Ongoing developments in nowcasting lightning initiation using GOES satellite infrared convective cloud information

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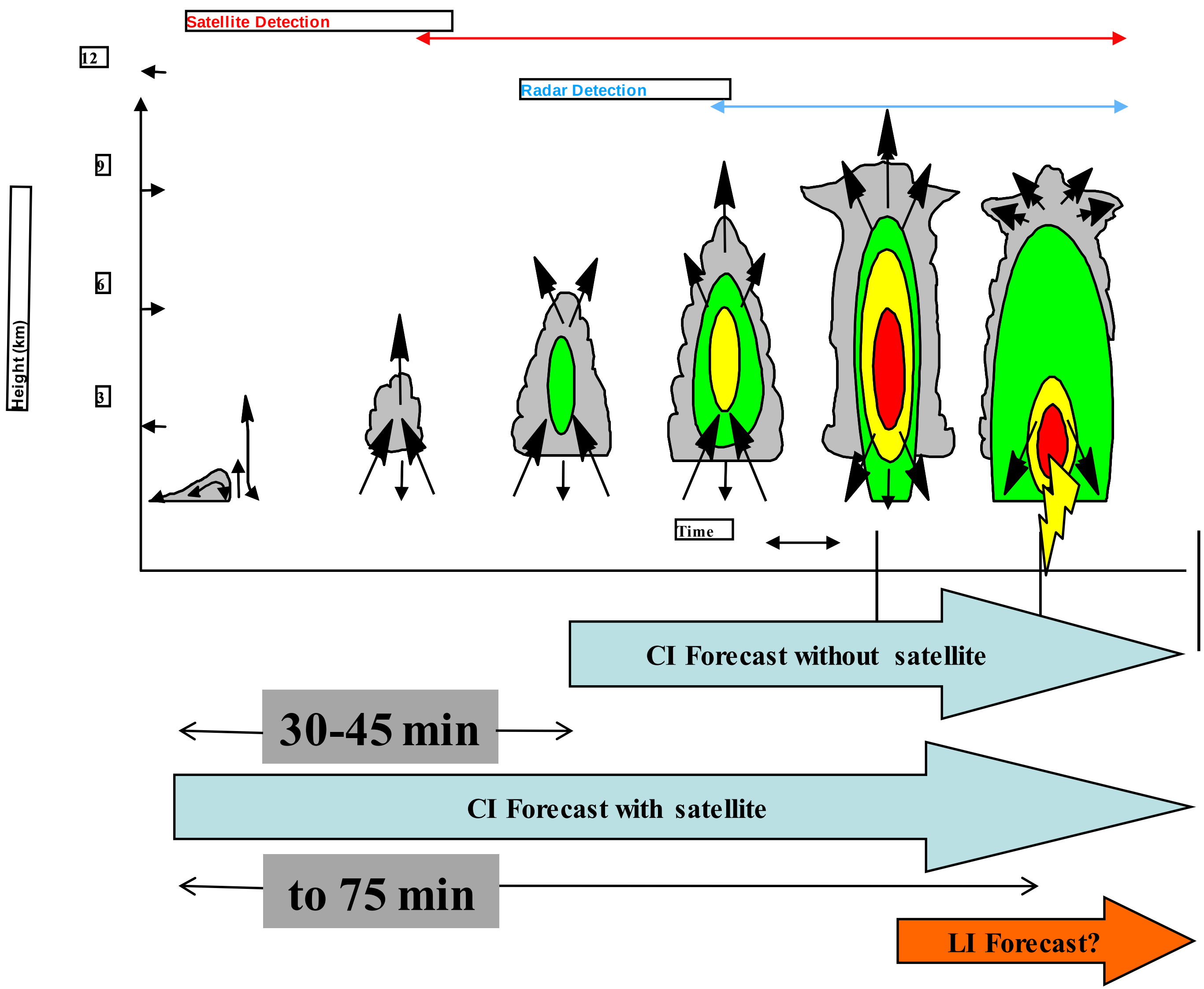
Motivation

- Lightning causes ~62 deaths / yr [1]
- Lightning causes $1B damage /yr[2]
- Convection-induced turbulence [3]
- Commercial Flight Impacts[4]
  - $150K per diverted flight
  - $40K per cancellation
  - Impacts on ground operations
- Cape Canaveral Air Force Station/Kennedy Space Center impacts [5]
  - Greatest lightning density in CONUS
  - 1/3 of launches delayed
  - 5% cancelled due to lightning

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)

- What is Lightning Initiation (LI)?
  - Defined as the <u>first lightning flash of any type</u> within a growing cumulus cloud
- Why use satellite data?
  - Satellites provide a constant, relatively high temporal resolution observational system for convection
  - A novel approach…
- Possible Impacts:
  - Improve severe weather nowcasting
    - Convective precipitation/flooding
    - Tornado development
    - Hail and severe wind
  - Forest fire prediction
  - Aviation and public safety

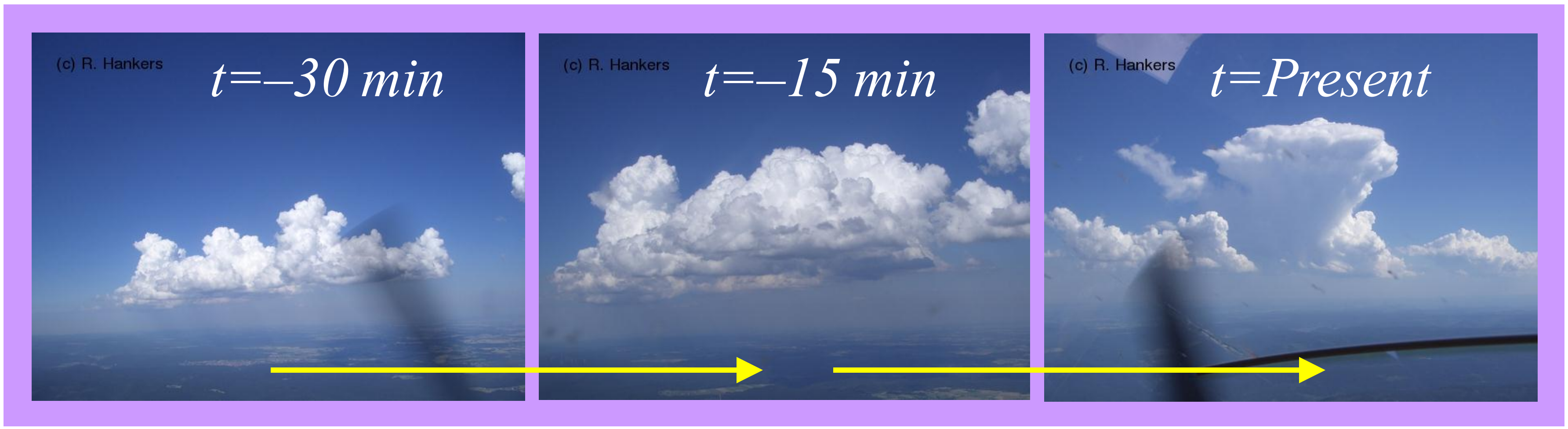
- Guiding Questions:
  - Are there any satellite signatures unique to LI within a convective storm?
  - What do these signatures tell us physically?
  - How can remote sensing of convection further improve the understanding of physical processes within convective storms?

