Natural and Anthropogenic Variability Observed in Seven Years of Data from the Atmospheric Infrared Sounder (AIRS)

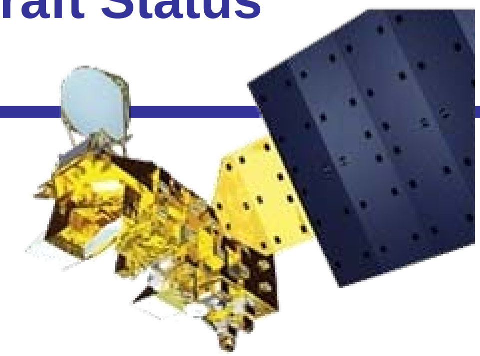
International TOVS Study Conference -17 (ITSC-17)
April 14-20, 2010
Monterey, Ca, USA

Thomas S. Pagano
AIRS Project Manager

National Aeronautics and
Space Administration

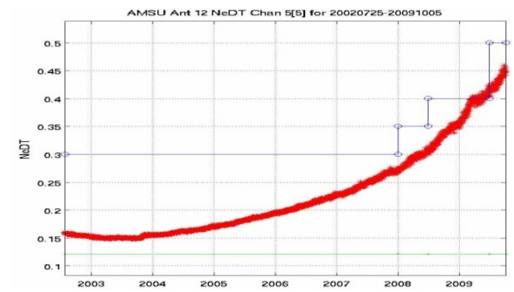
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

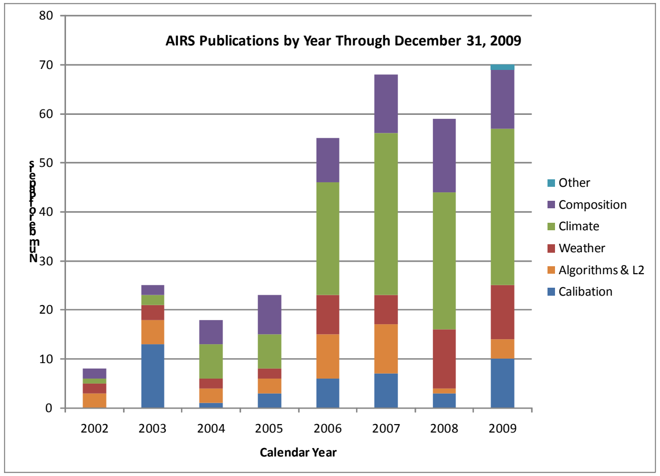
Instrument and Spacecraft Status



- Aqua in good health—fuel will last at least through 2017 and probably several years beyond
- AIRS is in excellent health
  - Most engineering parameters are not changing
  - A few are slowly varying
    - If their present trends continue they will be fine until well after Aqua fuel runs out
  - Planning Gain Table Update to Recover "Lost" Channels due to Radiation Exposure
- AMSU-A is in reasonable health
  - Channel 4 died (late 2007)
  - Channel 5 is degrading but should be useful until sometime this year
  - Channel 7 has been noisy since launch
- AIRS Science Strong
  - Over 325 Peer Reviewed Pubs to Date
  - Weather
  - Climate
  - Composition

AMSU Ch5 Noise





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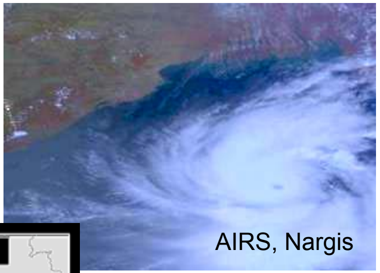
AIRS Improving Weather Forecasts

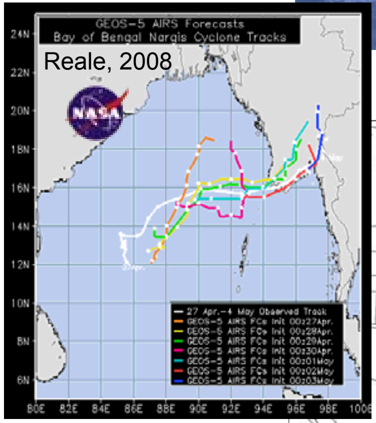
- **AIRS Operational at NCEP**
  - 6Hrs Improvement on 6 Day Forecast (LeMarshall 2005)
- **Key Publications in 2008/2009**
  - Le Marshall, J., Jung, J., Goldberg, M., Barnet, C., Wolf, W. Derber, J., Treadon, R., Lord, S., Using Cloudy AIRS Fields of View in Numerical Weather Prediction, Australian Meteorological Magazine, 2008, 57, 3, 249-254
  - 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
- **AIRS Data Used by NASA SPoRT in Real Time**
  - McCarty, W., G. Jedlovec, and T. L. Miller (2009), Impact of the assimilation of Atmospheric Infrared Sounder radiance measurements on short-term weather forecasts, J. Geophys. Res., 114, D18122, doi:10.1029/2008JD011626
- **AIRS Imagery Used by NASA Hurricane Center**
  - http://www.nasa.gov/mission_pages/hurricanes/main/index.html

Storm	Basin	Dates
Parma	W. Pacific	0/01/09, 10/05/09
Melor	W. Pacific	09/30/09, 10/01,02/09, 10/05,06/09
AL08	Atlantic	09/28/09
Grace	Atlantic	10/05/09, 10/06/09
Olaf	E. Pacific	10/01/09, 10/05/09

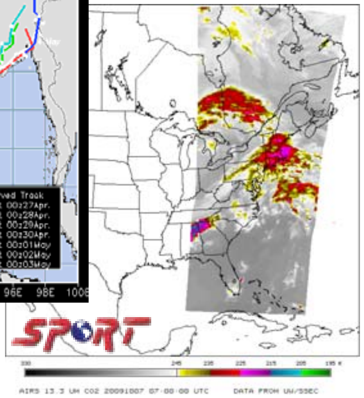
NOAA
NESDIS/NCEP

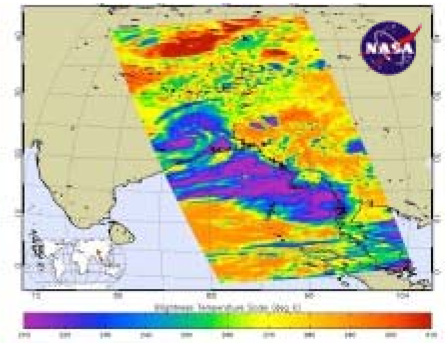
JCSDA


AIRS, Nargis



Reale, 2008




AIRS, Tropical Cyclone 03B, 9/10/2009

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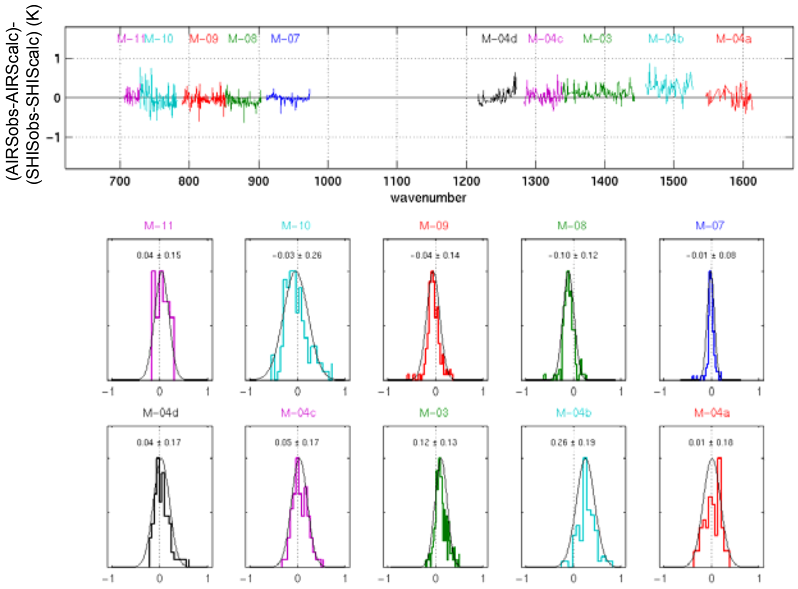
AIRS Demonstrates High Radiometric and Spectral Accuracy/Stability

Radiometric Accuracy

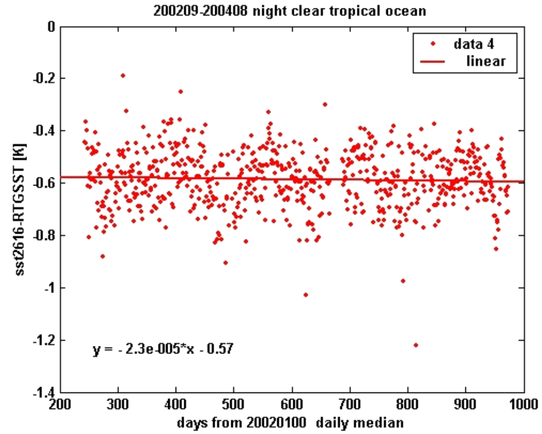
Scanning HIS Validates Rad Accy to 0.2K – H. Revercomb (UW)

