

Monitoring CO₂ Sources and Sinks from Space: The Orbiting Carbon Observatory (OCO) Mission

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NASA's Orbiting Carbon Observatory (OCO) will make the first space-based measurements of atmospheric carbon dioxide (CO₂) with the precision, resolution, and coverage needed to characterize the geographic distribution of CO₂ sources and sinks and quantify their variability over the seasonal cycle. OCO is currently scheduled for launch in 2008. The observatory will carry a single instrument that incorporates three high-resolution grating spectrometers designed to measure the near-infrared absorption by CO₂ and molecular oxygen (O₂) in reflected sunlight. OCO will fly 12 minutes ahead of the EOS Aqua platform in the Earth Observing System (EOS) Afternoon Constellation (A-Train). The instrument will collect 12 to 24 soundings per second as the Observatory moves along its orbit track on the day side of the Earth. A small sampling footprint (<3 km² at nadir) was adopted to reduce biases in each sounding associated with clouds and aerosols and spatial variations in surface topography. A comprehensive ground-based validation program will be used to assess random errors and biases in the X_{CO_2} product on regional to continental scales. Measurements collected by OCO will be assimilated with other environmental measurements to retrieve surface sources and sinks of CO₂. This information could play an important role in monitoring the integrity of large scale CO₂ sequestration projects.

1. INTRODUCTION

Precise measurements of atmospheric carbon dioxide (CO₂) have been collected from a network of sites since the late 1950's (Schnell et al. 2001). These data indicate that only about half of the carbon dioxide (CO₂) that has been emitted by fossil-fuel combustion and other human activities over this period has remained in the atmosphere. The rest has apparently been sequestered by the oceans and land biosphere. However, the available measurements do not have the spatial and temporal resolution and coverage needed to determine the nature and location of these CO₂ sinks or to characterize their efficiency on seasonal to interannual time scales. Available CO₂ measurements also show that the atmospheric CO₂ buildup varies substantially from year to year in response to relatively uniform input rates (Fig. 1; Randerson et al., 1997, 1999; Lee et al., 1998; Keeling et al., 1995; Houghton, 2000; Langenfelds et al., 2002). While some of this variability has been attributed to carbon cycle response to El Niño events, the existing measurements provide too little information to define a causal link. These shortcomings in our understanding of the nature and geographic distribution of these CO₂ sinks impede comprehensive studies of the processes controlling their behavior or how this might change as the climate

evolves. This not only precludes accurate predictions of future CO₂ increases and their effects on the climate, it also impairs efforts to identify new atmospheric CO₂ sequestration strategies.

Modeling studies indicate that global, space-based measurements of the column-averaged CO₂ dry-air mole fraction, X_{CO_2} could dramatically improve our understanding of the environmental processes that control the atmospheric CO₂ budget (Rayner and O'Brien, 2001; O'Brien and Rayner, 2002; Olsen and Randerson, 2004). Precise measurements of X_{CO_2} are needed for this application because carbon-cycle inverse models infer surface-atmosphere CO₂ fluxes from spatial and temporal variations in this quantity, and X_{CO_2} is expected to vary by no more than ~2% on regional to global scales (Warneke et al.2005). Modeling studies indicate that X_{CO_2} measurements with precisions near 0.3 to 0.5 % (~1 to 2 parts-per million (ppm) out of the ambient ~380 ppm CO₂ mixing ratio) on regional-to-continental scales are needed to identify surface CO₂ sources and sinks at these spatial resolutions and characterize their variability over the seasonal cycle.

The NASA Orbiting Carbon Observatory (OCO) is currently being designed to make the first space-based measurements of atmospheric CO₂ with the precision, resolution, and coverage needed to characterize the geographic distribution of CO₂ sources and sinks and quantify their variability. During its two-year primary mission, OCO will fly in a sun-synchronous polar orbit that provides near-global coverage of the sunlit portion of Earth with a 16-day repeat cycle. The observatory carries a single instrument that incorporates three high-resolution grating spectrometers, designed to measure the near-infrared absorption by CO₂ and molecular oxygen (O₂) in reflected sunlight. The orbit's early-afternoon equator crossing time maximizes the available signal and minimizes diurnal biases in CO₂ measurements associated with photosynthesis. Large numbers of coincident CO₂ and O₂ soundings will be collected at high spatial resolution to reduce the impact of random errors and minimize biases associated with clouds and other sources of spatial variability within each measurement footprint.

