Recent Research on Discerning Physical Relationships between Geostationary Infrared and Retrieved Fields, Radar and Lightning data

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Outline

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

2. Updates on 0–1 hour first flash lightning initiation (LI) nowcasting using infrared fields.

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

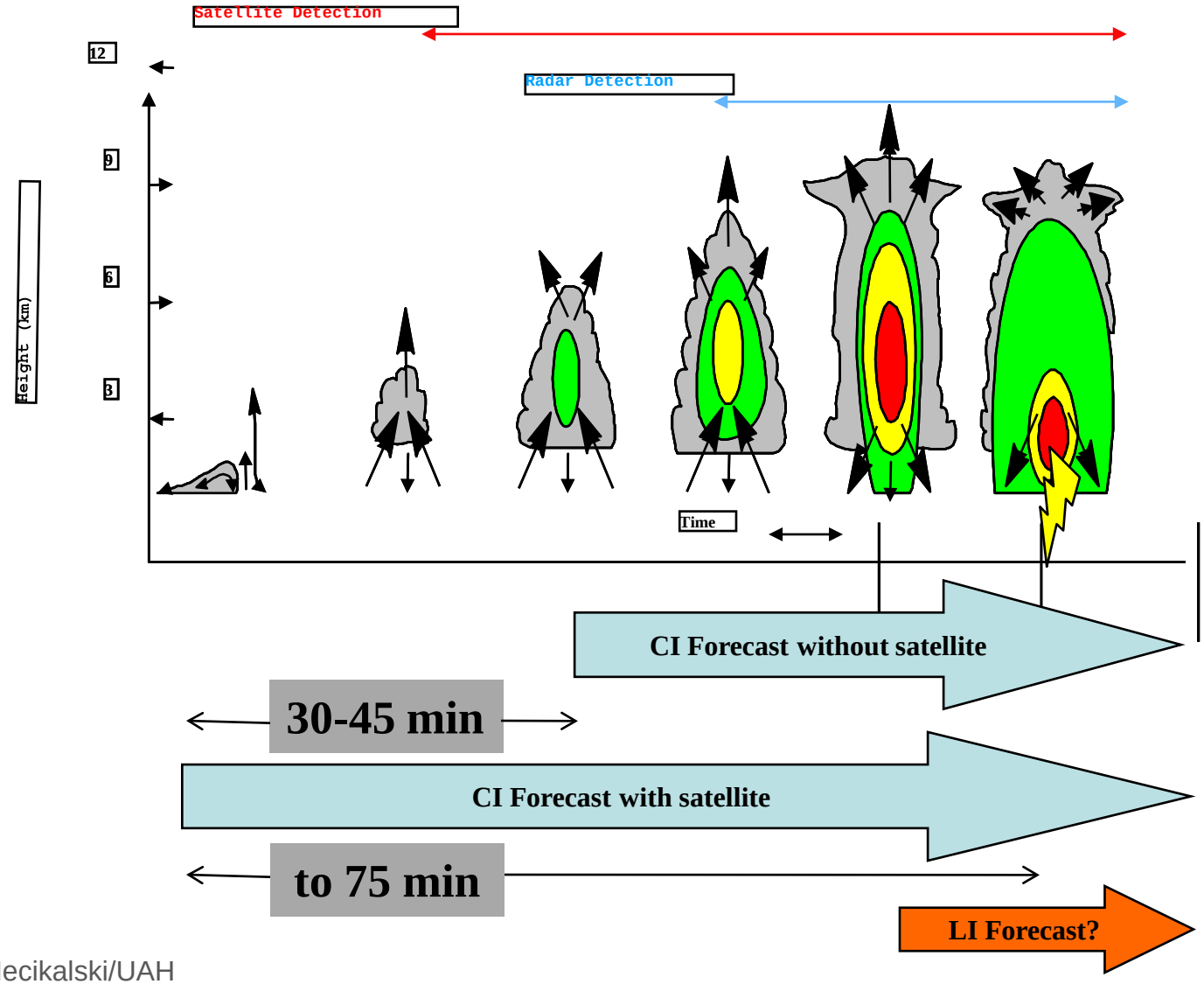
4. Relationships between dual-polarimetric radar, MSG infrared, and total lightning: Non-lightning vs lightning–producing convection.

Project/Science Goals

- 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).
- 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:
  - Test a LI nowcast algorithm in the Corridor Integrated Weather System (CIWS) of the FAA.
  - Forming multi–sensor approaches to nowcasting storm intensity, in preparation for GOES–R, GLM and GPM, that can be used within nowcasting systems.
  - Using Imager data (from GOES, MSG) to help identify where lightning will occur in the near future, which will “mesh” with observations from GLM and the MTG LI.

Lightning Initiation: Conceptual Idea

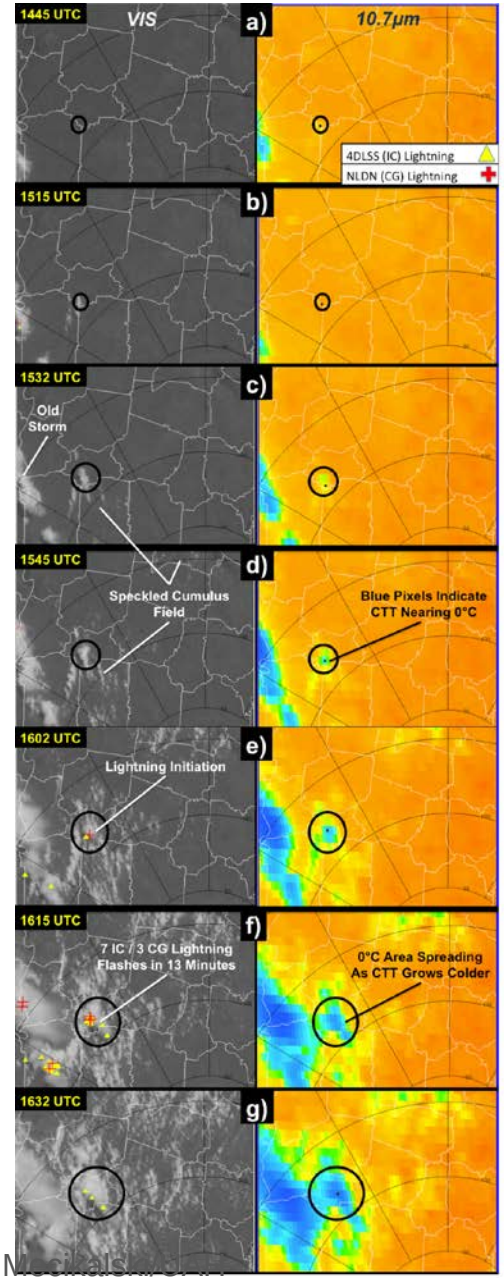
What is the current LI forecast lead time?



From 10-45 minutes added lead time for first flash LI using GOES Imager data

Lead time from radar alone is on the order of 10-13 minutes

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.
6. Evaluate and refine satellite indicators and assess performance.
7. Compare satellite fields with radar, so assess relationships.

