Eight Years of AIRS

SPIE Asia-Pacific Remote Sensing

Incheon, Korea

Oct 13, 2010

Sung-Yung Lee (Presentor)

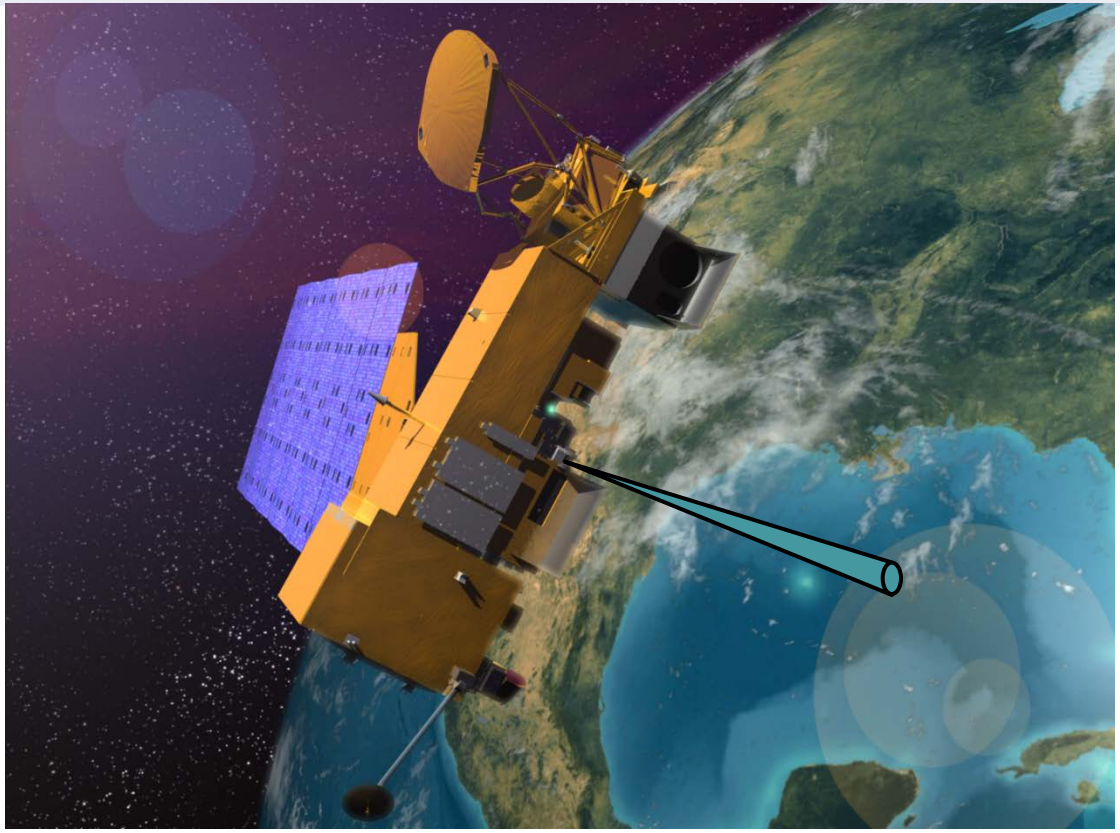
Thomas S. Pagano, Moustafa Chahine, Eric Fetzer

California Institute of Technology

Jet Propulsion Laboratory

Copyright 2010
California Institute of Technology
Government sponsorship acknowledged

Atmospheric InfraRed Sounder



AIRS Measures the Infrared Spectrum of Atmosphere With Global Daily Coverage

NASA Aqua Spacecraft

Launched May 4, 2002

<u>Mission Objectives</u>

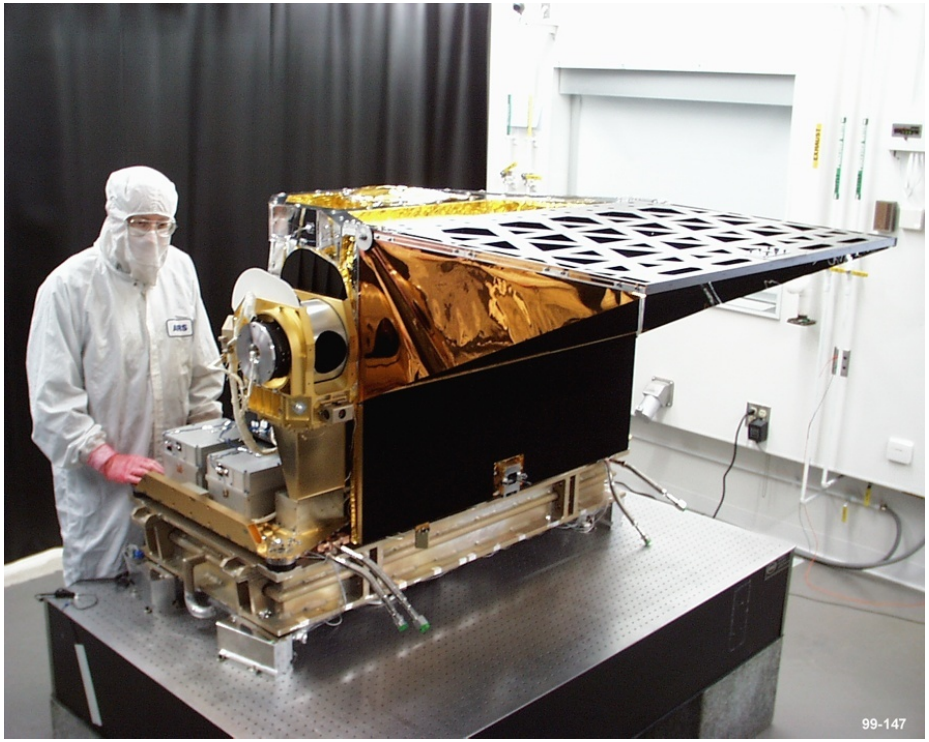
1. Improve Weather Forecast
2. Reduce Climate Uncertainty
3. Observe Greenhouse Gases
4. Technology Risk Reduction

The AIRS Instrument

- **Grating array spectrometer**
- **Actively-cooled focal plane**
- **Passively cooled, temperature-controlled optics**

AIRS Spec

- IFOV : 1.1° x 0.6° (13.5 km x 7.4 km)
- Scan Range: ±49.5° (Cross-track)
- IR Spectral Range: 3.74-4.61 µm, 6.2-8.22 µm, 8.8-15.4 µm
- IR Spectral Resolution: ≈ 1200 ($\lambda/\Delta\lambda$)
- Sampling resolution : ≈2400
- No. IR Channels: 2378
- VIS Channels: 4 (0.41-0.44 µm,0.58-0.68 µm, 0.71-0.92 µm,0.49-0.94 µm)
- VIS IFOV: 0.14° (1.7 km)
- Life: 5 years (7 years goal)

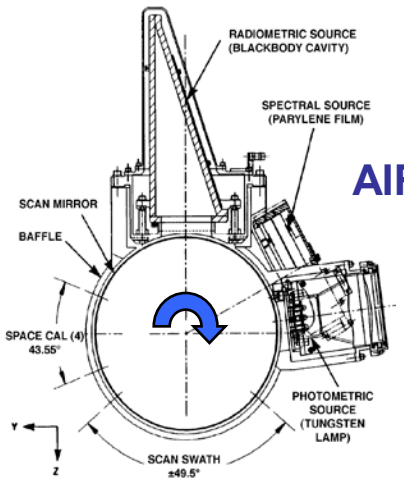


Jet Propulsion Laboratory
California Institute of Technology

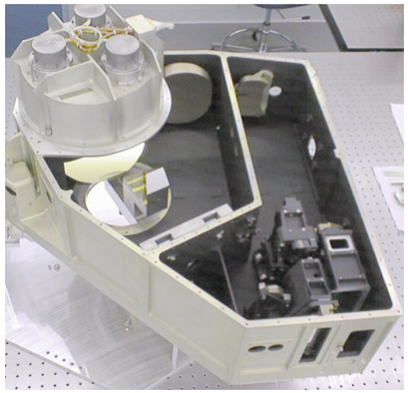
Hardware Elements that Contribute to AIRS stability and Accuracy

Elements

- Orbit: 705 km, 1:30pm, Sun Synch
- Pupil Imaging IFOV : 1.1° x 0.6° (13.5 km x 7.4 km)
- Scanner Rotates about Optical Axis (Constant AOI on Mirror)
- Full Aperture OBC Blackbody, ε>0.998
- Full Aperture Space View
- Solid State Grating Spectrometer
- Temperature Controlled Spectrometer: 158K
- Actively Cooled FPAs: 60K
- Mass: 177Kg,
  Power: 256 Watts

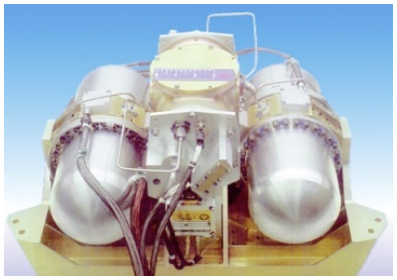


AIRS Scan Cavity



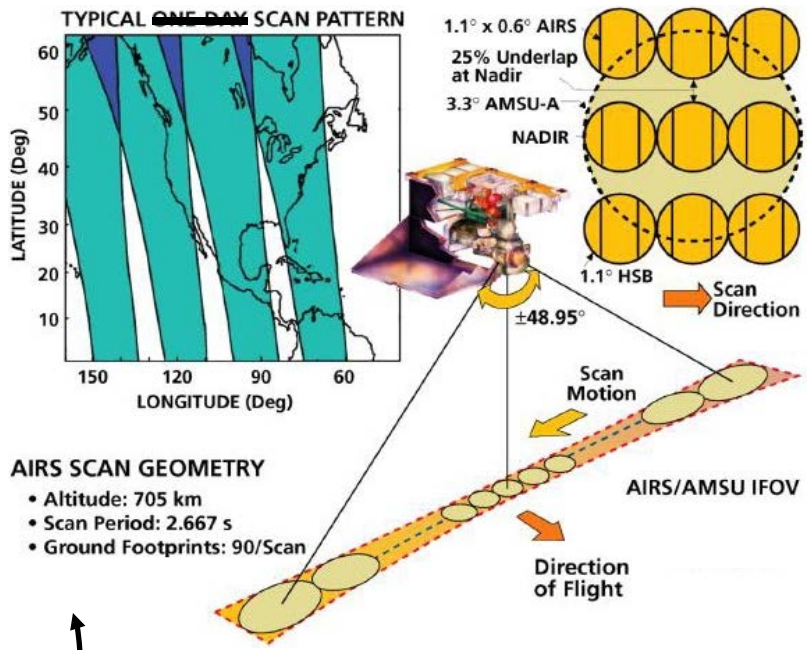
AIRS Spectrometer

Passively Cooled Spectrometer



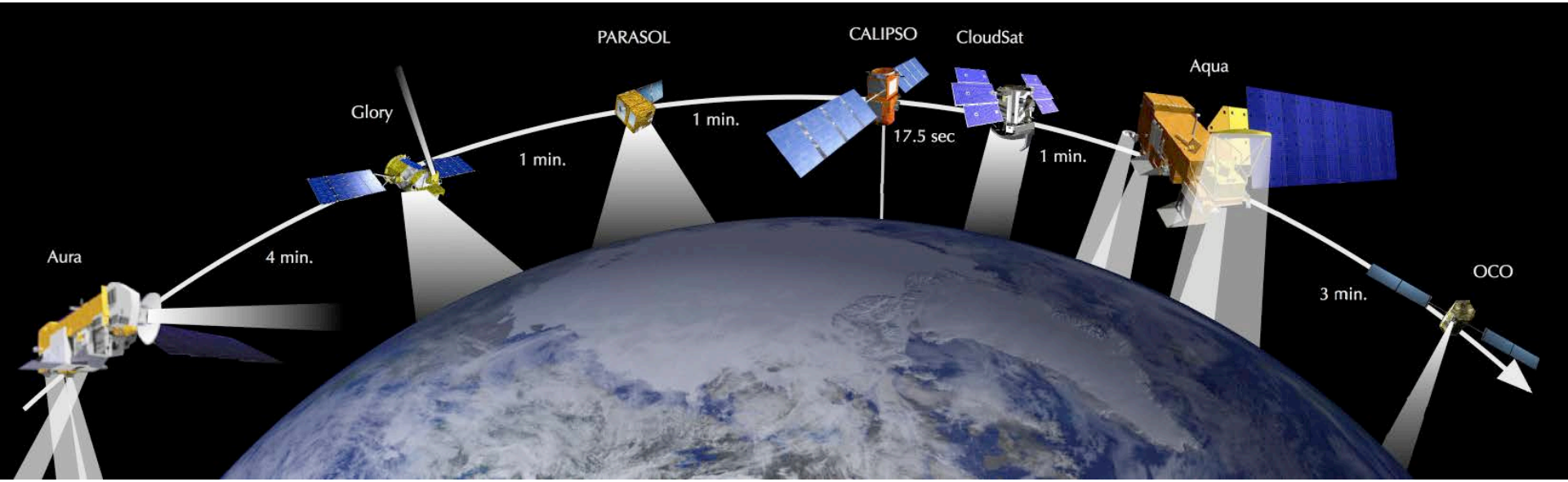
Active Dewar Cooling

AIRS Geometry and Sampling



1. AMSU footprint, 45 km across at nadir, contains 9 AIRS spectra
   - THIS IS THE RETRIEVAL GRANULARITY.
1. AMSU was rotated to better collocate AIRS/AMSU FOVs
1. Viewing swath 30 AMSU footprints or ~1650 km wide.
1. The result: 2,916,000 IR spectra and 324,000 microwave spectra & retrievals per day