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



Radiometric Stability

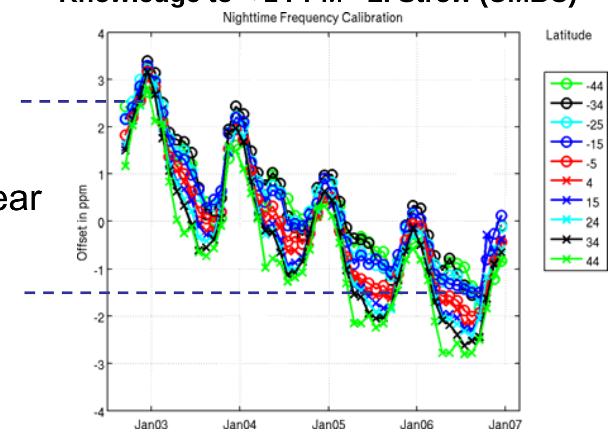
Stable to <8mK/Y – H. Aumann (JPL)



Spectral Accuracy/Stability

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

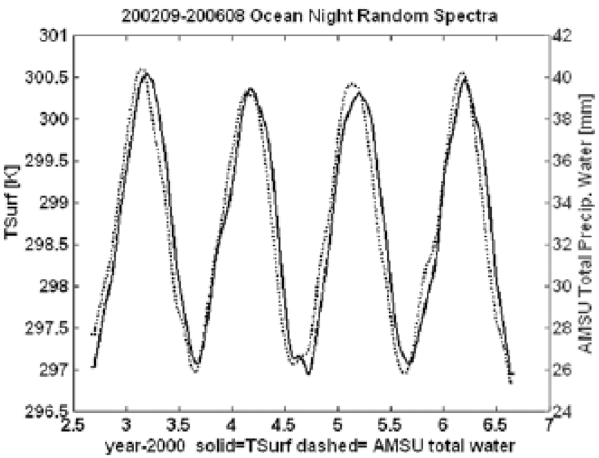
< 1 ppm/year



Reference: JGR, VOL. 111, April 2006

Phase Lag of Atmosphere in Seasonal Cycle Observed with AIRS and AMSU

Southern Hemisphere Phase Lag
4 Year Period Studied



	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

[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.

$$\Delta T = \frac{(1-\alpha)}{B}\Delta Q(t-\Delta)\frac{\tilde{f}}{\sqrt{1+(\tilde{f}\omega\tau)^2}} \qquad \tilde{f} = \frac{f}{\sqrt{1+D\mu^2 f\tau}}$$

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

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
= 0.32 W-Years/m^2-K

Pagano, 2010 Unpublished

•Aumann, H.H., Gregorich, D., Broberg, S., Elliott, D. (2007), Seasonal correlations of SST, water vapor, and convective activity in tropical oceans: a new hyperspectral data set for climate modeling. Geophys. Res. Lett., 34, L15813, doi: 10.1029/2006GL029191

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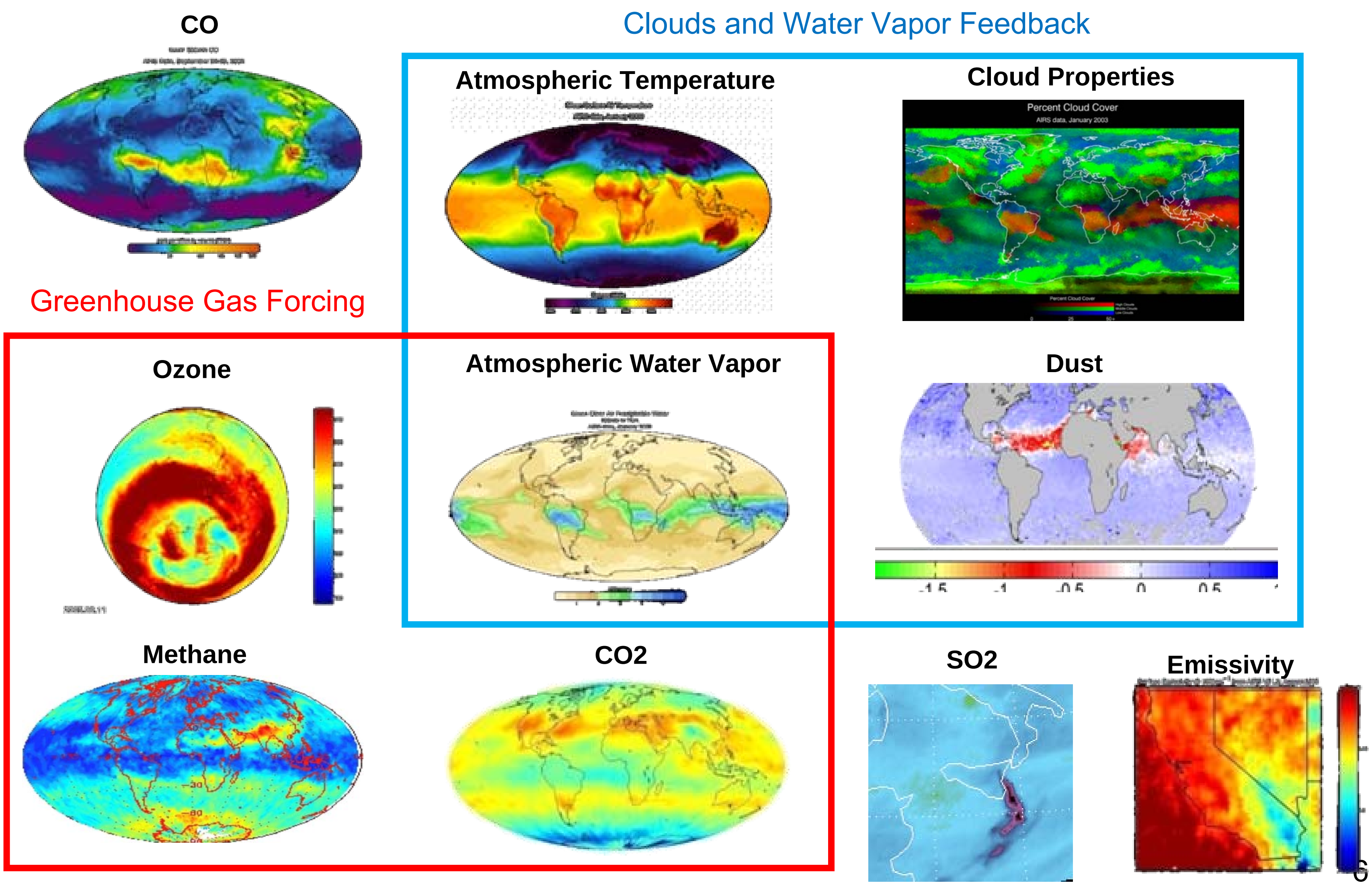
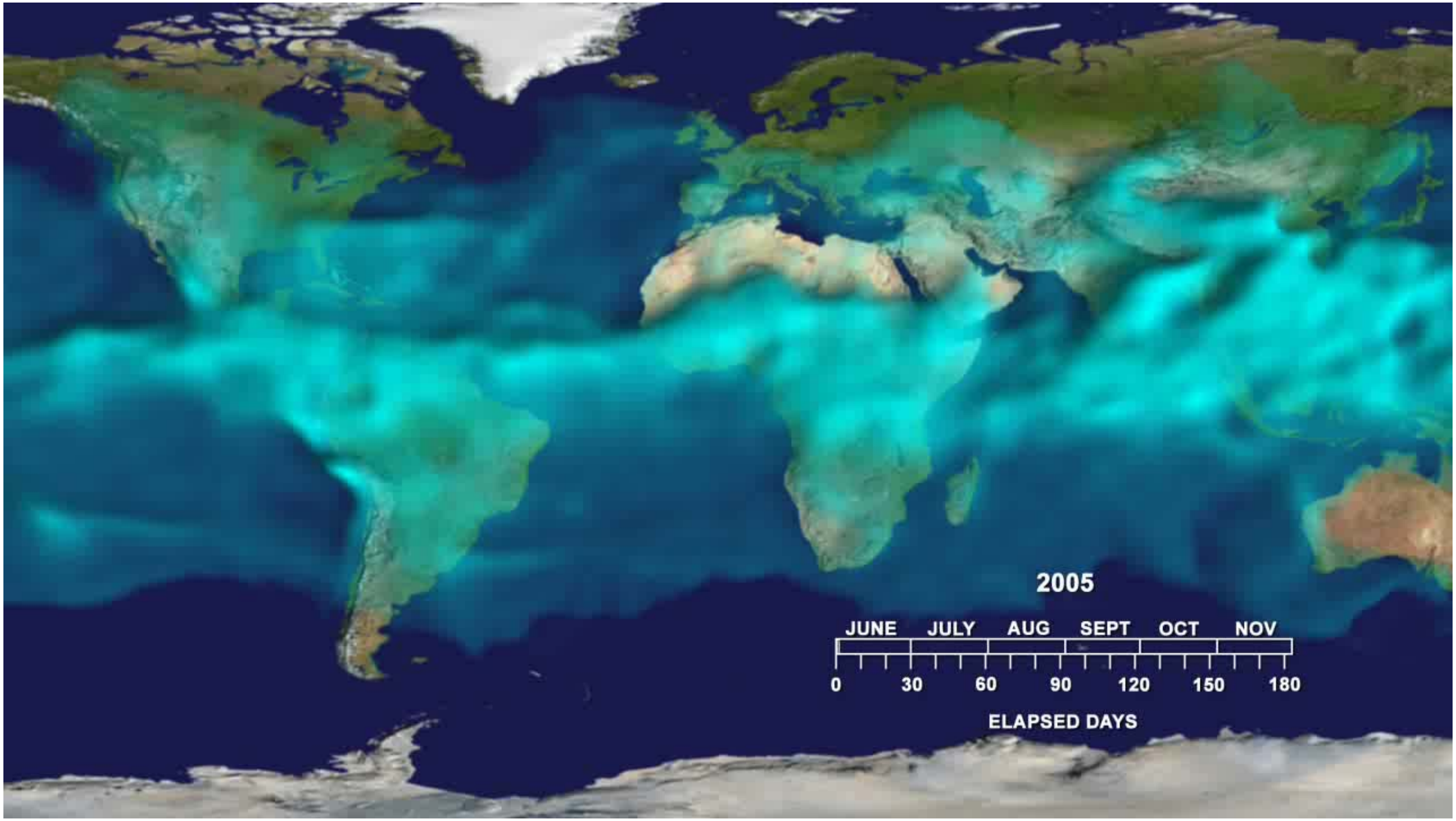
AIRS Geophysical Products