Remote-sensing retrieval algorithms will be used to process the CO₂ and O₂ measurements to estimate X_{CO_2} in each sounding. Independent calibration and validation approaches will be used to identify and correct regional scale (1000 × 1000 km) biases in the space-based X_{CO_2} measurements. These validation methods include ground and aircraft field measurements and modeling studies. Once validated, the space-based X_{CO_2} measurements will be combined with other environmental data in sophisticated carbon-cycle models to characterize CO₂ sources and sinks on regional scales at monthly intervals over two annual cycles.

2. MEASUREMENT APPROACH

The OCO spacecraft carries a single instrument that incorporates three high resolution imaging grating spectrometers. The instrument capabilities and sampling approach are described in this section.

2.1. Spectral Range and Resolving Power.

High-spectral resolution measurements of reflected sunlight in the near-infrared (NIR) CO₂ absorption bands are ideal for retrieving X_{CO_2} because these measurements provide high sensitivity near the surface, where most CO₂ sources and sinks are located. The weak CO₂ band near 1.61 μm is well suited for CO₂ column measurements because this spectral region is relatively free of absorption by other gases, and the observed absorption is most sensitive to the CO₂ abundance near the surface, where the sources and sinks are located (Figs. 2 and 3).

However, measurements of this band alone are not adequate for retrieving X_{CO_2} . Bore-sighted measurements in the 0.76- μm O₂ A-band provide information about the total (dry-air) atmospheric pressure and the optical path length between the top of the atmosphere and the reflecting surface. This information must be combined with the CO₂ column estimates to derive X_{CO_2} . Aircraft studies show that A-band observations can provide surface-pressure estimates with accuracies of ~ 1 millibar (O'Brien et al, 1998). A-Band spectra are also sensitive to clouds and aerosols, which could introduce errors in the X_{CO_2} retrievals if they are not adequately characterized.

Spectra of the strong 2.06- μm band are also needed to constrain the aerosol optical properties at near-infrared wavelengths, since these optical properties can change substantially between the O₂ A-band and the 1.61 μm CO₂ band. Sensitivity studies show that the use of all 3 bands dramatically improves the accuracy of X_{CO_2} retrievals in aerosol-laden conditions (Kuang et al. 2002). A single *sounding* therefore consists of bore-sighted spectra in the 0.76- μm O₂ A-band and the CO₂ bands at 1.61 μm and 2.06 μm .

In each of these 3 spectral regions, the spectral range includes the complete molecular absorption band as well as some nearby continuum to provide constraints on the wavelength dependent optical properties of the surface and airborne particles (clouds, aerosols). The spectral resolving power for each channel was selected to maximize the sensitivity to variations in the column abundances of CO₂ and O₂ and to minimize the impact of systematic measurement errors. A spectral resolving power, $R = \lambda/\delta\lambda > 20,000$ separates individual CO₂ lines in the 1.61 and 2.06- μm regions from weak H₂O and CH₄ lines and from the underlying continuum. For the O₂ A-band, a resolving power of $\sim 17,000$ is needed to resolve the O₂ doublets from the continuum (Fig. 2). With these resolving powers, the OCO retrieval algorithm can characterize the surface albedo and

solve for the wavelength dependence of the aerosol scattering throughout each spectral range, minimizing X_{CO_2} retrieval errors contributed by uncertainties in these properties.

2.2. *Spatial and Temporal Sampling Approach*

The spatial sampling strategy for OCO was designed to provide spatially-resolved, measurements X_{CO_2} over the sunlit hemisphere of the Earth on semi-monthly intervals. Complete, contiguous coverage of the entire Earth's surface is not essential to characterize atmospheric CO_2 variations on regional scales because CO_2 is dispersed over large areas as it is mixed through the atmospheric column. However, the full atmospheric column must be sampled to provide constraints on surface CO_2 sources and sinks.

2.2.1 Orbit track and spatial coverage. To provide global coverage of the sunlit hemisphere, OCO will be launched into a near polar (98.2° inclination) orbit from Vandenberg Air Force Base on a dedicated Orbital Sciences Taurus launch vehicle. The launch is currently scheduled for September 2008. It will initially be launched into a 635 km transfer orbit, and then the orbit will be raised to its 705 km altitude operational orbit, where it will fly in formation with the Earth Observing System (EOS) Afternoon Constellation (A-Train). As currently planned, OCO will fly 12 minutes ahead of the EOS Aqua platform, and its equator crossing time will be shifted to 1:18 PM, such that it shares the same ground track (Fig. 4).

