A Multi–Sensor Approach to Determining Storm Intensity and Physical Relationships in Lightning–Producing Storms

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Outline

1. Background and updates on lightning–radar relationships, and 0–1 hour lightning initiation (LI) nowcasting.

2. GOES-R Risk Reduction Storm Intensity project update – Use of multi–sensors to estimate storm parameters and define “intense” storms.

3. Evaluation of use of GOES LI indicators within Corridor Integrated Weather System (CIWS).

1. GOES–12 versus NEXRAD fields for LI events, coupled to environmental parameters.

2. Relationships between dual-polarimetric radar, MSG infrared, and total lightning: Non-lightning vs lightning–producing convection.

Overview

- GOES data can be processed to help identify the proxy indicators of the non–inductive charging process, leading to a 30–60 min lead time nowcast of first–flash lightning initiation (LI; not just CG; Harris et al. 2010).
- Lightning data from the TRMM LIS sensor can be used to help diagnose "storm intensity" (Jewett et al. 2012).
- Fundamental relationships are not well understood between:
  - ➢ GOES infrared fields of developing cumulus clouds in advance of LI, and NEXRAD radar profiles.
  - ➢ GOES infrared, NEXRAD radar and environmental parameters (stability & precipitable water, and their profiles; wind shear, cloud base height and temp).
  - ➢ Dual–polarimetric radar fields need to be related to infrared and total lightning data toward enhancing understanding.
- The main goals for this work include:
  - ➢ Enhancing a 0–75 min LI algorithm in the Corridor Integrated Weather System (CIWS) of the FAA.
  - ➢ Forming multi–sensor approaches to diagnosing storm intensity, in preparation for GOES–R, GLM and GPM, that can be used within nowcasting systems.

Using Lightning as Proxy for Storm Intensity

- Many studies have been performed defining intense storms using TRMM (Zipser et al. 2006, Nesbitt et al. 2000, Cecil et al. 2005 and Cecil 2009) and the Lightning Imaging Sensor (LIS) and the TRMM Microwave Imager (TMI) instruments.
- Its important to note that not all convective storms produced lightning and Cecil et al. (2005) suggest that some of those storms may be electrically active but LIS may not be able to reliably detect those flashes.
- Lightning flash rates from LIS have been broken into five categories:

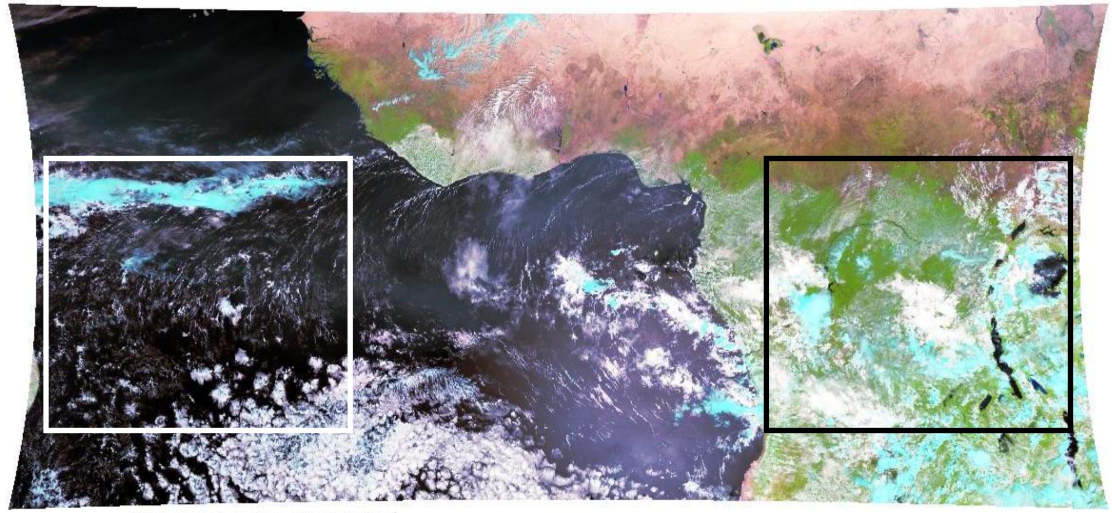
Cecil et al. (2005), Nesbitt and Zipser (2003), Nesbitt et al. (2000)

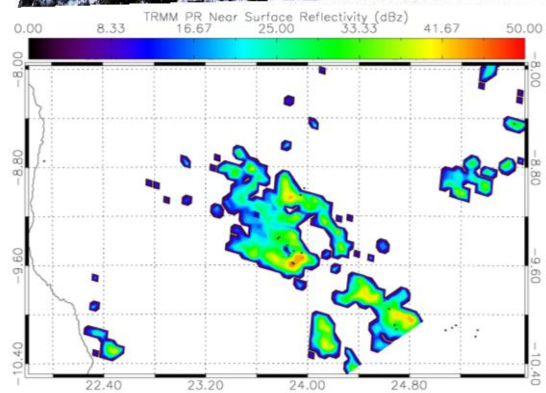
	Flash rate (fl min^{-1})
CAT-0	0-0
CAT-1	0.7-2.2
CAT-2	2.2-30.9
CAT-3	30.9-122
CAT-4	122-296
CAT-5	>296

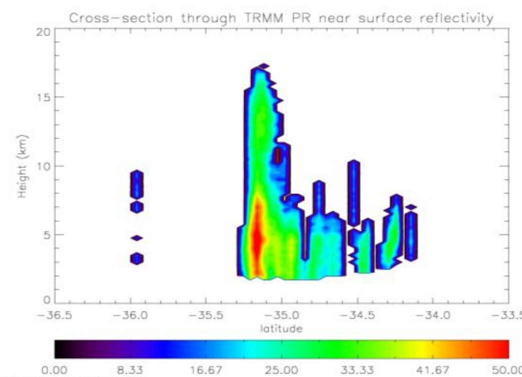
Diagnosing storm intensity using coupled TRMM Lightning Imaging Sensor and MSG in preparation for GOES-R

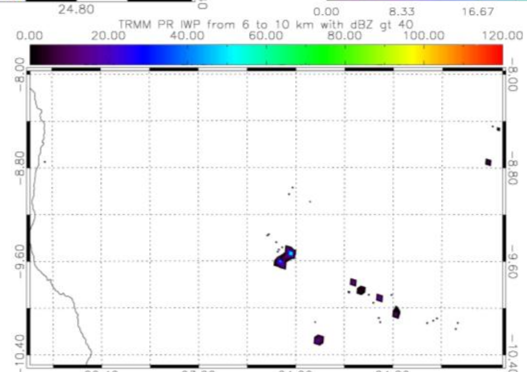
Methodology

- Convective events are first chosen from the precipitation feature database, January and August 2007 over tropical Africa and eastern tropical Atlantic
- Using the storm cell database developed by Leroy and Petersen (2011), analysis of individual storms cells within clusters and isolated can be performed with the benefit of having many different TRMM variables available in one location.
- Storm intensity is determined using the TRMM precipitation radar. Currently, intensity is being defined by the Ice Water Path (IWP) with reflectivities >40 dBz between 6 and 10 km (a mixed phase region important for lightning initiation).
- IWP is calculated for every cell feature over both land and water, making useful statistics when analyzing TRMM LIS and MSG imagery.
- LIS data is converted to flash rates by combining all the flashes for one IWP sample using a nearest neighbor technique and dividing by the average observation time (typically ~90 s).
- MSG data is being analyzed for each IWP sample time along with an hour of data before and after, allowing for temporal trends of convective interest fields.