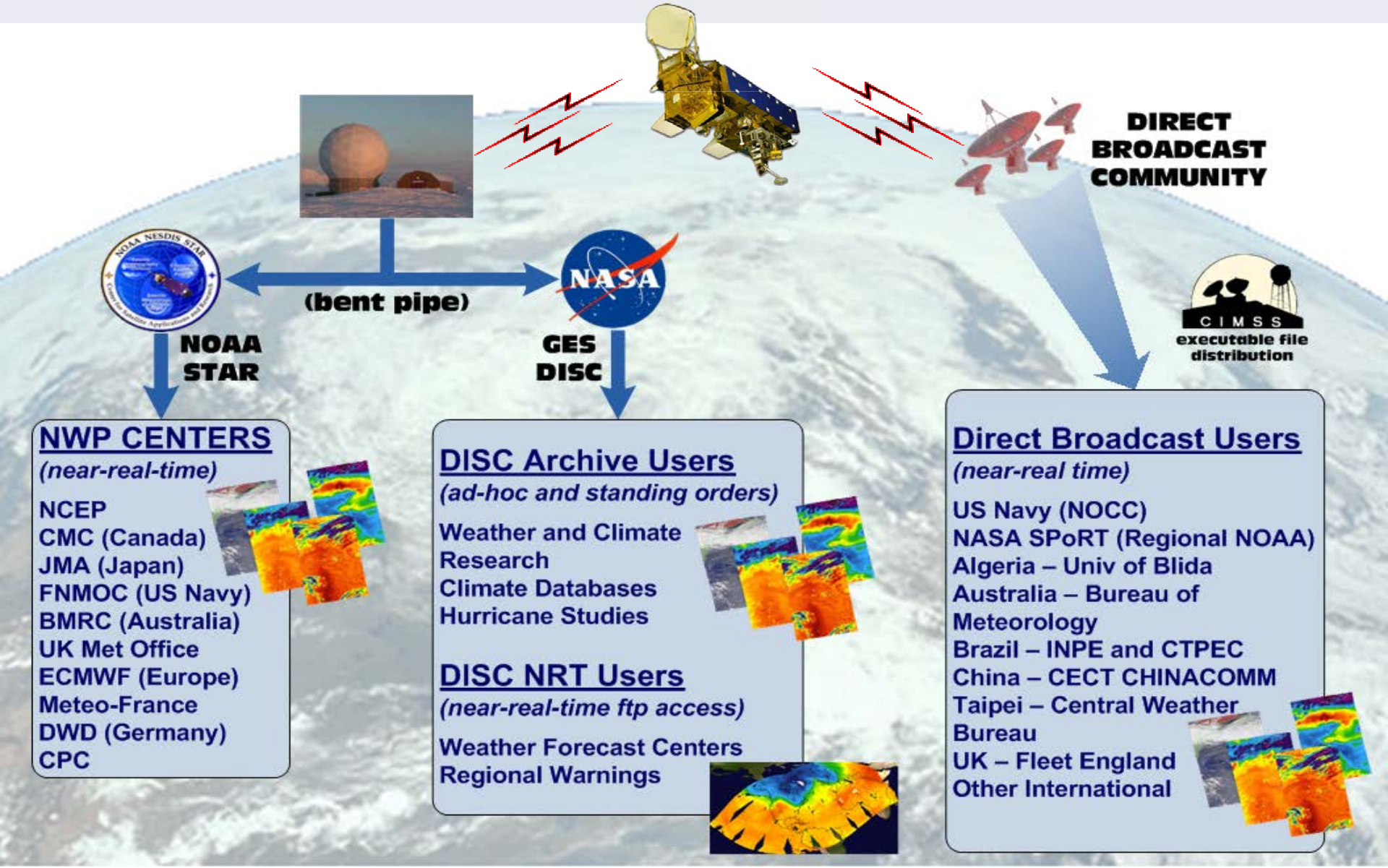
Aqua is a part of A-Train



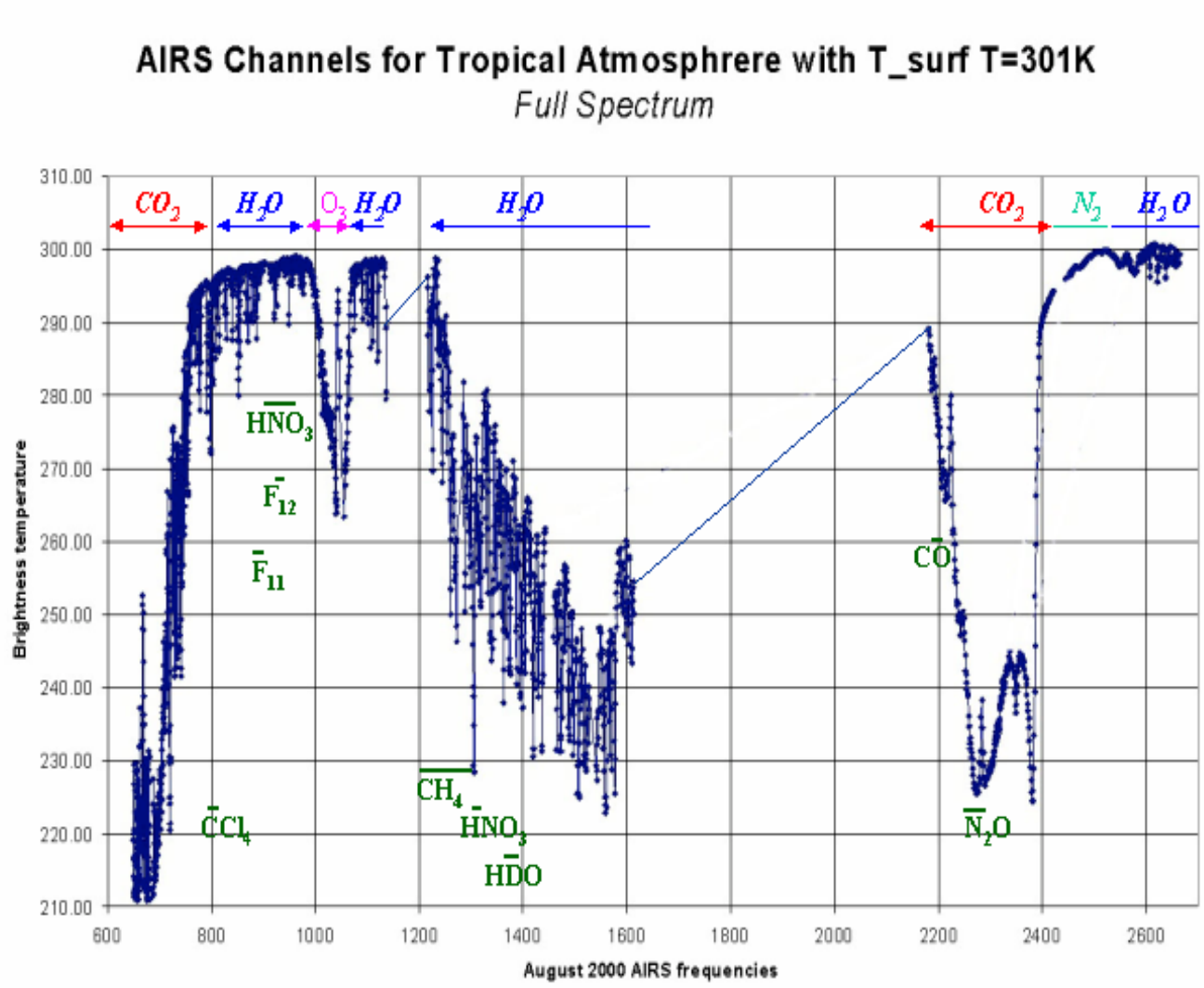
Jet Propulsion Laboratory
California Institute of Technology

AIRS Science Data Providers

using code developed and distributed by the AIRS Project



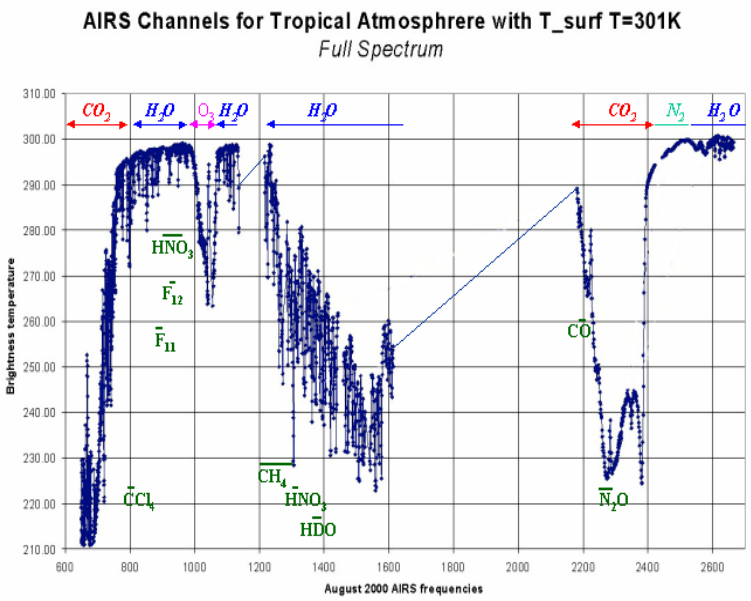
AIRS Computed Spectrum



Jet Propulsion Laboratory
California Institute of Technology

11 Core AIRS Products Measure Atmospheric/Surface IR State

AIRS Product	Product	Accuracy (V5)	Val Status (V5)
Core: Radiances			
AIRS IR Radiance	L1B-AIRS	<0.2K	Stage 3
AIRS VIS/NIR Radiance	L1B-VIS	15-20%	Stage 1
AMSU Radiance	L1B-AMSU	1-3 K	Stage 3
HSB Radiance	L1B-HSB	1-3 K	Stage 3
Core: Geophysical			
Cloud Cleared IR Radiance	L2	1.0 K	Stage 2
Sea Surface Temperature	L2	1.0 K	Stage 2
Land Surface Temperature	L2	2-3 K	Stage 1
Temperature Profile	L2	1 K / km	Stage 3
Water Vapor Profile	L2	15% / 2km	Stage 3
Total Precipitable Water	L2	5%	Stage 3
Fractional Cloud Cover	L2	20%	Stage 2
Cloud Top Height	L2	1 km	Stage 2
Cloud Top Temperature	L2	2.0 K	Stage 2
Carbon Monoxide	L2	15%	Stage 2
Carbon Dioxide	Post-Proc	1-2 ppm	Stage 1
Core: Necessary*			
Total Ozone Column	L2	5%	Stage 2
Ozone Profile	L2	20%	Stage 2
Land Surface Emissivity	L2	10%	Stage 1
IR Dust	L1B-Flag	0.5 K	Stage 1
Research Products			
Methane	L2	2%	Stage 1
OLR	L2-Support	5 W/m2	Stage 1
HNO3	L1B-Post	0.2 DU	Stage 1
Sulfur Dioxide	L1B-Flag	1 DU	Stage 1



*Necessary Products are required to retrieve accurate temperature profiles (1K/km) in all conditions

Validation Status Definitions (Common to all Aqua Instruments)

Stage 1: Validation Product accuracy has been estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program effort.

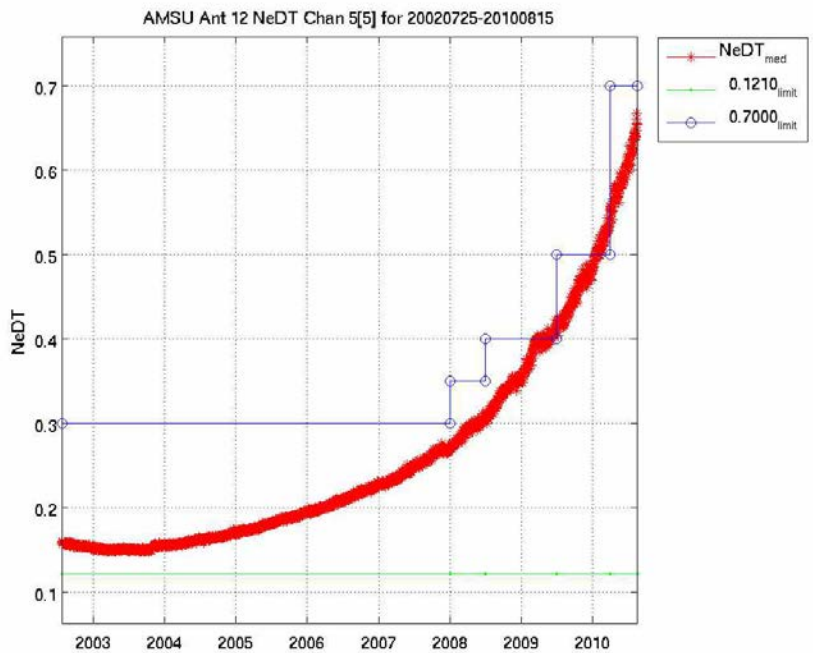
Stage 2: Validation Product accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts.

Stage 3: Validation Product accuracy has been assessed, and the uncertainties in the product well-established via independent measurements made in a systematic and statistically robust way that represents global conditions.

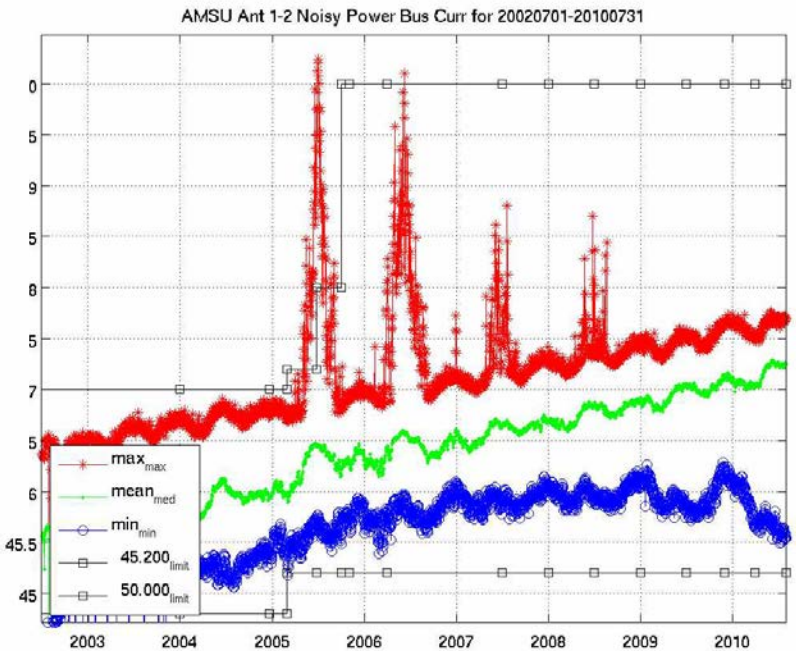
AIRS Sounding Suite Status

- Objectives Accomplished
  - Weather: AIRS Improves Operational Forecasts. More improvement pending
  - Climate: Model Validation and Water Vapor Feedback. Hyperspectral IR CDR
  - Greenhouse Gases: New Release of CO2. Regular Production of O3, CO, CH4
  - Science: Over 350 Research Publications to Date.
- AIRS Hardware Status
  - Excellent Health
  - No significant trend in engineering parameters
  - Expect Instrument to outlast spacecraft. Fuel runs out in 2017.
  - 8+ Years of Data Now Available at GES/DISC
- AMSU-A
  - AMSU-7 noisy since launch, AMSU-5 declared dead in Nov 2007, AMSU-4 becoming noisy (NeDT ~0.65K)
  - AMSU-A1-2 scanner power issue disappeared
- HSB
  - Scanner malfunction in Feb 2003
- AIRS only option available for level 2 processing

