# Lightning Initiation Nowcasting – Proxy Indicators using GOES

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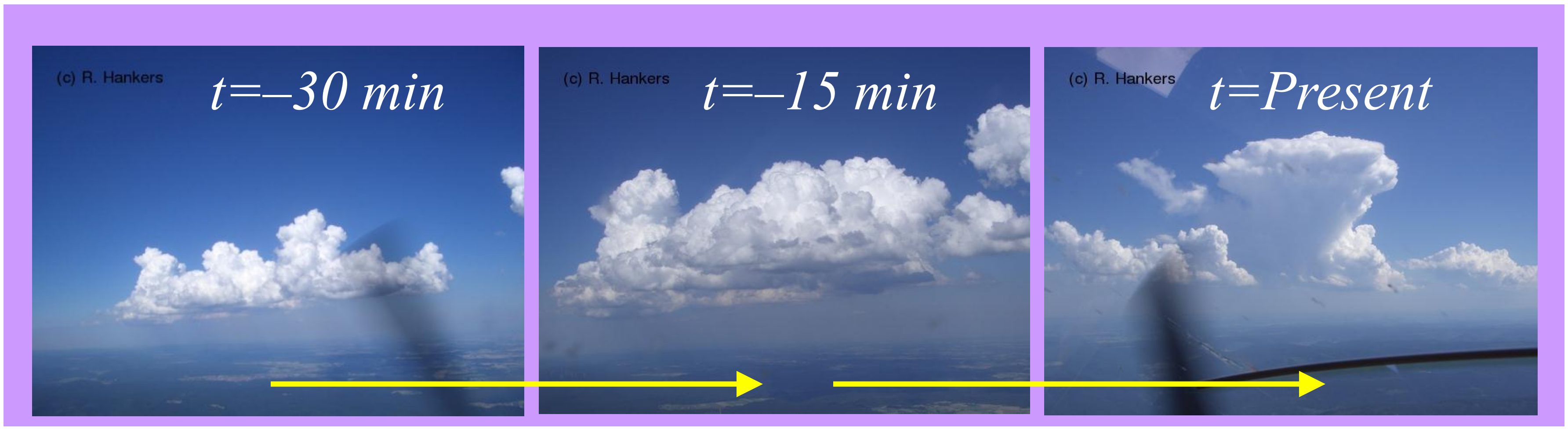
GLM Meeting 2010
Huntsville, Alabama 1-3 December 2010

# Outline

1. **Background and updates on 0-1 hour CI Nowcasting**
2. **Research toward estimating lightning initiation using GOES (NSF)**
3. **First evaluation of GOES LI indicators in Corridor Integrated Weather System (CIWS; NASA ROSES 2009 study)**
4. **GOES-R Risk Reduction Storm Intensity project update**
5. **Basic research on increasing understanding of relationships between dual-polarimetric radar, Meteosat Second Generation infrared, and total lightning in on-lightning versus lightning-producing convection (NSF)**

# Methods: Convective Nowcasts/Diagnoses

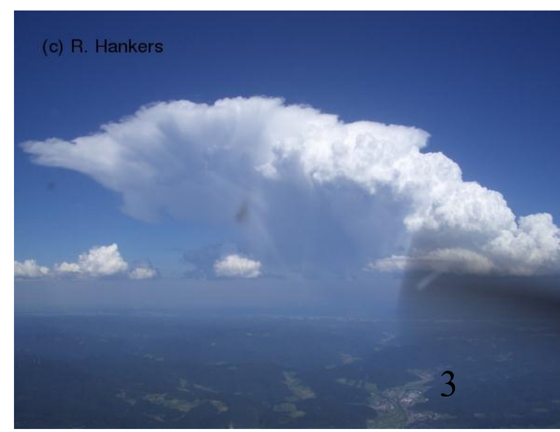
→: Satellites "see" cumulus before they become thunderstorms!
→: There are many available methods for diagnosing/monitoring cumulus motion/development in real-time (every 15-min). <u>See the published research.</u>




**Monitor… ~11 IR fields for GOES:**

SATellite Convection AnalySis and Tracking (SATCAST) System

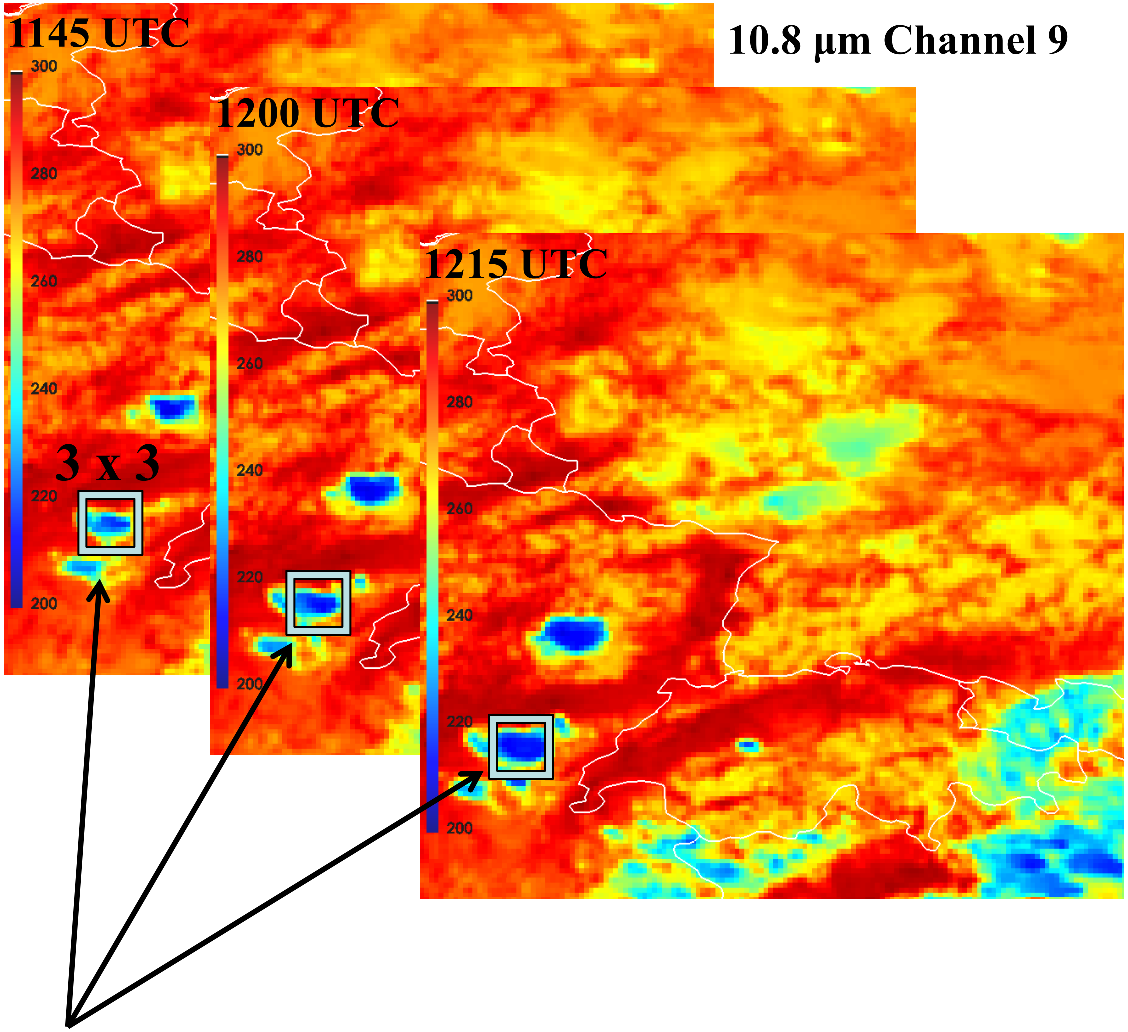
**CI Time →**
1st ≥35 dBZ echo at ground



# SATCAST Algorithm: *GOES IR Interest Fields*

| CI Interest Field | Purpose and Resolution | Critical Value |
|---|---|---|
| 6.5 – 10.7 μm difference **(IF1)** | 4 km cloud-top height relative to upper-tropospheric WV weighting function (Schmetz et al. 1997) | –35° C to –10° C |
| 13.3 – 10.7 μm difference **(IF2)** | 8 km cloud-top height assessment (Mecikalski and Bedka 2006; Mecikalski et al. 2008) | –25° C to –5° C |
| 10.7 μm $T_B$ **(IF3)** | 4 km cloud-top glaciation (Roberts and Rutledge 2003) | –20° C < $T_B$ < 0° C |
| 10.7 μm $T_B$ Drop Below 0° C **(IF4)** | 4 km cloud-top glaciation (Roberts and Rutledge 2003) | Within prior 30 mins |
| 10.7 μm $T_B$ Time Trend **(IF5, IF6)** | 4 km cloud-top growth rate/updraft strength (Roberts and Rutledge 2003) | < –4° C/15 mins<br>$\Delta T_B$/30 mins < $\Delta T_B$/15 mins |
| 6.5 – 10.7 μm Time Trend **(IF7)** | 4 km multi-spectral cloud growth (Mecikalski and Bedka 2006) | > 3° C/15 mins |
| 13.3 – 10.7 μm Time Trend **(IF8)** | 8 km multi-spectral cloud growth (Mecikalski and Bedka 2006; Mecikalski et al. 2008) | > 3° C/15 mins |
| 3.9 μm Fractional Reflectance **(IF9)** | 4 km cloud-top glaciation Lindsey et al. (2006) | ≤ 5% |
| 3.9 – 10.7 μm trend **(IF10)** | 4 km cloud-top glaciation Siewert (2008) | t – ($t_{-1}$) ≤ –5 K and<br>t – ($t_{+1}$) ≤ –5 K |
| 30-min trend in 3.9 μm fraction reflectance **(IF11)** | 4 km cloud-top glaciation Siewert (2008) | Continually decreasing below 10% |

