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CO_2 Vertical Profile Constraints from OCO and Thermal IR Measurements

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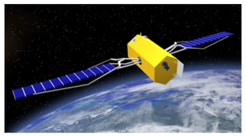
Abstract

Understanding changes in the concentrations, global sources and sinks, dynamics and other processes that control the variability of atmospheric carbon dioxide (CO_2) has emerged as one of the principal challenges of 21st century Earth system science. Satellite observations of atmospheric CO_2 are poised to revolutionize our understanding of global carbon cycle science by providing unprecedented spatiotemporal resolution and coverage. Major advances are expected with the launch of the Orbiting Carbon Observatory (OCO) in 2009.

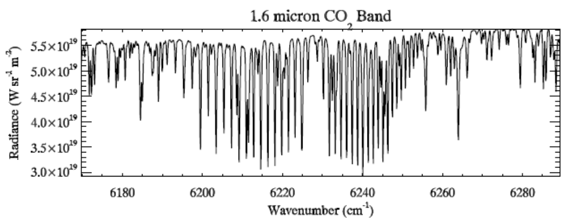
Here, we carry out an information content analysis for simultaneous retrieval of near IR (NIR) OCO and thermal IR data (e.g. TES and AIRS). Since thermal IR measurements are sensitive to changes in the middle and upper troposphere but CO2 sources and sinks in the lower troposphere are more detectable using NIR measurements, the simultaneous retrieval from AIRS or TES and OCO would provide complementary information on the CO_2 vertical profile. Preliminary results show a considerable increase in the information content and degrees of freedom in the combined retrieval compared to retrieval using only OCO or only TES or AIRS data. Combined retrievals from infrared and OCO data will significantly improve the estimation of atmospheric carbon sources and sinks by providing observational constraints on vertical as well as horizontal and temporal distributions of atmospheric CO_2 in data assimilation and data fusion approaches.

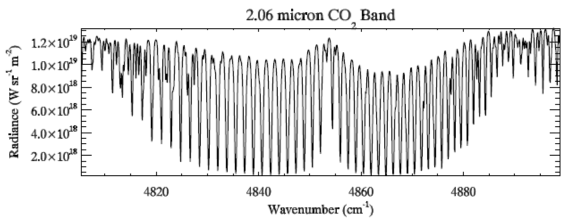
Orbiting Carbon Observatory (OCO)



OCO will for the first time provide global, space-based observations with high spatial resolution and high accuracy to identify CO_2 sources and sinks and quantify their variability over the seasonal cycle (Crisp, et al., 2004). The measurement of CO_2 from space has dramatically improved spatiotemporal coverage. OCO will measure reflected sunlight in three near-infrared spectral regions (the 0.76 µm O_2 A-band and in the CO_2 bands at 1.61 and 2.06µm).

OCO
- NIR solar radiation reflected from the surface
- Peak near the surface

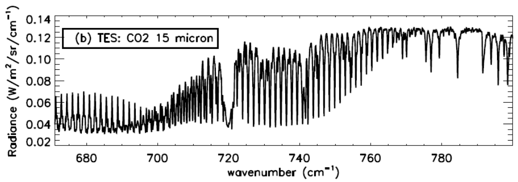




Tropospheric Emission Spectrometer (TES)

TES, launched aboard the Aura spacecraft in 2004, is a Fourier Transform spectrometer measuring infrared spectral radiances from 3.2 to 15.4 microns.
TES observes thermally active atmospheric or surface quantity. TES data routinely provides vertical profiles of the following: Ozone, Carbon monoxide, Temperature, Water vapor, HDO, and Methane.

