



Characterization of Tropospheric Emission Spectrometer (TES) CO₂ for carbon cycle science

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team



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Kevin Bowman – ASSFTS 14



Talk overview

Factors that affect CO₂ source and sink estimates

TES CO₂ results and characterization

OSSE to estimate TES CO₂ impact on source and sink estimates

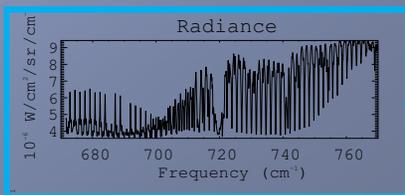
Conclusions



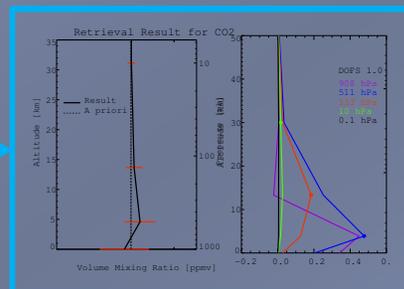


Quality of CO₂ source/sink estimates depends on:

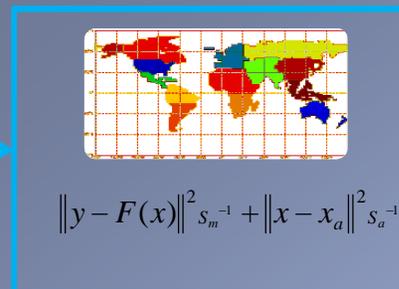
- instrument characteristics
- radiative transfer algorithm
- retrieval algorithms
- assimilation method
- chemistry and transport model
- atmospheric conditions (affects retrieval sensitivity)



radiances



radiative transfer
retrieval algorithms



assimilation and
modeling scheme

Region	Biosph Tg c/yr	Combust Tg c/yr
USA-48	205	5220
Alaska	160	75
Russia	-1220	1800

source / sink
estimates





Instrument characteristics

- AIRS, IASI, GOSAT, and TES instruments at mid-infrared (700 cm^{-1}):

	Native resolution	S/N @ native	S/N @ 0.5 cm^{-1}
AIRS	0.5 cm^{-1}	~ 525	$\sim 525^*$
IASI	0.5 cm^{-1}	~ 225	$\sim 225^{**}$
GOSAT	0.2 cm^{-1}	$> 300^{***}$	> 475
TES	0.1 cm^{-1}	~ 80	$\sim 200^{****}$

* <http://airs.jpl.nasa.gov/technology/specifications/> with 0.35K @ 250K; 9 footprint ave

** Crevoisier et al., 2009 0.22K error at 700 cm^{-1}

*** http://www.jaxa.jp/press/2009/02/20090209_ibuki_e.html, infrared band average

**** Shephard et al., 2008 table 2, with 0.3K @ 250K at AIRS resolution





Retrieval approach

- Based on the optimal estimation framework (Rodgers, 2000), temperature, H₂O, CO₂, cloud and surface parameters are jointly retrieved

$$C(\mathbf{x}) = \|\mathbf{y} - \mathbf{F}(\mathbf{x})\|_{\mathbf{S}_n}^2 + \|\mathbf{x} - \mathbf{x}_a\|_{\mathbf{S}_a}^2$$

- Optimal estimation framework provides a characterization of CO₂ estimates in terms of the accuracy, precision (Bowman, 2006; Worden, 2004):

$$\hat{\mathbf{x}}^j = \mathbf{x}_a^j + \mathbf{A}_{jj}(\mathbf{x}^j - \mathbf{x}_a^j) + \sum_{i=1, \neq j} \mathbf{A}_{ij}(\mathbf{x}^i - \mathbf{x}_a^i) + \textit{error terms}$$

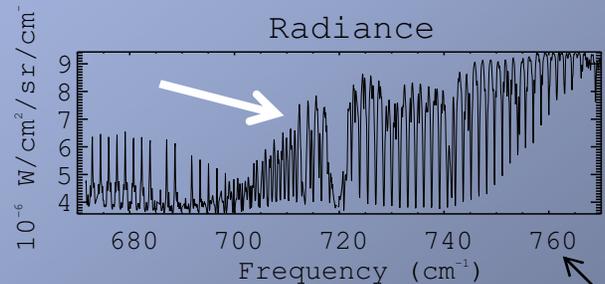
- Joint temperature, H₂O, CO₂ retrievals
 - Minimizes temperature, water bias
- Choice of windows
 - Choose broad set of windows in ν_2 and laser bands
 - Remove spectral areas that are not well fit
- Constraints based on altitude-dependent Tikhonov (Kulawik et al. 2006)
 - Use 6% variability near surface and 2% higher



