STAR Center for Satellite Applications and Research

formerly ORA — Office of Research and Applications

Advanced Infrared Sounding System for Future Geostationary Satellites

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 # SSEC/CIMSS, University of Wisconsin-Madison

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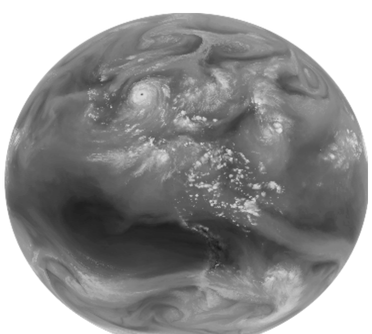


International TOVS Study Conferences (ITSC)-XVI

Angra dos Reis, Brazil, 7 - 12 May 2008

UW-Madison

Overview

- While broadband geo-sounder has proven useful, GEO hyper-spectral IR sounding instrument will provide measurements that better serve user requirements, this is very important for supporting regional and convective-scale NWP over CONUS.

- Nowcasting and very-short range forecasting will also benefit from these 3D fields from the monitoring of moisture convergence (with critical low-level moisture) and convective instability and improving warnings of location and intensity of convective storms.

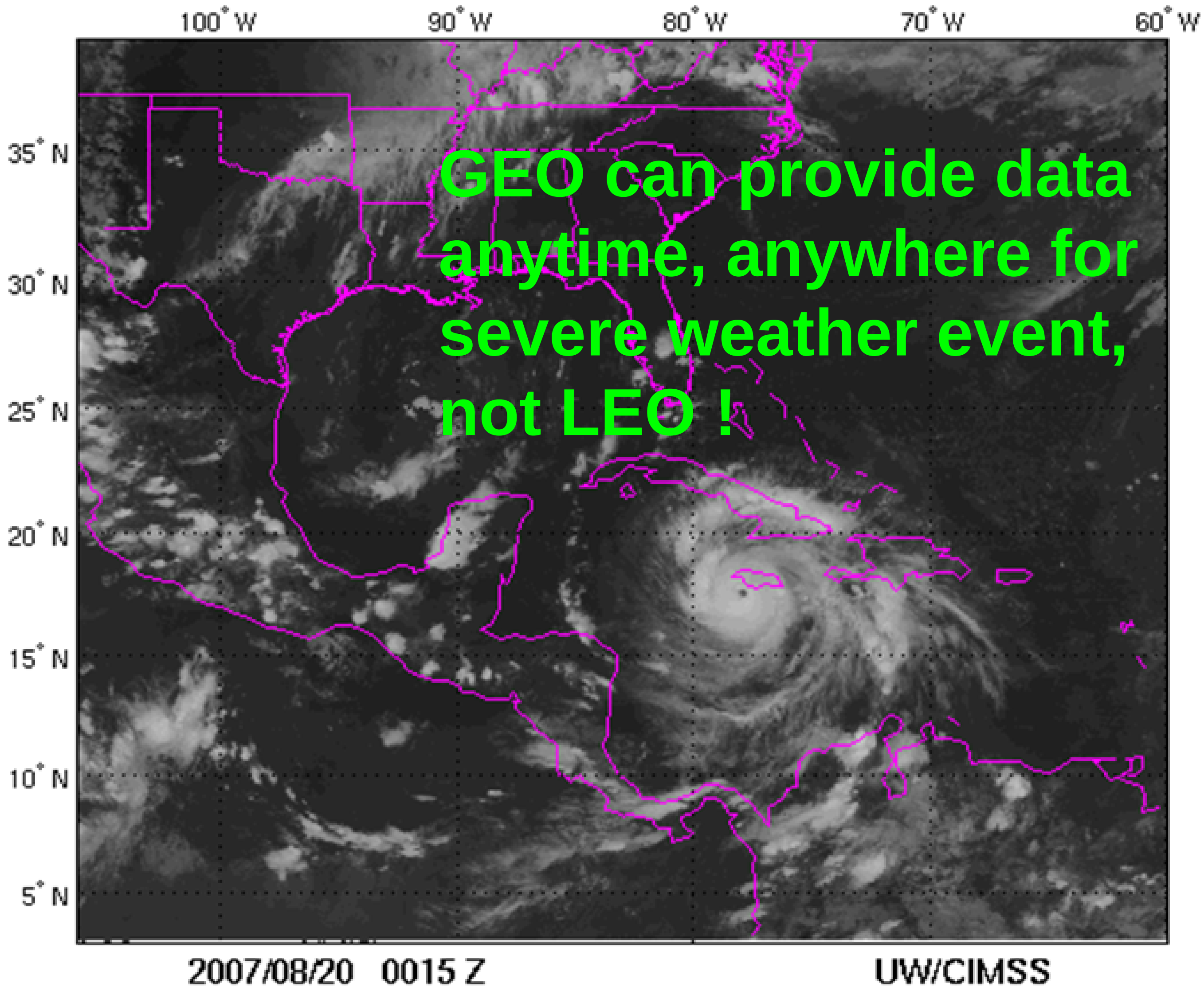
Outline

- GOES/GOES-R Summary
- 'Nowcasting' applications
- NWP applications
- Other applications
  - winds, air quality, SST, clouds, etc.
- Economic benefits
- Summary
- More information

AIRS measurements overlay on GOES IR image (Hurricane Dean)

LEO data have limitation on monitoring hurricane due to orbital gap and low temporal resolution.

High temporal resolution is unique aspect of GEO IR measurements



A geostationary hyper-spectral sounder could provide full hourly disk coverage rather than the partial coverage available with polar orbiting sounders.

GOES-R Instruments

- Advanced Baseline Imager (ABI)
  - Implementation phase
  - Contractor: ITT Corporation
- Space Weather

  Space Environmental In-Situ Suite (SEISS)
    - Implementation phase
    - Contractor: Assurance Technology Corporation (ATC)

  Solar Ultra Violet Imager (SUVI)
    - Implementation contract was awarded to Lockheed Martin Advanced Technology Center

  Extreme Ultra Violet/X-Ray Irradiance Sensor (EXIS)
    - Implementation phase
    - Contractor: Laboratory for Atmospheric and Space Physics (LASP)

  Magnetometer
    - Procured as part of spacecraft contract
- Geostationary Lightning Mapper (GLM)
  - Implementation contract awarded in December 2007
  - Contractor: Lockheed Martin Space Systems Company

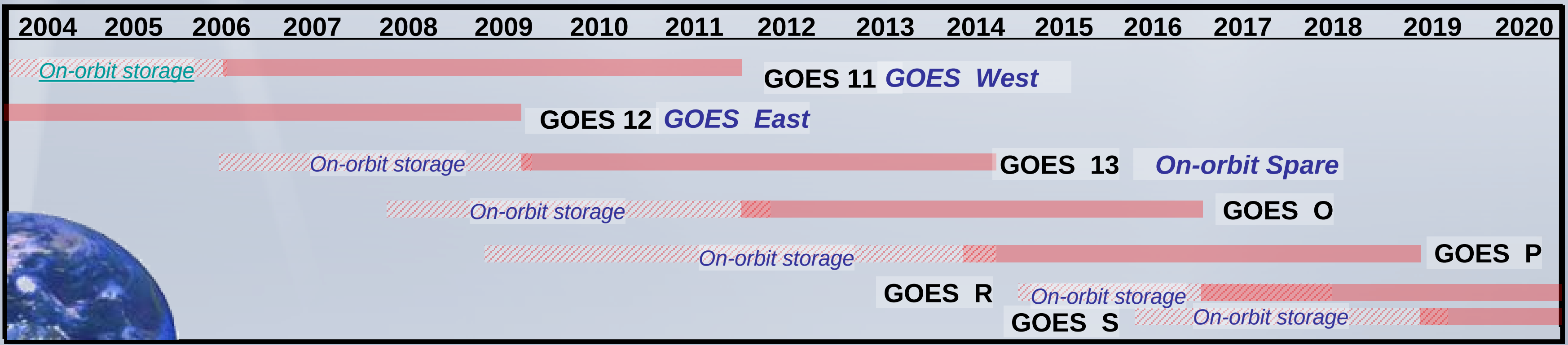
Advanced Sounding

- Hyperspectral Environmental Suite (HES) instrument removed from GOES-R program – August 2006
- Subsequent efforts included:
  - Assessment of ABI as source data for legacy GOES-like derived sounder products
  - NOAA Analysis of Alternatives (AOA) study
    - Advanced sounding
    - Coastal waters imaging
  - Contractor studies of advanced sounding concepts for later GOES spacecraft
- Current status
  - ABI can <u>approximate legacy</u> GOES sounder capabilities
  - A geostationary advanced sounder demonstration mission is being explored

Launch Schedule

- **GOES R series is a follow-on to the existing line of NOAA's geostationary weather satellites.**
  – GOES I series [8-12]: Operational since 1994
  – GOES N series [13]: N launched May 24 2006, O planned launch late 2008, P planned launch late 2009