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. D. Carey, E. W. McCaul, Jr., and T. A. Coleman, 2012: Regional comparison of GOES cloud-top properties and radar characteristics in advance of first-flash lightning initiation. *Mon. Wea. Rev*., In press.

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.

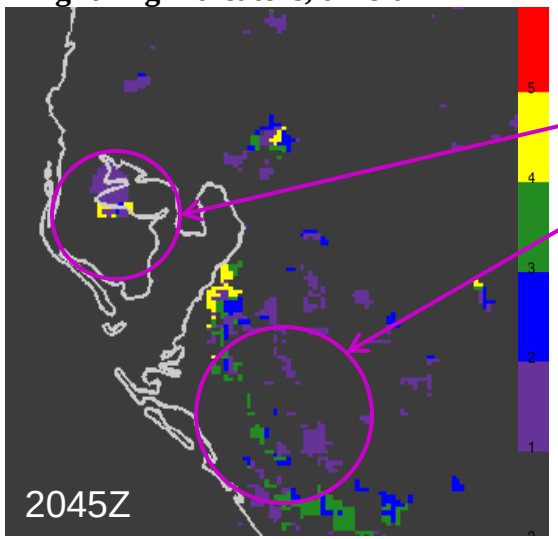
Provides up to a 75 lead time on first-time LI.

Interest Field	MB 2006 Value	Original Harris et al. (2010) value	Values for MIT study	
10.7 µm Brightness Temperature	< 0 ºC	-18 ºC to 0 ºC	**-18 ºC to -5 ºC**	Glaciation
3.9 µm Reflectance	Not Used	< 0.08	**< 0.09**	Glaciation
3.9 µm – 10.7 µm 15-min trend	Not Used	> 1.5 ºC	> 1.5 ºC	Glaciation
3.9 µm – 10.7 µm difference	Not Used	> 17 ºC	**>20 ºC**	Glaciation
3.9 µm Reflectance 15-min trend	Not Used	< -0.02	< -0.02	Glaciation
10.7 µm 15-min trend	< -4 ºC	< -6 ºC	**< -12 ºC**	Growth Rate
6.5 µm – 10.7 µm 15-min trend	> 3 ºC	> 5 ºC	> 5 ºC	Growth Rate
13.3 µm – 10.7 µm 15-min trend	> 3 ºC	> 4 ºC	Not Used	Growth Rate
6.5 µm – 10.7 µm difference	-35 to -10 ºC	> -30 ºC	**-20 ºC to -40 ºC**	Cloud Top Height
13.3 µm – 10.7 µm difference	-25 to -5 ºC	> -13 ºC	Not Used	Cloud Top Height

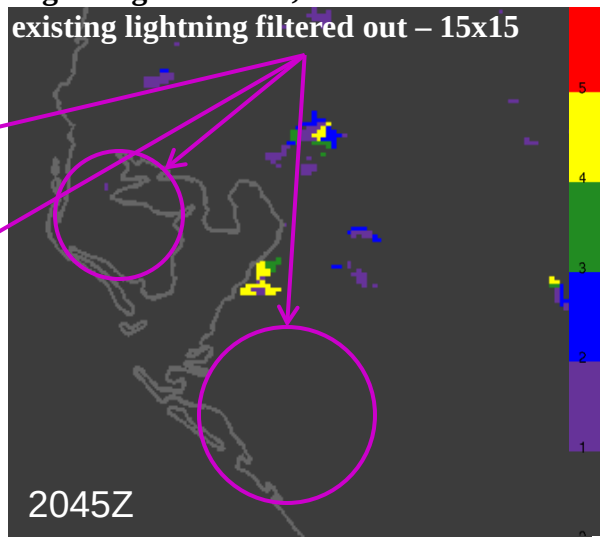
The 10.7 µm T_B, 3.9 reflectance, 15-min 10.7 µm cooling rate, and the 6.5–10.7 µm trend are the most important fields.

7/4/11 Tampa – removal of existing lightning and threshold adjustment

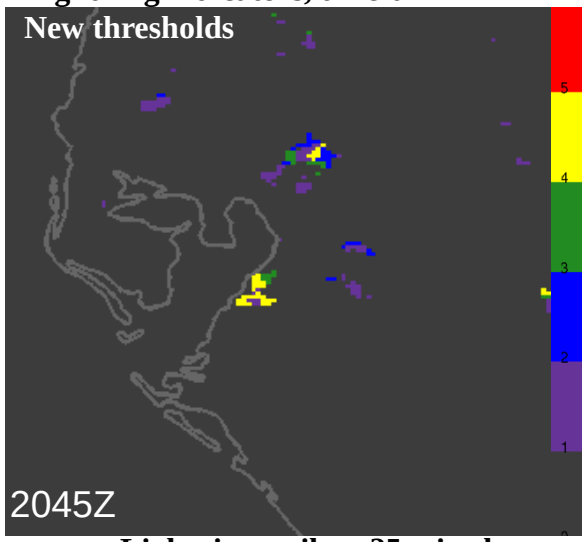
Lightning indicators, time 0



Lightning indicators, time 0
existing lightning filtered out – 15x15



Lightning indicators, time 0
New thresholds



Changes:

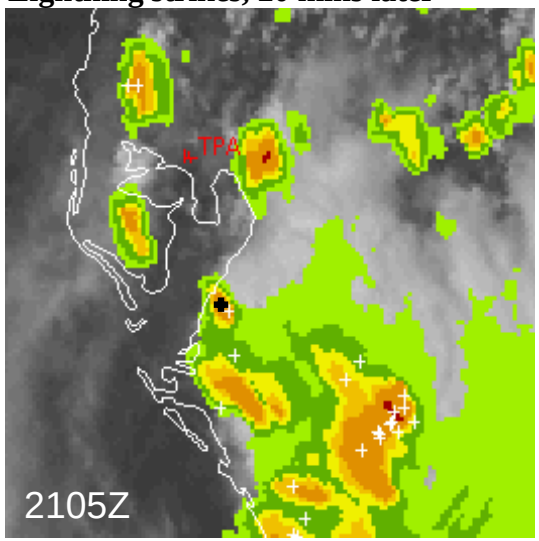
LI1: -18C > 10.7um > 0C AND 3.9um-10.7 > 17

LI1: -18C > 10.7um < -5C AND 3.9um-10.7 > 17

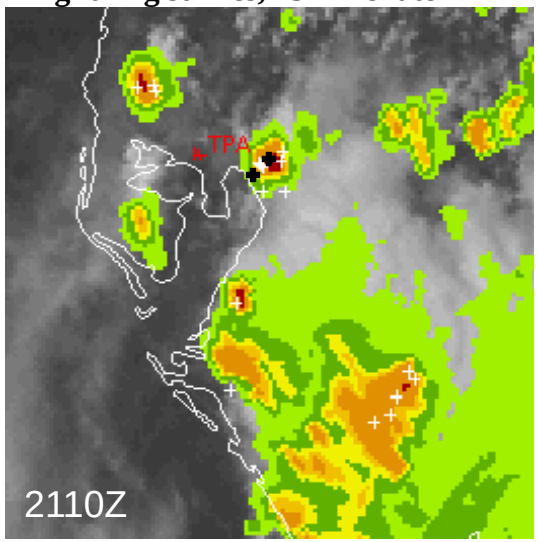
LI3: 3.9 < 0.11 AND 3.9 reflectivity 15 min trend is < -0.02

