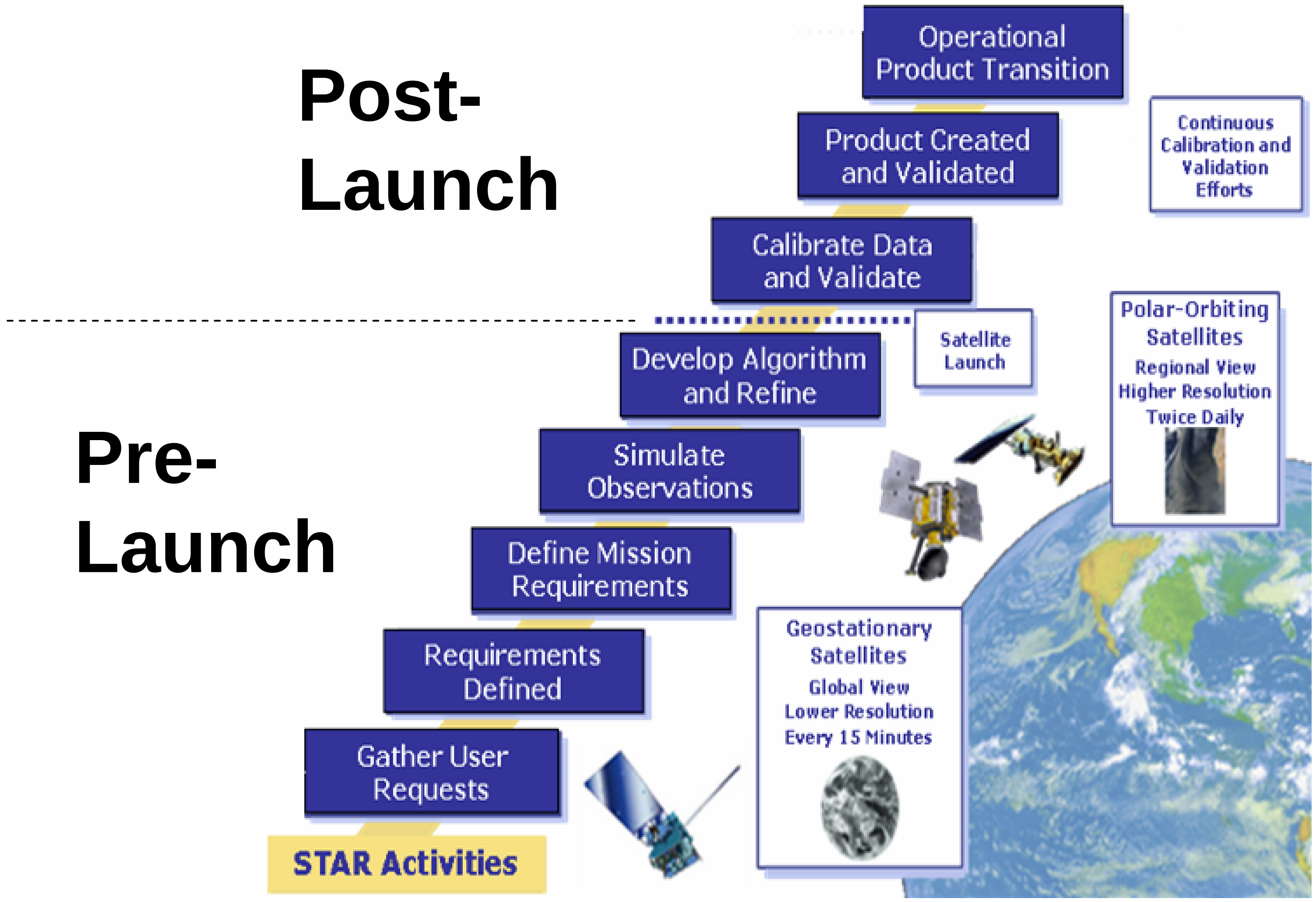
Operational Satellite Program Overview

Mitch Goldberg, Chief

Satellite Meteorology and Climatology Division

NESDIS/Center for Satellite Applications and Research (STAR)

Research Support for Satellite Earth Observations

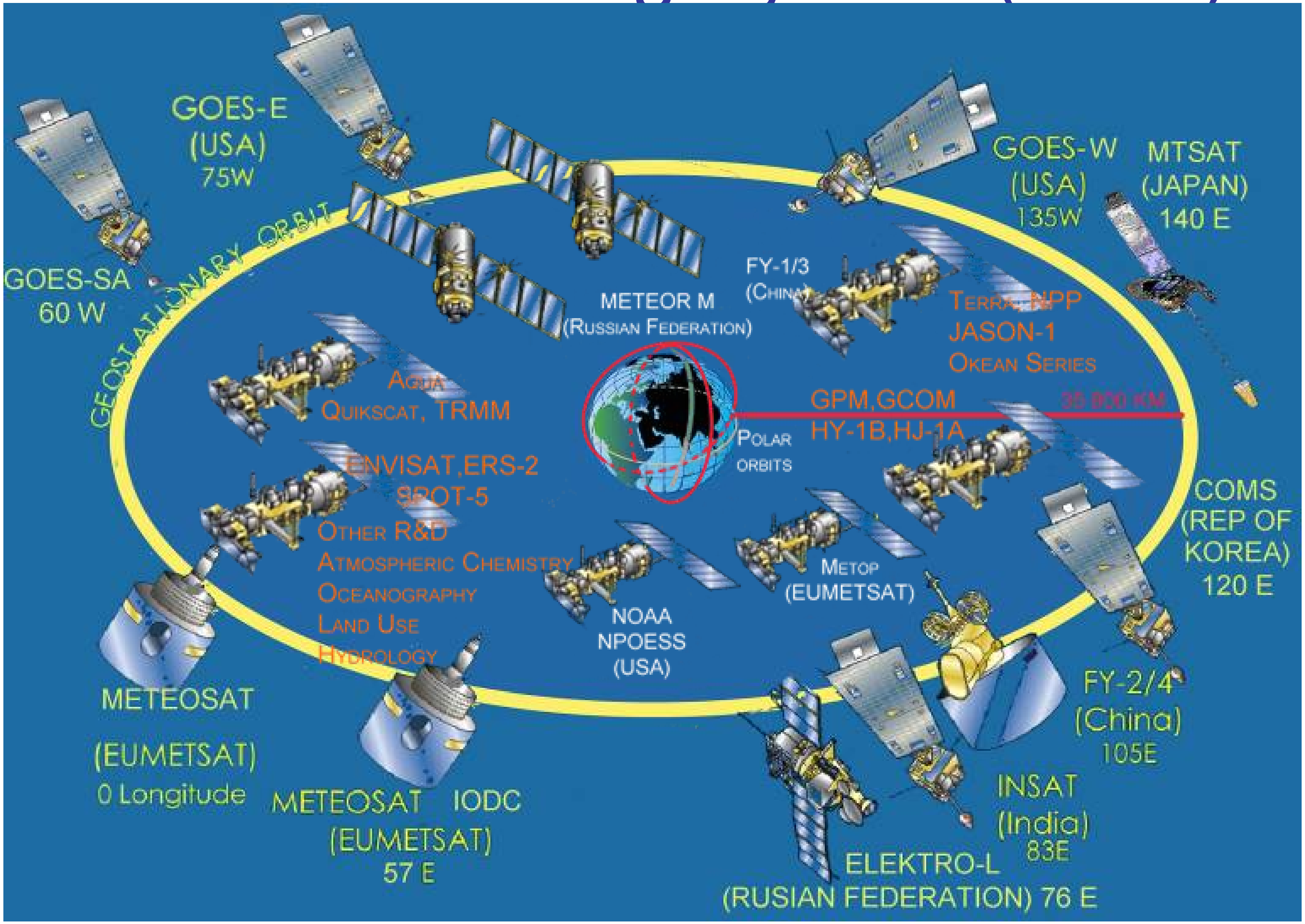


STAR always looks for improvements in our process

Satellite Program

- Provides continuity of essential observations (variables)
- Research missions provide new technological capabilities for observing essential variables with better performance
- Operational missions provide continuity of essential variables based on proven technology

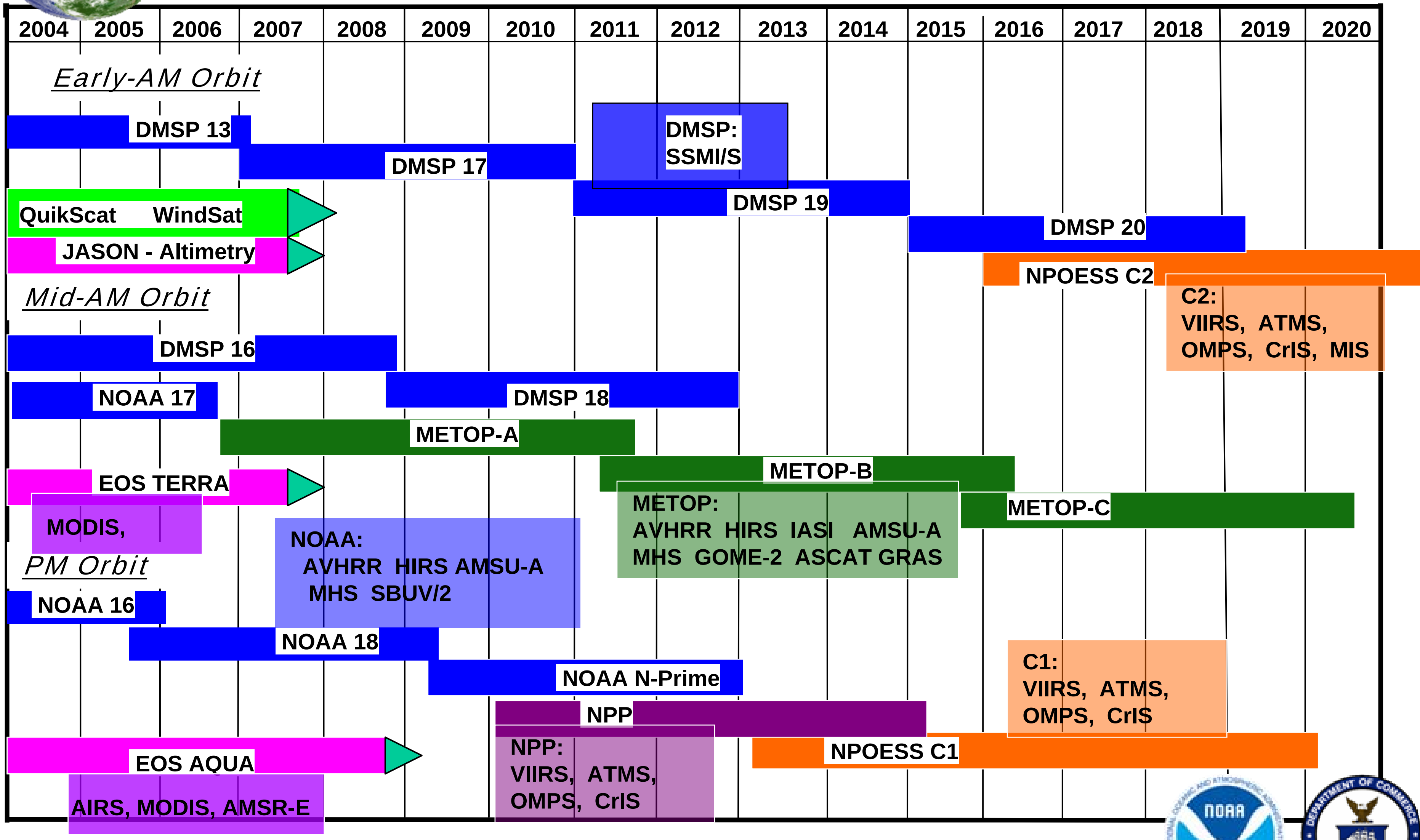
Space-Based component of the Global Observing System (GOS)



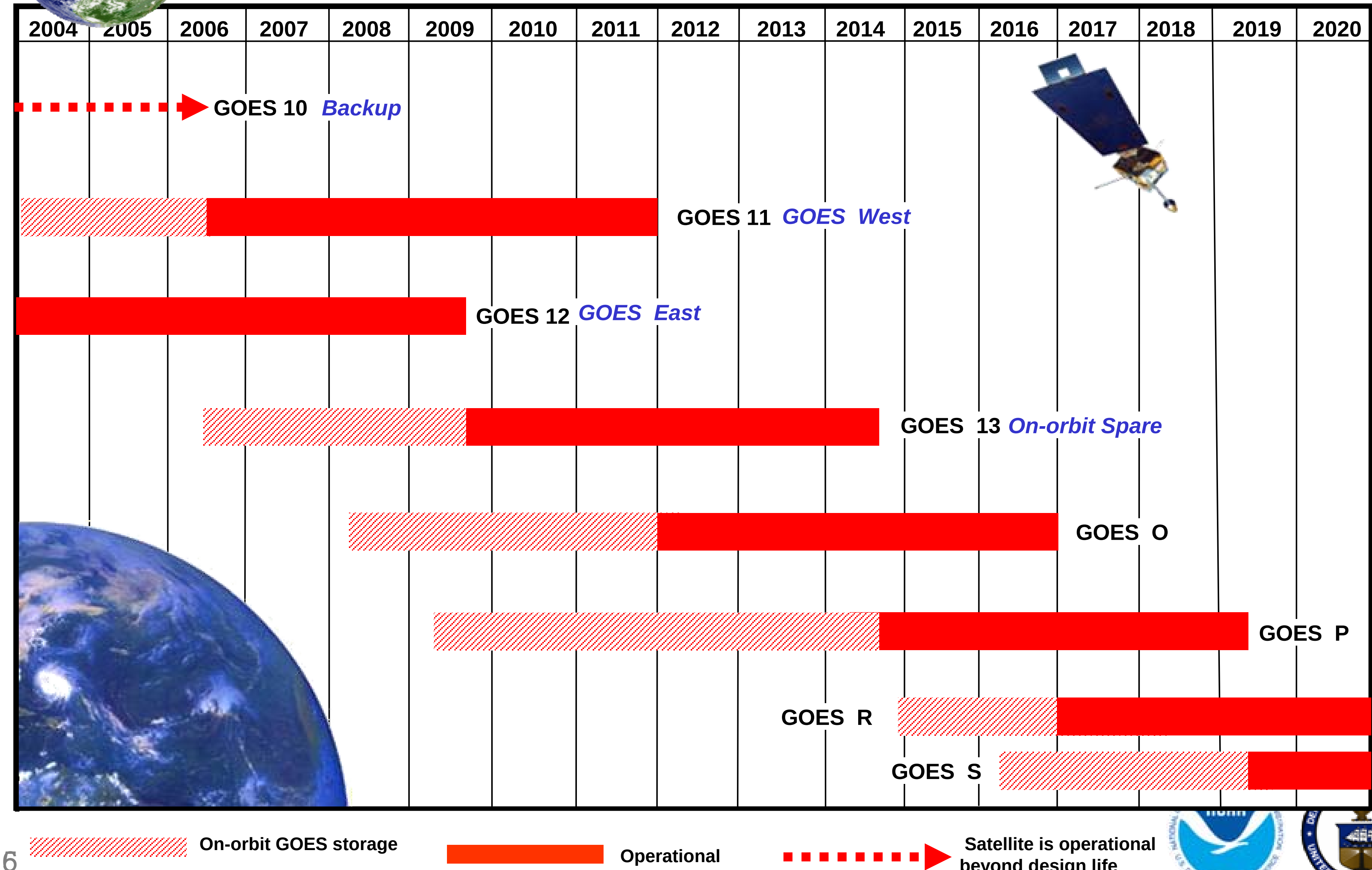
Topics

- Satellite fly-out charts
  - Polar orbiting satellites
  - Geostationary
- Map key variables to sensors
- Highlight near term opportunities
- GOES-R
- Summarize

Planned Missions - Polar



NOAA Planned Missions - Geostationary



Mapping Variables to Sensors - Atmosphere

Temperature	HIRS/AMSU A&B >> **AIRS**/AMSU/HSB >> **IASI**/AMSU/MHS >> **CriS/ATMS** SSMT/2 >> **SSMIS,** **COSMIC** **GRAS** **Advanced GEO Sounder**
Moisture	HIRS/AMSU A&B >> **AIRS**/AMSU/HSB >> **IASI**/AMSU/MHS >> **CriS**/ATMS SSMT/2 >> **SSMIS** **Advanced GEO Sounder**
Ozone	SBUV/2 >> OMI>> **GOME-2** >> **OMPS** **AIRS** >> **IASI** >> **CrIS**
Aerosols	AVHRR >> **MODIS** >> **Calypso (Lidar)** >> **GOME-2**>>**VIIRS** >> APS??
Clouds	AVHRR >> MODIS >> VIIRS AIRS >> IASI >> CrIS GOES-R ABI **CloudSat (Radar)**
Precipitation	SSMI >> **SSMIS** >> AMSR > MIS TRMM >> GPM
Wind Speed	GEO AMV, MODIS Polar Winds >> ADM??? GOES-R ABI, GEO Adv. Sounder
Trace Gases	**AIRS, IASI, GOME-2, OCO** GEO Adv Sounder

Mapping Variables to Sensors - Land

Sfc emissivity database	**AIRS, IASI**, CrIS **AMSR-E**
Vegetation Greenness Fraction; Leaf Area Index	AVHRR >> MODIS >> VIIRS GOES-R ABI
Snow/Ice	AMSU ,SSMI >> **SSMIS** >> MIS AVHRR, GOES Imager >> VIIRS >> GOES-R ABI
Land Surface Temperature	AVHRR >> MODIS >> VIIRS GOES Imager >> GOES-R ABI **AMSR-E**
Soil Moisture	**AMSR-E, SMOS**

Mapping Variables to Sensors - Ocean

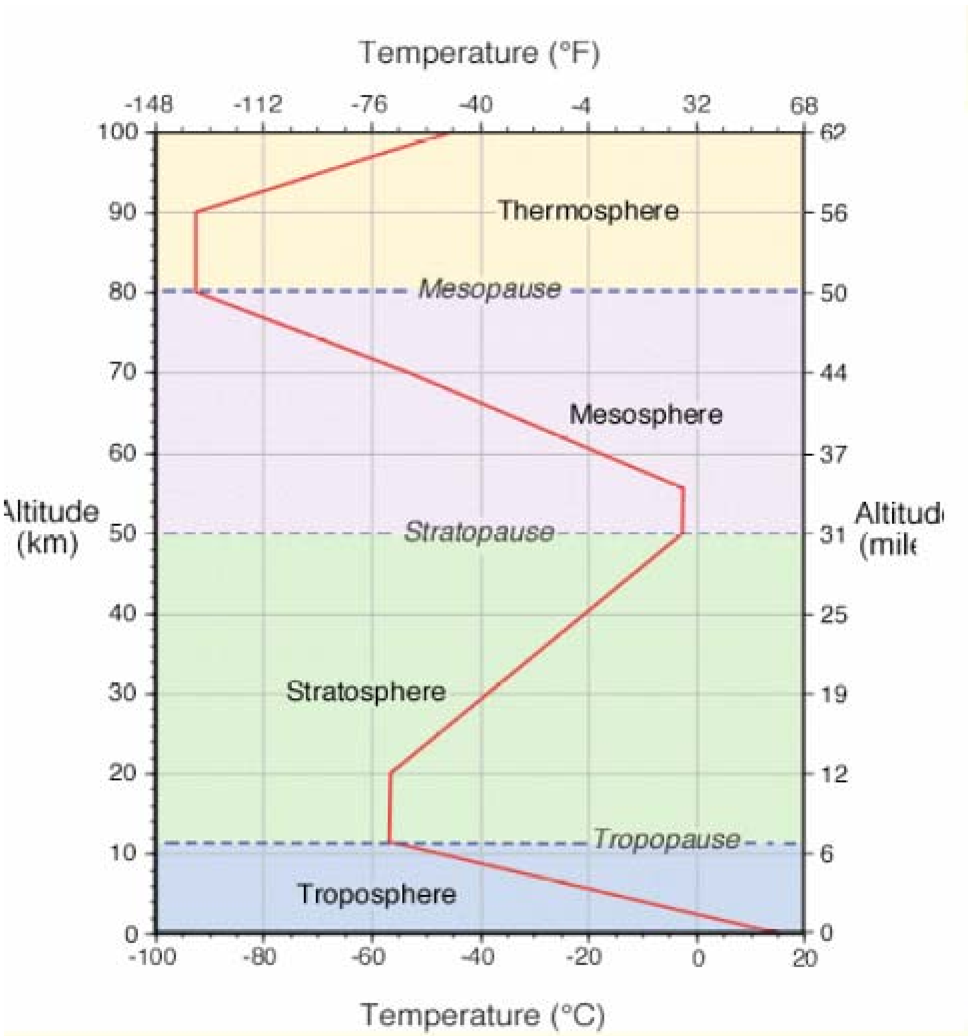
SST	AVHRR >> MODIS >> VIIRS WindSAT >>AMSR-E >> MIS?
SSH	JASON (need continuity mission)
SSW	**Quikscat, Windsat, ASCAT**
Salinity	SMOS (need to evaluate)
Sea Ice	SSMI, WindSAT, SSMIS, AMSR-E,
Ocean Color	SeaWifs >> MODIS >> VIIRS??

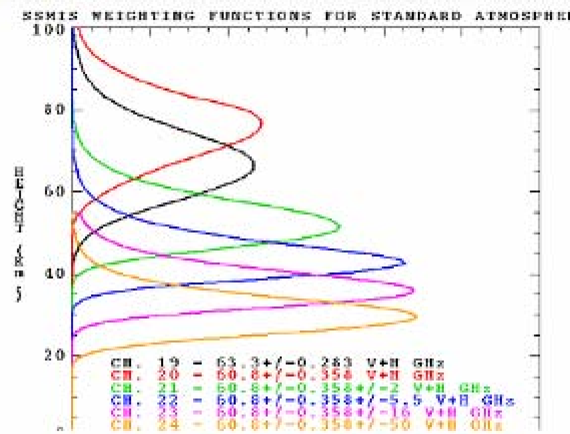
Near Term Opportunities

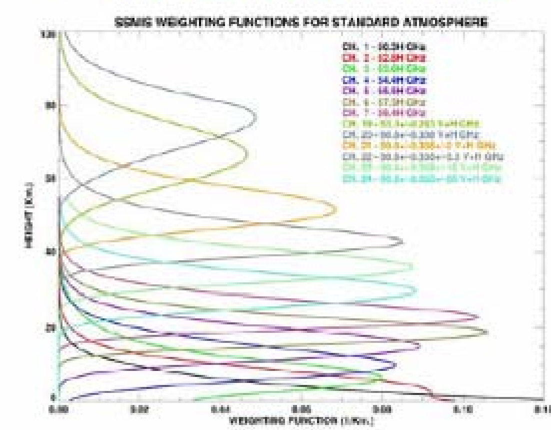
- SSMI/S, AIRS, IASI -- improve the model temperature analysis in the upper atmosphere
- SSMI/S -- Improving hurricane forecasts
- IASI – improve temperature and moisture soundings
- GOME-2 - air quality measurements
- ASCAT - ocean surface winds & more
- GRAS - radio occultation

SSMI/S extends profiling capability well into mesosphere.

