GHG ECV Parameters Generated at JPL

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Sept 2010

GHG ECVs at JPL

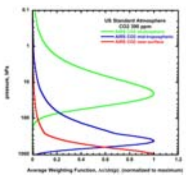
- **Outline:**
  - AIRS CO_2 products
  - TES CO_2 products
  - GOSAT/ACOS CO_2 products
  - The TCCON network
  - OCO-2 and OCO-3 CO_2 products
  - Other GHGs (CH_4, N_2O, O_3)
  - Summary

AIRS Measurements of CO_2 from Space

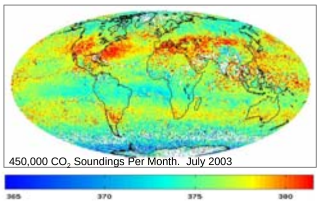
Mid-troposphere CO2 from AIRS

- Thermal infrared emission
- Spatial Resolution: 13.5 km
- All Weather Products: 45 km
- 3.7-15.4 μm, $\Delta\nu = 0.5$ cm^{-1}
- Measurement Precision: 1-2 ppm
- Day, Night, Land, Ocean, Polar
- 95% Global Daily Coverage
- 7.5 Years Now Available
- Vertical Resolution: 3 Levels
  - Mid Trop: Current
  - Stratosphere: In Progress
  - Near Surface: In Progress

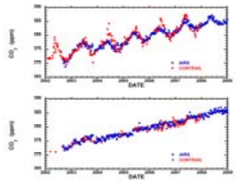
AIRS Normalized Sensitivities



More than 7 Years AIRS Mid Trop CO2 Now Available*



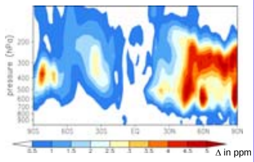
AIRS CO2 Data Validated Using Aircraft



What have We Observed?

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

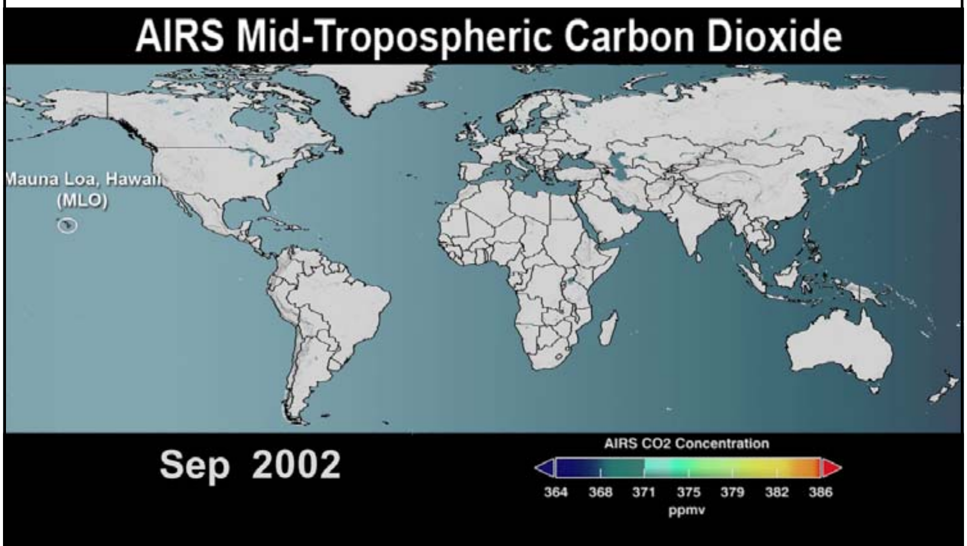
AIRS mid-trop CO_2 is assimilated into a chemical transport model



Results show elevated CO2 levels in the NH where major sources are located

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

AIRS Measurements of CO_2 from Space



UofH/JPL Study Finds Influences of El Niño in Mid-Trop CO2 Levels observed by AIRS

