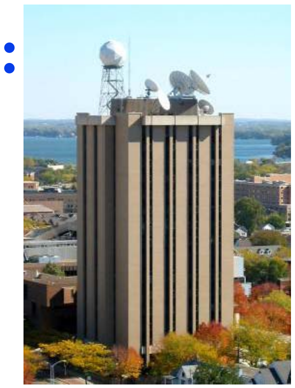
UW-Madison from SSEC, 21 October 2005

# IR Imaging Sounders for Geosynchronous Orbit:
## A key capability for future multi-national observing systems



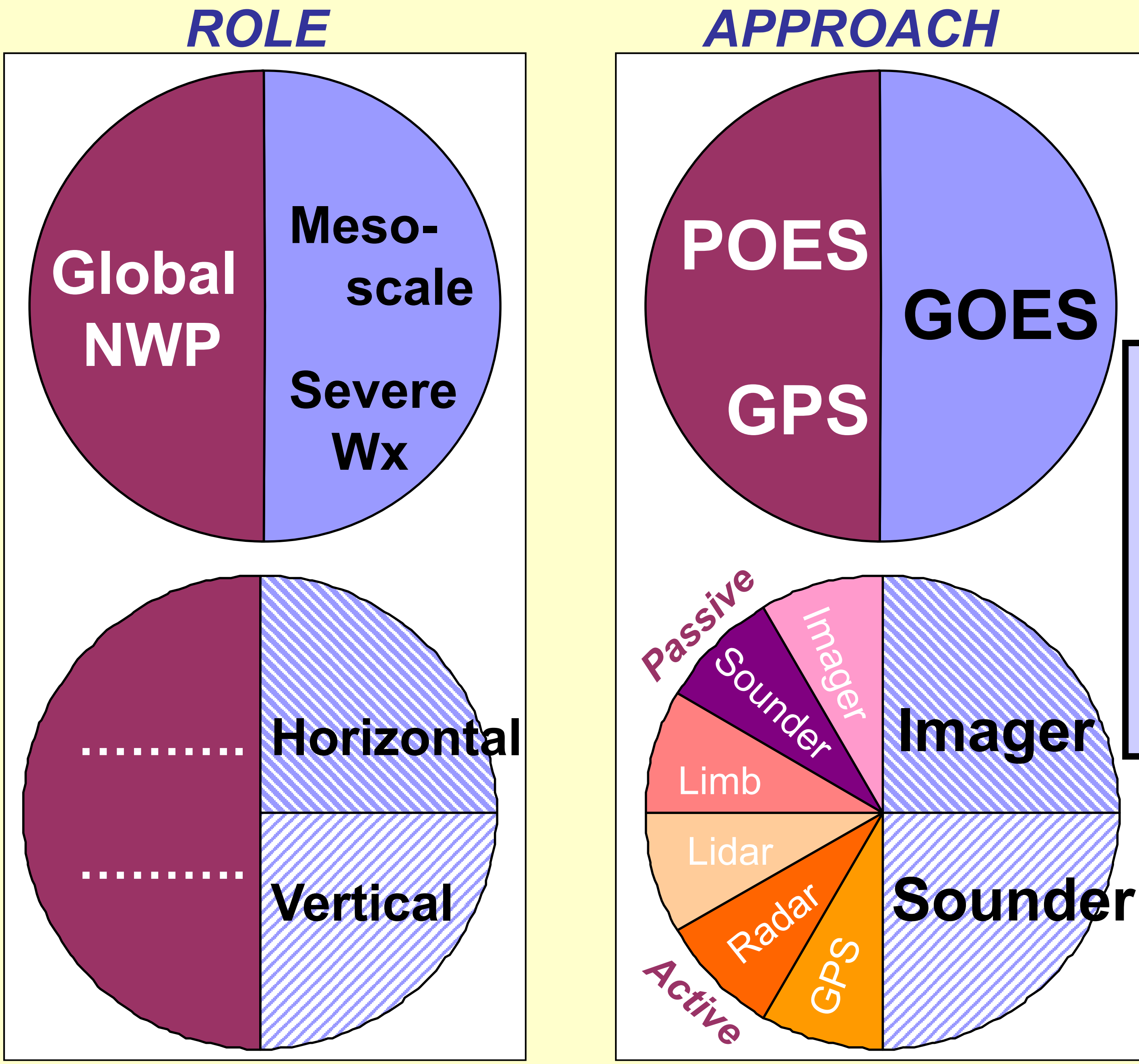
SSEC


**Hank Revercomb**

**University of Wisconsin-Madison,**
**Space Science and Engineering Center (SSEC)**


**AMS Annual Meeting**
**Meteorological and Environmental Satellite Observing Systems:**
**From 50 Years Ago to 15 Years Ahead**
**Atlanta, Georgia, 19 January 2010**

# Operational Weather Satellites




**GOES Sounder**

= ¼ Wx Sat. role

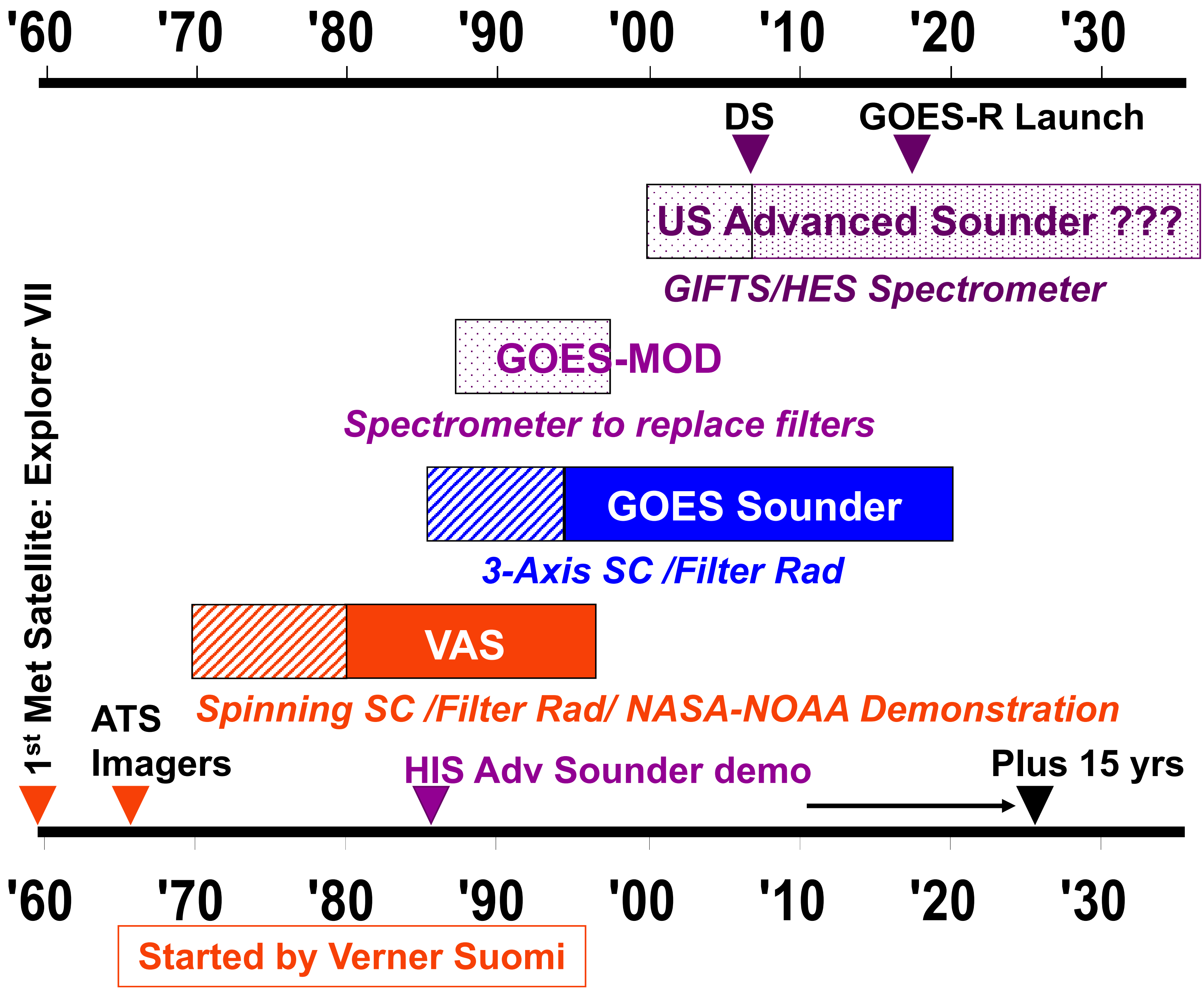
= ½ Severe Wx Sat. role

**Not just one in a long list!**

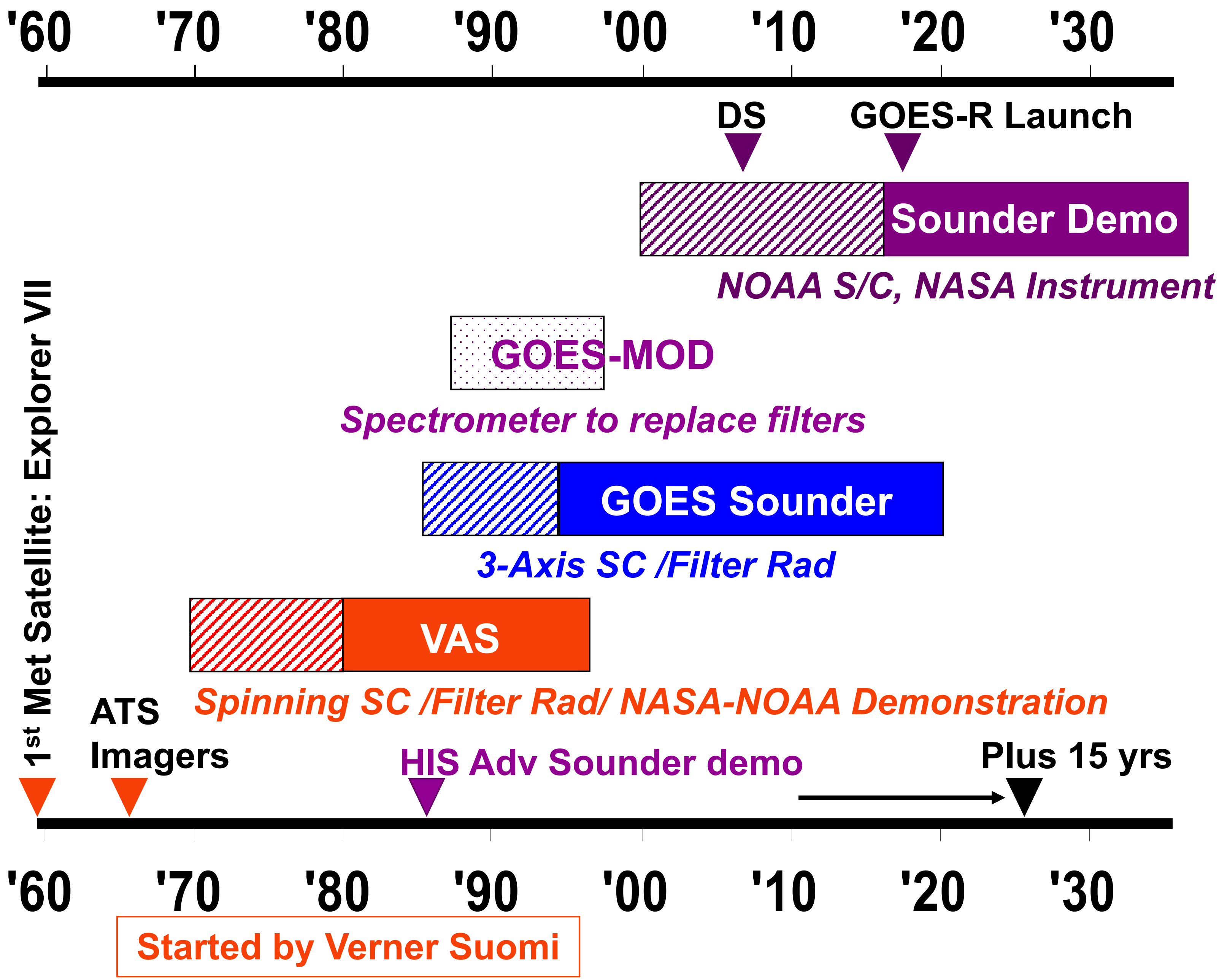
# IR Imaging Sounder
## Topics

1. Chronology: 50 years ago to 15 years ahead
2. Observing System Simulation Experiment (OSSE) shows hours of improved lead time for developing severe storms
3. Advanced GOES IR Sounder capabilities, status, and Technological Readiness

# GEO Sounder


'60
'70
'80
'90
'00
'10
'20
'30
DS
GOES-R Launch
US Advanced Sounder ???
GIFTS/HES Spectrometer
GOES-MOD
Spectrometer to replace filters
GOES Sounder
3-Axis SC /Filter Rad
VAS
Spinning SC /Filter Rad/ NASA-NOAA Demonstration
1st Met Satellite: Explorer VII
ATS
Imagers
HIS Adv Sounder demo
Plus 15 yrs
'60
'70
'80
'90
'00
'10
'20
'30
Started by Verner Suomi

# GEO Sounder


'60 '70 '80 '90 '00 '10 '20 '30
DS
GOES-R Launch
Sounder Demo
NOAA S/C, NASA Instrument
GOES-MOD
Spectrometer to replace filters
GOES Sounder
3-Axis SC /Filter Rad
VAS
Spinning SC /Filter Rad/ NASA-NOAA Demonstration
1st Met Satellite: Explorer VII
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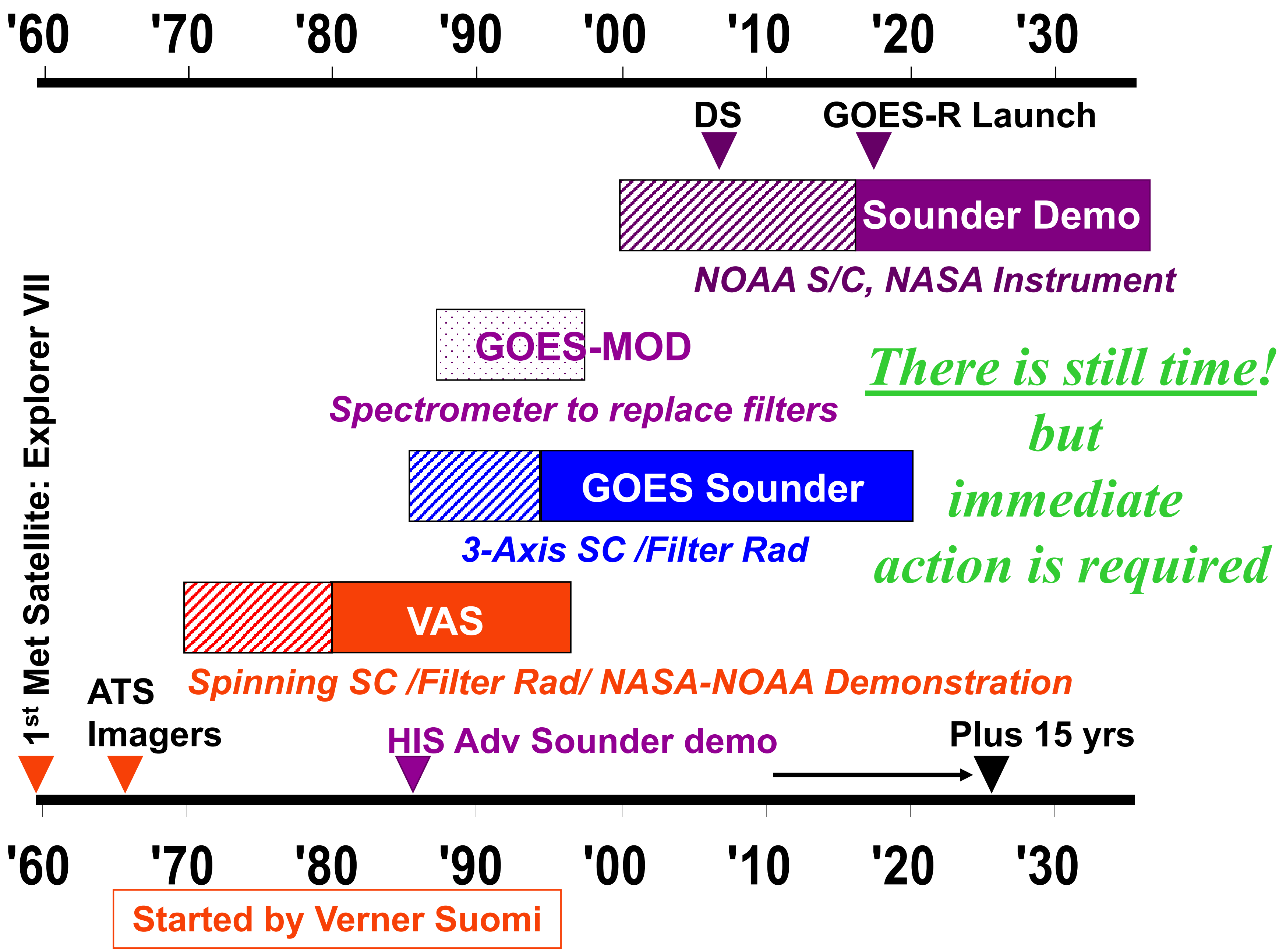
Plus 15 yrs
'60 '70 '80 '90 '00 '10 '20 '30
Started by Verner Suomi

