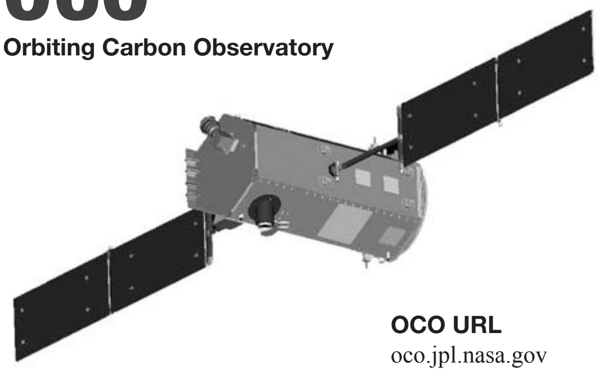
OCO

Orbiting Carbon Observatory



OCO URL
oco.jpl.nasa.gov

Key OCO Facts

Spacecraft: Orbital Sciences LeoStar-2

Orbit
Type: Near-polar, sun-synchronous
Ascending Node: 1:18–1:33 p.m..
Altitude: 705 km
Inclination: 98.2° ± 0.1°
Period: 98.8 minutes
Repeat Cycle: 16 day

Dimensions: 2.3-m long × 1.4-m diameter (stowed for launch)

Mass: < 530 kg (wet, spacecraft bus + observatory + fuel)

Power: 786 W (orbit average, end of life)

Design Life: 2 years

Data Links: X-Band @ 150 Mbps

Telemetry: S-Band @ 2 Mbps

Summary

OCO will provide space-based global measurements of atmospheric carbon dioxide (CO_2) with the precision and resolution needed to identify and characterize the processes that regulate this important greenhouse gas. Data collected by OCO will be combined with meteorological observations and ground-based CO_2 measurements to help characterize CO_2 sources and sinks on regional scales at monthly intervals for 2 years.

Instruments

- Three high-resolution grating spectrometers

Points of Contact

- *OCO Principal Investigator:* David Crisp, NASA Jet Propulsion Laboratory/California Institute of Technology
- *OCO Deputy Principal Investigator:* Charles E. Miller, NASA Jet Propulsion Laboratory/California Institute of Technology

Other Key Personnel

- *OCO Program Scientist:* Phil DeCola, NASA Headquarters
- *OCO Program Executive:* Eric Ianson, NASA Headquarters
- *OCO Project Manager:* Rod Zieger, NASA Jet Propulsion Laboratory/California Institute of Technology

Mission Type

Earth Observing System (EOS) Exploratory Measurements (Earth System Science Pathfinder)

Launch

- *Date and Location:* No earlier than 2008, from Vandenberg Air Force Base, California
- *Vehicle:* Taurus 3110 rocket

Relevant Science Focus Area

(see NASA's Earth Science Program section)

- Atmospheric Composition
- Carbon Cycle, Ecosystems, and Biogeochemistry

Related Applications

(see Applied Sciences Program section)

- Air Quality
- Carbon Management
- Public Health

OCO Science Goals

- Collect space-based measurements of atmospheric carbon dioxide (CO_2) with the precision, resolution, and coverage needed to improve our understanding of the geographic distribution of CO_2 sources and sinks (surface fluxes) and the processes controlling their variability on seasonal time scales.
- Validate a passive spectroscopic measurement approach and analysis concept that is well suited for future systematic CO_2 monitoring missions.

OCO Mission Background

CO_2 is produced every time we start a car, light a fire, or exhale. These and other human activities have increased the atmospheric concentration of this greenhouse gas by about 25% since the dawn of the industrial age, raising concerns about climate change. Our ability to predict future changes in atmospheric CO_2 concentration, and its impact on climate is hampered by limitations in our understanding of the role of CO_2 in the terrestrial carbon cycle. Precise ground-based measurements collected since the 1950s indicate that only about half of the CO_2 emitted into the atmosphere by fossil-fuel combustion has remained there. The oceans and land biosphere have apparently absorbed the rest of the CO_2. But the question is, where? Unfortunately, available measurements do not have the spatial and temporal resolution and coverage needed to determine where all of the CO_2 sinks are located or what controls their behavior. This precludes accurate predictions of how the behavior of these CO_2 sinks might evolve over time as the climate changes and thus complicates efforts to predict future CO_2 increases and their effects on the climate.