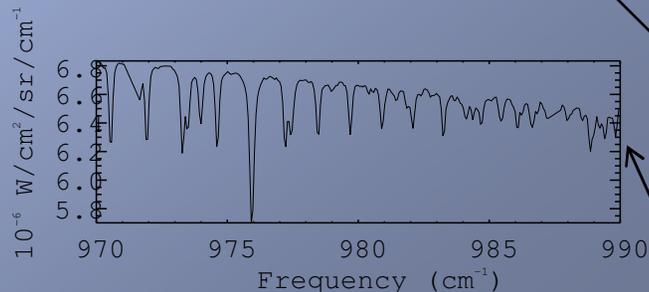
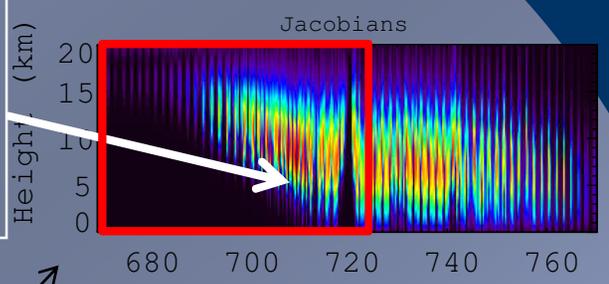
Information at infrared wavelengths



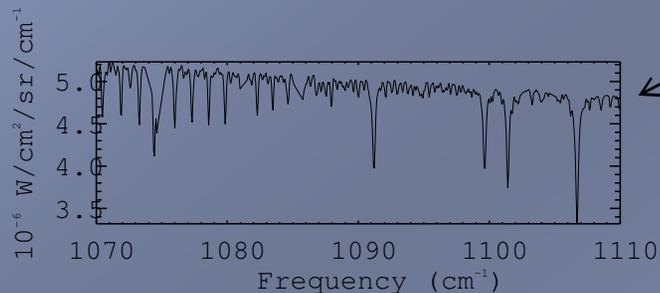
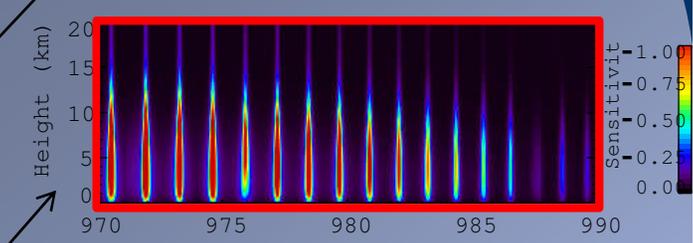
radiances and Jacobians



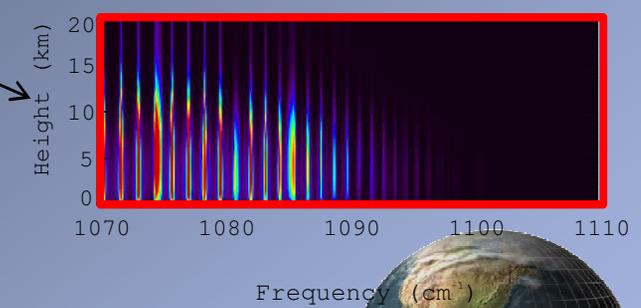
Jacobians show the sensitivity of radiances to changes in CO₂. This location shows the change in radiance at 715 cm⁻¹ when CO₂ at 5 km is changed



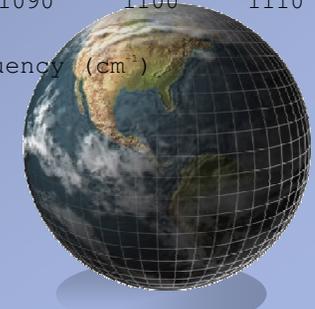
ν_2 band is mainly sensitive to CO₂ in the middle Troposphere through the lower Stratosphere



Laser bands are sensitive to middle Troposphere and below



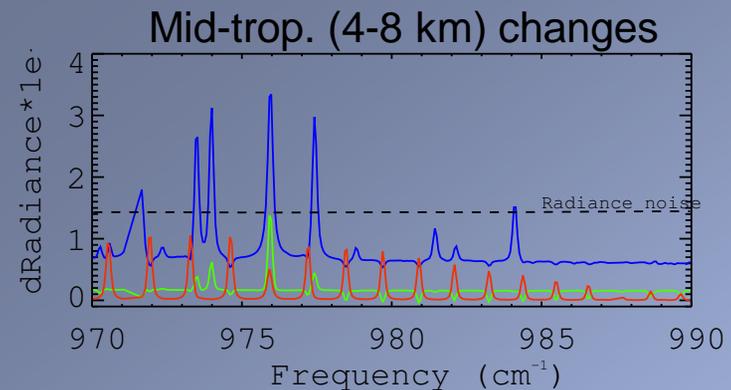
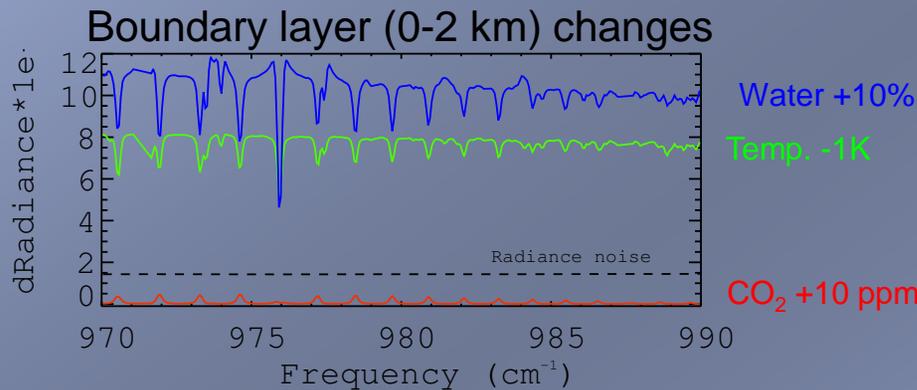
$$\text{Jacobian}[v,z] = d(\text{Radiance}[v]) / d\ln(\text{CO}_2[z]) / \text{radiance_noise}[v]$$