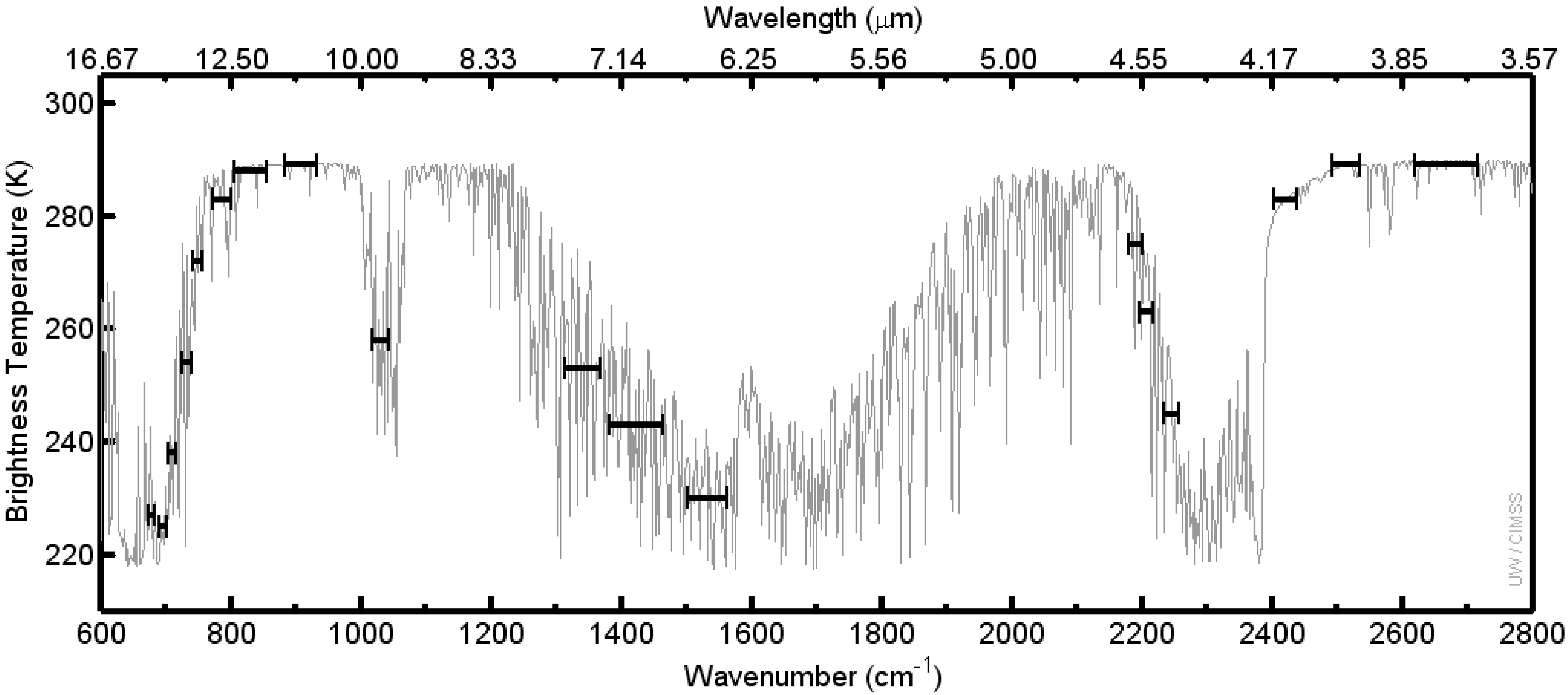
- **Based on an availability analysis of the current GOES I and N-series, a GOES-R launch is required in the 2014 timeframe to maintain mission data continuity**



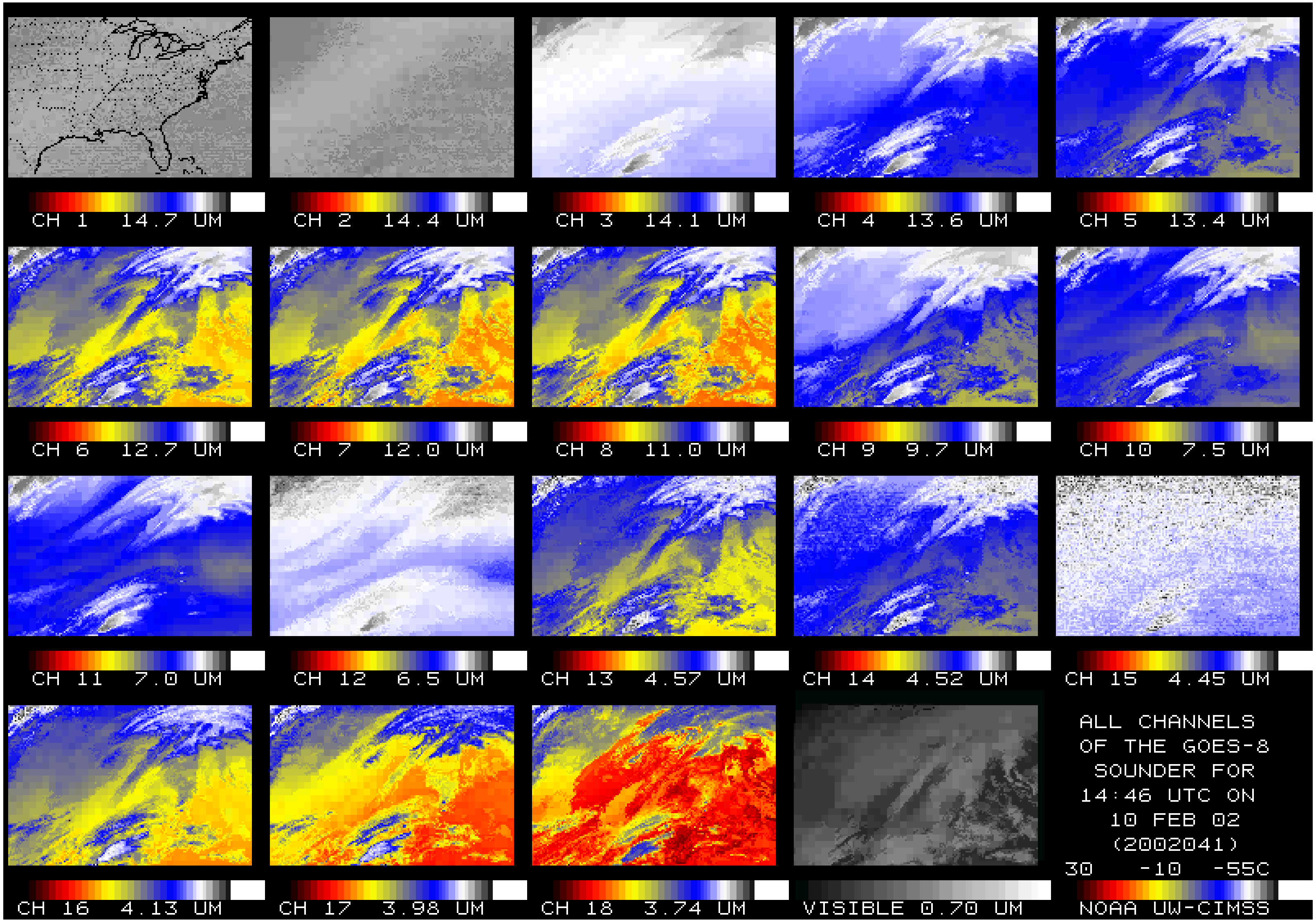
Note: Satellites are labeled with letters on the ground and changed to numbers on-orbit

***GOES T and U are currently not baselined for GOES-R series. Flight procurement includes these as options.**

Low vs High Spectral Resolution



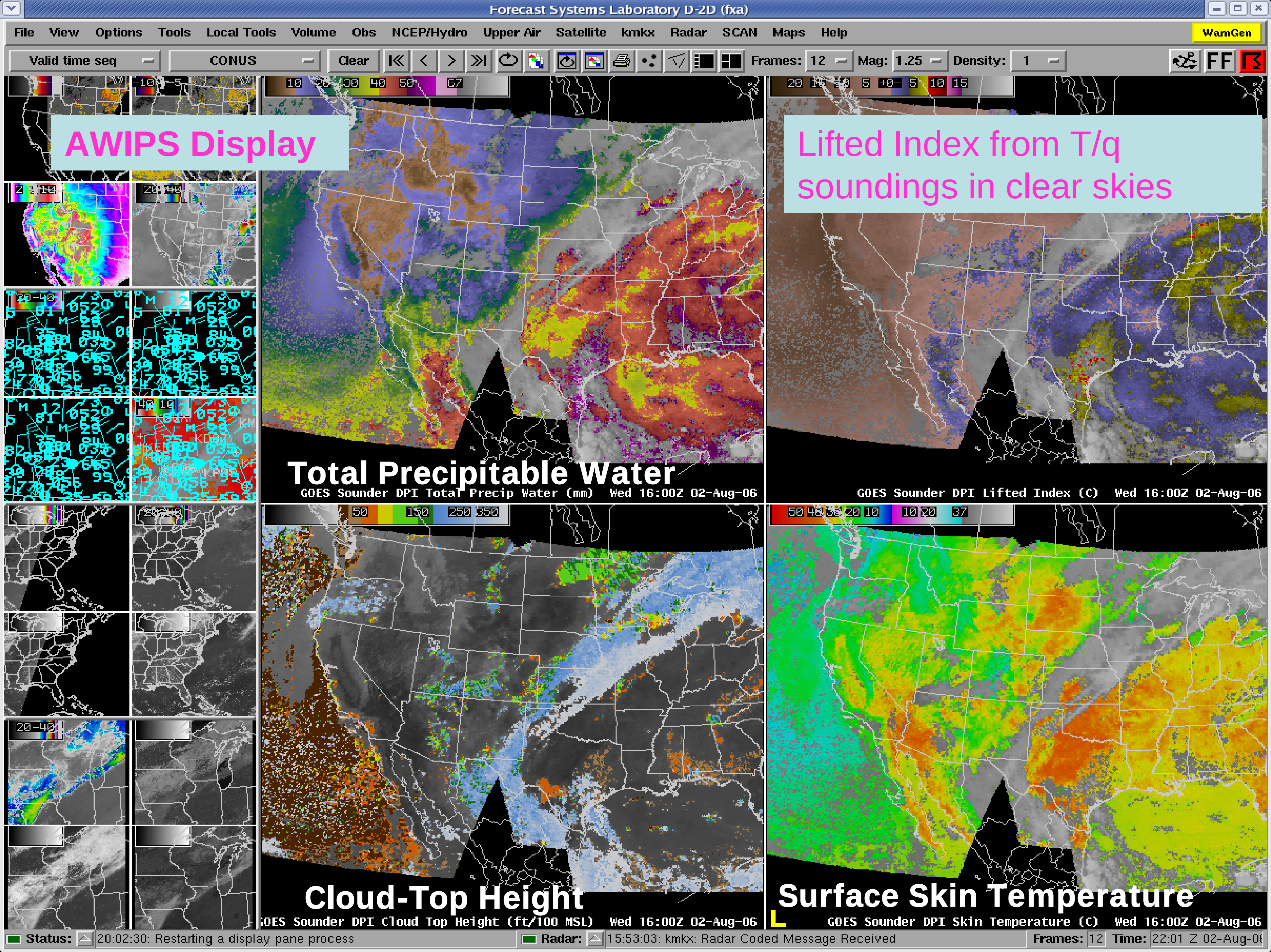
The current GOES Sounder has only 18 IR spectral data points, while a high spectral resolution sounder may have between 800 and 8000 spectral points. The broad-band nature of the current GOES limits the vertical resolution.



