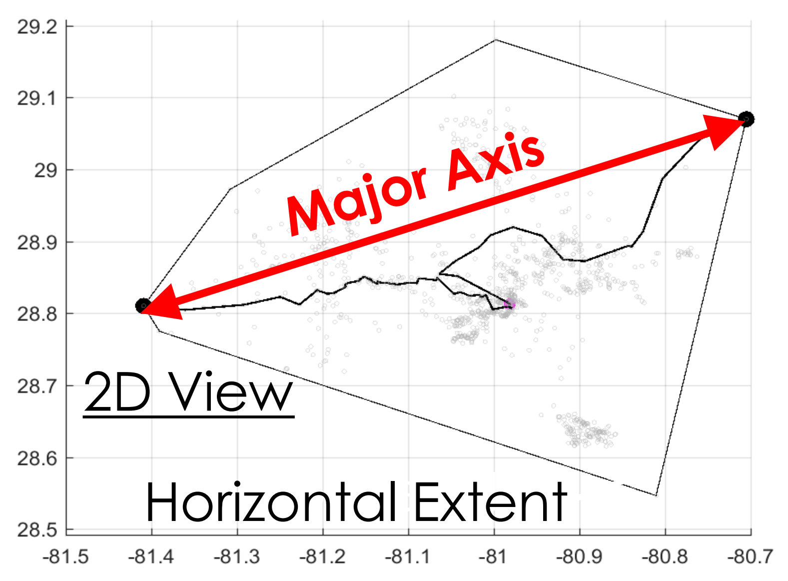
	MERLIN	KSC LMA	GOES-16 GLM
March 20, 2018 18-19 UTC			
March 20, 2018 19-20 UTC			

TECHNICAL APPROACH

- **Conceptual Bases:**
  - LMA can be relied-upon to
    - determine the start and minimal duration of almost all flashes
    - define the set of possible 3-dimensional paths for higher-current processes
  - High-current processes can occur well after channel development depicted by LMA (*so* *time coincidence requirements are very loose*)

- **Characterize LMA flashes in terms of:**
  - Duration
  - Area (convex hull)
  - Horizontal Extent (Major Axis)
  - Main Channel Length





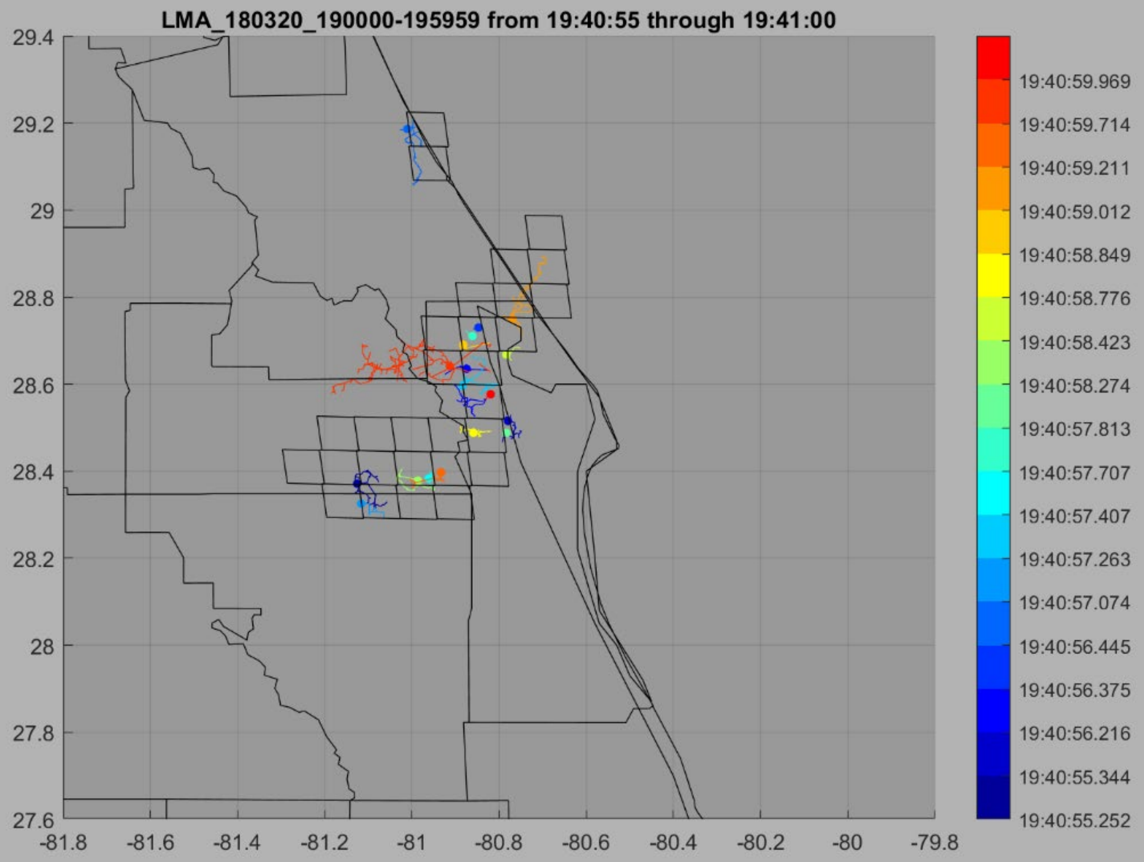
TECHNICAL APPROACH (CONT.)

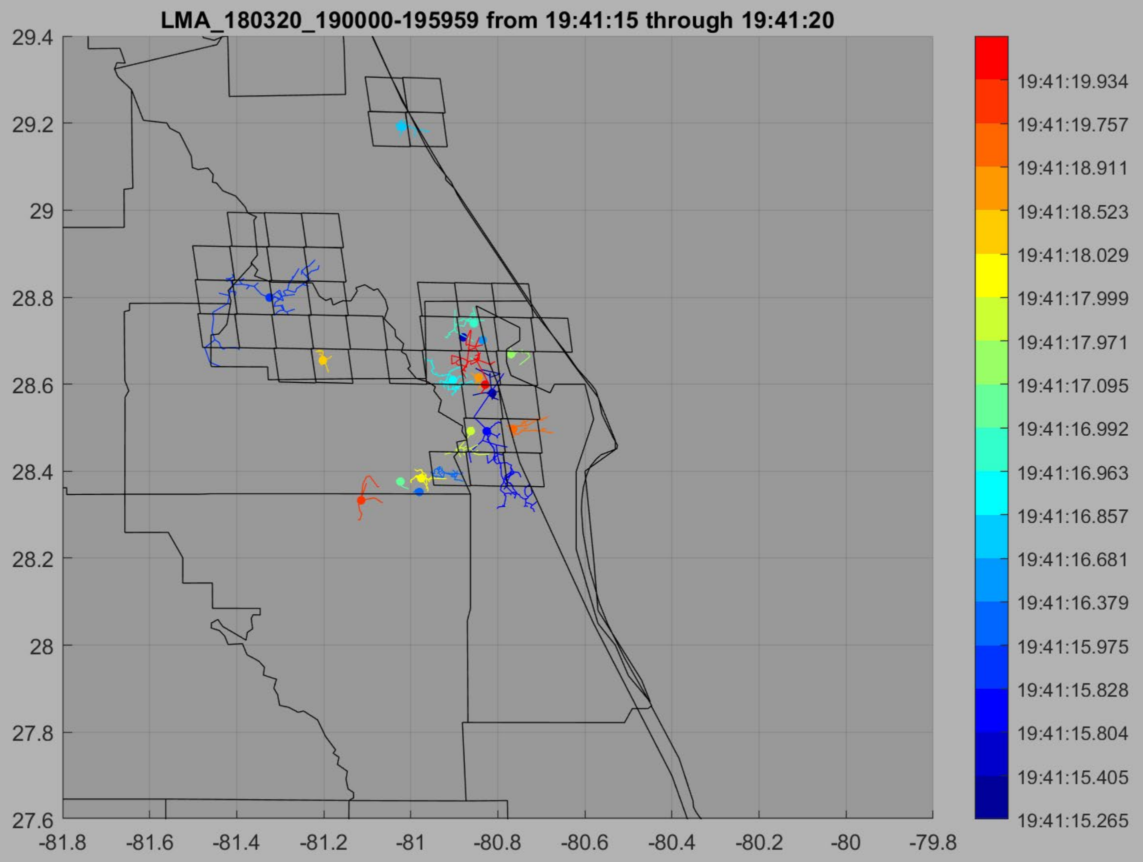
- Evaluate GLM Flash DE as a function of LMA flash parameters
- Evaluate diurnal variation of DE vs. flash “size”

- Analysis Period:
  - March 20, 2018 through February 27, 2019 (one full year)
  - ~250,000 LMA flashes on 22 storm days

TECHNICAL APPROACH (CONT.)

MISSING SOME SMALL FLASHES
(AND LATE PORTION OF A STRATIFORM FLASH (LEFT PANEL))

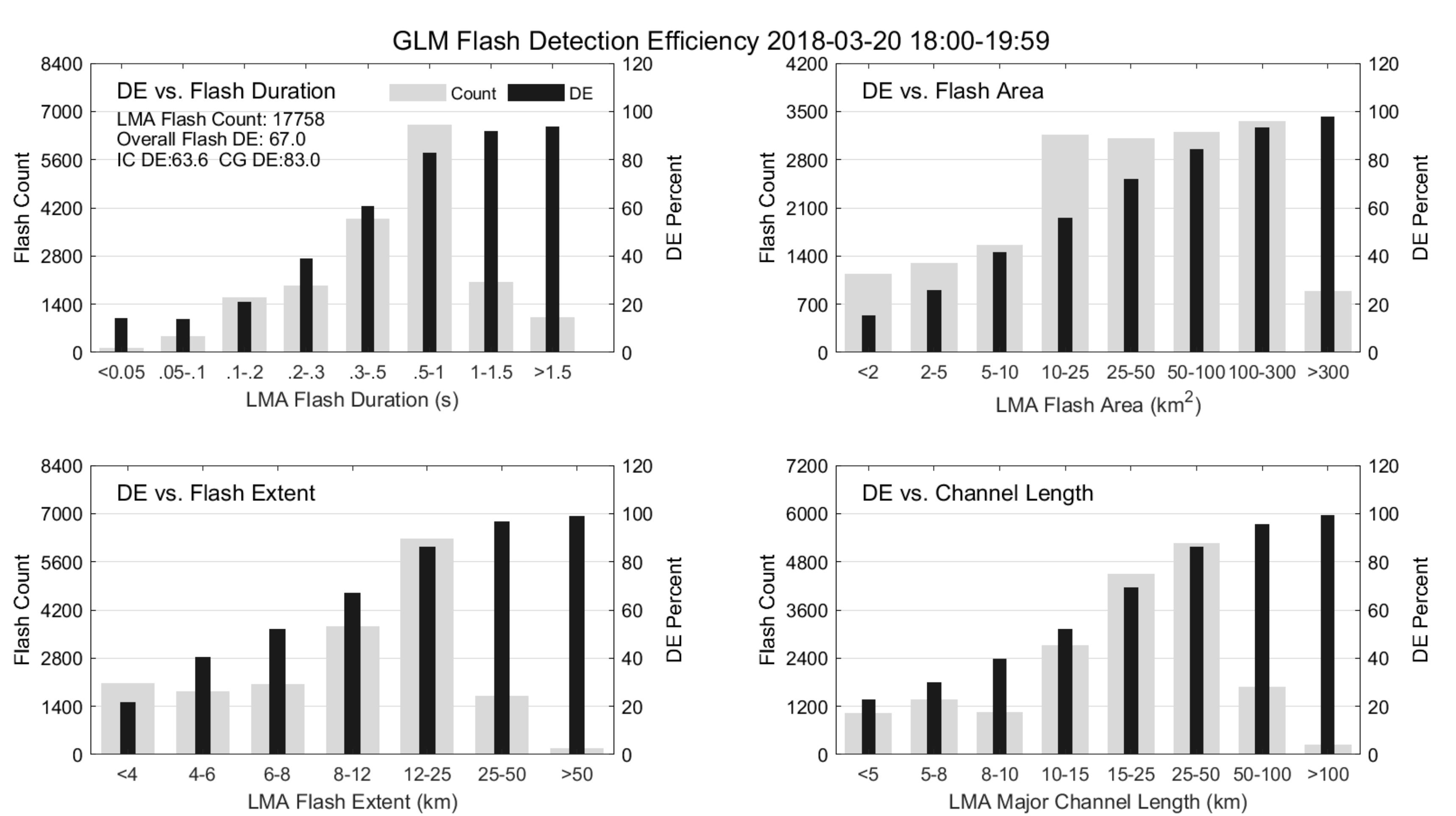




DETECTION ANALYSIS FOR EACH STORM (SAMPLE)

GLM flash DE is critically dependent on all characterizations of flash "size"

Note that GLM detection threshold in this region is the lowest (best) throughout CONUS (~ 1.5 fJ)

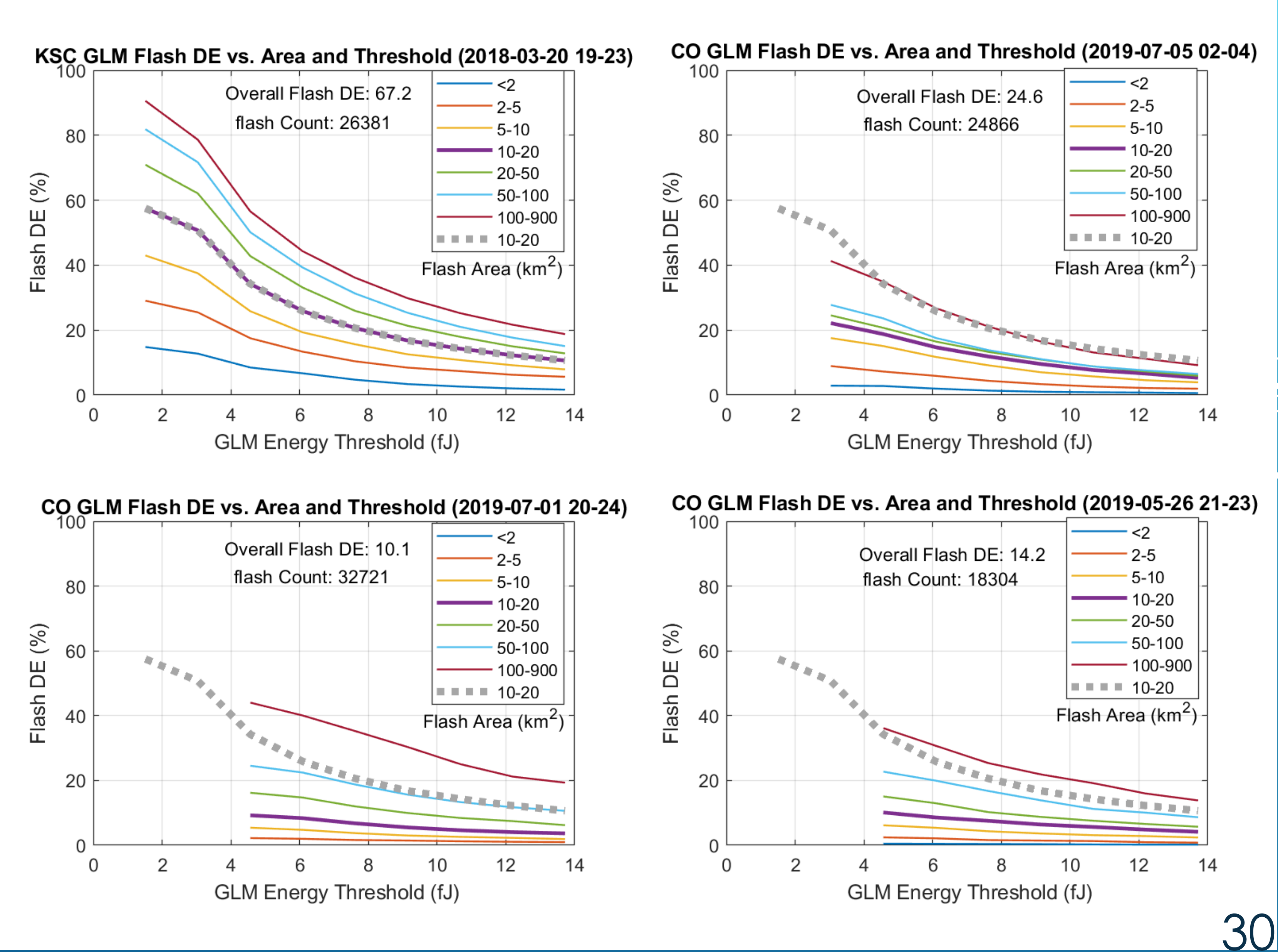


LMA STUDIES IN COLORADO SHOW MUCH LOWER DE

What is the basis for the differences between Colorado & Florida?

Flash DE vs. Flash area and synthesized thresholds =>

the remaining difference between regions (beyond threshold and flash area) **is likely due to greater optical depth in CO, thus <u>decreased cloud-top optical energy</u>**
(Rutledge et al., JGR2020)