AMSU Related Trend Plots



AMSU-5 Detector Noise



AMSU-A1-2 Noisy Power Bus Current

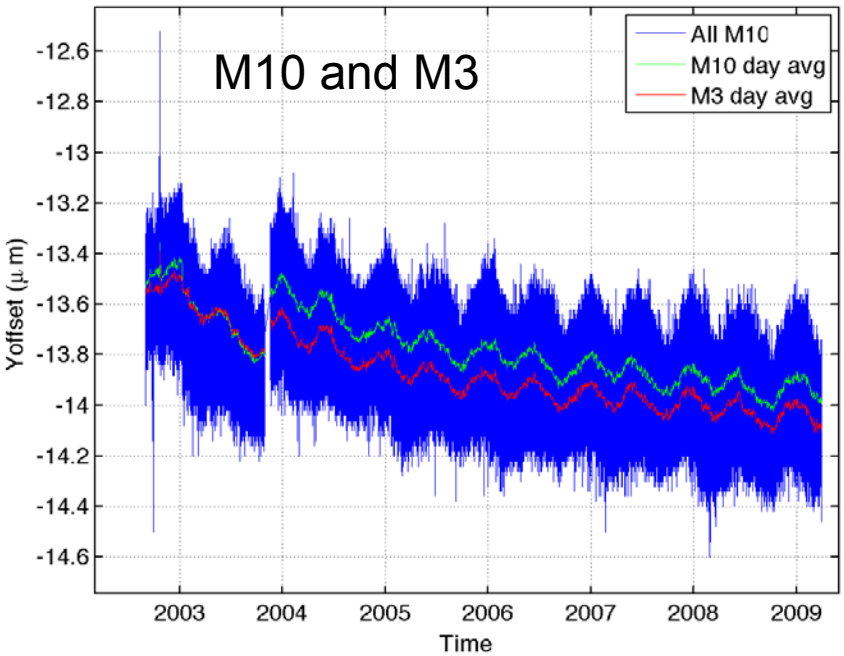
Version 6 Software

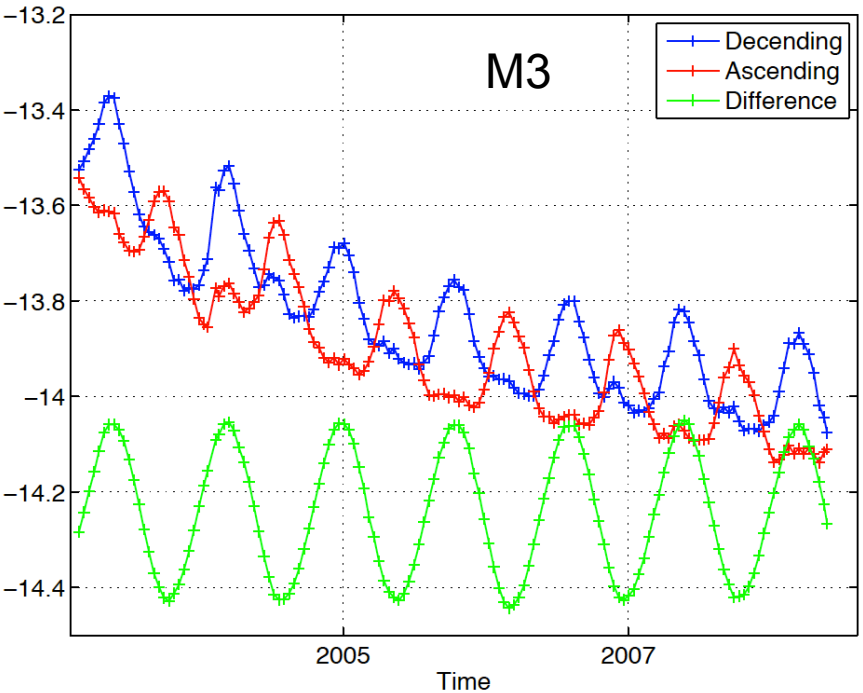
- Development of V6 is at the final stage.
  - Plan to release by early 2011
- Level 1B: Calibrated Radiances
  - Stable since version 3
  - No change is expected
- Level 1C: New data products
  - Frequency Stabilized
  - Fills Noisy/Dead Channels
- Level 2: Retrieved Geophysical Parameters
  - Improved Stability (Remove/reduce ~0.1K trend per year)
  - Improved Surface/Boundary Layer Sensitivity
  - New OLR forward model from AER
- New Products for V7: CO2 Boundary Layer, Cloud Properties, Dust

Trend in Level 2

- AIRS Version 5 Level 2 retrieved temperature profiles have spurious trends at roughly 0.1K/yr.
- Causes of the trend
  - Atmospheric CO2
    - V5 physical retrieval uses increasing CO2 VMR
  - Trend in regression retrievals.
  - Trend in AMSU only retrievals.
  - Use of N2O channels is a small component 20-30mK/year.
  - Shift in focal plane, causing small frequency shift.
- Prototype V6 Level 2 has much smaller trend

Focal Plane Shift

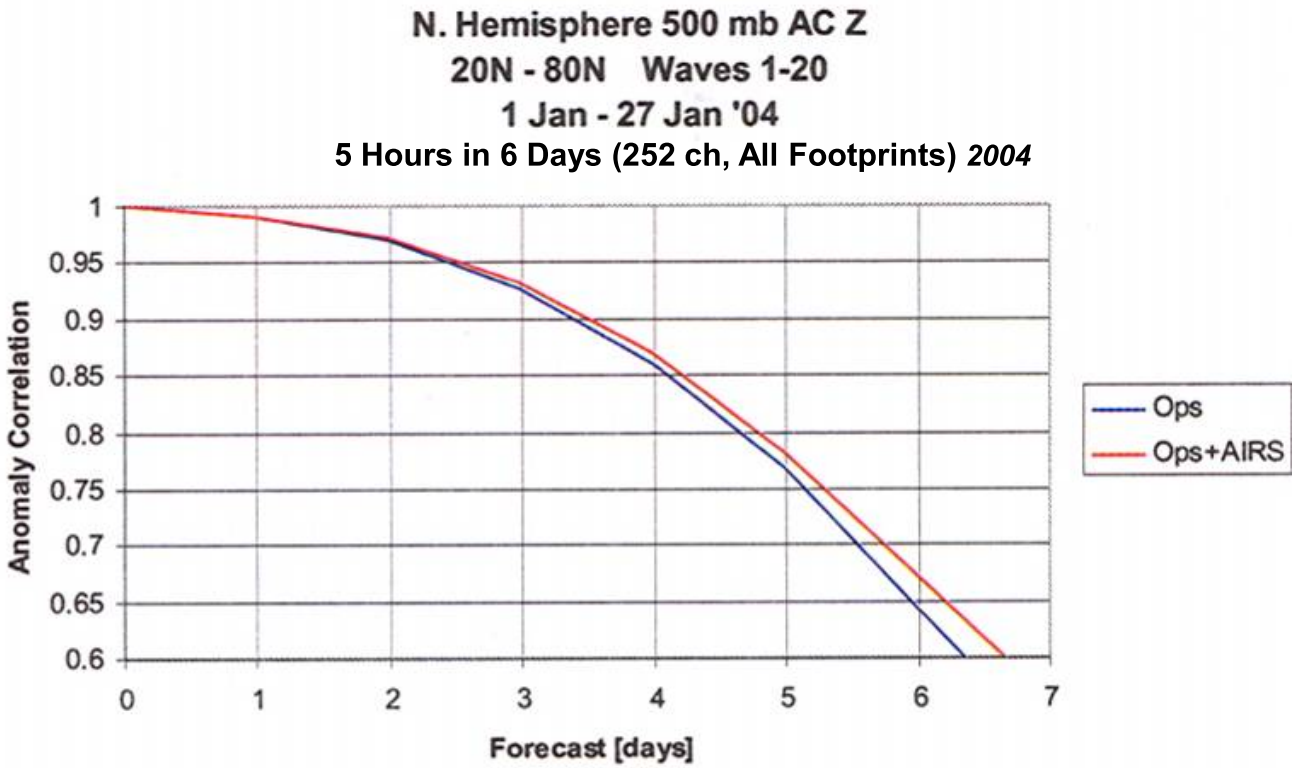




- AIRS has a slow drift of spectral properties.
- V6 forward model (SARTA V1.08) can handle the drift.
- Level 1C will shift the spectra to fixed frequency set.

Figure from Strow@UMBC

AIRS Operational Forecast Improvement



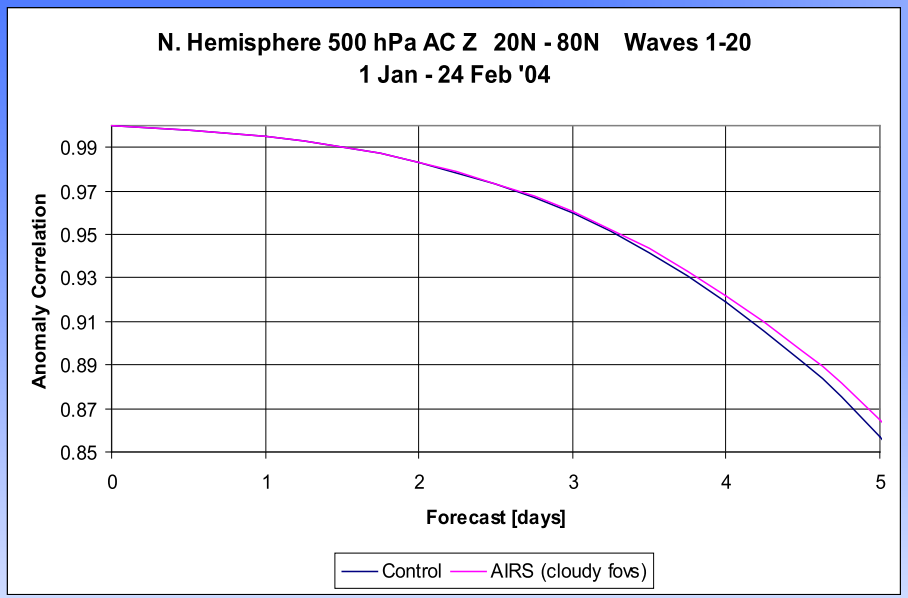
"This AIRS instrument has provided the most significant increase in forecast improvement in this time range of any other single instrument."

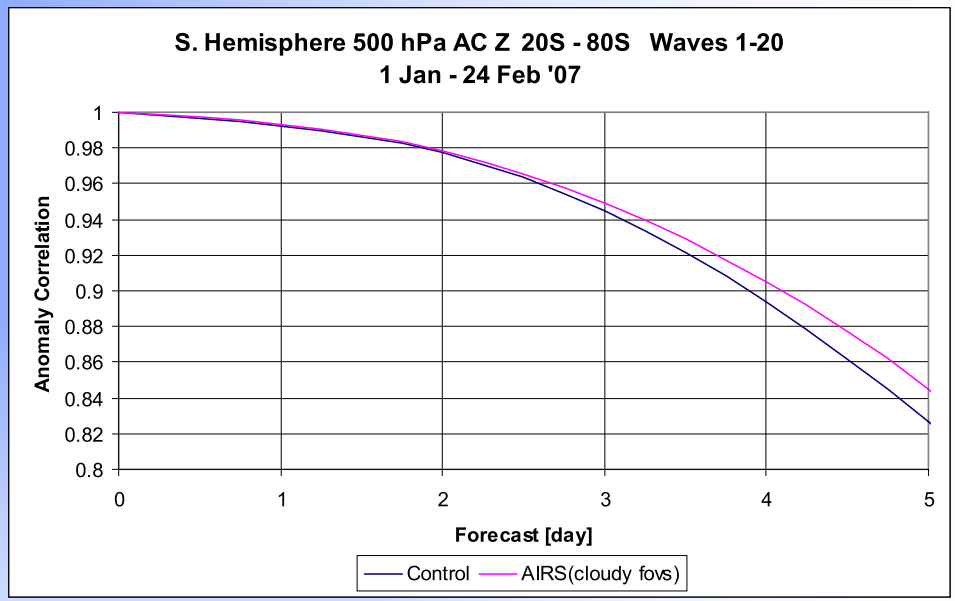
Retired Navy Vice Admiral Conrad C. Lautenbacher, Jr., Ph.D., Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator, August 24, 2005

Le Marshall, J., J. Jung, J. Derber, M. Chahine, R. Treadon, S. J. Lord, M. Goldberg, W. Wolfc, H. C. Liu, J. Joiner, J. Woollen, R. Todling, P. van Delst, and Y. Tahara (2006), "Improving Global Analysis and Forecasting with AIRS", Bulletin of the American Meteorological Society, 87, 891-894, doi: 10.1175/BAMS-87-7-891

AIRS Data Assimilation Using Cloudy Fields of View

1 January – 24 February 2007 Operational GFS system

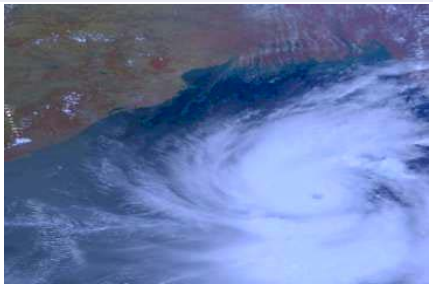




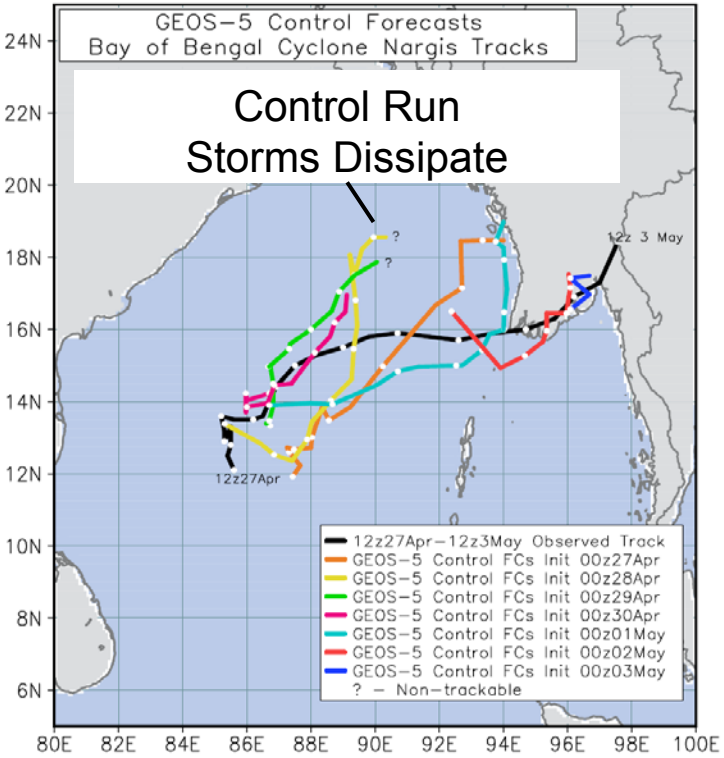
Le Marshall, J., Jung,J., , Goldberg, M.., Barnet, C., Wolf, W., Derber, J., Treadon, R. and S. Lord. 2008. Using Cloudy AIRS Fields of View in Numerical Weather Prediction . *Aust. Meteor. Mag.* , 57, 249-254.

