Question #9
With respect to the AIRS dispersive hyperspectral sensor – what are the applications, experiences, and the status of new JPL GHG research and what does AIRS show for the future of atmospheric measurements?

Moustafa **Chahine**, Edward Olsen

**NOAA Hyperspectral
Spectrometer Workshop**

March 29 - 31, 2011

Miami Florida

Question 9 – AIRS Specific

With respect to the NASA JPL Atmospheric Sounder AIRS (dispersive) hyperspectral sensor:
(Weather, Climate and Atmospheric Chemistry)

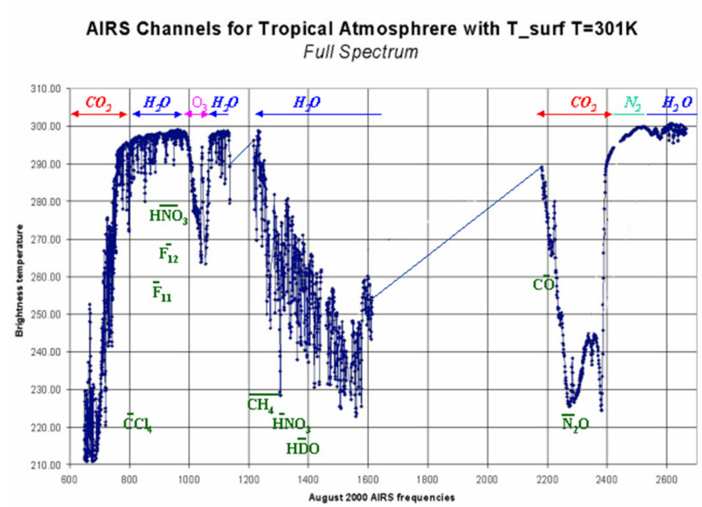
- **What are the applications and and experiences with the AIRS use?**
  Weather (addressed by Fetzer), Climate (Fetzer also), Composition
- **What have been the ranges of applications for AIRS?**
  O_3, CO, CO_2, CH_4, SO_2, NH_3, MJO, ENSO, TBO, Gravity Waves, Assimilation
- **What is the latest status of new JPL research in applying AIRS to GHG measurement?**
  Global Mid-trop CO_2 product operational
  Extension of CO_2 retrievals to Stratosphere and Lower Troposphere
- **What does AIRS show for future atmosphere measurements?**
  Higher spatial and spectral resolution required for PBL
  Global coverage, day and night, cloudy and clear required
- **The next GEN AIRS?**
  ARIES concept for high spatial and spectral resolution thermal sounder expanded to include shortwave

The Atmospheric Infrared Sounder on NASA's EOS Aqua Spacecraft

- AIRS Characteristics
- Launched: May 4, 2002
- Orbit: 705 km, 1:30pm, Sun Synch
- IFOV : 1.1° x 0.6°
  (13.5 km x 7.4 km)
- Scan Range: ±49.5°
- Full Aperture OBC Blackbody, ε > 0.998
- Full Aperture Space View
- Solid State Grating Spectrometer
  - IR Spectral Range:
    3.74-4.61 μm, 6.2-8.22 μm,
    8.8-15.4 μm
  - IR Spectral Resolution:
    ≈ 1200 (λ/Δλ)
  - # IR Channels: 2378 IR
- VIS Channels: 4
- Mass: 177Kg,
  Power: 256 Watts,
  Life: 5 years (7 years goal)
- Built: BAE Systems

AIRS

AIRS Spectra



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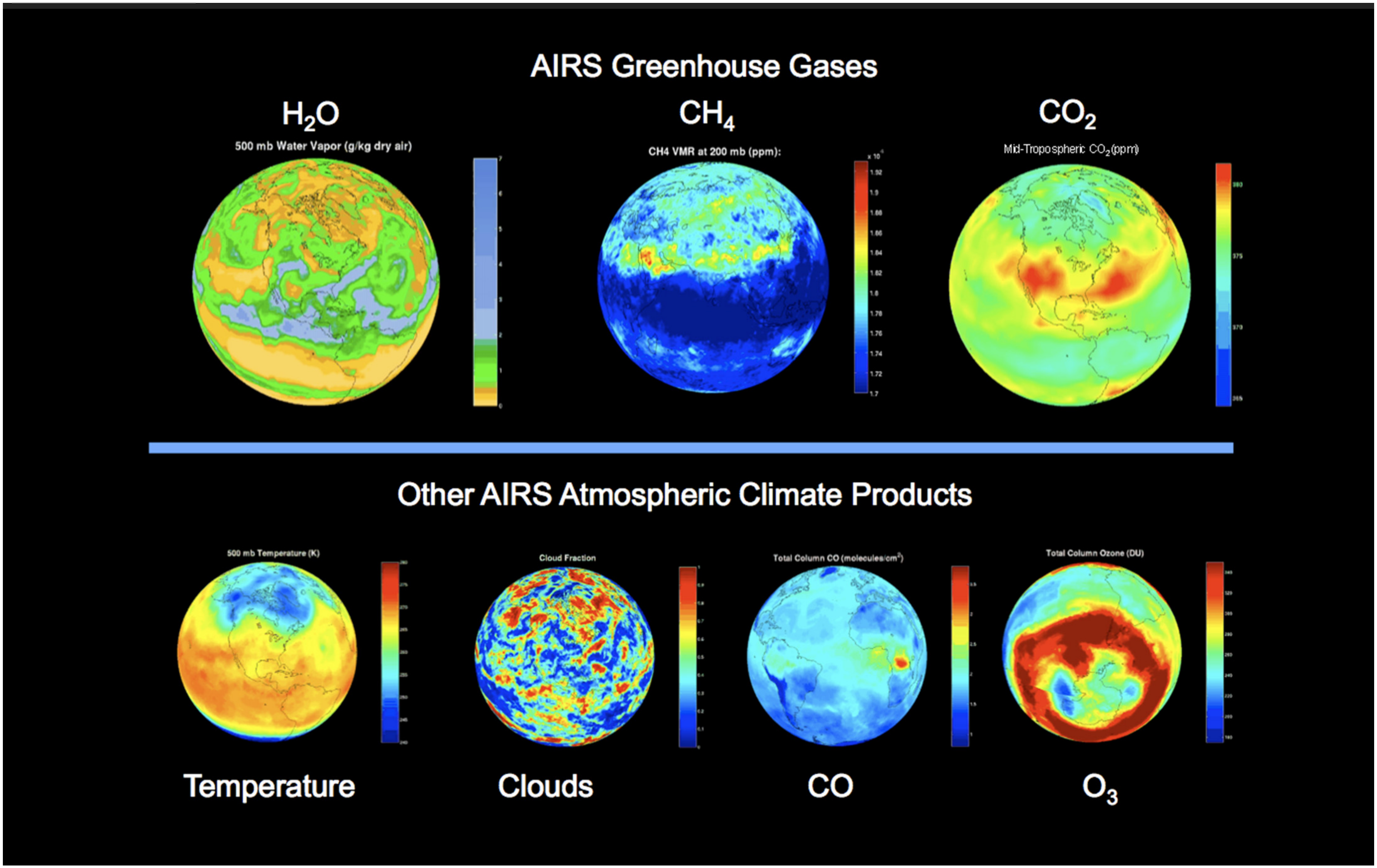
Atmospheric Infrared Sounder

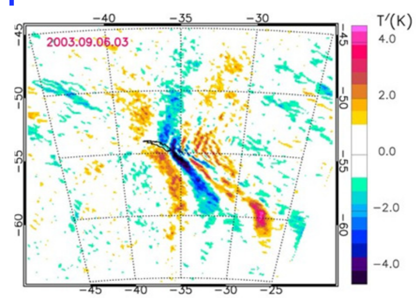
AIRS Products for Weather, Climate and Composition



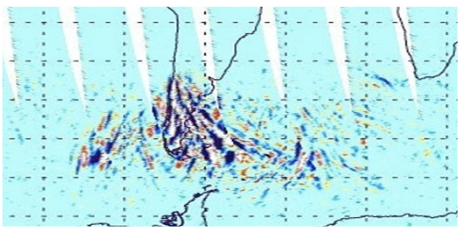
Gravity Waves

AIRS is providing new insights into the gravity-wave driven dynamics and chemistry of the Southern Hemisphere stratosphere

- **Mountain wave seeding the NAT PSCs that are critical for stratospheric denitrification & late-season ozone loss using AIRS radiance anomalies at 40 hPa (Eckermann et al, Geophys. Res. Lett., 2009)**
- **Energetic mountain waves from small island orography that GCMs do not currently parameterize (Alexander et al., Geophys. Res. Lett., 2009; Quart. J. Roy. Met. Soc., 2010)**



- **Complex multiscale gravity-wave dynamics in the planetary "hot spot" region over southern Andes & Antarctic Peninsula**



radiance fluctuations
at 2.5 hPa (~40 km)

Future AIRS Gravity-Wave Research in Southern Hemisphere

Climatology of Southern Ocean stratospheric gravity waves

Detailed event studies of "hot spot" gravity wave dynamics

Detailed climatology of wave momentum fluxes (drag)

Use of both radiances and high-resolution AIRS temperature retrievals for gravity-wave studies (Hoffmann and Alexander, 2009)

Stephen D. Eckermann

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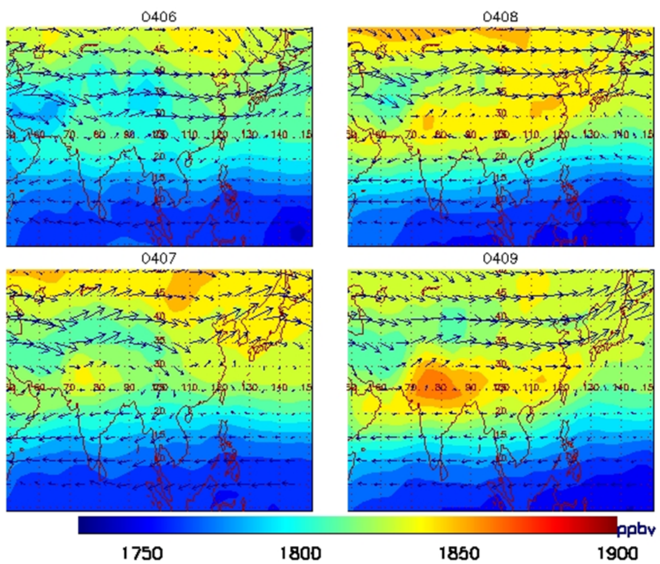
CH_4 Plume over South Asia (JJA)