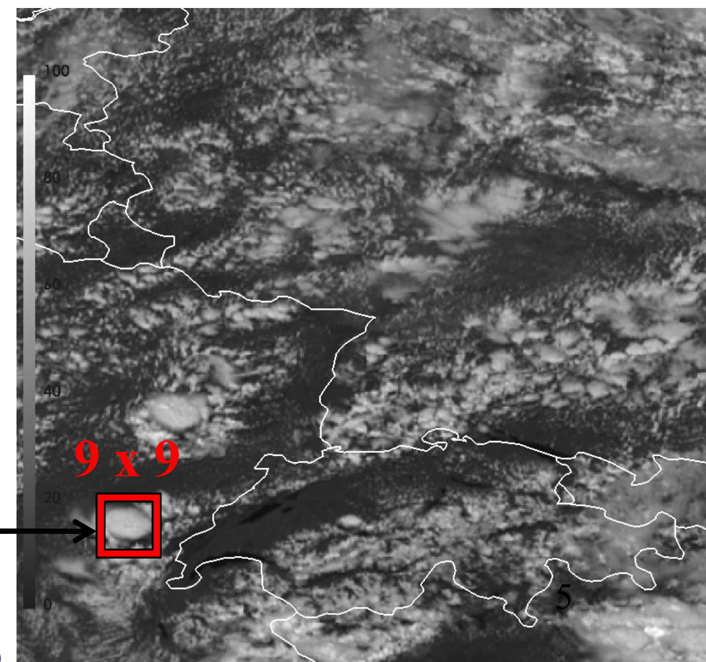
# SATCAST Algorithm: *COPS CI Events*




**10.8 µm Channel 9**

A CI "object" was evaluated per CI "event" as a unique cumulus cloud was observed to develop in MSG IR and visible data and produce a >35 dBZ echo (as see in POLIDAD and other radars).

**1215 UTC HRV**




**A "sort of" CI Event…**



GLM Meeting 2010
Huntsville, Alabama 1-3 December 2010

# 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

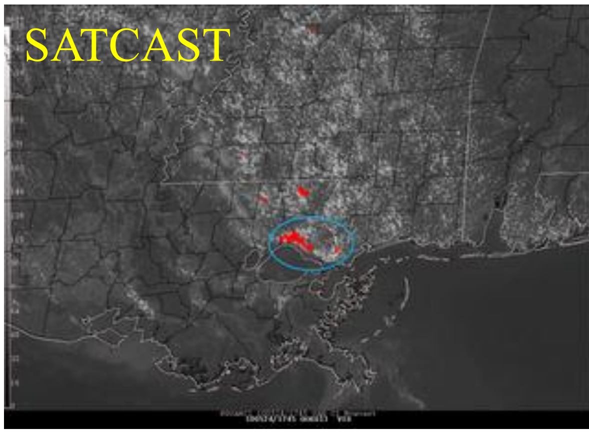
Channels related to the following were found to contain redundant information as they were highly correlated:

8.7-13.4 μm, 8.7-10.8 μm, 7.3-10.8 μm, 13.4-10.8 μm, 8.7-12.0 μm, and Time Trends of these fields.

**21 Unique IR indicators for Nowcasting CI from MSG (*GOES-R*).**

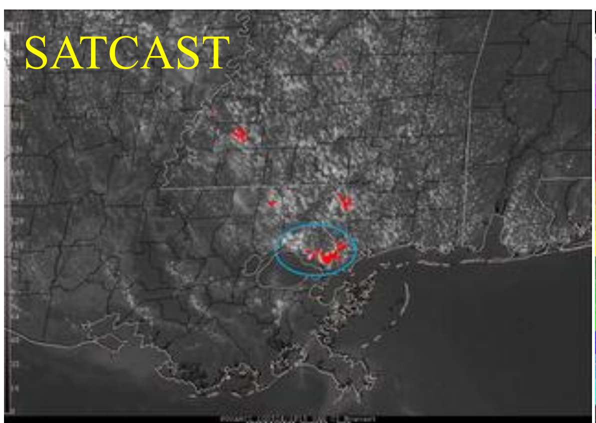
# Object Tracking: 24 May 2010 (New Orleans)

Funding through the NASA ASAP (Advanced Satellite Aviation Weather Products) initiative has helped in the development of an object tracking approach within SATCAST. This method is being demonstrated as the NOAA HWT, AWT, OPC and AWC, within 2011 and beyond.

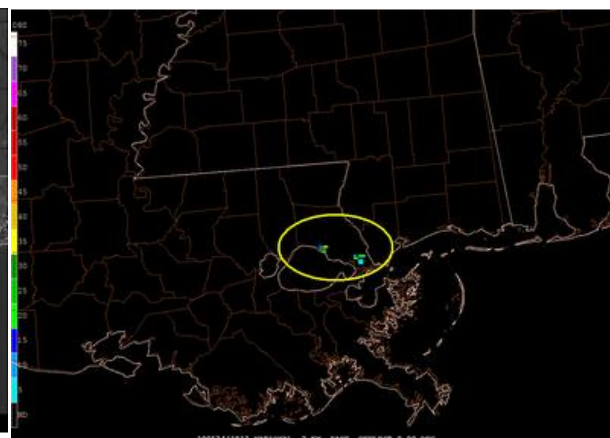



**1745 UTC**

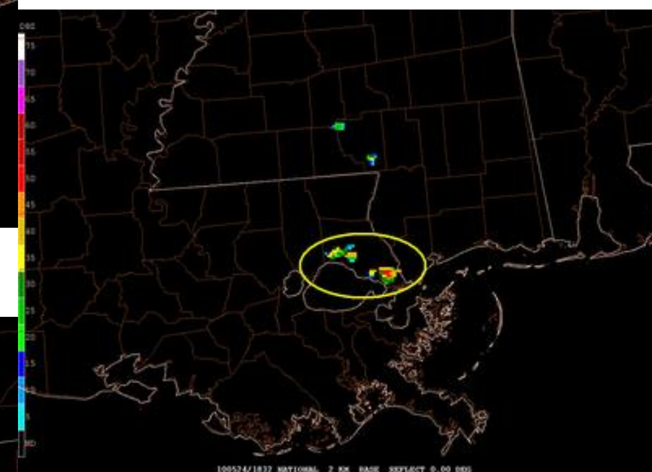
**1744 UTC**




**1815 UTC**



**1813 UTC**

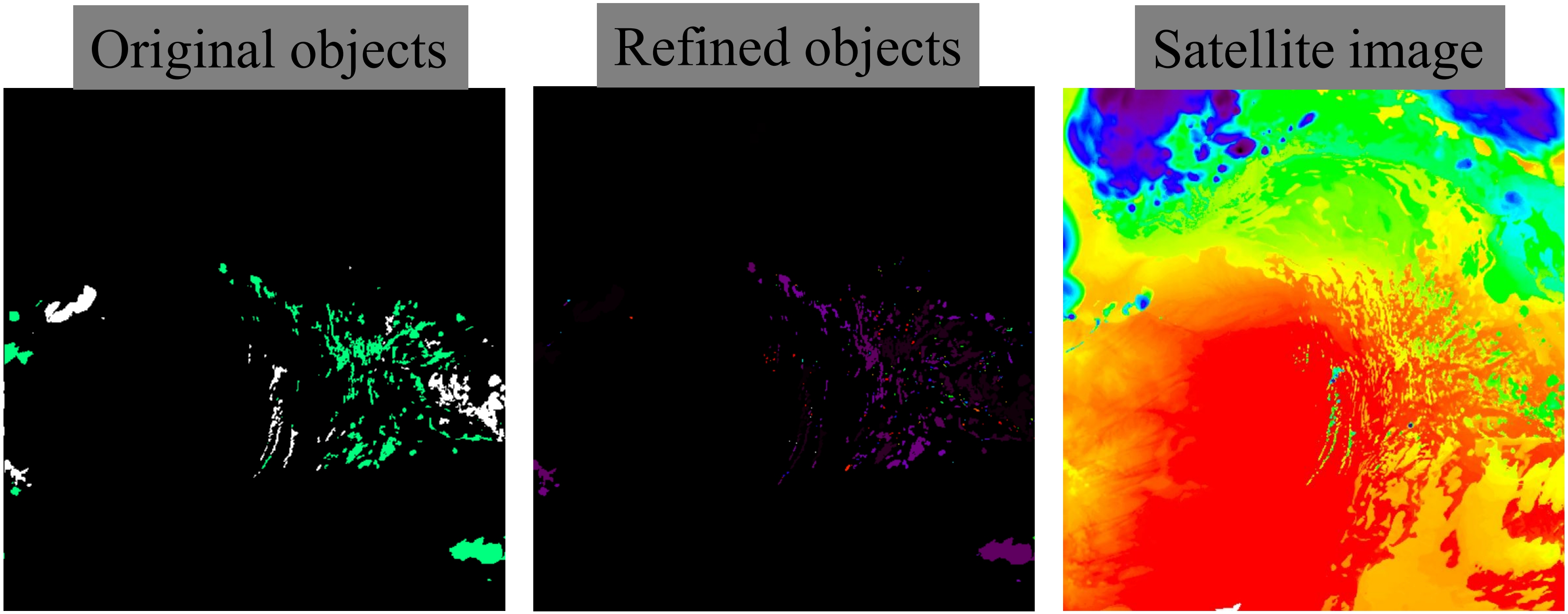


**1832 UTC**

**~20 to 30 minute lead-time**

Walker et al. (2011)