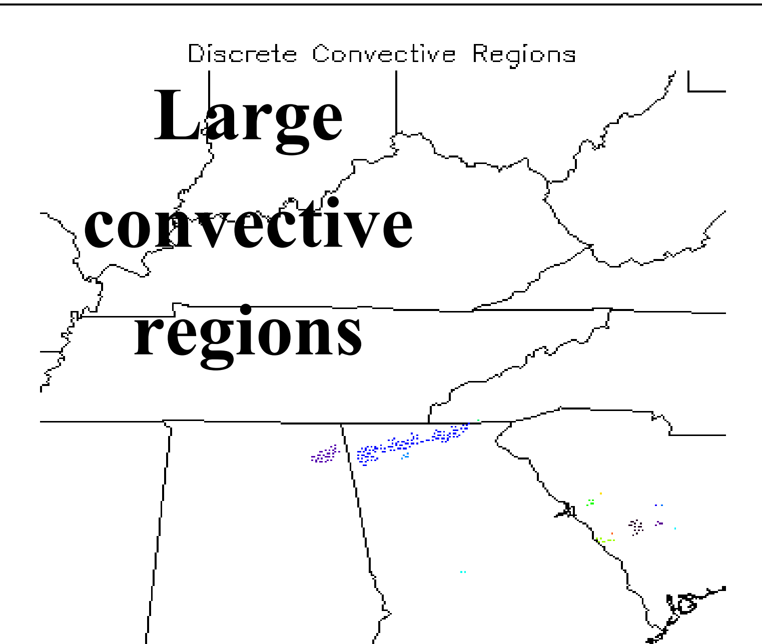


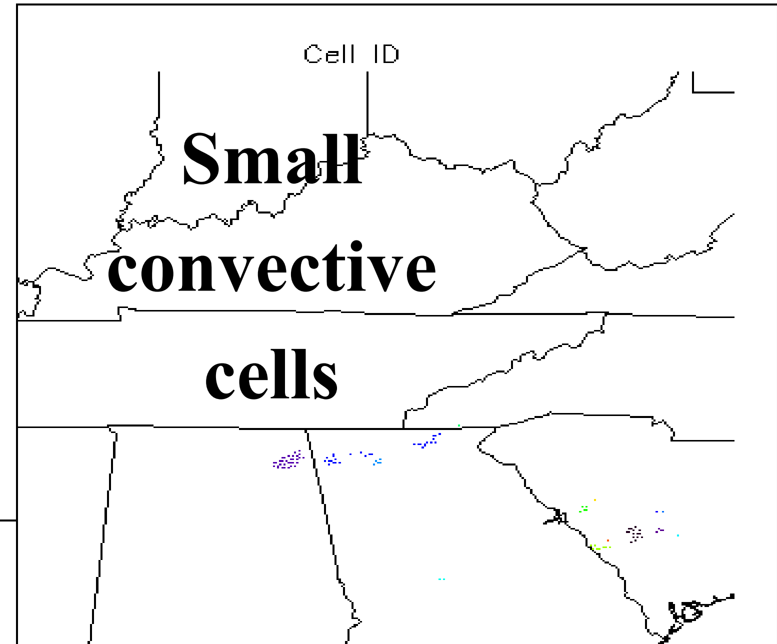


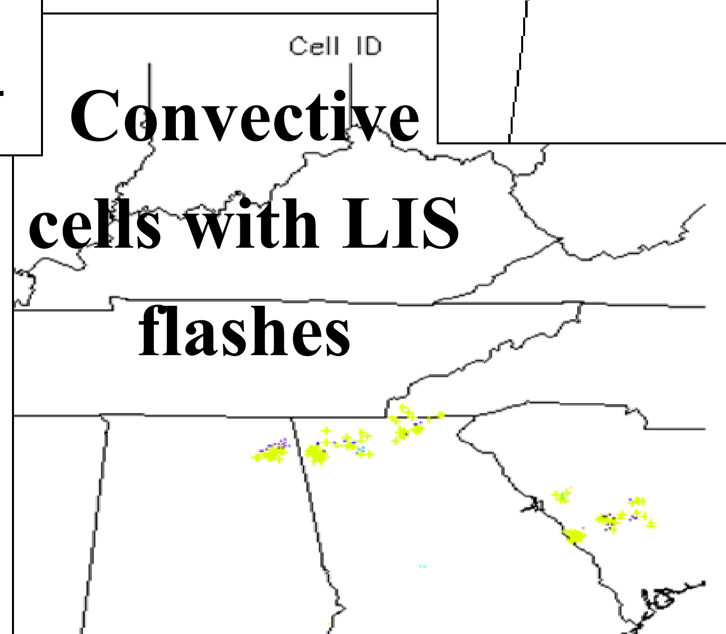




Cell Identification Algorithm



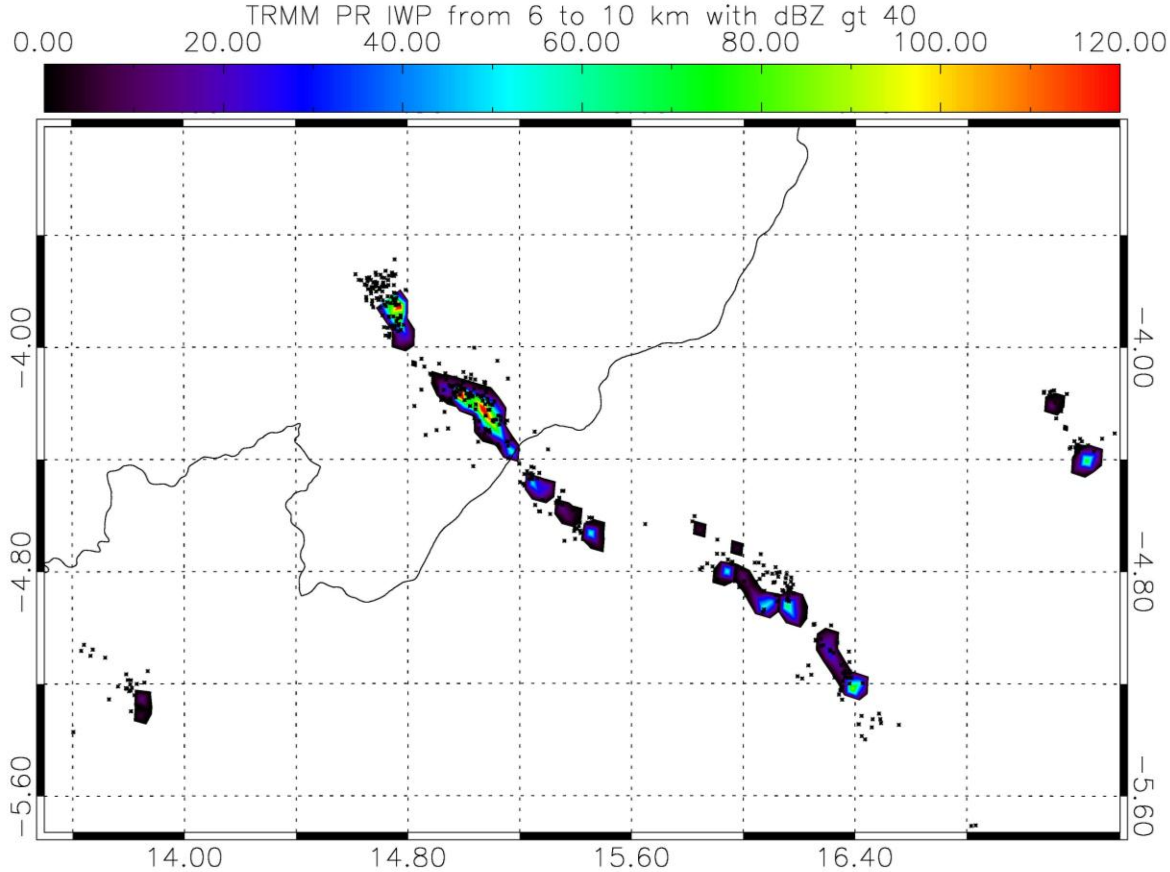




Courtesy: LeRoy (ESSC/UAHuntsville and Petersen (NASA/MSFC)