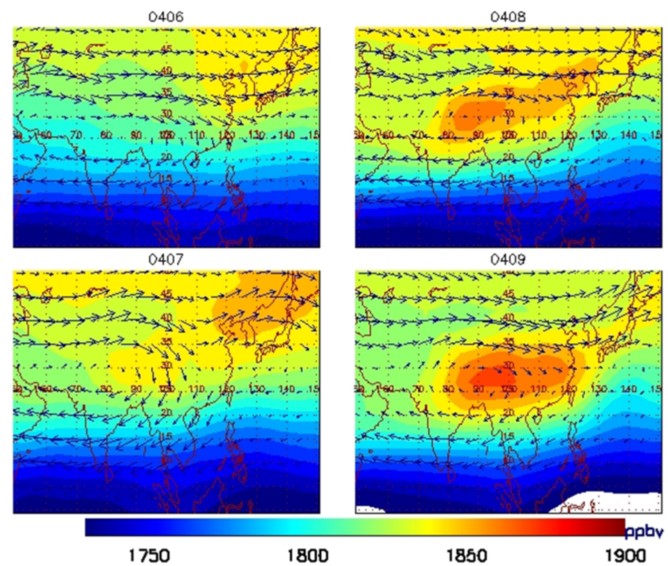
(Goldberg, Xiong, Barnet, Maddy et al., NOAA/NESDIS/STAR)

CH4 plume arises from large emission from rice paddies in summer, deep convection and the impact of the Tibetan anticyclone

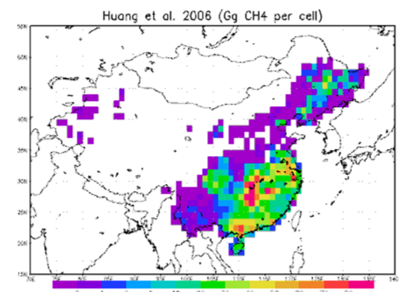
AIRS

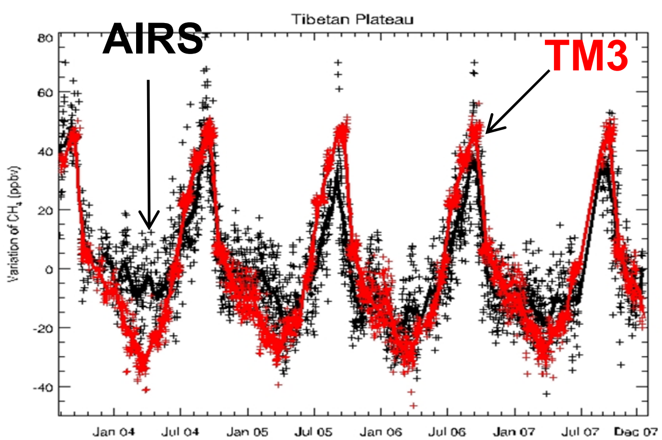


TM3

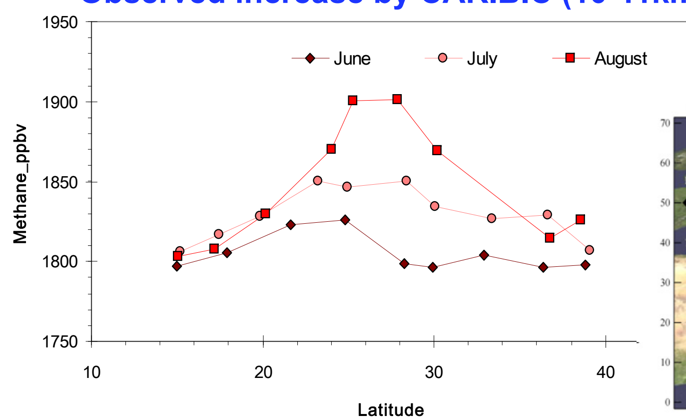


CH_4 Emission from rice paddies



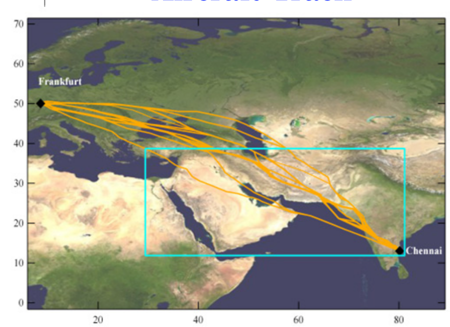


Observed increase by CARIBIC (10-11km)



Observed plume agrees well with aircraft measurements and likely a good tracer for monsoon onset and withdrawal

Aircraft Track



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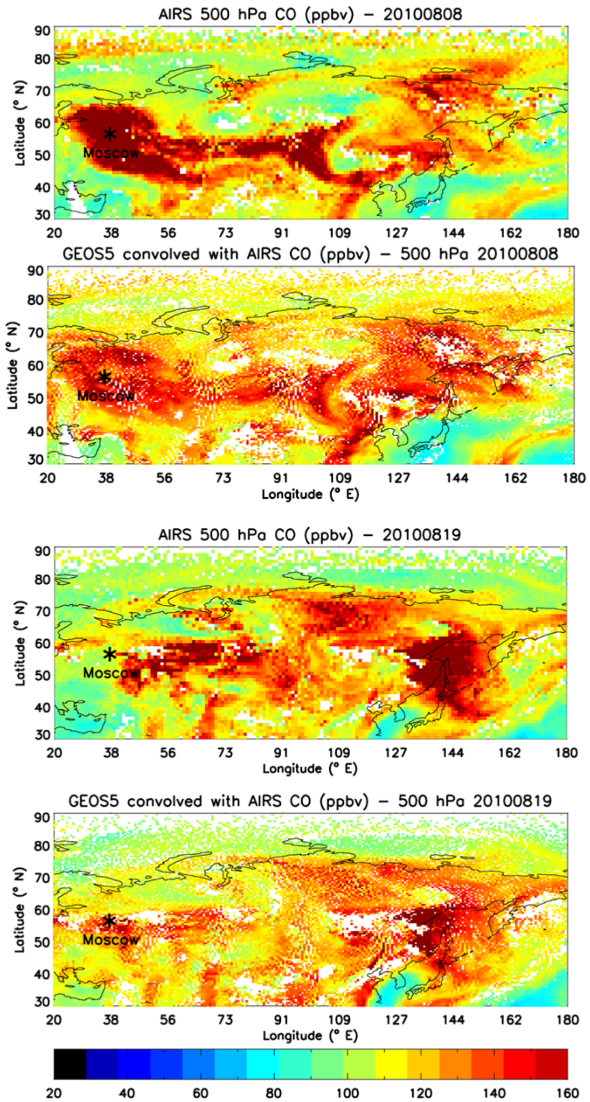
Atmospheric Infrared Sounder

Transport of CO @ 500 hPa Emitted by the Fires near Moscow and in Siberia

(Ott, Warner, Pawson, Wei, UMBC/GSFC, 2010)



8 August 2010

AIRS observes intense fire plume extending east and north of Moscow along with weaker fire activity in Siberia

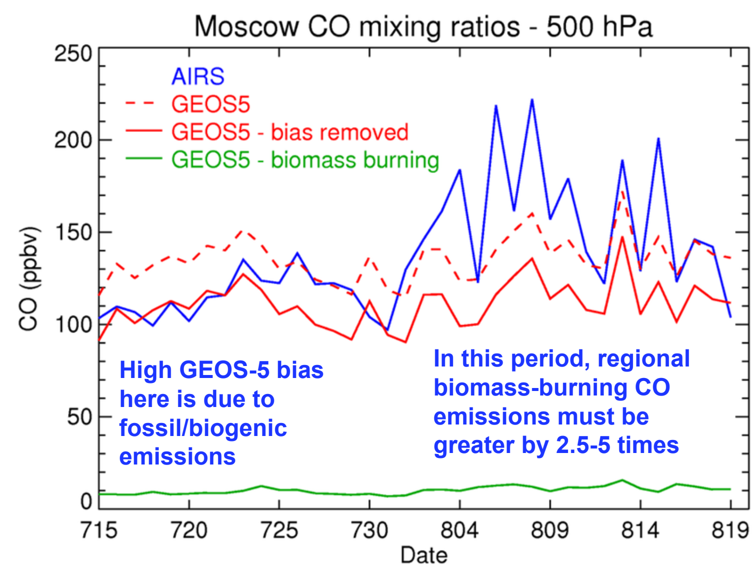
GEOS-5 reproduces pattern of horizontal transport well, but underestimates CO mixing ratios in fire plume while overestimating background mixing ratios

19 August 2010

Fire emissions have decreased and peak CO mixing ratios have moved east of Moscow. AIRS indicates CO mixing ratios in Moscow are near background levels

GEOS-5 CO mixing ratios over Moscow remain elevated due to model high bias

- Patterns of GEOS-5 CO distributions agree well with AIRS observations
- Comparison with AIRS CO reveals high bias in background CO mixing ratios over Europe
  - Fossil fuel emissions in operational GEOS-5 products taken from 2000-2005 inventories are likely too high over parts of Europe
  - Biogenic conversion factors in operational GEOS-5 system are larger than recommended by Duncan et al. (2007)
- Comparison with AIRS CO reveals low bias in CO mixing ratios during peak fire activity
  - Smoke may obscure MODIS fire detections leading to underestimate of fire extent
  - Emission factors may be too low if peat is not considered
  - No fire persistence is assumed (emissions only on day of fire detection)
  - Smoldering peat fires may be hard to detect from satellite



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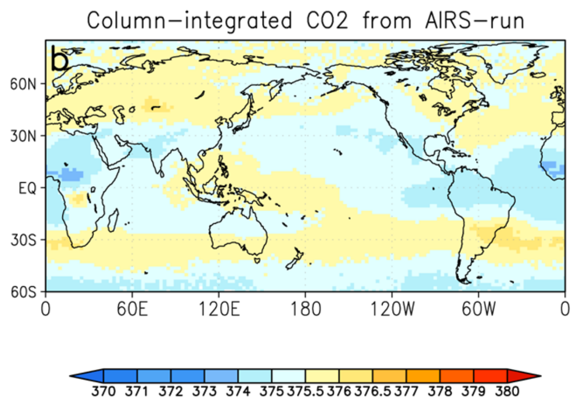
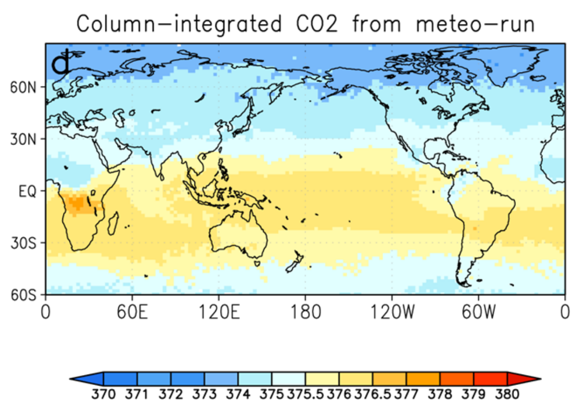
Atmospheric Infrared Sounder

Integrated Carbon Cycle Data Assimilation System
CAM3.5, LETKF Assimilating AIRS Mid-Trop CO_2

