STAR Center for Satellite Applications and Research
formerly ORA — Office of Research and Applications

Development of physical retrieval algorithm for clear sky atmospheric profiles from SEVIRI, GOES Sounder and ABI infrared radiances

Jun Li

Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison, Madison, WI 53706, U.S.A.

Jun.Li@ssec.wisc.edu, http://www.ssec.wisc.edu/~jli

Thanks to many CIMSS, STAR and EUMETSAT collaborators

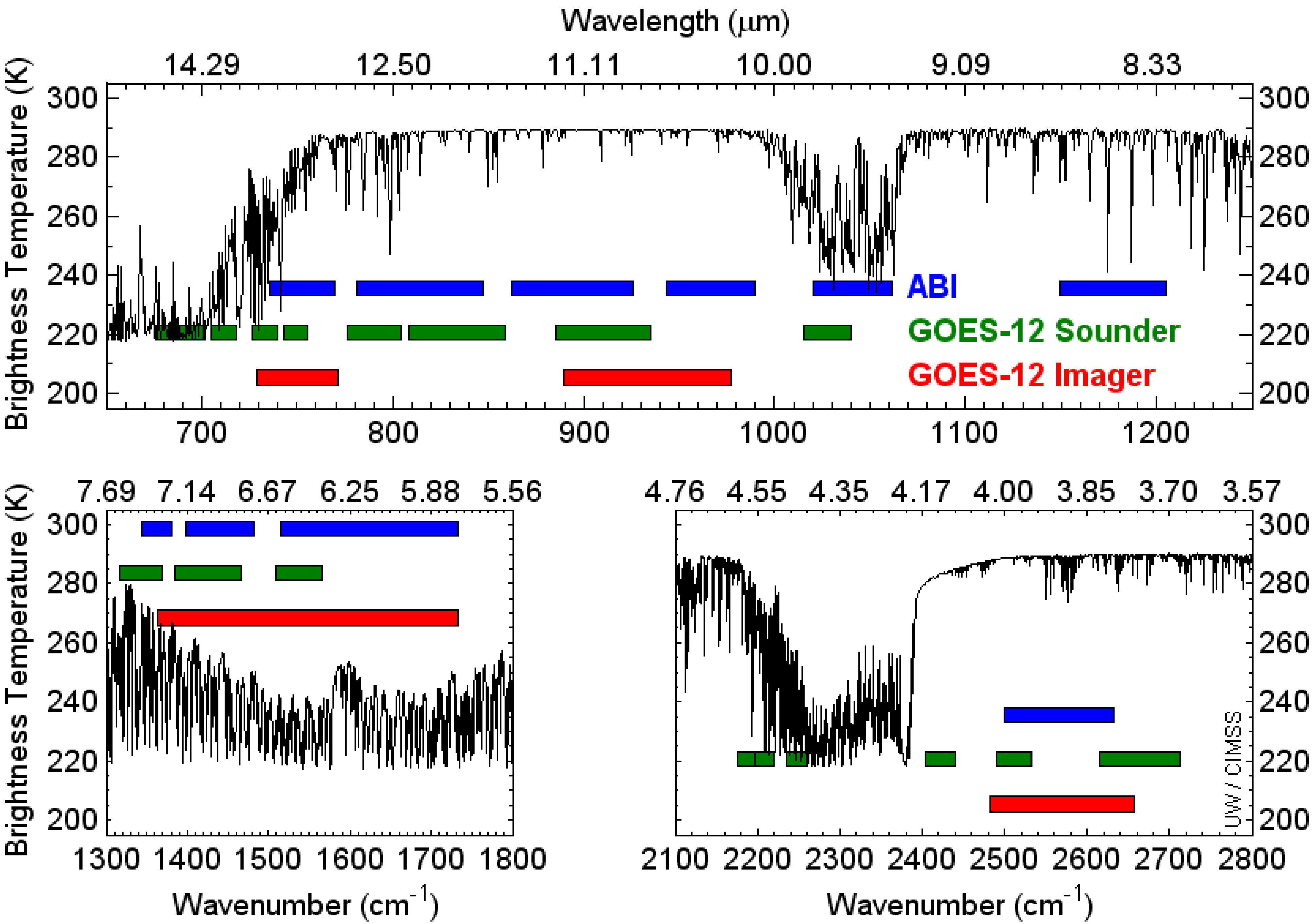
28 November 2007
CDOP NWC SAF Workshop on Physical Retrieval of Clear Air Parameters from SEVIRI Agenda

Outline

- **Introduction to GOES Sounder and ABI IR bands**
- **Algorithm development**
- **Results and validation**
- **Applications**

Considerations

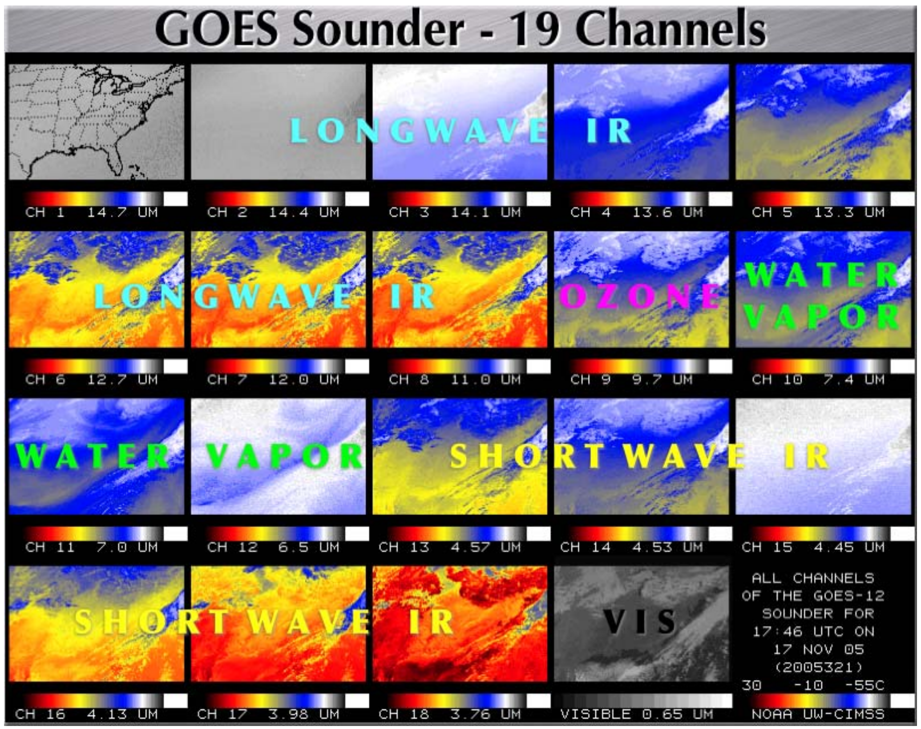
- Build upon the legacy operational GOES Sounder SFOV (Single Field of View) sounding algorithms for soundings and related nowcasting products
- Combing forecast information and IR radiances
- Incorporate temporal continuities into processing
- Better handling surface IR emissivities

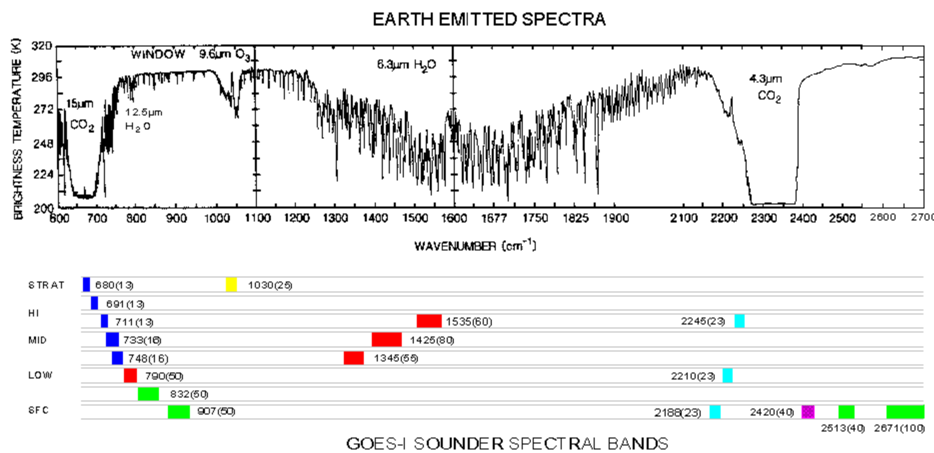


ABI (blue) and current GOES sounder (green) spectral coverage compared showing a high spectral resolution brightness temperature spectrum (black). ABI has few bands for upper level temperature. (Figure from Tim Schmit at STAR)

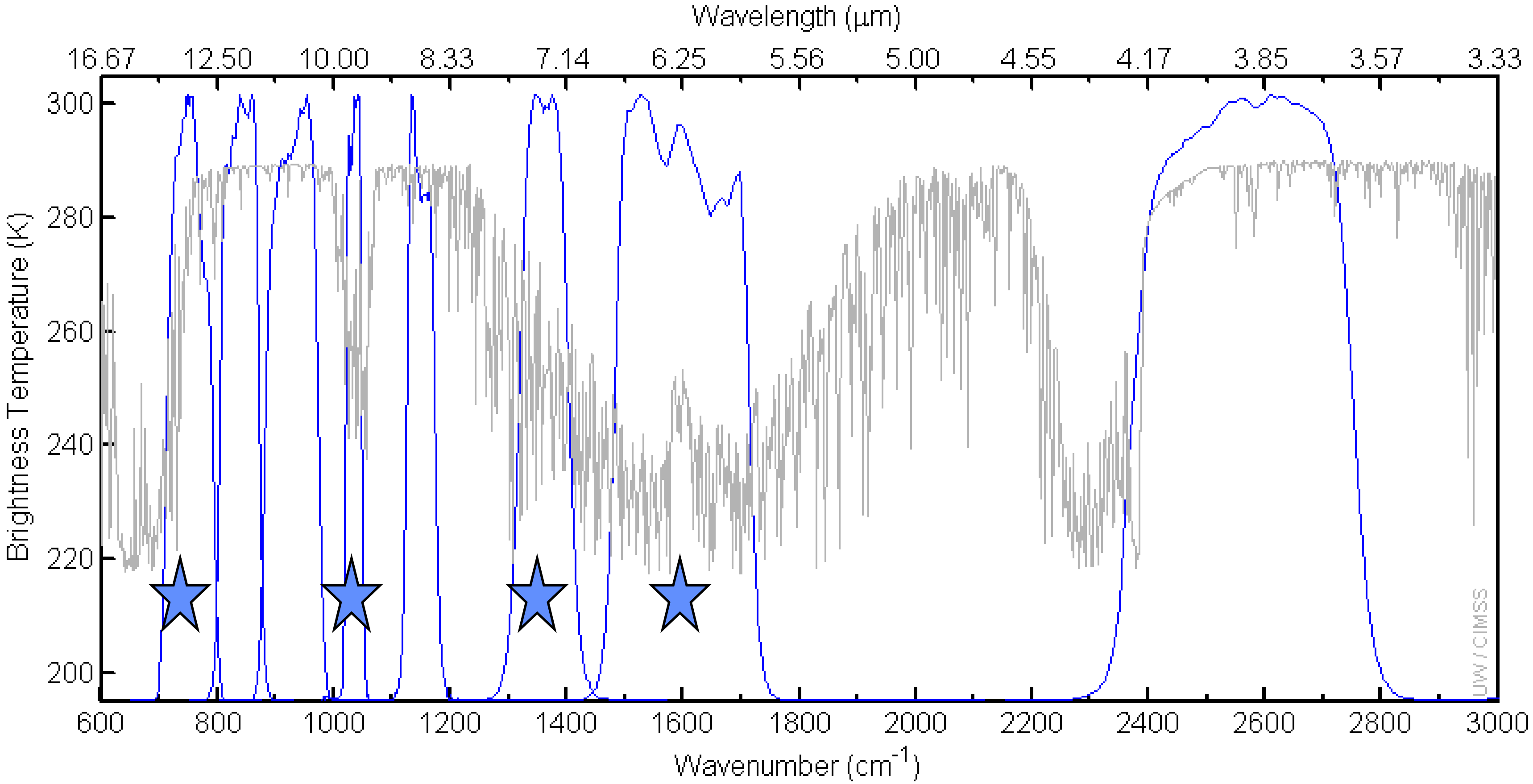
Description: GOES-I(8)/P Sounders

- 19 channels (18 Infrared; 1 Visible)
- Spatial resolution: ~ 10km
- Hourly scanning over CONUS and adjacent waters
- Products include standard imagery and derived, Level-2 products





COOPERATIVE INSTITUTE FOR METEOROLOGICAL SATELLITE STUDIES



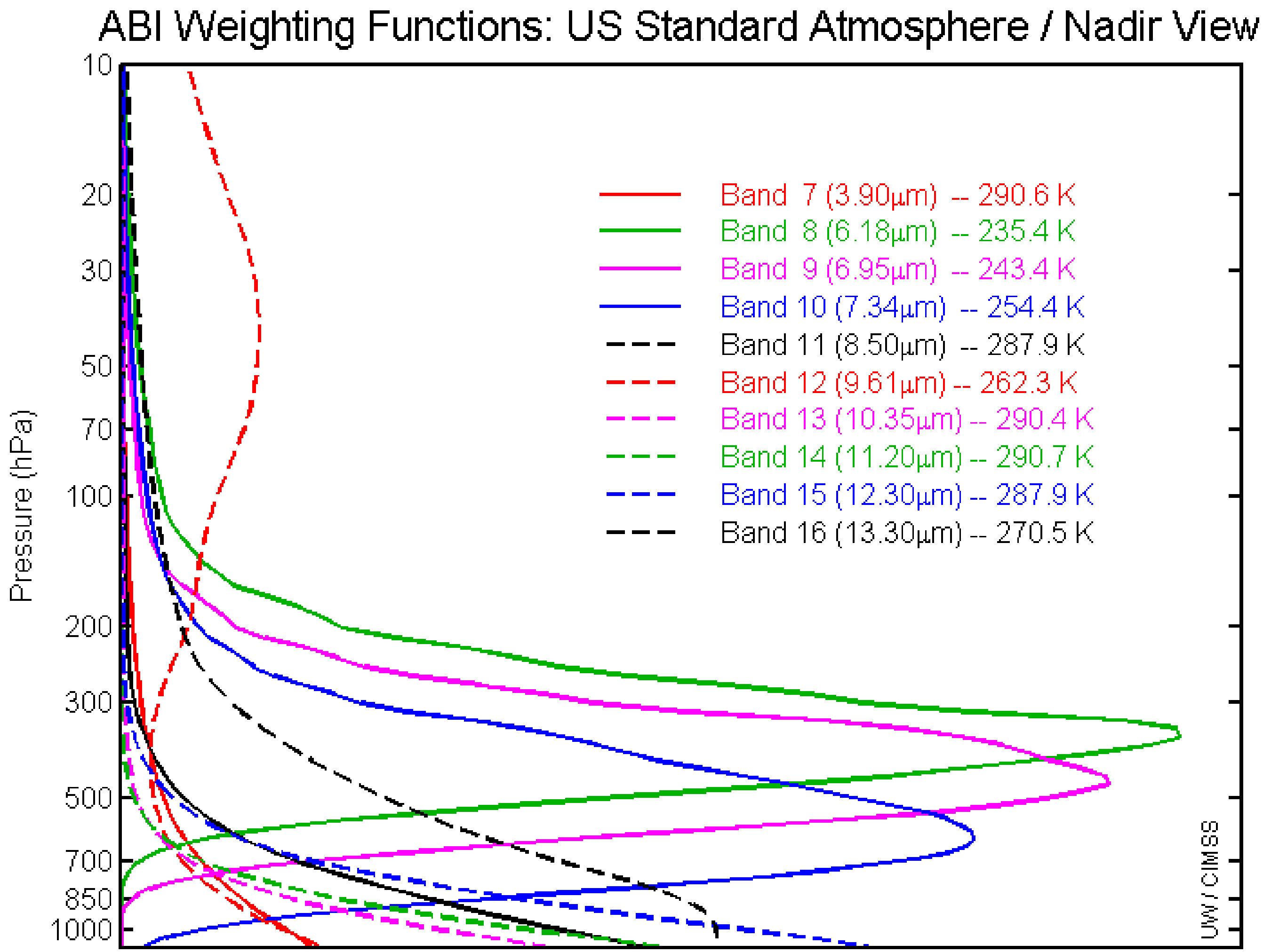
SEVIRI (blue) has only four sounding bands (one CO2, one O3 and two H2O) (Figure from Mat Gunshor at CIMSS)

ABI IR Bands

7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds
★ 8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall
★ 9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall
★ 10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall
★ 12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds
13	10.1–10.6	10.35	2	Surface and cloud
14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall
15	11.8–12.8	12.3	2	Total water, ash, and SST
★ 16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts

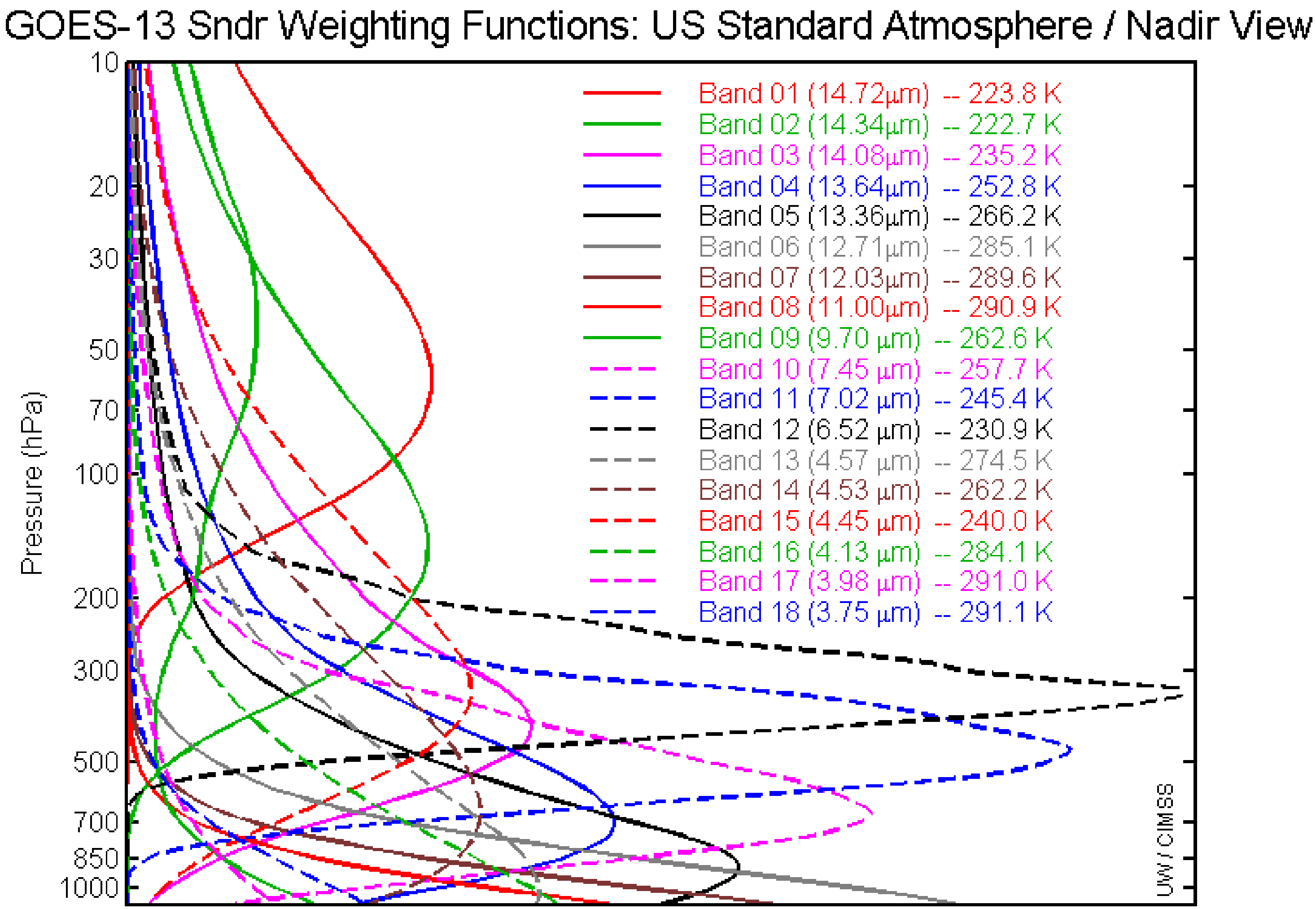
Schmit et al. 2005, BAMS – Introducing the next generation of ABI on GOES-R

GOES-R ABI Weighting Functions



ABI has only 1 CO_2 band, so upper-level temperature will be degraded compared to the current sounder

GOES-13 Sounder WFs



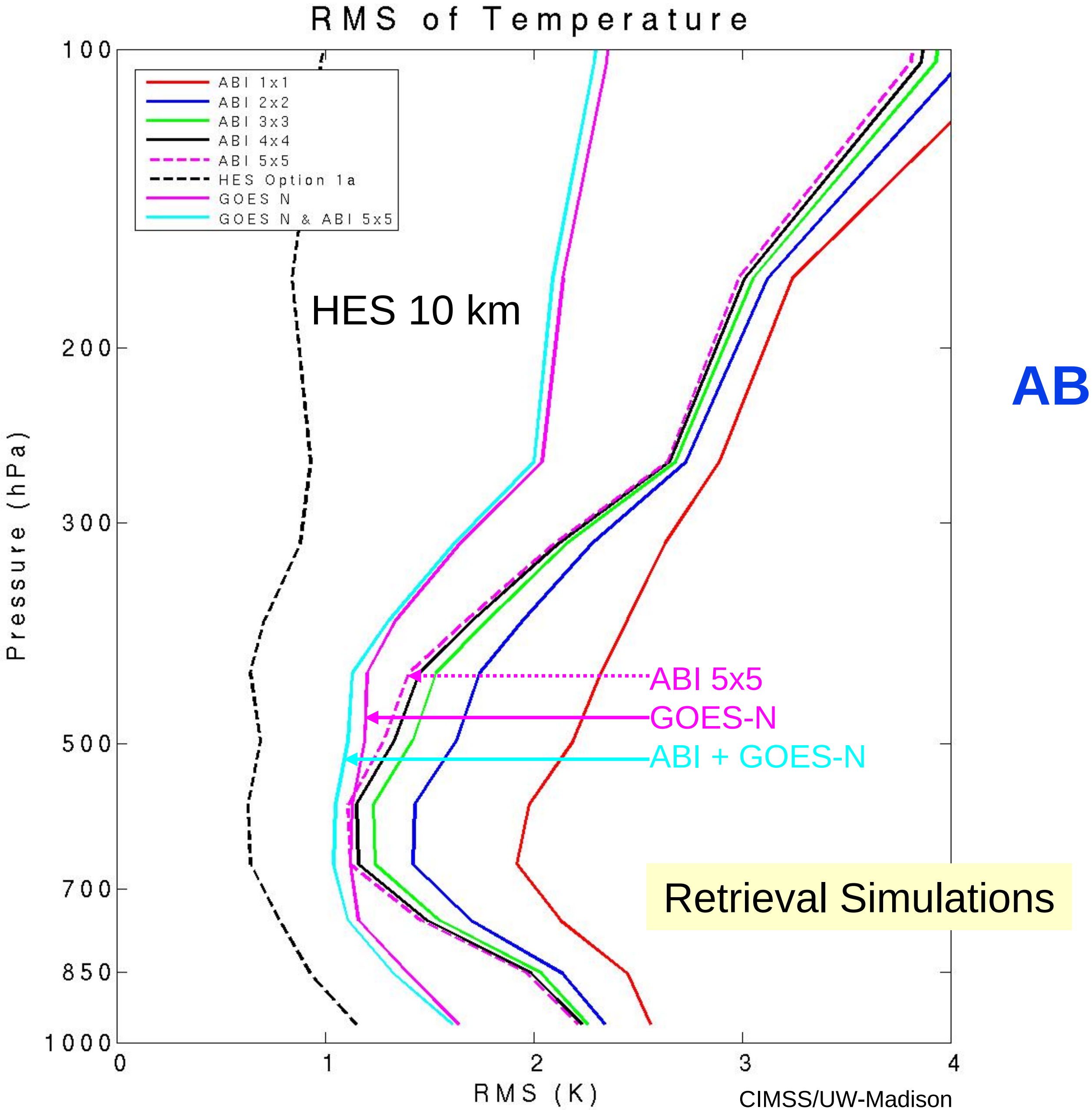
The GOES-N sounder has 5 CO_2 bands, and more SW bands than ABI

Question

- Can ABI be used to continue the GOES Sounder legacy product before we have hyperspectral IR sounding system on GEO orbit ?