Errors in CO₂ estimates strongly depend on the accuracy of temperature and water vapor

Change in TES calculated radiance when boundary layer values (0-2 km) or mid-Troposphere (4-8 km) are changed for optimal boundary layer viewing conditions (e.g. high thermal contrast):



We find that 1K temperature bias propagates into a 25 ppm CO₂ bias

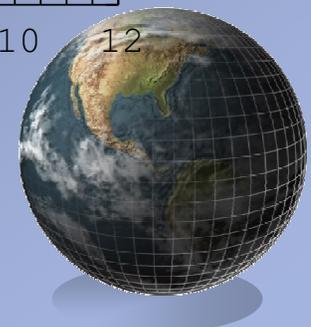
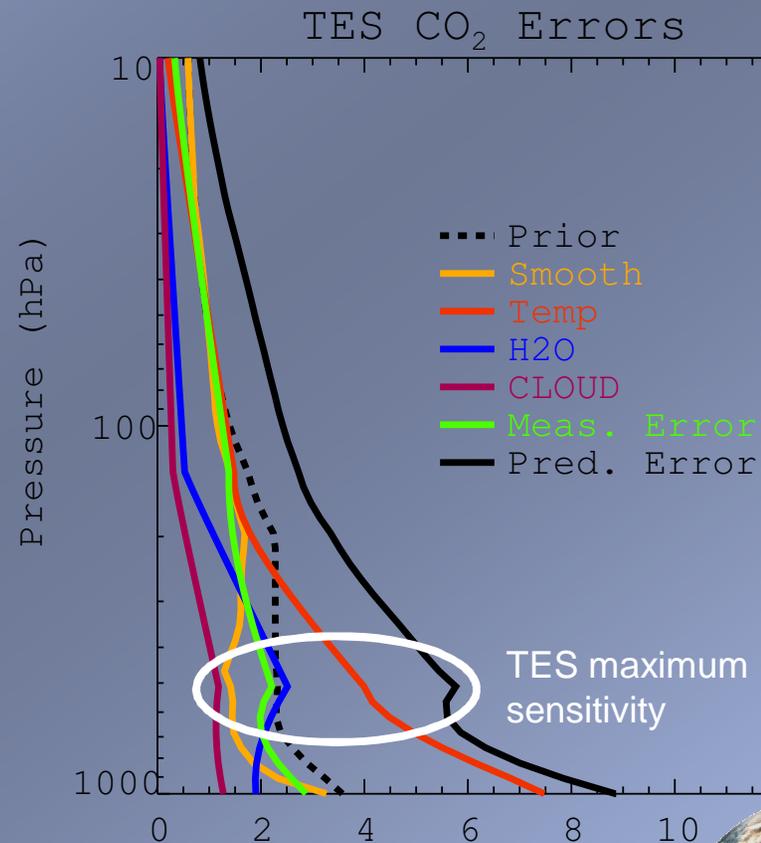




Typical TES single target errors

- Estimated TES single target error in the middle troposphere is ~8 ppm.
- Uncertainties in temperature and retrieval sensitivity (smoothing) are the dominant errors for CO₂ estimates using the IR bands

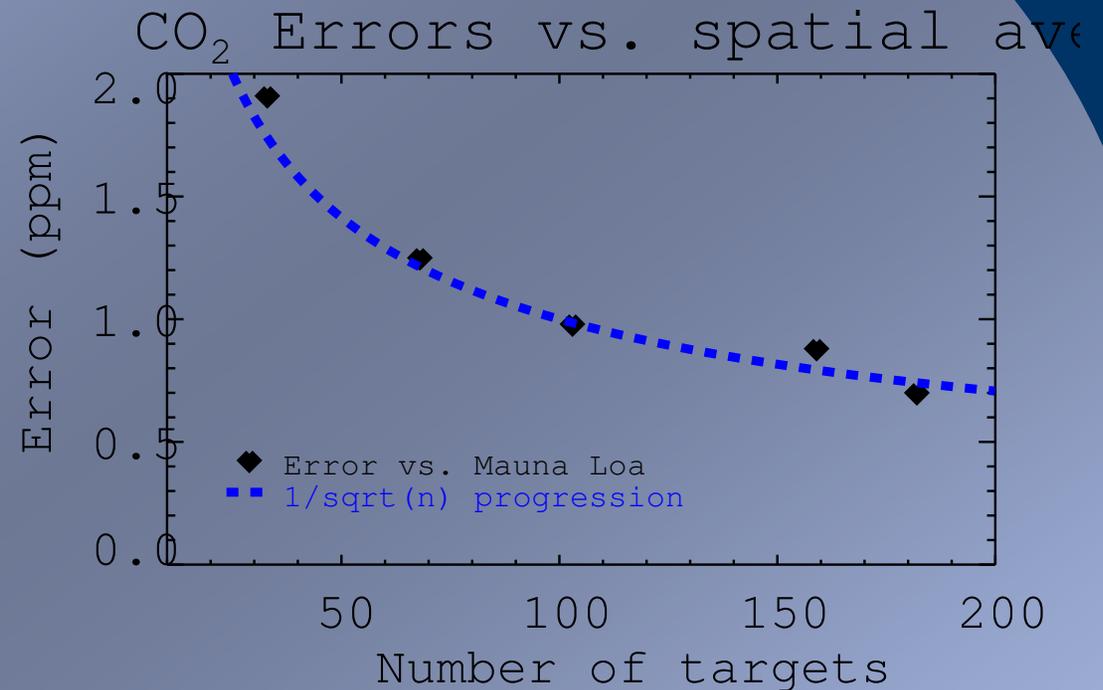
$$S_{total} = S_{smooth} + S_{meas} + S_{cross-state}$$