# Object Break-up for improved CI Nowcasing



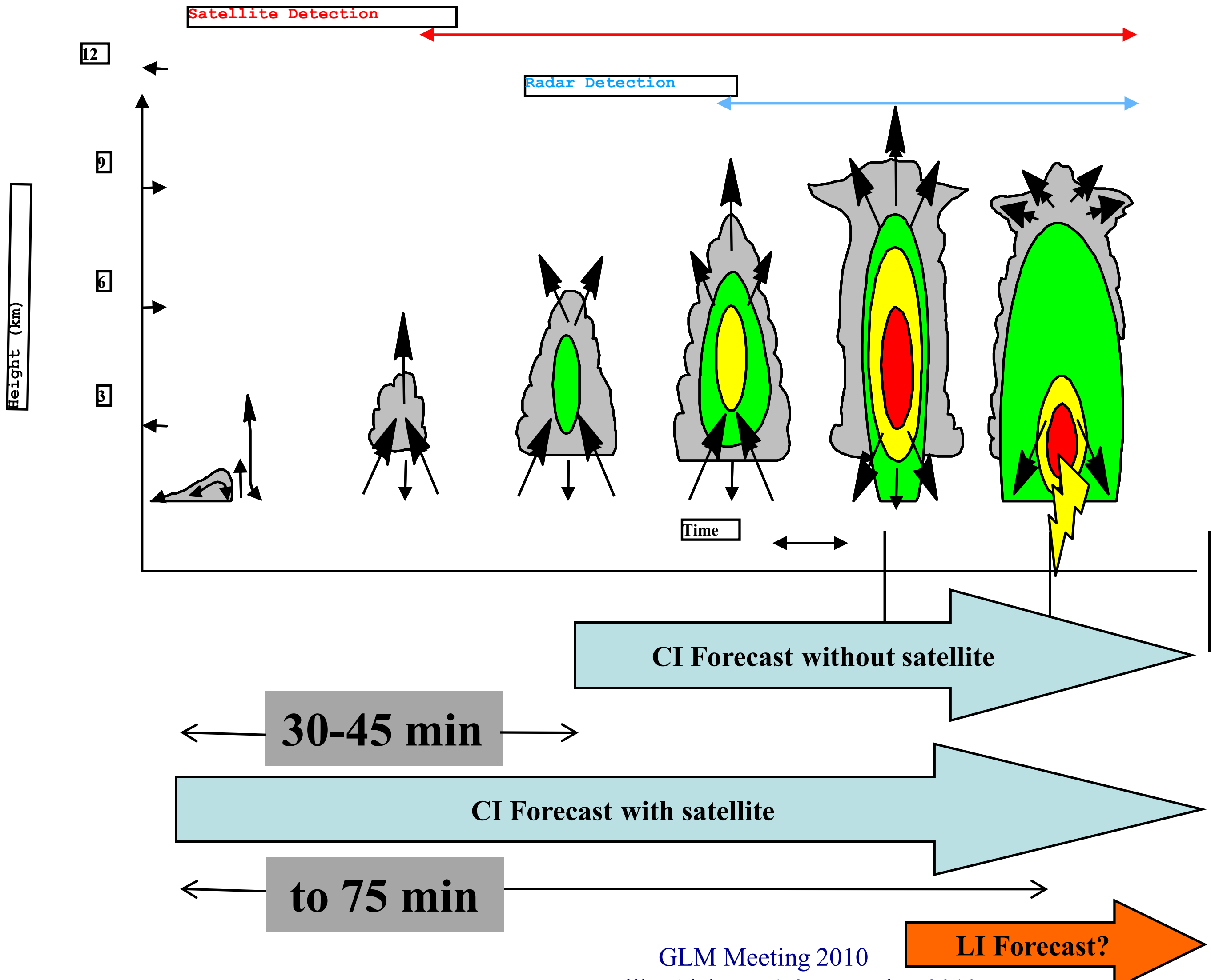

**An example of object break-up using simulated GOES-ABI data. In the upper left, the original defined objects, where the green object are those we will attempt to break into smaller objects.**

**In the image above, the colored, non-purple object are the resultant smaller objects formed through this analysis.**

**The original image is on the right.**

# 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 )**

# Introduction: Lightning Primer

**1** Warm-moist air
+
Instability
+
Trigger
||
Convective cloud

**2** Cloud top ascends to heights at T < 0° C
→ Precipitation processes often commence
→ Cloud droplets start to become supercooled

**3** Cloud top ascends to heights at
T = -5 to -15° C
→ Supercooled droplets pool here

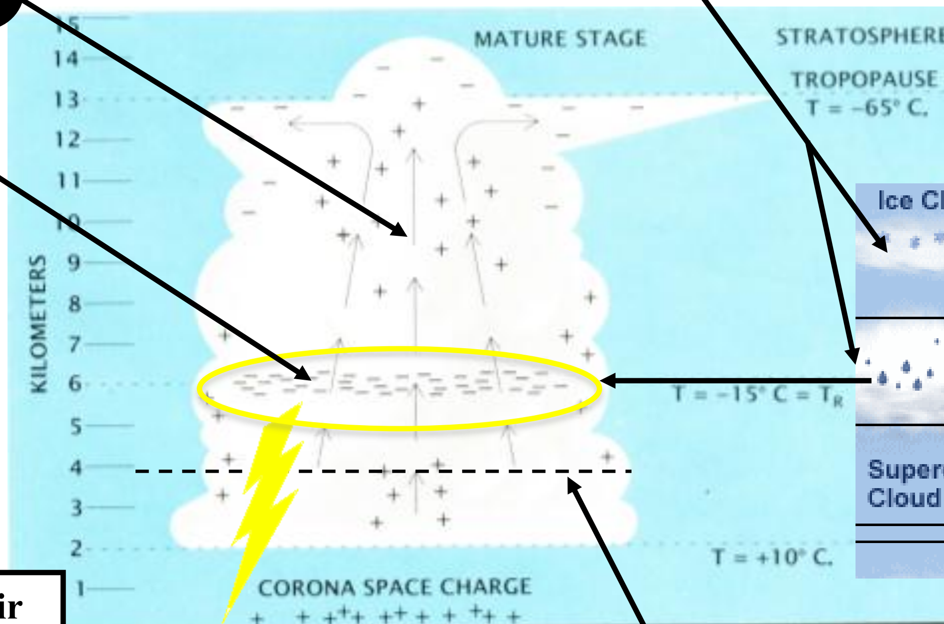
**4** Cloud continues vertical ascent to heights at T< -15 to -20° C
→ Ice crystal & graupel formation increase
→ Some formation between -5 to -15° C as ice crystals fall into the layer (mixed-phase region)

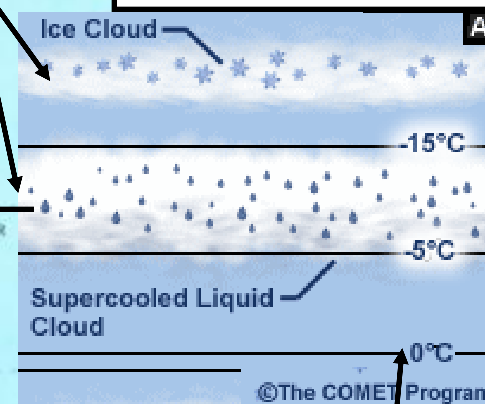
**5**
Ice crystal-Graupel, Precip & other collisions (particularly in updraft) displace charge

-- (+) charge carried to upper cloud

-- (-) charge settles in mixed-phase region
-- Ground under cloud switches polarity to (+)

**6** Electric field increases until insulating properties of air break down → Result is Lightning





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# Satellite Indicators of Lightning –Interest Fields

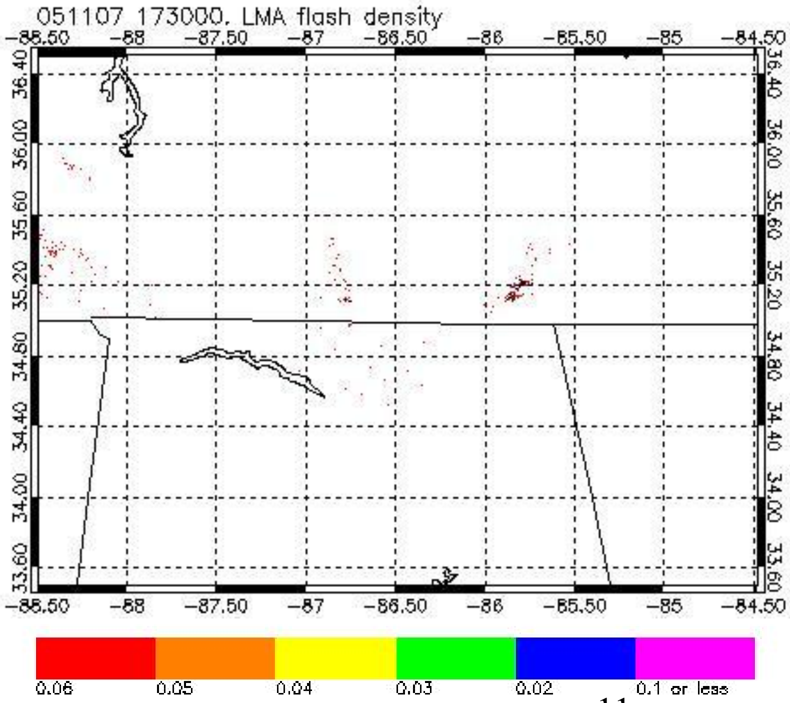
**Separate 3.9 um channel into reflected ($\alpha_{3.9}$) and emitted ($R$) components:**

- Uses methods developed by Setvak and Doswell (1991) and Lindsey et al. (2006)
- Low 3.9 reflectance values indicate ice aloft
- Most accurate for solar zenith angles up to 68° (morning to evening)
- Expect 3.9 reflectance values down to ~0.05 (5%) for ice clouds