This orbit facilitates comparisons of OCO observations with measurements taken by Aqua, Aura, and other A-Train missions (Aura, Parasol, CloudSat, and Calypso). The orbit's 98.7 minute period yields 14.56 orbits per day, with successive orbit tracks separated by $\sim 24^\circ$ of longitude. The 233 orbits included in each 16-day ground-track repeat cycle yield a mean longitude spacing of $\sim 1.5^\circ$, facilitating monitoring of X_{CO_2} variations on regional scales (1000 km x 1000 km) at semi-monthly intervals (Fig. 5).

This near-polar, sun-synchronous orbit samples the entire sunlit hemisphere at same time of day, minimizing uncertainties associated with the CO_2 diurnal cycle. This early afternoon sampling time is nearly ideal for spectroscopic observations of CO_2 in reflected sunlight because the sun is high, maximizing the measurement signal-to-noise ratio. CO_2 concentrations over forests and other photosynthetically active land biomes are also near their diurnally-averaged values at this time of day.

2.2.2 Spatial sampling resolution. Clouds and optically thick aerosols can hide the surface, precluding measurements of near-surface CO_2 amounts. Scattering by thinner clouds and aerosols can also introduce uncertainties in the optical path length, and introduce errors in the X_{CO_2} re-

trieval. Studies of MODIS cloud products indicate that the probability of sampling a cloud-free scene decreases from more than 24% with a footprint size of 3 square km to less than 15% for a footprint size of 36 square km. Large topographic variations and other sources of spatial variation within the footprint of an individual sounding can also introduce systematic biases that can compromise the accuracy of X_{CO_2} retrievals.

A small (<0.004 steradian) footprint size was therefore adopted to maximize the probability of viewing cloud-free scenes even in partially cloudy regions and to minimize the errors and biases introduced by spatial inhomogeneities with each sample. When the spacecraft is viewing at nadir, each sounding will have a surface footprint with an area no larger than 3 square kilometers.

To obtain enough soundings to accurately characterize the X_{CO_2} distribution on regional scales, the OCO instrument will continuously record 12 to 24 soundings per second as the spacecraft moves along its ground track at 6.78 km/sec (Fig. 6). It therefore collects ~ 196 to 392 samples per degree of latitude as it moves along its orbit track on the day side of the Earth. It therefore collects between 7 and 14 million soundings over the globe once every 16 days. 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 to 20% 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 (Spinhirne et al. 2005; Hart et al. 2005).

2.2.3 Viewing modes. OCO will collect science observations in Nadir, Glint, and Target modes. The dedicated spacecraft bus uses its reaction wheels to point the instrument, precluding the need for a dedicated pointing mechanism. The same data sampling rate (12 - 24 soundings/sec) is used in all three modes. The pointing accuracy is 4 milliradians (mrad) and pointing knowledge is 1.8 mrad in all three modes.

In Nadir mode, the satellite bus will point the instrument to the local nadir, and collect data along the ground track just below the Observatory (Fig. 6). Science data will be collected at all latitudes where the local surface solar zenith angle is less than 85° . As the Observatory travels along its orbit track, it rotates around the nadir vector, such that the instrument's viewing geometry remains constant with respect to the principle plane, defined by the sun, the surface target point, and the instrument aperture. This yaw maneuver serves two purposes. First, it helps to keep the solar illumination near normal to the solar panels, which have only one degree of freedom. It also maintains a constant orientation between the instrument's field of view and the principal plane. This is important because the OCO instrument is only sensitive to the reflected solar radiation that is polarized perpendicular to this plane. This maneu-

ver therefore minimizes intensity variations associated with polarization changes (e.g. Brewster angle effects) along the orbit track.

Nadir observations provide the highest spatial resolution on the surface and are expected to return more usable soundings in regions that are partially cloudy or over continental regions that have significant surface topography. The principal drawback of Nadir observations is that the ocean surface is very dark at the near infrared wavelengths used by OCO. Over a dark, nearly specular surface like the ocean, the reflected signal from the surface is reduced, and the X_{CO_2} estimates are more sensitive to optical path length uncertainties introduced by atmospheric scattering from thin clouds and aerosols.

The Glint mode was designed to specifically address this concern. In this mode, the spacecraft points the instrument toward the bright “glint” spot, where solar radiation is specularly reflected from the surface. Glint measurements are expected to provide much higher signal-to-noise ratios (SNR) over the ocean and comparable SNR over land (Fig. 7). The main drawback of Glint observations is that the viewing geometry and footprint size for each sounding varies systematically with latitude as the distance to the surface target location changes. The largest sounding footprints are produced near the polar terminators, where they can cover up to 10 times the area of a nadir footprint. As the size of the footprints grows, the probability of observing a cloud-free scene is reduced.