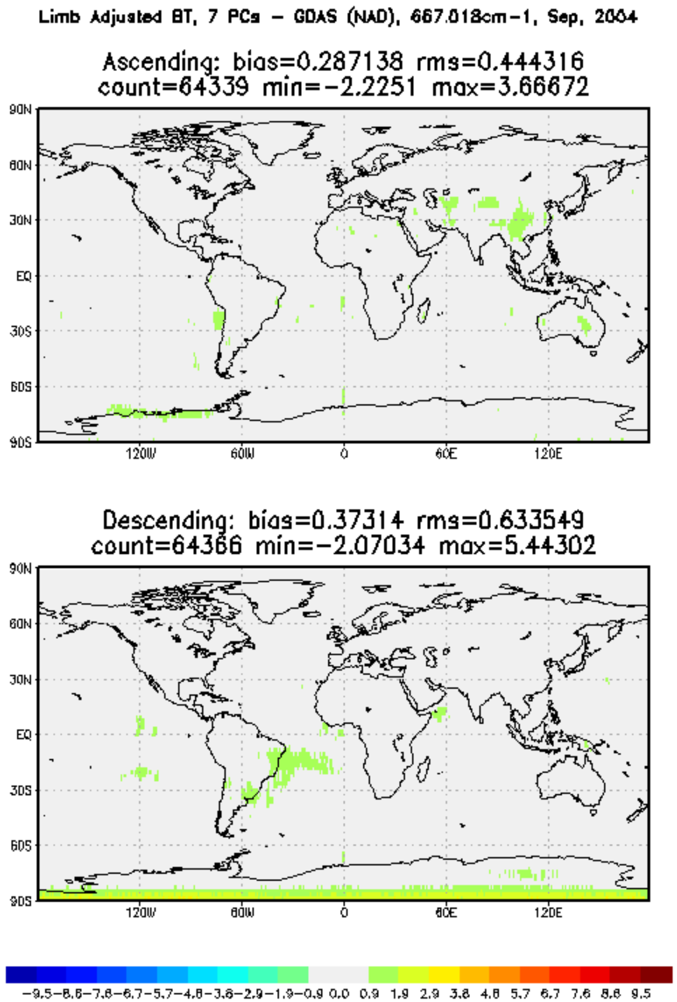
Opportunity to address model bias in upper stratosphere



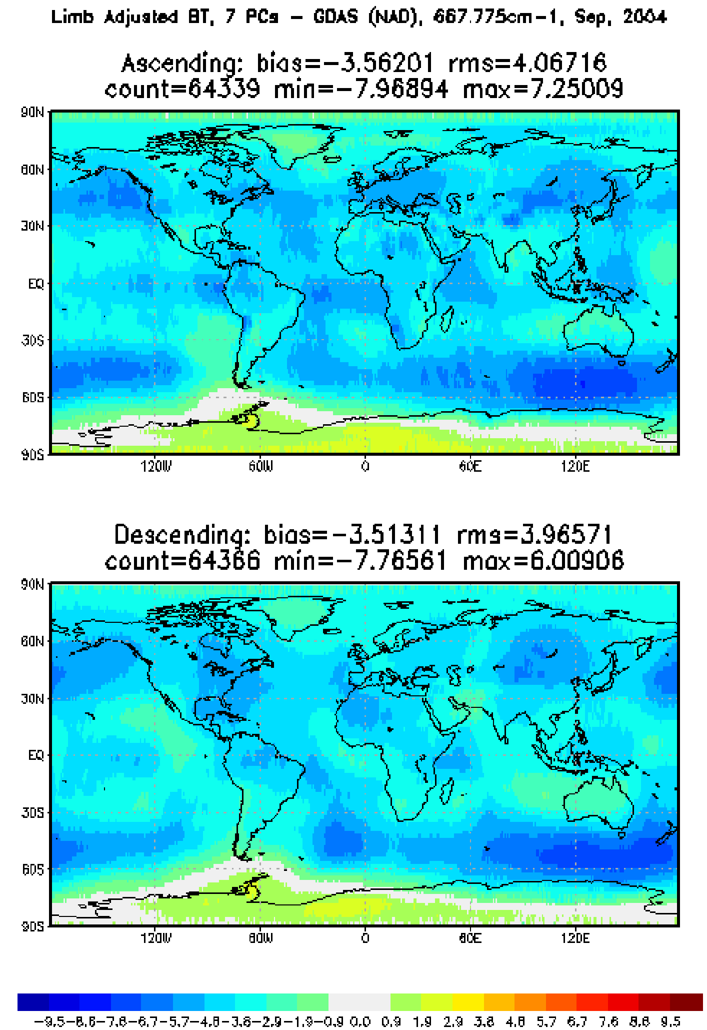




Calculated AIRS minus Observed AIRS show large model bias in upper stratosphere



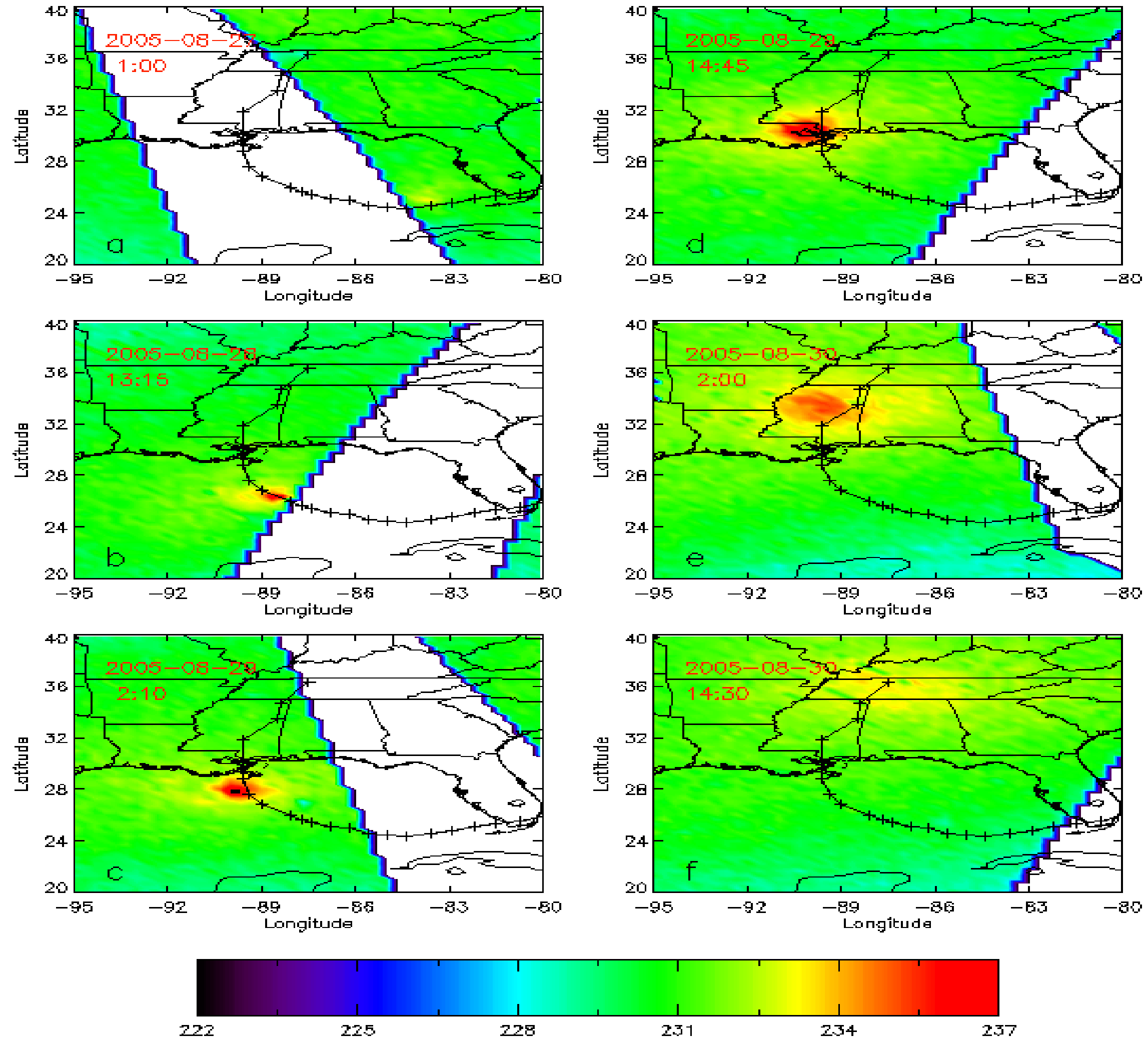
25 mb



Large Bias in Model Fields @ 1mb
when compared to AIRS

Hurricane Katrina from SSMIS Sounding Channel (54 GHz)

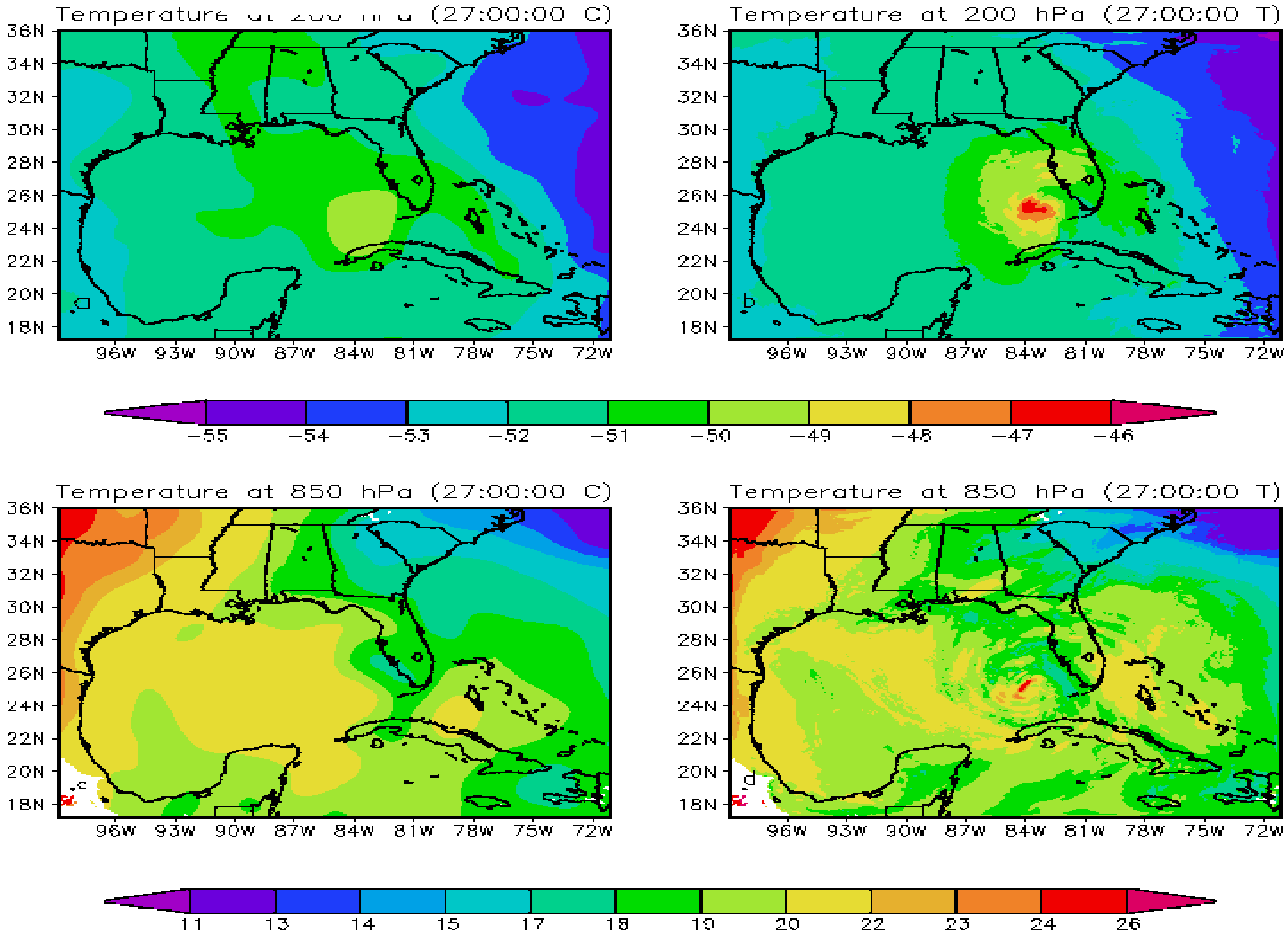
- **The Defense Meteorological Satellite Program (DMSP) successfully launched the first of five Special Sensor Microwave Imager/Sounder (SSMIS) on 18 October 2003.**
- **The SSMIS measures partially polarized radiances in 24 channels covering a wide range of frequencies (19 – 183 GHz)**
  - **conical scan geometry at an earth incidence angle of 53 degrees**
  - **maintains uniform spatial resolution, polarization purity and common fields of view for all channels across the entire swath of 1700 km.**



Liu and Weng, GRL, 2006

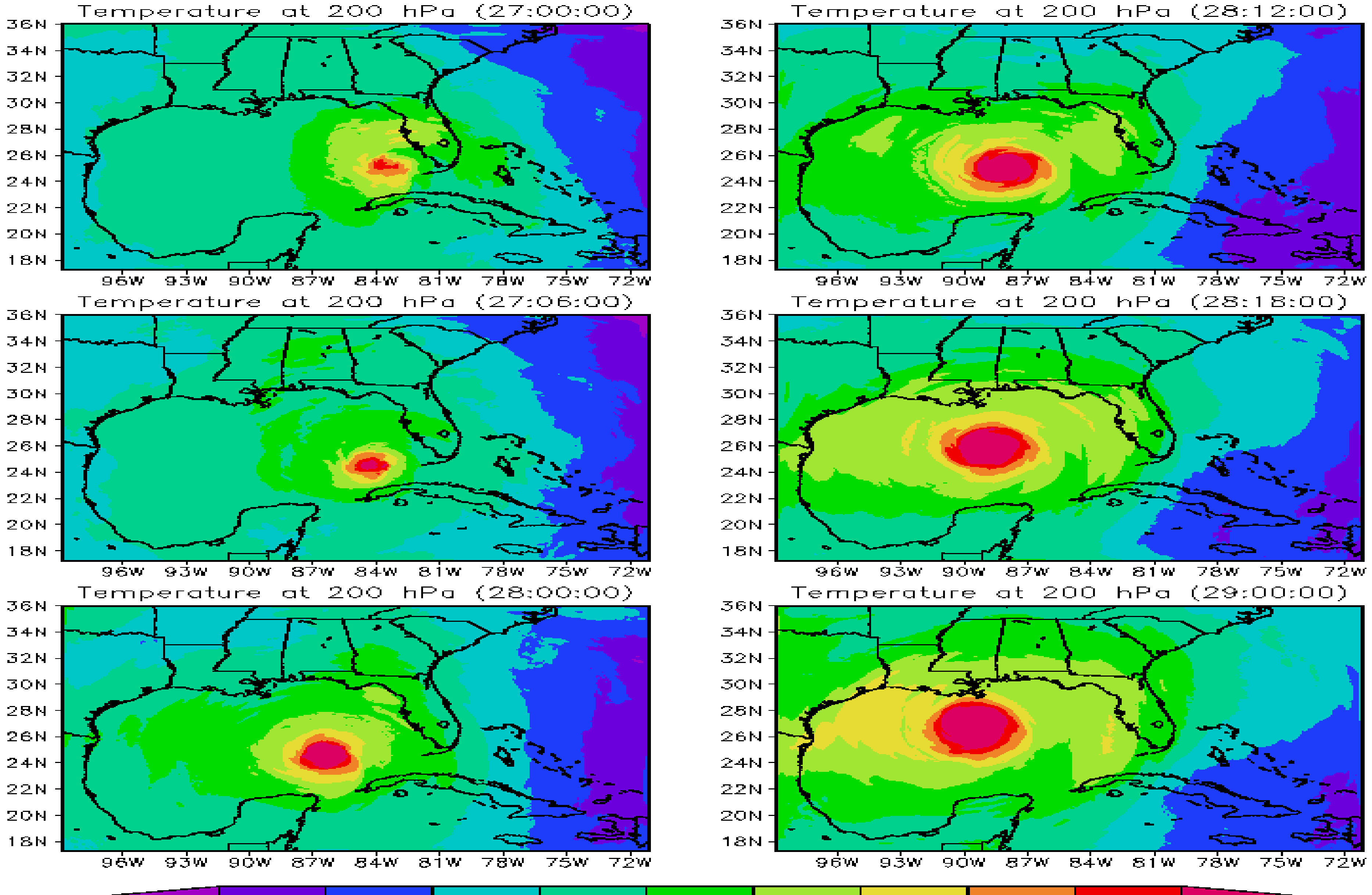
Impacts of SSMIS LAS on Hurricane Temperature Analysis

Control **Test**

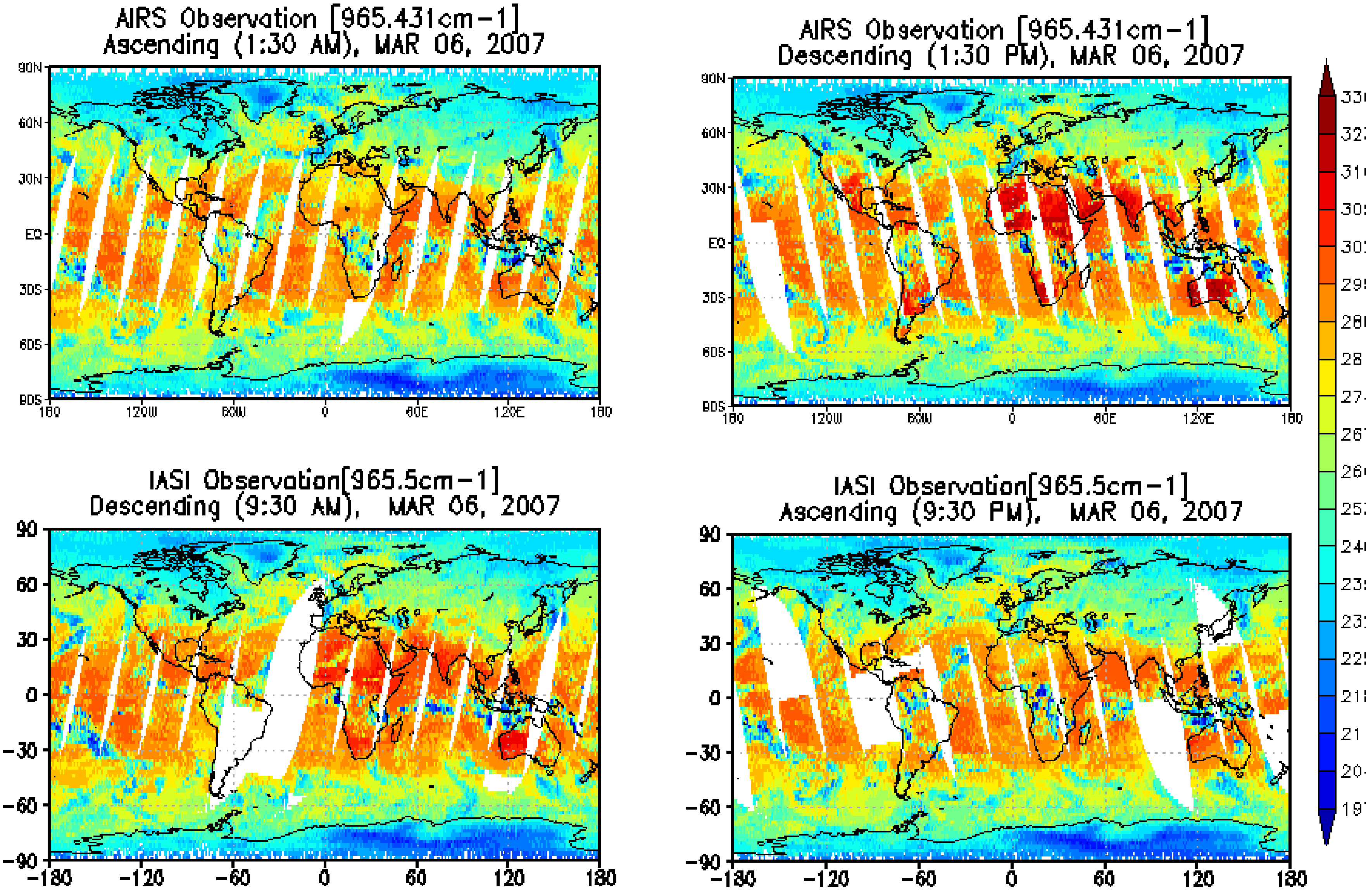


Liu and Weng, GRL, 2007

Katrina Warm Core Evolution

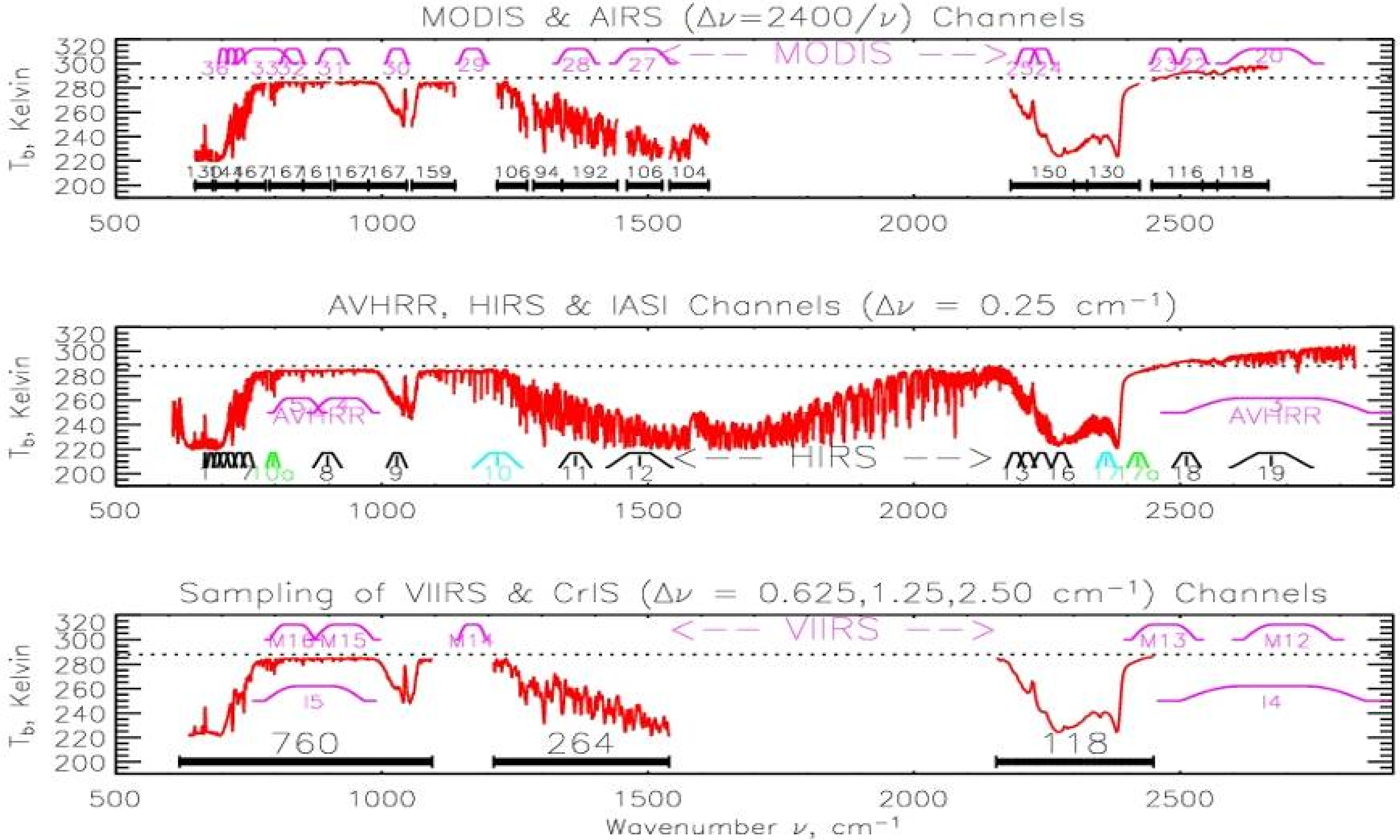


NESDIS is now receiving IASI data in real time

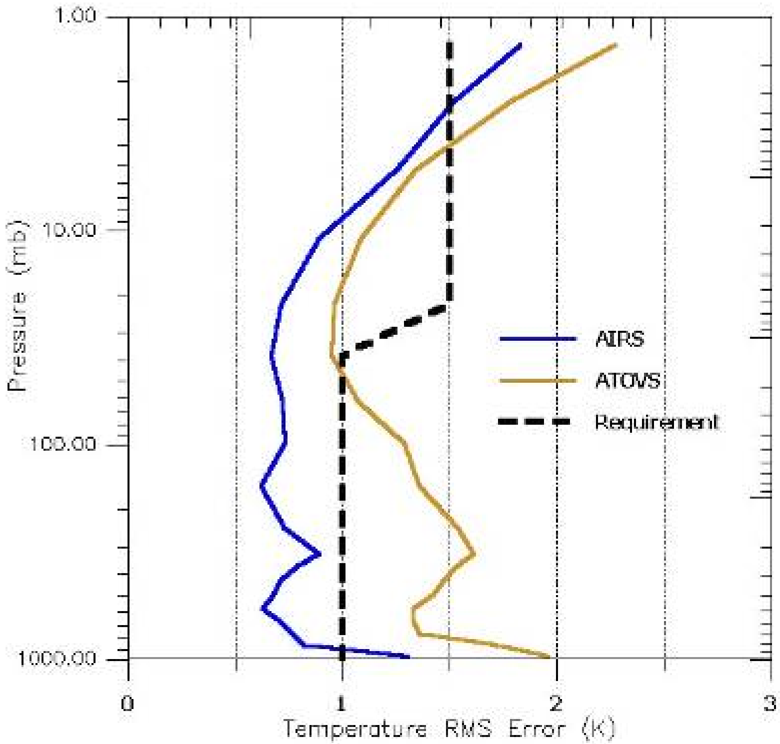


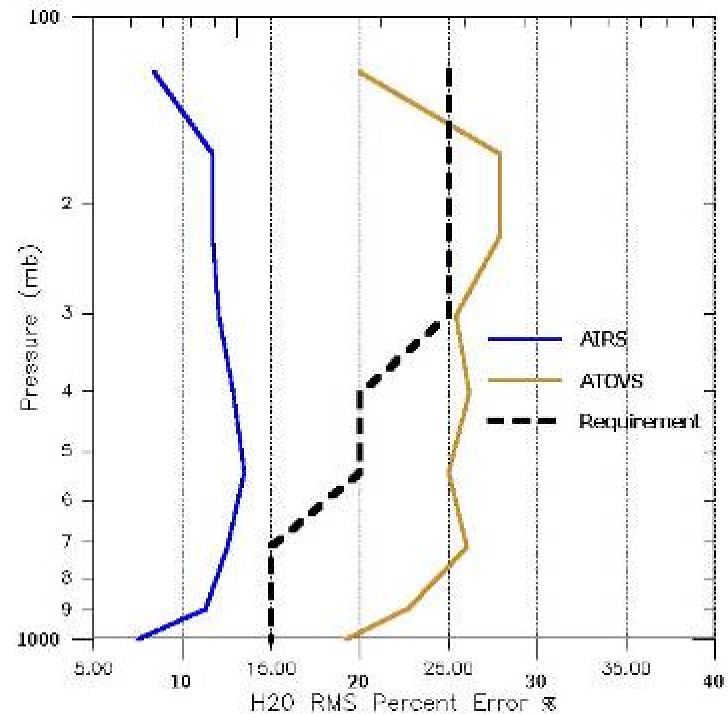
Comparison of AIRS and IASI (IASI instrument developed by CNES)