Carbon-cycle modeling studies indicate that global, space-based observations of the column-averaged CO_2 dry-air mole fraction (X_{CO2}) could dramatically improve our understanding of the environmental processes that control the atmospheric CO_2 budget. Precise measurements of X_{CO2} are needed for this application because carbon-cycle inverse models infer surface-atmosphere CO_2 fluxes from small spatial and temporal variations in this quantity. These models show that X_{CO2} measurements with precisions near 0.3% (~1 part per million (ppm) out of the ambient ~370 ppm CO_2 concentration) are needed to identify and characterize surface CO_2 sources and sinks on regional-to-continental spatial scales and seasonal time scales.

OCO will make the first 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**.** During its two-year 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 CO_2 and molecular oxygen (O_2) in reflected sunlight. The orbit's early-afternoon equator crossing time maximizes the available signal and minimizes diurnal biases in CO_2 measurements associated with photosynthesis. Large numbers of coincident CO_2 and O_2 soundings will be obtained at high spatial resolution to reduce the impact of random errors and minimize biases associated with clouds and other sources of spatial inhomogeneity within each measurement footprint.

Remote-sensing retrieval algorithms will be used to process the CO_2 and O_2 measurements to estimate X_{CO2} in each sounding. Independent calibration and validation approaches will be used to identify and correct regional-scale (1000 km × 1000 km) biases in the space-based X_{CO2} measurements. These validation methods include ground-based measurements of X_{CO2} obtained with upward-looking spectrometers as well as *in situ* measurements of CO_2 from aircraft, towers, and the existing ground-based network, with all validation measurements tied to an established CO_2 calibration standard. Once validated, the space-based X_{CO2} measurements will be combined with other environmental data in sophisticated carbon-cycle models to characterize CO_2 sources and sinks on regional scales at monthly intervals over two annual cycles.

Measurement Approach

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

Bore-sighted measurements in the 0.76-μm O_2 A-band provide direct constraints on the total (dry-air) atmospheric pressure of the reflecting surface. This information must be combined with the CO_2 column estimates to derive X_{CO2}. Aircraft studies show that A-band observations can provide surface-pressure estimates with accuracies of ~1 millibar (O'Brien and Mitchell, 1992). A-band spectra also provide a sensitive indicator of clouds and optically thick aerosols, which preclude full-column measurements of CO_2.

Spectra of the strong 2.06-μm band provide independent constraints on the aerosol optical properties at near-infrared wavelengths, dramatically improving the accuracy of X_{CO2} retrievals in aerosol-laden conditions. Bore-sighted measurements in this band also provide direct constraints on the atmospheric temperature and humidity along the optical path, minimizing systematic errors associated with uncertainties in these parameters. A single 'sounding' consists of bore-sighted spectra in the 0.76-μm O_2 A-band and the CO_2 bands at 1.61 μm and 2.06 μm.

The spectral range of each channel includes the complete molecular absorption band as well as some nearby continuum to provide constraints on the optical properties of the surface albedo and aerosols. The spectral resolving power for each channel was selected to maximize the sensitivity to variations in the column abundances of

CO_2 and O_2 and to minimize the impact of systematic measurement errors. A spectral resolving power, $\lambda/\Delta\lambda > 20{,}000$ separates individual CO_2 lines in the 1.61- and 2.06-μm regions from weak H_2O and CH_4 lines and from the underlying continuum. For the O_2 A-band, a resolving power of ~17,000 is needed to distinguish the O_2 doublets from the continuum. With these resolving powers, the OCO retrieval algorithm can characterize the surface albedo throughout the band and solve for the wavelength dependence of the aerosol scattering, minimizing X_{CO2} retrieval errors contributed by uncertainties in the continuum level.