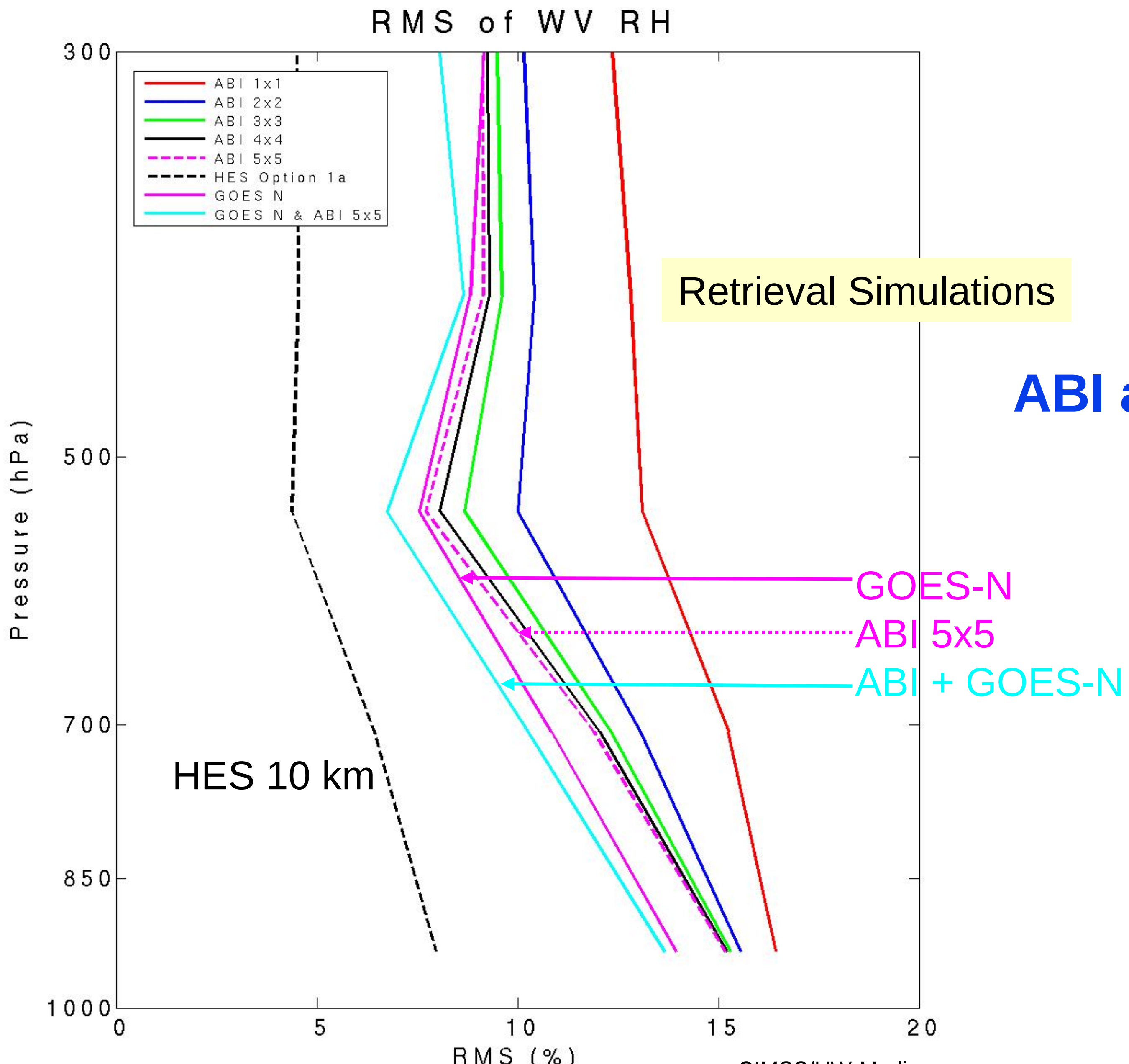
Near global simulation on ABI, GOES Sounder and HES alone

- ABI alone
- GOES Sounder alone
- HES alone



ABI alone !

CIMSS/UW-Madison



ABI alone !

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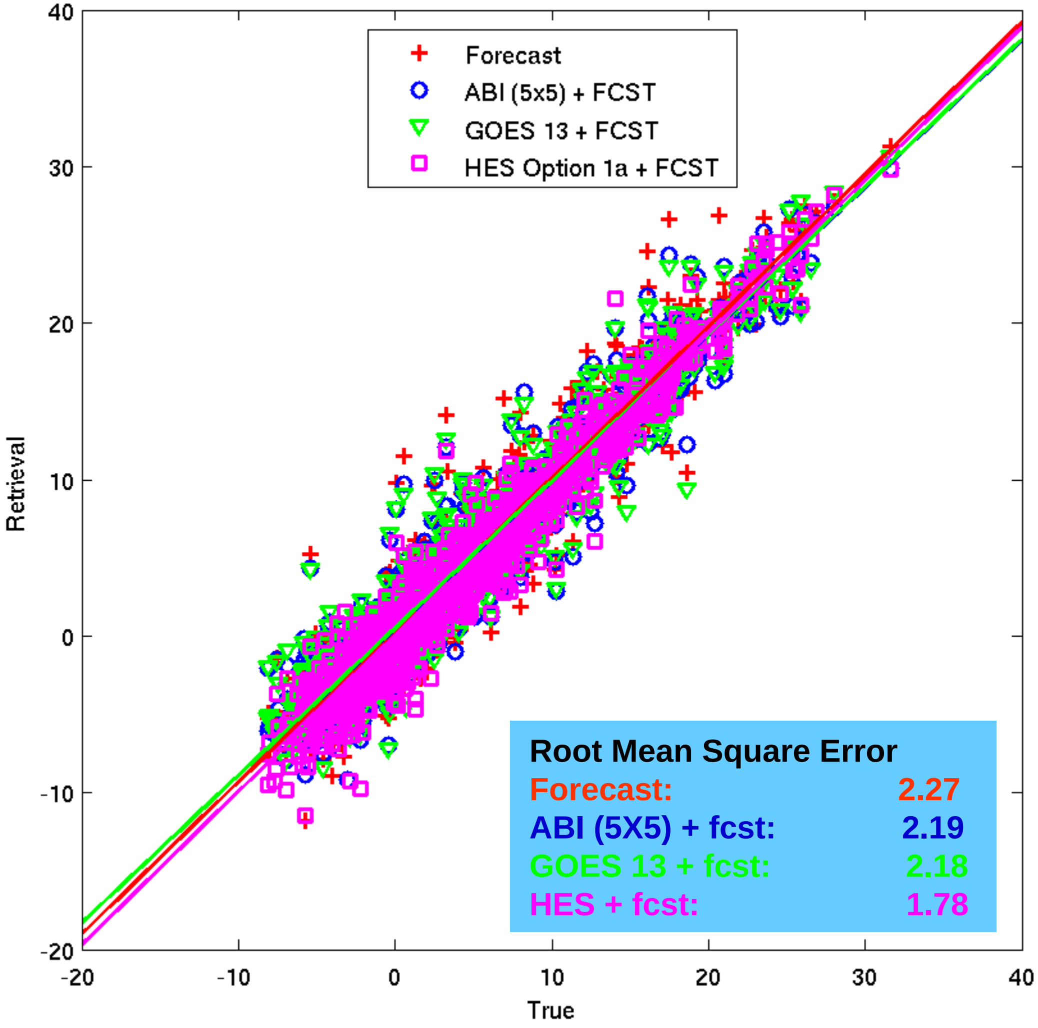
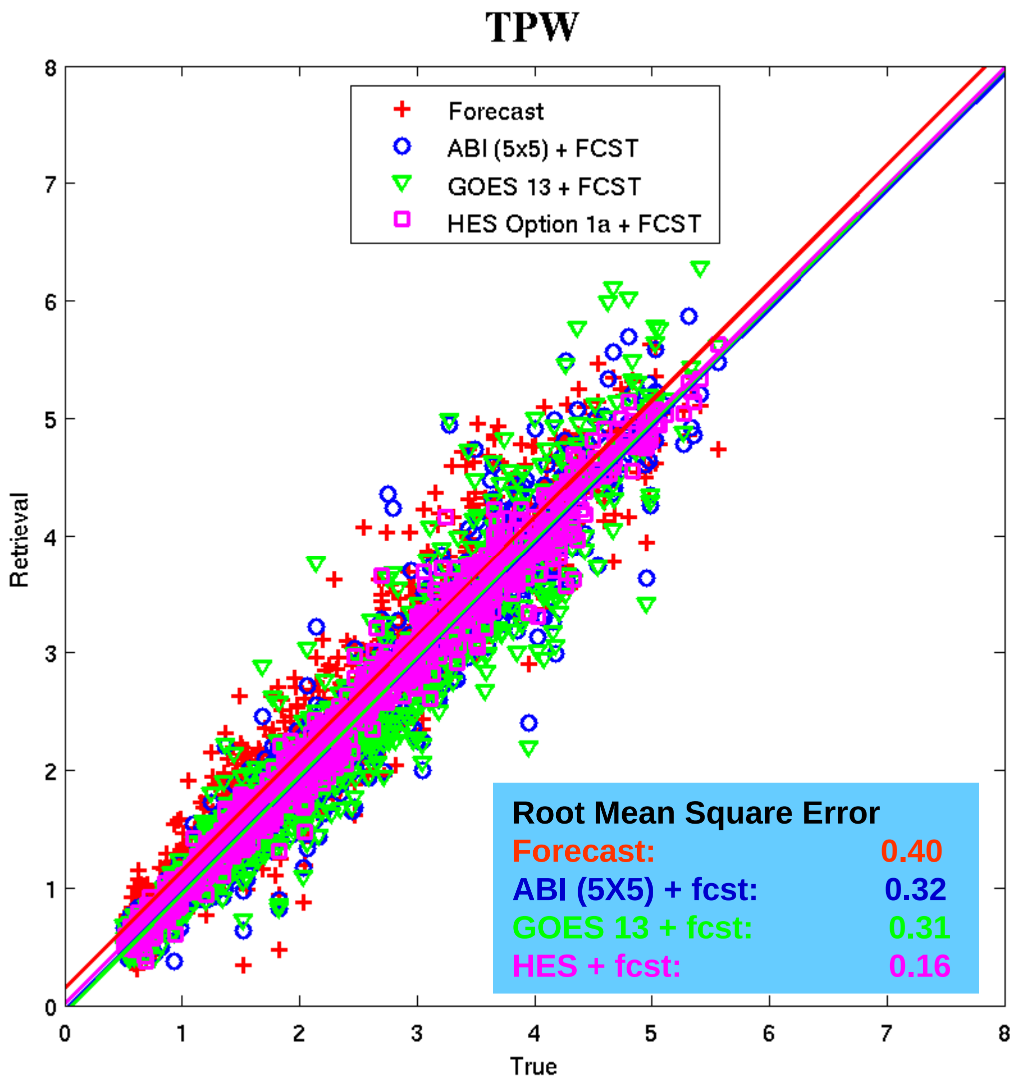
Regional simulation (using forecast information)

(update on 07 March 2007)

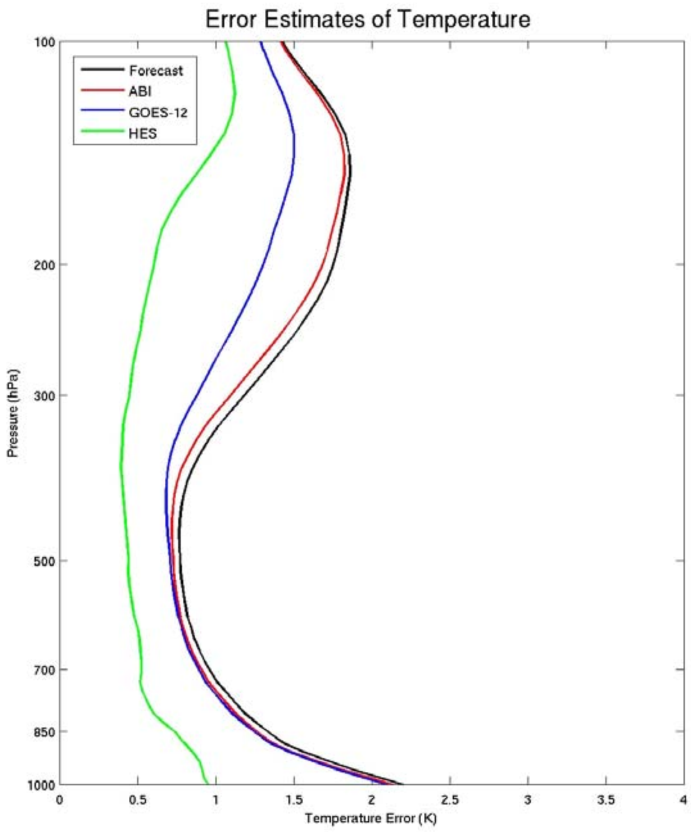
- Using time/space collocated RAOB/Forecast over CONUS
- HES end formulation assumption, GOES-13 (for current Sounder class), and ABI were used in simulation. PORD noise were used for HES and ABI,
- Total precipitable water (TPW) and Lifted Index (LI) are used for performance analysis

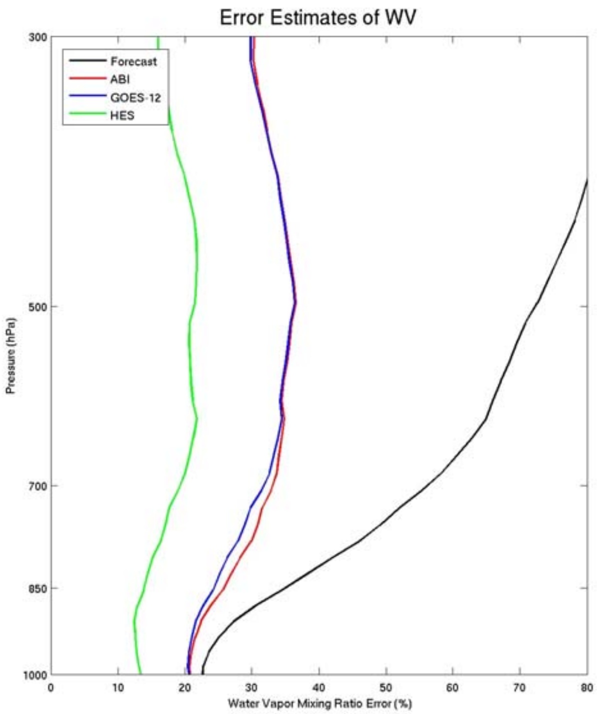
Lifted Index




TPW
Forecast
ABI (5x5) + FCST
GOES 13 + FCST
HES Option 1a + FCST
Root Mean Square Error
Forecast: 0.40
ABI (5X5) + fcst: 0.32
GOES 13 + fcst: 0.31
HES + fcst: 0.16
Retrieval
True
0
1
2
3
4
5
6
7
8

Error Analysis





Temperature (left panel) and water vapor mixing ratio (right panel) background error covariance matrix from forecast model, **B**, and analysis error covariances matrix, **A**, with ABI, GOES-12 Sounder and HES final formulation.

Summary of Simulations

- ABI/SEVIRI alone temperature is degraded significantly from GOES Sounder alone, ABI alone moisture has comparable information of GOES Sounder alone

- ABI/SEVIRI + forecast and GOES Sounder + forecast have similar precisions on temperature, moisture profiles, TPW, LI

- Both GOES Sounder and ABI/SEVIRI has significant less temperature and moisture information than HES like hyperspectral IR sounder

The ABI can provide *continuity* of current Sounder products

– Operational products –

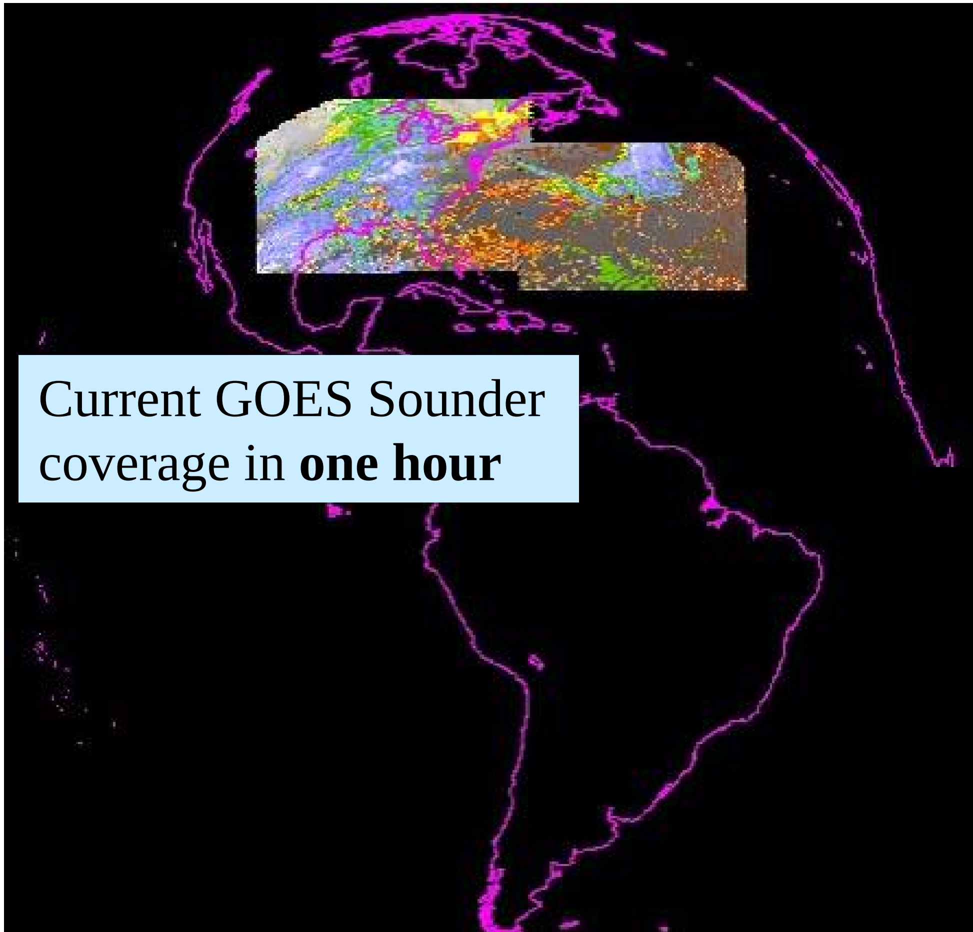
Product	Temporal /Latency	Spatial	Accuracy	Overall	Comments
Radiances	ABI ~ 20X faster	Comparable (when averaged)	Comparable	Comparable	Only 1 CO_2 band on ABI (18 vs 10 IR)
TPW/LI **Skin Temp**	ABI ~ 20X faster	Comparable (when averaged)	Sounder more precise	Comparable	
Profiles	ABI ~ 20X faster	Comparable (when averaged)	Sounder more precise	Comparable	Worse upper-level T and lower-level moisture

- For continuity only

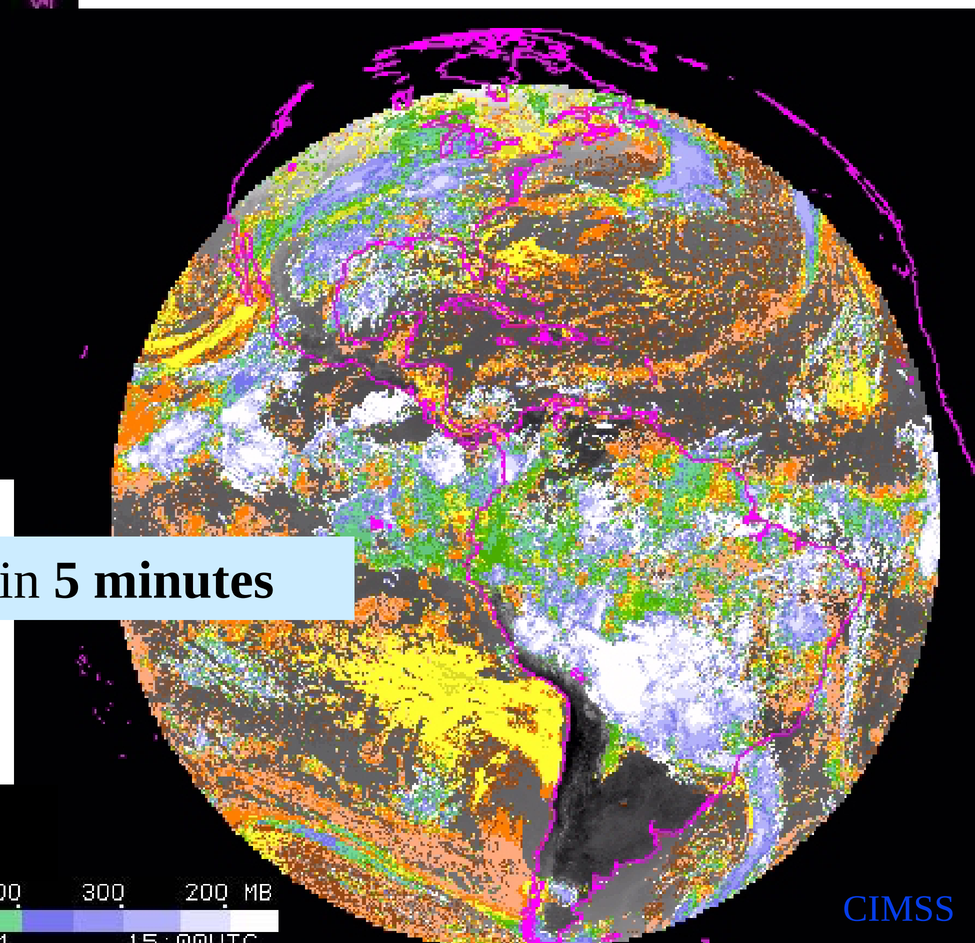
ABI better than N Sounder	ABI comparable to N Sounder	ABI worse than N Sounder, but acceptable	ABI worse than N Sounder, unacceptable

(Slide from Tim Schmit)

Much improved spatial coverage (and hence total product latency) with ABI over the current Sounder



