Ultraspectral Infrared Measurements from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft

INTERNATIONAL SYMPOSIUM ON
SPECTRAL SENSING RESEARCH 2003
(ISSSR 2003)

3 June 2003

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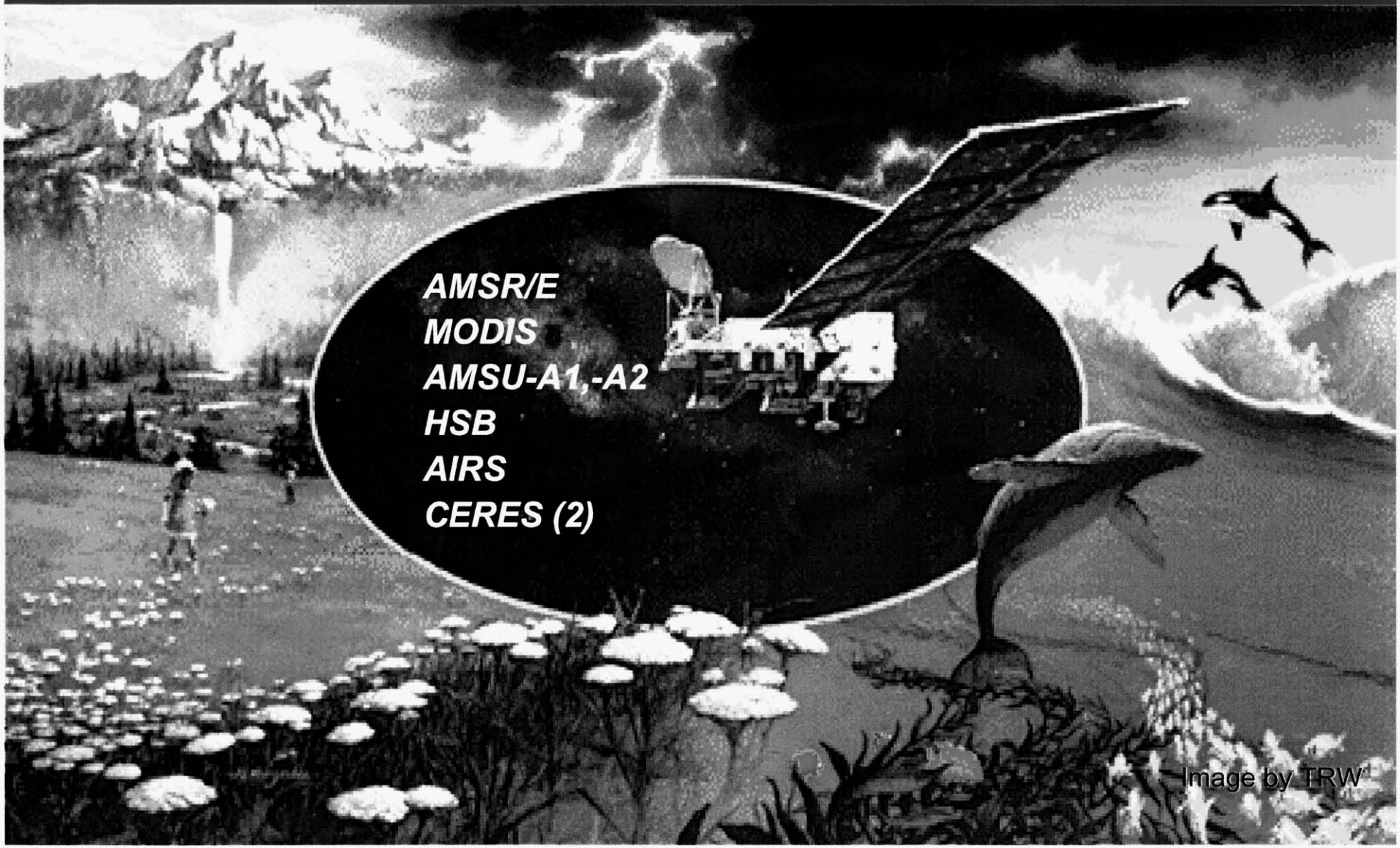
Agenda

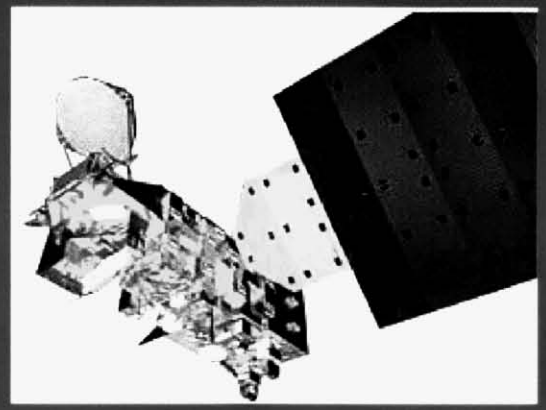
- Science Objectives
- AIRS/AMSU/HSB Instruments
- NASA Ultraspectral IR Technology Development
- In-Flight Performance
  - *Level 1B Radiances, Level 2 Temperature Products*
- Distribution Status
- Early Applications Results
- Future Mission Plans

AQUA MEASURES EARTHS WATER CYCLE, ENERGY FLUXES, VEGETATION, AND TEMPERATURES



AIRS/AMSU/HSB MISSION OVERVIEW

Spacecraft:	**EOS Aqua**
Launch Date:	**May 4, 2002**
Launch Vehicle:	**Boeing Delta II Intermediate ELV**
Mission Life:	**5-7 years**
Team Leader:	**Dr. Moustafa Chahine**



AIRS/AMSU/HSB EARTH SCIENCE QUESTIONS AND APPLICATIONS

1. **The global water and energy cycle:** Is the cycle of evaporation and precipitation on Earth accelerating?
2. **Determine the distribution and variations of water vapor -** Earth's primary greenhouse gas
3. **Climate weather connection:** Are current weather anomalies (hurricanes, droughts) connected to climate change and how?
4. **Improving weather prediction:** NOAA is a user together with 6 other weather prediction centers in Europe, America, Australia and Japan
5. **Trace Gasses:** Will provide the first satellite global map of the distribution of atmospheric concentration of CO_2

AIRS-AMSU-HSB

Atmospheric Infrared Sounder

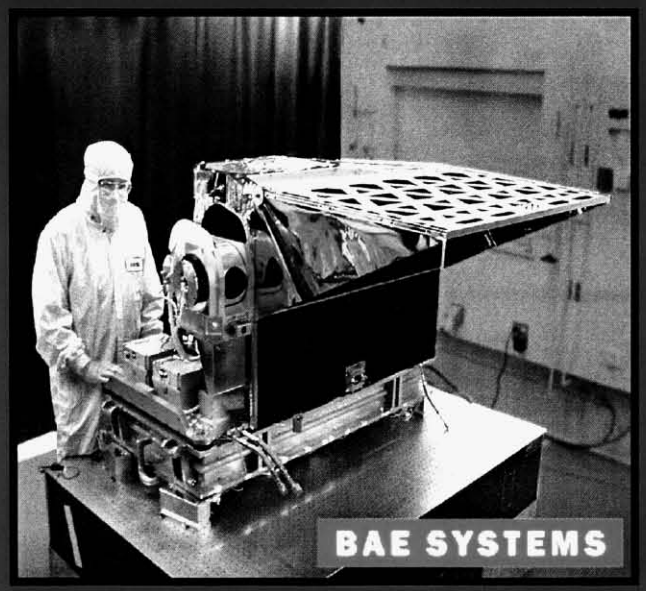
Advanced Microwave Sounding Unit

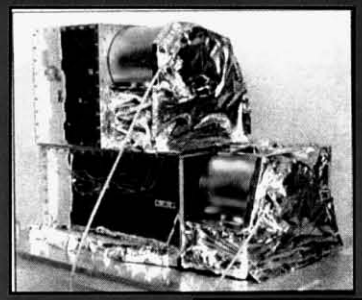
Humidity Sounder for Brazil

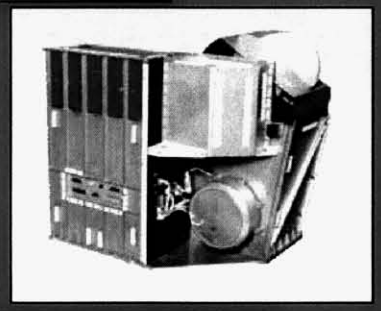
AIRS/AMSU/HSB ACHIEVE GLOBAL COVERAGE WITH RADIOSONDE ACCURACY

- Today radiosondes collect data with high accuracy but are mostly over land
  (Ocean is 70% of Earth's Surface)
- Earlier weather satellites had global coverage but were equipped with less accurate instruments
- AIRS/AMSU/HSB on Aqua achieves global coverage of temperature and water vapor with radiosonde accuracy
- 324,000 observations per day (4000 for radiosondes)
- Combined IR and Microwave observations permits sounding up to 80% cloudy
- Less than 2% of AIRS/AMSU/HSB Observations are truly clear

AQUA SOUNDING SUITE







AIRS

- Infrared: 3.74-15.4 μm, 2378 Channels
- IR Spectral Resolution: ≈ 1200 ($\lambda/\Delta\lambda$)
- IR IFOV : 1.1° x 0.6° (13.5 km x 7.4 km)
- Visible: 4 Channels, 2.3 km
- Scan Range: ±49.5°

AMSU

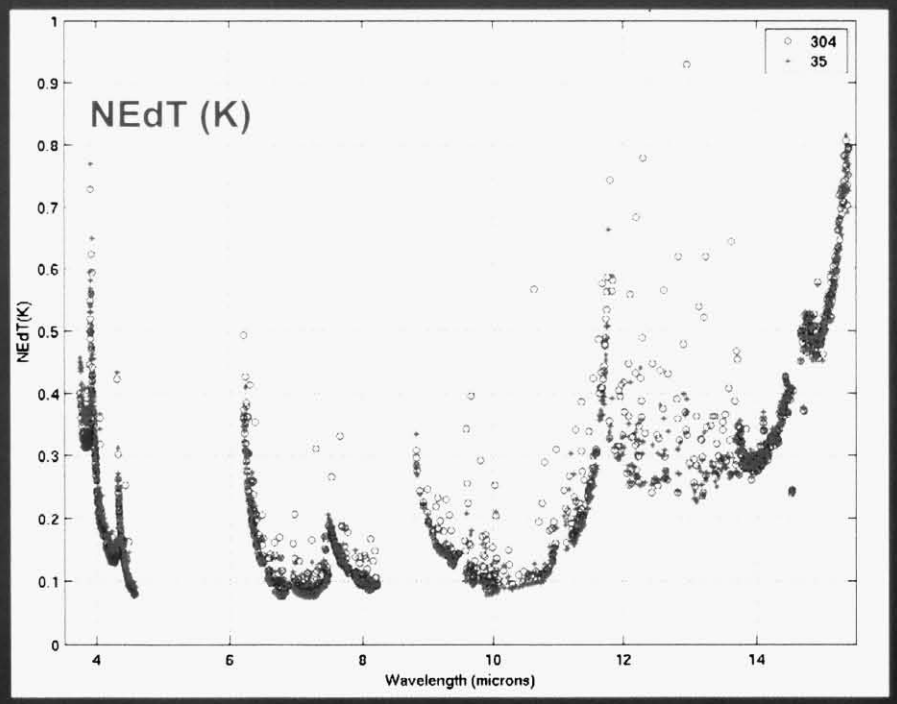
- Microwave: 23-89 GHz, 15 Channels
- IFOV : 3.3°, 43 km
- Scan Range: ±49.5°