TRMM Precipitation Radar Storm Intensity

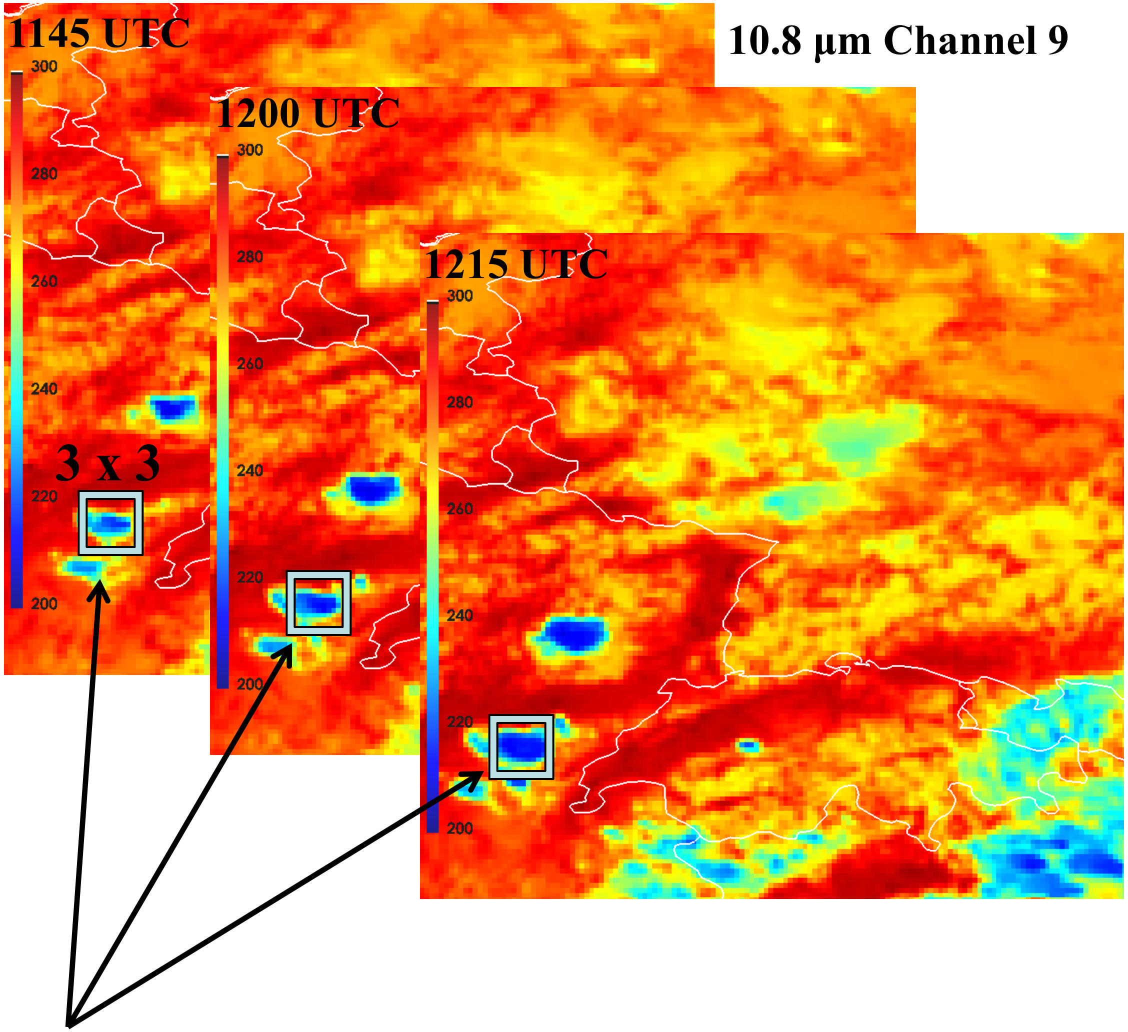
- Currently, intensity is being defined by the Ice Water Path with reflectivities >40 dBZ between 6 and 10 km. This ensures a mixed phase region, which is important for lightning initiation.
- Intense being relative to storm parameters like updraft strength, growth rate, etc.



Slightly Intense	Fairly Intense	Moderately Intense	Intense	Very Intense	Extremely Intense
1 - 10	10-50	50-100	100-150	150-200	>200

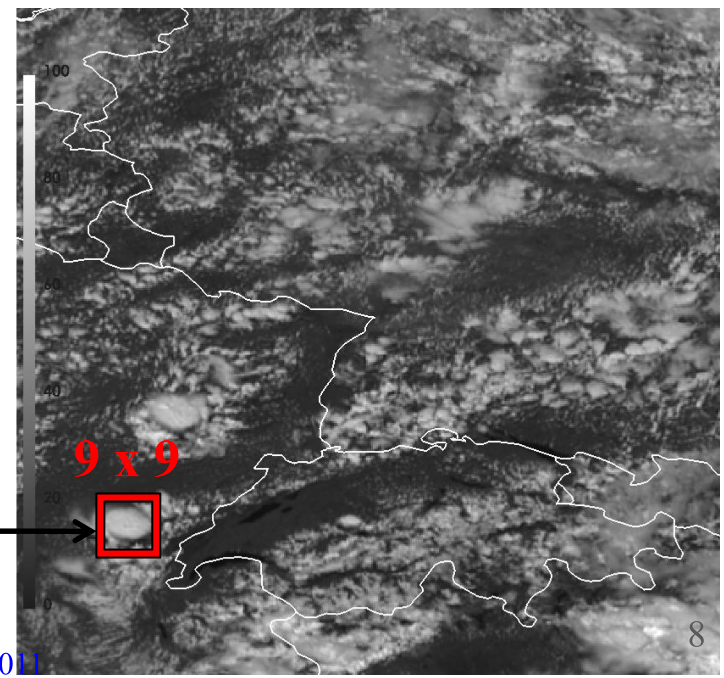
Use of MSG Fields – Storm Intensity

10.8 µm Channel 9



A cumulus cloud observed to develop in MSG IR and visible data and produce a >35 dBZ echo.

1215 UTC HRV



A “growing cumulus cloud” event…

MSG IR Interest Fields per Physical Process

Cloud Depth

- 6.2-10.8 μm difference
- 6.2-7.3 μm difference
- 10.8 μm T_B
- 7.3-13.4 μm
- 6.2-9.7 μm difference
- 8.7-12.0 μm difference

Glaciation

- 15-min Trend Tri-spectral
- Tri-spectral
- 30-min Trend Tri-spectral
- 15-min 8.7-10.8 μm
- 15-min 12.0-10.8 μm Trend
- 15-min 3.9-10.8 μm Trend
- 12.0-10.8 μm difference

Updraft Strength

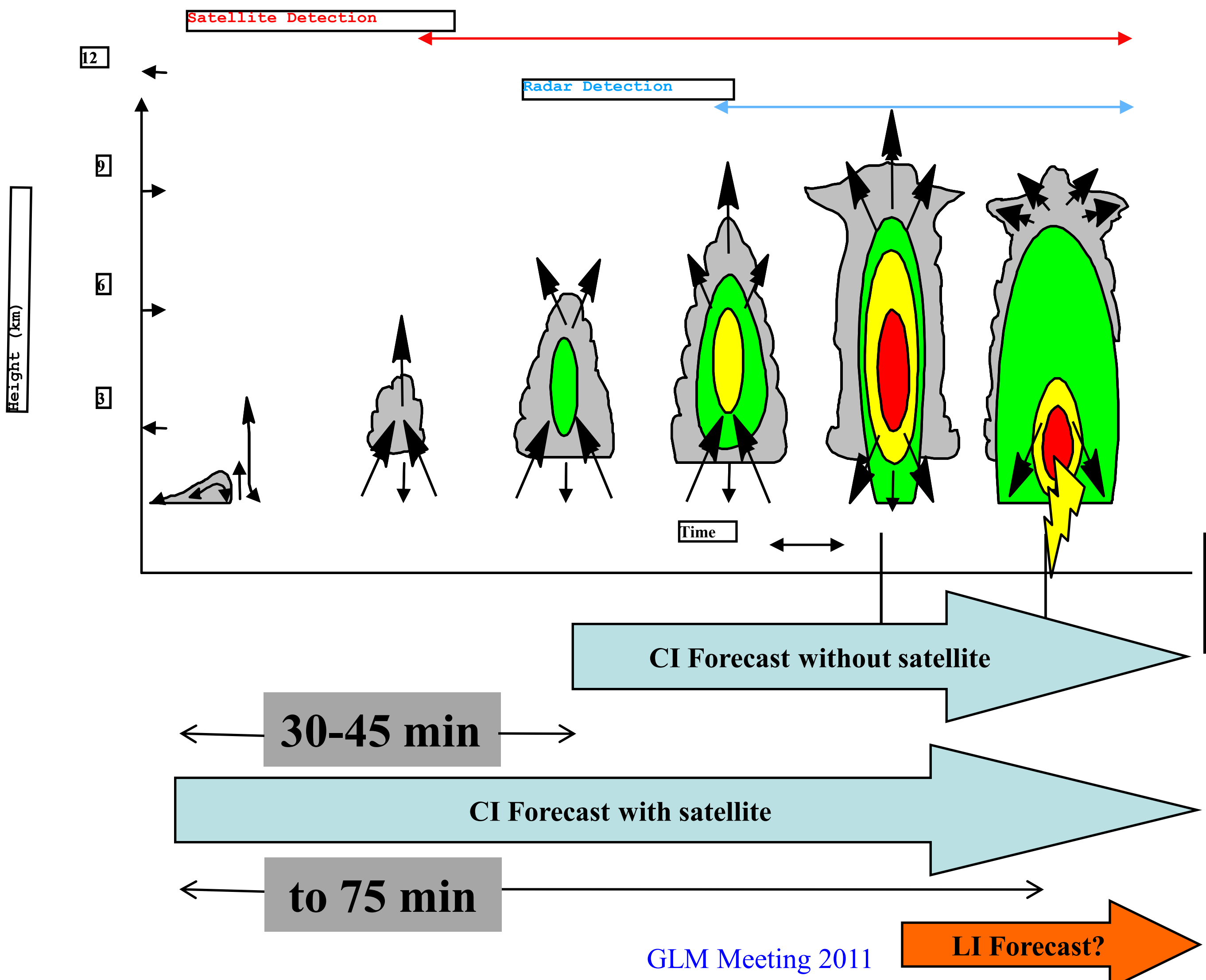
- 30-min 6.2-7.3 μm Trend
- 15-min 10.8 μm Trend
- 30-min 10.8 μm Trend
- 15-min 6.2-7.3 μm Trend
- 30-min 9.7-13.4 μm Trend
- 30-min 6.2-10.8 μm Trend
- 15-min 6.2-12.0 μm Trend
- 15-min 7.3-9.7 μm Trend

