GOES-R/JPSS Severe Weather and Lightning: Current and Future Scientific Advances

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NOAT Priorities

- **1. Convective Initiation**
- **2. Fog and Low Stratus**
- **3. Icing Threat plus Cloud Properties (cloud ice water path, cloud layers heights, cloud liquid water, cloud type). Note: these are all interrelated – cloud properties integral to this and other efforts. Also, specific guidance to pursue integrated NWP-centric approaches.**
- **4. SO_2 Detection**
- **5. Land Surface Model Related (emissivity, vegetation index, vegetation fraction)**
- **6. Precipitation (probability of rainfall, rainfall potential, QPE)**
- **7. Ice Cover**
- **8. Flood and Standing Water (at full resolution)**
- **9. Other Priority 2 Products not specifically noted (includes tropopause folding turbulence prediction, enhanced V overshooting top detection, visibility, and all others not covered above).**

Although demonstration of products should meet these priorities, NOAT accepts the demonstration of non-baseline products as acceptable if short-term value to operations is expected.

2012 GOES-R CI Recommendations

NWS Operational Advisory Team (NOAT)

- integrate CI, CTC, LTG Jump for next generation impact based warning DSS.

Independent Advisory Committee

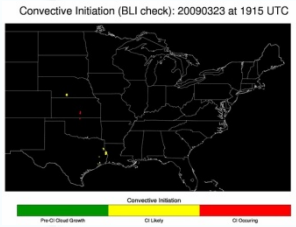
- Recommend further development using data fusion and modeling to improve accuracy and reduce FAR.
  - *High FAR is concern to wx forecasters.*
  - *Product needs to evolve to strength of vertical growth.*
  - *More warning time (pre-radar) will come from clear sky soundings*

NOAT
NWS Operational Advisory Team

A Potential Operational Example: Convective Initiation/Severe Wx

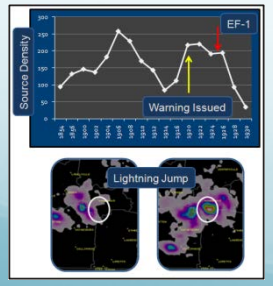
Can we integrate the information in future tools?

CI

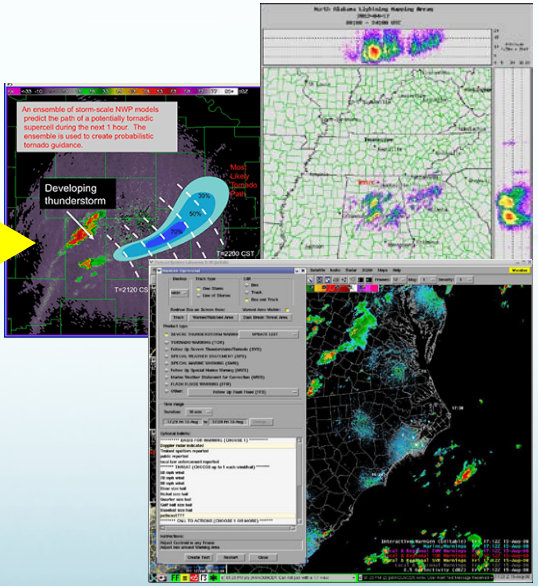


Over-shooting tops

Lightning Jumps



Next Generation Warning System



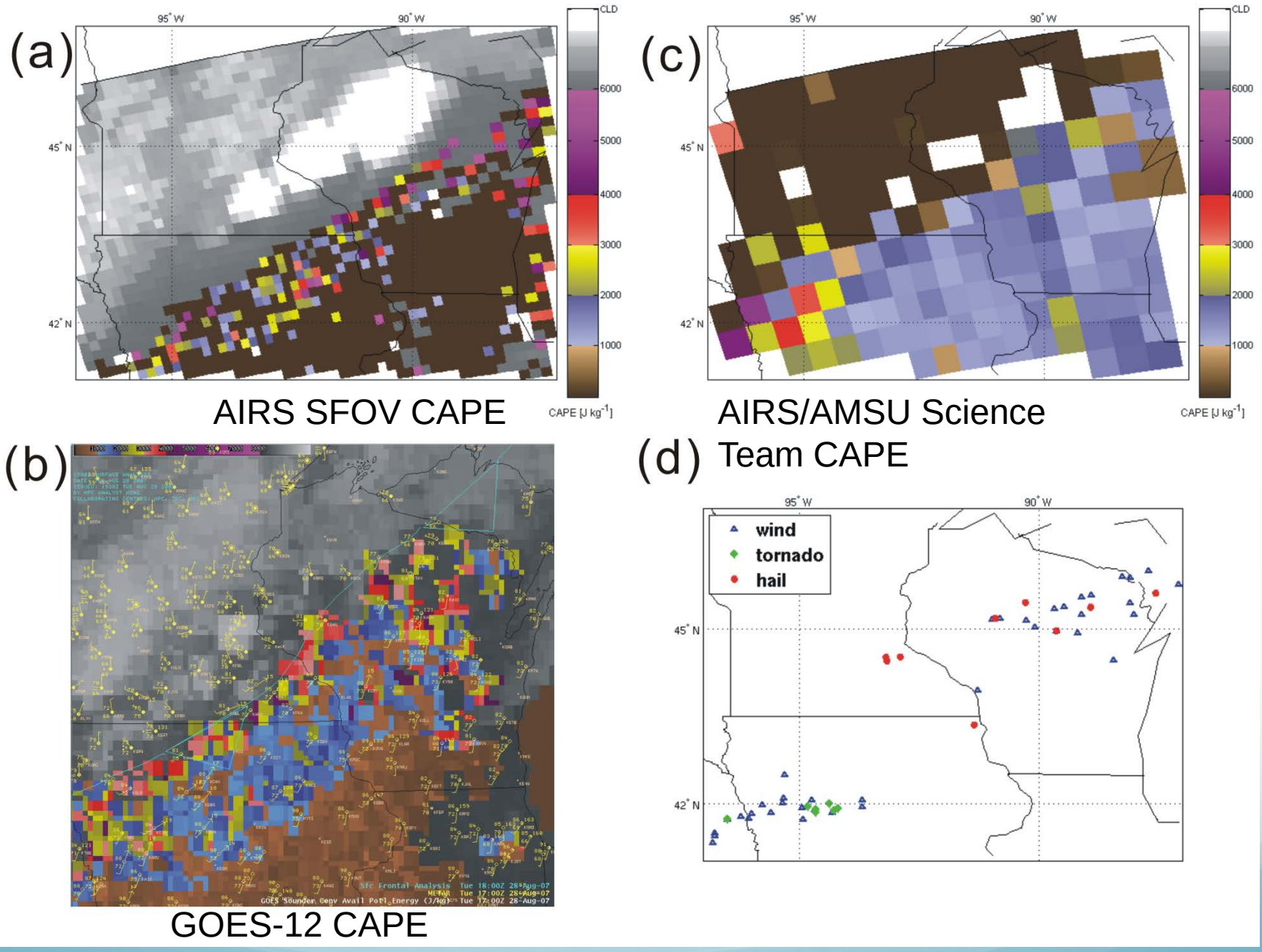
Why we need this?

Situational Awareness
Conv warning confidence
Decision Support (venues)

Pre-convective environment

- LEO/GEO atmospheric stability
  - Jun Li et al (UW-CIMSS)
  - Funded: GOES-R Sounding AWG/GEO Advanced Sounder Research
- Split-window Low Level Moisture Convergence
  - Daniel Lindsey, Louis Grasso, et al (CIRA)
  - Funded: GOES-R Risk Reduction
- Thermodynamic Nearcasting (0-8 hours)
  - Ralph Petersen (UW-CIMSS)
  - Funded: GOES-R Risk Reduction/JPSS Proving Ground
- Simulated ABI Bands using NWP models (0-8 hours)
  - Jason Otkin/Justin Sieglaff (UW-CIMSS) and Louis Grasso (CIRA)
  - Funded GOES-R Proxy/Imagery/Proving Ground

Optimizing GEO/LEO Atmospheric Stability

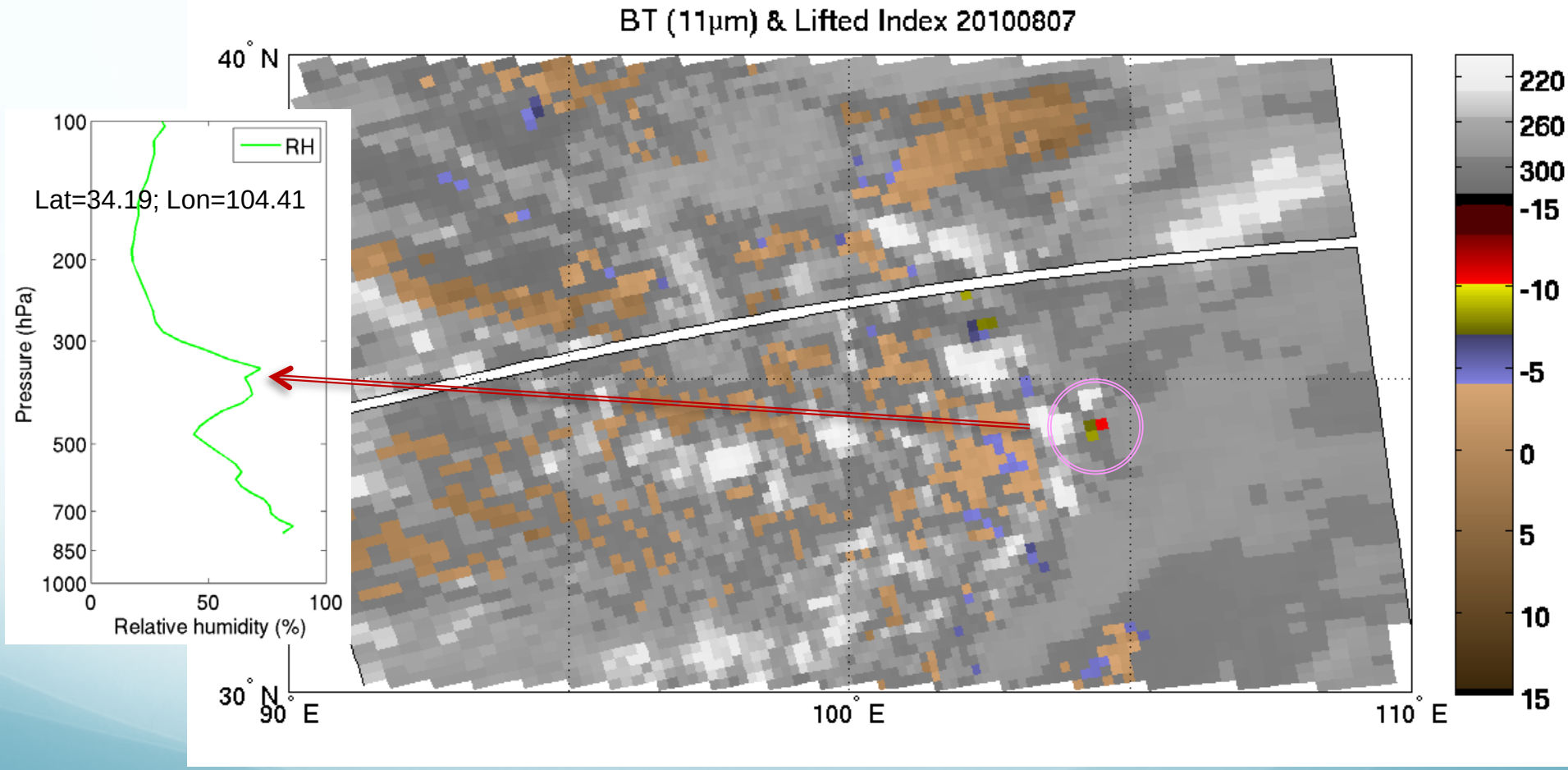


Li, et al. 2012 (Weather and Forecasting, 27, 515 – 524)

LI = T500 – Taa

0< LI → stable
-3< LI <0 → marginally unstable
-6< LI <-3 → moderately unstable
-9< LI <-6 → very unstable
LI <-9 → extreme instability

1. **Relative Humidity profile (left) at Zhou Qu in pre-convection environment**
2. **AIRS Lifted Index (right, color) in pre-convection environment overlaying on 11 μm brightness temperature (B/W)**

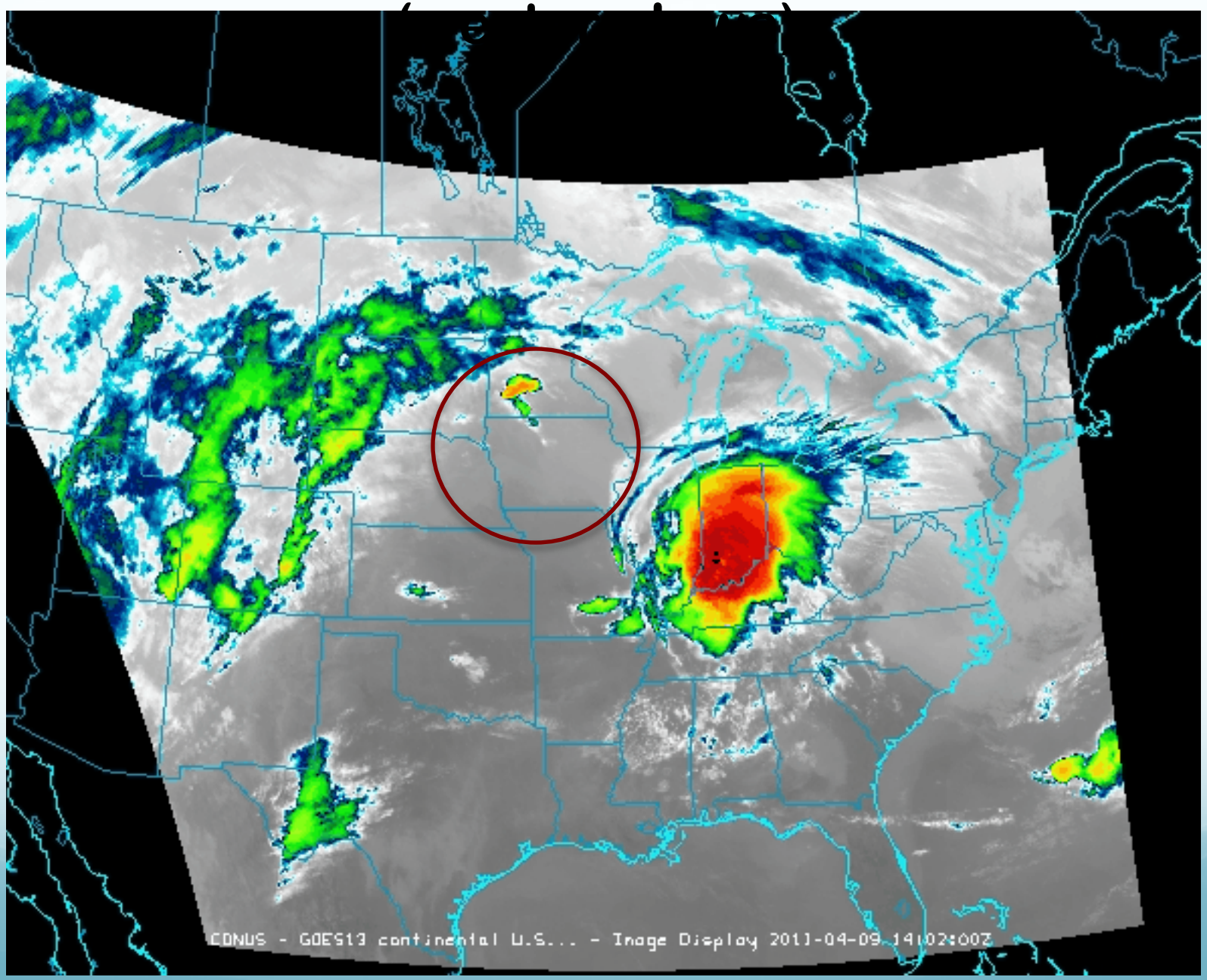


AIRS LI at 0635UTC on 07 August 2010 (1435 Local Time, storm starts 20 LT)
Li, et al. 2012 (Weather and Forecasting, 27, 515 – 524)