Spectral Coverage of AIRS, IASI, and CrIS



AIRS is providing significant improvements in temperature and moisture soundings over ATOVS in partially cloudy environments





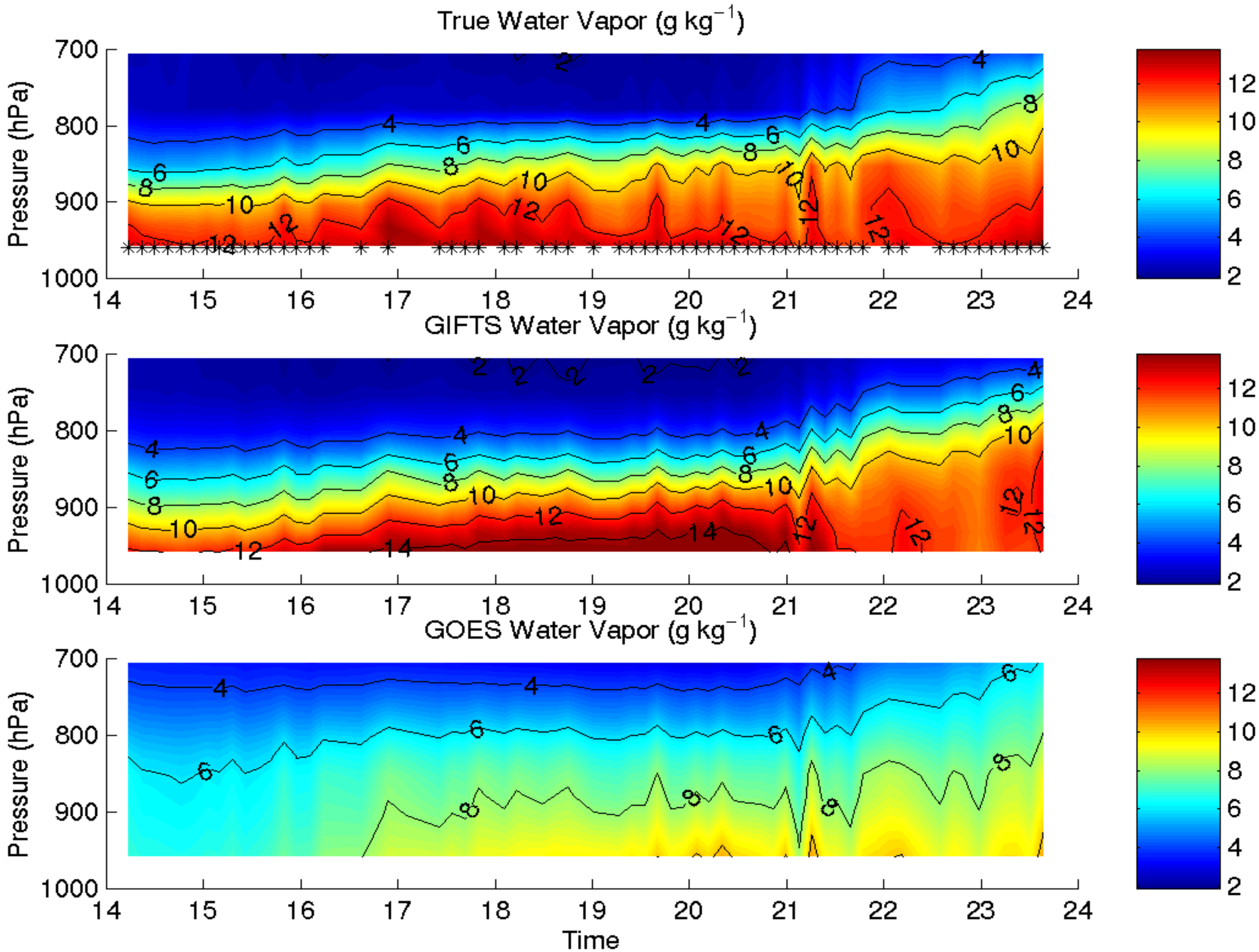
Time series of low-level vertical moisture structure during 9 hours prior to Oklahoma/Kansas tornadoes on 3 May 1999

Truth>

GIFTS>

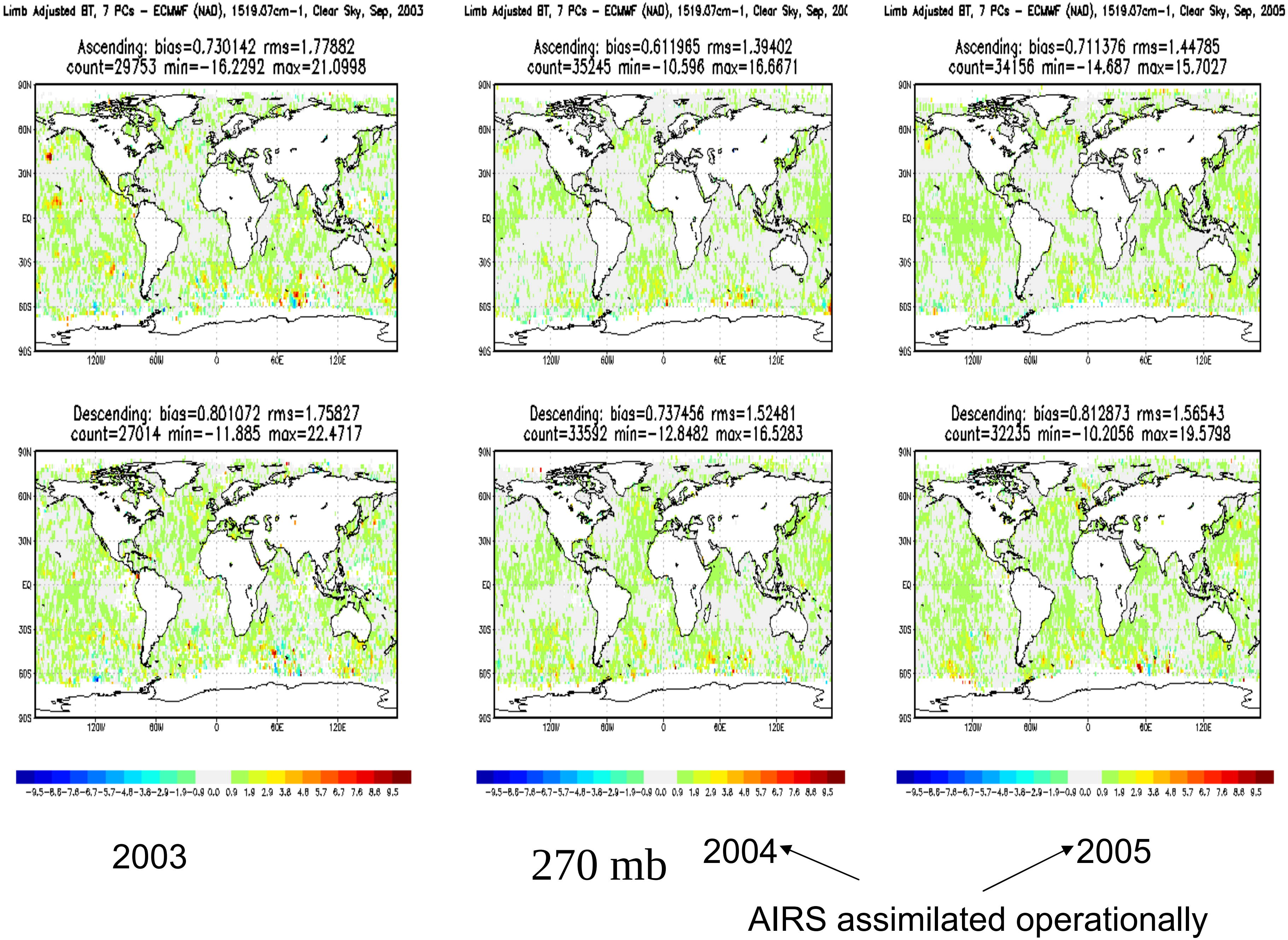
Note GIFTS retains strong vertical gradients needed to detect changes in convective instability

Current GOES>

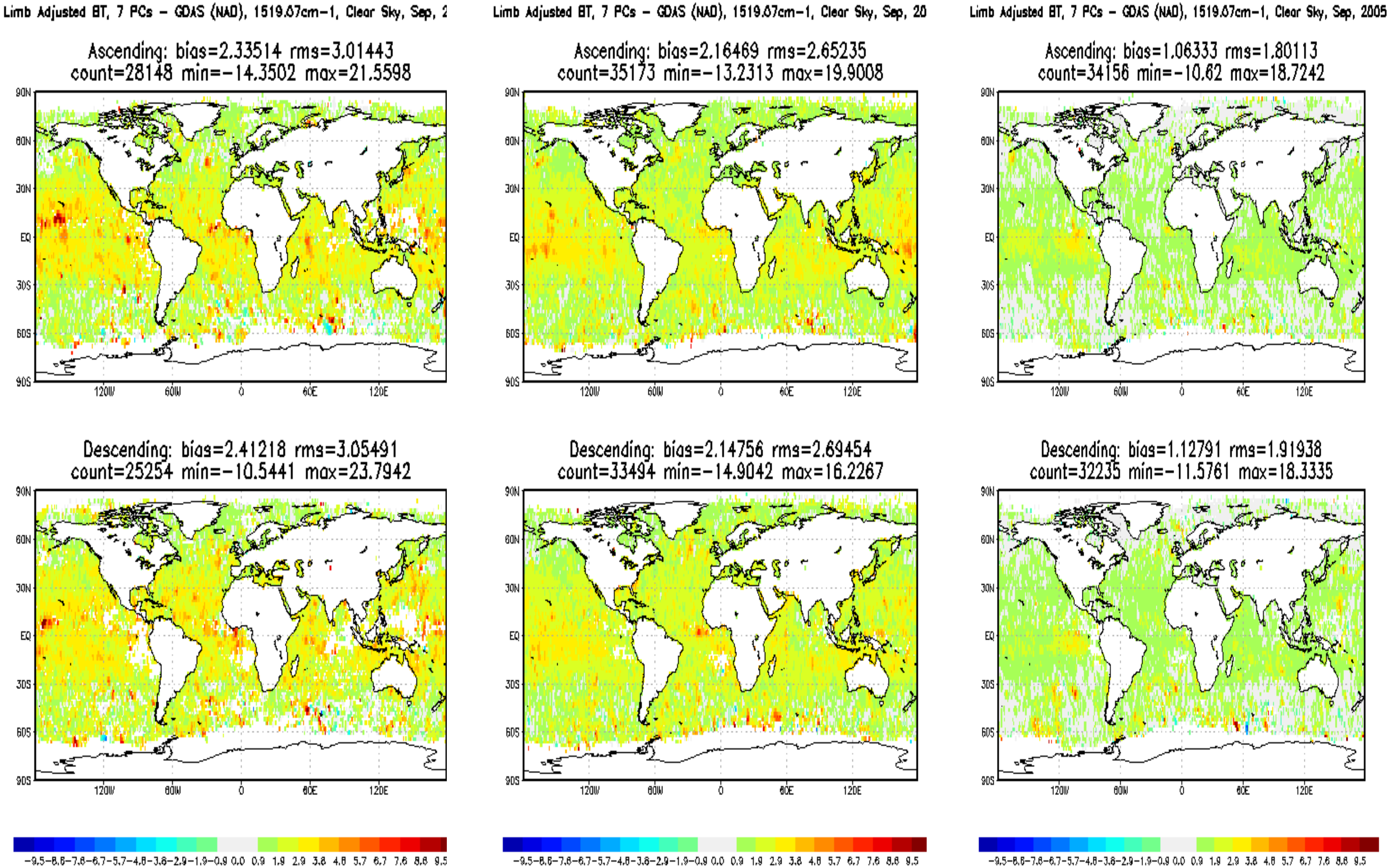


GIFTS traces moisture peaks and gradients with greatly reduced errors

Observed AIRS minus ECMWF Simulated AIRS for Upper Trop. Water Vapor



Observed AIRS minus NCEP Simulated AIRS for Upper Trop. Water Vapor



2003

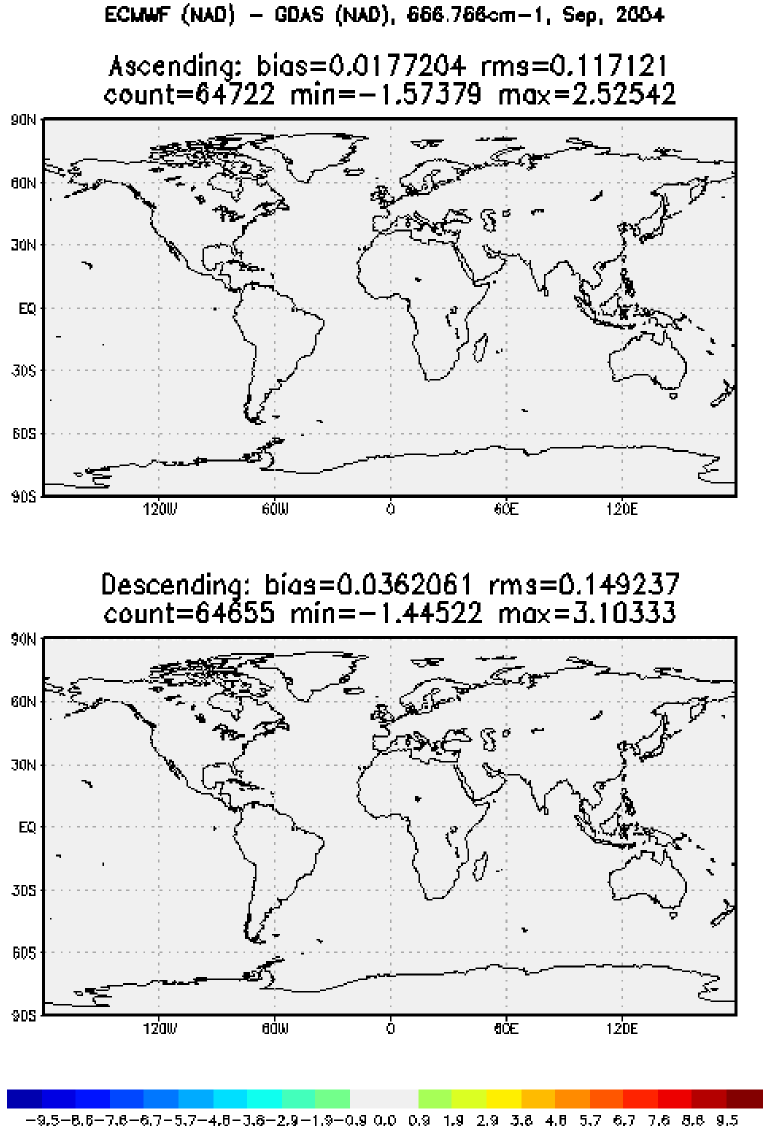
2004

270 mb

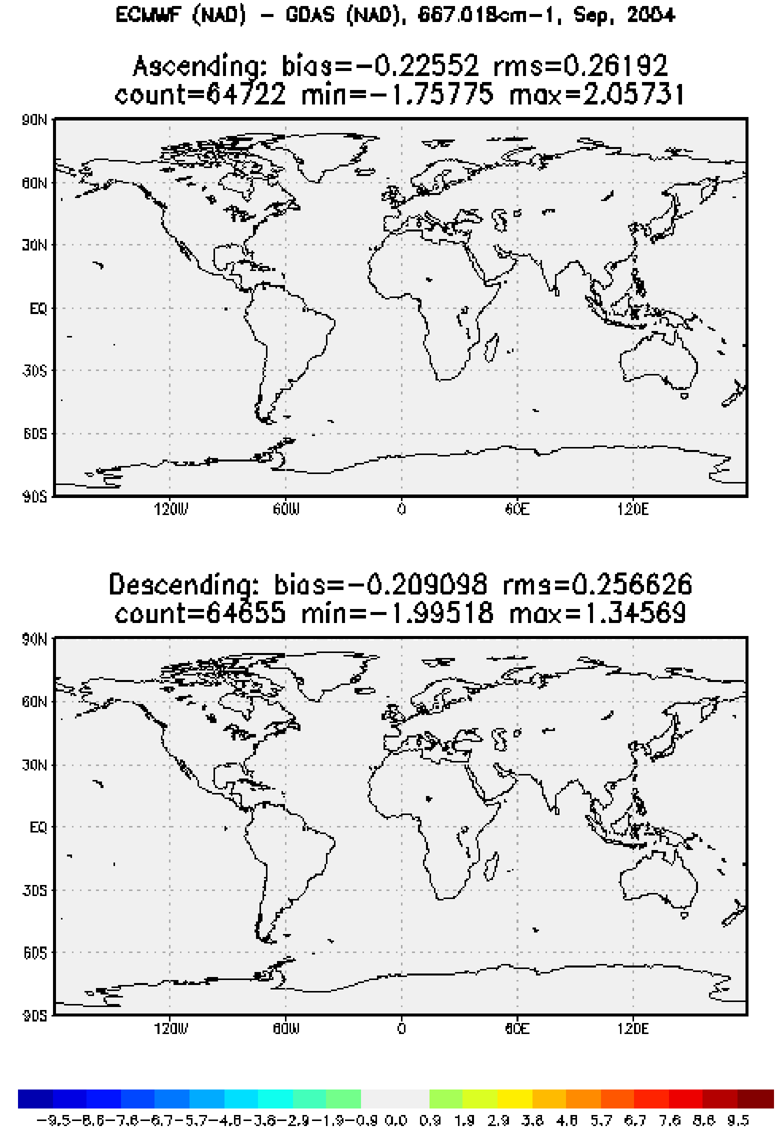
2005

AIRS assimilated operationally

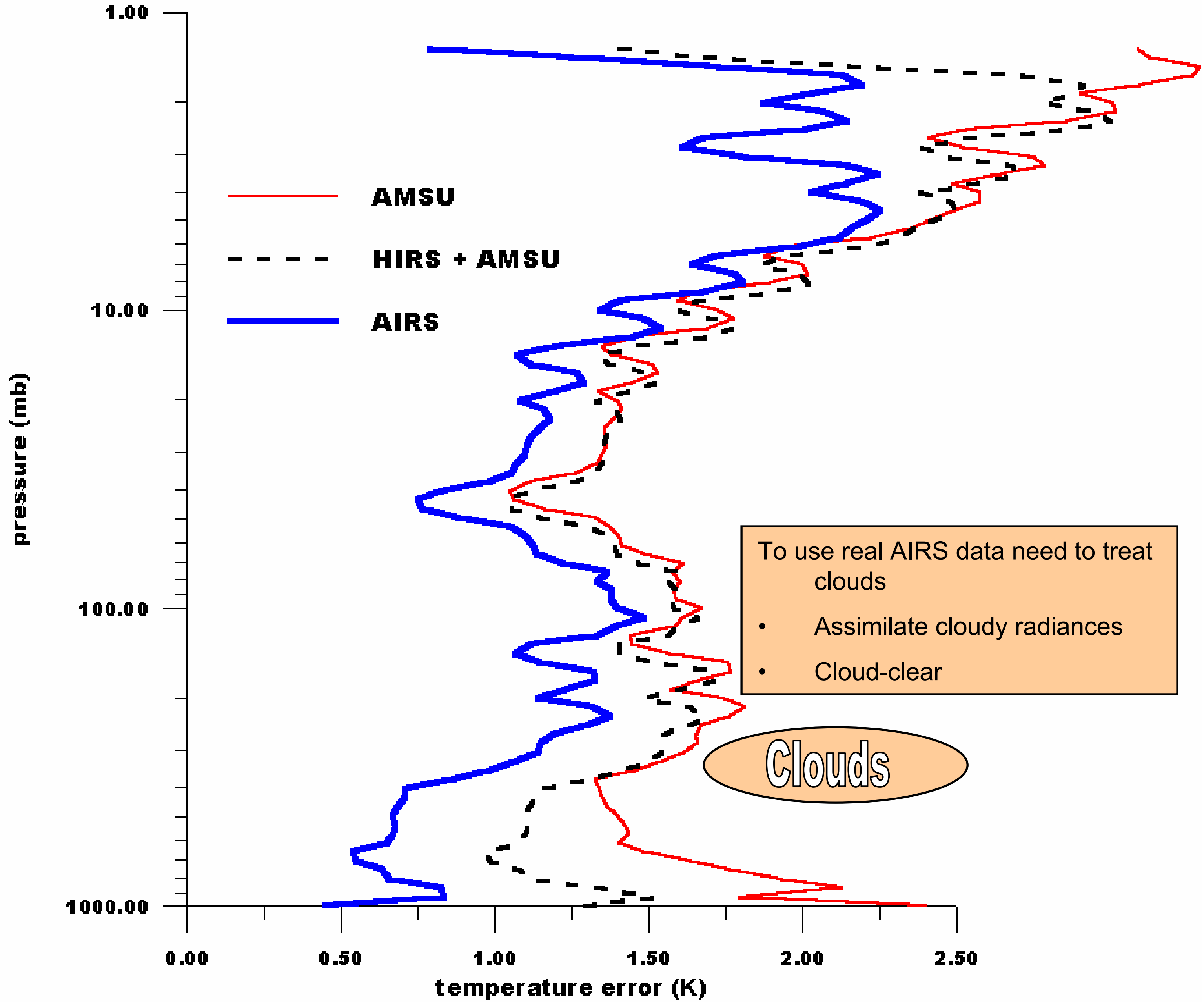
ECMWF and NCEP are nearly identical for temperature