21 Unique IR indicators for Nowcasting CI from MSG (*GOES-R*), and also for determining how "intense" a given storm may be.

More will be said on how MSG fields relate to storm intensity (i.e. LIS/lightning fields in the GOES-R3 talk (Wednesday 4:20 pm).

Lightning Initiation: Conceptual Idea

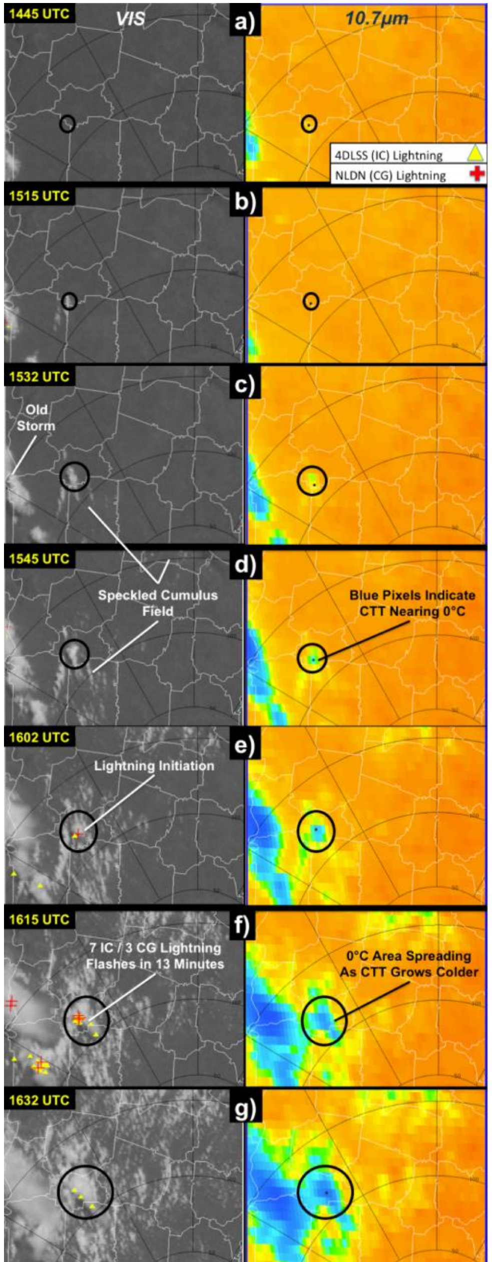
What is the current LI forecast lead time?



Up to ~60 min added lead time for LI using GOES

Lead time increases with slower growing cumulus clouds (i.e. low CAPE environments)

Satellite LI Indicators: Methodology



1. **Identify and track growing cumulus clouds from their first signs in visible data, until first lightning.**
2. **Analyze "total lightning" in Lightning Mapping Array networks, not only cloud-to-ground lightning, to identify for LI.**
3. **Monitor 10 GOES reflectance and IR indicators as clouds grow, every 15-minutes.**
4. **Perform statistical tests to determine where the most useful information exists.**
5. **Set initial critical values of LI interest fields.**

Harris, R. J., J. R. Mecikalski, W. M. MacKenzie, Jr., P. A. Durkee, and K. E. Nielsen, 2010: Definition of GOES infrared fields of interest associated with lightning initiation. *J. Appl. Meteor. Climatol*., 49, 2527-2543.

Mecikalski, J. R., X. Li, L. Carey, E. McCaul, and T. Coleman, 2011: Regional variations and predictability relationships in GOES infrared lightning initiation interest fields. In preparation. *J. Appl. Meteor. Climatol*. In preparation.

SATCAST Algorithm: *Lightning Initiation Interest Fields*

These indicators for LI are a subset of those for CI.

They identify the wider updrafts that possess stronger velocities/mass flux (ice mass flux).

In doing so, we may highlight convective cores that loft large amounts of hydrometers across the –10 to –25 ° C level, where the charging process tends to be significant.

Provides up to a 75 lead time on first-time LI.

Interest Field	MB06 Critical CI Value	Siewert LI Value	15 to 30-min Threshold (This LI Study)	Description
10.7 μm T_B	< 0°C	≤ –13°C	*< 0° C*	Cloud tops cold enough to support supercooled water and ice mass growth; cloud-top glaciation
10.7 μm T_B Time Trends[1]	< –4°C / 15 min (ΔTb / 30 min < ΔTb / 15 min)	≤ –10°C / 15 min	*< –6° C / 15 min*	Cloud growth rate (vertical)
Timing of 10.7 μm T_B drop below 0° C	Within prior 30 min	*Not used*	*Not Used*	Cloud-top glaciation
6.5–10.7 μm T_B difference	Tb Diff: –35°C to –10°C	≥ –17°C	*> –30° C*	Cloud top height relative to mid/upper troposphere
13.3–10.7 μm T_B difference	Tb Diff: –25°C to –5°C	≥ –7°C	*> –13° C*	Cloud top height relative to mid/upper troposphere; better indicator of early cumulus development but sensitive to cirrus
6.5–10.7 μm T_B Time Trend	> 3°C / 15 min	≥ 5°C / 15 min	*> 5° C / 15 min*	Cloud growth rate (vertical) toward dry air aloft
13.3–10.7 μm T_B Time Trend	> 3°C / 15 min	≥ 5°C / 15 min	*> 4° C / 15 min*	Cloud growth rate (vertical) toward dry air aloft
3.9–10.7 μm T_B Difference[3]	*Not used*	*Not used*	*> 17° C*	Cloud-top glaciation
3.9–10.7 μm T_B Time Trend[2]	*Not used*	T–T(t–1) < –5°C and T–T(t+1) < –5°C	*> 1.5° C / 15 min*	Sharp decrease, then increase indicates cloud-top glaciation
3.9 μm Fraction Reflectance[2]	*Not used*	≤ 0.05	*< 0.11*	Cloud top consists of ice (ice is poorer reflector than water at 3.9 μm)
3.9 μm Fraction Reflectance Trend[3]	*Not used*	*Not used*	*< –0.02 / 15 min*	Cloud-top glaciation rate

1 Represents two unique 10.7 μm T_B interest fields in MB06. No 30-min trends were used in Siewert (2008) or in this study.