# GEO Sounder


'60 '70 '80 '90 '00 '10 '20 '30
DS
GOES-R Launch
Sounder Demo
NOAA S/C, NASA Instrument
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Spectrometer to replace filters
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3-Axis SC /Filter Rad
VAS
Spinning SC /Filter Rad/ NASA-NOAA Demonstration
1st Met Satellite: Explorer VII
ATS
Imagers
HIS Adv Sounder demo
Plus 15 yrs
'60 '70 '80 '90 '00 '10 '20 '30
Started by Verner Suomi
There is still time!
but
immediate
action is required

# NRC Decadal Survey: Sounder is needed

## The Forgotten Recommendation

- *"Recommendation:* NOAA should restore several key climate, environmental, and weather observation capabilities to its planned NPOESS and GOES-R missions; namely:" *(followed by 4 bullets)*

- *4th bullet:* **"Develop a strategy to restore the previously planned capability to make high-temporal- and high-vertical-resolution measurements of temperature and water vapor from geosynchronous orbit."**

"the committee recommends consideration of the following approaches:

- **Working with NASA, complete the GIFTS instrument, deliver it to orbit via a cost-effective launch and spacecraft opportunity, and evaluate its potential to be a prototype for the HES instrument, and/or**
- **Extend the HES study contracts focusing on cost-effective approaches to achieving essential sounding capabilities to be flown in the GOES-R time frame."**

*from Executive Summary, p 5-6, 4 October 2007*

# Advanced GOES Sounder Development fits with Congressional view of NOAA & NASA Roles

## 2008 NASA Authorization Act

- **SEC. 204. TRANSITIONING EXPERIMENTAL RESEARCH INTO OPERATIONAL SERVICES.**
  - **It is the sense of the Congress that experimental NASA sensors and missions that have the potential to benefit society if transitioned into operational monitoring systems**
    **be transitioned into operational status whenever possible**

- **SEC. 203. DECADAL SURVEY MISSIONS.**

  **[Advanced GEO Sounder is the forgotten Recommendation!]**

- **SEC. 208. TORNADOES AND OTHER SEVERE STORMS.**
  - **The Administrator shall ensure that NASA gives high priority to … cooperative activities with NOAA …, with the goal of improving the Nation's ability to predict tornados and other severe storms.**

**(H.R.6063 became law on 15 October 2008)**

# Summary of Support

- **Best of the past:** Father of Satellite Meteorology, Verner E. Suomi
- **Best of the present:** National Research Council, Decadal Survey
- **Congress:** 2008 NASA Authorization Act
- **NWS Forecast Offices*:**
  -Jeff Craven, SOO,Milwaukee;
  looks to sounder for **"Warn on Forecast"**
  -Jack Beven, Nat. Hurricane Ctr, Lead Forecaster;
  **NHC could significantly benefit** from an advanced sounder on the GOES-R satellite series

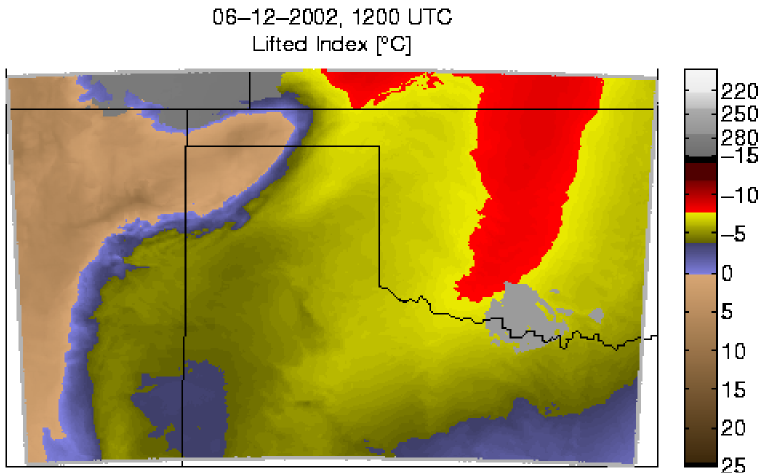
* *From GOES User Conference Townhall, 4 November 2009*

# 2. Observing System Simulation Expt (OSSE) showing hours of improved lead time for developing severe storms

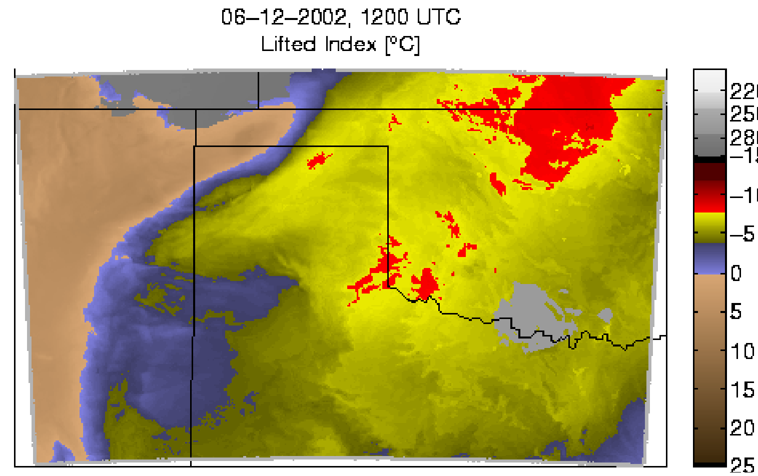
**A unique capability of the advanced GOES sounder**

# OSSE of GEO advanced IR sounder for storm Nearcasting

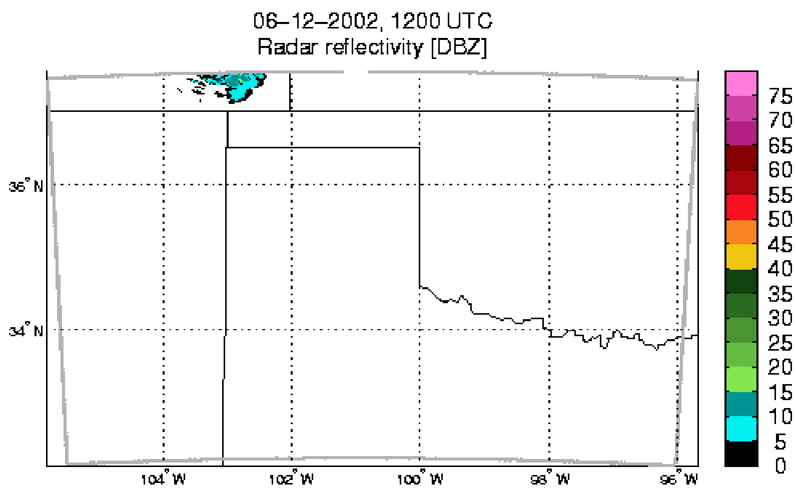
**True**




**GIFTS/HES/IRS**

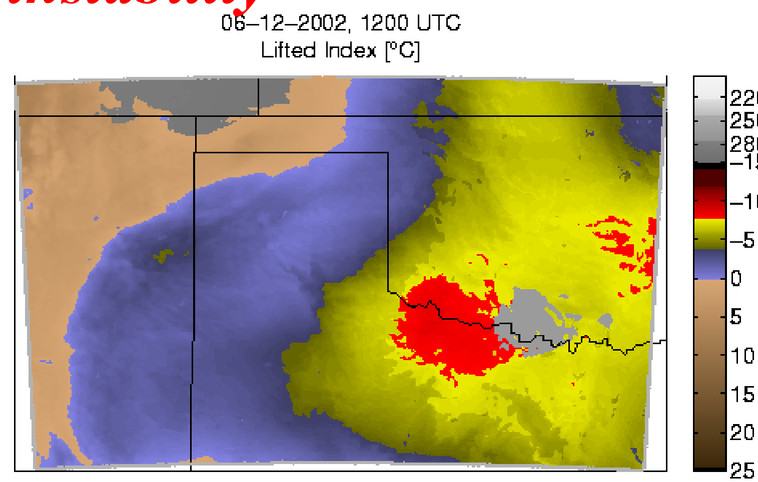



*Red = extreme instability*




**Simulated Radar**

UW/CIMSS




**ABI/GOES Sounder like**

UW/CIMSS

**Jun Li, Jinlong Li, Jason Otkin, and Tim Schmit**

# OSSE Description

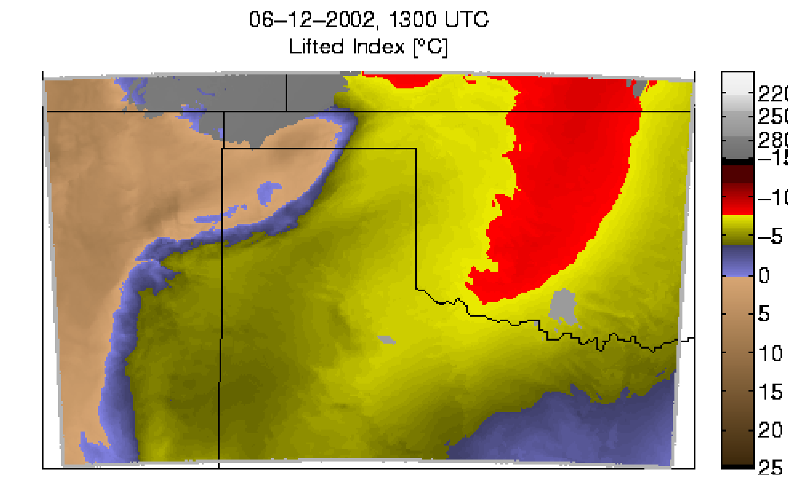
SSEC

- Based on detailed WRF model run produced as proxy data for GOES-R imager (ABI)
- 12-13 June 2002 IHOP experiment, Oklahoma
- 2 km model grid
- Realistic clouds verified with measurement comparisons

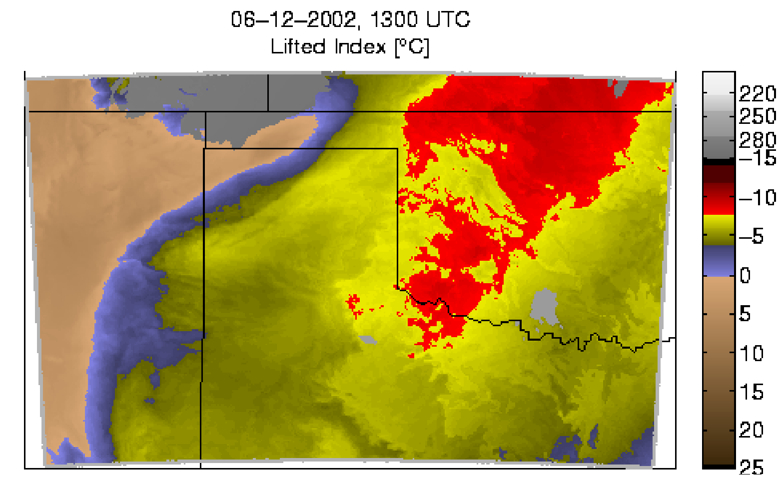
Jun Li, Jinlong Li, Jason Otkin, and Tim Schmit

