The Orbiting Carbon Observatory (OCO):

Watching the Earth Breathe—Mapping Carbon Dioxide from Space

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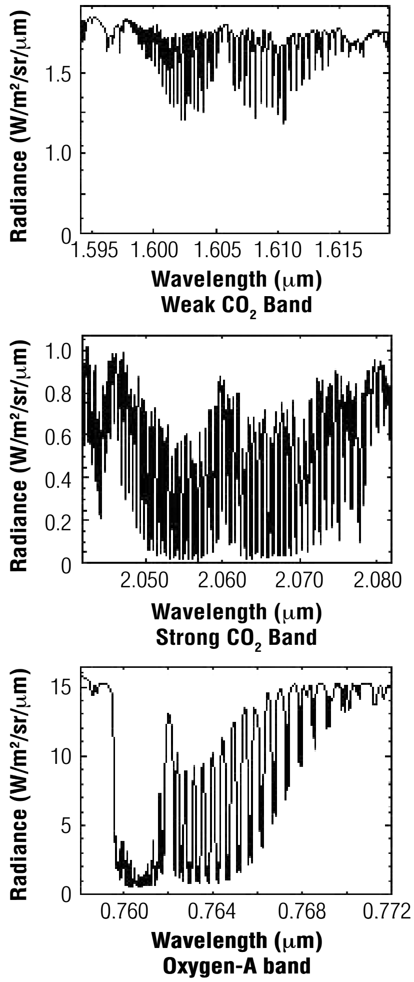
Background on Carbon Dioxide and OCO

Carbon dioxide (CO_2) is the principal man-made greenhouse gas and the primary atmospheric component of the global carbon cycle. Precise ground-based measurements of CO_2 made since the late 1950s indicate that the atmospheric CO_2 concentration has increased from ~310 to over 380 parts per million (ppm) over this period [*1*]. Interestingly, comparisons of these data with CO_2 emission rates from fossil fuel combustion, biomass burning, and other human activities indicate that only about half of the CO_2 that has been emitted into the atmosphere during this period has remained there. Surface *sinks* in the land biosphere or oceans have apparently absorbed the remaining amount [*1, 2, 3*]. These measurements also show that despite the steady long-term growth in the CO_2 abundance, the atmospheric CO_2 buildup varies dramatically from year to year in response to smoothly increasing emission rates. The ground-based CO_2 monitoring network does not have the spatial resolution, coverage, or sampling rates needed to identify the natural sinks responsible for absorbing this CO_2 or the processes that control how their efficiency changes from year to year.

NASA's Orbiting Carbon Observatory (OCO)—spacecraft drawing shown left—is an Earth System Science Pathfinder (ESSP) mission that is currently being developed to address these issues [*4*]. OCO will make space-based measurements of atmospheric CO_2 with the precision, resolution, and coverage needed to characterize the geographic distribution of CO_2 sources and sinks and quantify their variability over the seasonal cycle. The Observatory is scheduled for a January 2009 launch from Vandenberg Air Force Base in California on a *Taurus 3110* launch vehicle. During its two-year nominal mission, OCO will fly in a circular, 438 mi (705 km) altitude, near-polar, sun-synchronous orbit that provides global coverage of the sunlit hemisphere with a 16-day ground-track repeat cycle. The observatory carries a single instrument designed to measure the absorption of reflected sunlight by CO_2 and molecular oxygen (O_2) at near infrared (NIR) wavelengths. Co-boresighted spectroscopic measurements of the CO_2 and O_2 column abundance will be analyzed to retrieve spatial variations in the column averaged CO_2 dry air mole fraction (X_{CO_2}) where X_{CO_2} measurements have random errors and systematic biases no larger than 0.3-0.5% on regional scales. These measurements are expected to improve our understanding of the nature and processes that regulate atmospheric CO_2, enabling more reliable forecasts of CO_2 buildup and its impact on climate change.

How Does OCO Work?

The OCO spectrometers measure sunlight reflected off the Earth's surface. Carbon dioxide and molecular oxygen molecules in the atmosphere absorb light energy at very specific colors or wavelengths. So, the light that reaches the OCO instrument will display diminished amounts of energy at those characteristic wavelengths. The OCO instrument employs a *diffraction grating* (like the back of a compact disc) to separate the inbound light energy into a spectrum of multiple component colors. The *reflection gratings* used in the OCO spectrometers consist of a very regularly spaced series of grooves that lie on a very flat surface.