Averaging targets

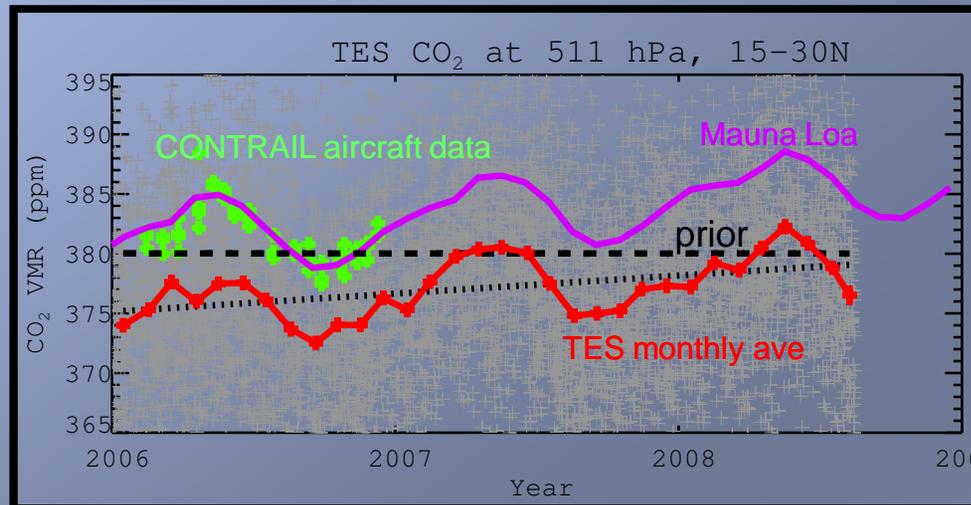
- Averaging more targets (over a larger spatial area) decreases error vs. Mauna Loa
- Progression agrees with $1/\sqrt{N}$ reduction in error for averages



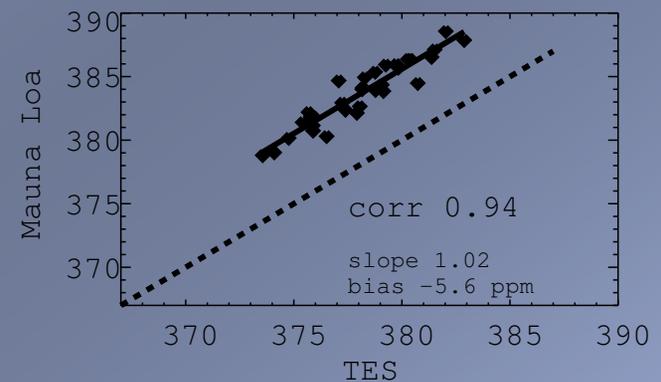
Tropospheric Emission Spectrometer CO₂



Observed yearly and seasonal variations are consistent with in situ data



Highly correlated with Mauna Loa CO₂



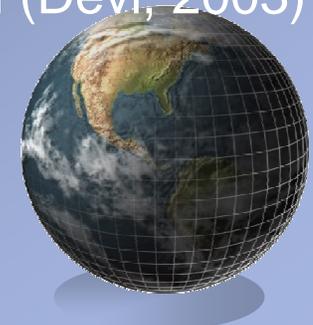
Monthly averages of ~200 targets

Monthly mean error is 0.9 ppm with 5.6 ppm bias

Bias close to estimated spectroscopic error of ~4 ppm (Devi, 2003)

Greatest sensitivity in middle Troposphere (500 mb)