HSB

- Microwave: 150-183 GHz 4 Channels
- IFOV : 1.1°, 13.5 km
- Scan Range: ±49.5°

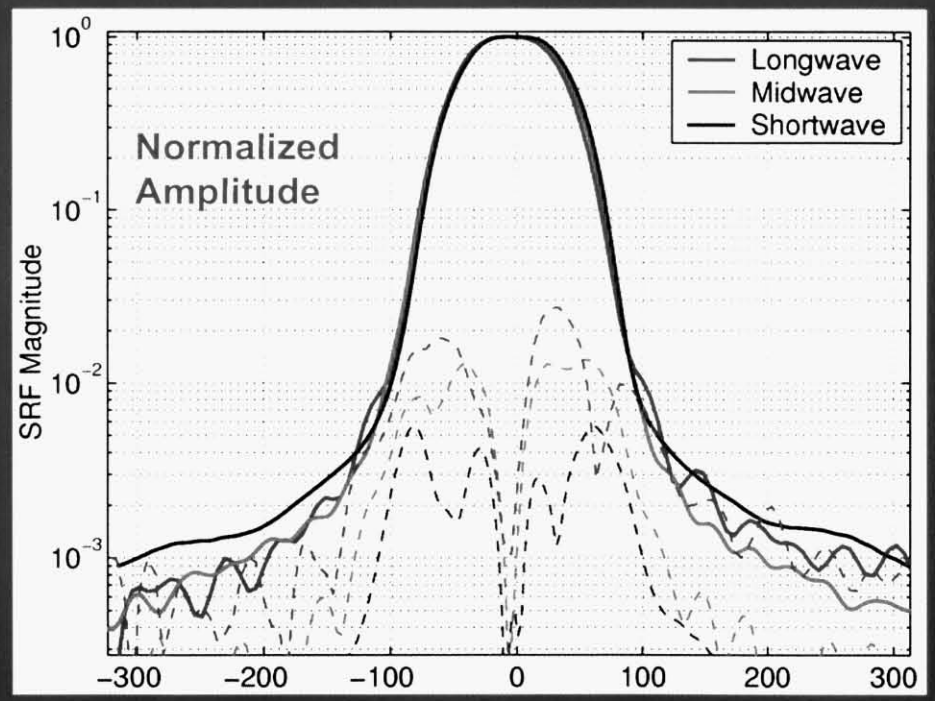
PRE-FLIGHT RADIOMETRIC SENSITIVY AND SECTRAL RESPONSE LOOK GOOD FOR AIRS

Radiometric Sensitivity is High Stable: Launch to Orbit



Wavelength (μm)

SRF Shape Well Characterized to <10^{-3}



Freq (% FWHM)

Temperature Dependence Well Behaved

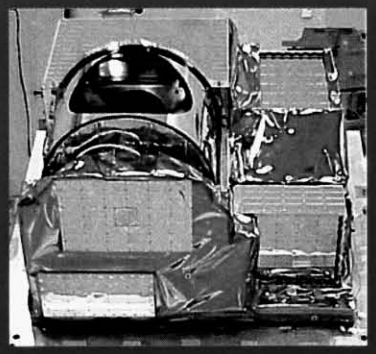
AQUA WAS LAUNCHED ON MAY 4, 2002

- Delta 2 Launch Vehicle
- 6 Strap On Boosters
- Extended Fairing
- 2:55 AM
- Vandenburg Air Force Base, California
- 705.3 km Orbit
- Polar Sun Synchronous
- 1:30 PM Equatorial Crossing
- Ascending Daytime

OPERATIONS AND CALIBRATION STATUS

- AIRS and AMSU Operating normally
  - *Icing under control. No need for defrost for a couple years*
  - *AIRS Radiometric and Spectral Calibration looks good.*
  - *No change to L1B radiometric calibration coefficients since before launch.*
  - *Spectral and Spatial Knowledge Determined to Required Accuracy*
  - *AMSU calibration under review*
- HSB Not Operating
  - *Feb 5, 2003 Motor stalled*
  - *Motor Current high*
  - *Several tests performed in March and April have not been successful*
  - *Apparent Loss of Motor Winding*

HSB



AIRS/AMSU/HSB DATA PRODUCTS

Radiance Products (Level 1B)	RMS Uncertainty*	Horizontal Resolution
AIRS IR Radiance	3%	15 x 15 km
AIRS VIS/NIR Radiance	20%	2.3 x 2.3 km
AMSU Radiance	0.25-1.2 K	45 x 45 km
HSB Radiance	1.0-1.2 K	15 x 15 km
Standard Core Products (Level 2)		
Cloud Cleared IR Radiance	1.0K	45 x 45 km
Sea Surface Temperature	0.5K	45 x 45 km
Land Surface Temperature	1.0K	45 x 45 km
Temperature Profile	1K	45 x 45 km
Humidity Profile	15%	45 x 45 km
Total Precipitable Water	5%	45 x 45 km
Fractional Cloud Cover	5%	45 x 45 km
Cloud Top Height	0.5 km	45 x 45 km
Cloud Top Temperature	1.0 K	45 x 45 km