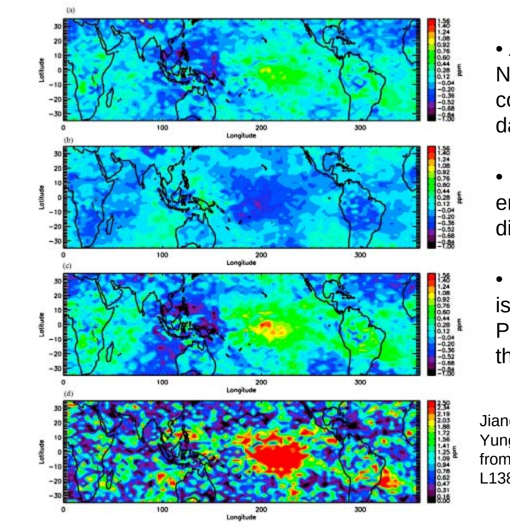


Figure 1. (a) AIRS detrended and deseasonalized CO_2 averaged for 11 El Niño months, (b) AIRS detrended and deseasonalized CO_2 averaged for 17 La Niña months, (c) AIRS CO_2 difference between El Niño and La Niña events, and (d) t-value for the CO_2 difference.

- Analysis suggests that the influences of El Niño events and polar vortex on the CO2 concentration are apparent in the AIRS data.
- During El Niño, mid-tropospheric CO2 is enhanced in central Pacific Ocean and diminished in the western Pacific Ocean.
- In the polar region, mid-tropospheric CO2 is diminished if the polar vortex is strong. Polar mid-tropospheric CO2 is enhanced if the polar vortex is weak.

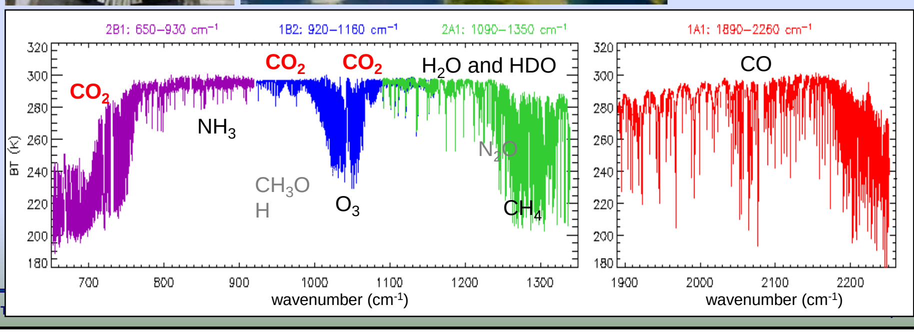
Jiang, X., M. T. Chahine, E. T. Olsen, L. L. Chen, and Y. L. Yung (2010), Interannual variability of mid-tropospheric CO2 from Atmospheric Infrared Sounder, Geophys. Res. Lett., 37, L13801, doi:10.1029/2010GL042823

Tropospheric Emission Spectrometer

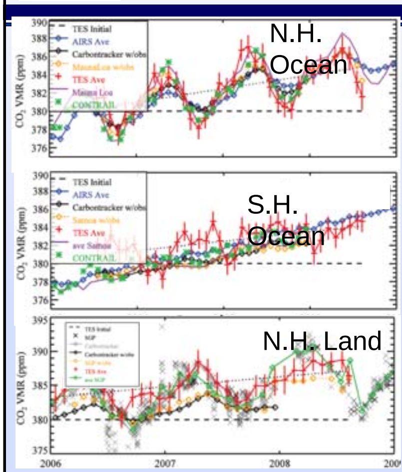
High spectral resolution (0.1 cm^{-1}) allows vertical profiling

Wide spectral bands in thermal infrared contain many trace gas signatures

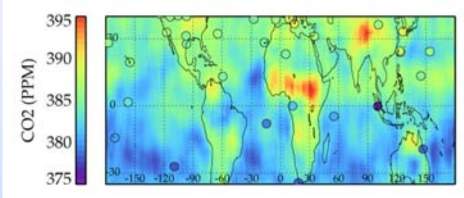
Small 5 x 8 km footprint



TES mid-tropospheric CO_2 product



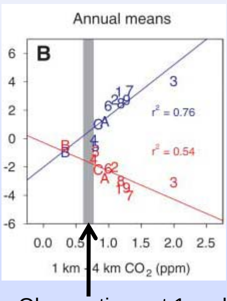
March-May, 2006 TES and GLOBALVIEW surface data