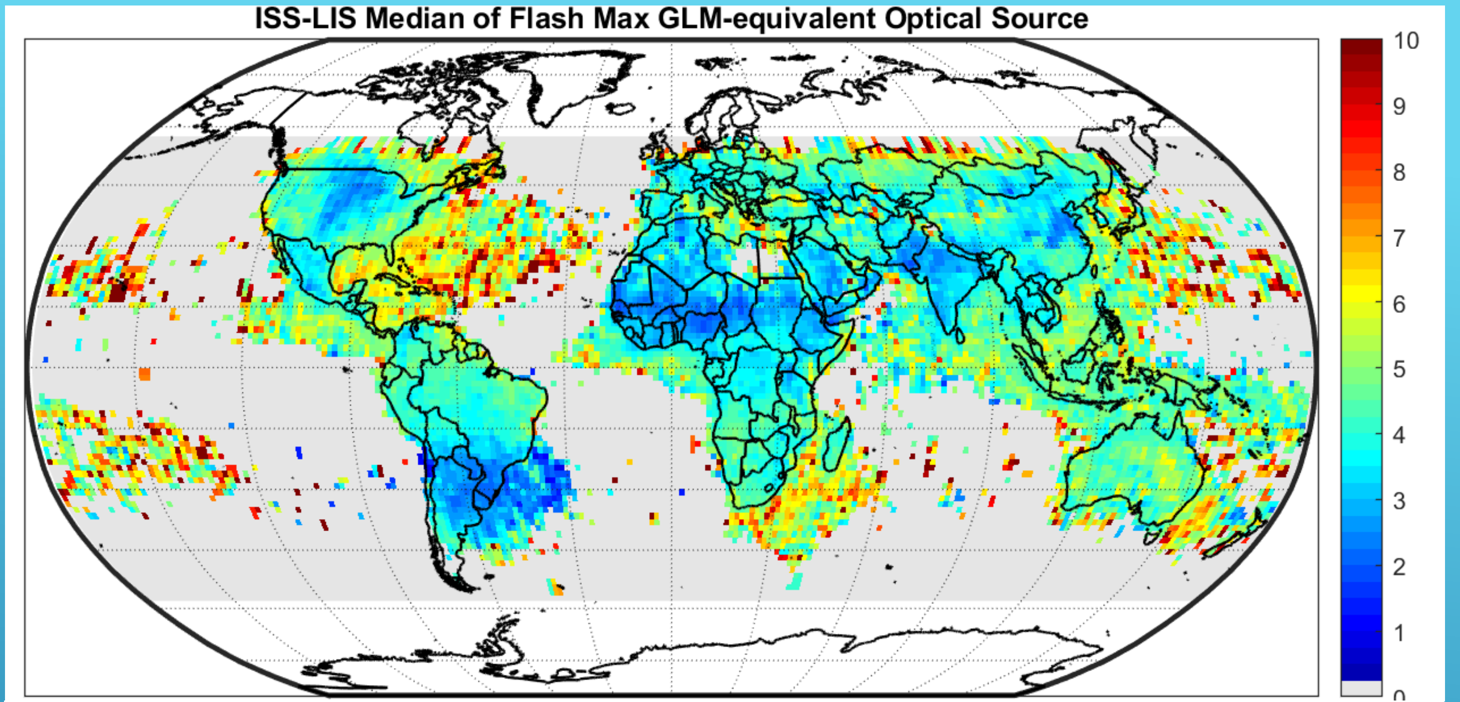


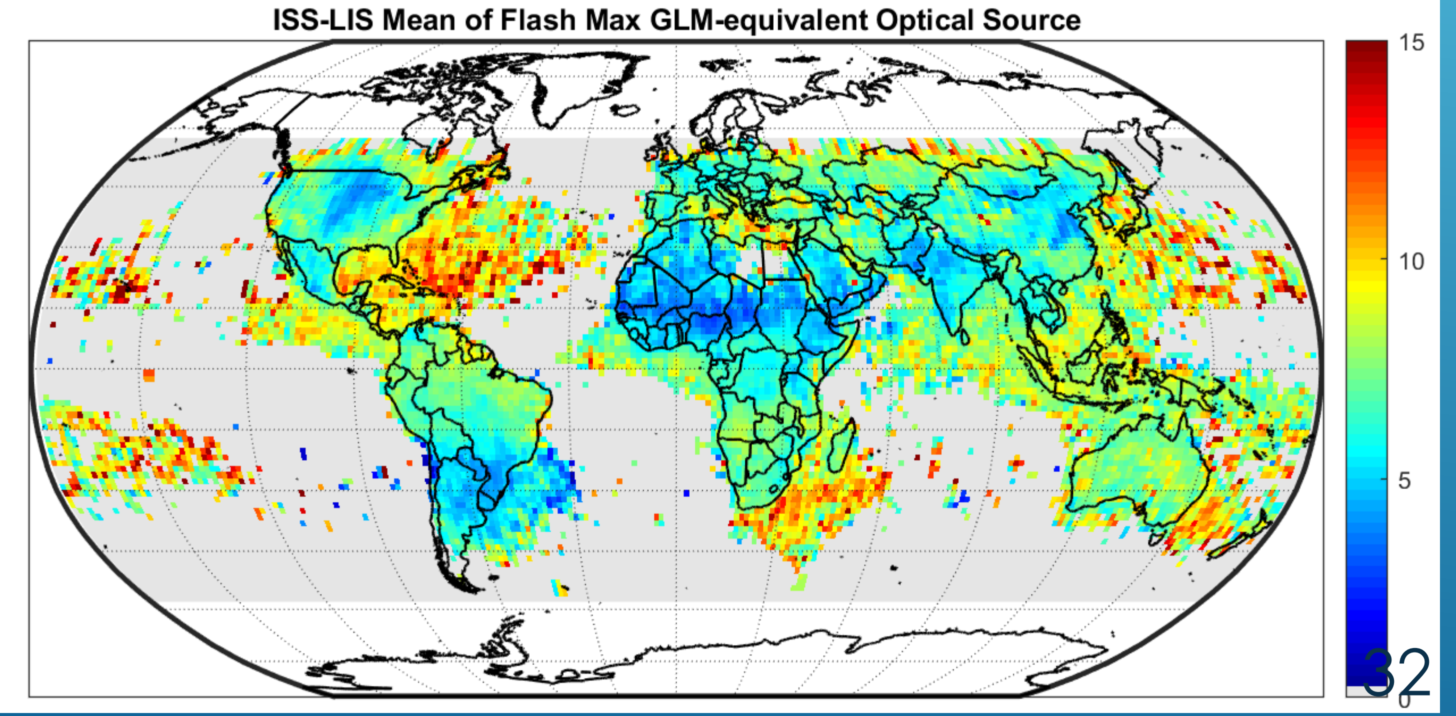
QUANTIFYING GLM DETECTION: FIRST-PRINCIPLES MODELING AND OBSERVATIONS

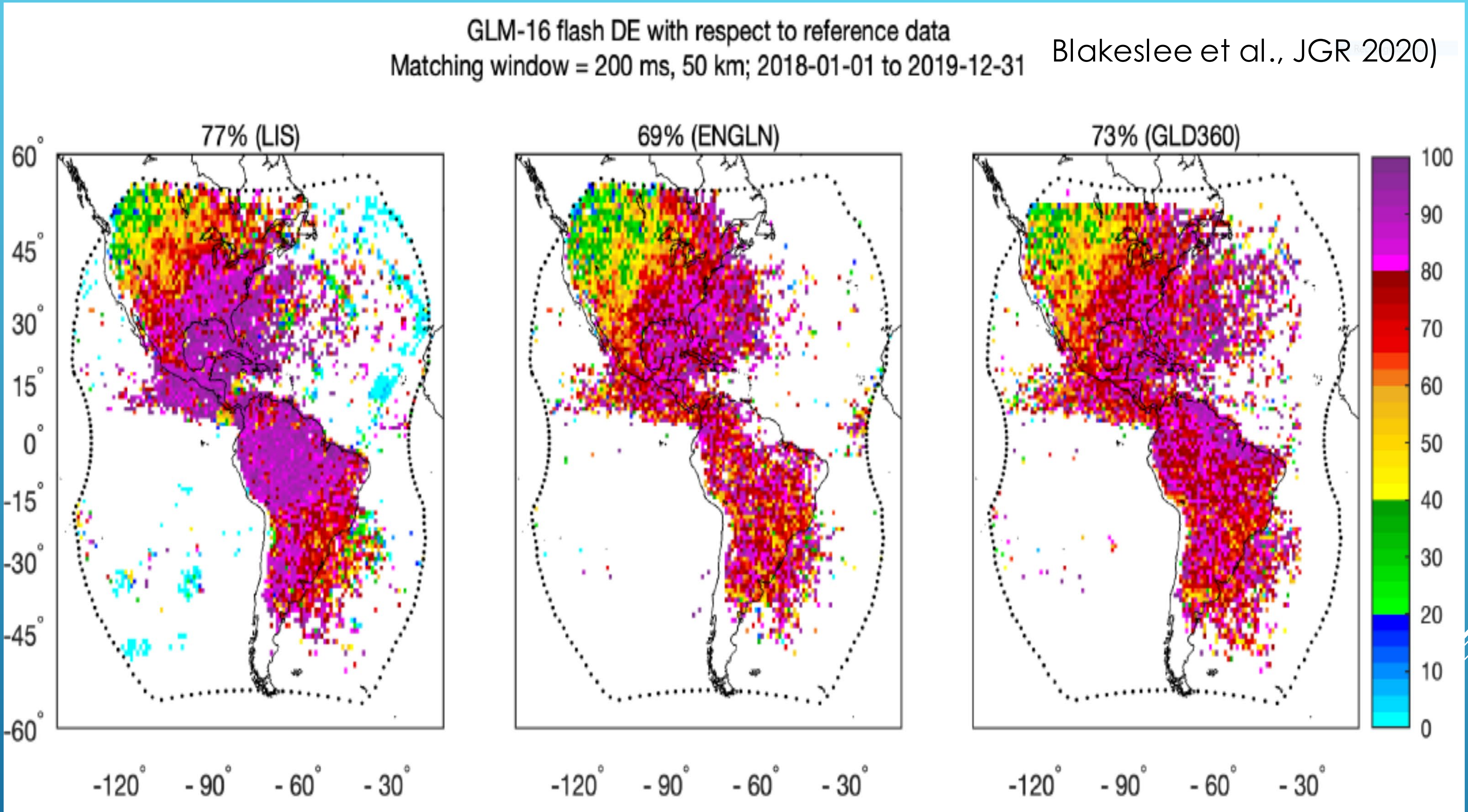
NEW TOPIC: GLOBAL GLM-EQUIVALENT EVENT ENERGY

- ISS-LIS data from October 2017 through September 2020
- GLM max event-in-flash estimate derived as per AMS extended abstract (*Cummins, 2021*)
- Energy distribution computed for 1.5 degree grids, with at least 100 observations with minimal smoothing

Mean and Median values show factor-of-three variation by region!



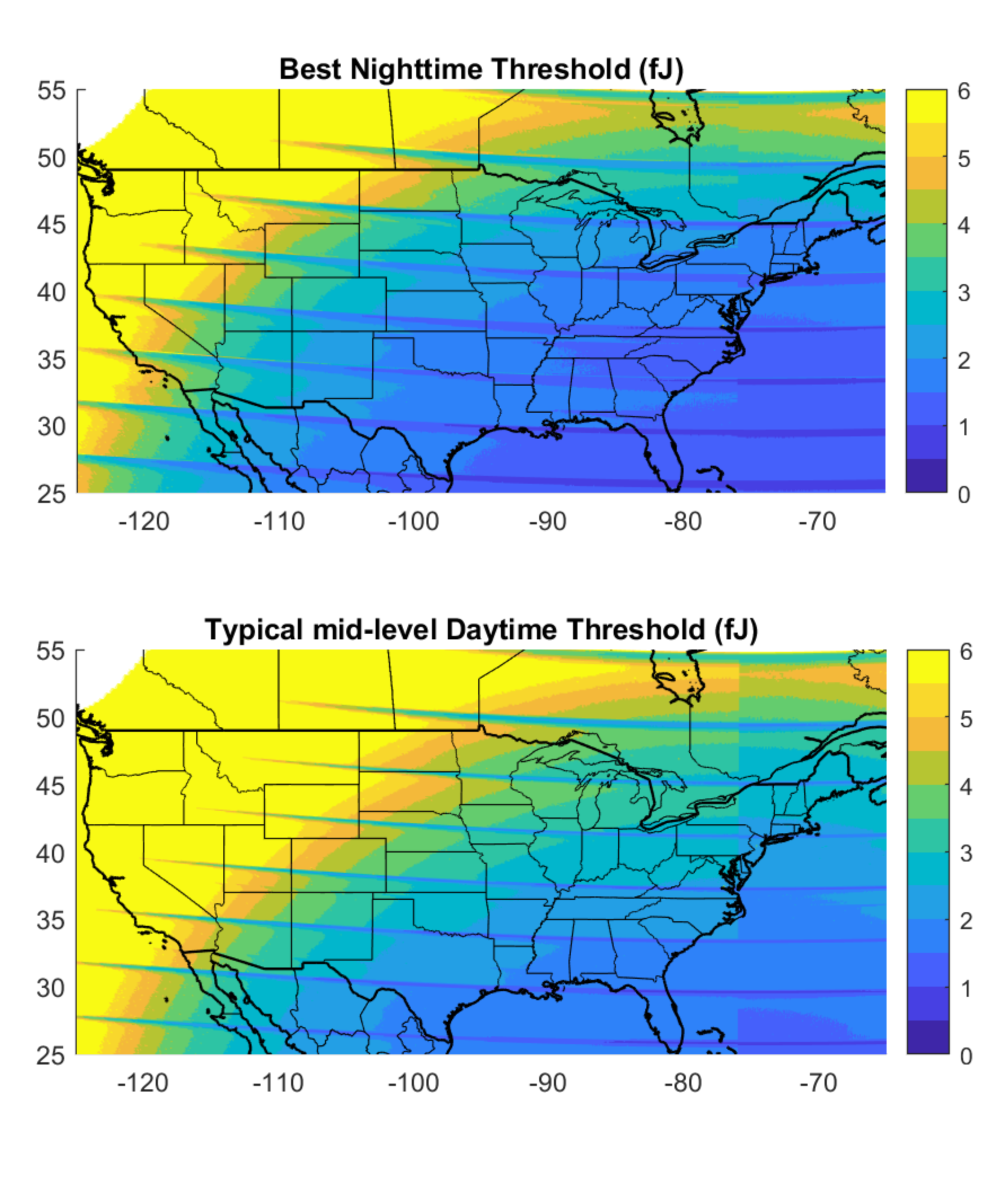




GLM-16 (GOES EAST) FLASH DETECTION ASSESSMENT

BASIS FOR REGIONAL DIFFERENCES IN GLM DETECTION

- INSTRUMENTAL VARIATION IN DETECTION THRESHOLD
- DIFFERENCES IN CLOUD-TOP OPTICAL ENERGY

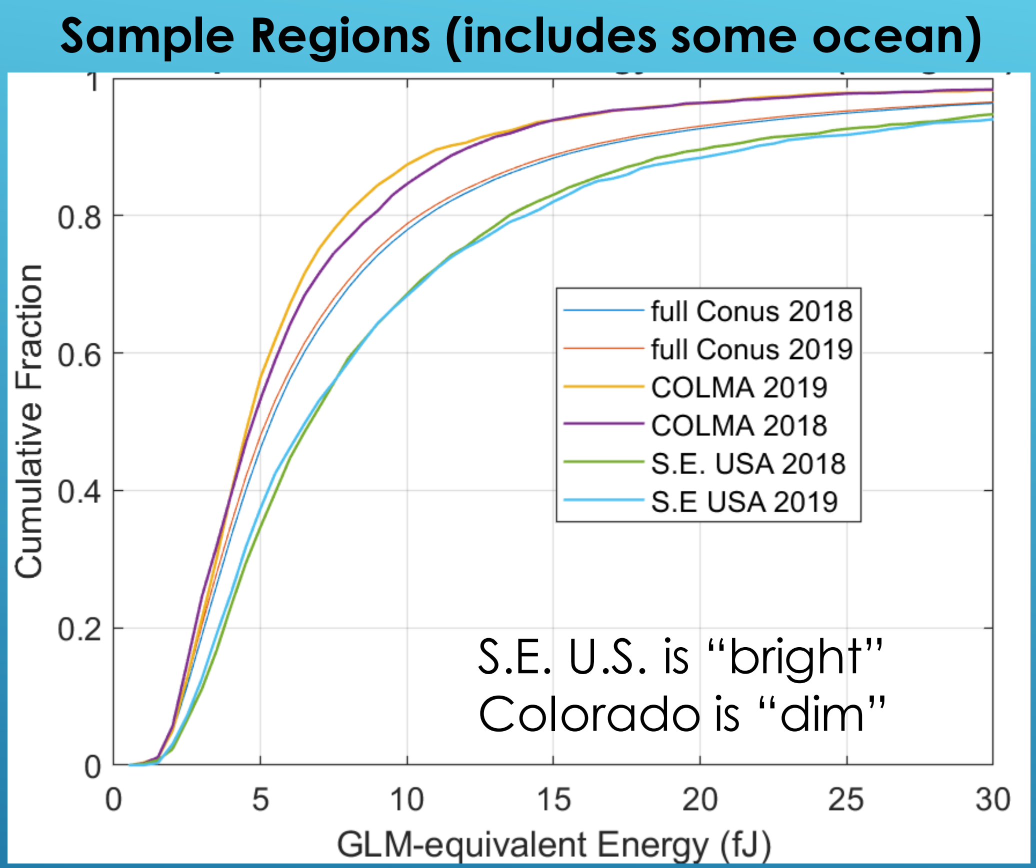


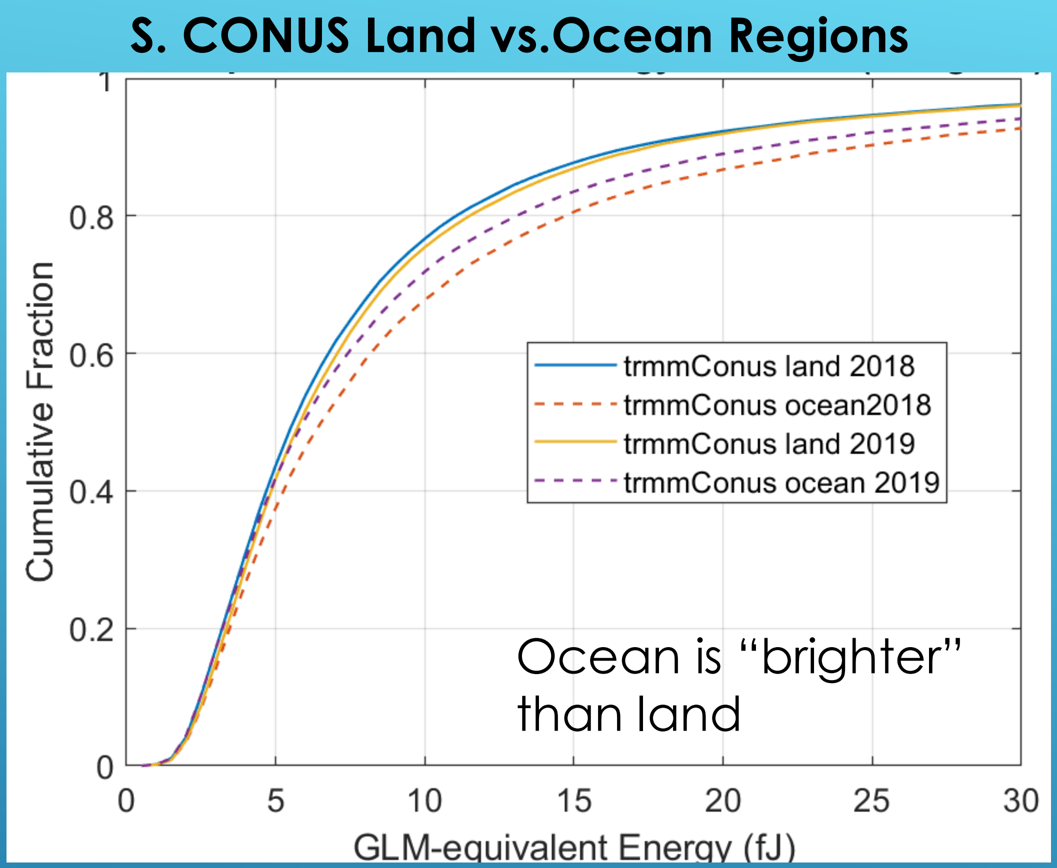
G16 Instrument Thresholds

The detection threshold increases towards the edges of the fields-of-view, driven by instrument threshold variations associated with GLM optics and viewing geometry.

This is illustrated in the maps to the left showing best-case (upper map) and mid-level thresholds (likely daytime – lower map) throughout CONUS for G16. The lowest threshold (~1 fJ) is in Florida, and it increases to higher than 6 fJ in the northwest.