AIRS Water Vapor Isosurface
(5kg H2O /kg Dry Air)



V. Realmuto, C. Thompson, T. Pagano, S. Ray
NASA/JPL

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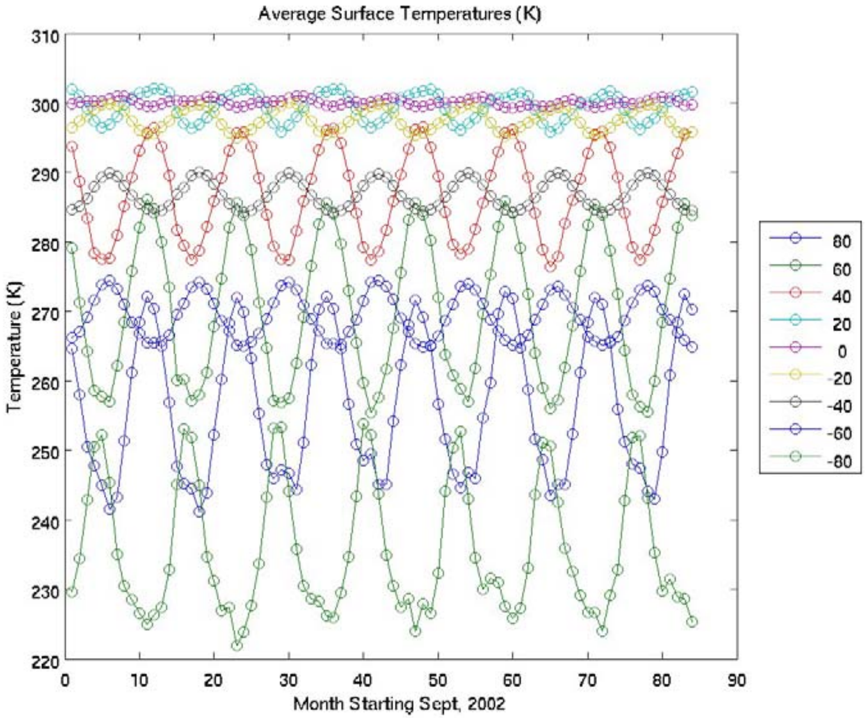
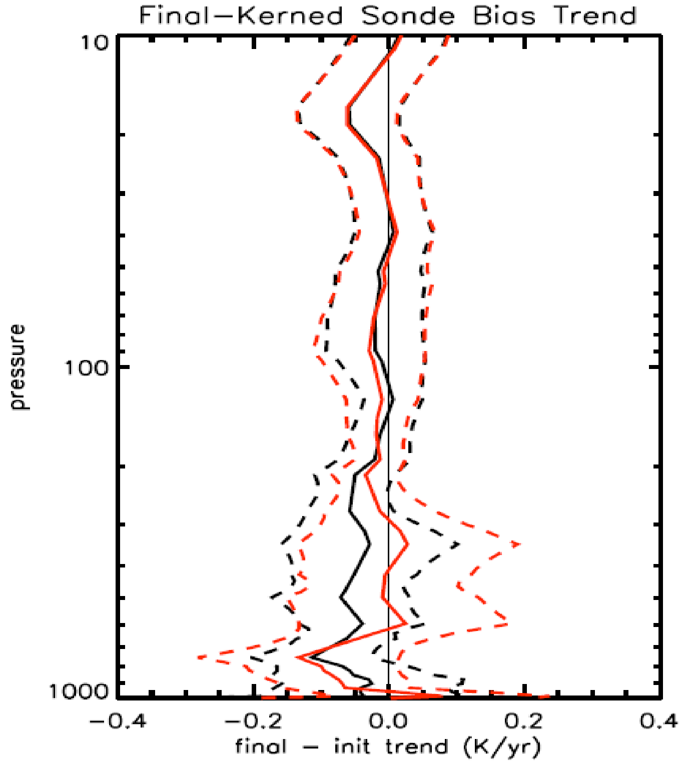
7.5 Year Record Now Available
Digital Video Record of Earth Atmosphere

- Plots show L3 Zonal Surface Temperature (Left)
- Record shows seasonal variability
- V5 Temperature stability good to < 100 mK/year (Not suitable for climate trending)

V5 Shows Bias Trend of
50-100mK/year
Significantly reduced in V6
(Irion, 2010 on NOAA Changes)



Pagano, 2009



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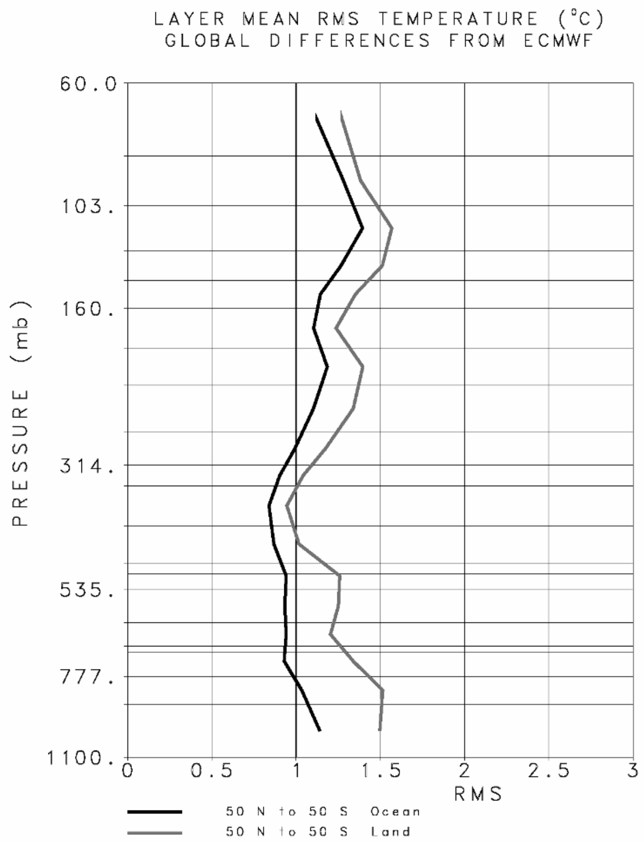
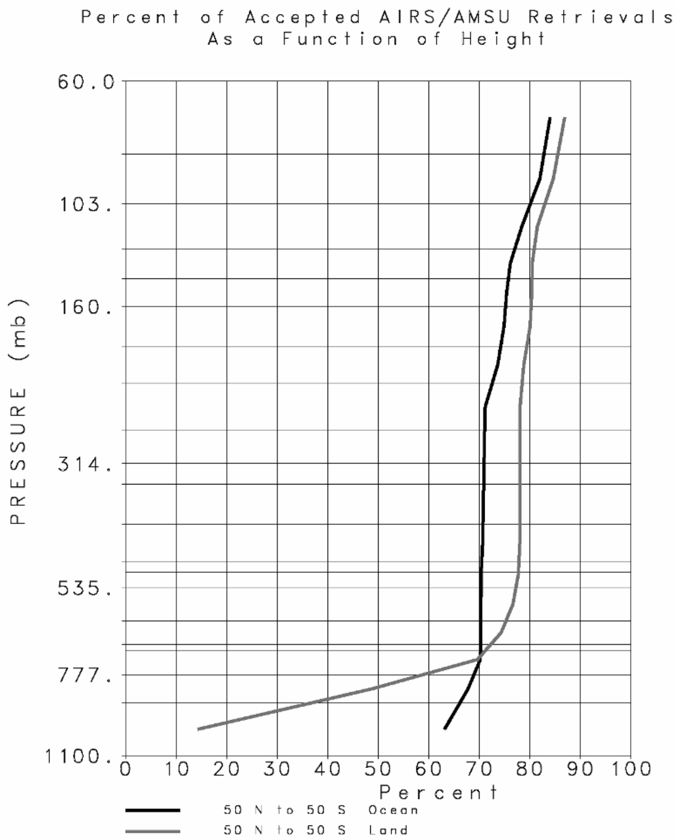
AIRS Yield and Accuracy Degrade Near Surface Over Land (V5)





Joel Susskind, NASA, 2008

Land cases limited by inadequate surface emissivity knowledge
Improvement seen in V6, but need higher spatial resolution observations