LI3: 3.9 < 0.08 AND 3.9 reflectivity 15 min trend is < -0.02

Lightning strikes, 20 mins later



Lightning strikes, 25 mins later



Lightning indicator values > 4 denote lightning strikes

7/3/11 New Orleans – Threshold Adjustment (25 min lead time)

Removal of false alarms

Changes:

LI1: –18 ° C > 10.7 µm > 0 ° C AND 3.9–10.7 µm > 17 ° C

LI1: 10.7 µm < –5 ° C AND 3.9–10.7 µm > 17 ° C

LI3: 3.9 µm < 0.11 AND 3.9 µm reflectivity 15 min trend is < –0.02

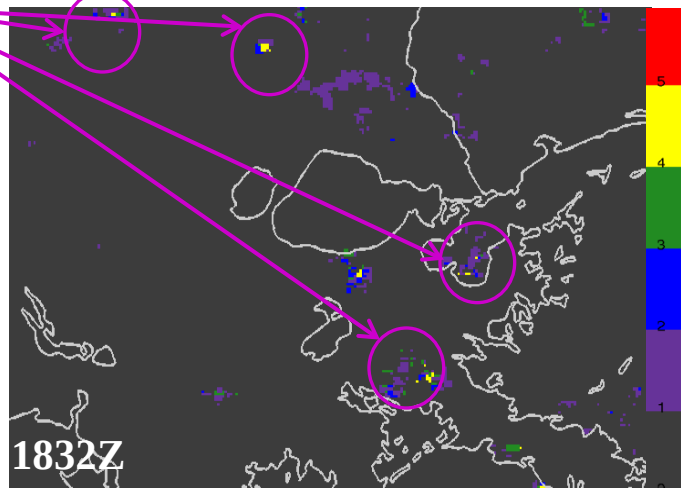
LI3: 3.9 µm < 0.08 AND 3.9 µm reflectivity 15 min trend is < –0.02

Improvement in hits vs. false alarms:

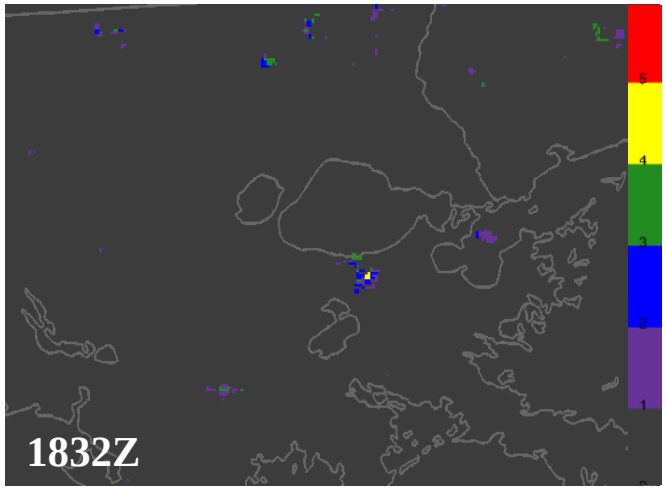
60% hits, 40% FA

67% hits, 33% FA

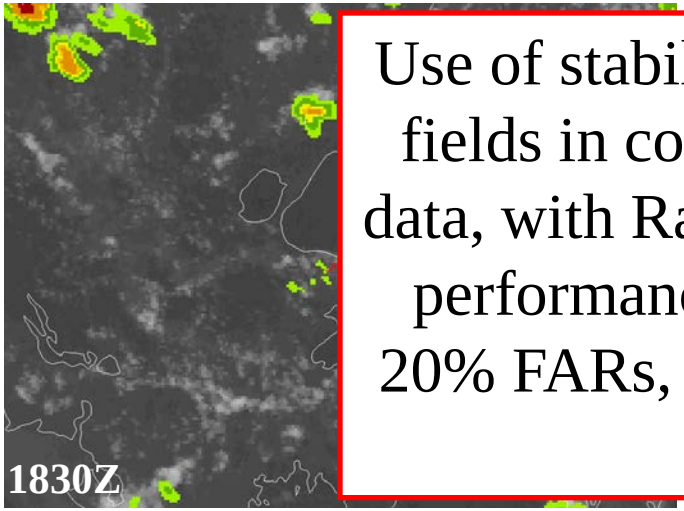
lightning indicators, time 0



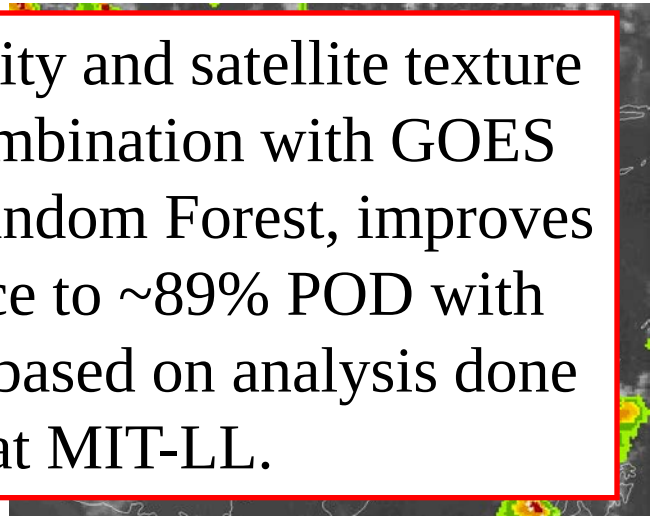
lightning indicators, time 0



lightning strikes, time 0

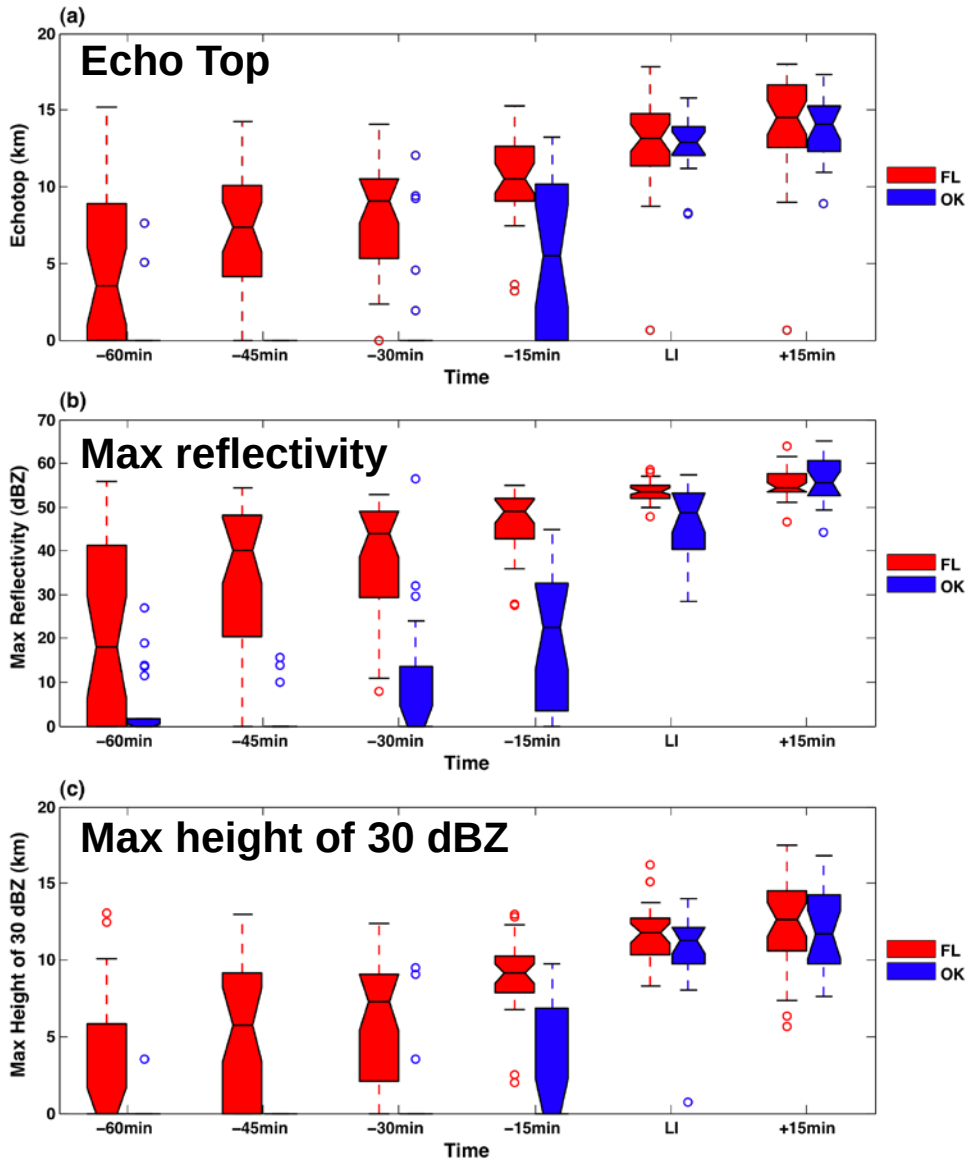


lightning strikes, 20 mins later



Use of stability and satellite texture fields in combination with GOES data, with Random Forest, improves performance to ~89% POD with 20% FARs, based on analysis done at MIT-LL.

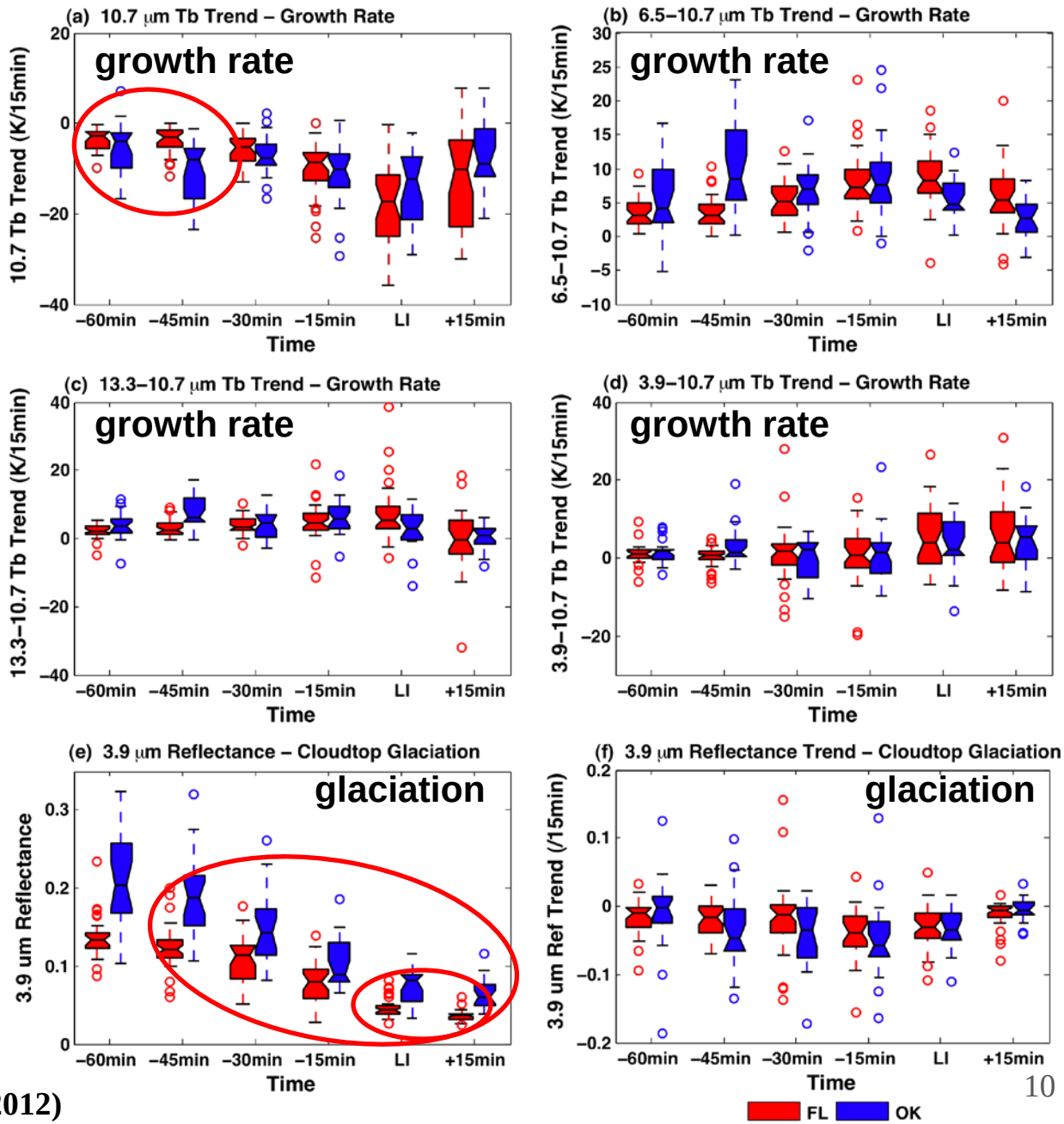
WSR–88D Radar Fields – Lightning Events (OK & FL)



- Rapid storm evolution occurs in OK (blue) compared to FL (red) leading up to LI.
- Implication from radar alone is that there is a longer forecast lead time for LI in more humid environments, where storm growth is slower.
- Lack of notch overlap between fields at a given time shows statistically, significantly different datasets up to the LI time.

