Use of GOES–R Data to Improve Convective Initiation and 0–6 hour Storm Forecasting

John Mecikalski[1]
Tracy Smith[2]
Stephen Weygandt[3]
Chris Jewett[4]
Steve Wanzong[5]
William Straka[5]
Andrew Heidinger[6]

[1]Atmospheric Science Department
[4]Earth Systems Science Center
University of Alabama in Huntsville
Huntsville, AL USA

[2]CIRA, [3]NOAA Earth Systems Research Laboratory
Boulder, CO USA

[5]CIMSS, [6]NOAA STAR
Madison, WI USA

Supported by:

NOAA GOES-R3 2012
National Science Foundation

Global Systems Division *Assimilation and Modeling Branch*

Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

Satellite Science Week 2014
Madison, Wisconsin, 11 March 2014

Outline

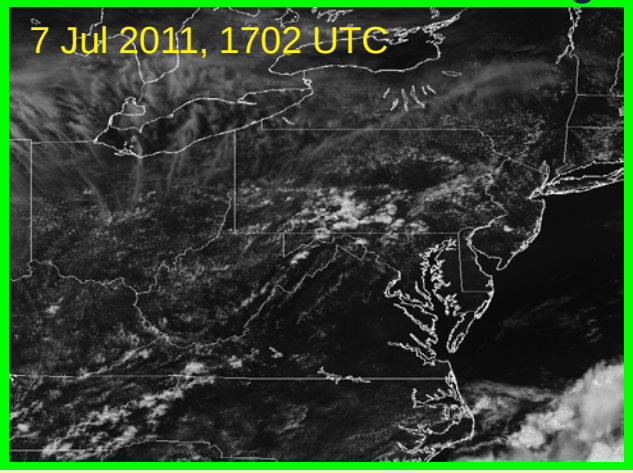
1. Overview of GOES-R Convective Initiation (CI) algorithm, with respect to forecaster feedback.

2. Recent algorithm improvements: Better performance over the GOES–West domain, and through the use of GOES-R Cloud Properties.

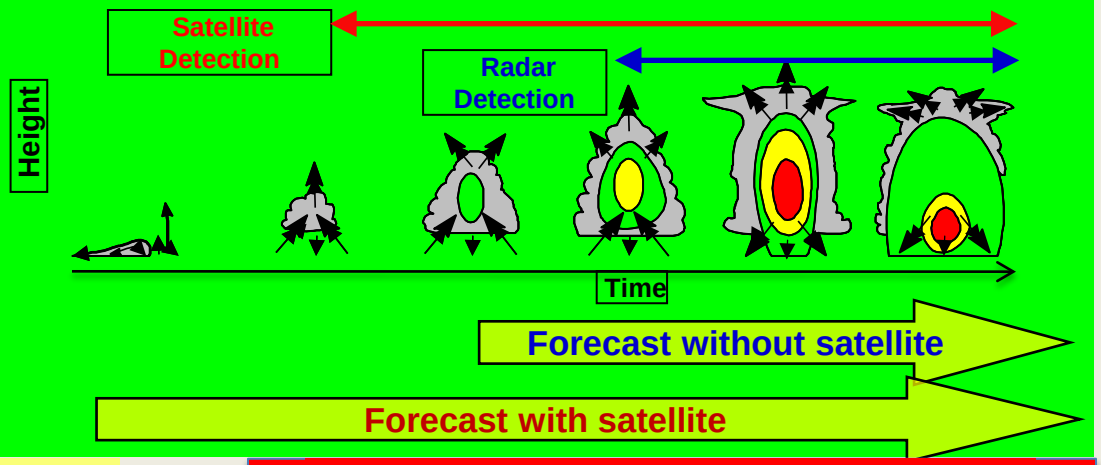
3. Data assimilation research involving the NOAA Rapid Update (RAP) and High Resolution Rapid Refresh (HRRR) models, and enhanced CI forecasts in these models.

GOES-R Convective Initiation Flowchart

Download latest satellite imagery…



Monitor Cumulus Cloud Development



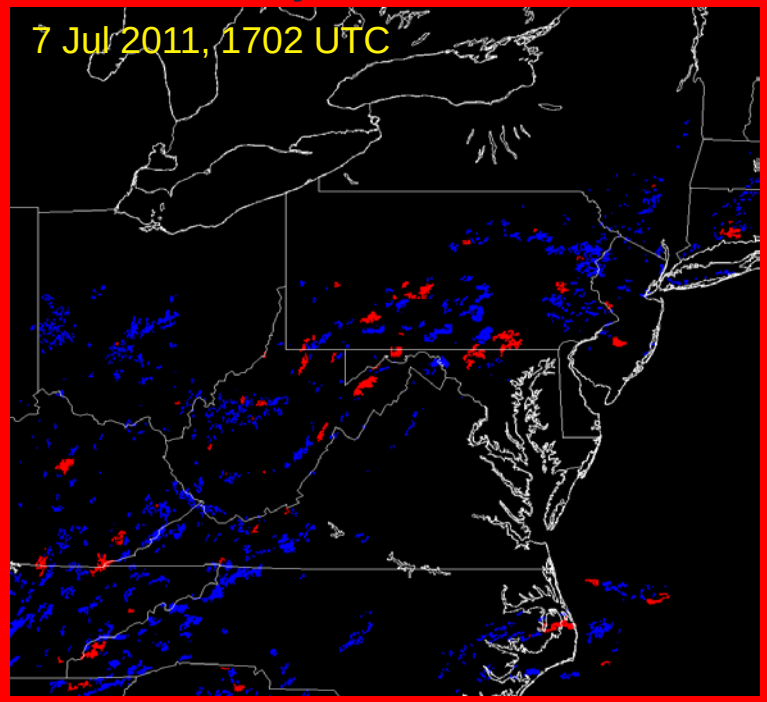
Make Cloud Mask

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 forecast



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

Logistical Regression Approach

Form on database of ~10,000 convective tracked objects, >4500 non-convective tracked objects

Test1: 10.7 μm T_B

Test2: 10.7 μm T_B Time Trend

Test3: 6.5-10.7 μm T_B

~~Test4: 6.5-10.7 μm T_B Time Trend~~

Test5: 13.3-10.7 μm T_B

Test6: 13.3-10.7 μm T_B Time Trend

Logistic Regression: Newton-Raphson Method

$$Pr(CI)=1/(1 + e^{-(3.04 + TEST1*0.0942 - TEST2*0.1391 - TEST3*0.0285 + TEST5*0.3038 - TEST6*0.1196)})$$

	TEST1	TEST2	TEST3	TEST5	TEST6
Standardized coefficients	0.469	–0.504	–0.122	**0.803**	–0.309

Indicators being sampled in CI Nowcasting

SATCAST:

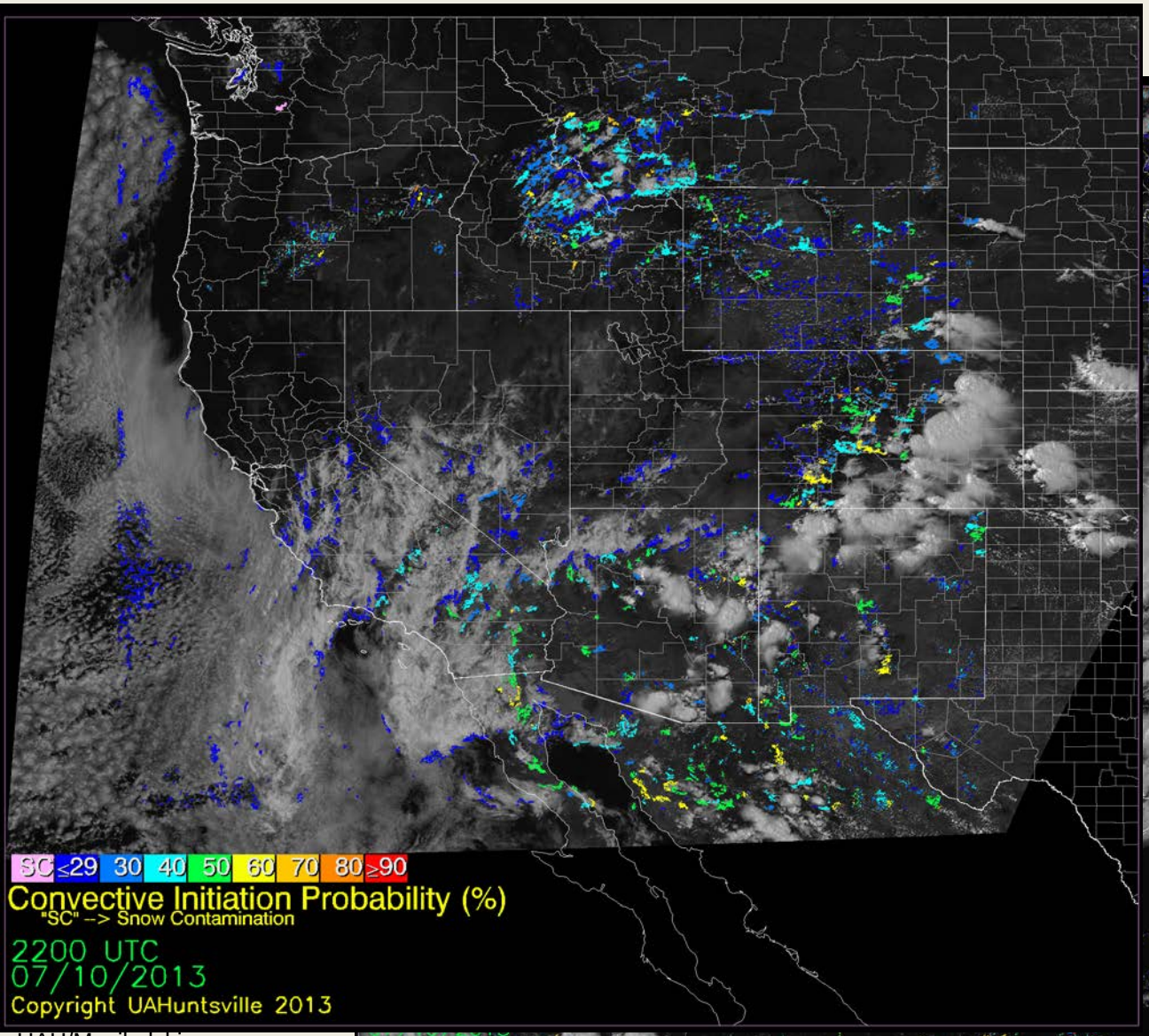
- 10.7 µm T_B
- 15 min 10.7 µm Trends
- 6.7–10.7 µm T_B difference & 15-min trend
- 13.3–10.7 µm T_B difference & 15-min trend
- Convective cloud mask at t1 and t2
- Convective cloud mask change (i.e., cumulus to towering cumulus, cumulus staying cumulus, etc.)
- Object size at t1 and t2
- Change in object size for t1 and t2
- Geographical locations (latitude/longitude)
- Solar time