TES
- Thermal infrared emission
- Peak in the middle & upper troposphere



Definition of information content (H) and degree of freedom (d_s)

$$\mathbf{I_n} - \mathbf{A} = (\mathbf{K}^T \mathbf{S}_\varepsilon^{-1} \mathbf{K} + \mathbf{S}_a^{-1}) \mathbf{S}_a^{-1} = \hat{\mathbf{S}} \mathbf{S}_a^{-1}$$

$$H = \frac{1}{2} \sum_i \ln(1+\lambda_i^2) = -\frac{1}{2} \ln|\mathbf{I_n} - \mathbf{A}|$$

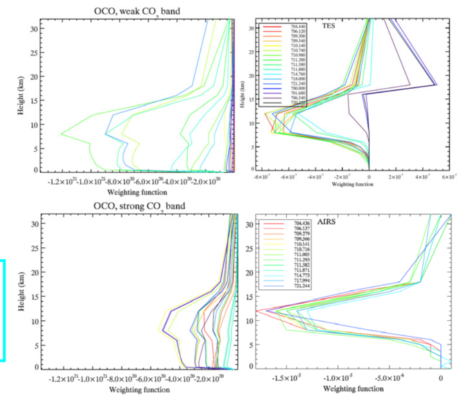
$$d_s = \sum_i \lambda_i^2/(1+\lambda_i^2) = tr(\mathbf{A})$$

$$\tilde{\mathbf{K}} = \mathbf{S}_\varepsilon^{-\frac{1}{2}} \mathbf{K} \mathbf{S}_a^{\frac{1}{2}}$$

$\mathbf{S}_a$: the a priori covariance matrix;
$\mathbf{S}_\varepsilon$: the measurement error covariance matrix;
$\mathbf{K}$: the Jacobian; $\mathbf{A}$: the averaging kernel;
λ_i : the eigenvalues of $\tilde{\mathbf{K}}$

Information Content Analysis

The OCO retrieval has high sensitivity to the lower troposphere. However, both TES and AIRS measure in the thermal IR. The peaks of their weighting functions are located in the middle and upper troposphere. The difference is that TES also includes stratospheric channels, whereas these channels were excluded in the AIRS retrieval."



Test of the covariance matrix

$$Sa_{ij} = Sa_{ii} e^{-|z_i - z_j|/z_h}$$

z_h=Scale Height

AIRS

Sa	H	d_s
Diagonal matrix	1.135	0.866
Scale Height=4 km	1.411	0.988
Scale Height=8 km	1.476	1.002
Scale Height=12 km	1.499	1.005

z_h=8 km →

OCO weak CO_2 band

Aerosol OD	Cloud OD	H	d_s
Low	Low	4.29	1.22
High	Low	5.67	1.52
Low	High	3.31	1.10
High	High	3.82	1.13

OCO strong CO_2 band

Aerosol OD	Cloud OD	H	d_s
Low	Low	5.86	1.51
High	Low	7.20	1.94
Low	High	5.17	1.47
High	High	5.37	1.38

OCO weak CO_2 + strong CO_2 band

Aerosol OD	Cloud OD	H	d_s
Low	Low	6.42	1.76
High	Low	8.01	2.16
Low	High	5.49	1.64
High	High	5.79	1.61

Simultaneous retrieval

		H	d_s
OCO (Clear sky)	wco2	4.29	1.22
	sco2	5.86	1.51
	wco2+sco2	6.42	1.76
TES		4.71	2.56
AIRS		1.48	1.00
TES & OCO		9.21	3.32
OCO & AIRS		7.24	2.26
TES & AIRS		4.95	2.64

- The correlation between the levels in the covariance matrix increases the degrees of freedom.
- OCO does well in clear sky and in the presence of clouds.
- Strong CO_2 band has more degrees of freedom than weak CO_2 band. However, the information from the two bands comes from different vertical levels.
- The anomalous increase in H and d_s for the high aerosol (Optical Depth) OD – low cloud OD is due to of backscatter from aerosol (which increase the signal to noise ratio), as indicated by the much larger surface Jacobian compared to the clear sky scenario.
- Using both CO_2 bands to do the retrieval provides more information content.
- TES has more degrees of freedom due to the choice of stratospheric channels, whereas these channels were excluded in the AIRS retrieval.
- Simultaneous retrieval of TES/AIRS and OCO would provide complementary information on the CO_2 vertical profile.

Conclusions

Information content analysis shows the benefit of the combined retrieval of OCO and TES/AIRS measurements. There is considerable increase in the information content and degrees of freedom in the combined retrieval compared to retrieval using only OCO or only TES data.

Future work

- Simultaneous retrievals of OCO and TES (and AIRS)
- Understand the eigenfunctions
- The continuous form of the weight function