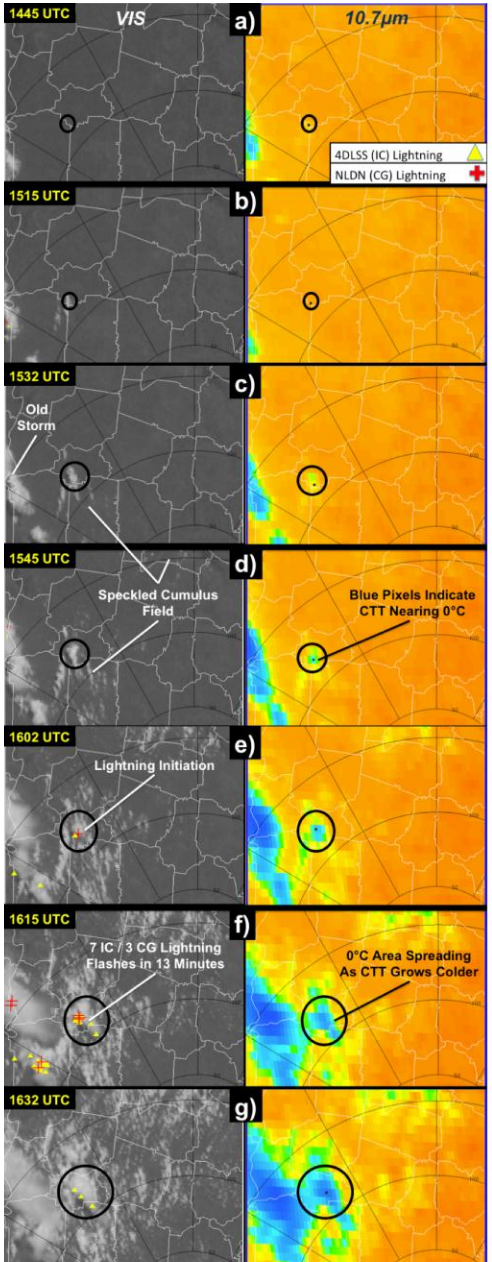
$$\alpha_{3.9} = \frac{R_{3.9} - R_{e_{3.9}}(T)}{S - R_{e_{3.9}}(T)}.$$

$$R = fk1 / [\exp(fk2 / (bc1 + (bc2 * temp))) - 1]$$

- $R_{3.9}$ calculated using 3.9 brightness temperature and constants
- $R_{e3.9}(T)$ calculated using 3.9 constants and 10.7 brightness temperature
- S calculated using 3.9 constants, sun temperature (5800 K), average radius of sun (A) and Earth's orbit (B), and solar zenith angle



# Satellite LI Indicators: Methodology

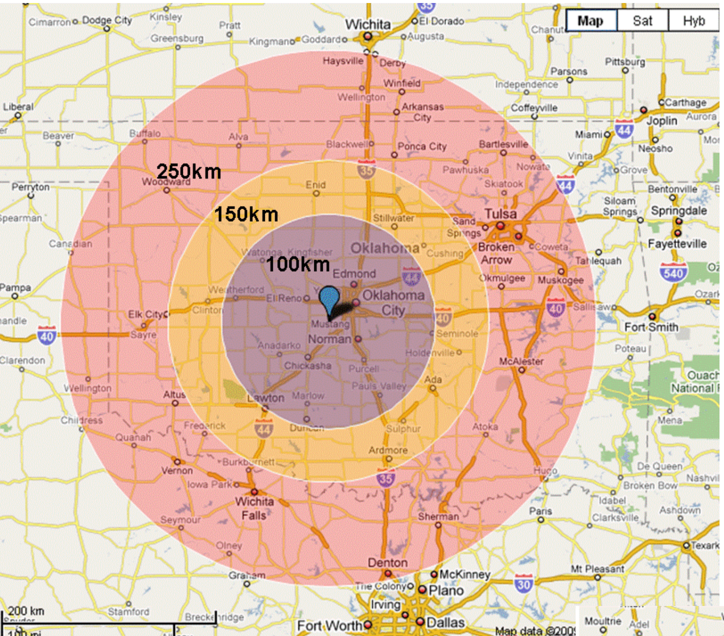



1. **Identify and track growing cumulus clouds from their first signs in visible data, until first lightning.**
2. **Analyze "total lightning" in Lightning Mapping Array networks, not only cloud-to-ground lightning, to identify for LI.**
3. **Monitor 10 GOES reflectance and IR indicators as clouds grow,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

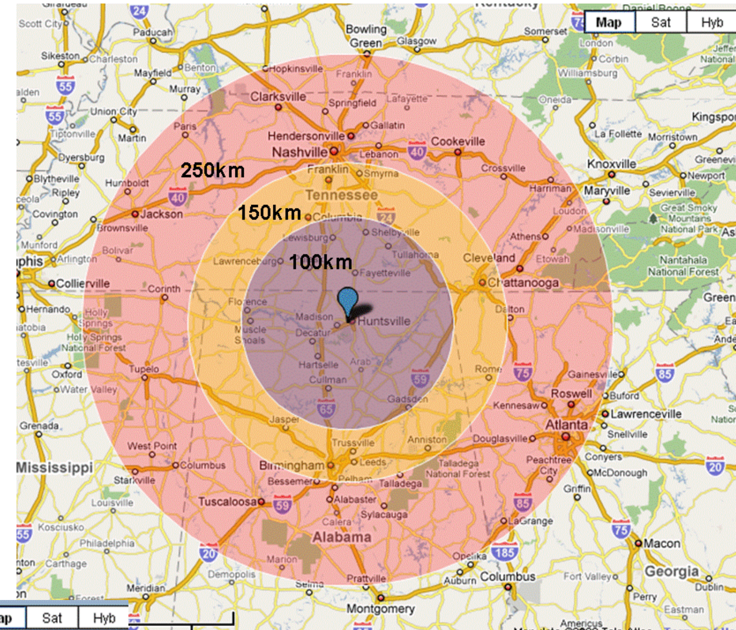
**Harris, R. J., J. R. Mecikalski, W. M. MacKenzie, Jr., P. A. Durkee, and K. E. Nielsen, 2010: Definition of GOES infrared fields of interest associated with lightning initiation. *J. Appl. Meteor. Climate*. Early-Online-Release.**

**Harris, R. J., P. A. Durkee, and K. E. Nielsen, J. R. Mecikalski, W. M. MacKenzie, Jr., 2011: Evaluating geographical variations in GOES lightning initiation interest fields. *J. Appl. Meteor. Climate*. In preparation.**

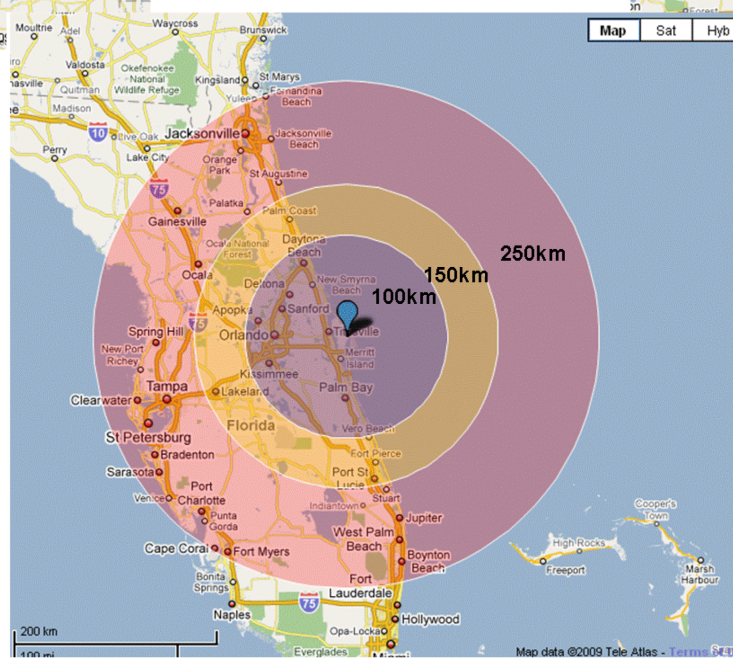
# Study Regions: Lightning Mapping Arrays




- **North Alabama (Huntsville)**
  - **Total-cloud lightning**
  - **Developed by New Mexico Tech**




- **Oklahoma City, OK**
  - **Total-cloud lightning**
  - **Developed by New Mexico Tech**




- **Cape Canaveral AFS, FL**
  - **Total-cloud lightning (LDAR-II)**
  - **Cloud-to-Ground lightning (CGLSS)**
  - **Developed by Vaisala**

- **DC LMA Also…**

# 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 -15 ° 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 |

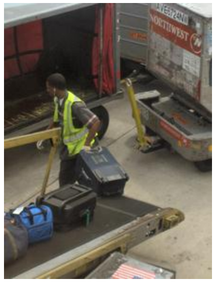
1 Represents two unique 10.7 μm $T_B$ interest fields in MB06. No 30-min trends were used in Siewert (2008) or in this study.

2 Added to MB06 fields by Siewert (2008).

3 Unique to this study.

# Lightning Hazard to Aviation

- Cloud-to-ground lightning represents a serious safety threat for terminal operations
  - Baggage Handlers
  - Aircraft Refuelers
  - Tug and Guidance workers
  - Food Caterers
  - Emergency Personnel





- Safety protocol requires that ramp operations be modified or discontinued when lightning is in the vicinity

- Limiting or halting ramp operations can lead to a disruption in aircraft ground operations

- Extended disruptions to ramp operations can lead to a disruption in airborne traffic

# Satellite Indicators of Lightning –Interest Fields

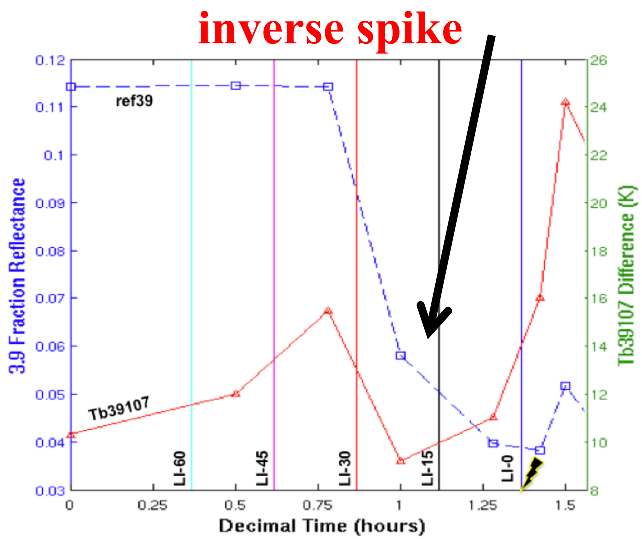
**Focus on 4 Lightning Initiation interest field to start…**

