Comparison of Aura TES Satellite Greenhouse Gas Measurements with HIPPO profiles

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Outline of Talk

Sources, Sinks, Processes, and Transport controlling atmospheric CO_2 and CH_4

Role of satellites for placing constraints on surface fluxes and emissions of GHG's

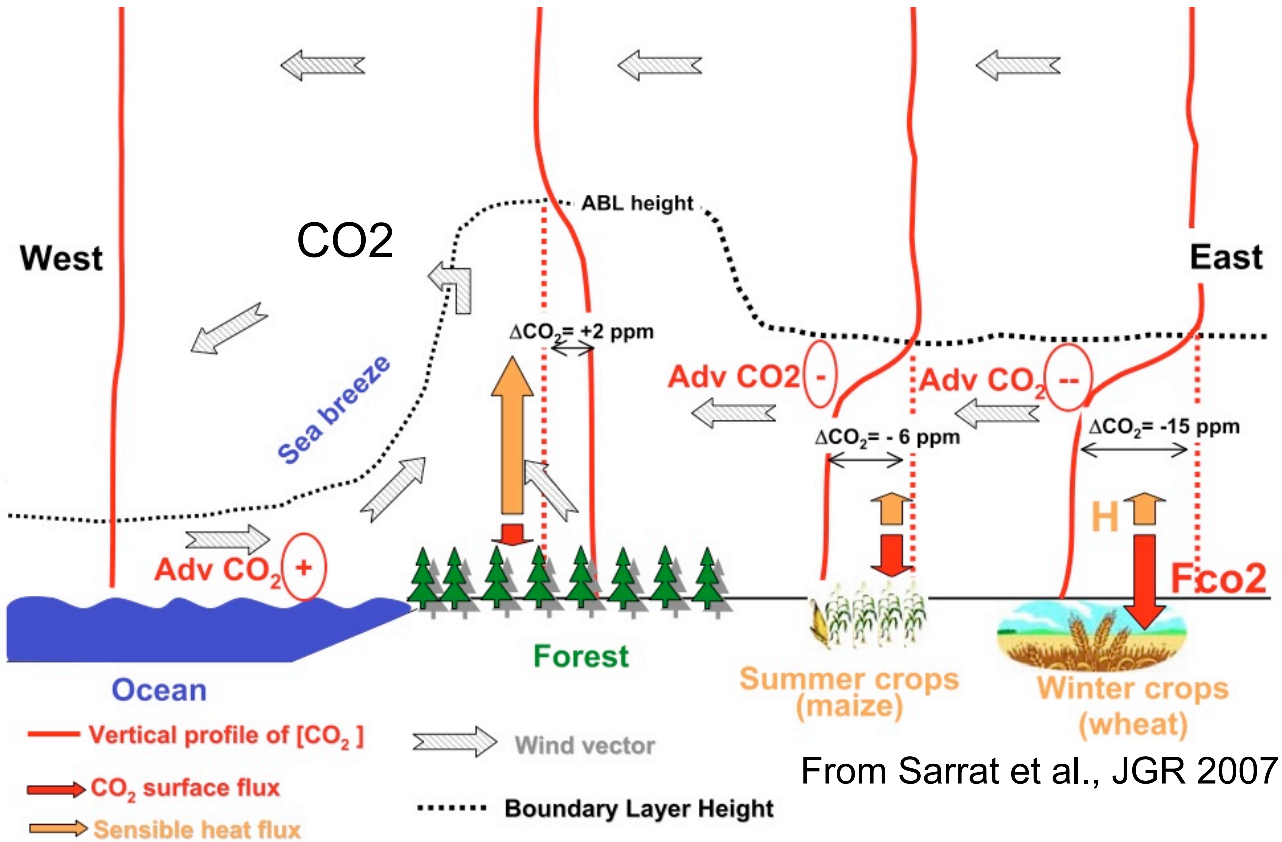
Importance of characterizing (1) satellite biases and (2) actual versus calculated errors for using satellite data to place constraints on surface fluxes and emissions.

Overview of Aura TES CO_2 measurements and comparisons with HIPPO

Overview of New TES retrievals of Methane Profiles and brief comparison to HIPPO data (more in Kevin Wecht's talk!)

Coordination of satellite and HIPPO measurements to improve satellite validation and increase information content of GHG flux / emissions estimates using satellite and HIPPO data.

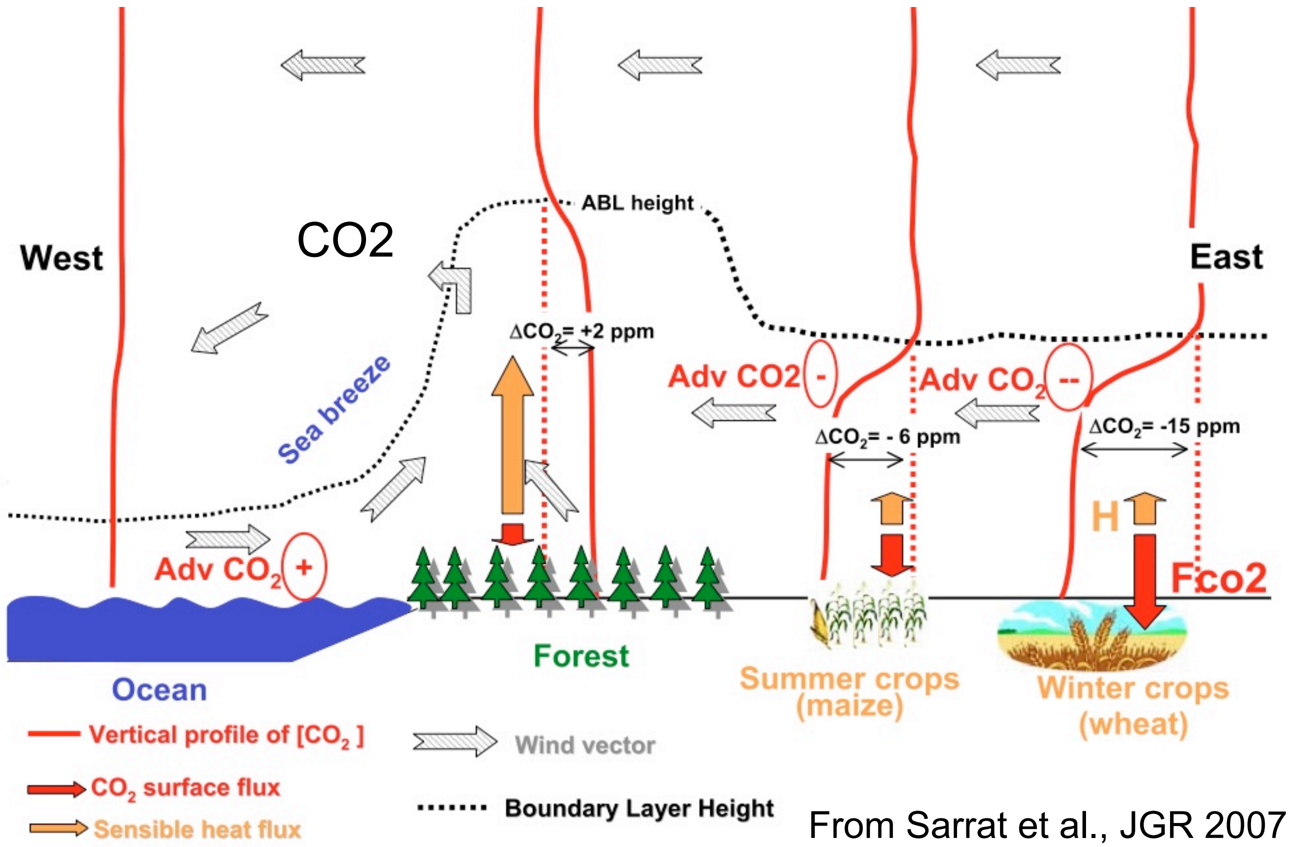
What are the sources, sinks, and processes controlling Atmospheric CO_2 (and CH_4)?



From Sarrat et al., JGR 2007

Atmospheric CO_2 concentrations depend on uptake and release from vegetation, polluting sources, advection, mixing between the free troposphere and PBL, and the planetary boundary layer (PBL) height. A similar set of sources and processes affect Methane concentrations but with an added sink due to reaction with OH in the troposphere and need to account for mixing with the stratosphere.

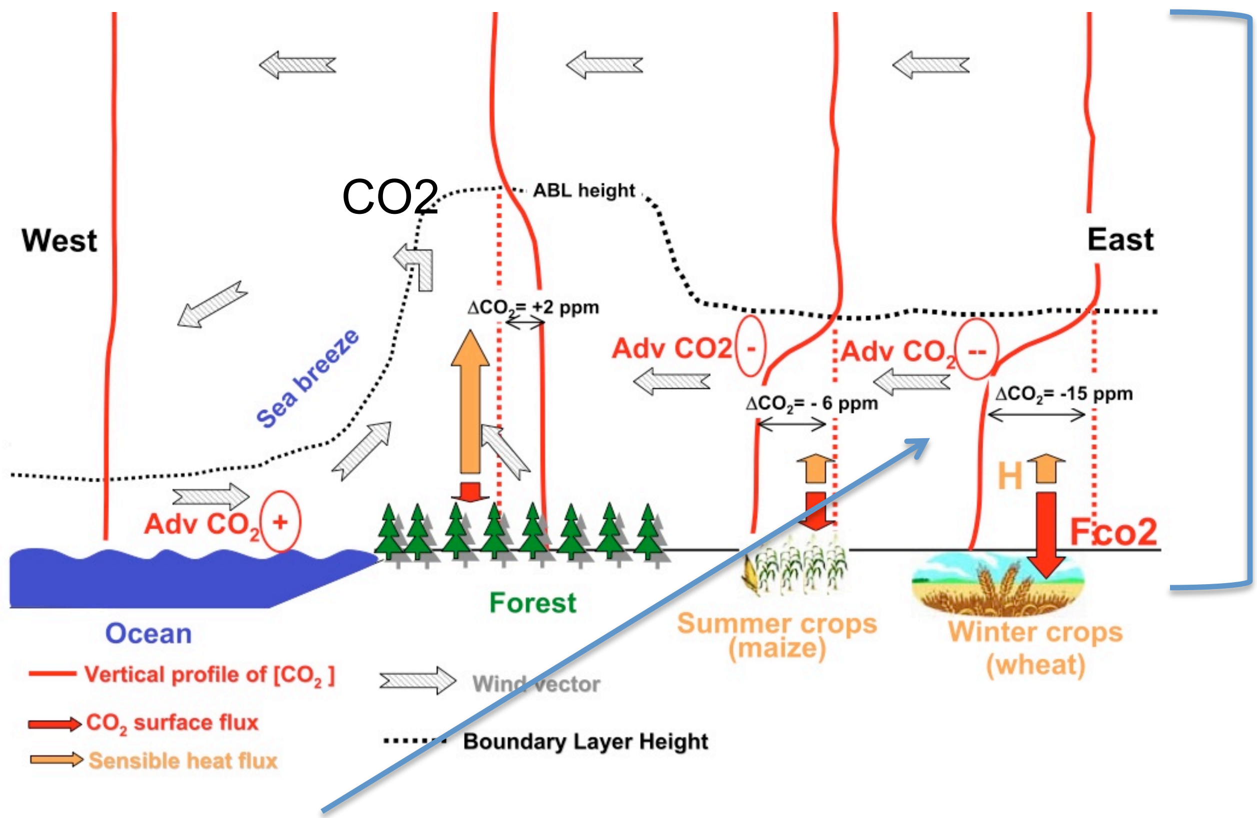
What are the sources, sinks, and processes controlling Atmospheric CO_2 (and CH_4)?