Note: the highest threshold in a region is (roughly) twice the "Best Nightime" values shown in the upper panel

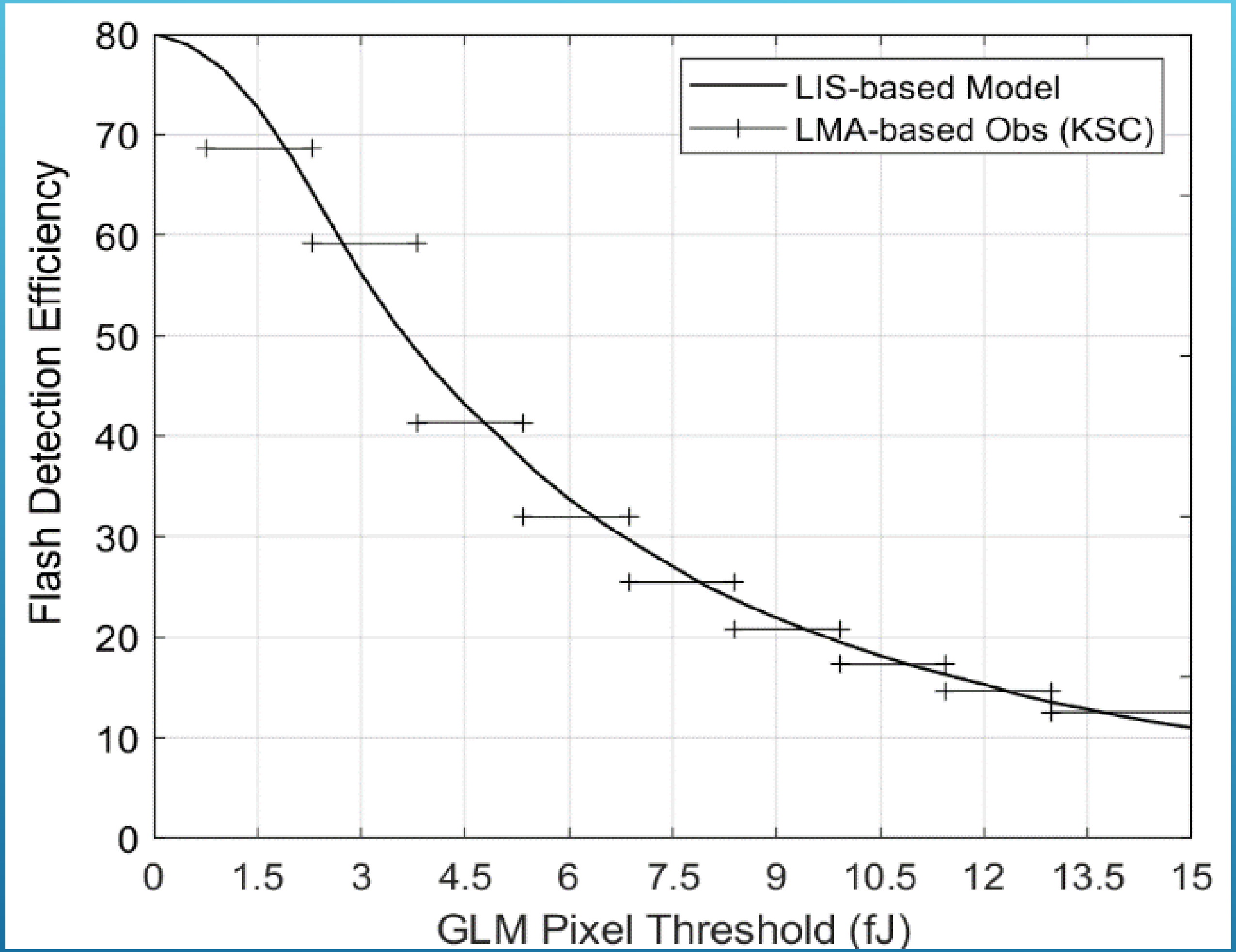




REGIONAL DIFFERENCES IN ISS-LIS OPTICAL SOURCE DISTRIBUTIONS

(GLM-EQUIVALENT BRIGHTEST EVENT IN EACH FLASH DERIVED FROM LIS GROUPS)

MODEL VERIFICATION AT KSC



FULL YEAR OF STORMS (2018-19)

- model curve derived using overall CONUS TRMM-LIS (2013) largest-in-flash optical sources (groups with 4 or fewer events)

- LMA-based observations (bars) obtained by eliminating flashes with group energy below the specified threshold

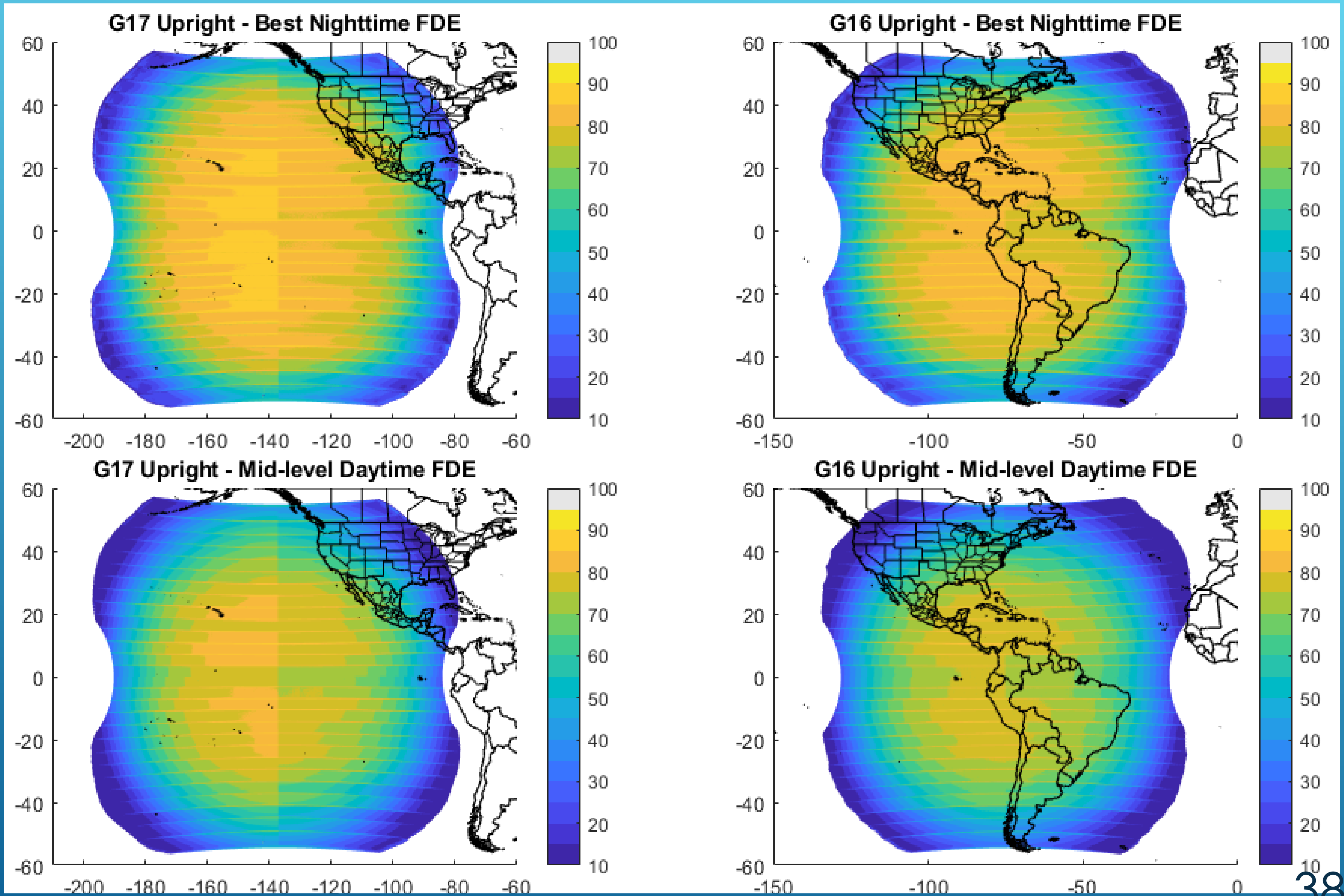
Flash DE decreases by 10-15% for *each 1.5 fJ increase in threshold*

DAY AND NIGHT GLM FLASH DE ESTIMATES

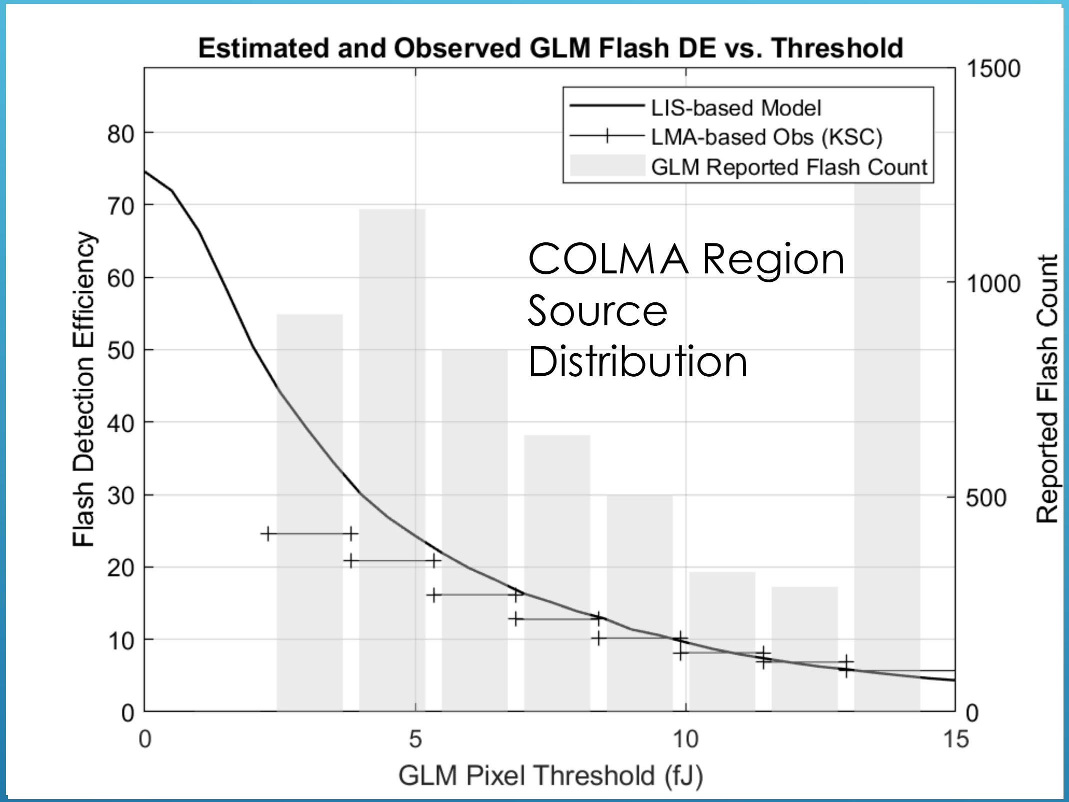
(FULL-CONUS SOURCE MODEL FROM ISS_LIS, ASSUMING 80% LIS FDE)

Regional differences in flash size, flash height, or cloud optical depth are not addressed in these estimates. (See Zhang & Cummins, 2020 and Rutledge et al., 2020 for related details)

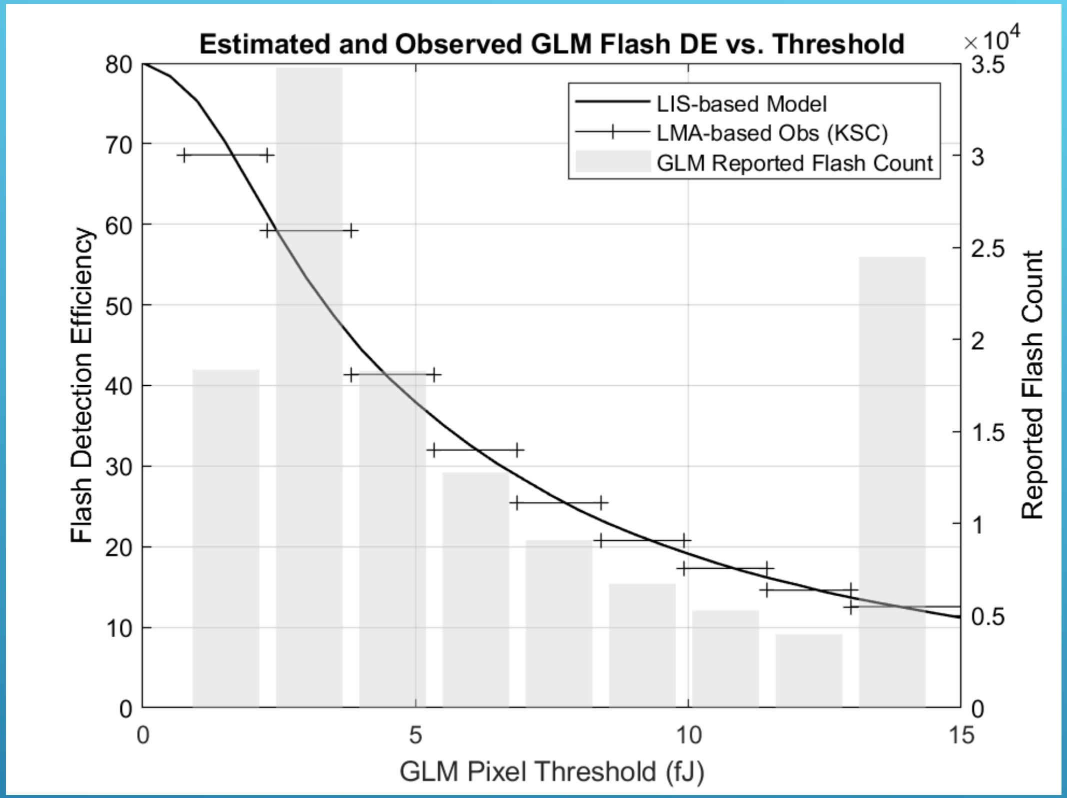
Based on known differences in source distributions and thresholds, the expected FDE in Colorado is about 10% lower than what is shown here, and the expected FDE in Florida should be 5-10% higher.



Colorado July 5, 2019



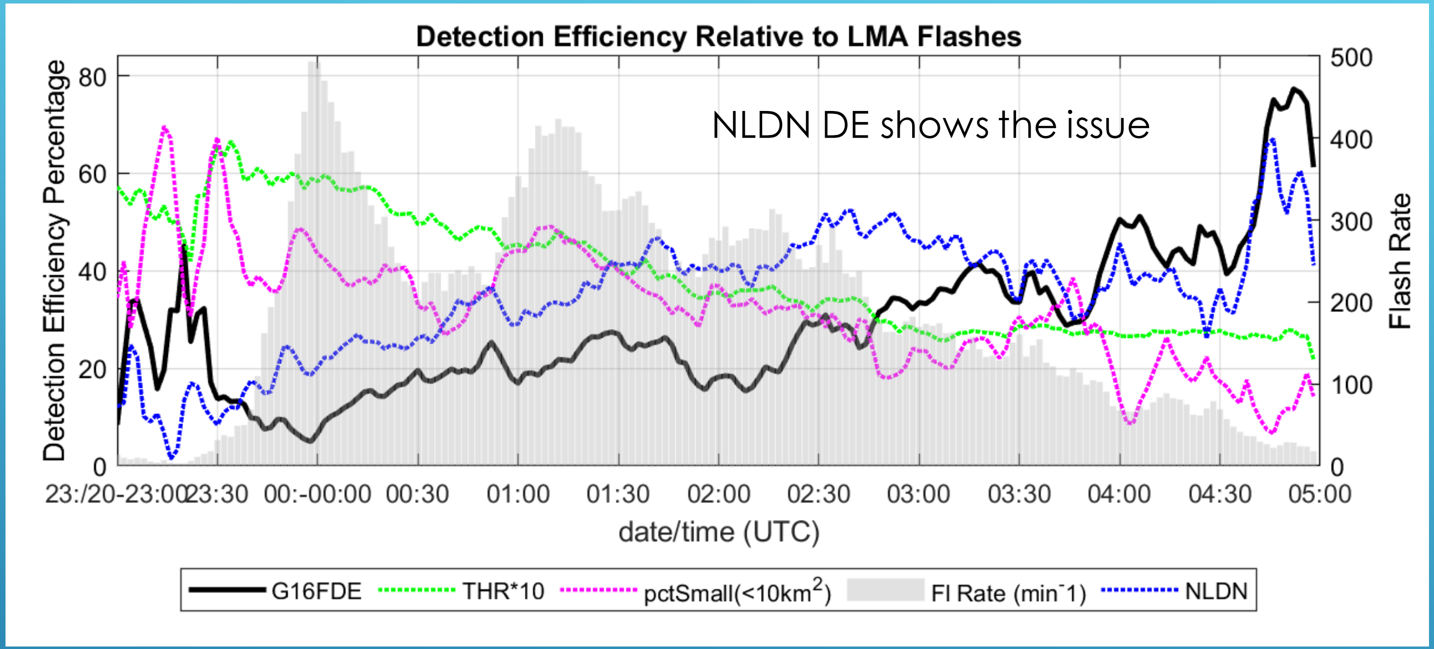
KSC Florida 2018-2019



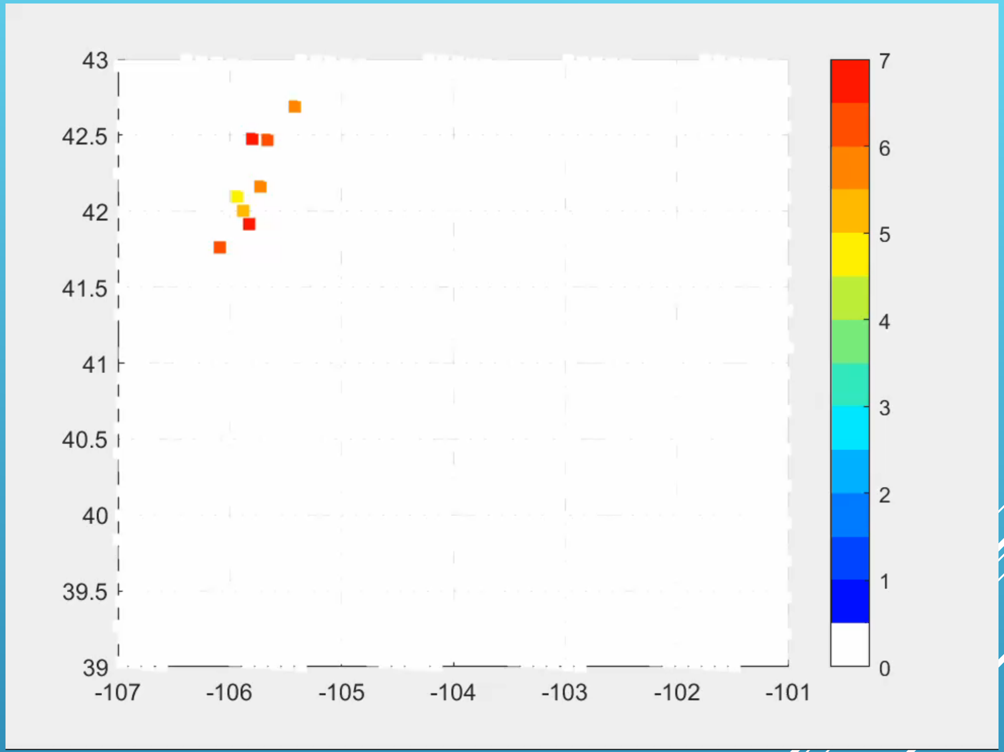
FLASH DE COMPARED TO MODEL IN COLORADO AND FLORIDA – IMPACT OF REGIONAL SOURCE DISTRIBUTIONS