< TES monthly averages (red) versus aircraft in situ data show consistent yearly and seasonal variations

- 40S to 45N for targets with cloud OD < 0.5 over land/ocean and day/night
- < 2 ppm error for monthly, regional averages
- 2.1% bias consistent with spectroscopic error estimates
- N.H. ocean agrees best with validation data (Correlation 0.92 to Mauna Loa)

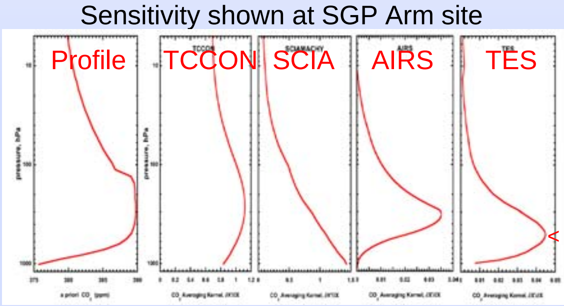
What does TES CO_2 add to the existing surface networks and column retrievals?



Observations at 1 and 4 km can constrain model vertical transport

Stephens, 2007 (*Science)* showed that model estimates of fluxes for Tropics land (blue) and NH land (red) strongly depend on model estimates of free troposphere and surface CO_2 differences.

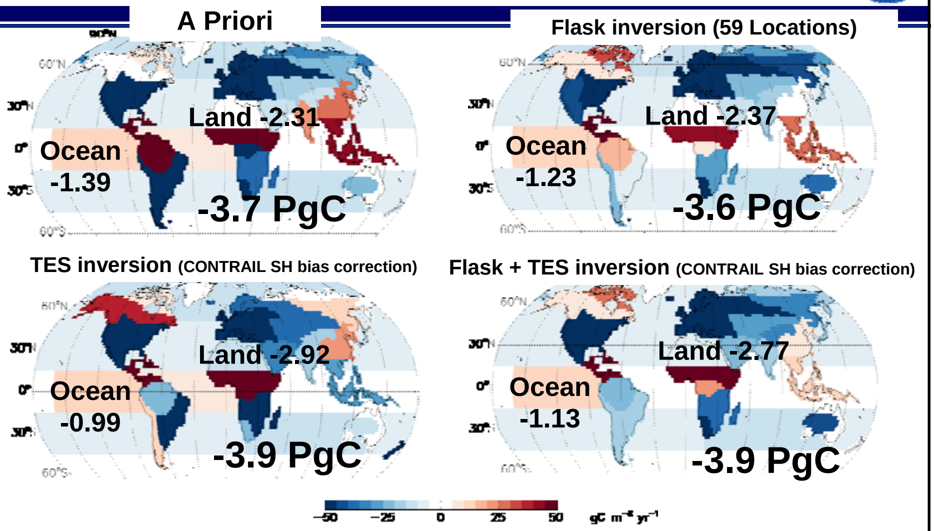
Sensitivity shown at SGP Arm site



Mid-troposphere measurements can constrain surface fluxes by providing information about vertical mixing

Flux estimates for 2006 using TES

Ray Nassar, Dylan Jones, et. al, paper in preparation

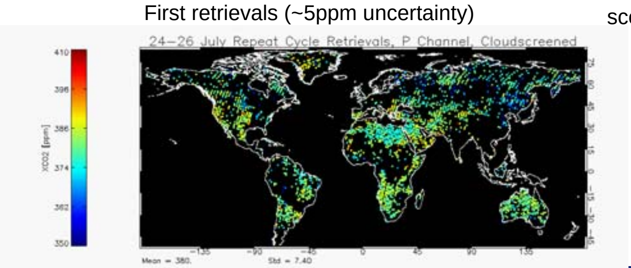


TES provides valuable information on tropical biospheric CO_2 fluxes, where the flask network is especially sparse