Junjie Liu UC Berkeley/JPL

Assimilation of AIRS mid-trop CO_2 improves spatial pattern

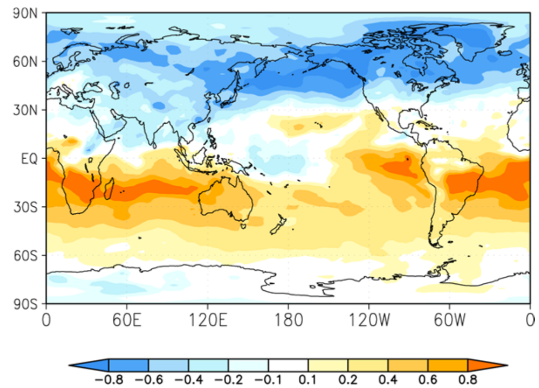




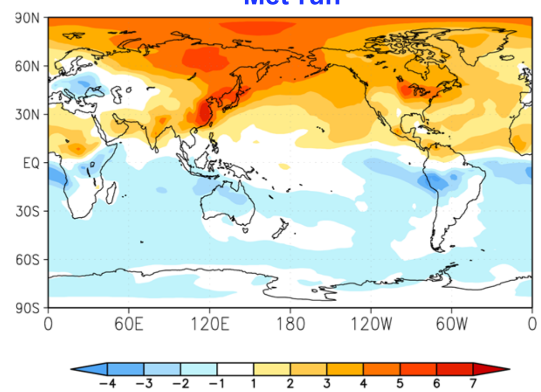
Spatial variability of AIRS-run is 0.53 ppm which is much larger than that of the Met-run (0.17 ppm)

Assimilation of AIRS mid-trop CO_2 adjusts vertical gradient May 2003: CO_2(850)-CO_2(400)

(AIRS-run) – (Met-run)

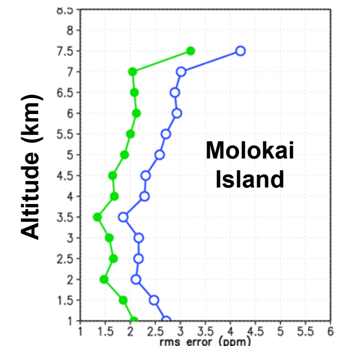


Met-run

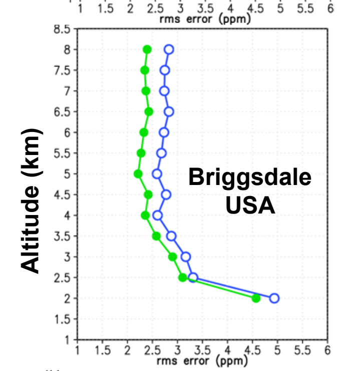


NH: CO_2(850)>CO_2(400): fossil fuel+ land carbon source
SH: CO_2(850)<CO_2(400):transported from the NH
NOTE: scale of Met-run is 7x that of difference run

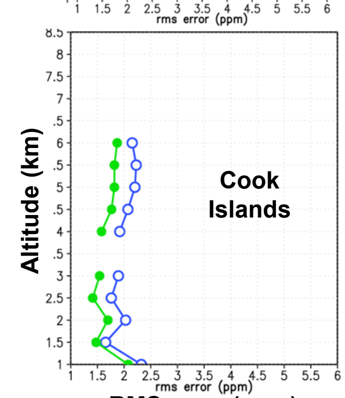
Assimilation of AIRS mid-trop CO_2 improves state estimate by 1 ppm



AIRS-run assimilate CO_2
Met-run no CO_2 obs



AIRS-run assimilate CO_2
Met-run no CO_2 obs



AIRS-run assimilate CO_2
Met-run no CO_2 obs

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Atmospheric Infrared Sounder

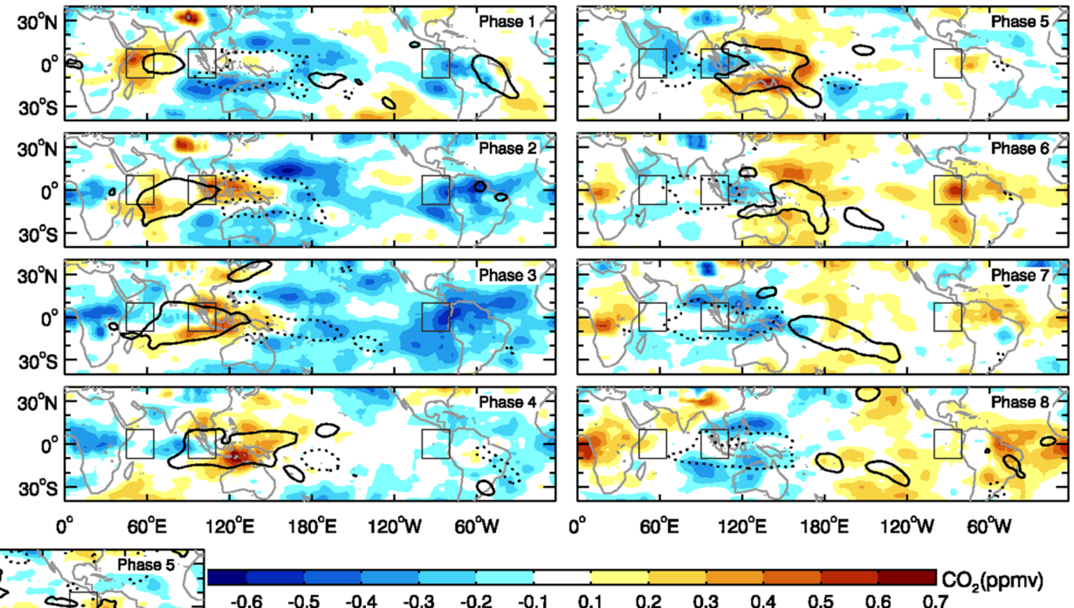
MJO-related AIRS Mid-Tropospheric CO_2 Anomaly
Intraseasonal CO_2 variability across the global tropics

King-Fai Li, Tian, B., Waliser, D.E. and Yung, Y.L. (2010), Tropical mid-tropospheric CO2 variability driven by the Madden-Julian Oscillation, PNAS, 107 (45), 19171-19175, doi: 10.1073/pnas.1008222107

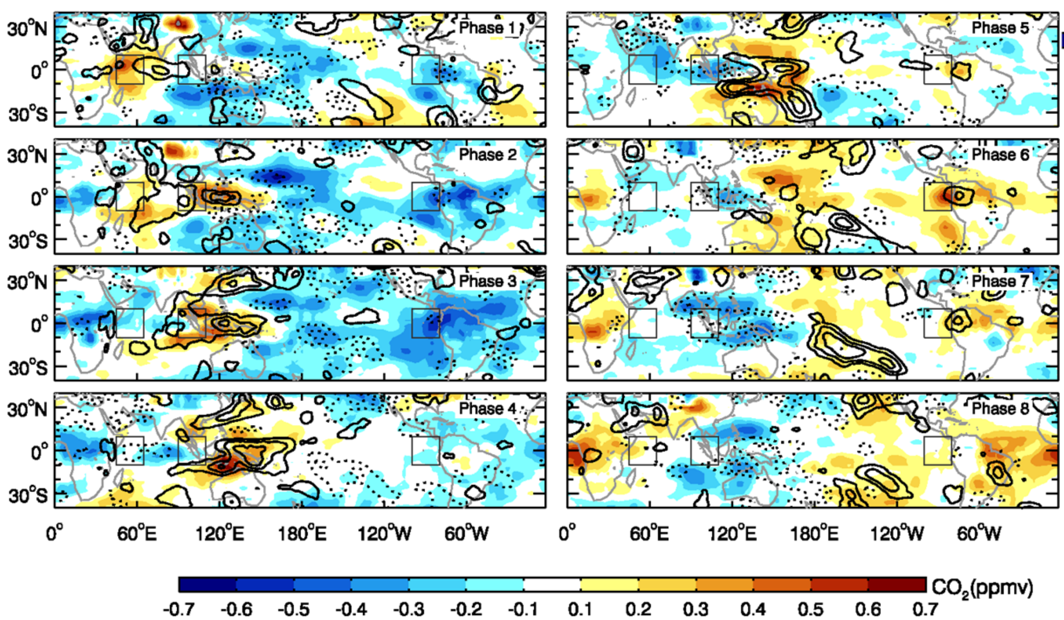
MJO has previously been studied via its impact on atmospheric winds, pressure, temperature, moisture and rainfall.

Its impact upon mid-tropospheric CO_2 has now been detected.

This provides a new window of study of this planetary-scale zonal overturning circulation anomaly.

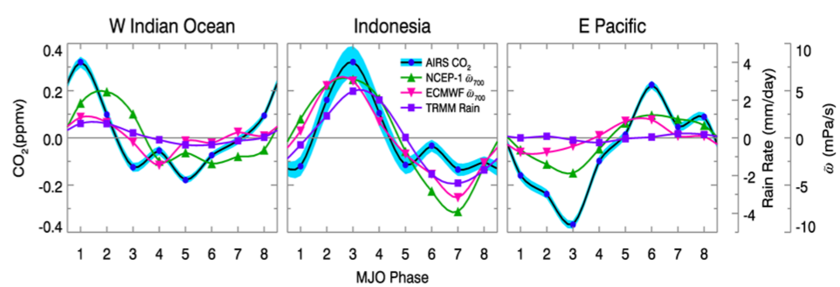


Contour lines represent TRMM Rain
(Dotted: -1 mm/day, Solid: +1 mm/day)



Contour lines: ECMWF-interim $\bar{\omega}_{700}$ (Dotted: -ve, Solid: +ve)
Contours start from ±4 mPa/s at an interval 4 mPa/s

The CO_2 anomaly is driven by the eastward-propagating vertical circulation of the MJO and implies that CO2 values are higher at the surface than in the upper troposphere.
This intraseasonal CO_2 variability provides a robustness test for chemical transport models.