DYNAMIC TRACKING OF GLM PIXEL THRESHOLD

COLORADO STORM DAY: MAY 20, 2020

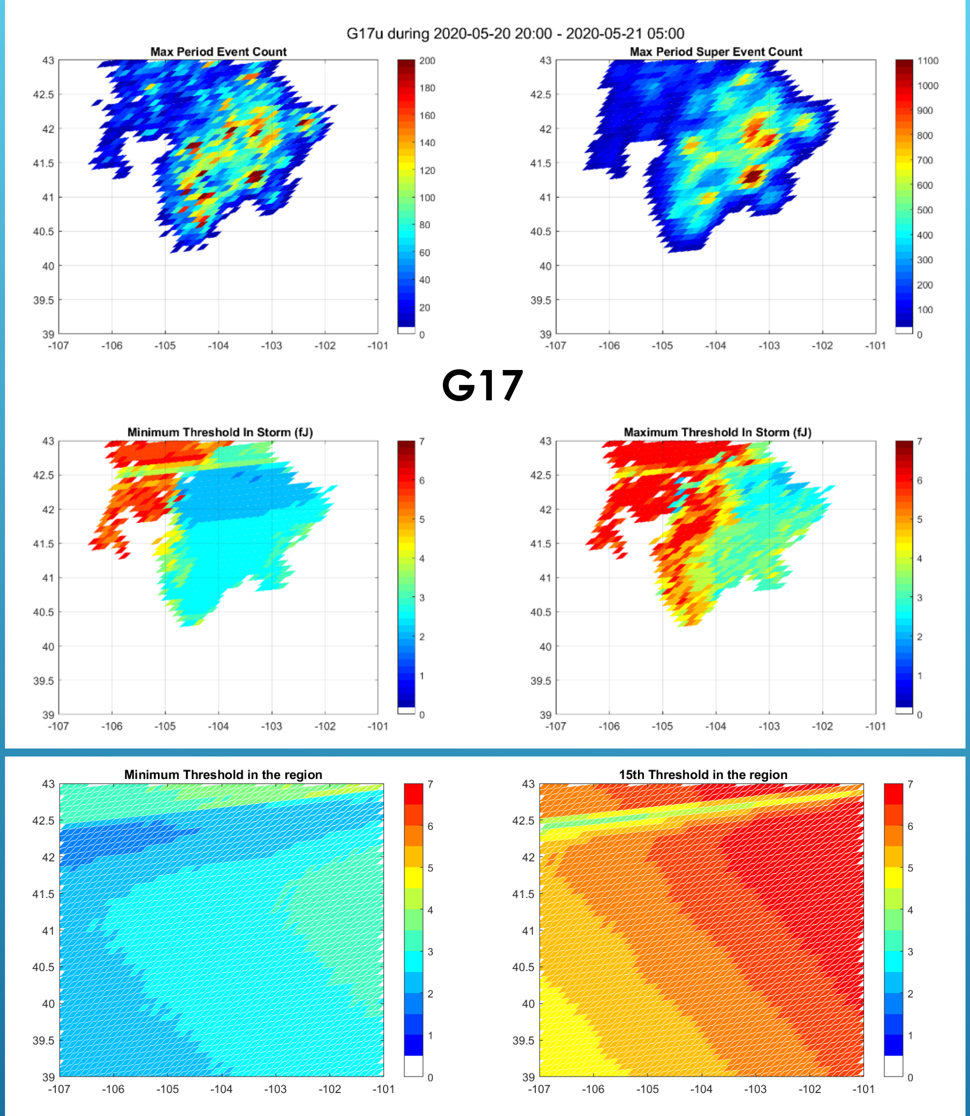


Threshold Animation (2-min frame rate)



Note: final image is the per-pixel minimum over whole case

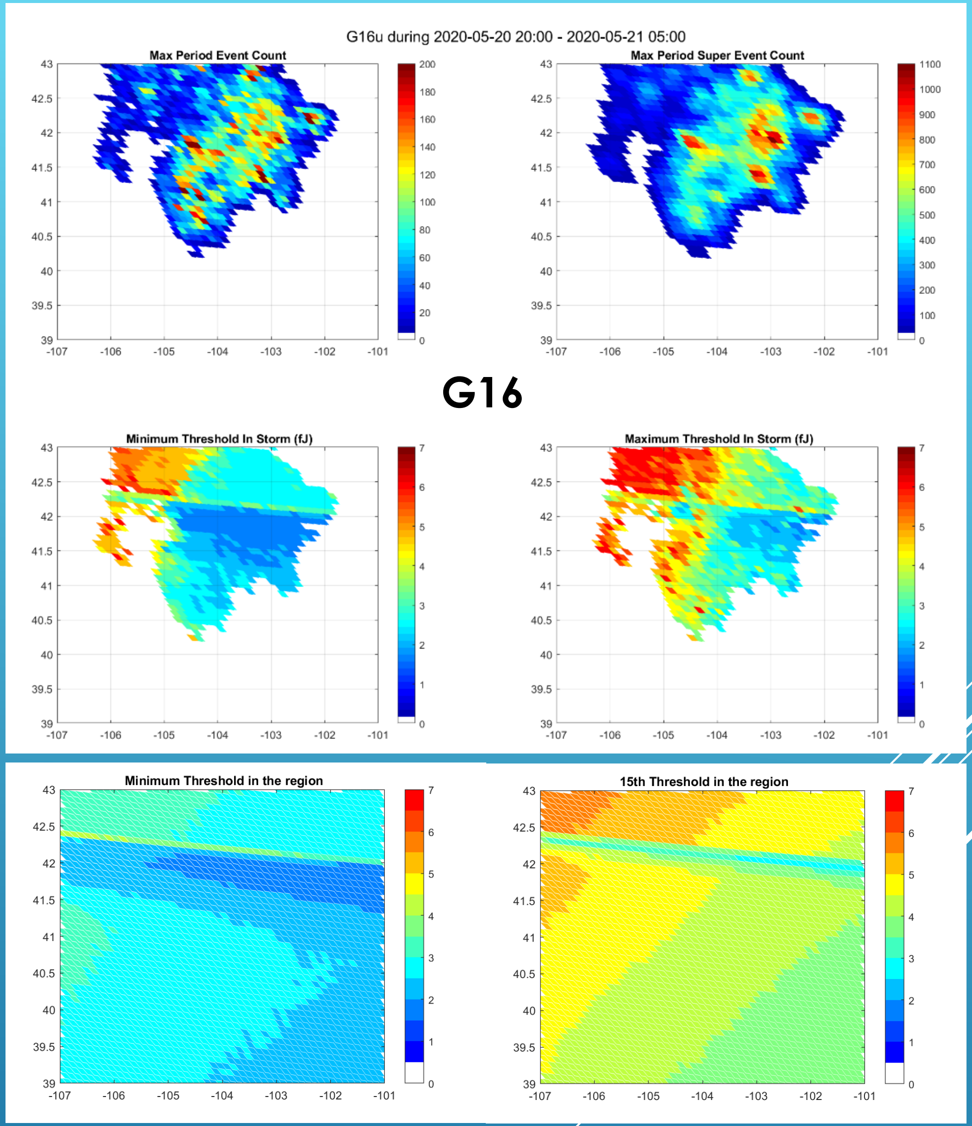
THRESHOLD VARIES BY REGION, AND LOCALLY BY A FACTOR-OF-TWO -- SO WE CAN BENEFIT FROM DYNAMIC TRACKING OF PIXEL THRESHOLD



2-minute Event Count (storm max)

Minimum and maximum 2-minute Observed Thresholds

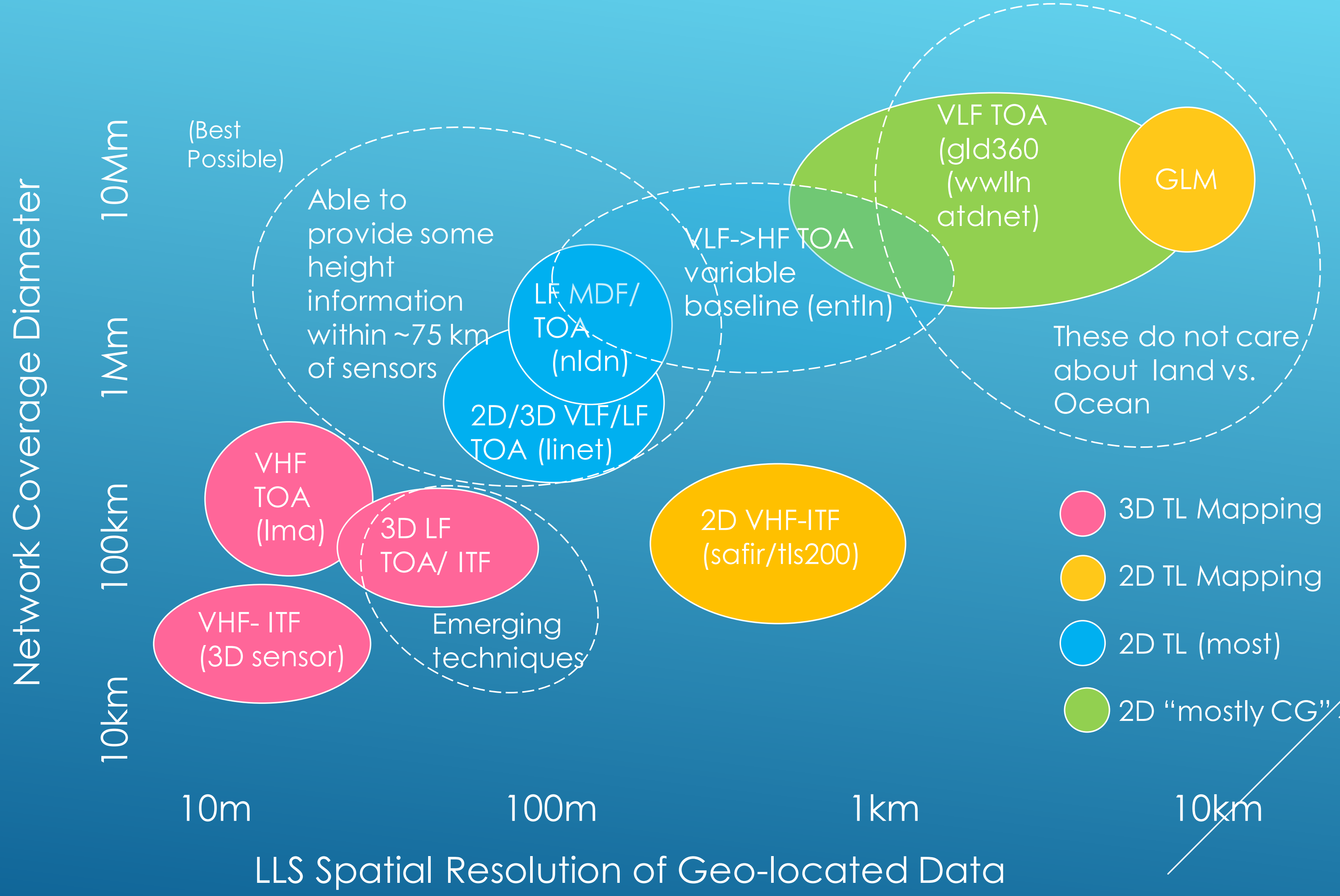
Instrument Threshold "Range"



Note that the observed L2 thresholds are similar for G17 and G17, even though their nominal day:night instrument values are quite different. Could this be a "Front Range Effect"?

SUPPORTING SLIDES

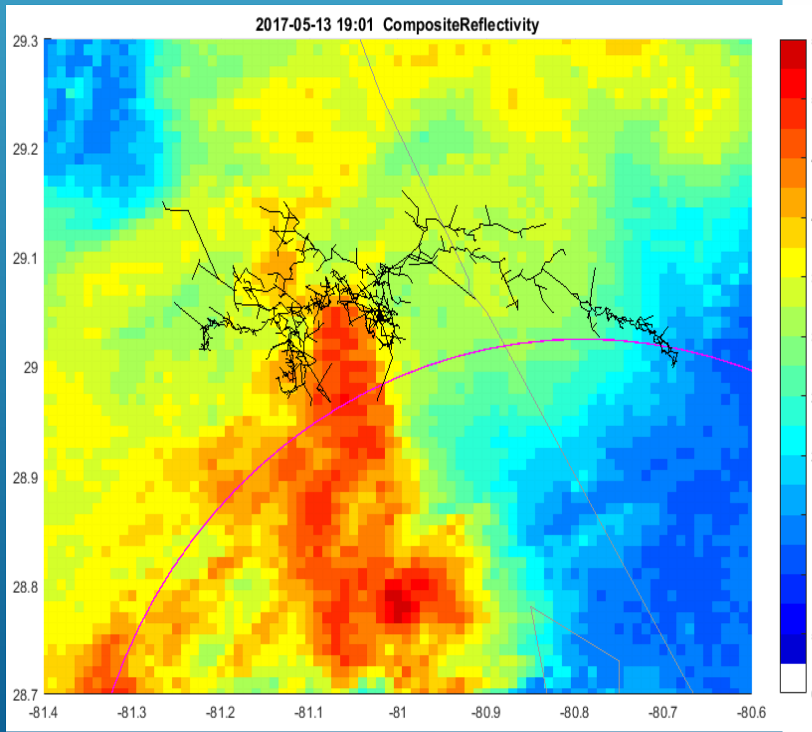
The Spectrum of Ground-based Lightning Locating Systems



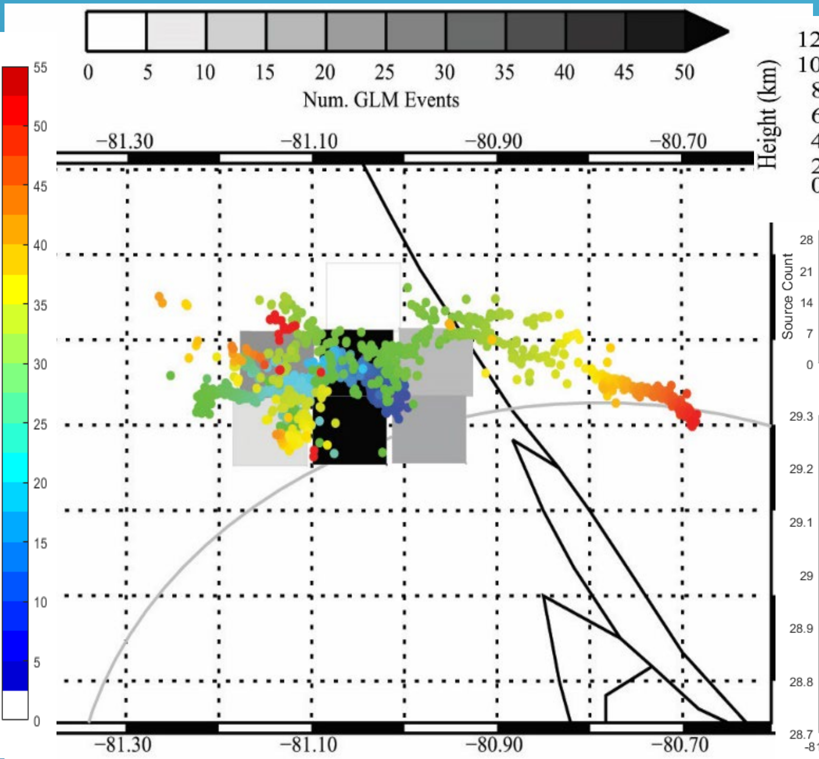
KEY POINT # 2 (examples of simultaneous observations

LMA=>VHF TOA **GLM**=>Satellite Optical **MERLIN**=>VHF ITF **NLDN**=>VLF/LF TOA

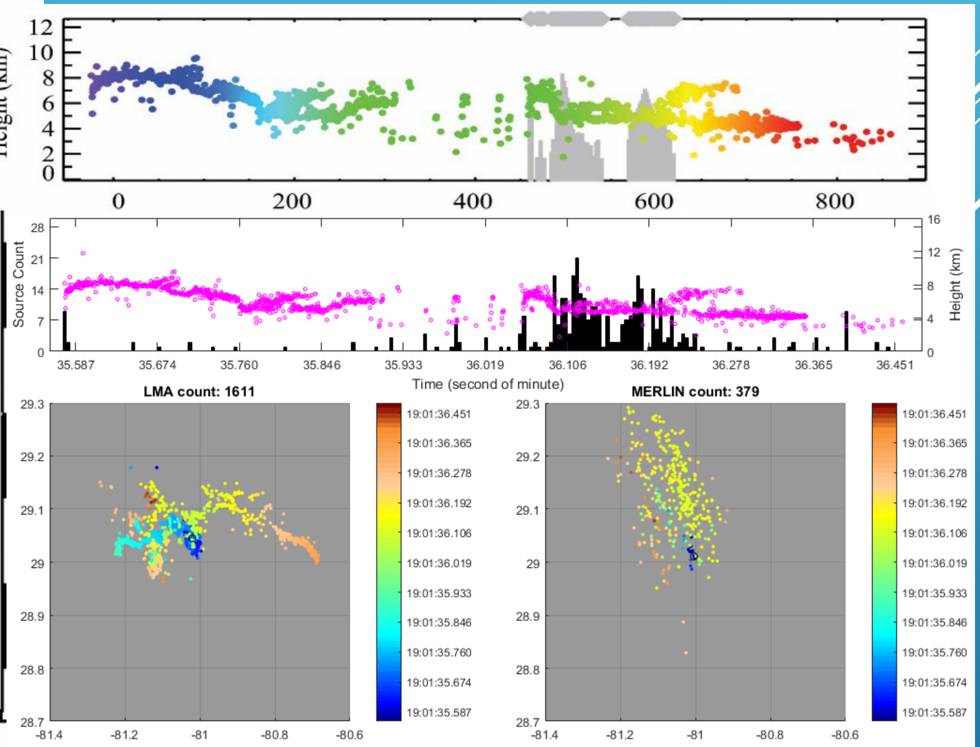
LMA + MRMS Composite Reflectivity



LMA + GLM + NLDN

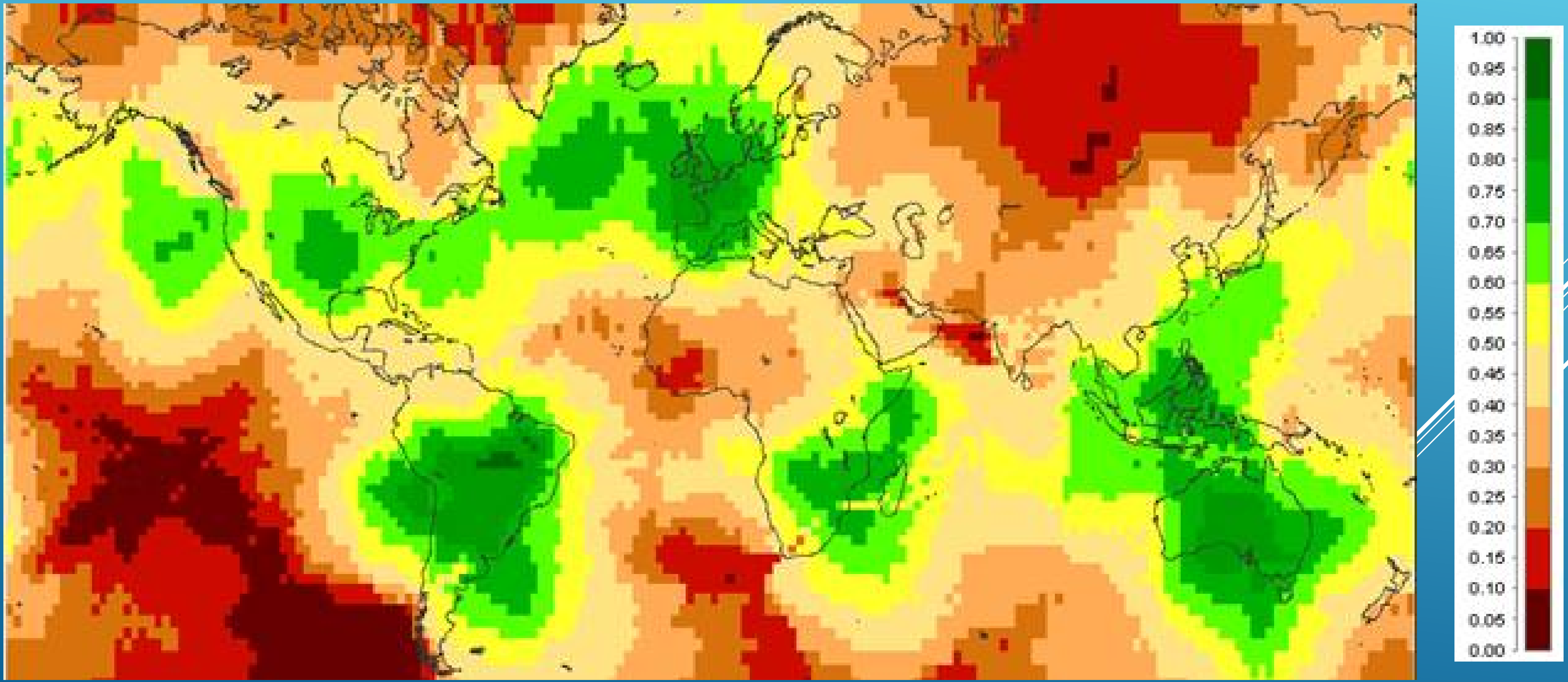


LMA + MERLIN + GLM + NLDN



GLD360 – TOTAL (IC+CG) MODELED FLASH DETECTION

(cloud-to-ground detection is much more uniform)