The three graphs show the near-infrared wavelength bands chosen to help OCO measure atmospheric CO_2. The bands were chosen because each wavelength band provides a specific contribution to the CO_2 measurement accuracy. (see article text for details)

OCO mission designers selected three specific NIR wavelength bands to help them measure atmospheric CO_2. The OCO instrument measures intensity over all three of these bands at the same location on the Earth's surface at the same instant: a *weak* CO_2 *band* centered around 1.61 μm, the *Oxygen* (O_2)*-A band* at 0.76 μm, and *a strong* CO_2 *band* centered around 2.06 μm. Each of the three selected wavelength bands provides a specific contribution to measurement accuracy.

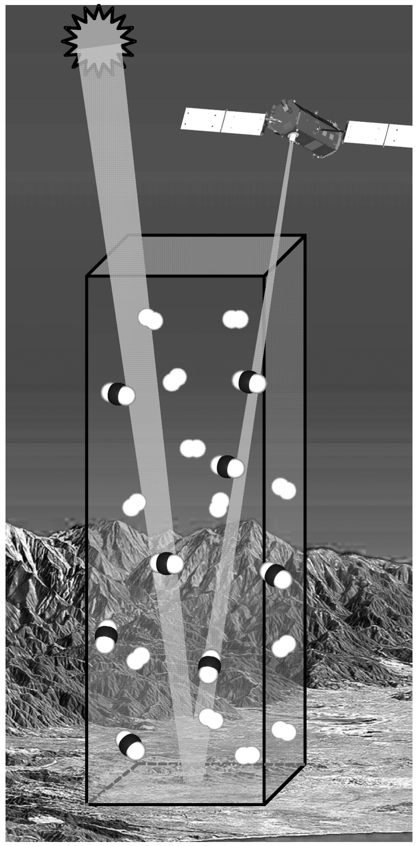
The strong CO_2 band was chosen because it provides a second and totally independent measure of the CO_2 abundance. The 2.06 μm band spectra are very sensitive to the presence of aerosols. The ability to detect and mitigate the presence of aerosols enhances the accuracy of X_{CO_2}. The 2.06 μm band measurements are also sensitive to variations in atmospheric pressure and humidity along the optical path.

The weak CO_2 band was chosen because it is most sensitive to the CO_2 concentration near the surface. Since other atmospheric gases do not absorb significant energy within this spectral range, band measurements at 1.61 μm are relatively clear and unambiguous.

Accurate derivation of X_{CO_2} using space-based readings of the CO_2 absorption requires comparative absorption measurements of a second atmospheric gas. The concentration of molecular oxygen (O_2) is constant, well known, and uniformly distributed throughout the atmosphere. Thus, O_2 is an ideal candidate for reference measurements. The O_2 *A-band* wavelengths provide the required absorption spectra. The O_2 *A-band* spectra is particularly useful because it also indicates the presence of clouds and optically thick aerosols that preclude full column measurements of CO_2.

The design and architecture of the OCO spacecraft bus is based on the successful Solar Radiation and Climate Experiment (SORCE) and Galaxy Explorer (GALEX) missions. The spacecraft structure is made of honeycomb panels that form a hexagonal shape. This structure houses the instrument and the spacecraft bus components. The total weight of the Observatory is about 1170 lb (530 kg). Panels with solar cells are attached and stowed such that the whole structure fits inside the small fairing of the Taurus launch vehicle. A metal ring, mounted to the bottom of the structure, attaches the Observatory to the launch vehicle and separates the two after launch.

The on-board computer, which is designed to fly in the harsh space environment, controls the spacecraft bus components. This computer hosts software, which receives commands from an Earth station through an *S-band* antenna and returns telemetry and science data back to Earth using a high data rate *X-band* transmitter—S-band and X-band refer to specific frequency ranges of microwave radiation used for transmitting data.



The diagram illustrates how OCO obtains an X_{CO_2} measurement within its 3km^2 *footprint*. Molecules in Earth's atmosphere, such as CO_2 absorb radiation at very specific wavelengths. This means that the light reaching the OCO spacecraft will display diminished amounts of energy at these same wavelengths—i.e., the gases leave their *fingerprint* on the radiation as it passes through the atmosphere. The OCO spectrometers are designed to *detect* these *footprints*. They measure the intensity of reflected sunlight at these specific wavelengths and the level of absorption displayed reveals exactly how much CO_2 is present within the *footprint* area.

The spacecraft computer manages the pointing of the spacecraft. Ground commands tell the computer where to point the instrument. The computer uses four wheels to move the spacecraft. A star tracker verifies that the spacecraft has reached the correct orientation. In addition to pointing the instrument, the spacecraft must know where on Earth the footprint of the instrument is located. An on-board Global Positioning System (GPS) receiver provides that information.