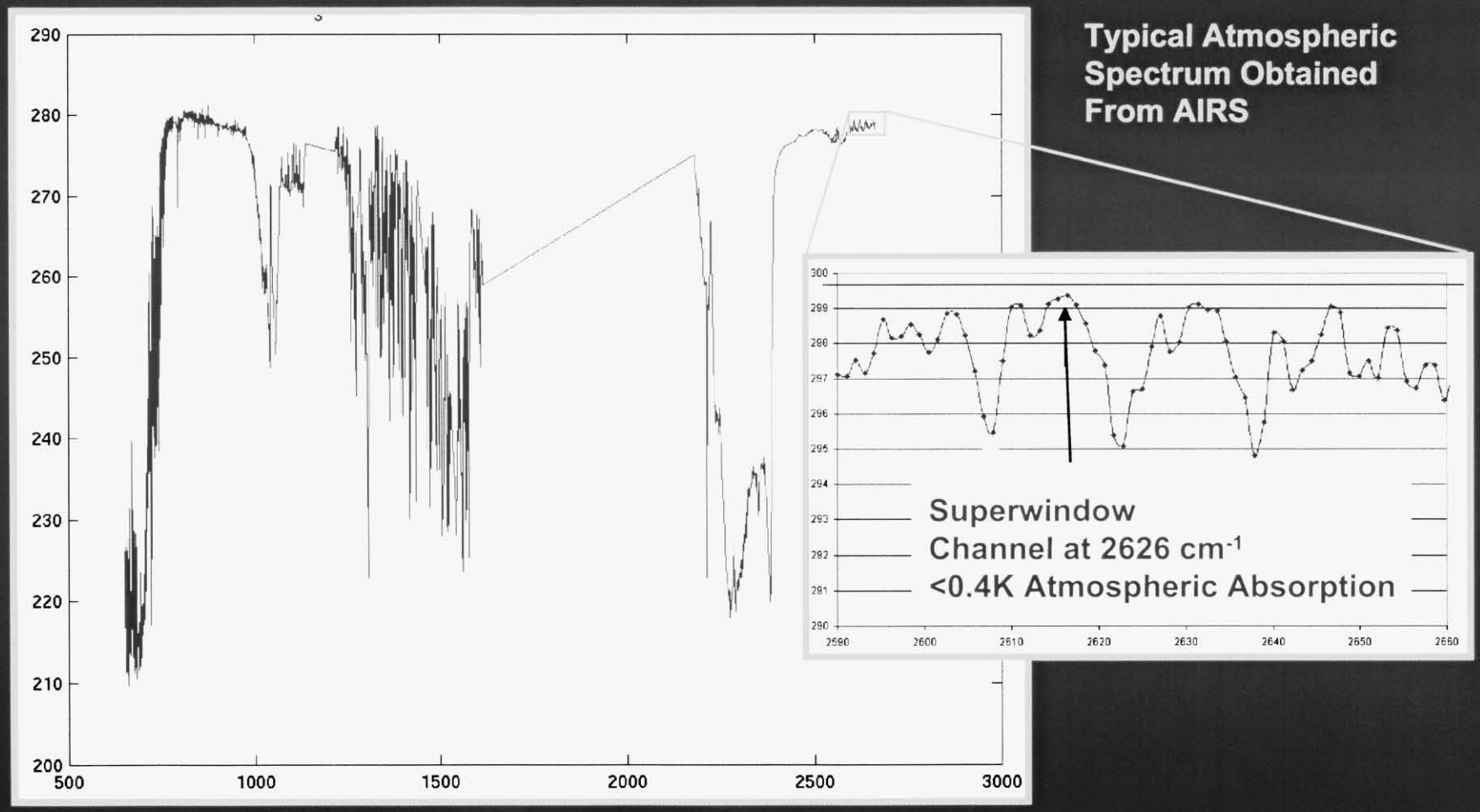
Vertical Resolution

1 km below 700 mb
2 km 700-30 mb

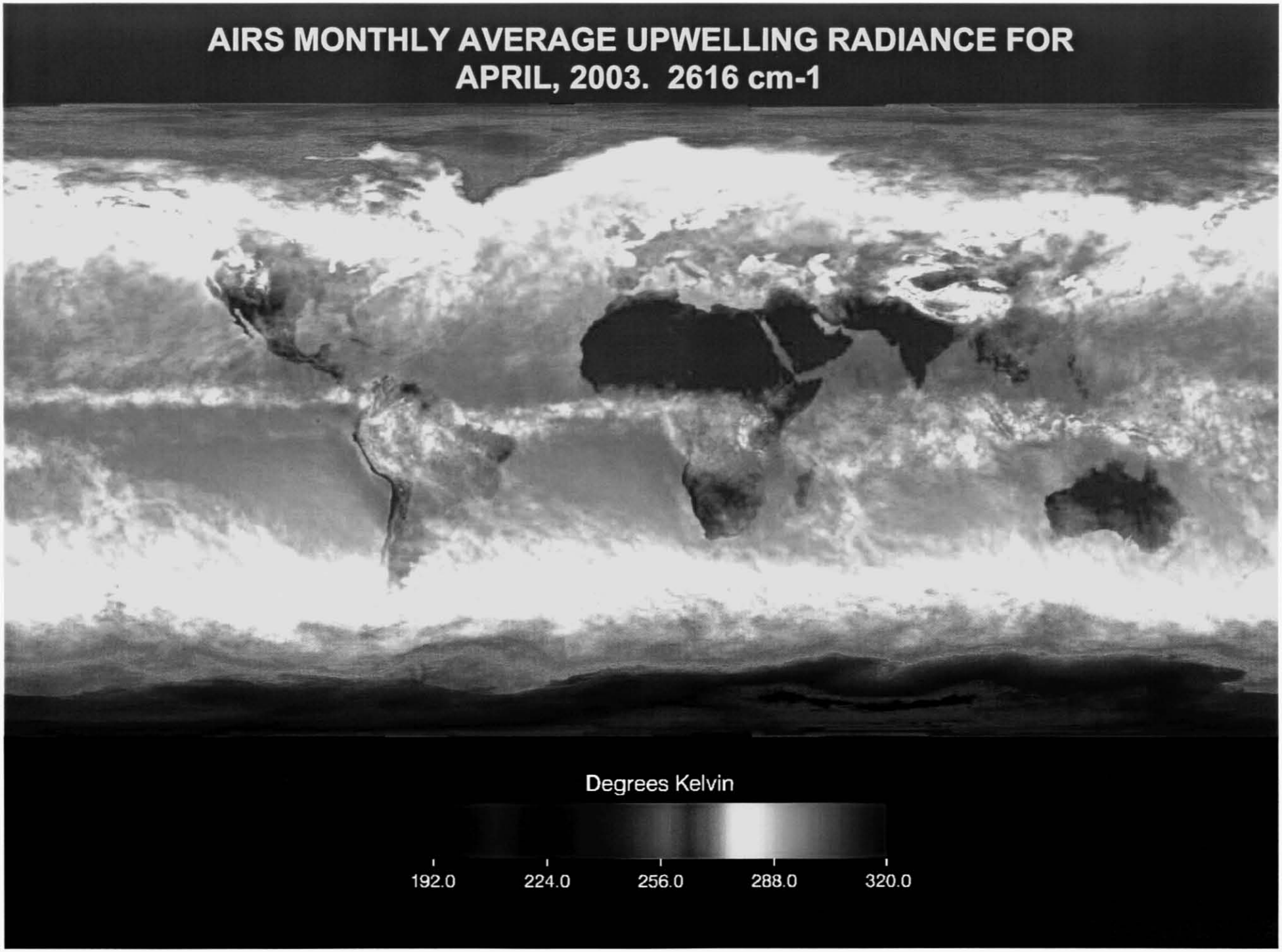
2 km in troposphere

LEVEL 1 PRODUCTS STATUS

ADVANCED MICROWAVE SOUNDING UNIT (AMSU) INSTRUMENTS AND SCIENCE



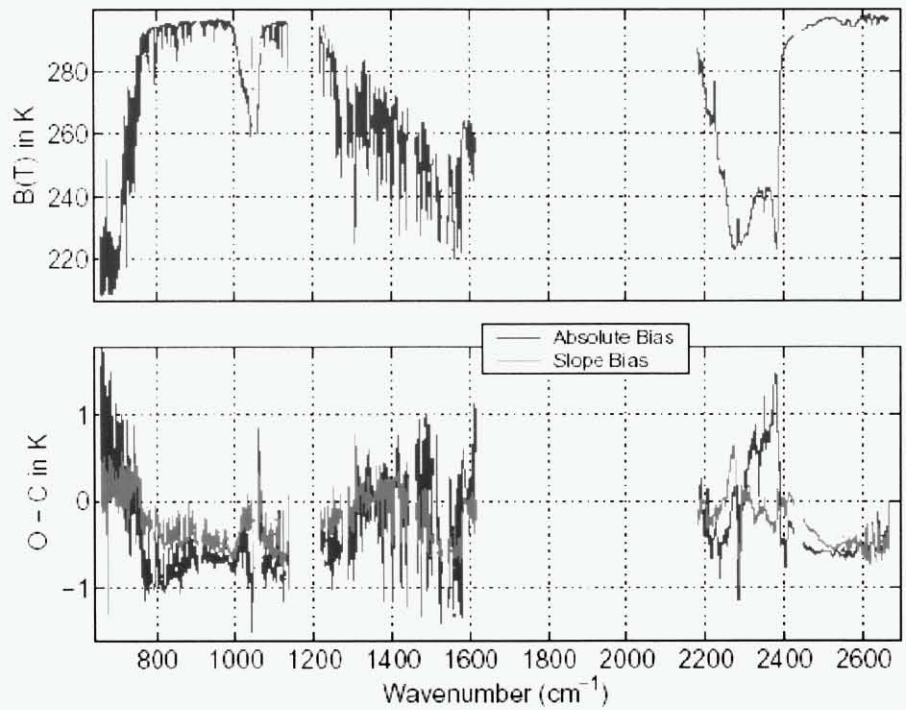
Typical Atmospheric Spectrum Obtained From AIRS


AIRS MONTHLY AVERAGE UPWELLING RADIANCE FOR
APRIL, 2003. 2616 cm-1
Degrees Kelvin
192.0
224.0
256.0
288.0
320.0

AIRS RADIANCES (LEVEL 1B) SHOW EXCEPTIONAL ACCURACY IN FLIGHT

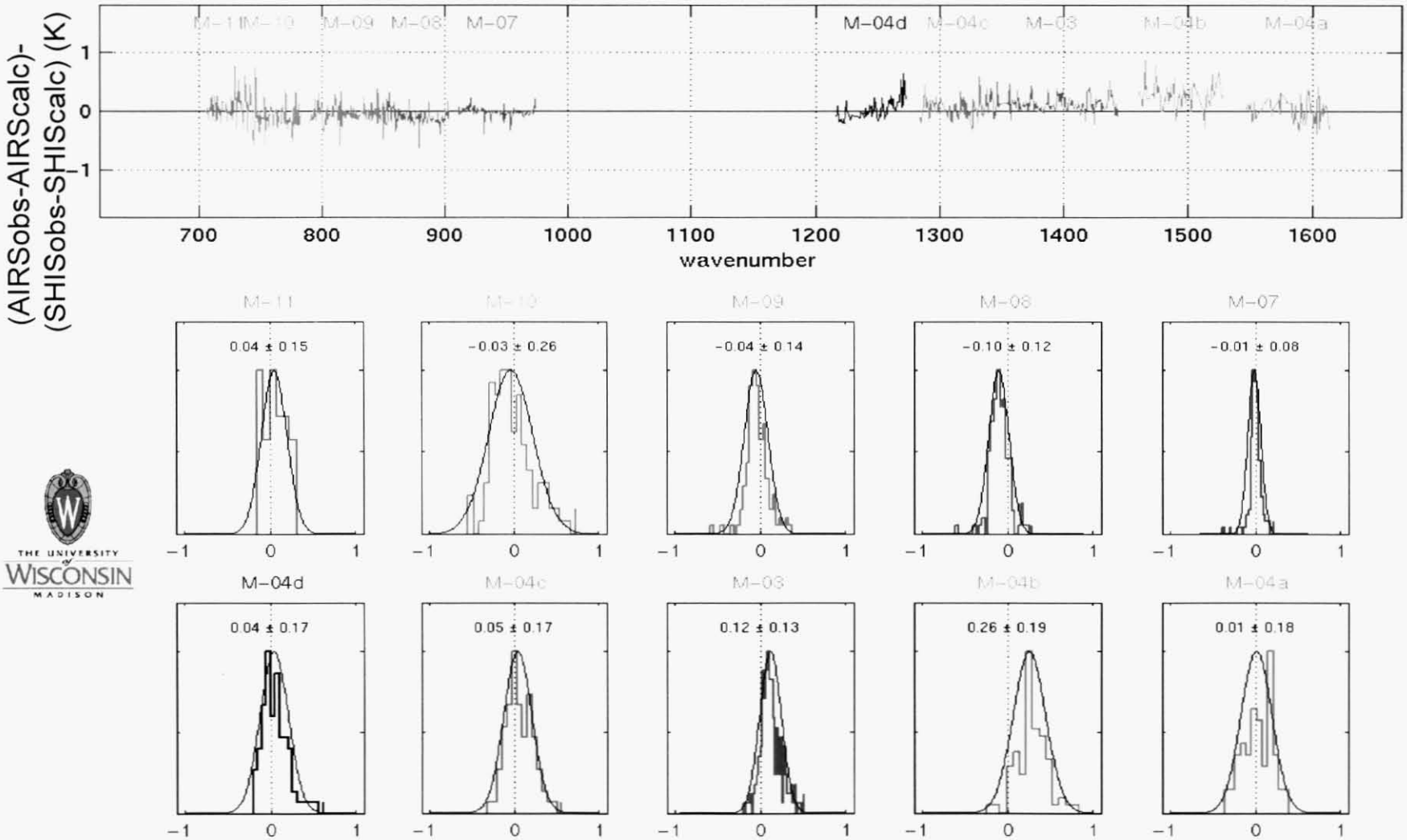
AIRS RADIANCE DATA VALIDATES ECMWF FORECAST MODELS

ECMWF Bias; Absolute, Bias Derived from Bias vs Secant(θ)



AIRS RADIANCE BIAS IS LESS THAN 0.5K ACROSS THE SPECTRUM

SCANNING HIS ON PROTEUS SHOWS RADIANCE AGREEMENT WITH AIRS TO 0.2K ACCURACY

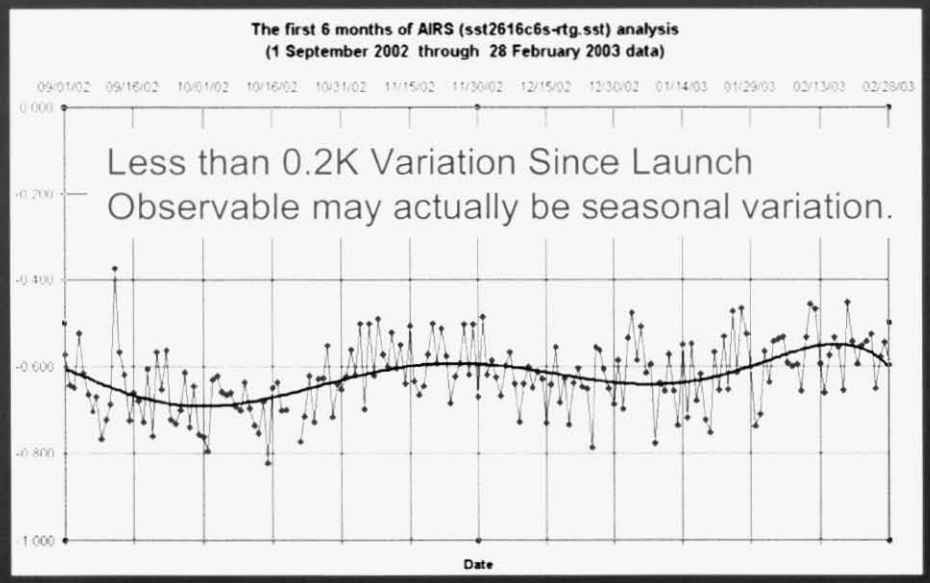


THE UNIVERSITY of WISCONSIN MADISON

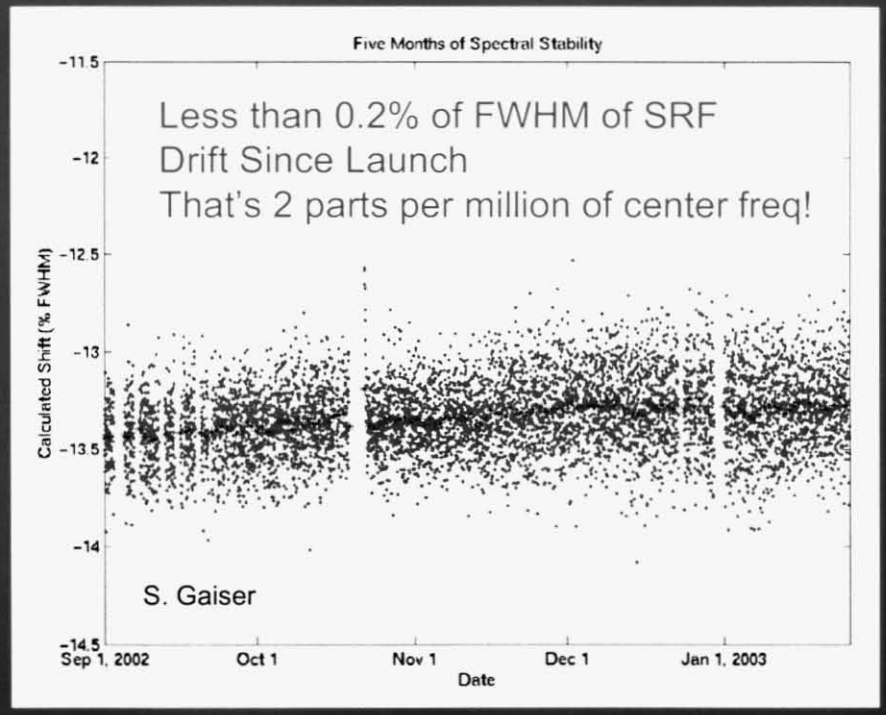
AIRS HAS DEMONSTRATED EXCELLENT IN-FLIGHT RADIOMETRIC AND SPECTRAL STABILITY

STABILITY IS CRITICAL FOR LONG TERM CLIMATE STUDIES

Radiometric Stability (K)
In Orbit Compared to Global SST



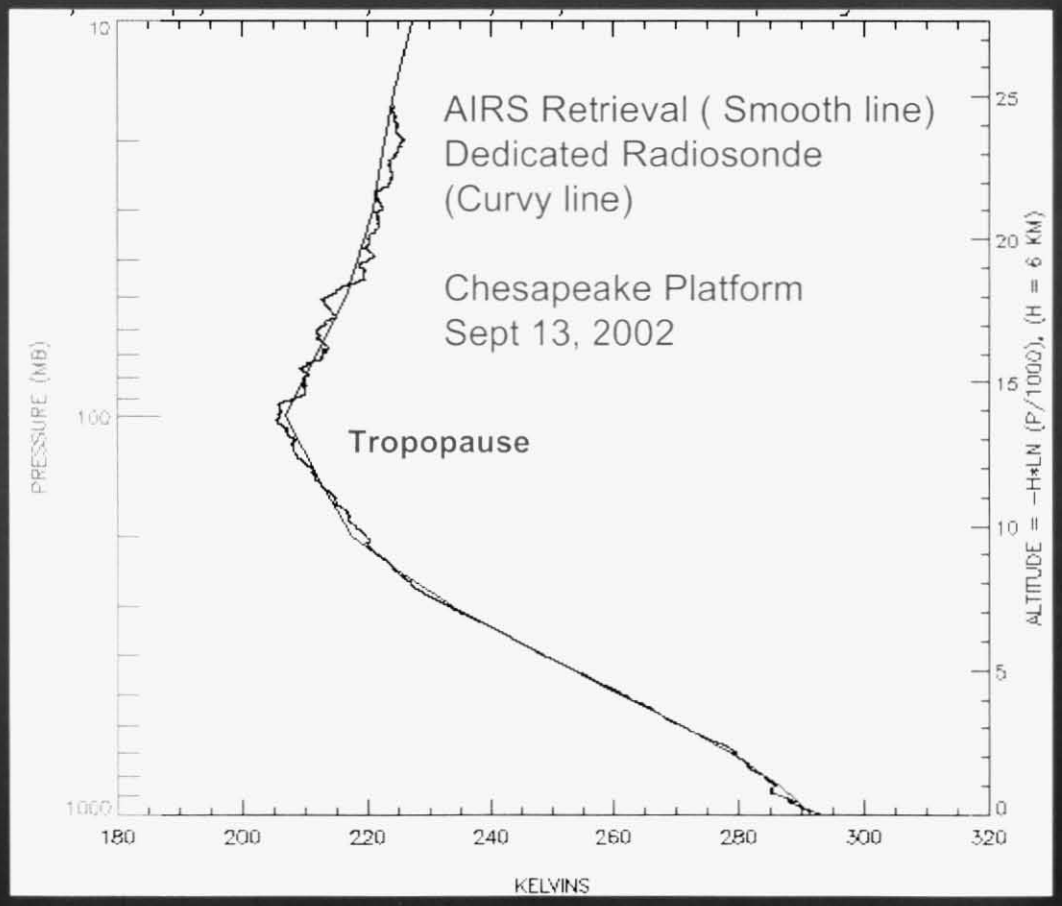
Spectral Stability (%FWHM)
In-Orbit Compared to Global Upwelling Features