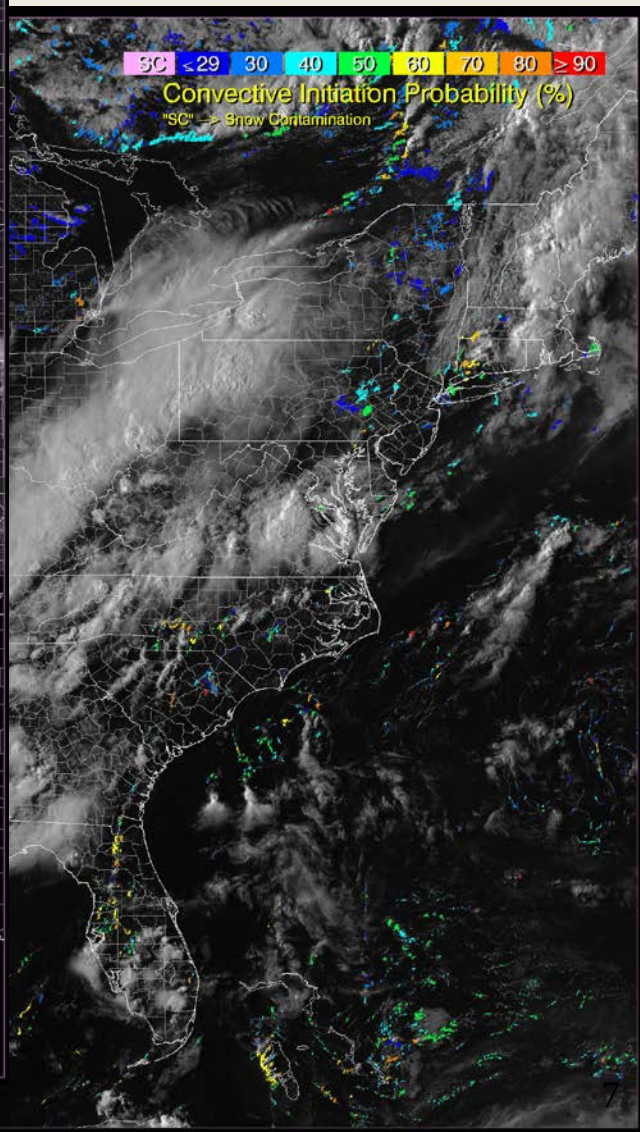
Environmental (**RAP Model**)

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

Use a >10,000 event database

Logistic Regression Probabilistic CI Nowcasts: <u>Satellite & NWP</u>





Copyright UAHuntsville 2013

DWD version of CI Nowcasting

Operational Interest Fields

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

1. 15-minute cooling rate in IR10.8 between time 3 and time2 (between -50 °C and -7.5 °C)
2. 30-minute cooling rate in IR10.8 between time 3 and time 1 (< 15-min cooling)
3. IR10.8 temperature at time 3 (between 253 K and 273 K)
4. Temperature difference WV6.2 – WV7.3 at time 3 (between -6 °C and -15 °C)
5. Temperature difference WV6.2 – IR10.8 at time 3 (between 0 °C and -20 °C)
6. Temperature difference IR8.7 – IR10.8 at time 3 (between -3 °C and -10 °C)
7. 15-minute trend of IR8.7 – IR10.8 between time 3 and time 2 (between 0.4 °C and 10 °C)
8. 15-minute trend of tri-channel difference(*) between time 3 and time 2 (between 0.5 °C and 10 °C)
9. 15-minute trend of WV6.2 – WV7.3 between time 3 and time 2 (between 0.2 °C and 10 °C)
10. 30-minute trend of WV6.2 – WV7.3 between time 3 and time 1 (between 0.6 °C and 10 °C)

(*):"tri-channel difference" is the temperature difference (IR8.7-IR10.8) – (IR10.8-IR12.0)

In Preparation for GOES–R

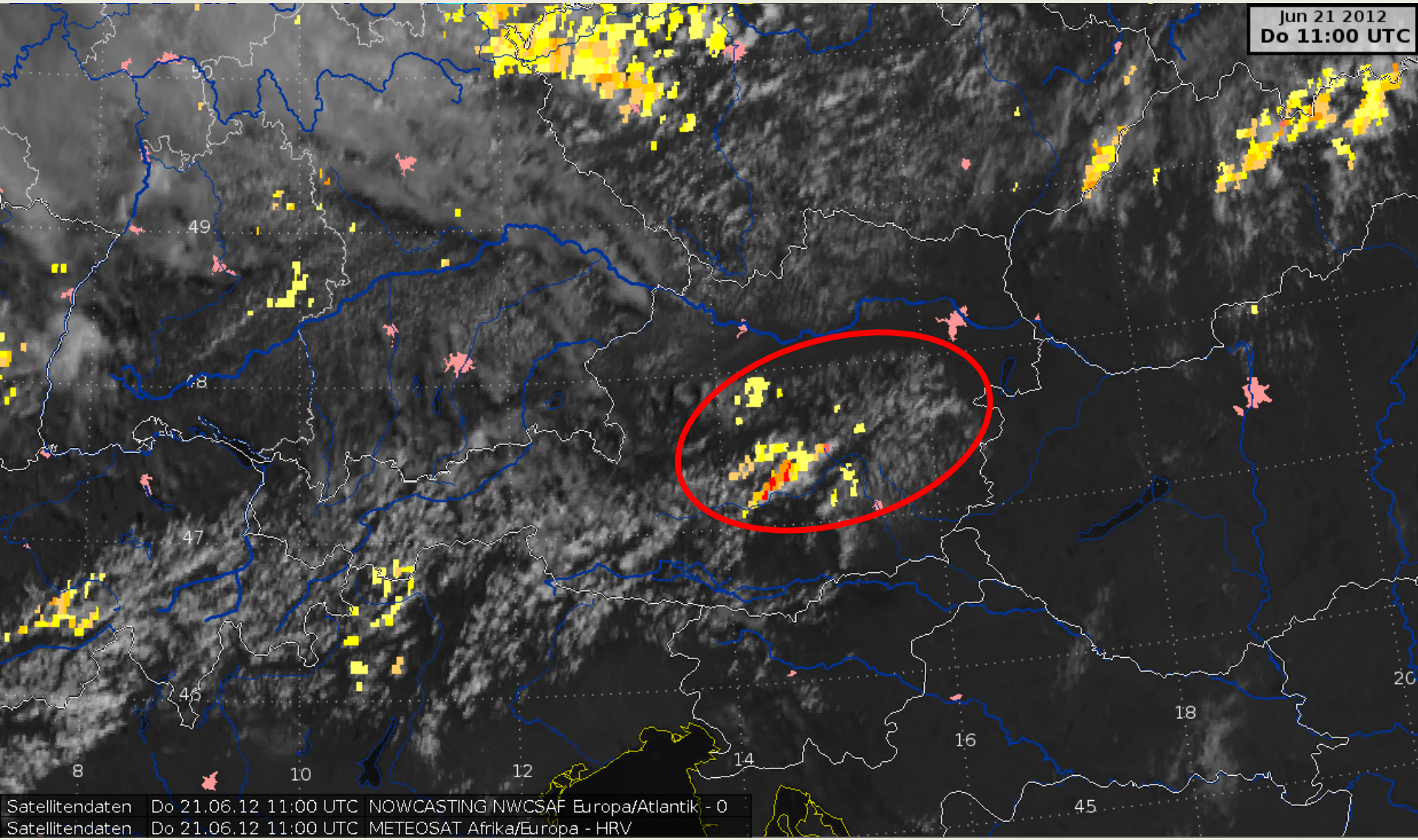
– Mecikalski et al. (2010a,b)
– Siewert et al. (2011)
– Mecikalski et al. (2013)

courtesy
Pierre Fritzsche
DWD

Around Noon: Rapidly Growing Cumulus

MSG HRV + CI-Produkt (pre-operational)

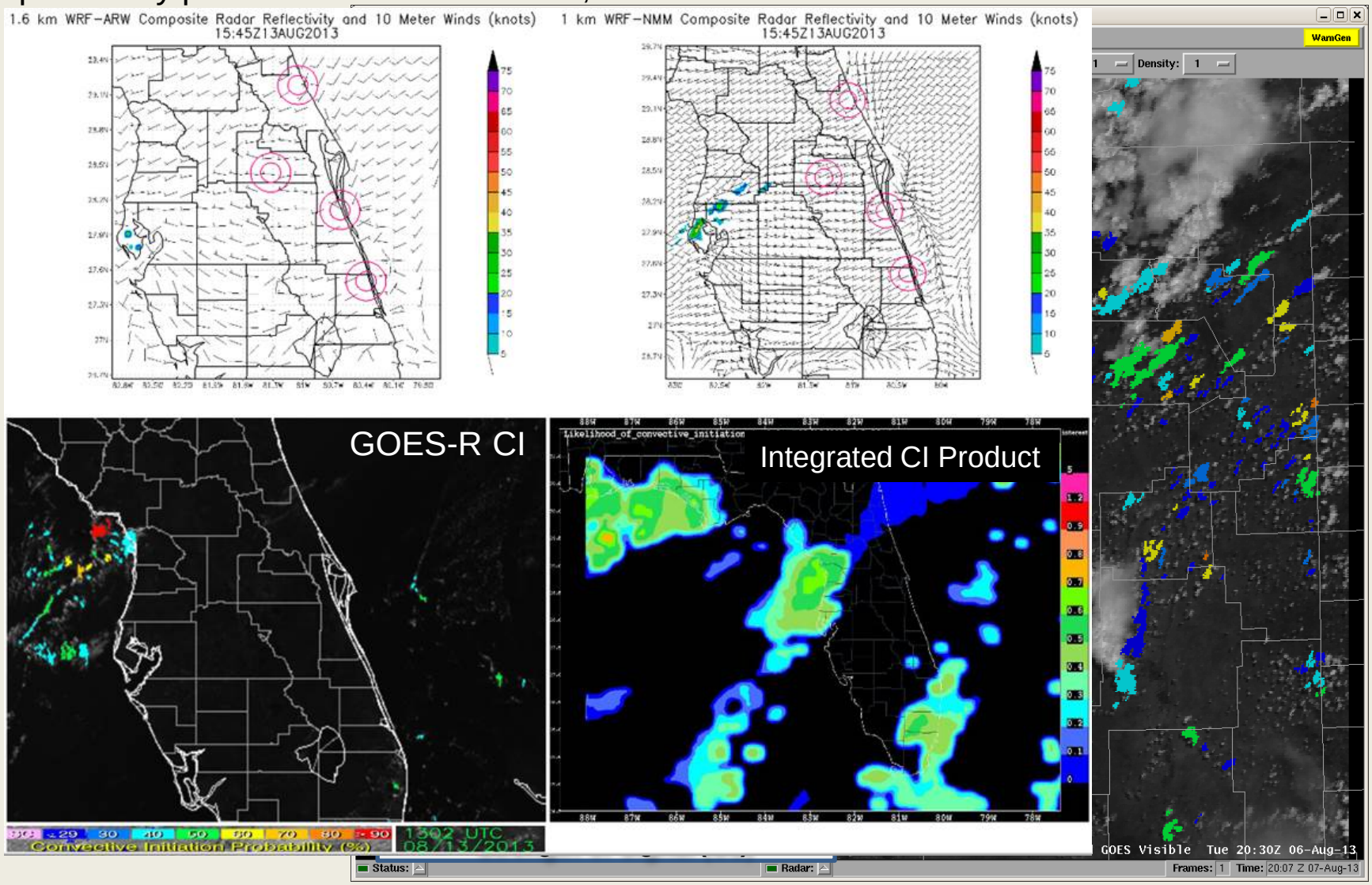
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Folie: H.J.Koppert