Spectral coverage (18 IR + 1 Visible band) for current GOES Sounder

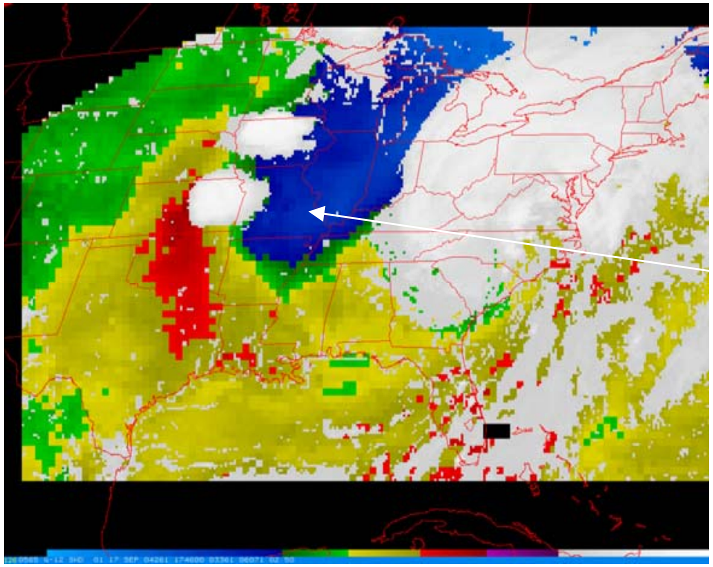
Current Sounder Operational Uses

GOES Sounder Product	*Operational Use within the NWS*
Clear-sky Radiances	**Assimilation into** NCEP operational regional & global NWP models over water
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
Cloud-top retrievals (pressure, temperature, cloud amount)	**Assimilation into** NCEP operational regional NWP models; **display and animation within** NWS AWIPS for use by forecasters at NWS WFOs; **supplement to** NWS/ASOS cloud measurements for generation of total cloud cover product at NWS/ASOS sites
Surface skin temperature	**Image display and animation within** NWS AWIPS for use by forecasters at NWS WFOs
Profiles of temperature & moisture	**Display (SKEW-Ts) 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
Water Vapor Winds	**Image display and animation within** NWS AWIPS for use by forecasters at NWS WFOs



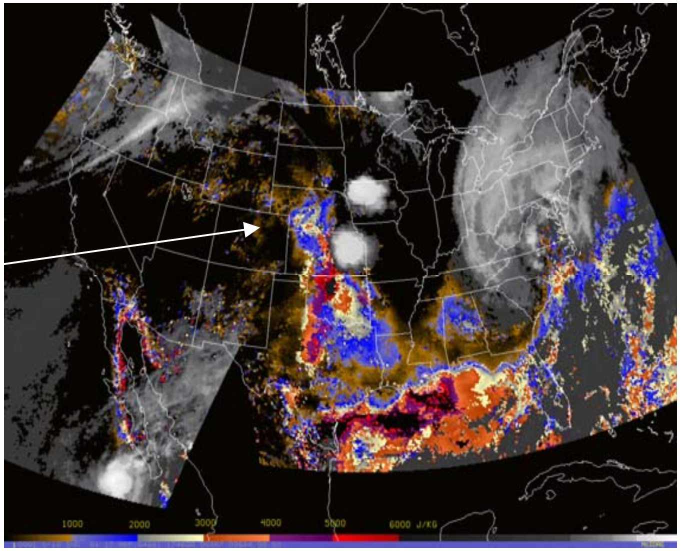
Forecast Systems Laboratory D-2D (fxa)
File View Options Tools Local Tools Volume Obs NCEP/Hydro Upper Air Satellite kmkx Radar SCAN Maps Help
WarnGen
Valid time seq
CONUS
Clear
Frames: 12
Mag: 1.25
Density: 1
AWIPS Display
Lifted Index from T/q soundings in clear skies
Total Precipitable Water
GOES Sounder DPI Total Precip Water (mm) Wed 16:00Z 02-Aug-06
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

GOES Sounder Stability Indices



GOES Best Lifted Indices

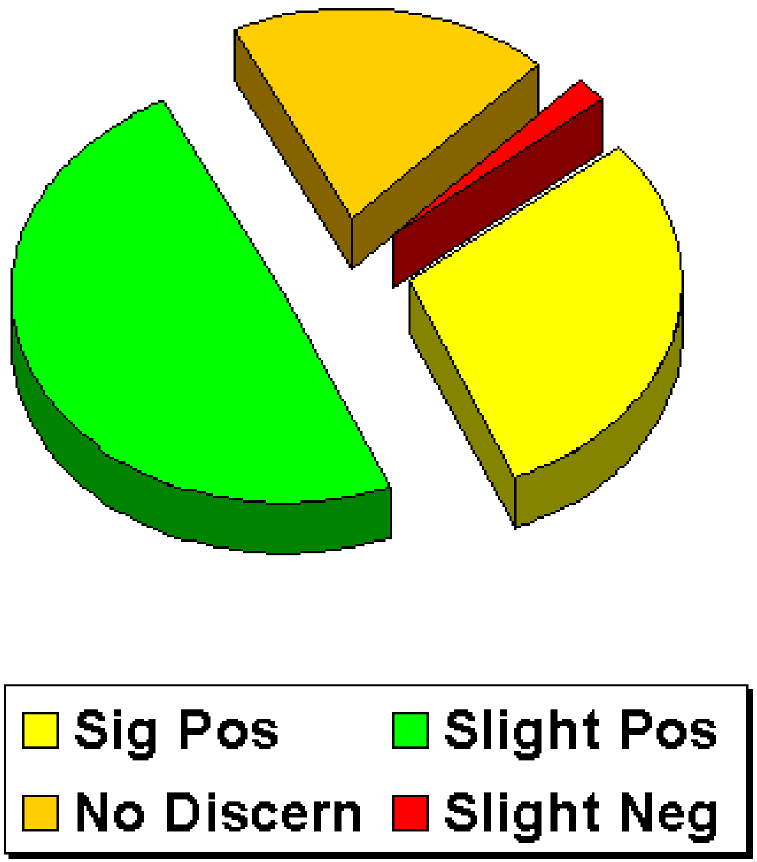
Note in both images that the instability axis lies upstream of incipient convection. Recent studies indicate that this is a favorable thermodynamic pattern for a slow moving MCS.



GOES Lowest 100mb MUCAPE (Most Unstable CAPE)

Courtesy of J. Daniels

Forecasters value the current sounder



NWS Forecaster responses (Summer of 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.