- Purpose of Project:
  - Develop and test a technique to detect LI from geostationary satellite data

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). See the published research.

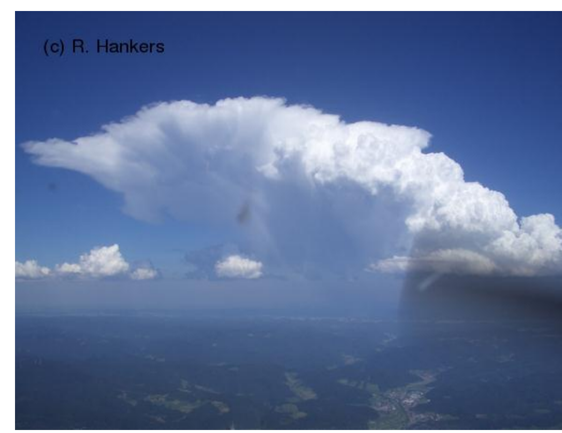


Monitor… 8 IR fields:

SATellite Convection AnalySis and Tracking (SATCAST) System

CI Time →

1st ≥35 dBZ echo at ground



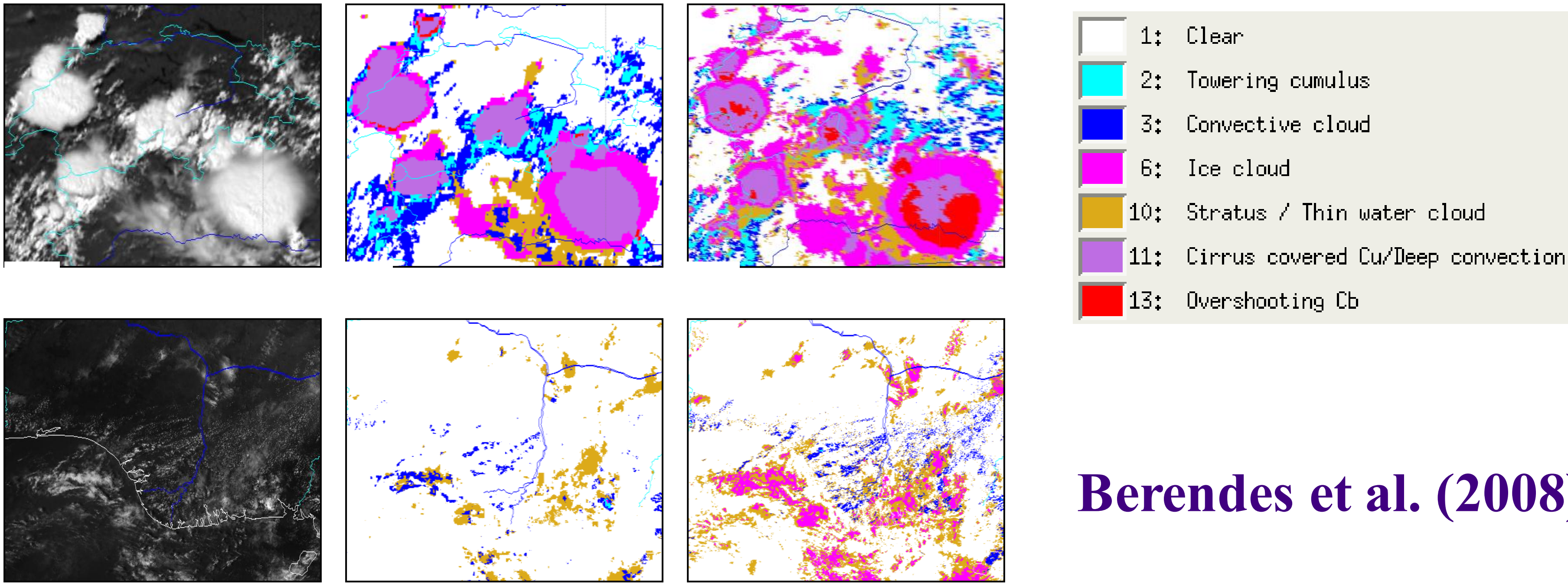
SATCAST Algorithm: *GOES IR Interest Fields*

CI Interest Field	Purpose and Resolution	MB06 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 ΔT_B/30 mins < ΔT_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

Note: There are additional IR & reflectance fields with MSG/ABI

Convective Cloud Mask

Visible Channel | MSG Convective Cloud Mask | MODIS Convective Cloud Mask



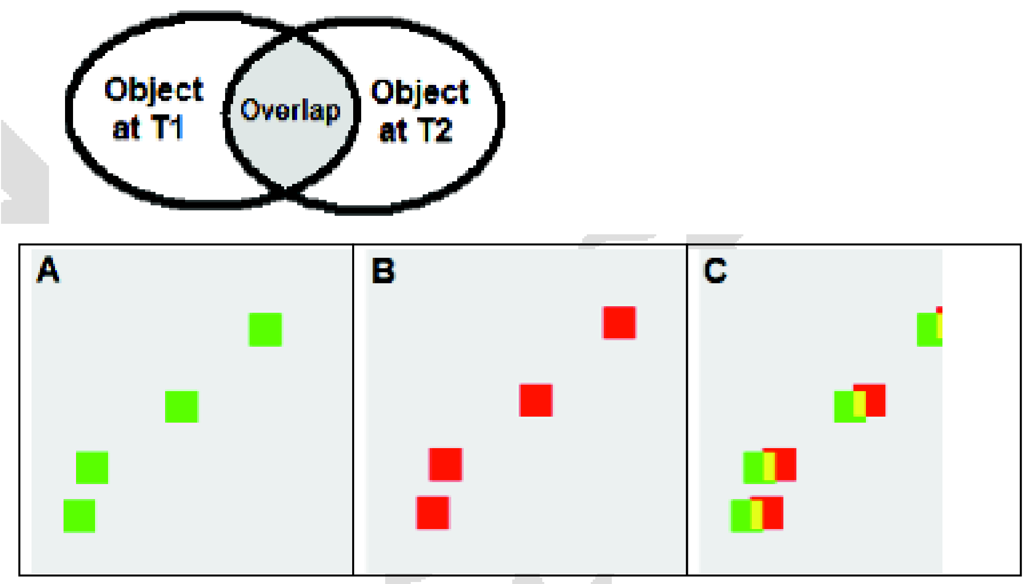
Berendes et al. (2008)