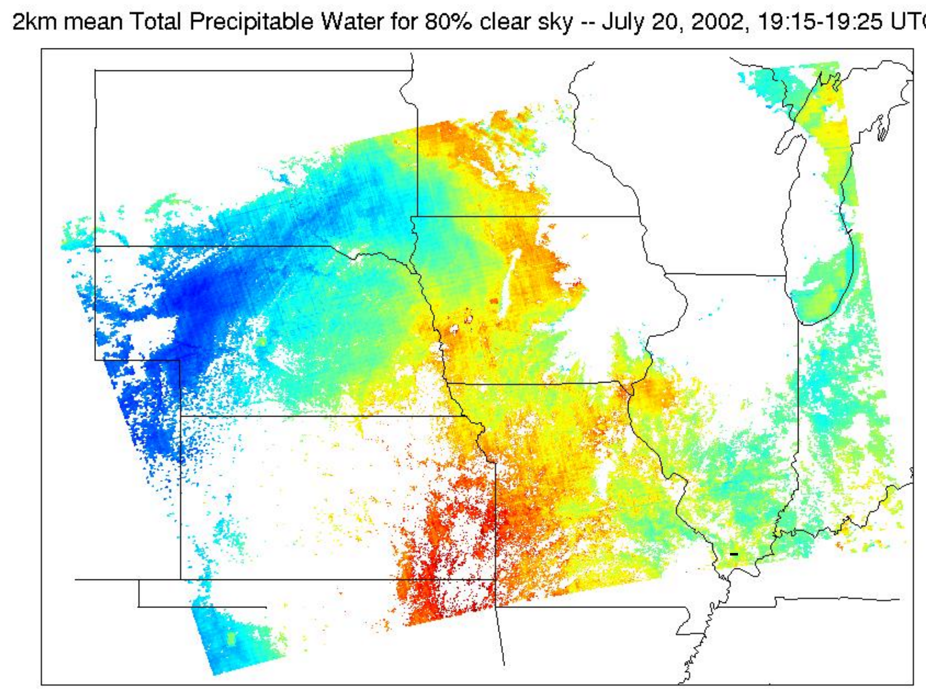
Current GOES Sounder coverage in **one hour**

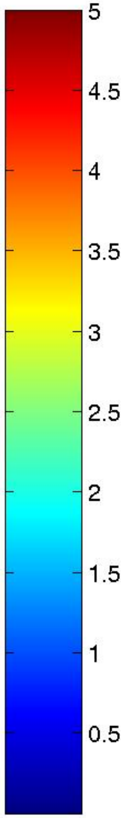


ABI in **5 minutes**

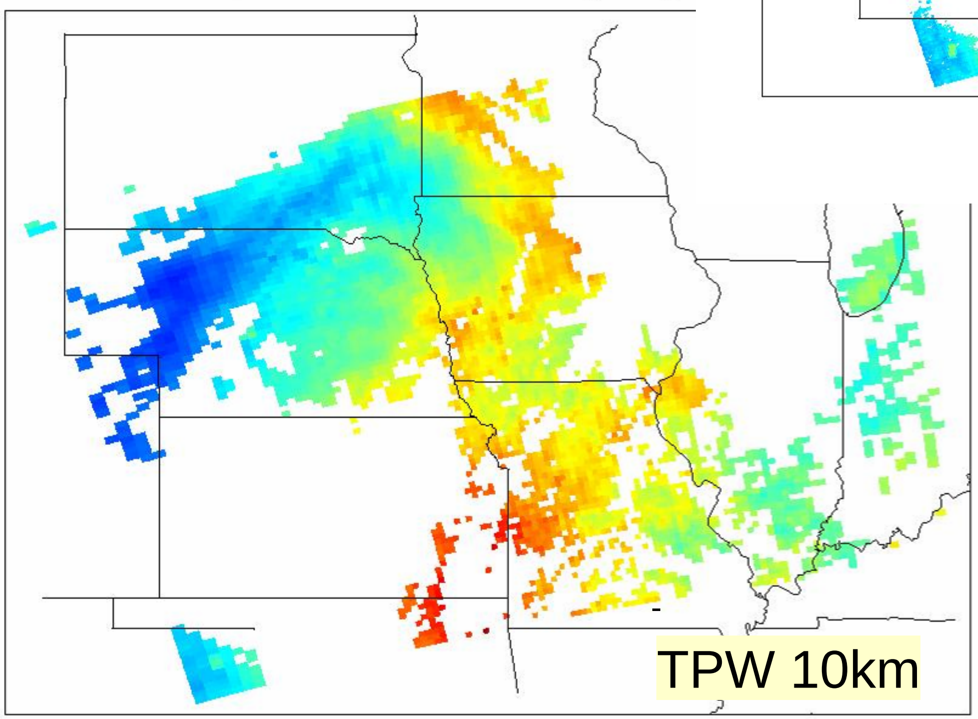
Cloud Top Pressure

Improved spatial resolution with ABI over the current Sounder

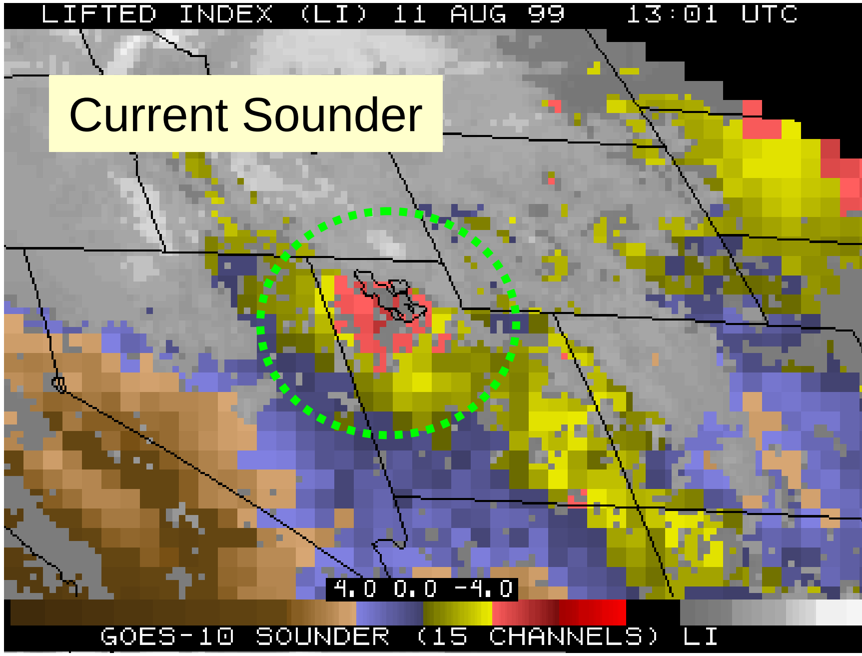


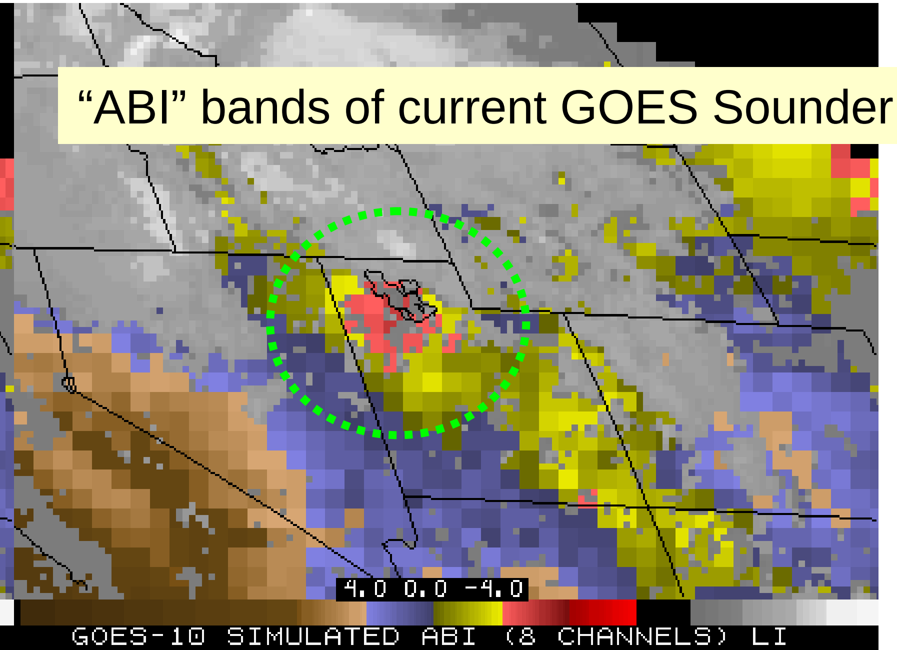


TPW 2km



Lifted Index simulations using GOES sounder

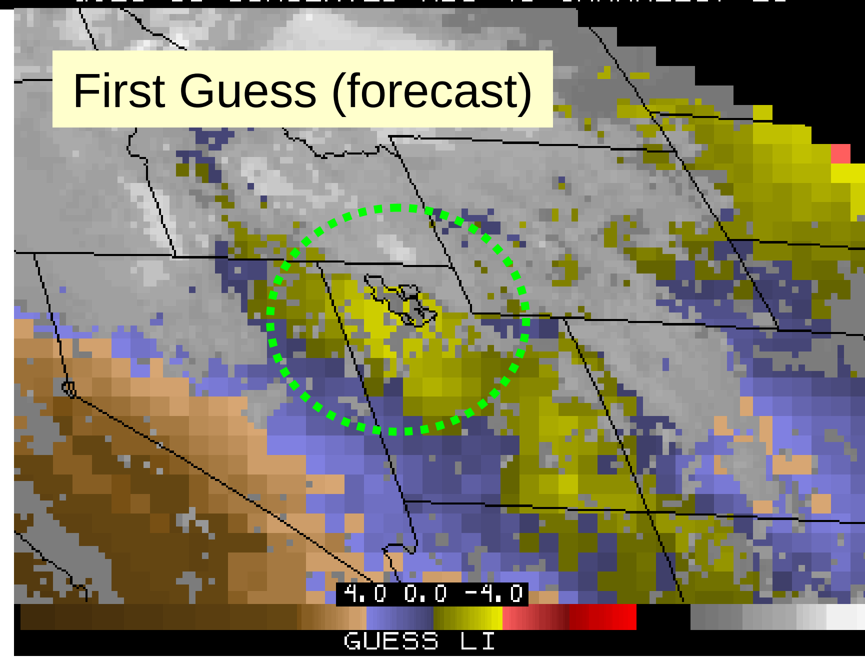




LI from Current GOES Sounder (GOES Sounder and forecast)

LI from “ABI” from GOES Sounder (via channel selection) and forecast

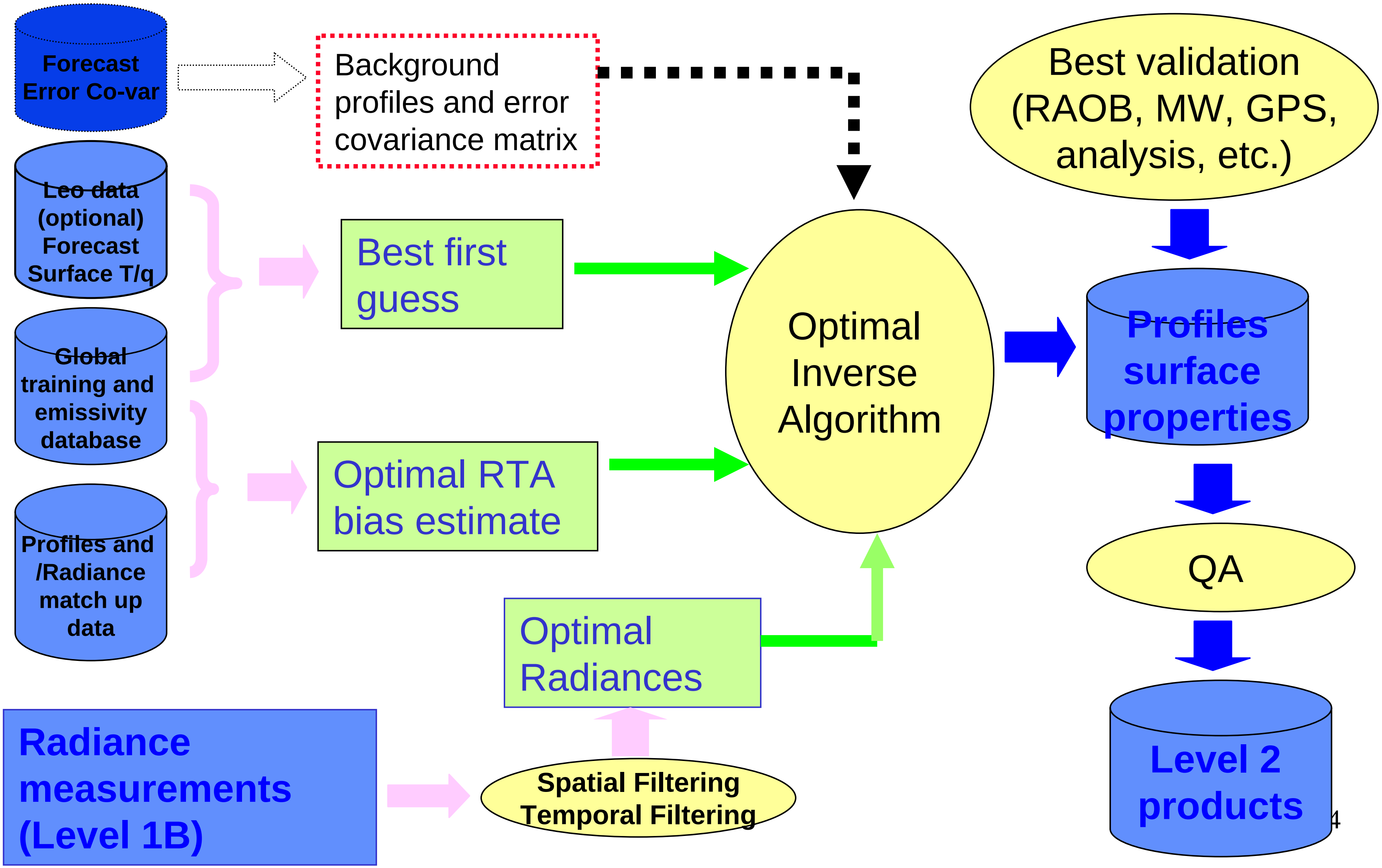
LI first guess (from forecast)



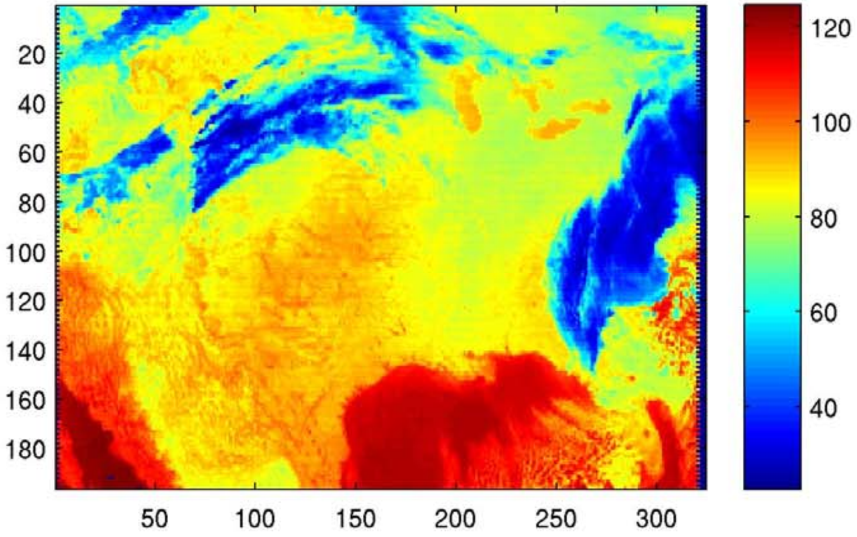
Algorithm development/improvement

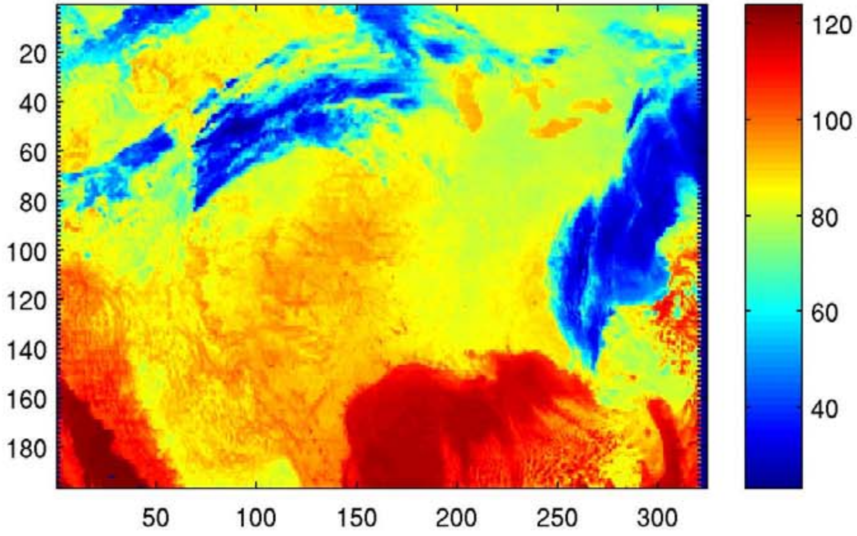
- Noise filtering for radiances – spatially and temporally
- Handling surface emissivities
- Physical inverse of radiances
- Using time continuity

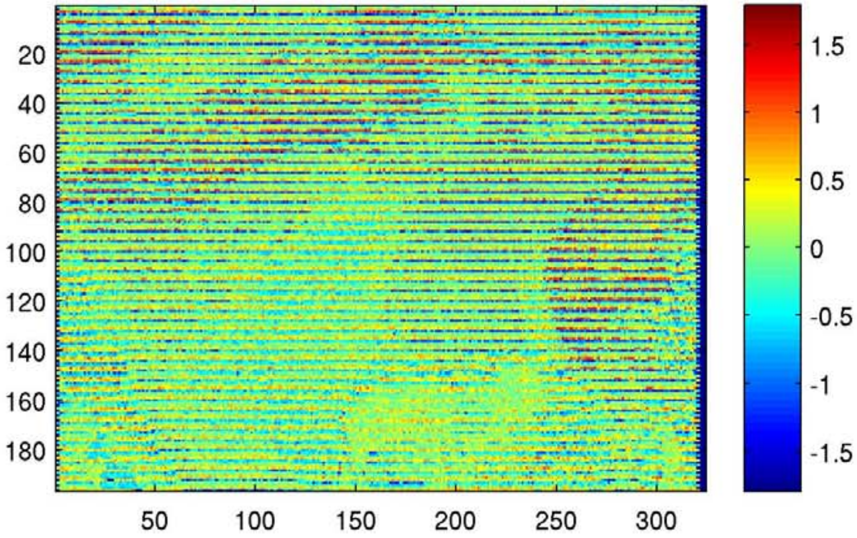
CIMSS Legacy Atmospheric Profile
Processing Overview



Noise filtering - destriping



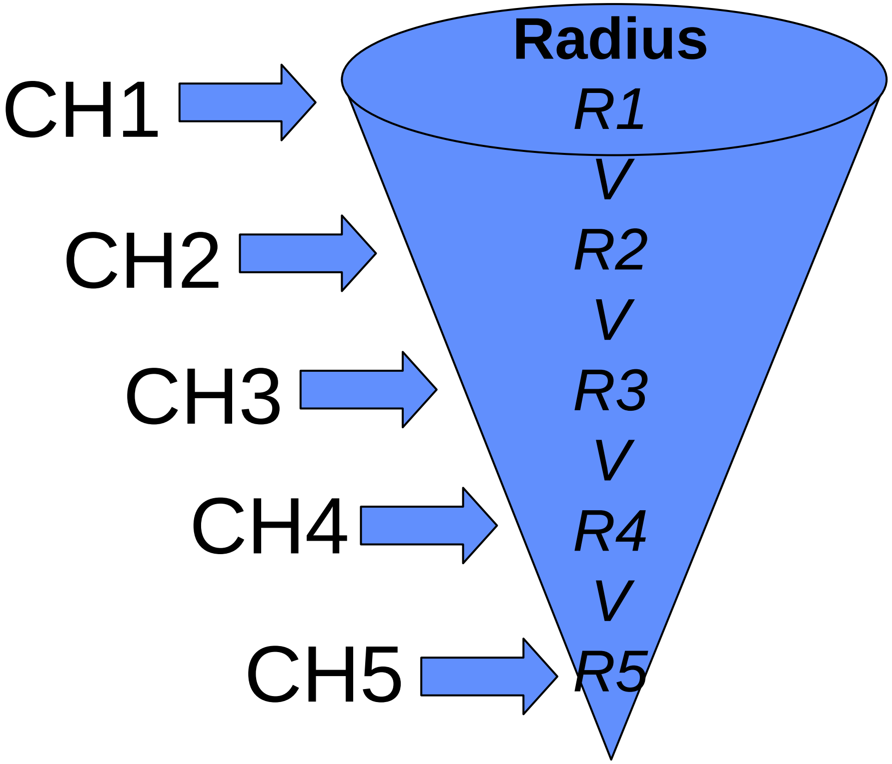




Example of GOES-13 band 7 radiances: before detriping (upper left), after destriping (upper right), and the differences (lower left)

Noise filtering – inverted cone idea from Paul Menzel

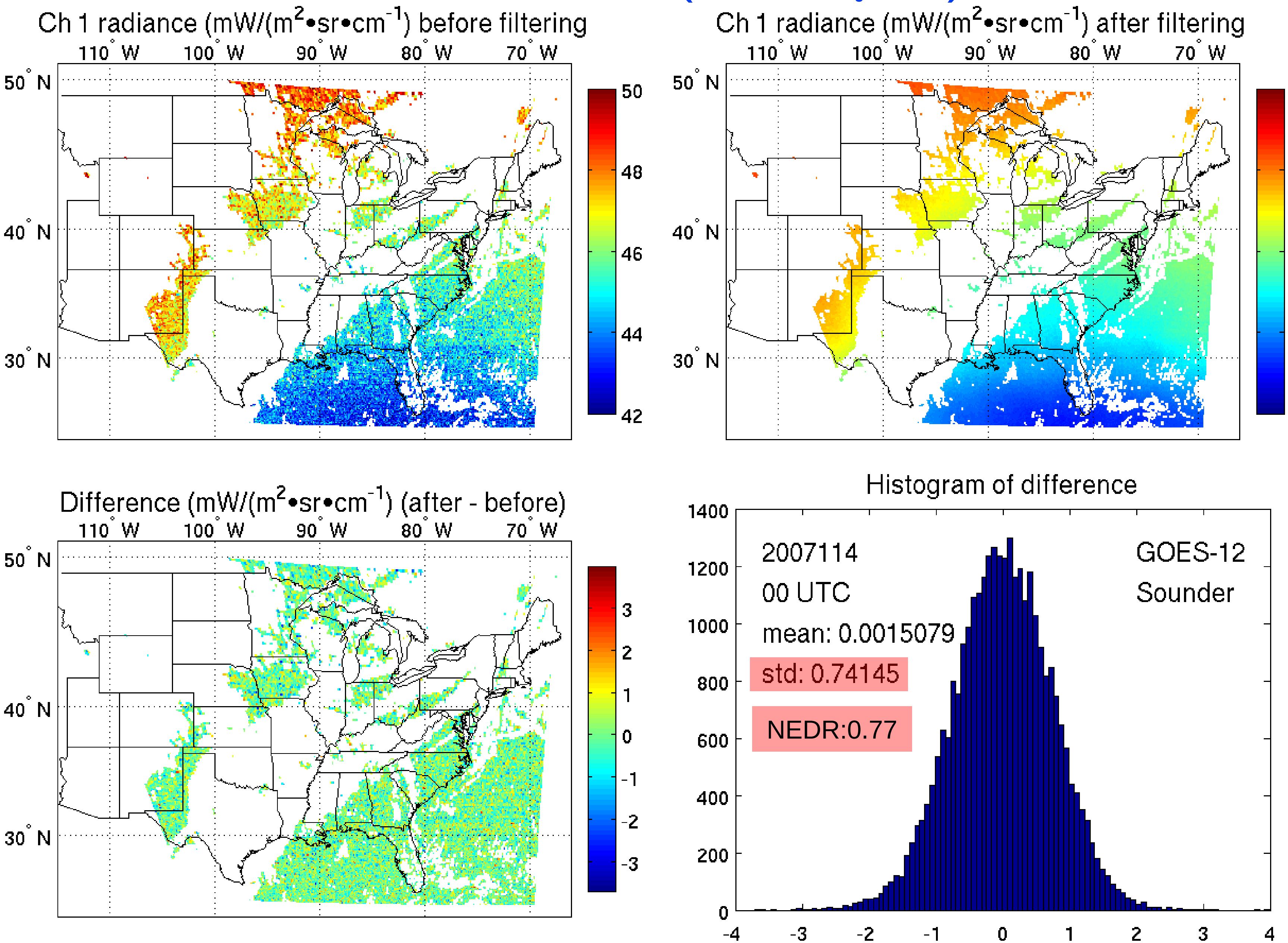
- Weighted averaging
- Closer FOVs have more weights
- Averaging area increases for channels peaking in the upper atmosphere