Spatial and Temporal Sampling Approach

The primary advantage of space-based X_{CO2} measurements is their global coverage and dense spatial sampling. OCO will fly at the front of the Earth Observing System (EOS) Afternoon Constellation (A-Train), about 15 minutes ahead of the Aqua platform. OCO will have a 1:15-p.m. equator crossing time and will share its ground track with Aqua. This local time of day is ideal for spectroscopic observations of CO_2 in reflected sunlight because the Sun is high, maximizing the measurement signal-to-noise ratio, and because the CO_2 concentrations are near their diurnally-averaged values at this time of day. This orbit also facilitates direct comparisons of OCO observations with measurements taken by Aqua, Aura, and other A-Train missions. The orbit's 16-day repeat cycle facilitates monitoring X_{CO2} variations on semi-monthly intervals.

While many X_{CO2} soundings are needed to adequately characterize the CO_2 variations on regional scales, contiguous spatial sampling is not required because CO_2 is transported over a large area 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. Clouds and optically thick aerosols preclude measurements of the complete column. Large topographic variations and other sources of spatial inhomogeneity within individual soundings can also introduce systematic biases that can compromise the accuracy of X_{CO2} retrievals.

To obtain enough useful soundings to accurately characterize the X_{CO2} distribution on regional scales, even in the presence of patchy clouds, the OCO instrument continuously records 4 soundings along a 0.4°-wide cross-track swath at 3 Hz, yielding 12 soundings/s. As the spacecraft moves along its ground track at 6.78 km/s, each sounding will have a surface footprint with dimensions of ~1.29 km × 2.25 km at nadir, and ~196 soundings are recorded over each 1^o-latitude increment along the orbit track.

OCO will collect science observations in Nadir, Glint, and Target modes. The same data sampling rate (12 soundings/s) is used in all three modes. In Nadir mode, the satellite points the instrument to the local nadir, so that data can be collected along the ground track just below the spacecraft. Science observations will be collected at all latitudes where the solar zenith angle is less than 85°. This mode provides the highest spatial resolution on the surface and is expected to return more usable soundings in regions that are partially cloudy or have significant surface topography. However,

Key OCO Instrument Facts

Heritage: The OCO instrument and measurement approach are new. However, key instrument components (optical approach, holographic grating, cryocooler, detectors) have been flight qualified for other missions, including the Total Ozone Mapping Spectrometer (TOMS), Atmospheric Infrared Sounder (AIRS), and Tropospheric Emission Spectrometer (TES).

Instrument Type: Three high-resolution grating spectrometers

Sampling Modes: Nadir, glint, and target (see text for details)

Spectral Range: 3 spectral channels (see table)

Standard Profile Spacing: 2.25 km (downtrack) × 1.29 km (crosstrack)

Spatial Resolution: 1.29 km × 2.25 km

Spectral Range and Resolving Power of Bands:

Minimum Wavelength
- O_2 A-Band: 0.758 μm
- Weak CO_2: 1.594 μm
- Strong CO_2: 2.042 μm

Maximum Wavelength
- O_2 A-Band: 0.772 μm
- Weak CO_2: 1.619 μm
- Strong CO_2: 2.082 μm

Resolving Power ($\lambda/\Delta\lambda$)
- O_2 A-Band: > 17,000
- Weak CO_2: > 20,000
- Strong CO_2: > 20,000

Dimensions: 1.6 m × 0.4 m × 0.6 m

Mass: < 150 kg

Power: < 165 W

Thermal Control: Active cryocooler and radiators

System Temperature:
- Optics: 268–273 K
- Detectors: 120–180 K

Field of View (FOV): 14-mrad wide cross-track swath

IFOV: ~0.09 mrad (single pixel)

Incidence Angle: Nadir, sun glint, or targeting of a stationary surface site these nadir observations may not provide adequate signal to noise over dark ocean surfaces.