2 Added to MB06 fields by Siewert (2008).

3 Unique to this study.

Satellite Indicators of Lightning –Interest Fields

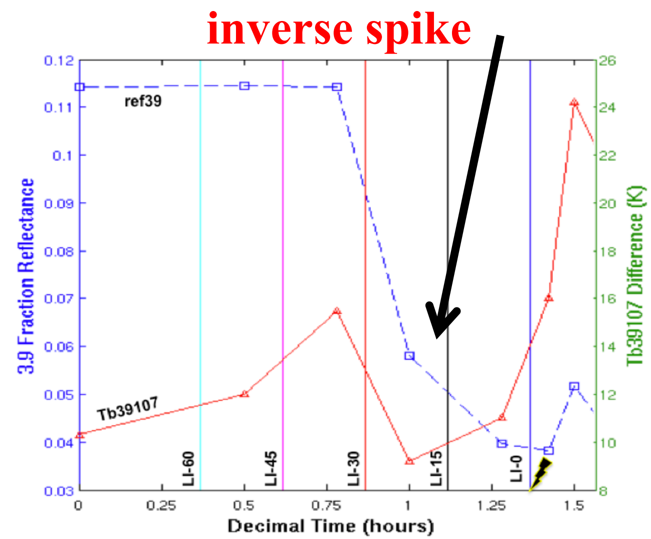
Focus on 4 Lightning Initiation interest field to start…

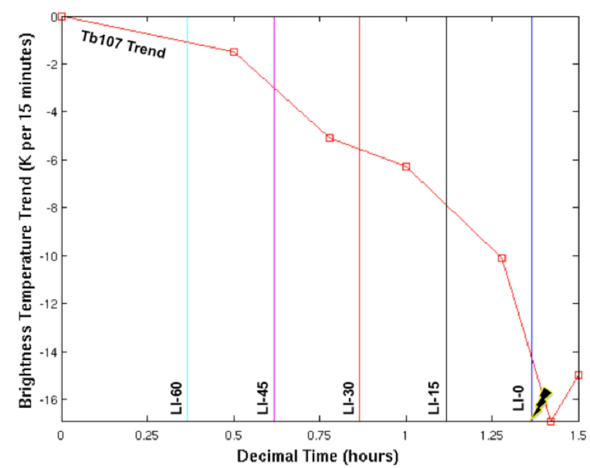
(1) 3.9 µm reflectance: Monitor clouds where the cloud-top reflectance consistently falls from >10% to near or below 5%. The rate found is ~2-4%/15-min.

(2) For clouds with 10.7 µm $T_B < 0^\circ$ C and >−18° C (255 K), use the 3.9−10.7 µm difference fields, with a threshold at >17° C degrees.

(3) Trends in the 3.9−10.7 µm difference should be >1.5 ° C/15-min. For ideal cases, the trend in 3.9−10.7 µm will reverse directions, falling by up to 5° C/15-min, then rising (by up to 5° C/15-min). This down-up "*inverse spike*" is the result of cloud-top glaciation, but as it only seems to occur for the "better" LI events, it may lead to lower detection probabilities in less prolific lightning-producing clouds.

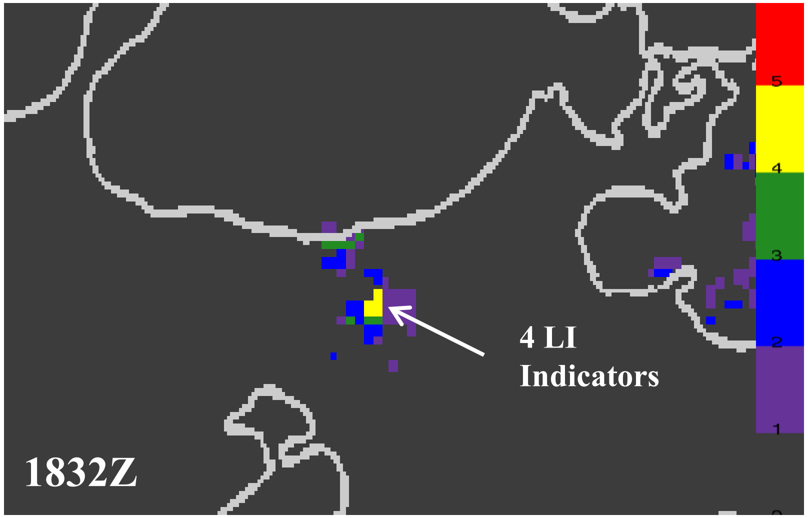
(4) The 15-min trend in 6.5−10.7 µm difference of >5° C. This is a good indicator of a strong updraft.



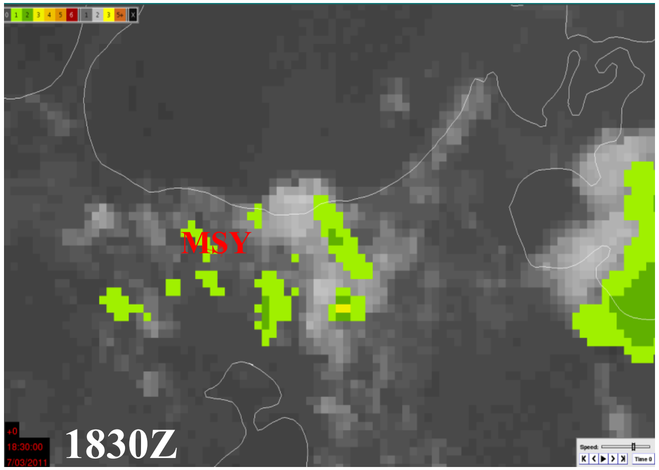


Lightning Initiation Indicators

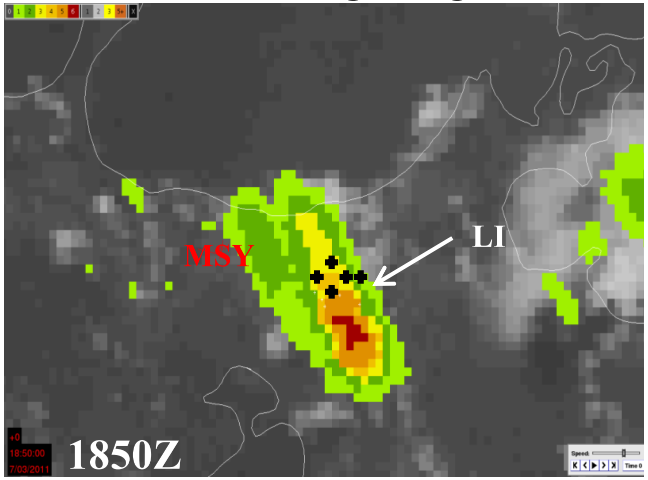
Number of LI Indicators



Visible Satellite, Radar Precipitation, and CG Lightning



Visible Satellite, Radar Precipitation, and CG Lightning



3 July 2011

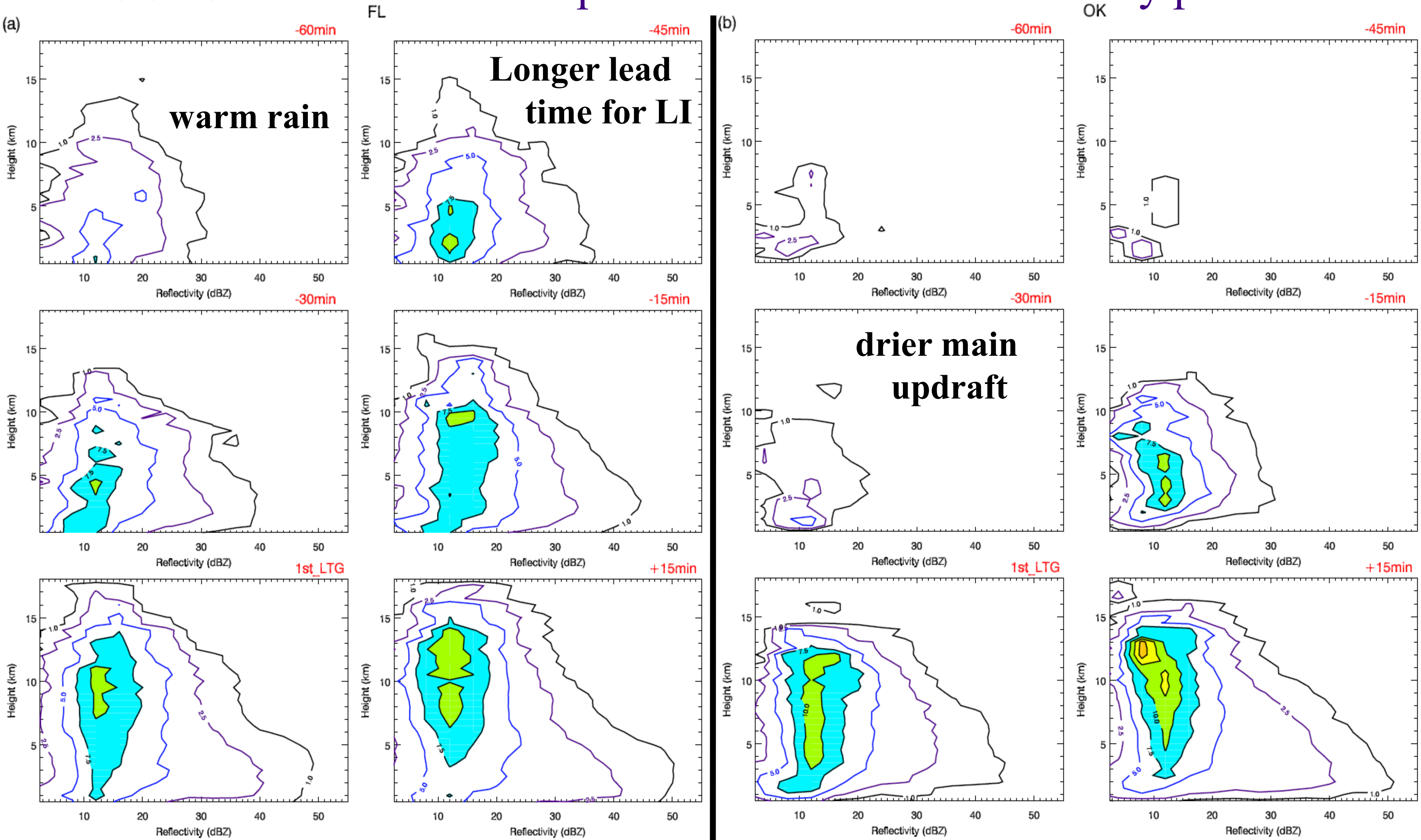
Five lightning Indicators (LI) are added cumulatively on a pixel by pixel basis:

LI1: –18˚C < 10.7 µm channel < 0 ˚ C AND
3.9–10.7 µm diff>17 ˚C
LI2: 6.7–10.7 µm 15 min trend > 5 ˚C
LI3: 3.9 µm reflectivity < 0.11 AND
3.9 µm reflectivity 15 min trend < –0.02
LI4: 3.9–10.7 µm 15 min trend > 1.5 ˚C
LI5: 10.7 µm 15 min trend < –6 ˚C

Goal: Couple to Lightning Potential algorithm

Physical Relationships

GOES LI Indicators compared to NEXRAD reflectivity patterns

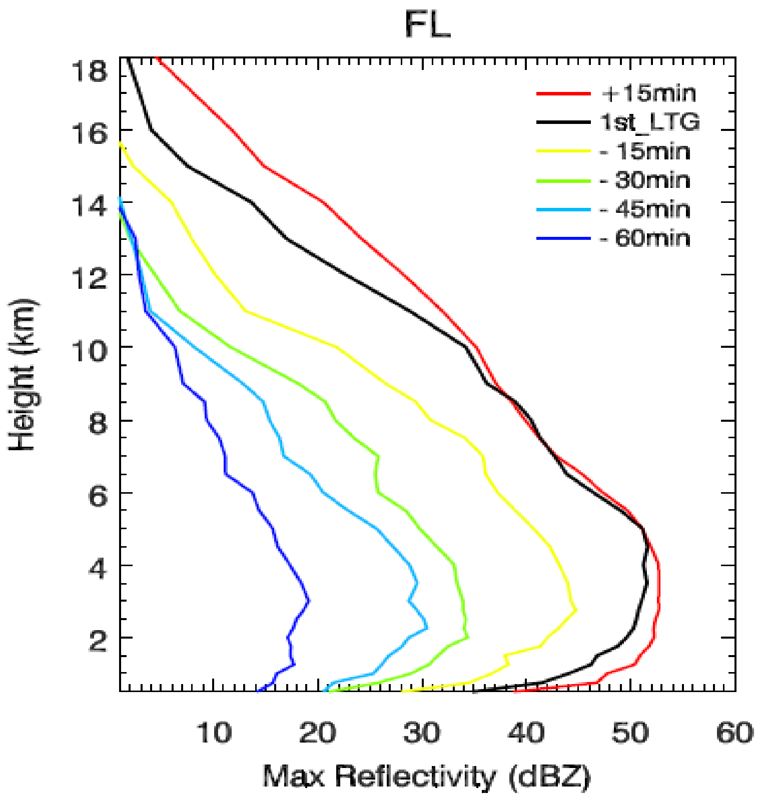


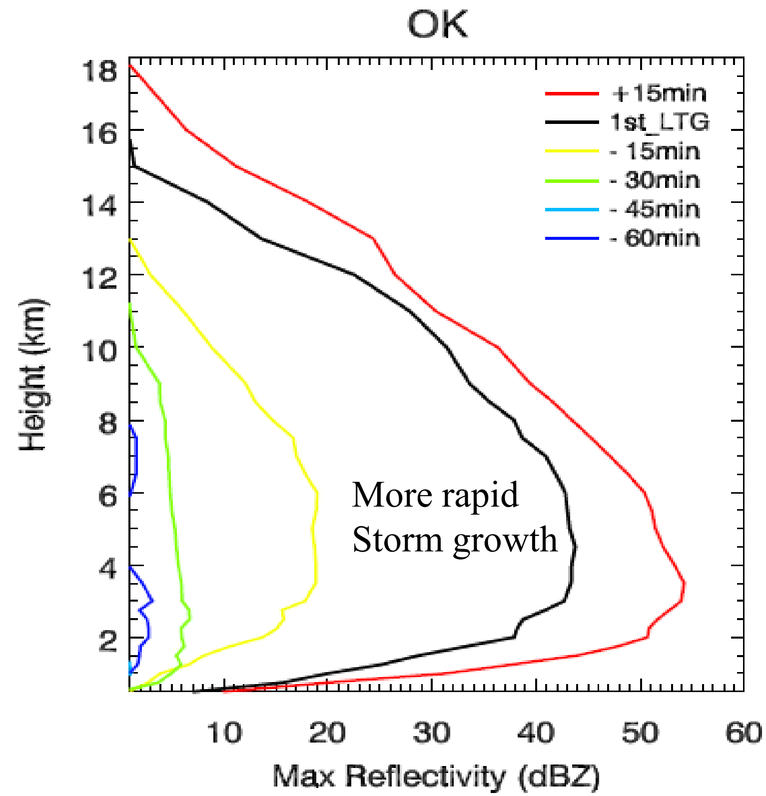
CFAD for 36 storms in Florida **CFAD for 23 storms in Oklahoma**