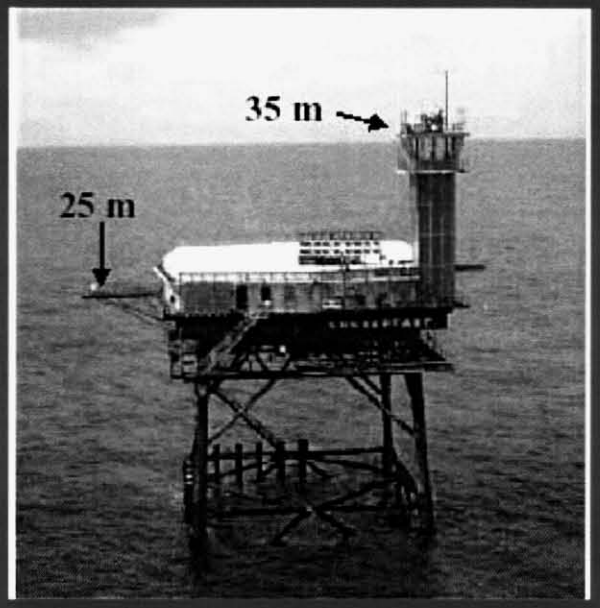


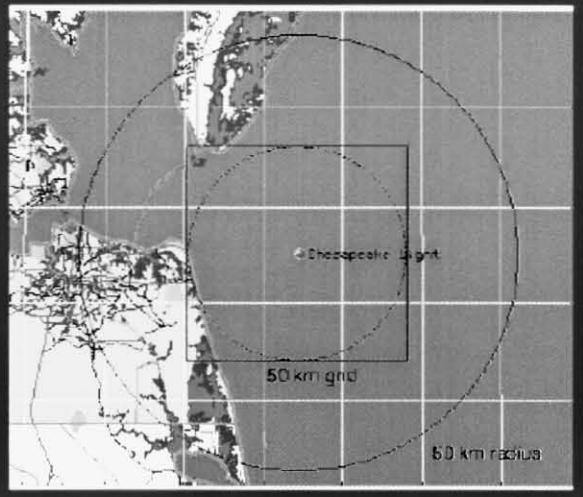
STABILITY PRIMARILY ATTRIBUTED TO USE OF COOLED GRATING SPECTROMETER OPTICS

LEVEL 2 PRODUCTS STATUS

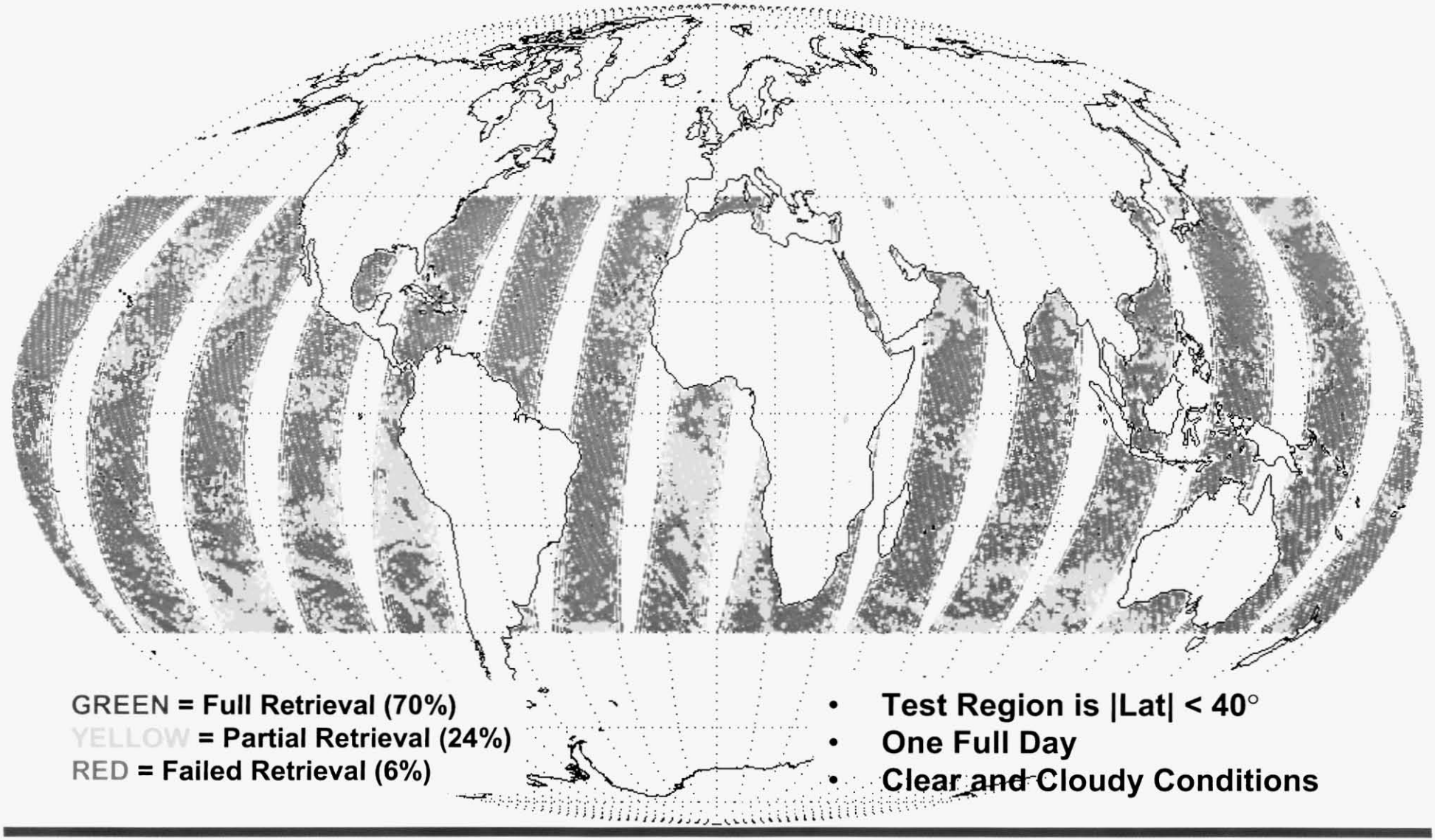
TEMPERATURE PROFILE (LEVEL 2) COMPARED TO VALIDATION SITES: RESULTS LOOK GOOD







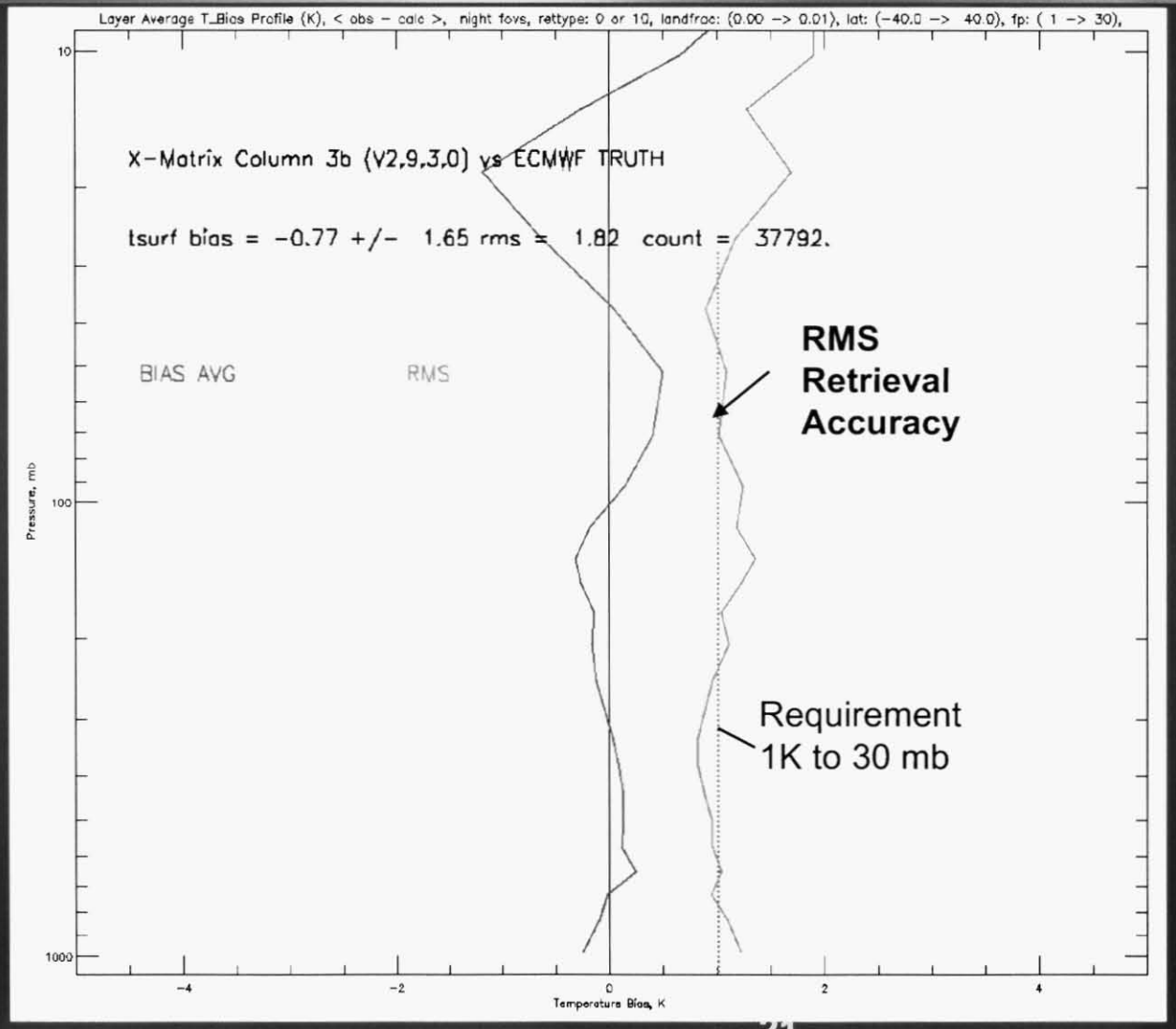
SUCCESSFUL LEVEL 2 YIELD OVER 70% OF TEST AREA