GOES-R CI AWIPS Display & Products

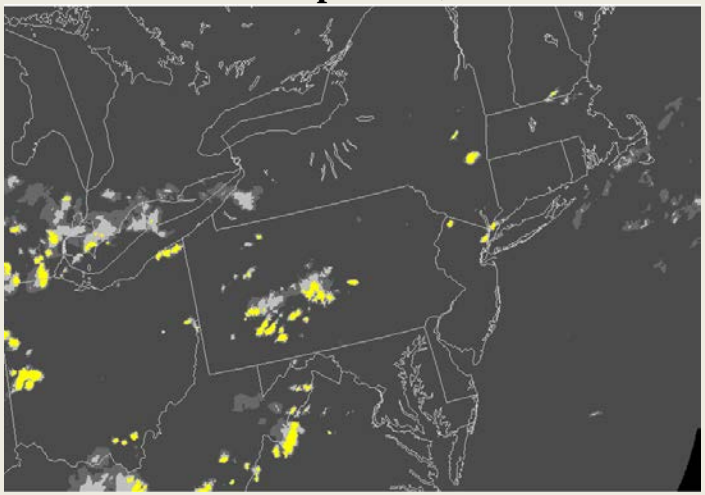
GOES-R CI plus WRF model and radar output combined to make a “CI probability product”. NWS Melbourne, FL USA



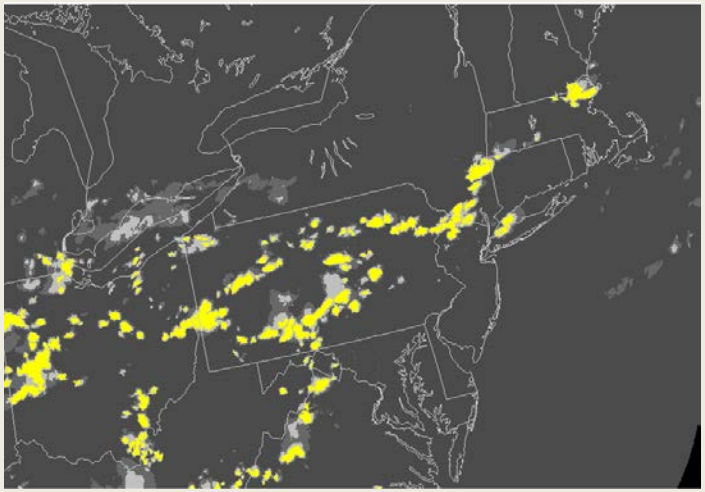
CI Forecast Example

FAA Corridor Integrated Weather System

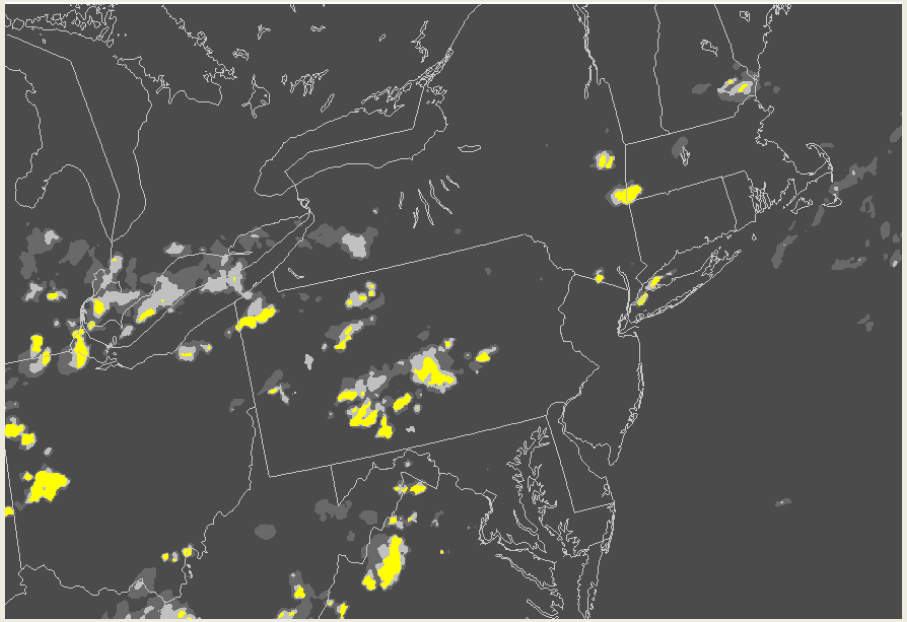
Radar Precipitation, Time 0



Radar Precipitation, Time +60 Minutes



60 Minute Forecast (Original SATCAST)



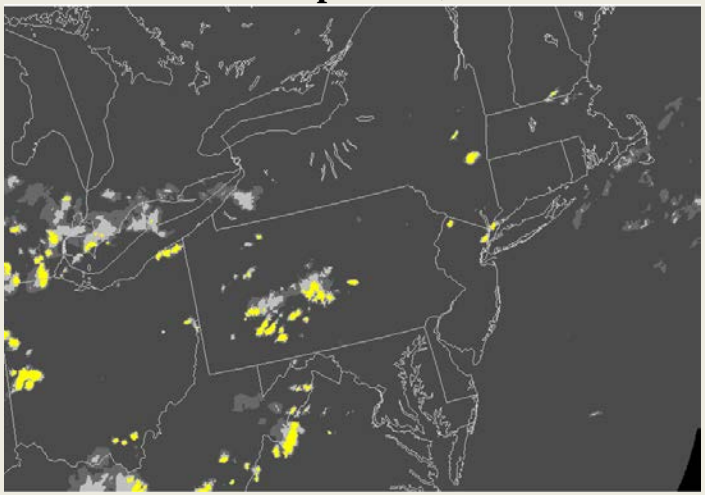
Regions of Aviation-impacting Weather

Valid: 18 July 2012 at 1630 UTC

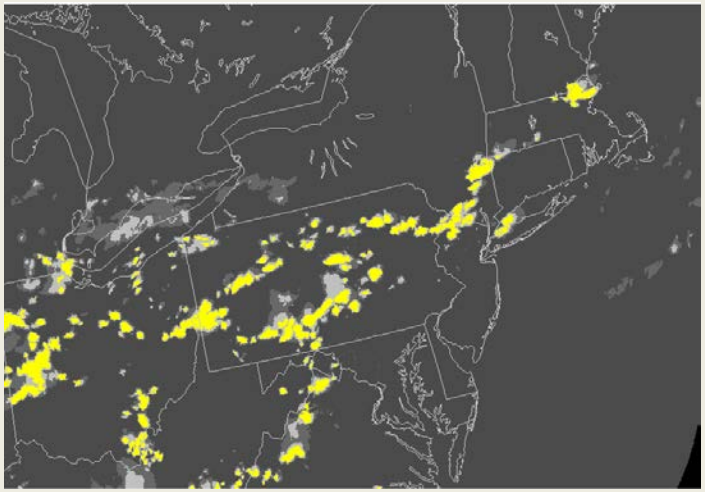
CI Forecast Example

FAA Corridor Integrated Weather System

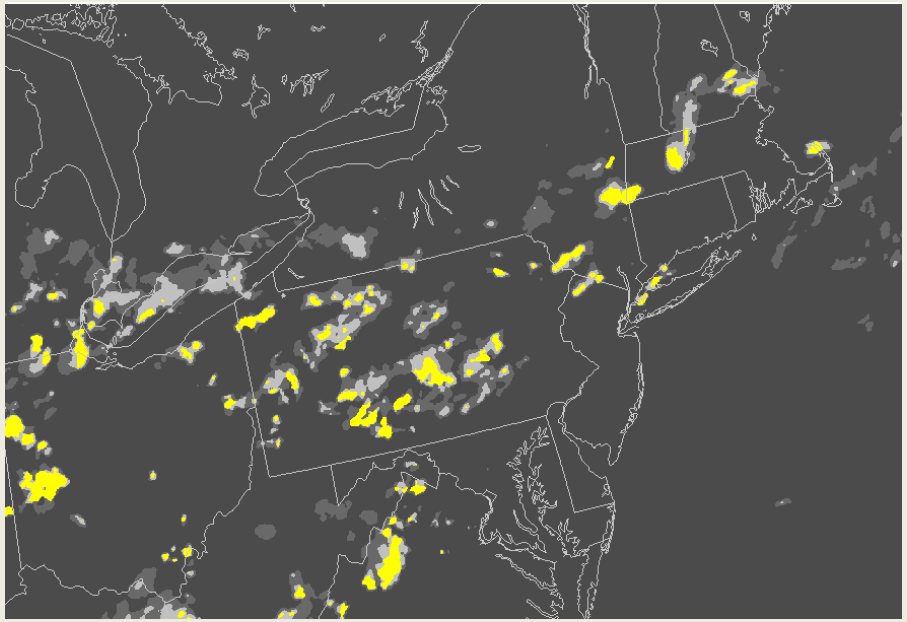
Radar Precipitation, Time 0



Radar Precipitation, Time +60 Minutes



60 Minute Forecast (Random Forest)



Regions of Aviation-impacting Weather

Valid: 18 July 2012 at 1630 UTC

Outline

1. Overview of GOES-R Convective Initiation (CI) algorithm, with respect to forecaster feedback.

2. Recent algorithm improvements: Better performance over the GOES–West domain, and through the use of GOES-R Cloud Properties.

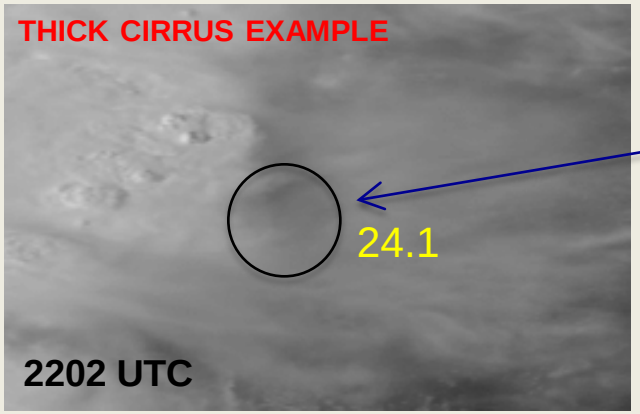
3. Data assimilation research involving the NOAA Rapid Update (RAP) and High Resolution Rapid Refresh (HRRR) models, and enhanced CI forecasts in these models.

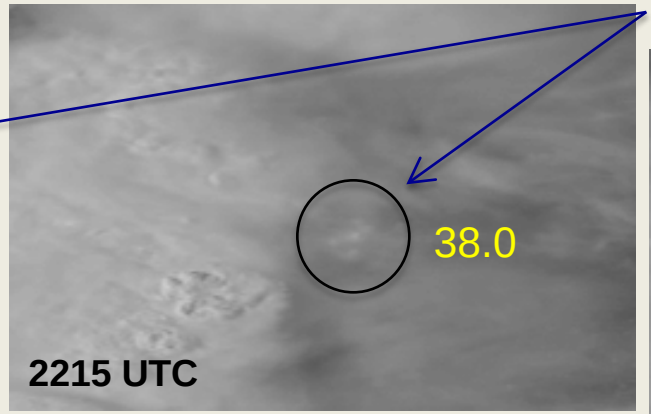
Study: Detecting CI Beneath Cirrus Clouds

Mecikalski et al. (2013) – Insights into detecting the “CI beneath cirrus” problem

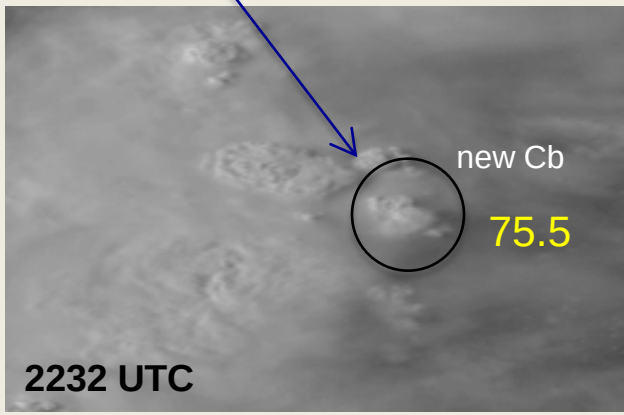
Goal: Evaluate the parameters of visible optical depth (VOD), liquid water path (LWP), as related to cloud effective pressure, for cumulus growing beneath cirrus.