bin size: 4 dBZ vertical resolution: 0.5km

Physical Relationships

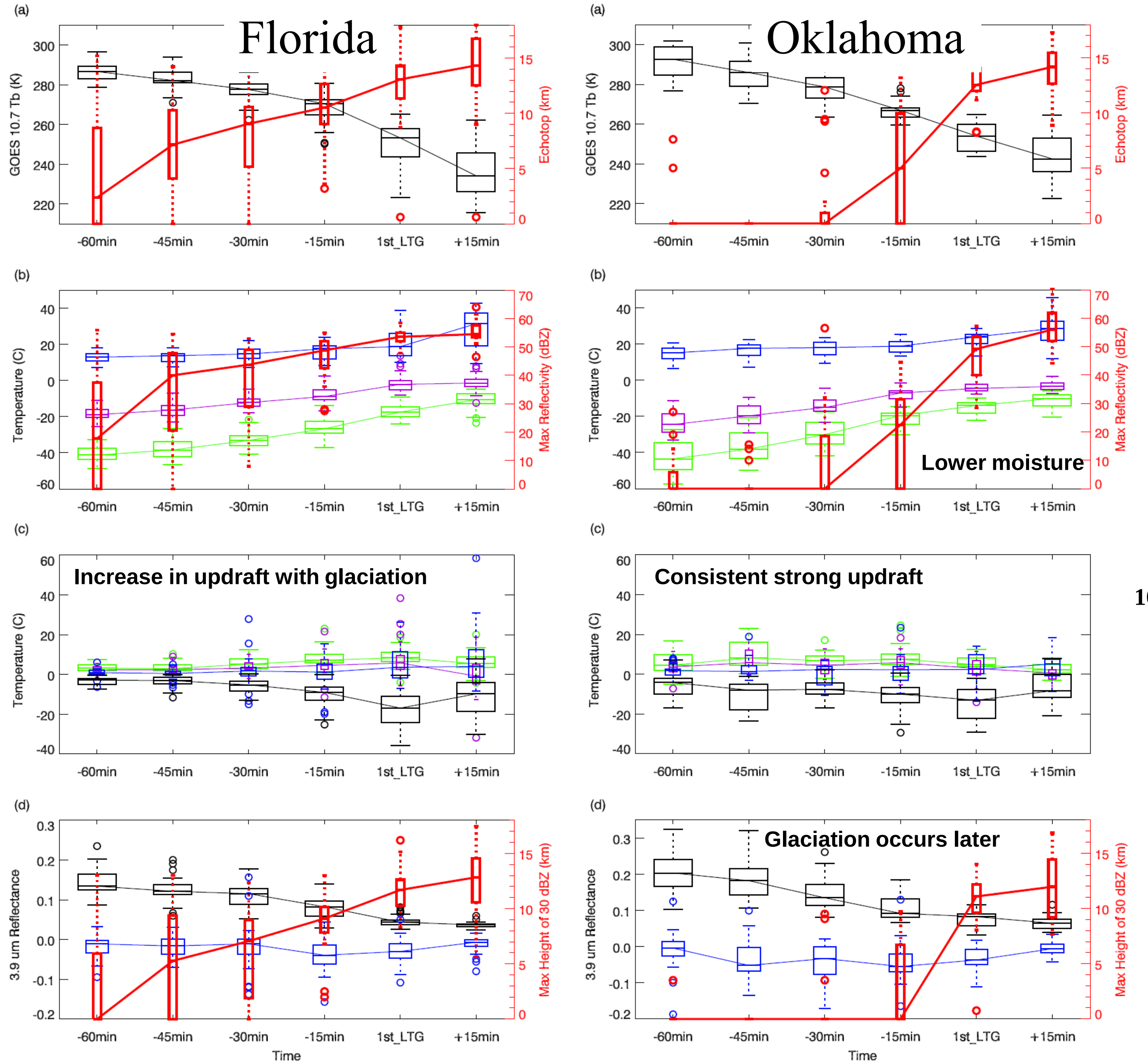
GOES LI Indicators compared to NEXRAD reflectivity patterns





Maximum reflectivity profiles averaged for 36 storms in FL

Maximum reflectivity profiles averaged for 23 storms in OK.



Echo top vs. GOES-12 10.7µm Tb

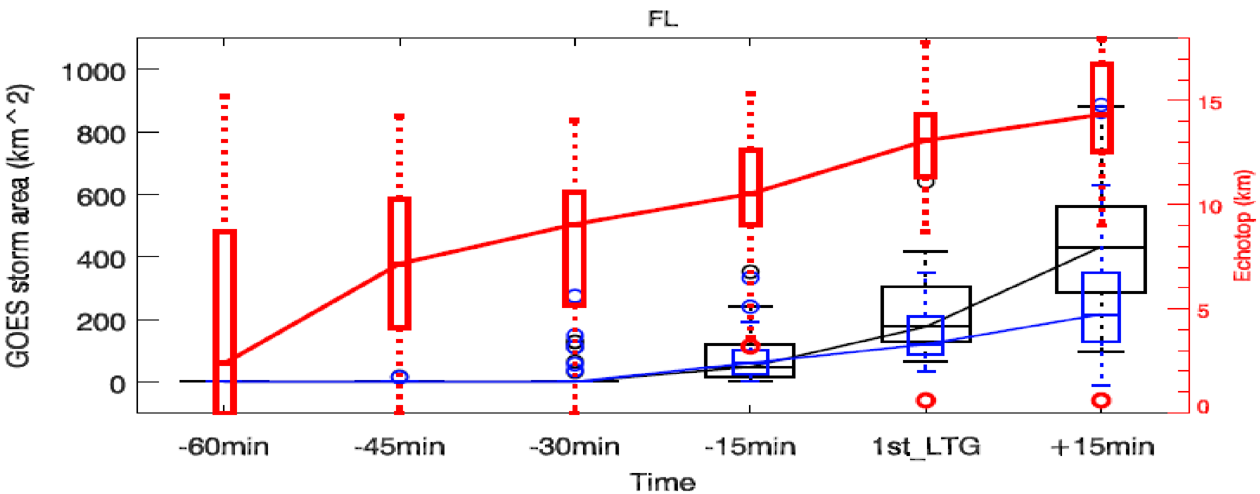
Maximum reflectivity vs. 6.5-10.7, 13.3-10.7, and 3.9-10.7

10.7 trend, 6.5-10.7 trend, 13.3-10.7 trend, and 3.9-10.7 trend

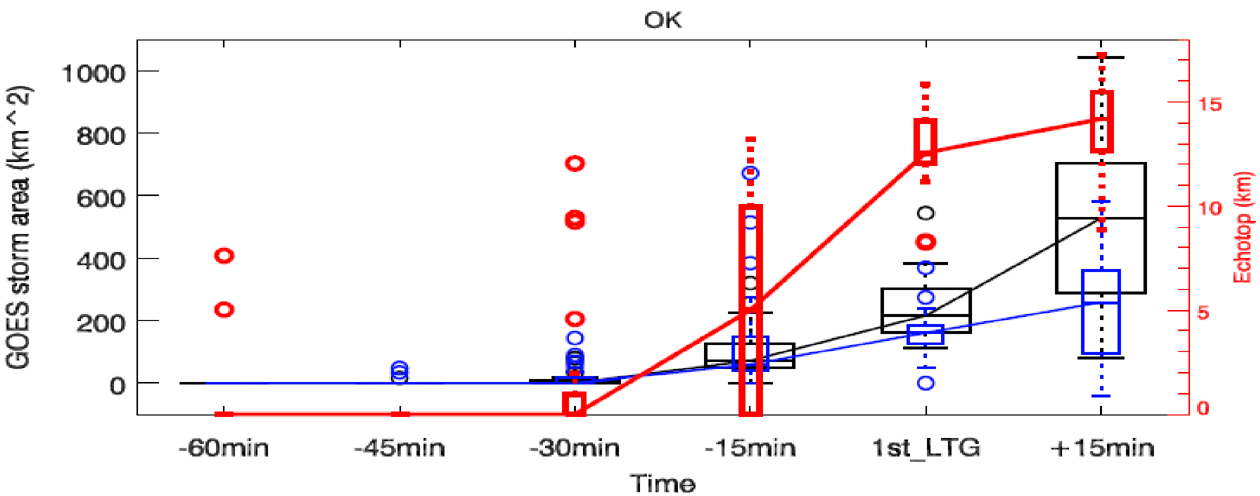
Max height of 30 dBZ vs. GOES 3.9 µm reflectance and trend

Physical Relationships

GOES LI Indicators compared to NEXRAD reflectivity patterns



Higher PW in Florida leads to higher hydrometeor volume, a well-defined warm rain process. Storms possess lower and warmer cloud bases.



More rapid storm growth in Oklahoma, yet with lower moisture (cooler and drier cloud bases). Storms tend to be large in the end, and likely produce more lightning.