Glint soundings will be collected at all latitudes where the local solar zenith angle is less than 75° . OCO will switch from Nadir to Glint modes on alternate 16-day global ground-track repeat cycles so that the entire sunlit hemisphere of the Earth is mapped in each mode on roughly monthly time scales. X_{CO_2} retrievals acquired from Glint and Nadir observations will be compared to assess biases introduced by either mode.

Target mode will be used to observe specific stationary surface targets as the satellite flies overhead. This mode is intended primarily as a validation mode, providing opportunities to identify and correct for regional scale biases in the space-based X_{CO_2} measurements. A Target Track pass will be conducted roughly once each day, such that data will be collected over validation sites covering a range of latitudes during every 16-day global repeat cycle. These sites include ground and tower based *in situ* CO_2 measurement systems (flasks, non-dispersive IR) as well as high-resolution, solar-looking Fourier transform Spectrometers (FTS's) that measure the column-integrated CO_2 and O_2 absorption in the same spectral regions as the space based instrument (Yang et al. 2002; 2005).

A Target track pass can last for up to 8 minutes, providing 5,000 to 10,000 soundings over a validation site at emission angles between 0 and $\pm 75^\circ$. During each pass, the observatory can scan the spectrometer field of view (FOV)

across a 14 mrad wide region centered near the nominal target location at ~ 2 cycles per minute. This approach ensures that the target is captured within the scan range and provides the data needed to characterize spatial variations in X_{CO_2} in the vicinity of the site.

3. MISISON IMPLEMENTATION APPROACH

The OCO mission is will make space-based X_{CO_2} measurements using a single instrument carried by a dedicated spacecraft bus that is launched by a dedicated launch vehicle. Details of this highly focused implementation approach are summarized in this section.

3.1. Instrument Implementation.

To implement this design, the OCO instrument incorporates 3 independent bore-sighted, long-slit, imaging grating spectrometers that are optimized for the O_2 A-band and the CO_2 bands at $1.61 \mu m$ and $2.06 \mu m$ CO_2 . These three spectrometers use similar optical designs and are integrated into a common structure to improve rigidity and thermal stability and share a common housing and a common F/1.8 Cassegrain telescope (Haring et al. 2005). The instrument configuration and optical path are shown in Fig. 8. Light that enters the telescope is first focused at a field stop. It then enters a relay optics assembly where it is collimated and then directed to the three spectrometers by beam splitters (for the two CO_2 bands) or a mirror (the O_2 A-band). It is then refocused on the spectrometer slits after passing through a narrow-band pre-disperser filter and a polarizer. The spectrometer slits are aligned to produce bore sighted fields of view that are 0.0001 radians wide by ~ 0.0146 radians long. The pre-disperser filter for each spectral range transmits light with wavelengths within $\sim \pm 1\%$ of the central wavelength of the CO_2 or O_2 band of interest and rejects the rest.

For the spectrometer design adopted here, the gratings efficiently disperse light that is polarized in the direction parallel to the slit, but are much less efficient in the orthogonal polarization. The polarizer was therefore added ahead of the slit to reject this light before it enters the spectrometer, where it could contribute to the scattered light background. Once the light enters a spectrometer slit, it is collimated, dispersed by a reflective plane holographic diffraction grating, and then focused on a 2-dimensional focal plane array (FPA), after traversing a second narrow-band filter. The second narrowband filter rejects thermal emission from the instrument (important only in the 1.6 and 2 CO_2 bands) and any light that leaks through pin holes in the first pre-disperser filter.

The spectrometers disperse the light onto the FPA's in the direction orthogonal to the long dimension of the slit, and spatially resolve the field of view along the slit. The

FPA's used in each spectrometer are 1024 x 1024 pixel arrays with 18 μm pixels that have a virtually 100% fill factor (ie. there are no spatial or spectral gaps between the pixels). The full-width of the slit is imaged by 2 to 3 pixels.

The two CO_2 channels use Mercury Cadmium Telluride (HgCdTe) HAWAII 1-RG arrays from Rockwell Scientific. The O_2 A-band uses a Rockwell Scientific HyViSI™ FPA, which uses same HAWAII 1-RG read-out-integrated circuit, simplifying the FPA readout electronics. The temperatures of the CO_2 FPA's are maintained at <120 K and the O_2 FPA is maintained < 180 K by an pulse-tube cryocooler that is thermally coupled to an external radiator though variable conductance heat pipes. The body of the spectrometer maintained at -5 °C by a thermal radiative shroud that is coupled to an external radiator by variable conductance heat pipes.