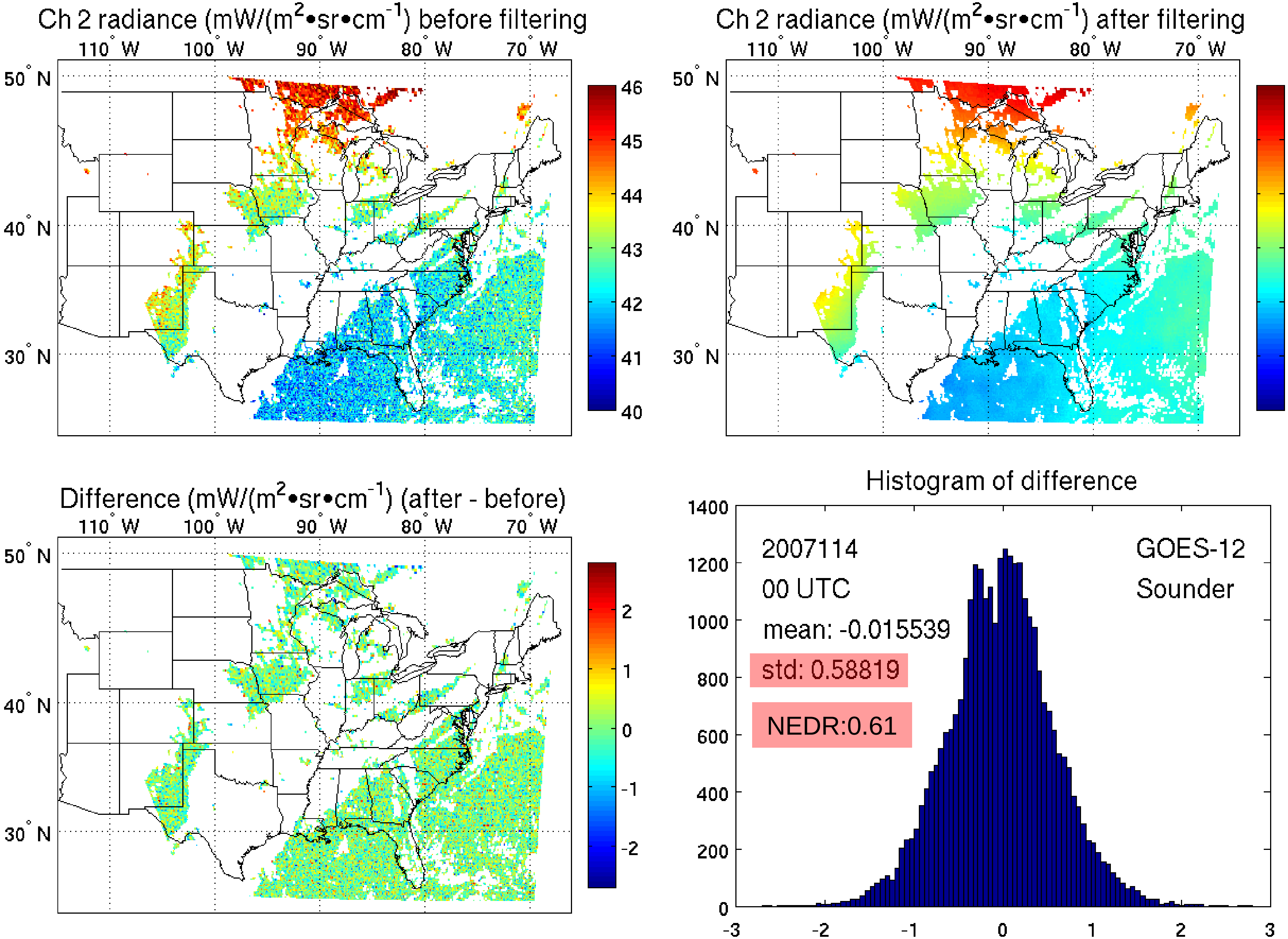
How to evaluate the results

- Compare the filtered and unfiltered
  - » The difference image should have a spatially evenly distributed noise pattern
  - » The difference should have a zero mean and comparable STD as the instrument's noise specifications
- Noise is better viewed on channel difference (close channels only) image, so after the filtering
  - » The gradient of signals should be preserved
  - » The random noise should be reduced

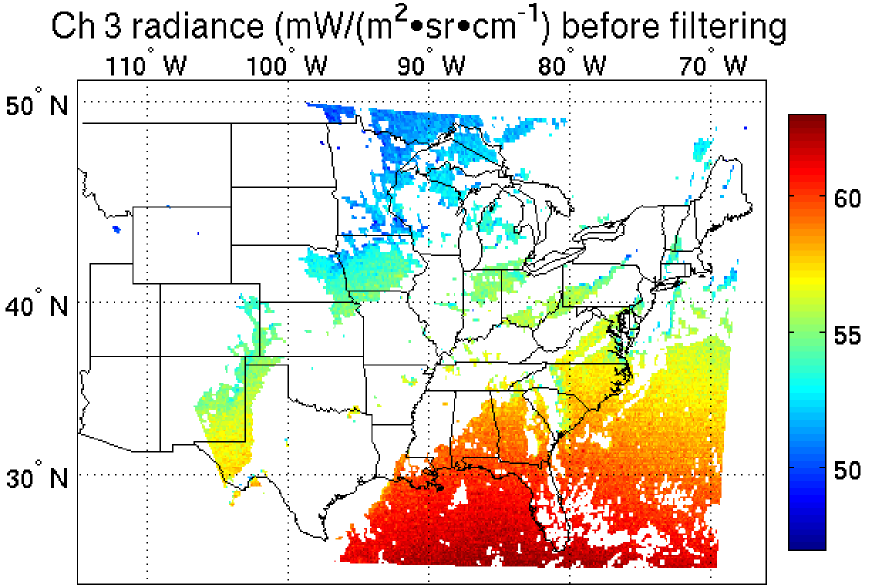
Channel 1 (14.72 µm)

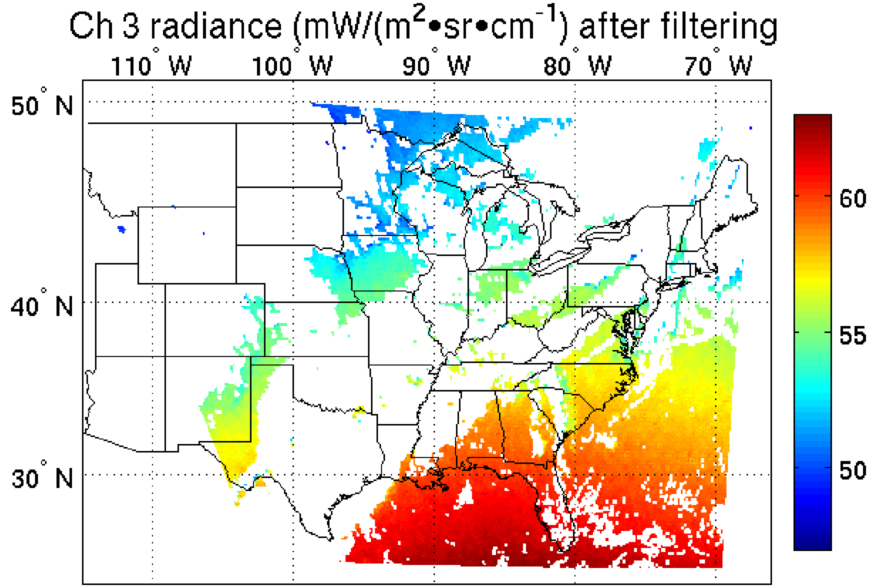


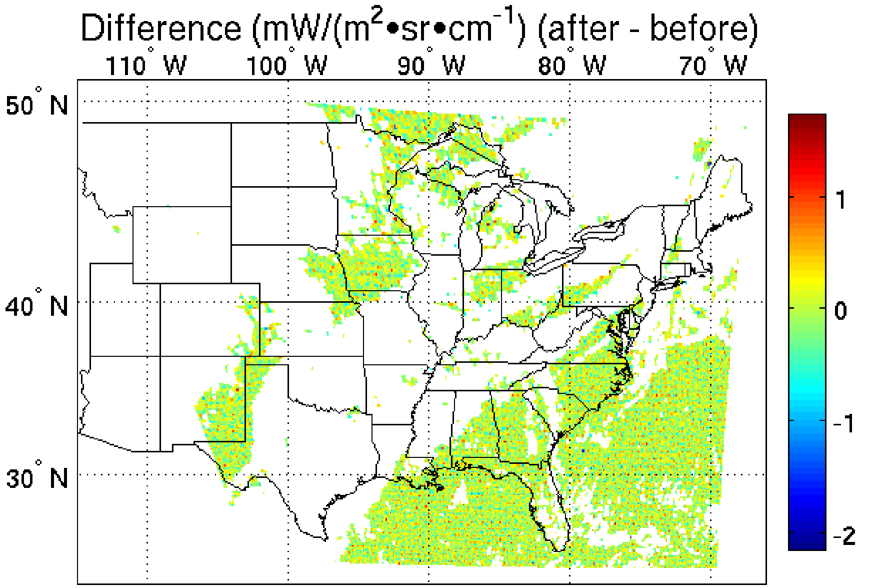
Channel 2 (14.34 μm)

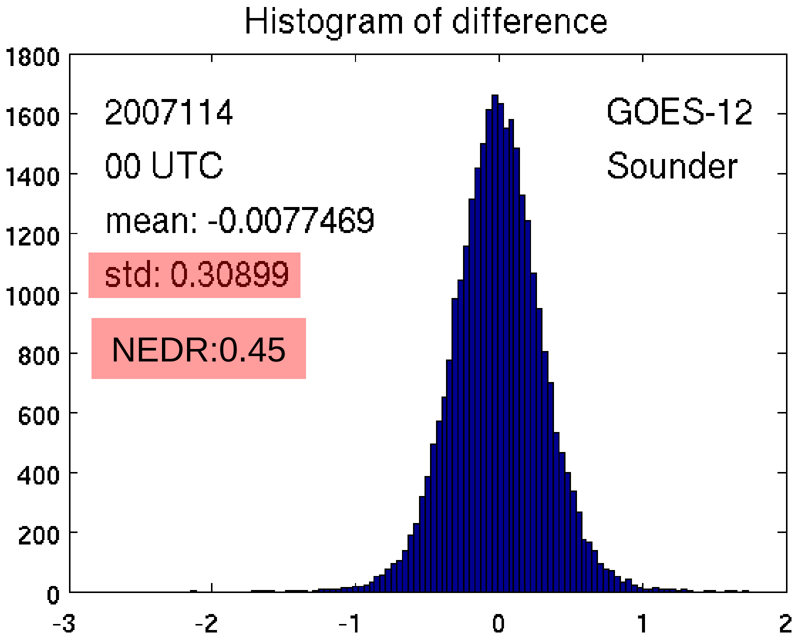


Channel 3 (14.08 μm)

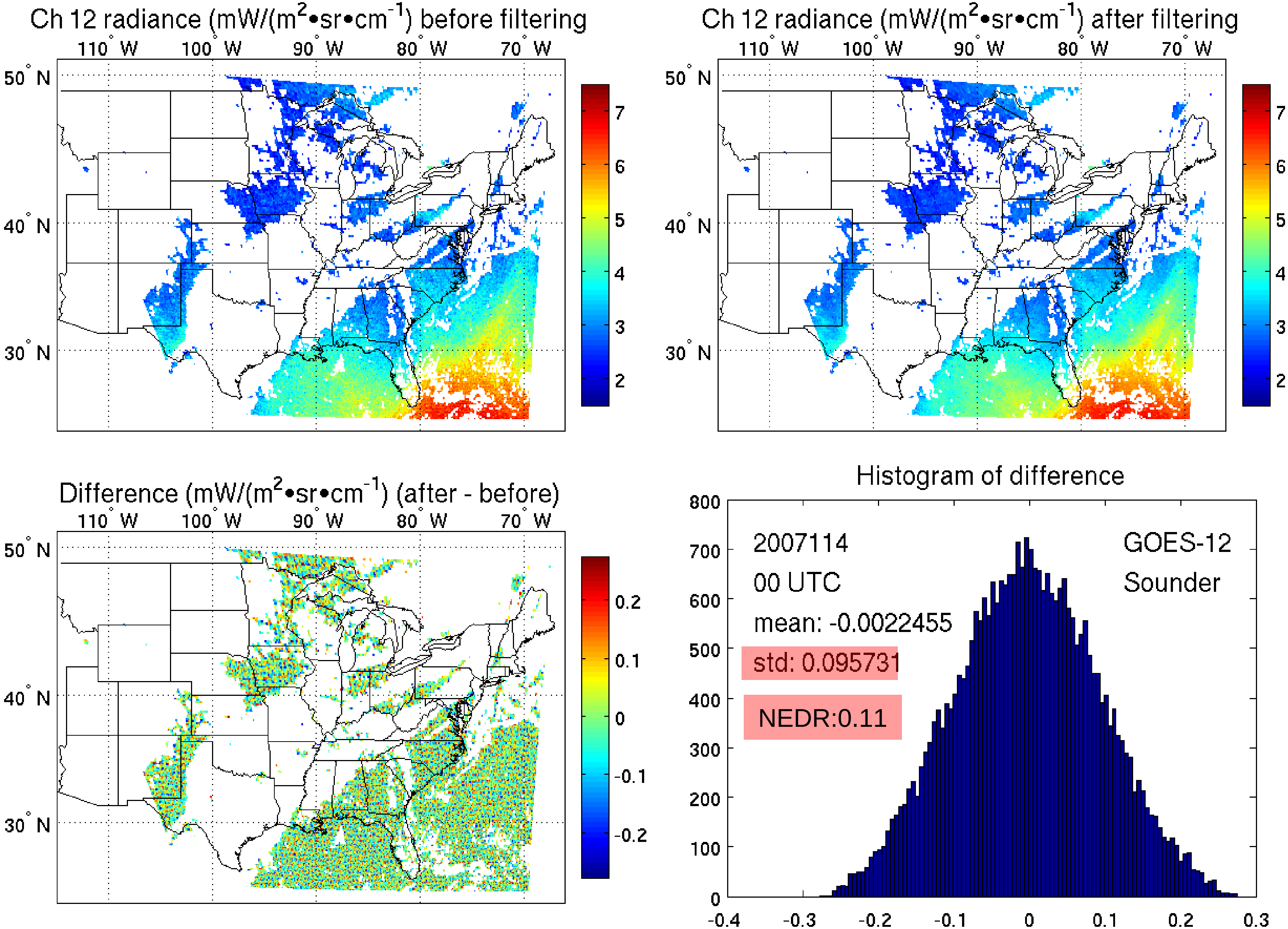




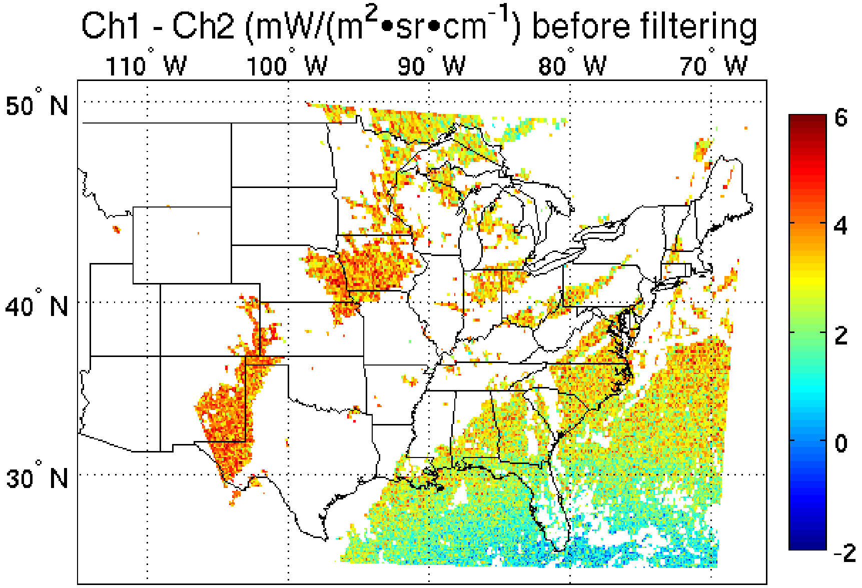


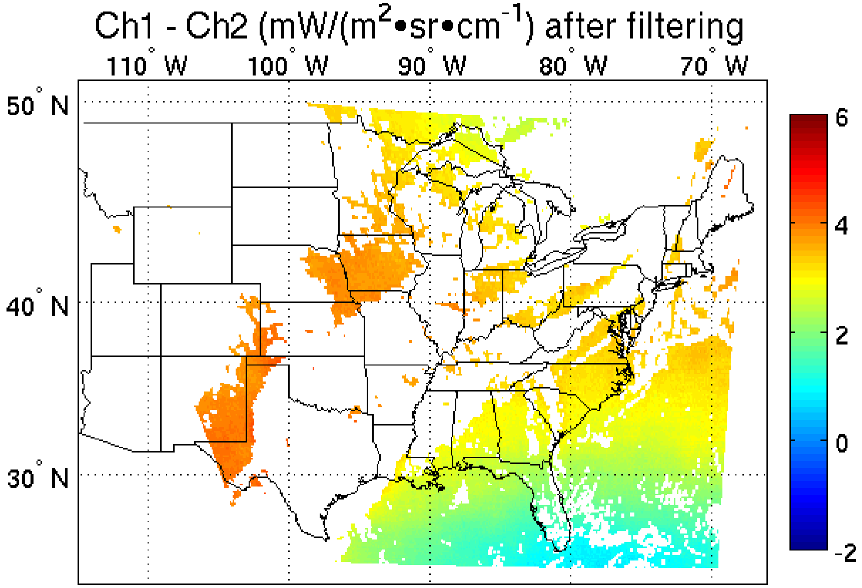


Channel 12 (6.52 µm)

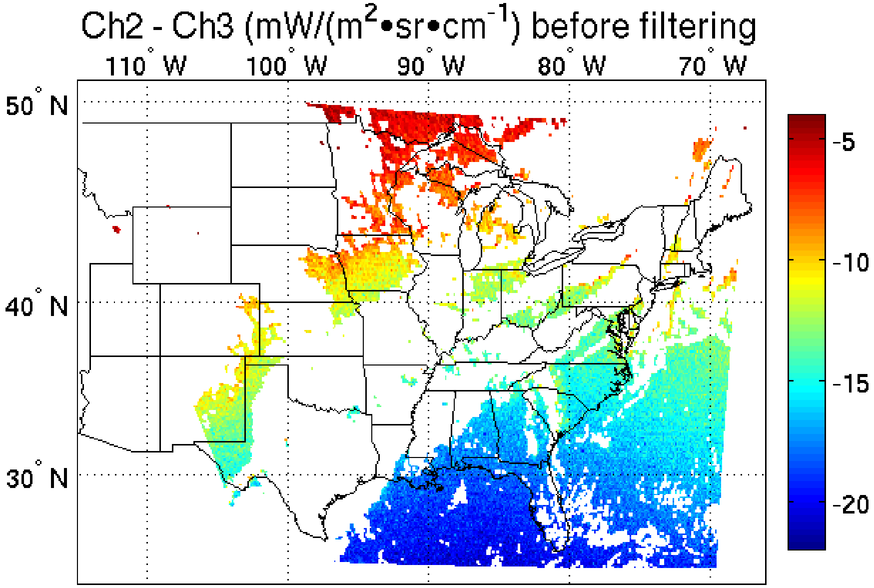


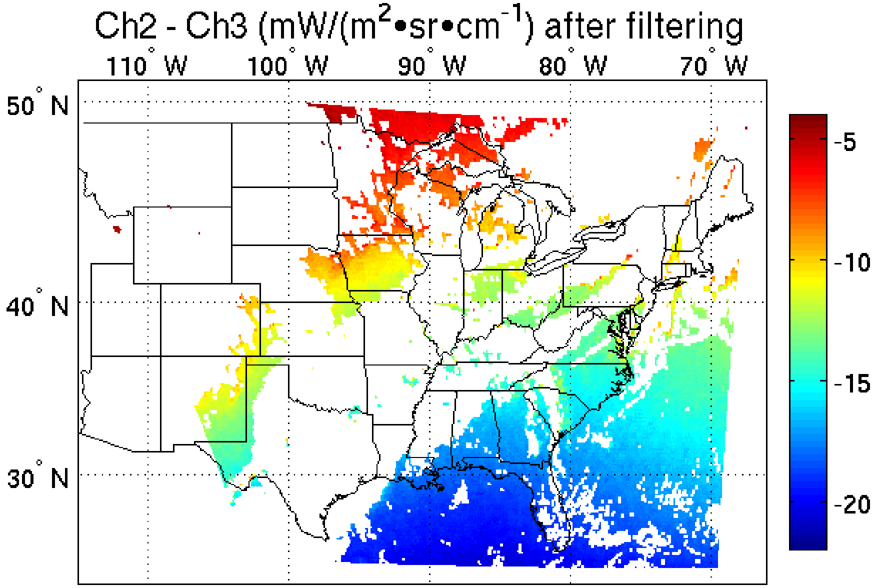
Channel 1 – Channel 2



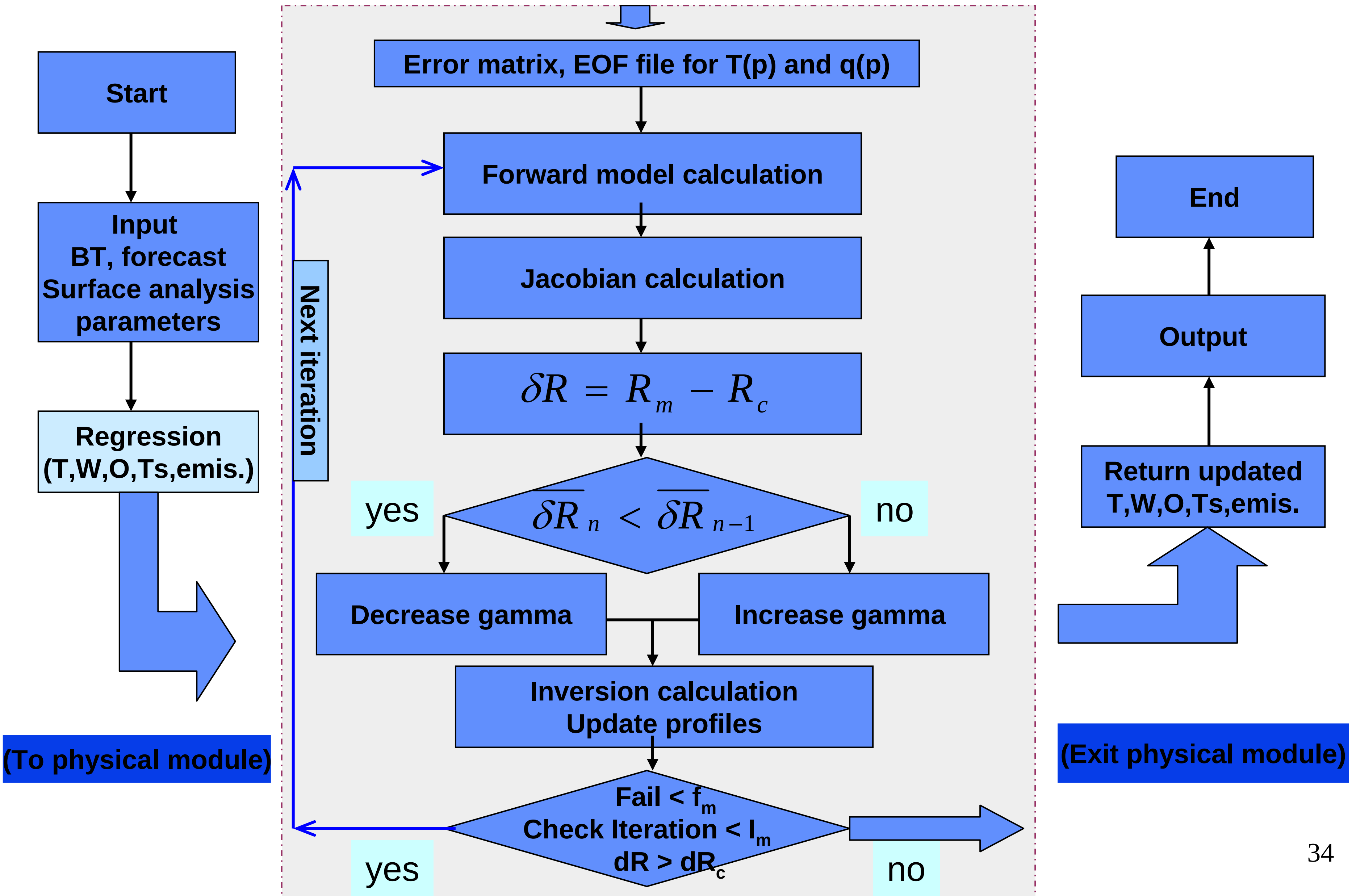


Channel 2 – Channel 3





Physical module Flow Chart



Algorithm Development Strategy

- **Use spatial continuities (users decide)**
  - » **For ABI**
    - – 2 km product
  - » **For SEVIRI**
    - – 3 km product
  - » **For GOES Sounder**
    - – 10 km product
- **Using forecast information (interpolated spatially, temporally, vertically)**
  - » Request forecast output at least every 3 hours, hourly data is the goal.
  - » The grid size of forecast should be 10 km if possible
- **Use two-step approach**
  - » Statistical retrieval that requires a nearly global representative training data set
  - » Physical retrieval takes into account the IR emissivities, surface pressure
    - – Pre-determined emissivities
    - – Surface pressure from forecast
- **Quality Control**
  - » Generate QA index during both statistical and physical procedures
    - – Residual Index (RI)
    - – Convergence Index (CI)
    - – Cloud Contamination Index (CCI)
    - – Estimated Error (EE)
    - – Quality Indicator (QI) derived from above parameters