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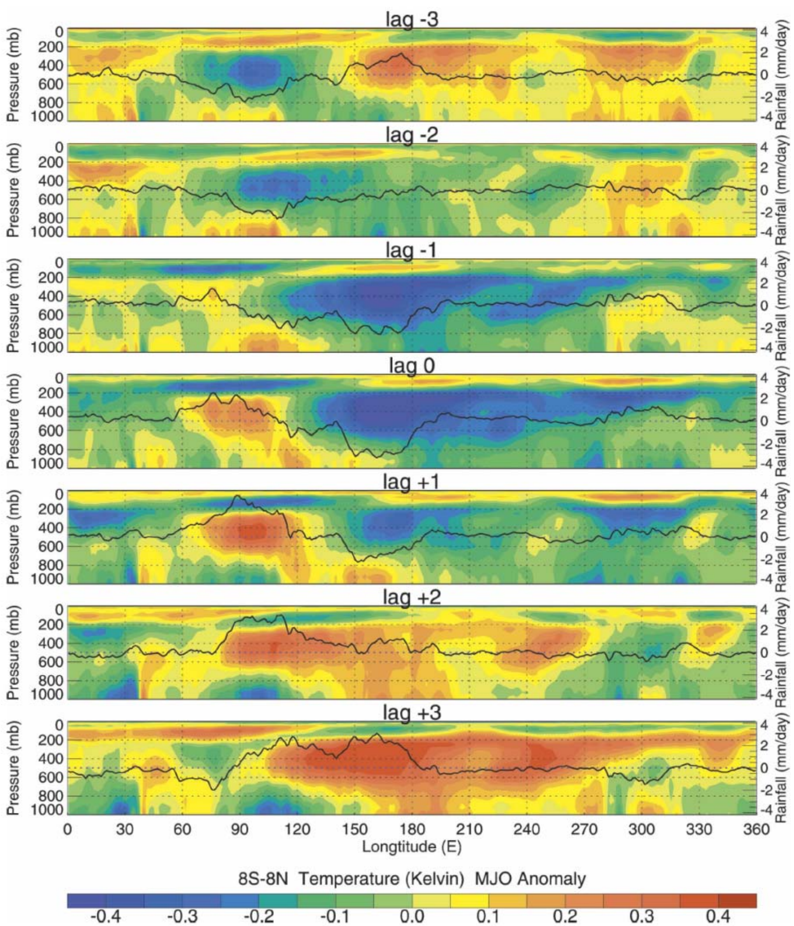
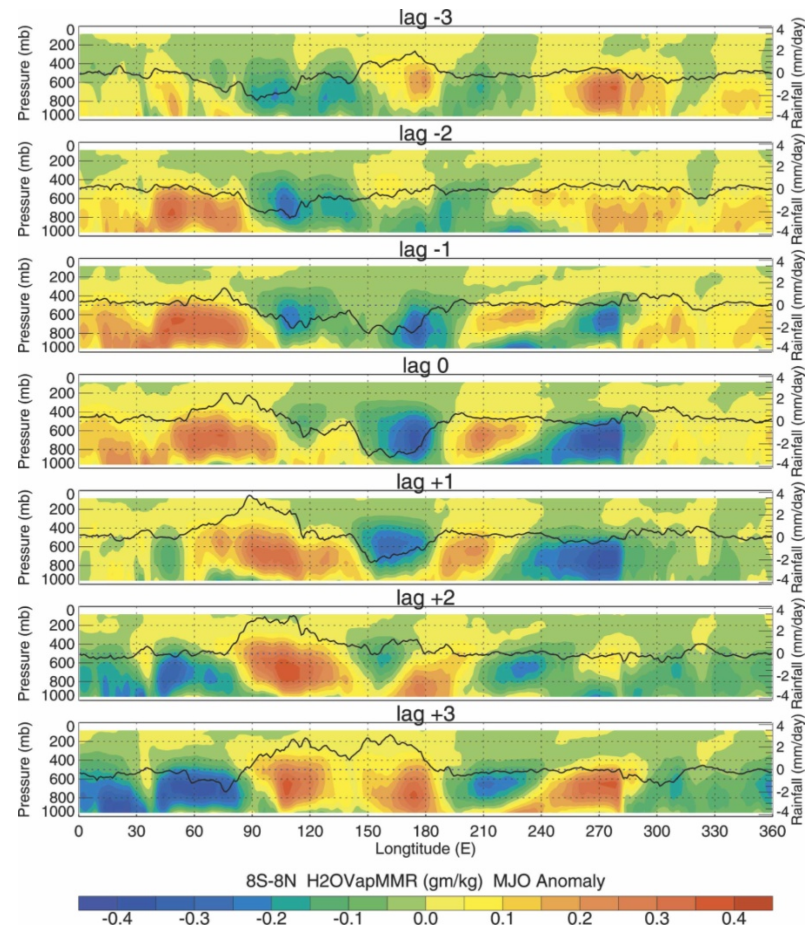
AIRS Sheds Light on Madden Julian Oscillation (MJO)

Vertical Temperature Anomaly



Vertical Water Vapor Anomaly



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

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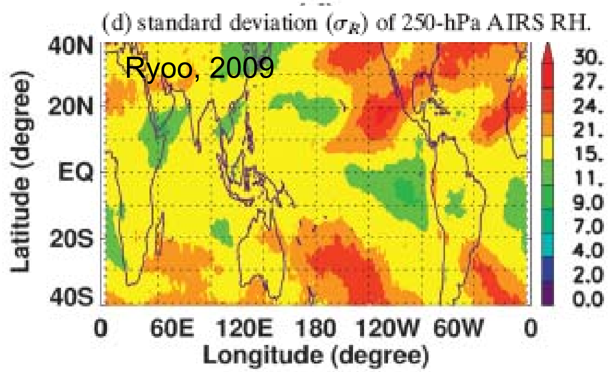
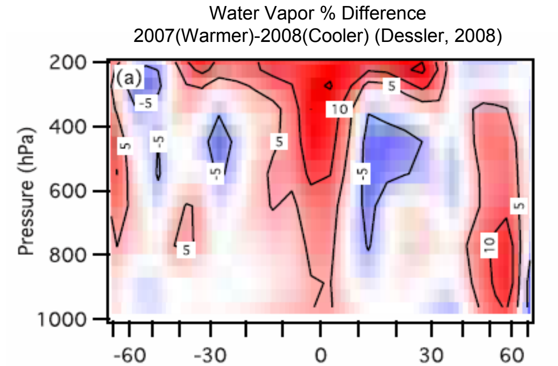
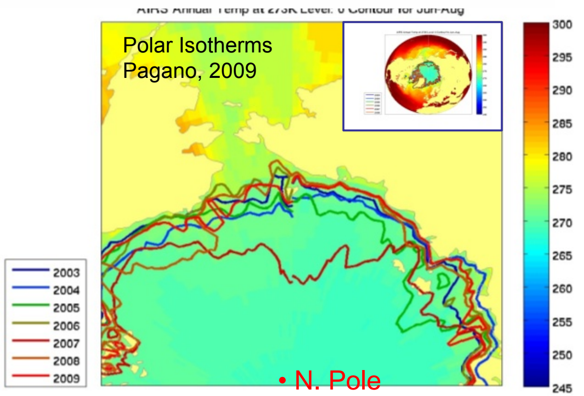
AIRS Improving Climate Prediction 2009 Highlights

- **Model Validation**
  - Ryoo,Ju-Mee; Igusa,Takeru; Waugh,Darryn W.,PDFs of Tropical Tropospheric Humidity: Measurements and Theory, J.Clim., 2009, 22, 12, 3357-3373,
  - Casey, Sean P.F., Dessler, A.E., Schumacher, Five Year Climatology of Midtropospheric Dry Air Layers in Warm Tropical Ocean Regions as Viewed by AIRS/Aqua, C., Journal of Applied Meteorology and Climatology, 2009, 48, 9, 1831-1842
- **Process Studies**
  - 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.
  - Zelinka, Mark D., Hartmann, Dennis L., Response of Humdity and Clouds to Tropical Deep Convection, J.Clim., 2009, 22, 9, 2389-2404
  - Savtchenko, A., Deep convection and upper-tropospheric humidity: A look from the A-Train, Geophys. Res. Lett., 36, L06814, doi:10.1029/2009GL037508, 2009
  - Wright, J. S., Fu, R., and Heymsfield, A. J., A statistical analysis of the influence of deep convection on water vapor variability in the tropical upper troposphere, Atmos. Chem. Phys. Discuss., 9, 4035-4079, 2009
- **Clouds**
  - Kahn, B. H., A. Gettelman, E. J. Fetzer, A. Eldering, and C. K. Liang (2009), Cloudy and clear-sky relative humidity in the upper troposphere observed by the A-train, J. Geophys. Res., 114, D00H02, doi:10.1029/2009JD011738