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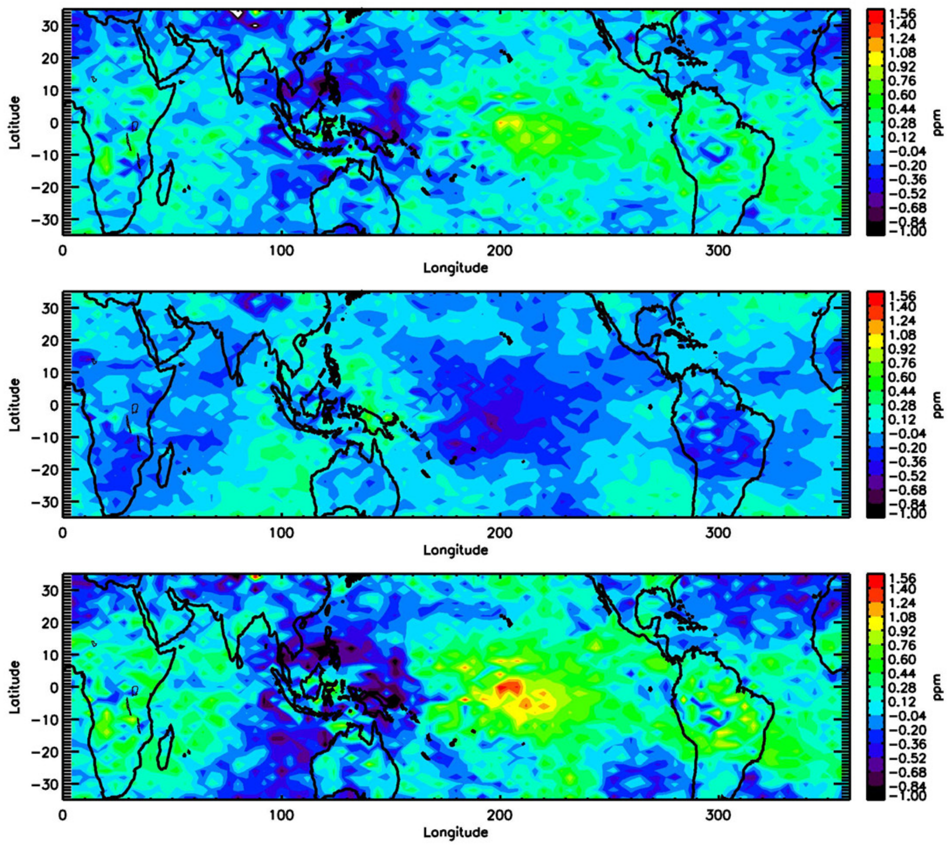
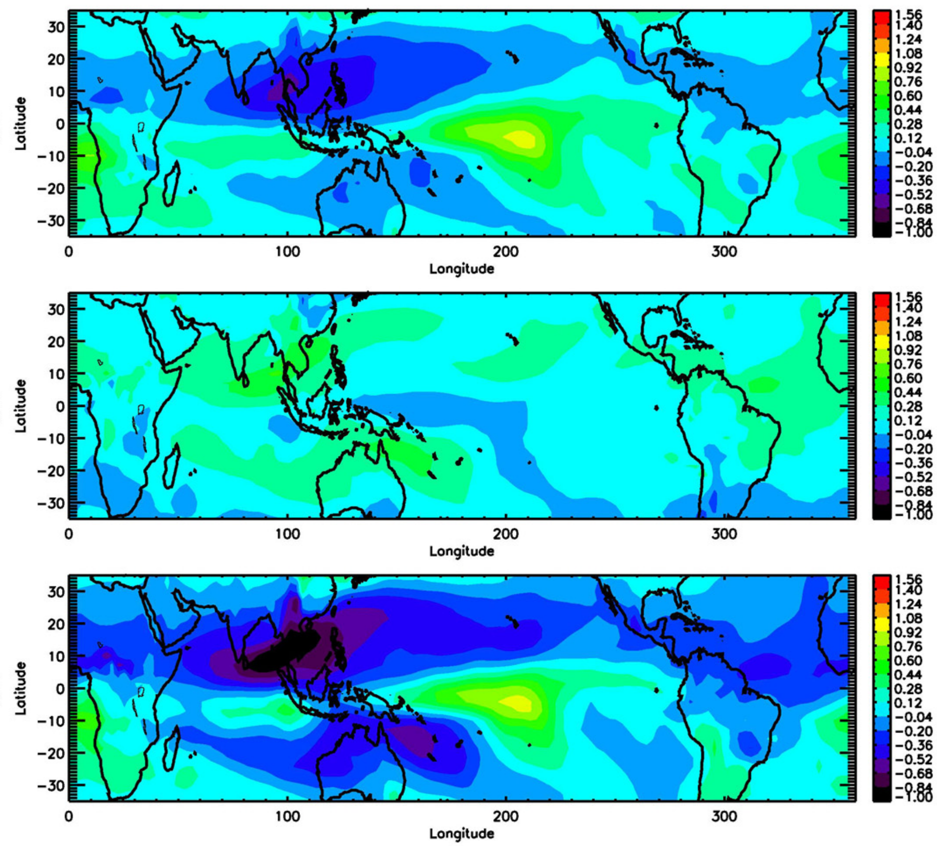
Influences of El Niño on Mid-Trop CO_2 From AIRS and MOZART-2

Xun Jiang University of Houston





TOP: **AIRS detrended and deseasonalized CO_2 anomaly averaged for 11 El Niño months**

MIDDLE: **AIRS detrended and deseasonalized CO_2 anomaly averaged for 17 La Niña months**

BOTTOM: **AIRS CO_2 anomaly difference (El Niño – La Niña) (Consistent with change in Walker Circulation)**

Jiang, X., M. T. Chahine, E. T. Olsen, L. L. Chen, and Y. L. Yung (2010), Interannual variability of mid-tropospheric CO2 from Atmospheric Infrared Sounder, Geophys. Res. Lett., 37, L13801, doi:10.1029/2010GL042823

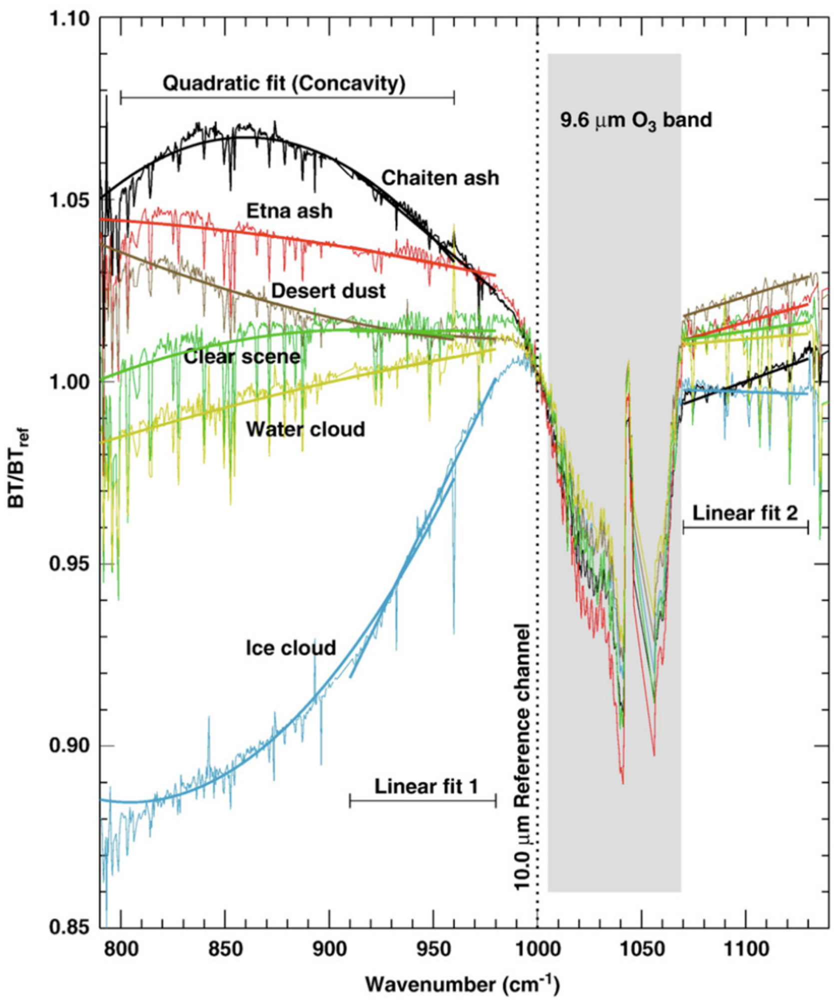
TOP: **MOZART-2 CO_2 anomaly during El Niño**

MIDDLE: **MOZART-2 CO_2 anomaly during La Niña**

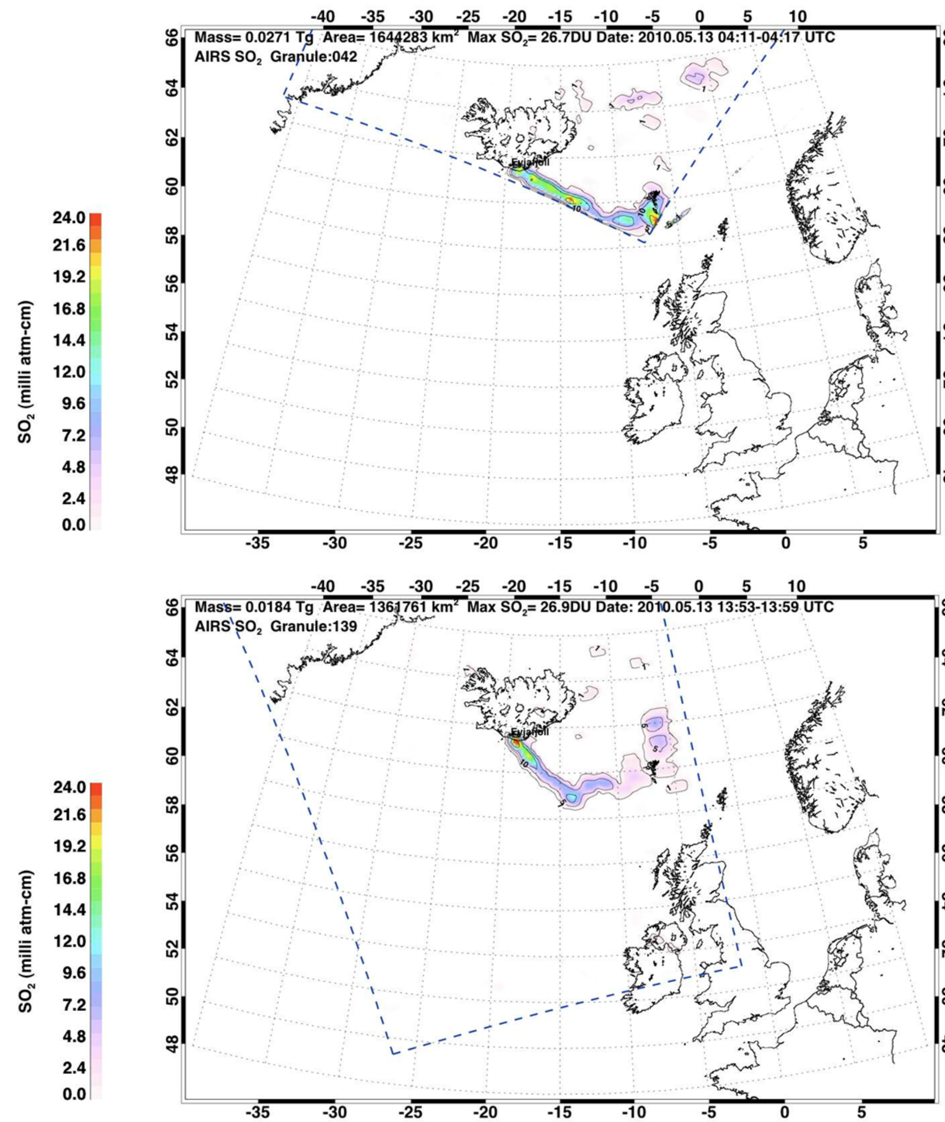
BOTTOM: **MOZART-2 CO_2 Difference (El Niño – La Niña) (Signal is smaller than observed by AIRS)**