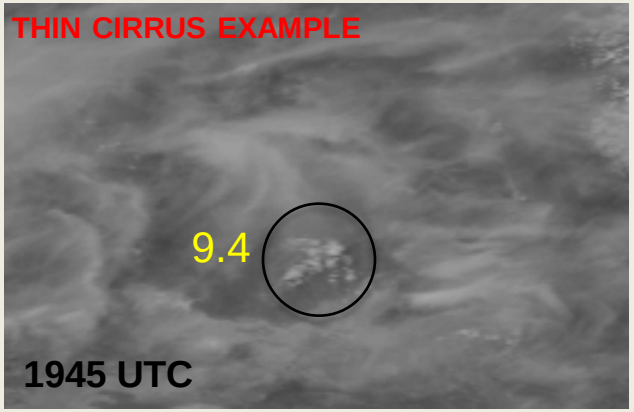
Result: When VOD is <15, infrared fields can be used similar to in clear sky conditions to nowcast CI.

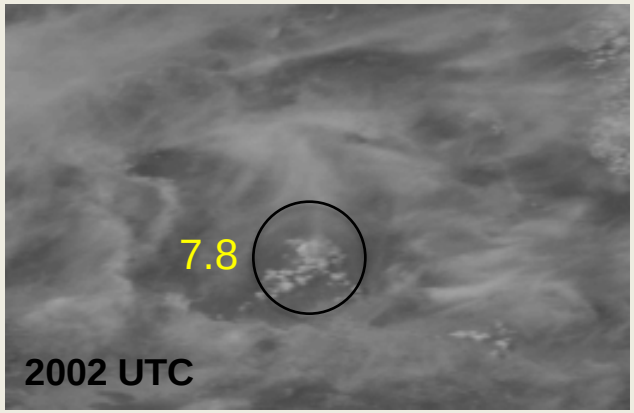


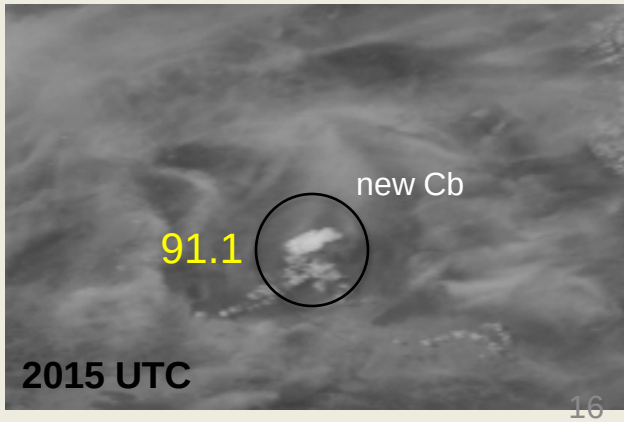


CI Event









Use of GOES Cloud Properties

Initial τ	01–10	11–20	21–30	31–40	41–50	>50
Events:	89	63	37	15	11	33
Reflectance (ρ)	0.38	0.62	0.73	0.77	0.79	0.89
T_B	261.6	244.3	232.8	236.7	239.0	232.1
Emissivity (ε)	0.011	1.001	1.002	0.993	1.001	1.003
Cloud water path (CWP)	0.07	0.23	0.53	0.72	0.78	1.75
Optical depth (τ)	5.0	14.2	24.3	33.5	44.0	89.7
Effective radius	19.5	26.9	34.7	28.6	29.9	30.8
Cloud top height (C_z)	6.7	9.9	11.5	11.2	11.0	11.1
	5.9	8.5	10.1	9.7	9.6	9.8
	4.7	5.1	5.7	5.2	4.7	4.3
30-min trend ρ	0.30	0.19	0.11	0.04	0.15	−0.02
30-min trend ε	0.508	−0.024	−0.004	0.008	0.000	−0.002
30-min trend τ	34.9	47.8	52.8	29.4	55.4	0.4
30-min trend CWP	0.69	1.02	1.23	0.58	1.24	0.17
30-min trend C_z	3.1	1.1	0.7	0.5	1.2	1.1
30-min trend T_B	−19.6	−12.1	−4.9	−3.2	−10.4	−7.7

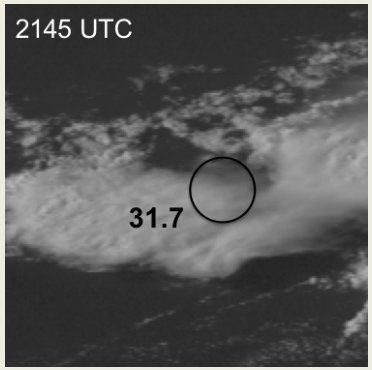
- Cloud properties are useful if the optical depth of higher clouds (cirrus) are less than ~20, and especially if <10.

- Time trends of cloud properties are valuable for detecting convective cloud growth (purple highlighted region).

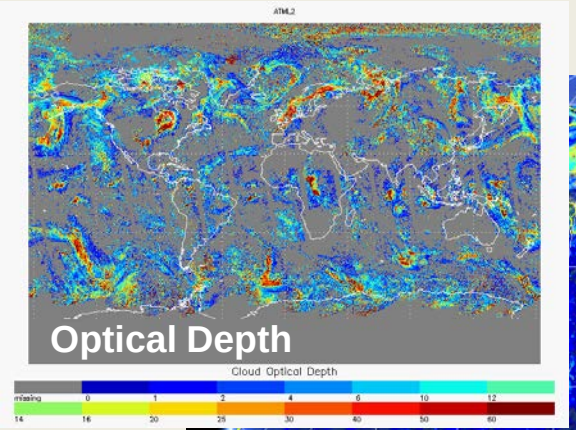
Mecikalski et al. (2013)

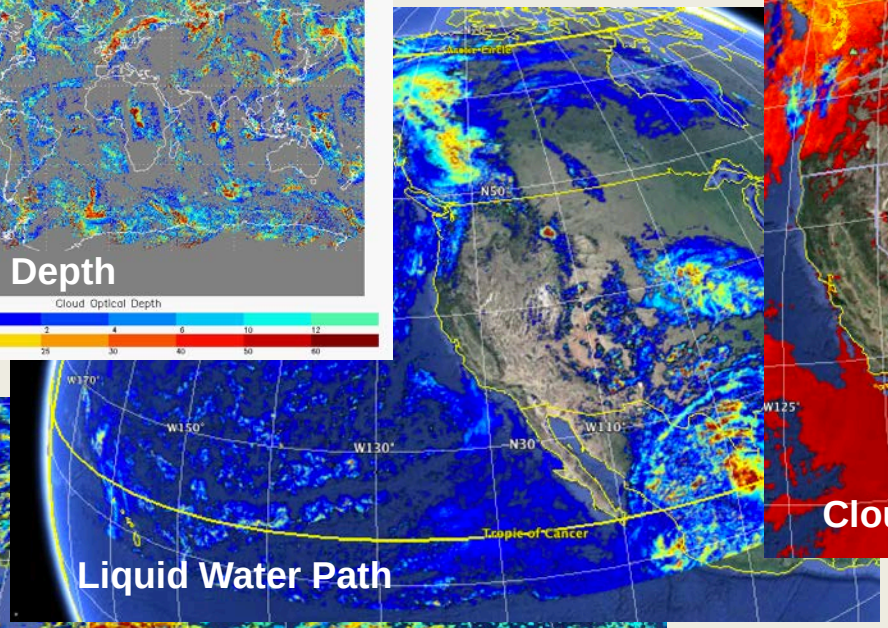
- The goal is to detect convective initiation is less than optimal situations, as shown to the right.

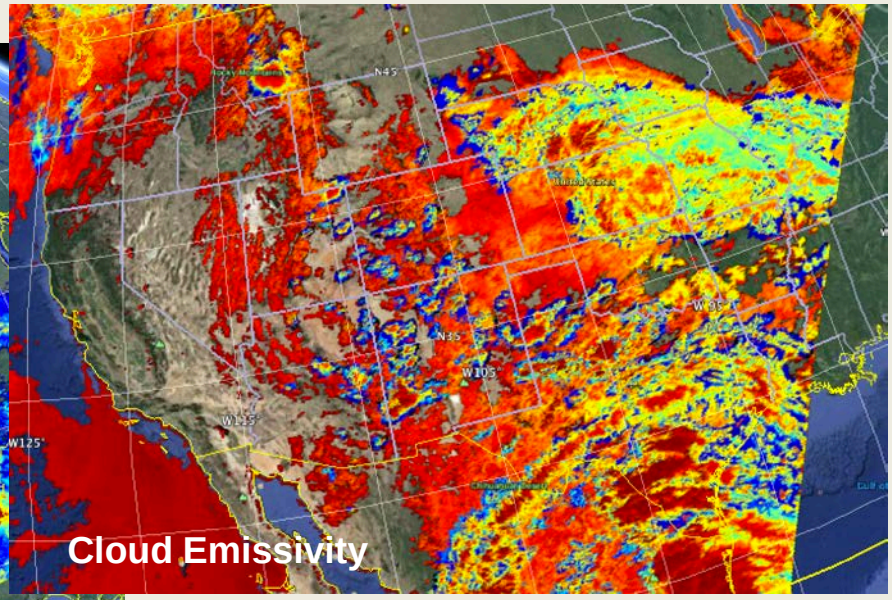
29 May 2011

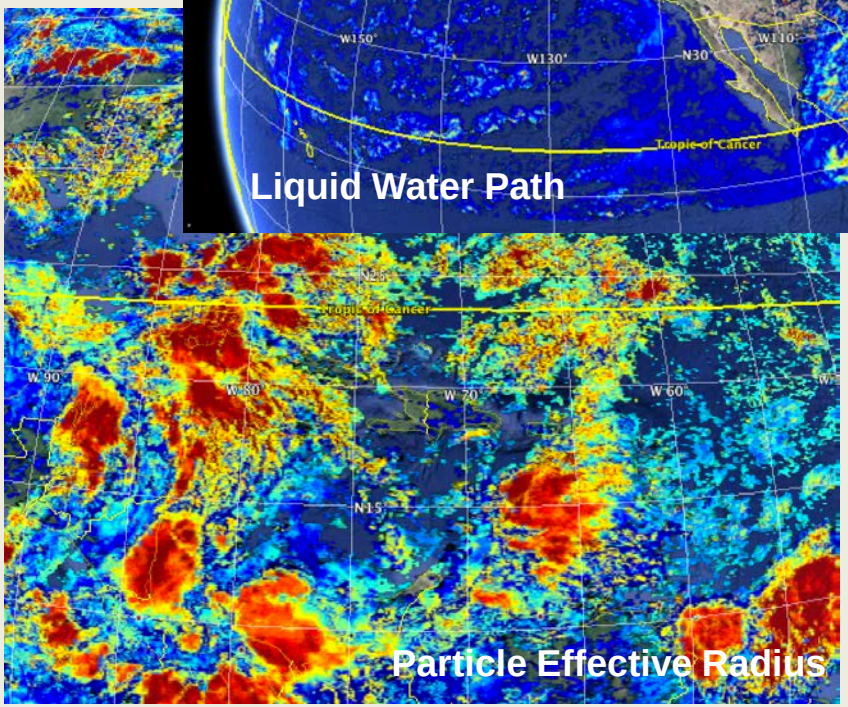


GOES-R Derived Cloud Properties









CLAVR-x generated cloud properties, for GOES-R. Done at the University of Wisconsin–Madison, CIMSS.