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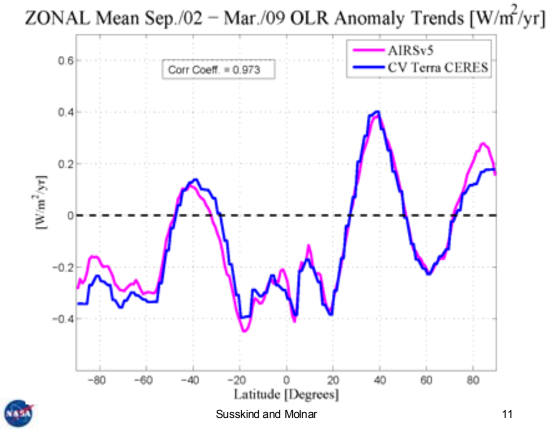
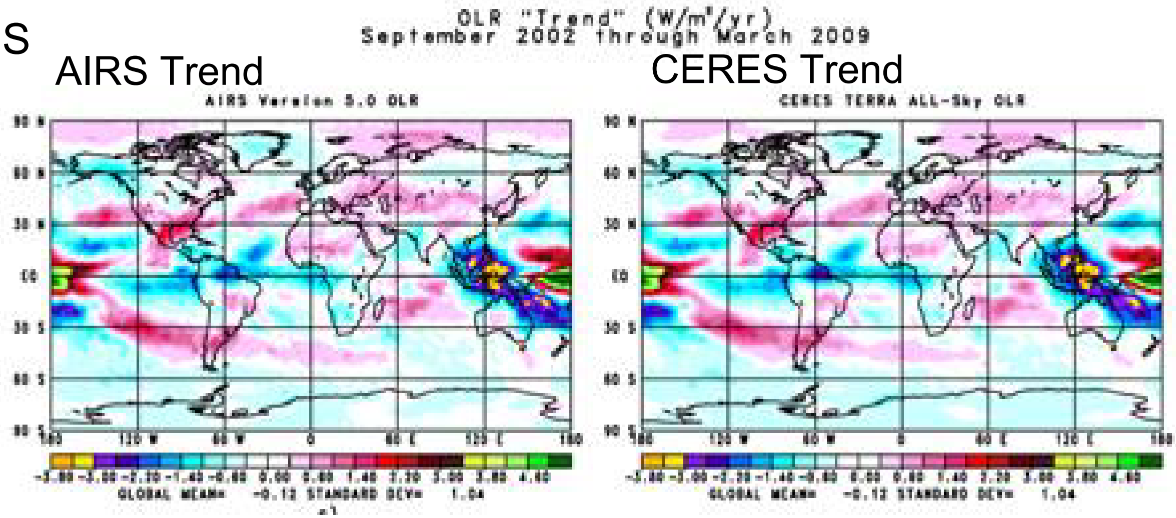
AIRS/CERES Observes Similar Trend in OLR

AIRS OLR Trend Matches CERES

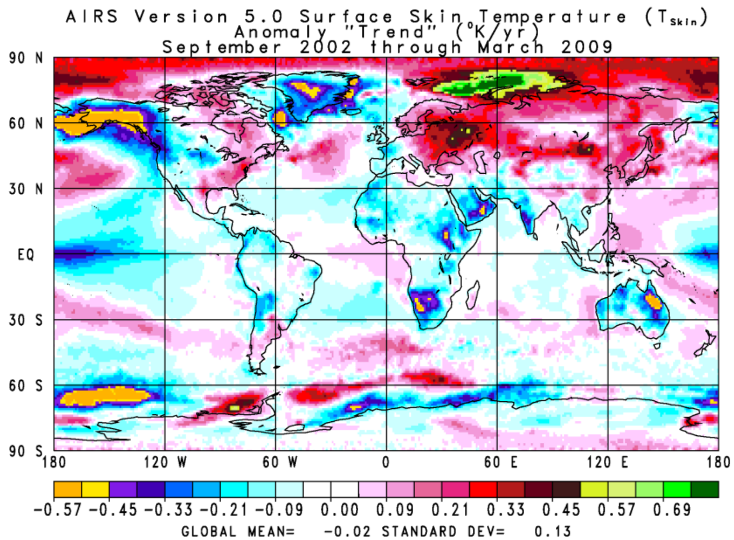


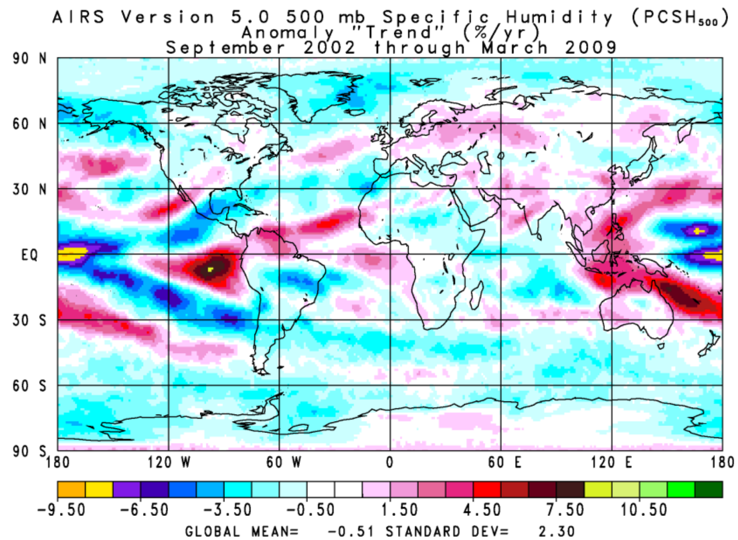
AIRS Trend

CERES Trend



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





Susskind 2009

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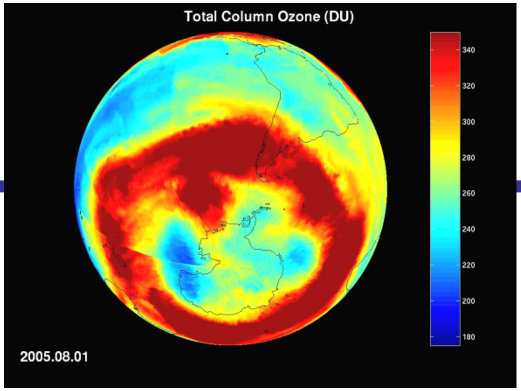
AIRS Ozone Shows Annual Circulation



Compares well with Other Sensors

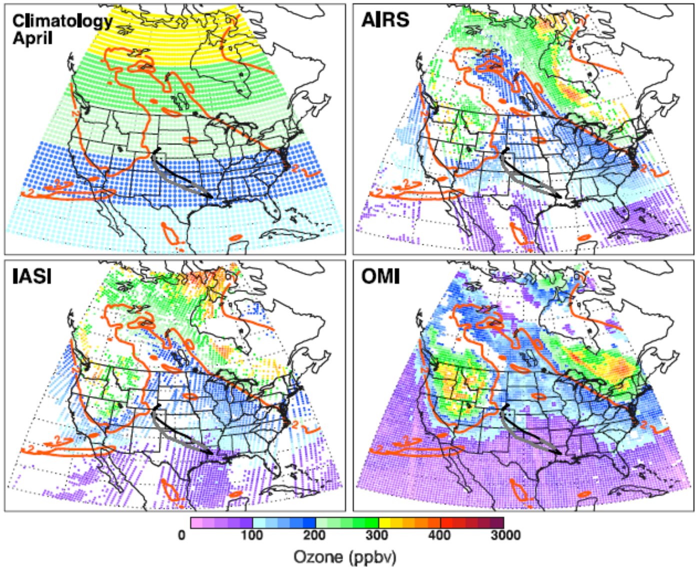
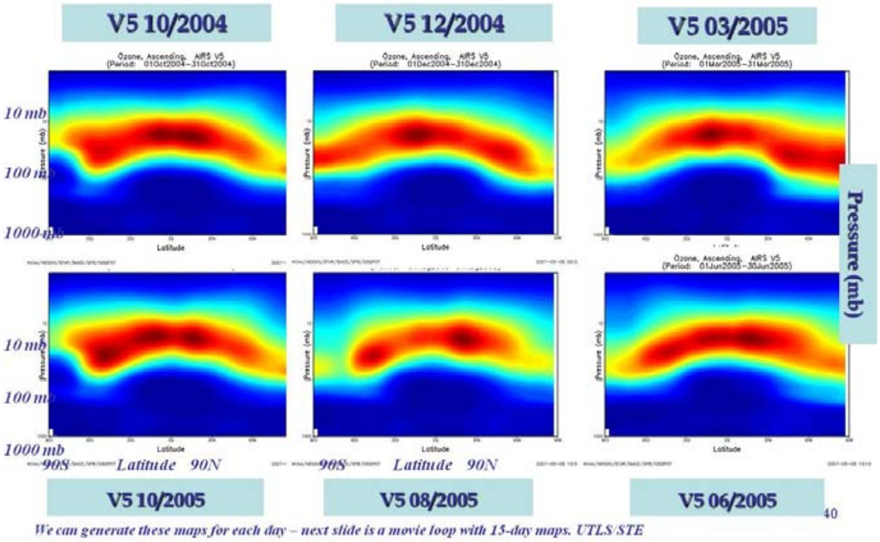


Figure 3. *McPeters et al.* [2007] April climatology used as the first guess in AIRS and IASI and as the a priori in OMI, and ozone retrievals for AIRS, IASI, and OMI in the 212–300 hPa pressure layer for the flight on 30 April 2008. GFS PV = 2 PVU contours derived at 250 hPa are shown in orange. This contour is used as a surrogate for the dynamical tropopause. In addition, the entire flight track is shown in black, with the geographical location of the aircraft while sampling the 212–300 hPa region is shown in gray. Satellite observations with more than 70% cloud fractions are excluded from these plots.

Pittman, J. V., L. L. Pan, J. C. Wei, F. W. Irion, X. Liu, E. S. Maddy, C. D. Barnet, K. Chance, and R.-S. Gao (2009), Evaluation of AIRS, IASI, and OMI ozone profile retrievals in the extratropical tropopause region using in situ aircraft measurements, J. Geophys. Res., 114, D24109, doi:10.1029/2009JD012493.