35 mb



26 mb



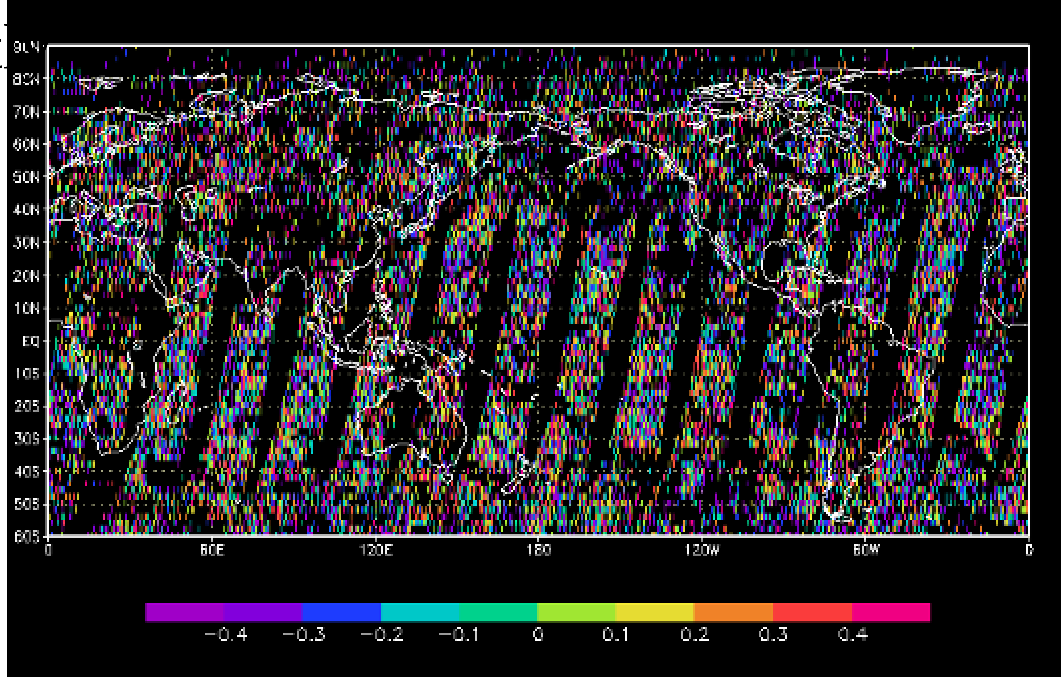
1.00
10.00
100.00
1000.00
pressure (mb)
AMSU
HIRS + AMSU
AIRS
0.00
0.50
1.00
1.50
2.00
2.50
temperature error (K)
To use real AIRS data need to treat clouds
• Assimilate cloudy radiances
• Cloud-clear
Clouds

Cloud clearing significantl improves data coverage

735.69 cm-1 (peak ~ 700 mb)

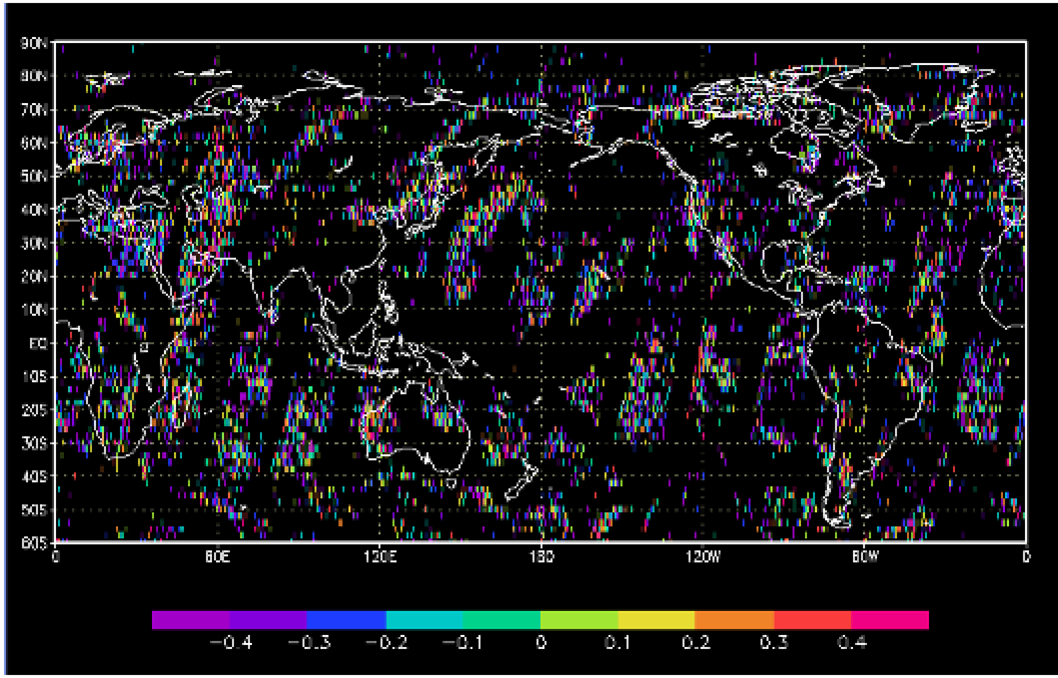
ALL diff < +- 0.5 K

Cloud-cleared minus clear simulated brightness temperatures



700 MB – Lower to Mid Troposphere

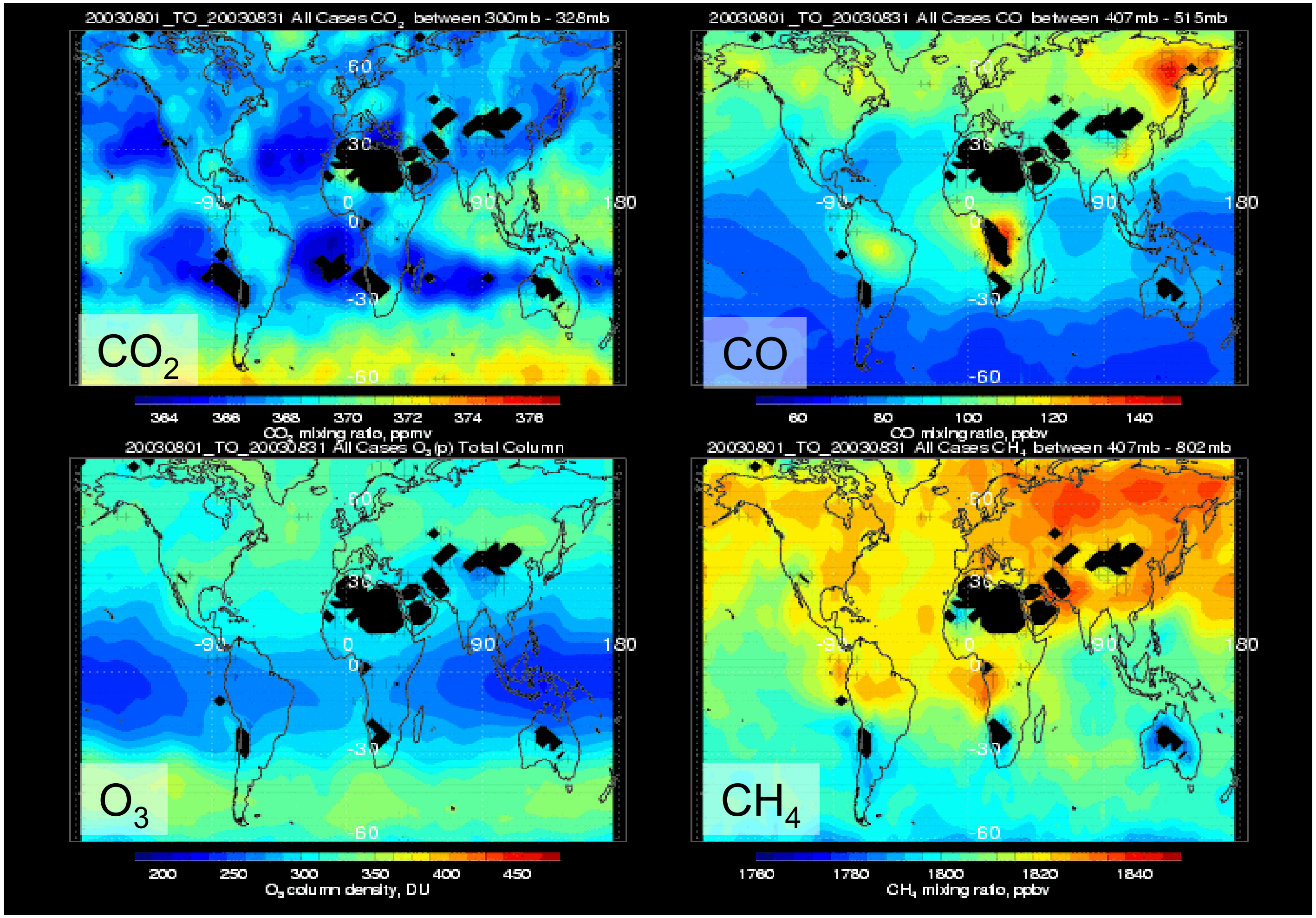
Observed minus clear simulated brightness temperatures



Trace Gas Product Potential from Operational Thermal Sounders

gas	Range (cm^{-1})	Precision (Goal)	Interference	
O_3	1025-1050	10%	H2O,emissivity	Working
CO	2080-2200	15%	H2O,N2O	
CH_4	1250-1370	20 ppb	H2O,HNO3	
CO_2	680-795 2375-2395	2 ppm 2 ppm	H2O,O3	
SO_2	1340-1380	500%	H2O,HNO3	In Work
HNO_3	860-920 1320-1330	40% 25%	emissivity H2O,CH4	
N_2O	1250-1315 2180-2250	10% 10%	H2O H2O,CO	
$CFCl_3$ (F11)	830-860	20%	emissivity	Held Fixed
CF_2Cl (F12)	900-940	20%	emissivity	
CCl_4	790-805	50%	emissivity	

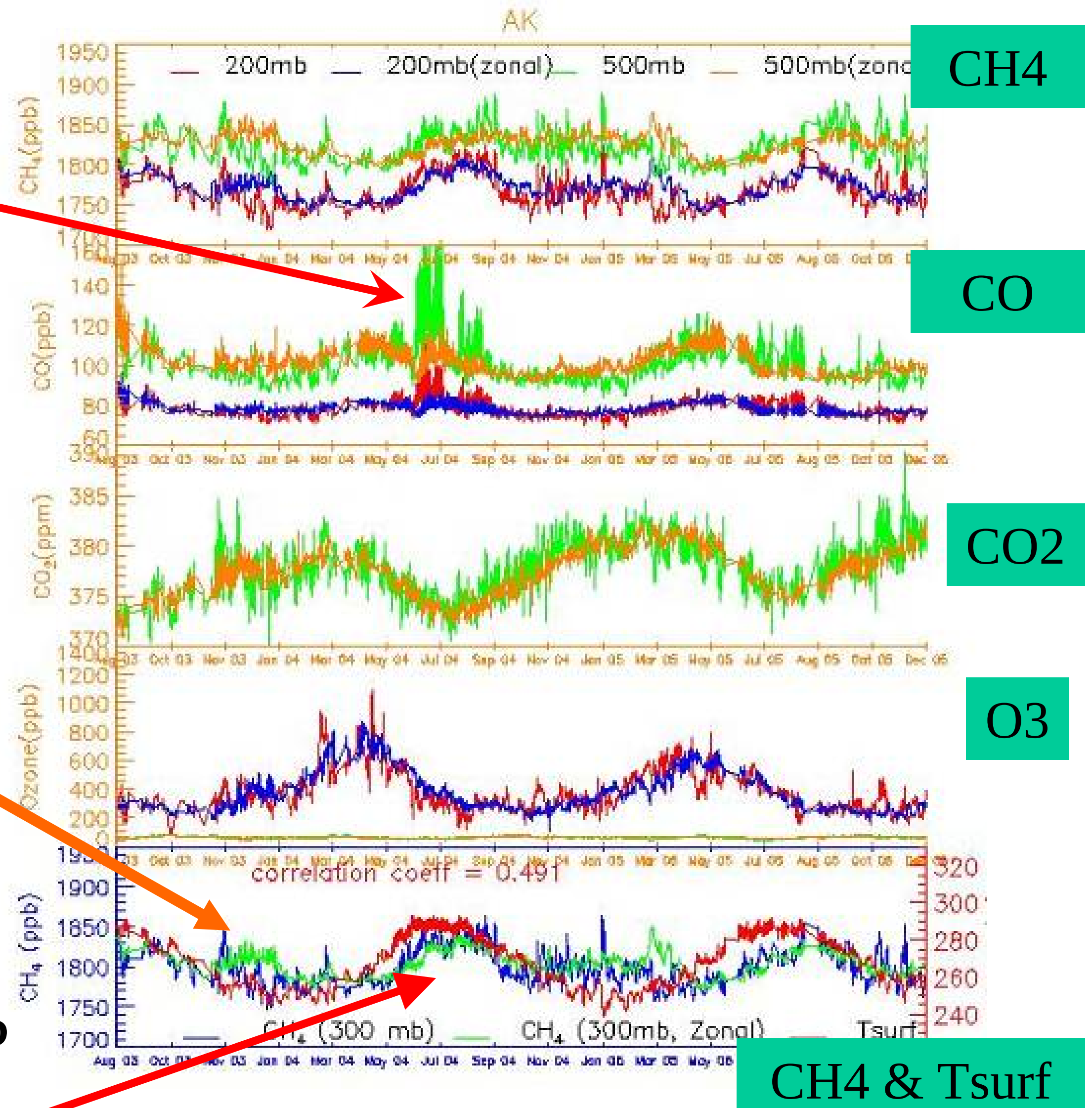
Improved Utilization of Satellite Observations



Greenhouse Gas Inventories: Monthly mean observations from AIRS help decision makers understand carbon sources and supports 2005 US Energy Bill

29 month time-series of AIRS products
Alaska & Canada Zone (60 ≤ lat ≤ 70, -165 ≤ lon ≤ -90)

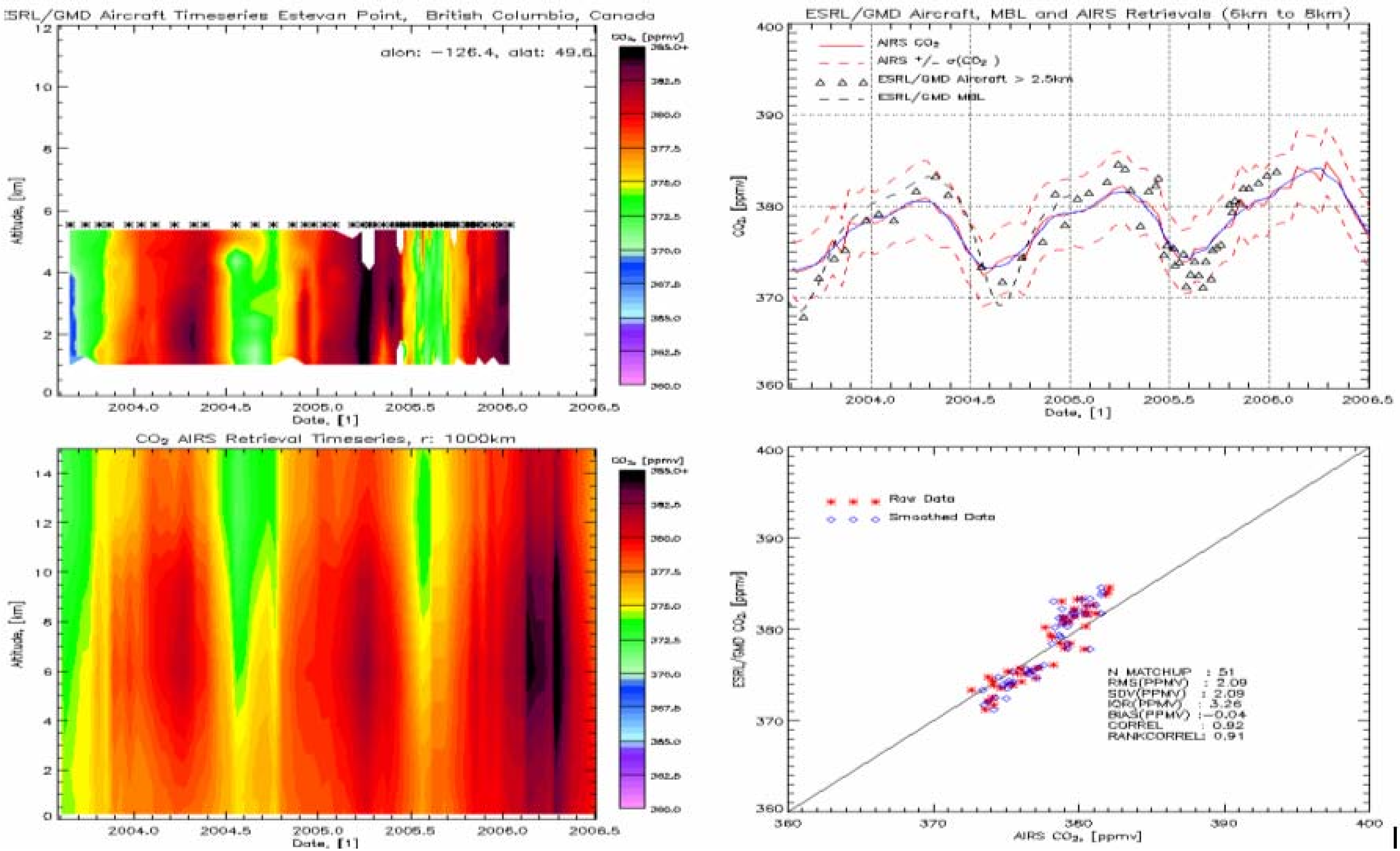
Fire
(7/04)



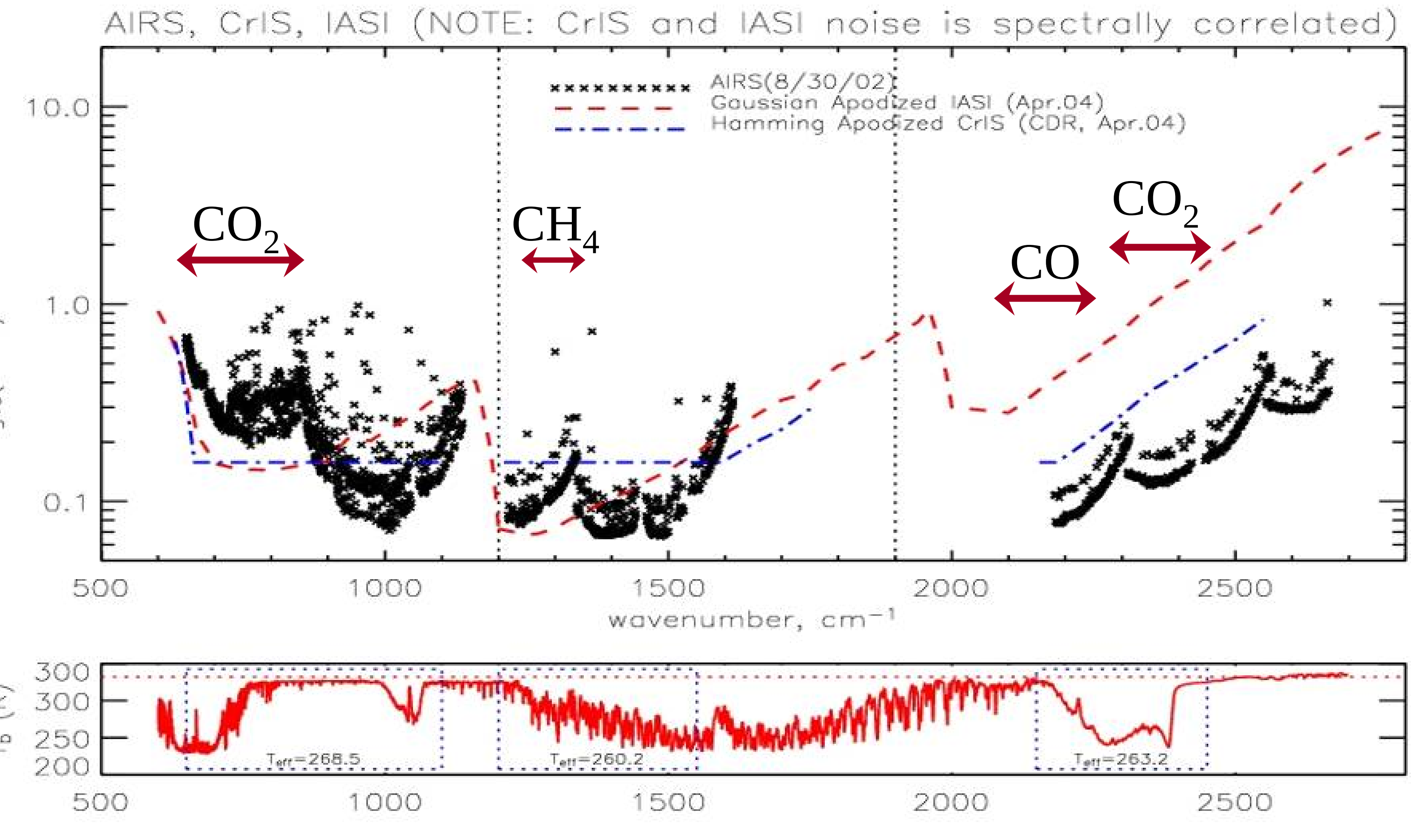
??

Peat
Wetlands?

AIRS CO2 agrees well with aircraft measurments



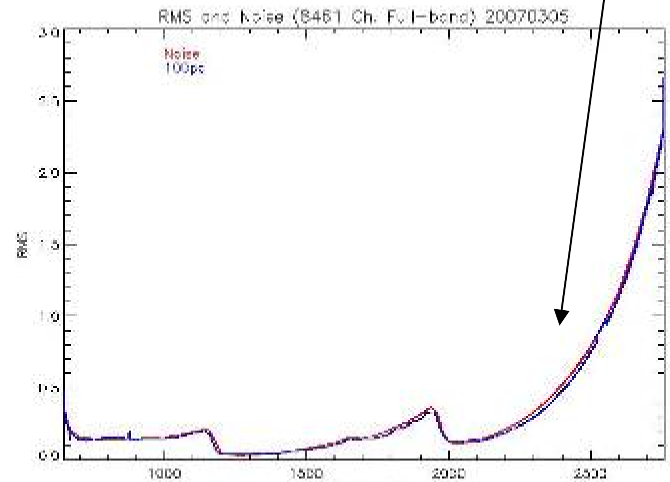
Instrument Noise, NEΔT at 250 K (Interferometers are apodized)



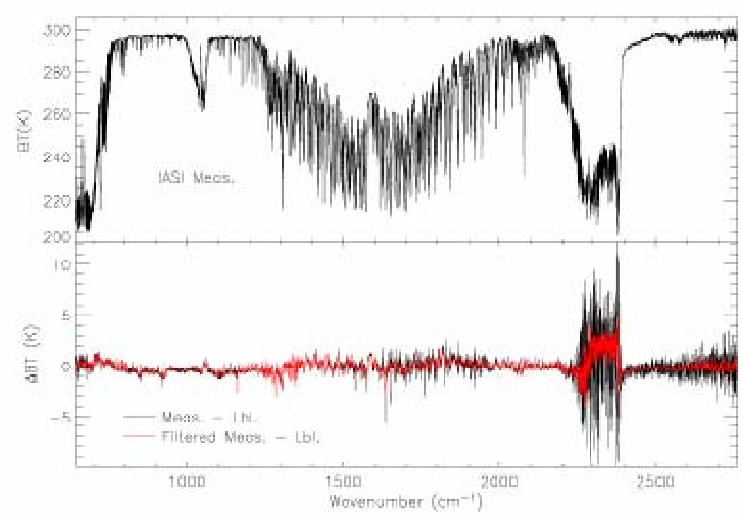
Eigenvector Analysis for Noise Reduction