The spectrum within each channel is dispersed to illuminate all 1024 pixels in spectral dimension on each FPA, but the length of the slit limits spatial field of view to only ~190 pixels in the spatial dimension. The nominal OCO soundings use an along-slit field of view is defined by ~160 of these 190 pixels. In normal science operations, 20 or more spatial pixels can be binned on board to produce up to 8 contiguous along-slit (spatial) fields view for each of the 1024 spectral samples. The along-slit dimension of each of these binned instantaneous fields of view is ~1.8 mrad (~1.3 km at nadir from a 705 km orbit). The FPA's are read out at 3 Hz, producing up to 24 samples per second in each of the three spectral ranges. As noted earlier, these bore-sighted soundings are combined to produce a single X_{CO_2} sounding.

In addition to these 8 spatially binned spectra, each spectrometer also returns 4 to 20 spectral samples (or "colors") without on-board spatial binning to provide the full along-slit spatial resolution. Each full-resolution "color sample" covers a 220 pixel wide region of the FPA that includes the full length of the slit (190 pixels) as well as a few pixels beyond the ends of the slit. These full-spatial-resolution *color samples* are used to detect spatial variability within each of the spatially-binned spectra and to monitor the thermal emission and scattered light within the instrument.

The instrument includes an on-orbit calibration system that has been integrated into the telescope baffle assembly. This system consists of a calibration mechanism that includes a cover and a transmissive diffuser, and a series of continuum lamps. The cover is closed to protect the instrument aperture from external contaminants during launch and orbit maintenance activities. It is also closed twice each orbit to measure the bias offset of the detectors. This cover has a diffusely reflecting surface on the inward facing side, which can be illuminated by one or more calibration lamps to assess spatial variations in the instrument gain. Once each orbit, the calibration mechanism will be

rotated 180 degrees from the closed position to place a transmissive diffuser in front of the telescope to allow direct observations of the sun. The calibration mechanism is rotated 90 degrees from either the closed or diffuser positions for science observations.

3.2. Observatory Implementation.

OCO uses a 3-axis stabilized spacecraft bus, based on the Orbital LEOStar-II architecture (Fig. 9). This bus was also used for the successful Galaxy Explorer (GALEX) and Solar Radiation and Climate Explorer (SORCE) missions. The single-string version of this bus was selected for the 2-year OCO mission. The instrument is entirely enclosed within the bus structure for thermal stability. Power is provided by two deployable solar panels that can be rotated about a single axis to track the sun. A hydrazine monoprop system is used to raise the orbit from the injection altitude (~635 km) to the operational orbit (705 km), maintain its position within the A-Train orbit during its operational lifetime, and then deorbit the Observatory at the end of the mission. A redundant pair of S-band receivers are used for receiving commands from the ground station. Housekeeping data are returned at up to 2 megabits/second using an S-band transmitter, while science data is returned at 150 megabits/second using a X-band transmitter. Reaction wheels to point the instrument to nadir, glint, specific ground targets, or toward the sun for calibration. They are also used to point the body-mounted X-band antenna at the ground station twice each day for science data downlink.

3.3. The OCO Data System.

The OCO instrument takes data continuously as the Observatory orbits the Earth, but it only stores the data in the solid state recorder for downlink to the Earth while over the day side of the orbit, and during calibration activities on the night side. As noted above, the 3 FPA's are read out 3 times each second, yielding up to 24 spatially-resolved soundings each second. Each sounding consists of a bore sighted 1024-element spectra for one of the 8 spatial fields of view from each of the 3 spectrometers. In addition, the spectrometer returns 4 to 20 full-resolution color samples from each spectrometer each time that the focal plane is read out. The instrument digitizes all of these samples to 16 bits. Hence, if the instrument is commanded to read out 8 (spatially-binned) spectra (1,179,648 bits/second) and 4 220-pixel full-spatial resolution color samples (126720 bits per second), the total data rate is 1,433,088 bits per second.

A typical Nadir orbit includes 43.5 minutes of science data and 7 minutes of calibration data, for a total data volume of ~4.34 gigabits of data per orbit or 63 gigabits/day. A typical Glint orbit includes 51.4 minutes of science data

and 7 minutes of calibration data, yielding 5.0 gigabits of data per orbit or 72.8 gigabits/day. Communications encoding and housekeeping data adds another ~10% to these volumes, yielding up to 80 gigabits (10 gigabytes) of data each day. This data is recorded in an on-board solid state recorder and transmitted to the ground station during two downlink passes each day.