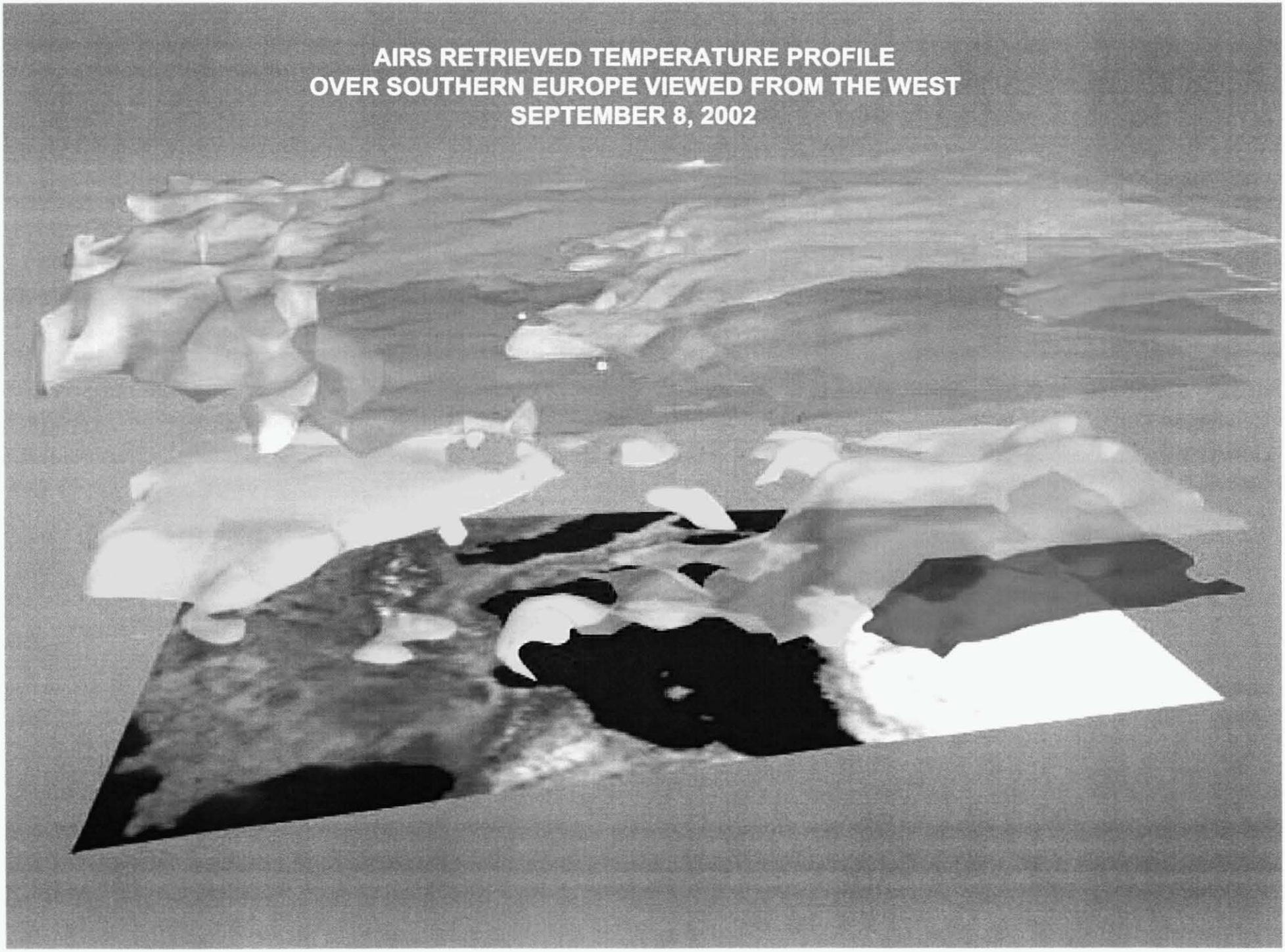
GREEN = Full Retrieval (70%)
YELLOW = Partial Retrieval (24%)
RED = Failed Retrieval (6%)

- Test Region is |Lat| < 40°
- One Full Day
- Clear and Cloudy Conditions

AIRS/AMSU/HSB RETRIEVALS SHOW GOOD AGREEMENT WITH ECMWF FORECASTS



- September 6, 2003
- Night, Ocean, |LAT| < 40°
- Clear and Cloudy: 70% Yield


AIRS RETRIEVED TEMPERATURE PROFILE
OVER SOUTHERN EUROPE VIEWED FROM THE WEST
SEPTEMBER 8, 2002

PRODUCT DISTRIBUTION STATUS

AIRS PRODUCT RELEASE STRATEGY

- All radiance products contained in individual files for each instrument
- One file for cloud cleared products
- Remaining Level 2 products contained within
  - *L2 Standard Products File*
  - *L2 Support File (more detail)*
- Each file contains 6 minutes of data
- All products will be released to the public with each delivery (First public release in July 2003)
- Products will be flagged to indicate quality and validation status
- A validation report accompanies each release

AIRS DISTRIBUTION CENTERS

NOAA NESDIS

GSFC DAAC

DIRECT BROADCAST

NWP Centers

- NASA/GSFC/DAO –*Bob Atlas*
- NOAA/NCEP – *Steve Lord*
- FNMOC – *Naval Research Lab*
- ECMWF – *Tony McNally*
- UK Met Office – *Roger Saunders*
- Meteo France – *Florence Rabier*
- Canada Met Service – *Clement Chuoinard*
- Japan NPD/JMA – *Masahide Kimoto*
- Australia (B of M) - *John Le Marshall*

- Science Community
- Public

- Universities
- Local Weather Stations
- Brazil (INPE)
- China
- DoD
- Other International

DATA PRODUCTS STATUS

- NOAA delivers 100% of rate buffered (RB) radiance data to NWP Centers within 2:50 from acquisition.
  - *Next: Distribution of Cloud Clear Radiances or L2*
- Version 2.7 (Level 1B Focus) delivered to NOAA and GSFC DAAC
  - *A press release titled "New Data on Weather Prediction" was issued to announce the Level 1B release.*
  - *Next: Distribution of Level 2 Products to Public, July 2003*
- AIRS/AMSU/HSB L1B Data Now Available at the GSFC DAAC
  - *http://daac.gsfc.nasa.gov*
- Version 3.0 Nearing Readiness for Public Release in Early July
  - *Quality Assessment Flags in Preparation*
  - *Validation Report needs high priority. Must be ready prior to public release.*

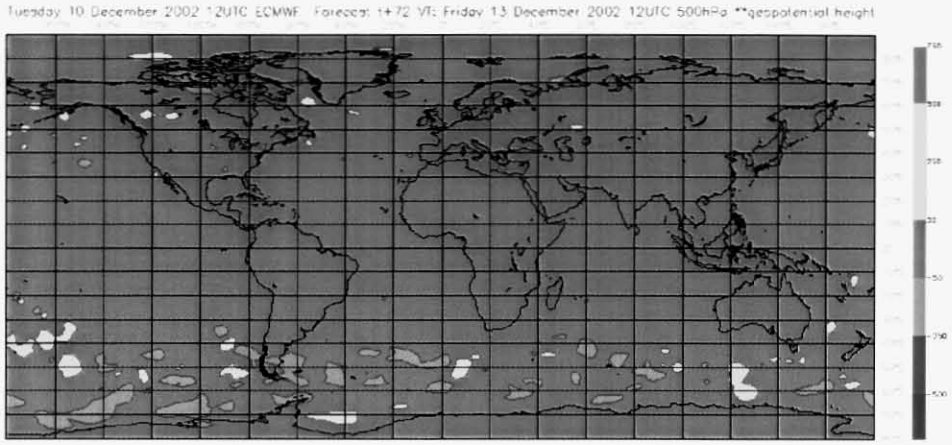
AIRS FORECAST IMPACT (ECMWF)

RMS of 500hPa geopotential forecast error averaged over 40 days (Dec 02/ Jan 03)

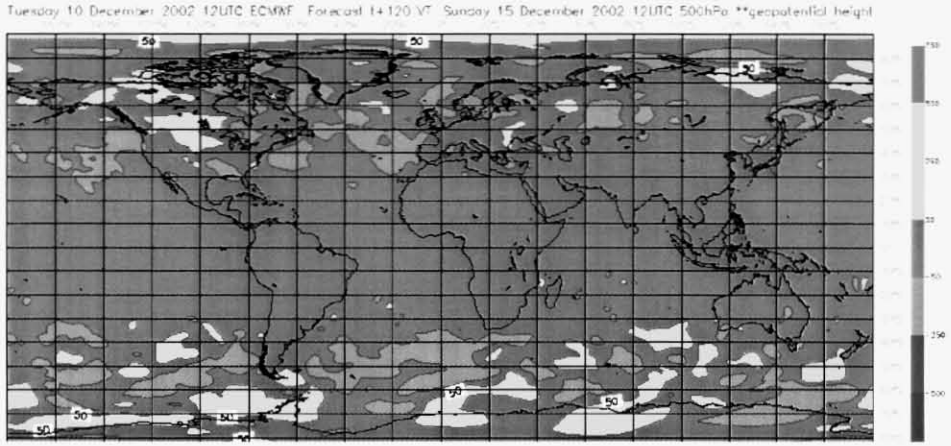
[AIRS error] minus [CTRL error]

The assimilation of AIRS radiances shows a small but consistent positive impact on forecast quality in all areas