Vertical Seasonal Behavior



Divakarla, AIRS Science Team Meeting, 10/2007
See also…
Divakarla, M., et al. (2008), Evaluation of Atmospheric Infrared Sounder ozone profiles and total ozone retrievals with matched ozonesonde measurements, ECMWF ozone data, and Ozone Monitoring Instrument retrievals, J. Geophys. Res., 113, D15308, doi:10.1029/2007JD009317.

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AIRS Methane in Upper Trop Result of Convective Transport

AIRS Methane Plume over South Asia

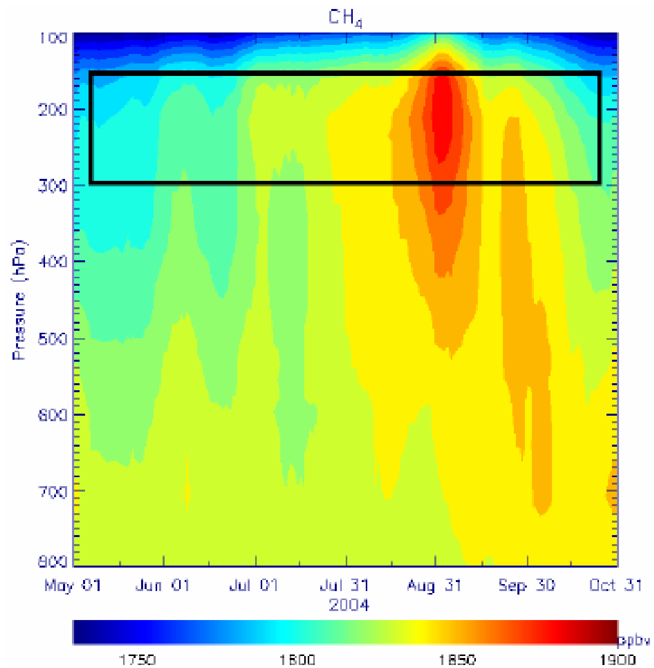
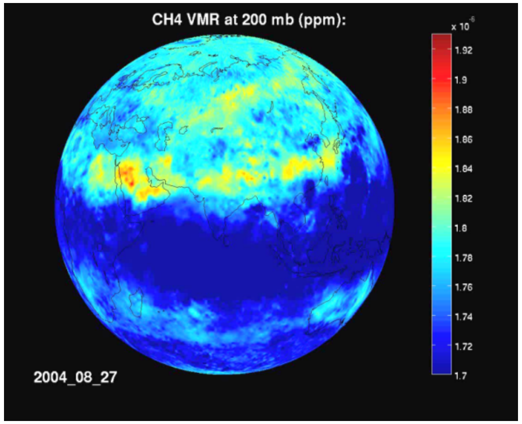
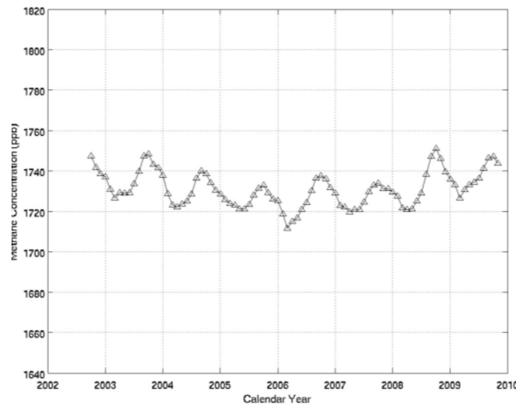


Fig. 3. Time-pressure cross section of AIRS CH_4 averaged in Region II. Data is from the ascending node (13:30 LST). Significant enhancement of CH_4 at the middle to upper troposphere is evident, with the maximum occurring in early September. The most sensitive region of AIRS to CH_4 at 150–300 hPa is highlighted in the box.

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

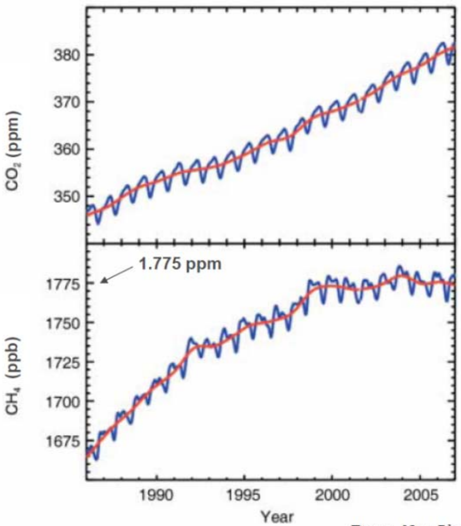
AIRS Methane (CH4) Time Series





Tom Pagano, Jet Propulsion Laboratory

Comparison of Atmospheric Time Series of CO2 and CH4



Evans, *New Phytologist*, 2007.
www.cmdl.noaa.gov

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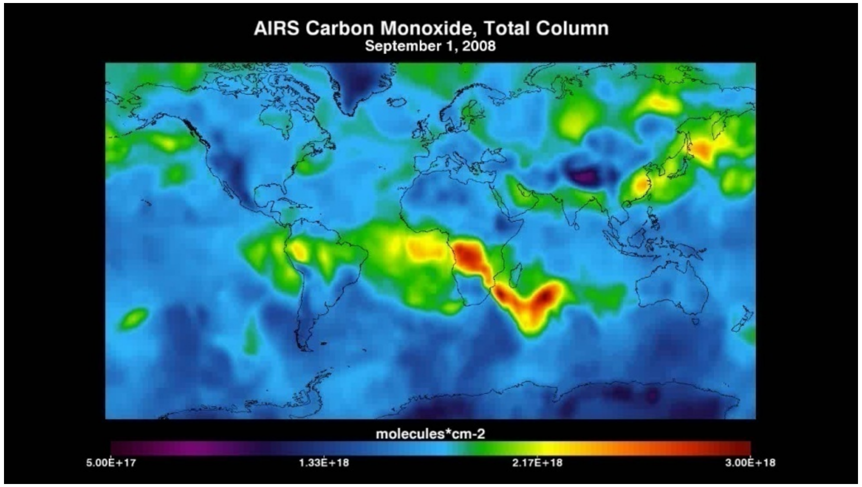
AIRS Captures Major Global Fire Events Sees Global Transport



California "Station Fire", August 2009

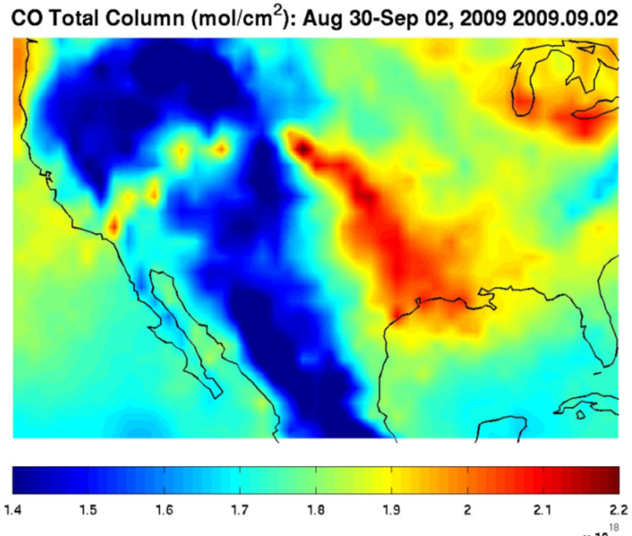
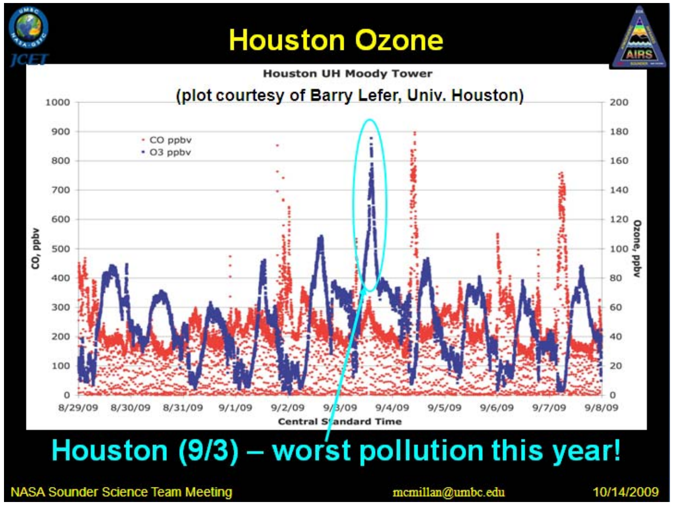


Image credit: T. Pagano, JPL



In Memory of

Wallace McMillan
UMBC

McMillan, W. W., et al. (2008), AIRS views transport from 12 to 22 July 2004 Alaskan/Canadian fires: Correlation of AIRS CO and MODIS AOD with forward trajectories and comparison of AIRS CO retrievals with DC-8 in situ measurements during INTEX-A/ICARTT, J. Geophys. Res., 113, D20301, doi:10.1029/2007JD009711.