The science data will be sent to OCO Ground Data System for processing within one week of acquisition on the ground. There it will be processed to yield Level 0 (raw, time-sequenced spacecraft data records), Level 1 (calibrated, geolocated spectral radiances), and Level 2 (geolocated X_{CO_2} soundings) data products. Six months after the start of routine science operations, Level 0 and Level 1 data products will be delivered to the NASA Distributed Active Archive Center (DAAC) within 6 months of acquisition by the ground station, and will be accessible to the science community. Beginning 9 months after the start of routine science operations, an exploratory Level 2 data product will be delivered to the DAAC. Higher level products, including gridded maps of CO₂ sources and sinks will be delivered to the DAAC as they are developed and validated. These are the products that will most likely be of greatest interest to the carbon cycle and carbon management communities.

3.3. *The OCO Validation Program.*

A comprehensive ground-based validation program will be used to assess random errors and regional to continental scale biases in the space-based X_{CO_2} product. The accuracy of this product will be referenced to the NOAA CMDL CO₂ standard, which has been designated as the reference standard by the World Meteorological Organization (WMO). This standard is based on *in situ* CO₂ measurements of the CO₂ from flasks, tall towers, and aircraft. To link these point measurements to the space based measurements of the CO₂ column, the OCO validation program will use independently calibrated column data from ground-based, solar-looking, Fourier Transform Spectrometers (FTS's). A series of these systems are currently being installed as part of the Total Column Carbon Network (TCCN). The OCO Project is installing two new FTS's at the Department of Energy Atmospheric Radiation Monitoring (ARM) sites near Darwin Australia and in Oklahoma, and upgrading at least 4 existing FTS facilities from the Network for Detection of Stratospheric Change (NDSC). Precise laboratory measurements of the strengths, widths, and positions of the absorption lines are being made to ensure the proper interpretation of the atmospheric spectroscopic data from the space based instrument and the ground based FTS's.

3. CONCLUSIONS

An improved understanding of the role of atmospheric CO₂ in the global carbon cycle is essential to predict the future buildup rates for this important greenhouse gas and project the time scales for its impact on the climate. Efforts to identify the natural processes that are currently absorbing almost half of the CO₂ emitted by fossil fuel combustion would also provide additional insight into effective, large scale carbon management strategies.

The OCO mission is being developed to address these needs. Once launched in 2008, it will make the first global, space-based observations of atmospheric CO₂ with the precision, resolution, and coverage needed to quantify CO₂ sources and sinks on regional scales. While OCO is an exploratory Earth System Science Pathfinder mission with a 2 year lifetime, it will validate technologies well suited for future, long-term CO₂ monitoring missions. Data from OCO and its follow-on CO₂ monitoring missions will support decision makers by providing a scientific basis for greenhouse gas policy formulation and treaty monitoring. These missions are also expected to play an important role in carbon management strategies by providing new insight into natural carbon sinks and a means to validating large scale CO₂ sequestration projects.

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

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FIGURE CAPTIONS

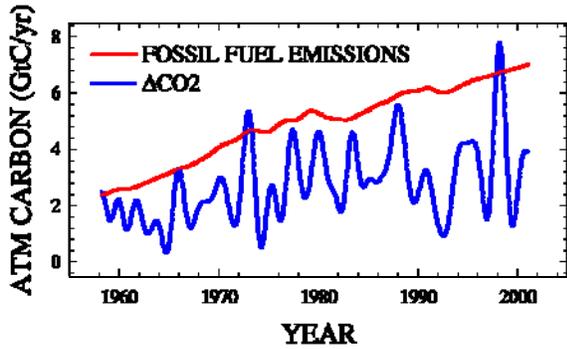


Figure 1. Year-to-year variability in the fossil fuel input (red) and atmospheric CO₂ buildup (blue). The geographic distribution and environmental processes controlling the year to year variability in the ocean and land based sinks are not currently well understood (Schnell et al., 2001).