NOTE: MOZART-2 results are preliminary. The boundary condition is a climatology and does not include interannual variability. (Courtesy of Maochang Liang for the MOZART-2 model run)

Thermal IR discriminates among volcanic ash, desert dust, water and ice; allows retrieval and tracking of volcanic SO_2 plumes



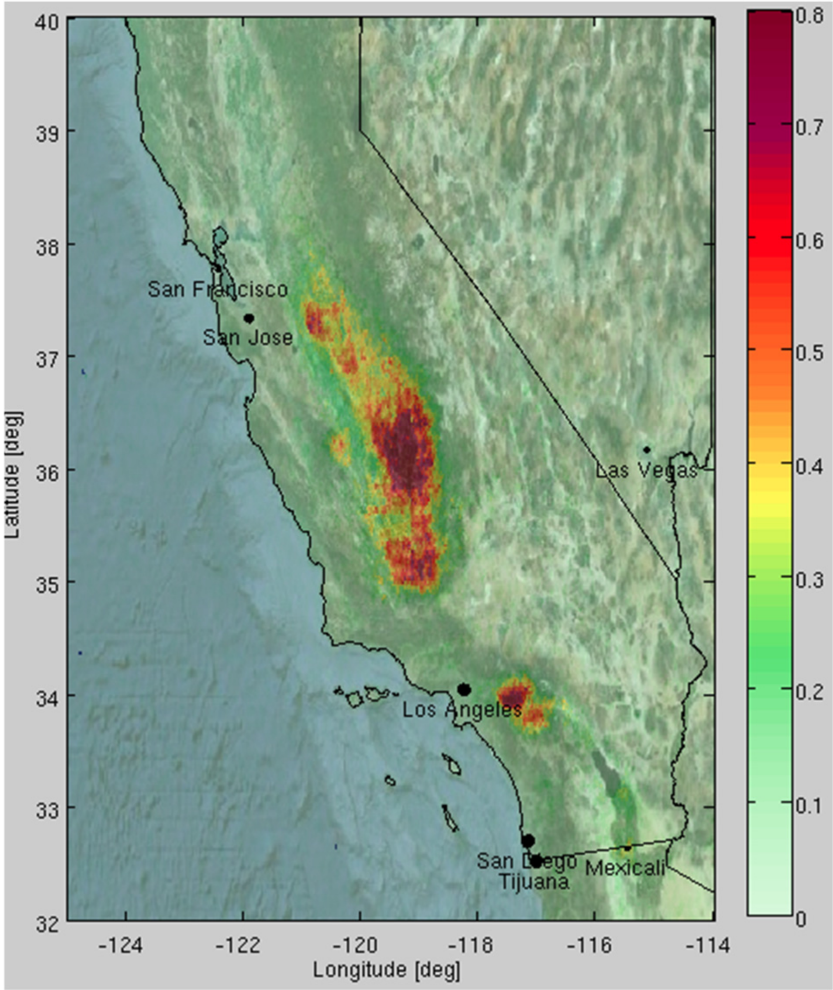
Gangale, G.,A.J. Prata and L. Clarisse (2010), The infrared spectral signature of volcanic ash determined from high-spectral resolution satellite measurements, Remote Sensing of Environment, 114, 414.



A. J. Prata (2010)

Thermal IR Has Sensitivity to Trace Gases Near to the Surface

AIRS Near Surface NH_3
(Strow, 2010)



AIRS Developing Product
Mid-Stratospheric CO_2
(25km)

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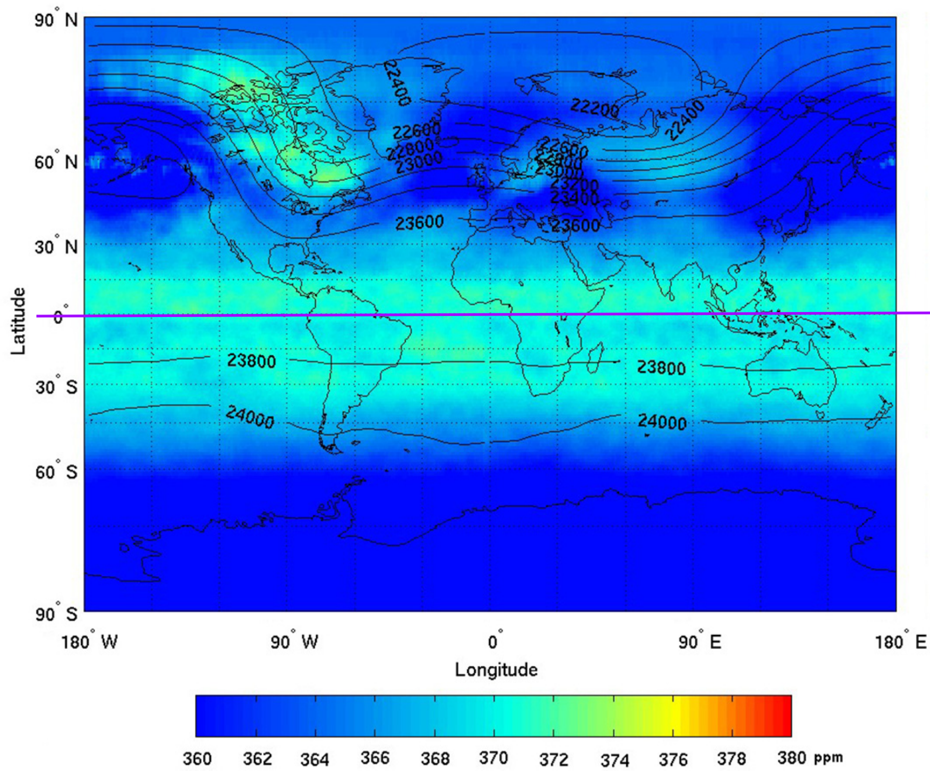
Atmospheric Infrared Sounder

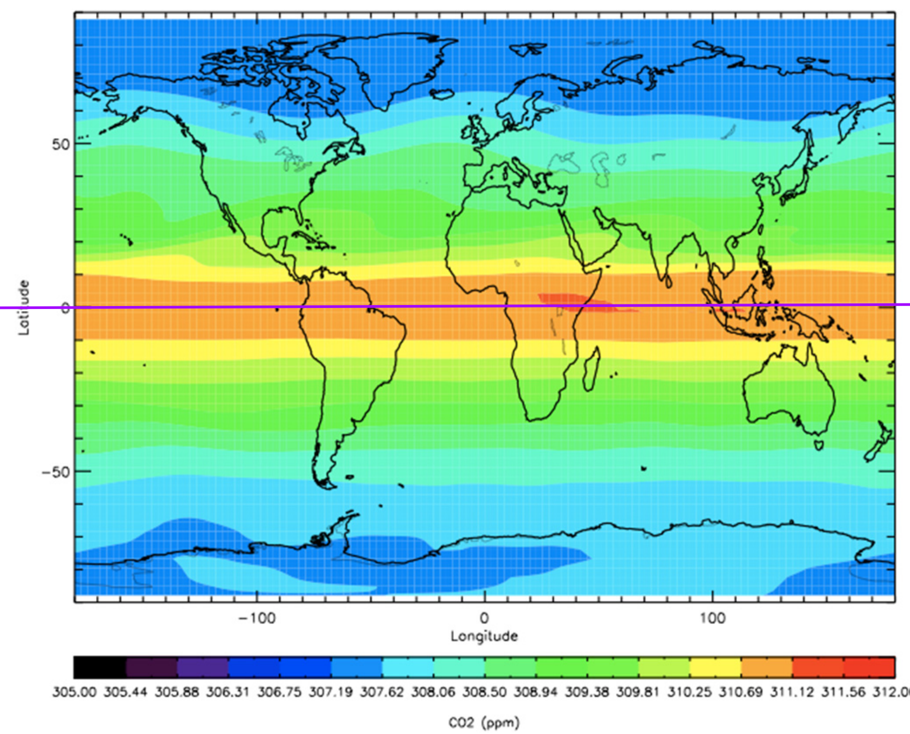
January 2003 Stratospheric CO_2 Retrieval Compared to Models

(AIRS Stratospheric Contribution Function Applied to Models)

AIRS Retrieved CO_2



3-D IMATCH CO_2



360 **Contours are 30 hPa GPH** 380

305 **Model profile weighted by AIRS sensitivity function** 312

PRELIMINARY

Both AIRS and models show presence of tropical pipe

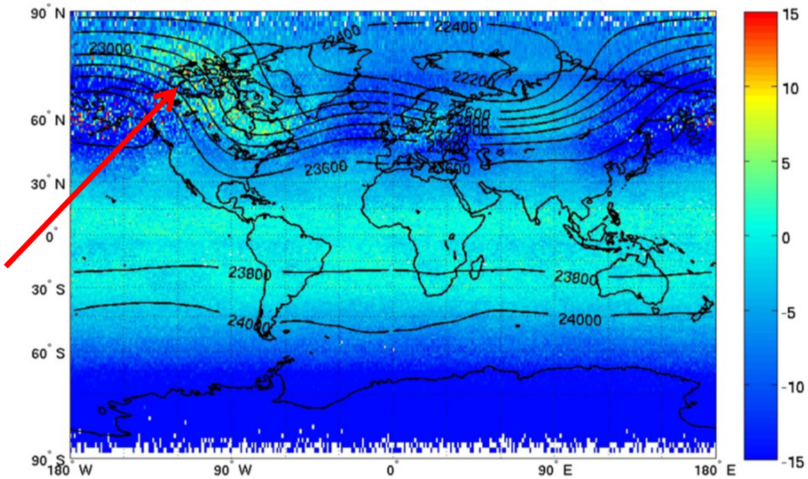
- **AIRS shows greater variation with latitude (~15 ppm vs ~4 ppm)**
- **AIRS shows additional troposphere intrusion at high latitude**

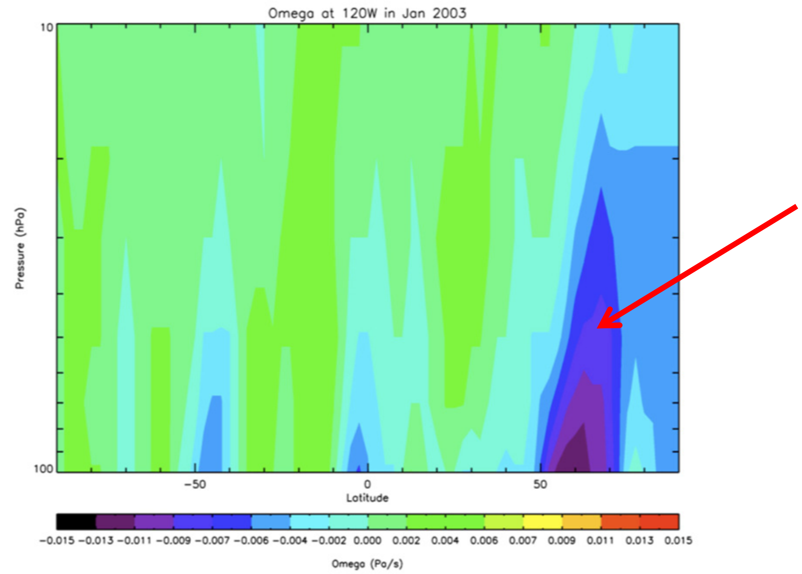
M. Chahine et. al. (JPL)