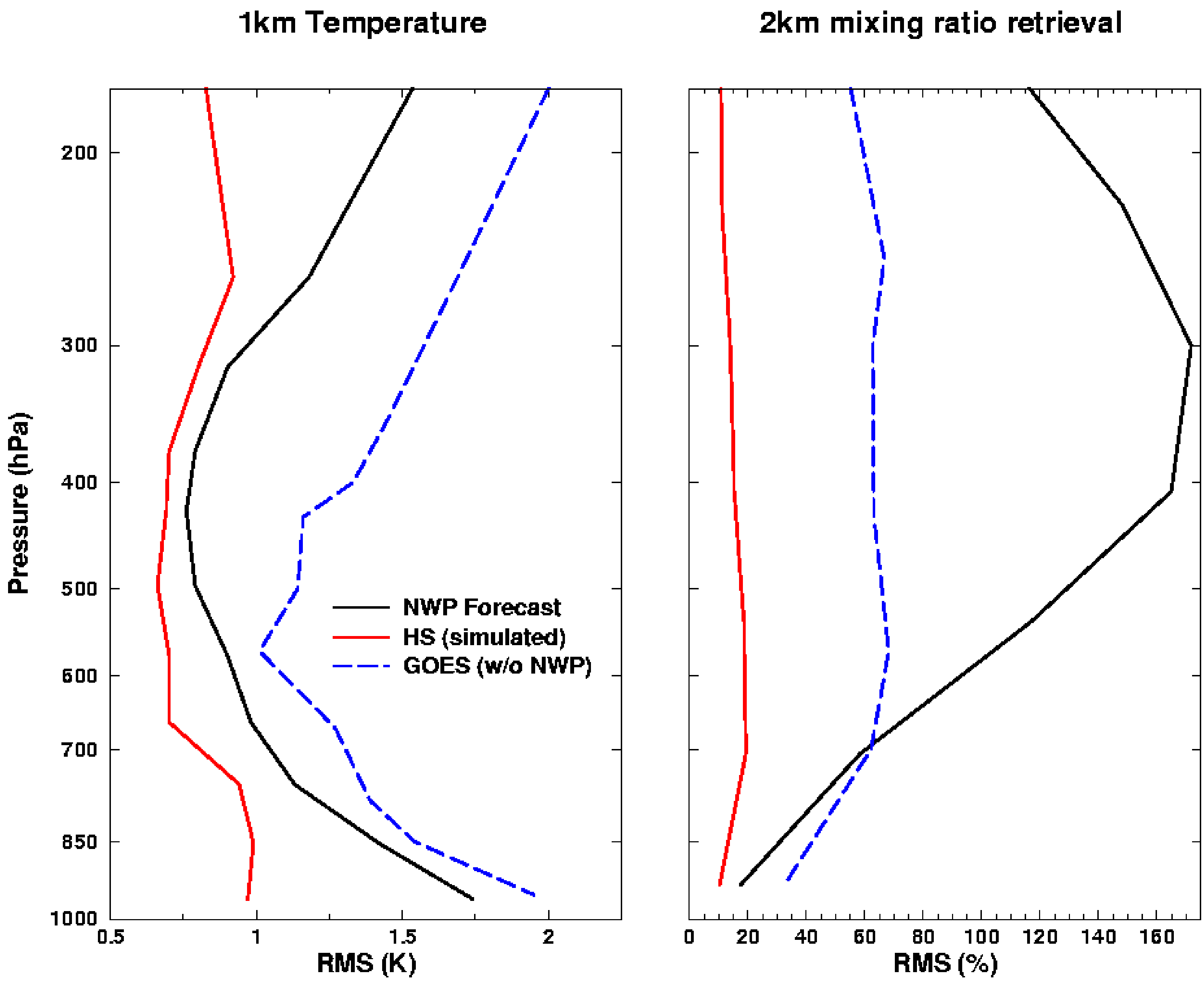
- Significant Positive Impact (30%)
- Slight Positive Impact (49%)
- No Discernible Impact (19%)
- Slight Negative Impact (2%)
- Significant Negative Impact (0)

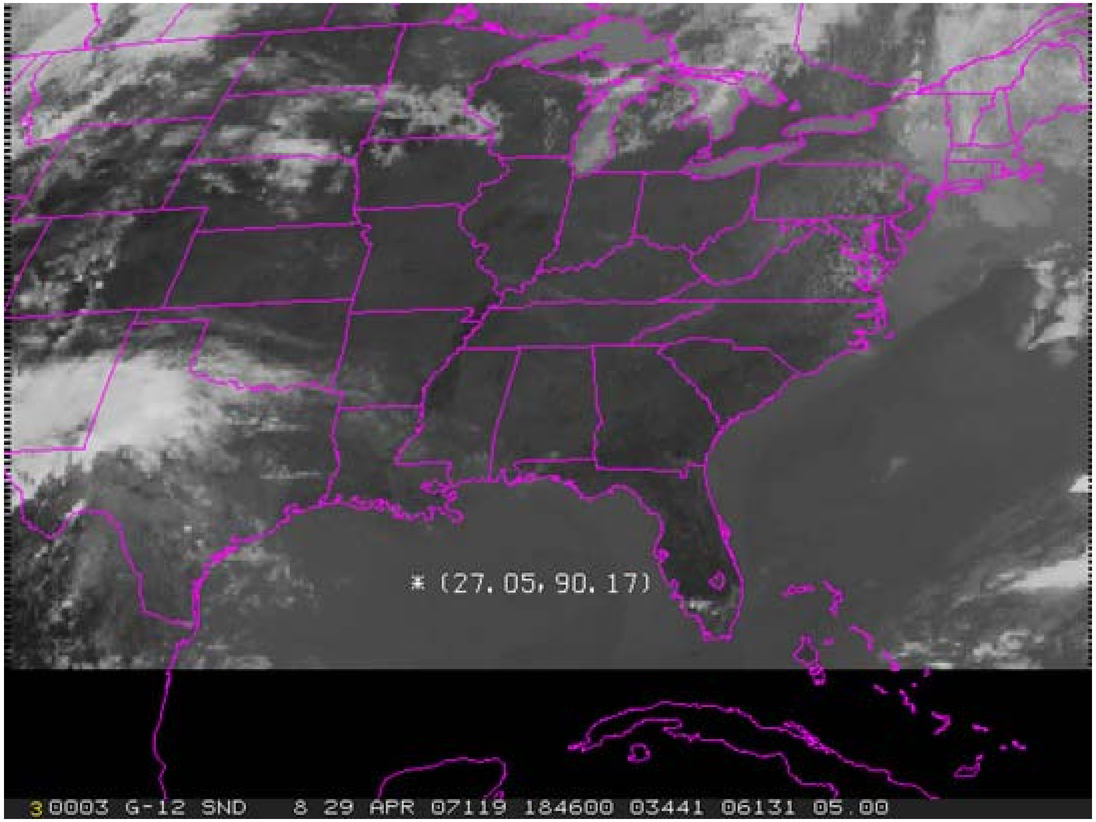
Forecasters need a better GEO sounder

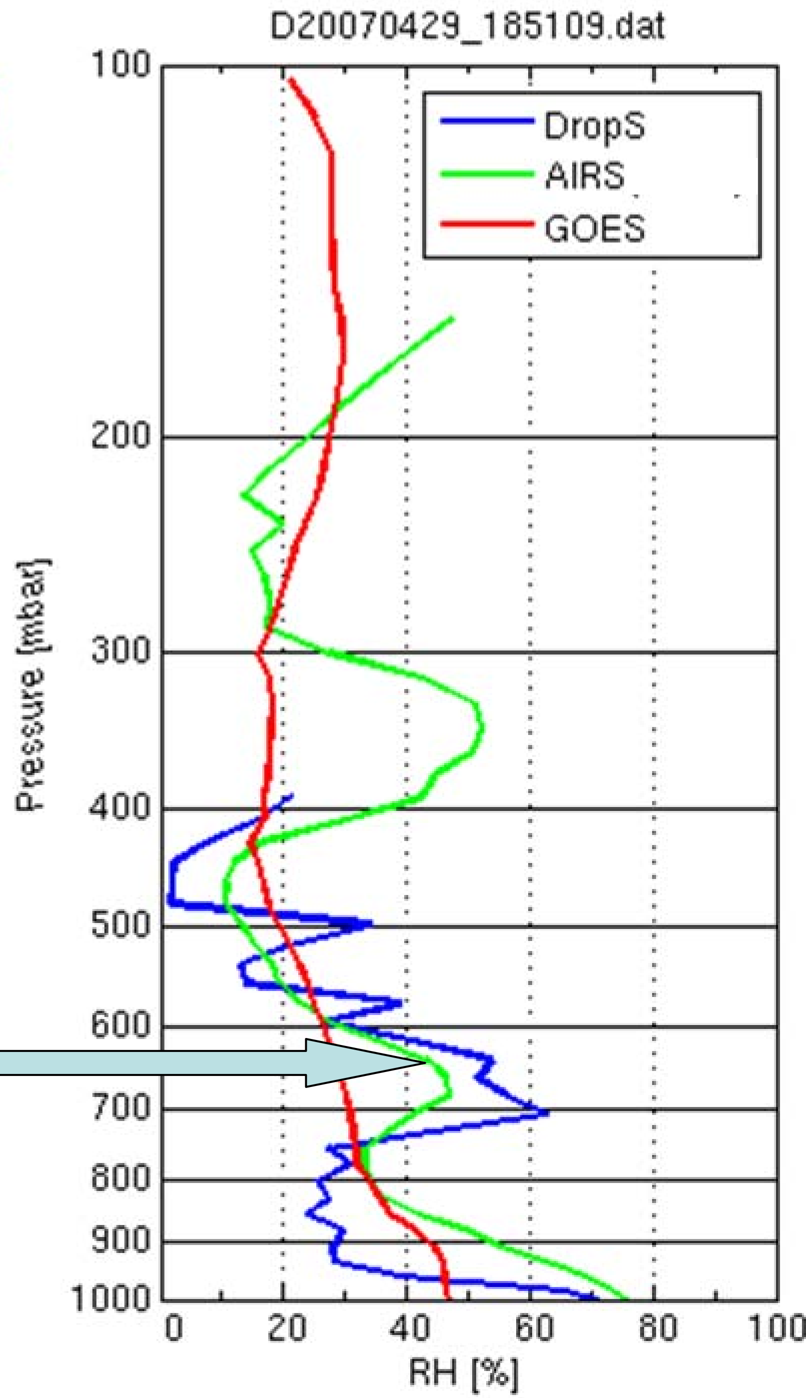
Forecasters value the current GOES sounder products; however, the same forecasters also noted several limitations of the current sounder:

- retrievals limited to clear skies;
- the scanning rate is relatively slow, which limits coverage;
- the vertical resolution from the current generation GOES radiometers is limited.