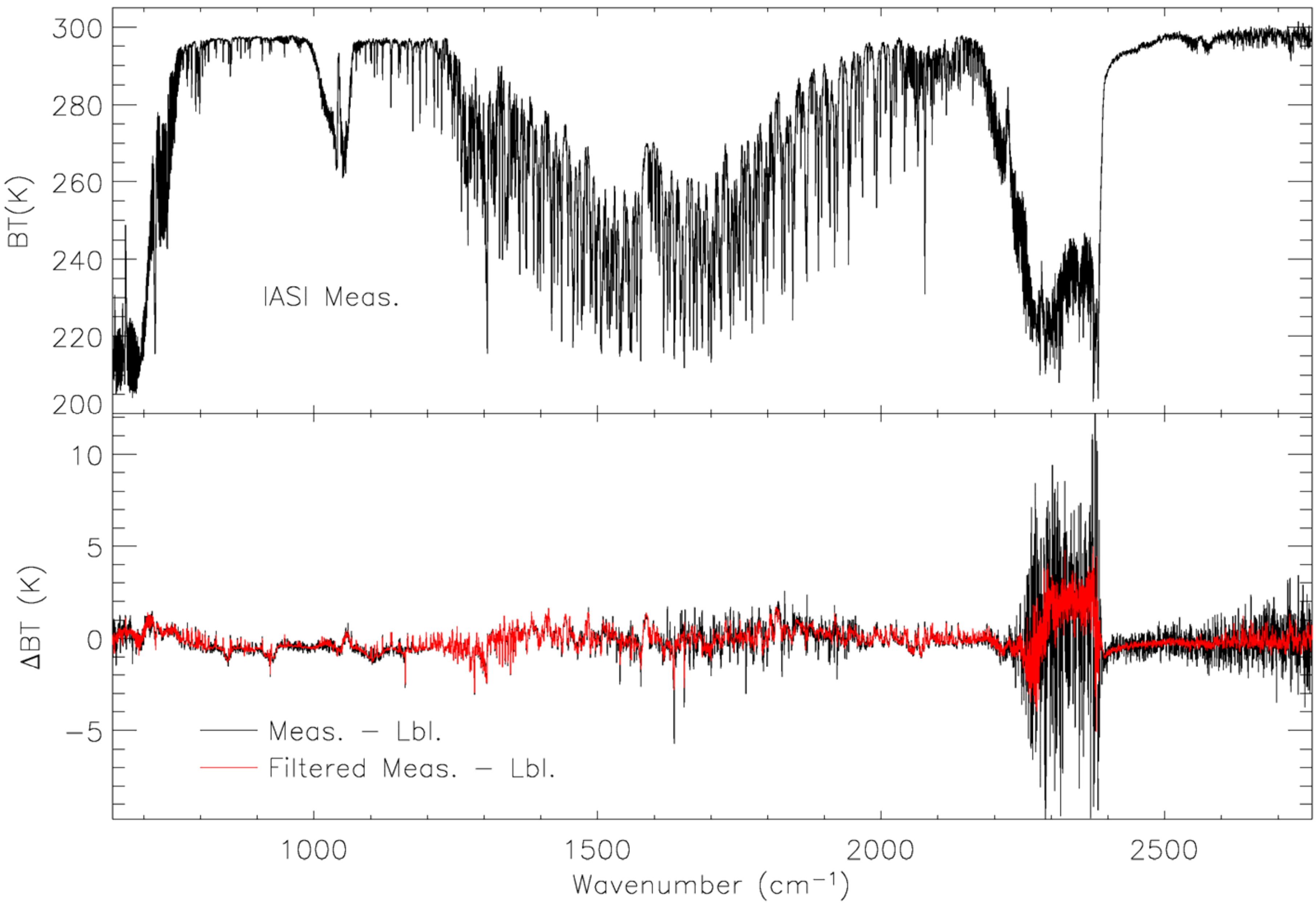
- Eigenvector analysis allows correlated data to be represented by a relatively small set of functions.
- 8461 channels can easily be represented by a 100 unique coefficients couples with 100 static structure functions (100 x 8461)
- Benefits: Noise filtering and data compression.   Distribute and archive 100 coefficients instead of 8461 channels (lossy compression) We can now use shortwave IR window channels for applications (LW vs SW cloud tests)

Independent assessment of noise from root mean
Square difference between measured and reconstructed noise.
The reconstructed radiances are noise filtered, therefore the rms
matches the instrument noise

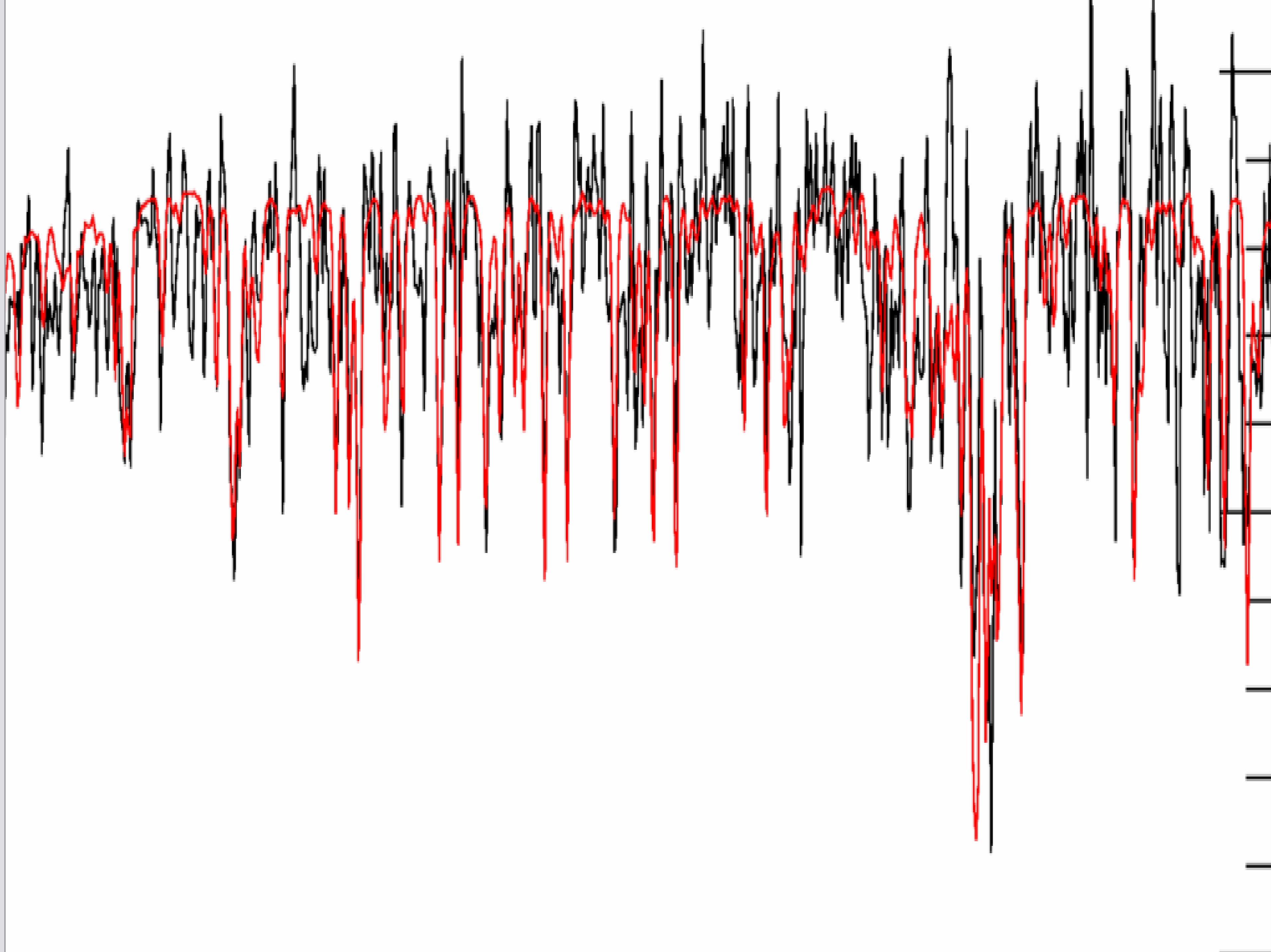


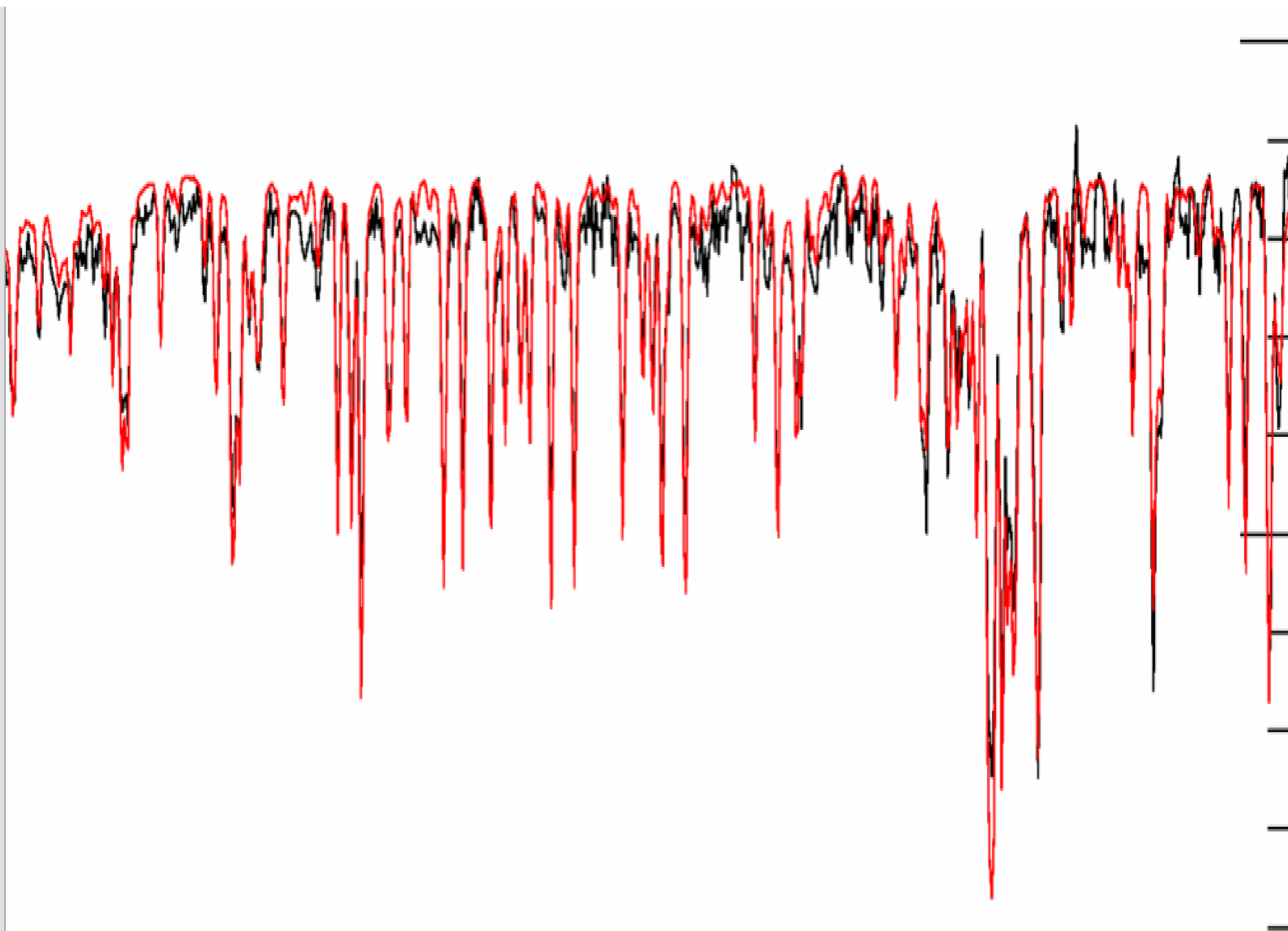
280 K





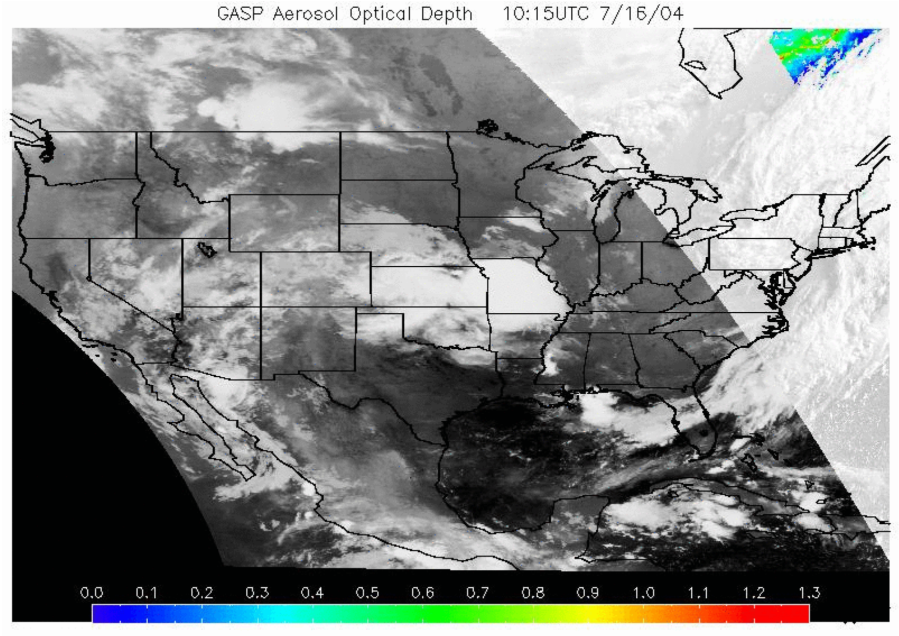
BT(K)
300
280
260
240
220
200
IASI Meas.
ΔBT (K)
10
5
0
−5
Meas. − Lbl.
Filtered Meas. − Lbl.
1000
1500
2000
2500
Wavenumber (cm⁻¹)





Opportunities to improve air quality monitoring and forecasting

- Congress mandates…
  - **NOAA must develop and deploy air quality forecast model at NCEP which produces 24 hour ozone and particulate matter forecasts nationwide**
- NOAA acts…
  - **Memorandum of understanding signed between EPA and NOAA to develop and implement an accurate air quality forecast program which includes joint research initiatives**
- NESDIS Role to Meet this Goal
  - Utilize satellite observations of aerosols, ozone and other trace gases to monitor air quality and improve air quality forecast by assimilation of satellite derived air quality products



Near Real Time Air Quality Products from MeTOP GOME-2 at NOAA/NESDIS

- **OMI DOAS algorithms will be employed, tested, and implemented**
- **Products will be made available in NRT in 2008**
- **Products will be available at 40 X 40 km^2 spatial resolution**

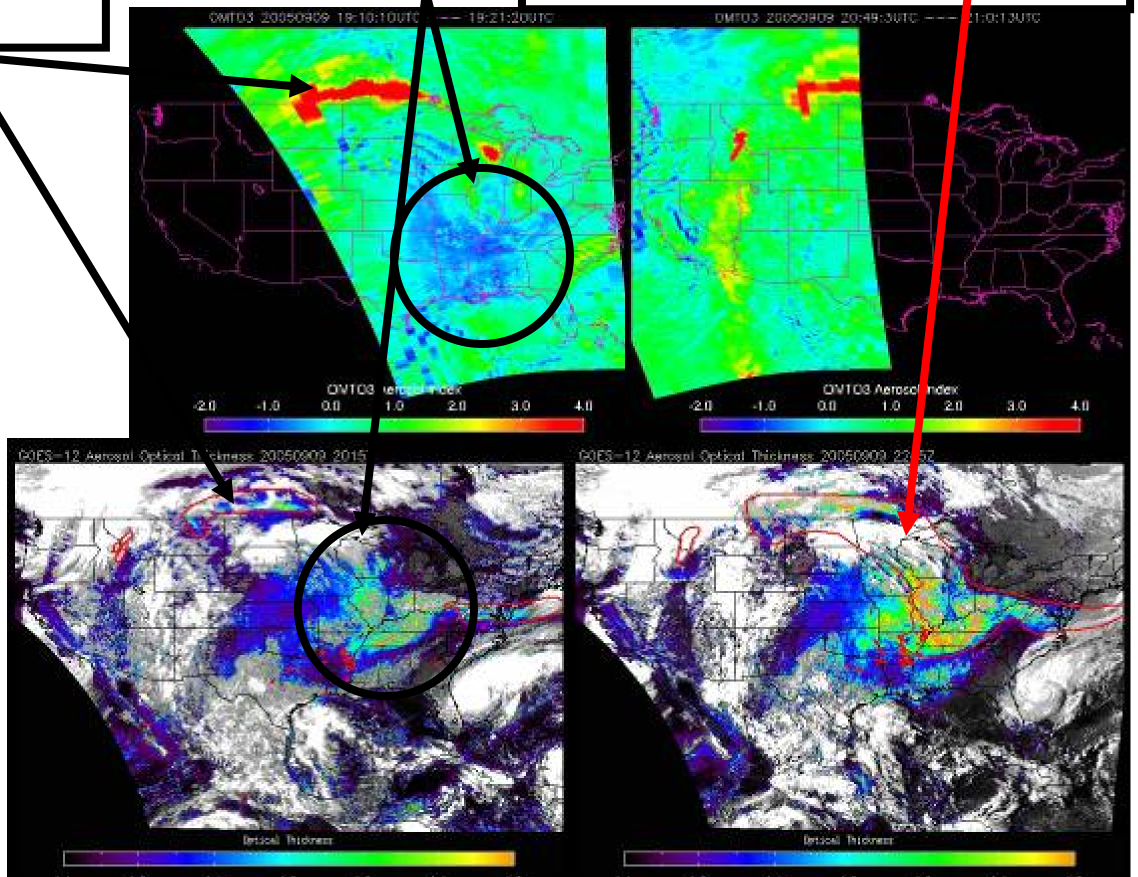
Product	**User**	**Example Application**
NO2 (425 – 450 nm)	EPA NWS	• Assessments •Constrain NOx emissions in air quality forecast model •Verification of precursor forecast fields
H2CO (337.5 – 359 nm)	EPA NWS	• Assessments •Constrain isoprene emissions in air quality forecast model •Verification of precursor forecast fields
Ozone (325 – 335 nm)	NWS	• Ozone forecast improvements
Aerosol optical Depth (absorption vs scattering) (multiple bands in the UV)	EPA NWS NESDIS	• PM2.5 Monitoring •PM2.5 and ozone forecast improvements •Hazard Mapping System
Volcanic SO2 (315 – 326 nm)	NESDIS	• Hazard Mapping System

Using Advanced Sensor Capabilities to Our Advantage: Applicability of OMI Aerosol Index Data in Improving Hazard Mapping System Smoke Analysis

GOES AOD product shows clouds mixed in with smoke aerosols. OMI can do a retrieval when aerosols are mixed in with clouds

OMI says this is scattering type of aerosol. So did the analyst as he did not draw a plume there

Few hours later analyst draws a big plume. Is this all smoke? It is unfortunately after the OMI pass, so cannot conclusively say. But OMI has a big potential to help analysts with these interpretations

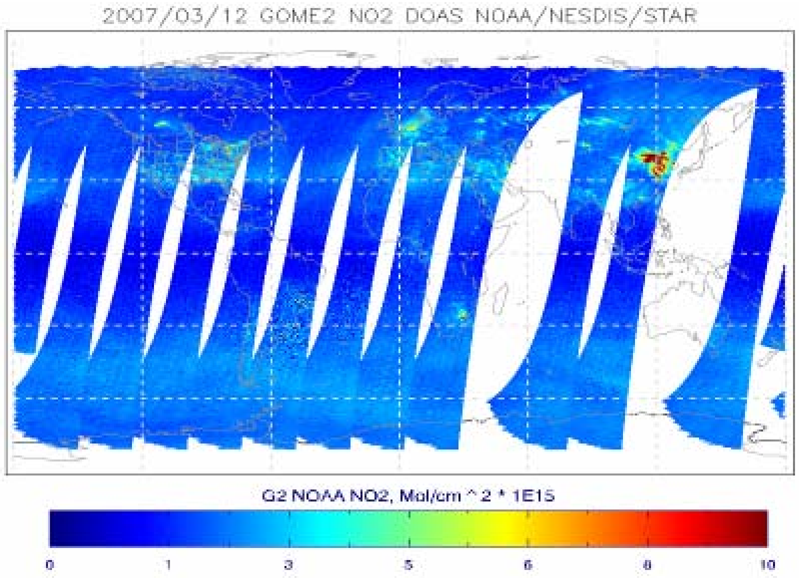


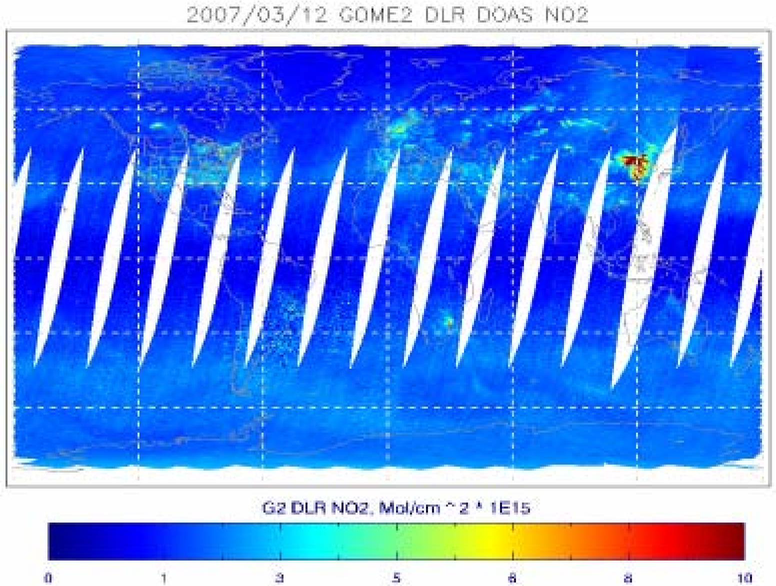
- **In the HMS, analysts use fire locations and visible imagery to draw smoke plumes. When plumes are removed from the source (fires), analysts have difficulty differentiating smoke from other aerosols**
- **NWS funded NESDIS/STAR to assess (QA/QC) the analyst drawn smoke plumes so they can be used in verifying HYSPLIT smoke forecasts**
- **GOES AODs (physical retrieval rather than interpretation) are being used to evaluate the HMS analysis. However, GOES cannot differentiate between smoke and non-smoke aerosols either**
- **OMI Aerosol Index can identify smoke from urban/industrial haze but cannot differentiate between smoke and dust**

OMI data courtesy of NASA

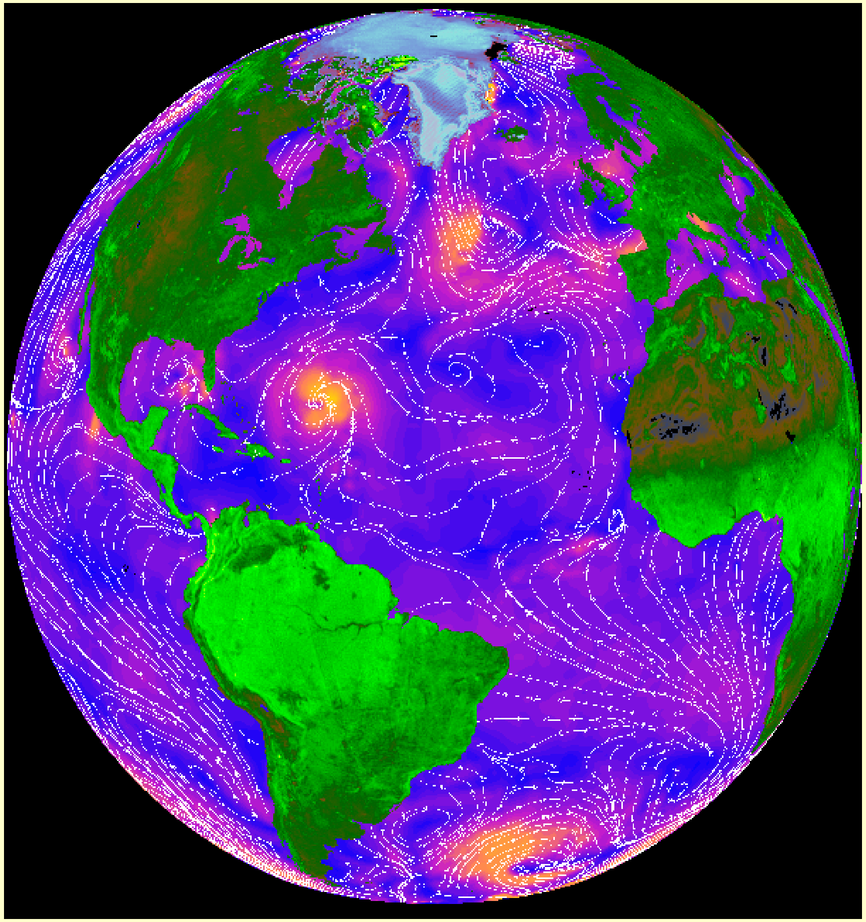
NO_2 from GOME-2 for March 12, 2007

• STAR GOME-2 NO_2 retrievals agree with EUMETSAT retrievals (top and middle panels).