Model Runs by Xun Jiang, University of Houston

AIRS Stratospheric CO_2 (tropospheric CO2 intrusion/vertical wind)

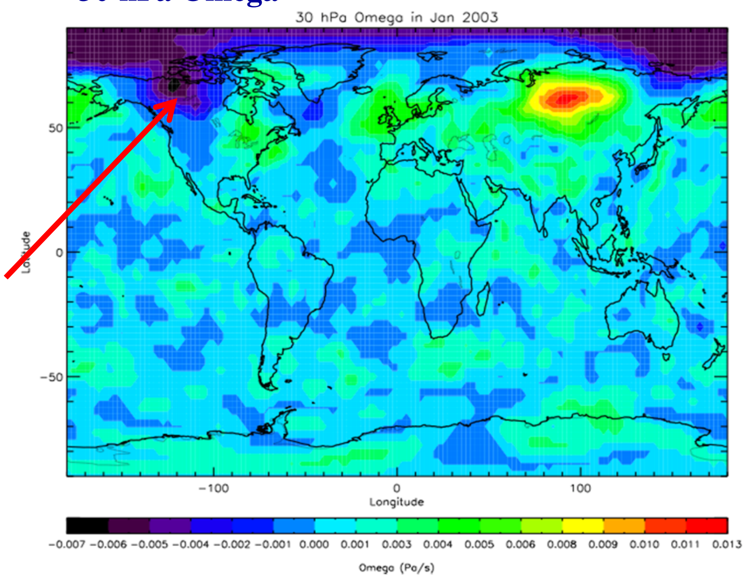
AIRS CO2 for January, 2003





Vertical velocity (dP/dt) at 120°W in January 2003 (NCEP2 Reanalysis)
Negative (positive) value represents upward (downward) motion. Units are Pa/s.

30 hPa Omega



Omega = dP/dt at 30 hPa (NCEP2 Reanalysis)
Negative Omega --- Upward motion;
Positive Omega --- Downward motion

Xun Jiang, University of Houston

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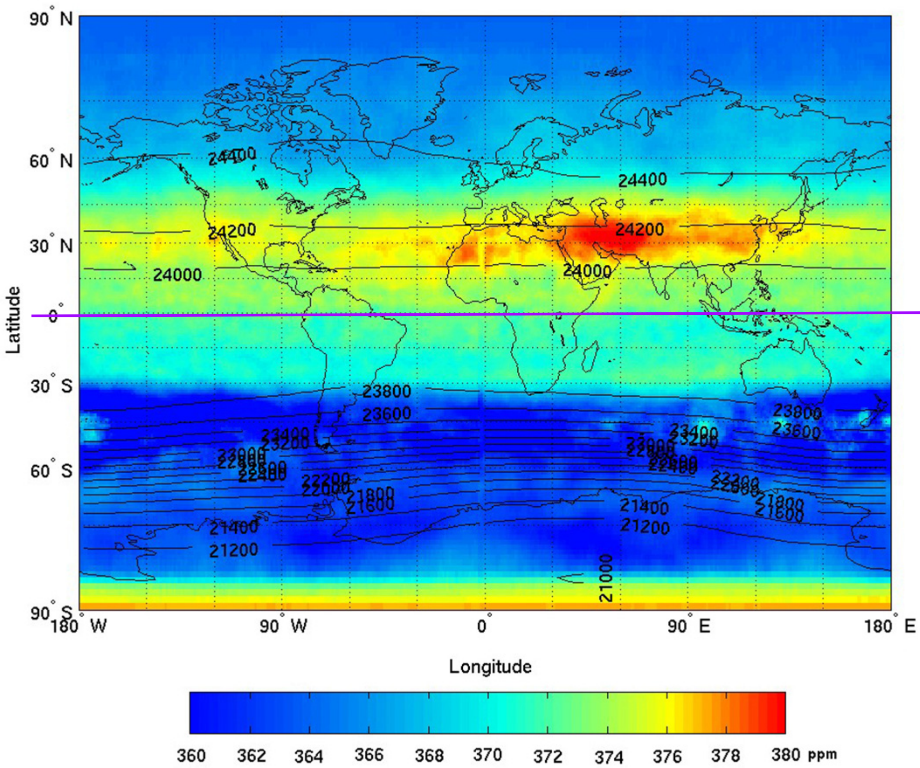
Atmospheric Infrared Sounder

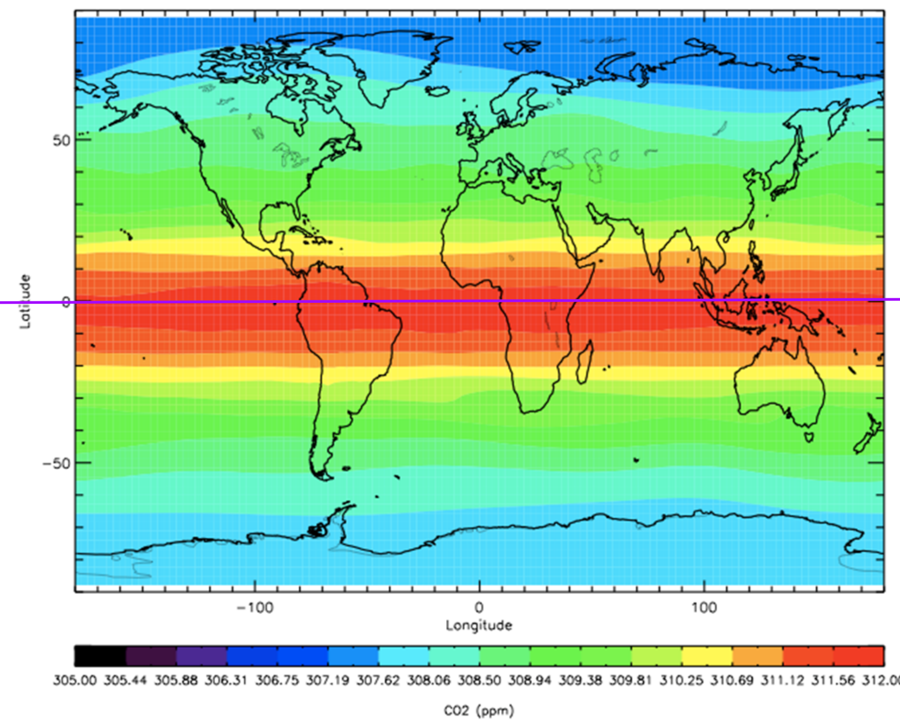
July 2003 Stratospheric CO_2 Retrieval Compared to Models

(AIRS Stratospheric Contribution Function Applied to Models)

AIRS Retrieved CO_2



3-D IMATCH CO_2



360 **Contours are 30 hPa GPH** **380**

305 **Model profile weighted by AIRS sensitivity function** **312**

PRELIMINARY

AIRS tropical Pipe shifts northward in July whereas model tropical pipe remains unchanged
- **AIRS shows greater variation with latitude (~15 ppm vs ~4 ppm)**

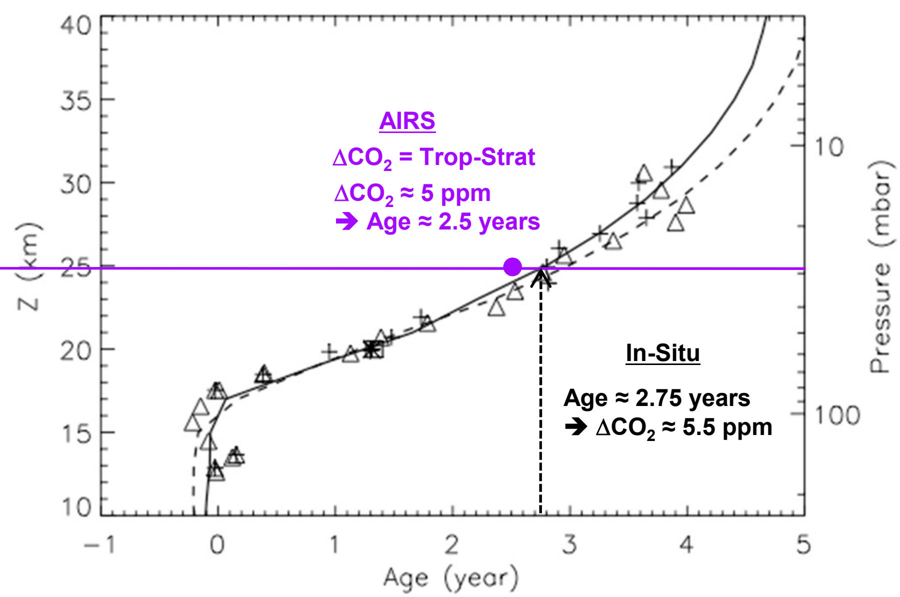
M. Chahine et. al. (JPL)

Model Runs by Xun Jiang, University of Houston

CO_2 Trop-Strat Contrast due to Age of Stratospheric Air

Hall et al (1999), Evaluation of transport in stratospheric models, JGR., 104, 18815

Altitude of maximum of
AIRS Contribution Function

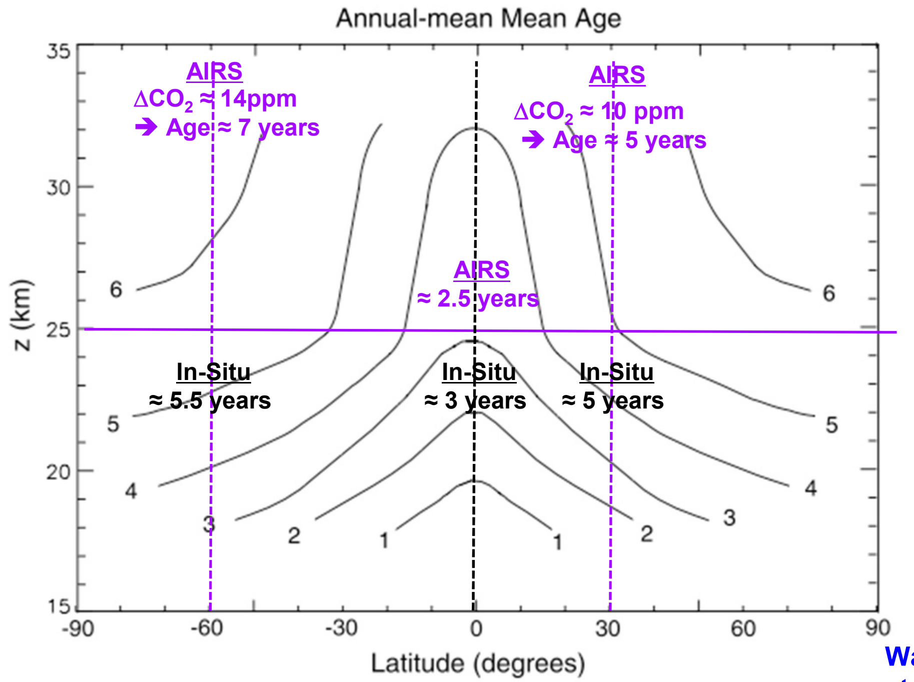


**Age of stratospheric air vs altitude
for |latitude| ≤ 10°**

The concentration of CO_2 in the stratosphere will be lower than in the troposphere by ~ 2 ppm for each year it lags behind due to interannual growth of tropospheric CO_2