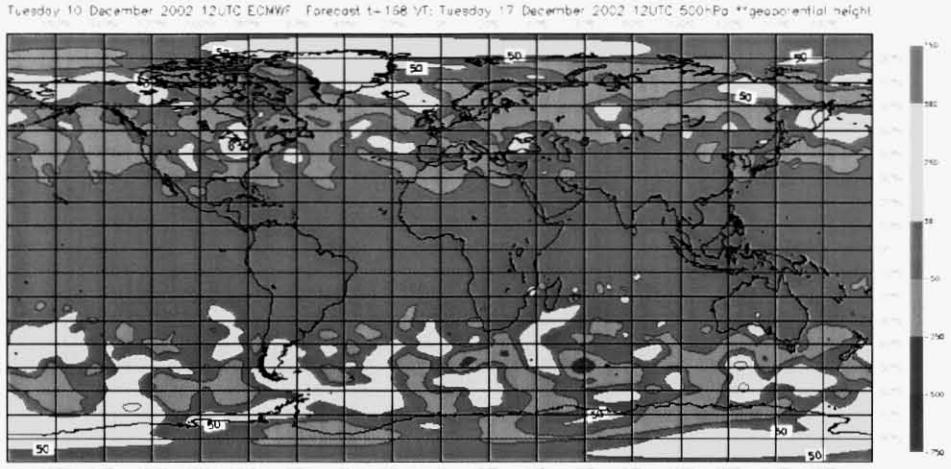
Day-3



Day-5

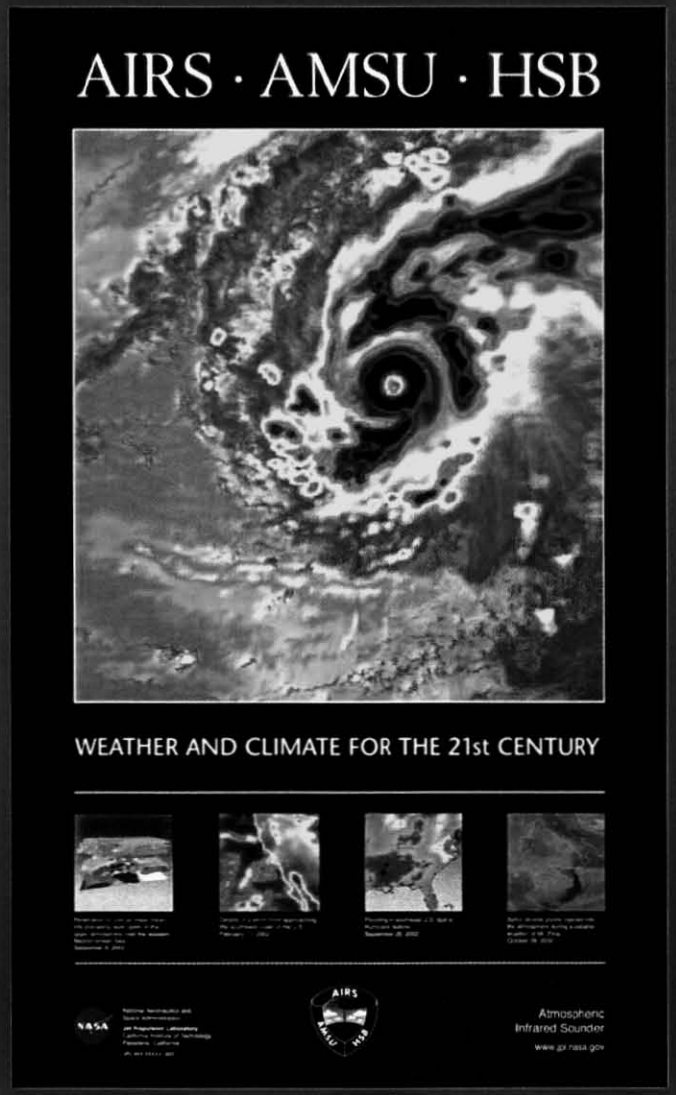


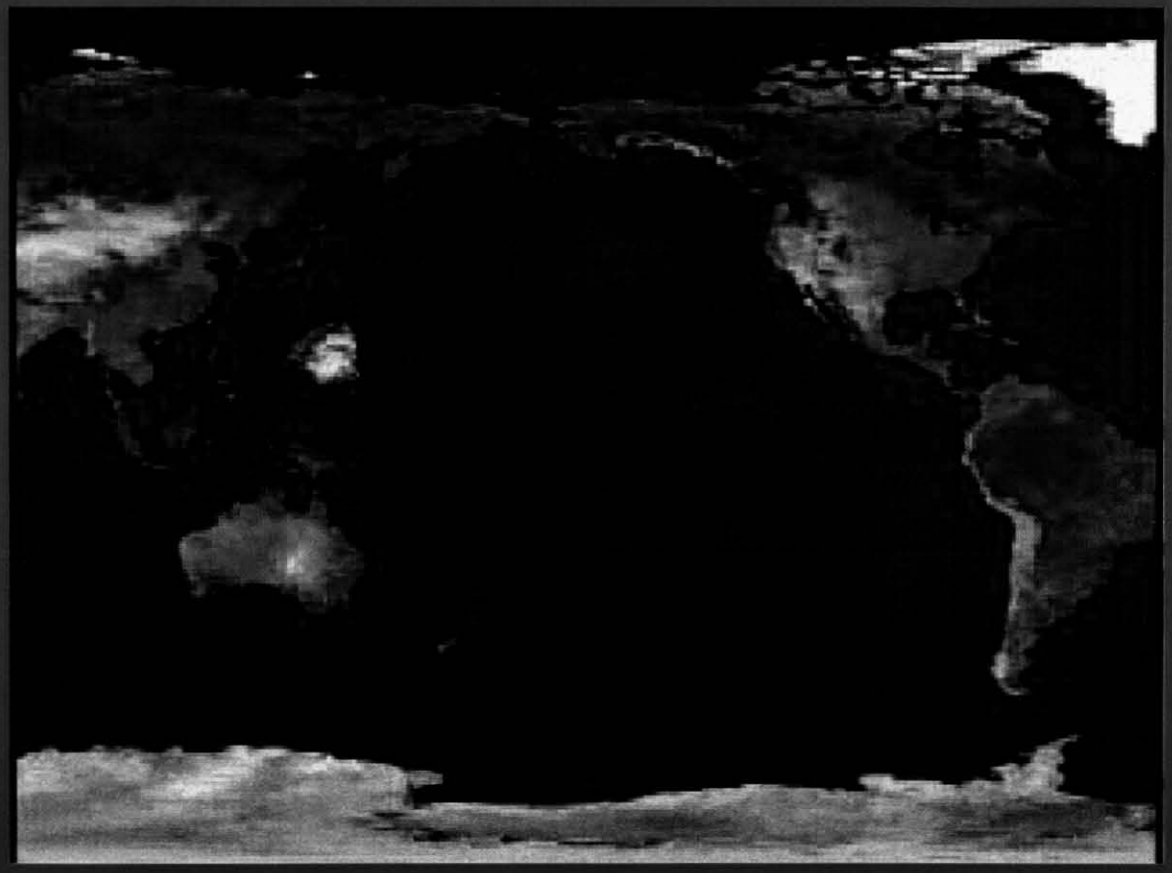
Day-7



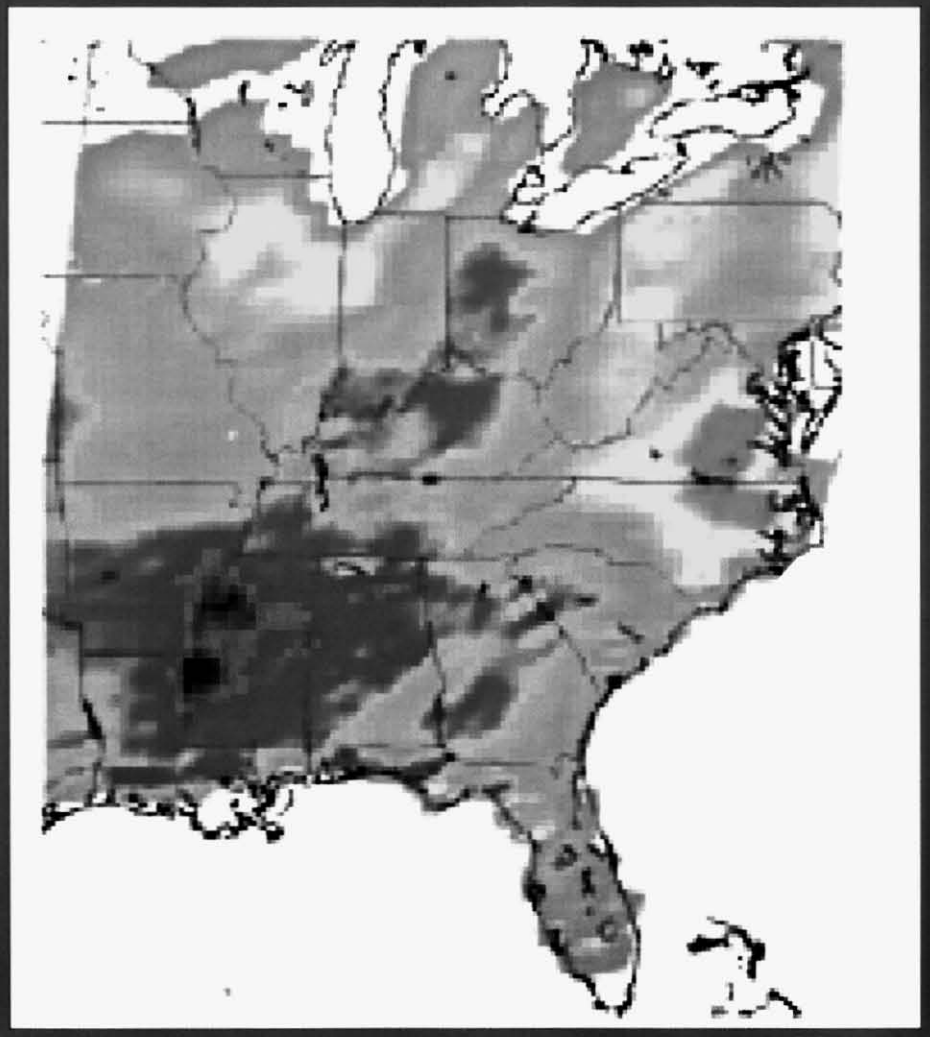
Supertyphoon Pongsona

December 8, 2002



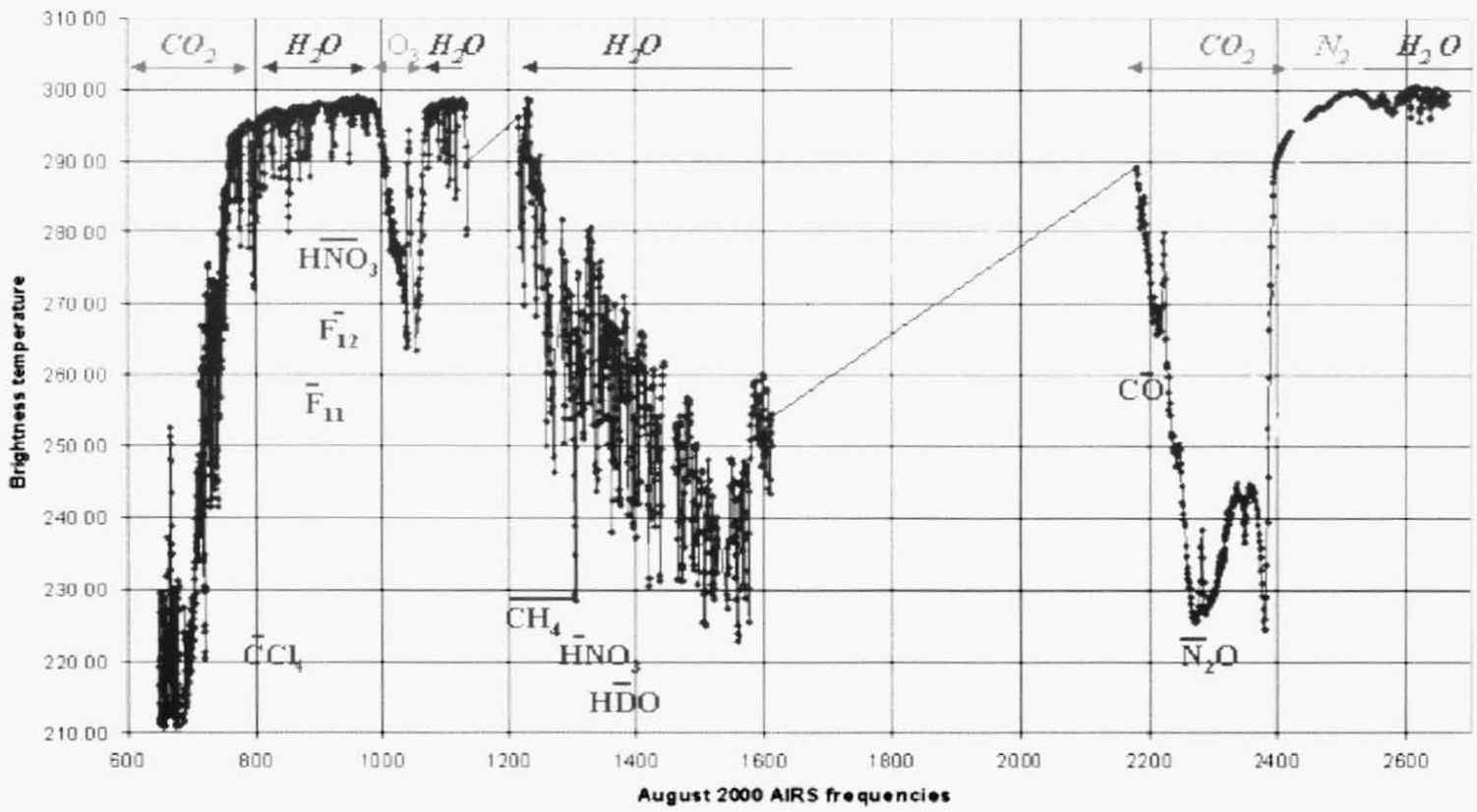


FLOODING FROM ISIDORE

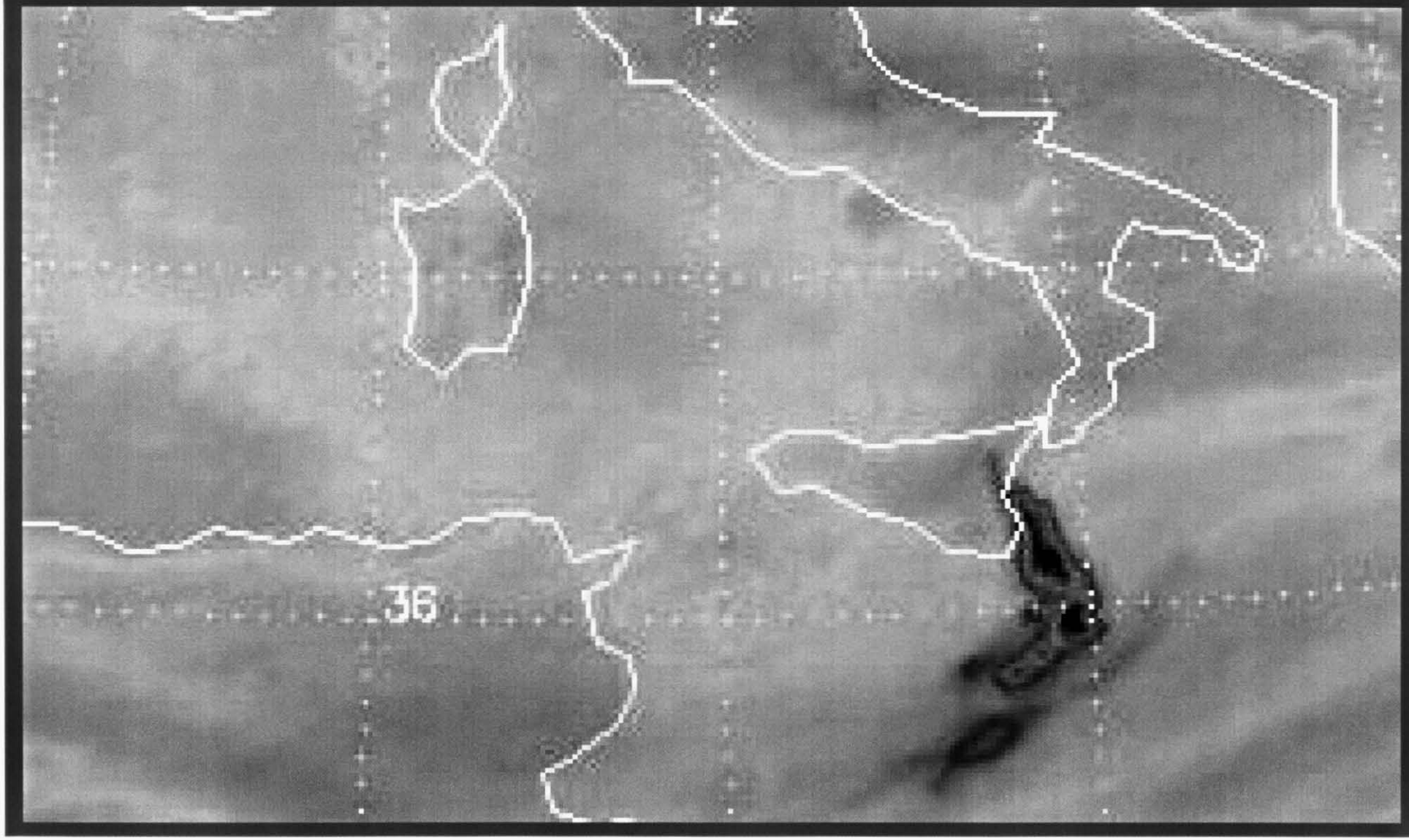


Difference between the AMSU Channel 2 on September 28 and September 12 identifies flooding Tropical Storm Isidore. In the difference image, white indicates no difference at all, green is very little difference, blue/purple indicates primarily heavy flooding. Red indicates warming likely due to warmer weather.

HIGH SPECTRAL RESOLUTION ALLOWS QUANTIFICATION OF MINOR GASSES



AIRS DETECTS SO_2 FROM MT. ETNA



MODIS	AIRS	SIRAS
1 km IR IFOV	13.5 km IR IFOV	0.6 km IR IFOV
3.7-14.2 μm IR	3.7-15.4 μm IR	3.7-15.4 μm IR
16 IR Channels	2378 IR Channels	1024 IR Channels
$\lambda/\Delta\lambda$ = 20-50	$\lambda/\Delta\lambda$ = 1200	$\lambda/\Delta\lambda$ = 1000
NEdT = 0.05 - 0.3 K	NEdT = 0.05 - 0.3 K	NEdT = 0.1 - 0.3 K
Refractive Optics	Grating Spectrometer	Grating Spectrometer
± 55° FOV	± 50° FOV	Refractive Optics
		15° FOV

NASA ATMOSHPERIC SOUNDING FUTURE MISSION PLANS

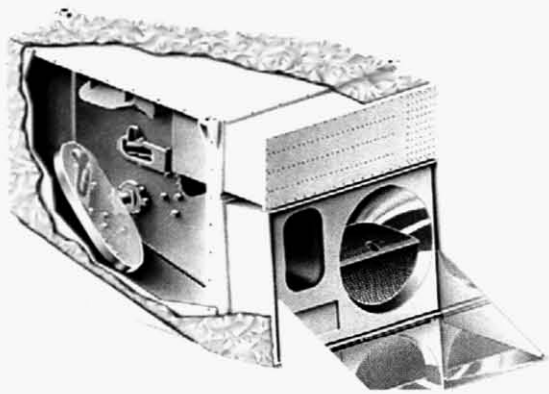
FUTURE REQUIREMENTS FOR EARTH SCIENCE ATMOSPHERIC SOUNDING

- Continue AIRS Capability
  - *15km LEO: Crosstrack Infrared Sounder (CrIS) by NOAA*