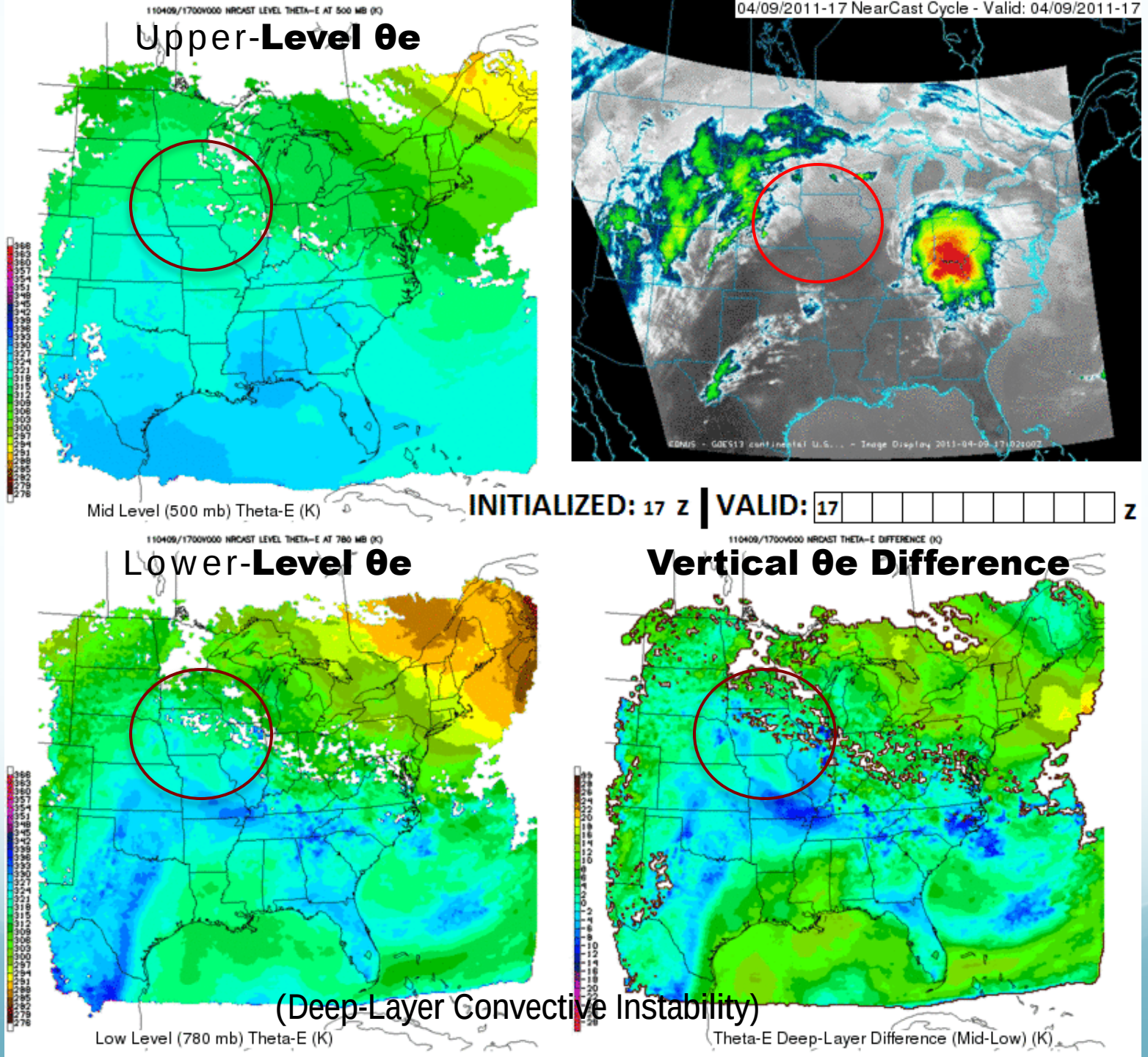
Satellite Stability Nearcasting

Ralph Petersen and Bill Line

Nearing Casting - April 9, 2011 – Mapleton, IA



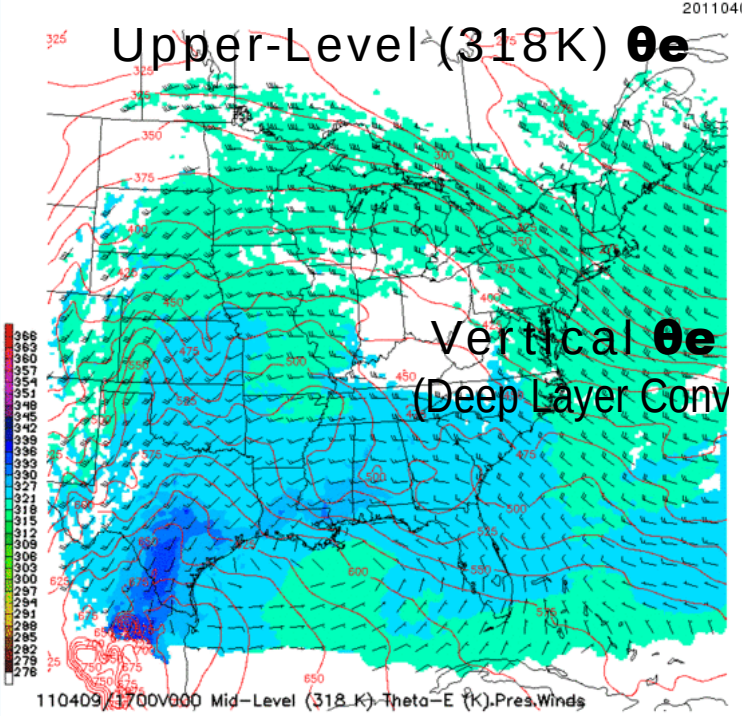
April 9, 2011 – Mapleton, IA (western Iowa)

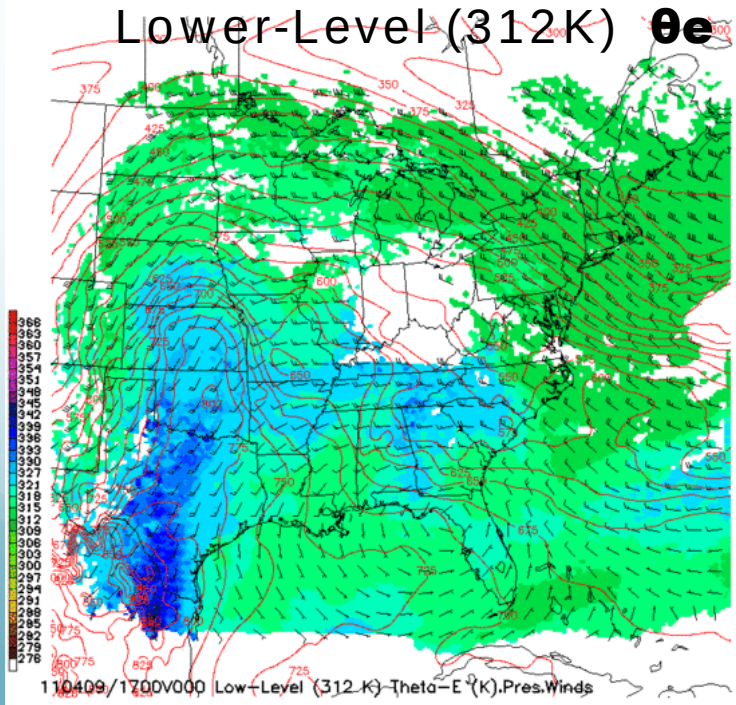


(Deep-Layer Convective Instability)

NearCast Images are avaialbe <10 minutes after observations on real-time NearCasting web site

April 9, 2011 – Mapleton, IA (western Iowa)





LATEST NEARCAST RUN

INITIALIZED: 17z | VALID: 17 z

Advantages of Isentropic Version of NearCasting Model

- GOES soundings are only made in cloud-free region where latent heating is negligible and therefore flow is adiabatic
- Isentropic coordinates implicitly include vertical motions
  - Upward transport at lower-level indicates potential lifting mechanisms
  - Downward transport of upper-level dryness (*which GOES observe best*) increases gradients and therefore should enhance signatures of Convective Instability
  - Covariance of separate sentropic mass and moisture fields differentiated heavy in MN precipitation from convection in IA

Note: - Stronger gradients at higher levels
- More continuous lower-layer moisture plume and
- Triggering ascent along lower-level surface

What Next?

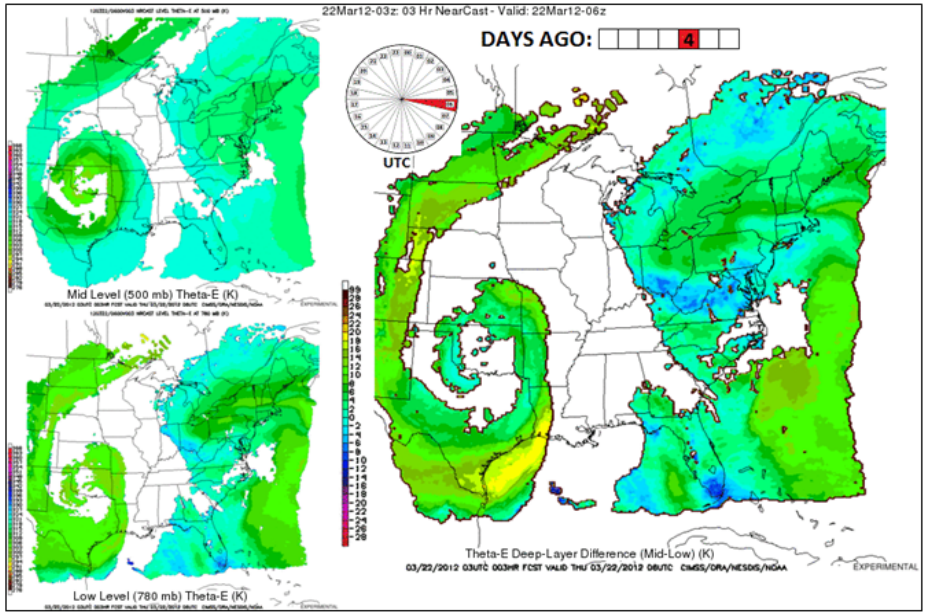
NearCast Model has been modified to run anywhere on the globe

- ***Uses NCEP GFS data for Heights and initial Winds***
- ***Uses EUMETSAT SEVIRI data as GOES-R surrigate***
  - ***Evaluation at ESSL planned for this summer***
- ***Bias removal underway over US***

Continued Testing and Evaluation

- ***More Proving Ground activities***
  - **Adding NCEP/OPC to SPC and AWC**
- ***Need to provide materials to WFOs for introducing more forecasters to NearCasts***
  - **E.g., daily exposure to loops of current events could help**

Exposing Forecasts to satellite NearCasts



6 day NearCast Loop

NearCasts are updated hourly and available within minutes of observations

CIMSS

GOES-R ABI Split Window Difference for Identifying Low-Level Water Vapor Convergence

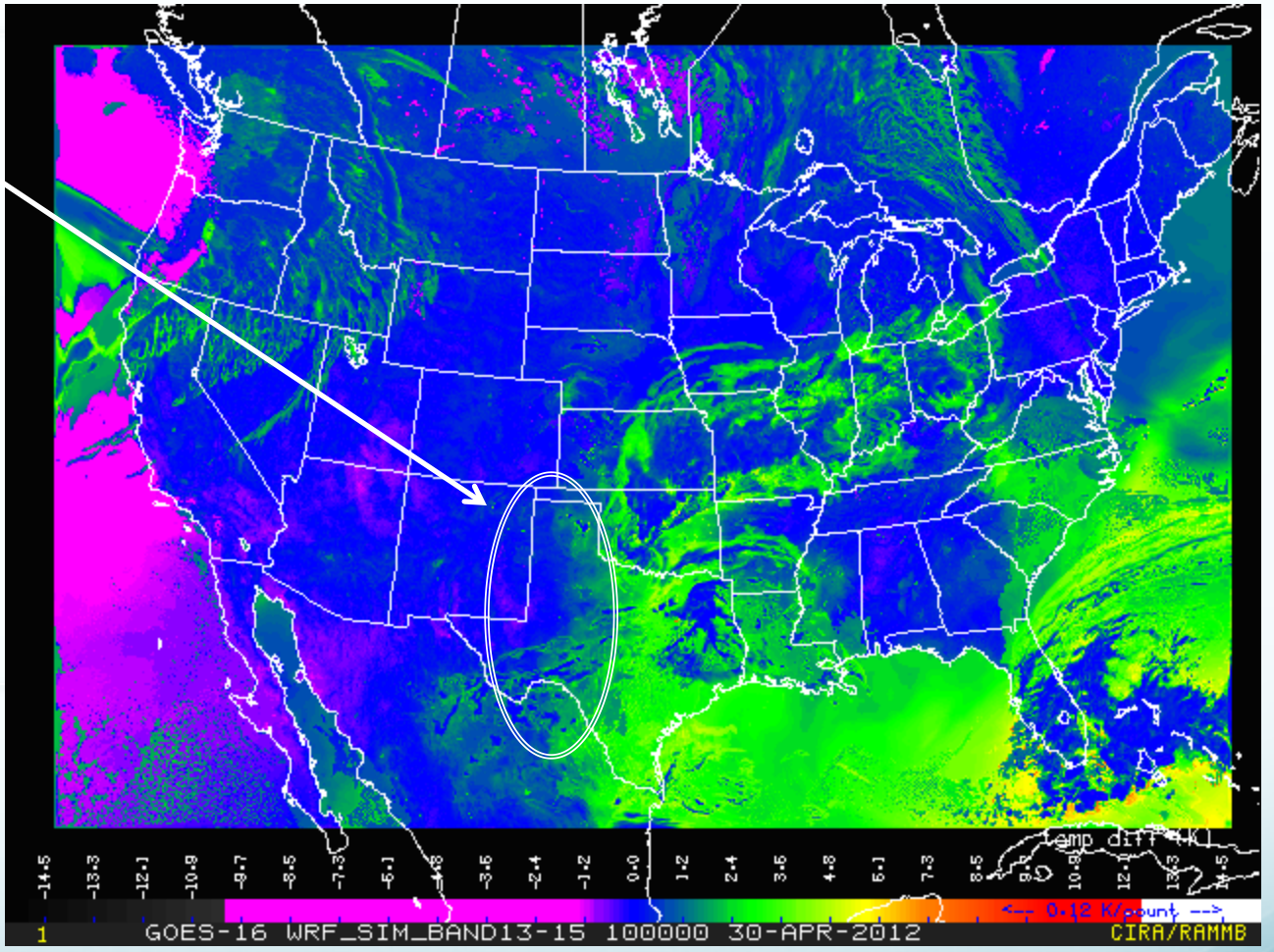
Dan Lindsey (STAR/RAMMB), Louie Grasso (CIRA), and Christopher Velden (CIMSS)