- Foundation of the CI nowcast algorithm: Calculate IR fields only where cumulus are present (10-30% of a domain)
- Utilizes a multispectral and textural region clustering technique for classifying all scene types (land, water, stratus/fog, cumulus, cirrus) in a GOES image
- Berendes et al. (2008) statistical clustering algorithm, for GOES & MSG

Object Tracking

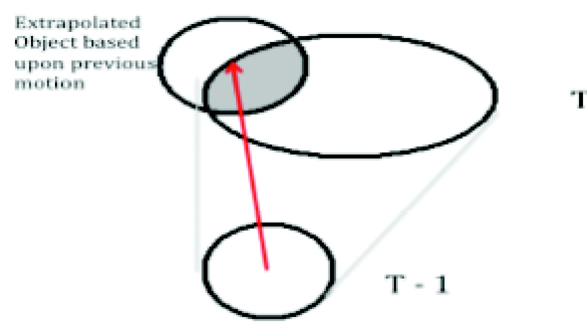
• The goal of object tracking is towards improving the tracking of growing cumulu clouds, and to better assess the degree that satellite nowcasts CI (i.e. validation).

• An "object" can be defined as a "cumulus" in a masking procedure.



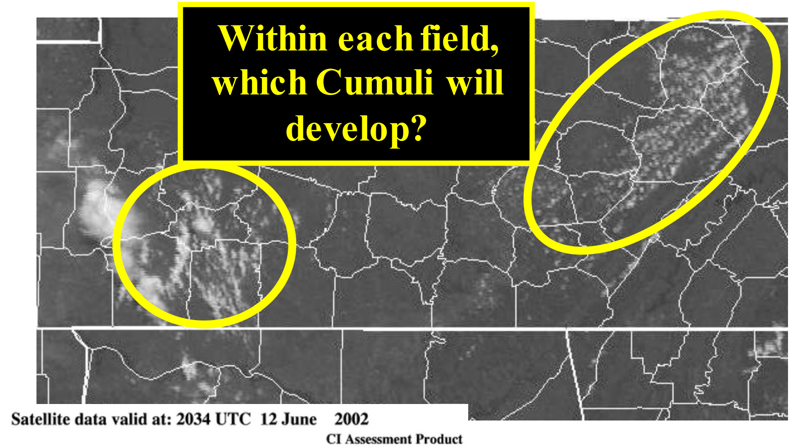
Object at Time 1 (A), Time 2 (B), and the "overlap" (yellow) between times.

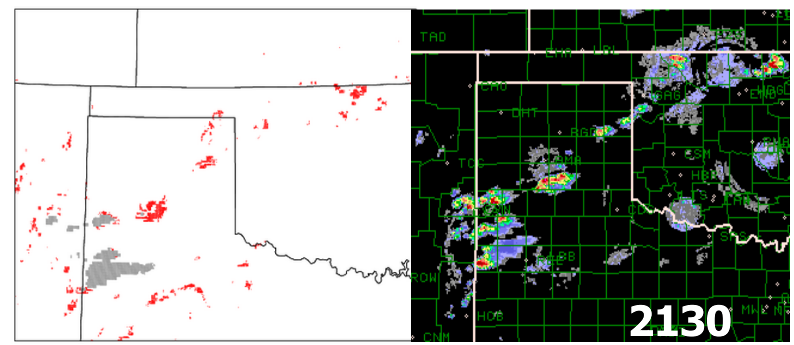
Zinner et al. (2008)

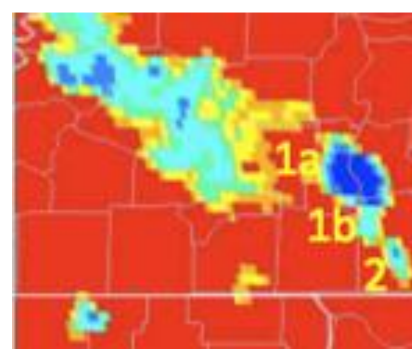


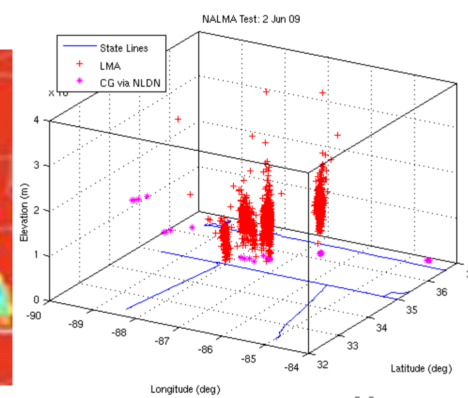
Introduction: Use of Satellite

- All cumuli are *not* created equal
- Evolution of LI Forecasting
  - Qualitative "eye-ball" analysis (Pre-historic)
  - Correlate IR cloud-top properties with radar signatures for CI forecasts (last 5-10 years)
  - Correlate IR cloud-top properties with lightning occurrence for LI forecasts (current)
  - Constrain LI forecast using NWP instability fields (current)



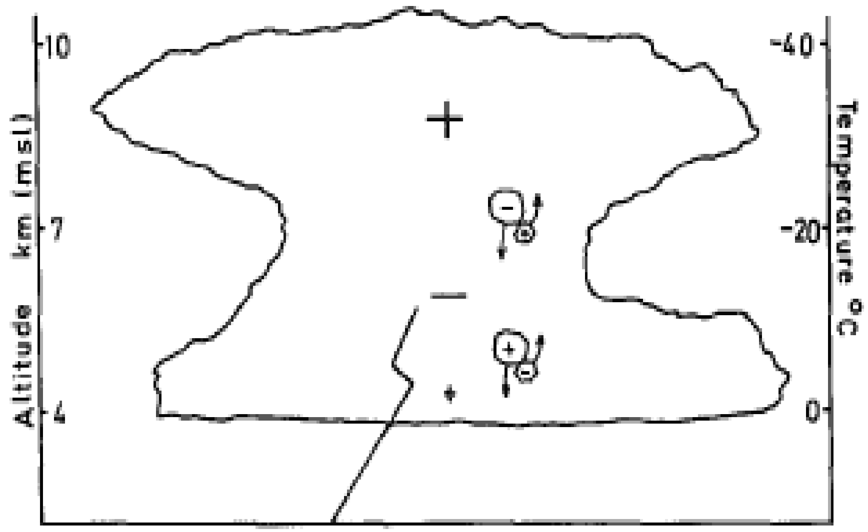






LI Theory

- Storm Electrification
  - Through graupel/ice interactions in the presence of supercooled water (non-inductive charge transfer, Reynolds 1957)
    - Particle collisions transfer charge
    - Temperature difference between particles and liquid water content determines charge transferred
    - Particles fall through or are carried upward in updraft and separate charge
  - Conditions to be observed from satellite:
    - Strong updraft
    - Ice particles
  - NWP model information:
    - CAPE
    - Ice/grauple flux through -10 to -15 C layer