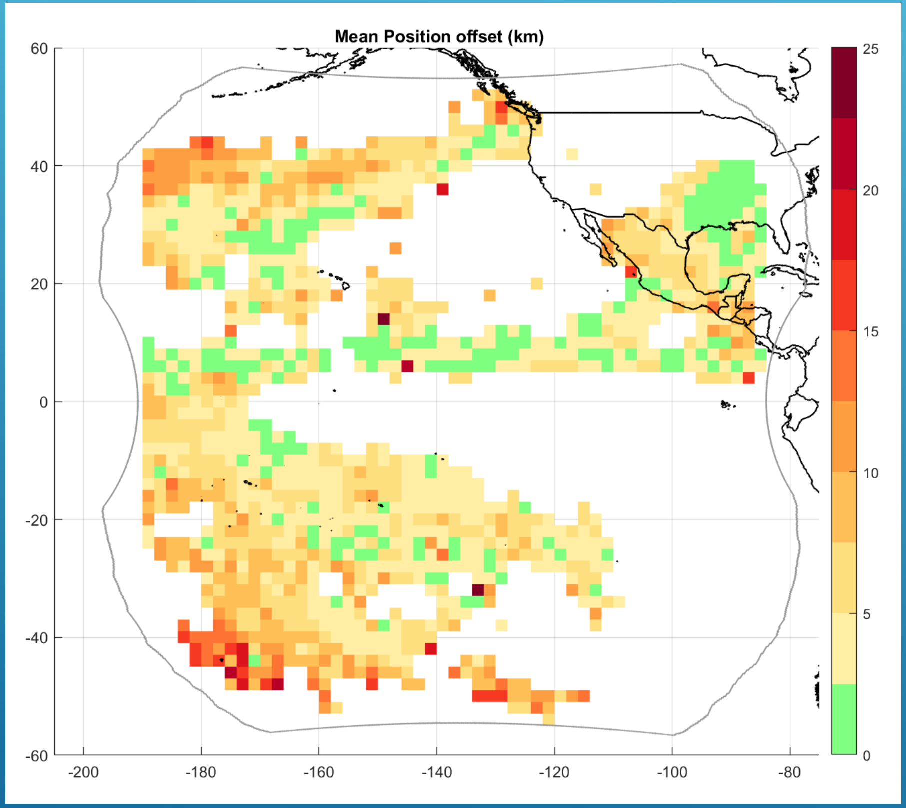


SPATIAL VARIATION IN MEAN LOCATION DIFFERENCE

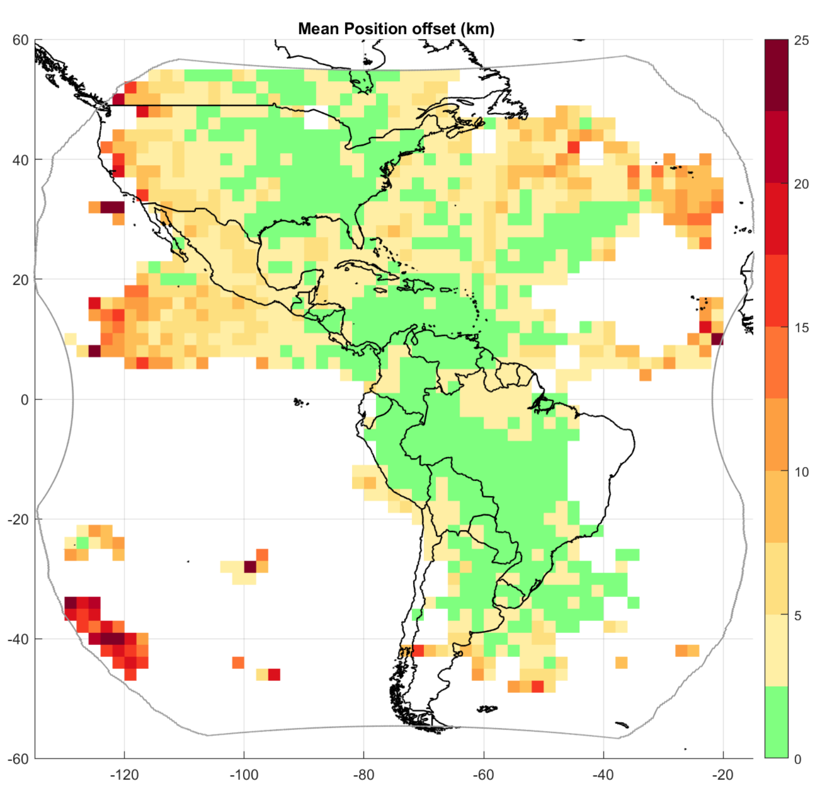
Comments

- *Mean differences generally less than 7.5 km near the center of the Field-of-view*
- *Both instruments exhibit their works mean (bias) err hear the edges of the Field-of-view*

G17: January 2020



G16:July 20 – Oct 2, 2018

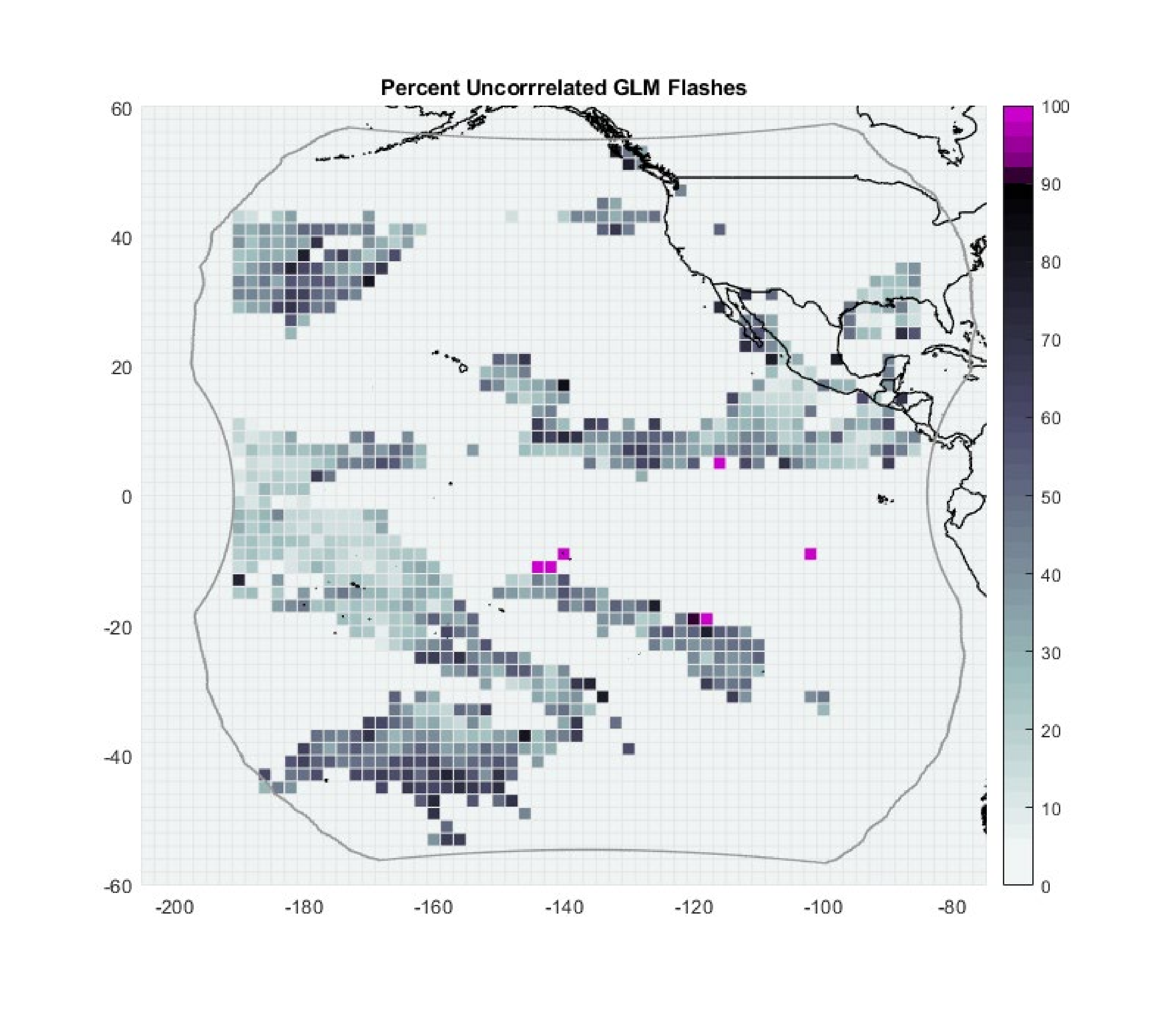


SPATIAL AND TEMPORAL FALSE REPORTS (AUTOMATIC)

***Storm-scale flash matching*:**

- *Accumulate GLD360, GLM, and matched flash centroids into 0.2x0.2° grids for all one-hour periods for 32 days (12/31/2019 through 1/31/2020*
- *Compute the fraction of all GLM flashes that had no GLD360 flashes within nearest-neighbor grids within 2 hours*
- *Assume that all flashes in grids with a fraction less than 0.95 were all false reports.* ***Only 3.8% were false reports*** *using this metric.*

G17 Sample plot December 31 through January 7

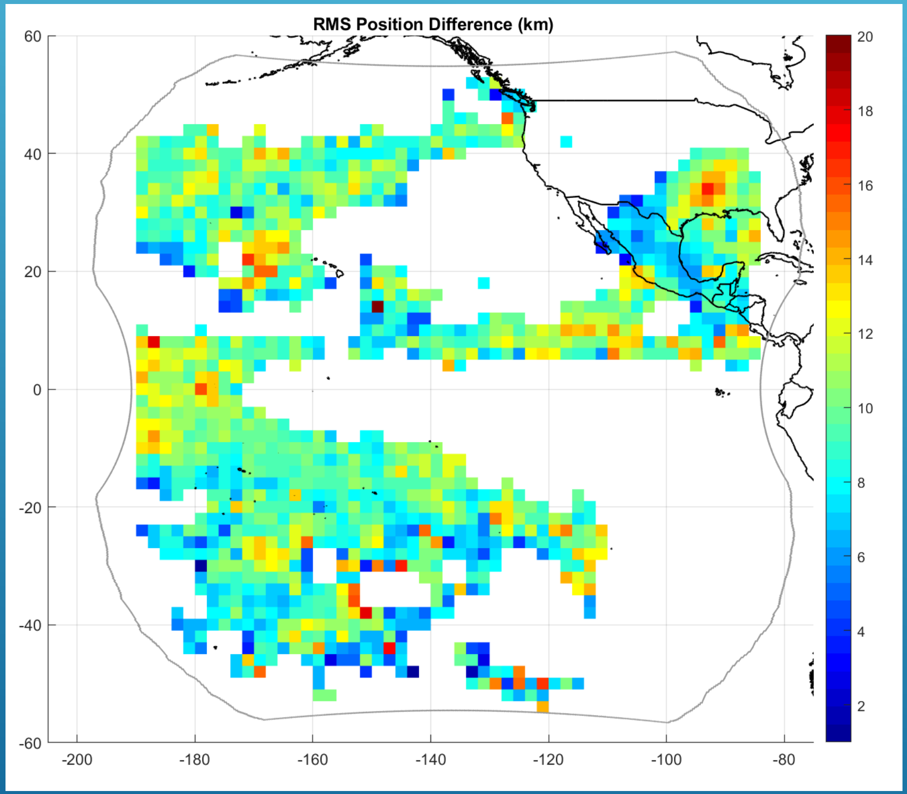


SPATIAL VARIATION IN RMS LOCATION DIFFERENCES

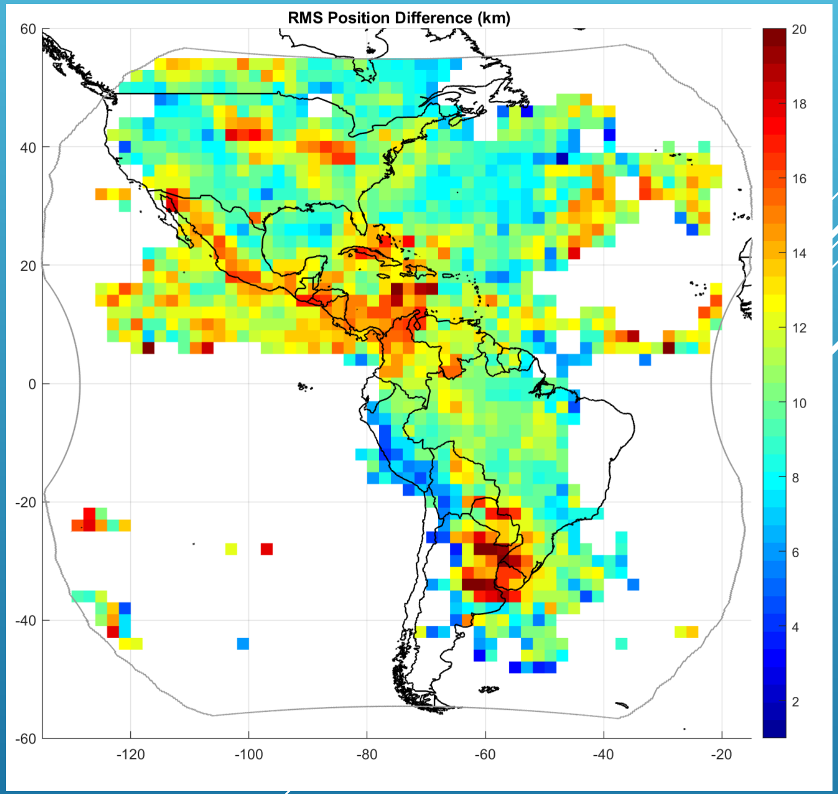
Comments

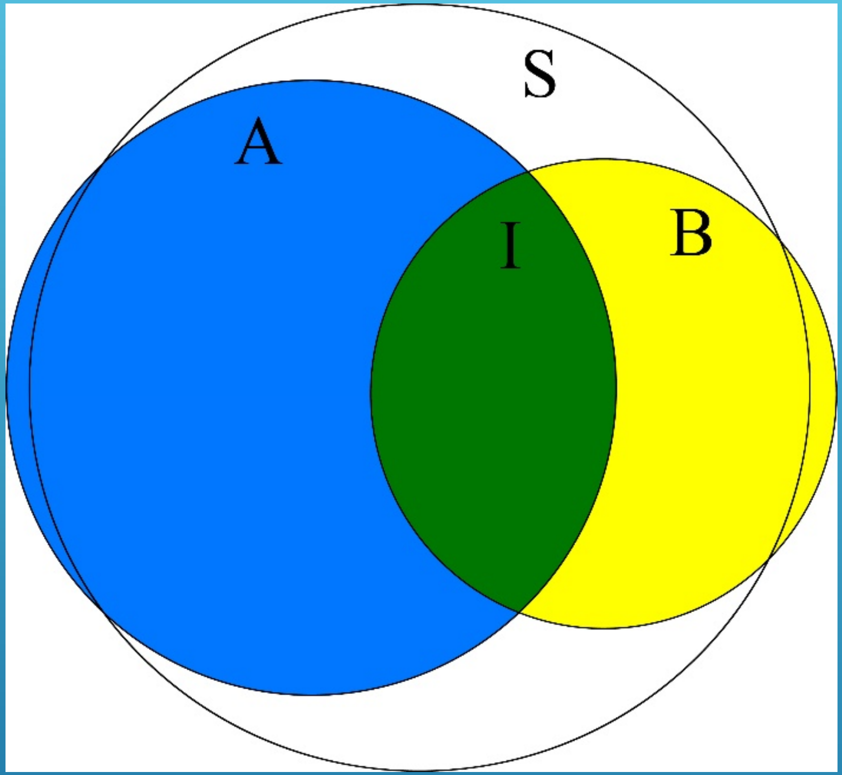
- *RMS location differences for G17 do not seem to exhibit the largest values (>20 km) seen with G16*

G17: January 2020



G16:July 20 – Oct 2, 2018





$$PR(A) = \frac{n_I}{n_B}$$

$$PR(B) = \frac{n_I}{n_A}$$

Relative DE ignores the "excess" seen by the LLS under test

$$PE(A) = \frac{n_A}{n_U} = \frac{n_A}{n_A + n_B - n_I}$$

$$PE(B) = \frac{n_B}{n_U} = \frac{n_B}{n_A + n_B - n_I}$$

Absolute DE tries to consider all flashes

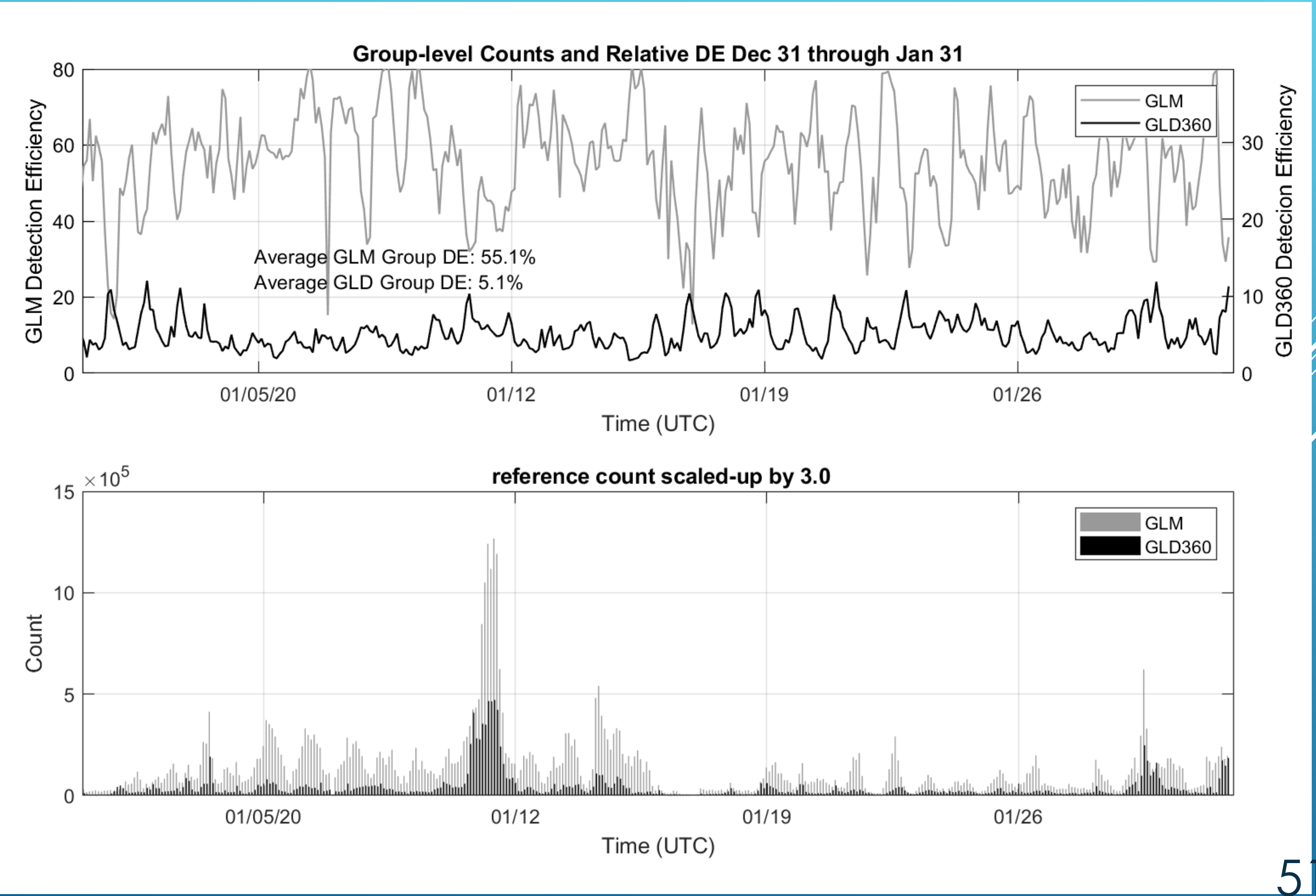
Note: $\frac{PR(A)}{PR(B)} = \frac{PE(A)}{PE(B)}$