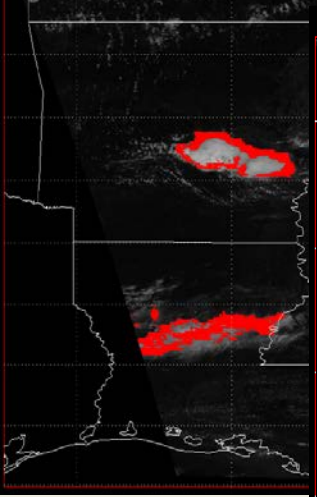
Walther and Heidinger (2012)
Walther et al. (2011)

http://cimss.ssec.wisc.edu/clavr/google_earth_main.html

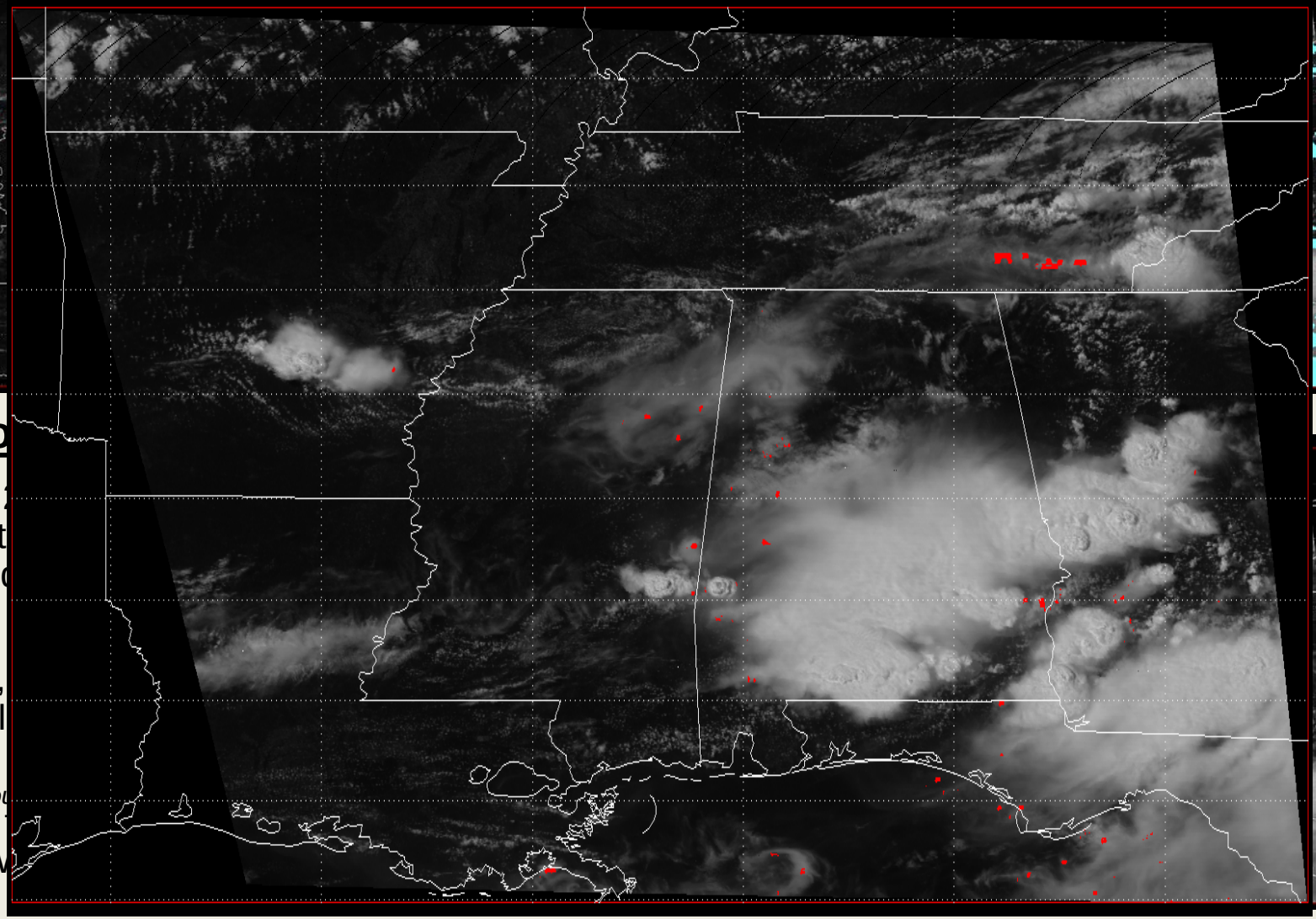
Detecting CI Beneath Thin Cirrus

Determine locations of “thin” cirrus from cloud mask and optical depth properties

Thin cirrus from Berendes et al. (2008) mask



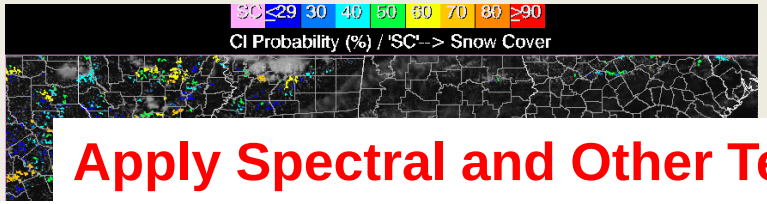
Cirrus with optical depth <30 (cyan), >30 (red)

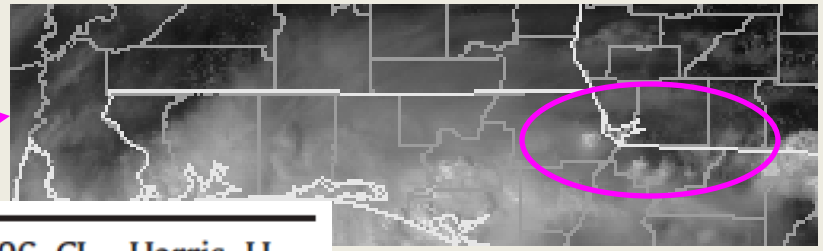


Methodolo

- Run a 20 x 2
  the criteria t
  the surroun
- Use results
  et al. (2011,
  pixel optical
- If $\tau > 2\sigma_{surrou}$
  object, and
  continues (V

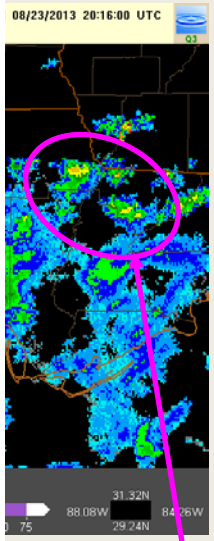
Detecting CI Beneath Thin Cirrus



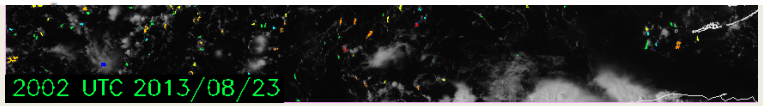


Apply Spectral and Other Tests

Initial τ	01–10	11–20	21–30	MB06_CI	Harris_LI
Events	89	63	37		
ρ	0.38	0.62	0.73	n/a	<0.11
30-min ρ trend	0.30	0.19	0.11	n/a	≤ -0.04[b]
T_B	261.6	244.3	232.8	<273	<273
30-min T_B trend	−19.6	−12.1	−4.9	<−4	≤ -12[b]
$T_{3.9-10.7\,\mu m}$	20.1	22.0	24.2	n/a	<17
$T_{6.5-10.7\,\mu m}$	−25.9	−12.9	−6.5	−35 to −10	≥−30
$T_{13.3-10.7\,\mu m}$	−14.8	−7.7	−4.3	−25 to −10	≥−13
30-min $T_{3.9-10.7\,\mu m}$ trend	4.9	2.7	2.7	n/a	>3[b]
30-min $T_{6.5-10.7\,\mu m}$ trend	12.5	4.7	1.7	>6[a]	>10[b]
30-min $T_{13.3-10.7\,\mu m}$ trend	7.3	2.4	1.1	>6[a]	>8[b]



CI detection, with objects that are of a size appropriate for convective clouds.



Outline

3. Data assimilation research involving the NOAA Rapid Update (RAP) and High Resolution Rapid Refresh (HRRR) models, and enhanced CI forecasts in these models.

Goals:

(1) Incorporate a satellite-estimated "CI signal" into the initial condition/analysis with the hope that convective storm develop and evolve in the model at the correct location, and at the correct time.

(2) Form an optimal procedure for translating a "cloud growth" signal to a latent heating profile, that the NWP model subsequently adjusts to (in terms of mass and momentum).

Use only GOES infrared fields.

Hourly Updated NWP Models

13km Rapid Refresh (RAP) (mesoscale)

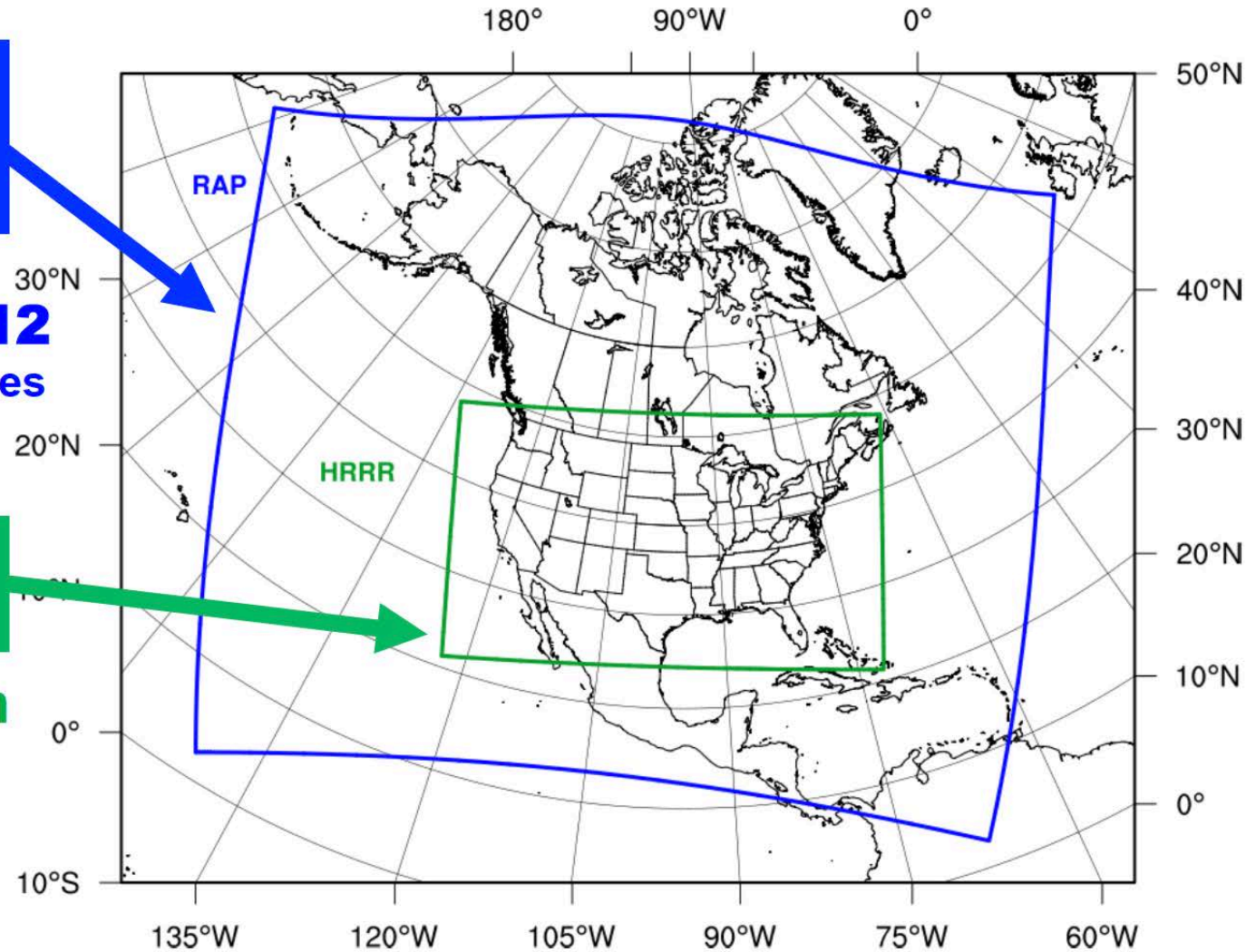
Replaced RUC at NCEP 05/01/12

WRF, GSI, RUC features

3km HRRR (storm-scale)