- This work is part of a GOES-R Risk Reduction Project to investigate ways to improve Convective Initiation forecasts 1-6 hours prior
- The ABI will have bands near 10.35 and 12.3 µm, and both simulations and proxy data from Meteosat Second Generation have shown that the 10.35-12.3 µm difference highlights regions of low-level water vapor pooling prior to cloud formation

Example: 4-km NSSL WRF Simulations from 30 April 2012

Note storm formation in west Texas – a maximum in the 10.35-12.3 µm is evident prior to cloud initiation

We'll zoom in on the next slide

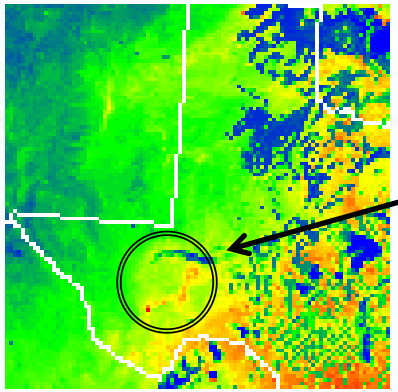


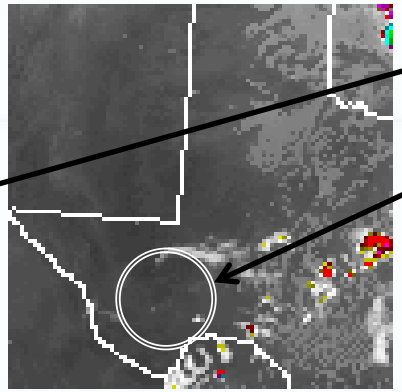
Synthetic GOES-R Tb(10.35) – Tb(12.3)

10.35-12.3 µm

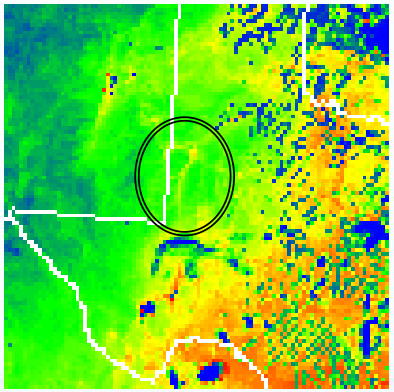
10.35 µm

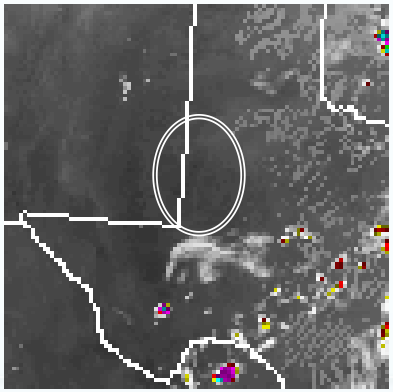
1800 UTC



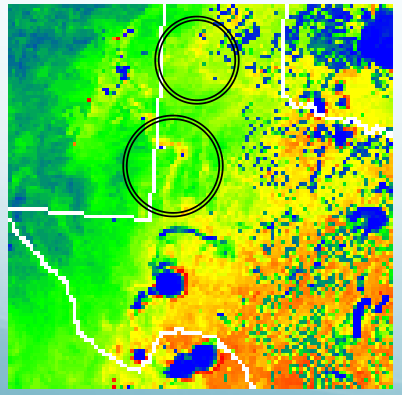


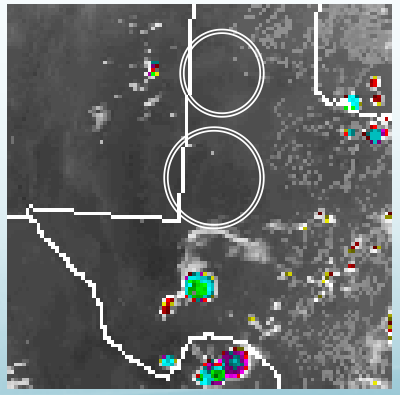
1900 UTC

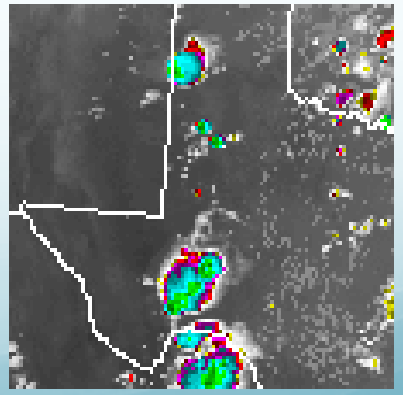




2000 UTC







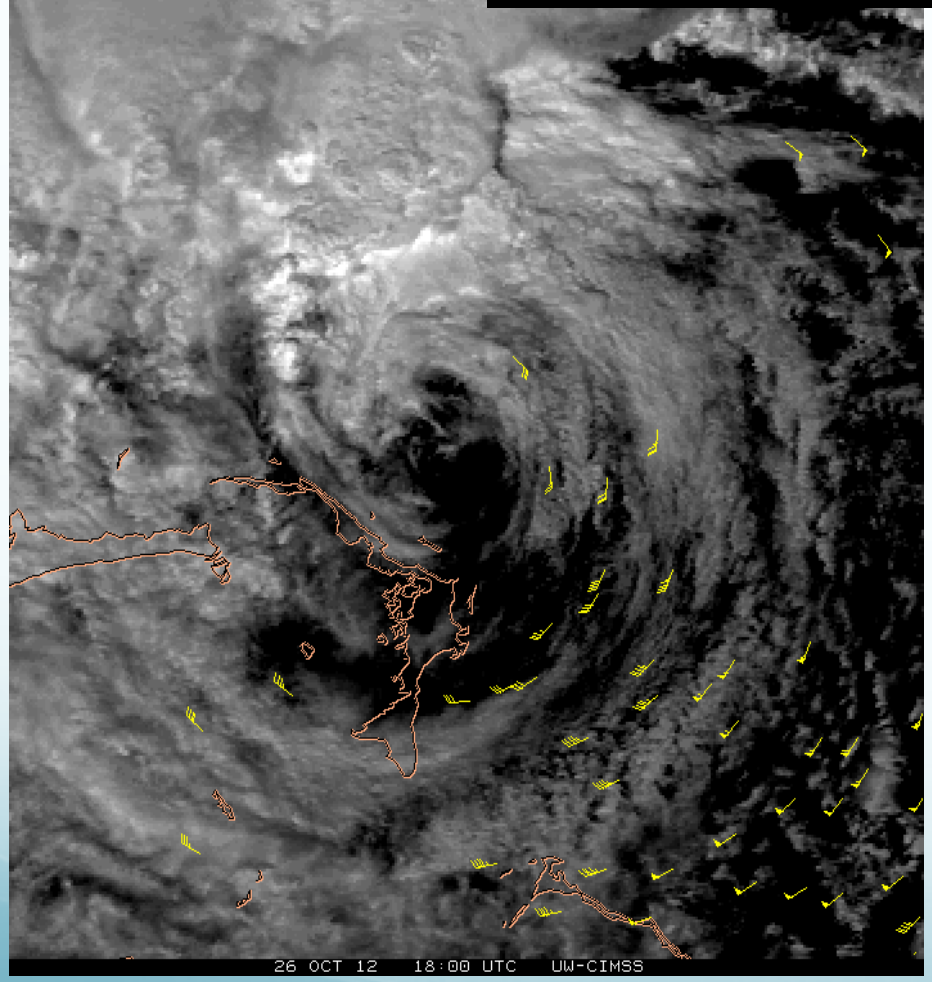
2200 UTC

- Note the yellows and reds (maxima) in the 10.35-12.3 images, and the corresponding lack of clouds in the IR images
- By 2200 UTC, convective initiation had occurred in those areas, so forecasters had a few hours notice as to the likely location of where storms would form

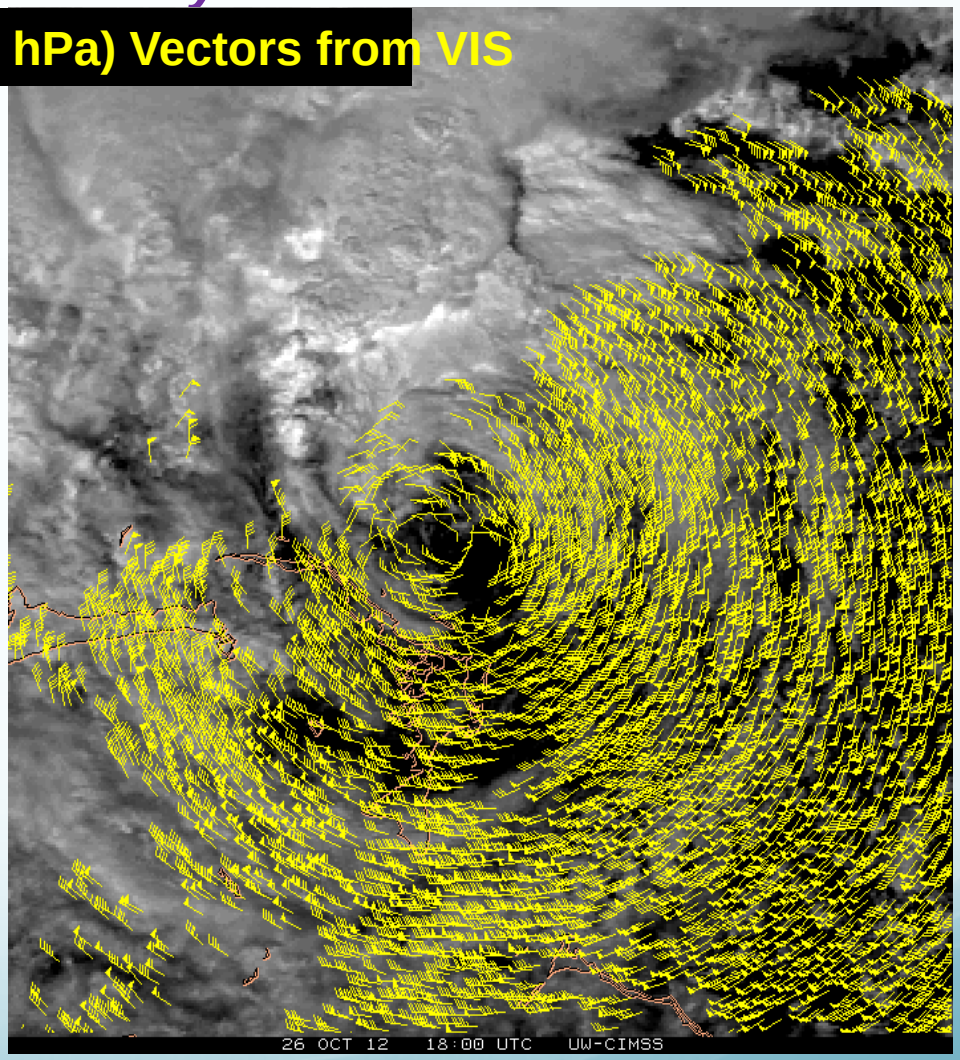
Atmospheric Motion Vectors from GOES-R

Proxy: AMVs from special GOES-14 super-rapid-scan ops during *Hurricane Sandy*

Low-Level (700-950 hPa) Vectors from VIS



AMVs from 15-min images (routine GOES sampling)



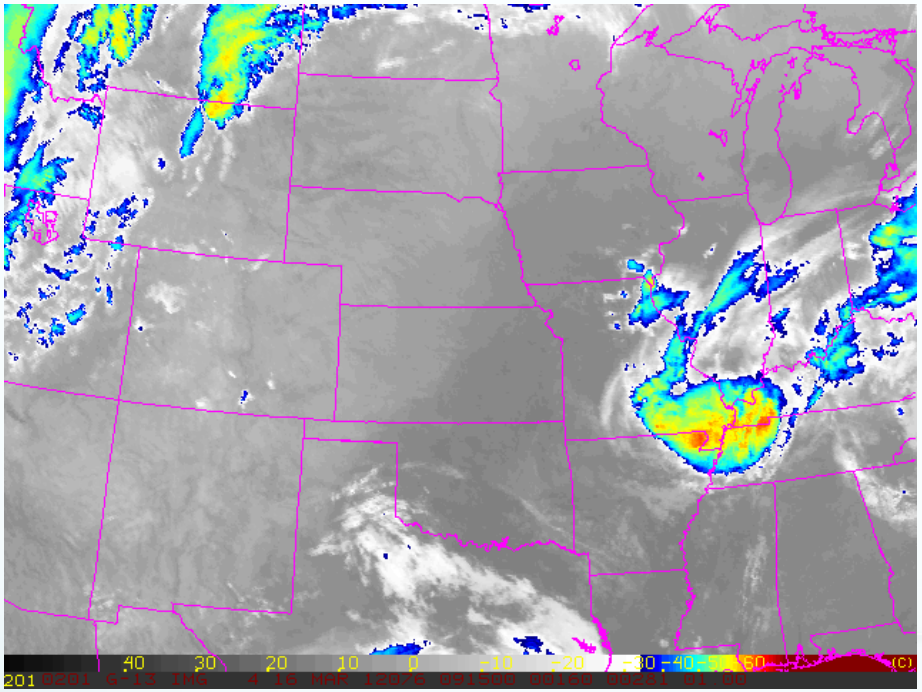
AMVs from 1-min images (meso GOES-R sampling)

1800 UTC 26 Oct, 2012

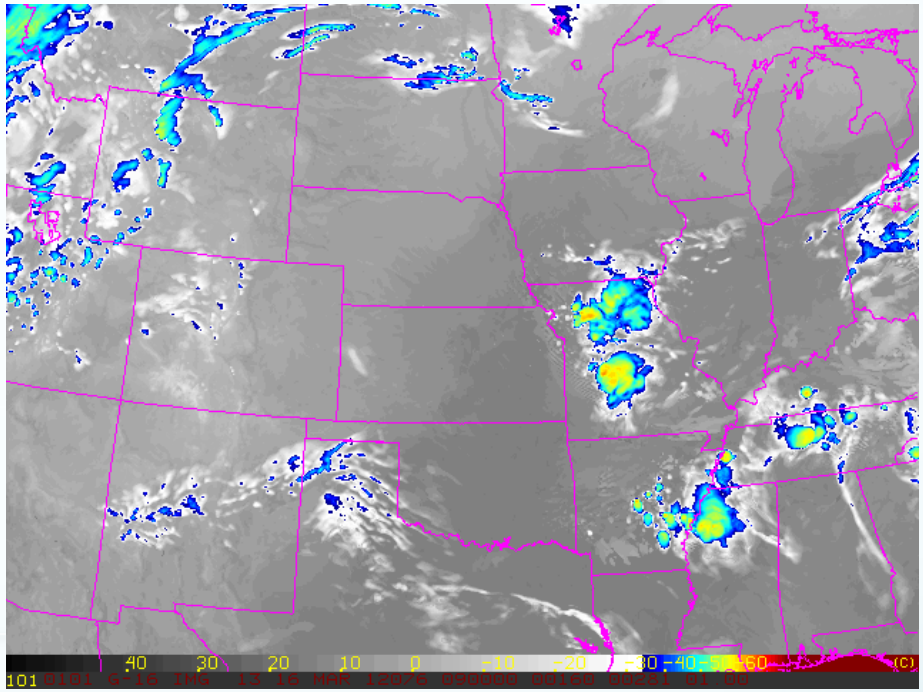
C. Velden (CIMSS)