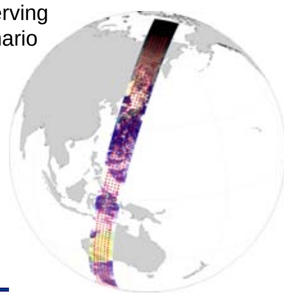
Greenhouse Gas Observing Satellite ("IBUKI")

- Also known as GOSAT
- Launched Feb 2009
- One of the TANSO instruments is an FTS with 3 bands covering NIR and one covering the thermal infrared wavelengths
- Cloud-free sampling is limited due to large footprint size (10 km)
- Future potential for multi-wavelength retrievals and include CH4 and N2O(?)

First retrievals (~5ppm uncertainty)



Observing scenario

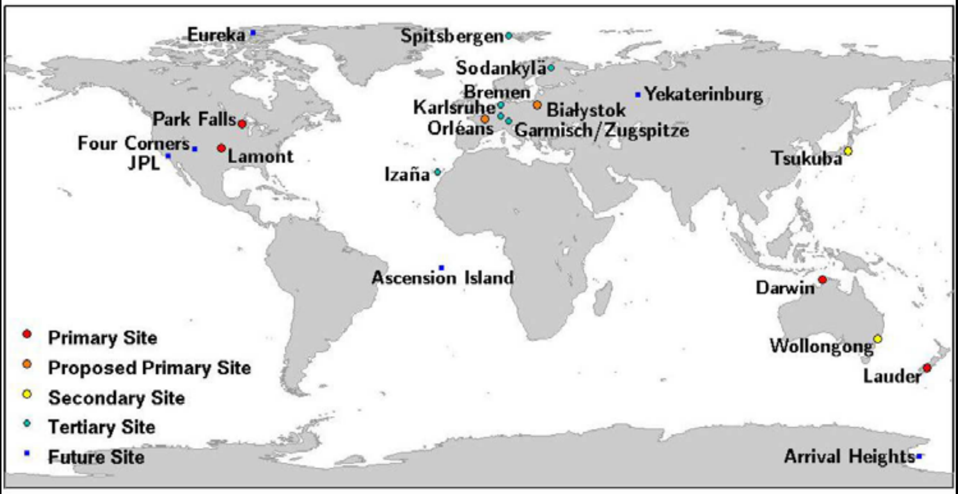


Courtesy JAXA

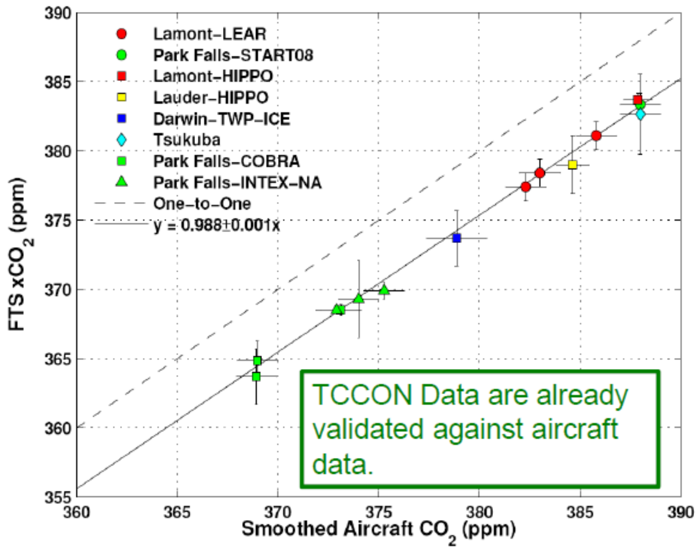
Validating GOSAT X_{CO2} against the Ground-Based Standard: TCCON

- A critical element of the validation strategy was the Total Carbon Column Observing Network (TCCON)
  - High resolution FTS's measure the absorption of direct sunlight by CO_2 and O_2, in the same spectral regions used by the TANSO-FTS.
  - Over-flights of TCCON stations by aircraft carrying *in situ* instruments calibrated with WMO referenced gases used to validate TCCON results.
    - Aircraft CO_2 profiles extending from the boundary layer to the middle troposphere are integrated to derive a value of X_{CO2}.
  - Simultaneous TCCON FTS and TANSO-FTS measurements will be compared to transfer the WMO standard to the spacecraft measurements.