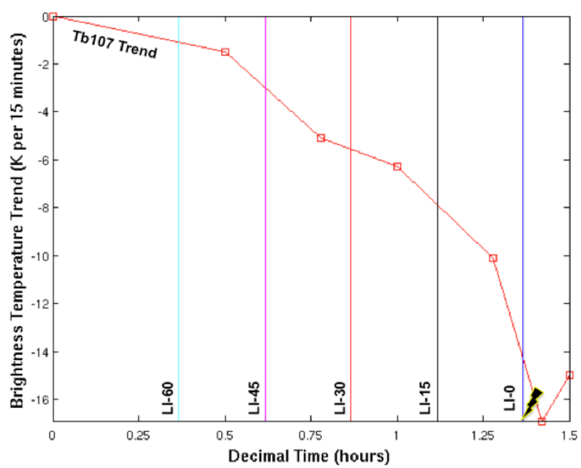
**(1) 3.9 µm reflectance: Monitor clouds where the cloud-top reflectance consistently falls from >10% to near or below 5%. The rate found is ~2-4%/15-min.**

**(2) For clouds with 10.7 µm $T_B$< 0° 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.**

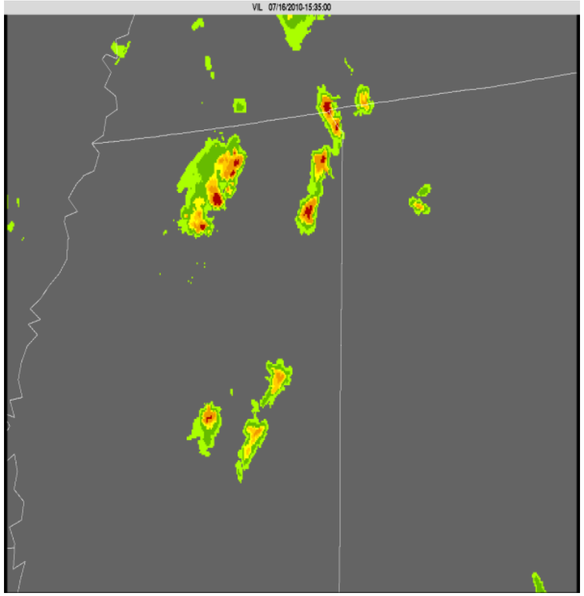
**(4) The 15-min trend in 6.5−10.7 µm difference of >5° C. This is a good indicator of a strong updraft.**



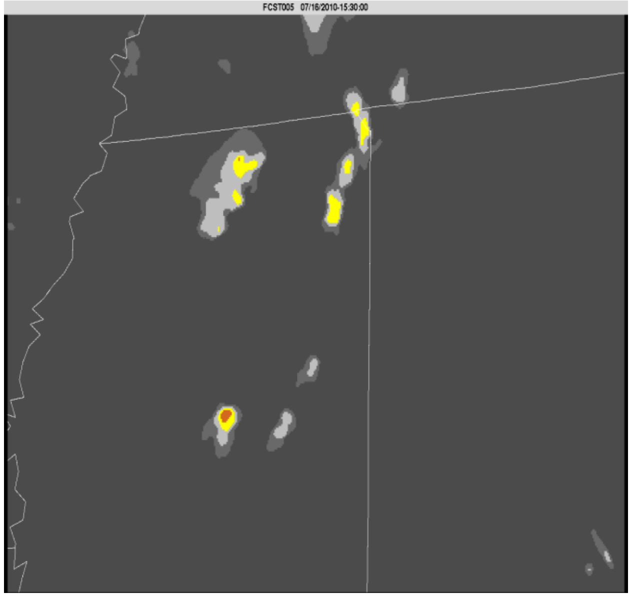



# Example of Convective Initiation 1 Hour Forecast

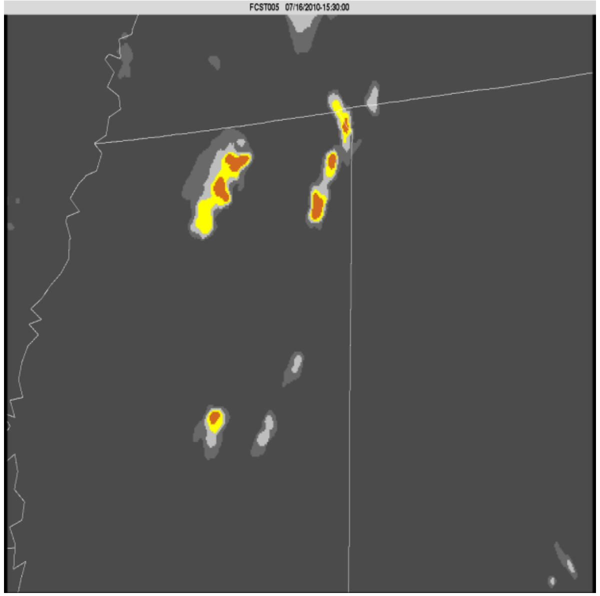
**Truth**




**Forecast with SATCAST CI**



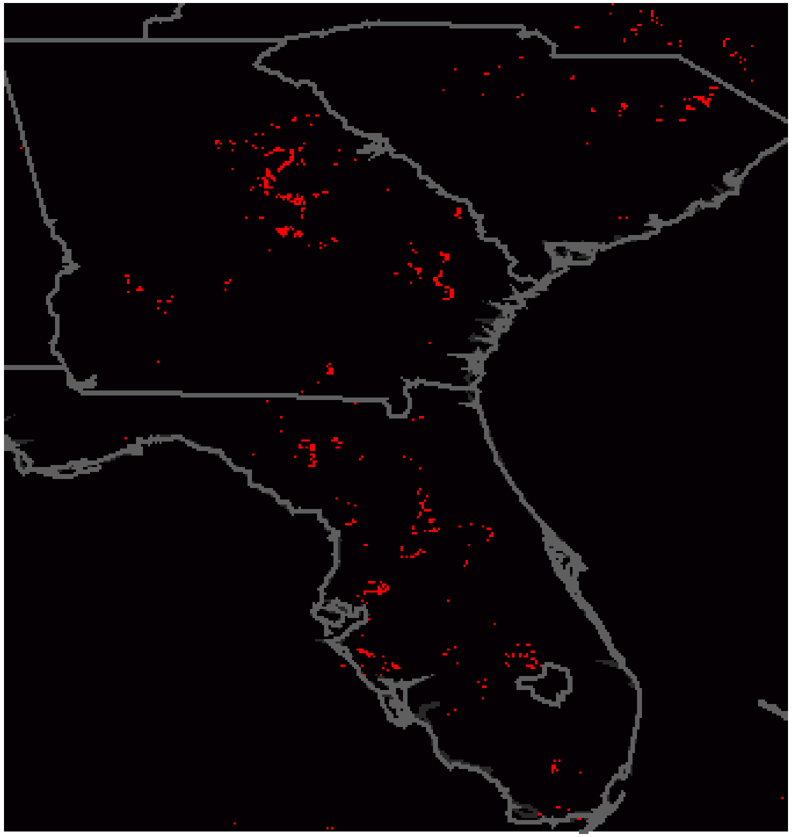

**Forecast without SATCAST CI**




**16 July 2010**

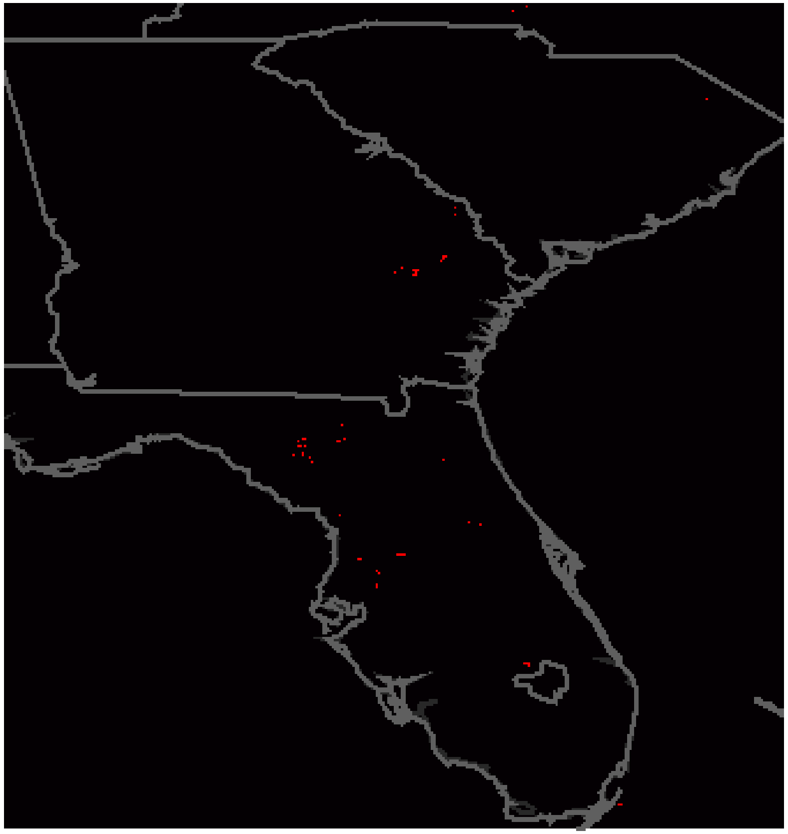
# Lightning Initiation 30-60 min Nowcasts