Simulated Forecast ABI Imagery

Simulated Imagery



GOES-13 data from 16 March 2012 valid 09 to 21 UTC

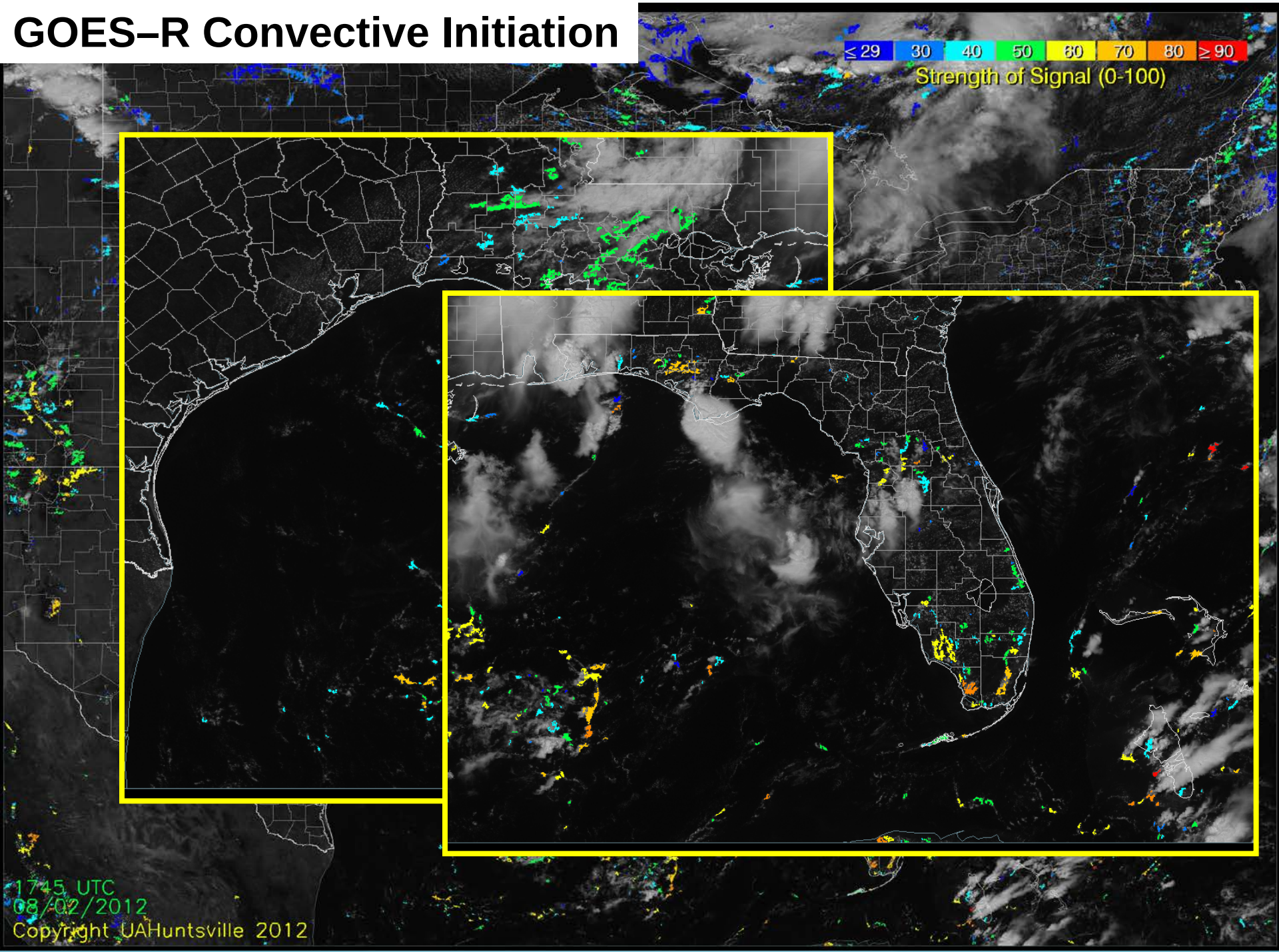


Simulated Imagery based on a 9- to 21-hour forecast from the WRF-ARW

Convective Initiation Nowcasting

- GOES-R Convective Initiation probability
  - John Mecikalski GOES-R Future Capability/Proving Ground
- Convective Cloud-top Cooling
  - Justin Sieglaff - GIMPAP/Proving Ground
- GLM Lightning Jump
  - Larry Carey – GOES-R Risk Reduction
- Probabilistic Hazard Information Fusion
  - Lakshmanan/Pavolonis – Future Risk Reduction Candidate

GOES–R Convective Initiation



Using UW-CTC at NOAA Hazardous Weather Testbed and CIMSS/NWS MKX Local Testbed

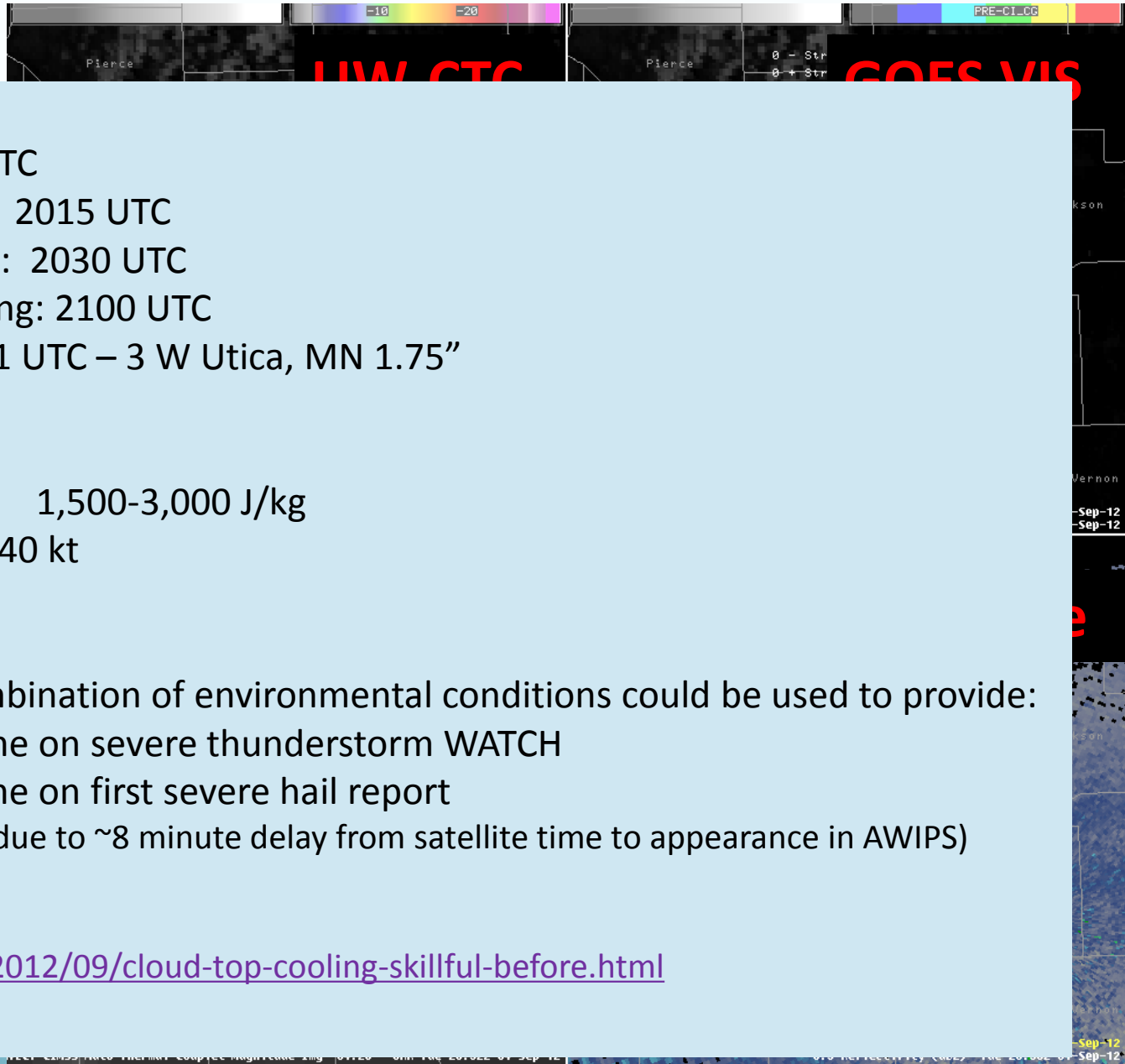
Results from testbeds have shown:

1) The use of UW-CTC rates combined with UW-CTC rate vs NEXRAD validation study results *AND*
2) Knowledge of synoptic/mesoscale meteorological conditions can be used to **increase warning lead-time by 1-3 radar volume scans**.

Satellite observations can provide very short-term nowcasting information related to convective storm intensity ***EVEN IN AREAS OF GOOD NEXRAD COVERAGE***

CIMSS/NWS MKX Local Testbed

September 4 2012



Timing

First UW-CTC signal: 2002 UTC
First 'strong' UW-CTC signal: 2015 UTC
Severe Thunderstorm Watch: 2030 UTC
Severe Thunderstorm Warning: 2100 UTC
First severe hail report: 2101 UTC – 3 W Utica, MN 1.75"

Environment

1900 UTC 100 mb ML CAPE: 1,500-3,000 J/kg
1900 UTC 0-6 km Shear: 30-40 kt

Summary

UW-CTC cooling rates in combination of environmental conditions could be used to provide:

- 15-25 minutes of lead-time on severe thunderstorm WATCH
- 35-50 minutes of lead-time on first severe hail report

(Lead-times above are lowered due to ~8 minute delay from satellite time to appearance in AWIPS)

See:
http://goesrhwt.blogspot.com/2012/09/cloud-top-cooling-skillful-before.html

May 24 2012

NOAA HWT Example

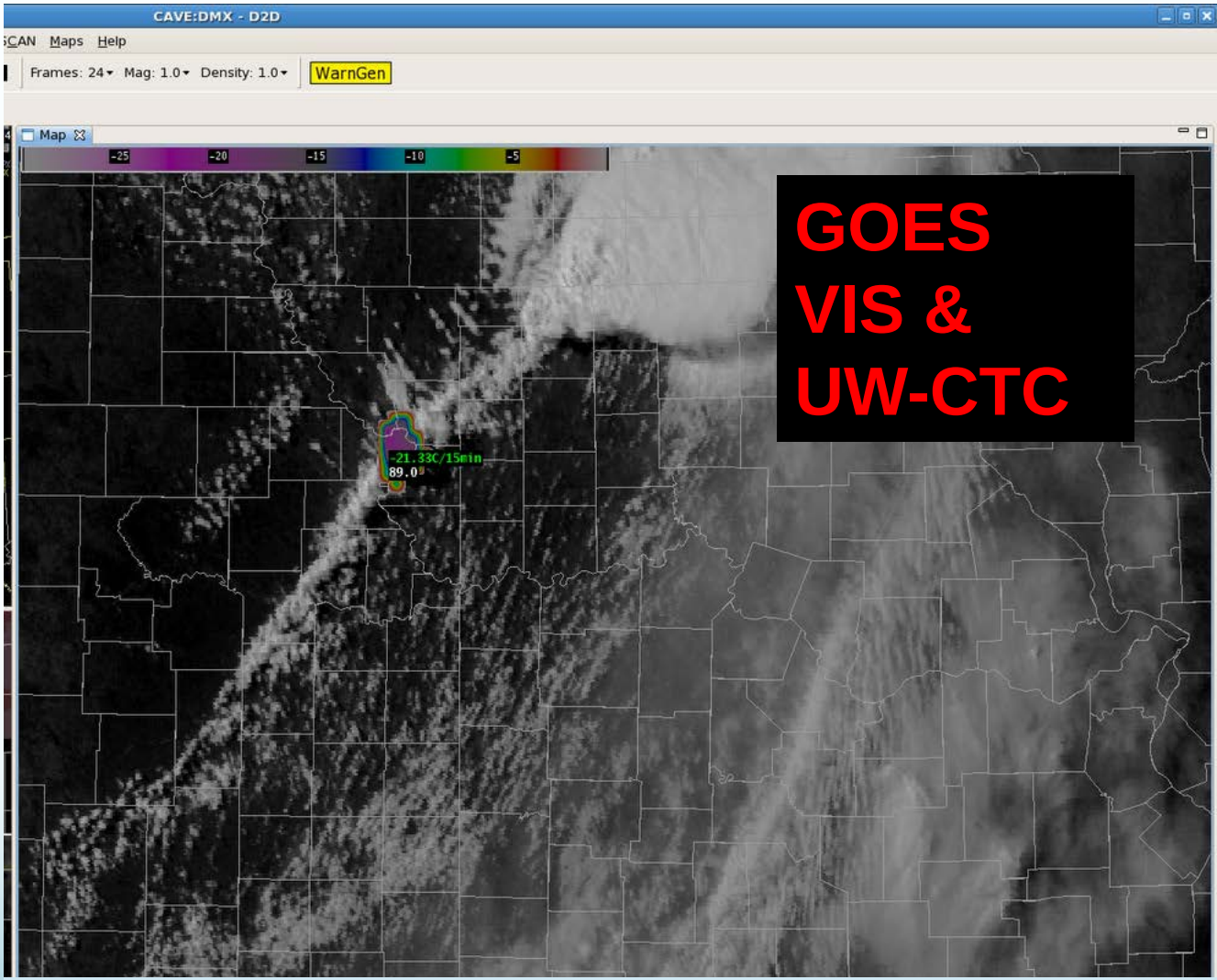
Strong UW-CTC signal ~ -21 K / 15 min over Buchanan county, MO at 2155 UTC

Severe Warning Issued:
2254 UTC

Severe Hail Report:
2305 UTC – 1.00”