The Glint mode was designed to 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 should provide much higher signal-to-noise ratios over the ocean. 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 Earth is mapped in each mode on roughly monthly time scales.

Finally, Target mode will be used to observe specific stationary surface targets as the satellite flies overhead. A Target track pass can last for up to 9 minutes, providing more than 6,480 samples over a given site at emission angles between 0° and ±85°. Target Track passes will be conducted over each OCO validation site at monthly intervals.

Validation Program

The OCO team is currently developing techniques to verify the accuracy of the space-based X_{CO2} measurements acquired from space. The validation program is based on measurements of X_{CO2} from a network of ground-based, solar-looking, Fourier Transform Spectrometers that obtain nearly continuous observations throughout the sunlit portion of the day, in the same spectral regions as the space-based grating spectrometers. The OCO project will also use *in situ* observations of the CO_2 mixing ratio from flasks, continuous sensors, tall towers, and aircraft. Precise laboratory instruments will determine the strengths, widths, and positions of the absorption lines to the level of precision required for proper interpretation of the atmospheric spectroscopic measurements. Research scientists will employ all of these sources of information to calibrate, verify, and improve the accuracy of the space borne OCO X_{CO2} measurements.

OCO Partners

NASA JPL leads the OCO project and is developing the science data system for the mission. Two primary partners are working with JPL. Orbital Sciences Corporation is responsible for manufacturing the spacecraft and for launch and ground operations, while Hamilton Sundstrand Sensor Systems is building the instrument.

OCO Instrument Technical Details

The observatory carries a single instrument that incorporates three high-resolution grating spectrometers, fed by a common telescope. Spatially resolved spectroscopic measurements of reflected sunlight in near infrared CO_2 and molecular oxygen (O_2) bands are used to retrieve X_{CO2}:

Key OCO Instrument Facts

(cont.)

Duty Cycle: On continuously, but science data are recorded only over the sunlit hemisphere.

Data Rate: ~1 mbps for 54 min each orbit

Transmission Frequency: X-band downlink, S-band uplink

Repeat Cycle: 16 days

Sampling Interval: 12–24 samples/s

Accuracy: Single sounding X_{CO2} accuracy of better than 2%, regional-scale X_{CO2} accuracy of 0.3% on monthly time scales

Calibration:

Absolute Radiometric: Diffuse solar spectrum transmitted through the entire optical system.

Relative Radiometric: Lamp 'flat fields' reflected from diffuser plate within each channel and diffuse solar observations for channel-to-channel.

Spectral Wavelength: Measurement of absorption-line positions in routine science observations.

Spectral Line Shape: Solar lines and high-altitude atmospheric lines observed with limb views.

Pointing: Bright stars observed to identify static pointing errors.

- The CO_2 column abundance is inferred from high-spectral-resolution ($\lambda/\Delta\lambda$ ~20,000) observations of the weak CO_2 band near 1.61 μm;

- Bore-sighted, high-spectral-resolution ($\lambda/\Delta\lambda$ ~17,000) measurements of the 0.76-μm O_2 A-band are used to infer the total atmospheric mass (surface pressure), and to assess the effects of clouds, aerosols, and surface topography on the photon path-length distribution;

- High-spectral-resolution ($\lambda/\Delta\lambda$ ~20,000) measurements in the strong CO_2 band near 2.06 μm provide additional constraints on the CO_2 column abundance and the effects of aerosols on the photon path length.

OCO Data Products

Product Name or Grouping	Processing Level	Coverage	Spatial/Temporal Characteristics
OCO Instrument			
Calibrated Radiance–Spectra of O_2 A-band, 1.61-and 2.06-μm CO_2 bands	1B	Atmospheric Column	1.29 km × 2.25 km horizontal resolution/ 16 days
Column-Averaged Dry-Air Mole Fraction, X_{CO2}	2	Atmospheric Column	1.29 km × 2.25 km horizontal resolution/ 16 days

OCO Data Products