Questions Remain

- How to better use of temporal continuity?

- Improving emissivity prior information, adjusting emissivity in physical approach? Study shows that adjustment on emissivities in hyperspectral sounding retrieval is reliable (Li et al. 2007 - GRL), but for broad bands ?

Algorithm Development Strategy

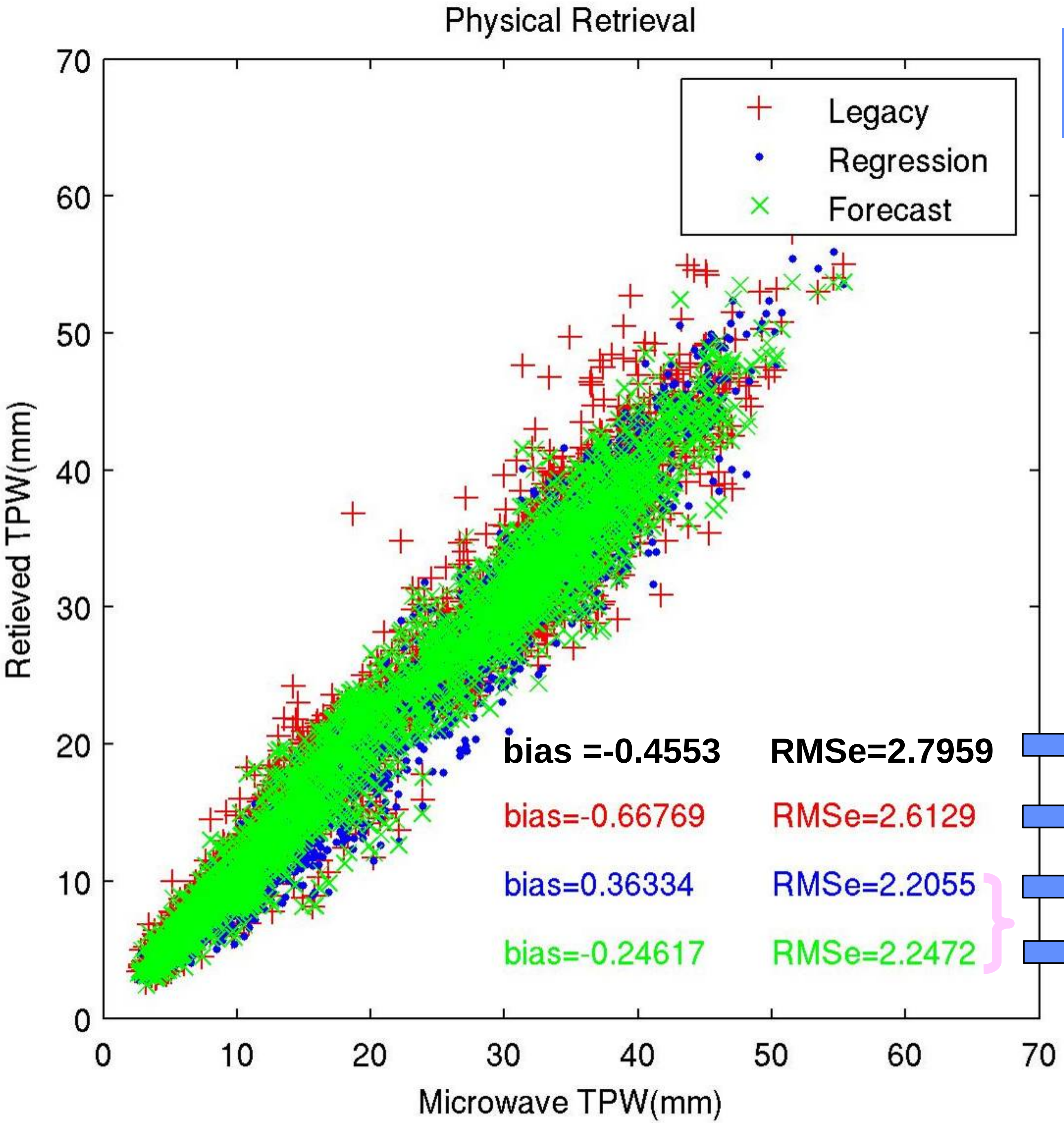
Validation:

- Truth data
  - » Rawinsondes
  - » Ground based microwave radiometer water vapor measurements
  - » GPS water vapor measurement
- Algorithm Test plan
  - » Develop analyses using truth data above on proxy/simulated cases discussed previously to perform verification/validation
- Error Estimation
  - » Based on our heritage approaches of validating sounding products
- Model impact
  - » Assimilate product in regional model for impact (this is suggested, need additional resource for this task)

Validation and Applications

- Validation of GOES sounding product
- Applications of GOES Sounder products on convective storm cases

Validation with ARM site measurements



Current GOES Sounder retrievals gives reasonable accuracy when compare with microwave radiometer TPW measurements. The new algorithm improves the legacy product.

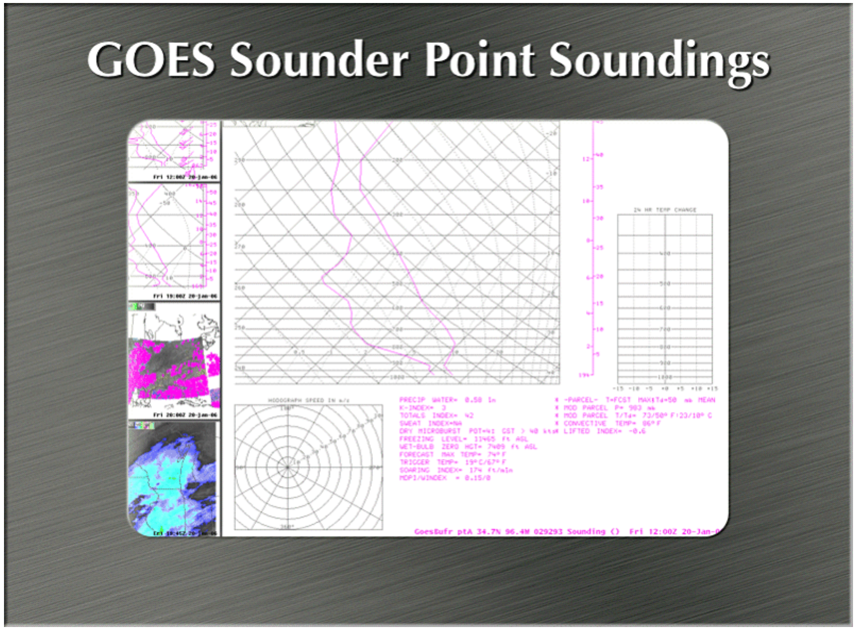
Forecast

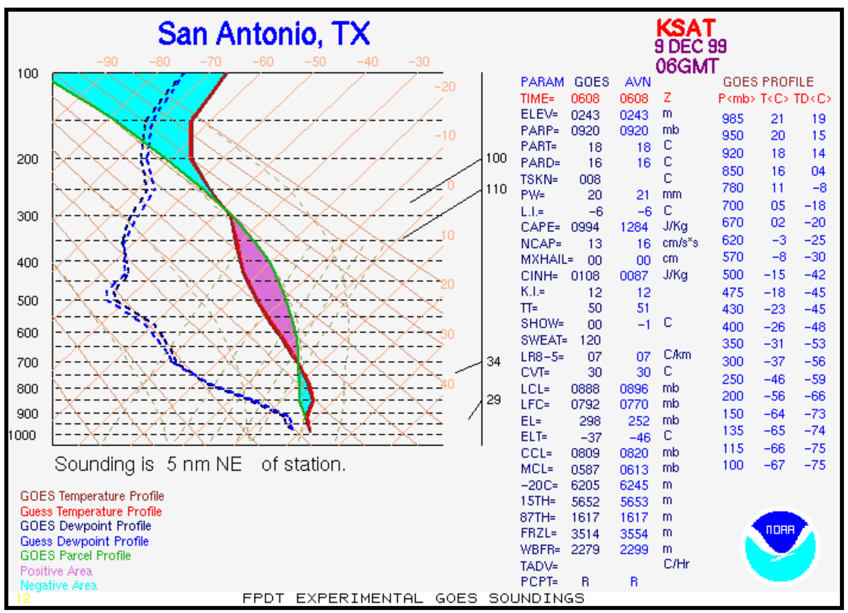
Legacy retrieval

New RTVL (reg guess)

New RTVL (fcst guess)

Temperature & Moisture Profiles





- **Physical Retrieval** (Ma et al, 1999)
  - » Short-term (< 12 hrs) GFS model forecasts provide first guess
  - » Hourly surface observations, NCEP SST analysis provide boundary conditions
  - » Computed at 40 levels
  - » Pixel level retrievals

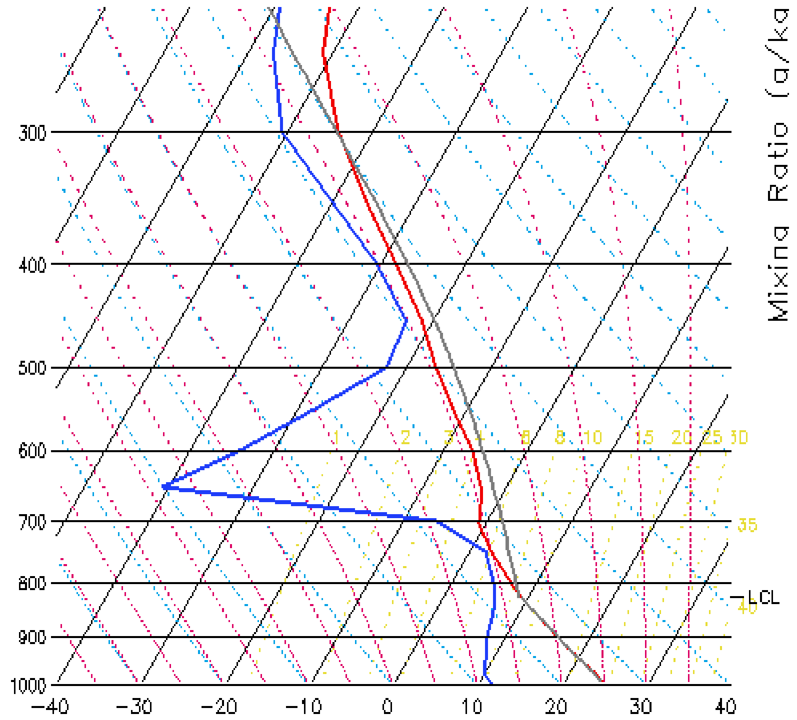
- **Distributed to AWIPS, NCEP**

- **<u>Operational Applications</u>**

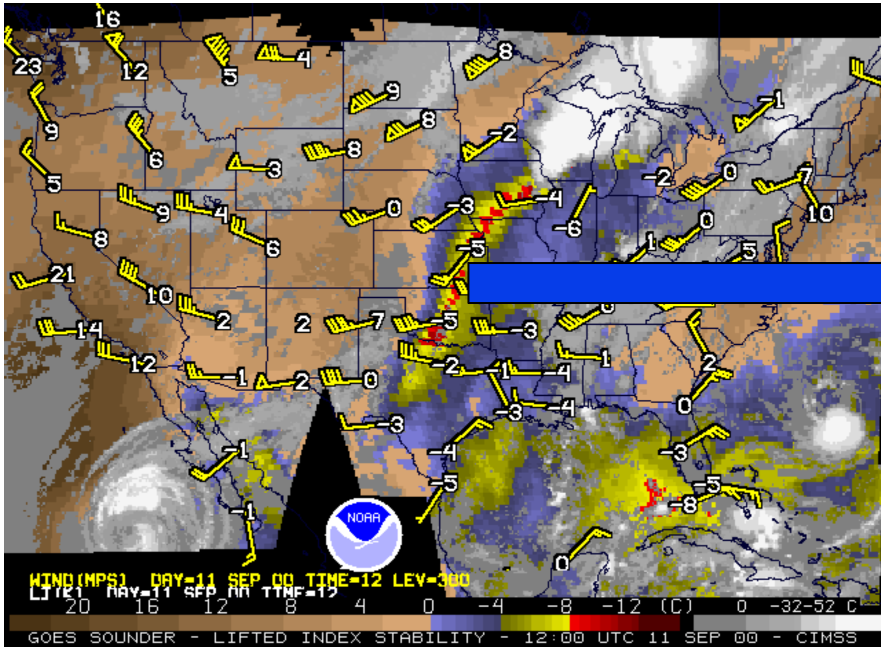
  Nowcasting
  - » Aids in monitoring of vertical structure of temperature and moisture of the atmosphere
  - » Fills in gaps between conventional observations
  - » Convective potential and morphology
  - » Situational awareness in pre-convective environments for potential watch/warning scenarios

The lifted index (LI)

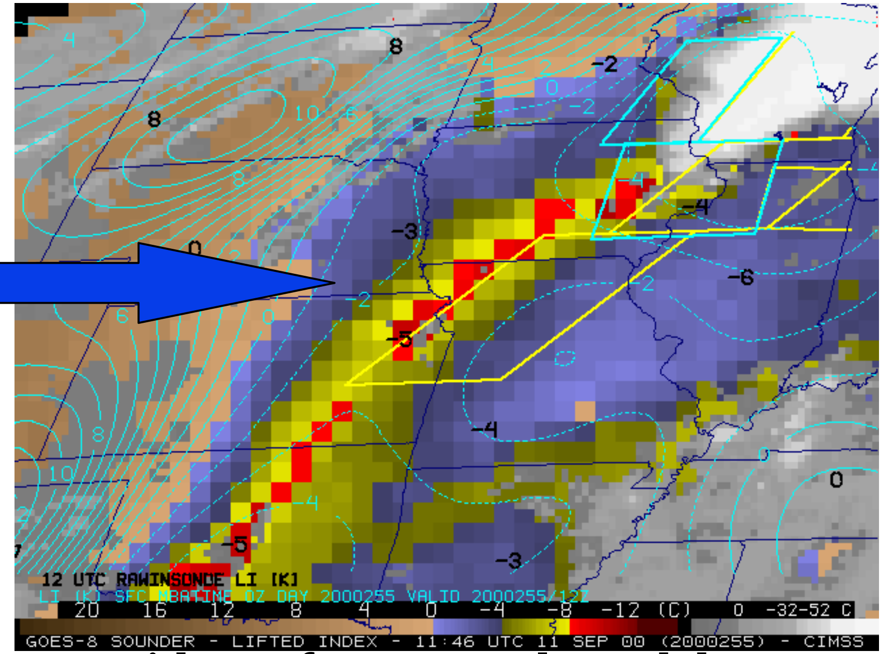
- The LI, a measurement of atmospheric instability
- positive → a stable atmosphere
- [0 -3] → **marginally unstable**
- [-3 -6] → **moderately unstable**
- [-6 –9] → **very unstable**
- <= -9 → **extreme instability**
- Best chances of a severe thunderstorm <= -6.



12 UTC **Sounder LI**



Zoomed in view:



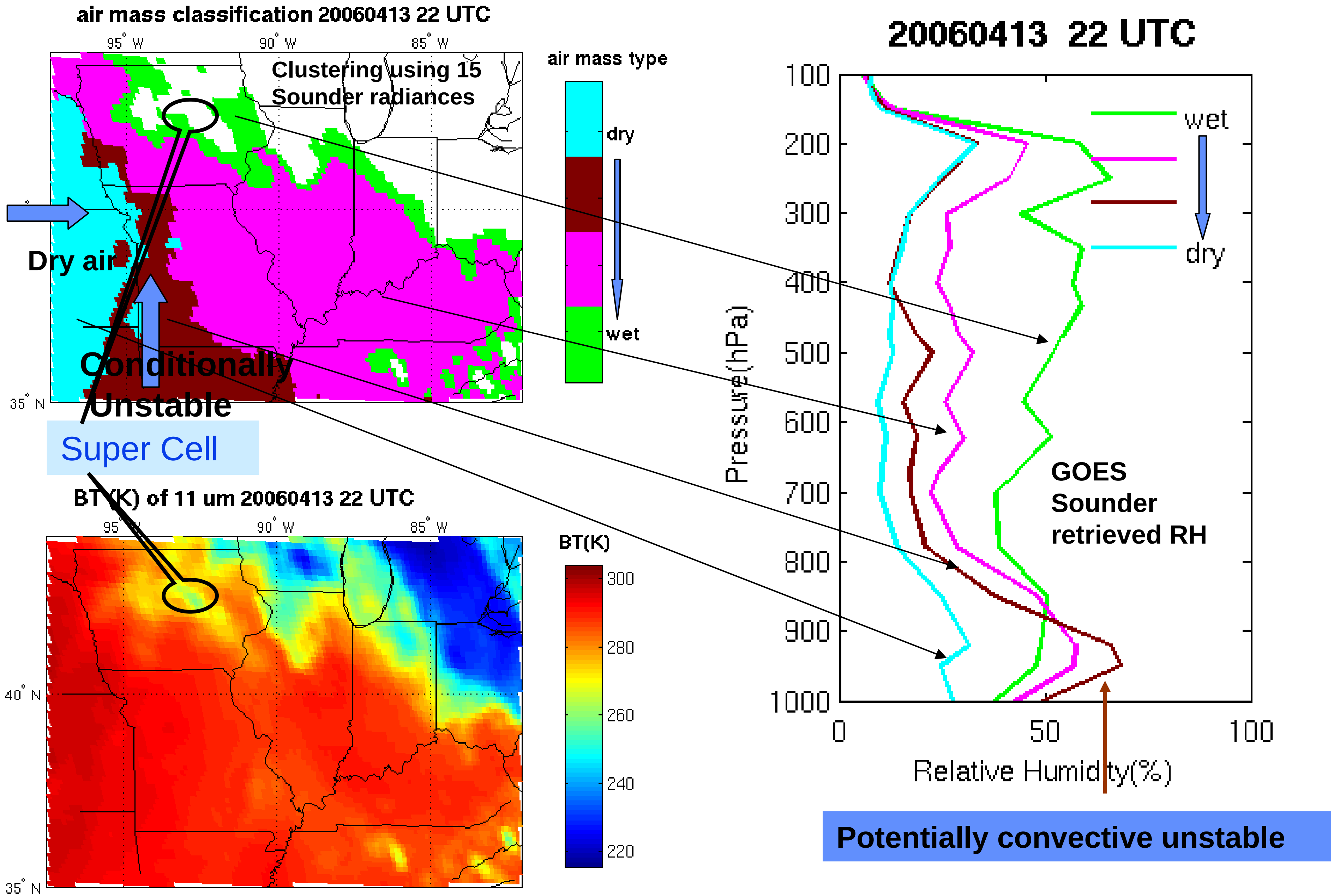
With Eta forecast and watch boxes

EXCESSIVE RAINFALL POTENTIAL OUTLOOK
HYDROMETEOROLOGICAL PREDICTION CENTER...NWS...CAMP SPRINGS MD

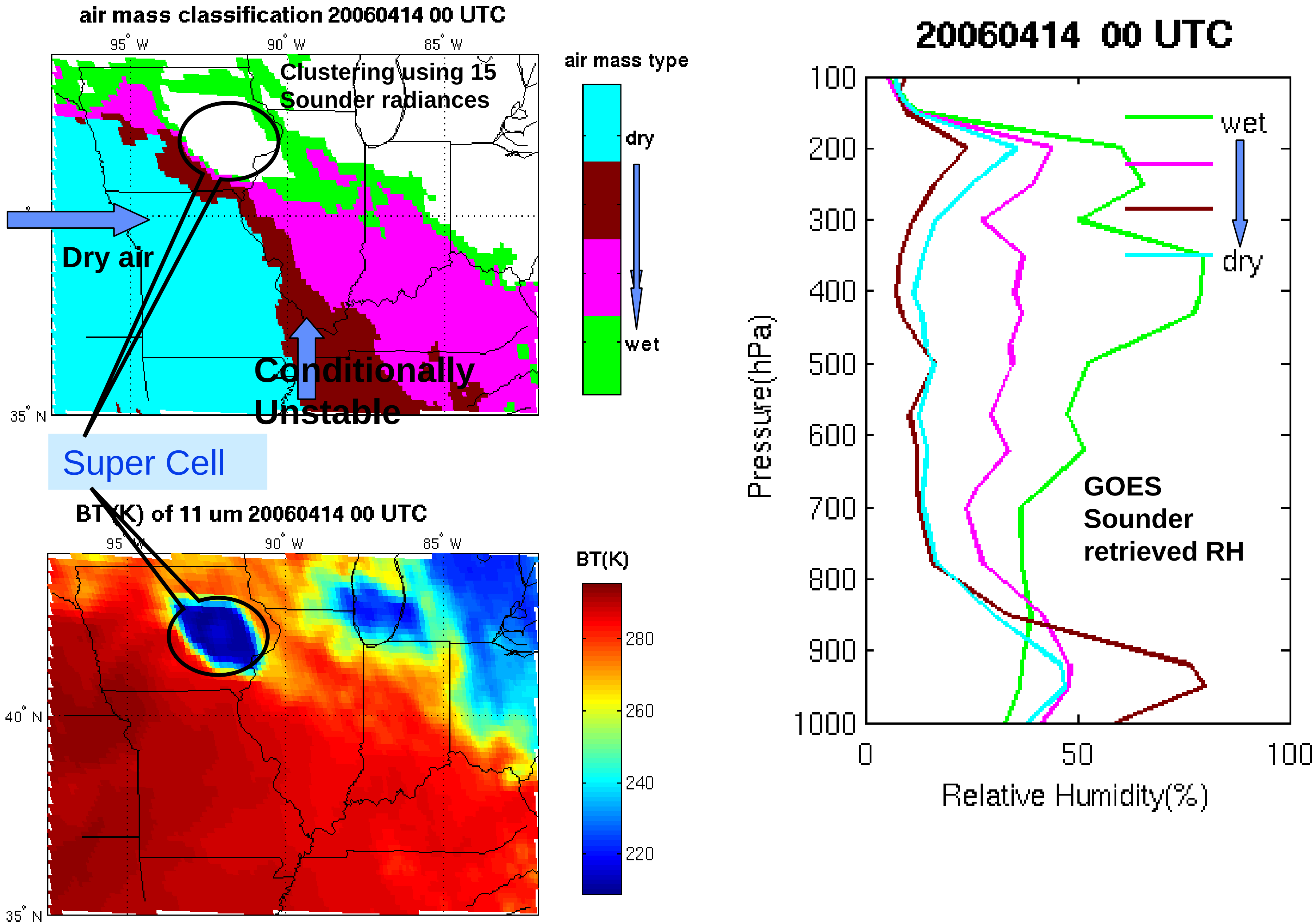
GOES SOUNDER DATA SHOWS Precipitable Water from the Sounder (PWS) SOUTH OF THE OUTFLOW BOUNDARY ARE IN THE 1.60 TO 1.70 INCH RANGE. THE SOUNDER DATA ALSO INDICATES THAT THE AIRMASS TO THE WEST ACROSS IL IS CONTINUING TO DESTABILIZE. ALL THE ABOVE ARGUE FOR THE POTENTIAL FOR ISOLATED 3 TO 5 INCH RAINFALL BEFORE THE SYSTEM STARTS SHIFTING EWD.