Each of these limitations can be mitigated with an advanced sounder in the geostationary perspective.


1km Temperature
2km mixing ratio retrieval
Pressure (hPa)
200
300
400
500
600
700
850
1000
0.5
1
1.5
2
RMS (K)
NWP Forecast
HS (simulated)
GOES (w/o NWP)
0
20
40
60
80
100
120
140
160
RMS (%)





AIRS SFOV Relative Humidity (RH) sounding depicts the vertical structure while the GOES sounding (independent of FCST) has limited vertical information

High Spectral (HS) data will help ABI

GOES-R Observational Requirements:

- Aerosol Detection (including Smoke and Dust)
- Aerosol Particle Size
- Suspended Matter / Optical Depth
- *Volcanic Ash* *
- Aircraft Icing Threat
- Cloud Imagery: Coastal
- Cloud & Moisture Imagery
- *Cloud Layers / Heights & Thickness* *
- *Cloud Ice Water Path* *
- Cloud Liquid Water
- Cloud Optical Depth
- Cloud Particle Size Distribution
- Cloud Top Phase
- *Cloud Top Height* *
- *Cloud Top Pressure* *
- *Cloud Top Temperature* *
- Cloud Type
- Convection Initiation
- Enhanced "V"/Overshooting Top Detection
- Hurricane Intensity
- Low Cloud & Fog
- Lightning Detection
- Turbulence
- Visibility

- Geomagnetic Field
- Probability of Rainfall
- Rainfall Potential
- Rainfall Rate/QPE
- *Legacy Atm. Vertical Moisture Profile* *
- *Legacy Atm. Vertical Temperature Profile* *
- *Derived Stability Indices* *
- *Total Precipitable Water* *
- *Total Water Content* *
- Clear Sky Masks
- Radiances *
- Absorbed Shortwave Radiation: Surface
- Downward Longwave Radiation: Surface
- Downward Solar Insolation: Surface
- Reflected Solar Insolation: TOA
- Upward Longwave Radiation *: Surface & TOA
- *Ozone Total* *
- *SO_2 Detection* *
- *Derived Motion Winds* *
- Fire / Hot Spot Characterization
- Flood / Standing Water
- *Land Surface (Skin) Temperature* *

- Surface Albedo
- *Surface Emissivity* *
- Vegetation Fraction: Green
- Vegetation Index
- Currents
- Sea & Lake Ice / Age
- Sea & Lake Ice / Concentration
- Sea & Lake Ice / Extent & Edge
- Sea & Lake Ice / Motion
- Ice Cover / Landlocked
- Snow Cover
- Snow Depth
- Sea Surface Temps
- Energetic Heavy Ions
- Mag Electrons & Protons: Low Energy
- Mag Electrons & Protons: Med & High Energy
- Solar & Galactic Protons
- Solar Flux: EUV
- Solar Flux: X-Ray
- Solar Imagery: extreme UV/X-Ray