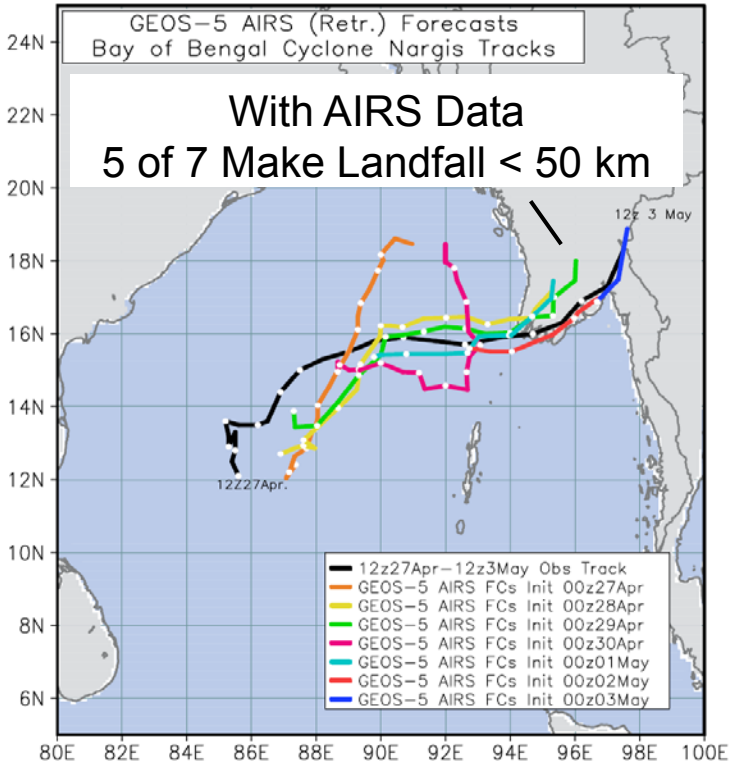
Jet Propulsion Laboratory
California Institute of Technology

AIRS Data Improves Prediction of Tropical Cyclones



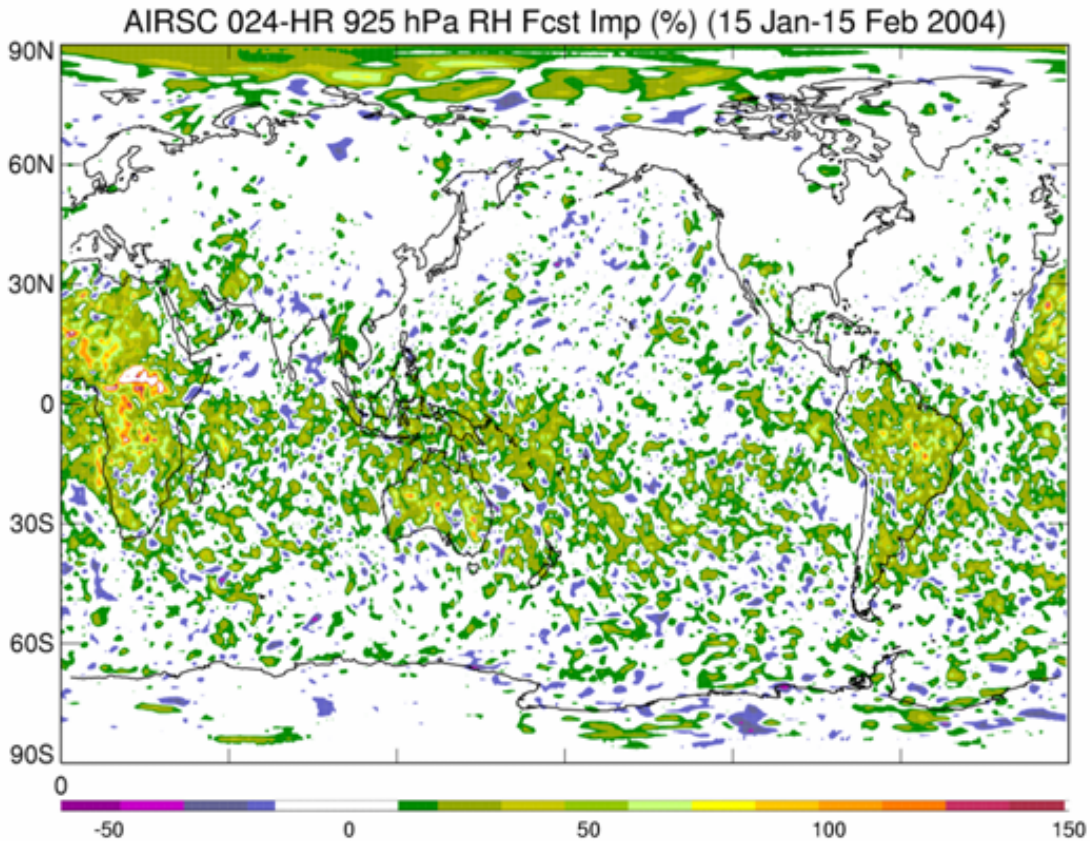
- Tropical Cyclone Nargis
- Killed over 140,000 People
- Worst Natural Disaster in history of Burma`
- O. Reale, GSFC, 2008





Reale, O., W. K. Lau, J. Susskind, E. Brin, E. Liu, L. P. Riishojgaard, M. Fuentes, and R. Rosenberg (2009), AIRS impact on the analysis and forecast track of tropical cyclone Nargis in a global data assimilation and forecasting system, Geophys. Res. Lett., 36, L06812, doi:10.1029/2008GL037122. http://www.agu.org/journals/gl/gl0906/2008GL037122/

AIRS Improves Forecast of Water Vapor



Forecast Impact improvement/degradation (%) of the 12 hr Relative Humidity forecast at 925 hPa .

24 hour Forecast
925 hPa
50-100% Improvement

J. Le Marshall, J. Jung, M. Goldberg, C. Barnet, W. Wolf, J. Derber, R. Treadon and S. Lord, "Using cloudy AIRS fields of view in numerical weather prediction". Aust. Meteorological Magazine, 2008, vol. 57, pp. 249-254

AIRS Water Vapor validated to better than 20% at this altitude when compared to radiosondes.

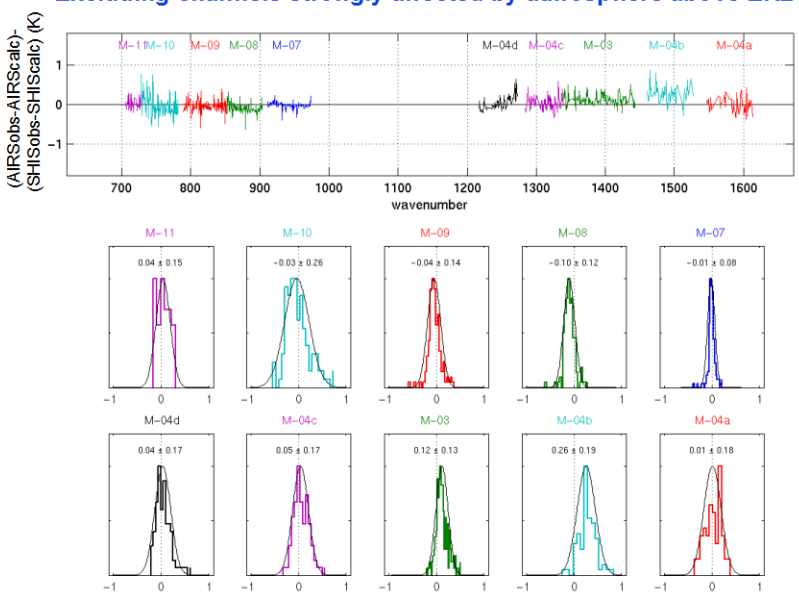
Jet Propulsion Laboratory
California Institute of Technology

AIRS Accuracy and Stability Validated In-Orbit

Radiometric Accuracy

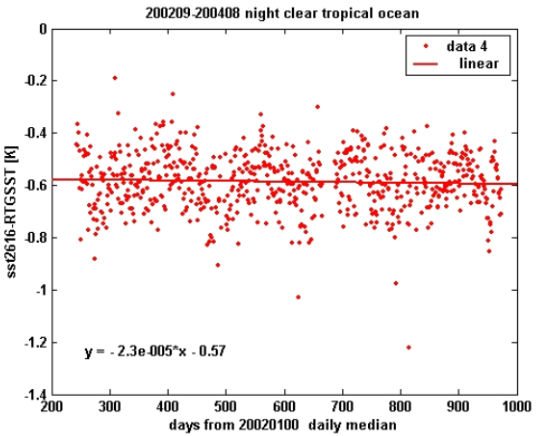
Scanning HIS Validates Rad Accy to 0.2K – H. Revercomb (UW)

Final "Comparison 2" (21 November 2002)
Excluding channels strongly affected by atmosphere above ER2



Radiometric Stability

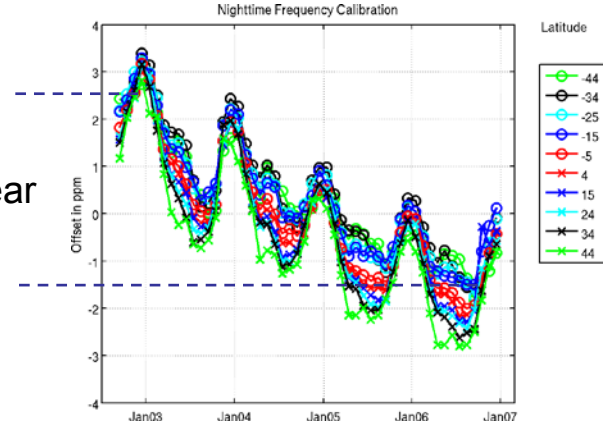
Stable to <8mK/Y – H. Aumann (JPL)



Spectral Accuracy/Stability

Knowledge to < 1 PPM - L. Strow (UMBC)

< 1 ppm/year



Reference: JGR, VOL. 111, April 2006

Highlights of Research with AIRS Data

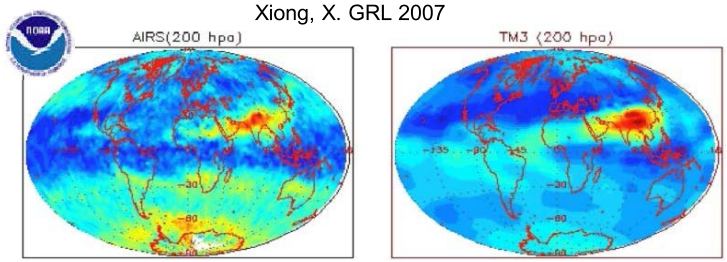
Jet Propulsion Laboratory
California Institute of Technology

AIRS Composition Highlights

- **CH4**
  - Xiong, X., Houweling, S., Wei, J., Maddy, E., Sun, F., and Barnet, C.: Methane plume over south Asia during the monsoon season: satellite observation and model simulation, Atmos. Chem. Phys., 9, 783-794, 2009
  - Xiong, X., Barnet, C., Wei, J., Maddy, E., Information-based mid-upper tropospheric methane derived from Atmospheric Infrared Sounder (AIRS) and its validation, Atmospheric Chemistry and Physics Discussions, Volume 9, Issue 4, 2009, pp.16331-16360
- **SO2**
  - S. A. Carn, J.S. Pallister, L. Lara, J.W. Ewert, S. Watt, A.J. Prata, R.J. Thomas, G. Villarosa, The Unexpected Awakening of Chaitan Volcano, Chile, EOS, transactions, American Geophysical Union, vol 90, No. 24, 16 June 2009, p. 205
- **CO**
  - Tanimoto, H., K. Sato, T. Butler, M.G. Lawrence, J.A. Fisher, M. Kopacz, R.M. Yantosca, Y. Kanaya, S. Kato, T. Okuda, S. Tanaka, J. Zeng, Exploring CO pollution episodes observed at Rishiri Island by chemical weather simulations and AIRS satellite measurements: Long-range transport of burning plumes and implications for emissions inventories,Tellus B, 61B, 394-407, 2009.
  - Yurganov, L. N., W. W. McMillan, A. V. Dzhola, E. I. Grechko, N. B. Jones, and G. R. van der Werf (2008), Global AIRS and MOPITT CO measurements: Validation, comparison, and links to biomass burning variations and carbon cycle, J. Geophys. Res., 113, D09301, doi:10.1029/2007JD009229.
- **Dust**
  - Peyridieu, S., Chédin, A., Tanré, D., Capelle, V., Pierangelo, C., Lamquin, N., and Armante, R.: Saharan dust infrared optical depth and altitude retrieved from AIRS: a focus over North Atlantic – comparison to MODIS and CALIPSO, Atmos. Chem. Phys. Discuss., 9, 21199-21235, 2009

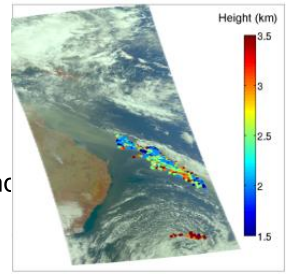
September minus May 2004 Methane difference

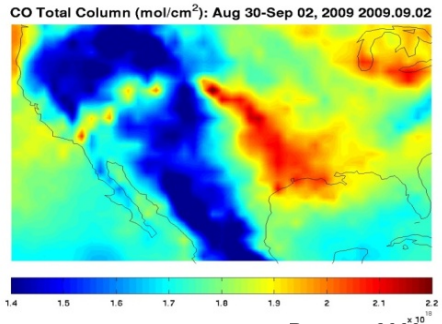
Xiong, X. GRL 2007



Chaitan Volcano
Carn 2009

AIRS Dust Score
DeSouza-Machado (UMBC)