# OSSE of GEO advanced IR sounder for storm Nearcasting

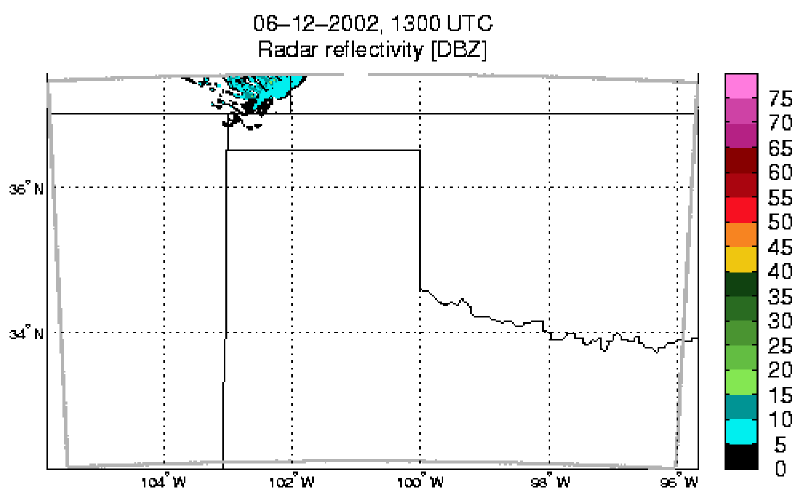
**True**




**GIFTS/HES/IRS**

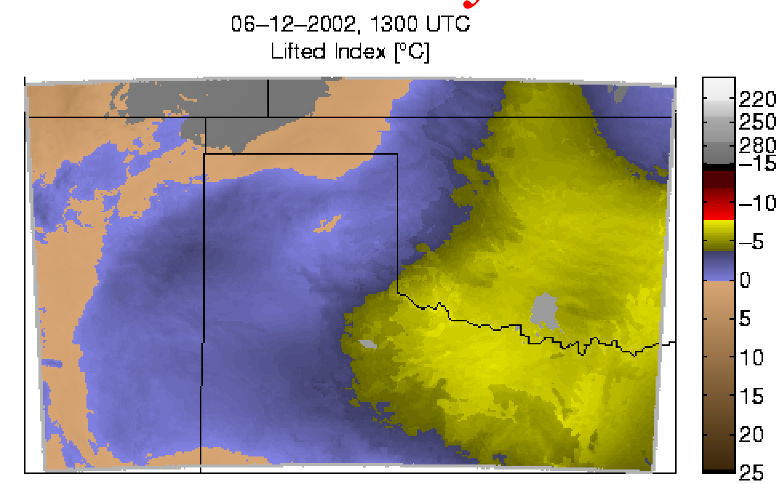



*Extreme instability indicated*




**Simulated Radar**

UW/CIMSS



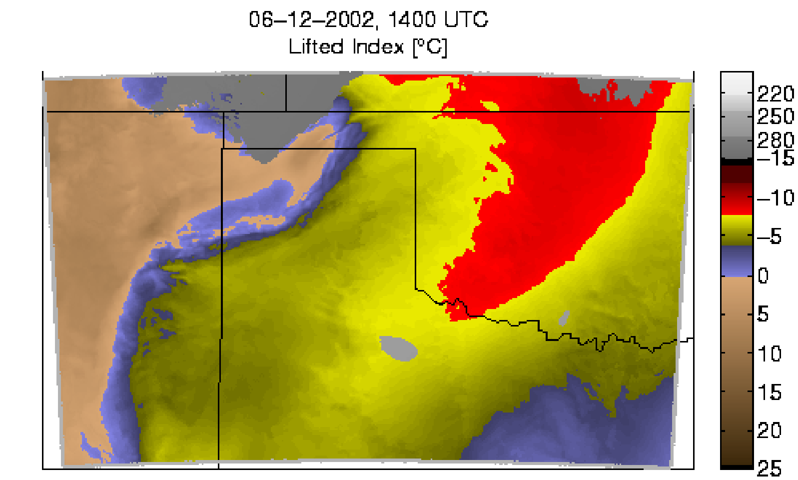

**ABI/GOES Sounder like**

UW/CIMSS

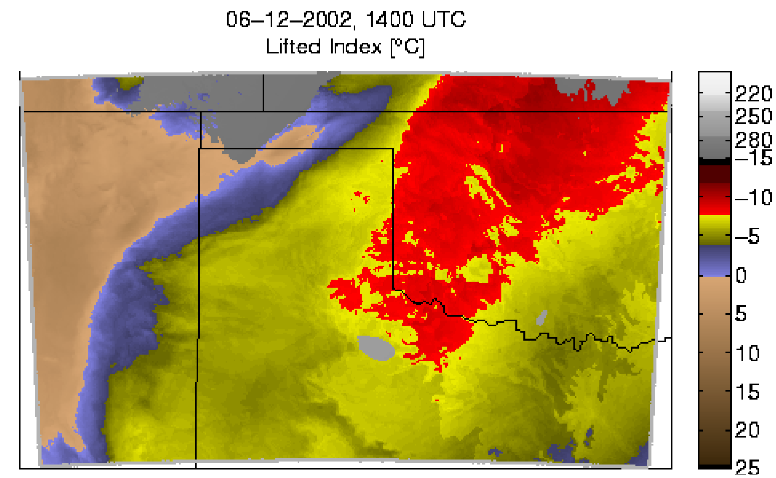
*1300 UTC*

# OSSE of GEO advanced IR sounder for storm Nearcasting

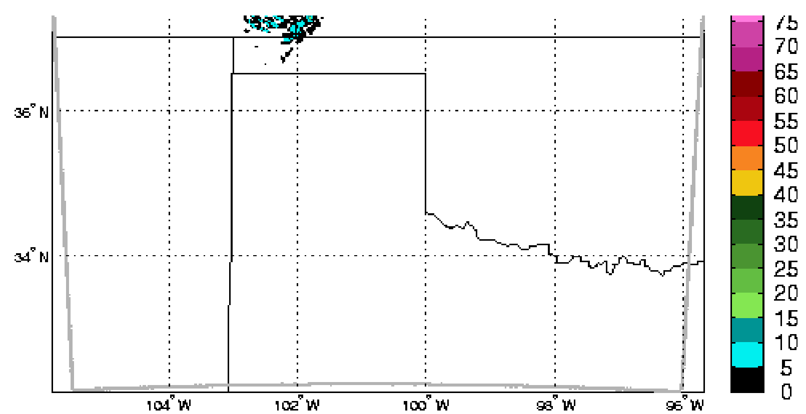
**True**



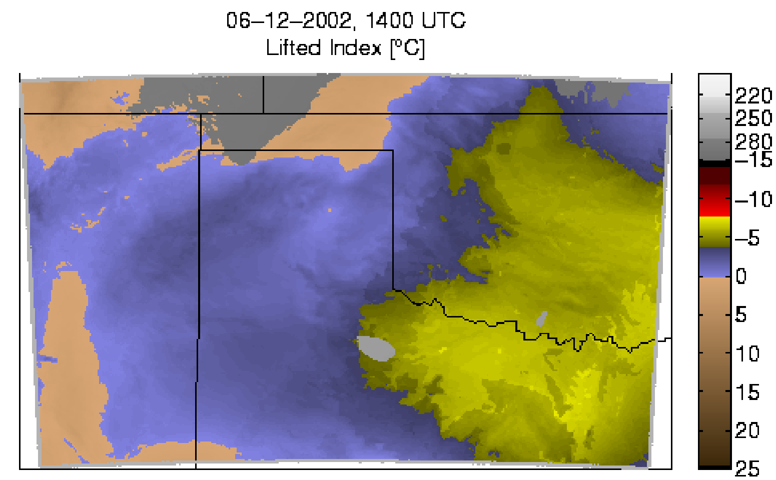

**GIFTS/HES/IRS**




UW/CIMSS




**Simulated Radar**



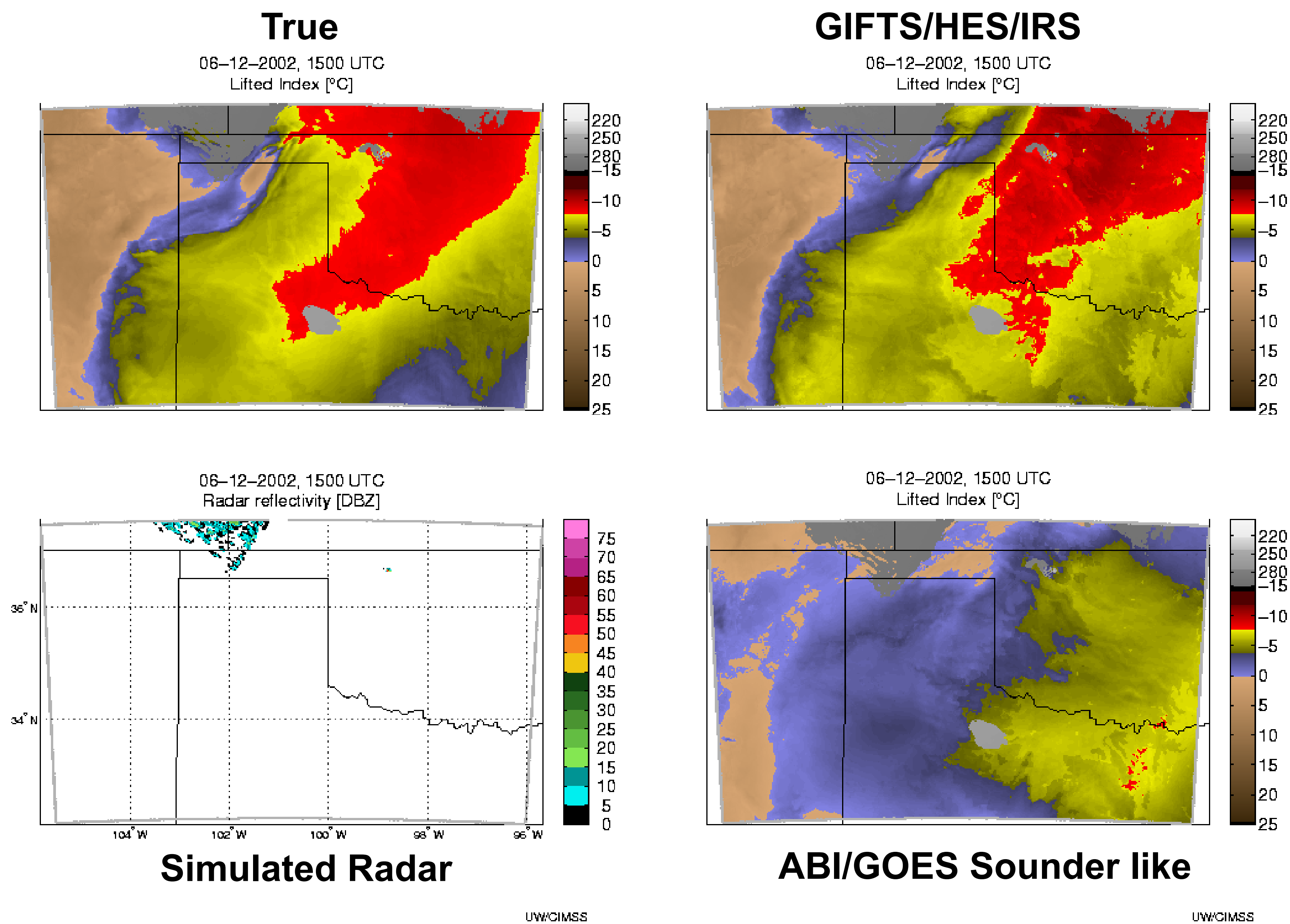

**ABI/GOES Sounder like**

UW/CIMSS

UW/CIMSS

***1400 UTC***

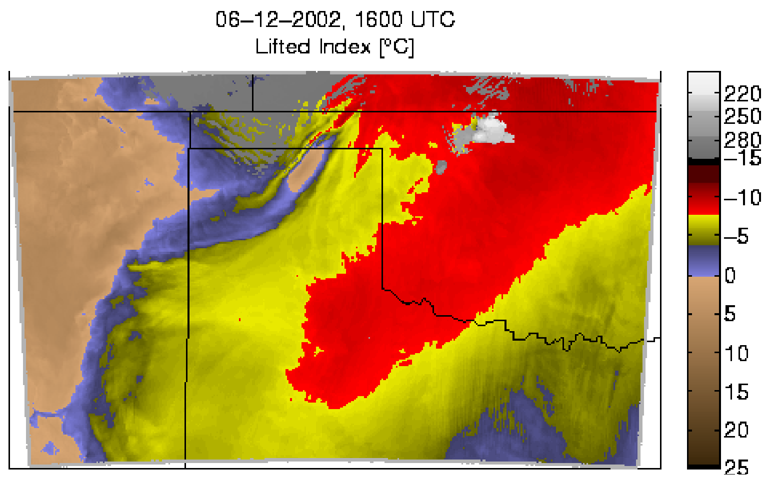
# OSSE of GEO advanced IR sounder for storm Nearcasting



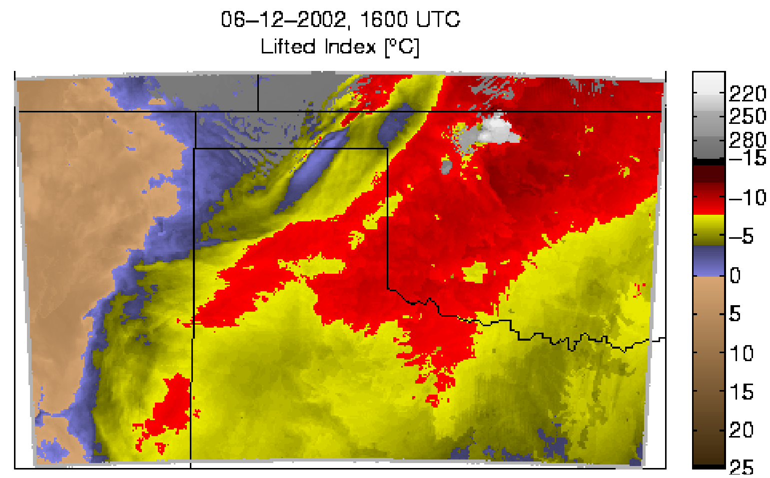

*1500 UTC*

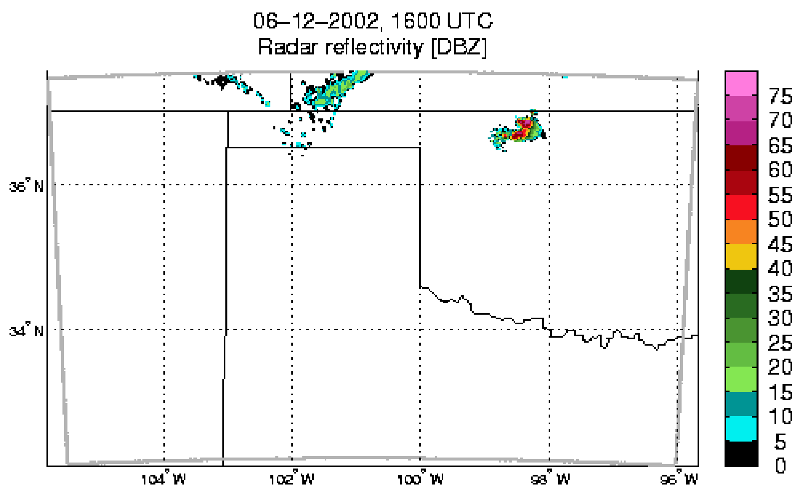
# OSSE of GEO advanced IR sounder for storm Nearcasting

**True**



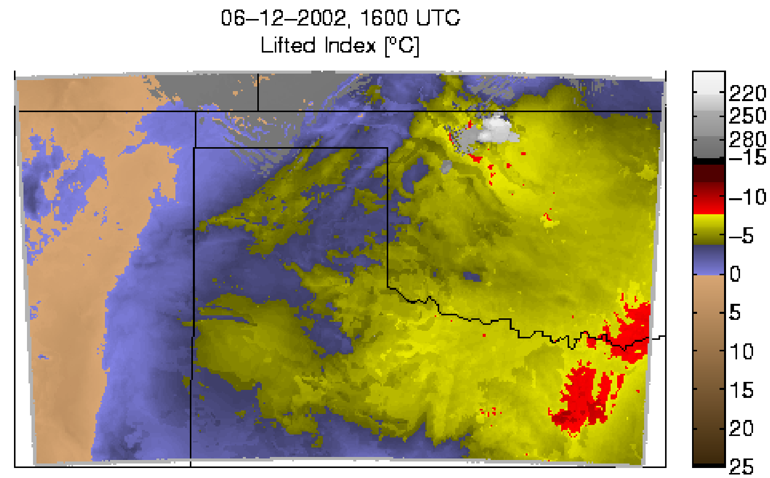

**GIFTS/HES/IRS**




**Simulated Radar**

UW/CIMSS



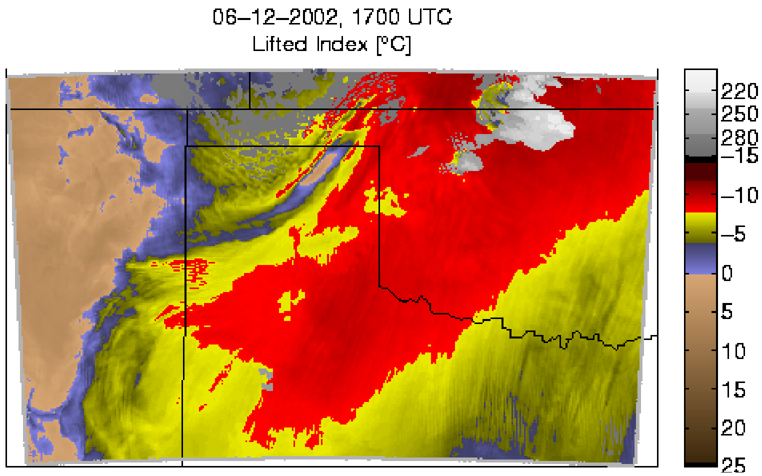

**ABI/GOES Sounder like**

UW/CIMSS

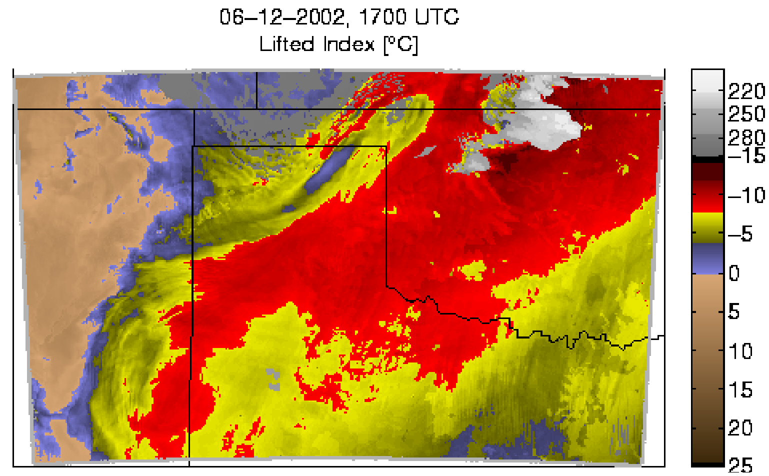
***1600 UTC***

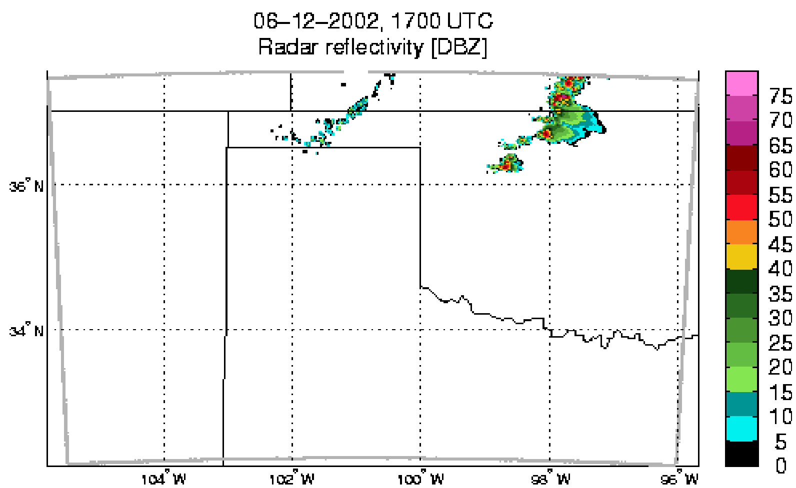
# OSSE of GEO advanced IR sounder for storm Nearcasting