Janesville, WI received 4 inches of rain; Sullivan, WI had 3 inches.

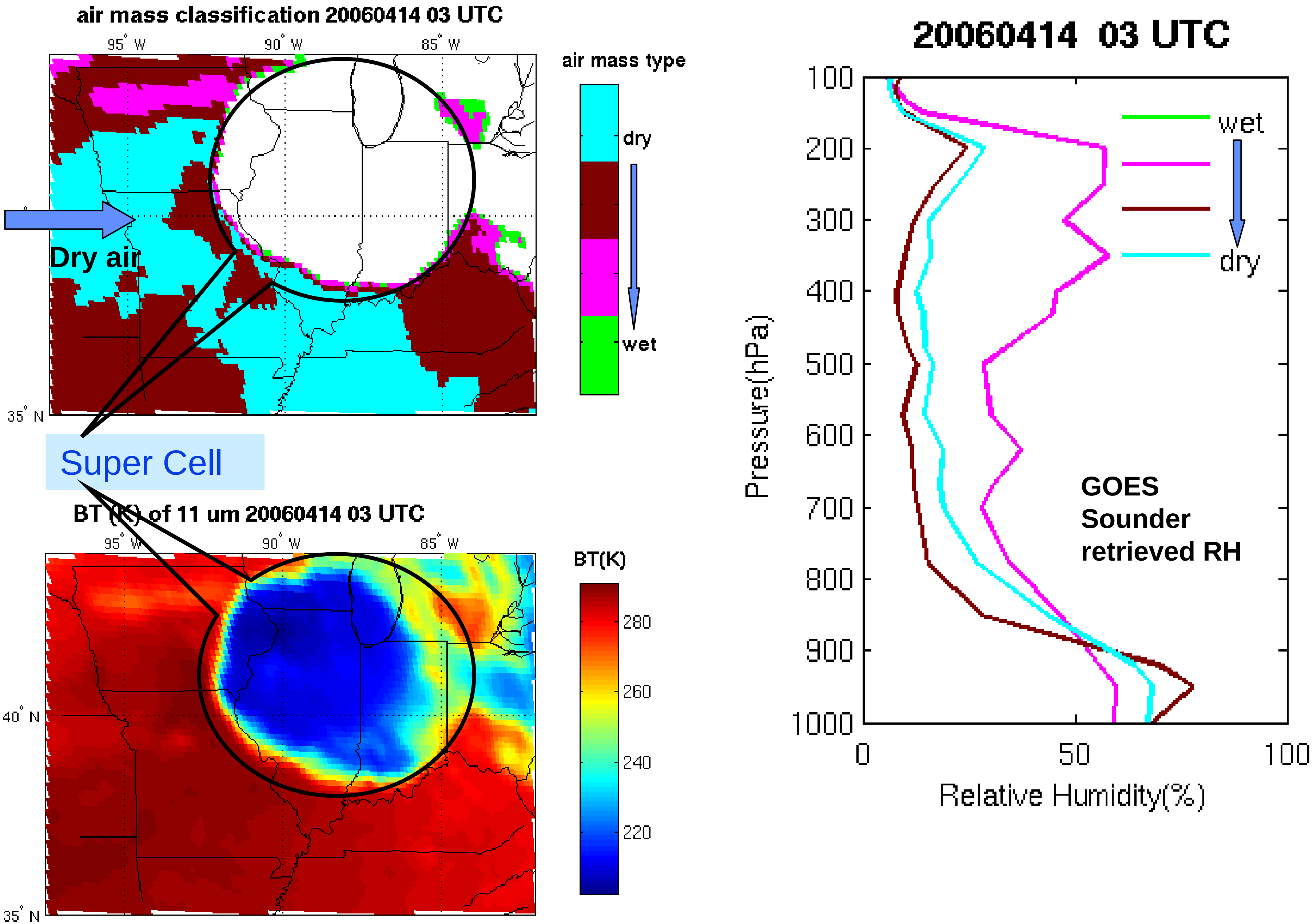
Air mass tracking 22 UTC, 13 April 2006

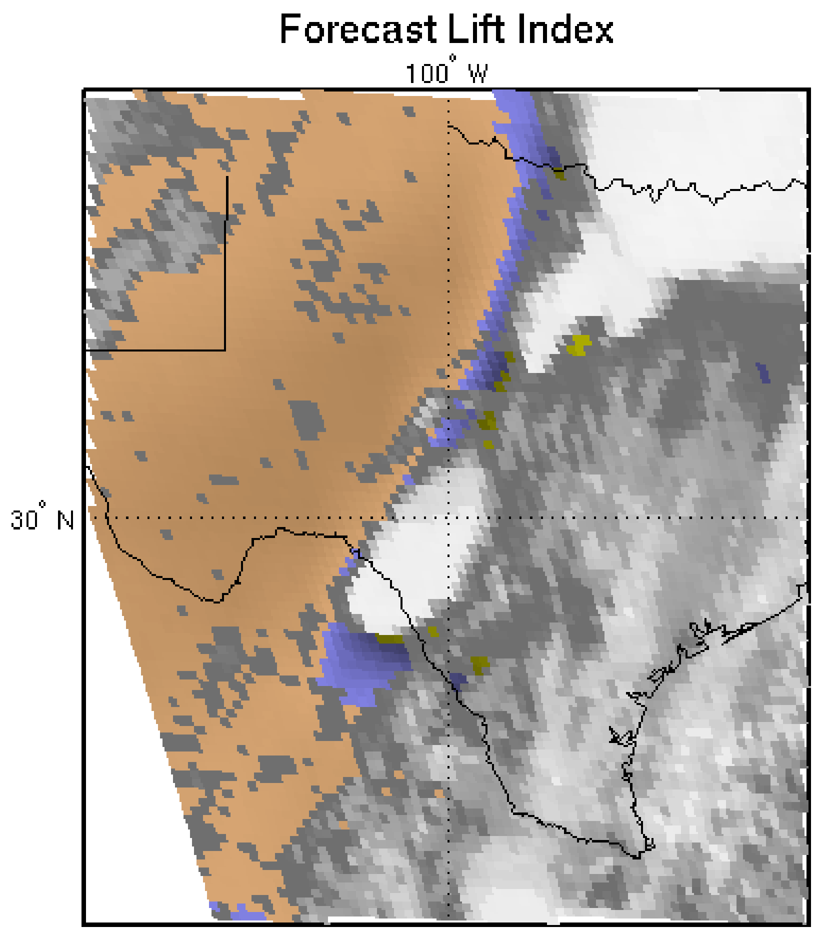


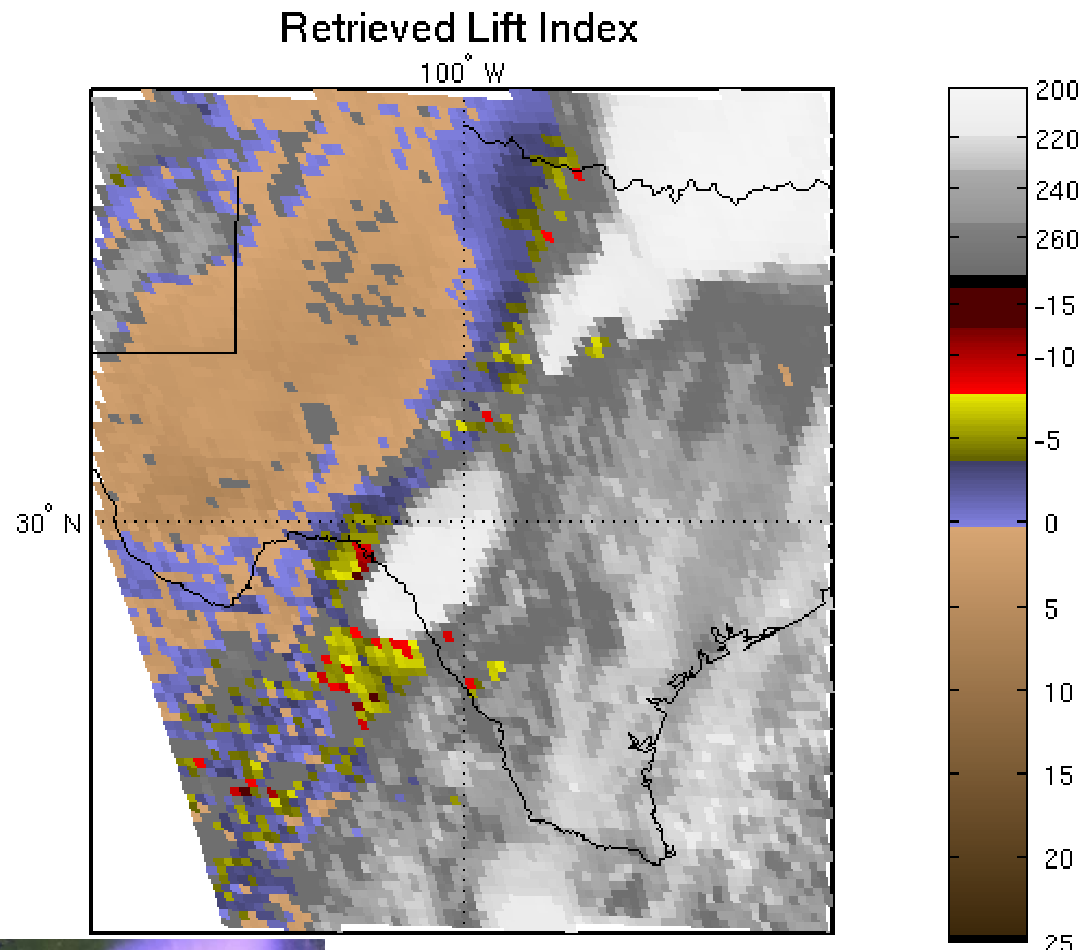
Air mass tracking 00 UTC, 14 April 2006



Air mass tracking 03 UTC, 14 April 2006





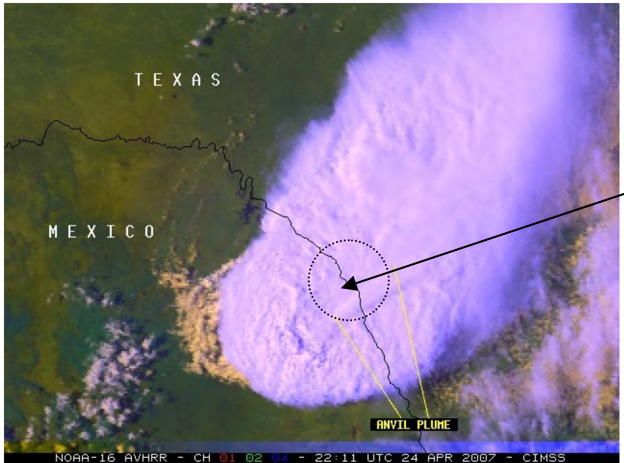


Forecast LI

GOES Sounder LI

UW/CIMSS

22 UTC on 24 April 2007

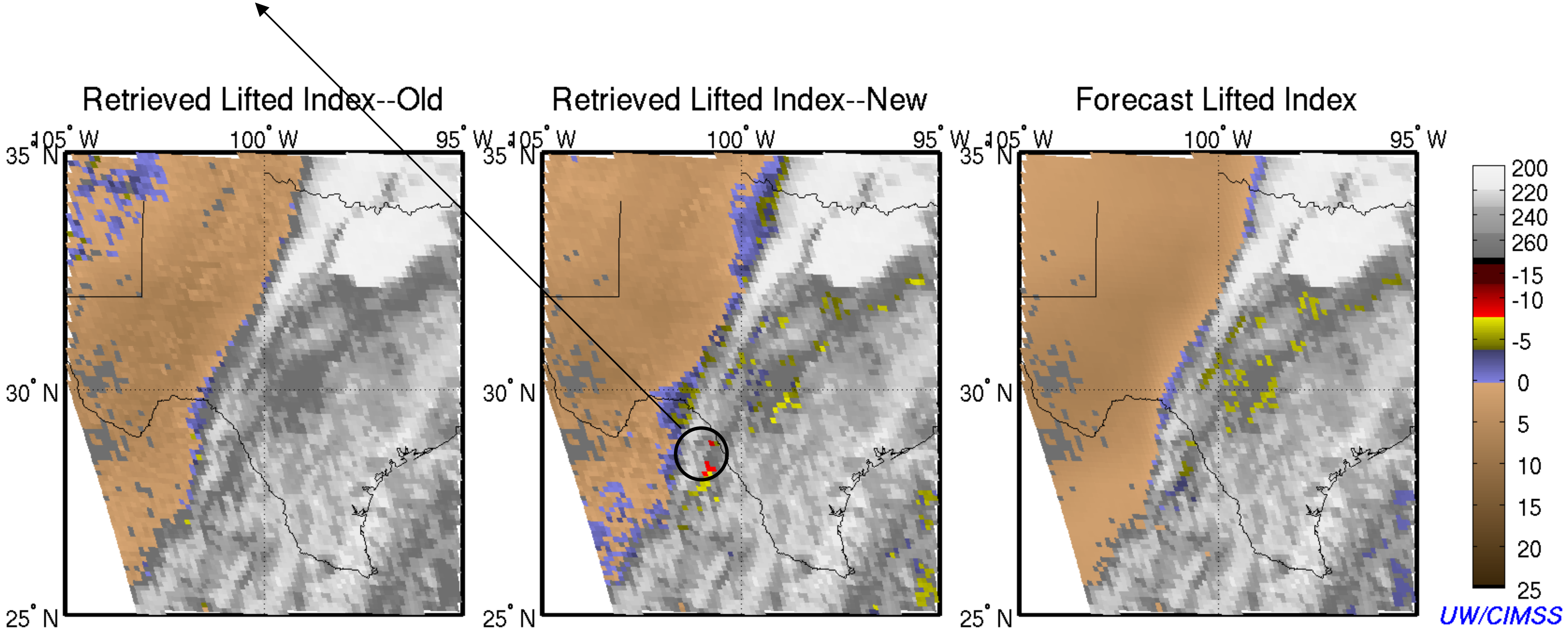


Tornado that killed 10 and injured 120 persons in the Eagle Pass, Texas area

19 UTC
24 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

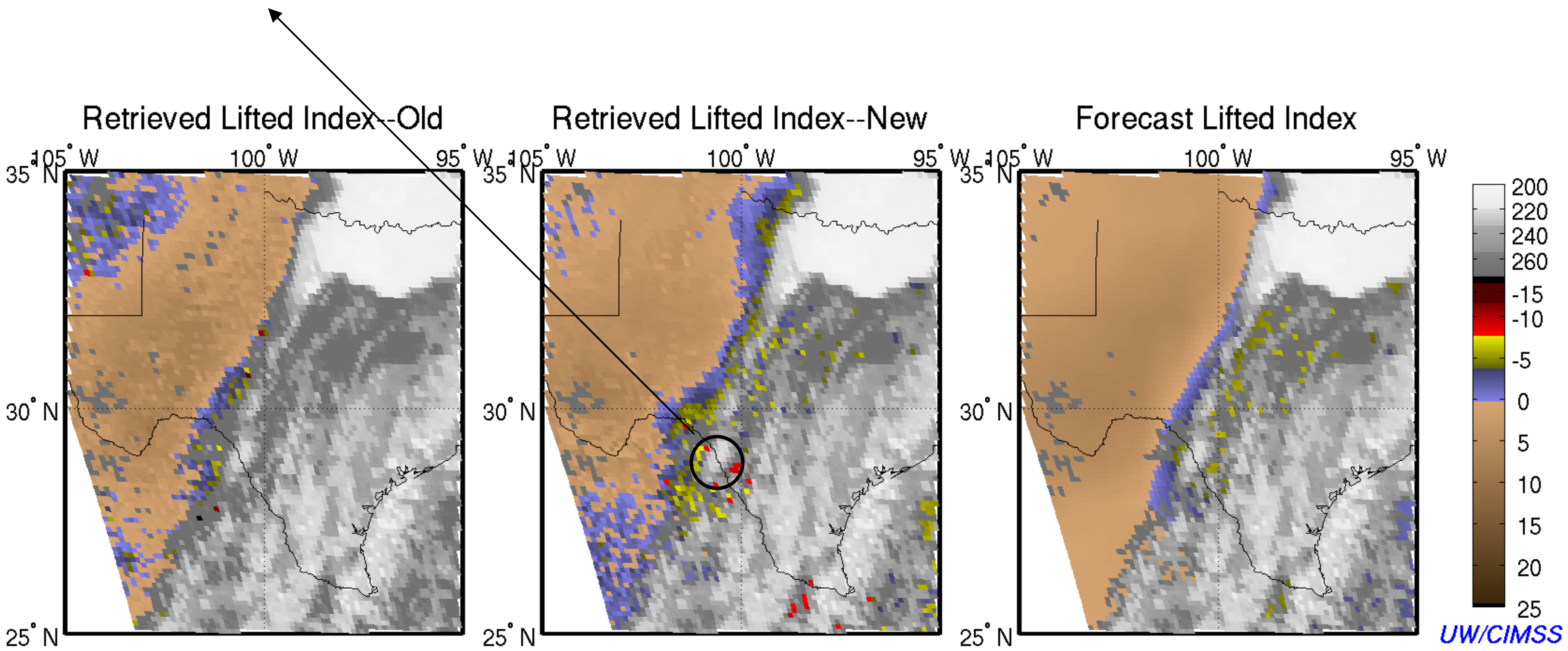
Large instabilities will initialize the supercell. It is also reasonable to assume instabilities under these clouds are large.



20 UTC
24 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

Increased areas of large instabilities.

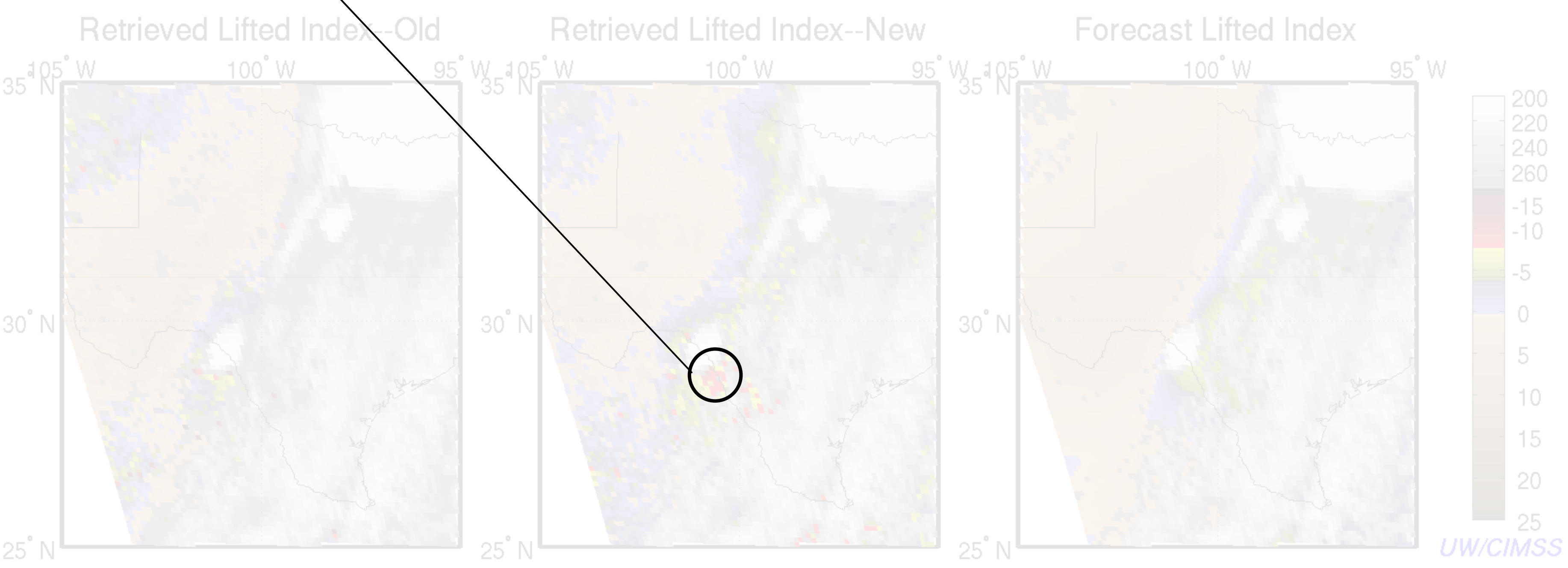


21 UTC
24 April 2007

Case 1, a tornadic supercell

Eagle Pass, Texas

Supercell formed. Large instabilities from the south support the supercell.