No Severe Watch--MD referenced stronger cap over Missouri

UW-CTC leadtime:
~ 60 minutes



http://goesrhwt.blogspot.com/2012/05/uw-ctc-prompts-experimental-warning.html

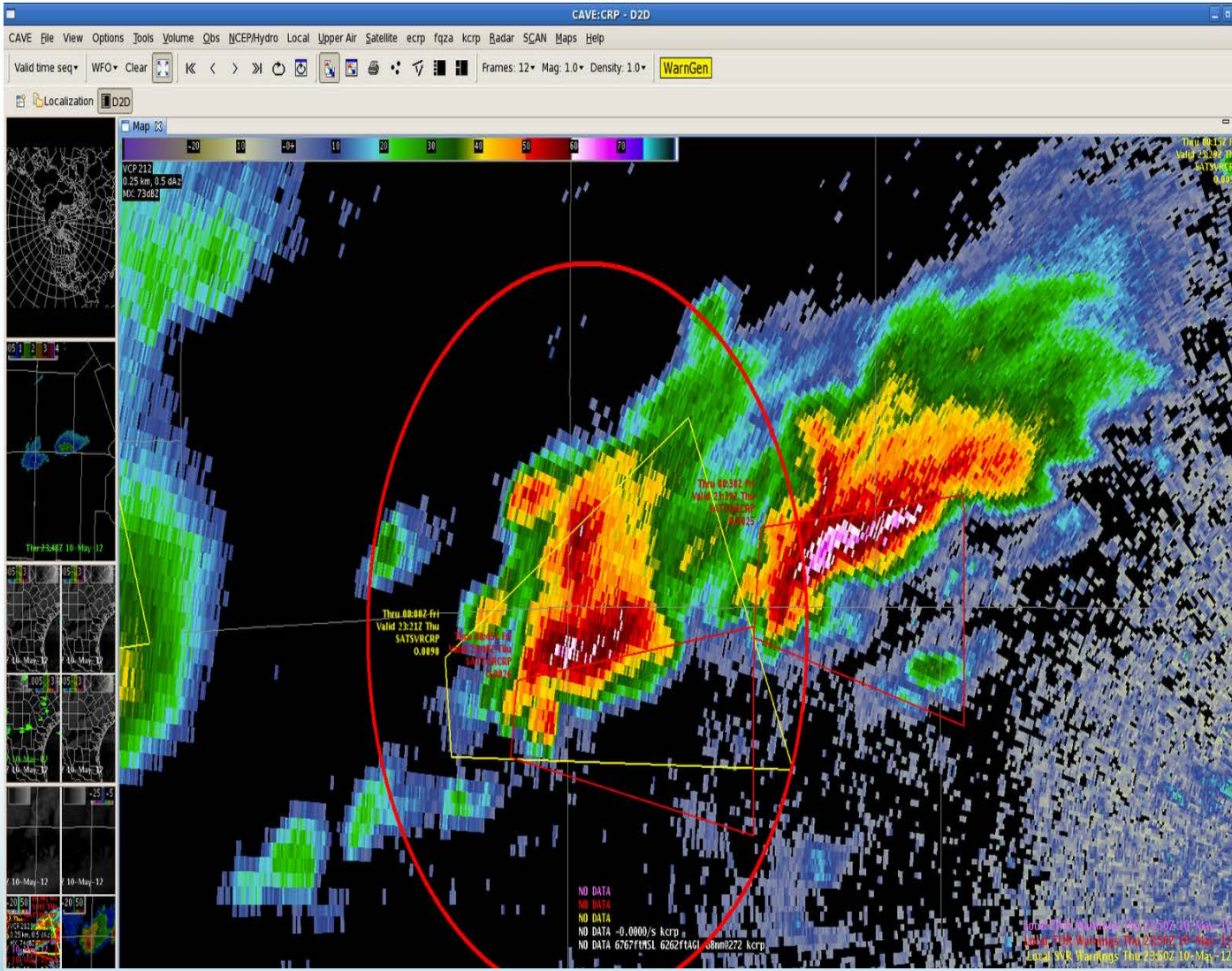
NOAA HWT Example

May 10 2012

Strong UW-CTC signal (-21 K / 15 min) on new storm developing along boundary over far NE Webb county, TX at 2310 UTC

CRP Base Ref at 2350 UTC

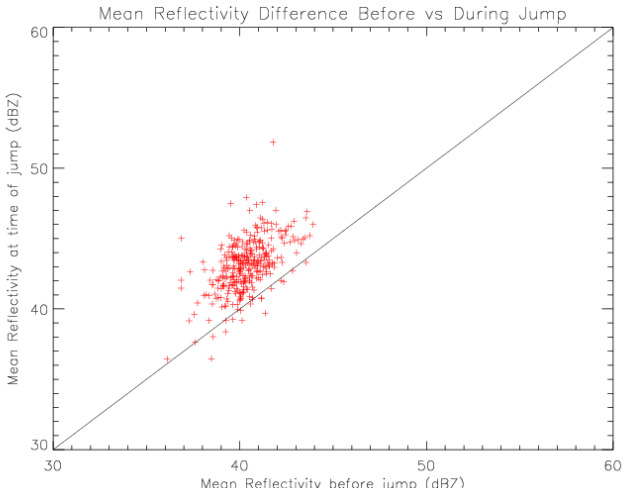
Radar severe hail indicated at 2340 UTC (20-30 minute leadtime for strong UW-CTC rate)

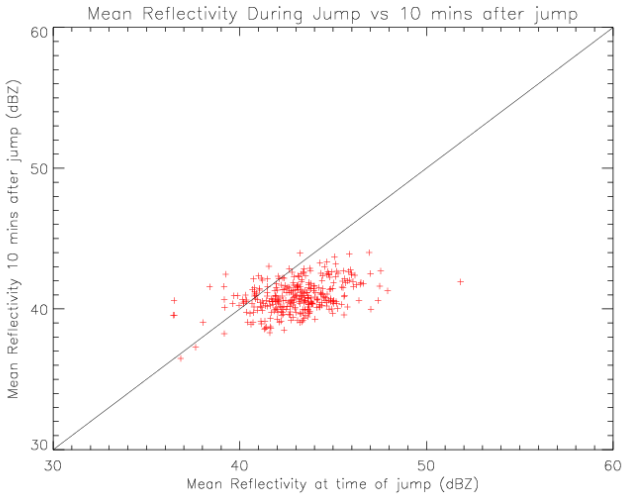


http://goesrhwt.blogspot.com/2012/05/ewp-severe-thunderstorm-warning-based.html

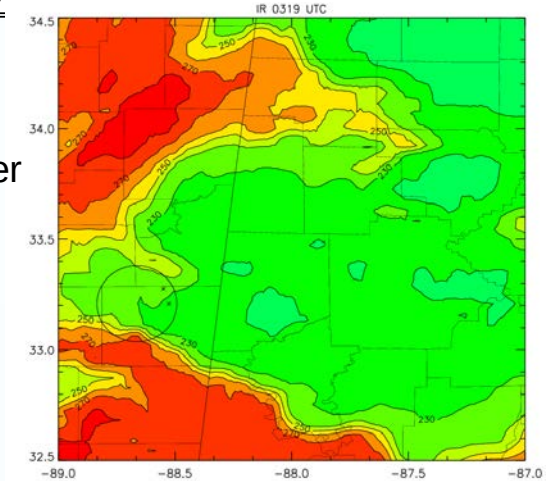
GLM Lightning

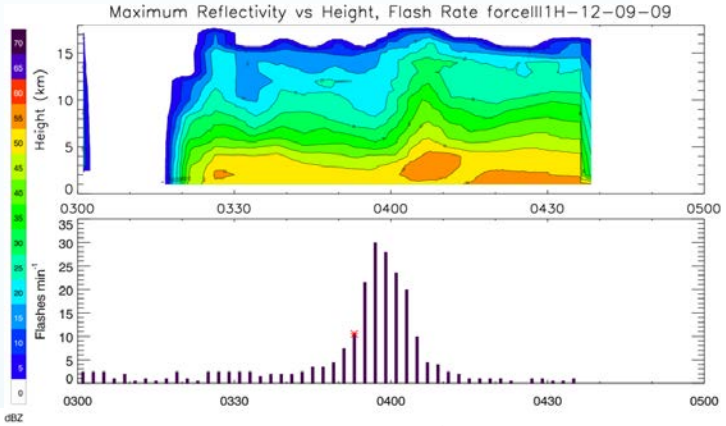
Connecting Lightning Jumps to Other Remote Sensing Observations (Based on methodology in Schultz et al. 2011)

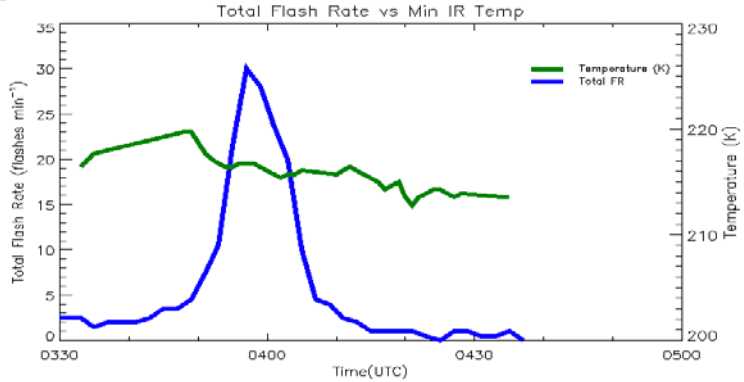




1 minute temporal IR Brightness temperature (10.7 um) from SRSO operations of GOES-O from December 9, 2009. Black asterisks represent lightning flash initiation points observed with the N. AL LMA. Black circle is the radar derived location of the storm.



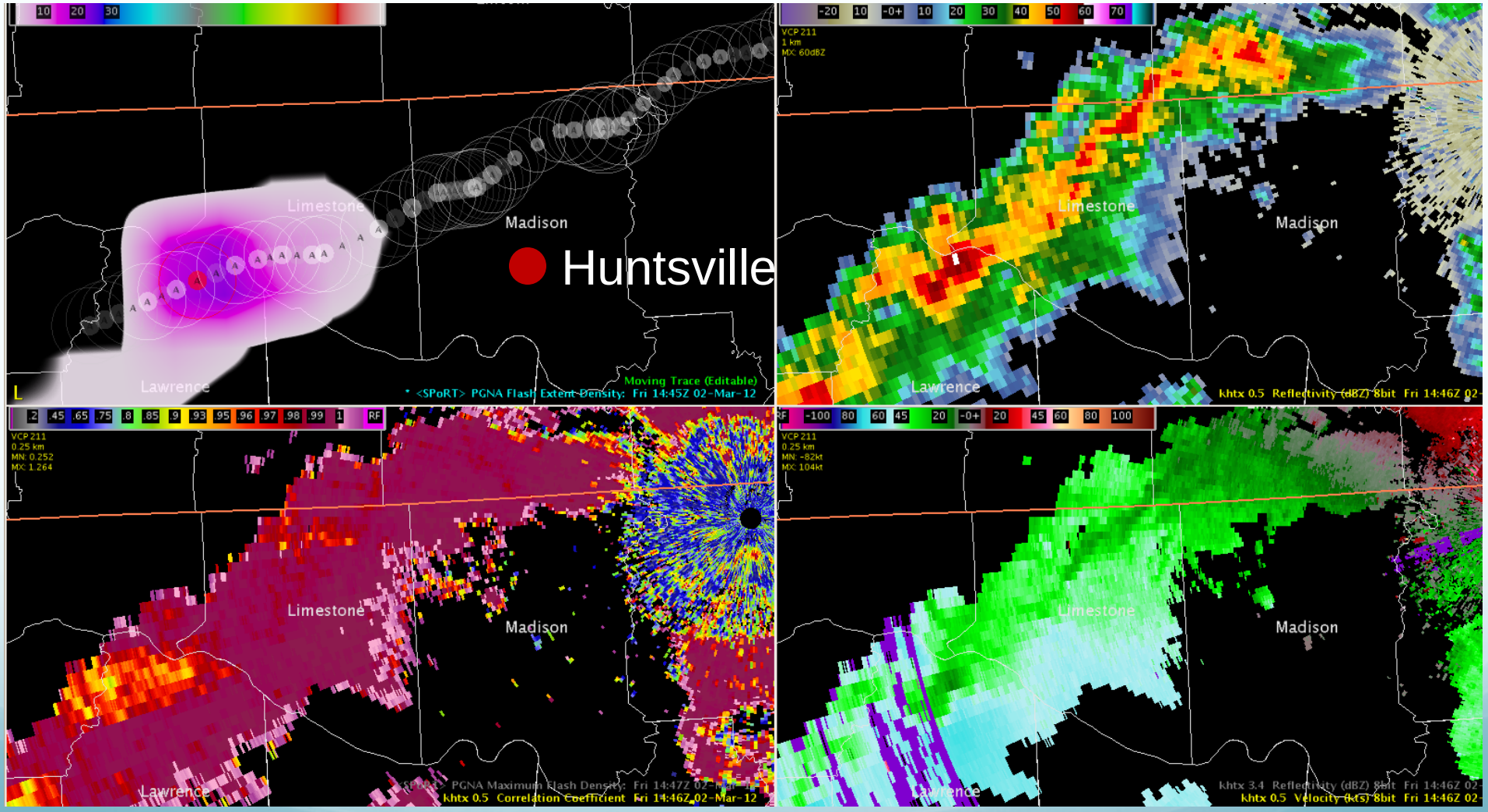




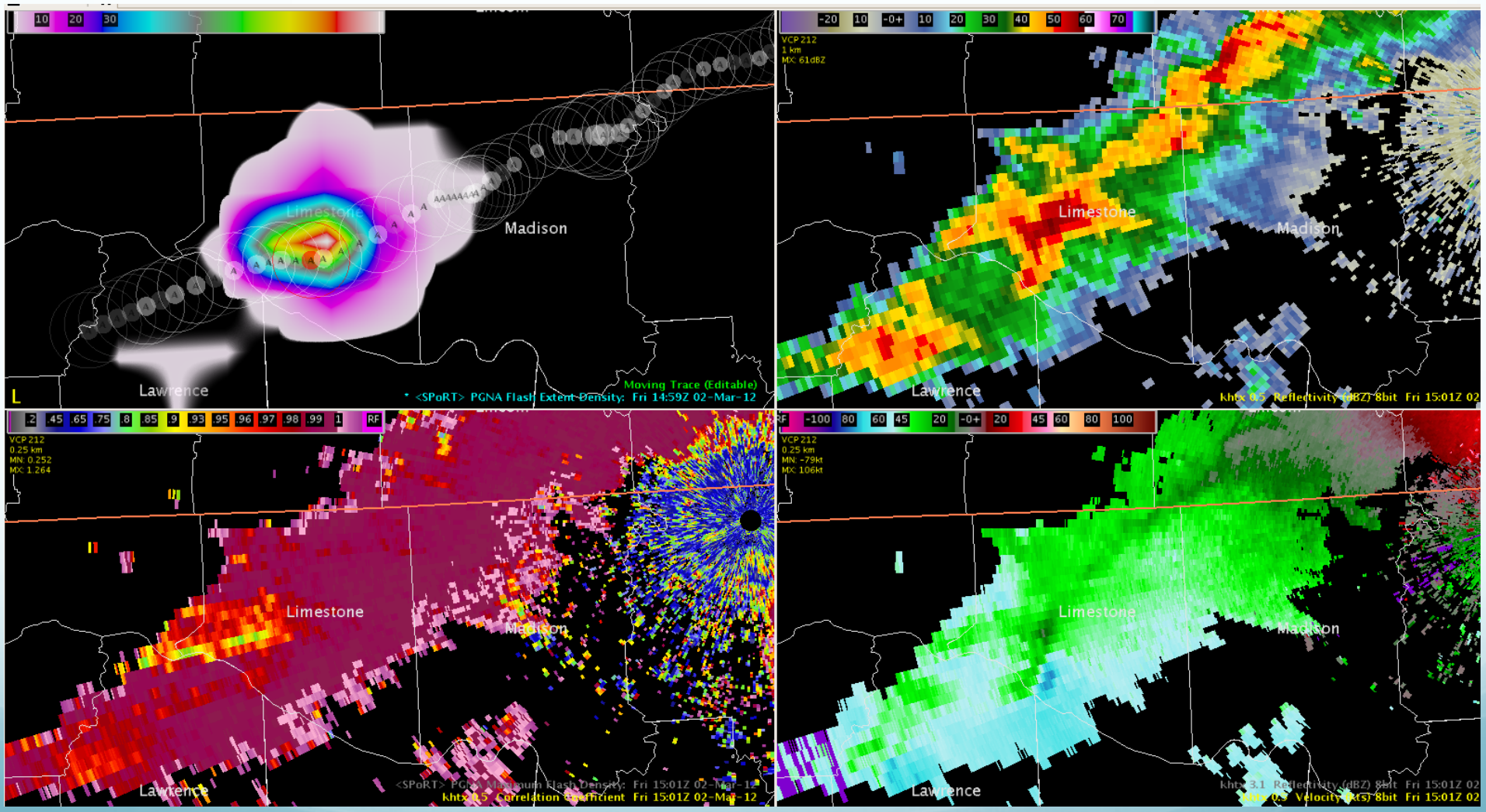
Time height section of reflectivity (top) total flash rate (purple bars; middle) and flash rate vs minimum 10.7 µm brightness temperature (bottom). Red asterisk indicates time of lightning jump. Blue boxes represent wind reports.