Current (and Future) TCCON Sites

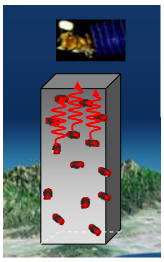


TCCON Measurements Validated Against Aircraft Observations



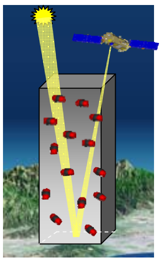
Atmospheric CO_2 Observations from Satellites

AIRS, TES, IASI

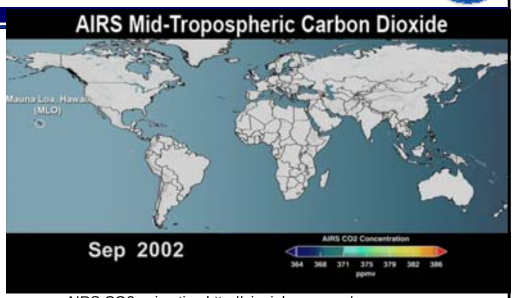


thermal-emission

SCIAMACHY, GOSAT



reflected sunlight



AIRS CO2 animation http://airs.jpl.nasa.gov/

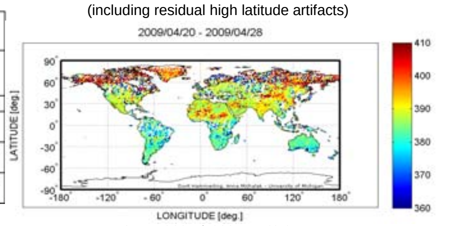
Source: Chahine et al., 2008

Current Operating Missions

Measurement Method	Instrument	CO_2 Measurement	CO_2 Product Precision*	Down-track Sampling	Other gasses retrieved
Reflected Sunlight	SCIAMACHY	Total Column	3-10 ppm	60 km	CH_4, N_2O, CO, O_3, NO_2, H_2O, SO_2, others
	GOSAT/IBUKI	Total Column	4 ppm	10.5 km	CH_4, O_2, O_3, H_2O
Thermal Emission	AIRS	Mid-Trop	1 – 2 ppm	45 km	CH_4, CO, O_3, H_2O, SO_2
	IASI-A	Mid-Trop	2 ppm	100 km	CH_4, N_2O, CO, O_3, H_2O, others
	TES	Mid-Trop	~5 ppm	~50 km	CH_4, N_2O, CO, O_3, H_2O, HNO_3

*CO_2 products often have different precision and spatial scale than for individual samples

Preliminary GOSAT/ACOS global CO2 map
(including residual high latitude artifacts)