**True**

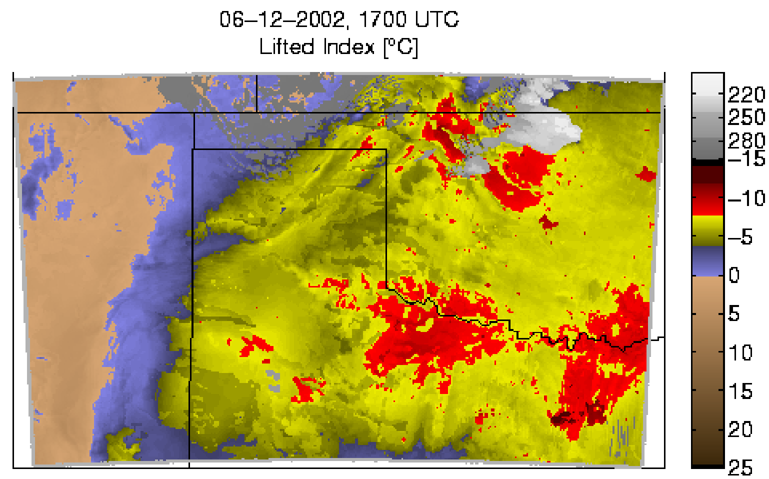



**GIFTS/HES/IRS**




**Simulated Radar**




**ABI/GOES Sounder like**

UW/CIMSS

*Start to see extreme instability*

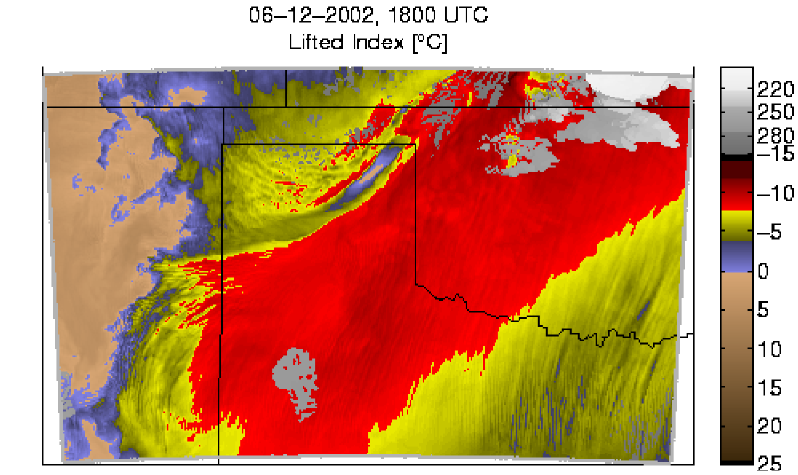
UW/CIMSS

*4 hours later*

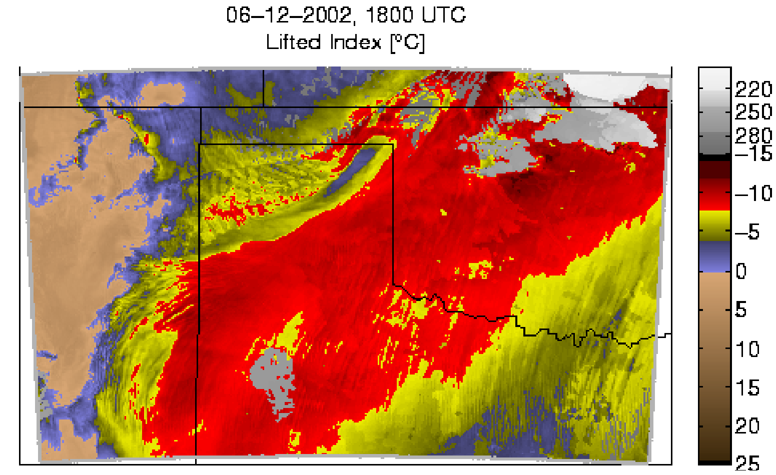
*1700 UTC*

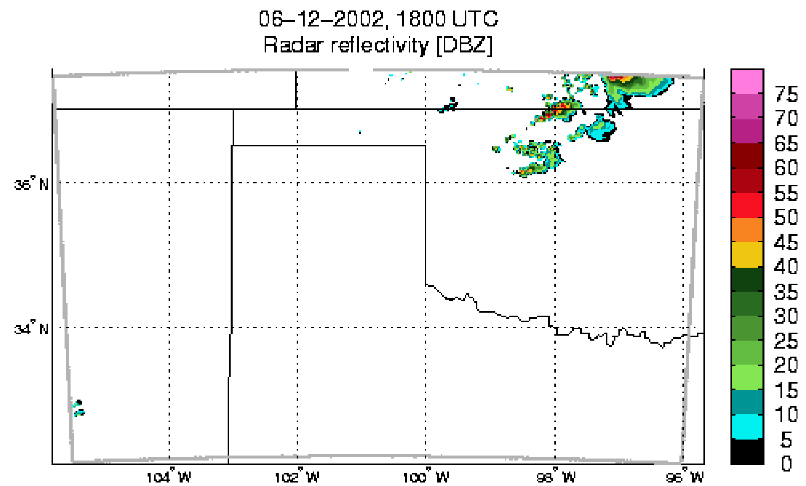
# OSSE of GEO advanced IR sounder for storm Nearcasting

**True**

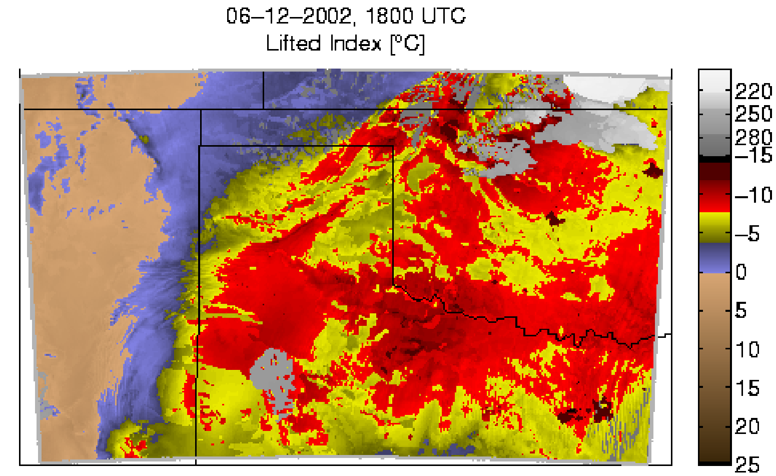



**GIFTS/HES/IRS**




**Simulated Radar**




**ABI/GOES Sounder like**

UW/CIMSS

UW/CIMSS

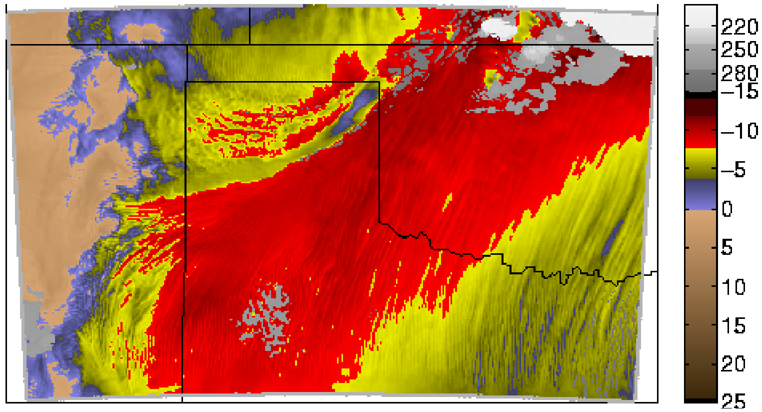
*1800 UTC*

*Extreme instability clearly shown 5 hours later, but note false alarms*

# OSSE of GEO advanced IR sounder for storm Nearcasting

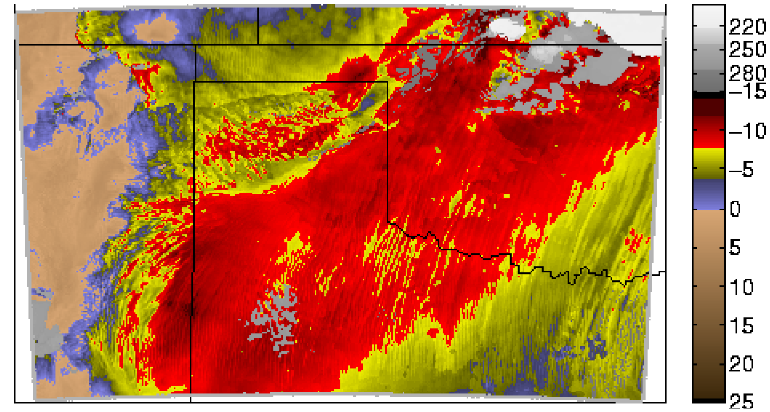
**True**

06–12–2002, 1900 UTC
Lifted Index [°C]

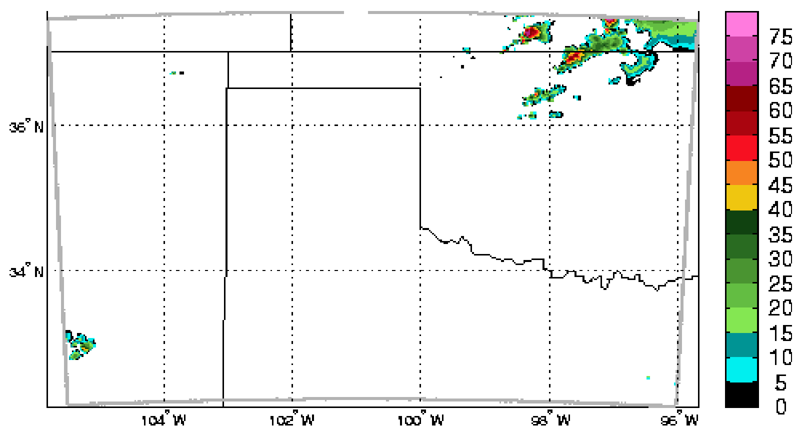



**GIFTS/HES/IRS**

06–12–2002, 1900 UTC
Lifted Index [°C]



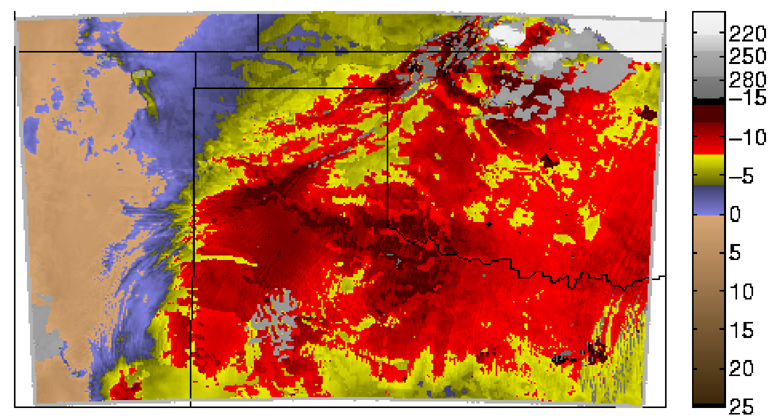

06–12–2002, 1900 UTC
Radar reflectivity [DBZ]




**Simulated Radar**

UW/CIMSS

06–12–2002, 1900 UTC
Lifted Index [°C]




**ABI/GOES Sounder like**

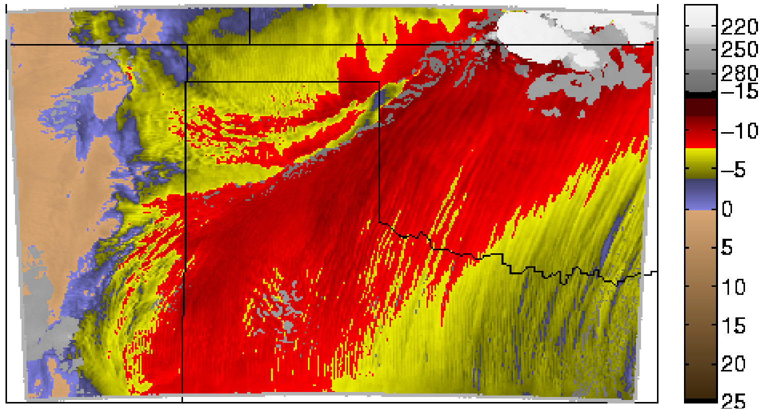
UW/CIMSS

*1900 UTC*

# OSSE of GEO advanced IR sounder for storm Nearcasting

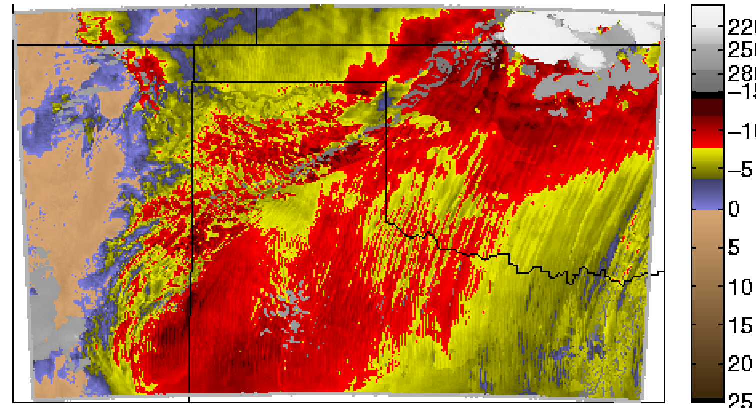
## True

06–12–2002, 2000 UTC
Lifted Index [°C]

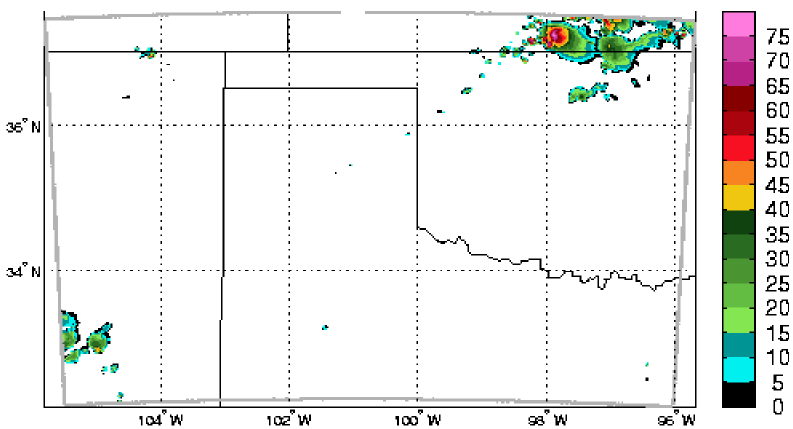



## GIFTS/HES/IRS

06–12–2002, 2000 UTC
Lifted Index [°C]



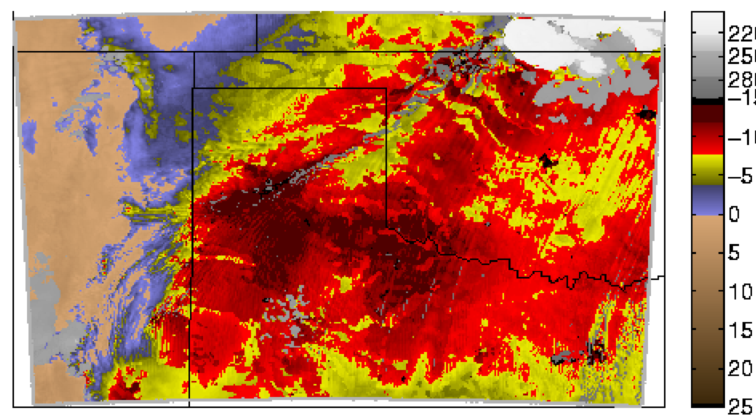

06–12–2002, 2000 UTC
Radar reflectivity [DBZ]




## Simulated Radar

UW/CIMSS

06–12–2002, 2000 UTC
Lifted Index [°C]



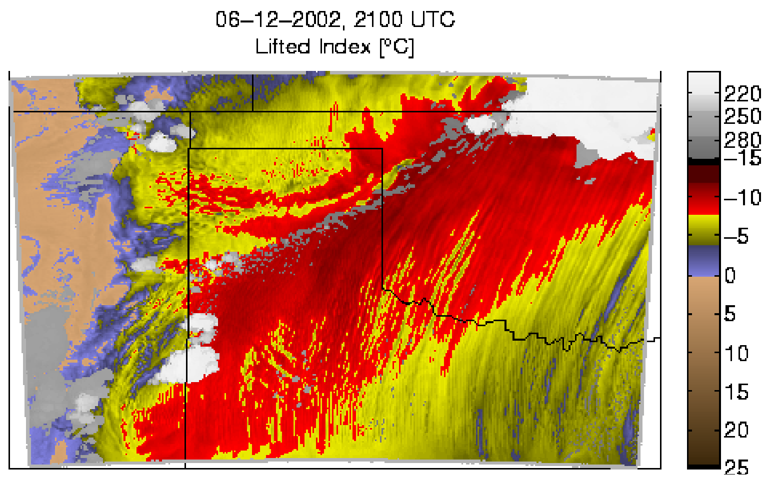

## ABI/GOES Sounder like

UW/CIMSS

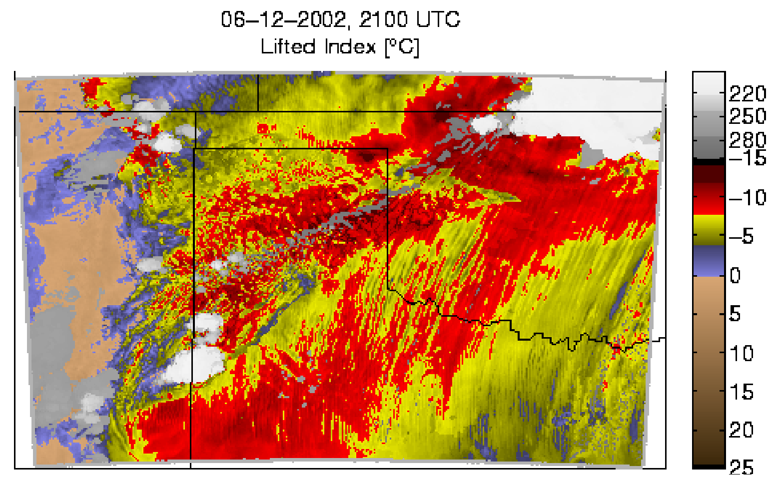
*2000 UTC*

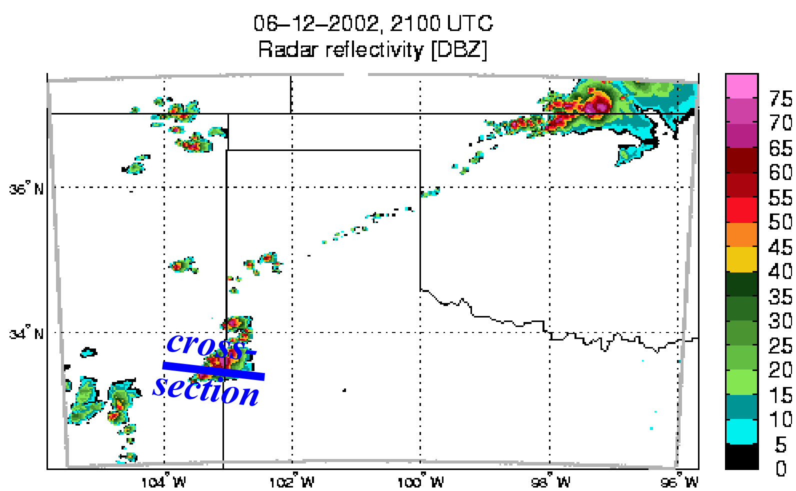
# OSSE of GEO advanced IR sounder for storm Nearcasting