- Improve Temporal Resolution
  - *4 km GEO: Geostationary Imaging FTS (New Millenium Program). Technology Demonstration*
  - *GOES-R: Next Generation NASA GEO Sounder*
  - *Medium Earth Orbit (Gives Global Coverage)*
- Improve Spatial Resolution
  - *1km Horizontal, 1km Vertical Resolution*
  - *Improved Global Circulation Models (Weather Forecasting) for Hurricane Tracks, Tornados, Regional*
  - *Improved Minor Gas Quantification*

NEXT GENERATION SOUNDER PROVIDES COMBINED AIRS AND MODIS IR CAPABILITY

The Spaceborne Infrared Atmospheric Sounder

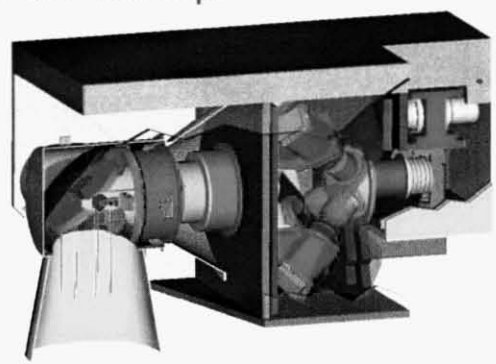
EOS Terra, Aqua



MODIS

- 1 km IR IFOV
- 3.7-14.2 μm IR
- **16 IR Channels**
- **$\lambda/\Delta\lambda$ = 20-50**
- NEdT = 0.05 - 0.3 K
- Refractive Optics
- **± 55° FOV**

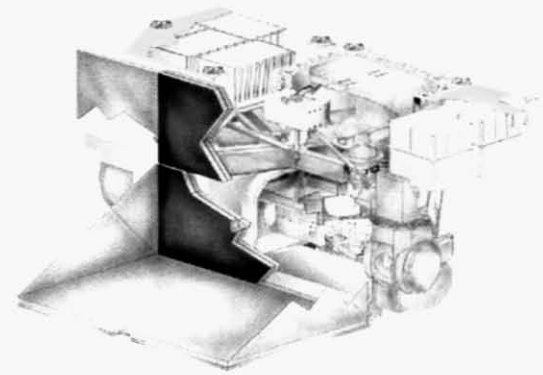
Future Concept



SIRAS

- 0.6 km IR IFOV
- 3.7-15.4 μm IR
- 1024 IR Channels
- $\lambda/\Delta\lambda$ = 1000
- Refractive Optics
- Grating Spectrometer
- NEdT = 0.1 - 0.3 K
- ± 30° FOV

EOS, Aqua

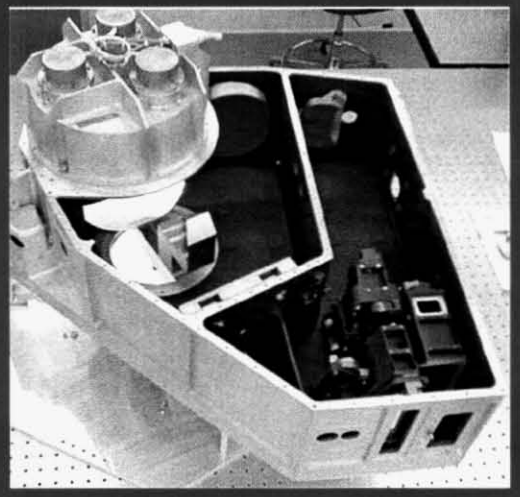


AIRS

- **13.5 km IR IFOV**
- 3.7-15.4 μm IR
- 2378 IR Channels
- $\lambda/\Delta\lambda$ = 1200
- Grating Spectrometer
- NEdT = 0.05 - 0.3 K
- **± 50° FOV**

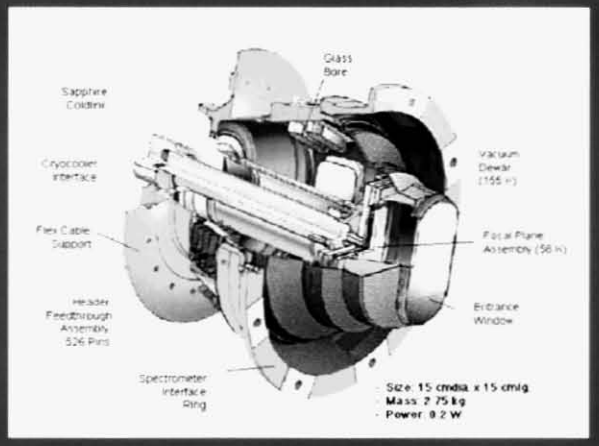
TODAYS IR SENSOR DEVELOPMENT BASED ON AIRS TECHNOLOGY INVESTMENT

AIRS Grating Spectrometer



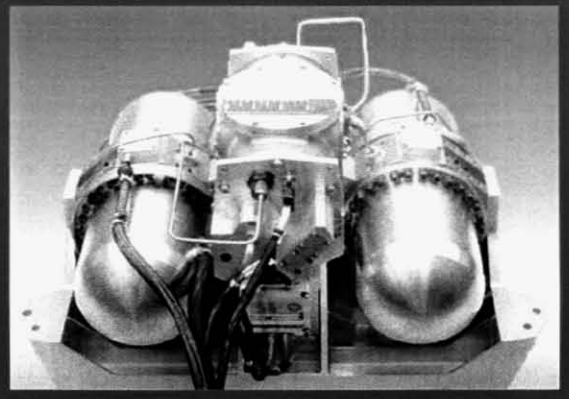
Miniature Spectrometers (SIRAS)