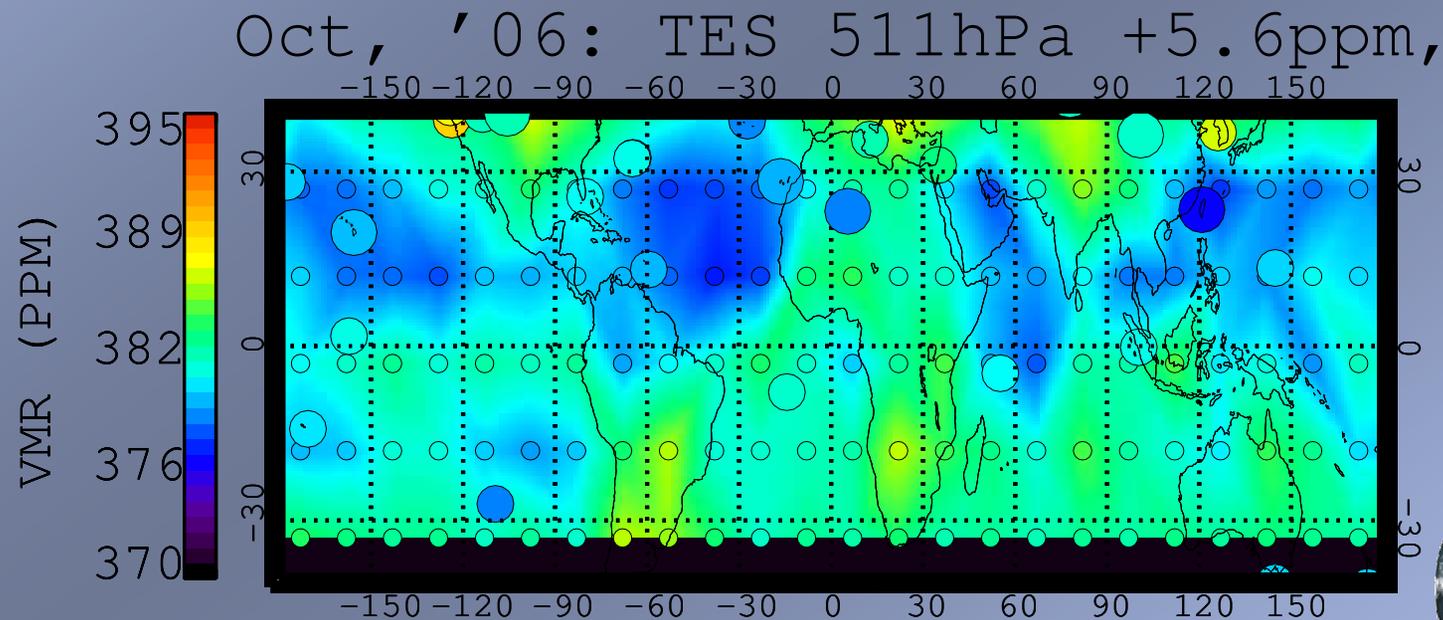
Validated for low O.D. cloud, ocean, 40S to 40N





Global (40S-40N) TES results

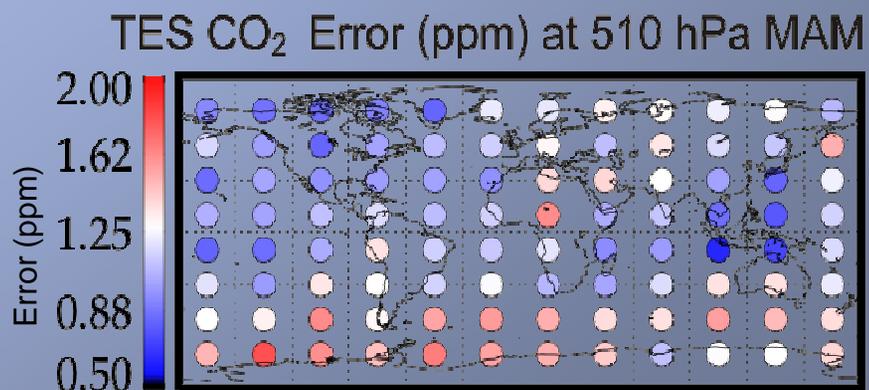
- Comparison of monthly mean TES gridded values (small circles and interpolated values at 511 hPa) and ground station data (large circles)
- A low bias correction of 5.6 ppm is added to TES CO₂





Approach for estimating CO₂ sources & sinks

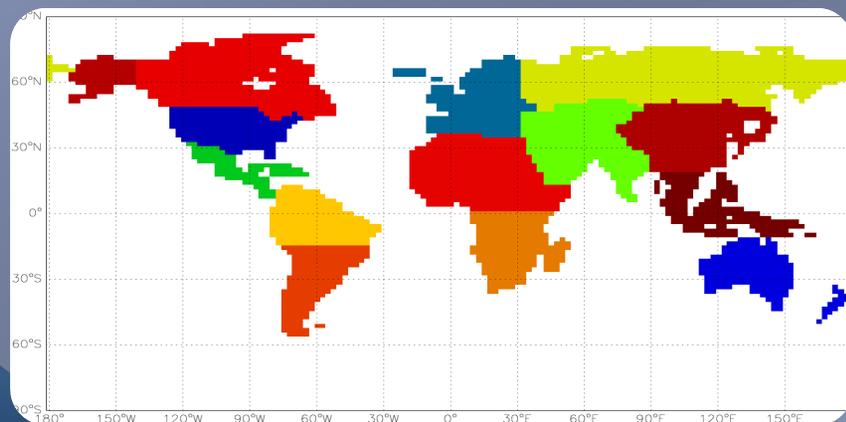
Observing System Simulation Experiment (OSSE) by Nassar et al., 2009



TES: 20 x 30 degree x 1 month averages
Errors are driven by number of clear sky profiles per bin