- Sample size: 329 thunderstorms with at least 1 lightning jump using the mean of all radar pixels above 35 dBZ
- Mean reflectivity increases by an average of 2.72 dB during the 10 minutes prior to the first observed lightning jump (Std Dev: +/- 1.60 dB)
- Then the reflectivity profile changes by an average of -2.19 dB during the 10 minute period after the jump (Std Dev: +/- 1.80 dB)

PGLM - 2 March 2012 (1445 UTC)

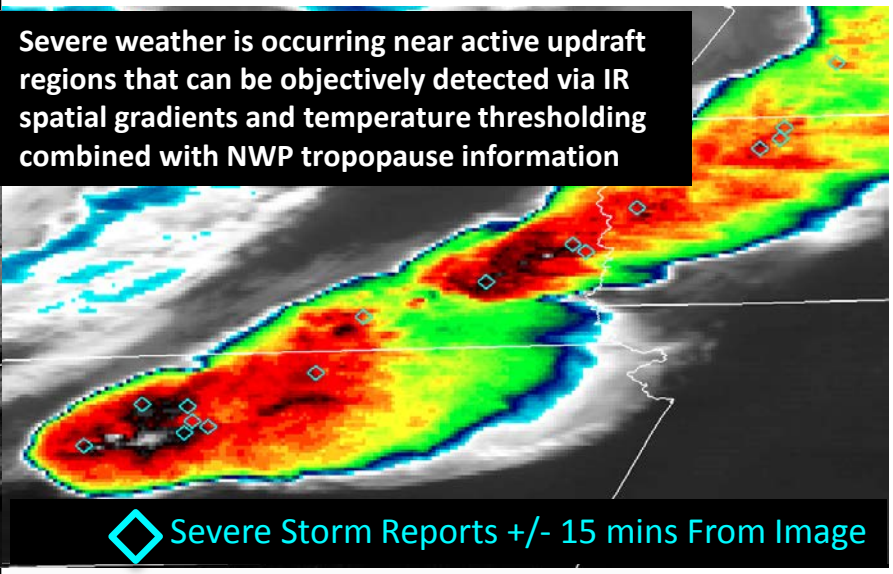


PGLM - 2 March 2012 (1459 UTC)



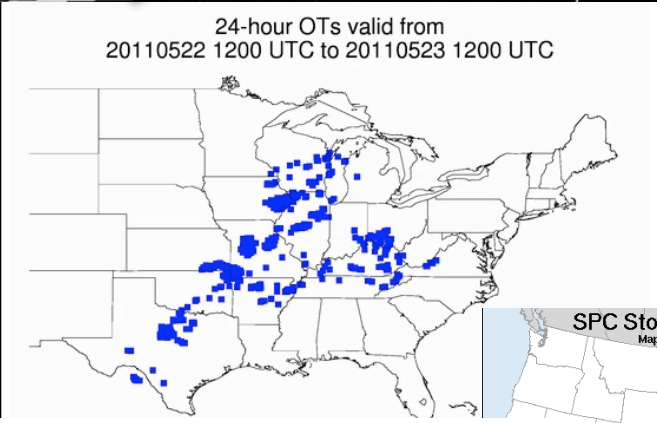
Overshooting Convective Cloud Top Detection

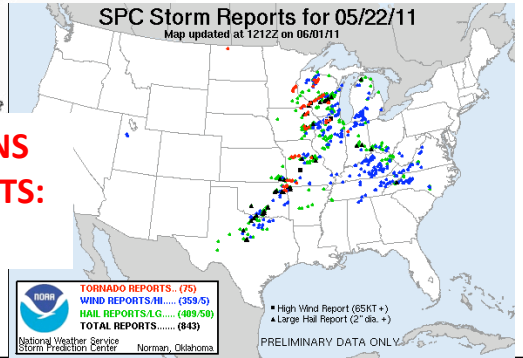
A Severe Weather Situational Awareness and Decision Aid



Frequency of Overshooting Top Detection Near Confirmed Severe Weather Events: April-September 2004-2009

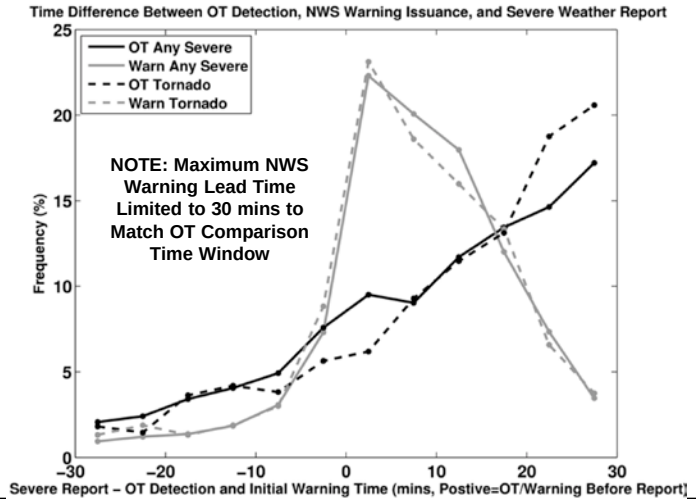
Severe Weather Type	# Severe Reports	OT Match %
Tornado	4,684	56.2%
Severe Wind	52,743	58.4%
Large Hail	56,114	51.3%
Any Type	113,541	54.8%





24 HOURS OF OT DETECTIONS VS. SEVERE WEATHER REPORTS: Joplin, MO Tornado Event

Satellite-Based Overshooting Top Detections Often Precede NWS Severe Weather Warnings By 20 Mins, Providing Valuable Situational Awareness Of A Hazardous Thunderstorm (Dworak et al. WAF, 2012)



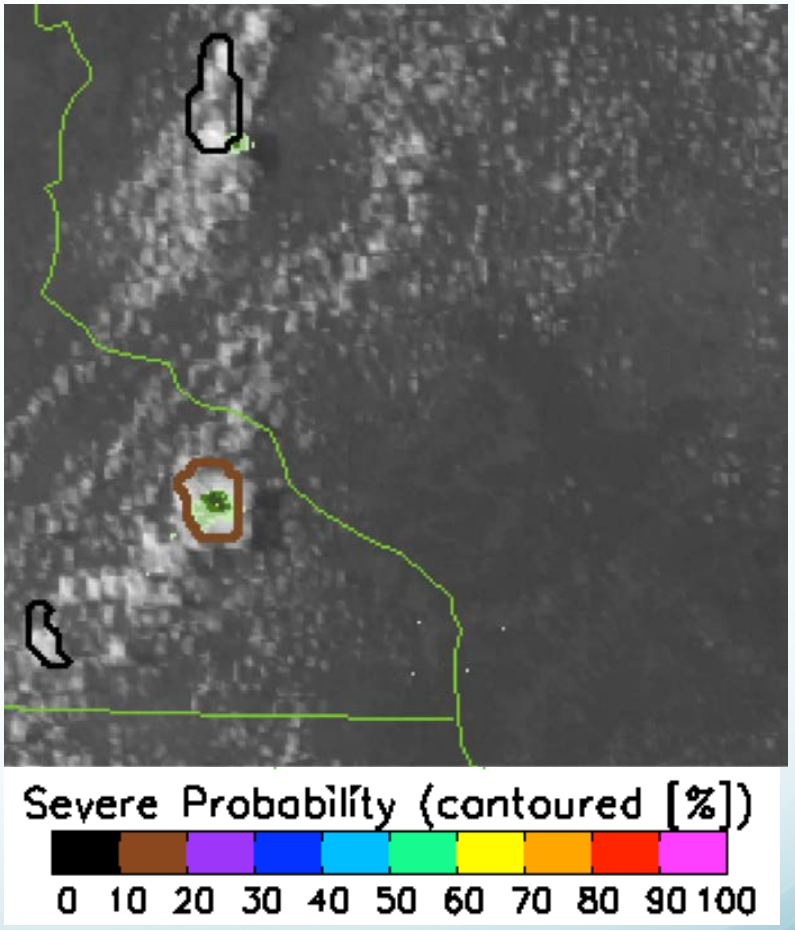
Utilizing Data Fusion to Probabilistically Forecast Severe Convection

A candidate project for GOES-R Risk Reduction

Mike Pavolonis (NOAA/NESDIS/STAR)
Valliappa Lakshmanan (OU-CIMMS/NOAA-NSSL)
Dan Lindsey (NOAA/NESDIS/STAR)
John Cintineo (UW-CIMSS)
Justin Sieglaff (UW-CIMSS)
Travis Smith (OU-CIMSS/NOAA-NSSL)

Research conducted under GIMPAP at NOAA/NESDIS/STAR and UW-CIMSS

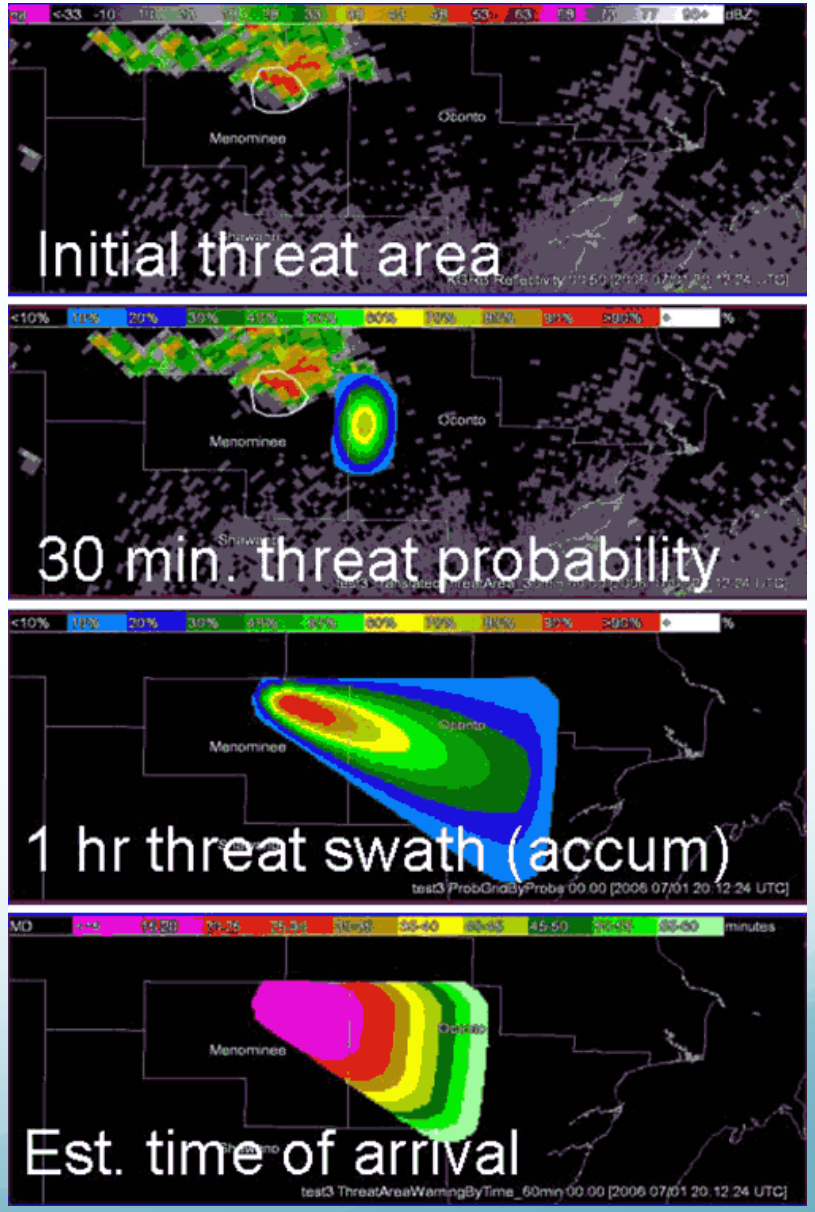
- A method for automatically tracking convective clouds using GOES was developed (Sieglaff et al. 2013 – *JTECH*).
- Robust, GOES-derived, metrics, that quantitatively characterize the vertical and horizontal growth of convective clouds, were developed (Cintineo et al. 2013 – *JAMC*).
- GOES and NWP metrics are used as predictors in a statistical model trained to determine the probability that a growing cumulus cloud will produce severe weather in the future (works day and night).
- 10 minutes or more of additional lead time compared to NEXRAD severe weather signatures is possible with this model.