Spacecraft software ensures that the solar arrays face the sun so that adequate power is always available to charge the battery and run all the components and the instrument. The power required to run the entire observatory is equivalent to the power needed for nine common household light bulbs.

Science Data Processing and X_{CO_2} Measurement

The principal science objective of the OCO mission is to gather global CO_2 data to help distinguish sources and sinks. **The OCO mission will not, however, *directly* measure CO_2 sources and sinks**. Computer based data assimilation models that use column averaged dry air CO_2 mole fraction (X_{CO_2}) data will infer the location of these sources and sinks.

To get the representative values of X_{CO_2}, the OCO instrument measures the intensity of reflected sunlight off of the Earth's surface at specific wavelengths. Gas molecules such as CO_2 in the atmosphere absorb radiation at specific wavelengths. So when the light passes through the Earth's atmosphere, the gases leave a distinguishing "fingerprint" on the residual radiation. The OCO spectrometers detect these molecular "fingerprints." The level of absorption displayed in these spectra will tell the number of molecules in the region where the measurement was taken.

The presence of clouds and optically thick aerosols such as smoke can block part of the distance, and thus partly block the complete measurement. Other conditions such as large topographic variations (over mountainous areas) within individual soundings can introduce additional uncertainty in length of the light column, which also affect the X_{CO_2} measurements. To counter this, the OCO instrument acquires a large number of densely spaced samples. Each sample covers an area of about 3 km^2—called a *footprint*—when the instrument is viewing locations looking straight down—or *nadir*—along the spacecraft's ground track. The OCO instrument can gather 39,600 of these soundings on the sunlit side of any orbit. With measurement footprints of this size and density, the OCO instrument can get a lot of high quality soundings even in regions where clouds, aerosols, and topographic variations are present.

Mission Operations

OCO will be launched from Vandenberg Air Force Base on a dedicated Orbital Sciences *Taurus XL (3110)* launch vehicle. It will initially be placed into a 398 mi (640 km) altitude, near-polar, dayside-ascending (i.e., moving south to north) orbit. The onboard propulsion system will be used to transfer the Observatory into its operational 438 mi (705 km) circular orbit. This orbit transfer and other in-orbit checkout activities are expected to take less than 45 days. Once in its operational orbit, OCO will fly in the Earth Observing System (EOS) Afternoon Constellation (A-Train). The OCO orbit will be maintained with respect to Worldwide Reference System-2 (WRS-2), with a 1:27 p.m. ascending equator crossing time such that it will share its ground track with Aqua. This orbit facilitates direct comparisons and combined analyses of OCO observations with measurements taken by Aqua, Aura, CloudSat, Cloud-Aersol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), and other A-Train satellites. The orbit's 16-day ground repeat cycle facilitates monitoring X_{CO_2} variations over the entire sunlit hemisphere on semi-monthly intervals. The orbit period is 98.8 minutes, yielding 14.57 orbits/day or 233 orbits every 16 days. While sequential ground tracks are separated by ~24° of longitude, the spacing between adjacent ground tracks for the 233 orbits obtained over a 16-day ground repeat cycle is only ~1.5° of longitude.

OCO will switch from *Nadir* to *Glint* observations on alternate 16-day global ground-track repeat cycles so that the entire Earth is mapped in each mode every 32 days. Comparisons between *Nadir* and *Glint* observations will provide opportunities to identify and correct for biases introduced by the viewing geometry. *Target* observation will be acquired over an OCO validation site roughly once each day.

The same data sampling rate is used for *Nadir*, *Glint*, and *Target* observations. While the instrument is capable of collecting up to 8 adjacent, spatially resolved samples every 0.333 seconds (24 samples per second), the nominal data transmission and ground processing approach has been sized to accommodate only 12 samples per second as a cost saving measure. At this data collection rate, the Observatory collects ~200 soundings per degree of latitude as it travels from pole to pole, or ~7 million soundings over the sunlit hemisphere every 16 day ground repeat cycle. Therefore, the data collection rate can be at 12 samples/seconds at any time during the mission. Clouds, aerosols, and other factors will reduce the number of soundings available for X_{CO_2} retrievals, but existing studies suggest that at least 10% of these data will be sufficiently cloud free to yield X_{CO_2} estimates with accuracies of ~0.3 to 0.5% (1 to 2 ppm) on regional scales at monthly intervals.

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