AIRS Measures Mid-Tropospheric Carbon Dioxide Concentrations with High Accuracy

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Measurement Features

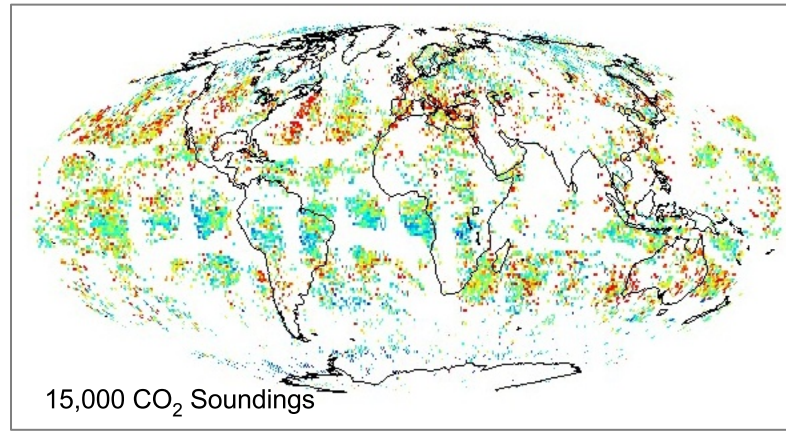
- Thermal infrared emission
- CO2 in the mid-troposphere
- Global Observations
- Day, Night, All Seasons
- 100 km Horizontal Resolution
- 15,000 soundings per day
- Level 2 data include individual soundings and statistics
- Level 3 data in daily, multi-day and calendar monthly at a spatial resolution of 2 deg latitude by 2.5 deg longitude
- Monthly Maps with 450,000 Soundings
- Measurement Precision: 1-2 ppm
- Valid in Latitude range 60 S to 90 N
- 7.5 Years Now Available

- 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.

**http://airs.jpl.nasa.gov/AIRS_CO2_Data/AIRS_and_CO2/*

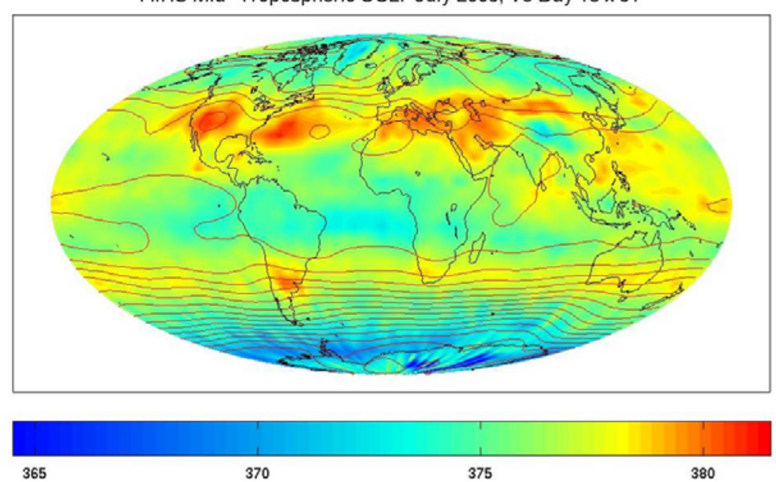
AIRS CO_2 For One Day
1°x1° Horizontal Resolution

AIRS V5 CO2: Day 2003 7 15 x 1



Distributions Follow Known Weather Patterns
AIRS CO_2 For One Month

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



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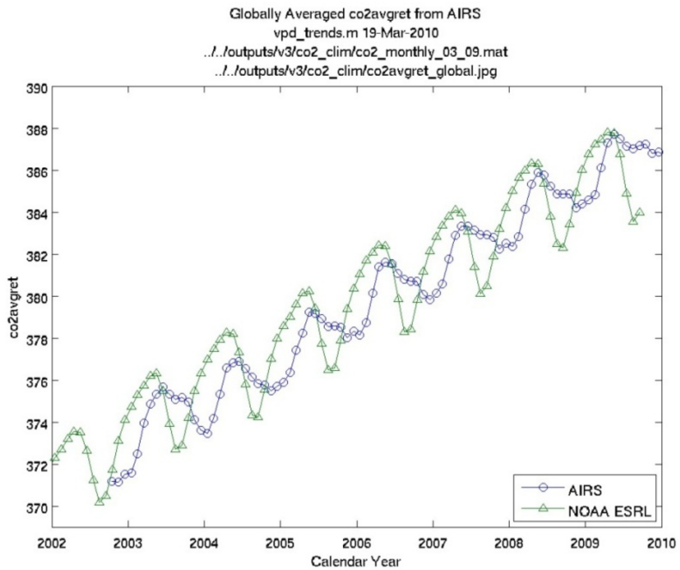
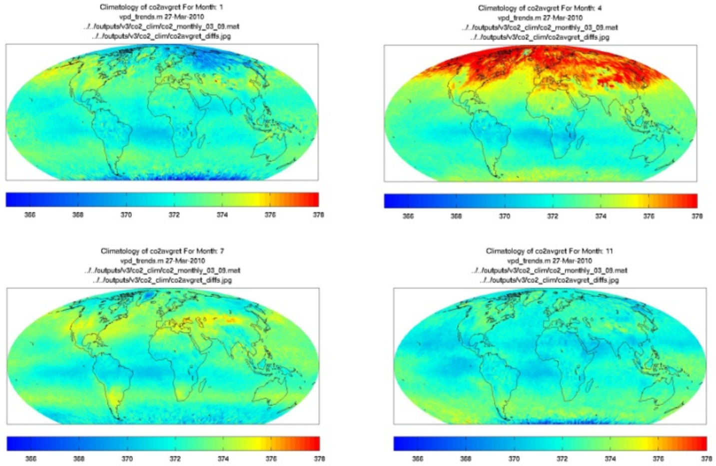
CO2 Data Shows Growth from Anthropogenic Sources and Global Seasonal Distribution





What have We Observed?

- *CO_2 is NOT Horizontally Well Mixed in the Troposphere*
- *Discovery of a CO2 Belt in the Southern Hemisphere*
- *Seasonal Cycle and Trend*
- *Vegetation uptake over Park Falls*
- *Intraseasonal and Interannual Variability*
- *Stratospheric-Tropospheric exchange*
- *Influence of ENSO on CO_2 during El Nino Event*

Data Support CO2 Inverse Model Development

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
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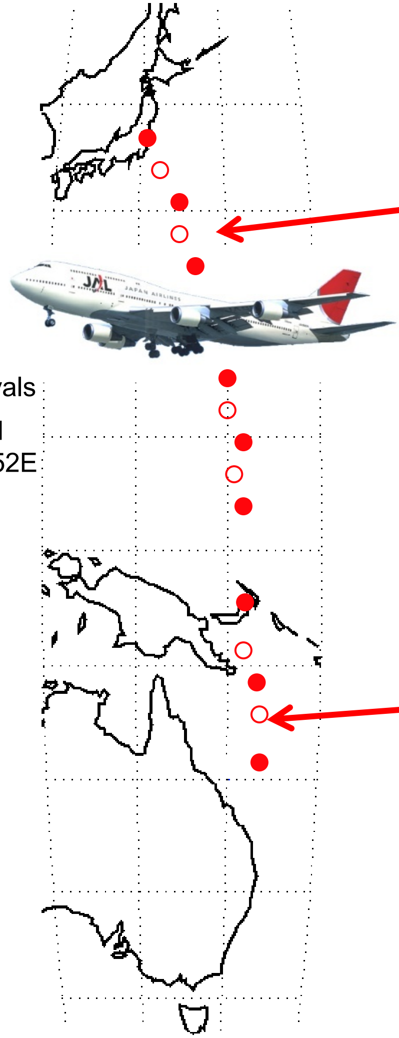
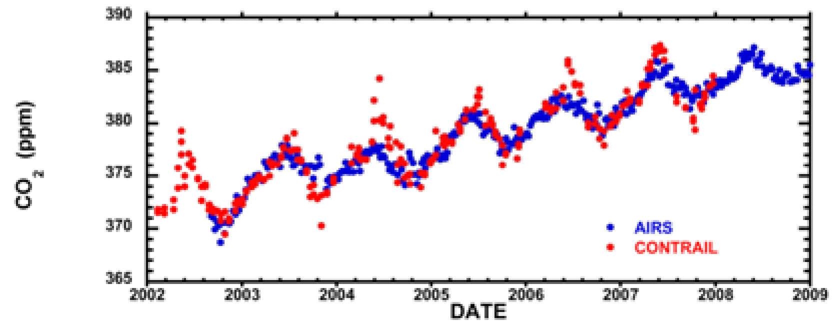
Comparison of V2 AIRS CO2 and CONTRAIL (Matsueda) Airborne Flask Measurements



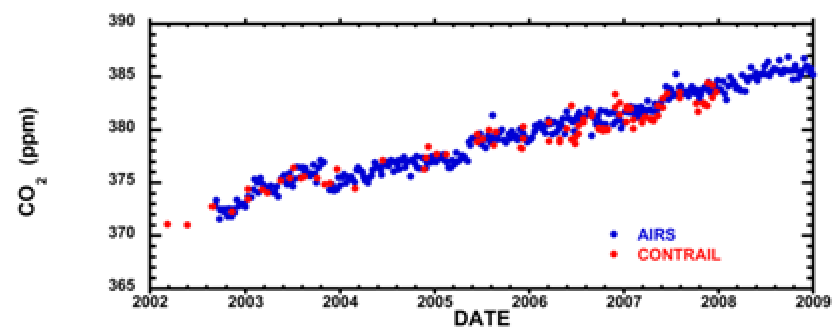
JAL Flights
~ two week intervals

30S ≤ LAT ≤ 33N
135E ≤ LON ≤ 152E

7-day averages of AIRS retrievals: LAT= +25° ± 5° LON = 143° ± 5°
CONTRAIL individual flask measurements: LAT = +25° ± 5°