We are researching possible ways to utilize NEXRAD to improve storm object identification and tracking and improve the statistical model

Research conducted at OU-CIMMS

- Development of Warning Decision Support System – Integrated Information (WDSS-II) for real-time radar object tracking and severe weather diagnosis
- Development of Multi-radar Multi-sensor products (MRMS)
- Probabilistic Hazards Information (PHI)
  - Utilizes WDSS-II and MRMS to calculate storm severity and timing with uncertainty estimates
- Participation in Hazardous Weather Testbed



Research conducted at OU-CIMMS

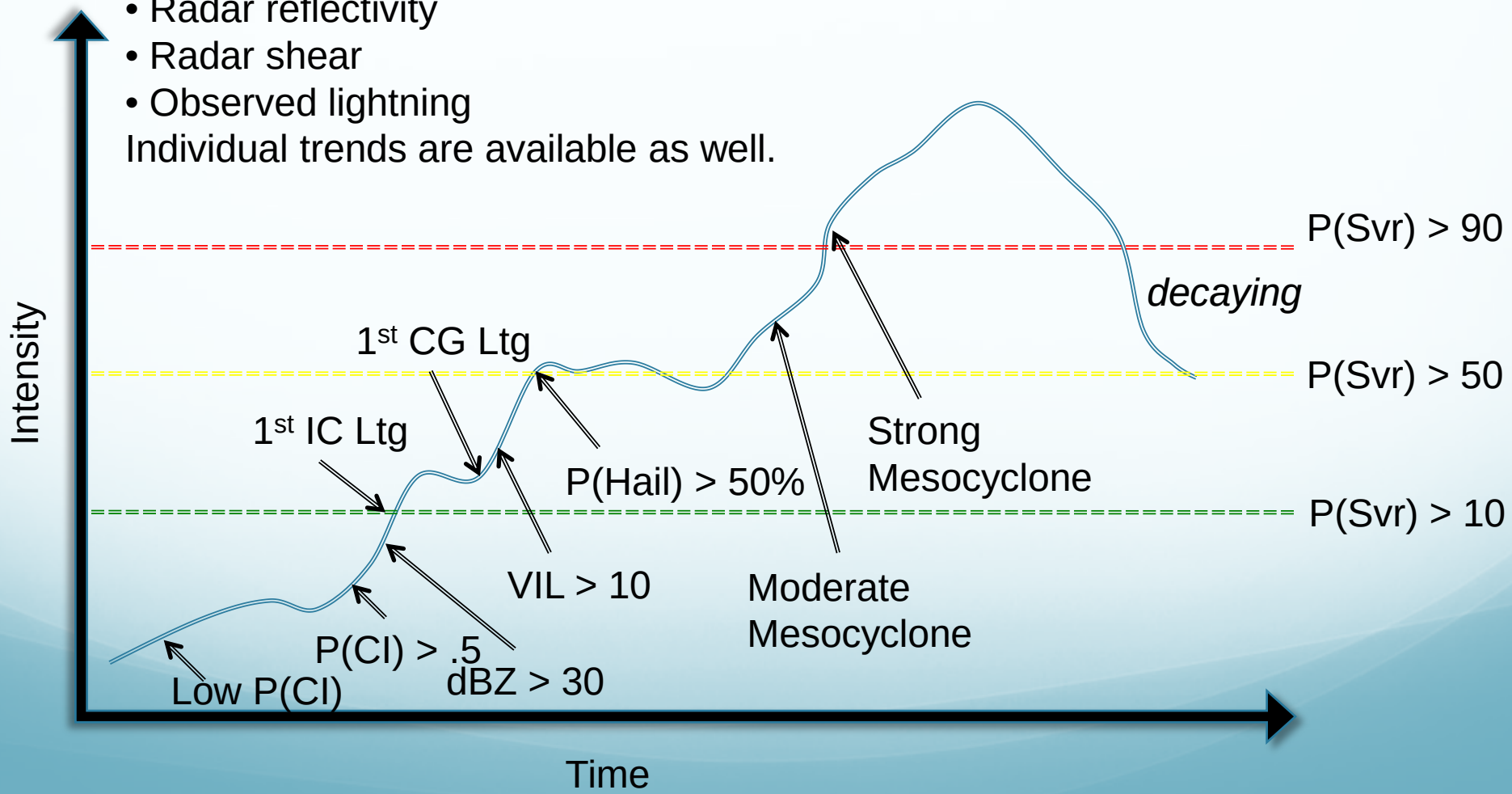
Integrated Severity Trend

Synthetic parameter based on (e.g.):

- Sat CI / Cooling
- Sat IR temp
- Radar reflectivity
- Radar shear
- Observed lightning

Individual trends are available as well.

Multi-sensor-based trend of storm severity.



Path Forward

A collaborative effort (between STAR/UW-CIMSS and OU-CIMMS and perhaps other groups) is needed to <u>fully</u> utilize high temporal resolution satellite measurements, NWP, NEXRAD, and lightning measurements to generate probabilistic severe weather forecasts that provide 10 minutes or more of added lead-time compared to current operational warning capabilities.

A working collaboration on this scale requires funding. Future GOES-R Risk Reduction project???

Path Forward

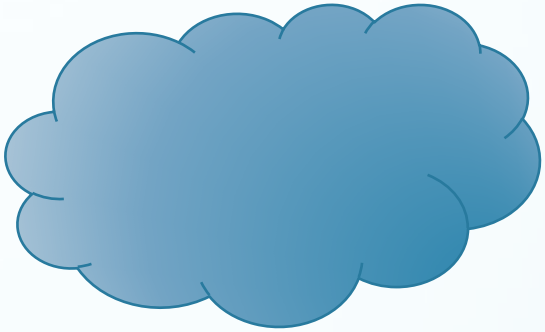
1. Identify and track objects in radar and satellite fields and use NWP to characterize background atmosphere

- Take full advantage of each data set; track storms from cradle to grave

2. Extract pertinent info from each data source

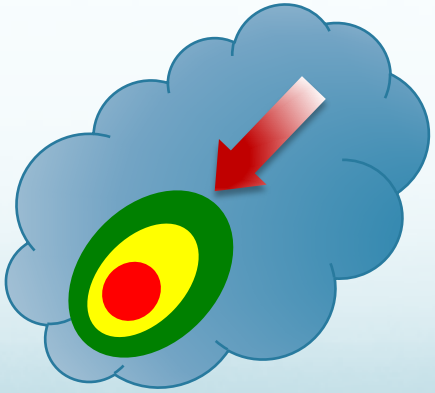
- Ref. @ -10°C
- 50-dBZ echo top
- VIL
- MESH
- Azimuthal shear

- Vertical growth
- Glaciation rate
- Anvil expansion
- Overshooting-tops
- ***Lightning***
- RAP/HRRR fields

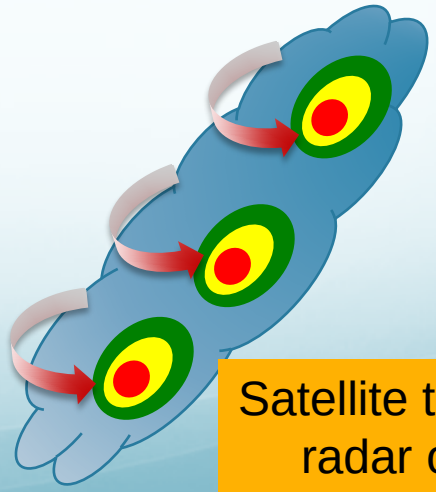


3. Merge satellite and radar storm object metrics

Radar to satellite



Satellite to radar



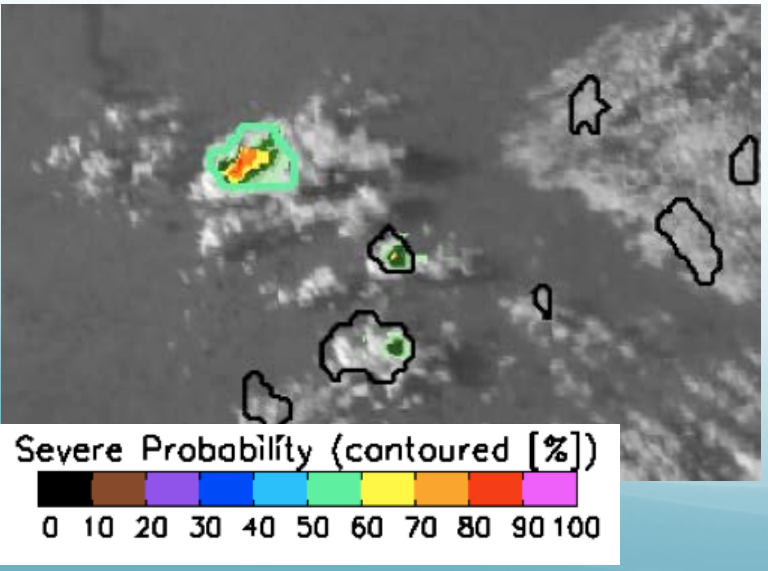
Satellite to multiple radar objects

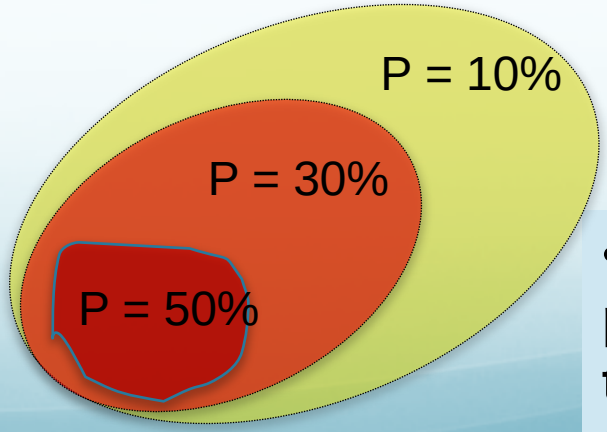
Path Forward

4. Compute probability of severe

- Use a statistical model (e.g. naïve Bayesian, neural network) to compute the probability that a storm will produce severe weather, hail, tornado, high wind, or flash flooding ***in the future*** (probabilistic short-term forecast that adds significant value to traditional radar metrics)

Display as storm referenced probability contour that easily integrates with existing operational AWIPS-II radar displays or construct spatial probability regions





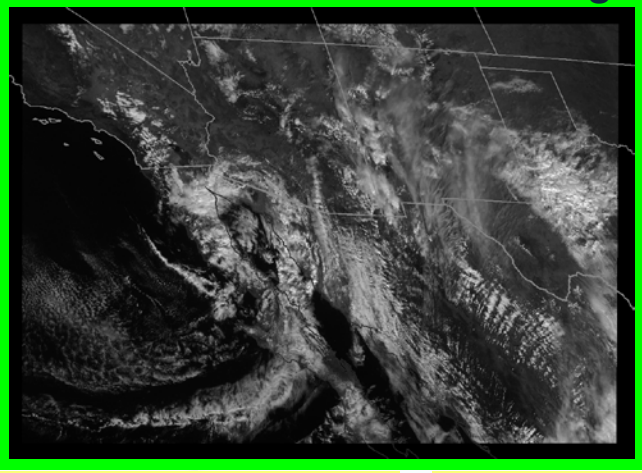
- **End results can possibly contribute to "Warn-on" forecast products.**

Satellite Convective Property NWP Model Data Assimilation

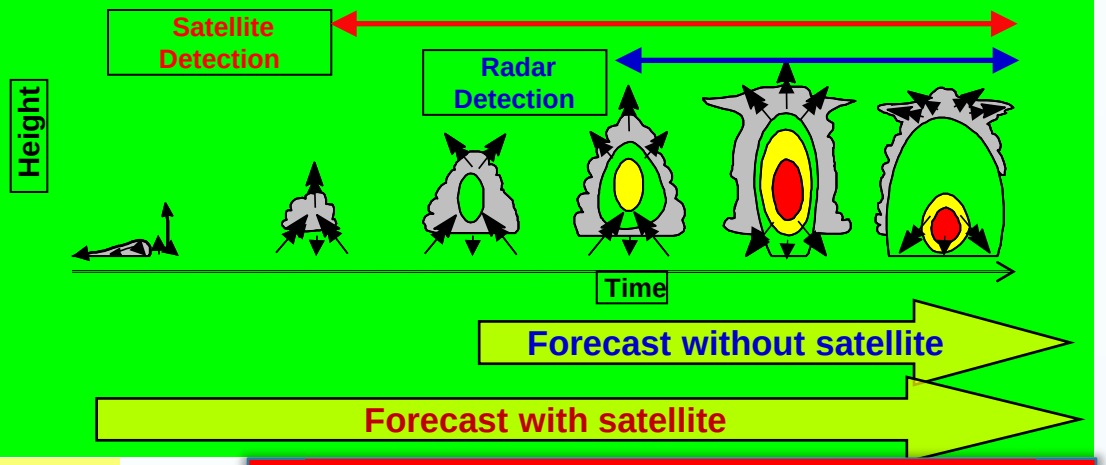
- GOES-R Convective Initiation Future Capability (2013 -)
  - John Mecikalski (UAHuntsville), Chris Jewett (UAHuntsville), GOES-R Risk Reduction Future Capability
  - Andrew Heidinger (NOAA ASPB – Madison, WI) Cloud properties
  - Tracy Smith (CIRA), Steve Weygandt (NOAA ESRL) – WRF data assimilation of convective cloud properties

GOES-R Convective Initiation Flowchart

Download latest satellite imagery…



Monitor Cumulus Cloud Development



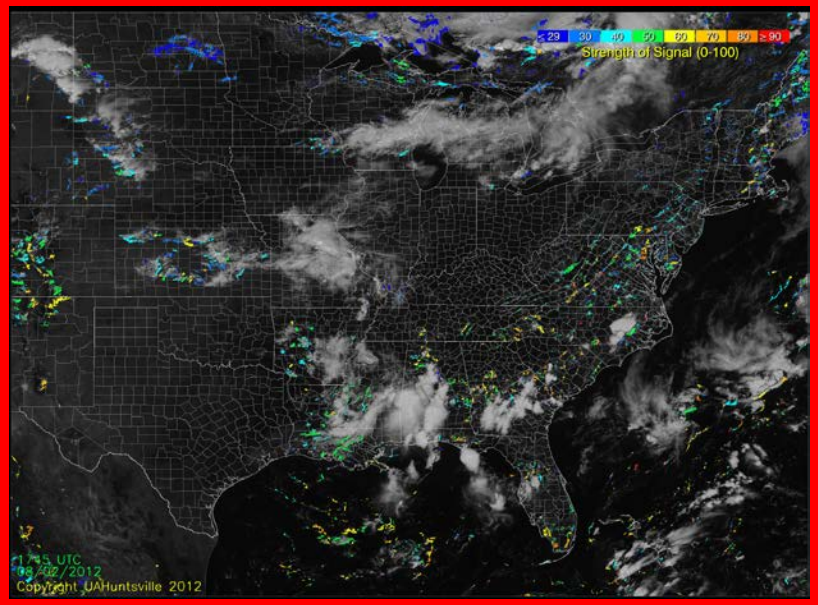
Make Cloud Mask

Produce MAMVs

Track "Cloud Objects" from 'T1' to 'T2' (Similar to "Cb-TRAM" Zinner et al. 2008)

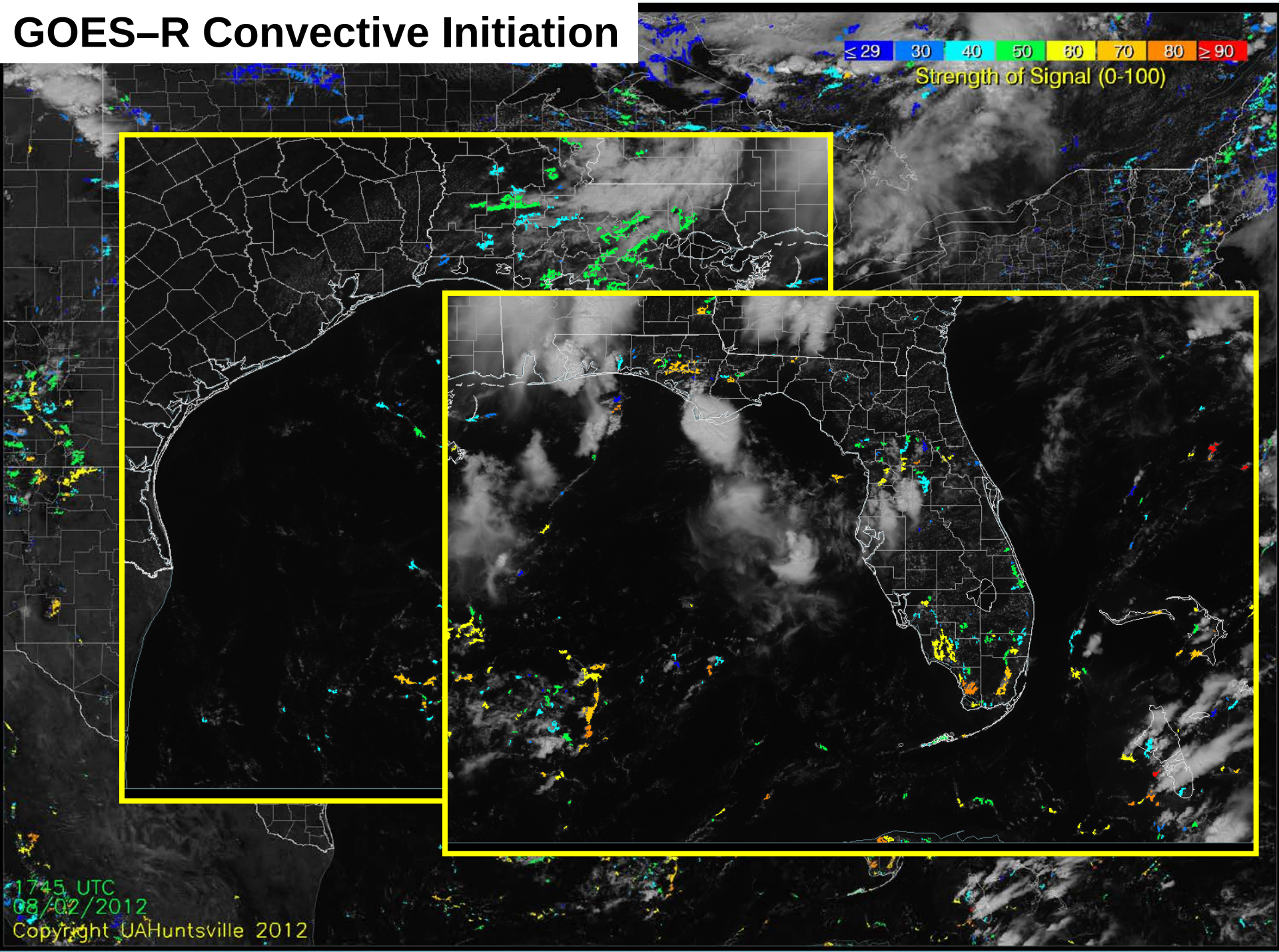
Determine CI forecast for each tracked Cloud Object using 6 spectral/temporal differencing tests (aka: "Interest Fields")

