MONITORING OCEAN CO_2 FLUXES FROM SPACE: GOSAT AND OCO-2

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1. INTRODUCTION

The ocean is a major component of the global carbon cycle, emitting over 330 billion tons of carbon dioxide (CO_2) into the atmosphere each year, or about 10 times that emitted fossil fuel combustion and all other human activities [1, 2]. The ocean reabsorbs a comparable amount of CO_2 each year, along with ~25% of the CO_2 emitted by these human activities. The nature and geographic distribution of the processes controlling these ocean CO_2 fluxes are still poorly constrained by observations. A better understanding of these processes is essential to predict how this important CO_2 sink may evolve as the climate changes.

While in situ measurements of ocean CO_2 fluxes can be very precise, the sampling density is far too sparse to quantify ocean CO_2 sources and sinks over much of the globe. One way to improve the spatial resolution, coverage, and sampling frequency is to make observations of the column averaged CO_2 dry air mole fraction, X_{CO2}, from space [4, 5, 6]. Such measurements could provide global coverage at high resolution (< 100 km) on monthly time scales. High precision (< 1 part per million, ppm) is essential to resolve the small, near-surface CO_2 variations associated with ocean fluxes and to better constrain the CO_2 transport over the ocean. The Japanese Greenhouse gases Observing Satellite (GOSAT) and the NASA Orbiting Carbon Observatory (OCO) were first two space based sensors designed specifically for this task. GOSAT was successfully launched on January 23, 2009, and has been returning measurements of X_{CO2} since April 2009. The OCO mission was lost in February 2009, when its launch vehicle malfunctioned and failed to reach orbit. In early 2010, NASA authorized a re-flight of OCO, called OCO-2, which is currently under development.

2. SPACE-BASED MEASUREMENTS X_{CO2}

X_{CO2} is defined as the ratio of the "column abundance" of CO_2 (i.e. the altitude-dependent CO_2 number density integrated over the atmospheric column) and the column abundance of dry air. Coincident estimates of the CO_2 and dry air column abundances can be derived from co-bore-sighted measurements of reflected sunlight in near-infrared CO_2 and molecular oxygen (O_2) absorption bands. The CO_2 column abundance can be derived from measurements of absorption lines in the CO_2 bands centered near 1.61 and 2.06 μm. Co-bore-sighted measurements of the absorption by the O_2 A-band near 0.765μm are ideal for defining the total dry air column abundance because the N_2/O_2 ratio is well known and almost constant. Measurements within the O_2 A-band and 2.06 μm CO_2 band also provide information on the vertical distribution and optical properties of clouds and aerosols along the path, reducing uncertainties in the optical path. Retrieving X_{CO2} over the ocean from measurements in these CO_2 and O_2 bands is intrinsically challenging because the ocean reflects little sunlight at these wavelengths. Most of this sunlight is reflected into the specular direction, forming the bright "glint spot." Much higher X_{CO2} sensitivity can therefore be obtained over the ocean by observing the glint spot.

3. GOSAT AND OCO-2 X_{CO2} MEASUREMENTS

Both GOSAT and OCO were designed to collect high resolution spectroscopic observations of the absorption of sunlight by the CO_2 bands near 1.6 and 2.06 μm, and by the 0.765μm O_2 A band. Both satellites were also able to collect glint as well as nadir observations. However, these two pioneering missions used different instrument types and operational strategies, reflecting different measurement priorities. GOSAT was optimized for spectral and spatial coverage. It flies in a 666 km altitude, 98° inclination, sun-synchronous orbit with an equator crossing time near 12:49 PM and a three-day (44-orbit) ground track repeat cycle [7]. It carries the Thermal and Near Infrared Sensor for carbon Observations-Fourier Transform Spectrometer (TANSO-FTS) to measure O_2, CO_2, methane (CH_4), water vapor (H_2O), and ozone (O_3) and the TANSO Cloud and Aerosol Imager (TANSO-CAI) to screen TANSO-FTS soundings with optically thick clouds and aerosols [8]. To retrieve X_{CO2}, the TANSO-FTS records spectra of reflected sunlight in the O_2 A band, the CO_2 bands near 1.57, 1.61, and 2.06 μm. It collects co-bore-sighted spectra with a 4-second integration time within a circular, 0.0157-radian diameter instantaneous field of view (IFOV), yielding 10.5 km diameter footprints at nadir. A 2-axis scan mirror directs the IFOV within ±35° of nadir in the cross-track direction and within ±20° of nadir along the spacecraft ground track. This scanner can target the glint spot over the ocean at latitudes < 20° from the sub-solar latitude. For ocean glint observations, it collects one sounding every ~28 km along the path of the apparent glint spot. For observations over land, and at higher latitudes over the ocean, the scan pattern includes either 3 or 5 cross-track IFOVs. The pointing mirror also provides image motion compensation during the instrument's 4-second integration time.

After the loss of the OCO mission, the GOSAT Project Team invited the OCO science team to collaborate in the analysis of GOSAT observations. NASA reconstituted the OCO science team as the Atmospheric CO_2 Observations from Space (ACOS) team. The ACOS team has helped to conduct annual vicarious calibration campaigns [9], retrieved X_{CO2} from TANSO-FTS spectra, and validated these retrievals against ground based observations of X_{CO2} from the Total Carbon Column Observing Network (TCCON) [10]. Global maps of X_{CO2} for different seasons are shown in Fig. 1. These results have been screened for clouds and optically-thick aerosols, and have passed all of the post-processing filters [10]. Over the ocean, only glint observations have adequate signal-to-noise (SNR) for X_{CO2} retrievals. Because the glint spot can only be viewed within 20° of the sub-solar latitude, the range of latitudes sampled varies seasonally. Comparisons of this X_{CO2} product with TCCON measurements indicate little or no global bias and typical accuracies of ~2 ppm on regional scales. While these results are not yet sufficiently accurate to yield reliable, quantitative estimates of ocean CO_2 fluxes, they should provide a useful constraint on CO_2 transport over the ocean, facilitating improved flux inversions over land.