AIRS Dewar Assembly



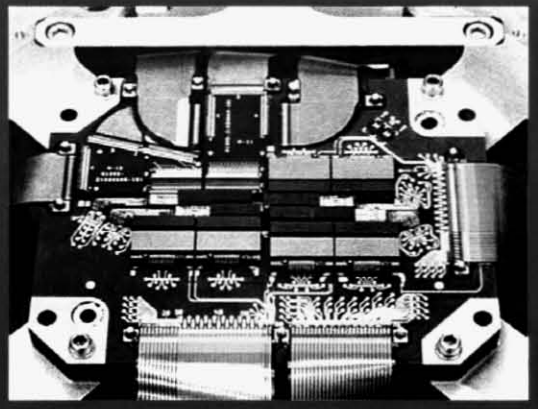
Miniature Low-Heat Load Dewars

AIRS Pulse Tube Cooler

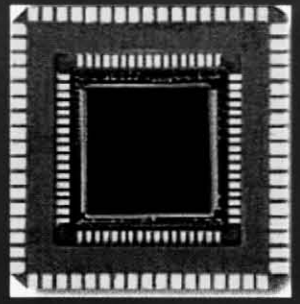


Miniature Pulse Tube Coolers

AIRS Focal Plane Assy



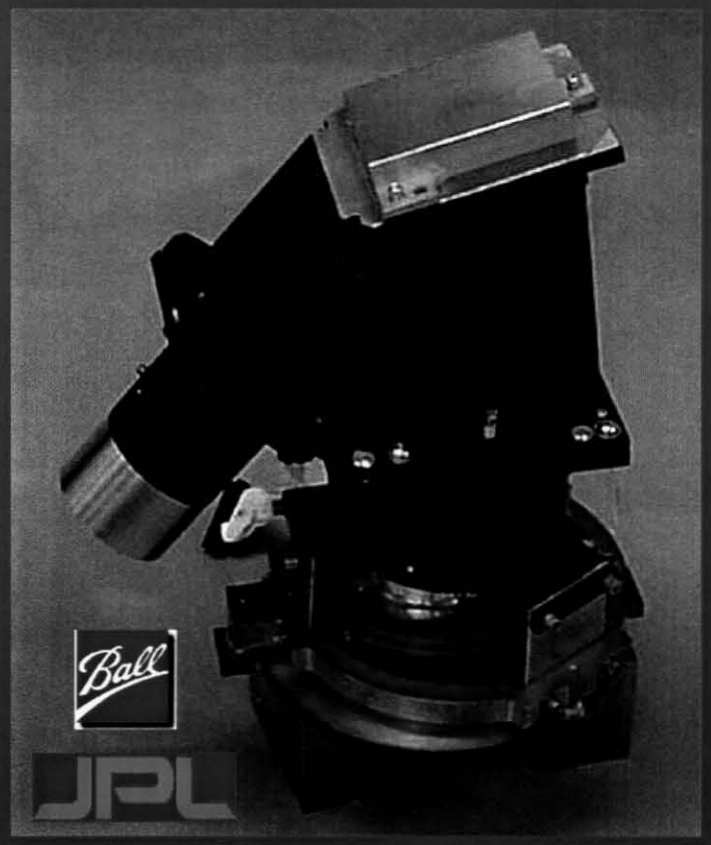
Large Format LW PVHgCdTe



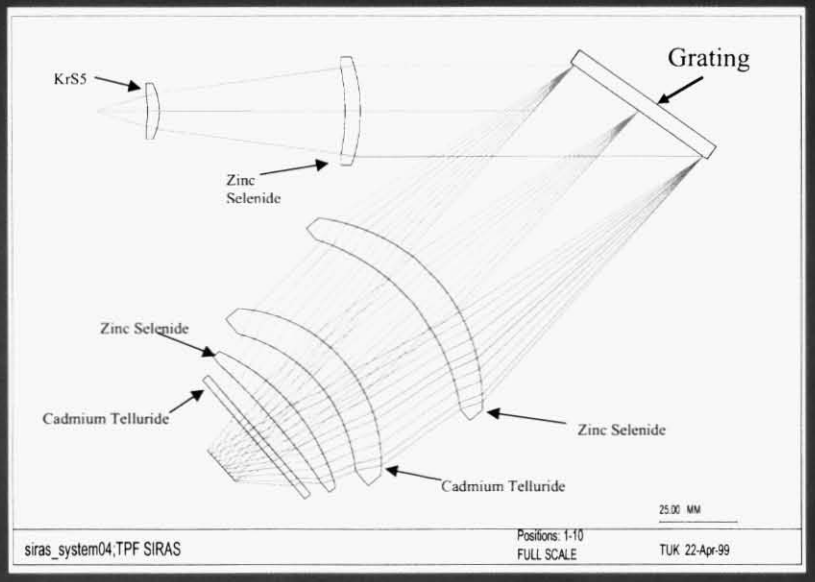
NASA INSTRUMENT INCUBATOR PROGRAM
HYPERSPECTRAL IR DEVELOPMENT

	2001 Complete	2006 In Progress
Spectral		
Range	12 – 15.4 μm	7.8 - 12 μm
Resolution ($\lambda/\Delta\lambda$)	1000	1000
Resolution	<0.8 cm^{-1}	<1.2 cm^{-1}
Spatial		
FOV	16°	13°
IFOV	1 mr	0.8 mr
No. Pixels	1 x 165	256 x 256
Radiometric		
Reference Temp.	250K	TBD
NEdT	0.2 K	TBD
Accuracy	0.2 K	TBD
Mechanical		
Size	10 x 10 x 14 cm	TBD
Mass	2 kg	TBD
Cooling	Liquid	Active

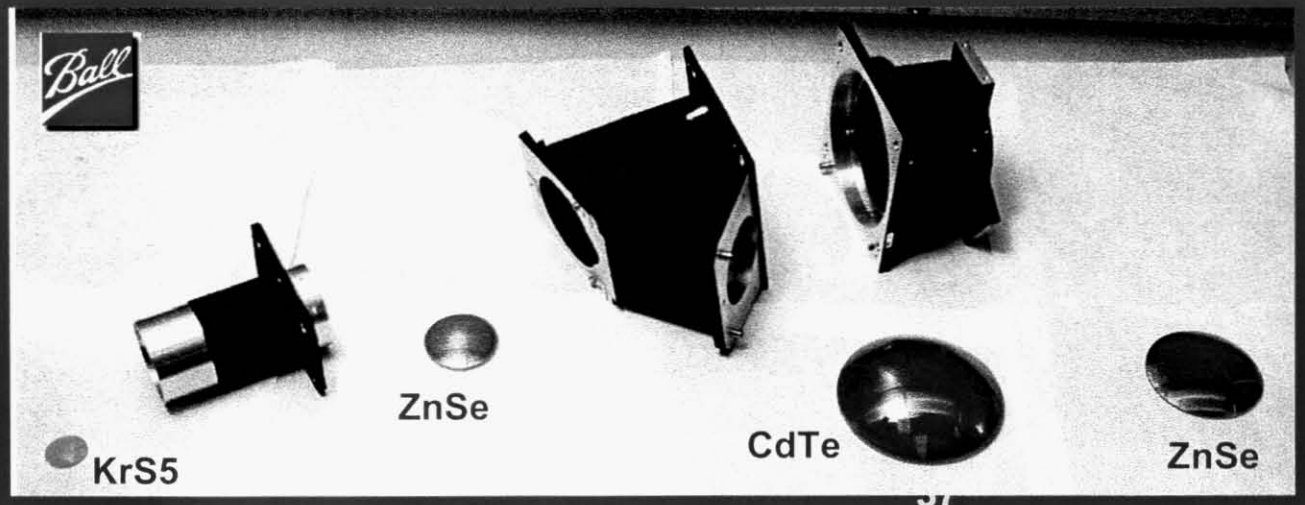
Spaceborne Infrared Atmospheric Sounder (SIRAS): 2001

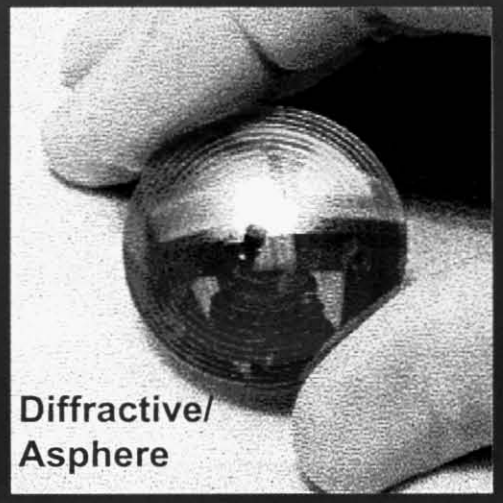


WIDE FIELD INFRARED REFRACTIVE OPTICS MAKE IT POSSIBLE



- **Grating Spectrometer**
  - *No Moving Parts*
  - *No Metrology Lasers*
  - *Vibration Insensitive*
  - *Stable*
- **Wide Field Refractive Optics**
  - *Compact*
  - *Maximum Number of Channels*
  - *Full Field Imaging*

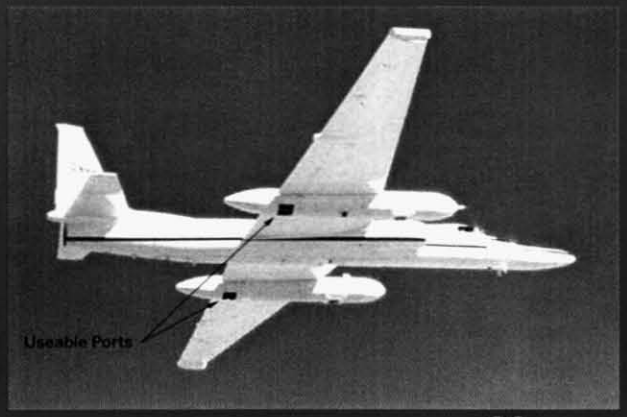




JPL DESIRES TO FLY SIRAS TO SUPPORT SCIENCE AND TACTICAL APPLICATIONS

	Concepts		Existing	
Parameter	SIRAS	WEDGE	SEBASS	AHI
λ (μm)	7.6-13.5	7.6-13.5	7.6-13.5	7-11.5
$\lambda/\Delta\lambda$(μm)	**450**	**70**	**125**	**80**
$\Delta\theta$ (mr)	1.0	1.0	1.0	1.0
N Spectral	256	32	128	32
N Spatial	256	256	128	256
FOV (deg)	14.6	14.6	7.3	7
F-Number	1.7	4	-	4
Mass (kg)	50	40	-	135
Center	JPL	JPL/SBRS	Aerospace	UH

ER2
Altitude: 18.3 km
Resolution: 18.3 m
Swath: 4.68 km

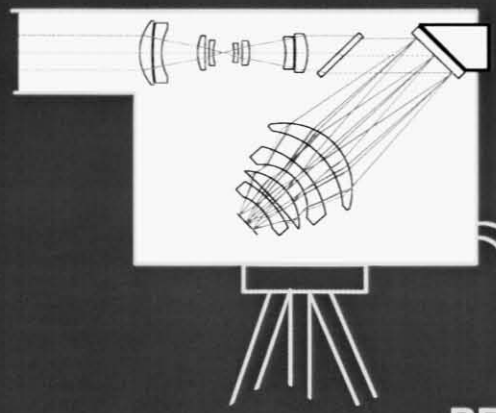


JPL HAS EXTENSIVE EXPERIENCE IN PASSIVE AIRBORNE PROGRAMS

- **AVIRIS (VIS/NIR)**
- **AIR MISR (VIS Multi-Angle)**
- **MASTER (Infrared)**
- **TIMS (Infrared)**
- **AES (infrared)**
- **HAMSR (Microwave)**

JPL SUPPORTS GROUND BASED SOLUTIONS USING SIRAS "TECHNOLOGY INSERTION"

SIRAS IS COMPACT AND LIGHTWEIGHT

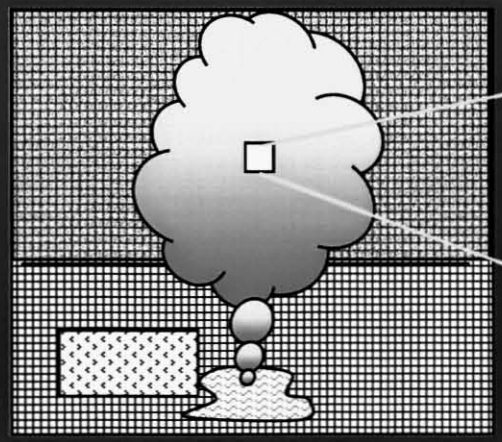


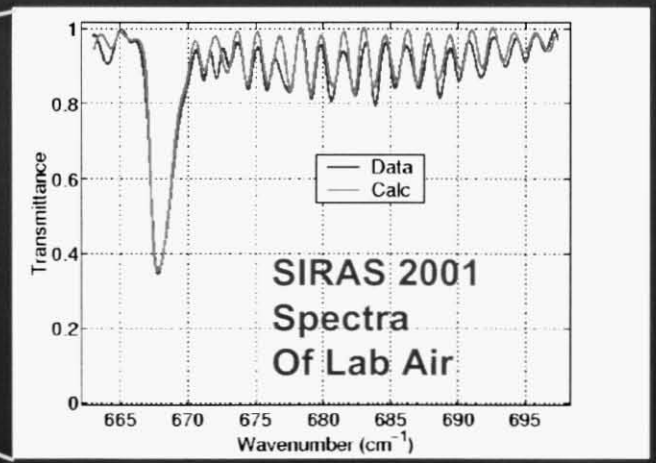
REALISTIC CONCEPT FOR PORTABLE SYSTEM

SIRAS 2006

N

256





SUMMARY AND CONCLUSIONS

- AIRS, AMSU and HSB Launched on the EOS Aqua Spacecraft in May of 2002
- AIRS and AMSU in good health, HSB scanner "off" due to high current reading. Under investigation
- AIRS has good radiometric and spectral sensitivity, stability and accuracy. Suitable for climate studies.
- Temperature products compare well with radiosondes and models over limited test range (|LAT| < 40°)
- Weather centers now receiving AIRS data
- Early trace gas products demonstrate potential of AIRS
- NASA developing next generation of hyperspectral IR imagers
- JPL Ready to participate with US government agencies and US industry to transfer AIRS technology and science experience