Per-Object CI probability nowcast



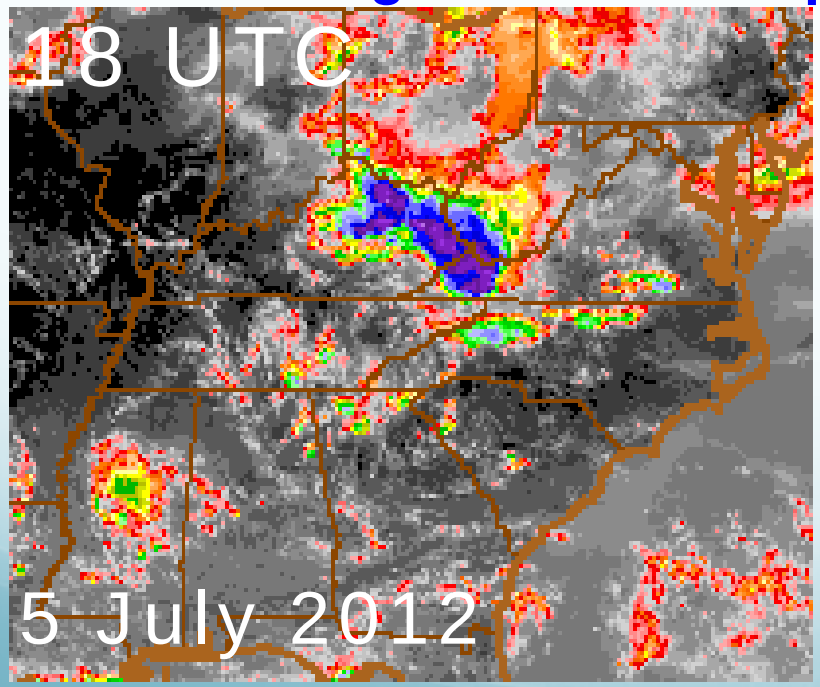
CI Definition: 1st ≥35 dBZ echo at ground, or at –10 ºC altitude

GOES–R Convective Initiation

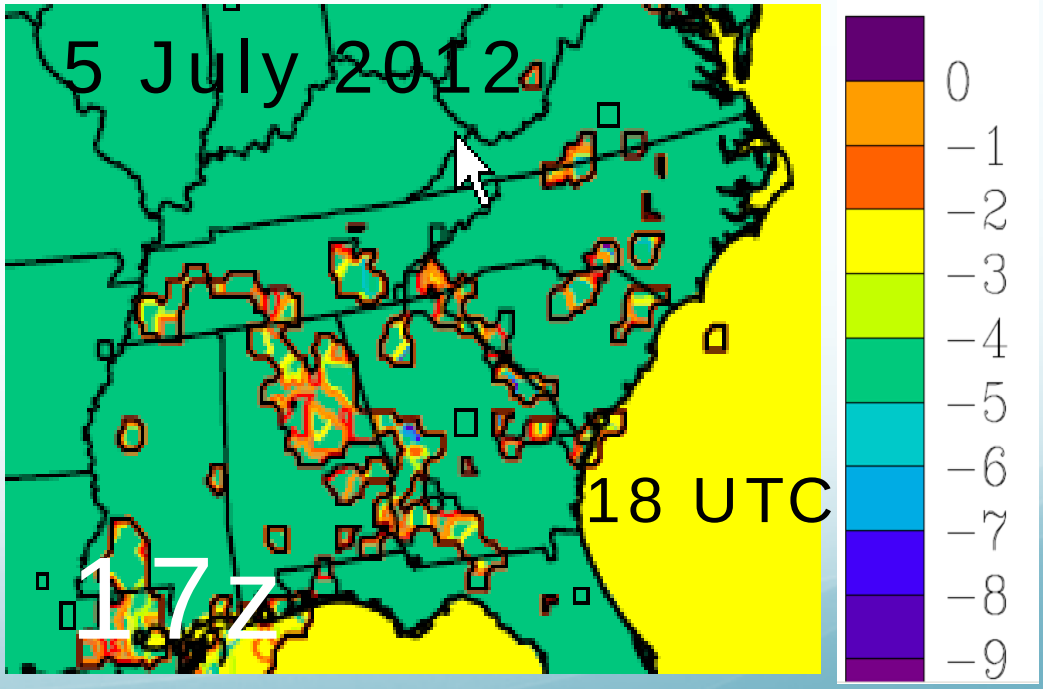


Assimilation of GOES-R CI cloud-top cooling rate and CI-indicator data

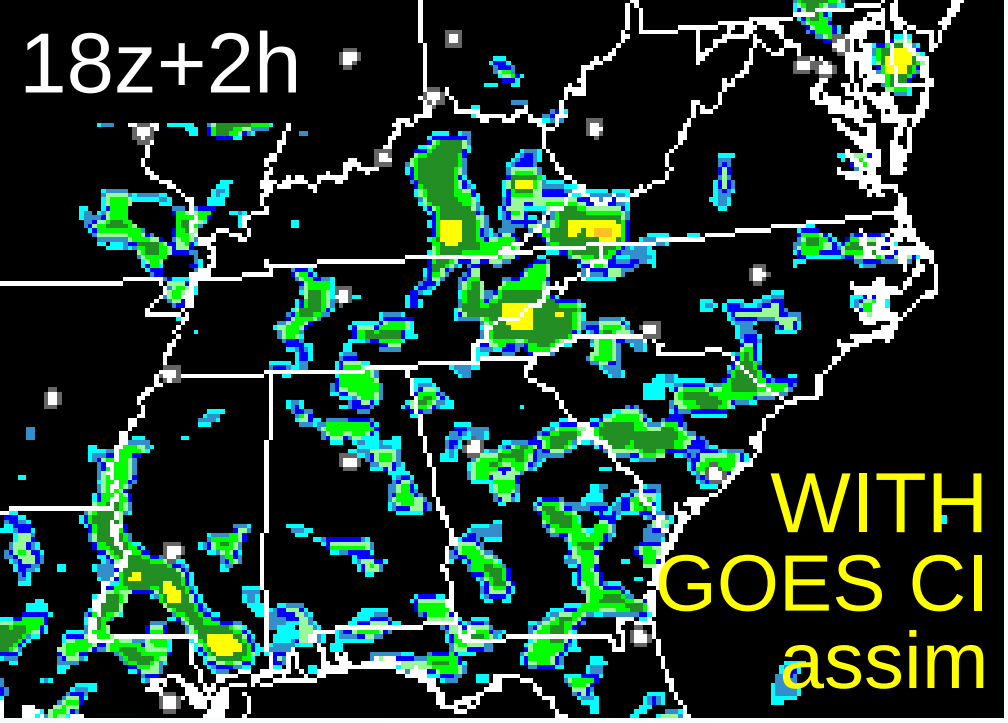
- **First tests show that GOES-R object-focused cloud-top cooling rate helpful for initializing developing convection in GSD RAP retro tests.**
- **Convective storms initialize in "correct" location and time.**
- **Initialization is performed using a digital filter that assigns a latent heating rate to developing convective clouds.**

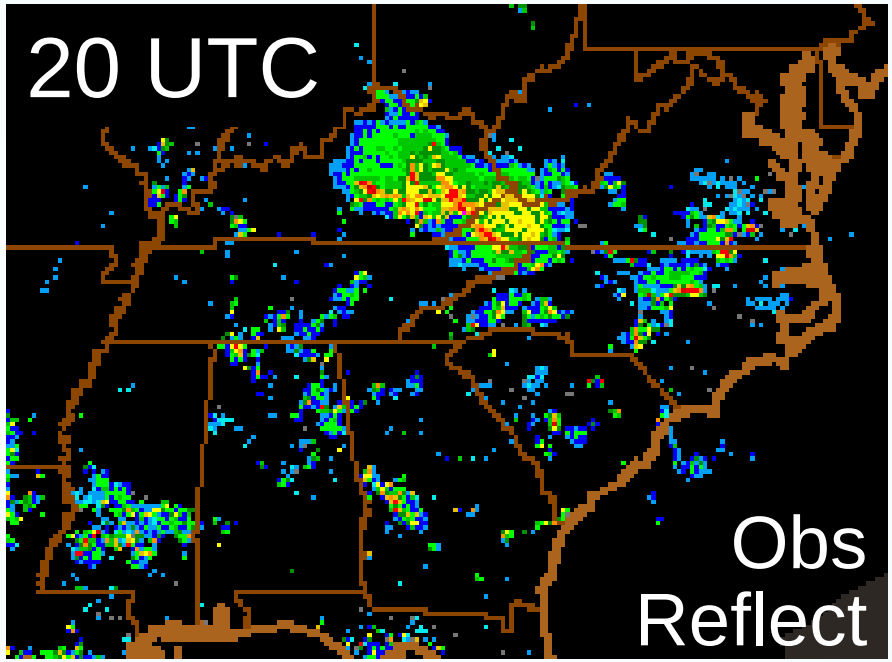


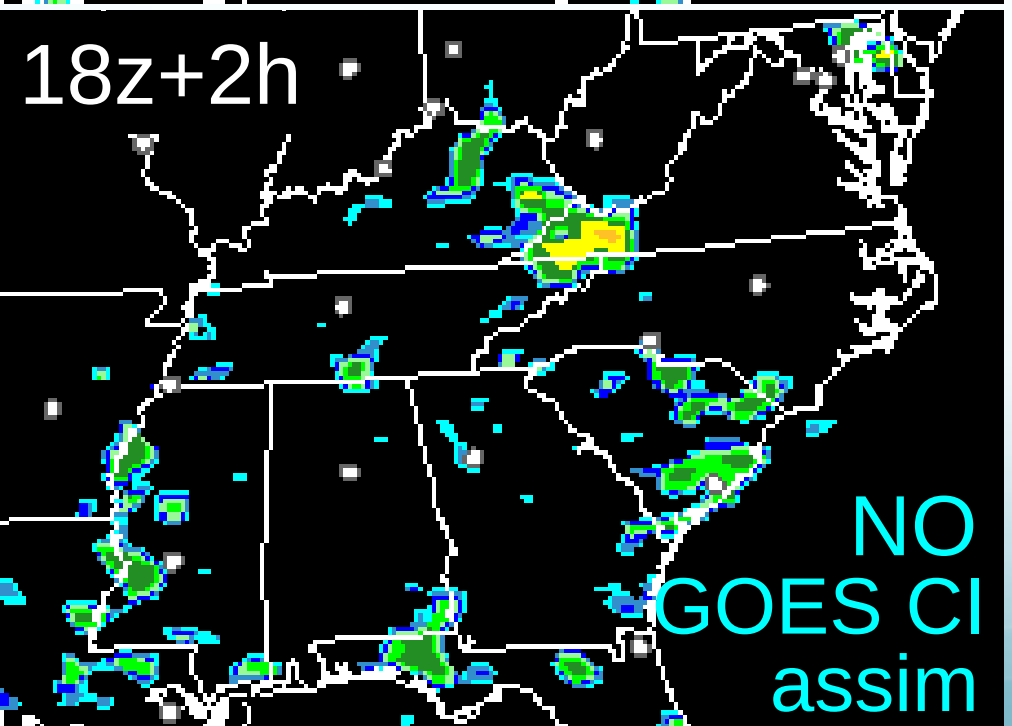
IR image



10.7 μm cooling rate (K / 15 min)







Assimilation of GOES CI cooling rates provide more realistic short-range forecast of convective initiation and development over time periods ≥2 hours

Ongoing Work: Adding Environmental Fields

GOES-R CI (**9**)

- o 10.7 µm & time trend
- o 6.7–10.7 µm
- o 13.3–10.7 µm & time trend

- o Cloud type at t1 and t2 (i.e., cumulus, towering cumulus)
- o Object size at t1 and t2
- o Land or Sea flag

RAP = Rapid Update Numerical Weather Prediction (NWP) model

Environmental from 13 km RAP (**15**)

- o Surface and most unstable convective available potential energy (CAPE)
- o Surface and most stable convective inhibition (CIN)
- o Convective temperature
- o Nearness to convective temperature
- o Surface and best lifted index (LI)
- o Lifted Condensation Level (LCL)
- o Level of Free Convection (LFC)
- o Convective Condensation Level (CCL)
- o 3 layers of Wind Shear
- o Height of Freezing Level

→ Logistic Regression will extend to use 9 GOES-R CI and 15 NWP model fields spring 2013.

Note: Only GOES-R CI data can be assimilated into the RAP, to avoid conflicts with model errors.

Satellite Research to Operations Convective "Toolkit" Summary

- Coordination of satellite convective research spans temporal evolution
- Pre-convective environment derived with LEO/GEO radiances and then Nearcast thermodynamics into future to bridge 1-8 hour nearcast time window
- Focus is on fusing satellite convective signal with all other remotely sensed or in situ data via mature fusion frameworks
    - OU-CIMMS Probabilistic Hazard Information (PHI)
    - WRF HRR data assimilation
- Use GOES-R algorithm derived cloud properties for data assimilation rather than just satellite derived

Recommendations

- Team of satellite, lightning, radar subject matter experts to look at co evolving fields from these observations
- Need a nice large sample. Need to determine value added vs current observing systems- ie, radar
- Focus on convective related field campaigns to allow “shake-down” of current GOES in super rapid scan mode with ground-based (uplooking) and aircraft (downlooking) atmospheric remote sensing of atmospheric state to better understand role of GOES-R/JPSS improved temporal resolution
    - PECAN (NSF proposal)
    - GOES-R Cal/Val?