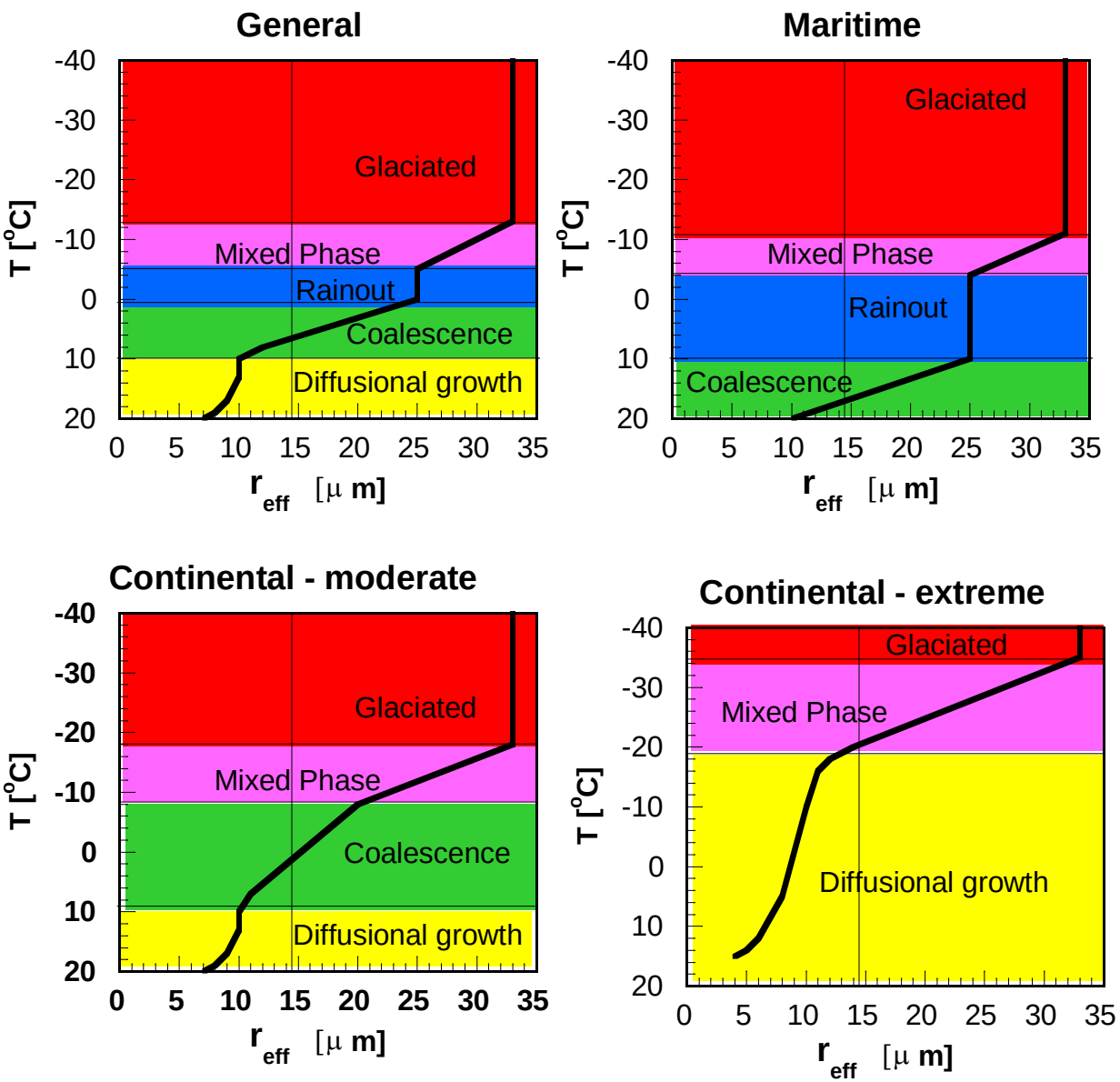
GOES Infrared Fields – Lightning Events (OK & FL)

- Tendency for stronger updrafts early in storm's life in OK, where CAPE's are larger.
- 3.9 µm reflectance show that the stronger updrafts in OK lead to more small ice particles at cloud top, and higher reflectance.
- Higher reflectance at cloud top in OK is a response to stronger updrafts there.
- *Well defined anvils in FL at time of LI, and slowing growth versus in OK.*
- *First flash nowcast lead time is >25-35 min using satellite (up to 75 min).*



Mecikalski et al. (2012)

The classification scheme of convective clouds into microphysical zones according to the shape of the temperature – effective radius relations



Note that in extremely continental clouds r_e at cloud base is very small, the coalescence zone vanishes, mixed phase zone starts at T<-15º C, and the glaciation can occur at the most extreme situation at the height of homogeneous freezing temperature of –39º C. In contrast, maritime clouds start with large r_e at their base, crossing the precipitation threshold of 14 mm short distance above the base. The deep rainout zone is indicative of fully developed warm rain processes in the maritime clouds. The large droplets freeze at relatively high temperatures, resulting in a shallow mixed phase zone and a glaciation temperature reached near –10º C.

Courtesy D. Rosenfeld

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

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.
- Focus on lightning and non-lightning case studies, ~30 of each storm type.
- Data from NPOL and MSG processed and co-located with lightning observations.
- Also analyzed MSG-derived fields of effective radius, optical thickness, cloud-top phase, and cloud-top pressure.

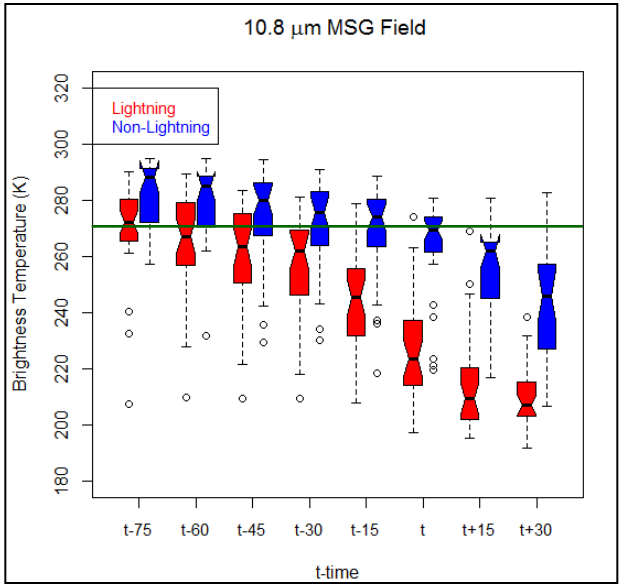
Results:

1. Found relatively understood relationships between hydrometeor fields, lightning onset, for both lightning and non-lightning events.
2. MSG data confirm a strong cloud-top glaciation signature at the time when large ice volumes are seen at cloud top.
3. The presence of well-defined anvils is provided by satellite infrared data when lightning is observed.
4. Strong updrafts and tall clouds correspond to lightning-producing clouds.
5. Unique “thresholds” are found in IR observations of cloud producing lightning.