Improved with HS

* = *Products degraded from original GOES-R requirements (e.g.; now no HES)*

ABI – Advanced Baseline Imager

Continuity of GOES Legacy Sounder Products from ABI

SEISS – Space Env. In-Situ Suite

EXIS – EUV and X-Ray Irradiance Sensors

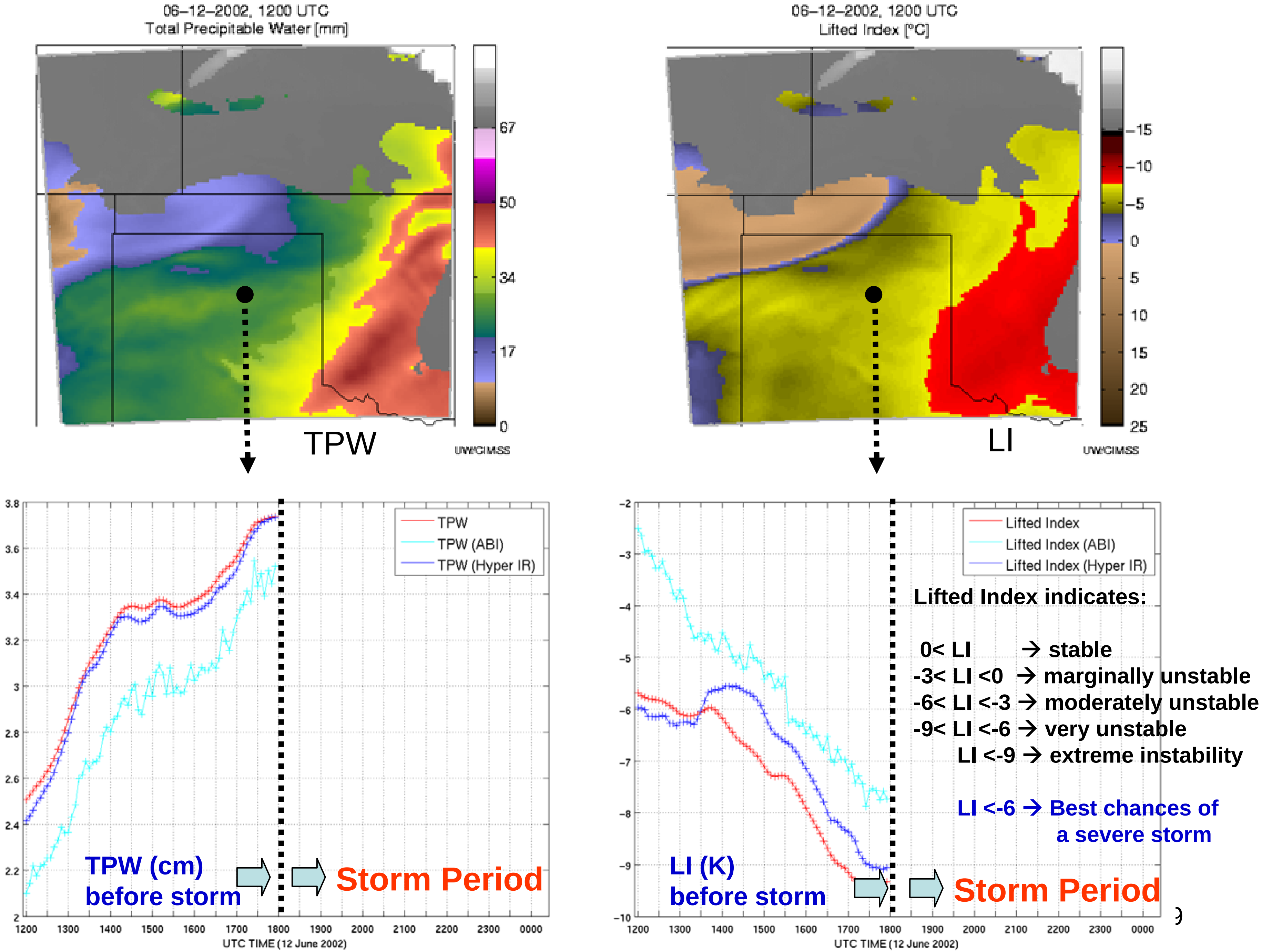
GLM – Geostationary Lightning Mapper

Magnetometer

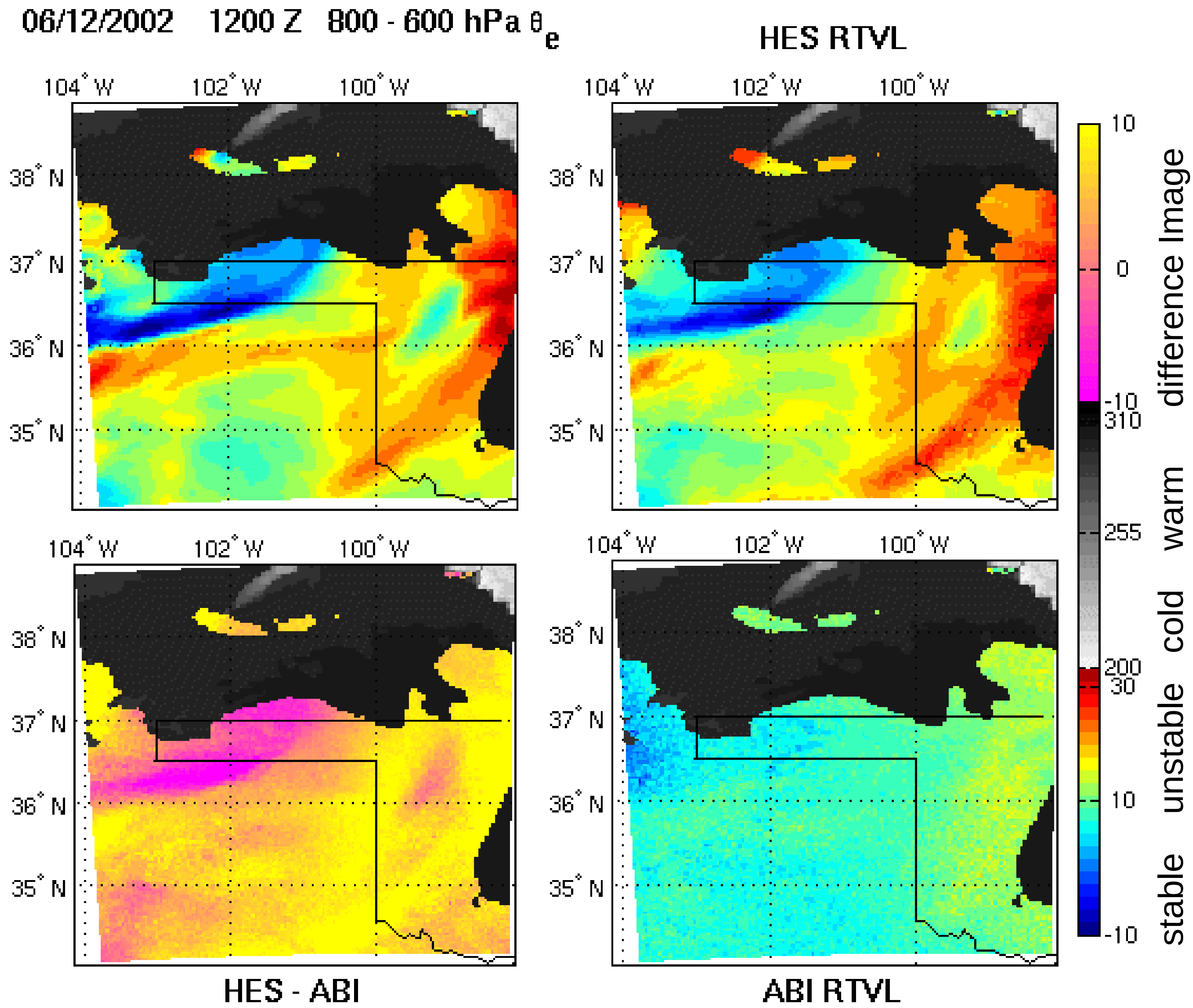
SUVI – Solar extreme UltraViolet Imager

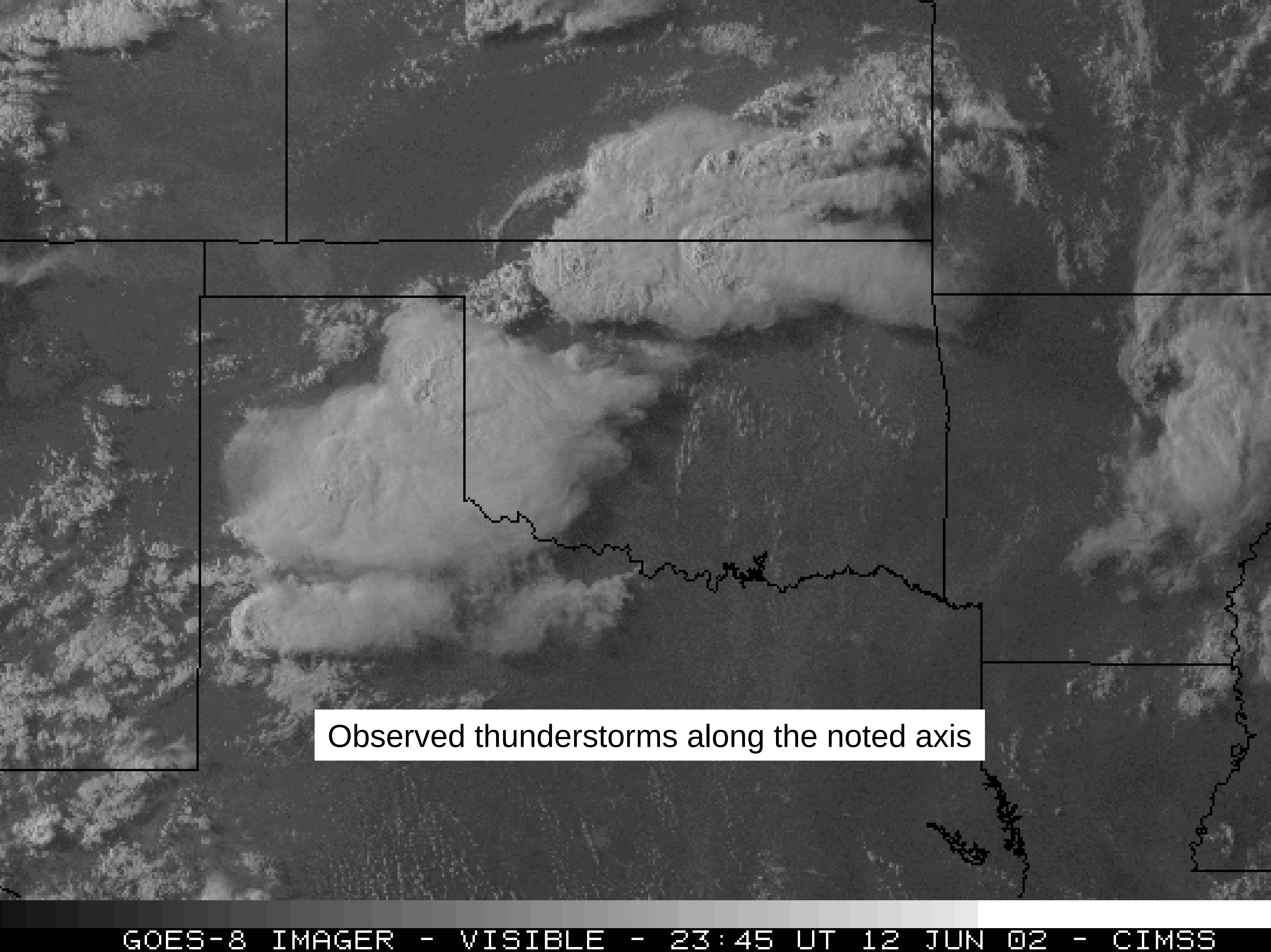
High-spectral for nowcasting

- Rapid storm growth in the 'truth' fields begins when the storm enters the area of convective instability.
  - Requires knowledge of strong vertical gradients of temperature and especially moisture.
- HES showed the development of instability earlier than the ABI alone – by several hours.
- ABI under-estimated the convective instability by 20-30% compared to the HES (for this case).



GOES Sounder and Advanced IR results are based on simulated retrievals


06/12/2002 1200 Z 800 - 600 hPa θe
HES RTVL
HES - ABI
ABI RTVL
104° W
102° W
100° W
38° N
37° N
36° N
35° N
10
0
-10
310
255
200
30
10
-10
difference Image
warm
cold
unstable
stable


Observed thunderstorms along the noted axis
GOES-8 IMAGER - VISIBLE - 23:45 UT 12 JUN 02 - CIMSS

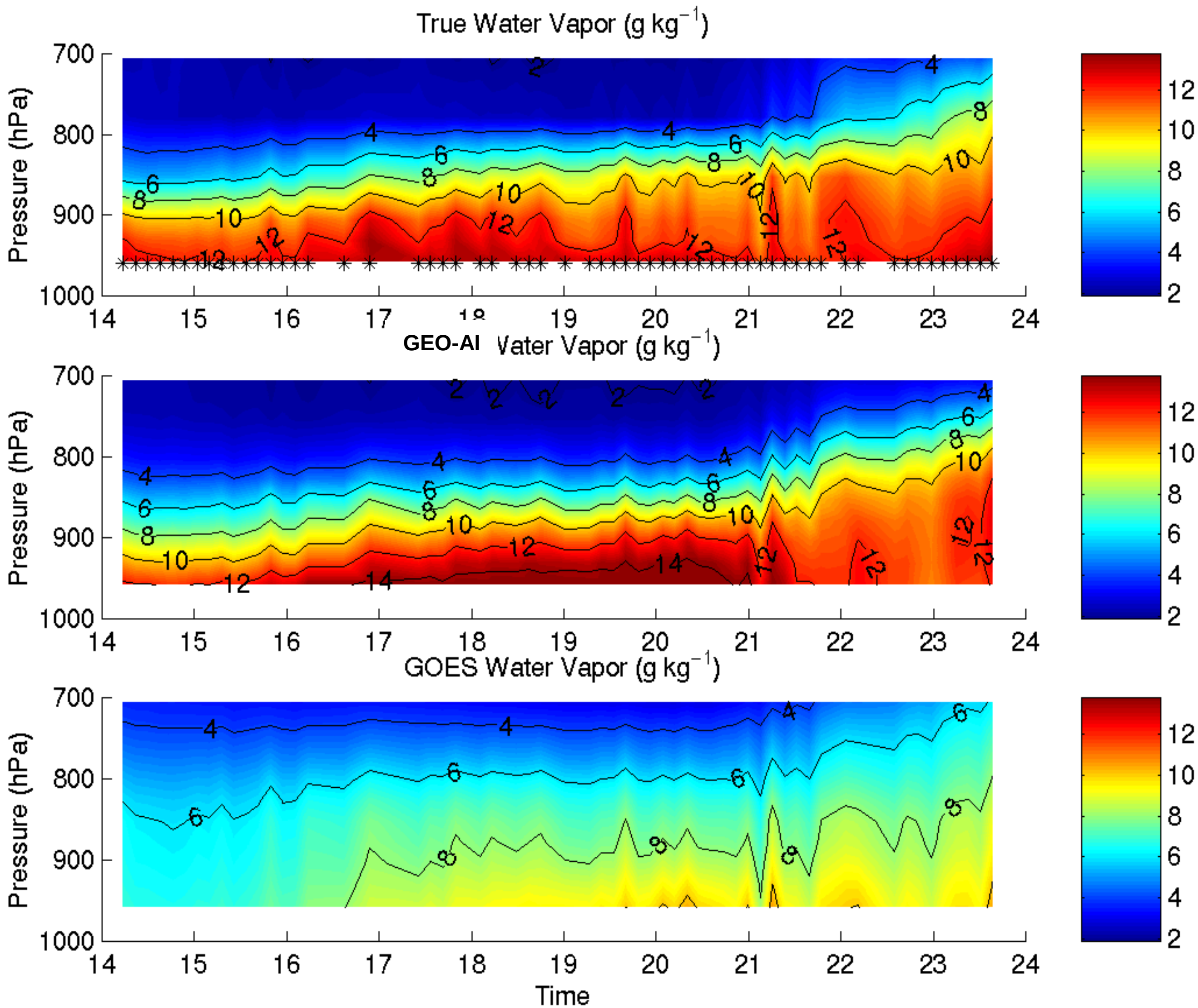
Time series of low-level vertical moisture structure during 9 hours prior to Oklahoma/Kansas tornadoes on 3 May 1999