Saunders (1993)

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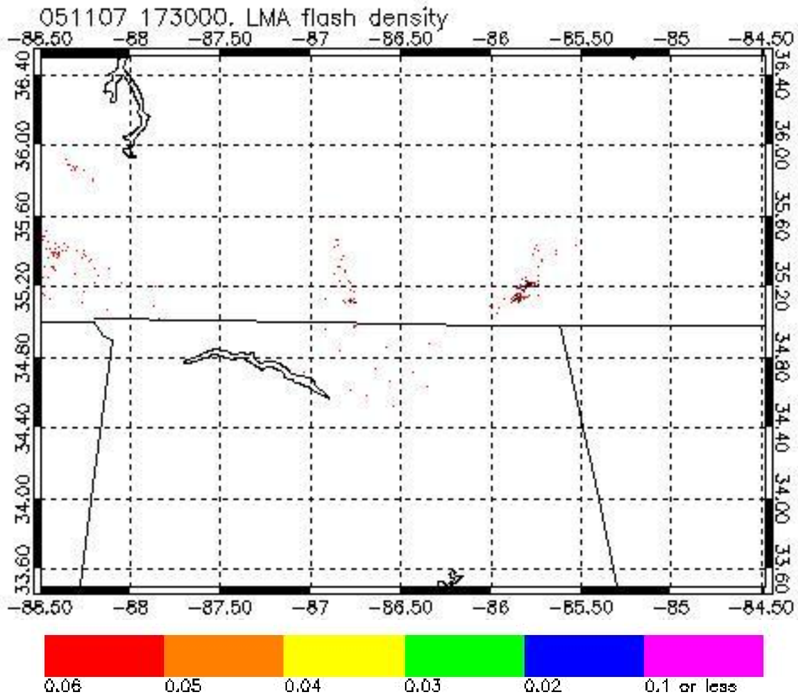
Daytime Cloud Microphysics: 3.9 μm

- Separate 3.9 reflection and emission
  - 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): Undefined > 90°
  - Expect 3.9 reflectance values ~ 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



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Cloud-Top Microphysics

- 3.9 μm fraction reflectance
  - Ice is a very efficient absorber of radiation at wavelengths of 3.5 to 4.0 μm
    - Low reflectance values (< 12%; Setvak and Doswell 1991)
  - Need to separate emission and reflection components from the observed radiance
    - Use method developed by Setvak and Doswell (1991) and Lindsey et al. (2006)
    - Most accurate for solar zenith angles up to 68^o (morning to evening)
      - Undefined > 90^o

3.9 – 10.7 μm Channel Difference

- Commonly used for nighttime fog detection (Ellrod 1995) and nighttime cloud microphysics (Key and Intrieri 2000)

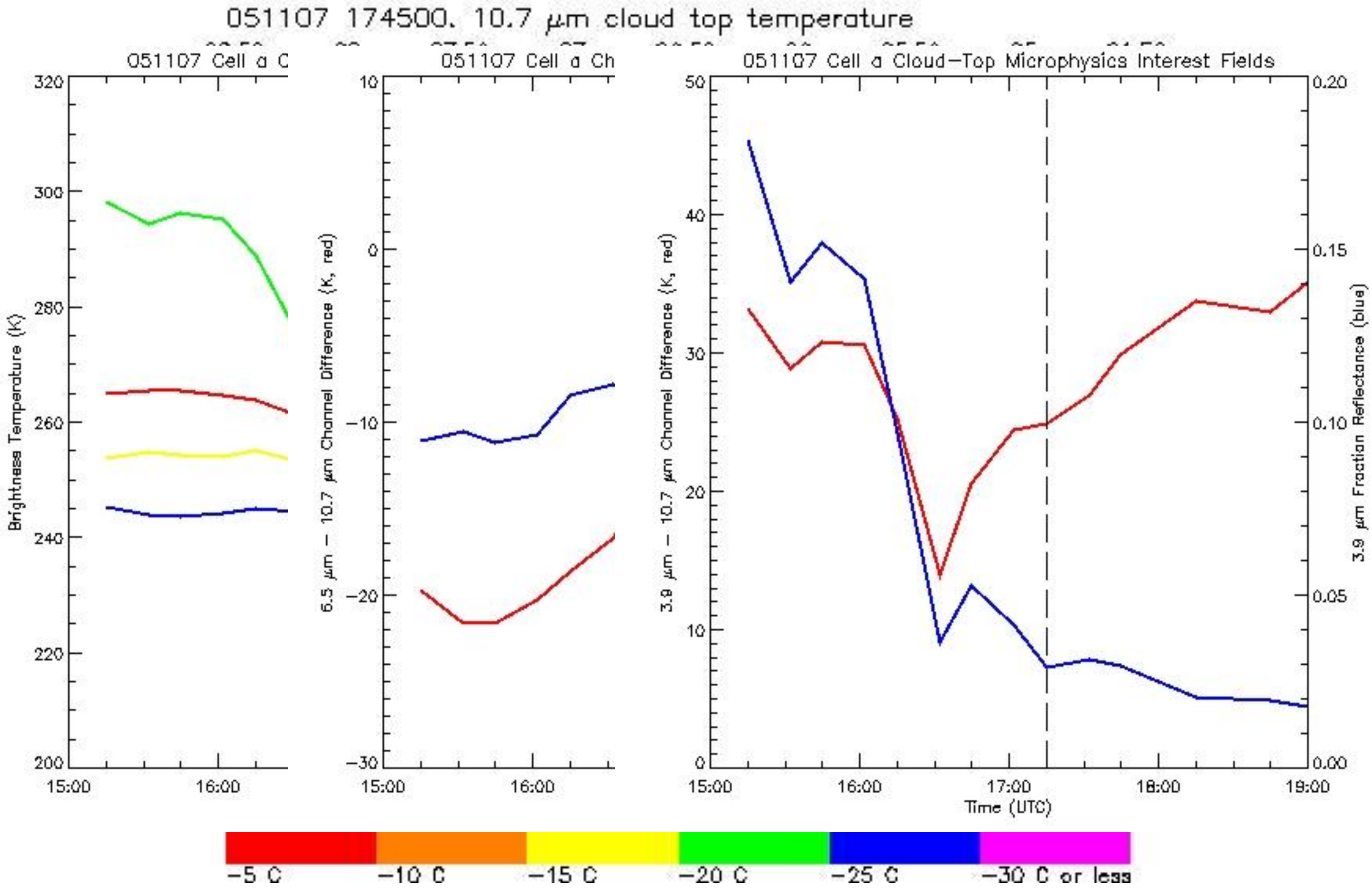
- Threshold value during daytime difficult to use
  - Rapid changes in 3.9 μm T_B from emitted and reflected sources