Source: GOSAT/ACOS team, 2010

The Future: OCO-2 and OCO-3

OCO animation http://www.nasa.gov/mission_pages/oco/multimedia

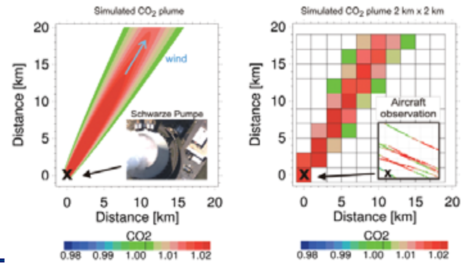
Planned Missions 2013-2020

Measurement Method	Instrument	CO_2 Measurement	CO_2 Product Precision*	Down-track Sampling	Other gasses retrieved
Reflected Sunlight	OCO-2	Total Column	1 ppm	2.3 km	O_2
	pre-Sentinel-5	Total Column	tbd	10km	CH_4, CO, O_3, NO_2, SO_2
	Sentinel-5	Total Column	tbd	tbd	tbd
Thermal Emission	IASI-B	Mid-Trop	2 ppm	100 km	CH_4, N_2O, CO, O_3, H_2O, others
	IASI-C	Mid-Trop	2 ppm	100 km	CH_4, N_2O, CO, O_3, H_2O, others
	JPSS CrIS	Mid-Trop	tbd	tbd	tbd
Active (LIDAR)	ASCOPE	Lower-trop	2 – 4 ppm	~100 km	CO
	ASCENDS	Lower-trop	2 – 4 ppm	~100 km	CO

*CO_2 products often have different precision and spatial scale than for individual samples

Application of OCO-like observations to point-source monitoring (Bovensmann et al., AMTD, 2010)

Resolution	Peak of CO_2 column relative to background (–)
20 m×20 m	1.126
40 m×40 m	1.125
1 km×1 km	1.053
2 km×2 km	1.031
4 km×4 km	1.017
10 km×10 km	1.005



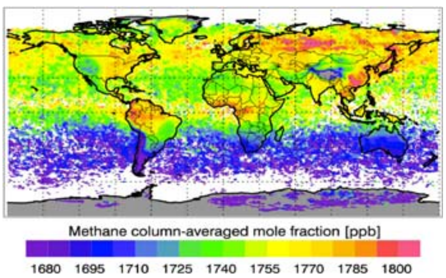
Medium size power plant (13 MtCO2/yr) , 2km res, green = background column CO2 concentration; red = 2% (8 ppm) enhancement, White = less than mean background

Measuring CH_4 Concentrations from Space

NIR Spectrometer

- NIR measurements of reflected sunlight
- Spectral range: 0.7 to 2 μm
- Spectral resolution: 0.02
- Daytime measurements only
- Spatial resolution: 10.5 km
- Measurement precision of <3-6 ppm
- Cloud-free conditions only
- Total column measurements

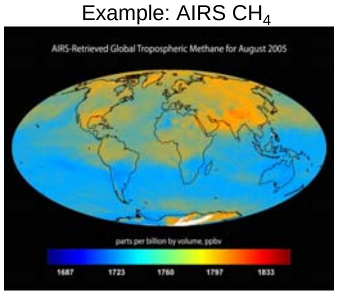
Example: SCIAMACHY CH_4



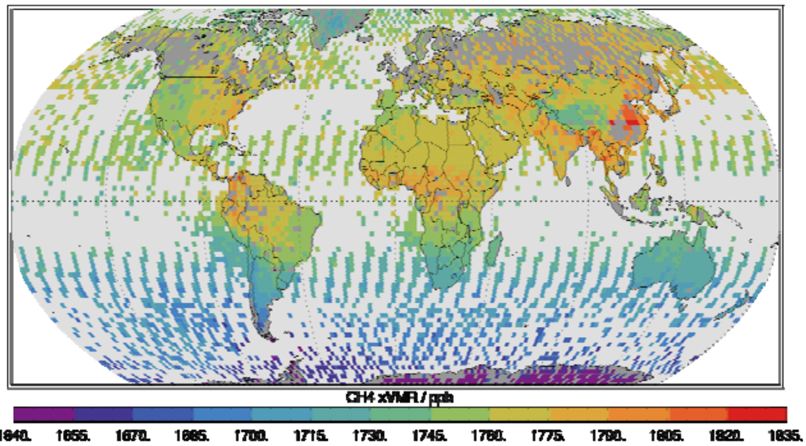
Thermal Emission Spectrometer

- Thermal emission bands
- Spectral range: 7.7 to 8.3 μm
- Spectral resolution: 0.5
- Day or night-time measurements
- Spatial resolution: 13.5 km
- Measurement precision of <9-27 ppb
- Mid- to Upper-Troposphere (10-15 km)
- Current systems: TES, AIRS and IASI