From Sarrat et al., JGR 2007

Estimates of surface fluxes are primarily derived from surface measurements, towers, and aircraft and then a global or regional transport model to infer fluxes from these measurements (more references then I can name). Large uncertainties exist in global scale flux estimates using these data due to sparse sampling and incomplete knowledge of transport

What Role Can Satellites Play In Estimating Surface Fluxes?

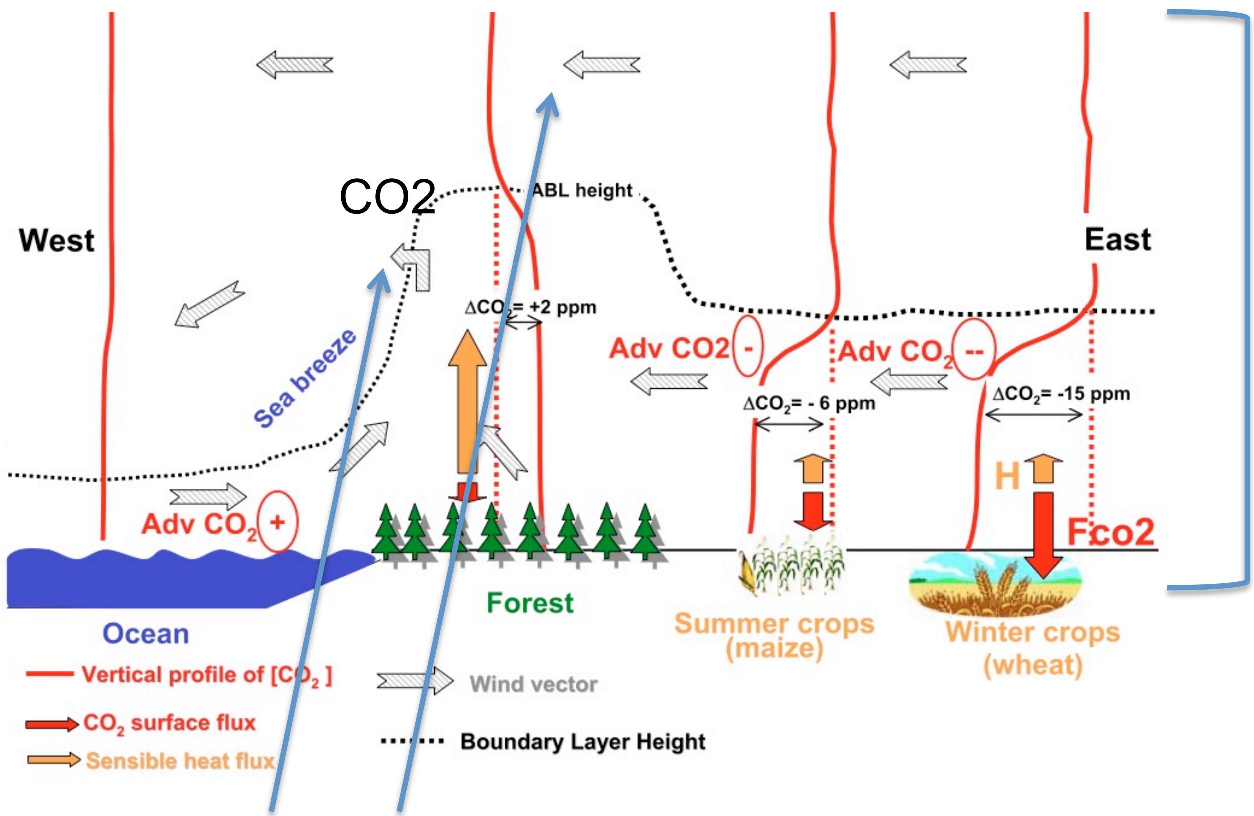


Satellites measuring near IR radiances can estimate global, total columns of CO_2

(e.g, GOSAT, SCIAMACHY OCO-2)

Total column measurements provide sensitivity to near surface CO_2 concentrations and its variability. Global, total column CO_2 estimates can therefore be used to estimate surface fluxes (e.g., Rayner et al., JGR 2001; Baker et al., ACP 2008 and references therein)

What Role Can Satellites Play In Estimating Surface Fluxes?

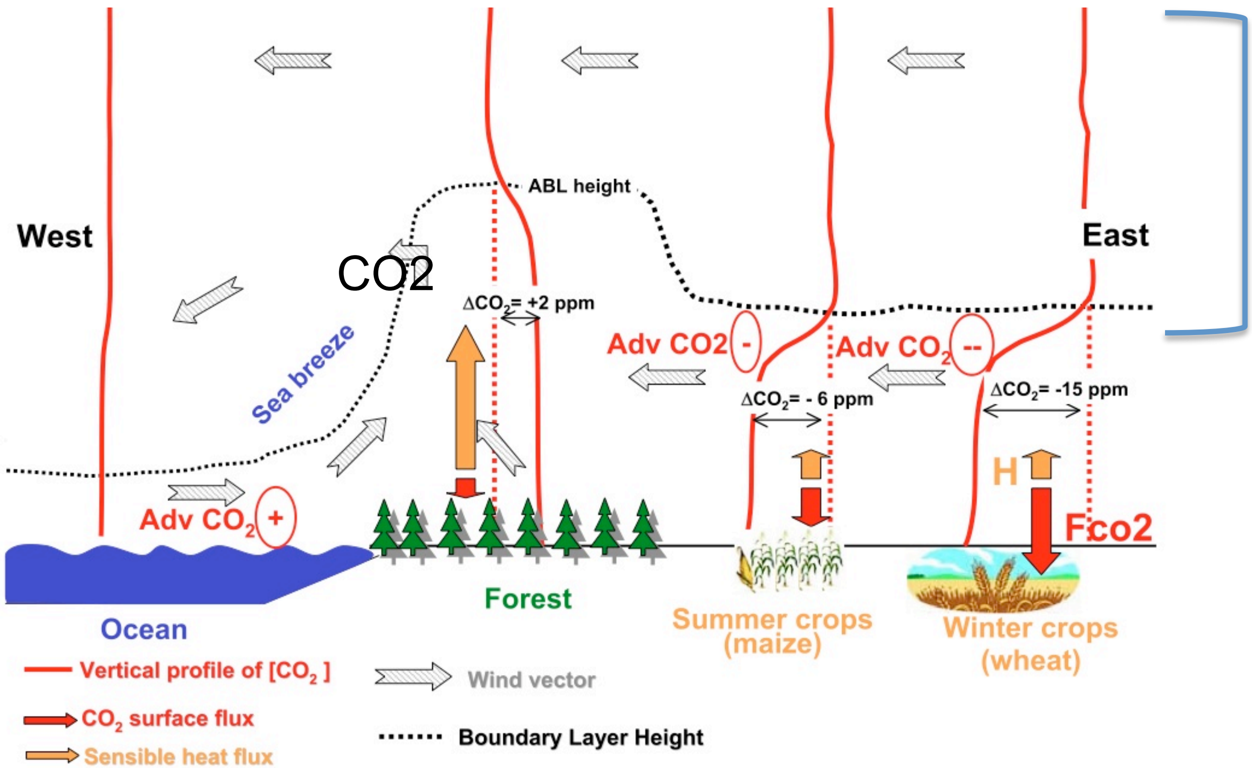


Satellites measuring near IR radiances can estimate global, total columns of CO_2

(e.g, GOSAT, SCIAMACHY OCO-2)

However, total column CO_2 measurements cannot distinguish between free troposphere and PBL CO_2 concentrations. Incomplete knowledge of the free troposphere and mixing between the free troposphere and the PBL can affect the accuracy of flux estimates (e.g, Stephens et al., Science 2007; Chan et al., JGR 2008; Houweling et al. ACP 2010; and references therein)

What Role Can Satellites Play In Estimating Surface Fluxes?