GLOBALVIEW: 76 surface stations

MODEL: GEOS-Chem with NASA GMAO met. fields, specialized CO₂ source/sink inputs



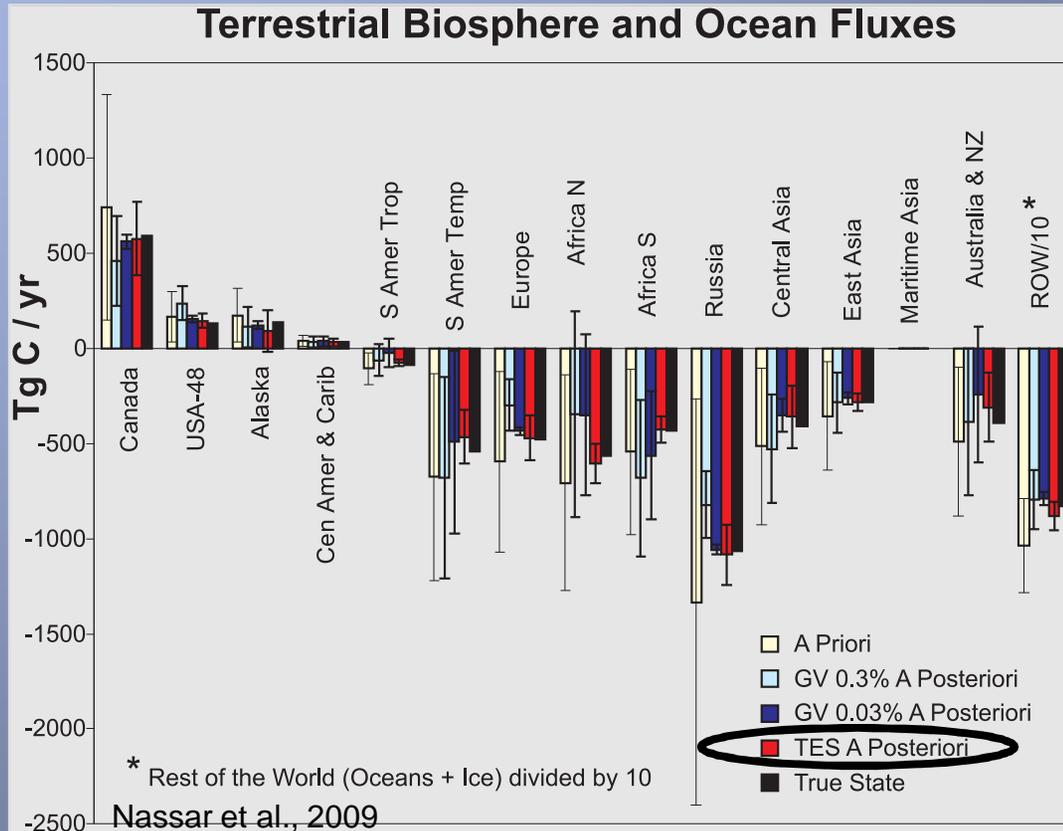
FLUXES

- 14 regions of combustion and terrestrial exchange + “rest of world” (29 elements)
- A priori flux uncertainty:
 - 100% for terrestrial biosphere
 - 30% for combustion





Estimates of biosphere & ocean fluxes



TES alone:

improves flux uncertainty from 100% initial uncertainty to 15-30%

76 surface stations alone (with 0.1 ppm errors assumed):

improves flux uncertainty from 100% initial uncertainty to 15-30%

Based on this analysis, the information content of TES is comparable to surface sites

TES (free troposphere) and surface station (boundary layer) sensitivities are complementary





Conclusions

TES observed yearly and seasonal variations are consistent with in situ data

TES CO₂ with error characterization can be used to improve estimates of CO₂ sources and sinks

Next steps

Using real TES data for source and sink estimates

Examine the use of other sensors for measuring CO₂ profiles to improve source and sink estimates

Validation versus aircraft data over land in progress





Acknowledgements

Work at JPL was carried out under contract to NASA with funds from ROSES 2007. Work by Nassar et al. funded by Natural Sciences and Engineering Research Council (NSERC) of Canada. We acknowledge use of GLOBALVIEW-CO₂ and Mauna Loa from NOAA-ESRL and CONTRAIL data from [World Data Centre for Greenhouse Gases \(WDCGG\)](#).

Thanks to H. Worden for S/N calculation help

References

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Shephard, M. W., H. M. Worden, et al. (2008). "Tropospheric Emission Spectrometer nadir spectral radiance comparisons." *J. Geophys. Res.* **113**.