**CI Nowcasts**



**2045 UTC 17 June 2009**

**LI Nowcasts (or regions where lightning flash rates will be high)**

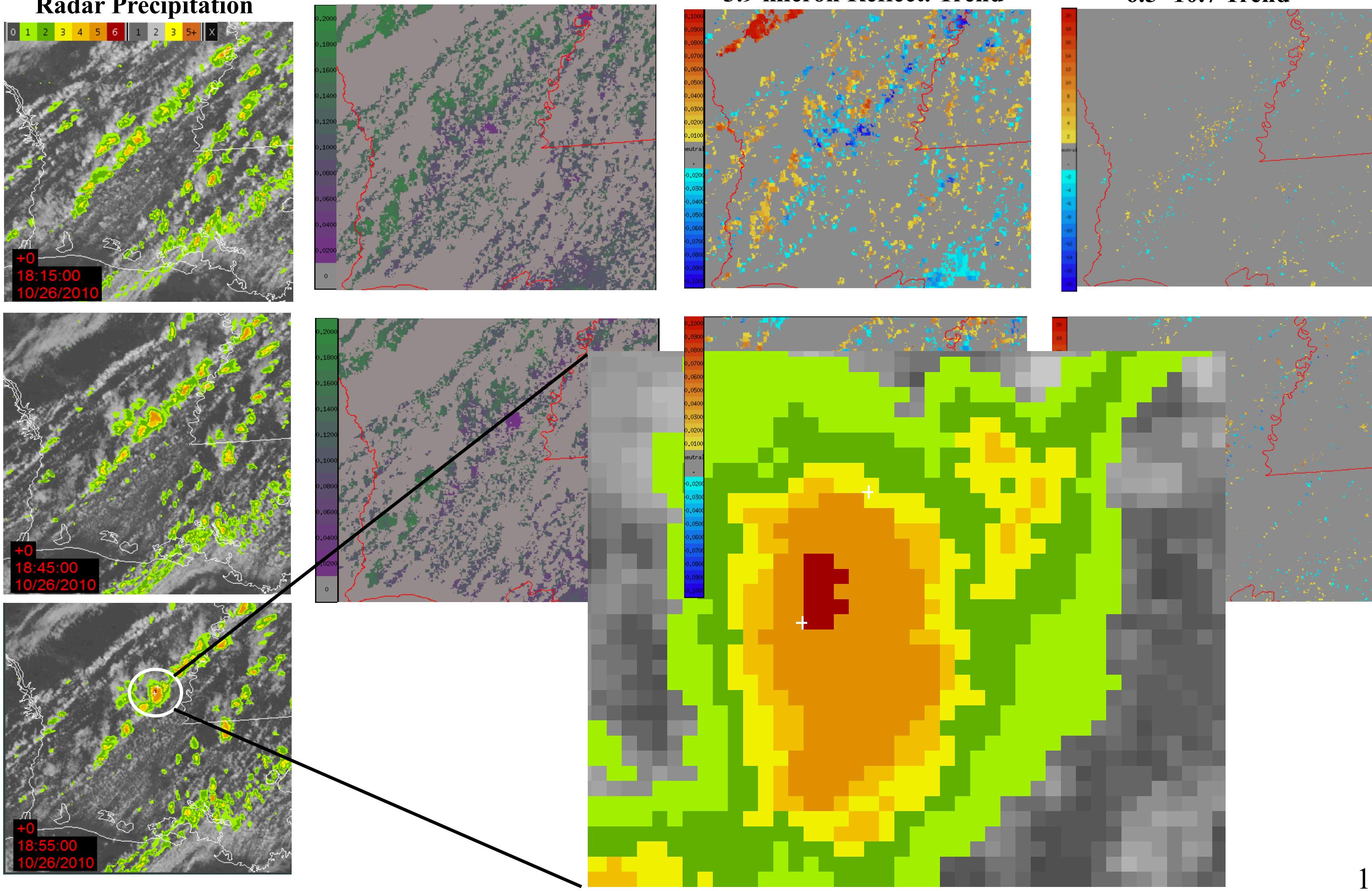


# Satellite LI Indicators

## Example

**26 Oct. 2010**

**Visible Satellite & Radar Precipitation** | **3.9 micron Reflect.** | **3.9 micron Reflect. Trend** | **6.5−10.7 Trend**

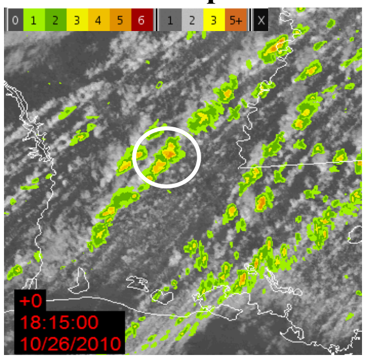


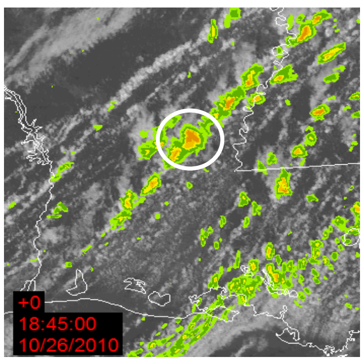
# Satellite LI Indicators

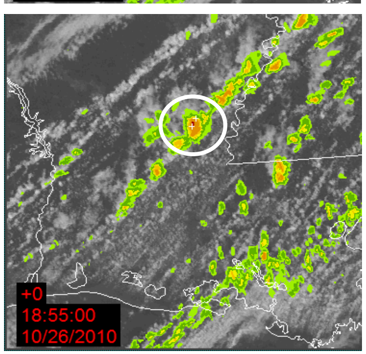
## Example

**26 Oct. 2010**

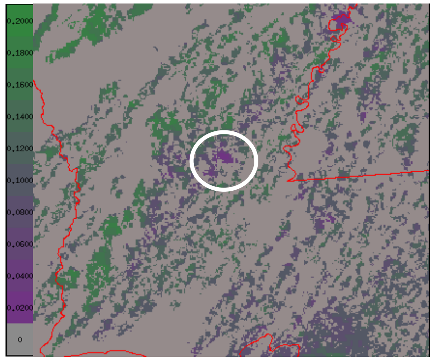
**Visible Satellite & Radar Precipitation**

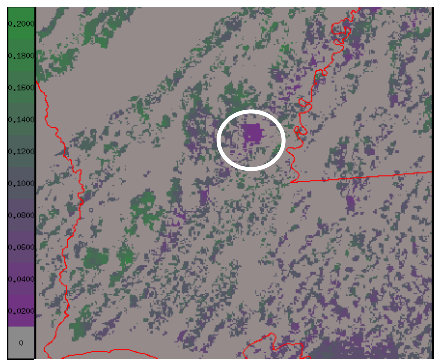


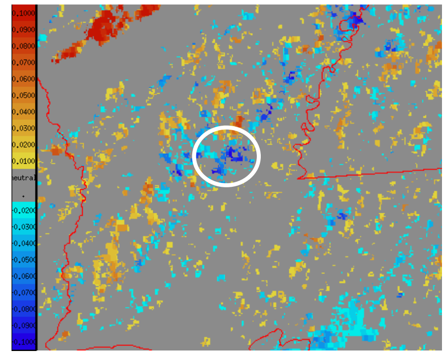



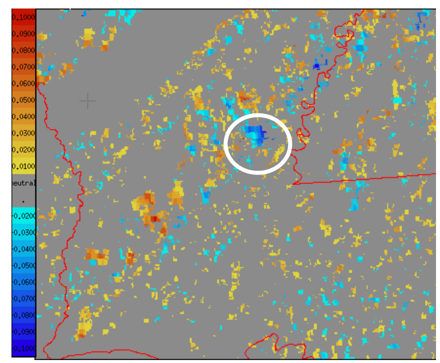

**3.9 micron Reflect.**



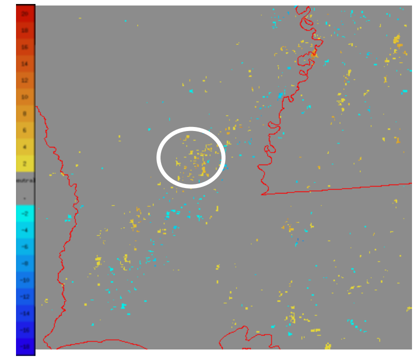


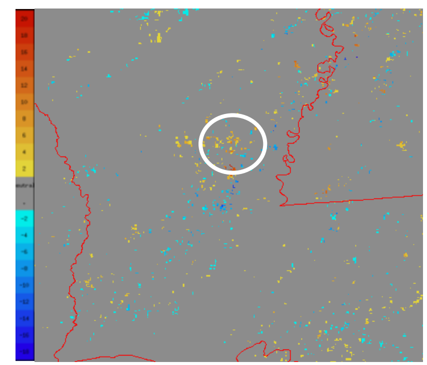
**3.9 micron Reflect. Trend**





**6.5−10.7 Trend**





**Construct a "detector" based upon the satellite LI indicators.**

**First results within past ~1 month… more in 2011.**

# What of these factors to consider towards diagnosing “Thunderstorm Intensity”?

- **Proxy GOES-R data will be supplied to this effort from MSG SEVIRI (8 IR and 1 HRV channel) and TRMM Lightning Imaging Sensor (LIS) Global Total Lightning Flashes product.**

- **Utilize established methods that determine the general vigor and strength of active moist convection will be used. These include:**
  - **Convective cloud identification algorithms (for GOES-R and research)**
  - **SEVIRI “object tracking” methods**
  - **Monitoring satellite temporal trends of the spectral channels.**
  - **SEVIRI IR and Visible data “interest field” research attributes**
  - **TRMM LIS data**
  - **Anvil expansion rates (see Shröder et al., 2009)**