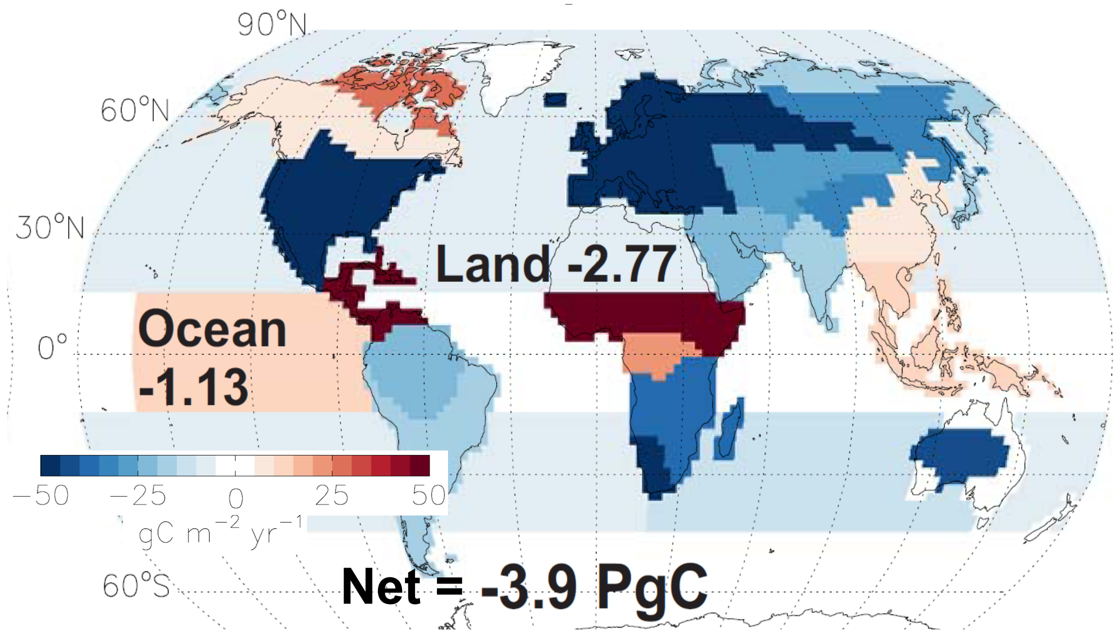


IR Sounders are primarily sensitive to trace gasses in the free troposphere (e.g., AIRS, IASI, and TES) with some sensitivity to the top of the PBL in the tropics (e.g. TES) depending on the spectral and noise characteristics of the sounder

IR sounders can place constraints on mixing and transport of CO_2 in the tropics (e.g., Jiang et al., 2010; Li et al., PNAS 2010) and chemical conversion of NMHC's and CO to CO_2 (Nassar et al., GMD 2010). Characterization of these processes are critical for understanding tropical fluxes where incorrect parameterization of the vigorous exchange between boundary layer and free tropospheric air can strongly affect flux / emission estimates (e.g., Kopacz et al. ACP 2010; Nassar et al., ACPD 2010 and many many other references therein)

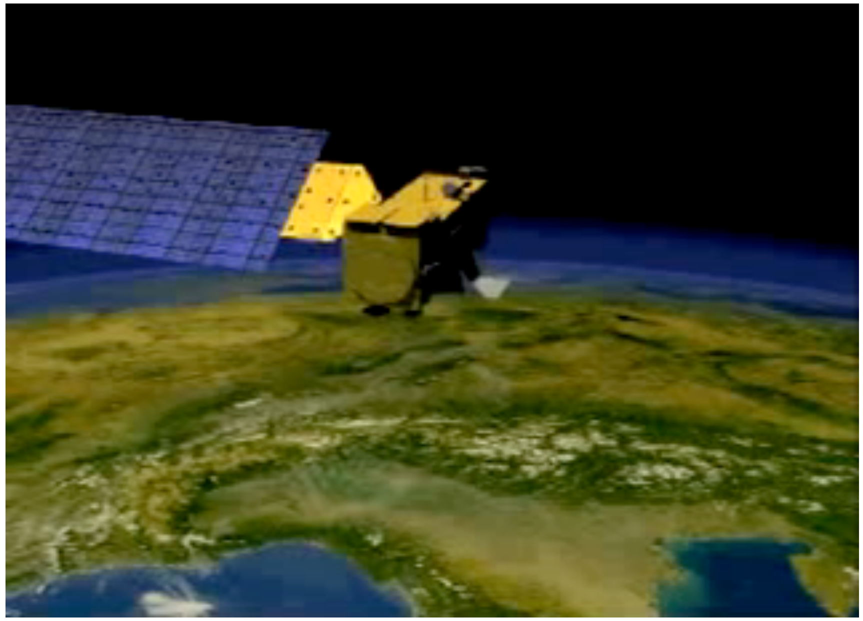
What Role Can Satellites Play In Estimating Surface Fluxes?

CO_2 surface fluxes estimated from TES CO_2, surface flasks and the GEOS-Chem model

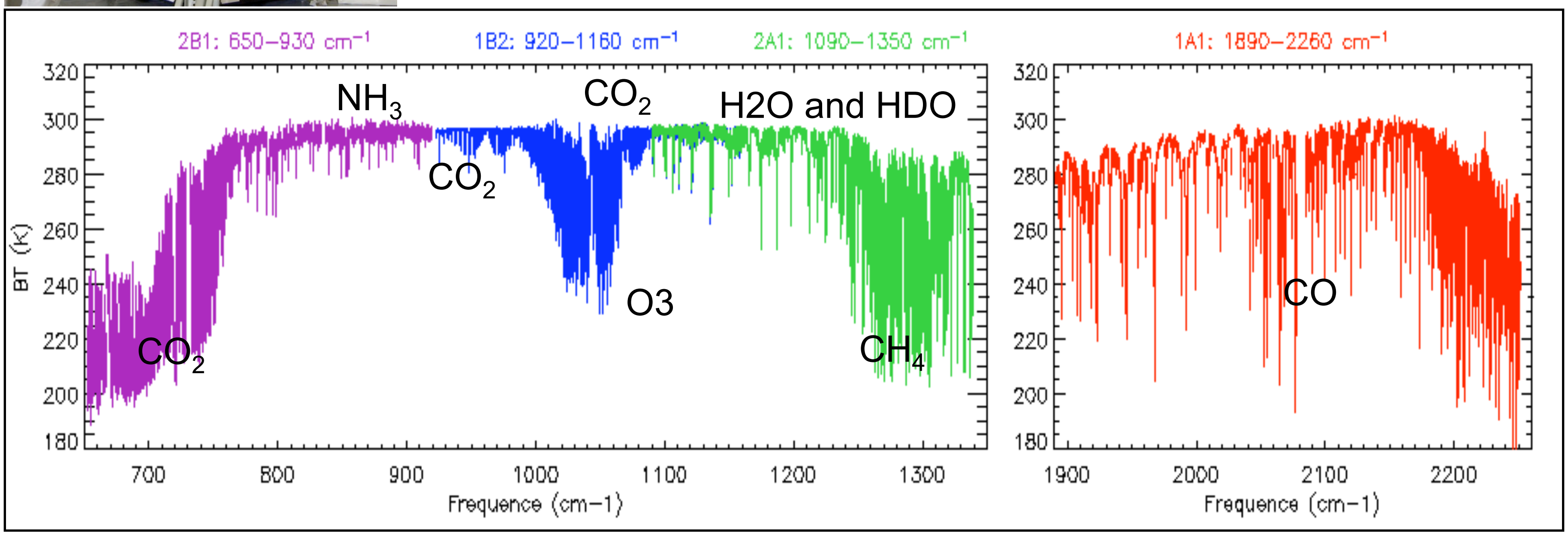


TES IR observations have increased sensitivity to the lower tropical troposphere, relative to other IR sounders, because of its spectral resolution and spectral coverage. TES data provide significant sensitivity to tropical biogenic fluxes where the current surface network is sparse. As discussed in Nassar et al (2010) we observe a net land sink, consistent with previous results, as well as a slight sink over the Amazon.

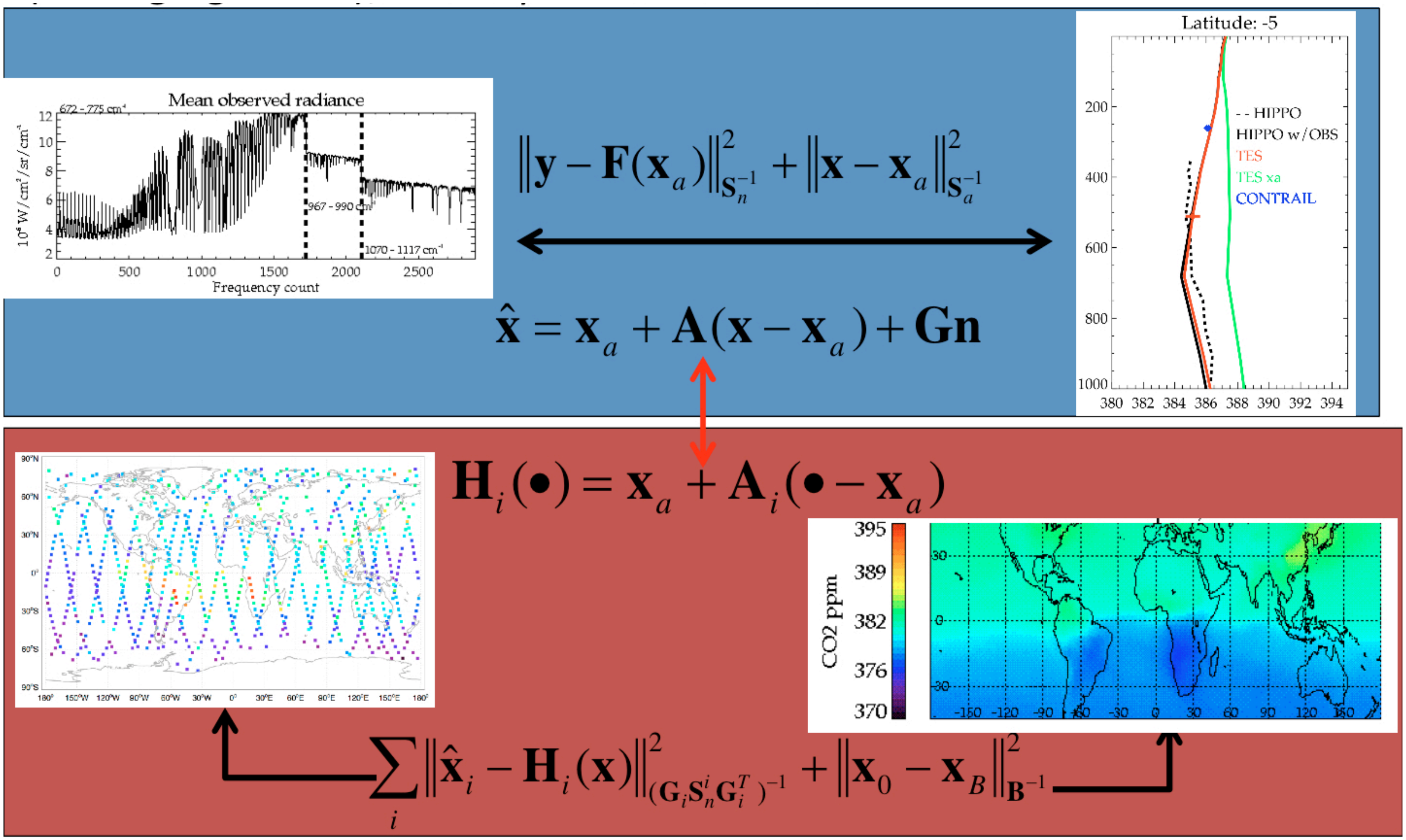
Tropospheric Emission Spectrometer



TES, launched aboard the Aura spacecraft in 2004, is a Fourier Transform Spectrometer measures infrared spectral radiances from 3.2 to 15.4 microns at 0.06 cm^{-1} spectral resolution