CO_2 Contrast due to Age of Stratospheric Air

The concentration of CO_2 in the stratosphere will be lower than in the troposphere by ~ 2 ppm for each year it lags behind due to interannual growth of tropospheric CO_2



Waugh and Hall (2002), Age of stratospheric air: theory, observations and models, Rev. Geophys., 40, 1010, doi:10.1029/2000RG000101

Age of stratospheric air vs latitude as a function of altitude
- **In-situ observations only taken in NH, thus the schematic is symmetrical**
- **AIRS retrievals agree with in-situ measurements in NH and may indicate slight asymmetry**

(Waugh and Hall mirrored the NH result to the SH, where no data existed)

AIRS First Results
Lower-Tropospheric CO_2
(2.2km)

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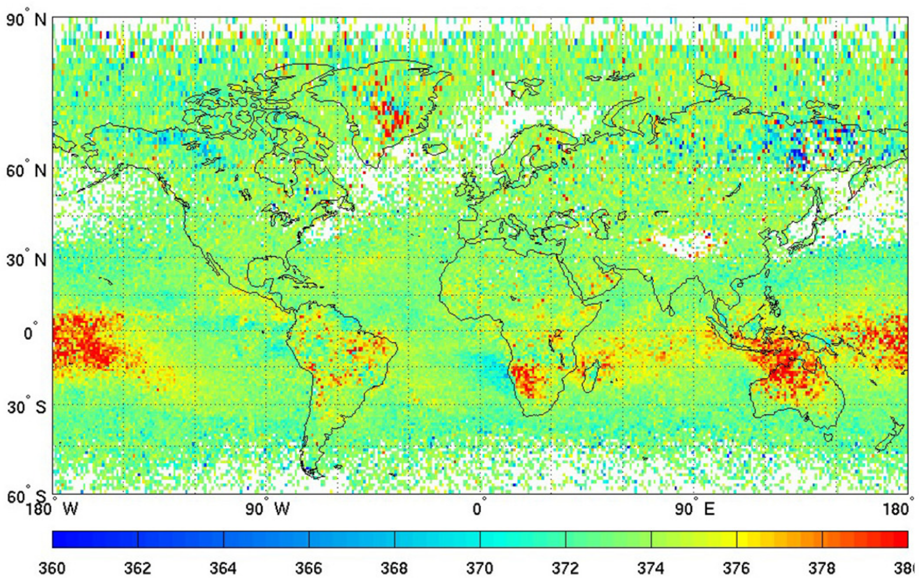
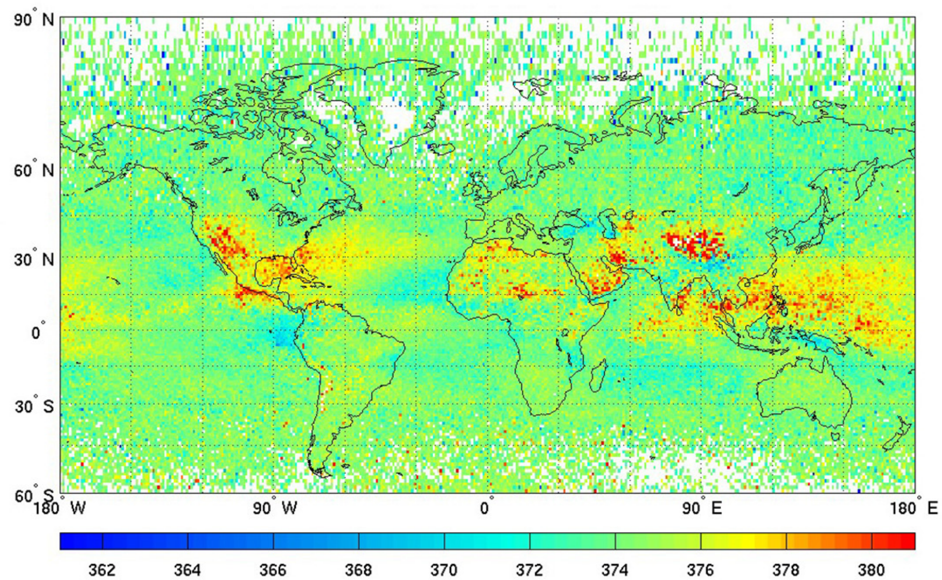
AIRS Lower-Tropospheric (2.2km) CO_2
(preliminary results – channel set not yet optimized)

January 2003
AIRS Lower Tropospheric CO2 Retrievals



July 2003
AIRS Lower Tropospheric CO2 Retrievals



M. Chahine et. al. (JPL)

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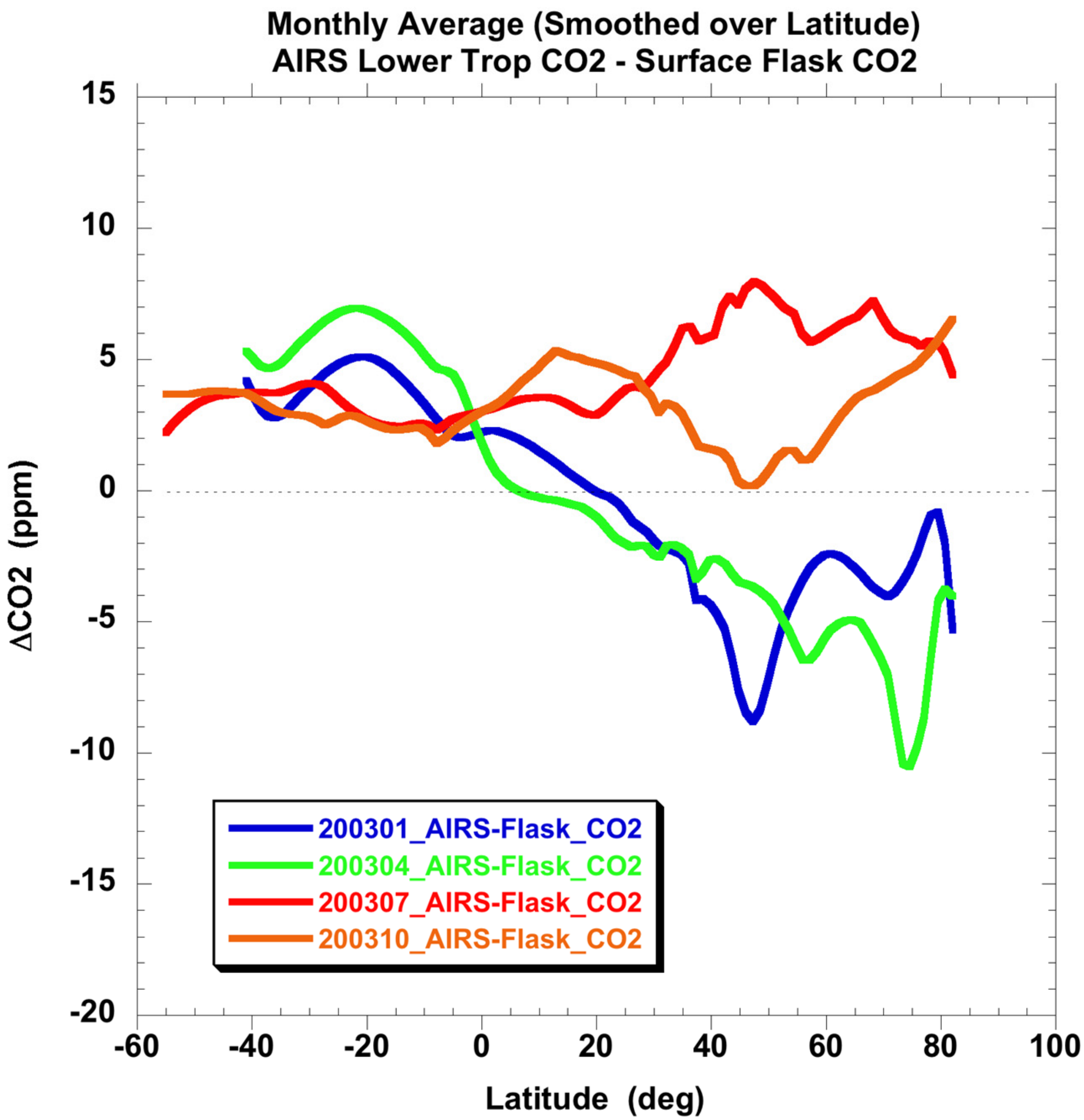
Atmospheric Infrared Sounder

Prelim AIRS Lower-Tropospheric (2.2km) CO_2

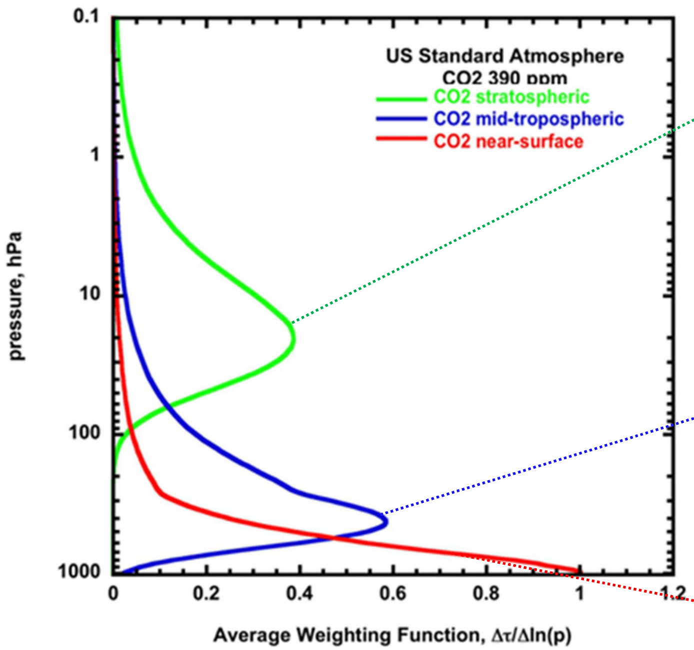
(comparison to collocated surface flask locations)

(Flask monthly averages; monthly average and std dev for AIRS retrievals within 250km)