22 UTC

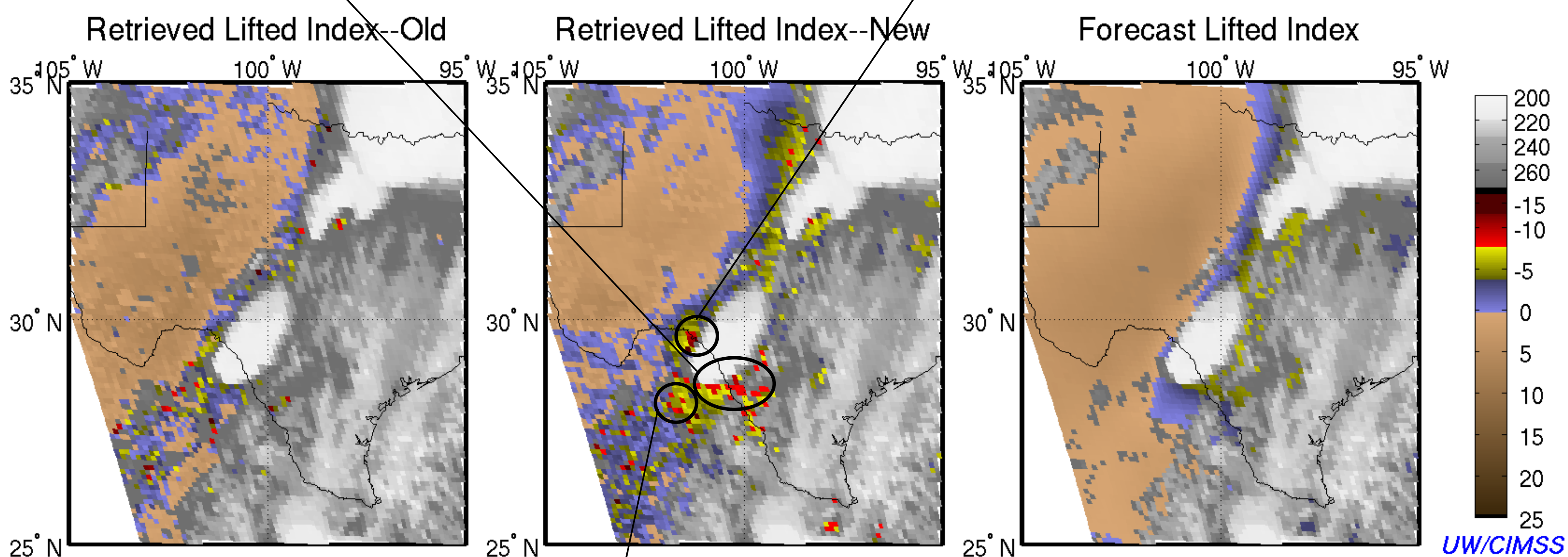
24 April 2007

Case 1, a tornadic supercell

Eagle Pass, Texas

Supercell kept growing. Large instabilities from the south still support the supercell.

This small area of extremely large instabilities will trigger another convective storm.



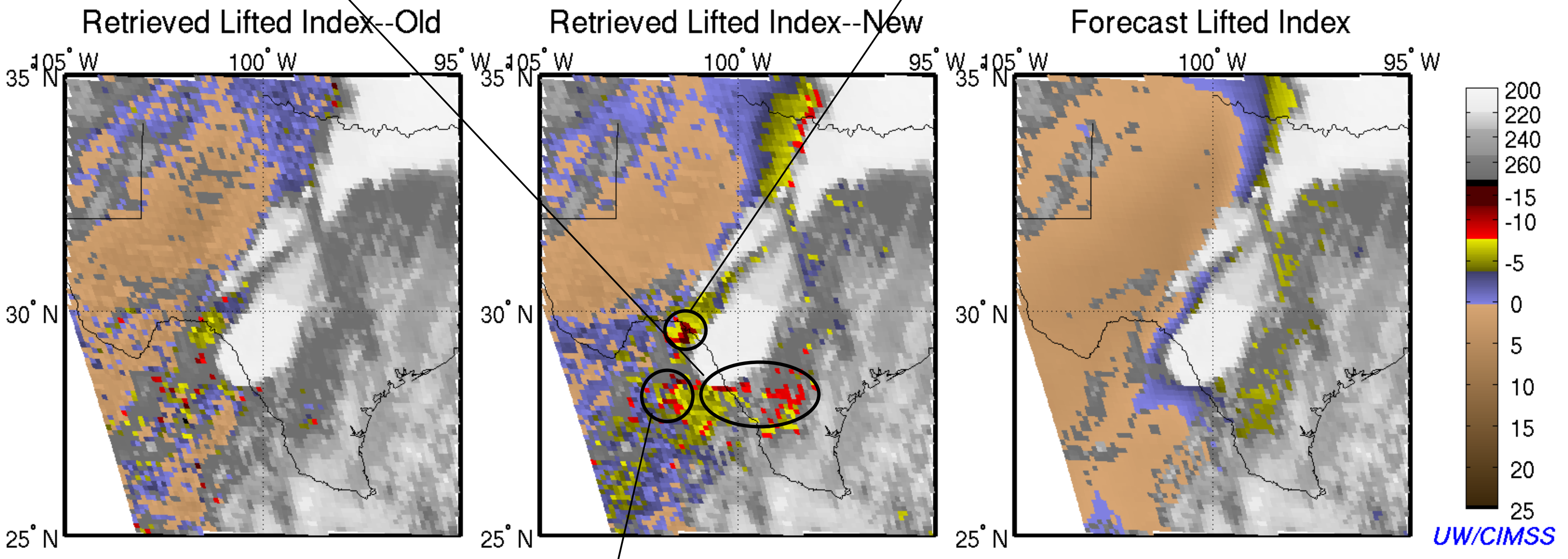
Watch out for this increasing instabilities here.

23 UTC
24 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

Supercell kept growing. Large instabilities from the south still support the supercell.

The second convective storm formed to the north of the supercell.



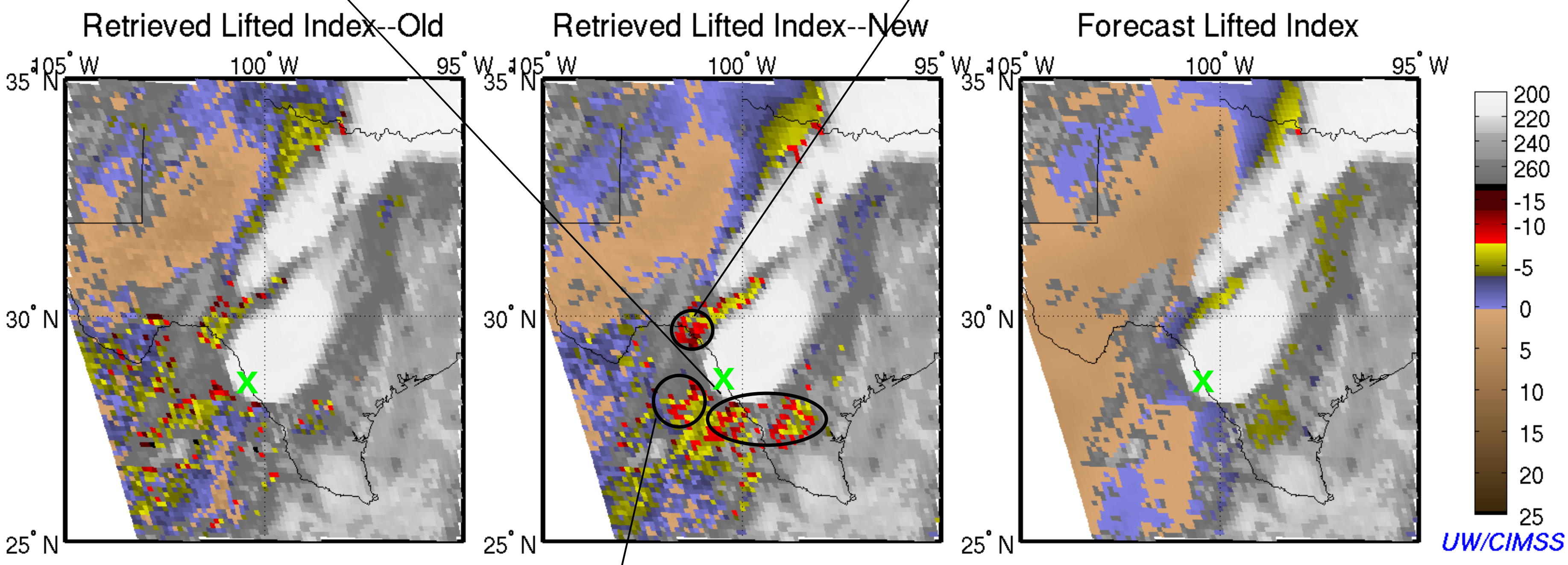
Instabilities kept growing here.

00 UTC
25 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

Supercell kept growing. Large instabilities from the south still support the supercell.

The second convective storm grew quickly with the support from the large instabilities.



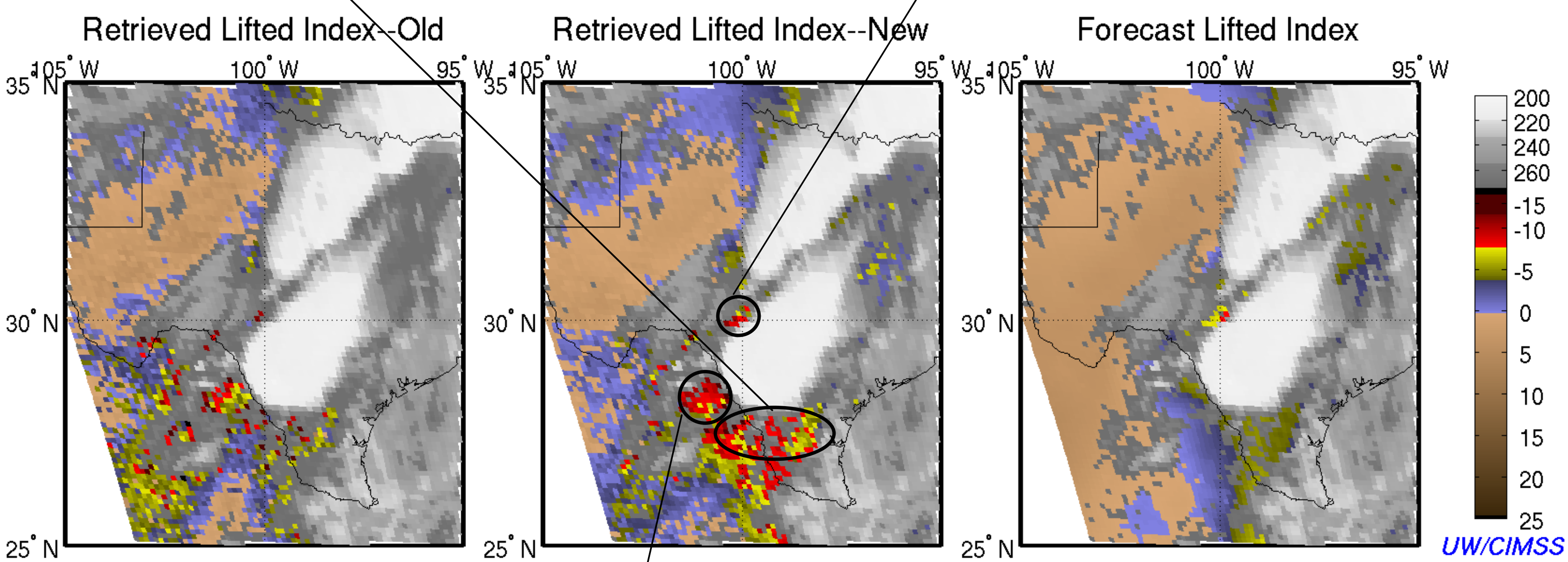
Instabilities kept growing here.

01 UTC
25 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

Supercell kept growing. Large instabilities from the south still support the supercell.

Without constant moisture supply, the instabilities stopped increasing. The convective storm died out.



Instabilities kept growing here.

02 UTC

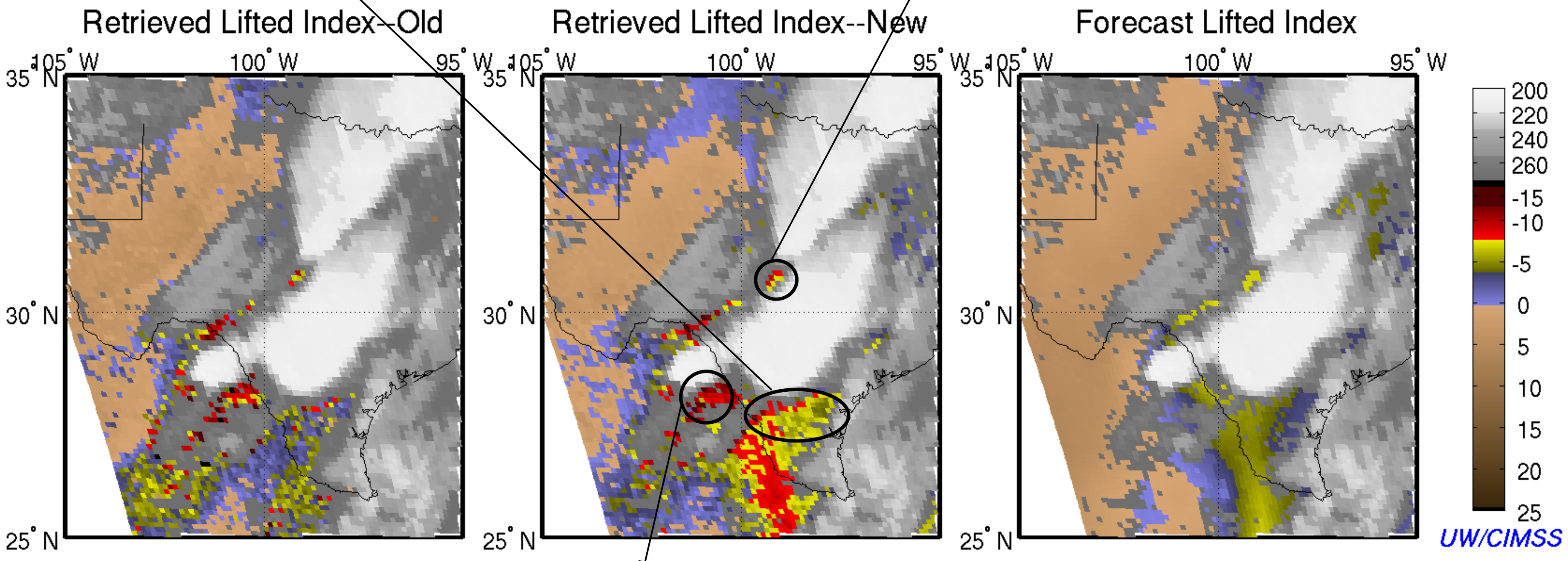
25 April 2007

Case 1, a tornadic supercell

Eagle Pass, Texas

The area of large instabilities was decreasing. The supercell began dying out.

The second storm was history.

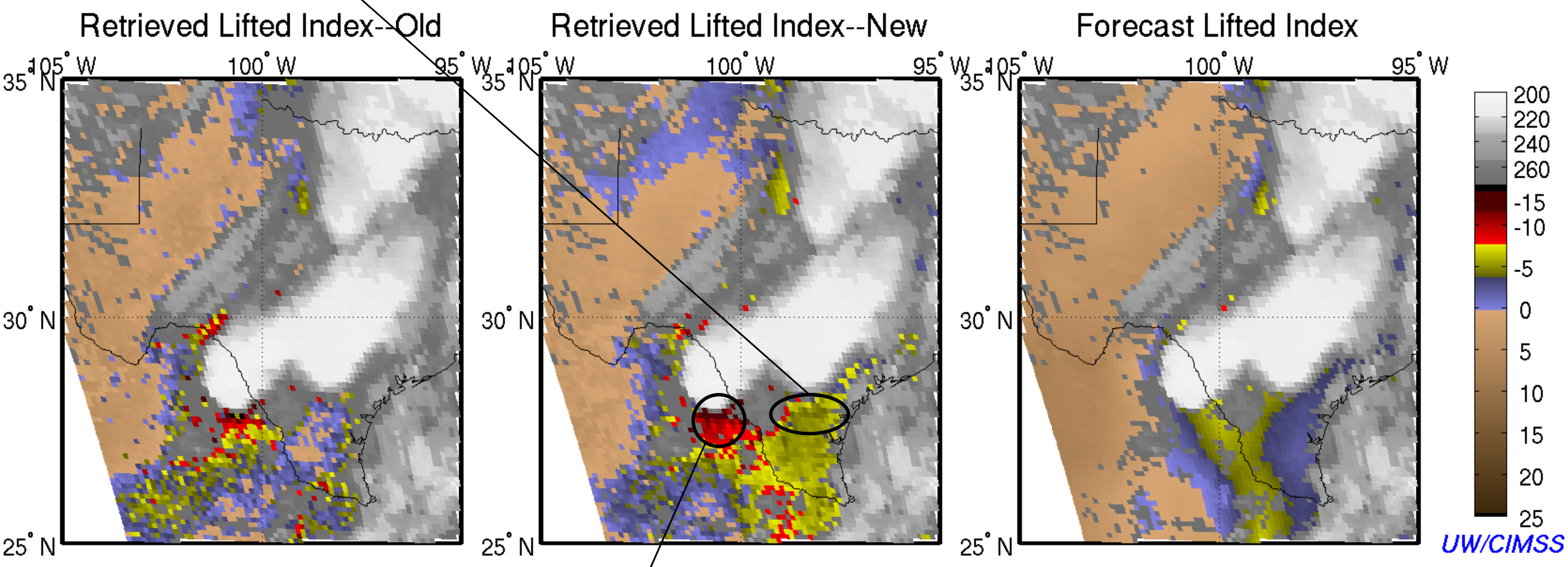


The third convective storm formed with the supply of large instabilities.

03 UTC
25 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

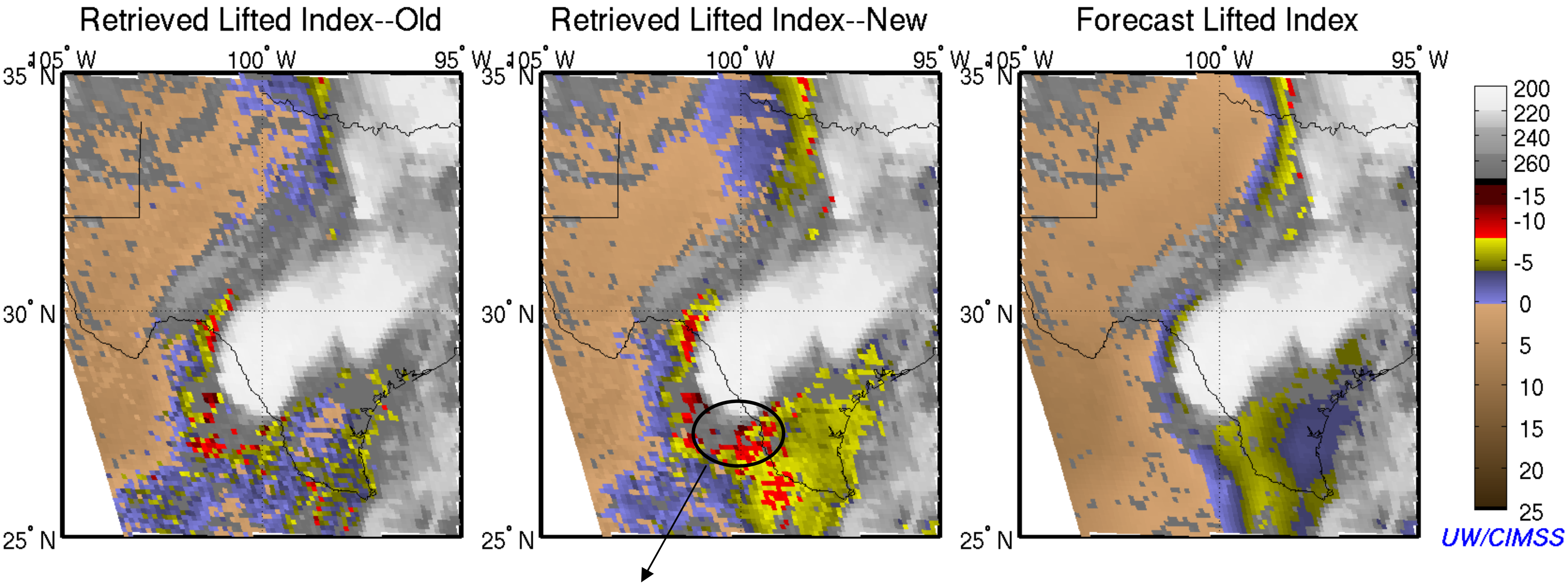
No instabilities support the supercell.
The supercell was history.



Increased area of instabilities kept the third convective storm growing quickly.

04 UTC
25 April 2007

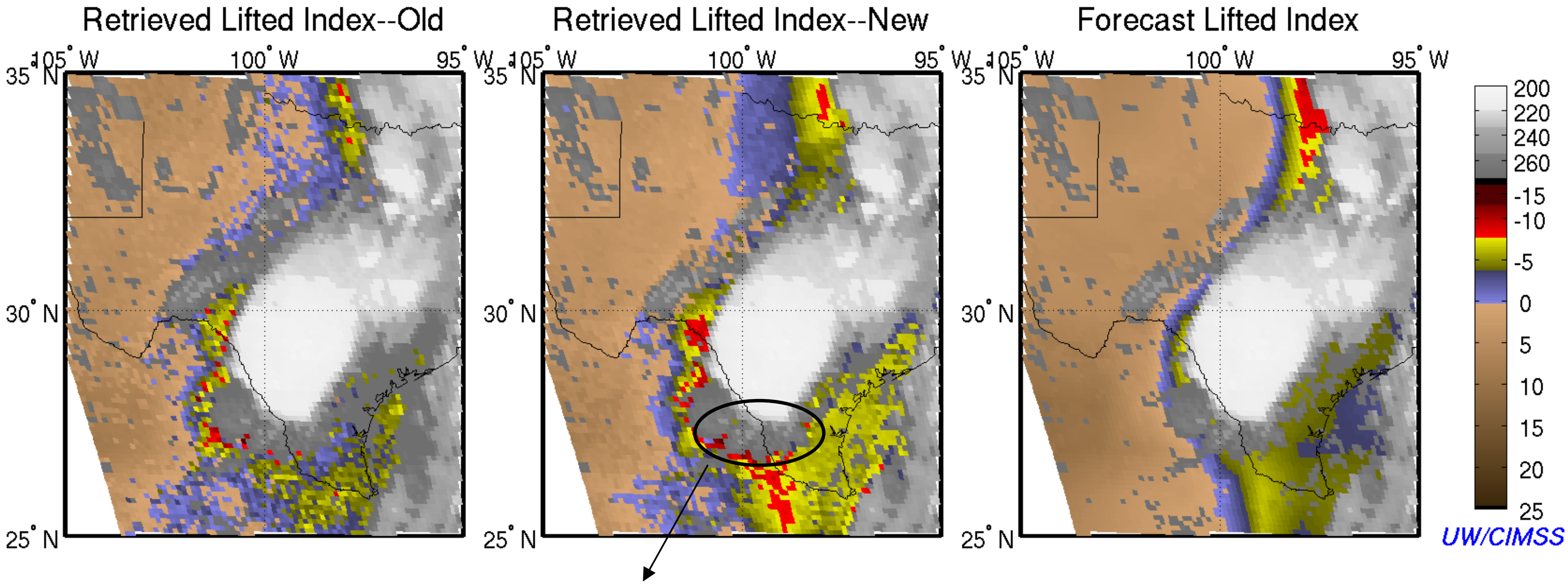
Case 1, a tornadic supercell
Eagle Pass, Texas



Increased area of instabilities kept the third convective storm growing quickly. It was reasonable to assume large instabilities under the clouds within this area.