- Examine the temporal trend for signals of cloud-top phase change
  - Combining the two channels may information on the microphysical phase as well as the updraft strength in one field
  - Provides additional information than just the reflectance alone
    - First occurrence of rapid glaciation detected without meeting a certain ice “yes” or “no” reflectance threshold

Development of LI Interest Fields

- **Co-location of satellite and LMA data**
  - Satellite data re-sampled to 1 km^2 grid
  - LMA has slightly smaller grid (~ 0.9 km^2)
    - Match the satellite data to an LMA pixel using nearest neighbor technique with latitude and longitude values

- **Time-series plot analysis**
  - Examine multiple cells from various case days
  - Allows for visual representation of interest fields with time in comparison to first flash within the cell
  - Isolate cell by drawing box around its movement area prior to and after the first flash.
    - Follow coldest pixel(s) in this box (assumed updraft region)
    - Average the brightness temperature values of these coldest pixels for all channels and perform channel differences
  - Plot values 2 hours prior and 1 hour after the first flash within the cell
  - Compare to expected results and define appropriate initial threshold values for LI interest fields



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Lightning Initiation Interest Fields

LI Interest Field	Threshold Value
10.7 µm T_B	≤ 260 K
10.7 µm 15 minute trend	≤ –10 K
10.7 µm 30 minute trend	≤ –15 K
6.5 – 10.7 µm channel difference	≥ –17 K
6.5 – 10.7 µm 15 minute trend	≥ 5 K
13.3 – 10.7 µm channel difference	≥ –7 K
13.3 – 10.7 µm 15 minute trend	≥ 5 K
3.9 µm fraction reflectance	≤ 0.05
3.9 – 10.7 µm trend	$t - (t_{-1}) \leq -5$ K and $t - (t_{+1}) \leq -5$ K

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

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

In doing so, they highlight convective cores that loft large amounts of hydrometeers across the -10 to -15° C level, where the charging process tends to be significant.

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Findings

- It is possible to detect signals of LI 30 minutes prior to the first flash using satellite IR data alone
  - On occasion it was possible to detect signals 45-minutes to 1 hour prior
- Thirty minutes prior to the first flash within an area of interest, most of the LI interest fields met their threshold values
- The LI interest fields occurred very near and were spatially distributed similarly to the first lightning flashes
- The LI interest fields become contaminated when cirrus is overhead

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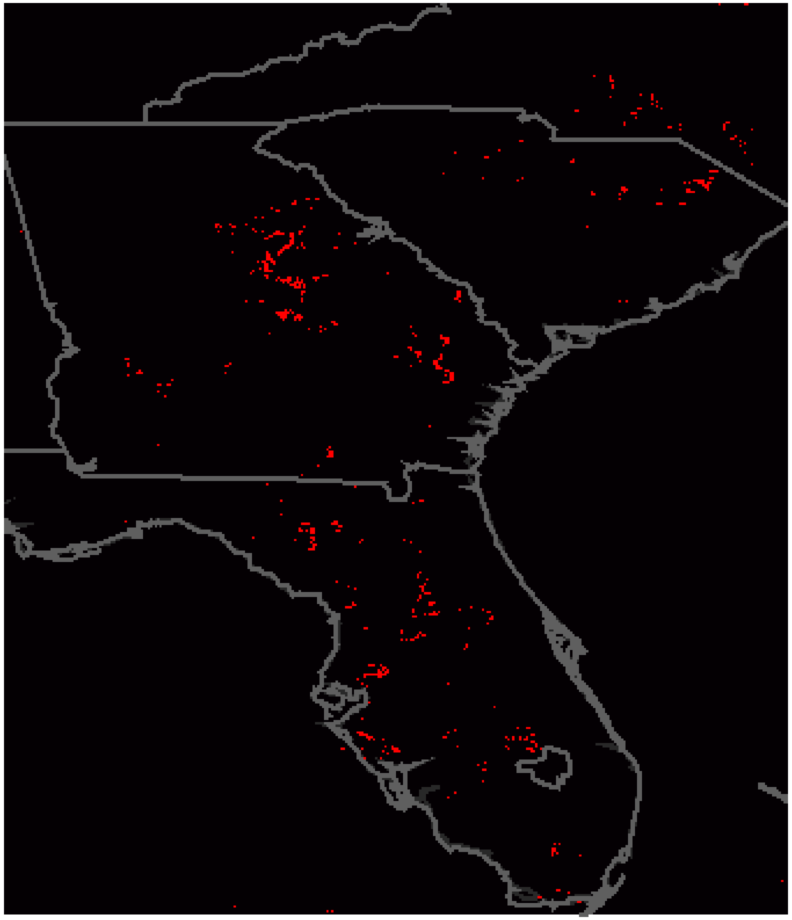
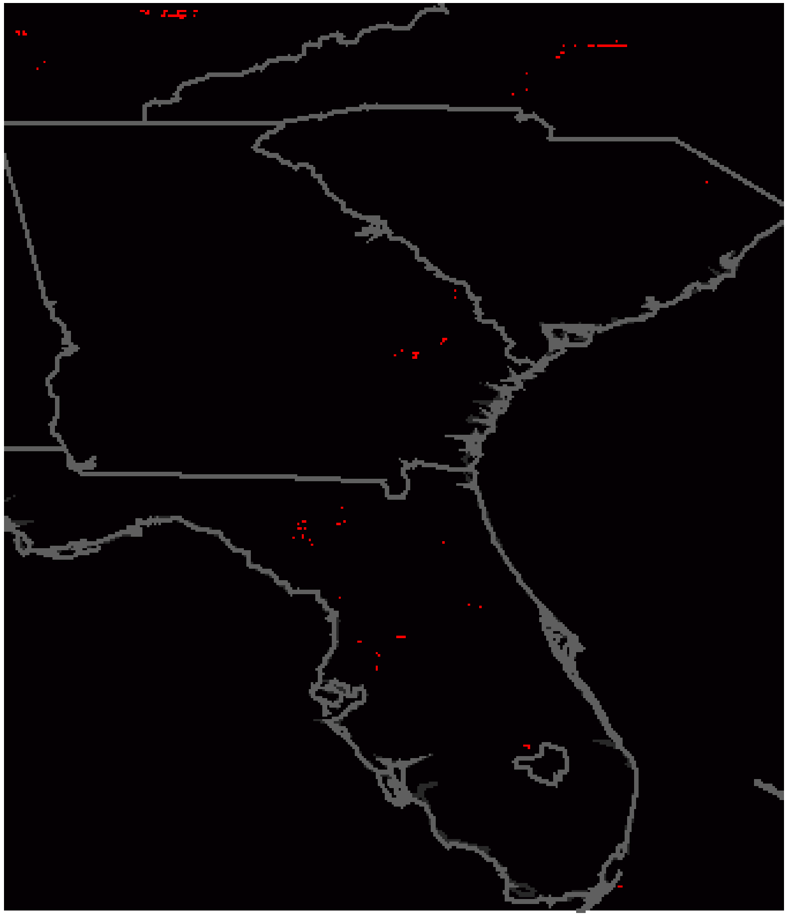
Lightning Initiation 30-60 min Nowcasts