Example: AIRS CH_4



Initial GOSAT results… (for CH_4)



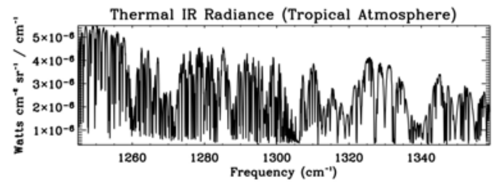
Christian Frankenburg, JPL

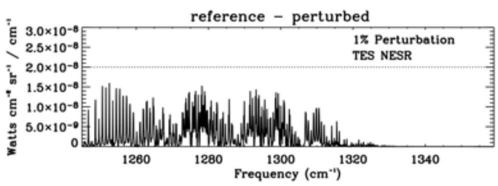
Measuring N_2O concentrations from Space using Passive Sensors

Thermal Emission Spectrometer

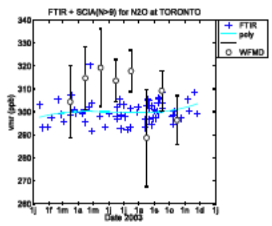
- •Possibly at the 2% level
- •However N_2O varies by less than 1%
- •Spectral Resolution = 0.1cm-1
- •Current Noise from TES (NESR) is larger than 1% signal
- •Spatial Resolution 40 km^2
- •Spectral Range (1250 - 1320 cm^{-1})

Example: TES spectra in N_2O bands





Example: SCIAMACHY N_2O compared with ground-based FTS



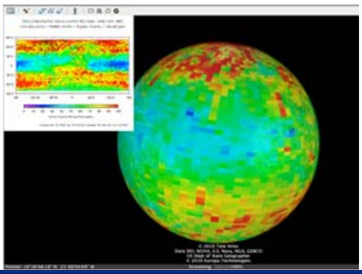
Dild, B. et al, Atmos. Chem. Phys., 6, 1953–1976, 2006

Measuring Tropospheric Ozone Profiles and its Greenhouse Gas Effect from Space using Passive Sensors

TES Thermal Emission Spectrometer

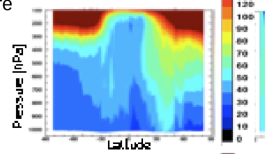
- Spectral range: 9 to 10 μm
- Spectral resolution: 0.1
- Day or night-time measurements
- Spatial resolution: 5 km
- Measurement precision of <TBD
- Separation of upper troposphere and lower troposphere (see right)

Example: TES O_3 at 215 mb

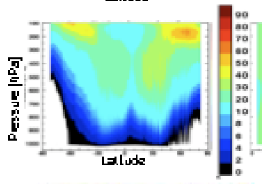


TES estimates of ht.-resolved ozone show radiative forcing is largest in the tropical and extra-tropical middle-to-upper troposphere

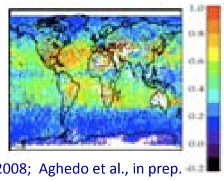
Zonal-mean ozone and models' bias [ppbv]



All-sky zonal mean instantaneous radiative forcing and models' bias [milli-Watts/m^2]



All-sky instantaneous radiative forcing and models' bias [Watts/m^2]



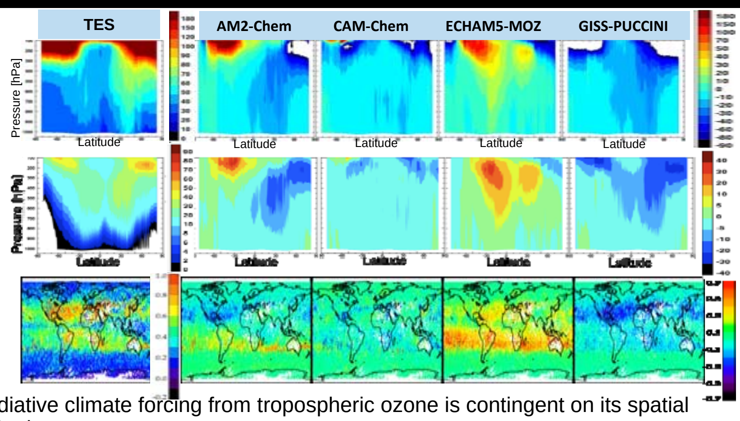
H. Worden et al. ,Nature Geoscience, 2008; Aghedo et al., in prep.