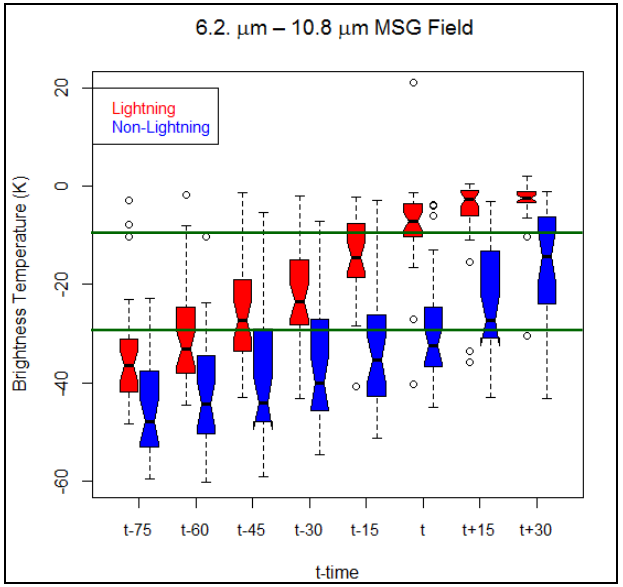
Matthee and Mecikalski (2012); Matthee et al. (2013a,b)

MSG Infrared Fields: Lightning/Non-Lightning Events

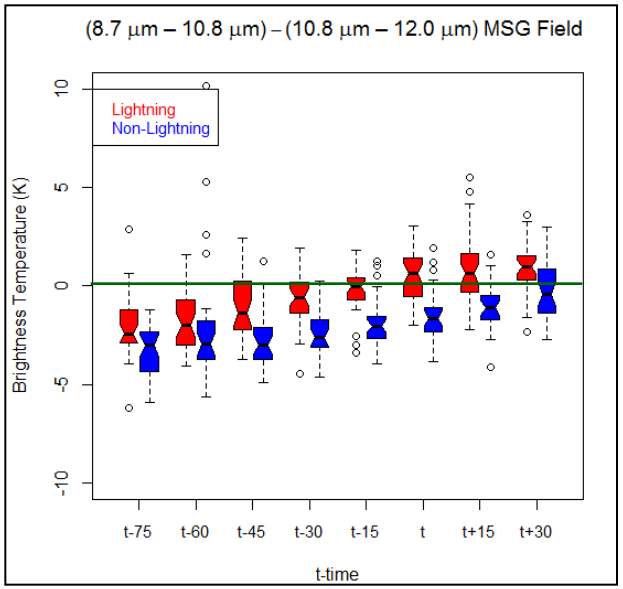
Updrafts



Cloud depth



Cloud top Glaciation



Lightning storms Non-Lightning storms

<u>Lightning Events:</u>

- Strong updrafts, with anvil formation (not seen in non-lightning events)
- Clouds continue to deepen after first CG lightning (non-lightning; shallow clouds)
- Strong glaciation signature in IR fields (weak signature in non-lightning)

Behavior of MSG Infrared Fields: CG Lightning Events

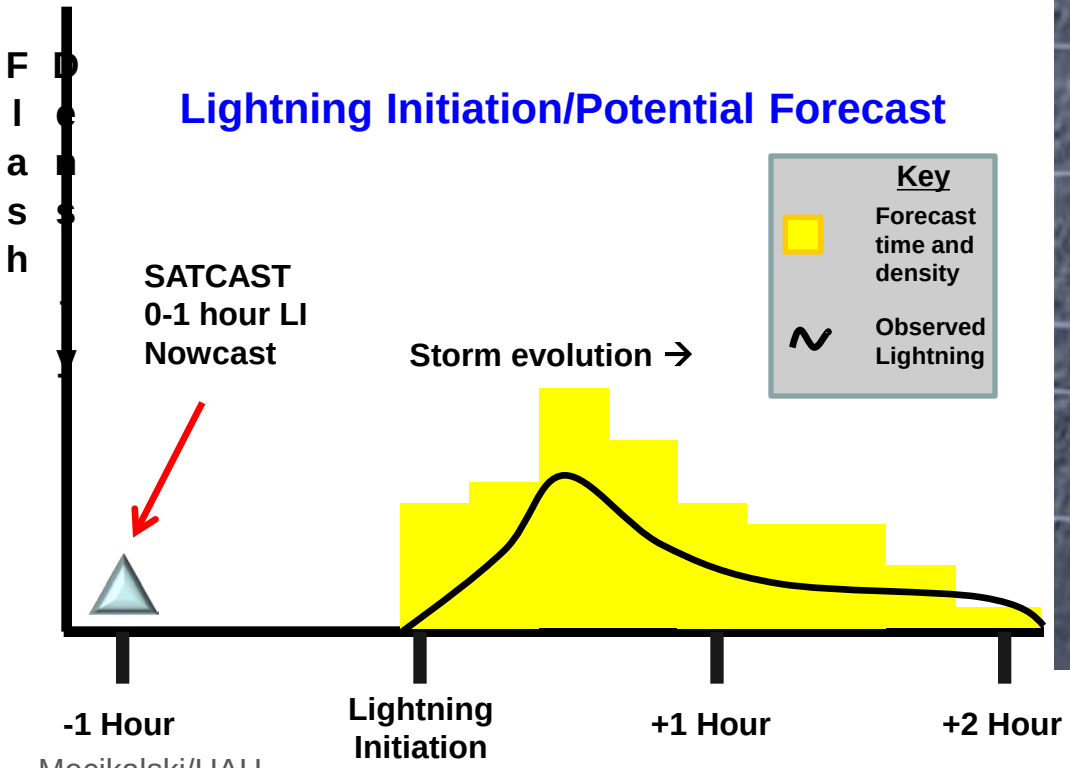
- Main Finding: MSG "interest fields" for growing cumulus clearly delineate CG-lightning from non-lightning cumulonimbus clouds.