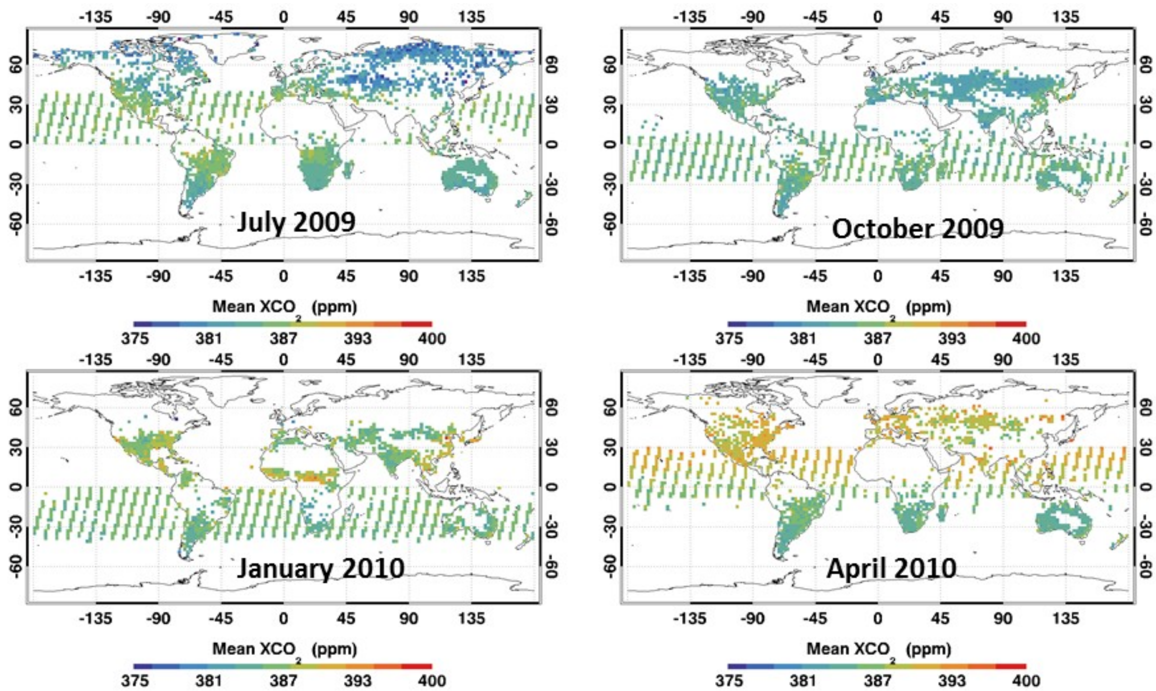

Figure 1: Monthly maps of X_{CO2} retrieved from GOSAT observations by the ACOS team. Each data point shows the average value for a 2° by 2° box for the month.

Once OCO-2 is successfully launched, it data are expected to complement the GOSAT X_{CO2} measurements while providing improvements in coverage, resolution, and sensitivity [5]. OCO-2 will fly in the Earth Observing System Afternoon Constellation (EOS A-Train). This 705 km altitude, sun-synchronous orbit has a 1:30 PM ascending nodal crossing time and a 16-day ground track repeat period. The OCO-2 spacecraft carries and points a single instrument that incorporates 3, co-bore-sighted high-resolution, imaging, grating spectrometers to measure reflected sunlight within the CO_2 bands centered near 1.61 and 2.06 μm, and within the 0.764 μm O_2 A-band. Each spectrometer collects 3 samples per second in 4 to 8 footprints along its narrow (0.8°) slit. This sampling rate yields > 200 soundings per degree of latitude or > 500,000 soundings each day over the sunlit hemisphere. The relatively small sounding footprints (< 1.29 km by 2.25 km at nadir) provide high spatial resolution along the measurement track. In addition, with this small footprint, 20 to 30% of these footprints should be sufficiently cloud free to retrieve full-column estimates of X_{CO2}. To obtain high signal-to-noise (SNR) data over both continents and the ocean, OCO-2 can view either the local nadir or the glint spot over the full range of latitudes on the sunlit hemisphere. This capability, combined with the instrument intrinsically higher sensitivity over dark, ocean and ice-covered surfaces and larger sampling rate should yield much better coverage of the ocean than GOSAT. OCO-2 will collect nadir and glint observations over the globe on alternate 16-day ground track repeat cycles to optimize the sampling over both continents and ocean at monthly intervals.

11. CONCLUSIONS

GOSAT and OCO-2 are the first satellites designed to measure atmospheric CO_2 from space with the precision needed to quantify CO_2 fluxes on regional scales over the seasonal cycle. GOSAT is currently returning a high quality global dataset that is providing valuable insight into the X_{CO2} retrieval process. If all goes as planned, OCO-2 will be launched by 2015, in time to complement and extend this space based CO_2 measurement record.

11. ACKNOWLEDGEMENTS

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11. REFERENCES

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