"RELATIVE" (*PR*) VS. "ABSOLUTE" (*PE*) DETECTION EFFICIENCY

HOURLY TIME SERIES OF RELATIVE GROUP DETECTION EFFICIENCY

Comments

- *Group matching is very sensitive to small variation in detection – **<u>useful</u> for "microscopic" analyses***
- *GLM (G17) exhibits large diurnal variations in group relative DE*
- *GLD360 group DE is quite low, as expected (only allow GLD to match ONE GLM group)*

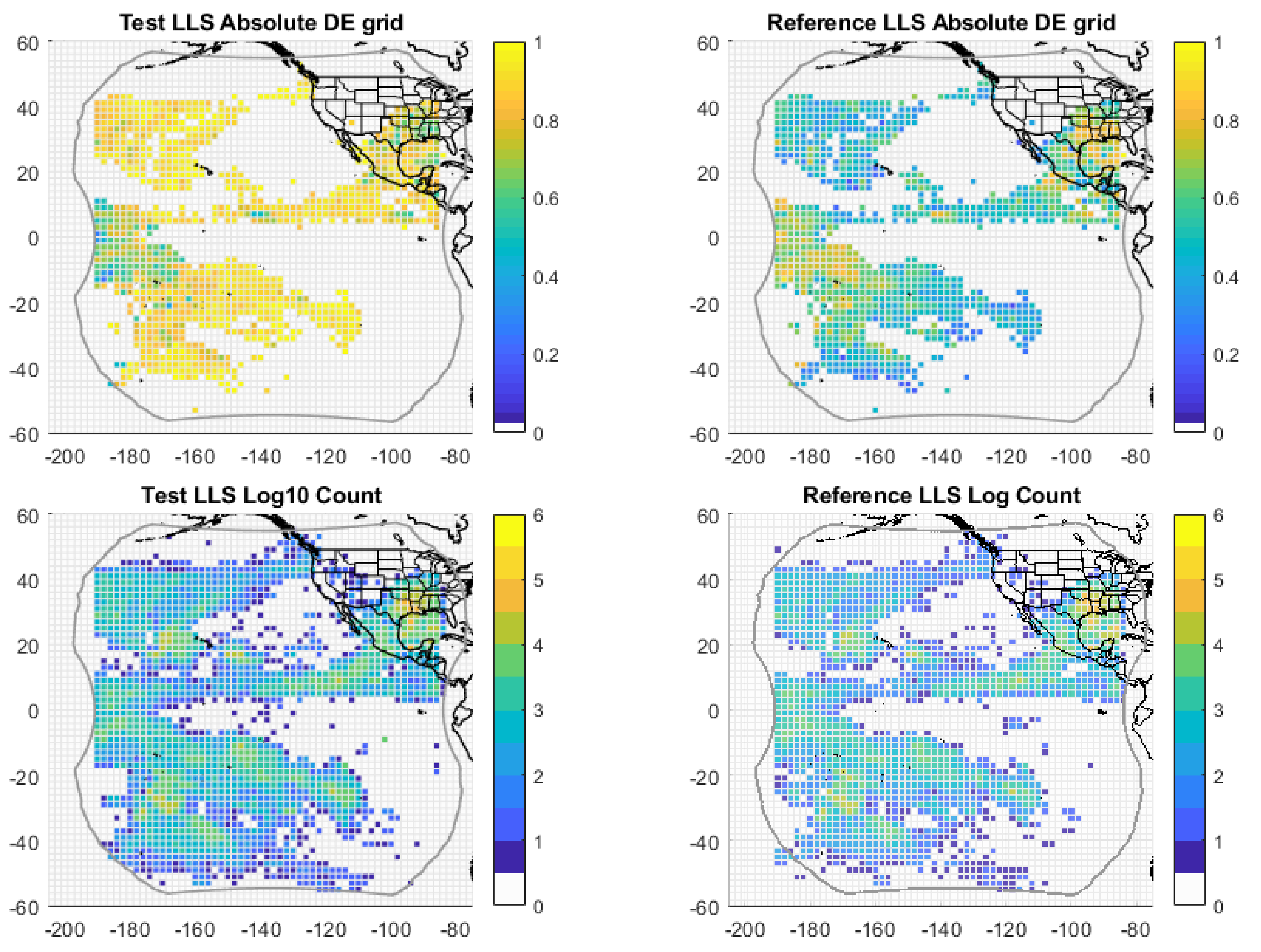


GLM (G17) AND GLD360 "ABSOLUTE" FLASH DETECTION EFFICIENCY (GLM=TEST; GLD=REFERENCE)

G17: Dec 31 2019 through Jan 31, 2020

Comments

- *GLM exhibits expected lower flash DE near edges of the field-of-view*
- *GLD360 flash DE is quite low in the mid-Pacific.*
- *Vaisala expects GLD360 flash DE to be 20% lower (on average) in the GOES-West domain compared to the GOES-East domain, with even lower values in the south-central Pacific.*