## True

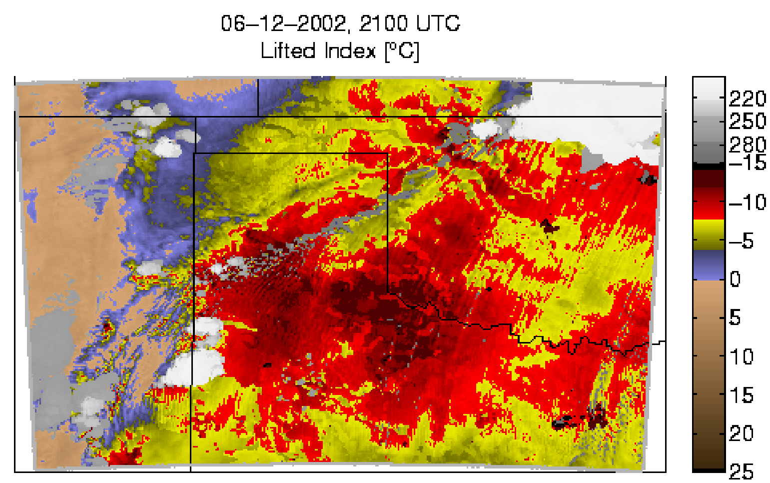



## GIFTS/HES/IRS




## Simulated Radar




## ABI/GOES Sounder like

UW/CIMSS

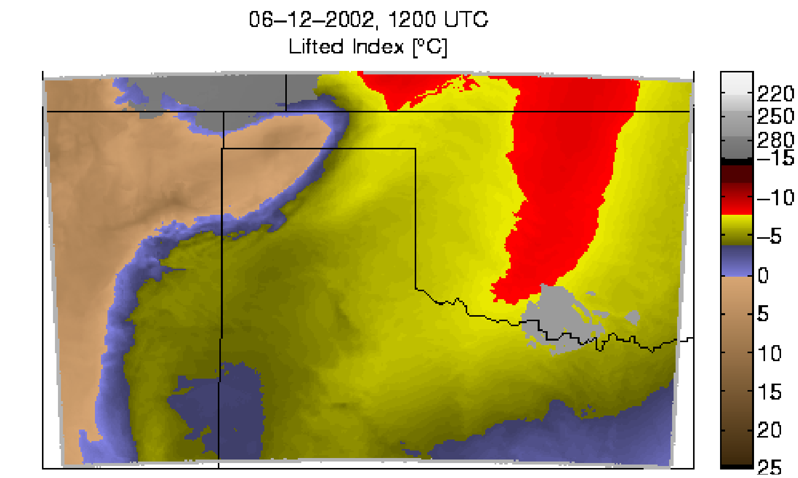
UW/CIMSS

***Rain line shows in radar 8 hours later***

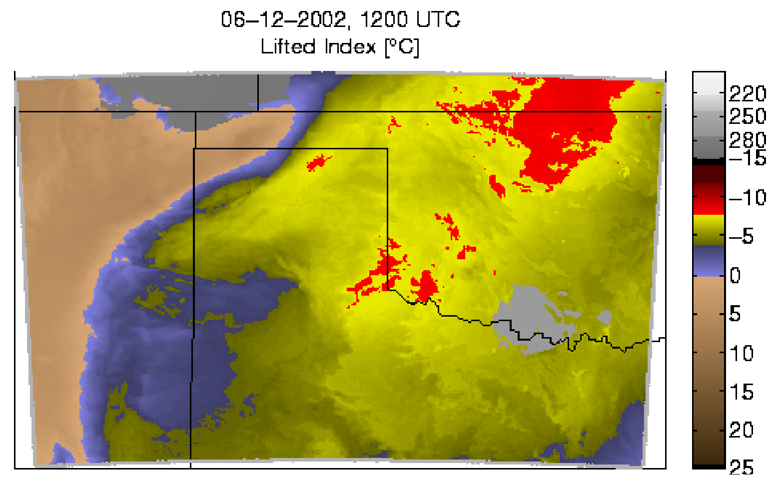
***2100 UTC***

# OSSE of GEO advanced IR sounder for storm Nearcasting

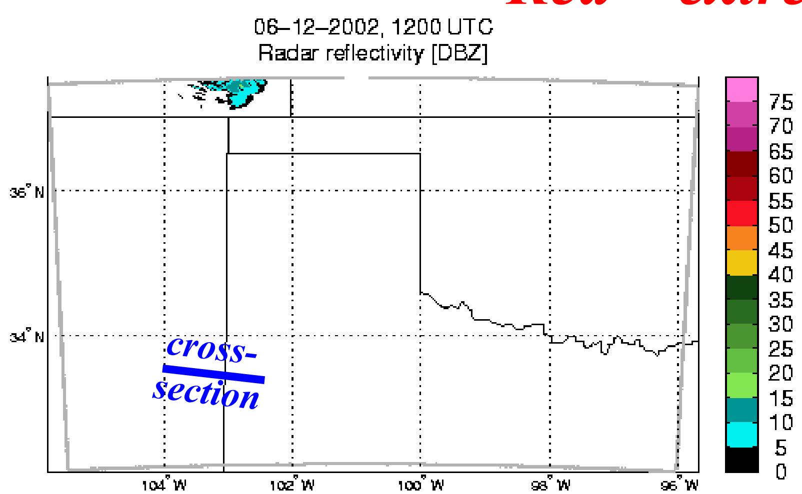
**True**



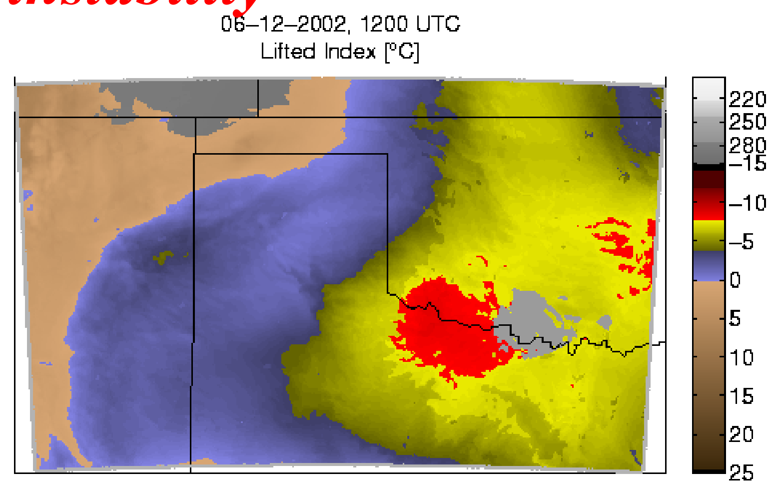

**GIFTS/HES/IRS**




*Red = extreme instability*




**Simulated Radar**



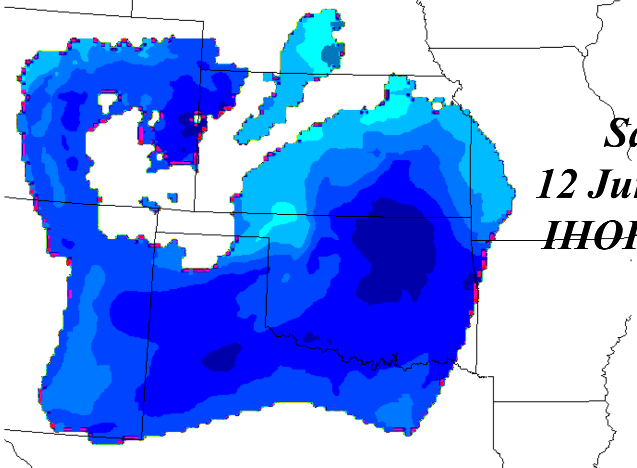

**ABI/GOES Sounder like**

**GIFTS/HES/IRS provides needed instability and warning information hours earlier than current GOES Sounder (+4-5 hrs) and Radar (+8 hrs)**

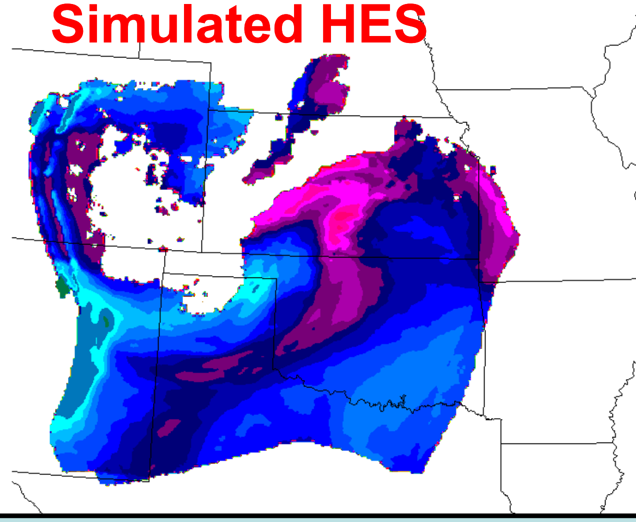
# New Nearcasting Approach Demonstrates Power of Sounder

**5-hour Nearcast for 2000 UTC using Equivalent Potential Temperature (Theta-E)**

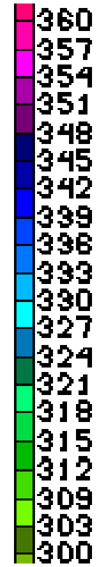
**Simulated ABI**



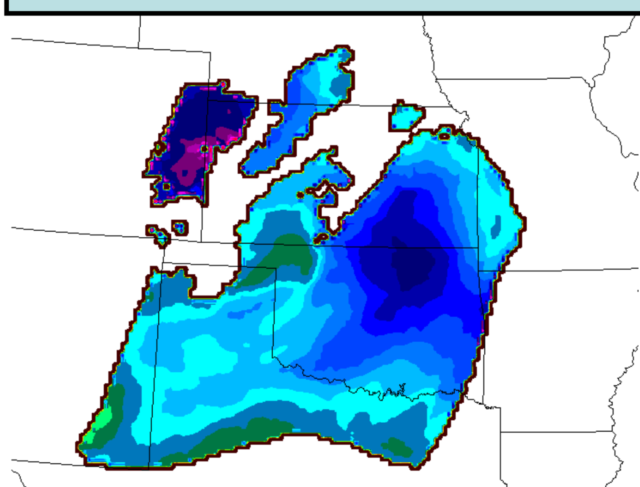
**Simulated HES**

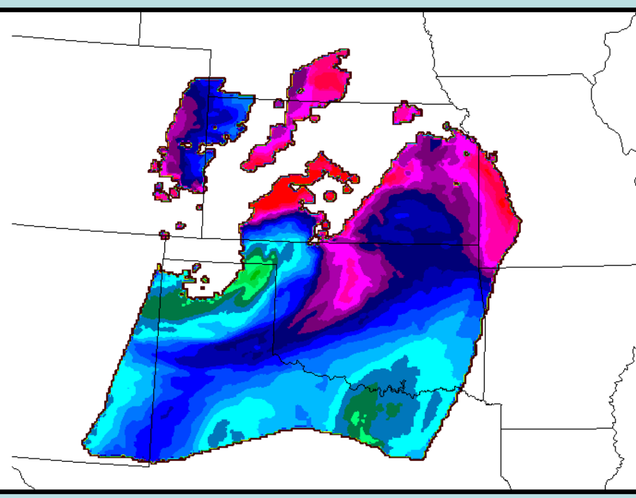


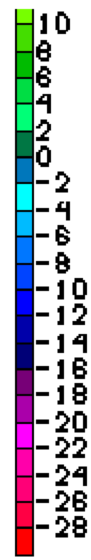
*Same*
*12 June 2002*
*IHOP OSSE*




**Strong, localized low-level Theta-E gradients seen by HES, not ABI**
**(enhanced vertical resolution gives HES much higher sensitivity to low level moisture)**








**Vertical Theta-E Differences (500-800 mb) indicate where instability (large negative) supports severe deep convection**

**CIMSS Nearcasting**

**multi-layered observations projected forward in time along Lagrangian trajectories (using winds from RUC)**

*Robert Aune*
*(NESDIS)*

*Ralph Petersen*
*(UW-SSEC/CIMSS)*

# Using the GOES-12 Sounder to Nearcast Severe Weather

*Robert Aune (NESDIS) and Ralph Petersen (CIMSS)*

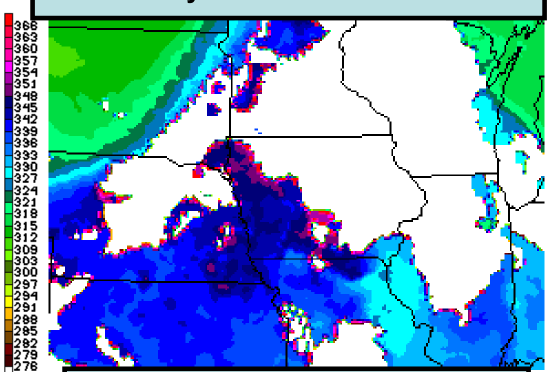
**The CIMSS Near-casting Model uses hourly GOES Sounder retrievals of layered precipitable water (PW) and equivalent potential temperature (Theta-E) to predict severe weather outbreaks up to *6 hours in advance!***

**Hourly, multi-layered observations from the GOES Sounder are projected forward in time along Lagrangian trajectories forced by gradient winds. "Trajectory observations" from the previous six hours are retained in the analysis. Destabilization is indicated when theta-E decreases with height.**

**Limitations:**
- **Sounder channels support only two layers for near-casting**
- **Only useful for elevated convection – Sounder can't detect low-level moisture**
- **Frequent false alarms – Sounder can't detect inversions**

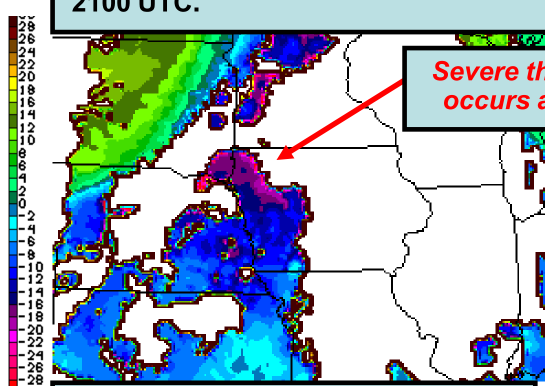
## One Example of a Successful Near-cast

**Low-level Theta-E NearCast shows warm moist air band moving into far NW Iowa by 2100 UTC.**



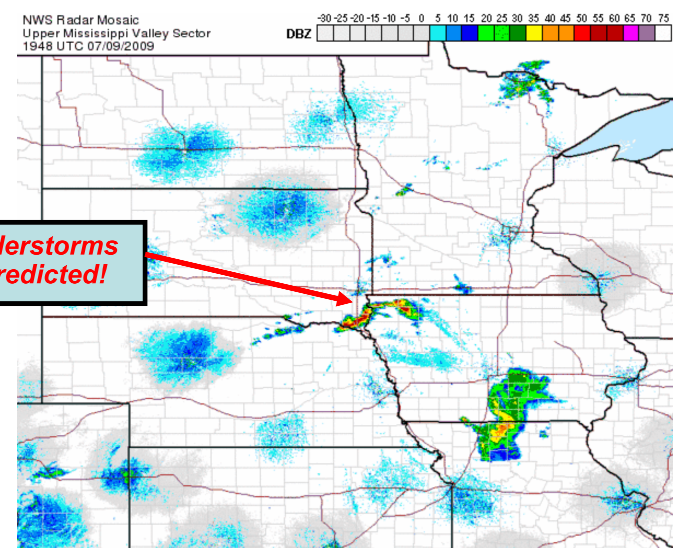
**6-hour NearCast for 2100 UTC**
**Low level Theta-E**