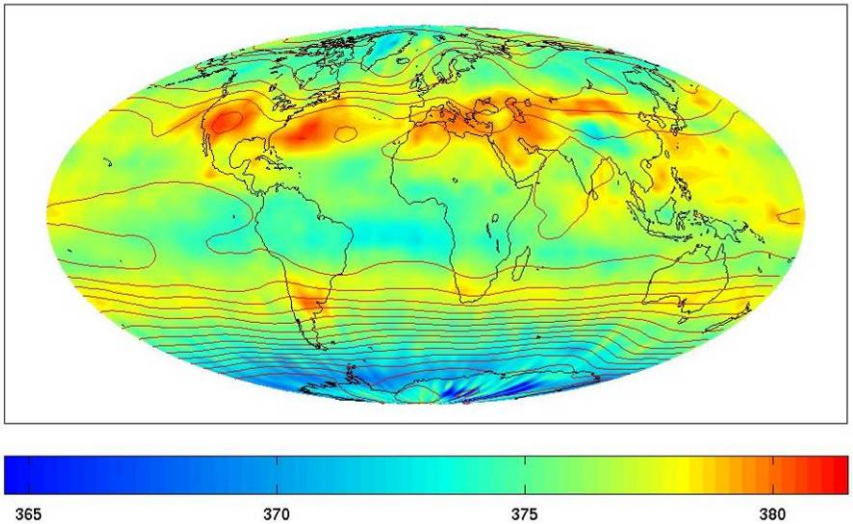
Pagano, 2009

Jet Propulsion Laboratory
California Institute of Technology

AIRS Mid-Tropospheric CO2 Data Now Available to Users

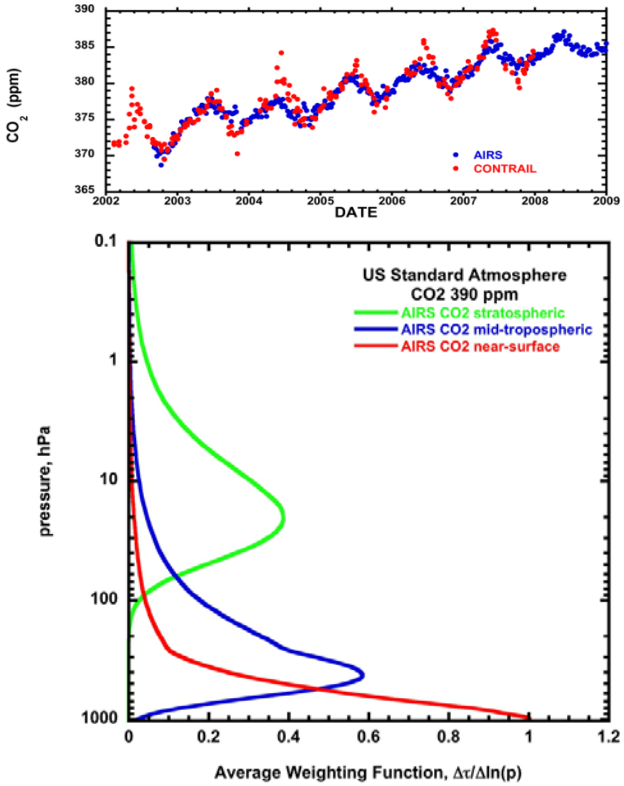
AIRS Mid-Troposphere CO2 Product (Chahine)

AIRS Mid–Tropospheric CO2. July 2003, V5 Day 16 x 31



7 Years of AIRS Mid Tropospheric Daily/Global CO2 Data Now Available*

Validated to 1-2 ppm: Chahine (2009)

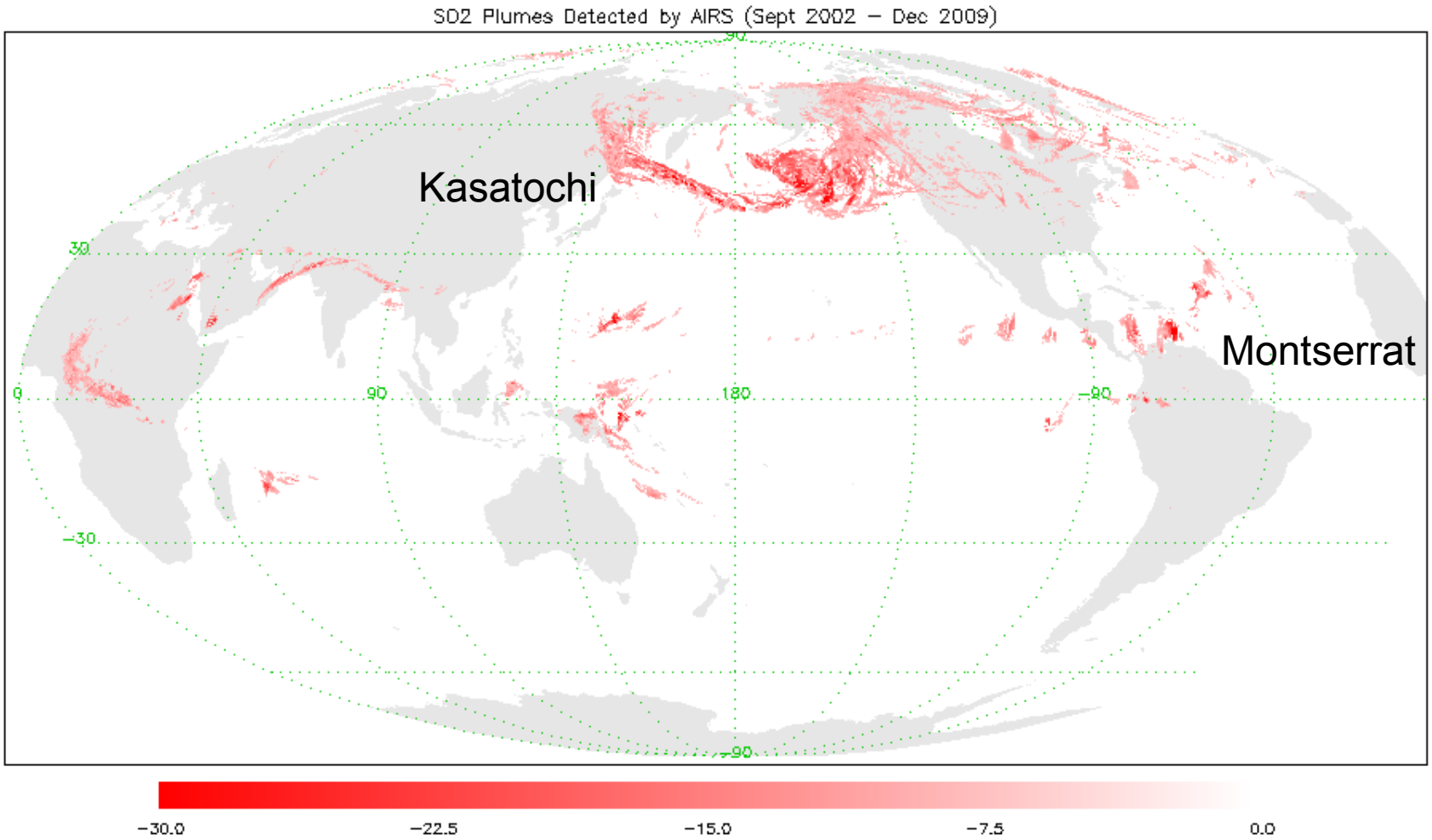


Recent Publications:

1. Chahine, M. T., L. Chen, P. Dimotakis, X. Jiang, Q. Li, E. T. Olsen, T. Pagano, J. Randerson, and Y. L. Yung (2008), Satellite remote sounding of mid-tropospheric CO2, Geophys. Res. Lett., 35, L17807, doi:10.1029/2008GL035022.
2. Strow, L. L., and S. E. Hannon (2008), A 4-year zonal climatology of lower tropospheric CO2 derived from ocean-only Atmospheric Infrared Sounder observations, J. Geophys. Res., 113, D18302, doi:10.1029/2007JD009713.

AIRS Project Under Contract with NASA
To Retrieve Stratosphere and Near Surface CO_2

AIRS Detects Volcanic SO2 Plumes

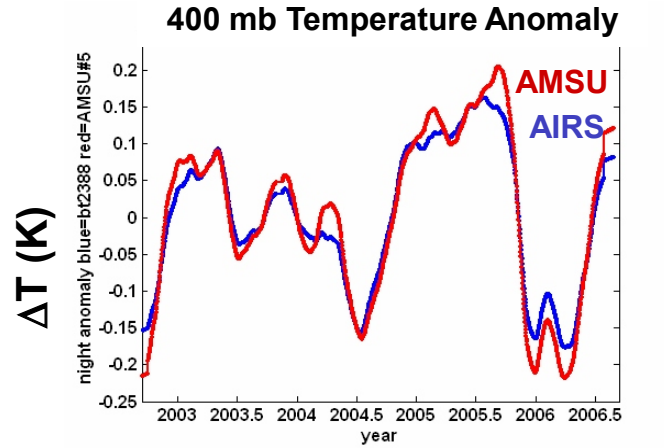


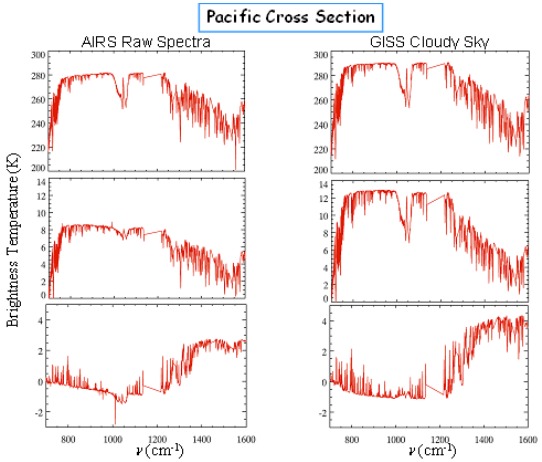
Tb1361 – Tb1433

AIRS Spectra Directly Used for Climate Studies

- Trending
  - The four year anomaly of AMSU and AIRS temperatures at 400 mb shows a pronounced quasi-bi-annual fluctuation of about 0.4 K peak-to-peak.
  - This fluctuation severely limits the ability to interpret trends on a four year time scale in terms of climate relevance.
  - It also makes it difficult to compare the mean of four years from today with similar data taken 20 years ago or 20 years from now, even if they were intrinsically accurate at the 100 mK 3 sigma level.
  - Aumann (2007)

- Principal Component Analysis
  - Difference in EOF1 suggest there is a problem in the boundary layer humidity.
  - Huang, X., and Y. L. Yung. (2005). “Spatial and spectral variability of the outgoing thermal IR spectra from AIRS: A case study of July 2003.” J. Geophys. Res.: 110 D12102/2004JD005530.





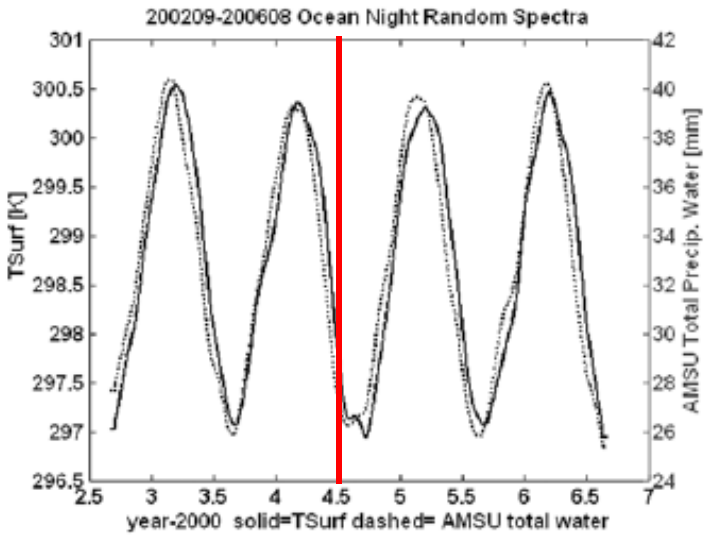
AIRS L1B (Hyperspectral IR) Climate Data Subset Available from GES/DISC

Jet Propulsion Laboratory
California Institute of Technology

AIRS/AMSU Measure Phase Lag of 63 days in response to Seasonal Solar Forcing

Southern Hemisphere Phase Lag

4 Year Period



	Mean	P-P	Peak	Peak-SS	Minimum	Min-WS
NH						
SST	300.2 K	2.4 K	21 Sept	90 days	21 Feb	90 days
T(5 km)	258.8 K	1.4 K	24 Aug	63 days	12 Feb	51 days
PW	39.5 mm	14.2 mm	24 Aug	63 days	15 Feb	54 days
UTW300	0.14 mm	0.06 mm	21 Aug	60 days	6 Feb	45 days
DCC count	1709	2274	24 Aug	63 days	12 Feb	51 days
SH						
SST	298.8 K	3.5 K	15 Mar	84 days	1 Sept	70 days
T(5 km)	258.3 K	1.6 K	27 Feb	68 days	21 Aug	60 days
PW	32.6 mm	14.5 mm	27 Feb	68 days	15 Aug	54 days
UTW300	0.11 mm	0.07 mm	3 Mar	64 days	27 Jul	36 days
DCC count	1156	1016	12 Feb	51 days	15 Aug	54 days

Temperature
Water Vapor

[a]Northern Hemisphere, NH; Southern Hemisphere, SH; tropical ocean temperature, SST; total water vapor, PW; 5 km temperature, T(5 km); 300 mb water vapor, UTW300; summer solstice, SS; winter solstice, WS.

$$C = \frac{B}{f}\frac{1}{(\omega/\tan(\omega\Delta) - D\mu^2)}$$

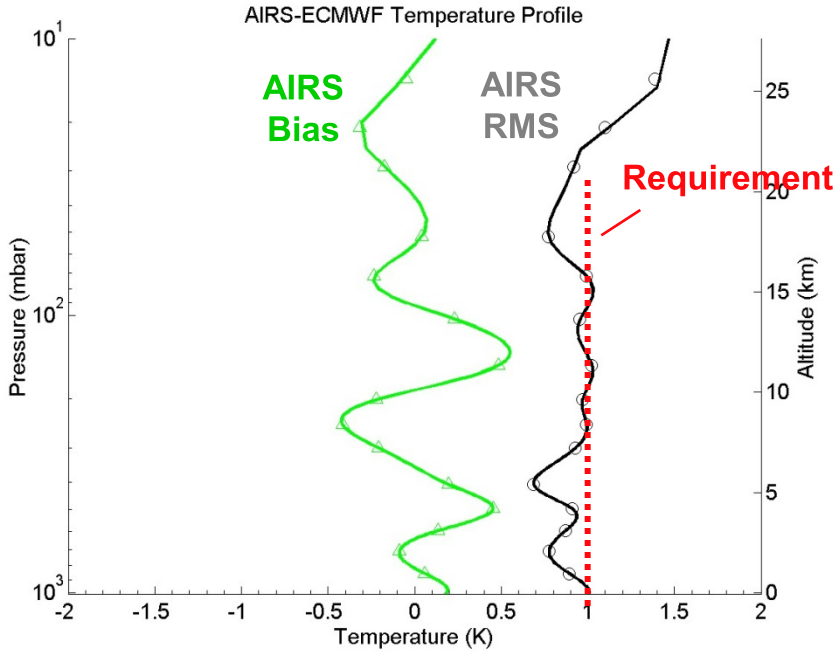
Name	Variable	Value	Units
Frequency	ω	0.0172	days^{-1}
Atmosphere Emis.Gain	B	1.9	W/m^2/K
Ocean Flux	D	8.64	m^2/day
Inverse Penetration Depth	μ	0.01	m^{-1}
Phase Lag	Δ	63	days
Timescale of Feedback	$f\tau$	121.41	days
Feedback	f	2.5	
Atm. Heat Capacity	C	92.28	W-days/m^2-K
Atm. Heat Capacity	C	0.25	W-years/m^2-K

Heat Capacity of Air*
1,006 Joules/K-kg x 10^4 kg/m^2
= 10^7 W-s/m^2-K
= 0.317 W-Years/m^2-K