7-day averages of AIRS retrievals: LAT= -25° ± 5° LON = 150° ± 5°
CONTRAIL individual flask measurements: LAT = -25° ± 5°



Rate of Growth:	**AIRS**	**= 1.98**	**±0.05**	**ppm/year**
(30°S to 30°N)	**CONTRAIL**	**= 2.01**	**± 0.04**	**ppm/year**

Summary and Conclusions

- AIRS Instrument fully operational and stable
- Video record of atmosphere since operational in October 2002
- Natural and Anthropogenic Variability Digitally Recorded
- Data show
  - Atmospheric Response to Solar Forcing and Surface Effects
  - Seasonal Distributions and Horizontal transport (T, q, O3)
  - Vertical transport (MJO, CH4, O3, CO2)
  - Transport and increase of greenhouse gases due to biomass burning (CO and CO2)
- Data support climate models and process studies
- All data available at the GES/DISC for entire mission to date
- http://airs.jpl.nasa.gov

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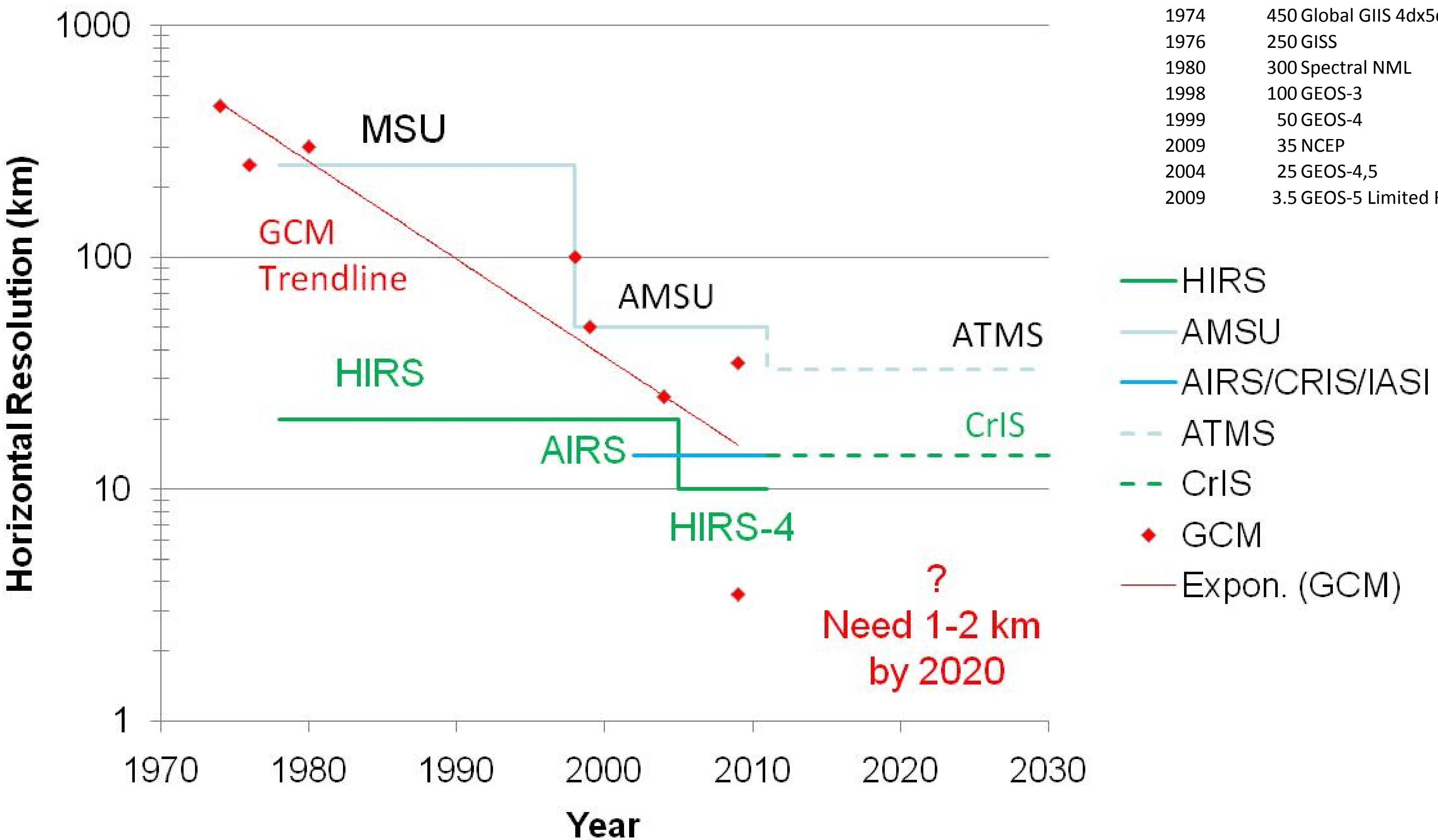
Model Resolution Improving Exponentially with Time

Global Models

1974	450	Global GIIS 4dx5d
1976	250	GISS
1980	300	Spectral NML
1998	100	GEOS-3
1999	50	GEOS-4
2009	35	NCEP
2004	25	GEOS-4,5
2009	3.5	GEOS-5 Limited Run



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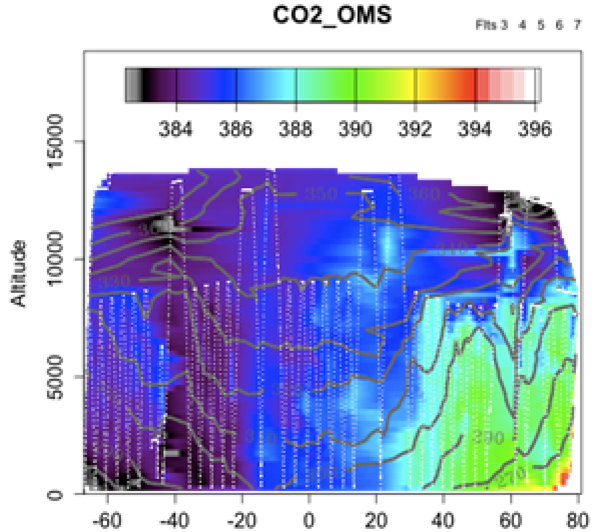
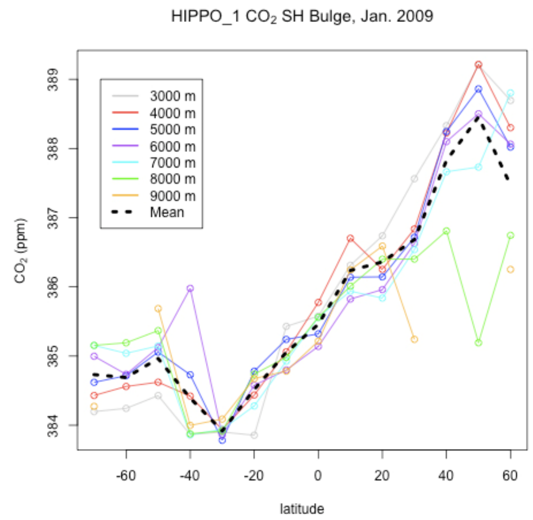
HIAPER Pole-to-Pole Observations 2009 (“HIPPO”)
Data Show Evidence of Belt in SH

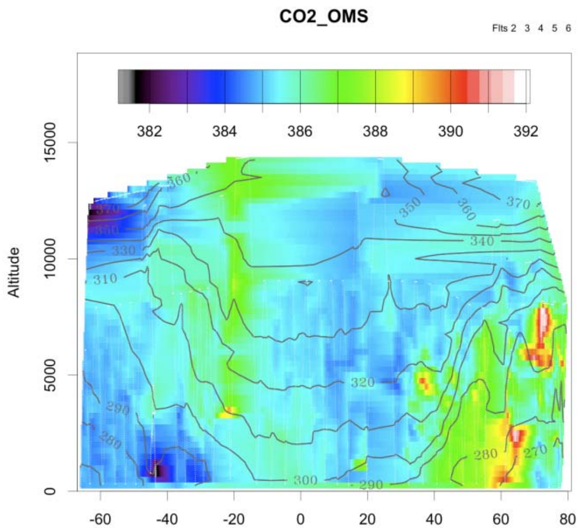


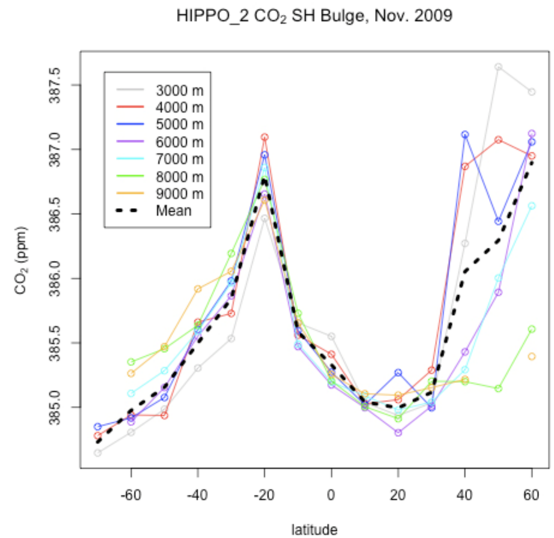


HIPPO_1

Xsects along the Dateline

Jan 2009





HIPPO_2

Xsects along the Dateline

Nov 2009

Steven C. Wofsy