Opportunities for Coordinated Observations of CO₂ with the Orbiting Carbon Observatory (OCO) and Greenhouse Gases Observing Satellite (GOSAT)

By David CRISP¹⁾ and the OCO Team

¹⁾ Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, U.S.A.

(Received April 17th, 2008)

The Orbiting Carbon Observatory (OCO) and the Greenhouse Gases Observing Satellite (GOSAT) are the first two satellites designed to make global measurements of atmospheric carbon dioxide (CO₂) with the precision and sampling needed identify and monitor surface sources and sinks of this important greenhouse gas. Because the operational phases of the OCO and GOSAT missions overlap in time, there are numerous opportunities for comparing and combining the data from these two satellites to improve our understanding of the natural processes and human activities that control the atmospheric CO₂ and its variability over time. Opportunities for cross-calibration, cross-validation, and coordinated observations that are currently under consideration are summarized here.

Key Words: Carbon Dioxide, Climate, Remote Sensing

Nomenclature

CO ₂ :	Carbon dioxide gas
ESRL	Earth Science Research Laboratory
FTS	Fourier Transform Spectrometer
GOSAT	Greenhouse Gases Observing Satellite Instantaneous Field of View
JPL	Jet Propulsion Laboratory, California Institute of Technology
NASA	U.S. National Aeronautics and Space Administration
NOAA	U.S. National Oceanic and Atmospheric Administration
OCO	Orbiting Carbon Observatory
TCCON	Total Carbon Column Observing Network
WMO	World Meteorological Organization
X_{CO_2}	Column averaged CO ₂ dry air mole fraction
λ	Wavelength of light (color)
$\Delta\lambda$	Minimum resolvable difference in wavelength

1. Introduction

The Orbiting Carbon Observatory (OCO) is currently under development at the Jet Propulsion Laboratory (JPL), in preparation for a launch early in 2009¹⁾. Like the Greenhouse Gas Observing Satellite²⁾ (GOSAT), this NASA Earth System Science Pathfinder mission will make global, space-based measurements of the column-averaged atmospheric carbon dioxide (CO₂) dry air mole fraction, X_{CO_2} . This is a particularly challenging space-based measurement because the surface sources and sinks of CO₂ must be inferred from subtle spatial and temporal variations in X_{CO_2} . Modeling studies predict that

X_{CO_2} variations will rarely exceed 8 parts per million by volume (ppm), or about 2% of the ambient ~385 ppm background on regional scales.³⁾ Validation of these space-based measurements will also be a challenge because few measurement systems can sample the entire atmospheric CO₂ column in the same way as these spacecraft. Fortunately, the operational phases of the OCO and GOSAT missions overlap, providing numerous opportunities for cross-calibrating and cross-validating the data from these two satellites. This paper summarizes those opportunities.

2. OCO Measurement Approach

OCO consists of a dedicated 3-axis stabilized spacecraft bus that carries a 3-channel, imaging grating spectrometer designed to make coincident measurements of reflected sunlight in near-infrared CO₂ and molecular oxygen (O₂) bands. High spectral resolution ($\lambda/\Delta\lambda > 24,000$) measurements of the CO₂ bands near 1.61 and 2.06 μm yield CO₂ column abundance estimates that are most sensitive CO₂ variations near the surface, where most sources and sinks are located. High resolution ($\lambda/\Delta\lambda > 21,000$) measurements within the 0.765- μm O₂ A-band constrain the total atmospheric mass and provide cloud and aerosol profiles to reduce pathlength uncertainties associated with multiple scattering.

Each spectrometer collects 12 measurements per second while the spacecraft is over the sunlit hemisphere of the Earth, yielding contiguous measurements with a small measurement footprint ($< 3 \text{ km}^2$ at nadir). Coincident measurements of the CO₂ and O₂ spectra are analyzed to retrieve spatial variations in X_{CO_2} . Each spectrometer channel also returns 4 to 20 “colors” at 20 times the nominal spatial resolution to facilitate the detection of clouds and aerosols.

3. Comparisons of GOSAT and OCO Measurement Approaches

The primary features of the GOSAT and OCO missions are compared in Table 1. GOSAT retrieves X_{CO_2} from the same CO_2 and O_2 absorption bands used by OCO, but uses a high resolution Fourier transform spectrometer (TANSO-FTS) rather than a grating spectrometer to make its measurements. An independent Cloud and Aerosol Imager (TANSO-CAI) is used to identify cloudy scenes²⁾. The grating and FTS techniques both offer unique advantages for this application. For example, TANSO-FTS provides greater spectral coverage and slightly higher spectral resolution, while the OCO instrument provides greater spatial resolution and slightly higher signal-to-ratios in each sounding. Comparisons of X_{CO_2} retrievals from these two measurement techniques could help to identify and correct subtle measurement biases that might otherwise be missed.