# 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:

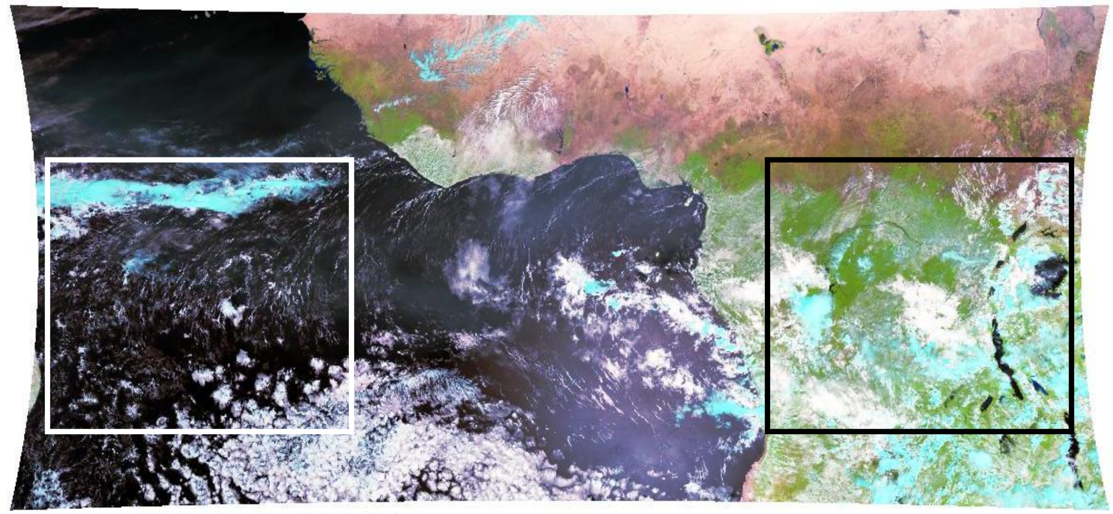
**Cecil et al. (2005), Nesbitt and Zipser (2003), Nesbitt et al. (2000)**

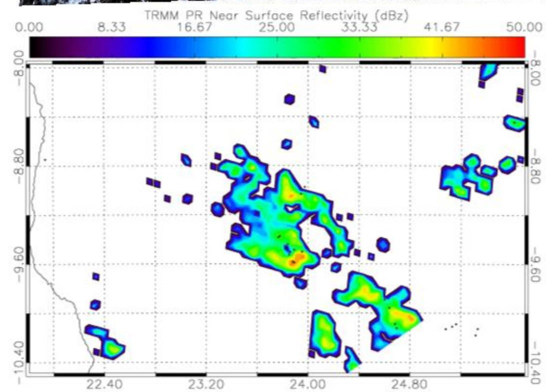
| | Flash rate (fl $min^{-1}$) |
|---|---|
| CAT-0 | 0-0 |
| CAT-1 | 0.7-2.2 |
| CAT-2 | 2.2-30.9 |
| CAT-3 | 30.9-122 |
| CAT-4 | 122-296 |
| CAT-5 | >296 |

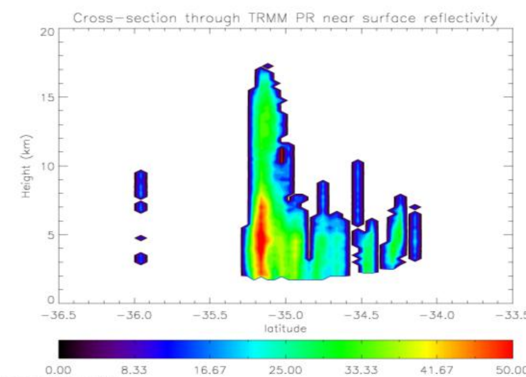
# Diagnosing storm intensity using coupled TRMM Lightning Imaging Sensor and MSG in preparation for GOES-R

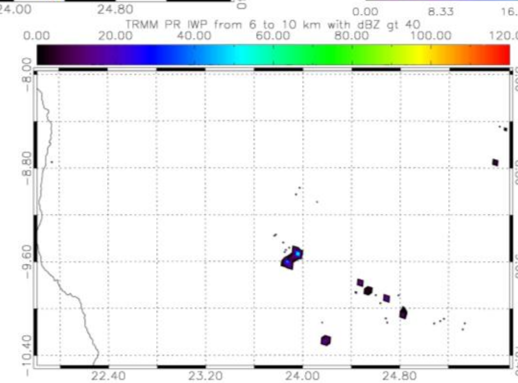
## Methodology

- Convective events are chosen from the precipitation feature database for the months of January and August 2007 over tropical Africa and eastern tropical Atlantic
- 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 precipitation 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). Black dots represent lightning flash location in figures to the right.
- MSG data will be collected for each IWP sample time along with an hour of data before and after, allowing for temporal trends of convective interest fields.





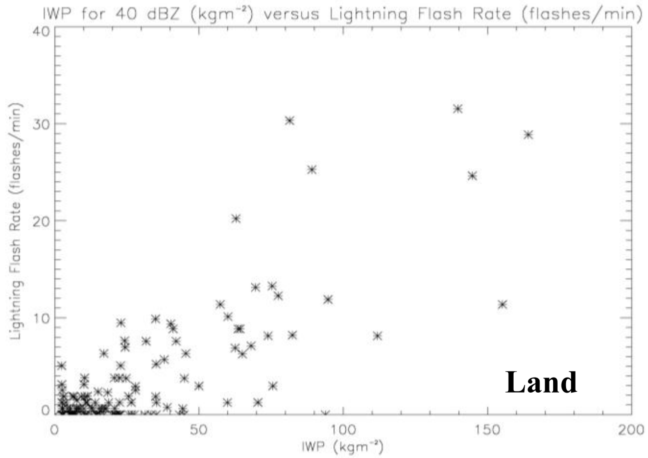



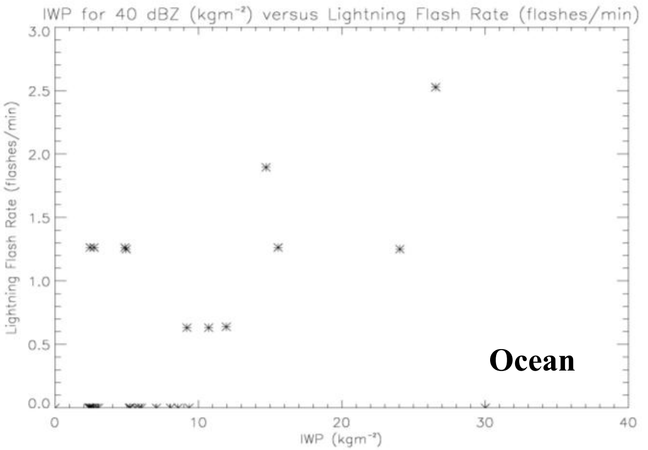



# Diagnosing storm intensity using coupled TRMM Lightning Imaging Sensor and MSG in preparation for GOES-R

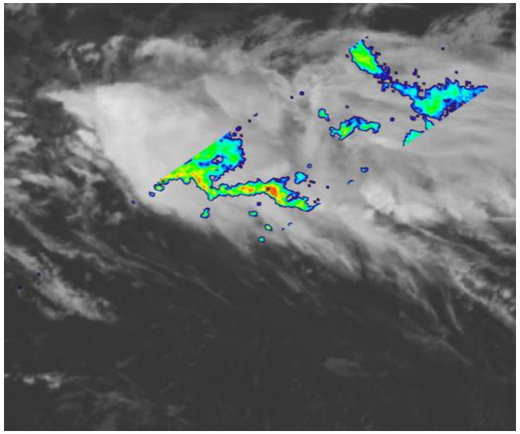
Preliminary Results

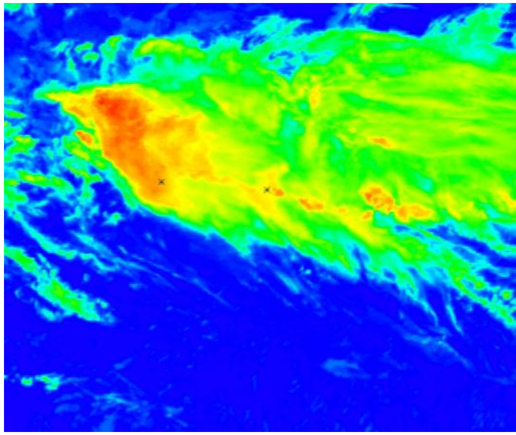
- January and August 2007, maximum IWP observed was approximately 160 $gm^{-2}$.
- Initial results from January 2007 show that there is a correlation between the IWP and lightning flash rate for both ocean and land cases, with a correlation coefficient of ~0.8.




The first analysis involves correlating the 10.8 μm brightness temperatures with the TRMM IWP samples. Below is TRMM near surface reflectivity overlaid on MSG imagery (stars represent where the IWP sample is located). It should be noted that there could be up to an 7-8 minute difference between TRMM and MSG scan times, which may result in some temporal differences.





## Future Work

- Develop intensity bins from IWP data.
- Correlate IWP samples to MSG interest fields, including 10.8 μm brightness temperatures, 6.5-10.8 μm spectral difference, and other spectral differences.
- Examine temporal trends previous to TRMM overpasses.
- As the system evolves, from before to the current TRMM observation, obtain statistics on storm system behavior (size, expansion rates, and other IR-observable phenomena).