**Vertical Theta-E Differences predict strong convective instability by 2100 UTC.**



**6-hour NearCast for 2100 UTC**
**Low to Mid level Theta-E Differences**

***Severe thunderstorms occurs as predicted!***




**Rapid Development of Convection over NW Iowa between 2000 and 2100 UTC 9 July 2009**

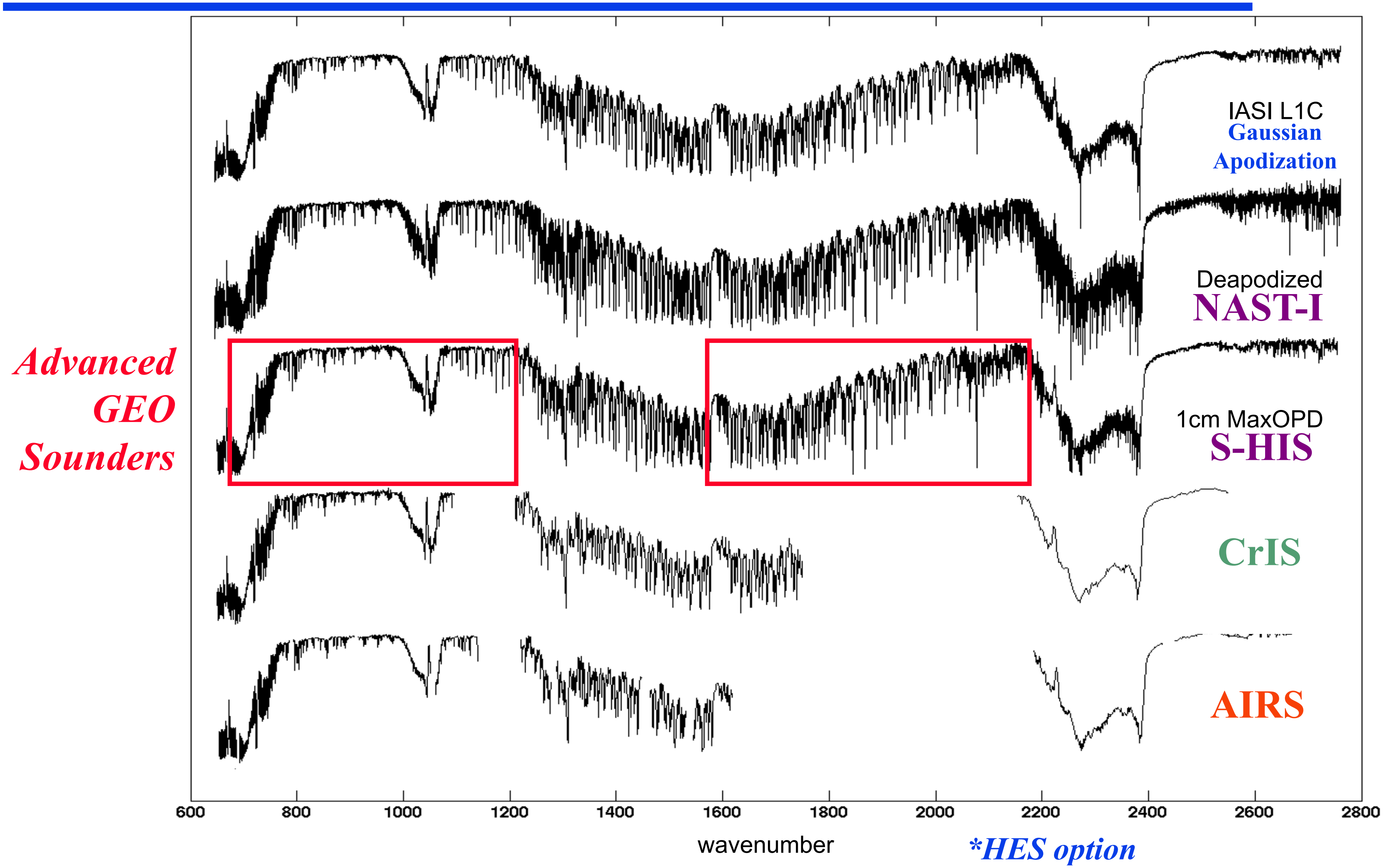
# GEO IR Imaging Sounder capability is unique

- **Polar Sounders**:
  Inadequate temporal coverage
- **GPS**: Inadequate spatial resolution and temporal coverage
- **Current GEO Sounder**:
  Vertical resolution 2-3 times lower
- **ABI Imager**:
  Inadequate vertical resolution
- **GEO Microwave**:
  Vertical resolution 2-3 times lower

# 3. Advanced GOES IR Sounder Capabilities, Status & Technological Readiness

# Spectral Coverage of GIFTS/IRS/HES*

## Compared to IASI, CrIS, AIRS, S-HIS & NAST-I

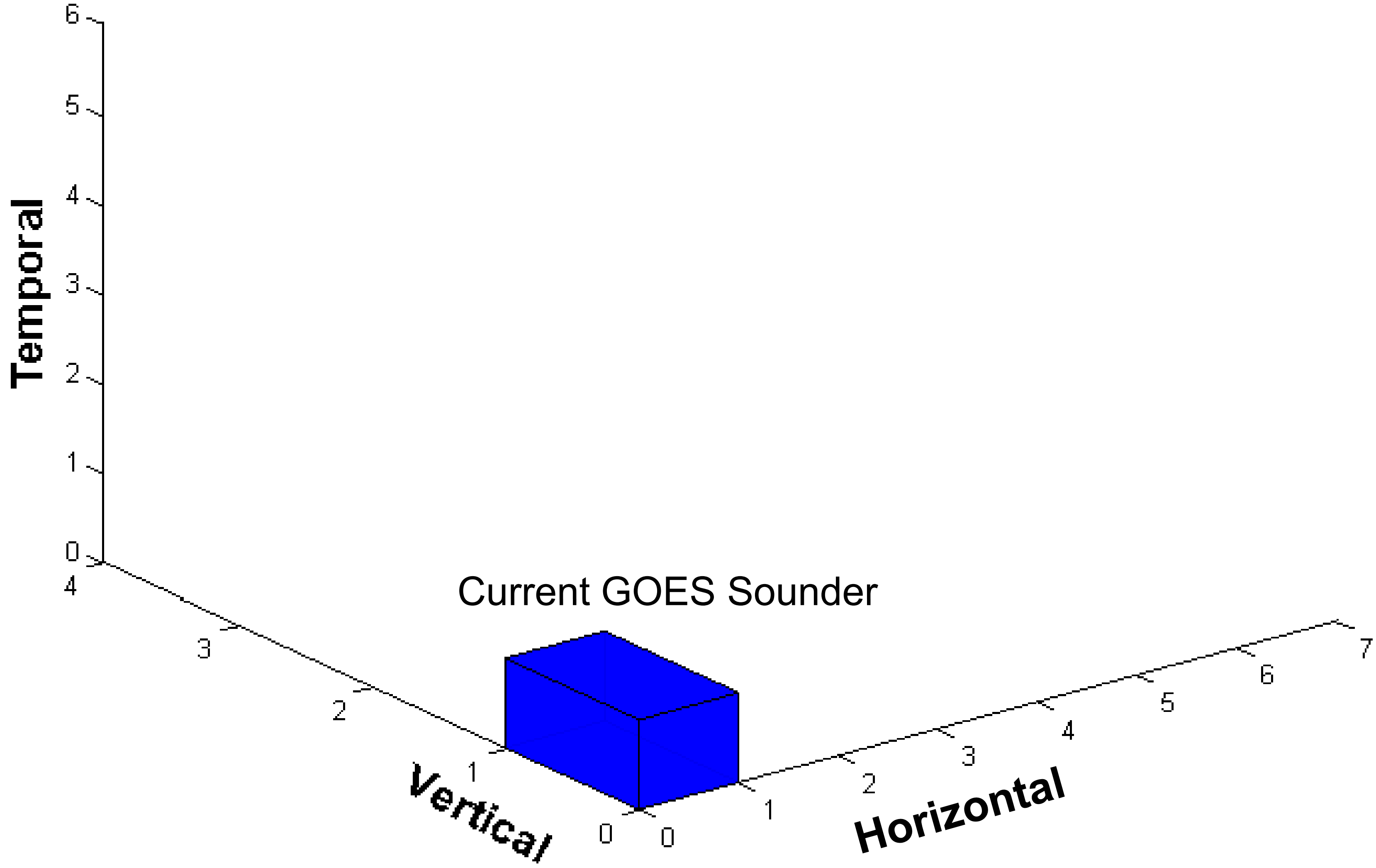


# Advanced Sounder Capabilities
## (GIFTS example)

- **Spectral Coverage & resolution:** broad contiguous coverage, resolving power >1000
- **Vertical Resolution:** increased by x 3
- **Horizontal Image Sampling:** increased from 10 km to 4-5 km
- **Temporal Sampling Rate:** increased by x 5.5 at full spectral resolution

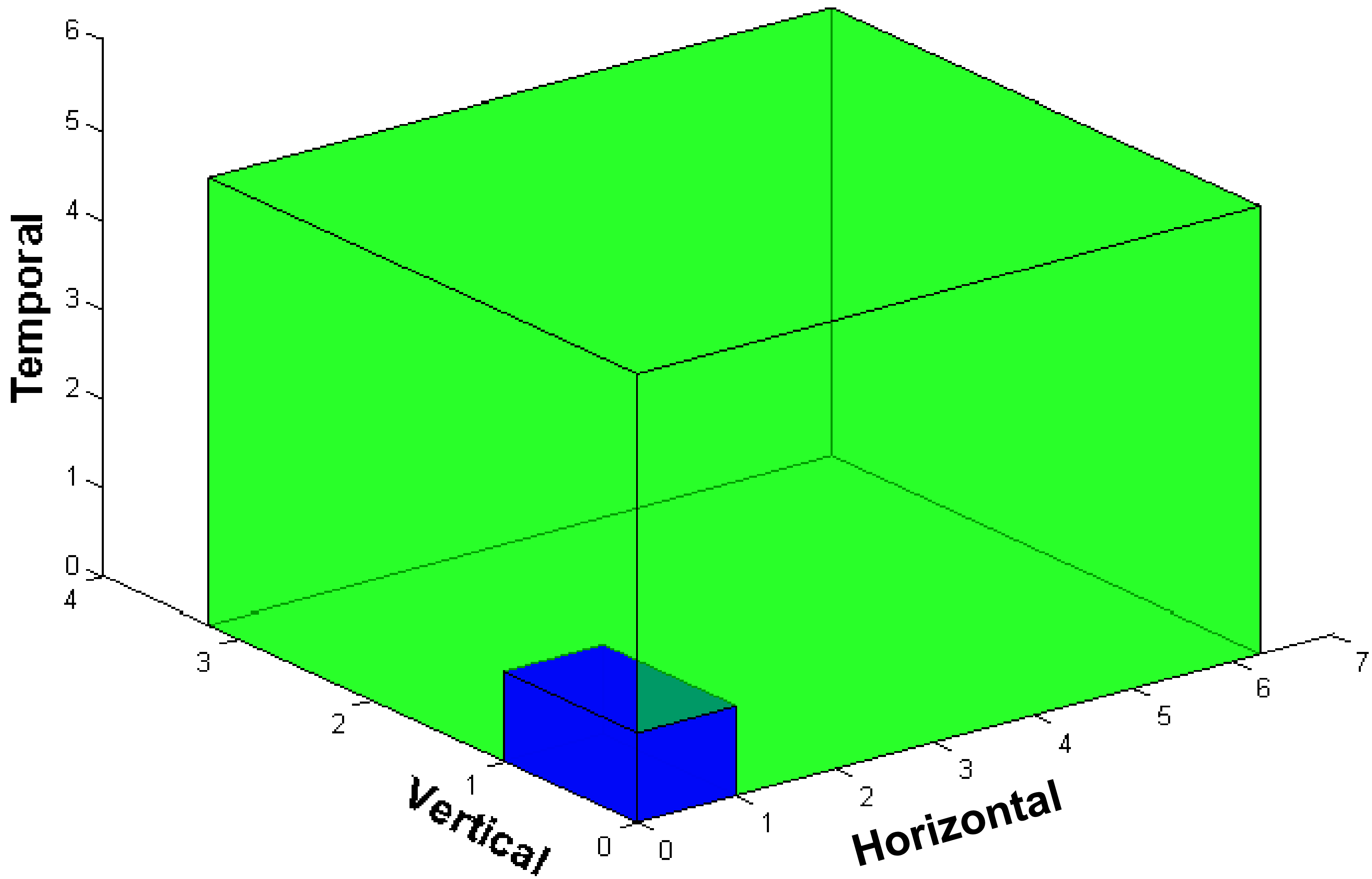
***Factor of 100 improvement in spatial/temporal detail***

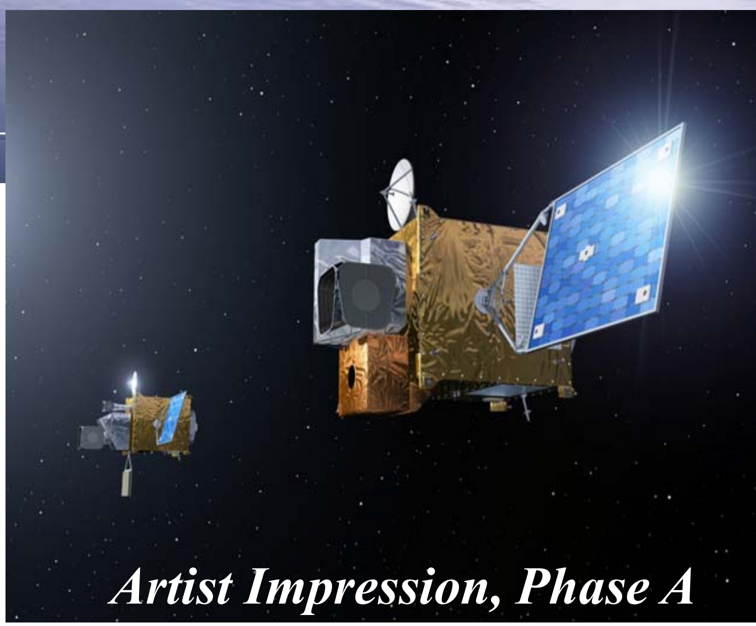
# Current Sounder Information Volume



# Advanced Sounder (GIFTS example)

## *This is where the extra 4-5 hours come from*





Artist Impression, Phase A

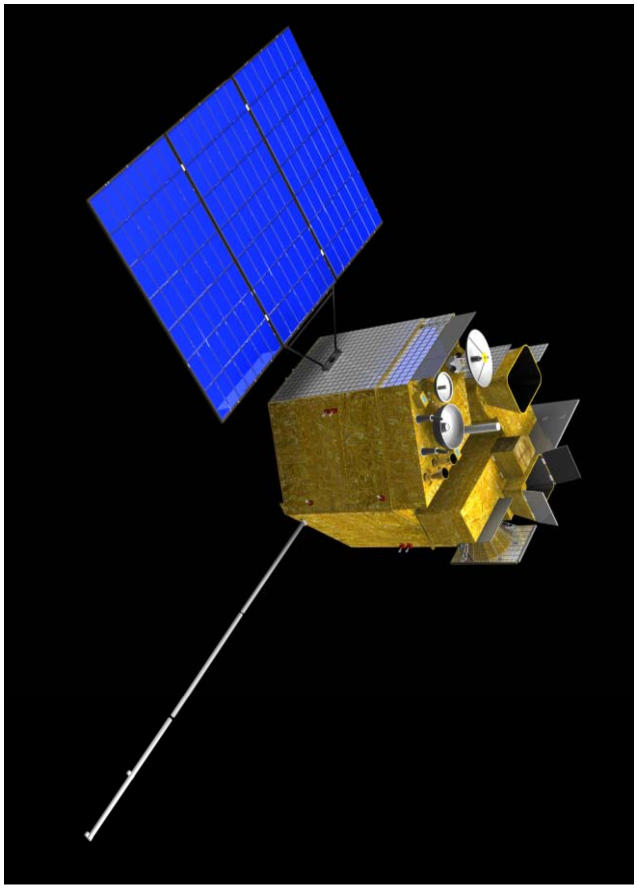
# EUMETSAT/ESA plan for advanced IR Sounder (IRS) to fly on Meteosat 3rd Generation (MTG) in 2017

*Joe Schmetz, Goes Users Conference, 4 Nov 2009*

EUMETSAT

# *China has an Advanced Sounder Plan too!*

## Next Generation of GEO satellite FY-4



Prototype structure of FY-4A

***4 main instruments***

- **Interferometric Infrared Sounder**
- **Multiple Channel Scanning Imager**
- **Lightning Mapper**
- **Solar X-EUV imaging telescope**
  **(not available on 1st satellite)**

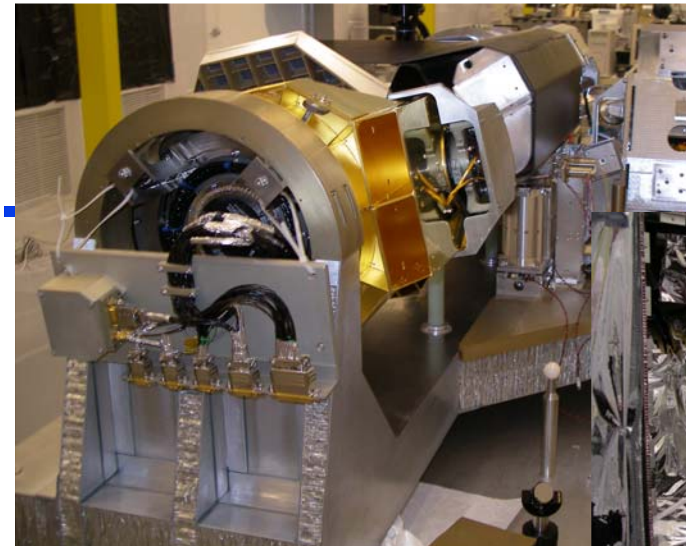
| No. | Plan Launch | Design Life | Status |
|---|---|---|---|
| FY-4A | 2014 | 5 years | R&D |
| FY-4B | 2017 | 7 years | Op. |
| FY-4C | 2019 | 7 years | Op. |