CI Nowcasts



LI Nowcasts

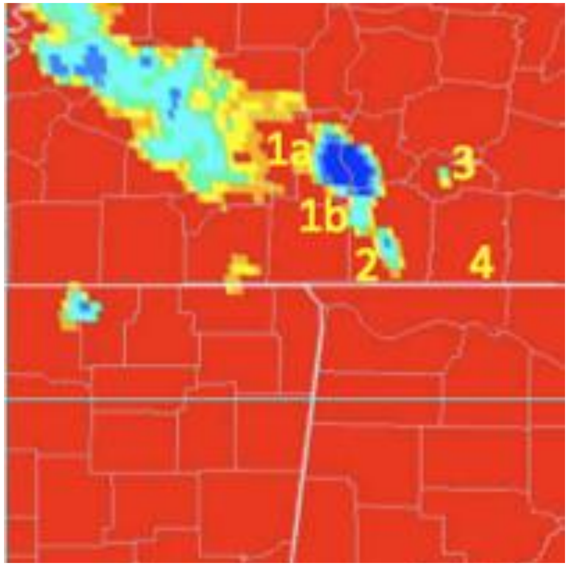


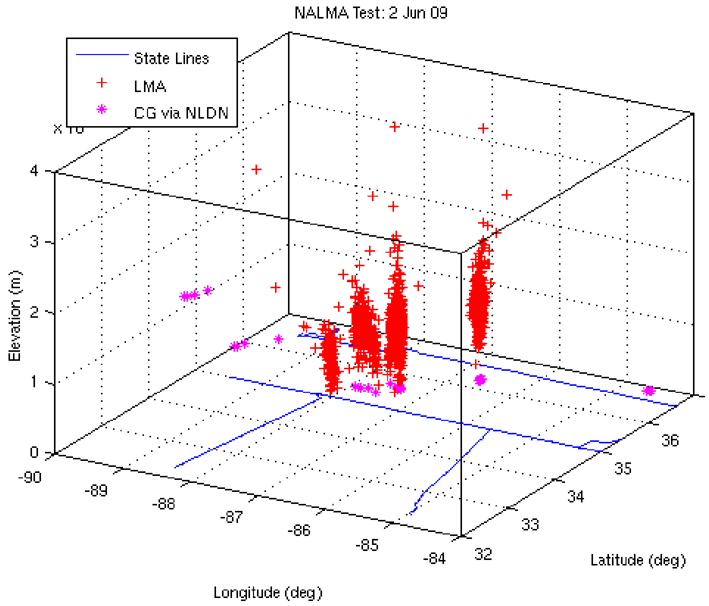
2045 UTC 17 June 2009

How well are we doing? Onto validation…

LMA Validation: Data

- SATCAST Algorithm
  - ~10 GOES-based Interest Fields
  - Found via IR and Channel-differencing techniques
  - Developed by MB06
- LMA* (2 Regions)
- 4DLSS* (Florida)
- NLDN*
- 13-km RUC* Model
- Radar?