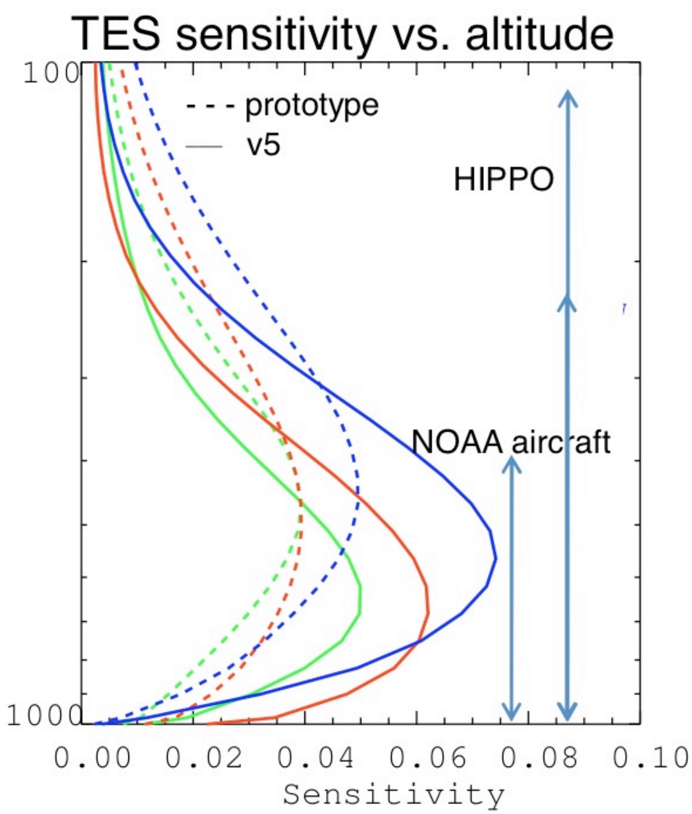
***Connecting radiances to trace gas profiles to fluxes*: Need *a priori retrieval constraints*, vertical sensitivity (averaging kernel), and careful characterization of errors.**

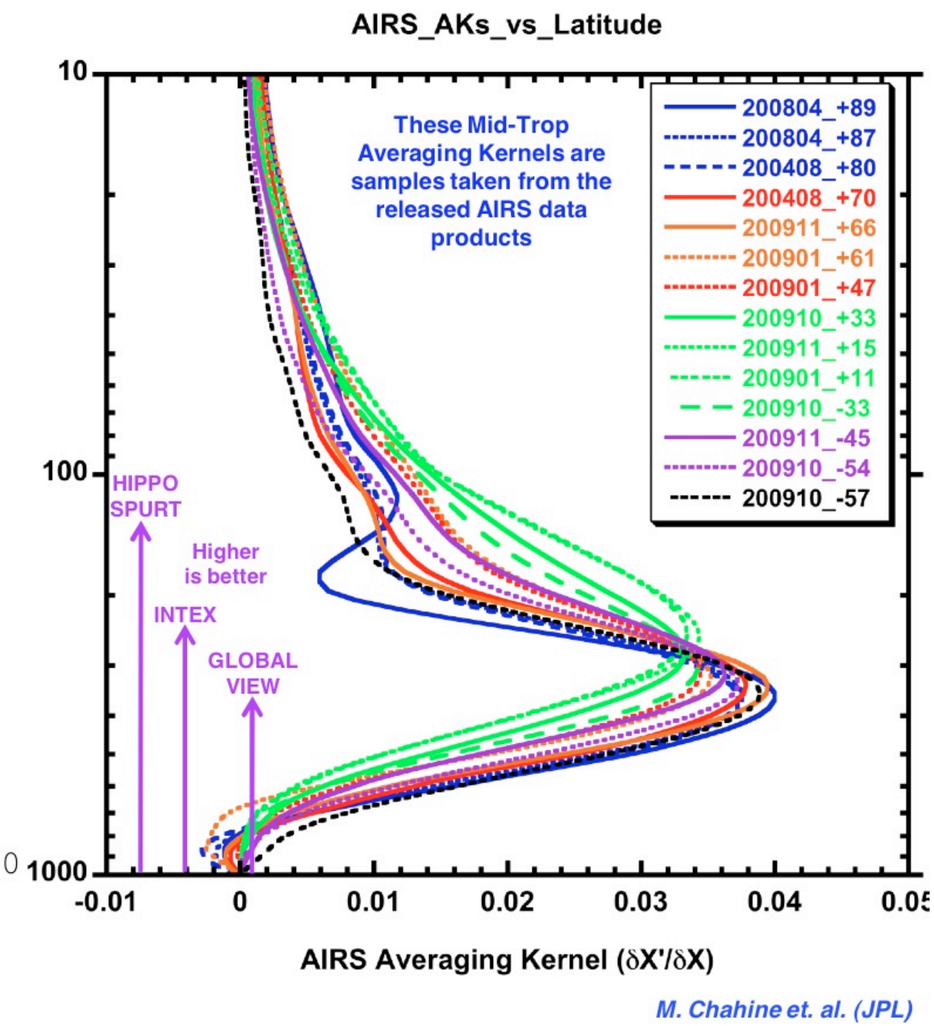


Are calculated errors consistent with actual errors? What are the biases in the satellite data? These questions can only be answered using measurements that are much more accurate and have much finer vertical resolution than the satellite data

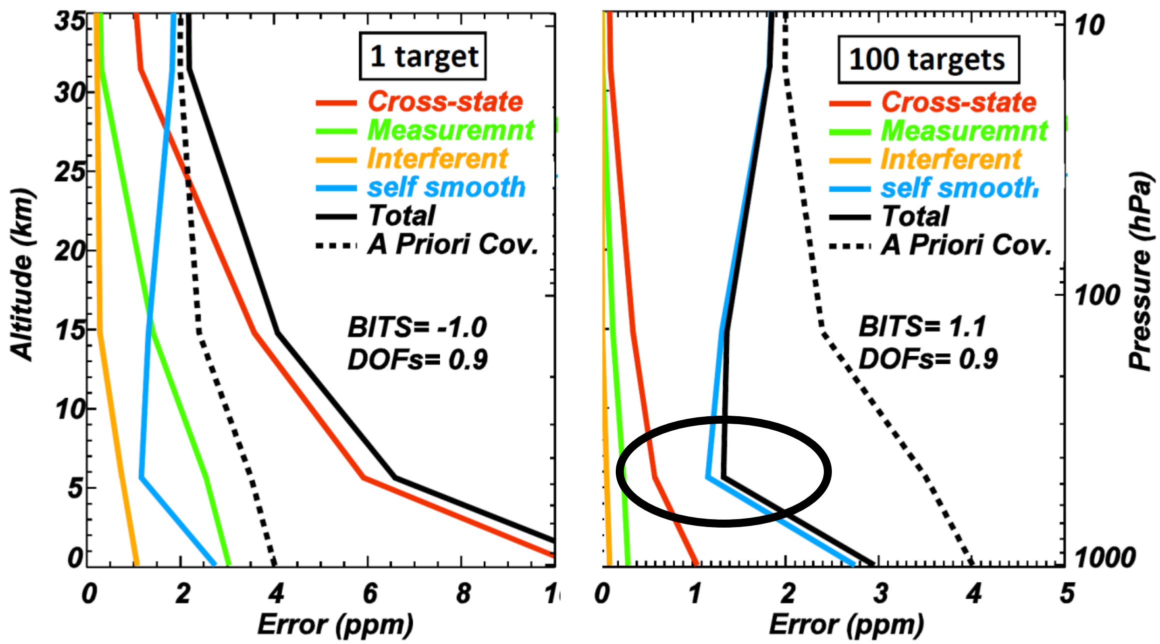
HIPPO vertical coverage, accurate measurements, and sampling of a wide variety of atmospheric states have provided the best overall validation of satellite IR GHG measurements.

Increased vertical coverage from aircraft data reduces uncertainty in satellite / aircraft comparisons due to the coarse vertical resolution of the satellite data → Can better characterize actual errors and biases in satellite data.





Error Characterization of TES CO_2



1 observation: ~7 ppm error

T_{atm} error is dominant

100 target: ~1.3 ppm error

Smoothing error is dominant

1 target:

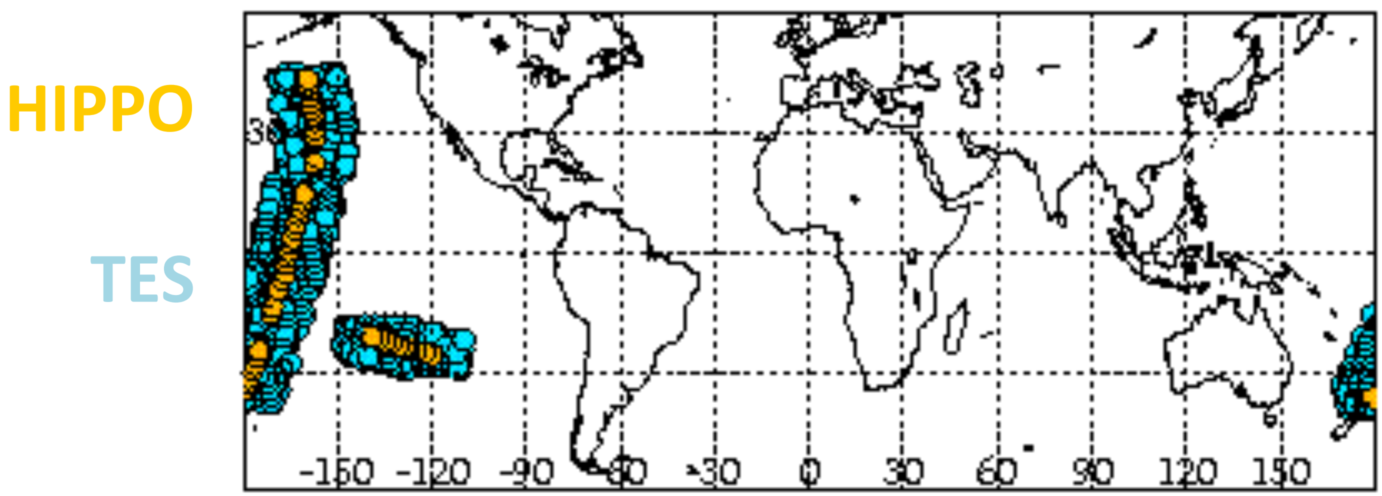
$$\mathbf{S}_{total} = \mathbf{S}_{smooth} + \mathbf{S}_{meas} + \mathbf{S}_{cross-state}$$