05 UTC
25 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

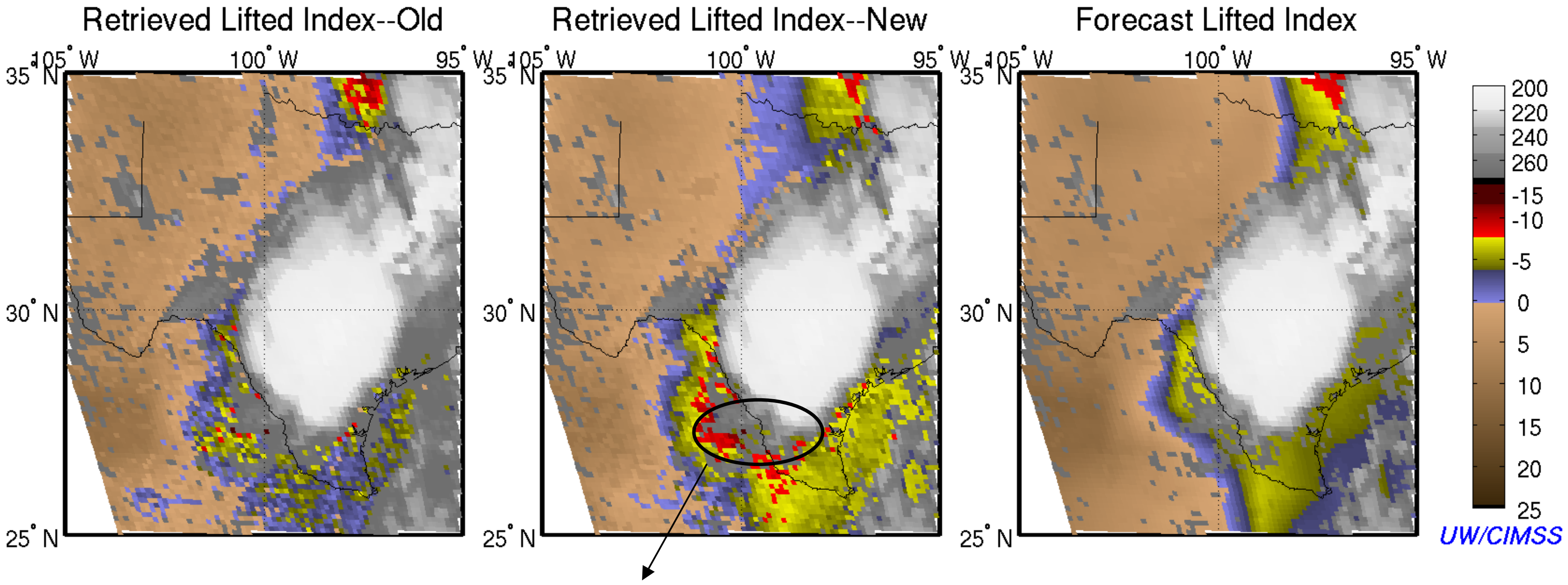


A lot of areas were covered by clouds. And the storm kept growing.

06 UTC
25 April 2007

Case 1, a tornadic supercell

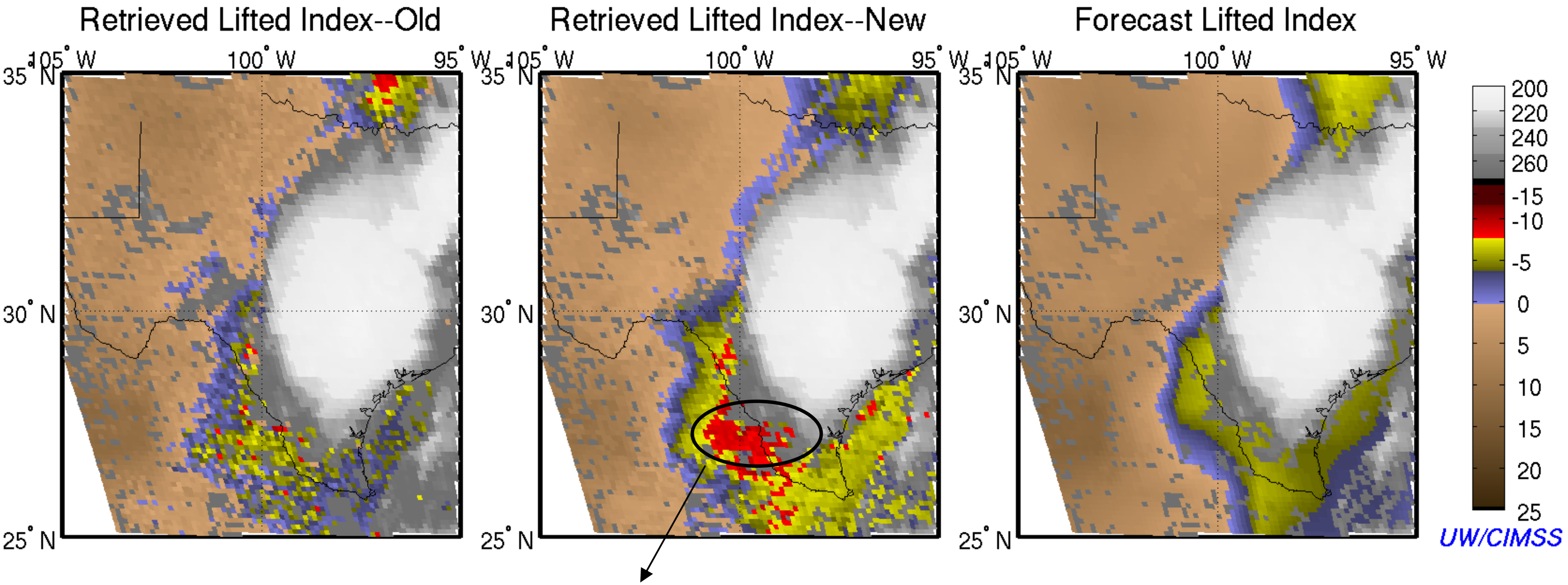
Eagle Pass, Texas



A lot of areas were covered by clouds. And the storm still kept growing.

07 UTC
25 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas



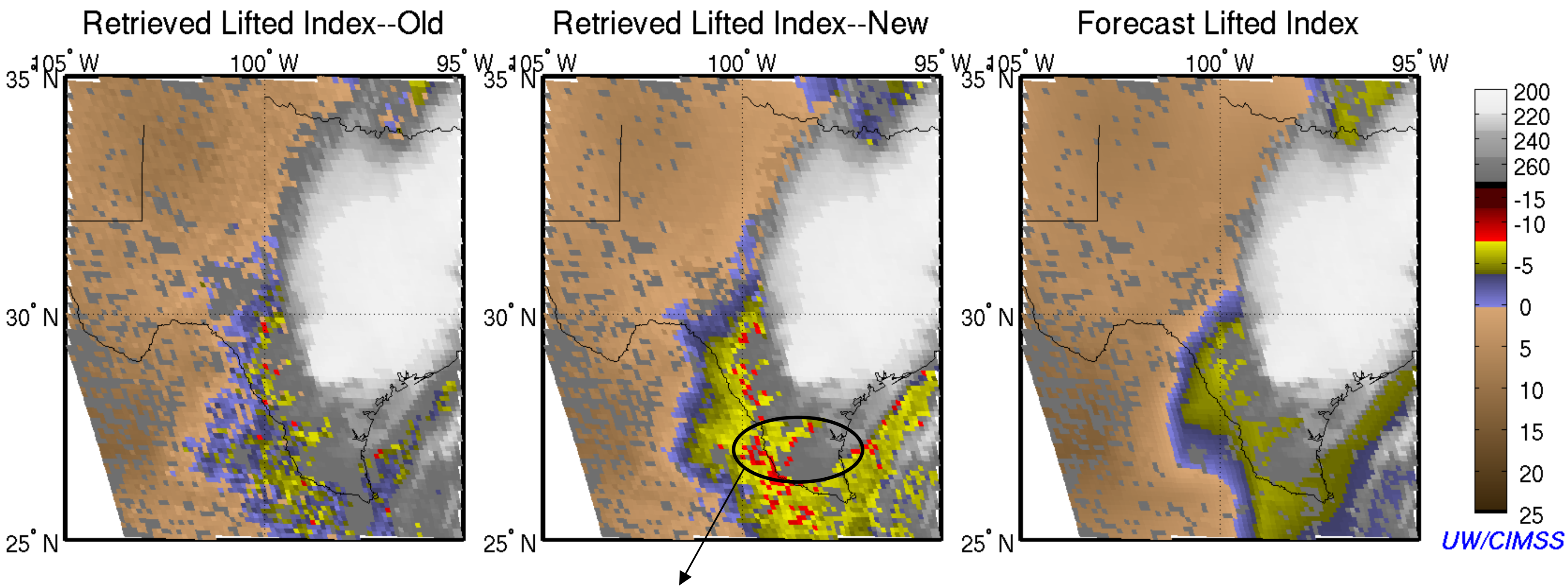
A lot of areas were covered by clouds. And the storm still kept growing.

08 UTC

25 April 2007

Case 1, a tornadic supercell

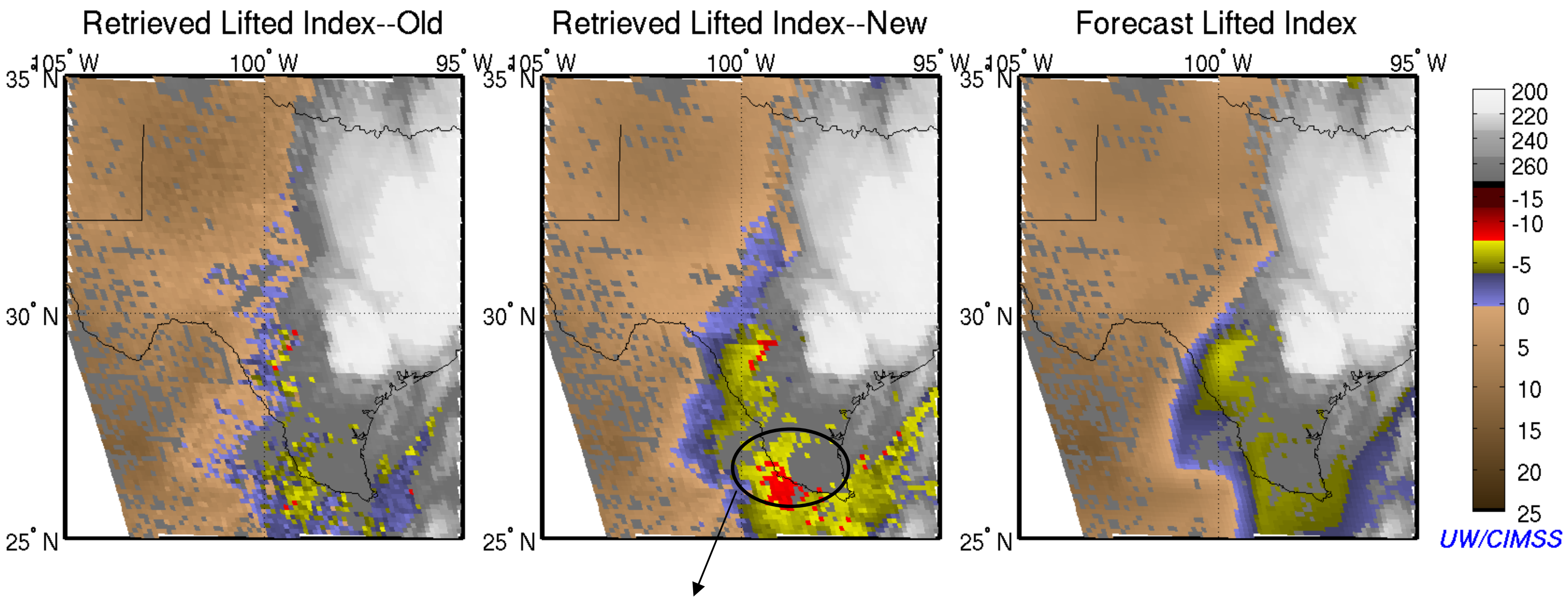
Eagle Pass, Texas



A lot of areas were covered by clouds. The area of large instabilities began decreasing. The storm began dying out.

09 UTC
25 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

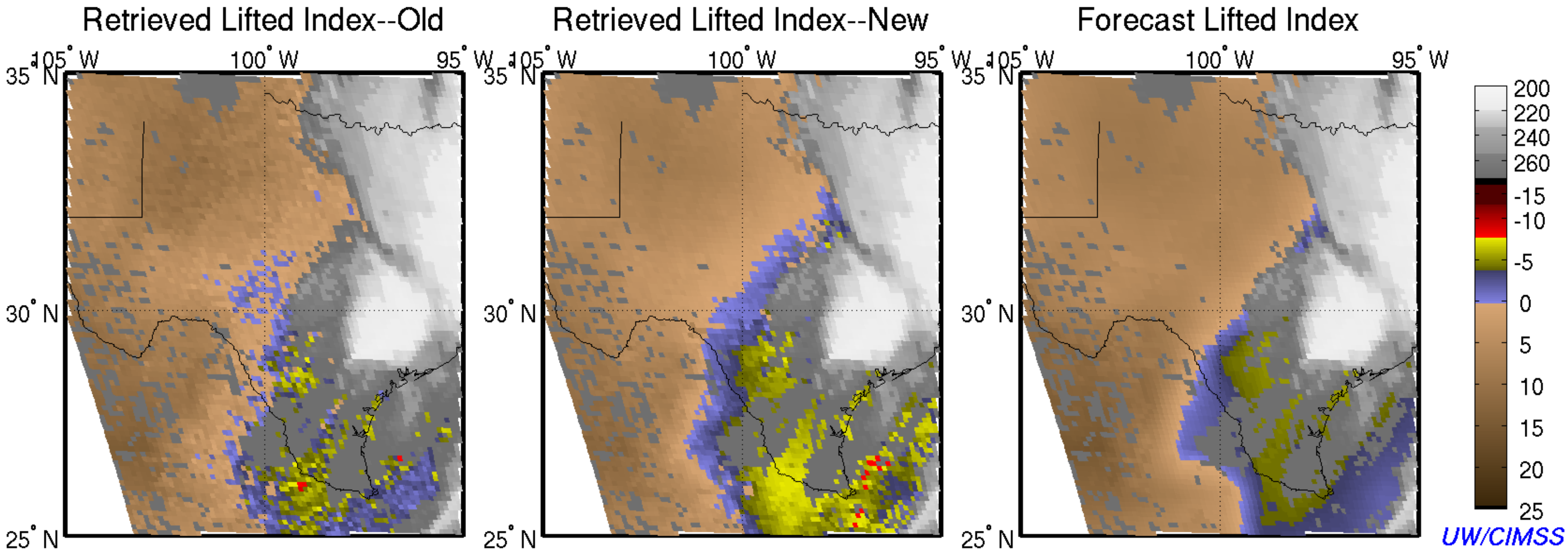


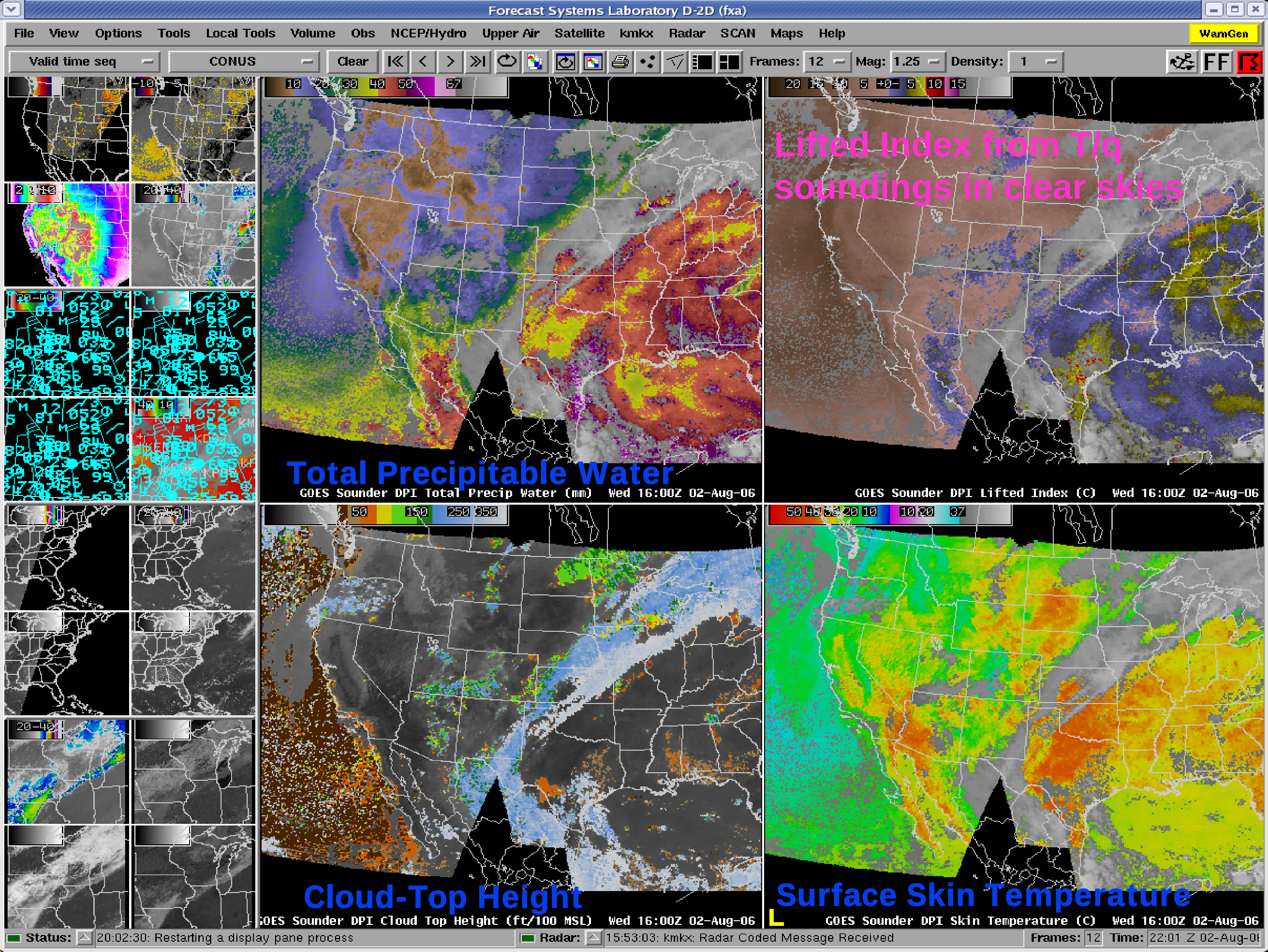
These instabilities were too far away from the storm. The storm kept dying out.

10 UTC
25 April 2007

Case 1, a tornadic supercell
Eagle Pass, Texas

All storms were gone!!!

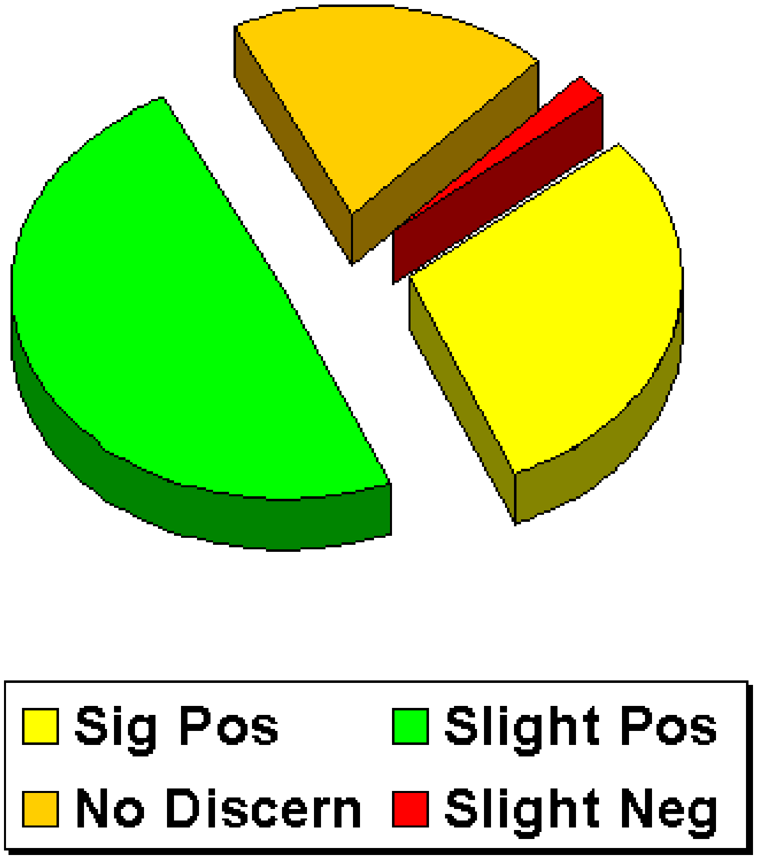



Forecast Systems Laboratory D-2D (fxa)
File View Options Tools Local Tools Volume Obs NCEP/Hydro Upper Air Satellite kmkx Radar SCAN Maps Help
WarnGen
Valid time seq
CONUS
Clear
Frames: 12
Mag: 1.25
Density: 1
Total Precipitable Water
GOES Sounder DPI Total Precip Water (mm) Wed 16:00Z 02-Aug-06
Lifted Index from T/q soundings in clear skies
GOES Sounder DPI Lifted Index (C) Wed 16:00Z 02-Aug-06
Cloud-Top Height
GOES Sounder DPI Cloud Top Height (ft/100 MSL) Wed 16:00Z 02-Aug-06
Surface Skin Temperature
GOES Sounder DPI Skin Temperature (C) Wed 16:00Z 02-Aug-06
Status: 20:02:30: Restarting a display pane process
Radar: 15:53:03: kmkx: Radar Coded Message Received
Frames: 12
Time: 22:01 Z 02-Aug-06

Legacy products and operational applications

GOES Sounder/ABI Profile Related Legacy Products	***Operational Use within NWS***
Layer & Total Precipitable Water	**Assimilation** into NCEP operational regional & global NWP models; **display and animation** within NWS AWIPS for use by forecasters at NWS WFOs & National Centers in forecasting precipitation and severe weather
Surface skin temperature	**Image display and animation** within NWS AWIPS for use by forecasters at NWS WFOs
Profiles of temp & moisture	**Skew-T diagram display** within NWS AWIPS for use by forecasters at NWS WFOs in forecasting precipitation and severe weather
Atmospheric stability indices	**Image display and animation** within NWS AWIPS for use by forecasters at NWS WFOs in forecasting precipitation and severe weather

NWS 1999 Survey: GOES Sounder Atmospheric Instability



NWS Forecaster responses (summer 1999) to:

"Rate the usefulness of LI, CAPE & CINH (changes in time / axes / gradients in the hourly product) for location/timing of thunderstorms."

There were 248 valid weather cases.

- Significant Positive Impact (30%)
- Slight Positive Impact (49%)
- No Discernible Impact (19%)
- Slight Negative Impact (2%)
- Significant Negative Impact (0)

Selected References

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Summary

- Same improved algorithm can be used for SEVIRI, ABI and GOES Sounder
- Forecast and its error covariance matrix are needed as background information. This is essential for SEVIRI and ABI since only a few “sounding” bands are available
- Handling surface emissivities is very important in sounding process
- Radiance noise filtering is very useful for quality retrievals
- Time continuity should be taken into account in the process, this area needs further investigation
- Geostationary sounding product is very useful for severe storm nowcast