# A dual-polarimetric, MSG, and total lightning view of convection

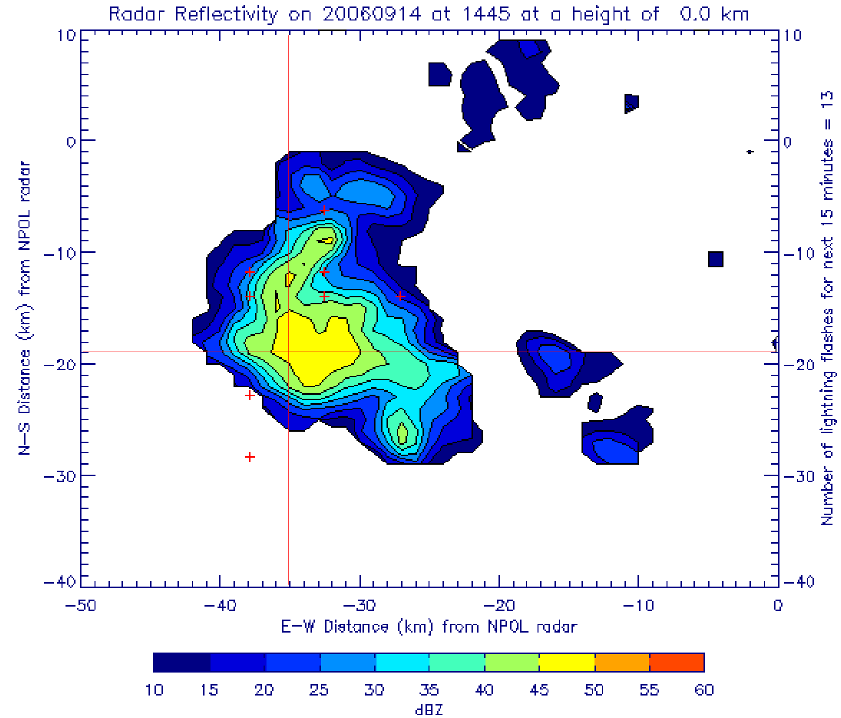
- NSF funded. Masters student, Retha Matthee
- In collaboration with Larry Carey, Bill McCaul, Walt Petersen
- Goal: To determine relationships between infrared (cloud-top) estimates of physical processes (updraft strength, glaciation and phase, and microphysical parameters, e.g., effective radius), 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, ~3-5 of each.
- Will evaluate NEXRAD precipitation patterns with respect to known LI events over the North Alabama LMA

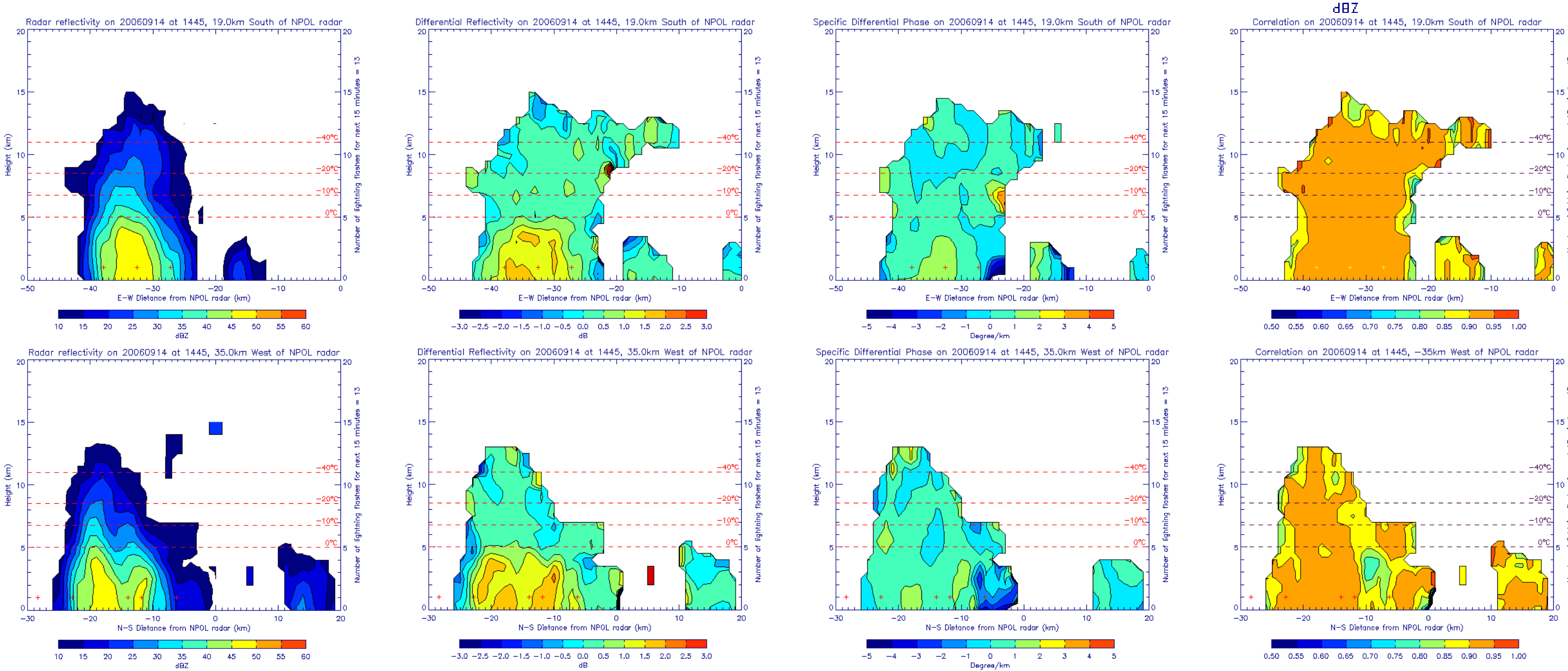
**Results are preliminary at this time:**

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. Found relatively known relationships between hydrometeor fields, lightning onset, for both lightning and non-lightning events

# Lightning-Producing (14:45 UTC)

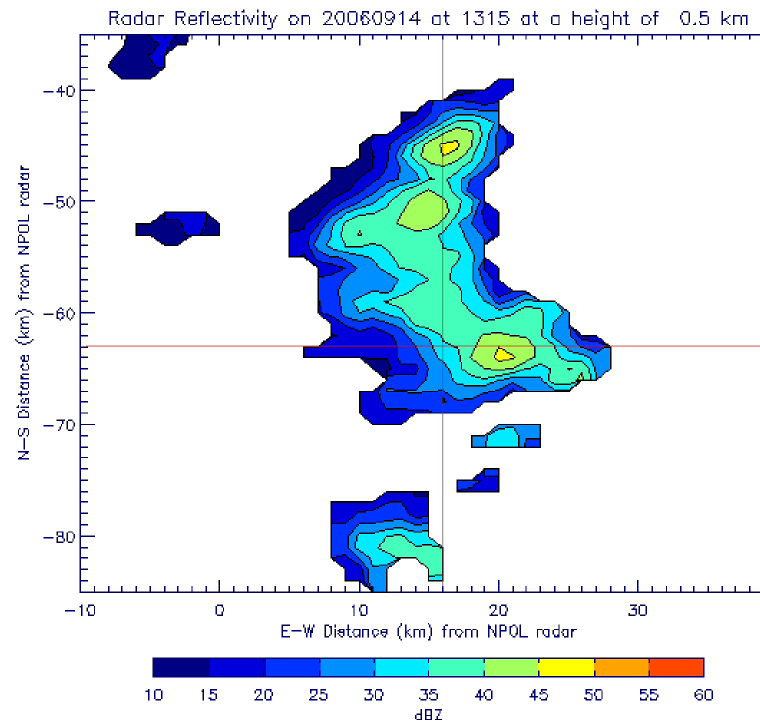
Horizontal cross at 19 km South (top row) and Vertical cross at 35 km West (bottom row) of radar

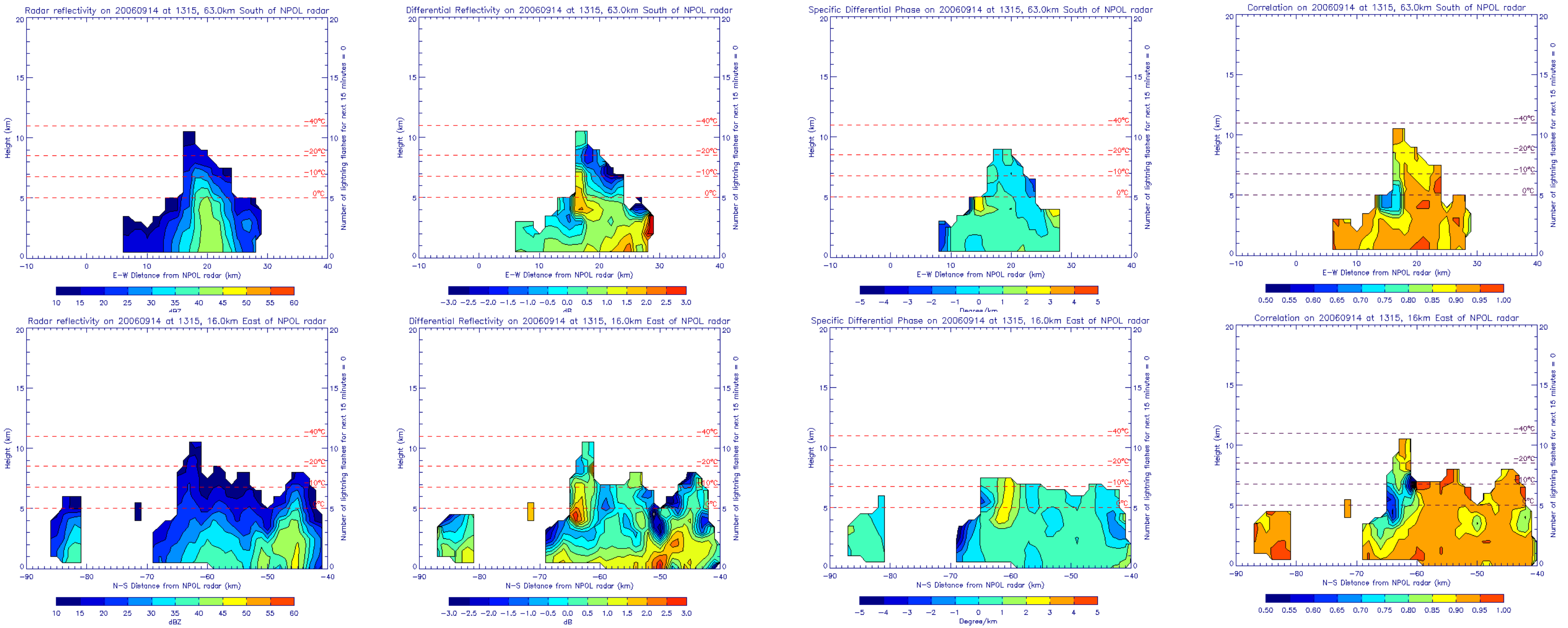


# Non-Lightning (13:15 UTC)

Horizontal cross at 63 km South (top row) and Vertical cross at 16 km East (bottom row) of radar



# 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. Evolve storm intensity research to include infrared fields, and estimated aspects of rapid storm growth, from MSG.

3. Continue research on NSF project…