Truth>

Geo-Adv. IR>

Note Geo-AI retains strong vertical gradients for monitoring convective instability

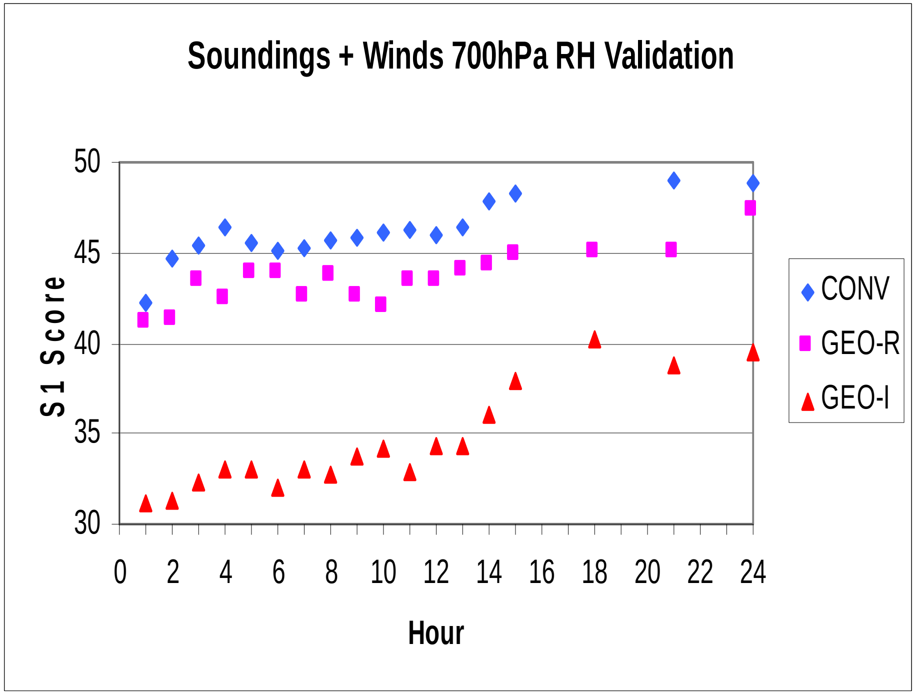
Current GOES>

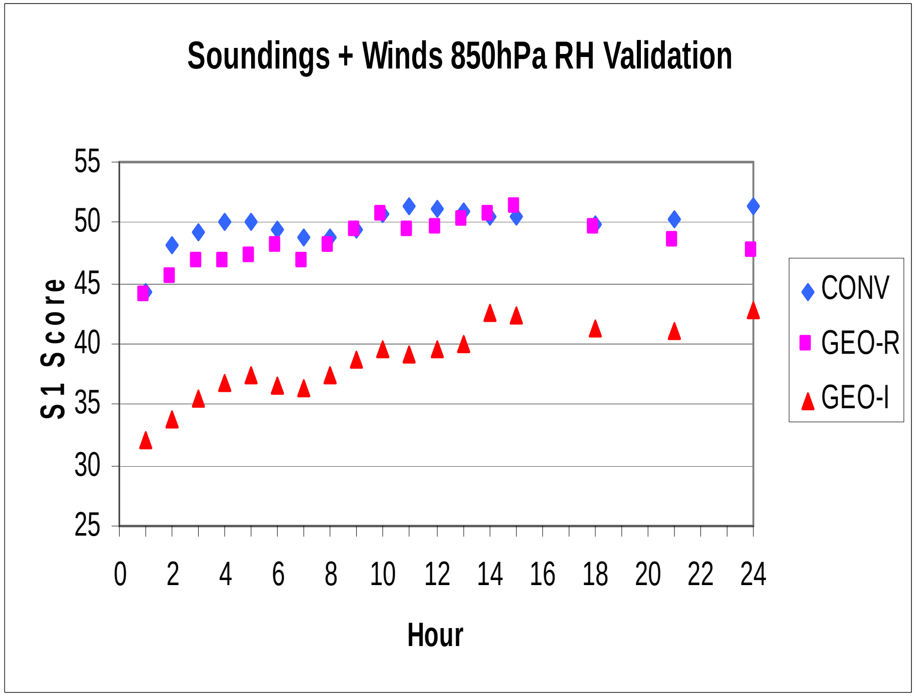


Geo-AI traces moisture peaks and gradients with greatly reduced errors

Geo Hyperspectral IR sees Boundary Layer Moisture

Geo-Increased Spectral Resolution Sounder (Geo-I) sees into Boundary Layer (BL) providing low level (850 RH) moisture information; Geo-Broadband Radiometer (Geo-R) only offers information above BL (700 RH)