High-Resolution Rapid Refresh

Experimental 3km nest inside RAP, hourly 15-h fcst

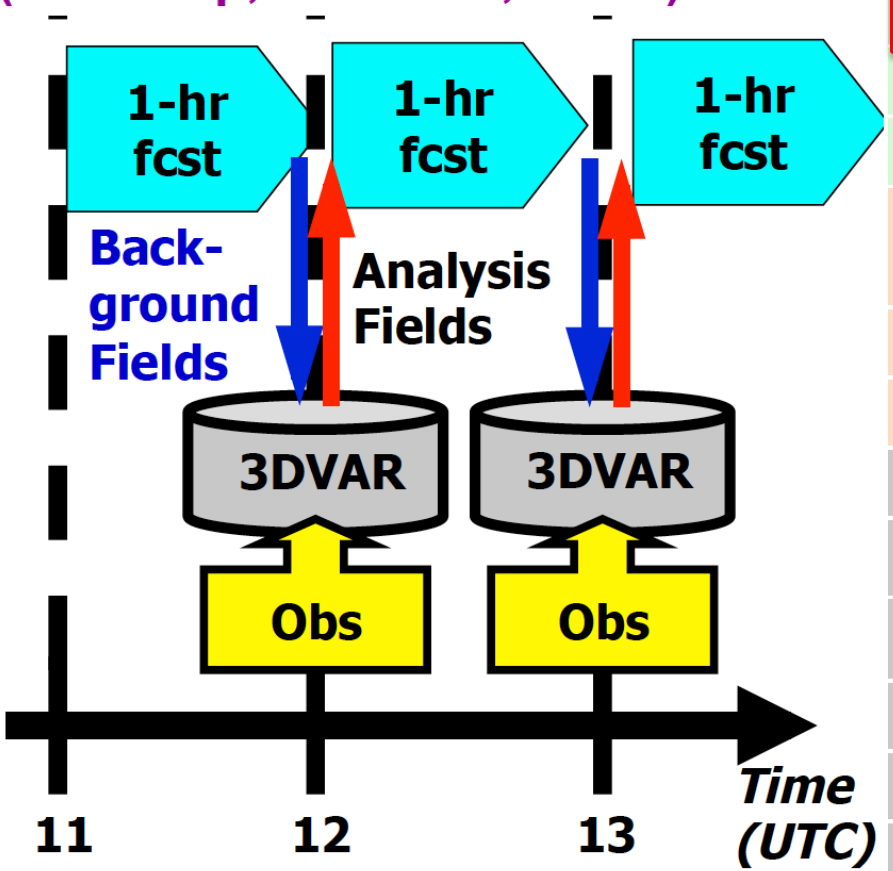


Rapid Refresh
Hourly Update Cycle

Partial cycle atmospheric fields – introduce GFS information 2x/day

Cycle hydrometeors

Fully cycle all land-sfc fields (soil temp, moisture, snow)



Hourly Observations	RAP 2013 N. Amer
Rawinsonde (T,V,RH)	120
Profiler – NOAA Network (V)	21
Profiler – 915 MHz (V, Tv)	25
Radar – VAD (V)	125
Radar reflectivity - CONUS	1km
Lightning (proxy reflectivity)	NLDN, GLD360
Aircraft (V,T)	2-15K
Aircraft - WVSS (RH)	0-800
Surface/METAR (T,Td,V,ps,cloud, vis, wx)	2200- 2500
Buoys/ships (V, ps)	200-400
Mesonet (T, Td, V, ps)	flagged
GOES AMVs (V)	2000- 4000
AMSU/HIRS/MHS radiances	Used
GOES cloud-top press/temp	13km
GPS – Precipitable water	260
WindSat scatterometer	2-10K
Nacelle/Tower/Sodar	20/100/10

RAP Digital Filter-based technique for assimilating atmospheric convection / precipitation indicators

➔ Radar reflectivity ➔ Lightning
➔ Satellite cloud-top cooling rate (CI)

- Diabatic digital filter initialization used in 13 km resolution RAP to control noise for hourly cycling
- Involves time averaging of model states from backward and forward model integrations
- For assimilation, replace model temperature tendencies with those derived from observations

(radar reflectivity, lightning, satellite cooling)

RAP Digital Filter Assimilation

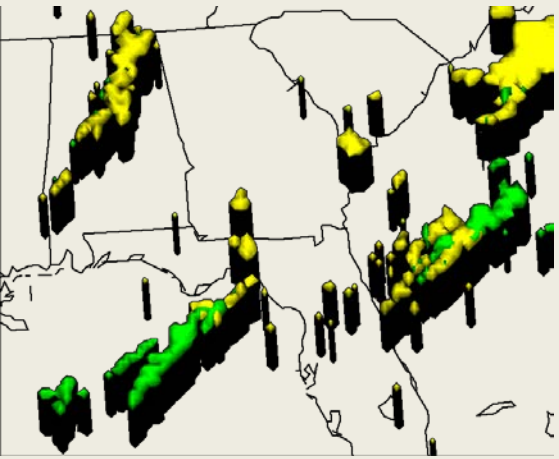
Digital filter-based assimilation initializes ongoing / developing convection / precipitation regions

Use for following obs types:

- ➔ **Radar reflectivity**
- ➔ **Lightning**
- ➔ **Satellite cloud-top cooling rate**

-20 min **-10 min** **Initial** **+10 min** **+ 20 min**

Backwards integration, no physics



Forward integration,full physics with obs-based latent heating

Initial fields with improved balance, storm-scale circulation

RAP / HRRR model forecast

Diabatic Digital Filter Initialization (DDFI)

1. Translate GOES cloud-top cooling signature into latent heating rates.

2. Heating rate should be proportional to updraft strength, consistent with cumulus convection

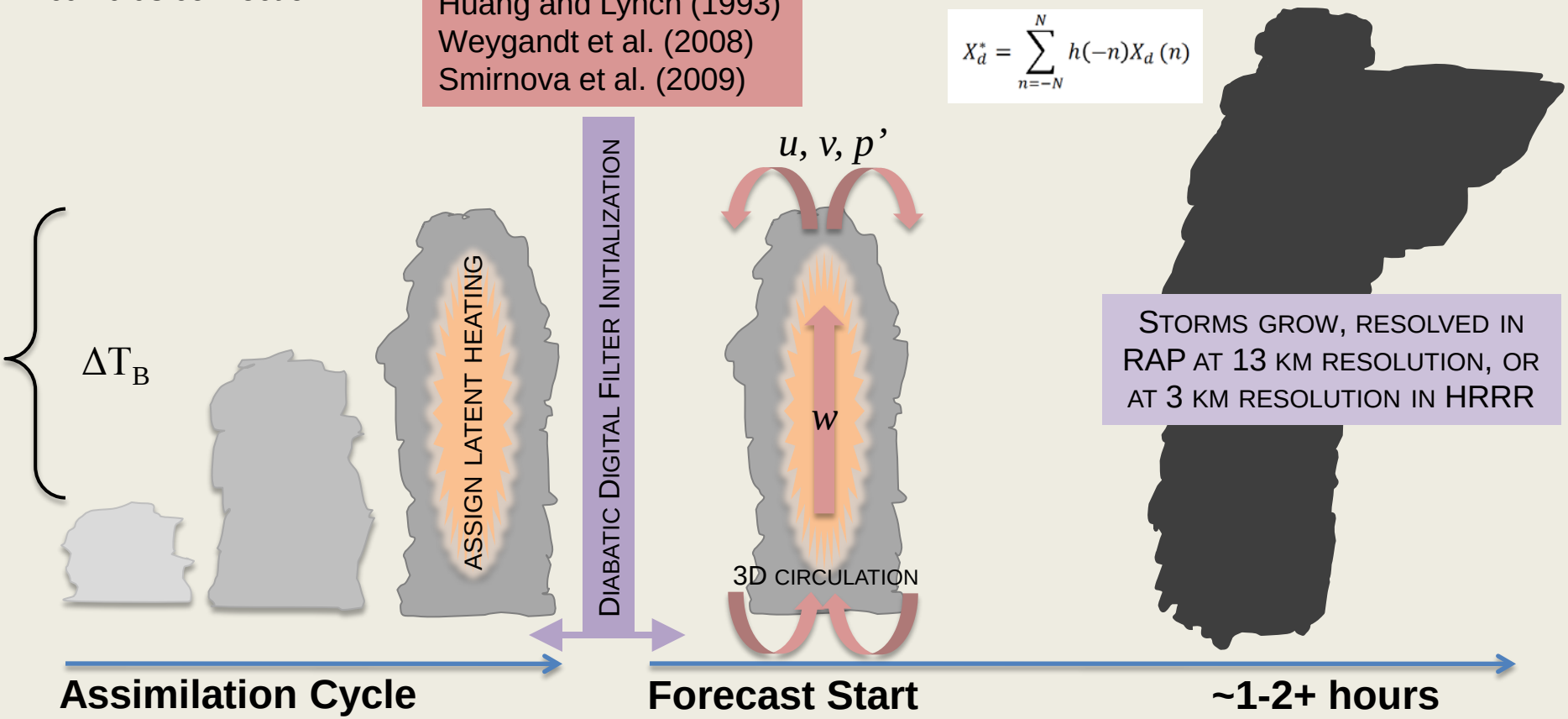
3. In RAP model form a 3D circulation that then preserves convective feature

4. DDFI is applied to a short time series generated by model integration of the initial data. The model is integrated diabatically forward, and then adiabatically backward, forming a centered time series, $X_d(n)$.