100 targets:

$$\mathbf{S}_{total} = \mathbf{S}_{smooth} + (\mathbf{S}_{meas} + \mathbf{S}_{cross-state})/100$$

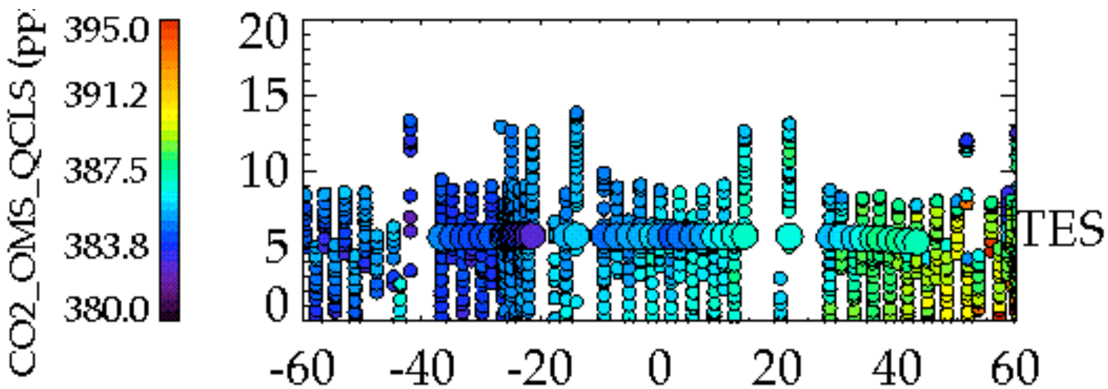
Comparisons of TES and HIPPO (OMS + QCLS) CO_2

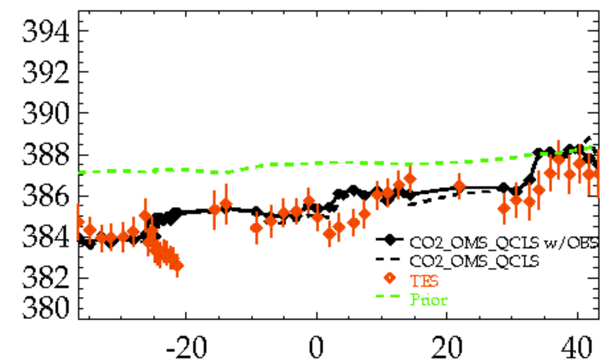
- TES data averaged within 14 days, 4 degrees latitude and 10 degrees longitude of HIPPO measurements
- TES error calculated using HIPPO variability as the a priori covariance and observation error scaling with # TES coincidences
- Compare predicted and actual errors, correlation, and biases



HIPPO-1 versus TES CO_2

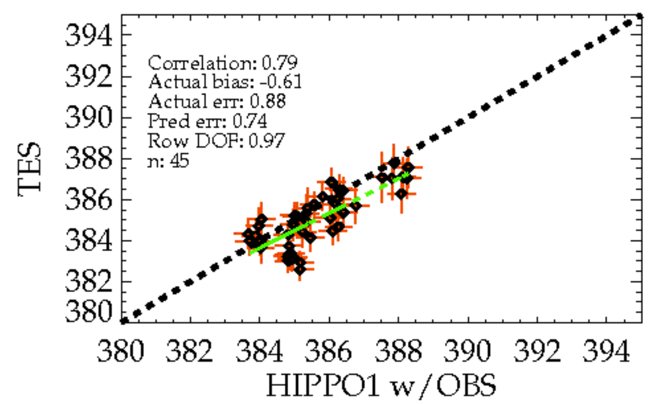
January, 2009





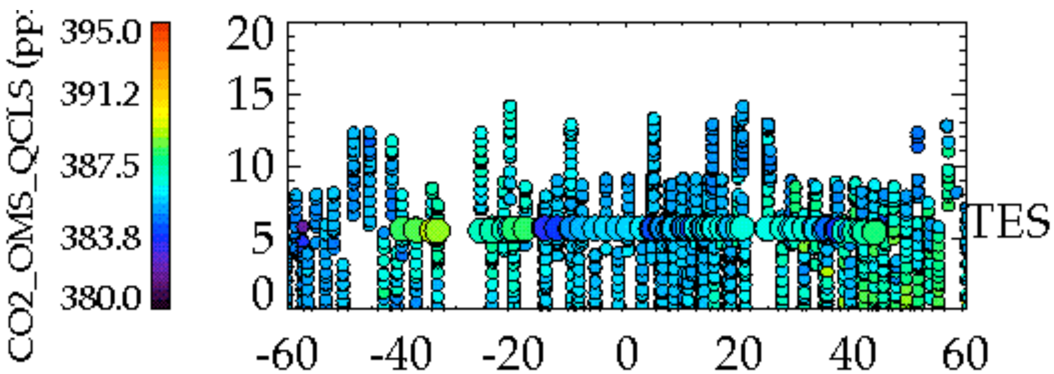
45 TES/HIPPO coincidences:

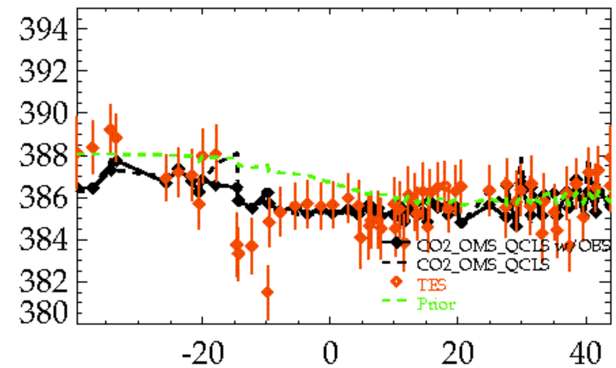
* 0.79 correlation
* -0.61 ppm low bias
* Predicted (Noise, TATM, and H2O) and actual random errors (RMS of TES-HIPPO) agree



HIPPO-2 versus TES CO_2

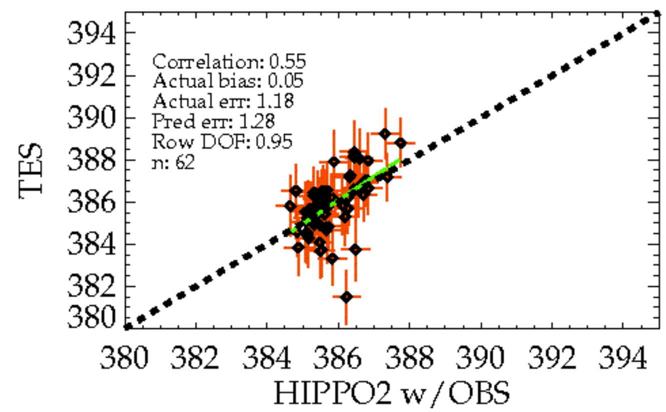
November, 2009





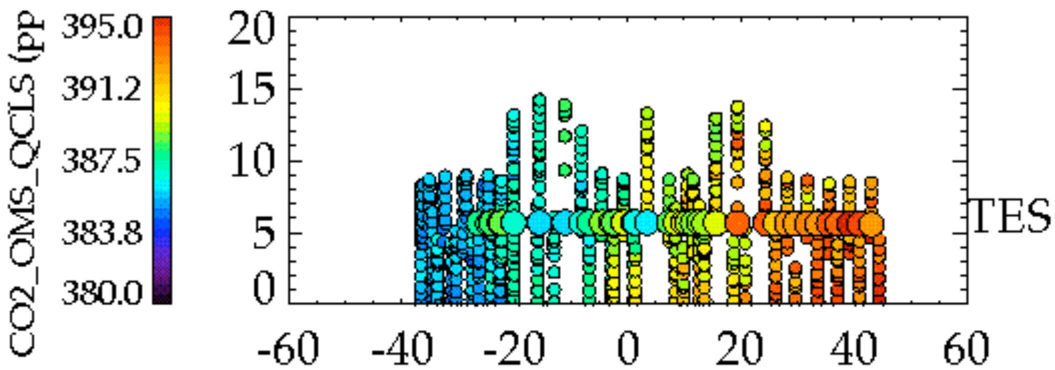
62 TES/HIPPO coincidences:

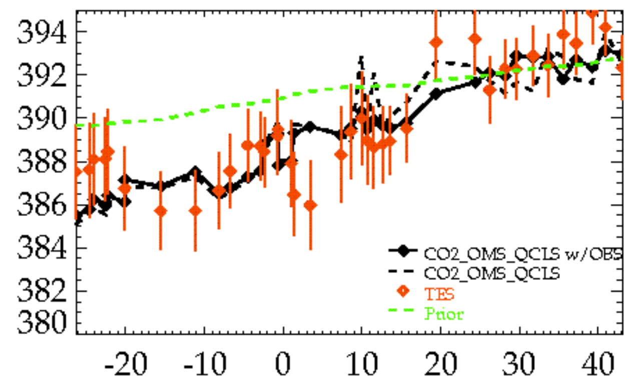
* 0.55 correlation
* 0.05 ppm high bias
* Predicted and actual random errors agree



HIPPO-3 versus TES CO_2

April, 2010 (TES off for March, 2010)