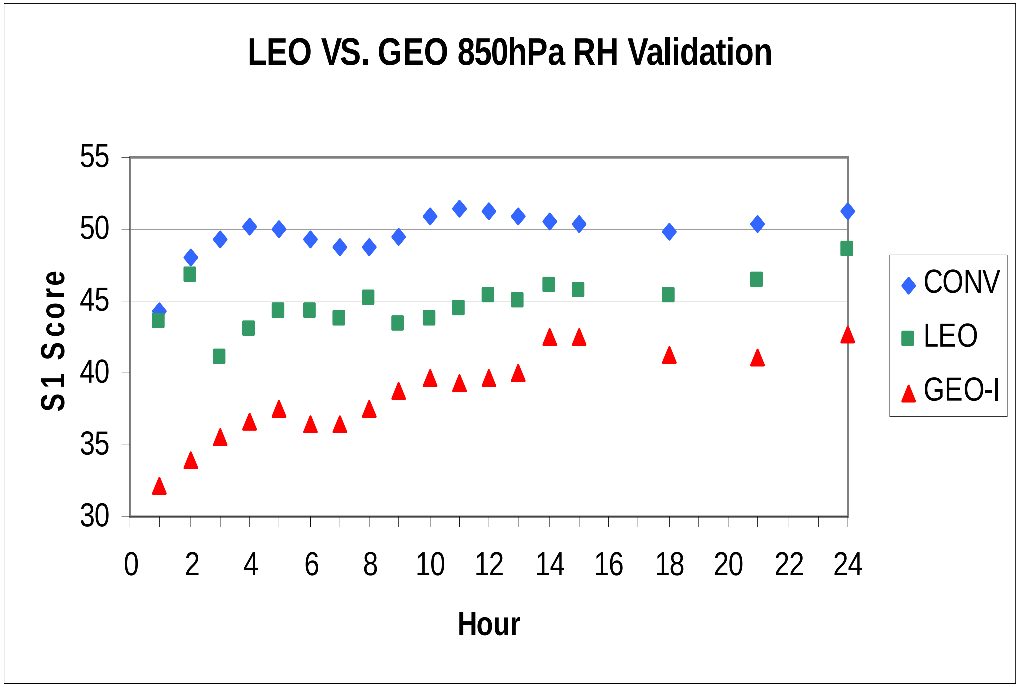




OSSE 12 hr assimilation followed by 12 hr forecast

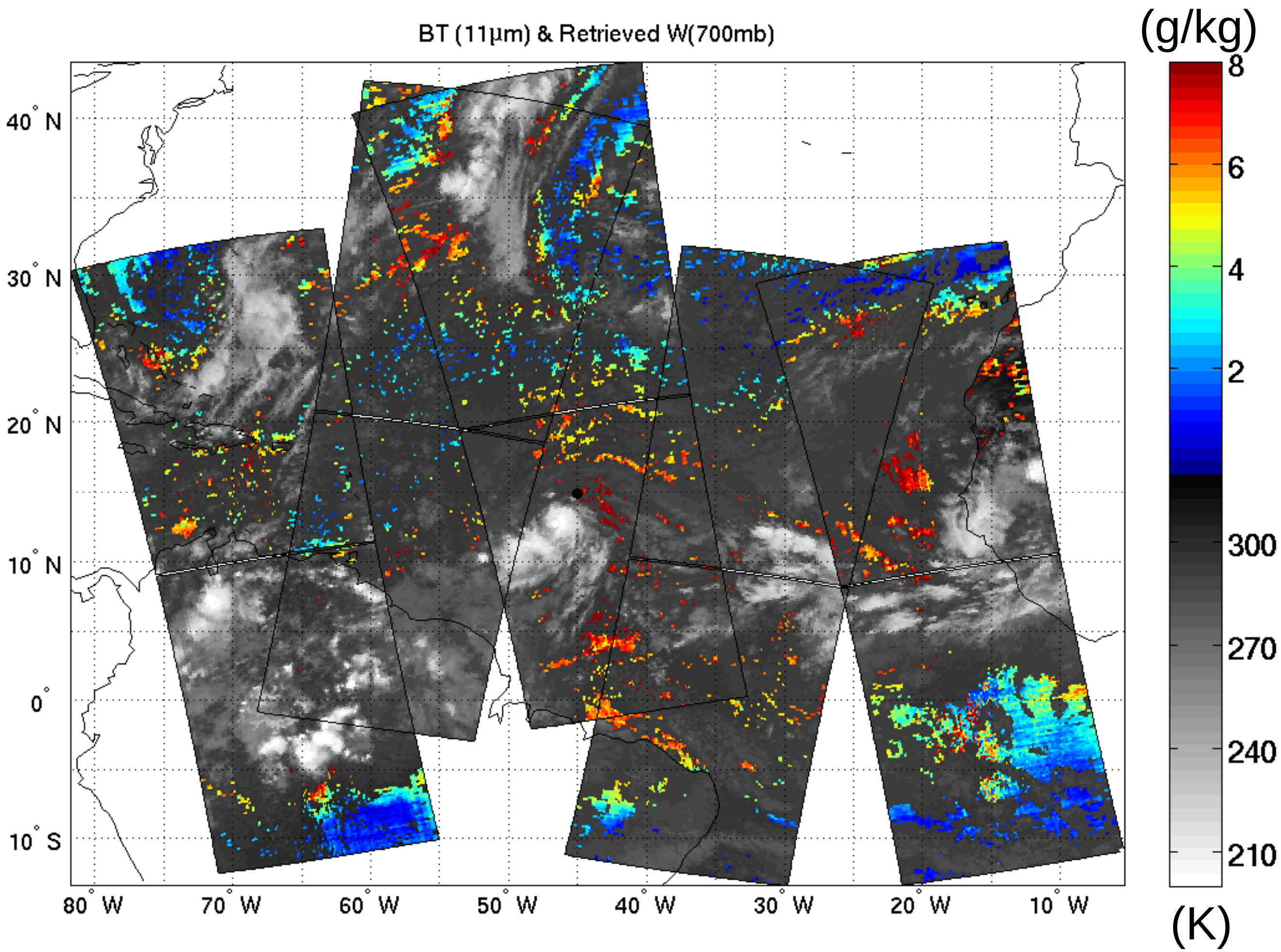
Time frequency of Leo Hyperspectral IR insufficient to track changes in BL moisture

Two polar orbiting interferometers (Leo) do not provide temporal coverage to sustain forecast improvement out to 12 hours. Only hourly Geo-Increased Spectral Resolution Sounder (Geo-I) observations depict moisture changes well enough for forecast benefit.



Aune et al, 2000

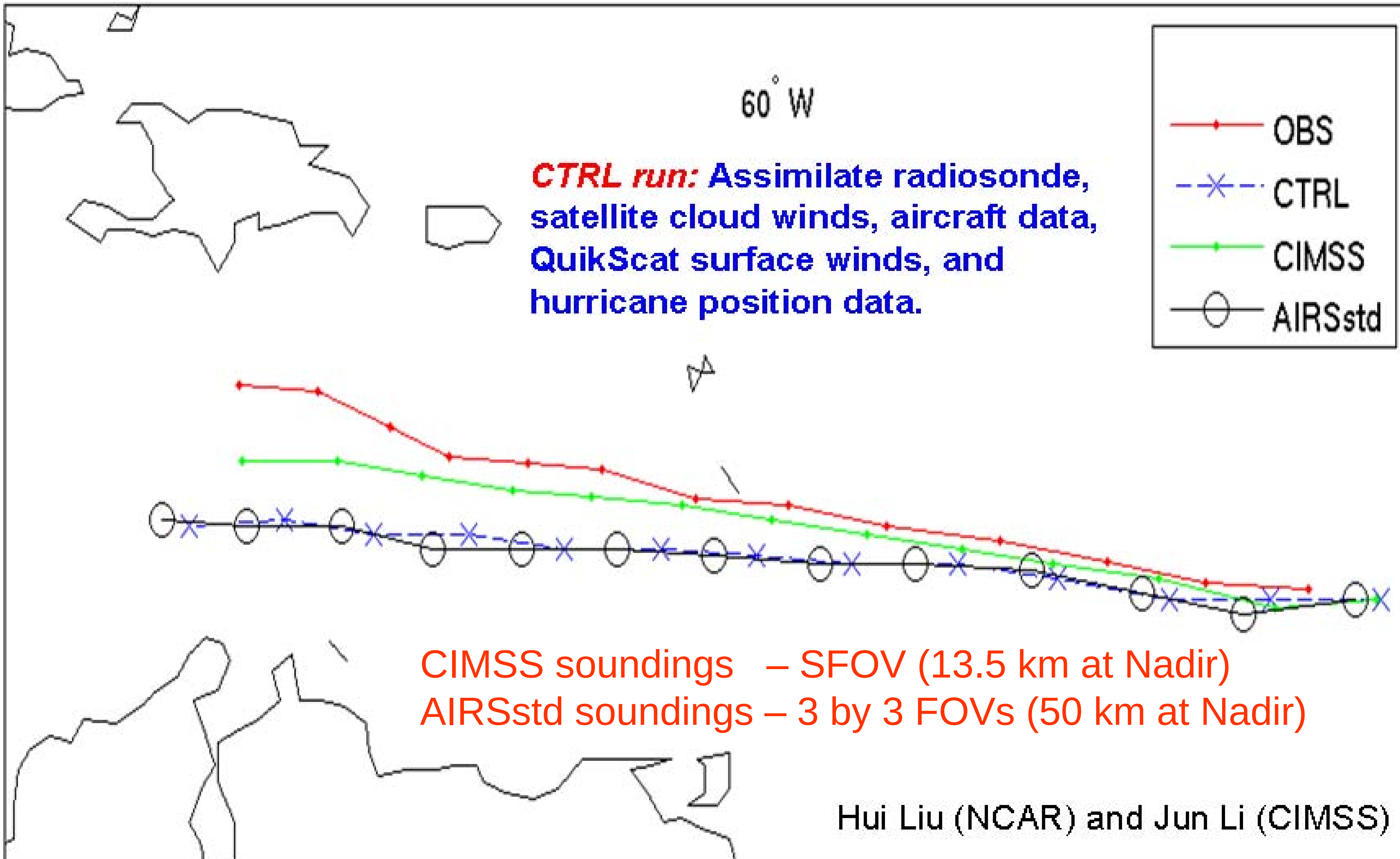
OSSE 12 hr assimilation followed by 12 hr forecast



(CIMSS/UW)

Clear sky AIRS SFOV water vapor retrievals at 700 hPa on 15 August 2007, each pixel provides vertical temperature and moisture soundings.

Tracks of 72h forecasts on Hurricane Dean



Forecast starts at 00 UTC, 16 August 2007

NCAR WRF/DART ensemble assimilation system at 36 km

Economic Benefits

- Previous cost-benefit analysis studies on the positive economic impact of GOES- were conducted by MITRE Corporation. The studies explored the potential for economic benefit from aviation, energy – both electricity and natural gas, irrigated agriculture, and recreational boating. These studies have concluded that **the benefits of high-temporal/spectral data are expected to be several billions of dollars.**

- The Centrec Consulting Group LLC recently prepared a report on the benefits of GOES. This effortwas an extension of the previous cost-benefit analysis studies. At a 7% discount rate, the estimated present value amounts to more than $4.5 billion.

- Based on expert judgment provided by scientists consulted during the project, **the HES benefits are estimated to be about half of the $4.5 billion.** This is above the benefit of just continuing the current sensors.

- **An operational HES-type instrument will allow societal benefits by leveraging past expenditures on GIFTS and HES.**

Summary

- High vertical resolution profiles of temperature and water vapor are fundamental for improved weather forecasting and climate monitoring

- High spectral resolution measurements can meet requirements of
  - 1 degree Celsius for temperature and
  - 15% for water vapor mixing ratio

- Capabilities demonstrated by advanced infrared sounders in Low Earth Orbit (LEO)
  - Atmospheric InfraRed Sounders (AIRS) 2002 –
  - Infrared Atmospheric Sounding Interferometer (IASI) 2006 -2022
  - Cross-track InfraRed Sounder (CrIS) 2010 – 2022

- These requirements are not being met in GEO orbit
  - Current GOES, GOES-R and –S (present – 2022)
  - Current instruments and data processing have succeeded in showing how to make a revolutionary advance with low technical risk

Summary (Continued)

- **Validated, user requirements** can only be met with a high-spectral sounder in geostationary orbit.
- Many groups (national and international) have agreed with the recommendation for a **fully capable advanced sounder**. Risk would be mitigated with an on-orbit demonstration.
- The uses of these data include not only **nowcasting and numerical weather prediction**, but a host of other applications (winds, air quality, Sea Surface Temperature, clouds, hazards, etc).
- **Societal benefits** of high spectral/temporal information outweigh the costs.

More Information

- GOES and NASA:
  - http://goespoes.gsfc.nasa.gov/goes/index.html
  - http://goes.gsfc.nasa.gov/text/goes.databookn.html
- GOES-R
  - http://www.goes-r.gov
- ABI Research Home page:
  - http://cimss.ssec.wisc.edu/goes/abi/
  - AMS BAMS Article on the ABI (Aug. 2005)

6th GOES Users' Conference

Bringing Environmental Benefits to a Society of Users

November 3–5, 2009
Madison, WI

http://www.goes-r.gov

International TOVS Study Conference, 16th, ITSC-16, Angra dos Reis, Brazil, 7-13 May 2008. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2008.