U.S. Department of Commerce | National Oceanic and Atmospheric Administration Earth System Research Laboratory | Global Monitoring Division <http://www.esrl.noaa.gov/gmd/dv/site/SMO.html>



Backup

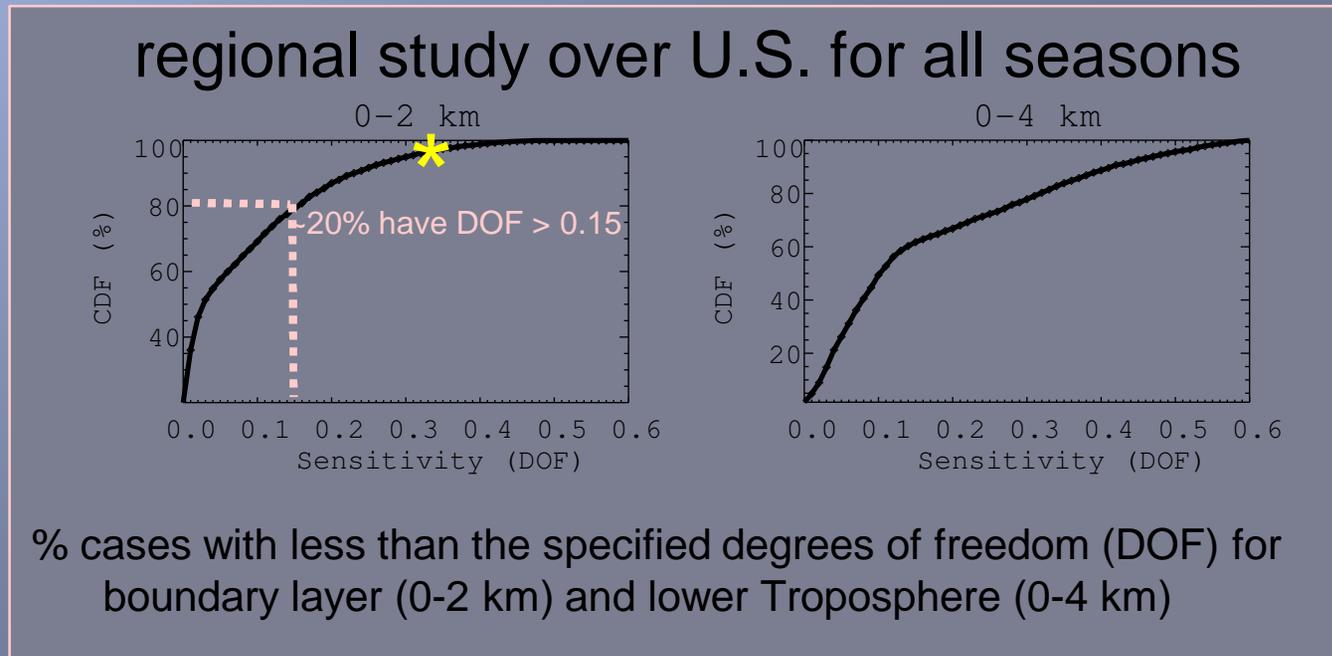


S. Kulawik – March, 2009

Increased sensitivity to boundary layer CO₂ → improved CO₂ source/sink estimates

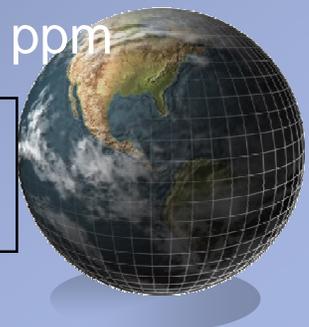


- how often does TES observe CO₂ in the boundary layer?



- highest sensitivity for daytime, summer; ~5% with better than 0.3 DOF
- 0.3 DOF: for a 20 ppm enhancement, TES would observe +6 ppm

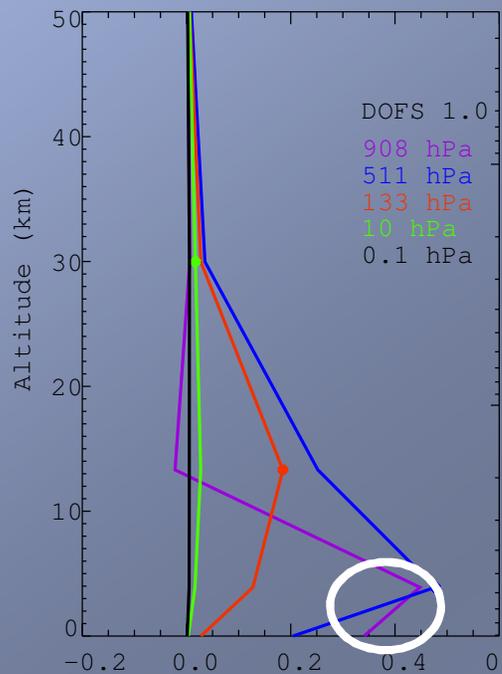
DOF = Trace(\mathbf{A}), where \mathbf{A} , the averaging kernel, is the sensitivity of the retrieved state to the true state, $\mathbf{A} = d\mathbf{x}_{\text{ret}}/d\mathbf{x}_{\text{true}}$



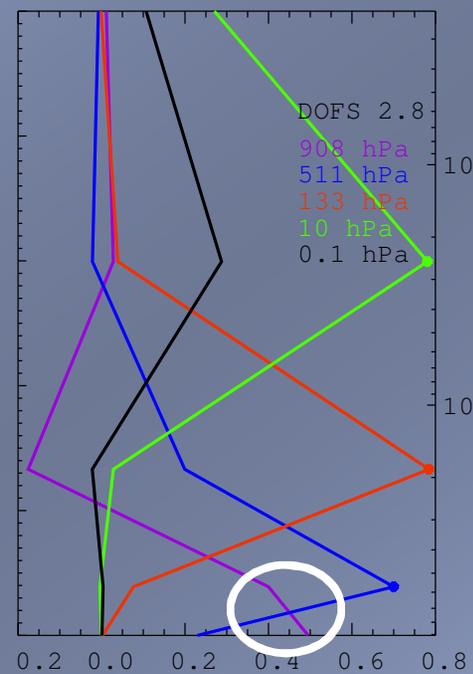


Boundary layer sensitivity

Summertime land case (* on previous page)