FULL-YEAR DIURNAL GLM FLASH DE

Long Flashes =>

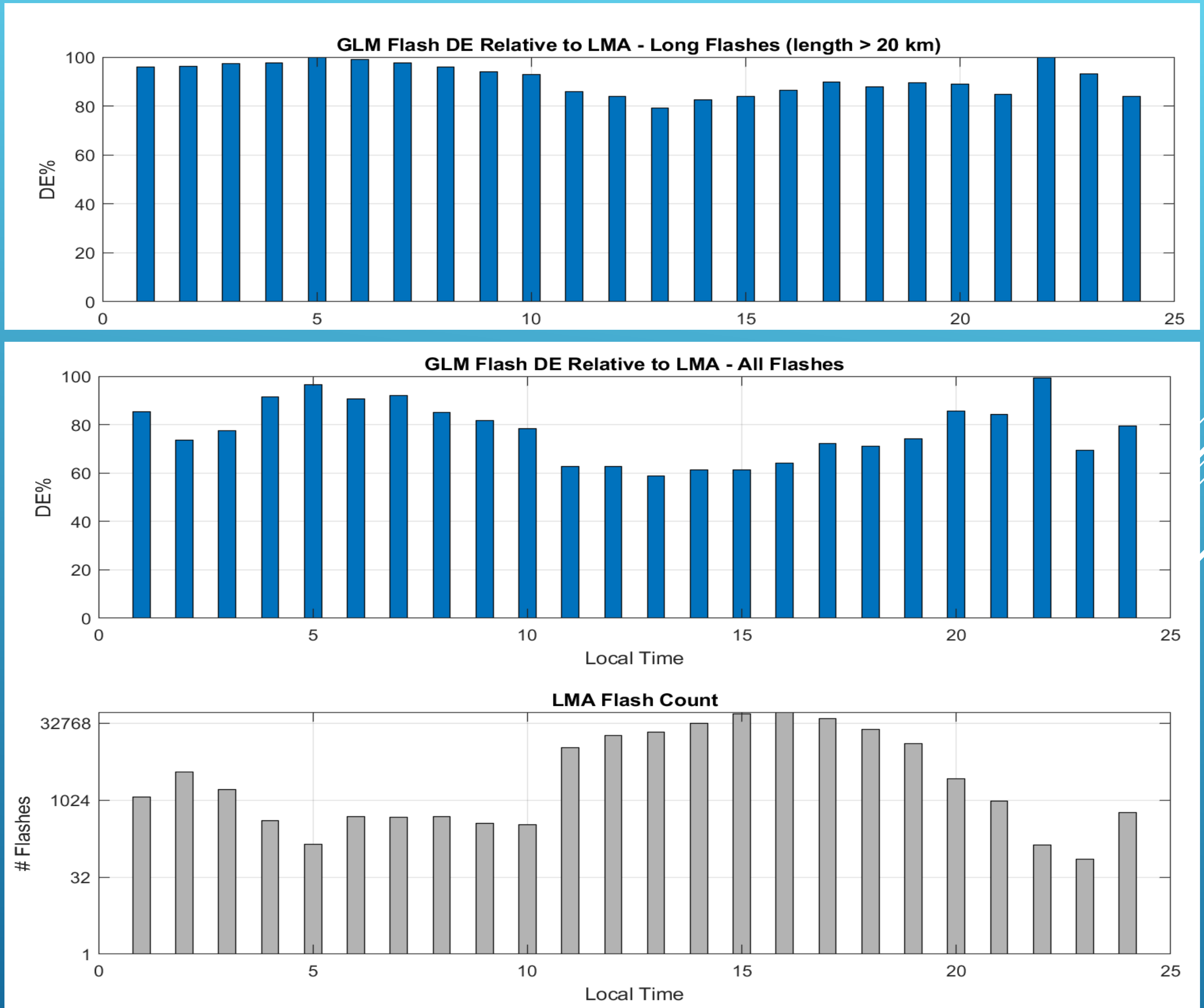
- Modest diurnal variation

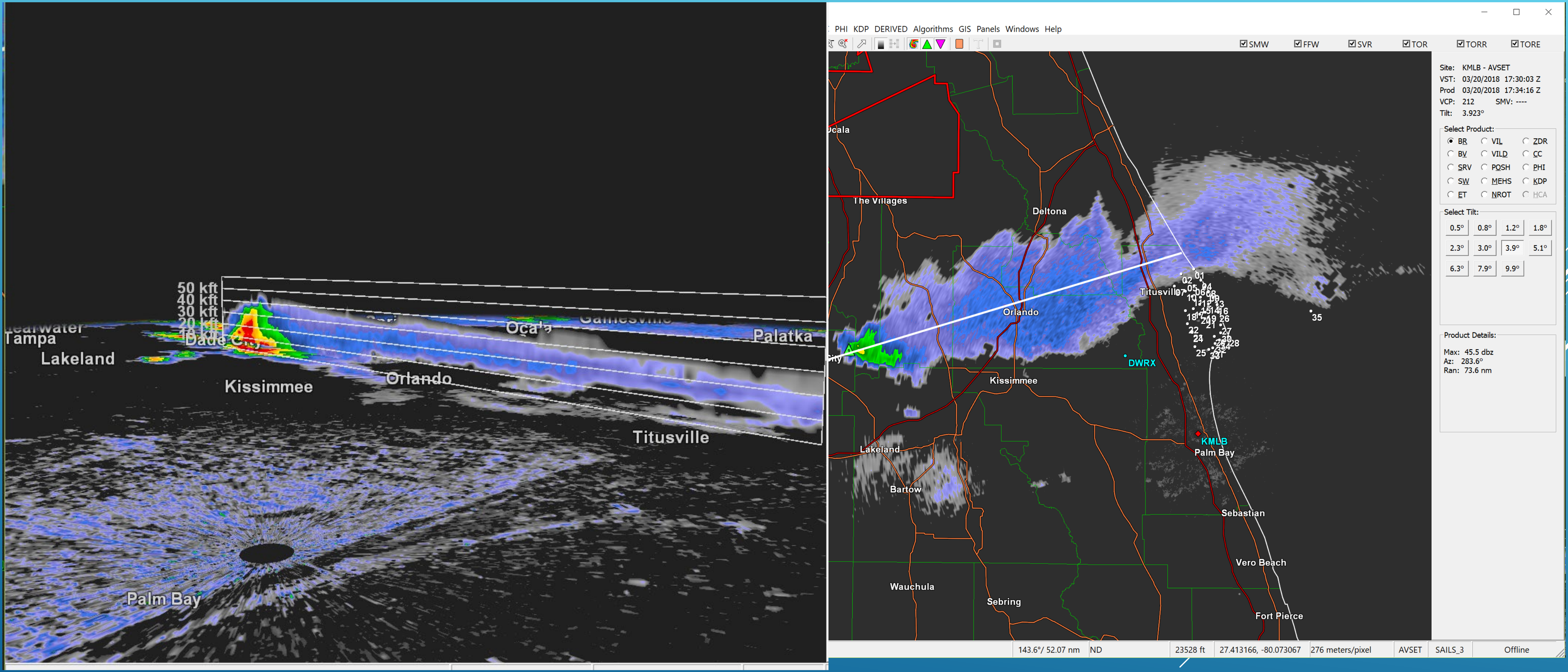
All Flashes =>

- ~25% diurnal variation for GLM

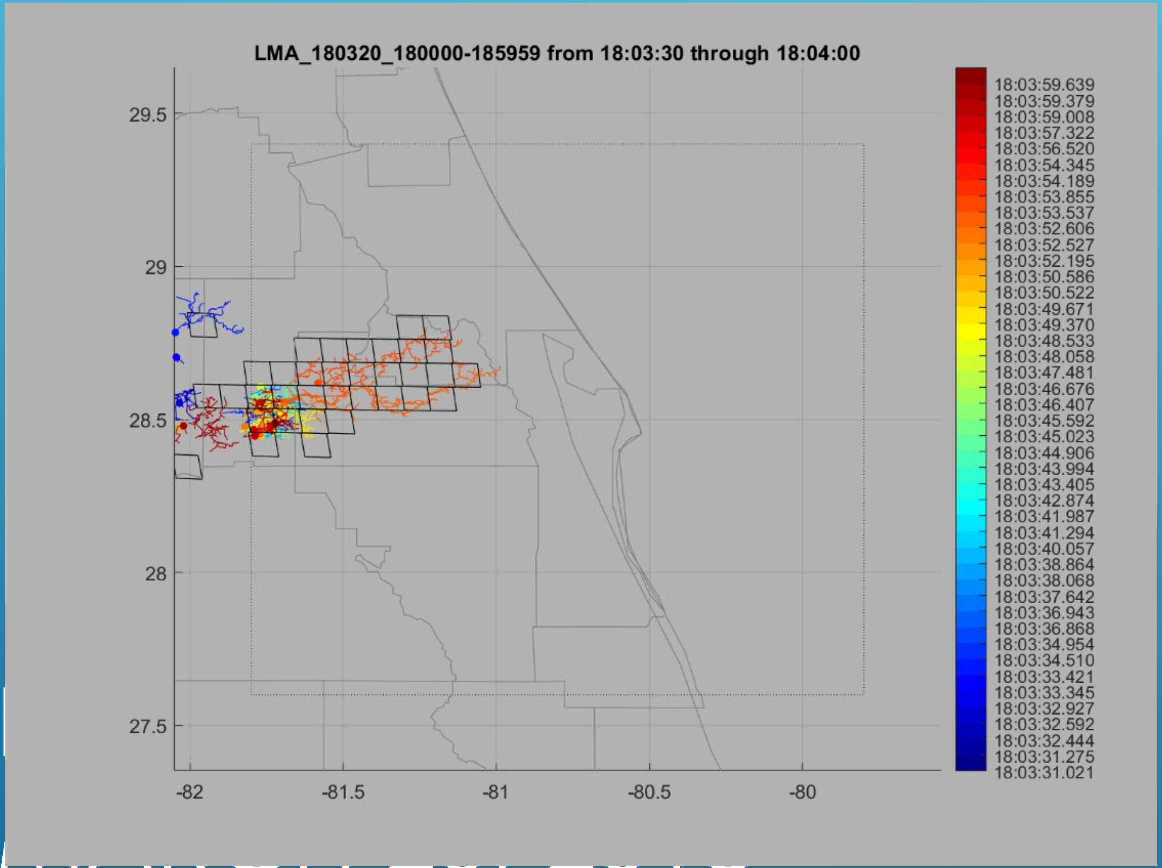
Many-more daytime flashes

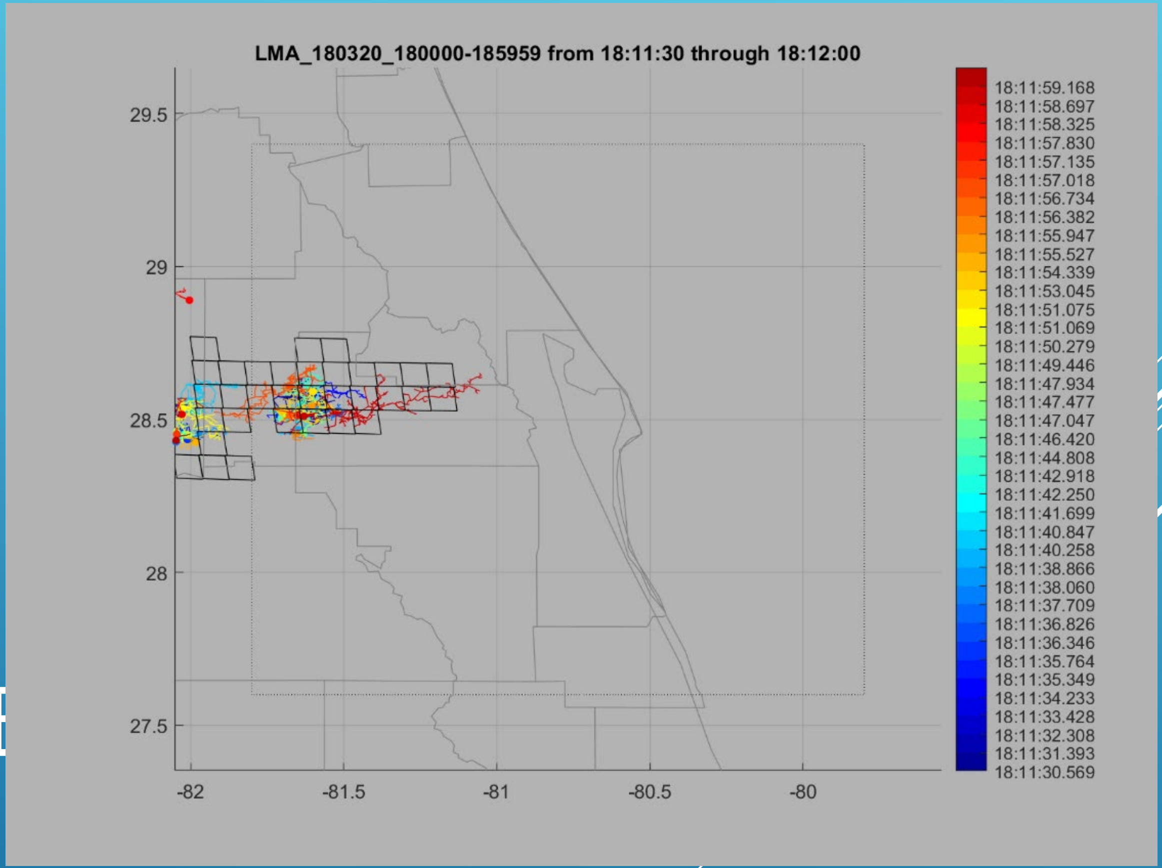
- Note log scale



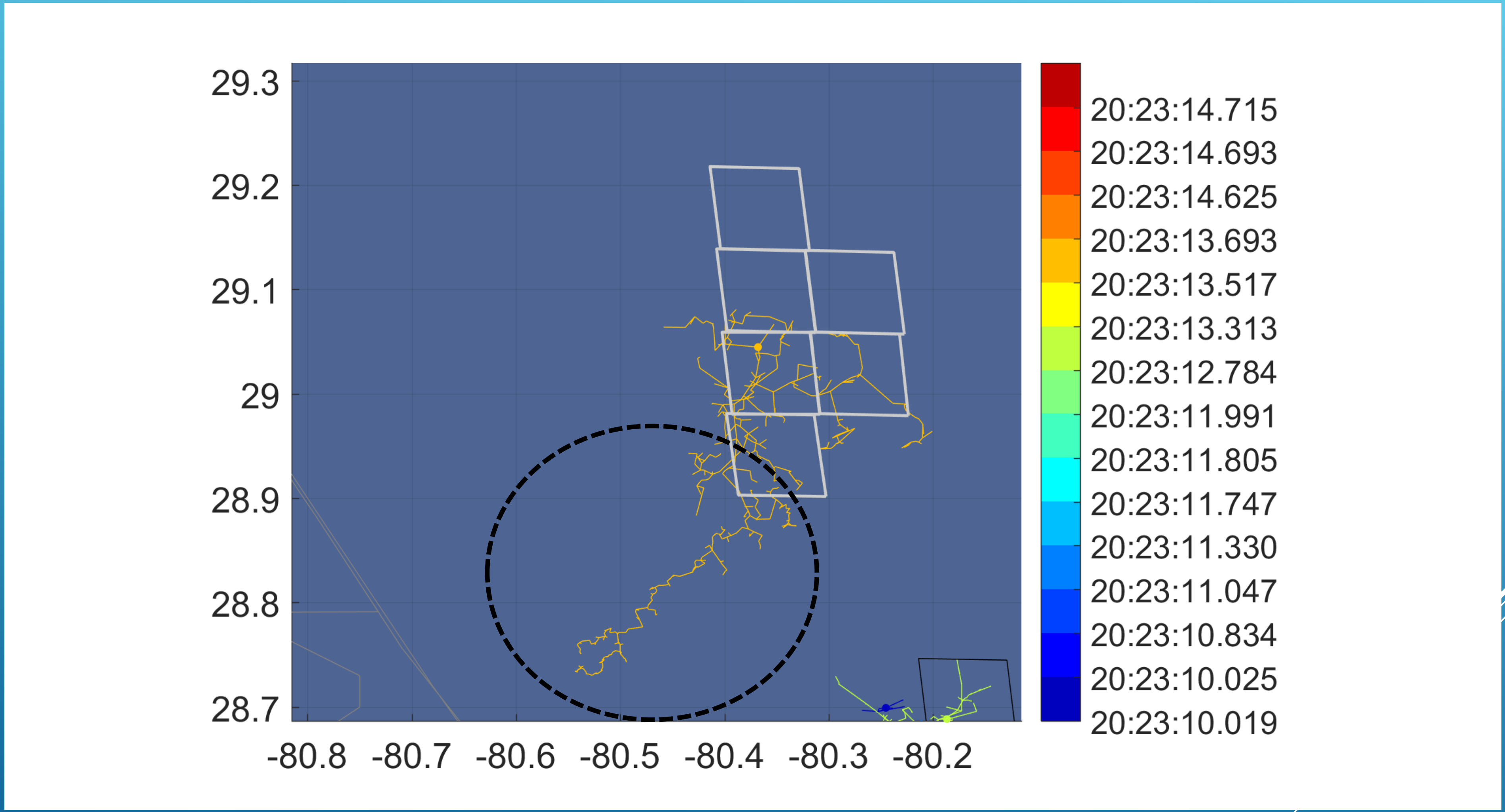


50 kft
40 kft
30 kft
20 kft
Tampa
Lakeland
Kissimmee
Orlando
Ocala
Palatka
Titusville
Palm Bay
PHI KDP DERIVED Algorithms GIS Panels Windows Help
SMW FFW SVR TOR TORR TORE
The Villages
Deltona
Orlando
Kissimmee
DWRX
KMLB
Palm Bay
Lakeland
Bartow
Wauchula
Sebring
Sebastian
Vero Beach
Fort Pierce
Site: KMLB - AVSET
VST: 03/20/2018 17:30:03 Z
Prod 03/20/2018 17:34:16 Z
VCP: 212 SMV: ----
Tilt: 3.923°
Select Product:
BR VIL ZDR
BV VILD CC
SRV POSH PHI
SW MEHS KDP
ET NROT HCA
Select Tilt:
0.5° 0.8° 1.2° 1.8°
2.3° 3.0° 3.9° 5.1°
6.3° 7.9° 9.9°
Product Details:
Max: 45.5 dbz
Az: 283.6°
Ran: 73.6 nm
143.6°/ 52.07 nm ND 23528 ft 27.413166, -80.073067 276 meters/pixel AVSET SAILS_3 Offline


LMA_180320_180000-185959 from 18:03:30 through 18:04:00
29.5
29
28.5
28
27.5
-82
-81.5
-81
-80.5
-80
18:03:59.639
18:03:59.379
18:03:59.008
18:03:57.322
18:03:56.520
18:03:54.345
18:03:54.189
18:03:53.855
18:03:53.537
18:03:52.606
18:03:52.527
18:03:52.195
18:03:50.586
18:03:50.522
18:03:49.671
18:03:49.370
18:03:48.533
18:03:48.058
18:03:47.481
18:03:46.676
18:03:46.407
18:03:45.592
18:03:45.023
18:03:44.906
18:03:43.994
18:03:43.405
18:03:42.874
18:03:41.987
18:03:41.294
18:03:40.057
18:03:38.864
18:03:38.068
18:03:37.642
18:03:36.943
18:03:36.868
18:03:34.954
18:03:34.510
18:03:33.421
18:03:33.345
18:03:32.927
18:03:32.592
18:03:32.444
18:03:31.275
18:03:31.021


LMA_180320_180000-185959 from 18:11:30 through 18:12:00
29.5
29
28.5
28
27.5
-82
-81.5
-81
-80.5
-80
18:11:59.168
18:11:58.697
18:11:58.325
18:11:57.830
18:11:57.135
18:11:57.018
18:11:56.734
18:11:56.382
18:11:55.947
18:11:55.527
18:11:54.339
18:11:53.045
18:11:51.075
18:11:51.069
18:11:50.279
18:11:49.446
18:11:47.934
18:11:47.477
18:11:47.047
18:11:46.420
18:11:44.808
18:11:42.918
18:11:42.250
18:11:41.699
18:11:40.847
18:11:40.258
18:11:38.866
18:11:38.060
18:11:37.709
18:11:36.826
18:11:36.346
18:11:35.764
18:11:35.349
18:11:34.233
18:11:33.428
18:11:32.308
18:11:31.393
18:11:30.569

LATE-IN-FLASH DETECTION ISSUE? Missed extensive channels



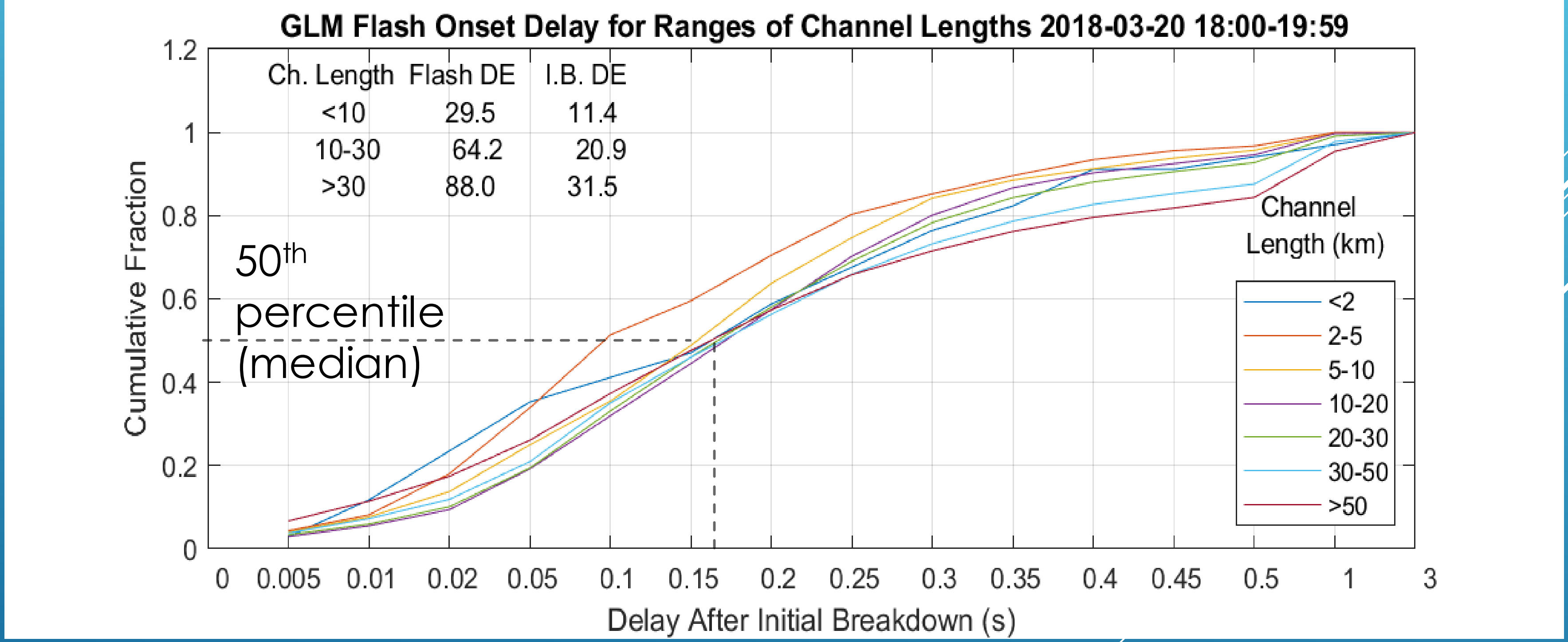
22 storm days (25 storm cases) from
March 20, 2018 through February 27, 2019

- Overall Flash DE: 73.8%
  - IC Flashes: 71.8%
  - CG Flashes: 86.5%
  - Short Flashes (<8 km): 40.4%
  - Long Flashes (>50 km): 96.3%
- Night DE: 10-20% better
- Average Detection Lag from start-of-flash
  - ~100 ms overall
  - ~38 ms at night

NOTE: best GLM DE is 0-10 and 22-24 UTC; worst DE is 13-17 UTC
No detailed analyiss in 2017 due to "uncalibrated" GLM
local midnight is about 05 UTC

										GLM DE Relative to LMA										
index	Date	UTC startTime	UTC endTime	sunrise	noon	sunset	GeneralComments	LMA Flash Count	CG Flash Count	overall	IC	CG	<8 km (# / DE)		15-25 km (# / DE)		>50 km (# / DE)		50th Percentile 10-20 km Len Lag Time (ms)	10-30 km I.B. DE
1	2018-03-20 18	18	20	10:36	17:30	23:58	Major Squall/Disturbed	17758	3106	67	63.6	83	1367	29.8	4487	69.4	1669	95.3	180	20.9
	2018-03-20 20	20	22	10:36	17:30	23:58	Major Squall/Disturbed	24572	2868	73.6	71.7	88.4	1892	47.3	6977	78	1804	94.3	120	33
	2018-03-20 22	22	24	10:36	17:30	23:58	Major Squall/Disturbed	9519	1209	75.6	73.9	87.2	538	38.5	2532	76.4	1169	96.9	100	37.9
2	2018-04-07 00	22	24	10:14	17:25	0:08	Disturbed system	6040	978	67	65.3	75.7	206	34.5	1821	59.5	523	93.9	80	31.5
3	2018-04-10 15	15	17	10:10	17:24	0:10		19417	2912	62.7	60.2	77.1	1377	23.2	5305	64.8	1660	92.6	150	18.9
	2018-04-10 17	17	20	10:10	17:24	0:10		17315	3035	58.6	58.7	57.9	977	20.1	4446	53.7	2089	89.6	150	17.7
4	2018-04-11 00	3	8	10:10	17:24	0:10		2413	794	86.4	85.1	89.2	50	56	450	77.6	625	96.6	25	60.4
5	2018-04-23 00	18	23	9:56	17:21	0:18		11564	1861	63.6	59.7	84	771	15.8	3290	69	881	95.1	130	30.7
6	2018-05-15 00	19	23	9:35	17:19	0:32		31030	4476	74.7	73.4	82.5	2435	45.3	9080	80.1	2128	95.4	120	36.5
7	2018-05-31 00	19	24	9:27	17:20	0:42		13920	1481	59.8	56.4	88	1121	18.2	4147	64.2	807	94.5	140	21.4
8	2018-06-04 00	14	20	9:26	17:21	0:44		522	44	74.9	73.2	93.2	56	35.7	205	87.8	4	96.2	130	37.1
9	2018-06-06 00	14	20	9:26	17:21	0:44		21402	3314	67.7	65.4	80	1487	24.5	6166	72.5	1612	95.2	130	28.5
10	2018-07-18 00	16	20	9:39	17:29	0:47		10495	2423	65.9	60.8	82.9	699	27.8	3379	69.3	583	95	130	37.5
11	2018-08-10 00	19	24	9:55	17:28	0:31		1652	275	50.8	44.2	83.6	125	20.8	549	56.1	62	90.3	150	18.8
12	2018-08-23 00	18	24	10:03	17:25	0:18		16822	3010	67	63.1	85	1539	32.6	4802	75.6	786	92.8	170	25.4
13	2018-09-19 00	17	23	10:13	17:20	23:58		11547	1262	71.2	69.5	84.7	1282	38.1	3350	84.4	395	96.2	100	44.6
14	2018-11-12 00	17	22	10:50	17:07	22:55		507	122	94.7	94.2	99.2	9	66.7	136	96.3	70	100	20	61.9
15	2018-11-23 00	5	8	10:58	17:09	22:52		3210	67	74.2	73.6	100	431	39.7	886	91.9	83	100	80	46.8
16	2018-12-03 00	17	24	11:05	17:13	22:51		6523	469	77	76	88.9	644	40.8	1993	91.2	166	99.4	90	47.5
17	2018-12-15 00	6	10	11:13	17:18	22:54		647	130	88.4	86.7	95.4	28	42.9	164	91.5	110	100	40	58.1
18	2018-12-20 00	14	22	11:15	17:20	22:56		5337	442	64.4	63.7	72.4	558	32.1	1516	73.1	259	98.5	100	32.5
19	2019-01-24 00	10	15	11:21	17:35	23:20		1287	55	91.8	91.6	94.5	45	62.2	320	91.2	190	100	30	44.2
20	2019-02-12 00	20	24	11:12	17:37	23:35		7445	468	84.3	83.8	91.2	638	52	1990	93	639	99.8	80	51.5
21	2019-02-13 00	0	10	11:12	17:37	23:35		2261	91	98.3	98.3	98.9	129	92.3	758	98.8	148	100	15	48.3
22	2019-02-27 00	20	24	10:59	17:35	23:45		527	60	85.2	83.3	100	29	72.4	140	80.8	68	100	50	52.4
								243732	34952	73.8	71.8	86.5	18433	40.4	68889	77.8	18530	96.3	100.4	37.8
										overall	IC	CG	<8 km (# / DE)		15-25 km (# / DE)		>50 km (# / DE)			

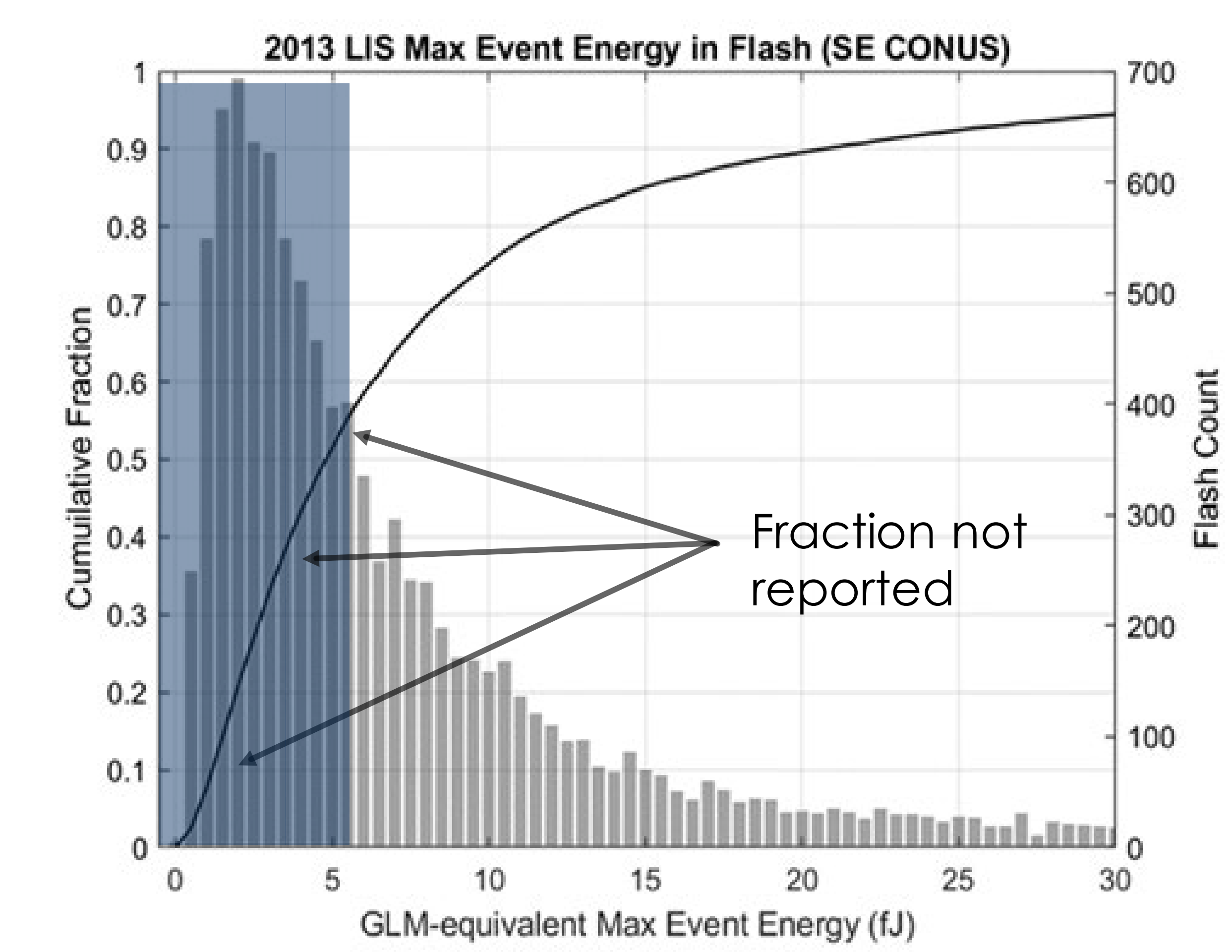
DETECTION ANALYSIS FOR EACH STORM



FUNDAMENTAL PRINCIPLE OF FLASH DETECTION:

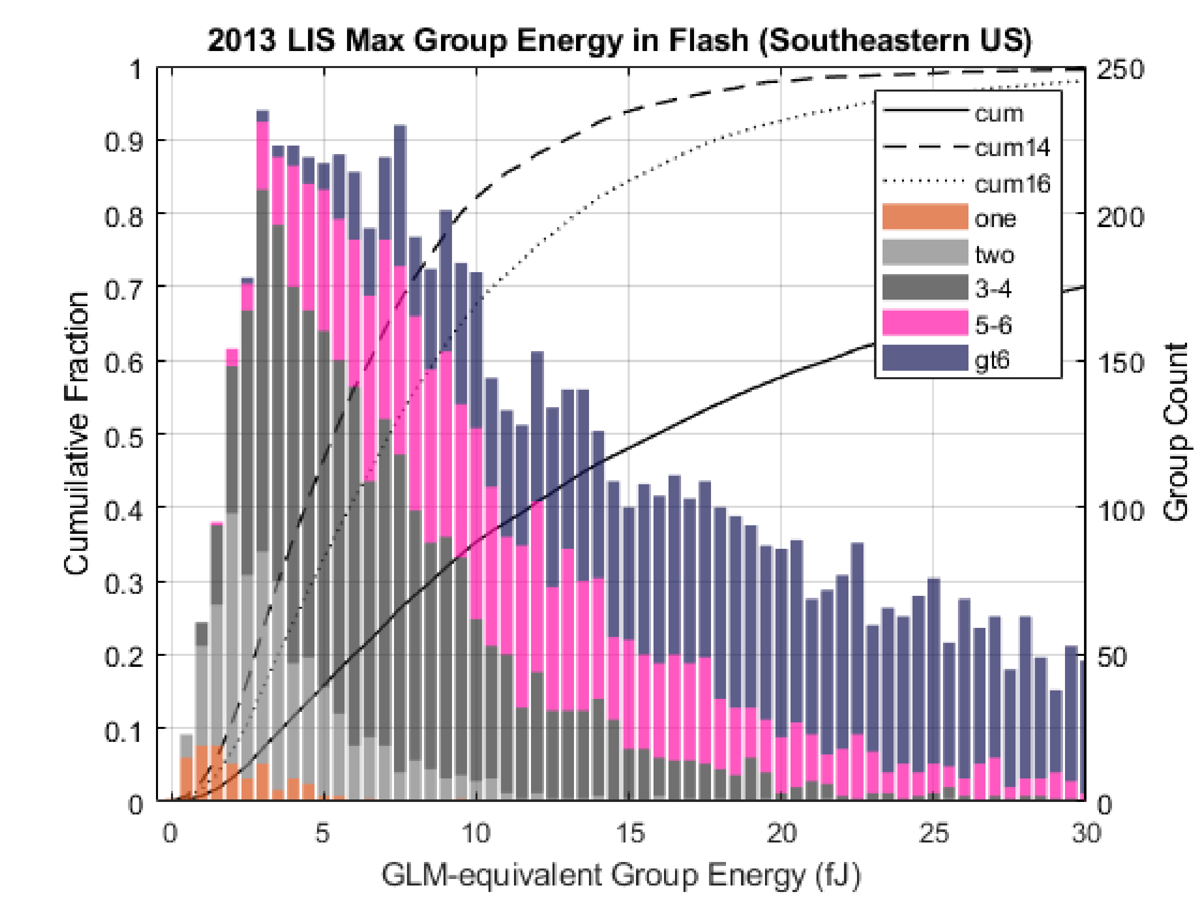
if the brightest events in a flash exceeds the detection threshold in at least one GLM pixel, then the flash is detected