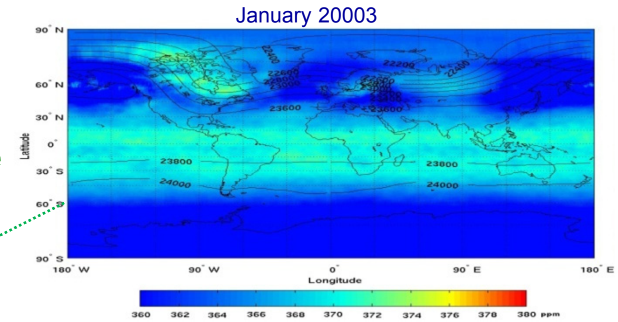
M. Chahine et. al. (JPL)

3 Layers of CO_2 Derived from AIRS
Summary



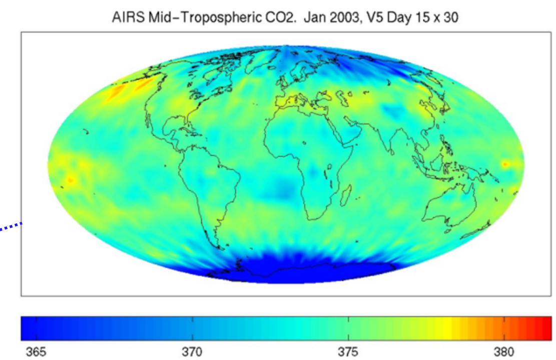
Sensitivity of AIRS Channels to CO2

Stratosphere



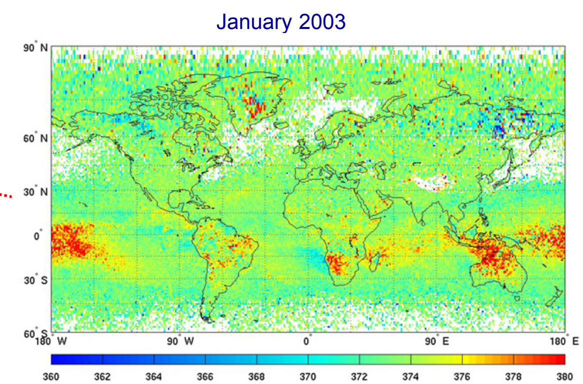
Preliminary

Mid-Troposphere



Complete
Sept 02 - Present

Lower Trop



Preliminary

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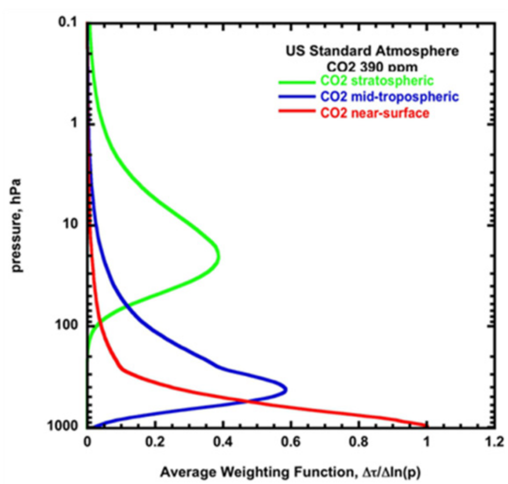
Factors Affecting the CO_2 Retrievals

	Mid-Troposphere -*10km*	Stratosphere – *30km*	Lower Trop – *2.2km*
ν range:	13 CO_2 channels: 700 cm^{-1} – 722 cm^{-1}	17 CO_2 channels: 650 cm^{-1} – 680 cm^{-1}	10 CO_2 channels: 730 cm^{-1} – 745 cm^{-1}
$T(p)$	Strong	Very strong	Strong
O_3	Strong	Weak	Medium
H_2O	Medium	No impact	Medium
Surface emission, E_s (T_s, ε_s)	Very weak	No impact	Medium
$\Delta G/\Delta CO_2$*	~0.4	~0.2	~0.5

*($\Delta G/\Delta CO_2$) describes the sensitivity of observed spectra to changes in CO_2. It is a function of the lapse rate of atmospheric temperature profiles which is 7 K/km in the mid-troposphere, 1.5K/km in the stratosphere and 10K/km near surface.



- Mid-troposphere: Operational and Released to the Public (Sept 2002 – Present)
- Stratosphere: Algorithm Completed, QA and Validation Underway (8/2010)
- Lower troposphere: Algorithm Nearly Complete, Channel Optimization and Preliminary Retrievals Underway (12/2010)

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Moustafa T. Chahine
1935 - 2011

ARIES can map GHG emissions from large cities and counties?

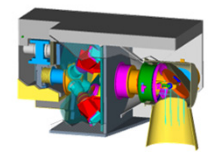
<u>ARIES Characteristics:</u>
- Extension of AIRS Methodology
- Global Maps Daily (±55° Swath)
- Spatial Resolution: 2 km
- Spectral Range: 3.0 – 15.4 µm
- Spectral Resolution: 0.5 cm^{-1}

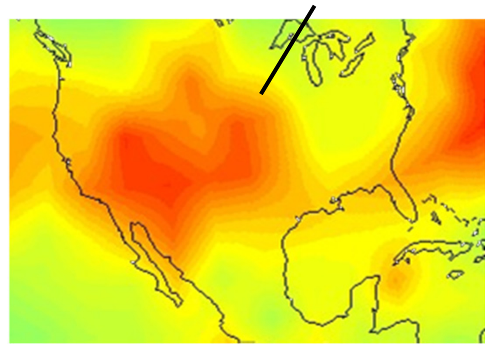
Over 5000 Channels

<u>Products</u>: Vertical Profiles of, T, H_2O CO_2, CH_4 CO, N_2O, SO_2, HNO_3, O_3

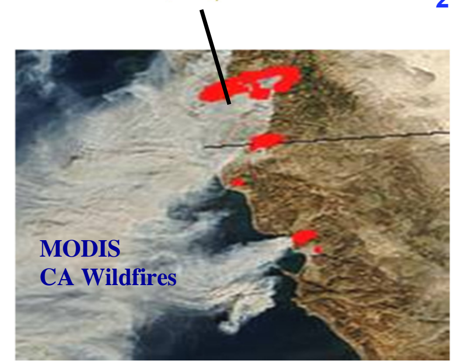
AIRS
14 km
45 km CO_2

ARIES
1 km
3x3 km CO_2





AIRS CO_2 Map, July 2003



ARIES CO_2 Map Resolution

Products	IFOV (km)	λ_1 (µm) ν_1 (cm^{-1})	λ_2 (µm) ν_2 (cm^{-1})	R,$\Delta\nu$ (cm^{-1})
Temperature, CO_2,CH_4,N_2O,CO	1	3.39 2950	4.76 2100	2.0
Water, CH_4, SO_2, HNO_3	1	6.20 1613	8.70 1150	1.0
O_3, HNO_3	1	8.70 1150	11.36 880	0.5
Temperature, CO_2	1	11.36 880	15.38 650	0.5

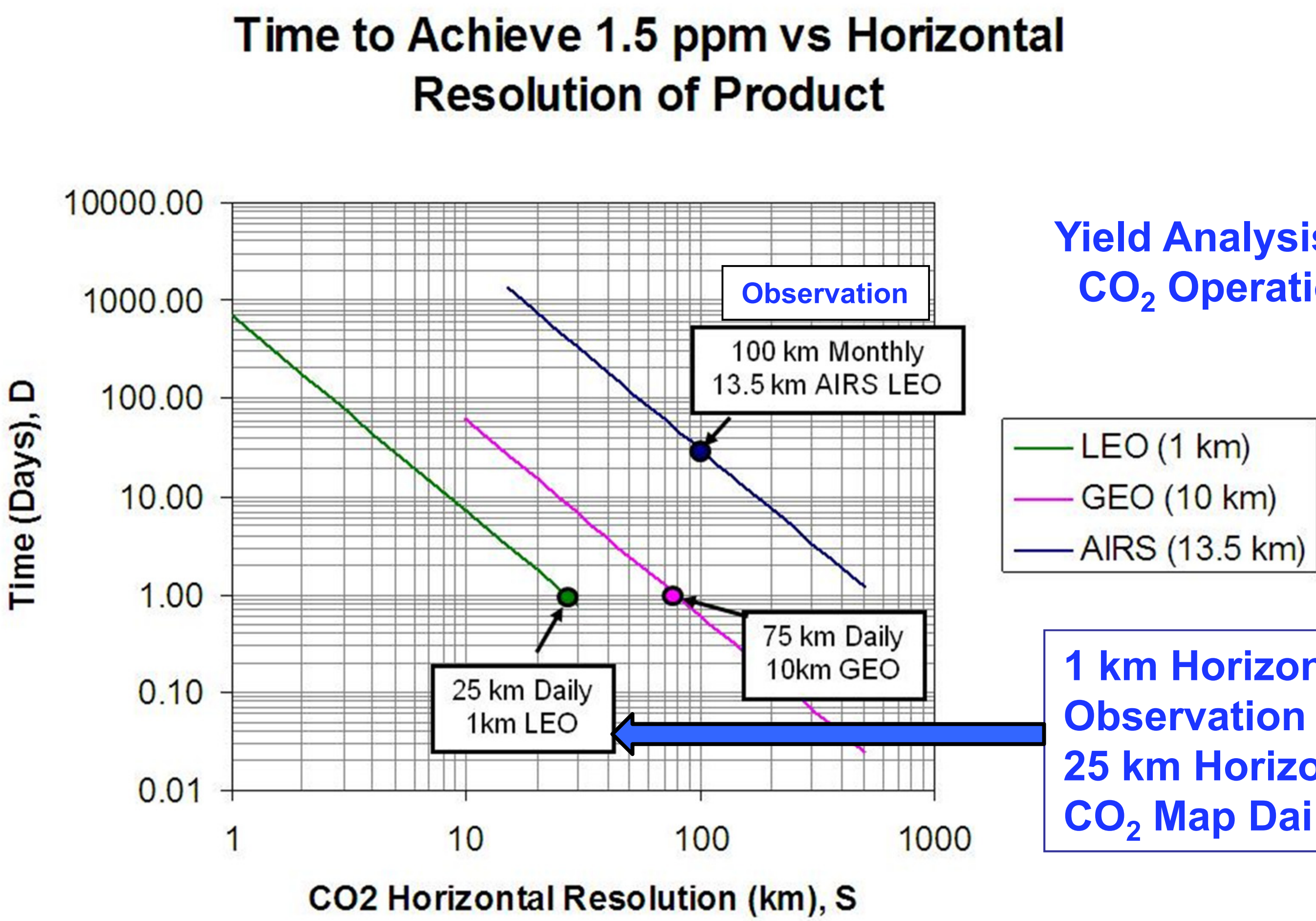
T. Pagano et. al. (JPL)

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Atmospheric Infrared Sounder

ARIES greatly improves CO_2 yield over AIRS and provides daily global coverage



Yield Analysis Scaled from AIRS CO_2 Operational Data Product

1 km Horizontal Resolution Observation gives 25 km Horizontal Resolution CO_2 Map Daily

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