Echo top vs. storm area and trend

Storm area: GOES-12 10.7 µm brightness temperature above 0 ºC

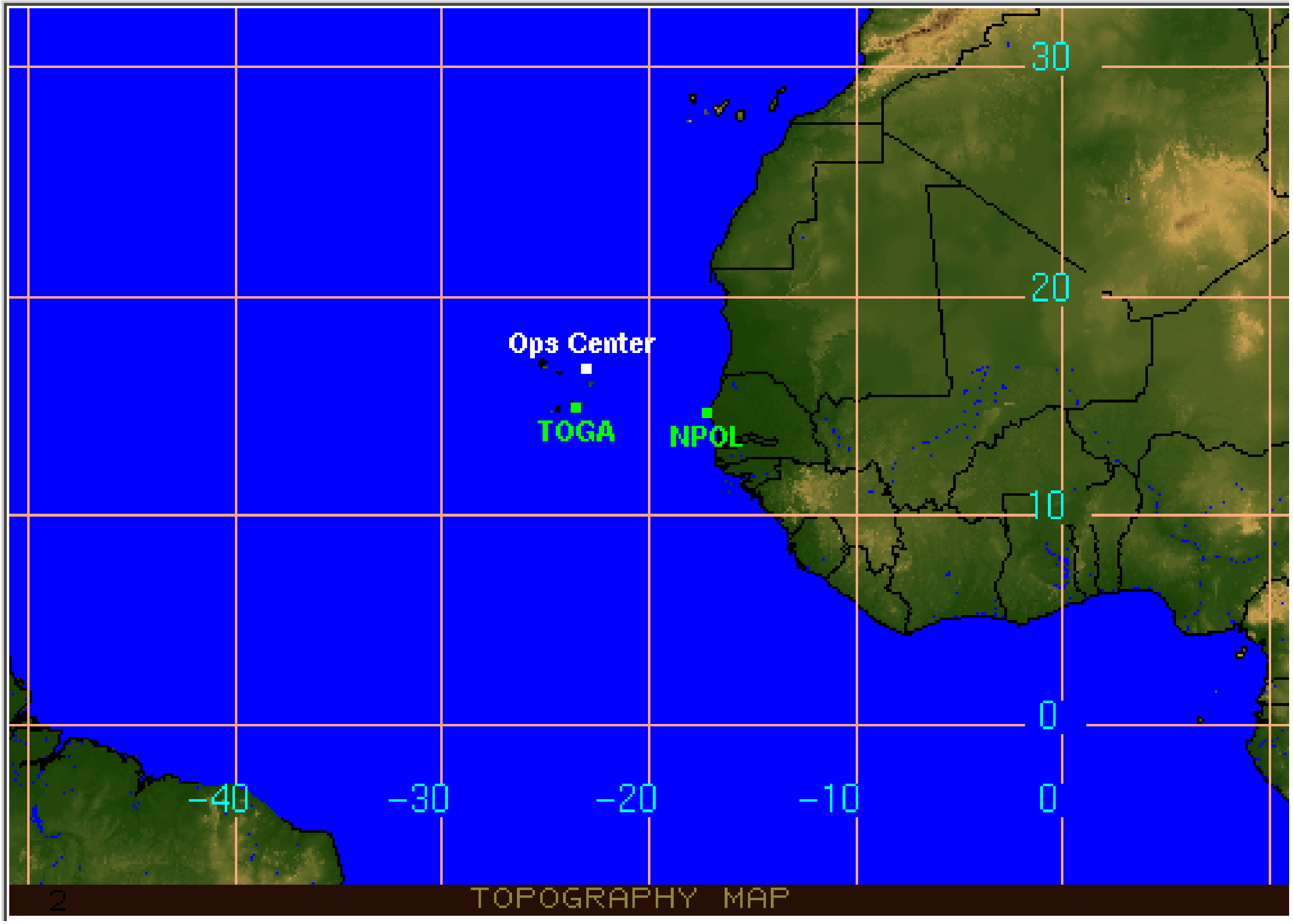
A Dual-Polarimetric, MSG, and Total Lightning View of Convection

• NSF funded. Masters student, Retha Matthee
• In collaboration with Larry Carey, Bill McCaul, Walt Petersen
• Goal: To determine relationships between infrared (cloud-top) estimates of physical processes (updraft strength, glaciation and phase, and microphysical parameters, e.g., effective radius, cloud optical thickness), dual-polarimetric derived hydrometeor fields, and total lightning.
• Done for select convective storm events over the NAMMA field experiment region in western Africa and the equatorial east Atlantic ocean.
• Focus on lightning and non-lightning case studies, ~20-30 of each storms.

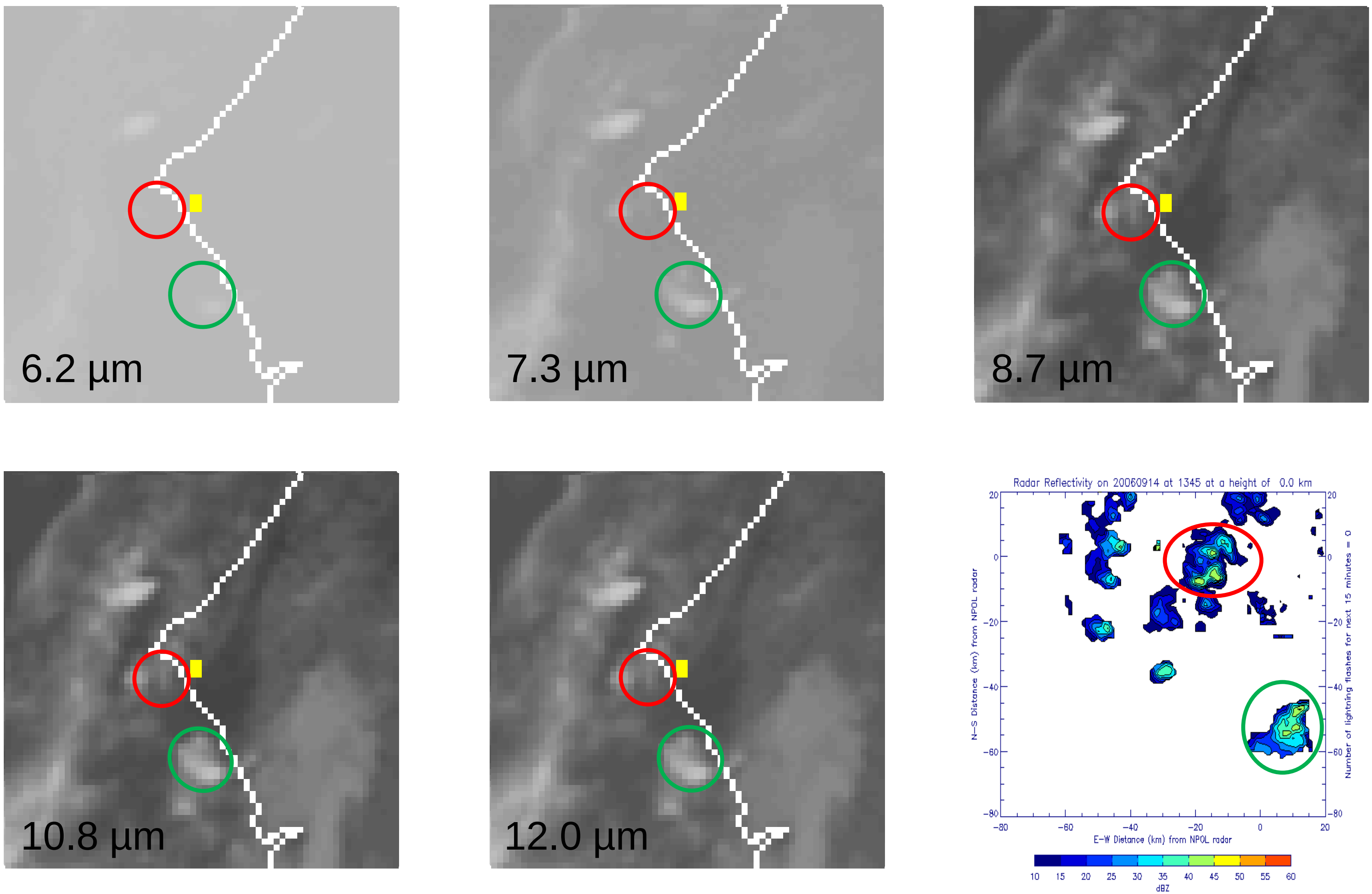
Results are preliminary at this time:

1. Data from NPOL processed and co-located with lightning observations.
2. Processing MSG data for locations for identified convective storms
3. Waiting on MSG-derived fields of effective radius, optical thickness, cloud-top phase, and cloud-top pressure
4. So far… Found relatively known relationships between hydrometeor fields, lightning onset, for both lightning and non-lightning events
5. Key results will comes when MSG data are added to the mix.

- Map showing the location of the NPOL radar (located in Kawsara, Senegal on the west coast of Africa)



1345 1400 1415 1430



Red = Lightning **Green = Non-lightning**

Near-term Plans

1. Continued testing of LI indicators in CIWS/CoSPA; apply with latest improvements to object tracking.

2. Evaluate value in lightning probability nowcasts for improving efficiency in airport operations.

1. Enhance estimates of "storm intensity" and "storm life cycle" (storm decay) for assessing turbulence/hazard potential

2. Link lightning initiation to a lightning potential (SPoRT) product for a more quantitative forecast product.

3. Follow-on NSF project…