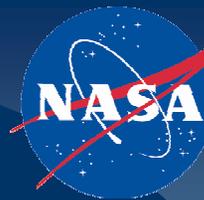
TES



improvements

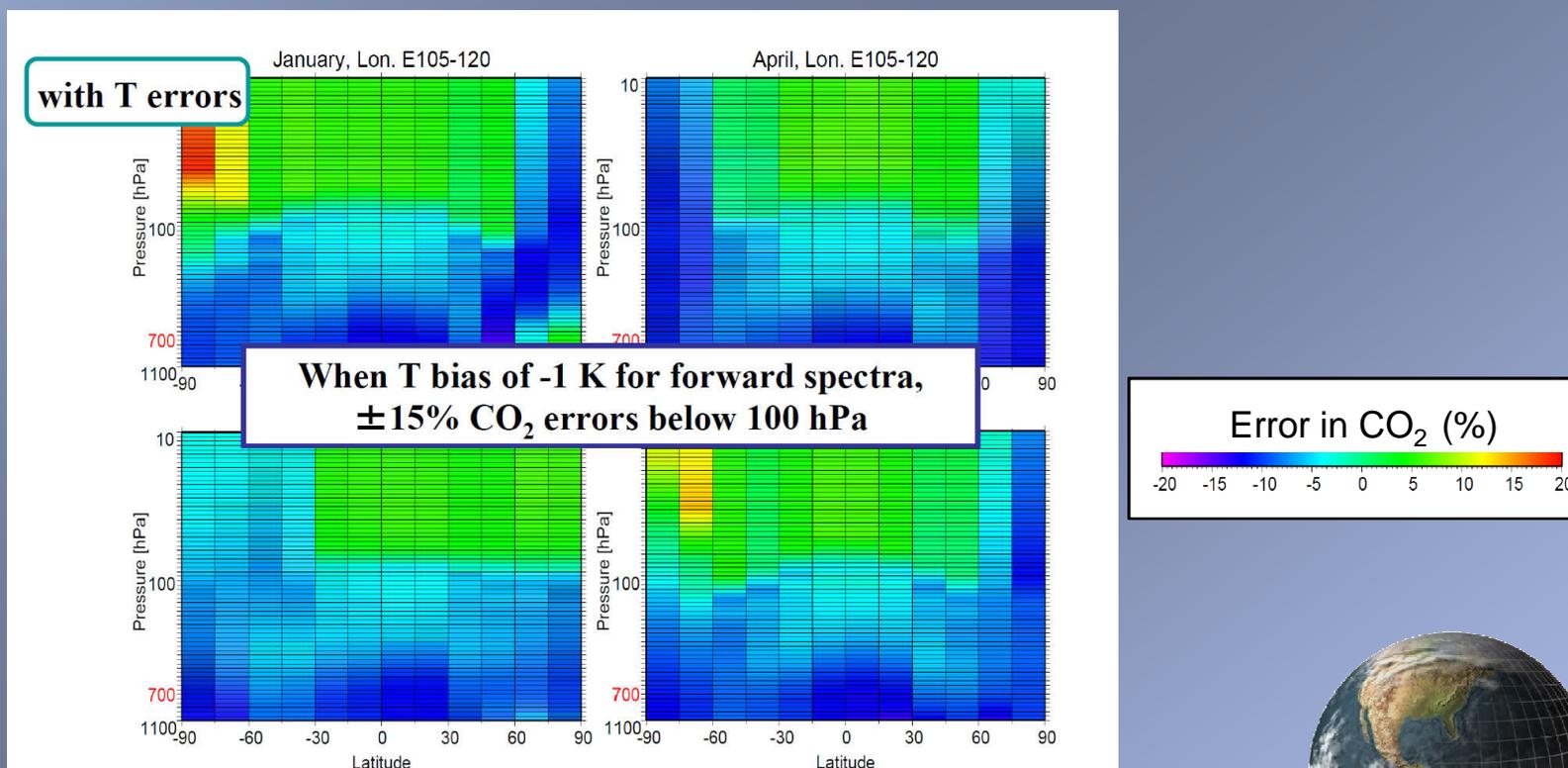
- TES IR measurements (left) can be sensitive to the boundary layer but cannot distinguish the boundary layer from the free troposphere
- For 3x increased signal to noise and independently obtained temperature, boundary layer CO₂ can be discriminated from the free trop. in some cases





GOSAT temperature study

- Uncertainty in temperature propagates into CO₂
- 1K bias error → up to 60 ppm errors in CO₂
- Simulation study



http://www.gosat.nies.go.jp/eng/proposal/download/WS/05_lmasu.pdf

Kevin Bowman – ASSFTS 14