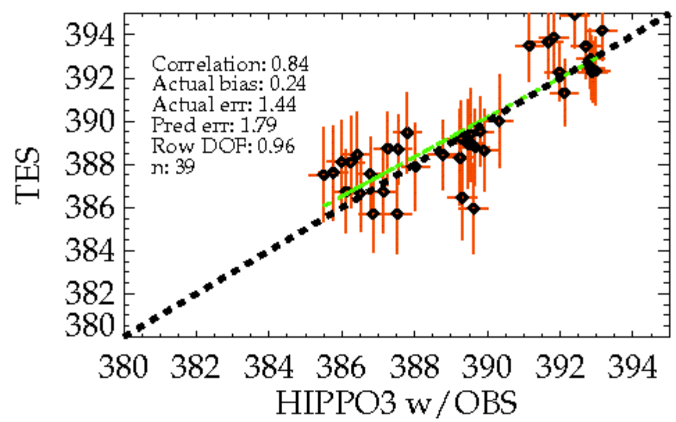


39 TES/HIPPO coincidences:

* 0.84 correlation

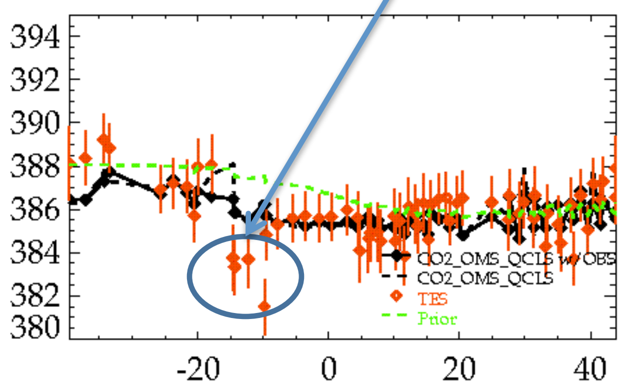
* 0.24 ppm high bias

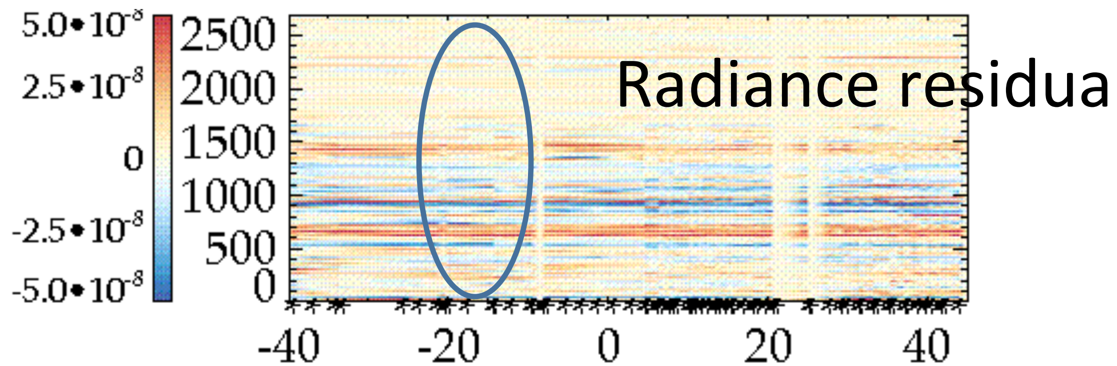
* Predicted and actual random errors agree

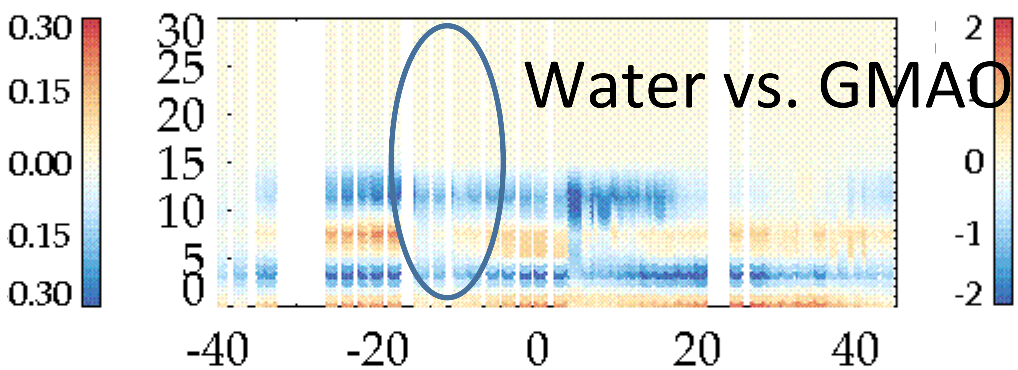


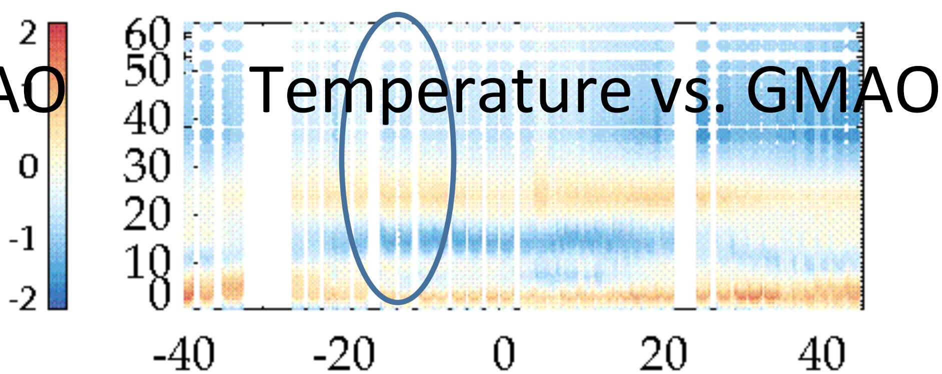
Why are TES – HIPPO CO_2 biases (-.064 - 0.24 PPM) different between HIPPO flights?

Comparisons of anomalous TES retrieval radiance residuals as well as TES temperature and water vapor estimates relative to initial guess (GMAO) do not show obvious differences for anomalous TES CO_2 measurements.









Improved co-location will reduce sampling error and provide information on water and temperature that drive the satellite retrieval errors

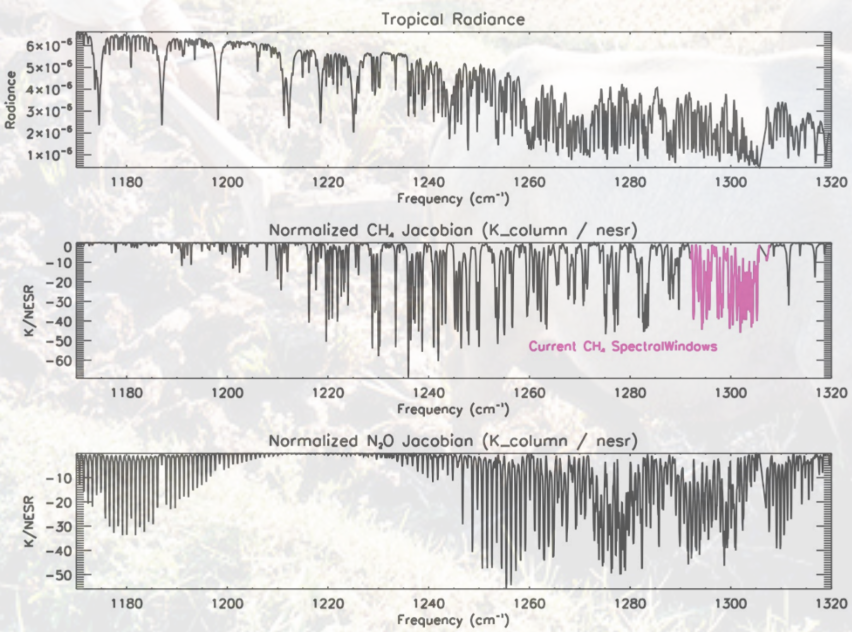
New TES profiles of Tropospheric Methane

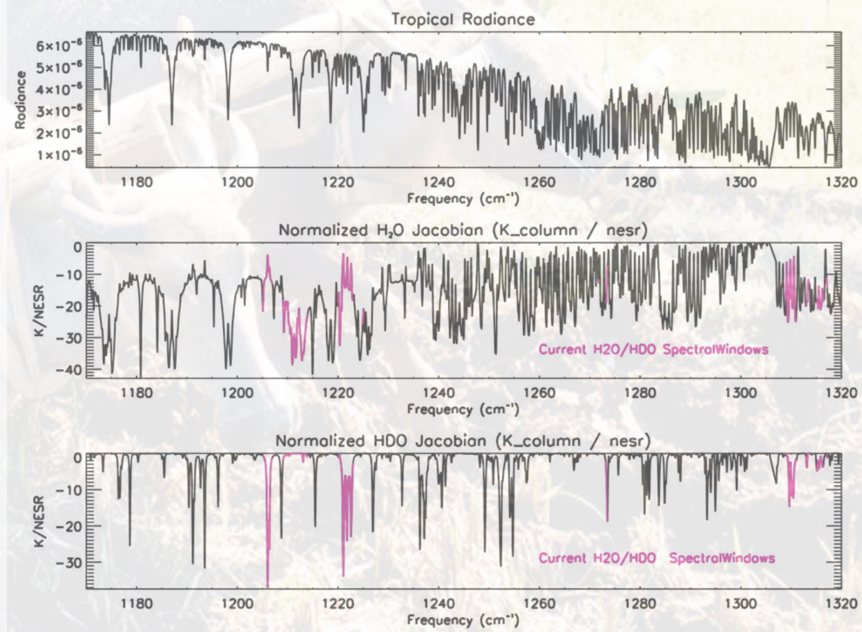
Increases CH_4 lower troposphere retrieval sensitivity by using weak absorption lines near 1240 cm^{-1} where surface-to-space transmittance is higher

Simultaneous profile retrieval estimate of CH_4, H_2O, HDO, and N_2O using spectrally resolved radiances from 1170 cm^{-1} to 1320 cm^{-1}