5. The filtered model state time series, X_d^* then initializes the forecast.

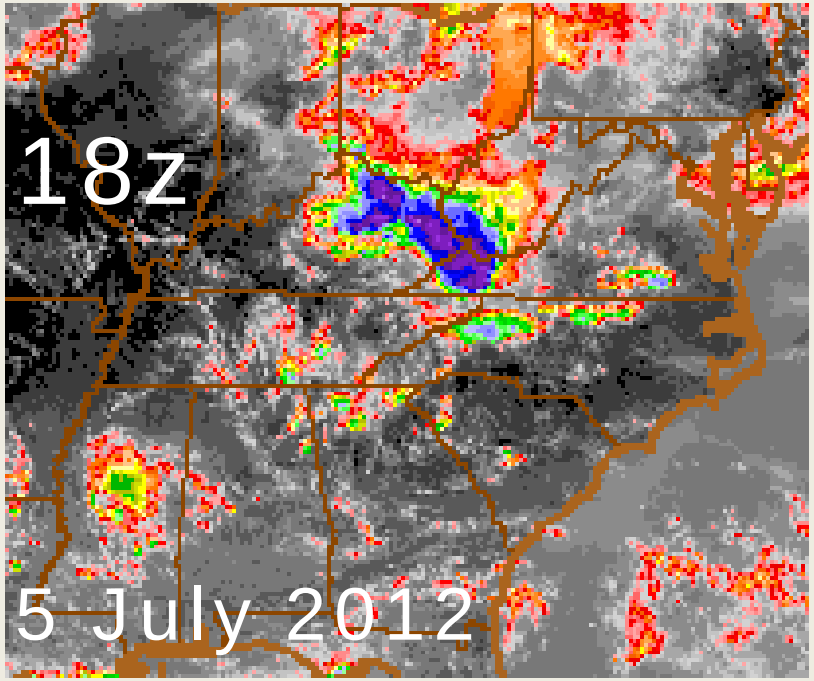
Huang and Lynch (1993)
Weygandt et al. (2008)
Smirnova et al. (2009)

$$X_d^* = \sum_{n=-N}^{N} h(-n) X_d(n)$$

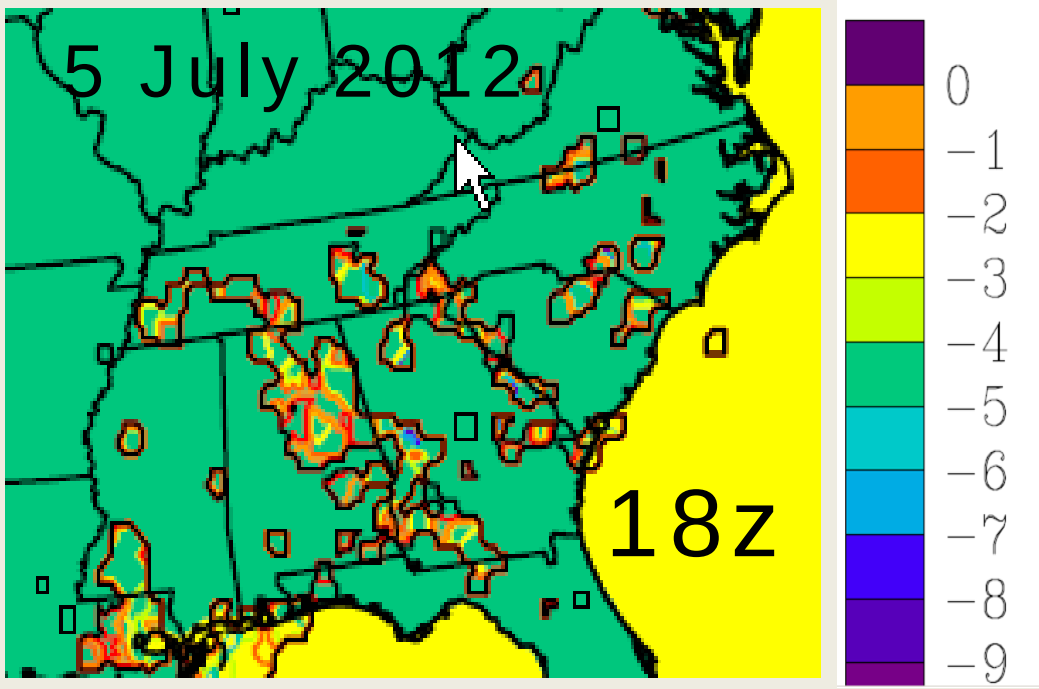


Assimilation of GOES-R CI cloud-top cooling rates

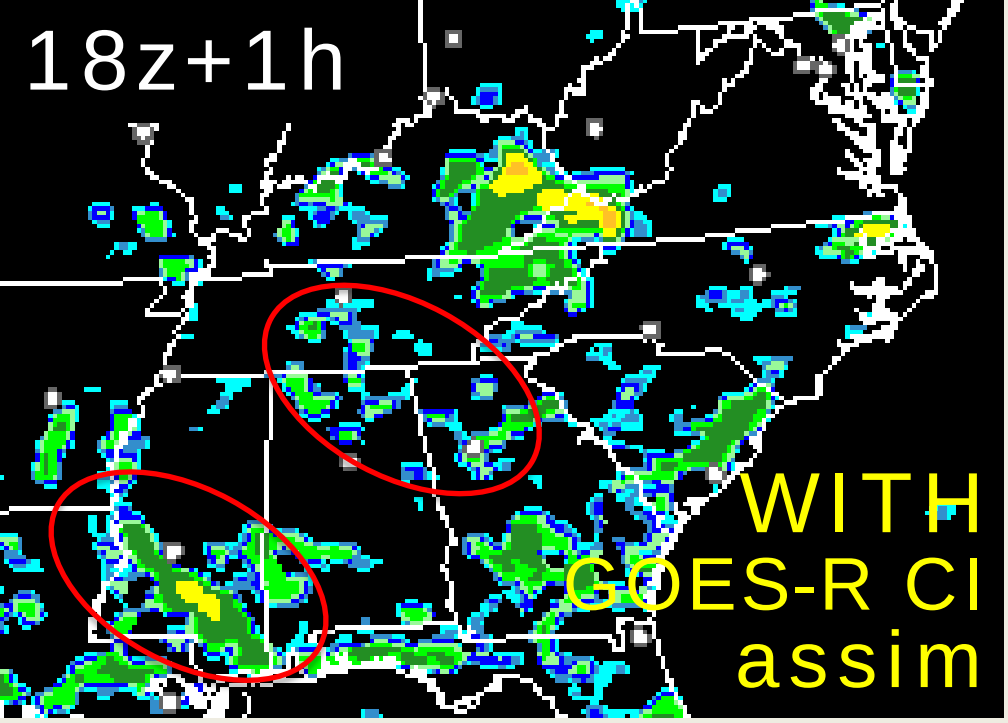
Cloud-top cooling rate helpful for initializing developing convection in GSD RAP retro tests

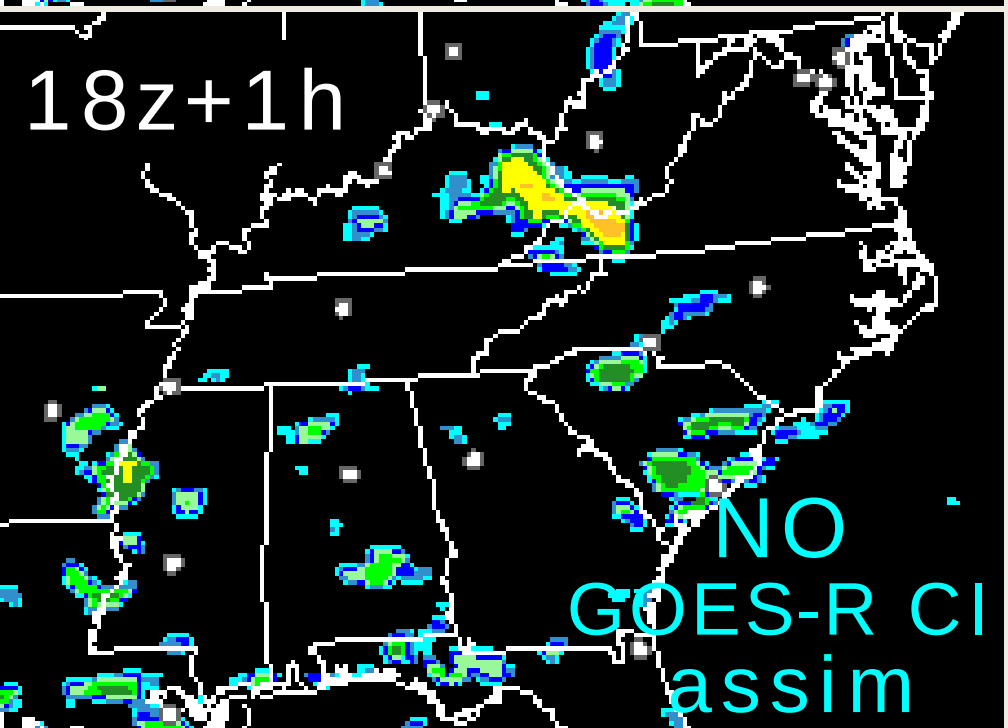


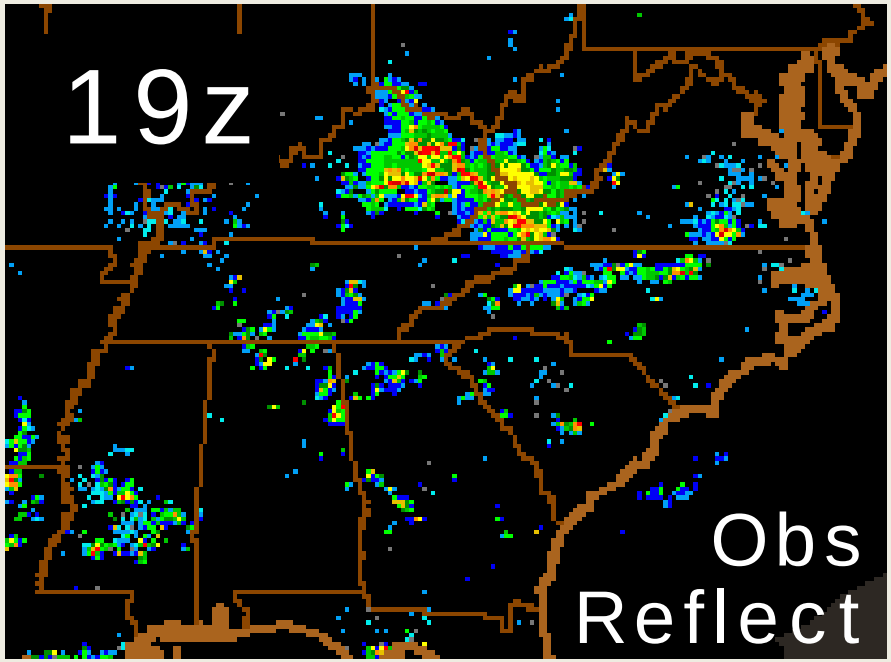
IR image



cooling rates (K / 15 min)







First test case

Assimilation of GOES cloud-top cooling rates provides more realistic short-range forecast of convective initiation and development

Assimilation Update: 23 January 2014

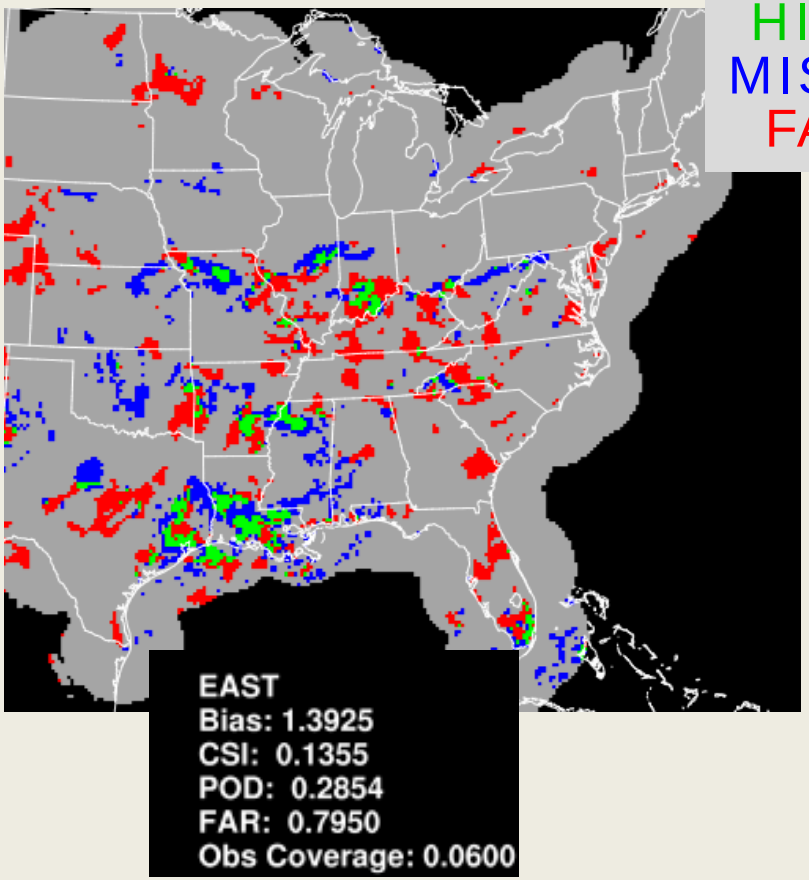
Run 3 assimilation cycles, a control run without the data for five days, a run using the data with a lower bound cloud top cooling rate of -3 C for the same 5 days, and a shorter one day using a cooling rate of -5 C.