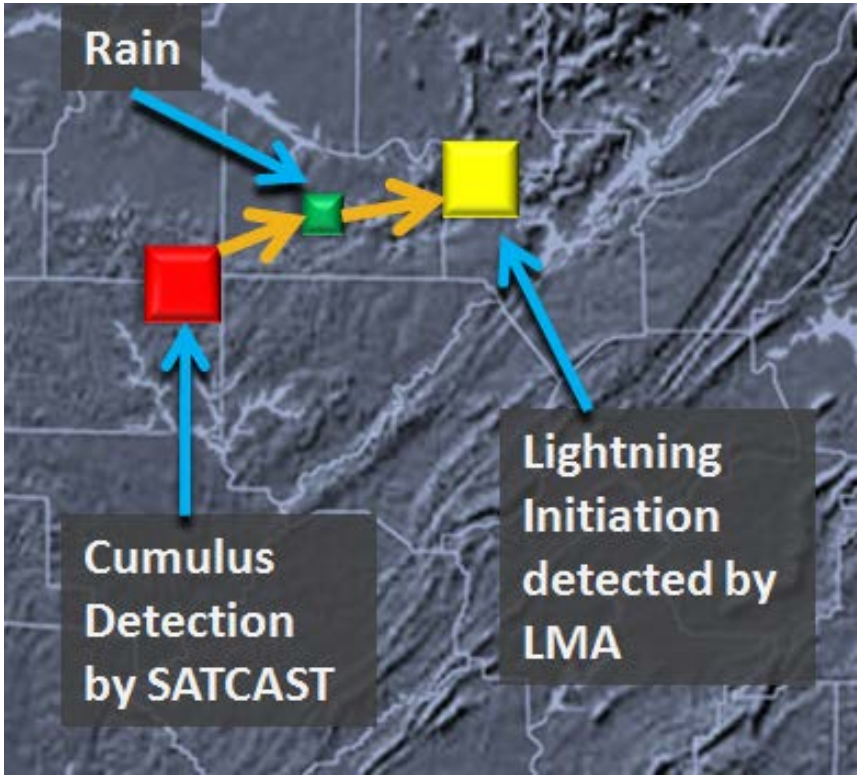
- Glaciation signatures plus stronger updraft-strength indicators are key.

Channel differencing and time trends	Category	Critical value for CG lightning initiation
15 minute Trend 6.2–7.3 μm	Updraft strength	Positive trends for ≥30 minutes with ≥2 °C increase during this time
30 minute Trend 6.2–7.3 μm	Updraft strength	Positive trends for ≥30 minutes with ≥4 °C increase during this time
15 minute Trend 10.8 μm	Updraft strength	≤ –10 °C
30 minute Trend 10.8 μm	Updraft strength	≤ –20 °C
6.2–7.3 μm	Cloud depth	≥ –5 °C
6.2–10.8 μm	Cloud depth	≥ –10 °C
8.7–10.8 μm	Cloud–top glaciation	≥ 0.5 °C
15 minute Trend 8.7–10.8 μm	Cloud–top glaciation	N/A*
(8.7–10.8)–(10.8–12.0) μm	Cloud–top glaciation	≥ 0.5 °C
15 minute Trend (8.7 –10.8)–(10.8–12.0) μm	Cloud–top glaciation	N/A

WRF/SATCAST Lightning Initiation & Threat Forecast

- **Created an algorithms that links 0-1 hour lightning initiation to forecast of a short-term lightning threat (density), or potential amounts per storm.**
- **Explore distance-weighted method to account for expected differences in lightning/storm initiation location and WRF-based lightning threat forecasted storms.**
- **Validate using LMA for truth flash density.**
- **Refine GOES lightning initiation method.**
- **Preparing for GLM**

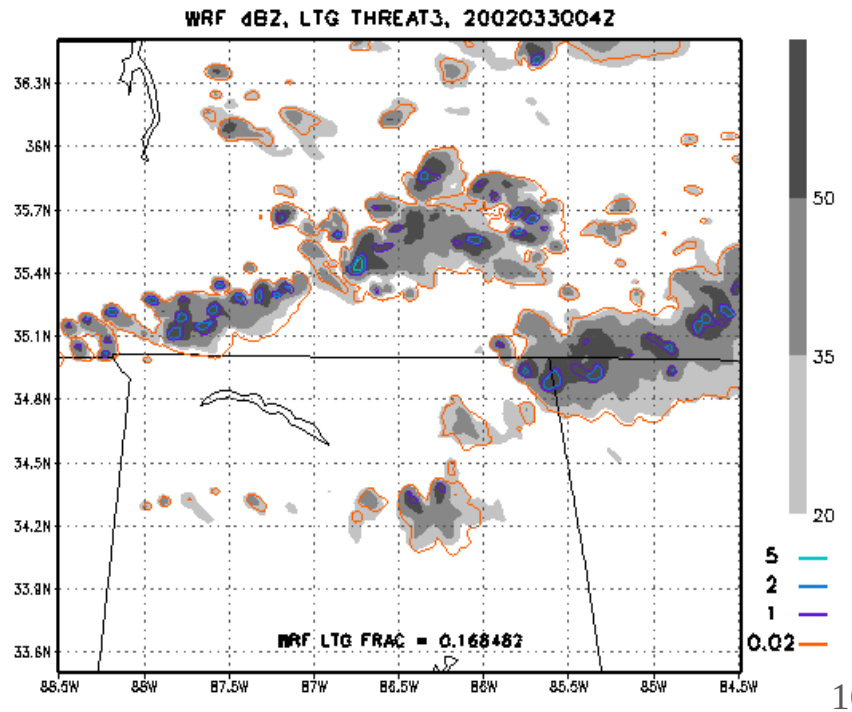




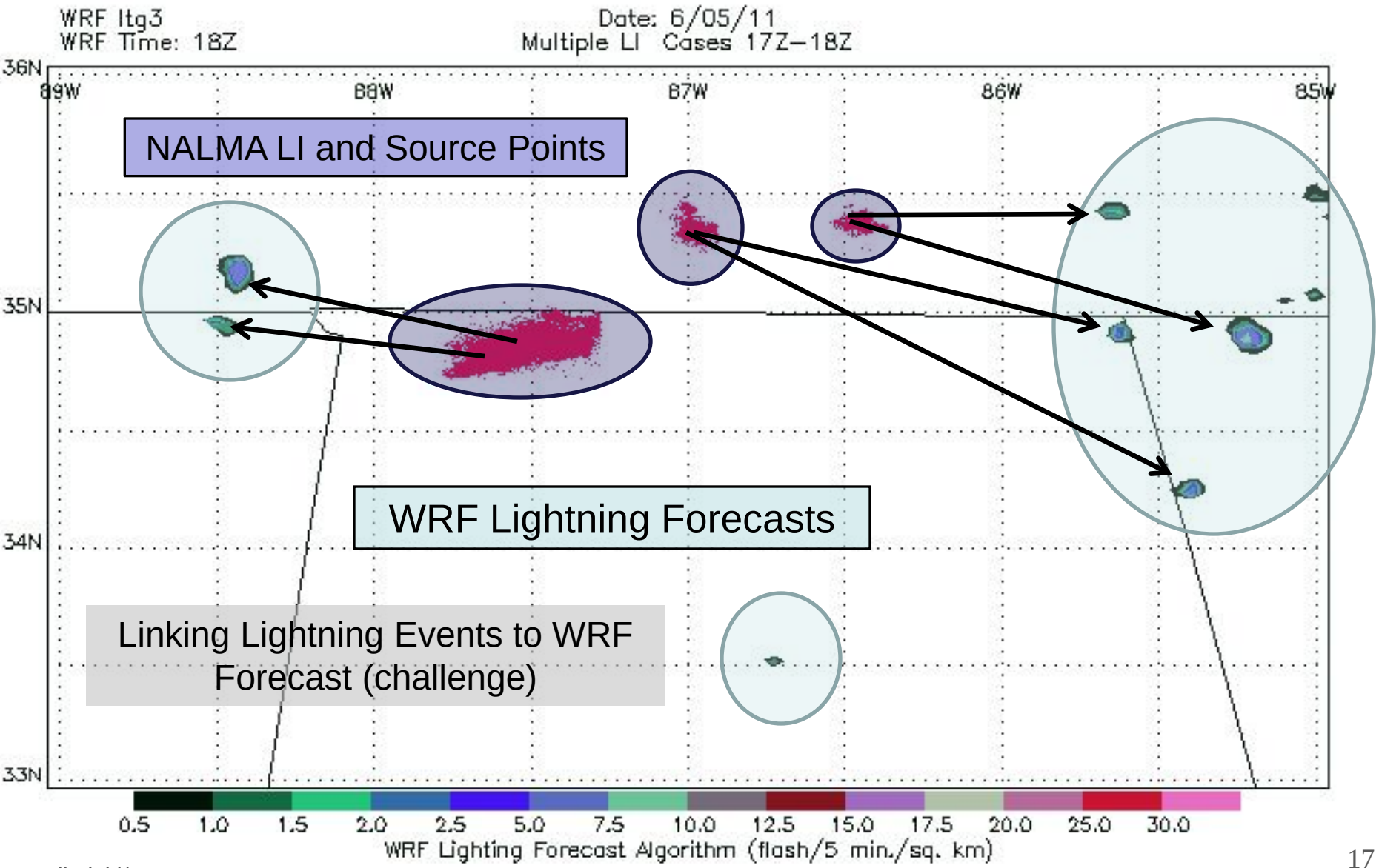
WRF/SATCAST Lightning Initiation & Threat Forecast