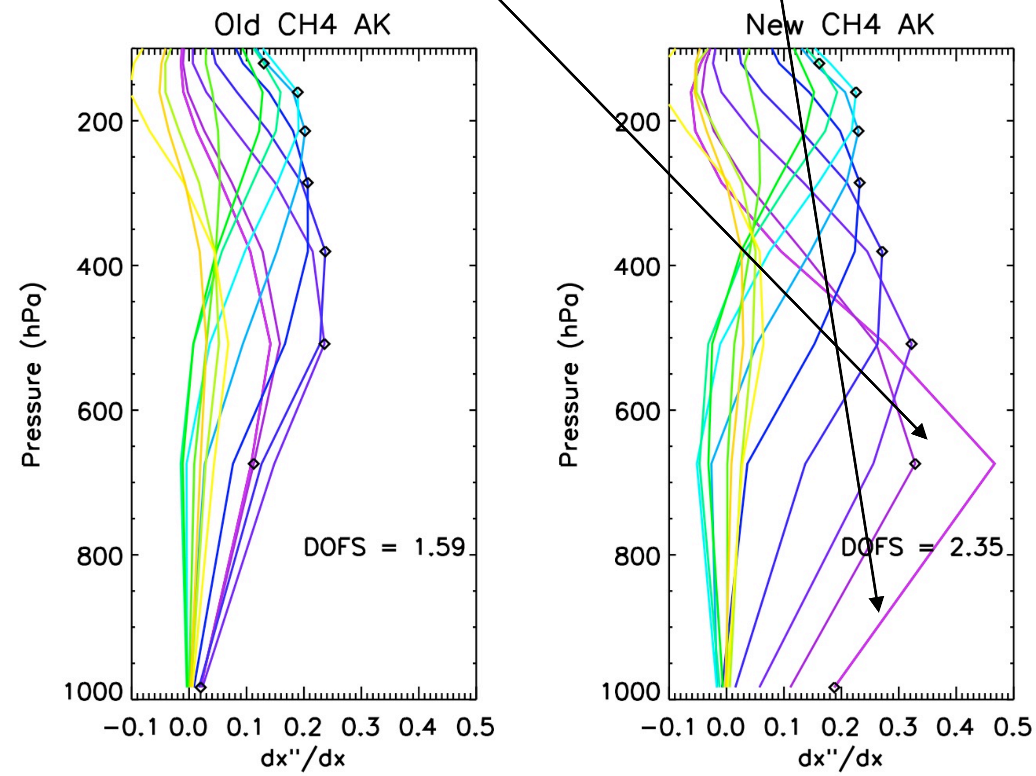
TES spectral resolution, simultaneous profile retrieval, and increased spectral coverage minimizes interference error

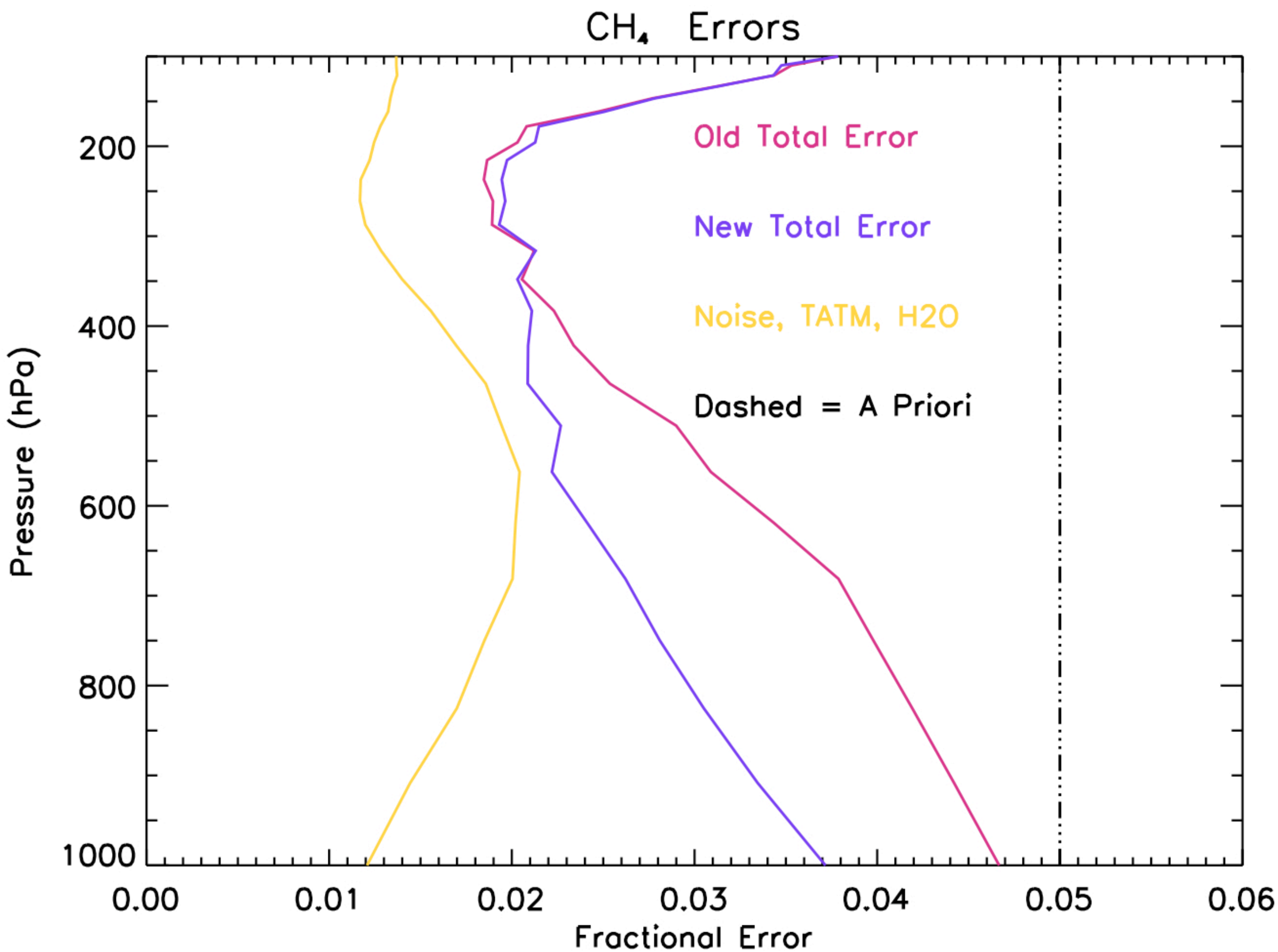
Referencing methane profile to N_2O profile minimizes errors due to systematic uncertainties in temperature and water vapor





New approach to methane retrieval Increases sensitivity to lower troposphere and PBL

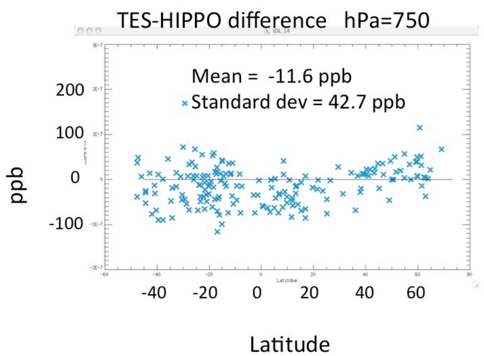


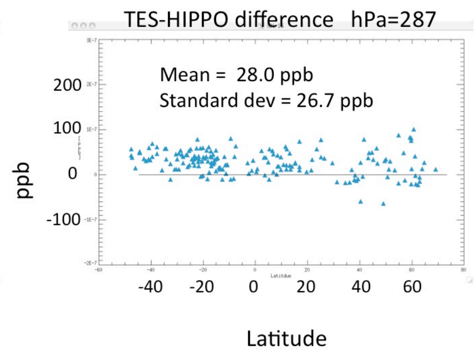


Random uncertainties of ~35 PPM in lower troposphere and ~25 PPM in the upper troposphere

Comparison of new TES methane profile estimates with HIPPO methane profiles

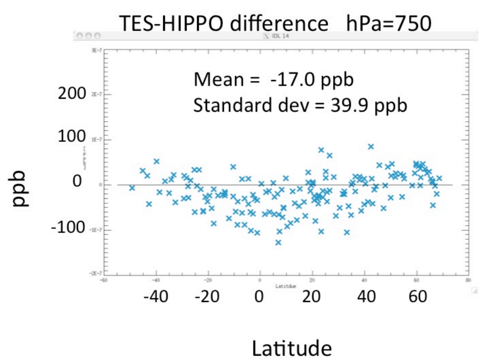
Comparisons to HIPPO 1 in lower and Upper Troposphere

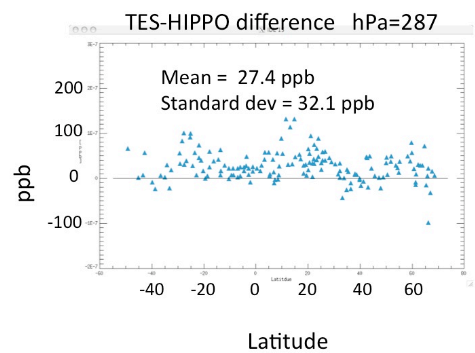




Biases and RMS differences are consistent between HIPPO flights

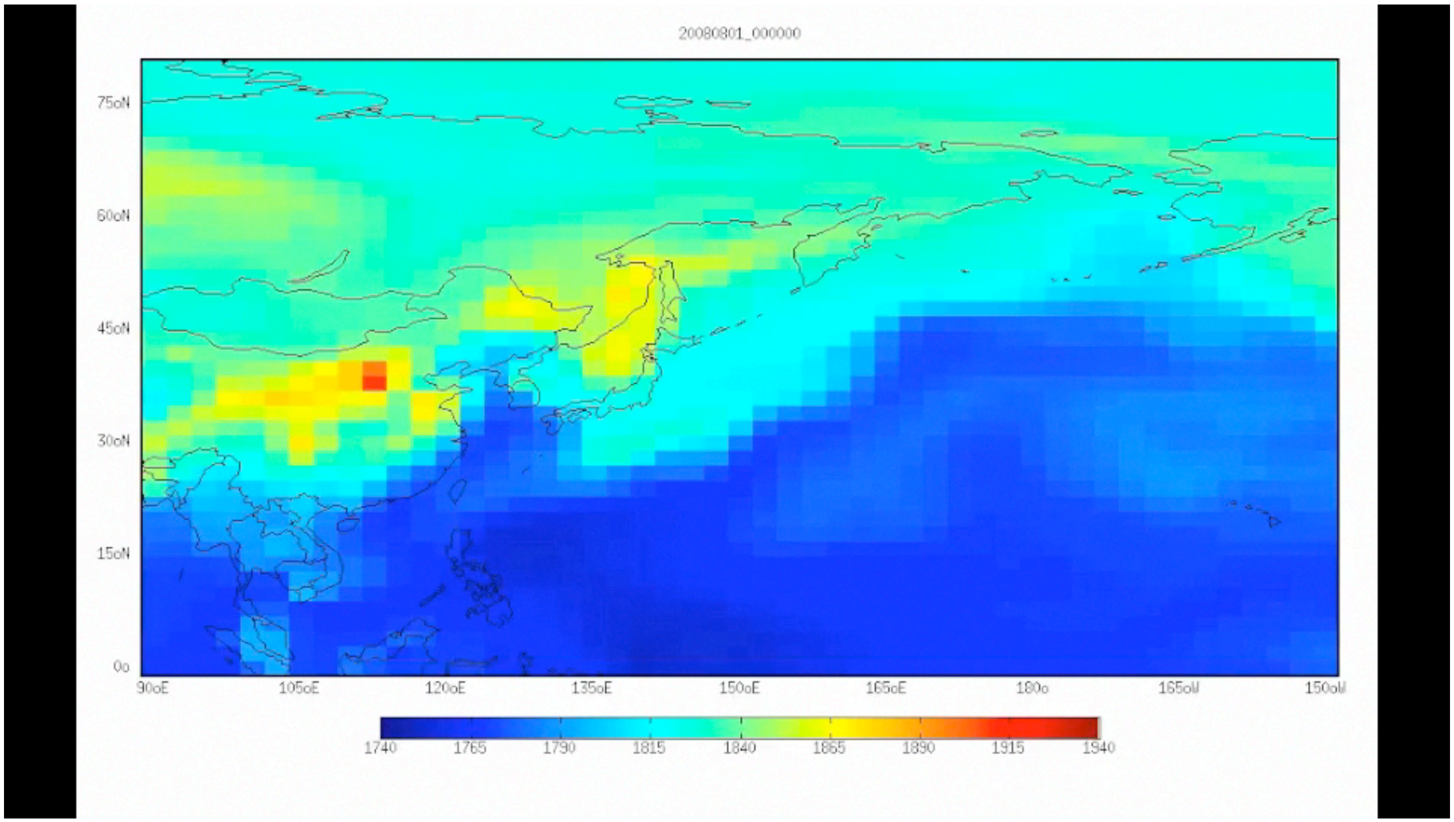
Comparisons to HIPPO 2 in lower and Upper Troposphere