(animation showing increasing detection threshold)



LIS Group Parameters Related to Flash Detection

Broken-down by the number of events in the group

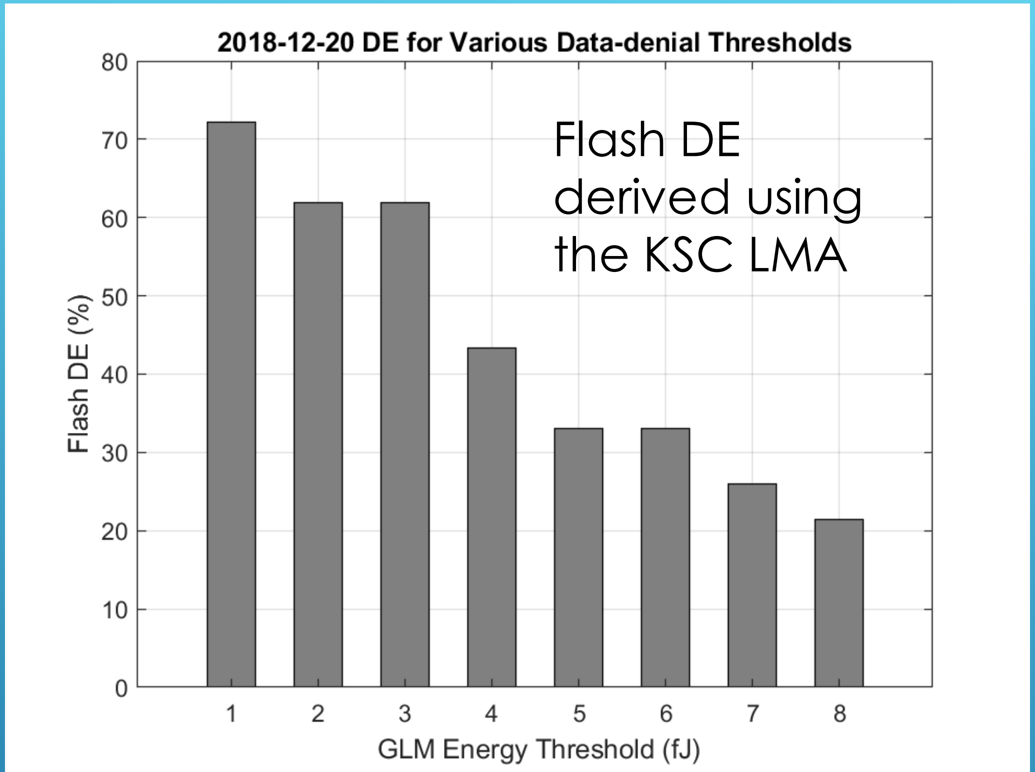


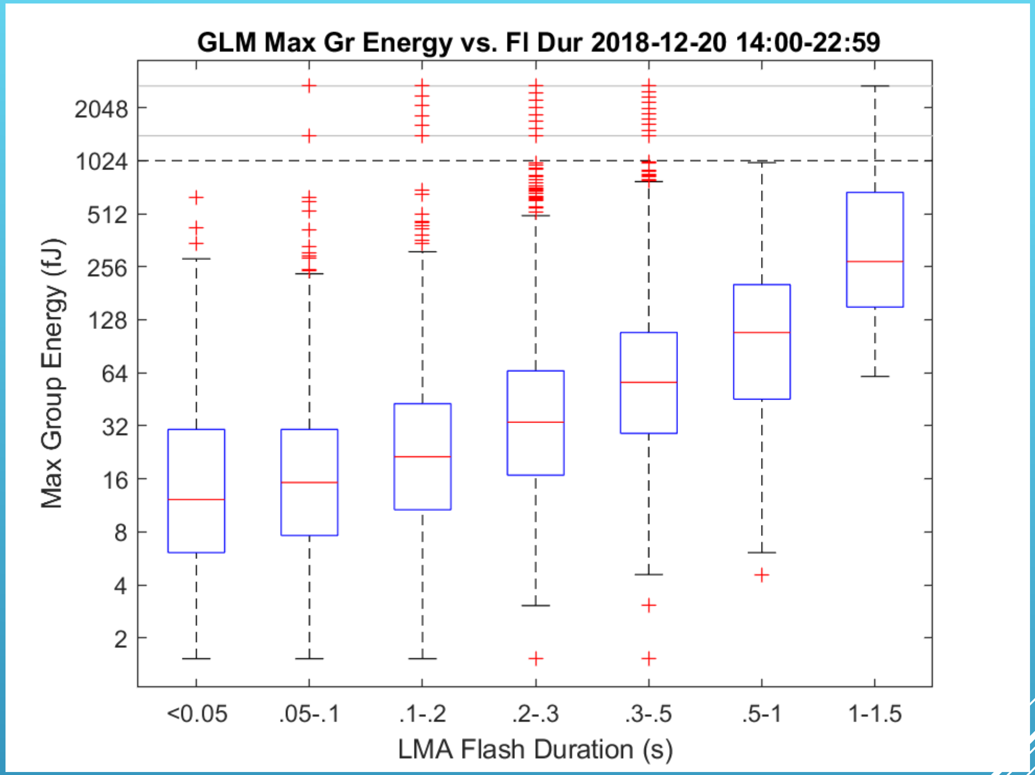
See Zhang and Cummins (JGR, 2020) for conversion of LIS Radiance to GLM-equivalent Energy

A flash will be reported by GLM or LI ***IFF*** at least one group is reported, meaning that at least one of its events has optical energy above threshold

Therefore, the distribution of the maximum pixel-sized event energy in flash can be used to produce a direct estimate of group and flash DE, given local thresholds

The associated cumulative distributions are approximately (1 – fractional DE)



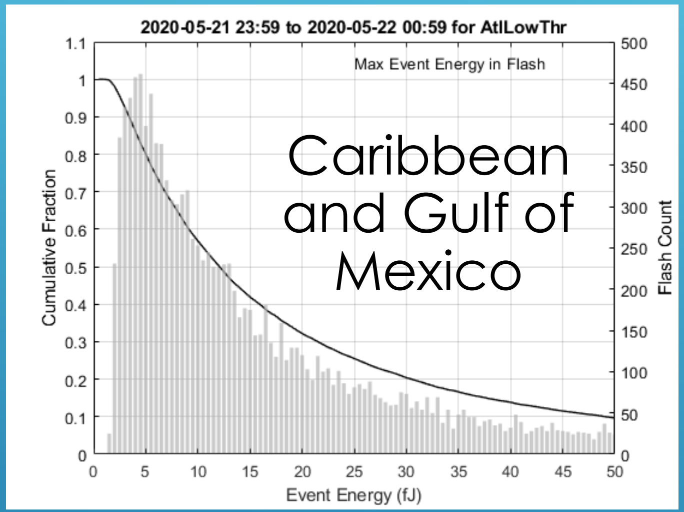


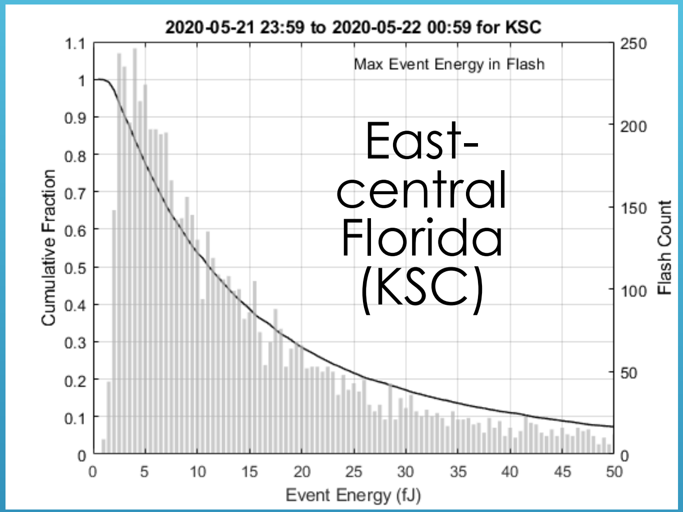
Since the instrument threshold in Florida is quite low, we can assess overall flash DE vs. threshold by re-processing the GLM data with artificially elevated event threshold values (see results above)

The Box plot (above) shows that short-duration flashes have the smallest "maximum group energy in the flash" values. Therefore they will be lost first when instrument thresholds increases

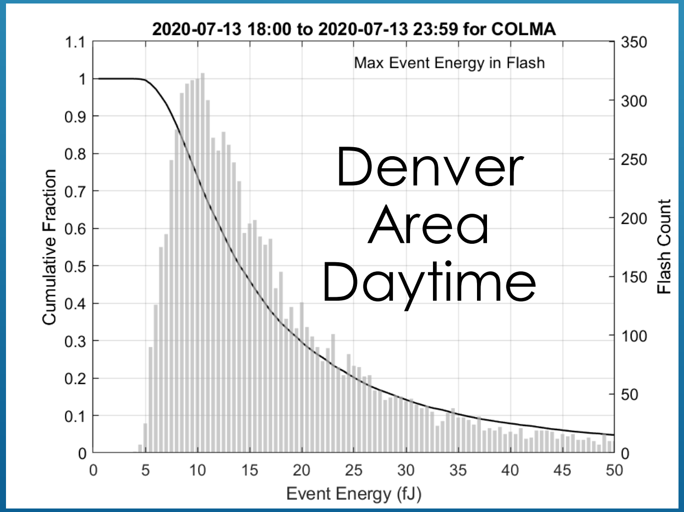
Boxes are25th – 75th percentiles. Red +'s are extreme values. Note log scale for energy.

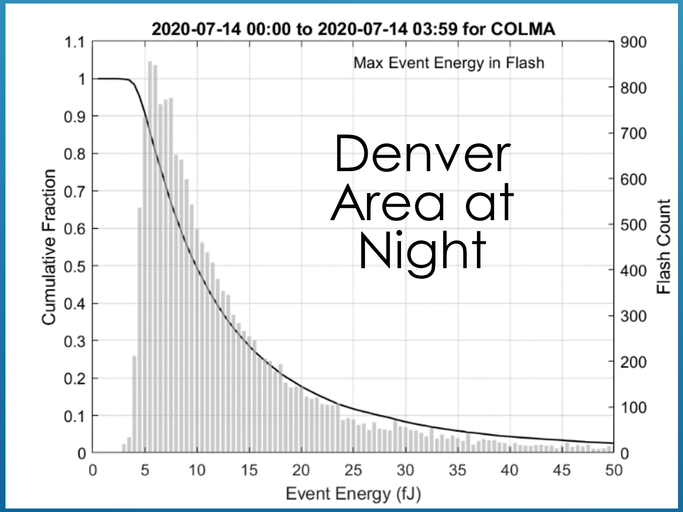
Quick look at GLM Max Event Energy by Region





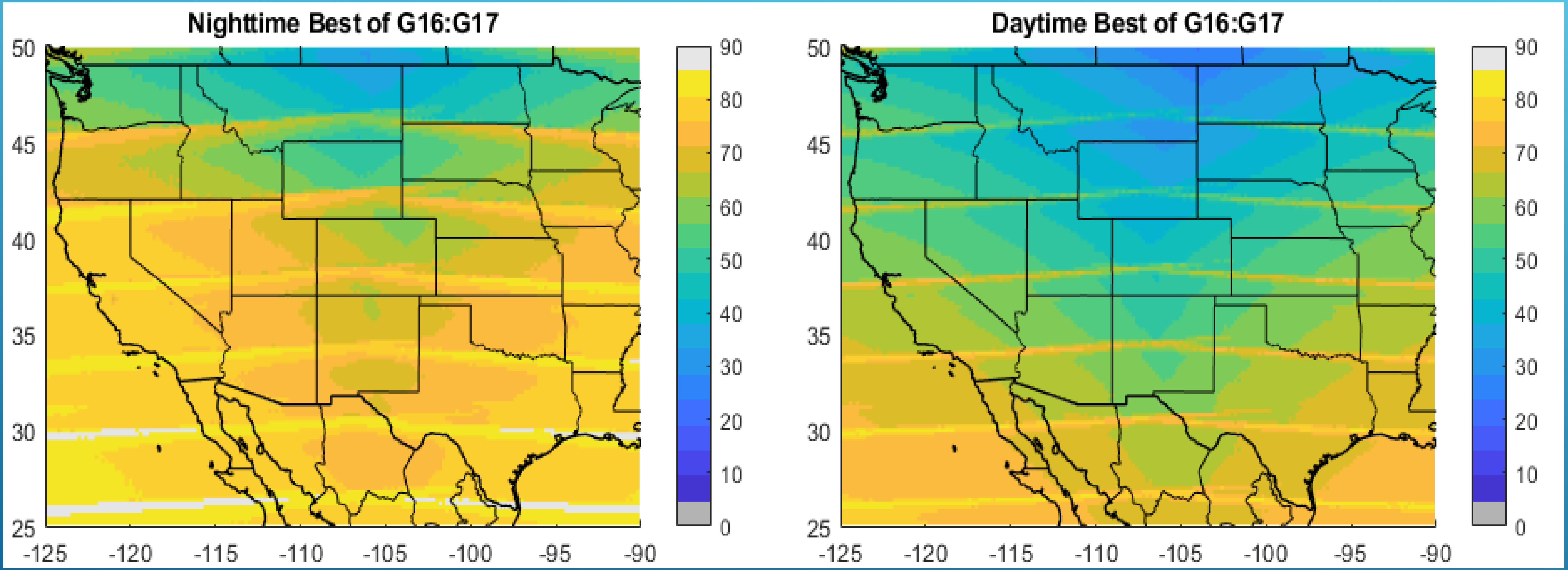
KSC and the high-sensitivity Caribbean regions are similar, but with a larger fraction of "brighter" events (higher energy) over the water





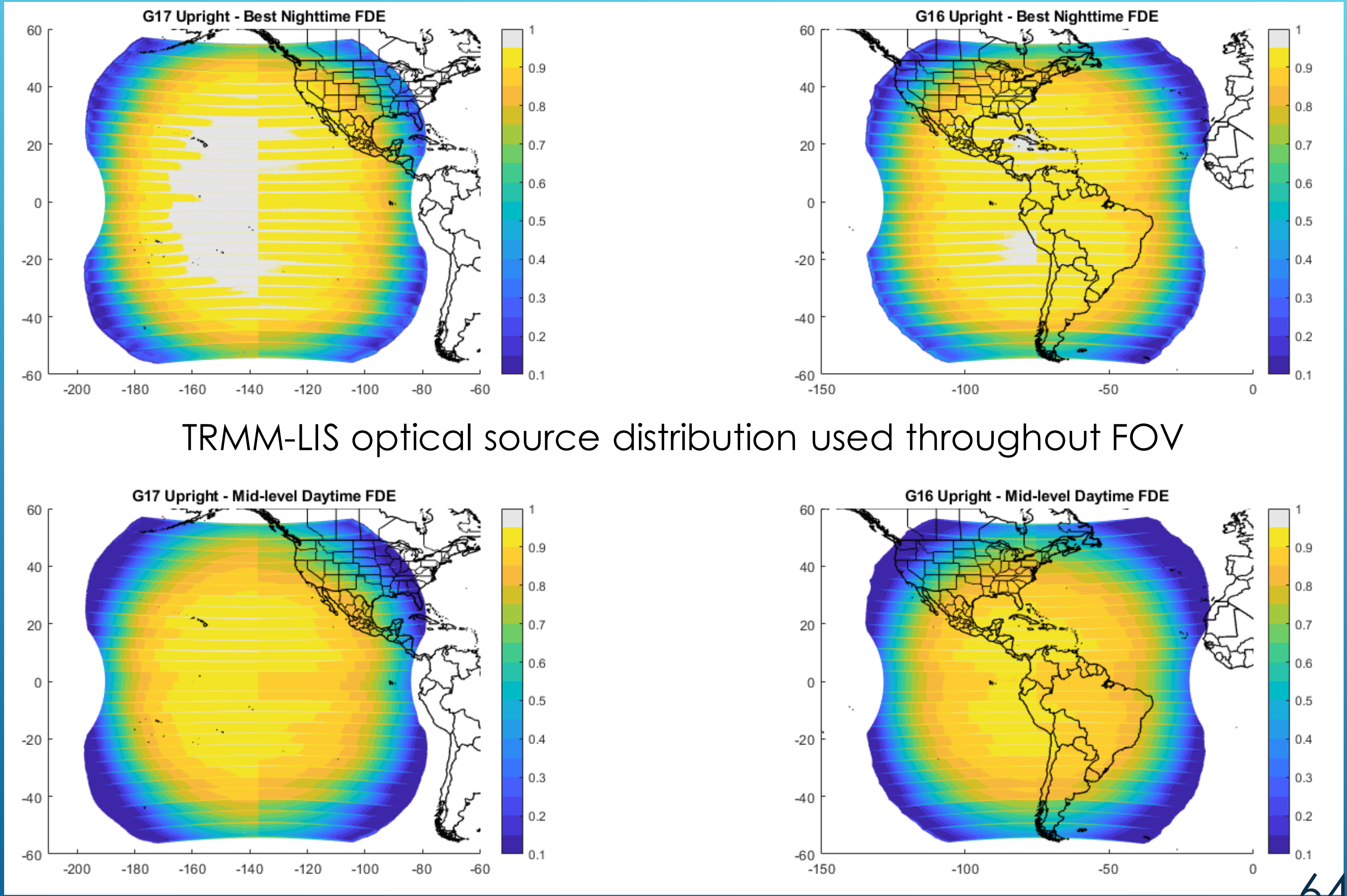
The impact of GLM threshold is clear in the Colorado area. There are also fewer high-energy events in this region, compared to KSC and the Caribbean

WHAT FLASH DE (RELATIVE TO LIS) CAN WE GET WITH THE BEST OF GOES-EAST AND WEST?



DAY AND NIGHT GLM FLASH DE ESTIMATES (THRESHOLD-ONLY EFFECTS: KSC MODEL)

Regional differences in flash size, flash height, or cloud optical depth are not addressed in these estimates. (See Zhang & Cummins, 2020 and Rutledge et al., 2020 for related details)



30-SECONDS PERIODS

This slide sequence illustrates the loss of detection of light within the body of the active storm as flash rate increased

(Note: optical depth, at least in terms of 0 dBZ radar cloud-top, also increased)