Table 1: Mission Comparison

	GOSAT	OCO
Gases Measured	CO_2 , CH_4 , O_2 , O_3 , H_2O	CO_2 , O_2
Instruments	SWIR/TIR FTS, CAI	Grating Spectrometer
IFOV / Swath (km)	FTS: 10.5 / 80-800 CAI: 0.5 / 1000	1.29 x 2.25 / 5.2
Sampling Time (sec)	1.1, 2, and 4	0.333
Spectral Ranges (μm)	0.758-0.775, 1.56-1.72, 1.92-2.08, 5.56-14.3	0.757-0.772, 1.59-1.62, 2.04-2.08
Observatory Mass	1750 kg	441 kg
Power	3800 Watts	887 Watts
Orbit Altitude	666 km	705 km
Local Time	13:00 $\pm$ 0:15	13:30 $\pm$ 0:1.5
Revisit Time	3 Days	16 Days
Launch Vehicle	H-IIA	Taurus 3110
Launch Date	January 2009	January 2009
Nominal Life	5 Years	2 Years

4. Opportunities for Coordinated Observations

Combining the OCO and GOSAT datasets would benefit the carbon cycle science community by increasing the spatial coverage and decreasing the interval between observations by either satellite, alone. To combine these datasets without introducing biases, the OCO and GOSAT measurements must be validated a common measurement standard. Fortunately, the OCO and GOSAT mission plans are quite synergistic, providing numerous opportunities for cross validation.

OCO will fly in a 98.8 minute, 705 km altitude, sun-synchronous, orbit with a 16-day ground track repeat

cycle, and an ascending nodal crossing time of ~1:26 PM. Soundings are acquired either along the ground track at the local nadir or in the direction of the “glint spot,” where sunlight is reflected specularly from the Earth’s surface. GOSAT will fly in a 666 km altitude sun-synchronous orbit with a 1 PM descending equator crossing time and 3-day ground repeat cycle. TANSO-FTS uses a scanner to acquire discrete soundings over a broad cross-track swath centered on the local nadir or in the direction of the glint spot. The OCO and GOSAT orbits cross many times every day, providing numerous opportunities for comparing coincident observations from these two satellites.

5. Opportunities for Cross Validation

To diagnose and resolve any disagreements between coincident OCO and GOSAT measurements, both satellites can validate their results against a common validation standard. A key element of the OCO validation plan is the Total Carbon Column Observing Network (TCCON), an array of high-resolution, ground-based, solar-looking Fourier Transform Spectrometers (FTS’s). These instruments retrieve X_{CO_2} from measurements of direct sunlight in the same near-infrared CO_2 and O_2 bands used by the OCO and GOSAT flight instruments. Several TCCON stations are co-located with NOAA Earth Science Research Laboratory (ESRL) CO_2 measurement sites, so that they can serve as transfer standards between the spacecraft and the ground-based World Meteorological Organization (WMO) CO_2 standard.

Fig.1. The OCO mission is part of a global CO_2 monitoring network that includes the NOAA ESRL flask and tower networks, aircraft, and the ground-based TCCON FTS’s.

Comparisons of TCCON observations from Park Falls, Wisconsin and Darwin, Australia with in-situ CO_2 measurements from aircraft indicate that these sites can retrieve X_{CO_2} with precisions much better than 1 ppm. Regular observations of TCCON sites would therefore provide an effective method for cross-validating

measurements from the OCO and GOSAT instruments.

6. Opportunities for Cross Calibration

Combining X_{CO_2} data from the OCO and GOSAT missions would be facilitated by cross-calibrating the radiometric performance of their instruments. To exploit this opportunity, the OCO and GOSAT calibration teams have cross-calibrated the radiometric standards used for pre-launch calibration. The first half of the pre-launch cross-calibration experiment was conducted at the NASA Jet Propulsion Laboratory in April of 2008. The second half of the pre-launch cross calibration experiment was performed in December 2008 at the JAXA Tsukuba Space Center. After launch, the OCO and GOSAT calibration teams plan to collect and share ground based and space based measurements over their vicarious calibration sites.

7. Conclusions

Once they are in orbit in early 2009, the OCO and GOSAT spacecraft will make the first global measurements of atmospheric carbon dioxide with the sensitivity and accuracy needed to identify and characterize its surface

sources and sinks on regional scales. To ensure the accuracy of these measurements, and their early acceptance by the science community, the OCO and GOSAT science teams are continuing to work together to explore opportunities to collaborate on the cross-calibration and cross-validation of the data from these two missions.

Acknowledgements

This work was performed by the Jet Propulsion Laboratory of the California Institute of Technology, under contract to the National Aeronautics and Space Administration.

References

- 1) Crisp, D., et al.: The Orbiting Carbon Observatory (OCO) mission, *Adv. Space. Res.* **34** (2004), pp. 700-709.
- 2) Yokota, T.: GOSAT Greenhouse Gases Observing Satellite, *NDACC Newsletter*, **3** (2008), pp. 61-66.
- 3) Miller, C. E., Crisp, D., DeCola, P. L., et al.: Precision requirements for space-based X_{CO_2} data, *J. Geophys. Res.* **112** D10314 (2007) [doi:10.1029/2006JD007659].