AIRS Shows High Vertical Accuracy and Horizontal Resolution of Temperatures

Temperature Profiles Accurate to 1K/km to 30 mb

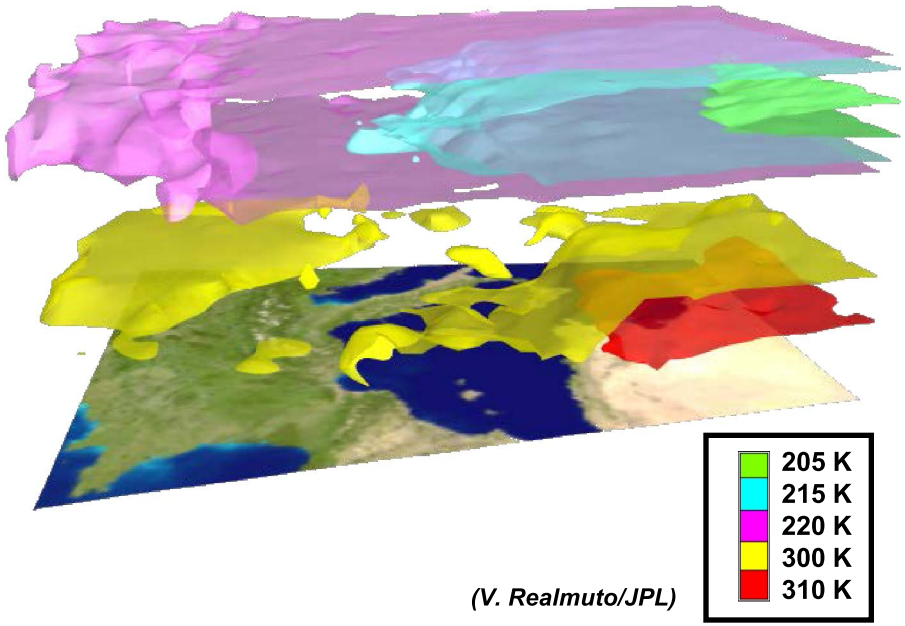
Ocean, Mid Latitude vs ECMWF



(T. Hearty/JPL)

Isotherms Show Good Horizontal Resolution

September 8, 2003

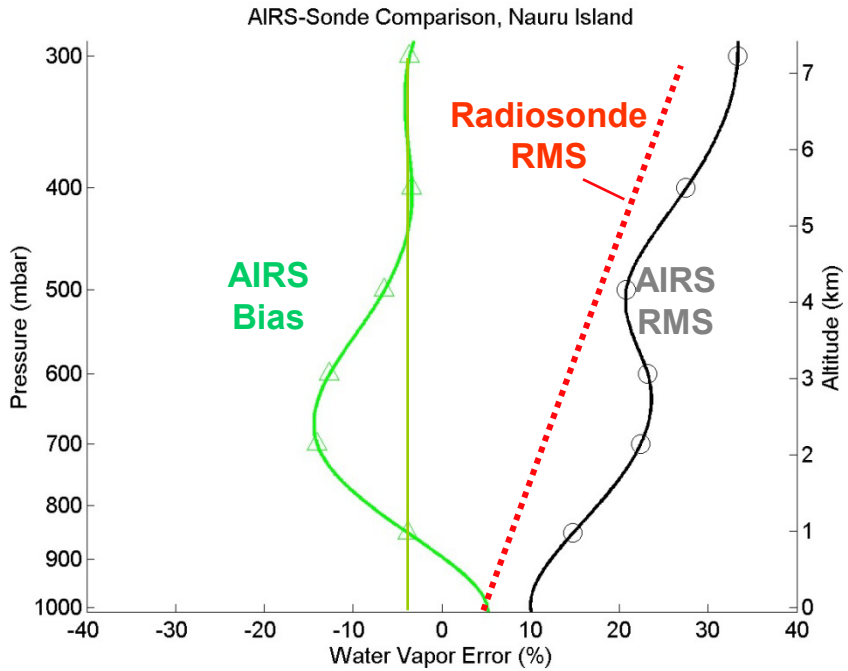


(V. Realmuto/JPL)

AIRS Shows High Accuracy and Horizontal Resolution of Water Vapor

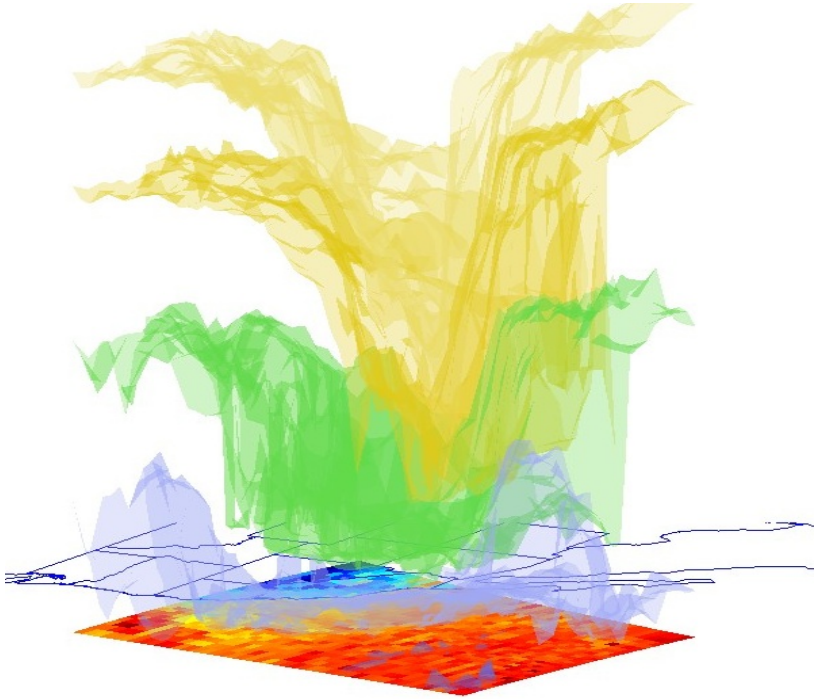
Water Vapor Profiles Match Radiosondes

Nauru Island Radiosondes



(E. Fetzer/JPL)

Isohyets Show Good Horizontal Resolution



T. Pagano (JPL)

Jet Propulsion Laboratory
California Institute of Technology

AIRS 3D Water Vapor Validates Strong Water Vapor Feedback

Dr. Andrew Dessler, Texas A&M

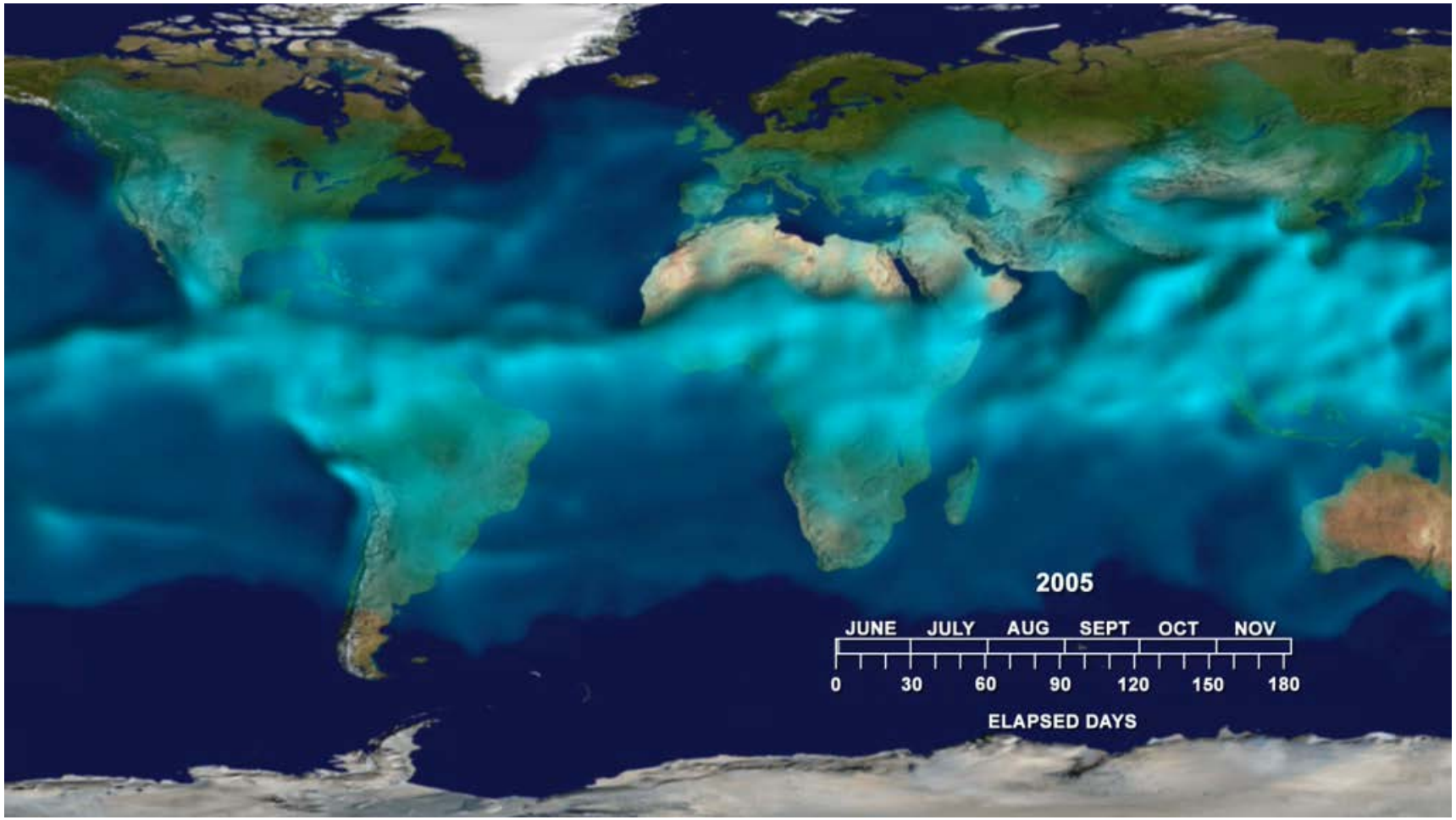
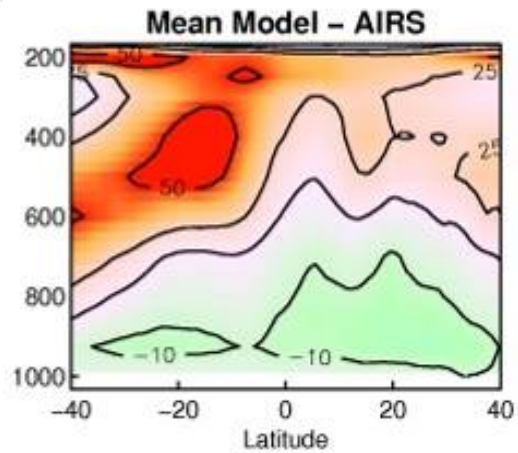


Image credit: V. Realmuto, JPL

Jet Propulsion Laboratory
California Institute of Technology

AIRS Finds Bias in Climate Model Moisture Fields

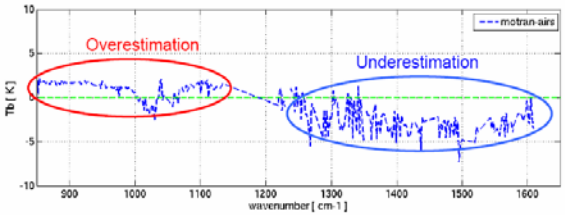
- AIRS finds major climate models are too dry below 800 mb in the tropics, and too moist between 300 mb and 600 mb especially in the extra-tropics. (Pierce, John, Gettleman).
- Radiance biases of opposite signs in different spectral regions suggests that the apparent good agreement of a climate model's broadband longwave flux with observations may be due to a fortuitous cancellation of spectral errors (Huang).



Water Vapor
Vertical Climatology
(Pierce, Scripps)

1. Pierce D. W., T. P. Barnett, E. J. Fetzer, P. J. Gleckler (2006), Three-dimensional tropospheric water vapor in coupled climate models compared with observations from the AIRS satellite system, Geophys. Res. Lett., 33, L21701, doi:10.1029/2006GL027060.
2. John, V.O. and Soden, B. J., Temperature and humidity biases in global climate models and their impact on climate feedbacks, Geophys.Res. Lett., 34, L18704, doi:10.1029/2007GL030429
3. Gettleman, Collins, Fetzer, Eldering, Irion (2006), "Climatology of Upper-Tropospheric Relative Humidity from the Atmospheric Infrared Sounder and Implications for Climate", J. Climate, 19, 6104-6121. DOI: 10.1175/JCLI3956.1
4. Huang, Y., Ramaswamy, V., Huang, X.L., Fu, Q., Bardeen, C., A strict test in climate modeling with spectrally resolved radiances: GCM simulation versus AIRS observations, Geophys.Res.Lett., 2007, 34, 24, L24707

Unit: W m^{-2}	OLR		Window band	
	Total sky	Clear sky	Total sky	Clear sky
CERES	241.73	275.87	66.94	83.28
AM2	240.63	263.43	73.99	87.56
AM2-CERES	-1.10	-12.44	7.05	4.28

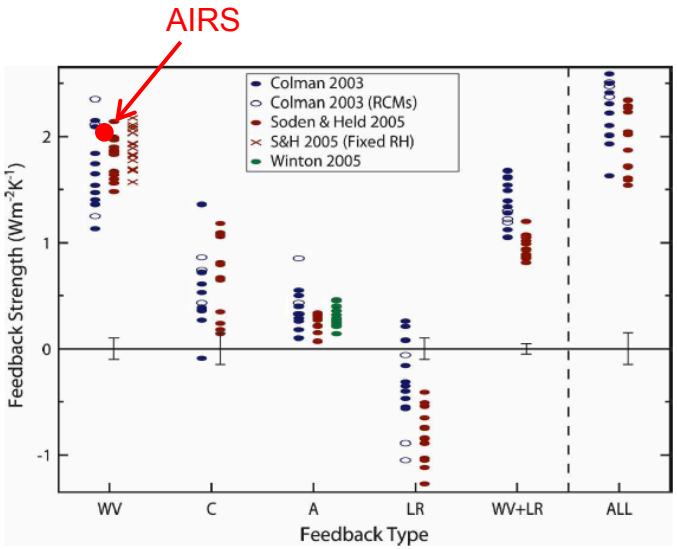


Outgoing Longwave Radiation
(Huang, Univ. of Mich)

Jet Propulsion Laboratory
California Institute of Technology

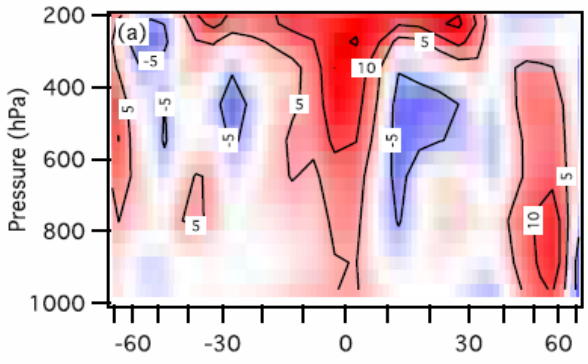
AIRS Data Used to Understand Climate Feedbacks

- AIRS Water Vapor Profiles provide good sensitivity to interannual differences
- Difference between warm year and cooler years give a measure of response of water vapor to warming
- Results show a positive upper tropospheric water vapor feedback
- High vertical structure to variations
- Some regions have lower water vapor feedback, most notably subtropical-mid troposphere between 10N-20N



Bony, S., et al., "How Well Do We Understand and Evaluate Climate Change Feedback Processes?", Journal of Climate, Vol 19, p 3445-3482.