RMS differences in upper troposphere are ~30 PPM and ~40 PPM in lower troposphere, consistent with calculated vertical error distribution

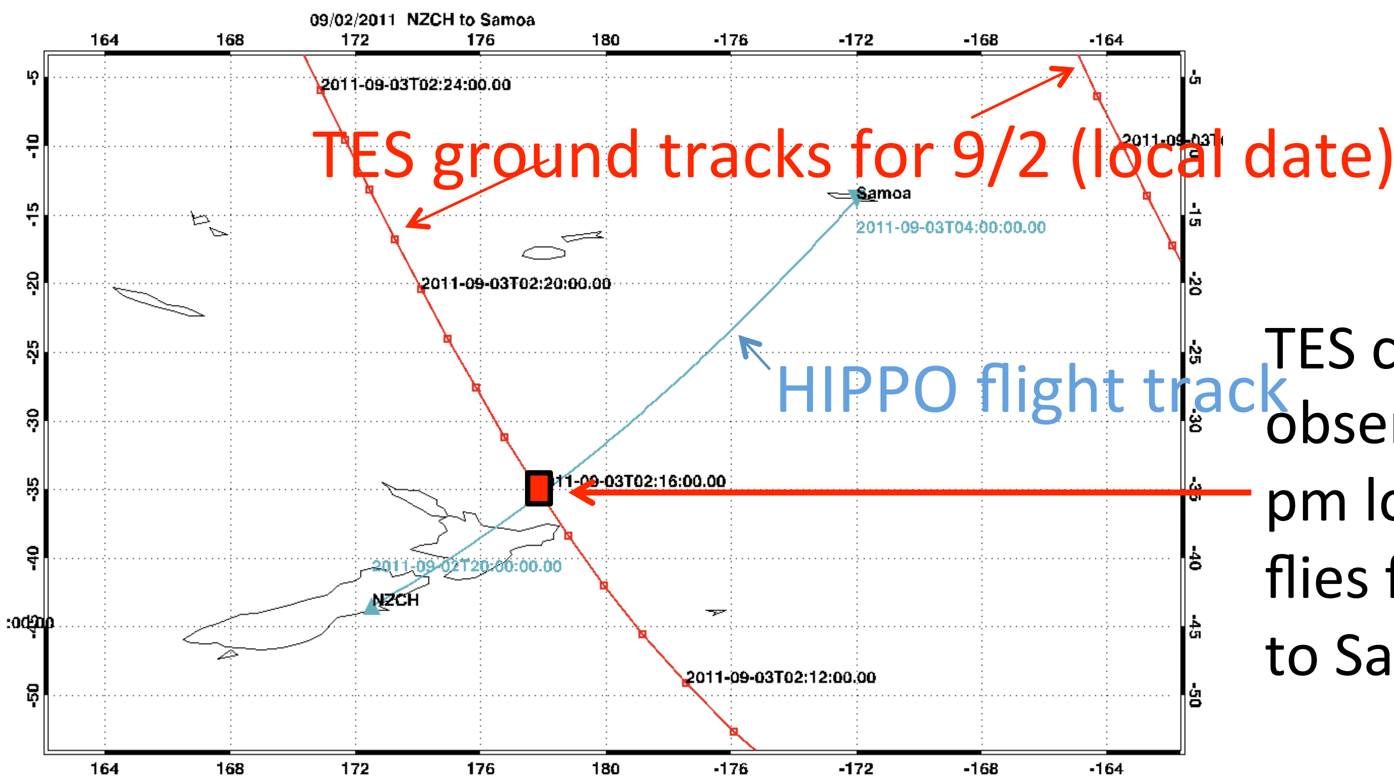
Can we coordinate satellite and aircraft data for next campaigns?



Co-located observations of TES and HIPPO as well as TES and SCIAMACHY data over Asia could place strong constraints on Asian methane emissions and subsequent transport

TES-HIPPO coincidence planning for HIPPO-4 and 5

- TES needs ~1 month to plan new Special Observation locations (SO's)
- TES needs ~1 week to schedule or change dates of existing SO's
- Every other day TES takes Global Survey observations and cannot schedule SO's
- TES overpass times are fixed, approximately 1:30 pm local time
- TES can observe up to about 2 degrees off of the ground track



TES can take a stare (32 observations) at ~1:30 pm local time as aircraft flies from New Zealand to Samoa

Summary: Comparisons of TES and HIPPO measurements

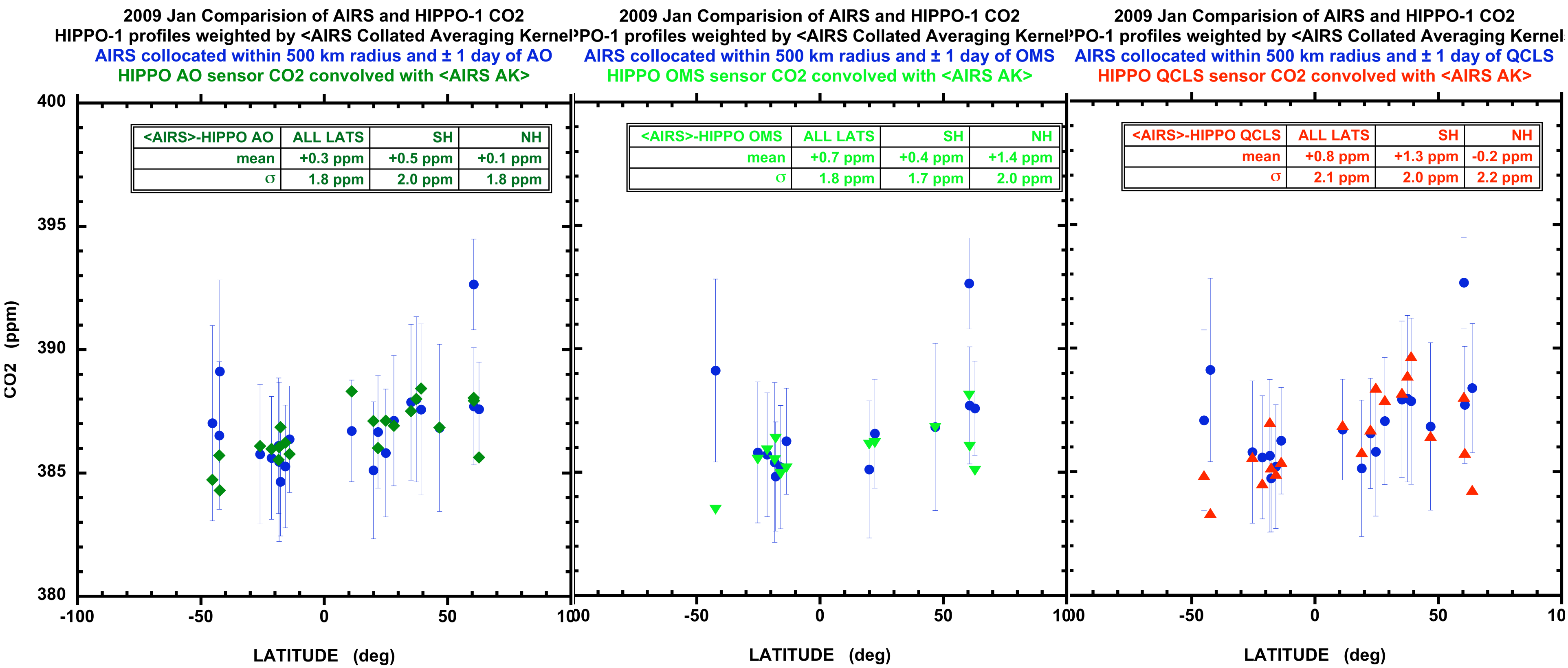
HIPPO profiles are critical for assessing biases and random errors in satellite GHG estimates

Consequently, the HIPPO data increase the information content of the satellite retrievals and the flux/emission estimates using these data

Can we coordinate satellite observations with the next HIPPO flights?

- Reduces comparison uncertainties resulting from sampling
- Provides additional information (temperature and water vapor) that strongly affects satellite GHG estimates
- Increases the science return (especially in outflow and source regions) of both HIPPO and satellite data

Comparison of 'Collocated' AIRS CO_2 Retrievals with January 2009 HIPPO Data for profiles ranging from near surface to p < 200 hPa



HIPPO CO_2 vertical profile profile data column averaged with average of collocated AIRS Averaging Kernels

HIPPO CO2 vertical profile data courtesy of Steven C. Wofsy

M. Chahine et. al. (JPL)