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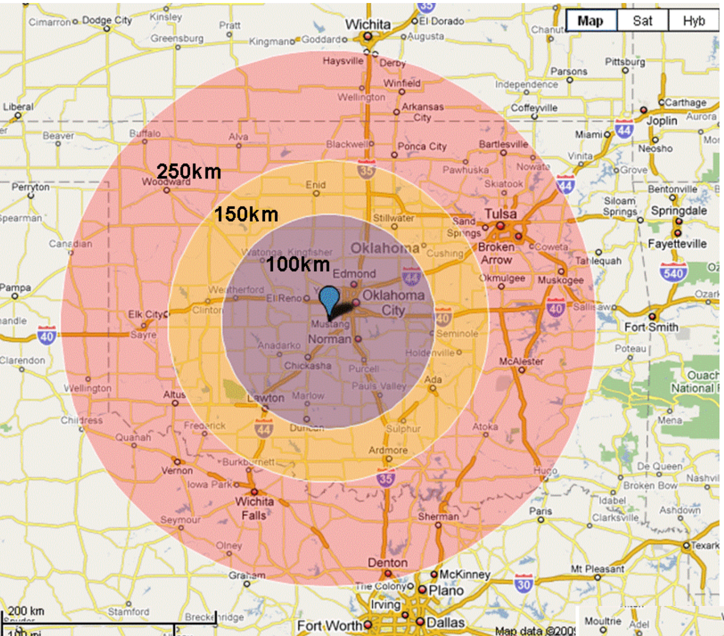
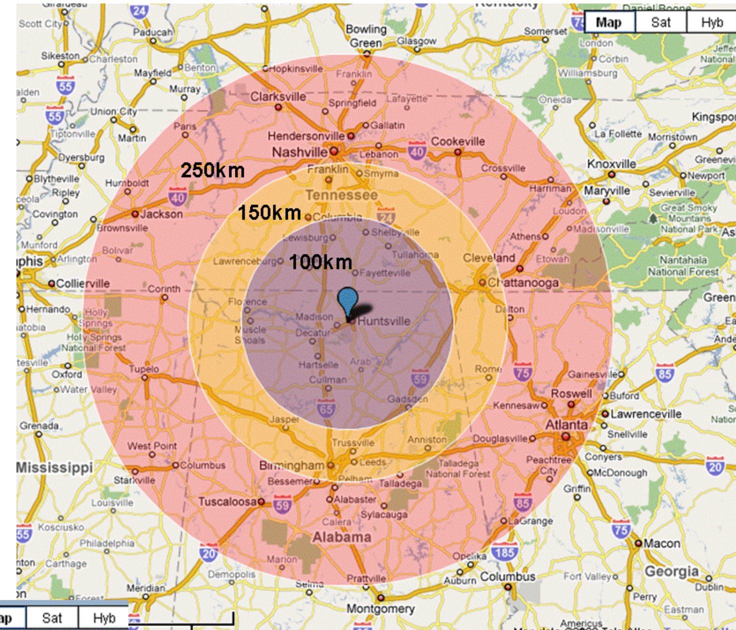
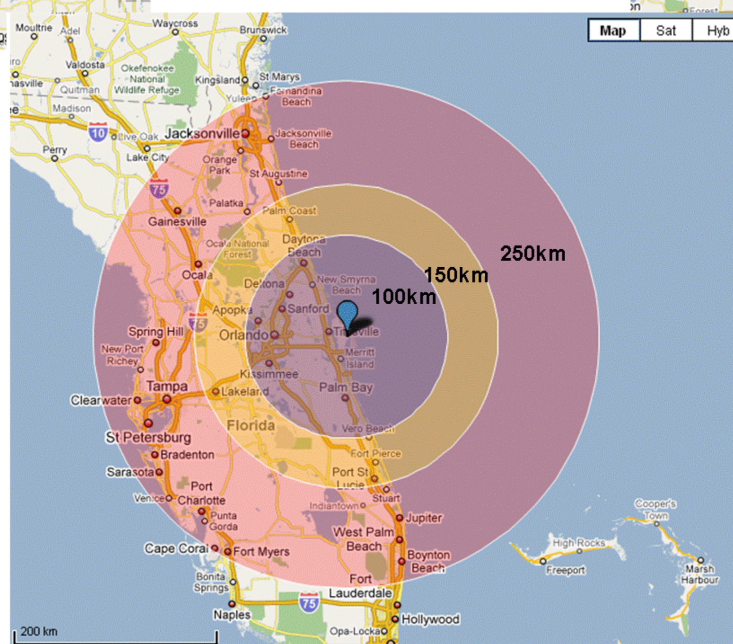
Study Regions



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



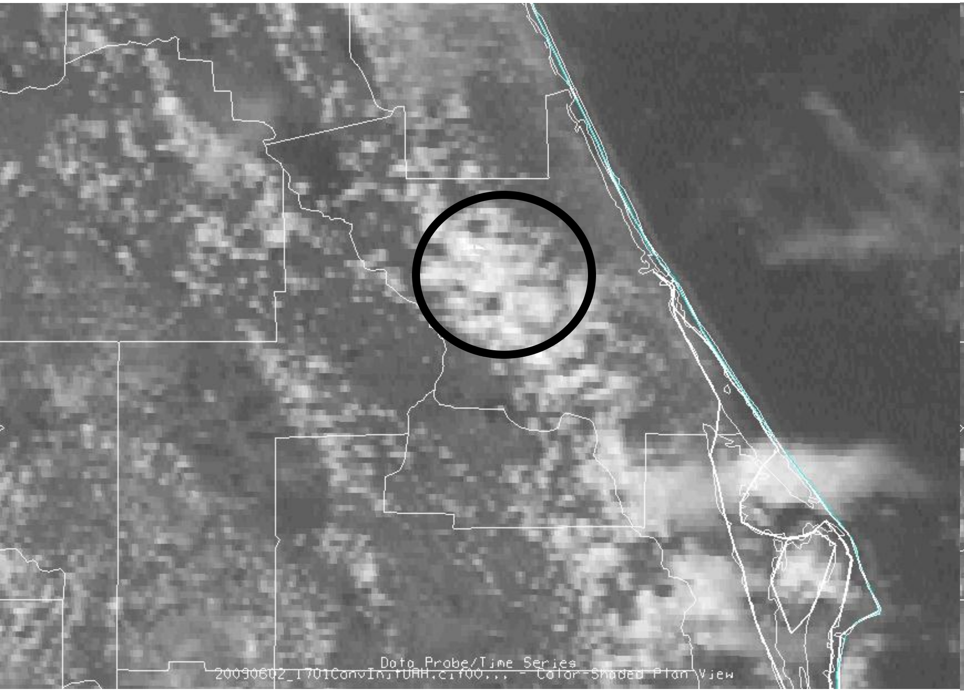
- Oklahoma City, OK
  - Total-cloud lightning
  - Developed by New Mexico Tech



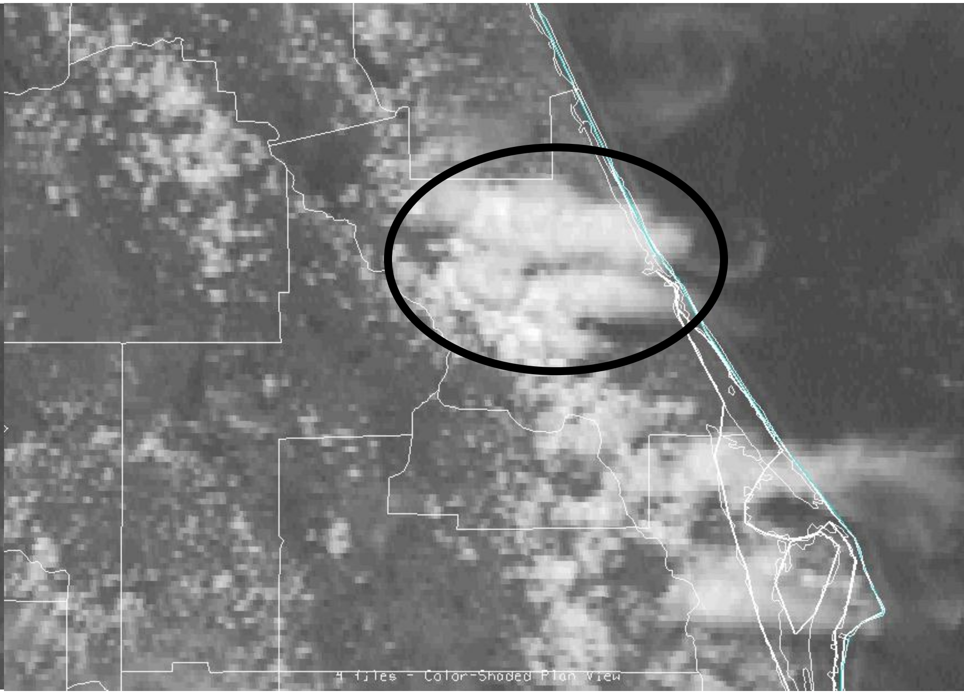
- Cape Canaveral AFS, FL
  - Total-cloud lightning (LDAR-II)
  - Cloud-to-Ground lightning (CGLSS)
  - Developed by Vaisala