Water Vapor % Difference
2007(Warmer)-2008(Cooler) (Dessler, 2008)

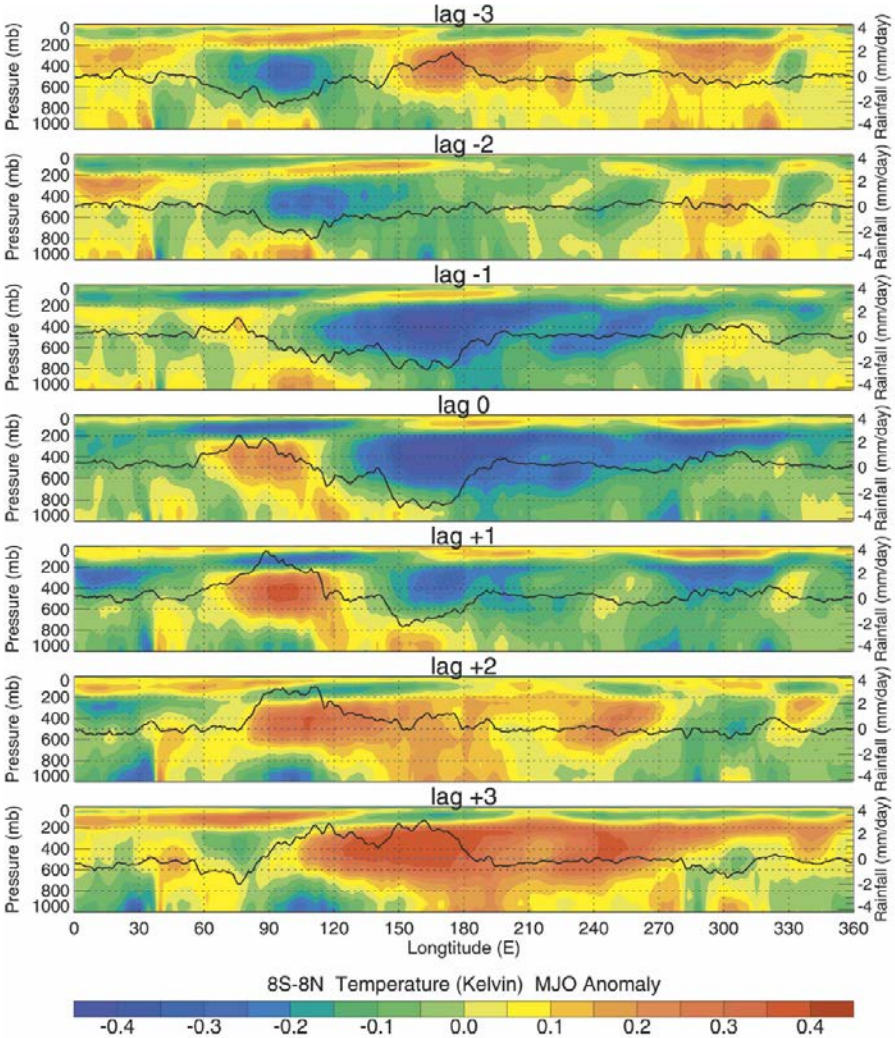


- *Dessler, A. E., Z. Zhang, and P. Yang (2008), Water-vapor climate feedback inferred from climate fluctuations, 2003-2008, Geophys. Res. Lett., 35, L20704, doi:10.1029/2008GL035333.*
- *Gettelman, A., Fu, Q., "Observed and simulated upper-tropospheric water vapor feedback", Journal of Climate, 2008, 21, 13, 3282-3289*

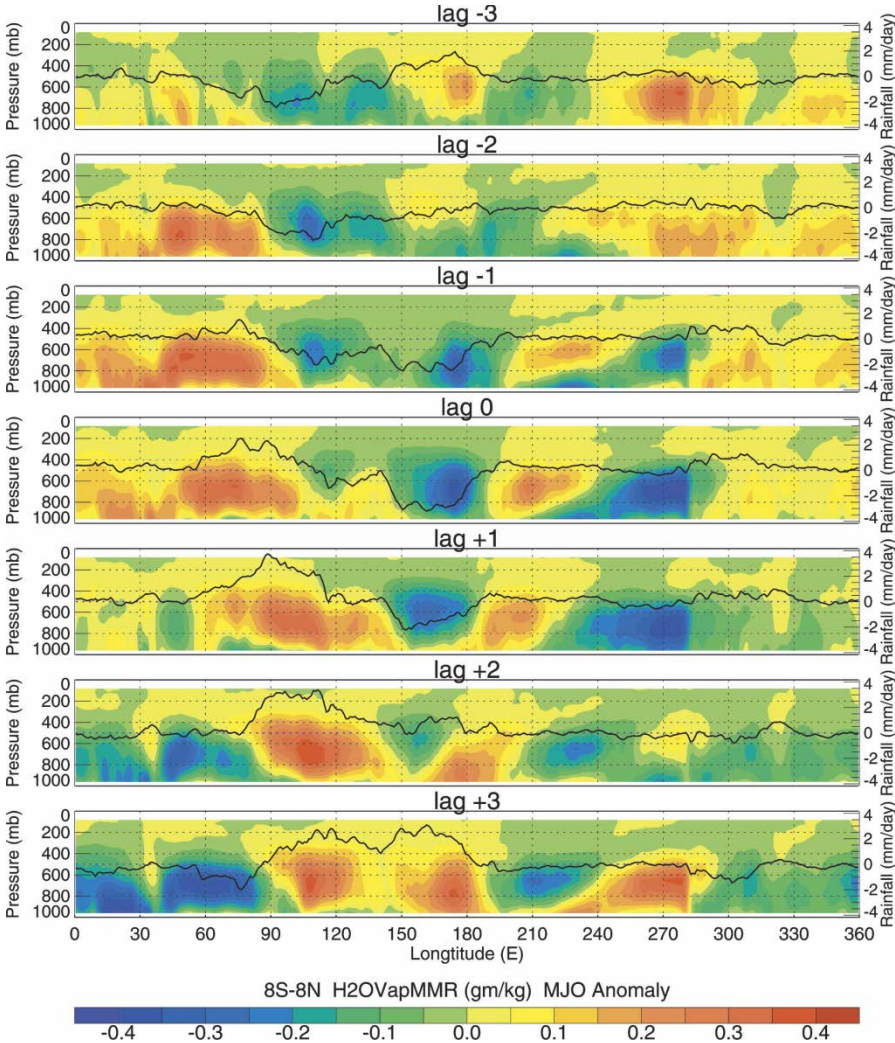
Jet Propulsion Laboratory
California Institute of Technology

AIRS Sheds insight into MJO

Vertical Temperature Anomaly



Vertical Water Vapor Anomaly

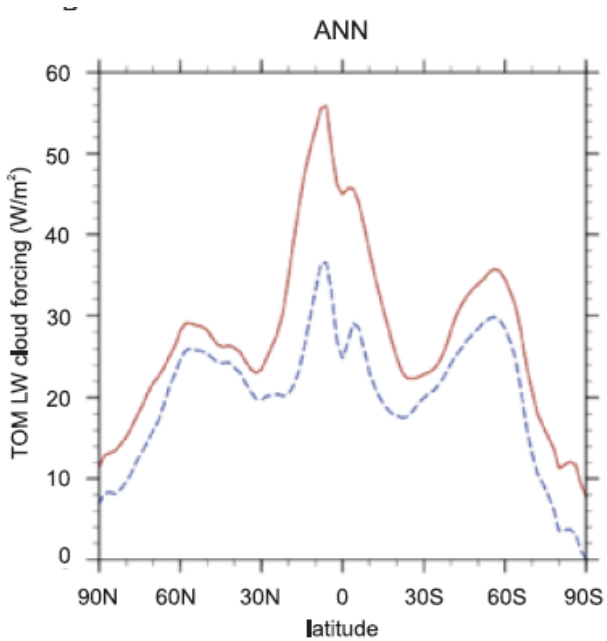


1. Tian, B, et. al, “Vertical Moist Thermodynamic Structure and Spatial–Temporal Evolution of the MJO in AIRS Observations”, Journal of the Atmospheric Sciences, vol 63, pp 2462-2484, 2006

Jet Propulsion Laboratory
California Institute of Technology

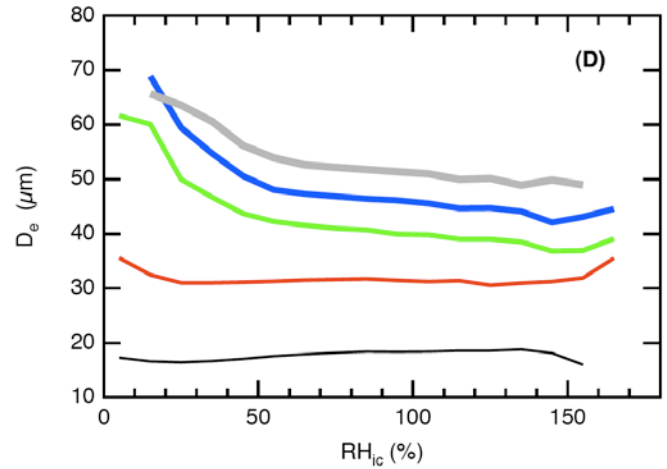
New AIRS Cloud Microphysics Research at JPL to Help Climate Modeling

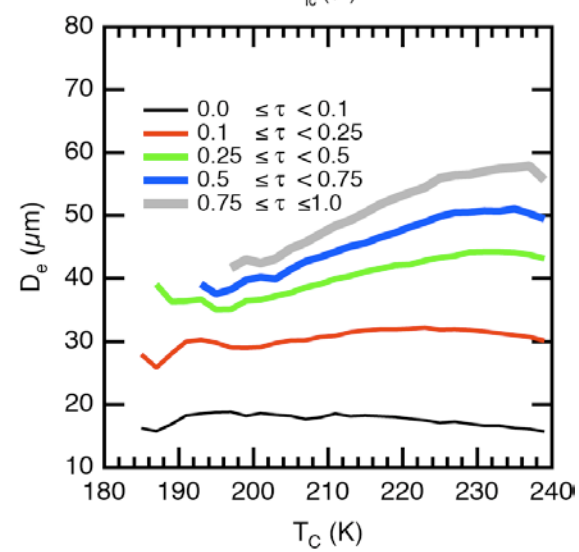
Two Different Assumptions of Ice Particle Size Distributions Lead to Significantly Different TOA SW/LW Forcing



Ice Particle Size Distribution from Tropics (red) and midlatitudes (blue) in NCAR CAM. The tropical Ice distributions have smaller ice particles. Mitchell et al. 2008, GRL

AIRS Provides Ice Microphysics Simultaneously With Relative Humidity

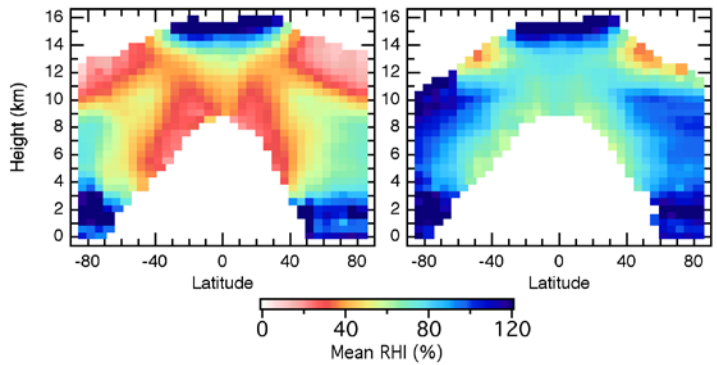




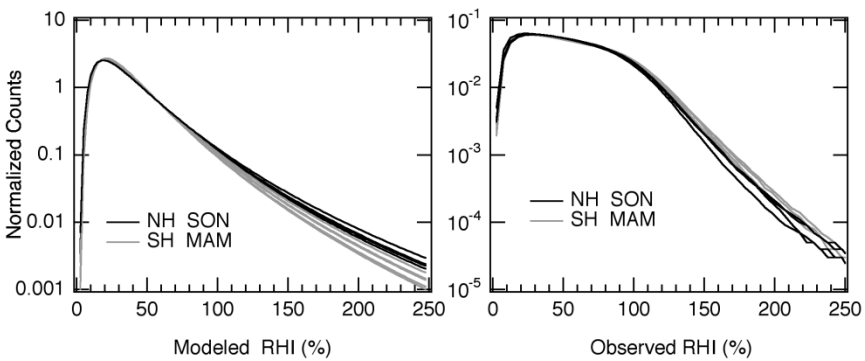
Kahn et al. 2008, Atmos. Chem. Phys.

Jet Propulsion Laboratory
California Institute of Technology

A combined view of RHI from AIRS, CloudSat, and CALIPSO



RHI annual mean: clear (left) and ice cloud (right)



"Modeled" RHI from temperature variability (left); "Observed" RHI (right)

Question: What do CloudSat and CALIPSO together tell us about cloudy- and clear-sky relative humidity w.r.t ice (RHI)?