*Jun Yang, GOES Users Conference, 4 Nov 2009*

# Other GEO IR Sounders: Status

- Japan is considering implementation following GOSAT Success
- India is flying the 1st non-US filter-based sounder on INSAT-3D early 2010
- In the US, GOES-R is proceeding without a sounder, in spite of strong endorsements, and technological demonstrations of low risk approaches
  - GIFTS: NASA Engineering Demonstration Unit was successfully tested in 2006, showing readiness to proceed with a demonstration mission
  - HES: NOAA funded efforts by BAE, Ball, and ITT yielded other mature designs for the Sounder that have been assessed as low risk

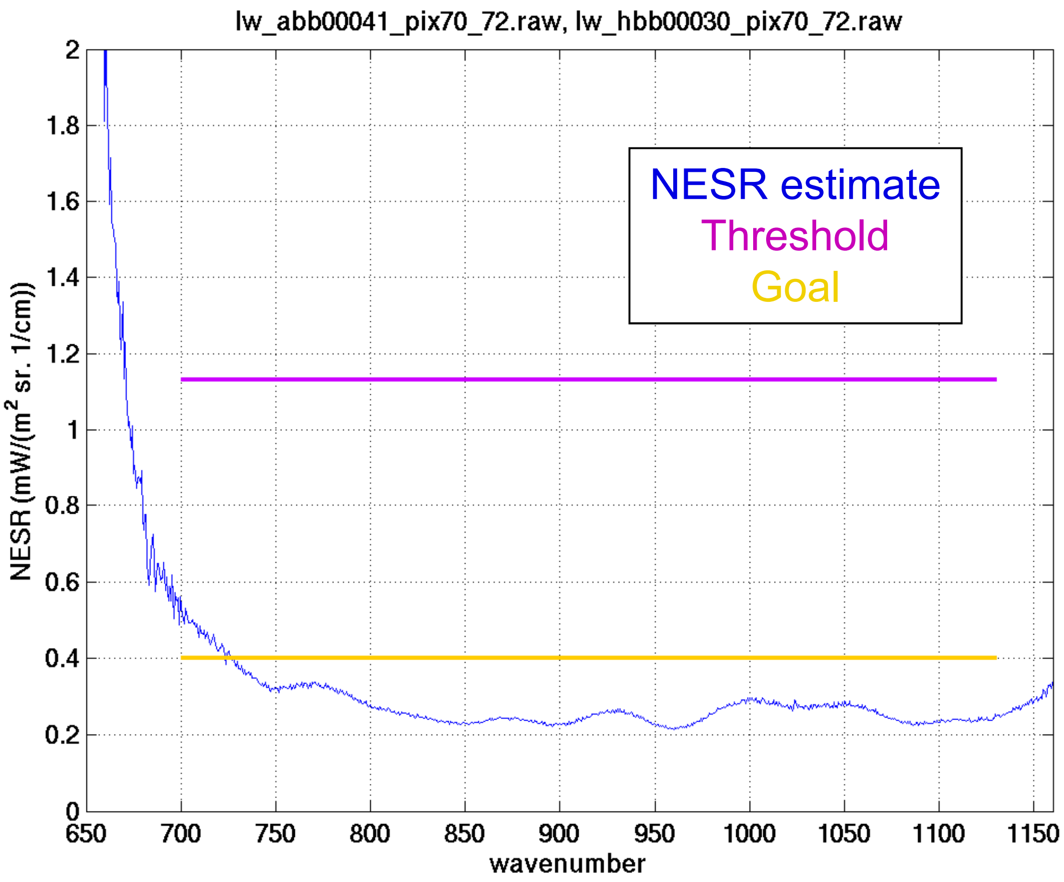
# Geosynchronous Imaging FTS



GIFTS EDU


- **GIFTS Proof of Concept was successfully demonstrated in 2006 with the Engineering Development Unit Thermal/Vacuum & Sky Viewing Tests**
  (expected long-poles are working well: LW detector with good sensitivity and operability, Long-lived stable laser, mechanical cooler and cryogenic thermal design, imaging FTS radiometric integrity, plus many others)
- **Results Demonstrate that NOAA Requirements for a Successful GOES Imaging Spectrometer are achievable with a GIFTS Flight Model**
  (spatial coverage and resolution, spectral coverage, spectral calibration and Instrument line shape knowledge, and spectral scale standardization)

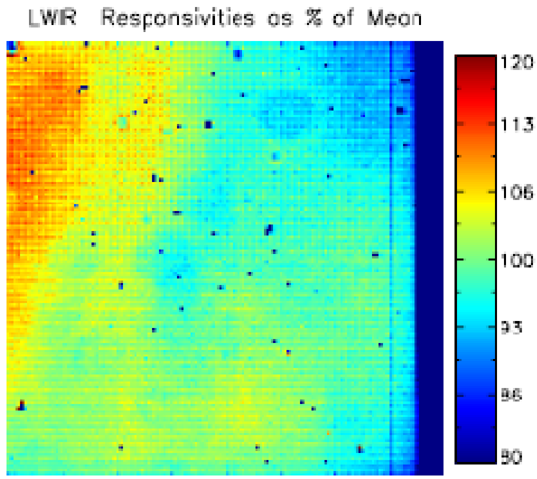
# Cold Test 3, LW Random (spectrally uncorrelated) Noise

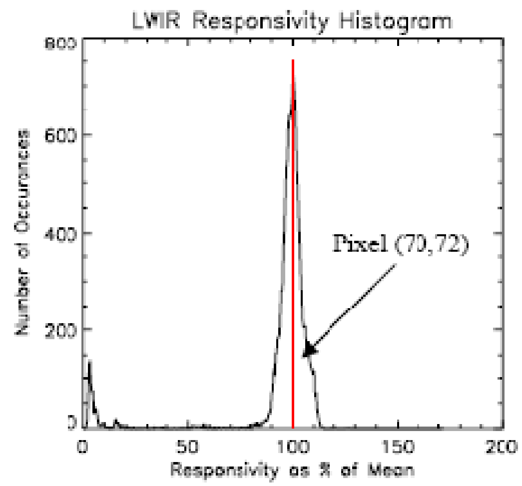



Meets goal for total NESR at all but the longest wavelength end of the band

- Count Noise computed from STDDEV of real part of complex spectra in out-of-band region (4000-4500 $cm^{-1}$) (~279 counts) and then divided by the magnitude responsivity to get random (spectrally uncorrelated) NESR:

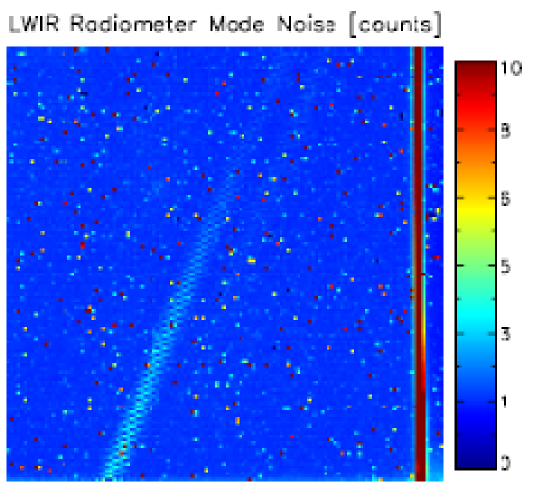
# LWIR Cold Test 3 Active Pixel Inventory
# Radiometer Mode

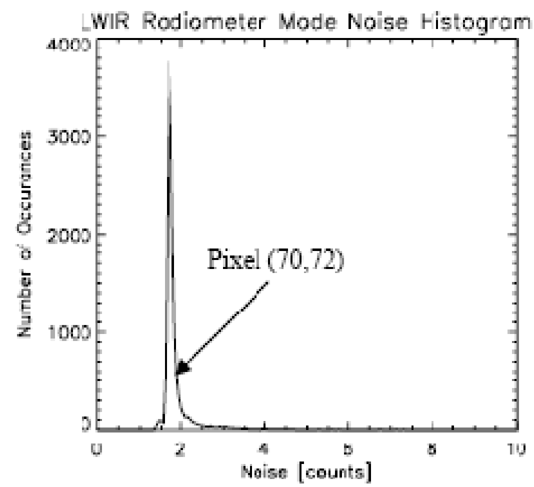



**LWIR FPA Statistics**

| | |
|---|---|
| Vignetted pixels excluded from statistics | 768 |
| Pixels with responsivity in range 80%-120% of mean | 98.2% |
| Pixels with noise less than 3X mean noise | 96.3% |
| Active pixels (those that meet both responsivity & noise criteria) | 95.9% |