- Dataset currently ~50 Cases from North Alabama LMA
  - More being added
  - Creating Flash Origin Densities to validate WRF output
- NSSL WRF Output on corresponding days acquired/being processed
- SATCAST tracking tool being implemented to obtain infrared fields
- Current Challenge: Overlaying WRF output to the observed LMA data
  - Spatial and Temporal difficulties
  - Looking into using other parameters from WRF output to create a range-weighted and time-weighted approach

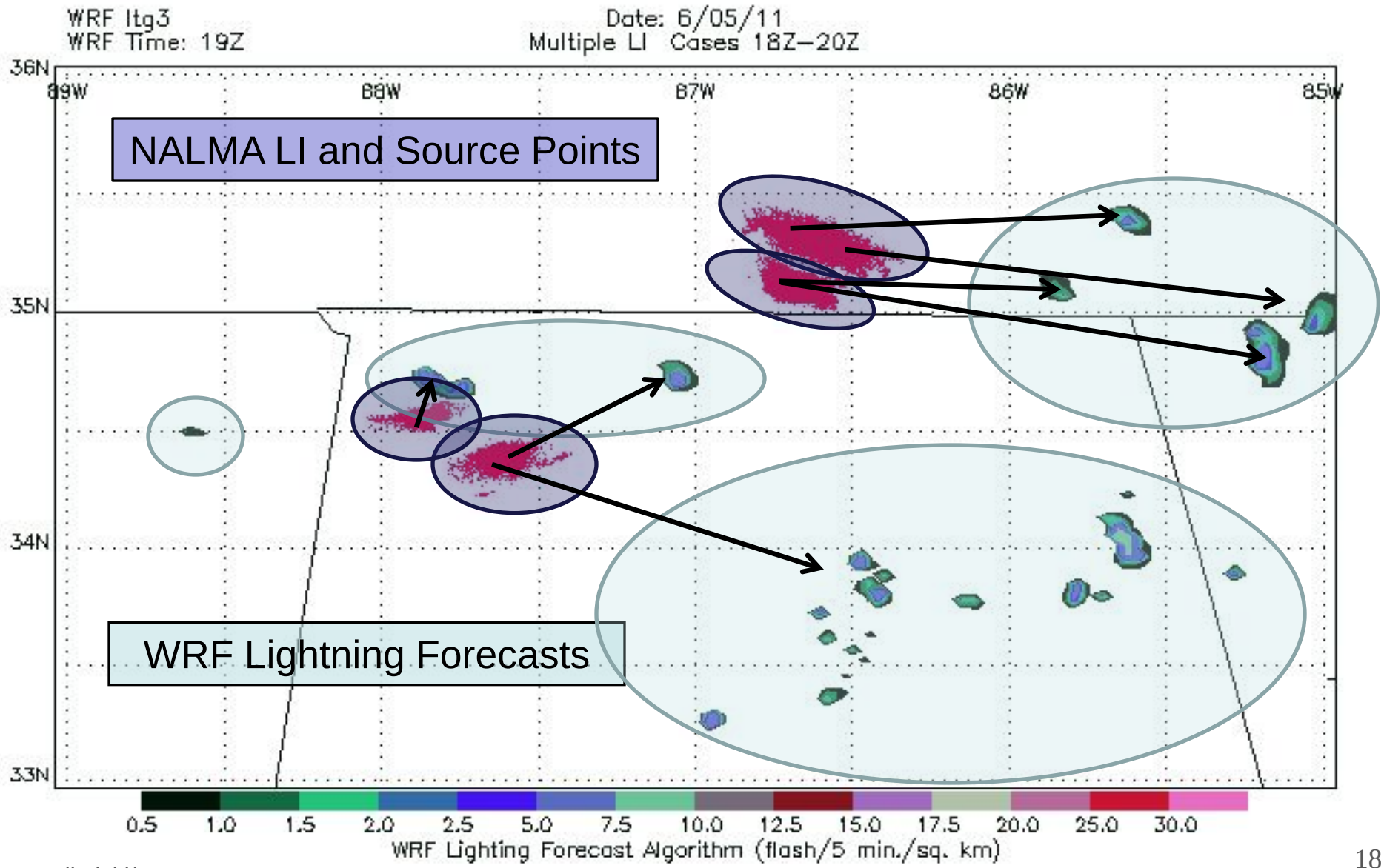
Use McCaul et al. (2009) fields to estimate how much lightning is possible, while using GOES to determine when and where lightning will occur. Use LMA to show truth, and verify WRF model fields, and help refine how GOES infrared data are used in nowcasting first-flash LI.



Linking LI Nowcasts with WRF Lightning Threat



Linking LI Nowcasts with WRF Lightning Threat



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 (i.e. the “10 mile” rule).

1. Enhance estimates of “storm intensity” and “storm life cycle” (storm decay) for assessing turbulence/hazard potential. Evaluate how to enhance use of infrared data for nowcasting specific, locally intense storms.

2. Development of a GOES lightning initiation training database, with possible plans for HWT demonstration.

3. Evaluate how GOES Imager nowcasts of LI can be combined with GLM observations, for process studies.