Result: Large differences between clear/cloudy sky. Also, asymmetry in RHI between NH and SH mid-latitudes not explained by asymmetry in temperatures

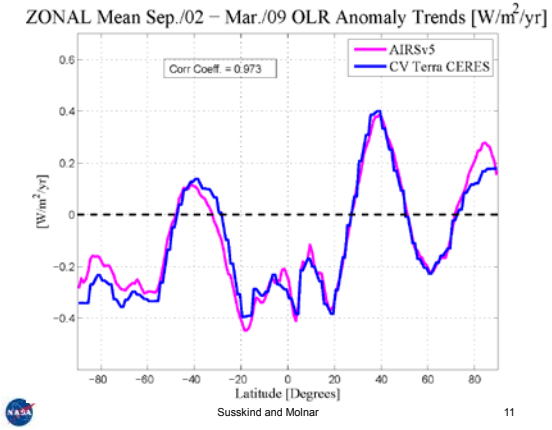
Significance: Clear/cloudy humidity necessary for climate model benchmarking. Hemispheric asymmetries consistent with an aerosol indirect effect on ice clouds

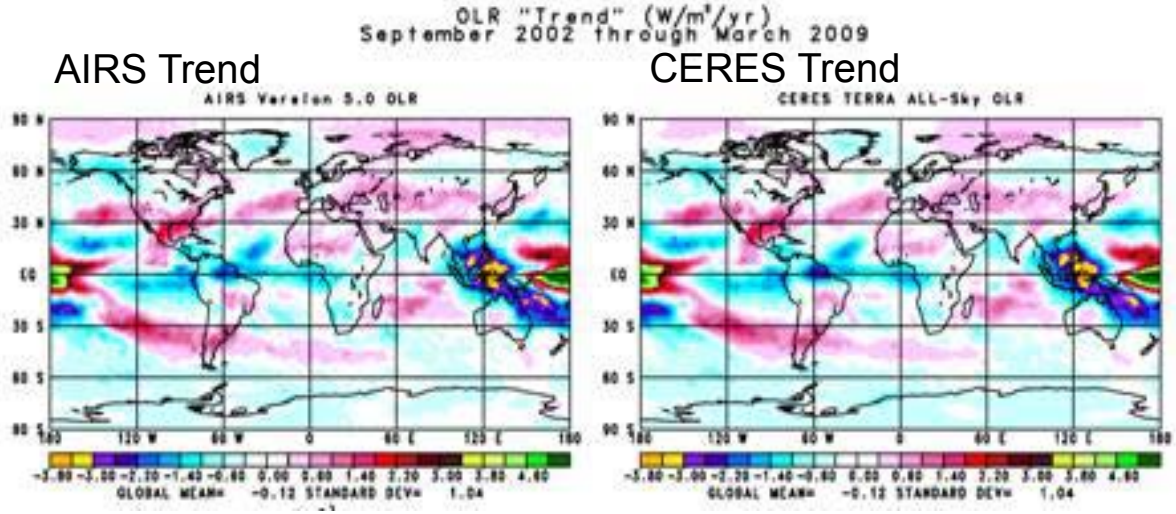
B. H. Kahn, A. Gettelman, E. J. Fetzer, A. Eldering, and C. K. Liang (2009), *JGR*, 114, D00H02, doi:10.1029/2009JD011738.

Jet Propulsion Laboratory
California Institute of Technology

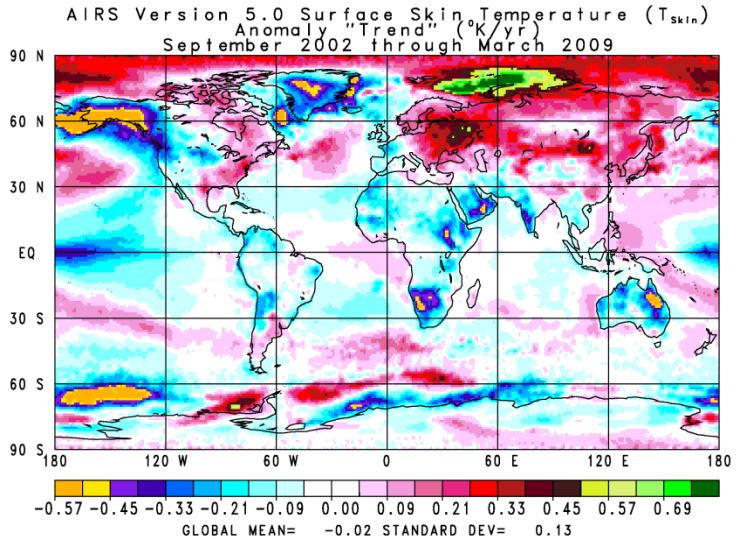
AIRS Useful for Understanding Trends in Outgoing Longwave Radiation (OLR)

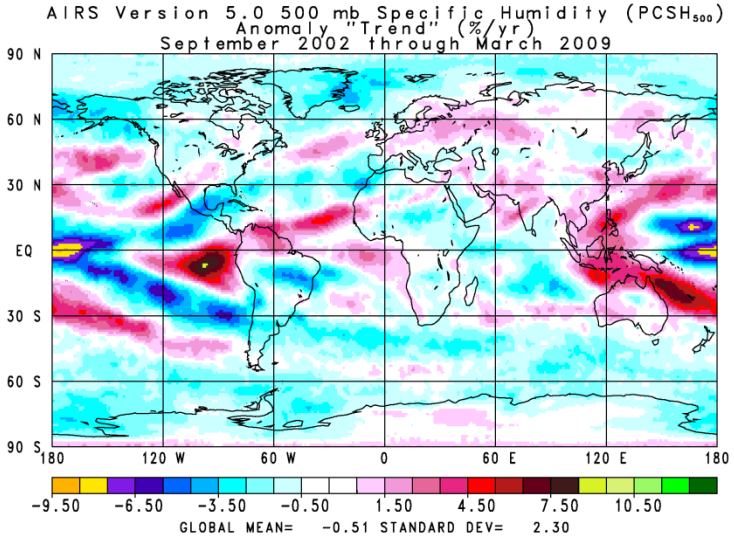
AIRS OLR Matches CERES





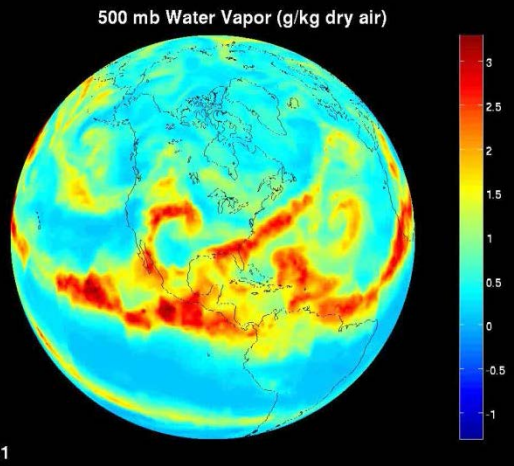
AIRS Allows Attribution of Observed OLR to T, H2O, O3,Clouds, etc.



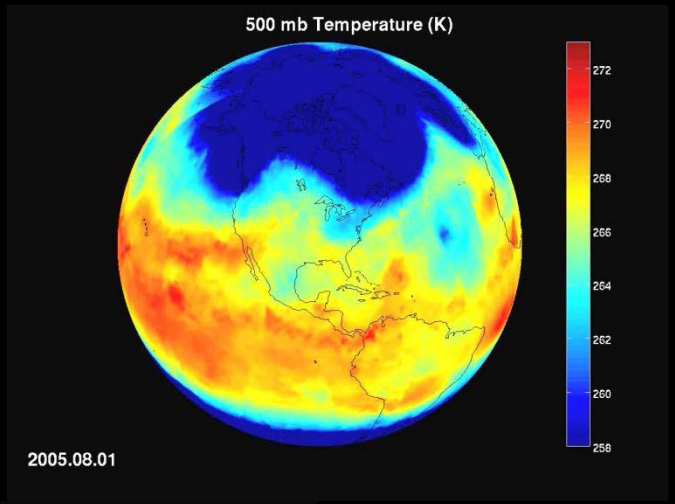


Susskind 2009

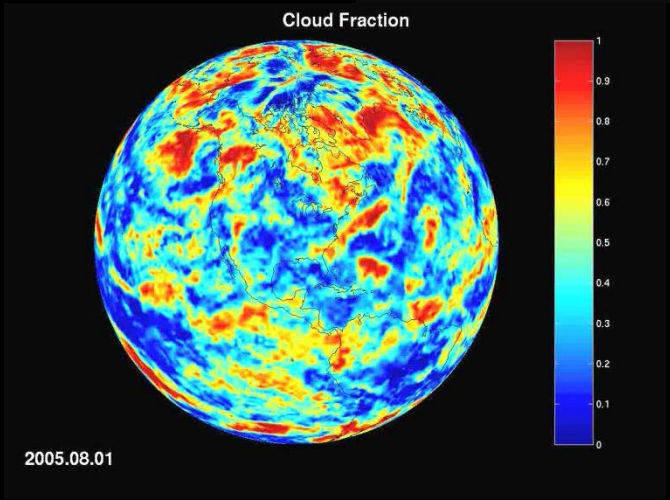
AIRS Climate Products



Water Vapor

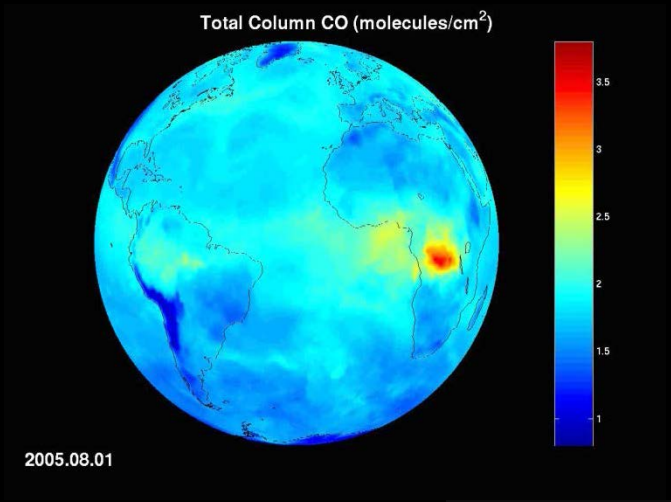


Temperature

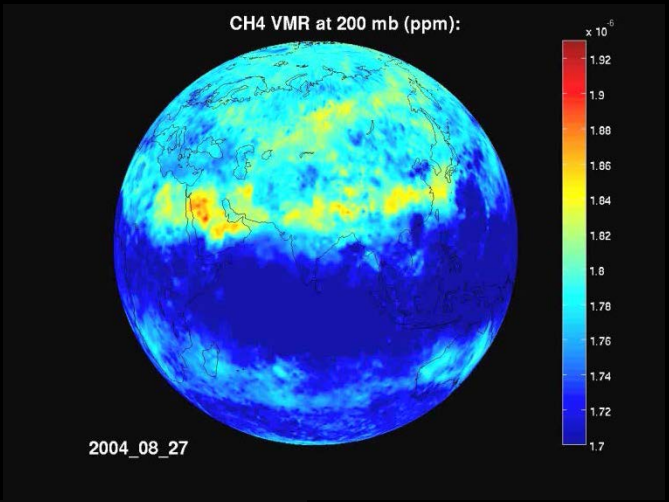


Clouds

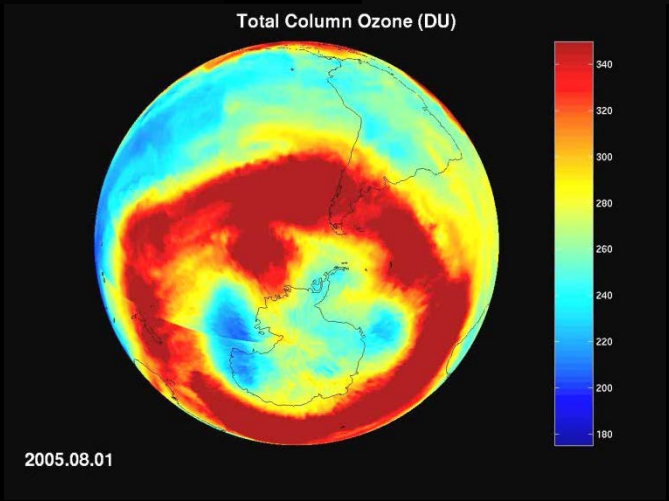
AIRS Greenhouse Gases



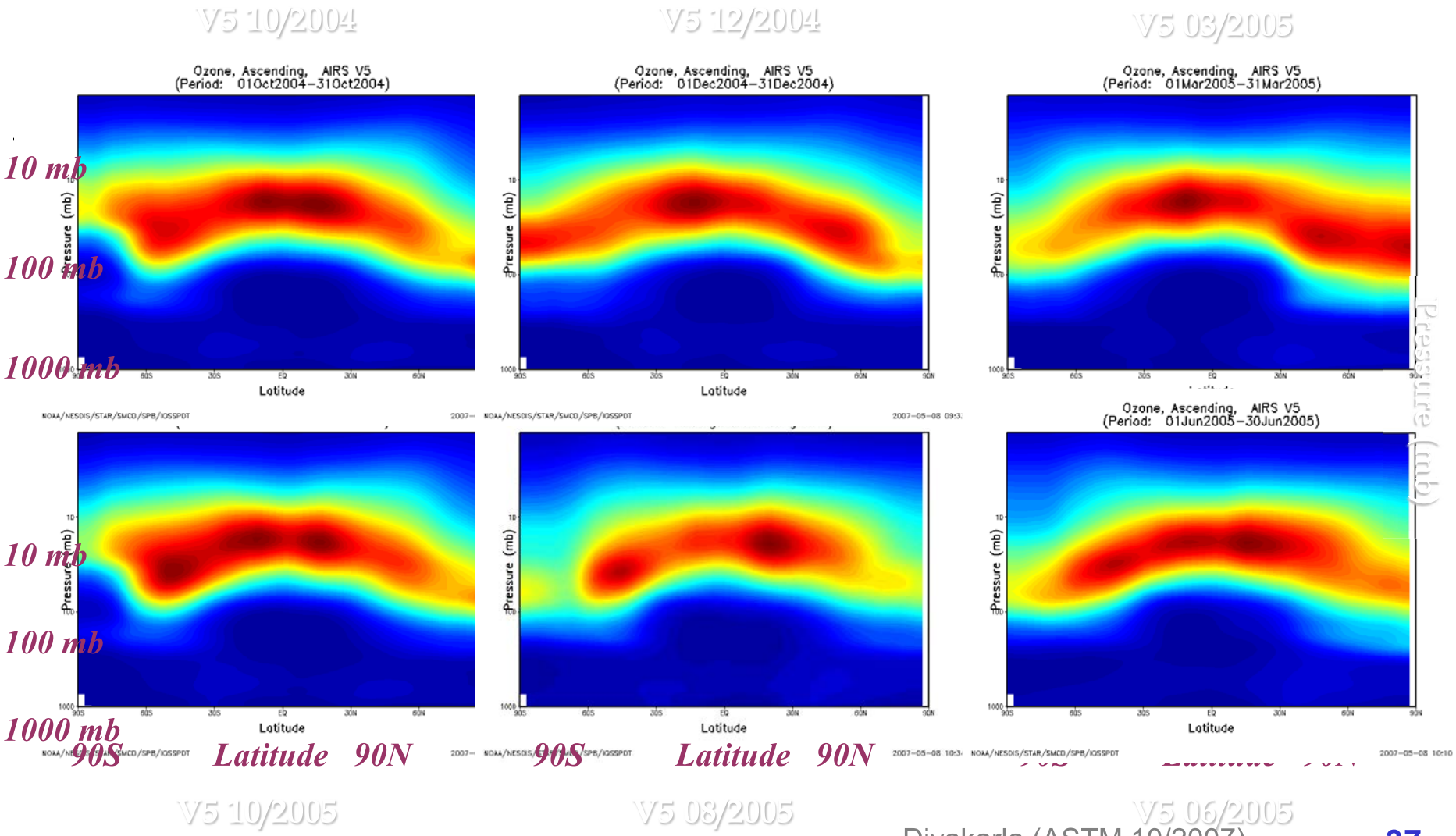
Carbon Monoxide



Methane



Ozone

Jet Propulsion Laboratory
California Institute of Technology

BD Circulation Features As Seen with AIRS V5 Monthly Averages of O3 Profile Latitude vs. Pressure