ASCAT Scatterometer Measurements

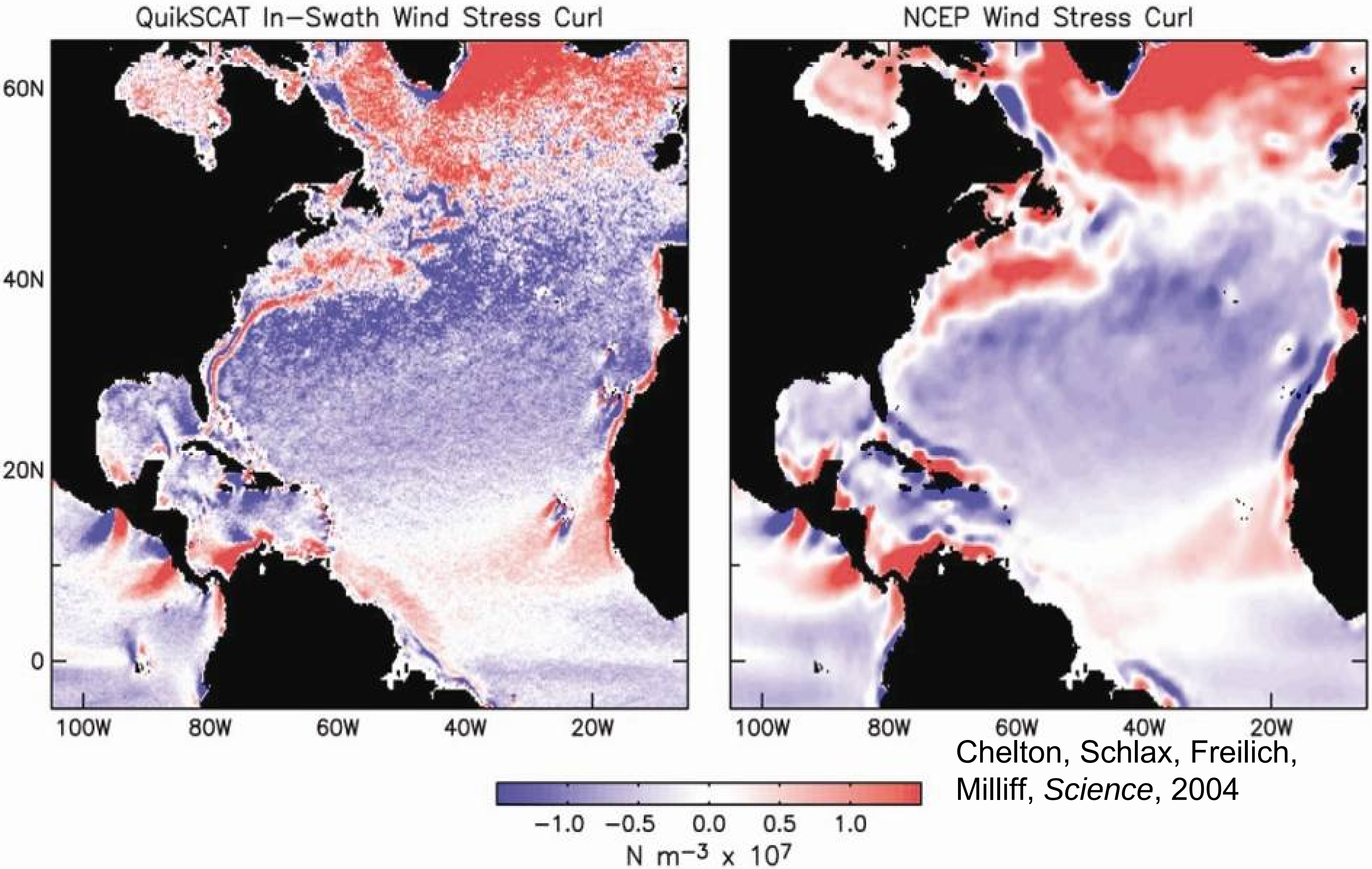


© Dave Long, BYU, 2005

- Wind scatterometers for ocean wind
  - Direct measurement is surface backscatter
  - Geophysical model function relates wind and backscatter
  - Locating ocean storms, mesoscale winds
- Other applications of backscatter measurements
  - Sea ice age, extent
  - Melt/thaw
  - Soil moisture
- ASCAT data has good daily coverage
  - Weather and sun independent observation capability

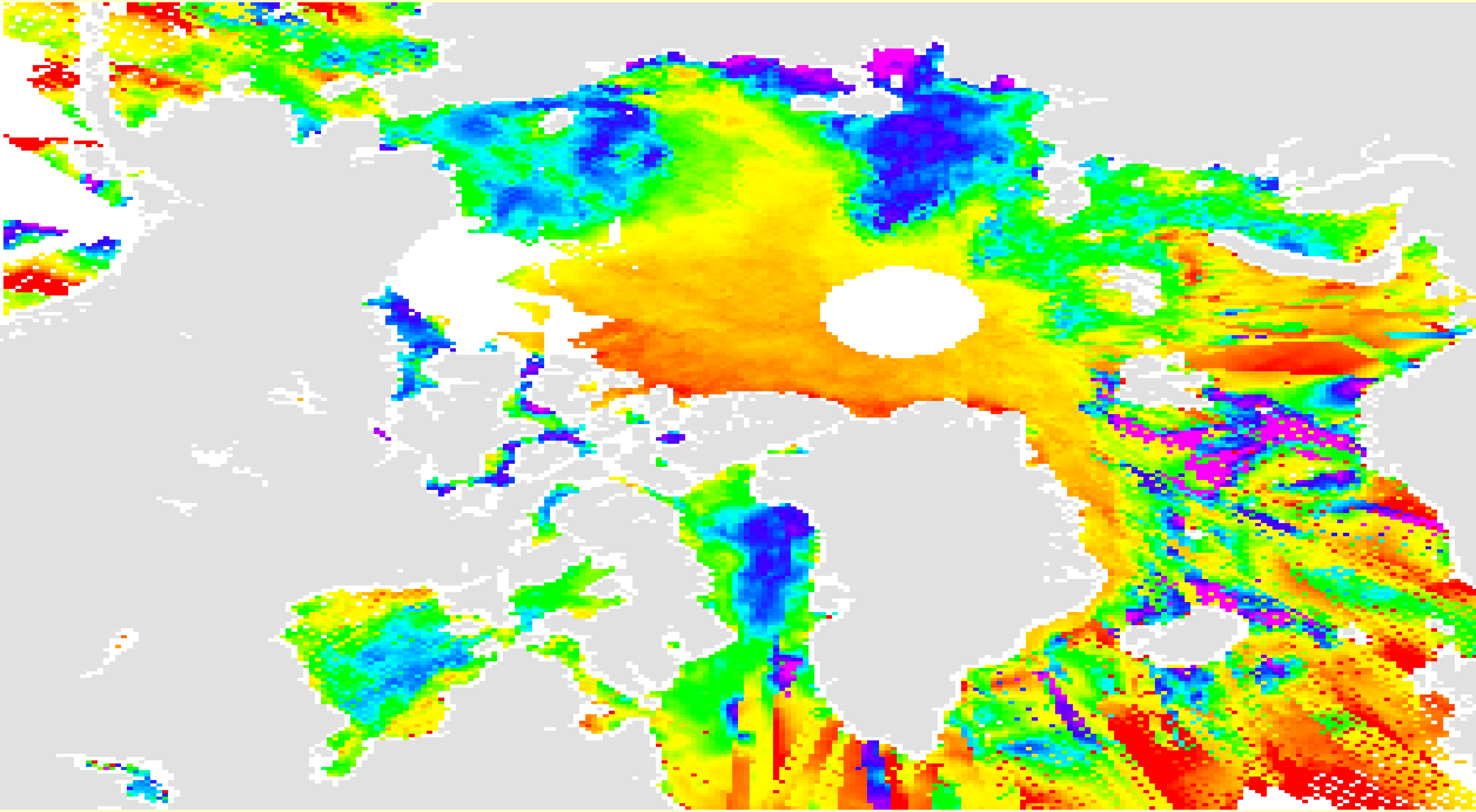
Oceanographic Application

8/99-7/03 4-year Average Wind Stress Curl

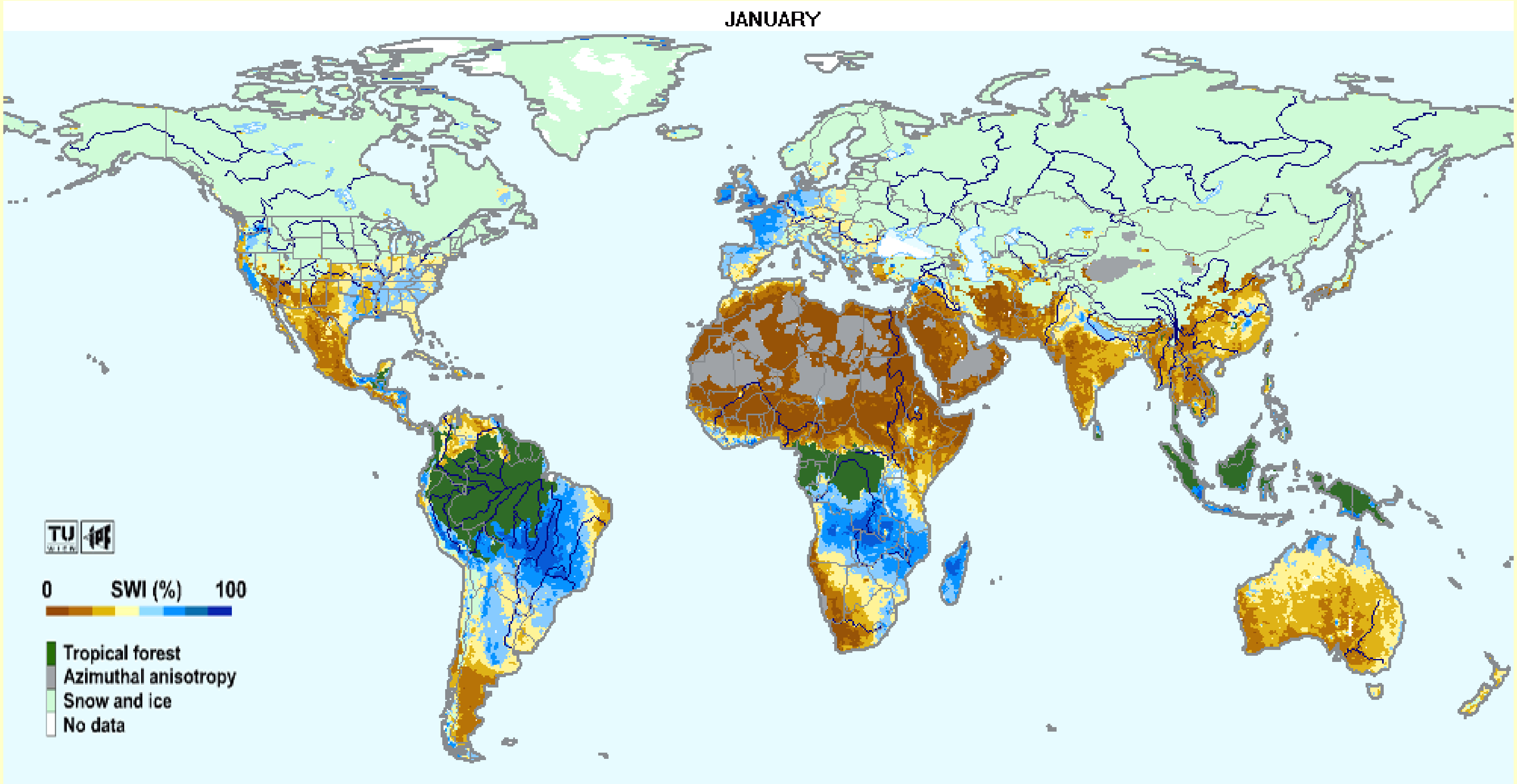


Chelton, Schlax, Freilich, Milliff, *Science*, 2004

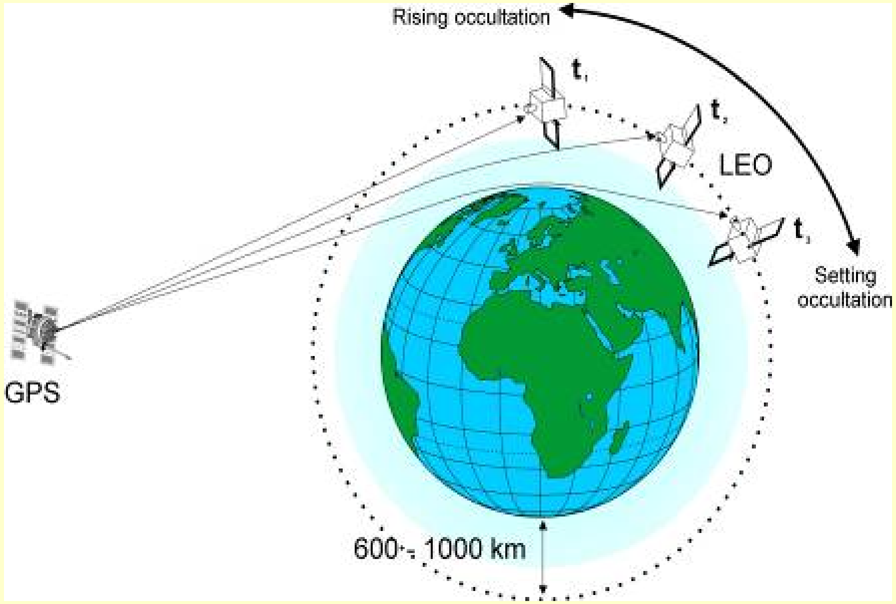
ERS Scatterometer Ice age

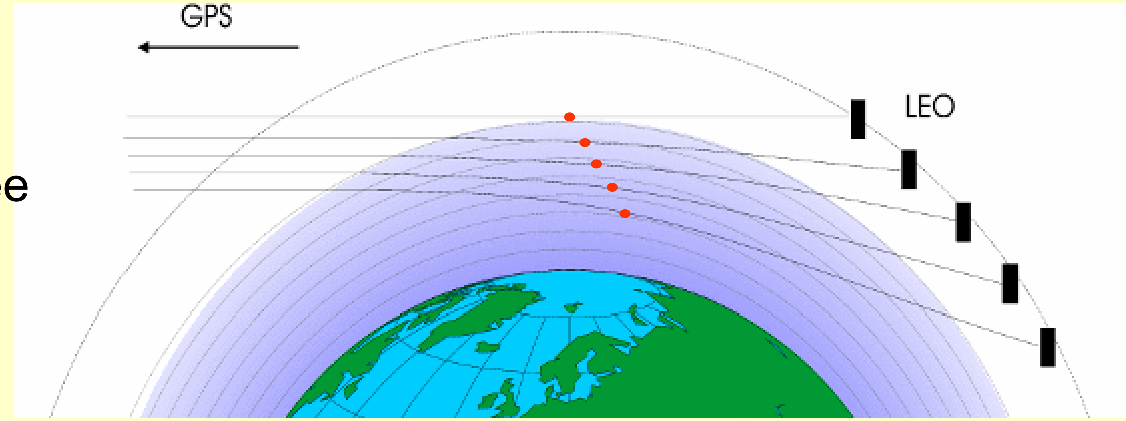


Soil Water Index



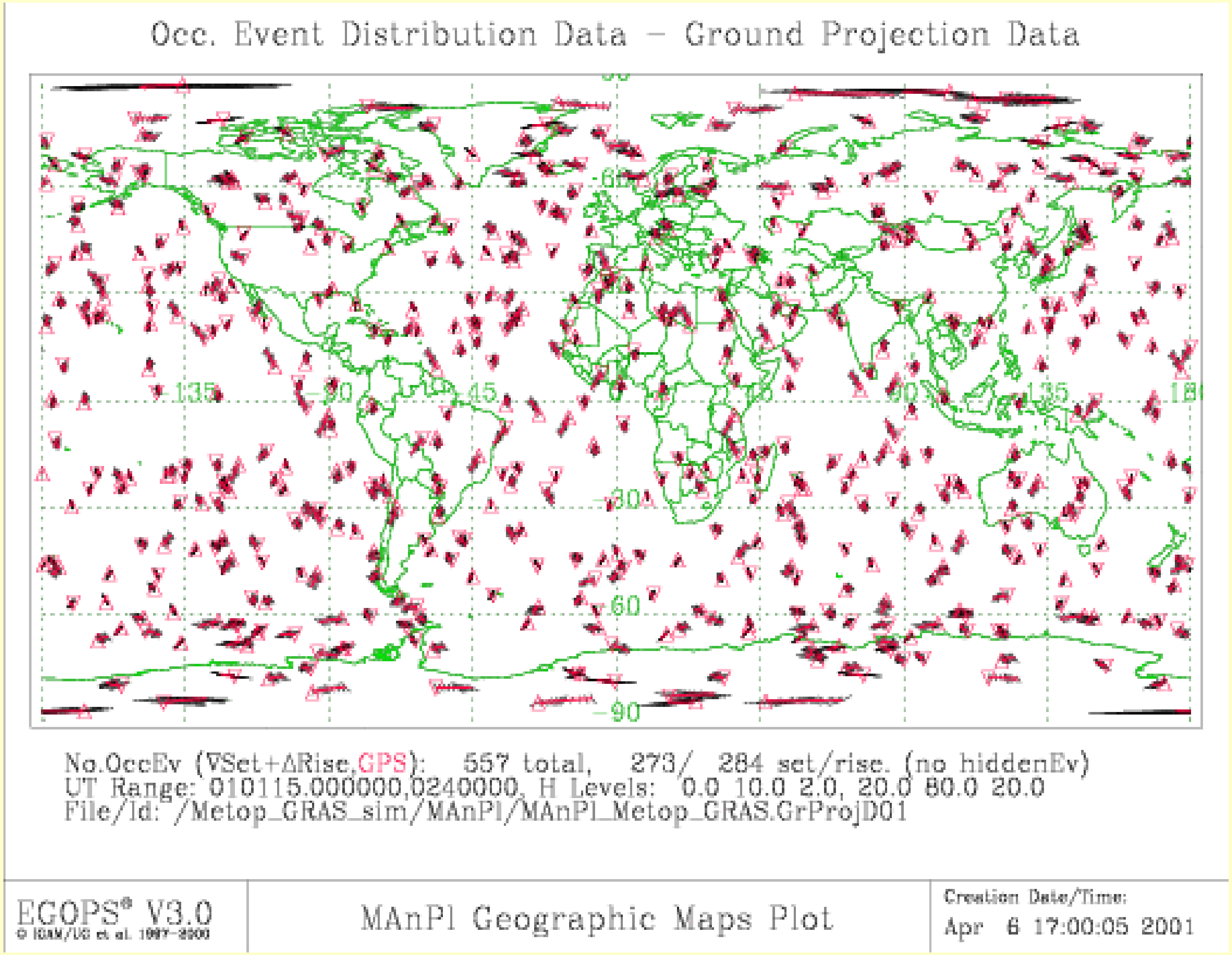
GRAS Radio Occultation (RO) sounding





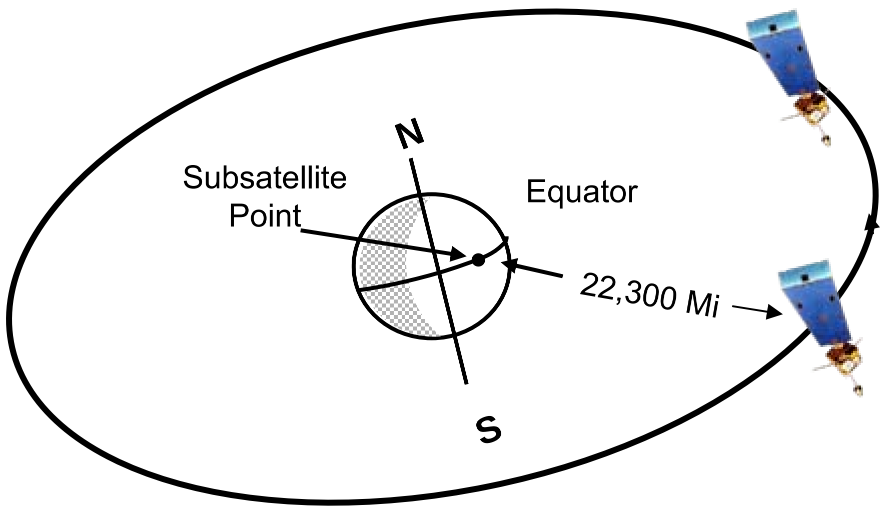
• = the path of the ray perigee through the atmosphere

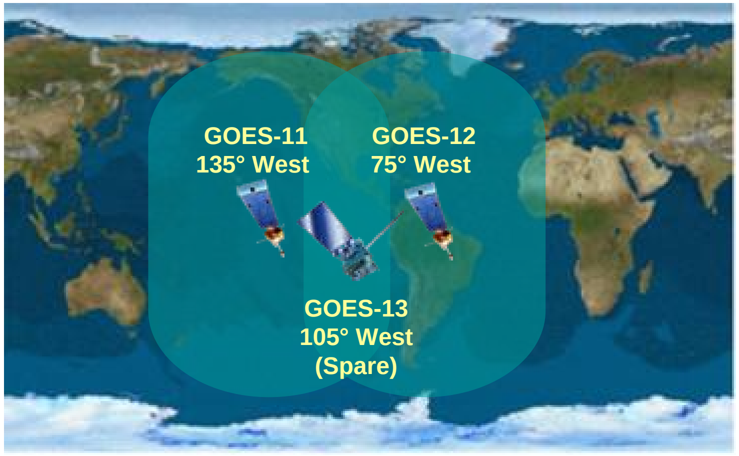
GRAS sounding distribution over 24 h



GOES Constellation Today

Primary Requirement: Continuity of Capability



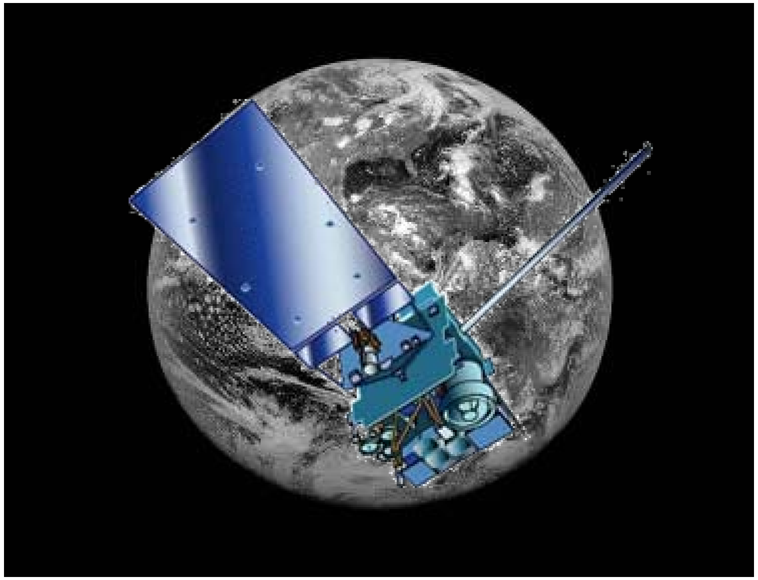


Two operational satellites and on-orbit spare

- GOES I-M (8-12)* series operational since 1994
  - **GOES-10 operational at 60º W in support of South America beginning December 2, 2006**
  - **GOES-11 operational as GOES West beginning June 21, 2006**
  - **GOES-12 operational as GOES East beginning April 1, 2003**
- GOES N-P
  - **GOES-13 launched May 24, 2006, storage at 105º W**
  - **GOES-O in ground storage**
  - **GOES-P in factory testing phase**
- GOES-R series will replace the GOES-N series no earlier than 2014