Comparing Radar Verification

- **In general, the runs with the cloud top cooling rates verify better than the control run.**
- Using -3 results in a bit more noise than the run with -5, using -5 cuts down on the false alarm rates, especially in the 0 and 1h forecasts. The false alarms in the 3h forecasts hurts both the -3 and -5 C runs compared to control.
- **The runs using -3 verify better at 3 and 6 h, especially at the lower dBZs**.

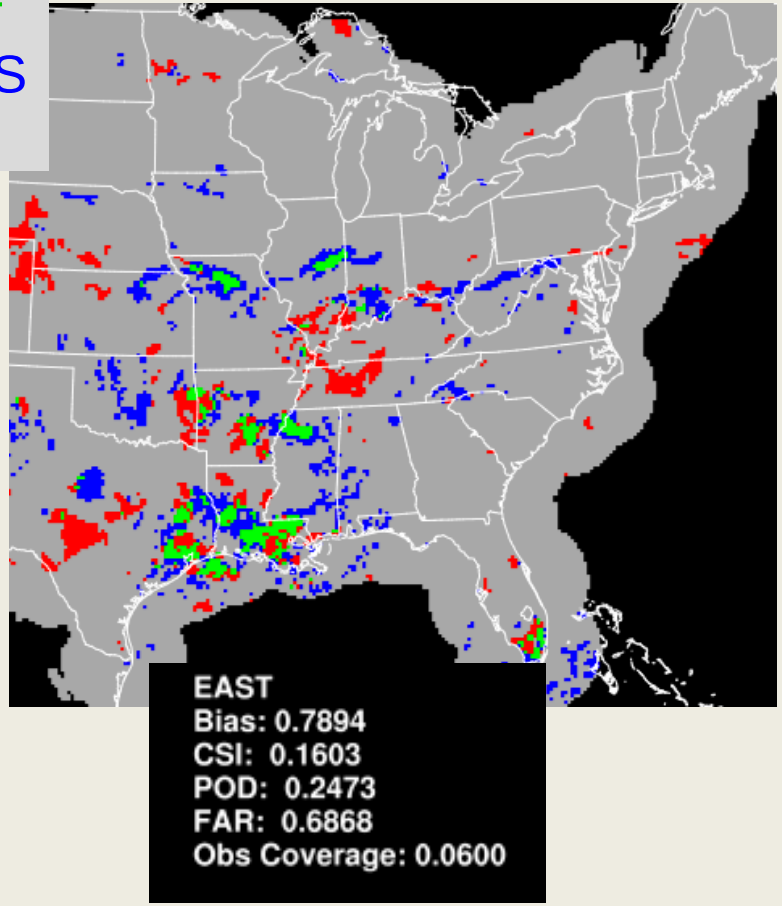
1h forecast 20 dBz from 17z, valid 18z, 8 July 12

–3 CTCR



HIT
MISS
FA

–5 CTCR

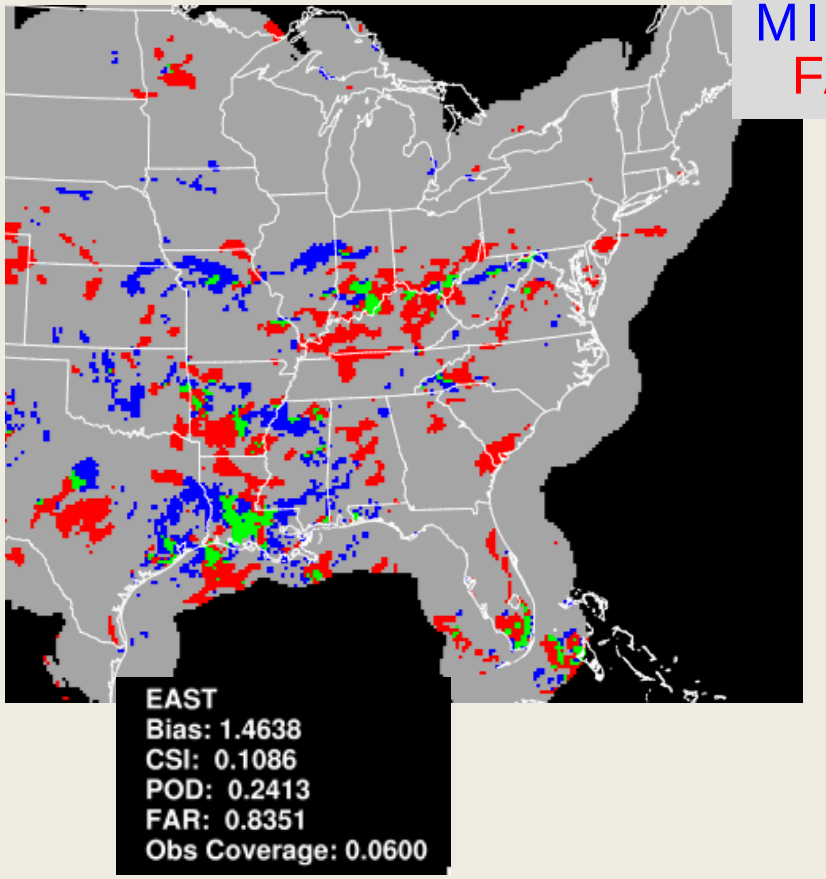


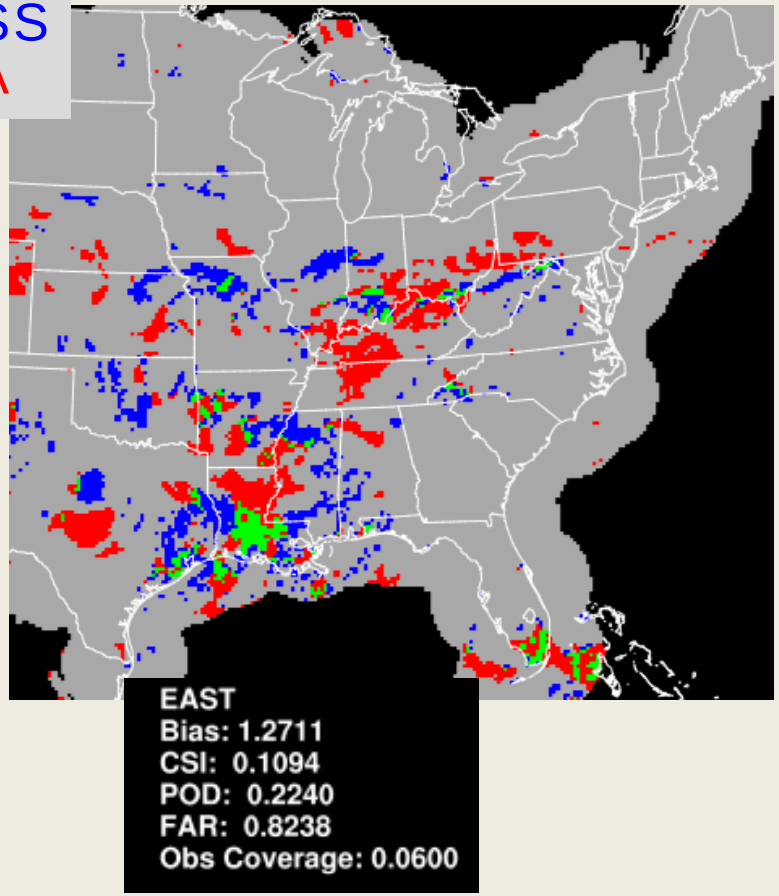
3h forecast 20 dBz from 15z, valid 18z, 8 July 12

–3 CTCR

HIT
MISS
FA

–5 CTCR





CSI at 15, 20, 25, 30, 35, 40, 45 dBz

CTCR	1 h forecast			3 h forecast			K/15 min
	CNTL	**–3**	**–5**	**CNTL**	**–3**	**–5**	
	0.158	0.143	0.166	0.131	0.128	0.129	
	0.152	0.135	0.160	0.109	0.108	0.109	
	0.129	0.116	0.144	0.089	0.088	0.085	
	0.087	0.084	0.105	0.058	0.057	0.056	
	0.007	0.008	0.011	0.003	0.010	0.007	
	0.000	0.000	0.000	0.000	0.000	0.000	
	0.000	0.000	0.000	0.000	0.000	0.000	

Equitable Threat Score at 15, 20, 25, 30, 35, 40, 45 dBz

CTCR	**CNTL**	**–3**	**–5**	**CNTL**	**–3**	**–5**	K/15 min
	0.1149	0.0941	0.1293	0.0851	0.0779	0.0825	
	0.1206	0.0998	0.1337	0.0759	0.0719	0.0749	
	0.1071	0.0915	0.1269	0.0665	0.0631	0.0613	
	0.0755	0.0717	0.0969	0.0471	0.0446	0.0437	
	0.0061	0.0066	0.0102	0.0022	0.0084	0.0052	
	0.000	0.000	0.000	0.000	0.000	0.000	
	0.000	0.000	0.000	0.000	0.000	0.000	

RAP/HRRR assimilation GOES-CI

Ongoing work

- Examine strength of assumed heating rate
- Plan experiments with direct heating in 3 km resolution HRRR (utilizing HRRR radar assimilation approach)

→ **Likely better scale match to GOES-CI data**

Development Plans: 2014–2017

- Continue to use and explore the incorporation of various cloud properties in GOES-R CI, and maintain as a stand-alone product:
  - Cloud optical depth and emissivity for enhanced nighttime CI detection.
  - Draw cloud properties into logistic regression (or random forest decision tree) framework (*complete two science papers on this subject*).
  - Include reflectance and other cloud-top glaciation indicators. Evaluate use of effective radius toward estimating future storm intensity.
  - Evolve more into lightning nowcasting/decision support.
- RAP/HRRR data assimilation
  - Assist CIRA/NOAA ESRL to properly use more of GOES-R CI fields/probabilities.
  - Formulate improved function for representing latent heating profile that uses both CI probabilities and other IR fields (beyond just the 10.7 µm trend), across a depth and more appropriately within DDFI framework.
  - Weight data across 3- and 13-km domains by CI probabilities.

In 2014–2015…

- Continue to obtain NWS forecaster feedback, and respond to suggestions
- Leverage NASA SPoRT & GOES-R collaboration and infrastructure
- Work within NOAA Testbed framework as GOES-R CI moves to operations
- Evaluate improvements to RAP/HRRR model forecasts within User community
- Develop science paper (*Gravelle et al.*) around combining ~4 GOES-R products for assessing pre-storm situational awareness.