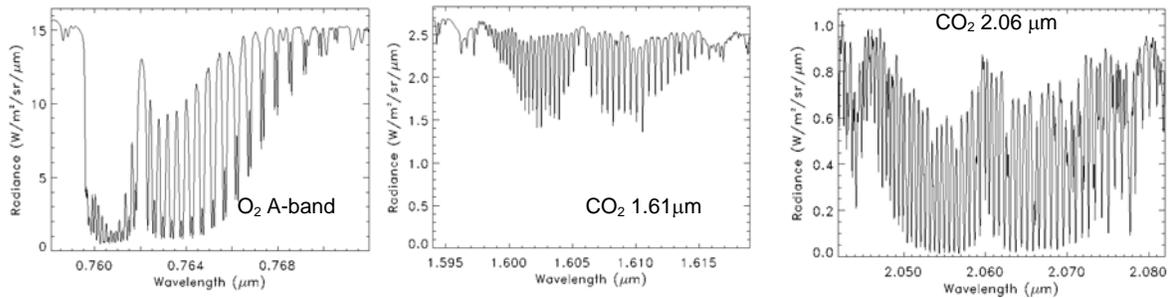


Figure 2. The three spectral channels used by OCO, illustrating their spectral range and resolving power.

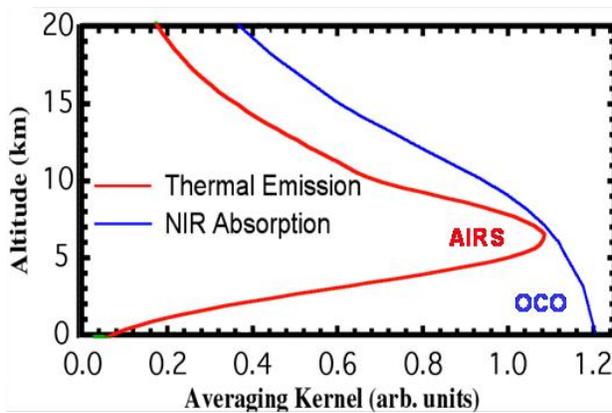


Figure 3. Vertical weighting functions from the 1.61. μm CO₂ band (blue) provide the most information near the surface, where most sources and sinks are located. CO₂ weighting functions from thermal IR instruments such as AIRS are peaked in middle and upper troposphere.

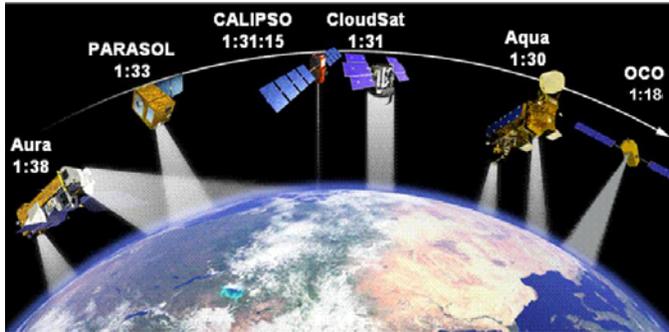


Figure 4. A-Train Satellites, showing equator crossing times.

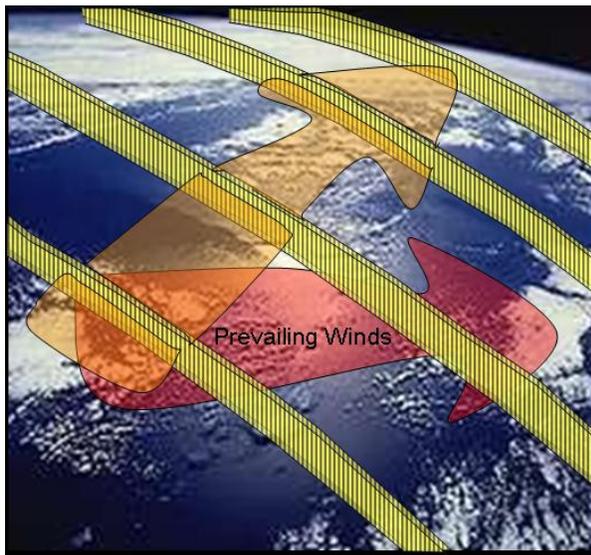


Figure 5. OCO provides dense spatial sampling along the orbit track, but the adjacent tracks accumulated over a 16-day global repeat cycle are separated by ~ 1.5 degrees of latitude.