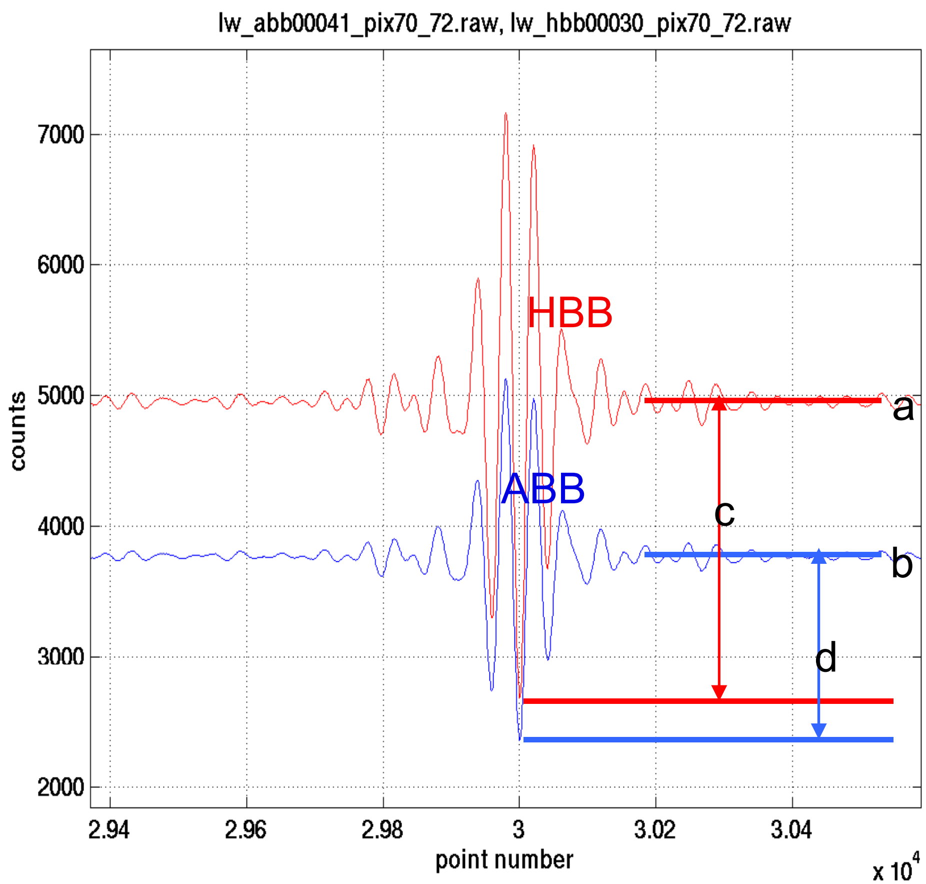



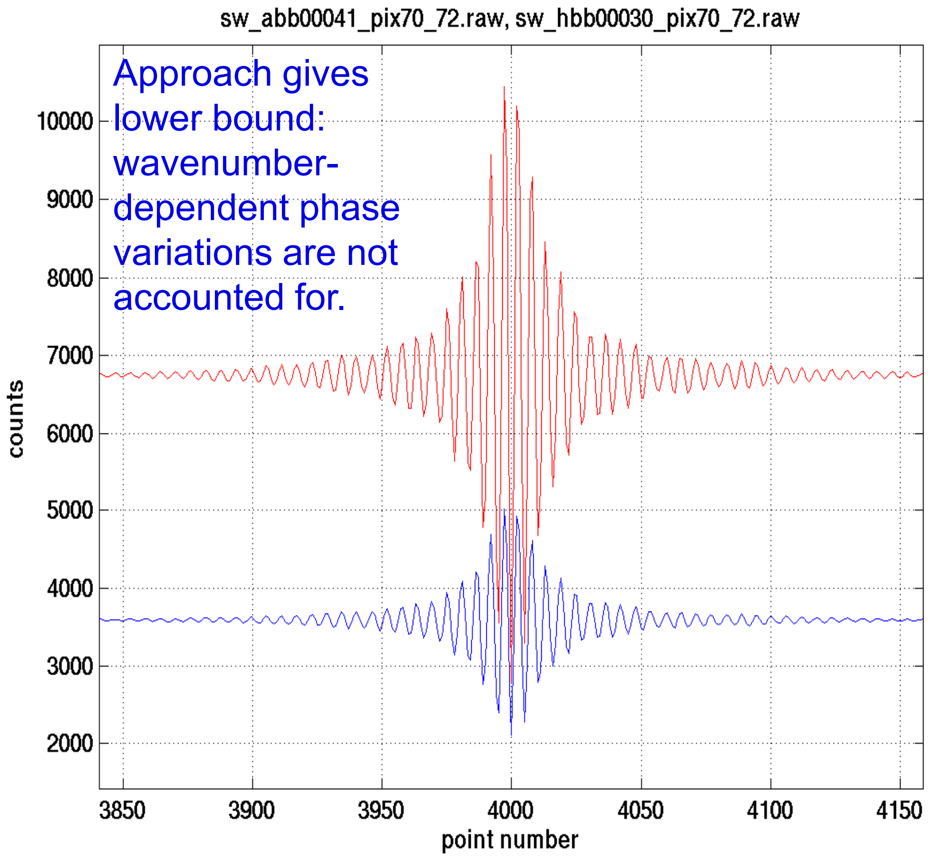

Pixel (70,72) shown on later slides for responsivity and NESR

**Very Good (96%) Operability**

# Cold Test 3, Interferometer Modulation Efficiency

- Modulation Efficiency = (c-d)/(a-b) = 72.6% LW, 78.9% SW

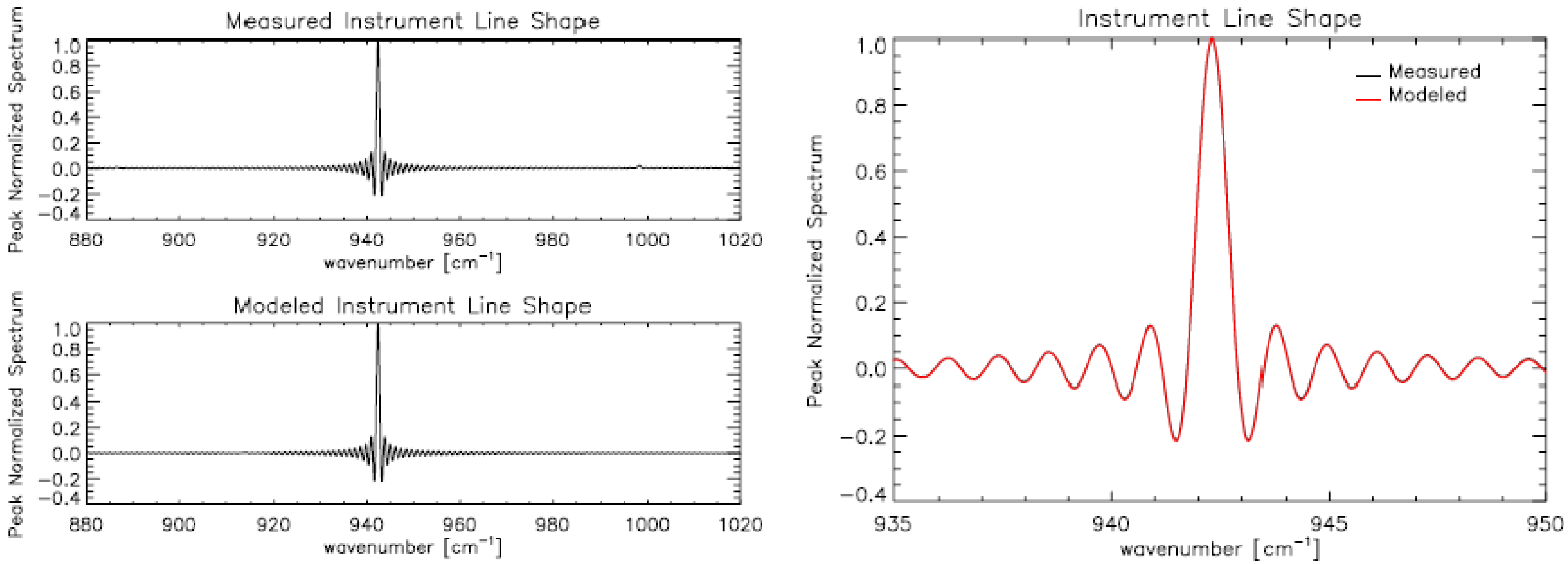



**Demonstrates proper functioning of interferometer**

# GIFTS EDU Measured Instrument Line Shapes are Essentially an Ideal Sinc Function

## $CO_2$ Laser Input Line Source

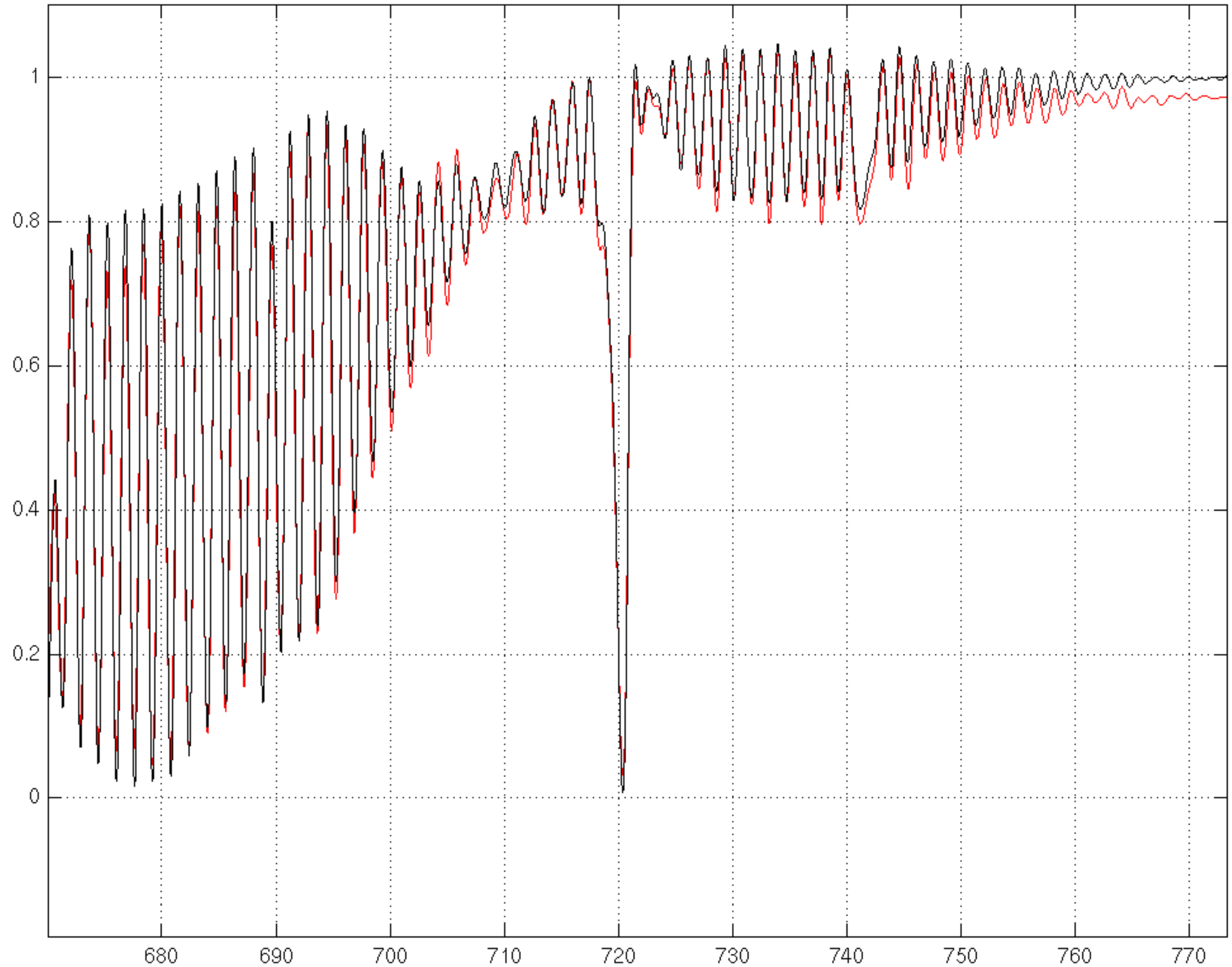



Spectral file lwp_ILS00010_00.h5
Factor of 32 interpolation

**Excellent Line Shape Confirmation**

# Gas Cell: $CO_2$ Transmission

## (Preliminary comparison of GIFTS and Model)

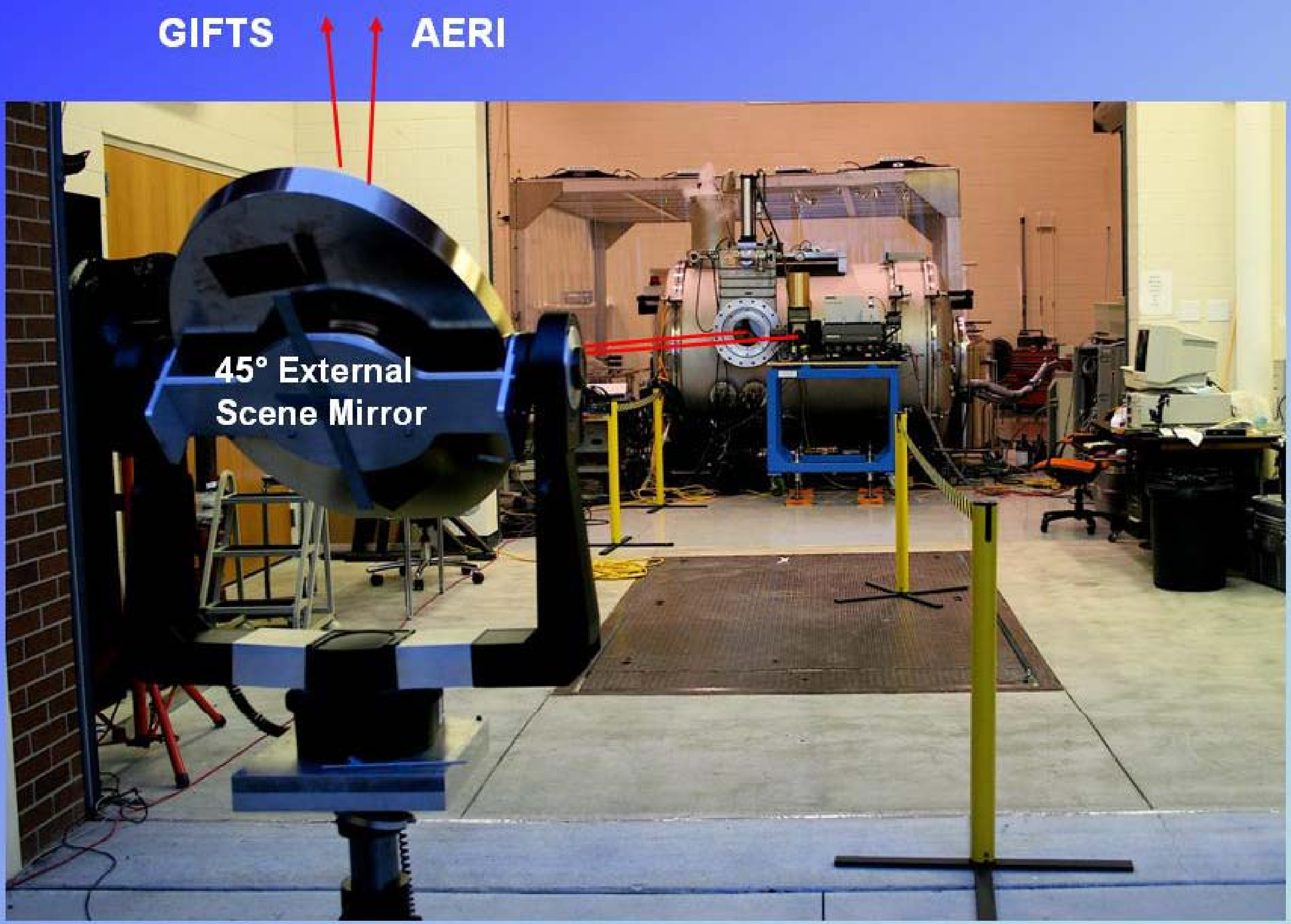



GIFTS = Red

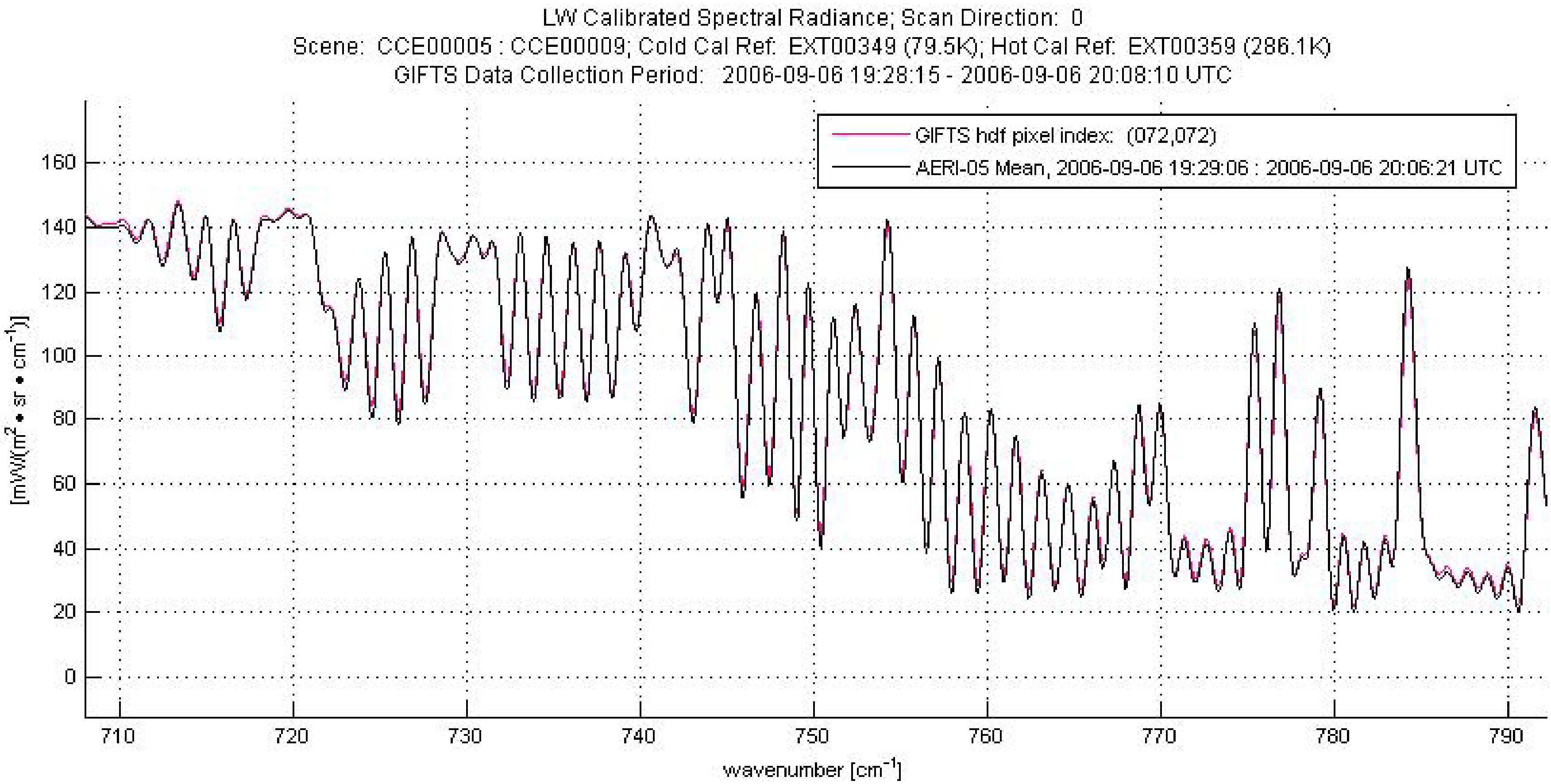
Modeled = Black

**Very good agreement**

# GIFTS and AERI Viewing Sky

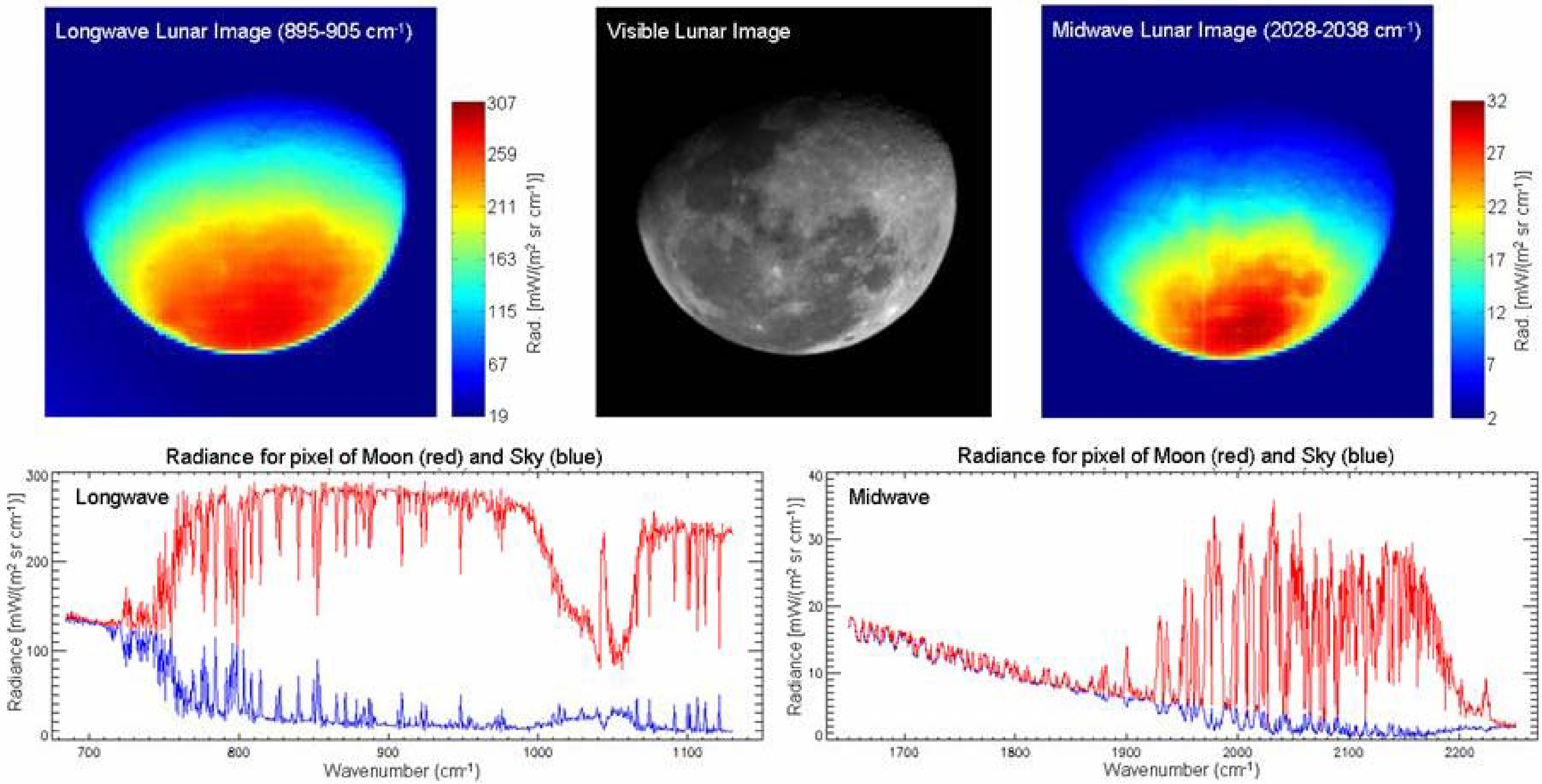


# LW, GIFTS-AERI05, pixel 72,72




**708-792 $cm^{-1}$, 15 micron $CO_2$ band**

# Lunar Views Demonstrate GIFTS Imaging Capability




Results from a single interferometer scan of the moon, viewed in the visible, mid-wave IR, and long-wave IR. Also the spectral intensities of two selected pixels from the IR images, one viewing the moon, the other the clear sky background.

Space Dynamics LABORATORY
Utah State University Research Foundation

# Summary

- The advanced GEO sounder concept represents a dramatic new capability to provide longer lead times for severe weather
- Implementation is proceeding in Europe and Asia (and International agreements call for sounders on all GEOs)
- US has proven technological capability
- US plans need a fresh look – The advanced sounder fits with the Congressional view of NASA & NOAA Roles (NASA Auth. Act, 2008)
- GEO Research Platform Strongly Recommended for Sounder Demonstration & other pioneering Decadal Survey missions—NASA/NOAA Partnership