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

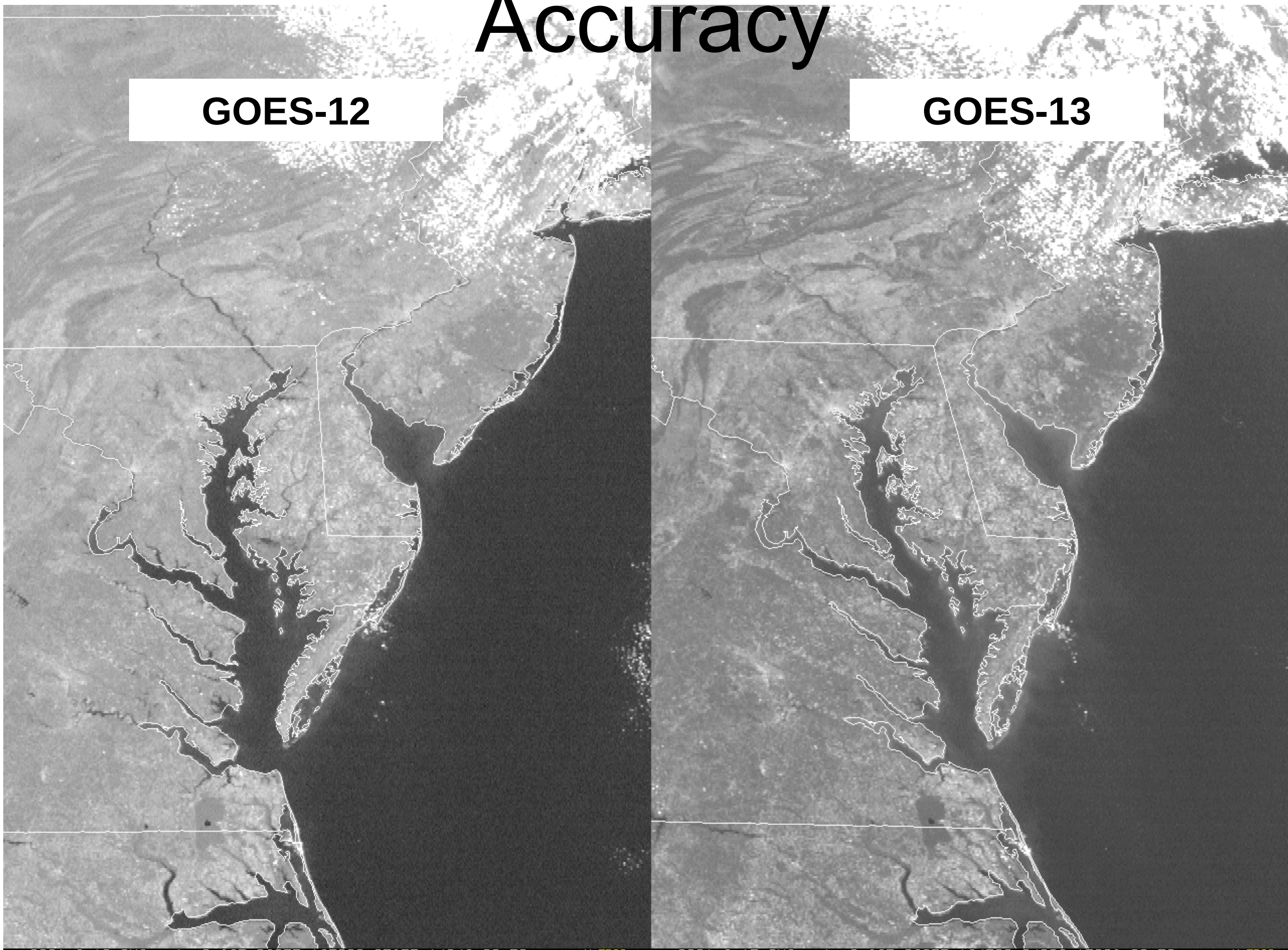
Today's Constellation GOES-13



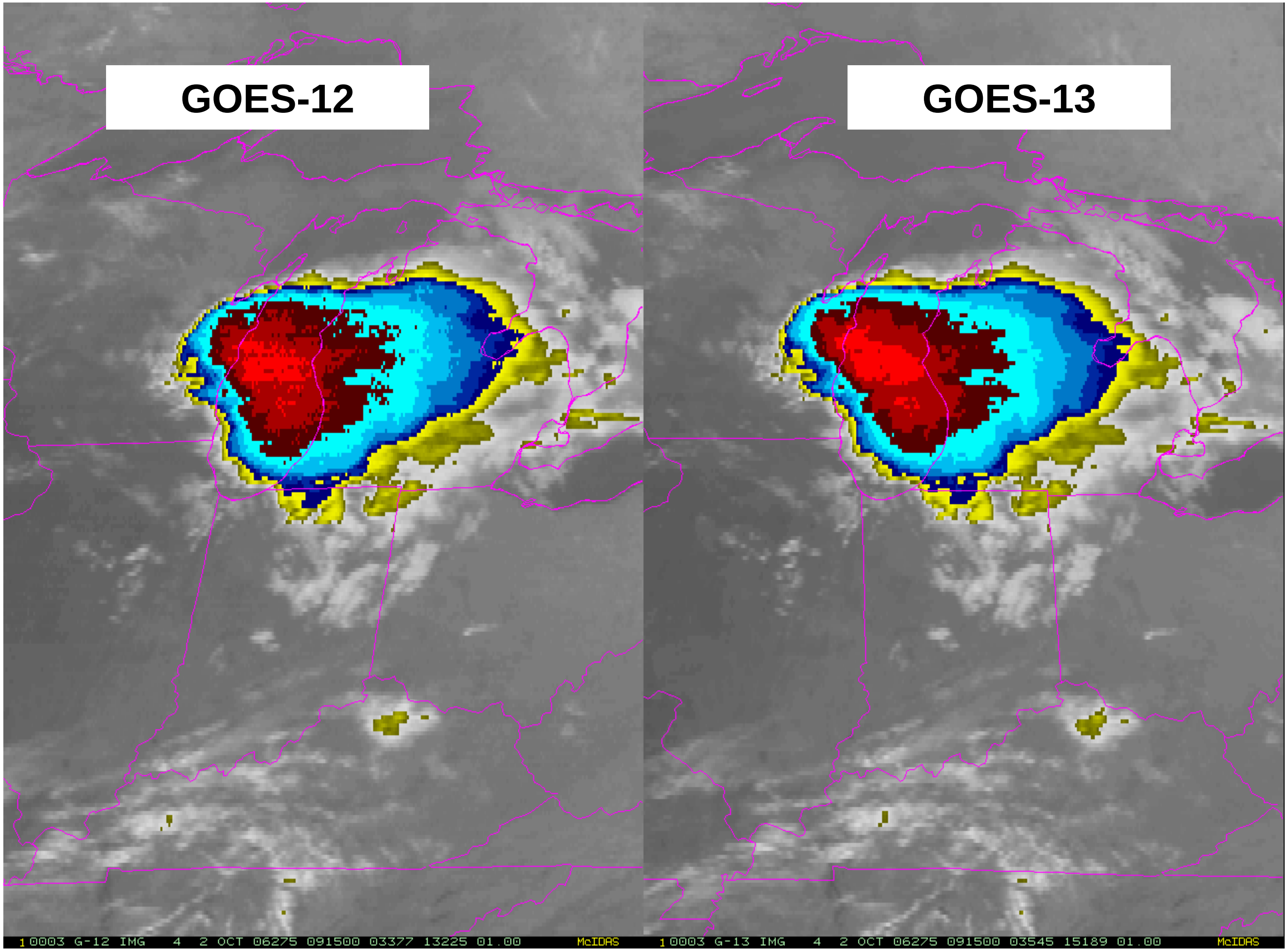
- Bus: 8x9x3m
- Deployed length: 19m
- Weight: 7076 lbs

- Instruments similar to GOES 10 - 12, but hosted on a more advanced bus
  - Improved power subsystem permits operations during eclipse periods
  - Improved pointing accuracy and less thermal distortion
  - Repositioned boom allows colder detectors -- less instrument noise
- Simultaneous independent imaging & sounding allows frequent imaging
- Flexible scan control allows for improved short-term local weather forecasts

GOES-13: Improved Pointing Accuracy



GOES-13: Less Thermal Distortion



GOES-R Baseline Instruments Provides Critical Products to the Nation

- **Advanced Baseline Imager (ABI)**
  - Monitors and tracks severe weather, winds, hurricanes, hazards, etc.
  - Images clouds to support forecasts
  - Aerosols for Air Quality & Climate Applications
  - Volcanic ash tracking, fire and smoke detection, winds and icing detection

- **Hyperspectral Environmental Suite (HES)**
  - Provides atmospheric moisture and temperature profiles to support environmental models, forecasts and climate monitoring
  - Monitors coastal regions for ecosystem health, water quality, coastal erosion, harmful algal blooms, sea surface temperature
  - Geostationary sampling of ocean color allows coastal resource management

- **Geostationary Lightning Mapper (GLM)**
  - Detects lightning strikes as an indicator of severe storms
  - Previous capability only existed on polar satellites

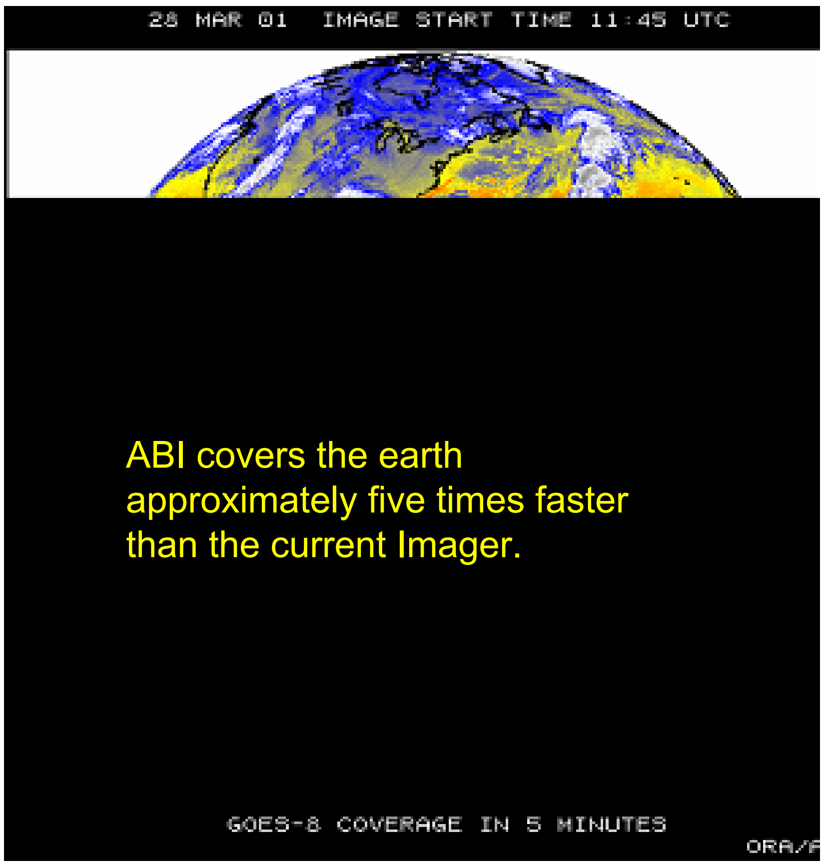
- **Solar Imaging Suite (SIS) and Space Environmental In-Situ Suite (SEISS)**
  - Images the sun and measures solar output to monitor solar storms (SIS)
  - Measures magnetic fields and charged particles (SEISS)
  - Enables early warnings for satellite and power grid operations, telecom services, astronauts, and airlines

- **Auxiliary Services**
  - Environmental Data Relay
  - Search and Rescue

ABI Improvements

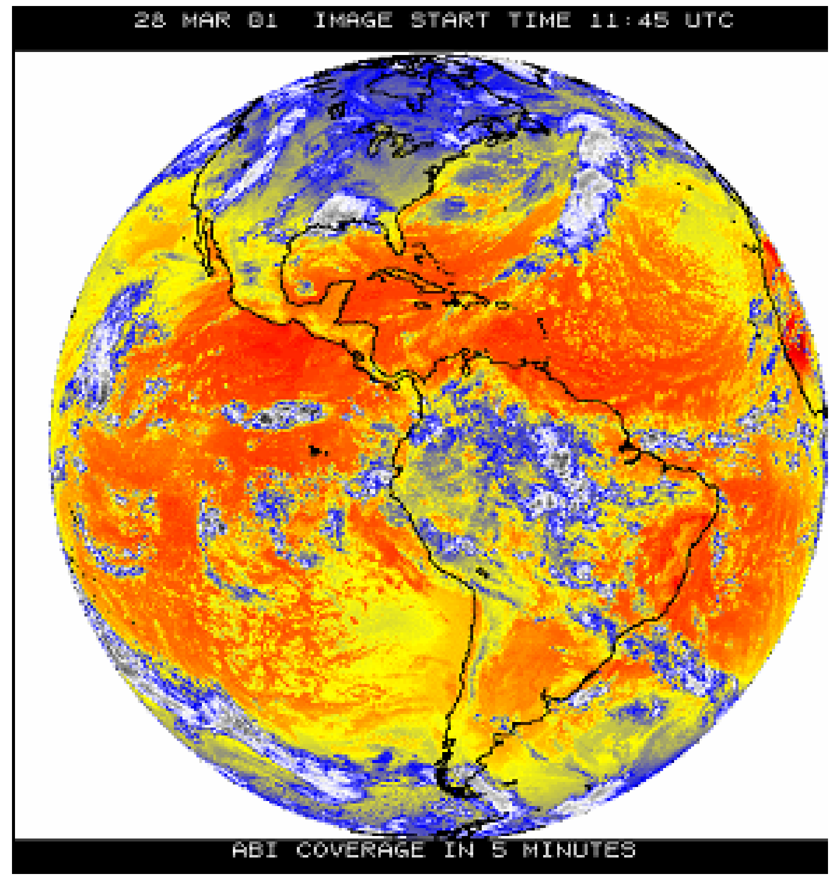
5 Minute Coverage

GOES-I/P



1/5 Disc

GOES-R



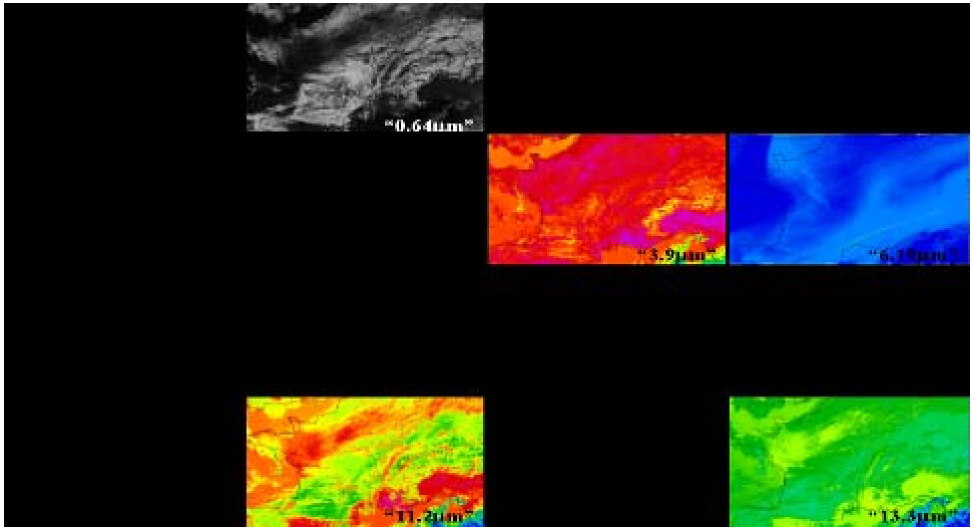
Full Disc

Sounder Status

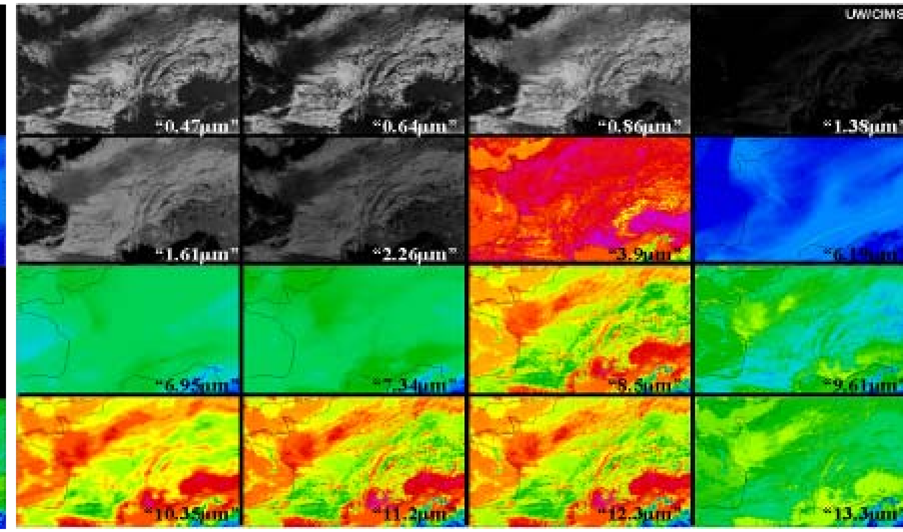
- Hyperspectral Environmental Suite was de-scoped from GOES-R this summer
- NOAA is evaluating how to meet continuity requirements for sounding products
- Final decision will be part of GOES-R Key Decision Point C/D planned for Summer 2007
- Office of Satellite Development currently working an Analysis of Alternatives for Advanced Sounder and Coastal Waters capability

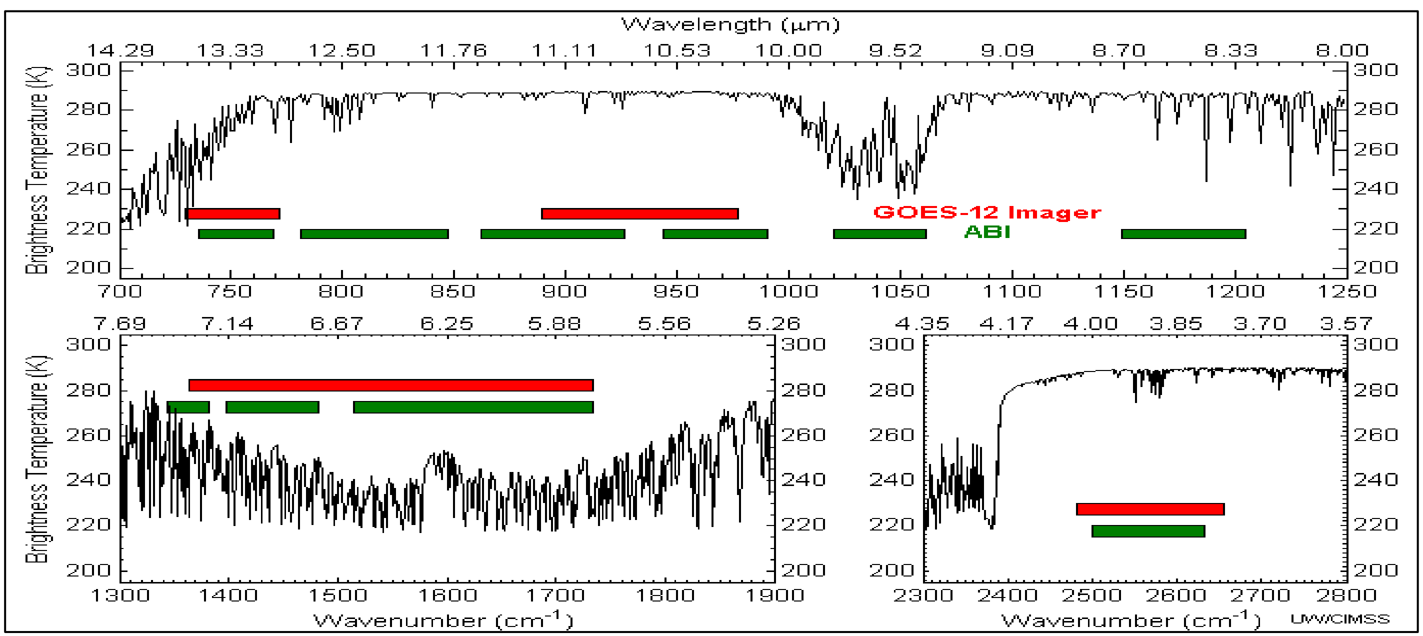
ABI: Improved Resolution . . .

Corresponding Simulated GOES Imager Spectral Bands:



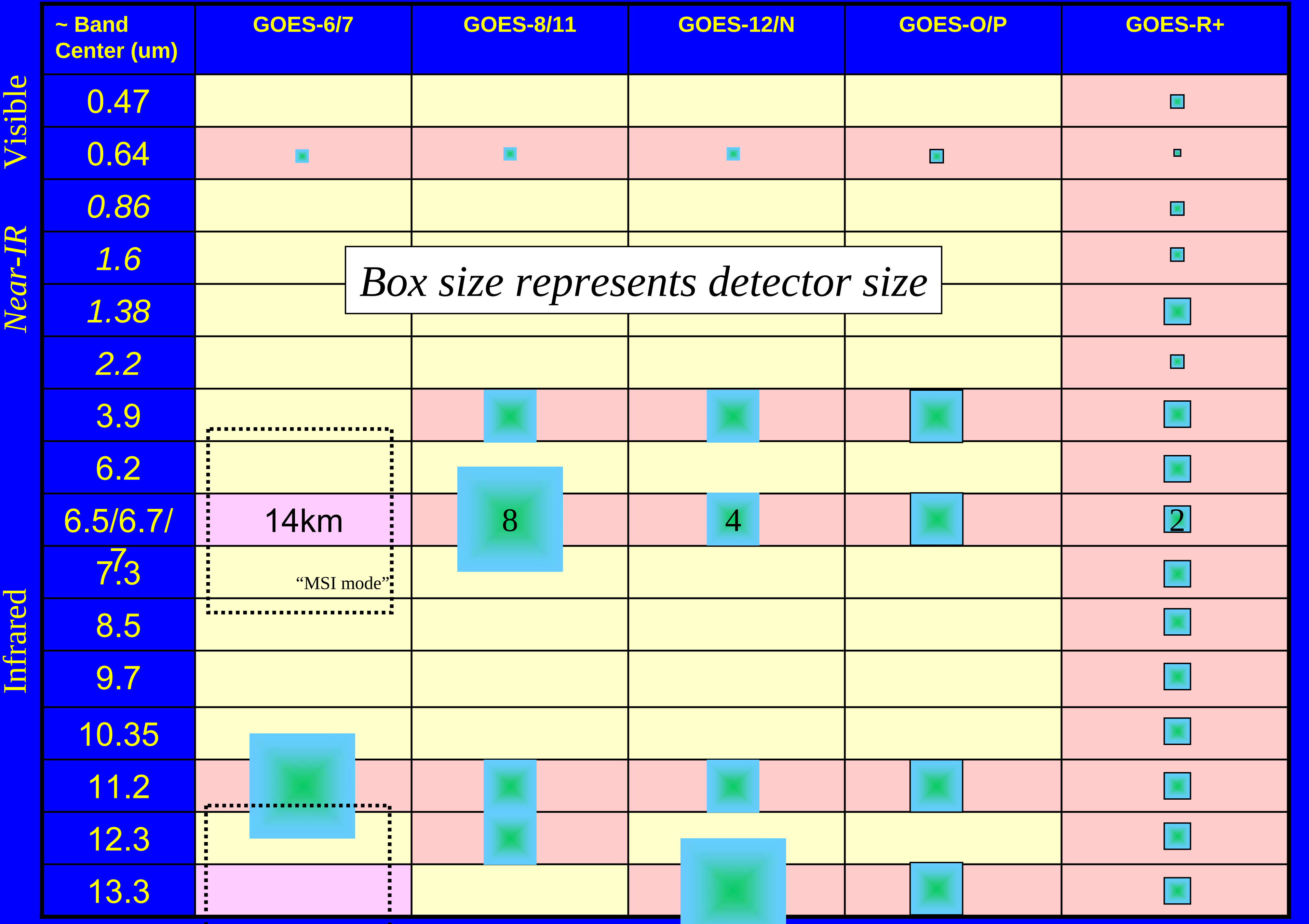
Simulated "ABI" Spectral Bands:

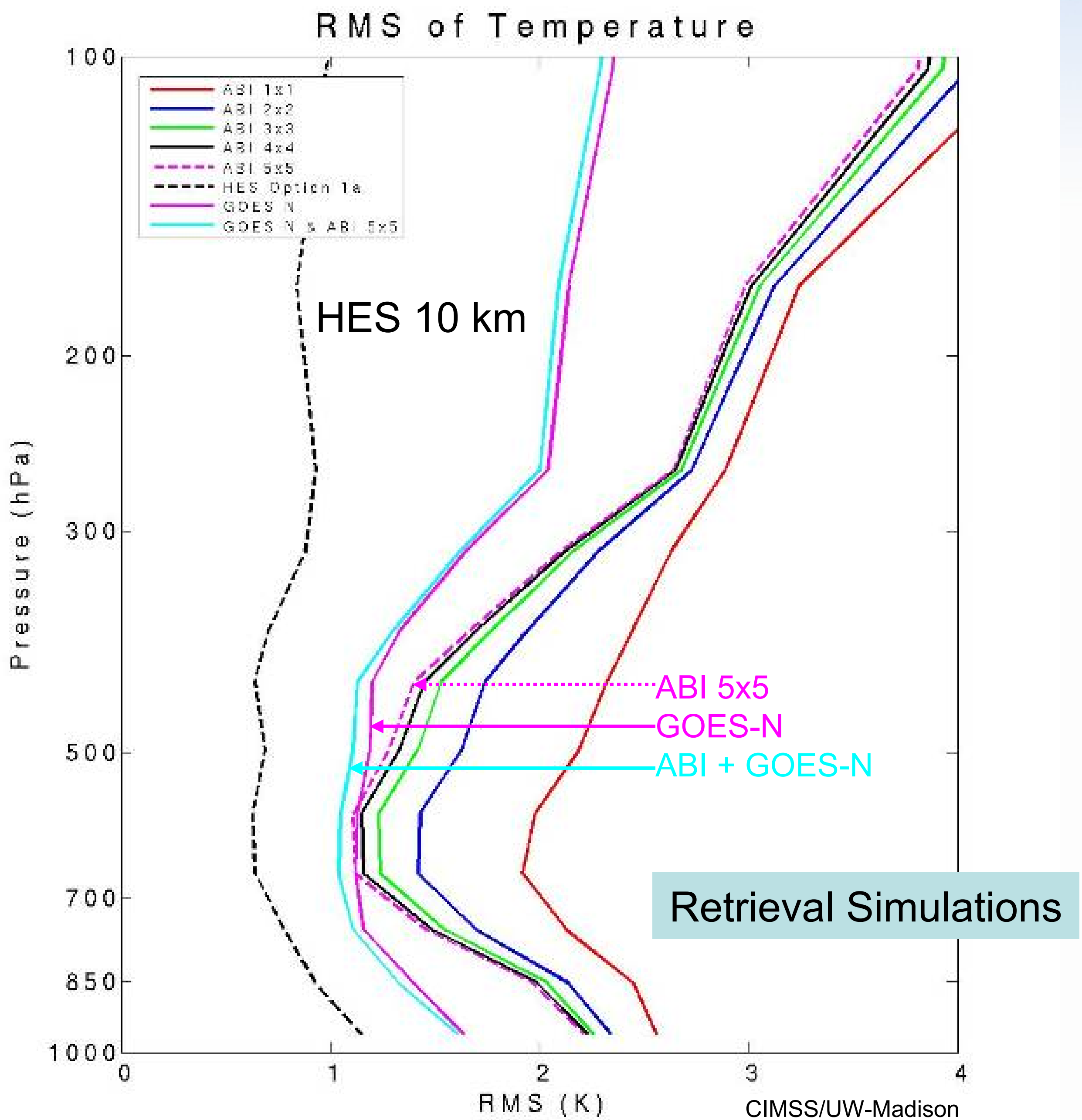


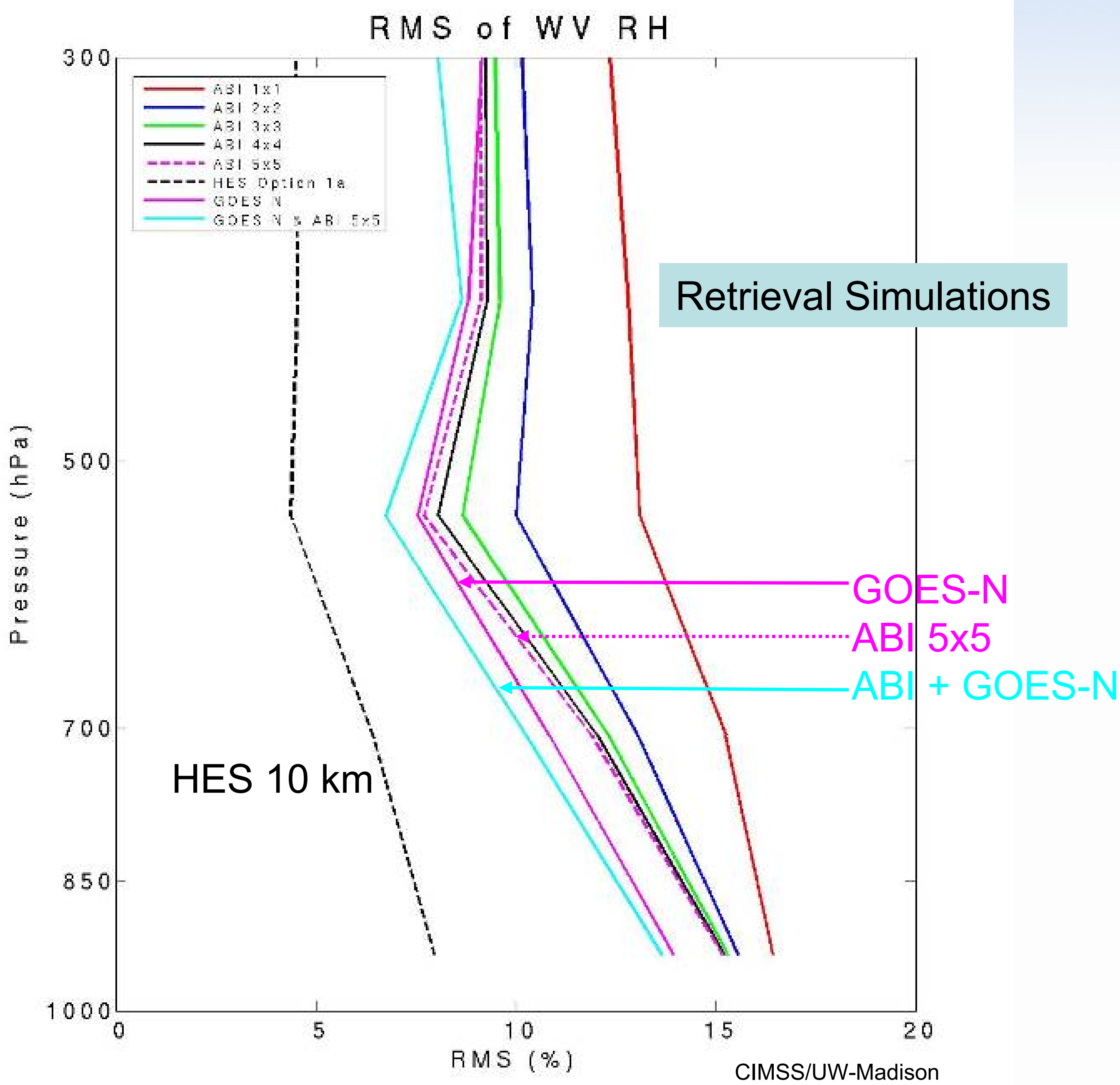


. . . over a wider spectrum

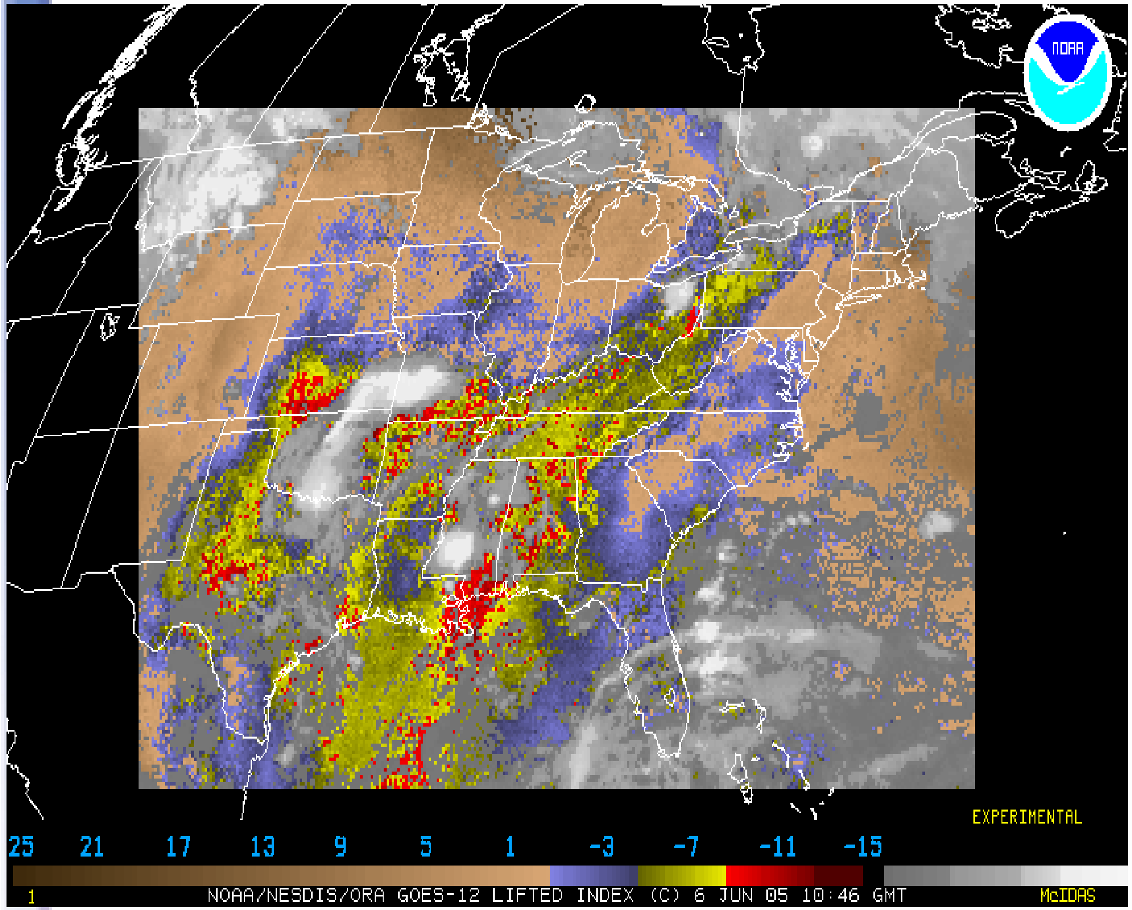
Approximate spectral and spatial resolutions of US GOES Imagers




RMS of Temperature
ABI 1x1
ABI 2x2
ABI 3x3
ABI 4x4
ABI 5x5
HES Option 1a
GOES N
GOES N & ABI 5x5
HES 10 km
ABI 5x5
GOES-N
ABI + GOES-N
Retrieval Simulations
Pressure (hPa)
100
200
300
500
700
850
1000
0
1
2
3
4
RMS (K)
CIMSS/UW-Madison


RMS of WV RH
ABI 1x1
ABI 2x2
ABI 3x3
ABI 4x4
ABI 5x5
HES Option 1a
GOES N
GOES N & ABI 5x5
Retrieval Simulations
GOES-N
ABI 5x5
ABI + GOES-N
HES 10 km
Pressure (hPa)
300
500
700
850
1000
0
5
10
15
20
RMS (%)
CIMSS/UW-Madison

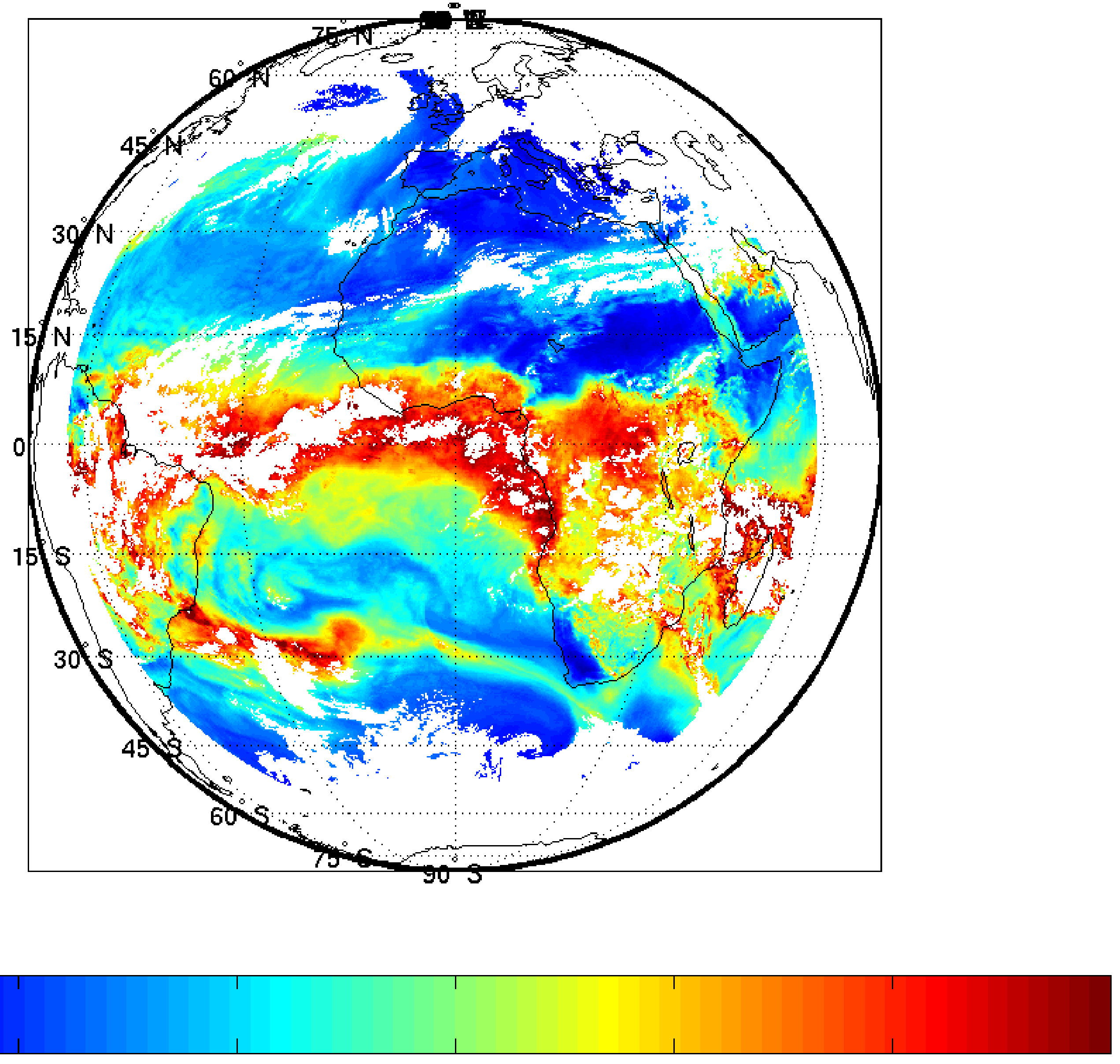
Lifted Index



- Computed from retrieved temperature and moisture profiles
  - **Parcel lifted mechanically from 1000 mb mixed layer up to 500 mb**
  - **Pixel level retrievals**
- Distributed to AWIPS
- <u>Operational Applications</u>

  Nowcasting
  - **Convective potential**
  - **Convective morphology**
  - **Situational awareness in pre-convective environments for potential watch/warning scenarios**

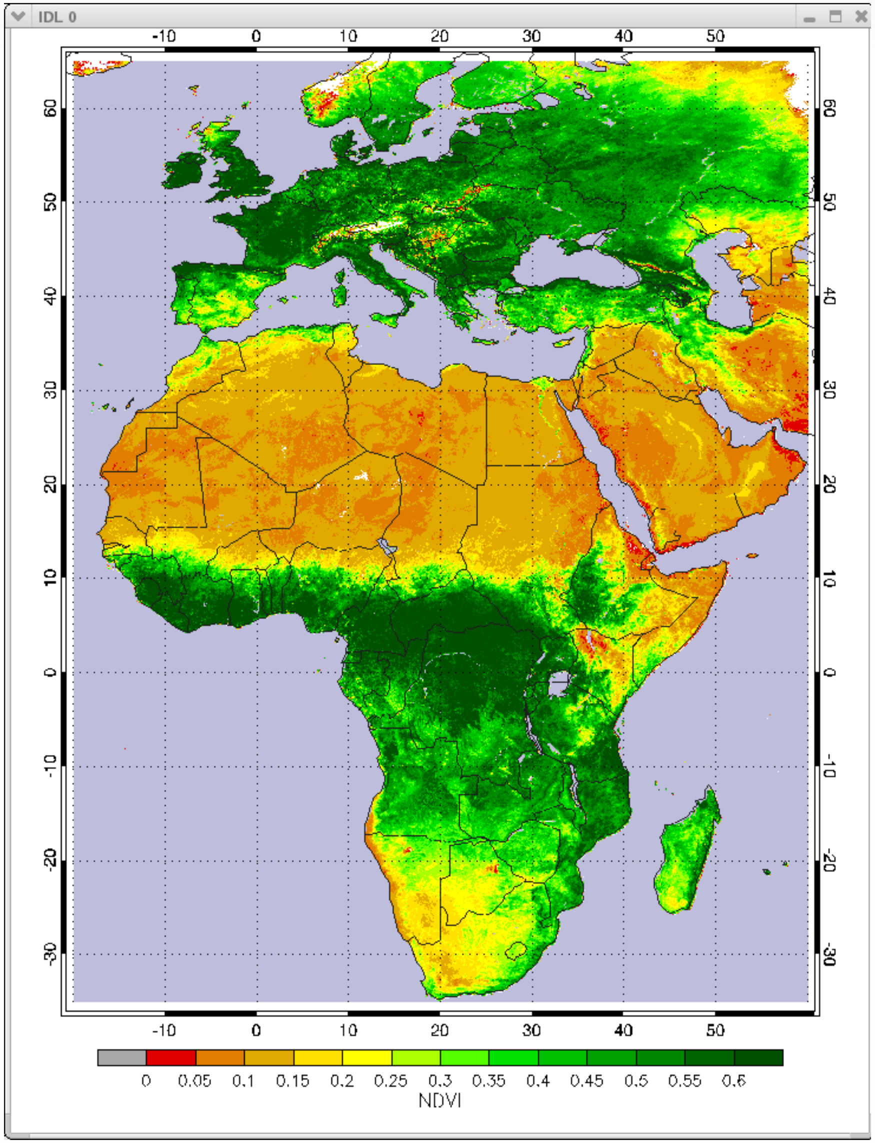
Level 2 Products from SEVIRI



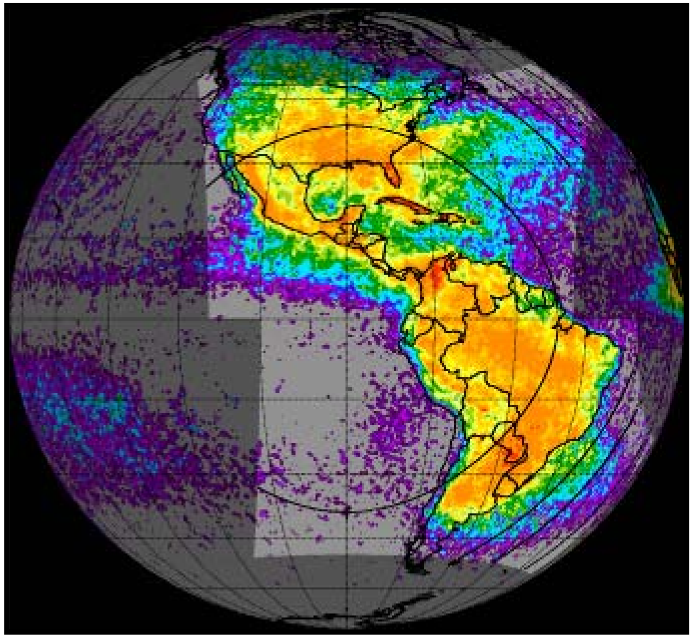
Totoal precipitable water (mm) at ---2006045:12:00

Highlight: Composite Vegetation Index from SEVIRI – GOES-R Proxy Product

- **Vegetation Index from MSG – SEVIRI – a proxy land surface product for GOES-R**
- **Image to the right is a composite from May 29-June 4**
- **Used ½ hourly images to eliminate clouds on a daily basis**
- **Composited daily images over 7 days, saving the highest NDVI**
- **This image shows the power of multiple looks per day in eliminating clouds from vegetation index maps.**



Geostationary Lightning Mapper (GLM)



- **Detects total strikes: in cloud, cloud to cloud, and cloud to ground**
  - **Compliments today's land based systems that only measures cloud to ground (about 15% of the total lightning)**

- **Increased coverage over oceans and lands**
  - **Currently no ocean coverage, <u>and</u> limited land coverage in dead zones**

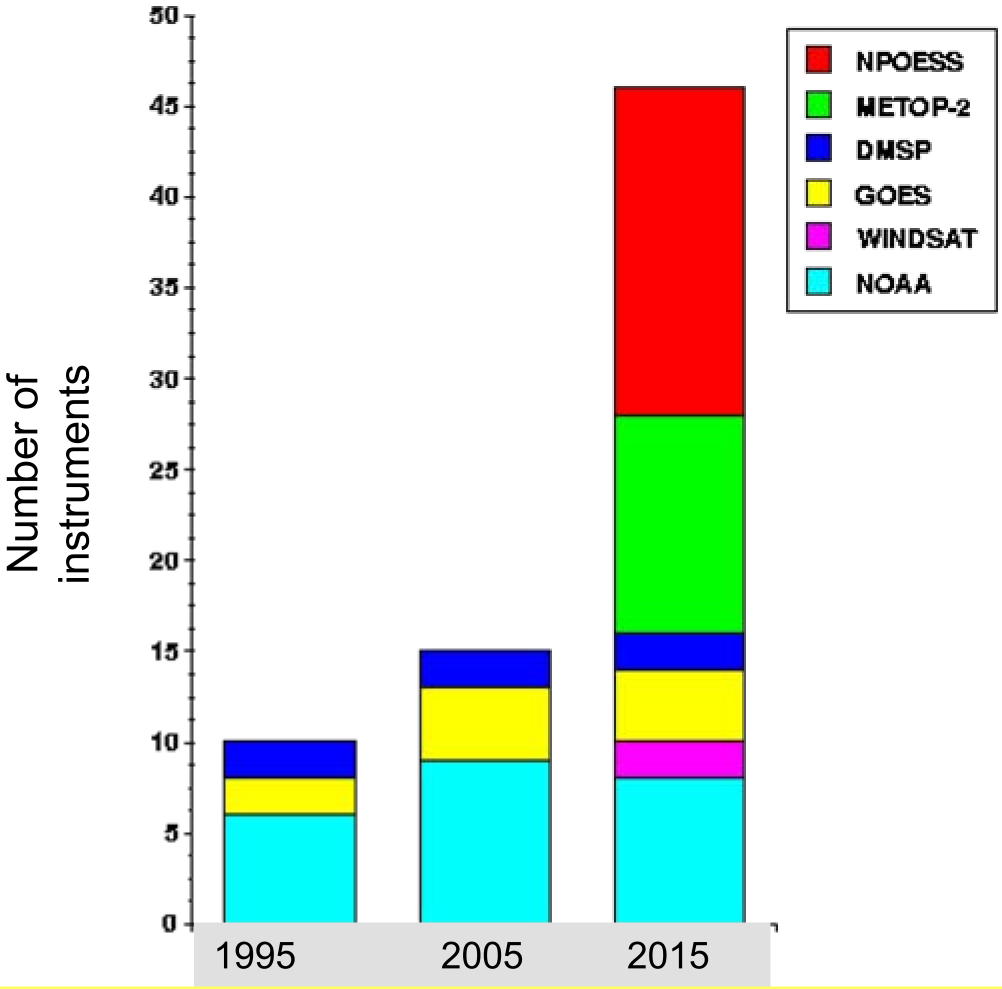
GLM Objectives:

Provide continuous, full-disk lightning measurements for storm warning and nowcasting.

Provide early warning of tornadic activity.

Summary

- Evolution of satellite instrumentation is providing new data assimilation opportunities to further improve forecasting and verification capabilities
- Challenge for JCSDA is to keep up.
- Satellite Capitalization Plan for post 2025



# of instruments triple over 20 years: need to integrate rather than continue stovepipe processing and applications

New and Old Algorithm Product Capabilities

POES | GOES | Aqua | METEOSAT | MTSAT | DMSP

POES Algorithm Processing

GOES Algorithm Processing

Aqua Algorithm Processing

Meteosat Processing

MTSAT Algorithm Processing

DMSP Algorithm Processing

POES produ

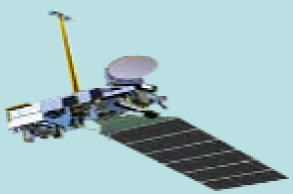
Aqua products

METEOSAT products

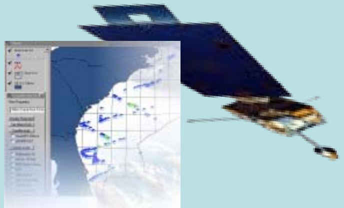
MTSAT products

DMSP products

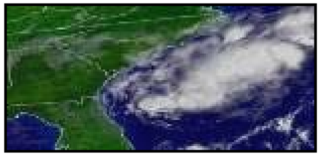
Old era: Software and algorithms tailored to specific satellite data streams

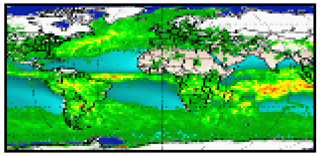


Satellites and Measurements from GEOSS

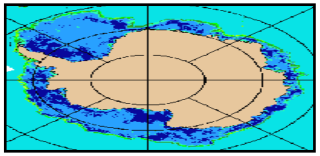


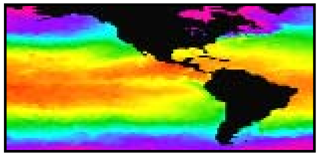
Integrated Algorithm and Product Processing System





<u>Best earth observations & products</u>





New era: Software and algorithms work for variety of satellite and in-situ data streams