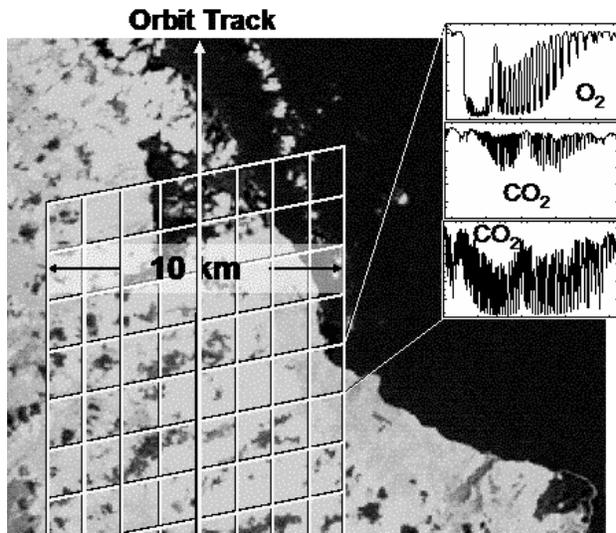


Figure 6. OCO ground track showing 8 cross-track elements collected within the instrument field of view when viewing at nadir. The 1.29 km width of the footprint is determined by the number of spatial pixels summed on board. The 2.25 km downtrack length of the footprint is determined by the 0.333 second exposure time. Bore-sighted spectra within the 3 spectral ranges are collected in each spatial footprint.

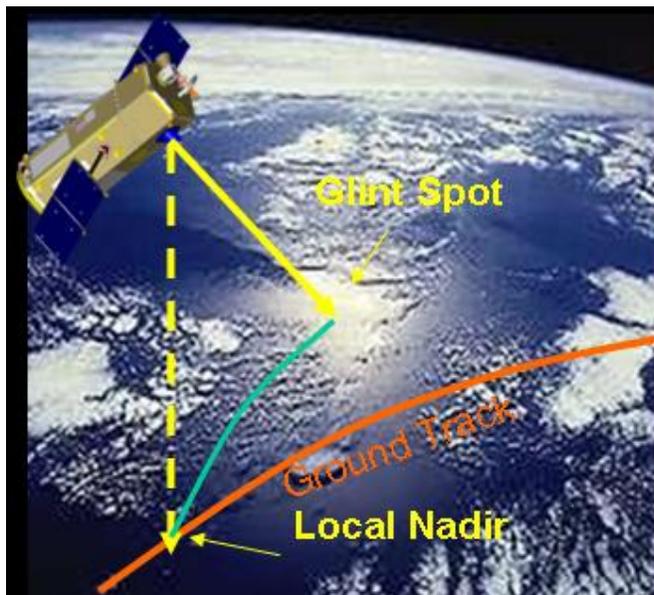


Figure 7. For Glint observations, the instrument bore sight is pointed at the surface “glint” spot.

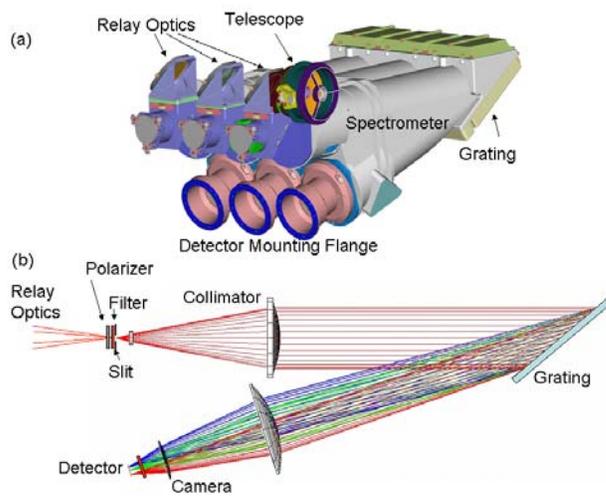


Figure 8. (a) Instrument layout showing input telescope, relay optics and common spectrometer structure. (b) Optical path for a single spectrometer channel showing major subsystems.

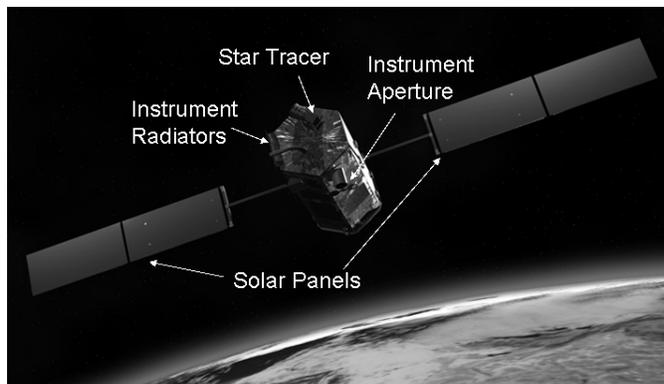


Figure 9. Artist rendition of the OCO spacecraft above the Earth, showing major components.

THE ORBITING CARBON OBSERVATORY (OCO) MISSION

AUTHOR NAMES

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