2 June 2009: Visible

1701 UTC



1731 UTC



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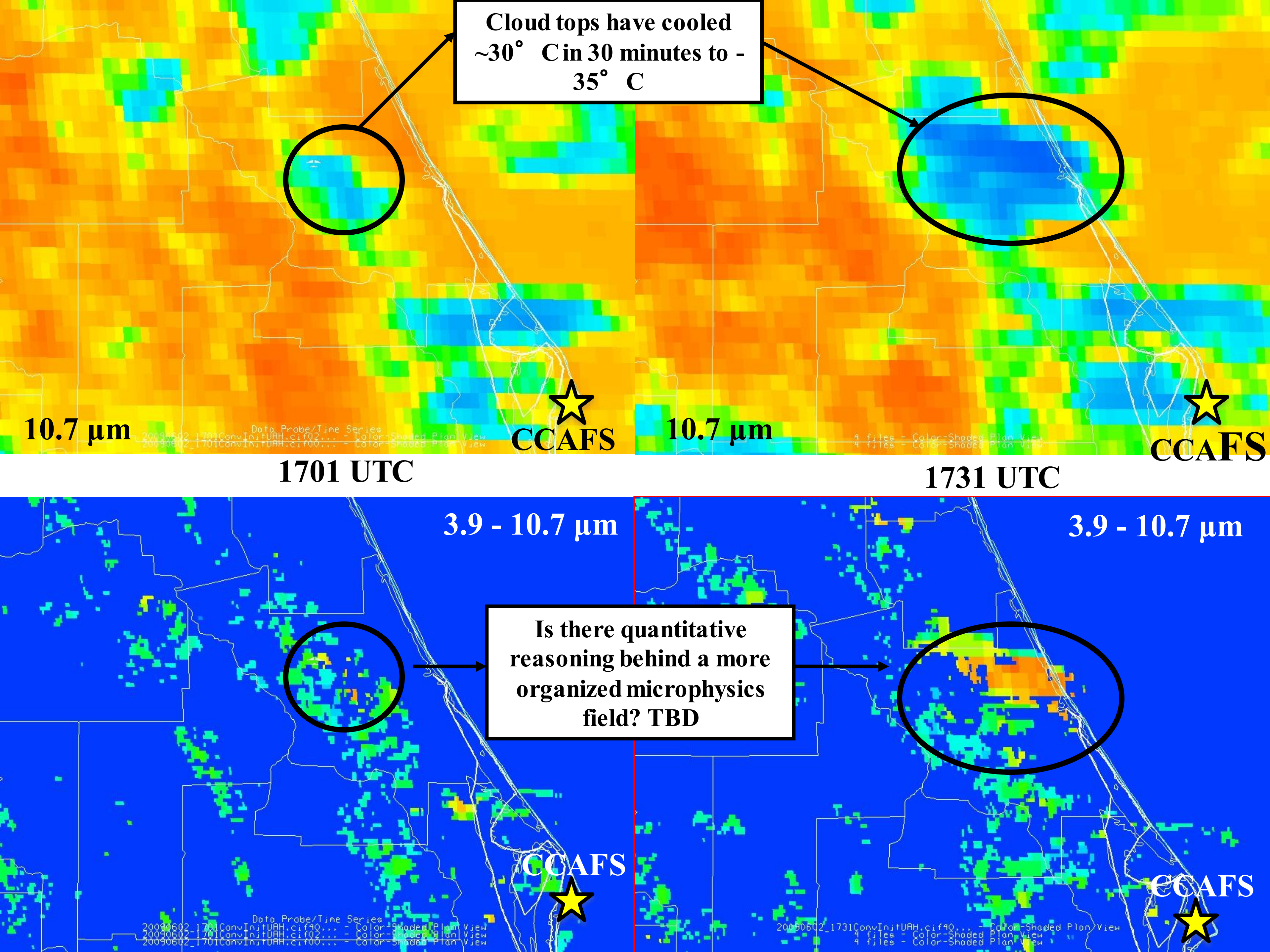
Cloud tops have cooled ~30° C in 30 minutes to -35° C
10.7 µm
CCAFS
1701 UTC
10.7 µm
CCAFS
1731 UTC
3.9 - 10.7 µm
Is there quantitative reasoning behind a more organized microphysics field? TBD
3.9 - 10.7 µm
CCAFS
CCAFS

Outstanding Questions: *New Avenues*

- **How many interest fields are *important* when performing 0-1 hour nowcasting of lightning? What fields are <u>more</u> important, and which fields are <u>most</u> important in**: (a) particular environments, and (b) across environments? **Understanding how satellite IR data relate to the physics of cumulus convection, and then, *appropriately* use the satellite data. NASA ROSES is a path towards answering these questions.**

- **How can satellite-based LI nowcasts be integrated into other lightning "warning" or "potential" algorithms?** Satellite fields could "trigger" lightning onset, and hence lightning warnings (once the potential is known).

- **How to constrain satellite CI and LI nowcasts (NWP data)?**
- **Minimizing errors: Better tracking & detection of cumuli.**

- **Integration with GLM?**

(a) Correlation studies to relate LI nowcasts to GLM observations (bias, R^2)
(b) Development of an integrated IR-GLM *Storm Intensity* product
(c) Integration with QPE estimates (from SATCAST—new), GLM and ABI (SCaMPR estimates).

Acknowledgements:

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Publications:

Siewert, C. W., 2008: Detection of lightning initiation using geostationary satellite data. Masters thesis, Atmospheric Science Department. University of Alabama in Huntsville. 105 pp.

Mackenzie, W.M., Siewert, C. W., and J. R. Mecikalski, 2009: Enhancements to a geostationary satellite-based convective nowcasting method: Use of the GOES 3.9 μm channel for 0-1 h nighttime convective initiation and lightning initiation nowcasting. In Review. *J. Geophys. Res.*

Harris, R., 2010: Validation of geostationary satellite lightning initiation nowcasts using lightning mapping array data. Masters thesis, Department of Meteorology. Naval Postgraduate School. In preparation.