Observational-constraint on predicted tropospheric ozone radiative forcing

Zonal-mean ozone and models' bias [ppbv]

All-sky zonal mean instantaneous radiative forcing and models' bias [milli-Watts/m^2]

All-sky instantaneous radiative forcing and models' bias [Watts/m^2]

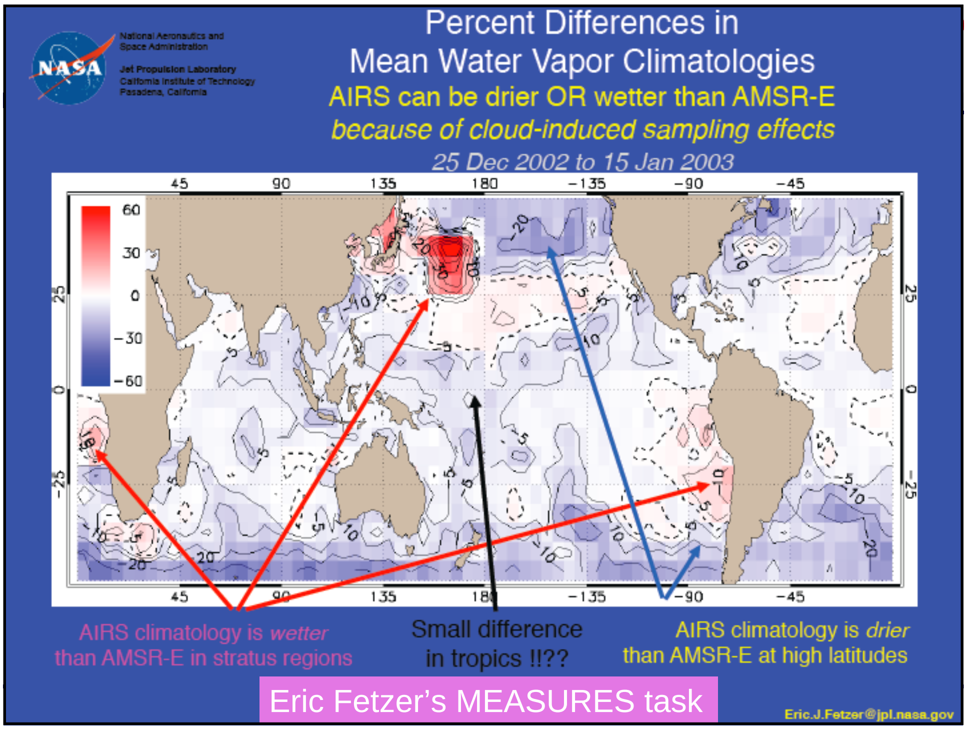


Problem: The radiative climate forcing from tropospheric ozone is contingent on its spatial and vertical distribution.

Results: For August 2006, TES data quantifies a zonal-average bias of about -30 to +40 mWatts/m^2 and regional bias of about -40 to +70 mWatts/m^2 in the radiative forcing of tropospheric ozone predicted by four state-of-the-art climate-chemistry models.

Significance: Uncertainty in the radiative forcing of tropospheric ozone is largest in the tropical and extra-tropical middle-to-upper troposphere.

Aghedo et al., in prep.



Summary

- JPL is currently generating ECVs for CO2 from AIRS, TES and GOSAT
- AIRS is generating CH4 products for the mid-troposphere
- Exploratory products are also being generated:
  - N_2O from TES
  - Tropospheric O_3 from TES
  - Stratospheric and Lower Troposphere CO2 from AIRS
  - CH_4 from GOSAT
- Future measurements include:
  - Total Column CO_2 from OCO-2 and OCO-3