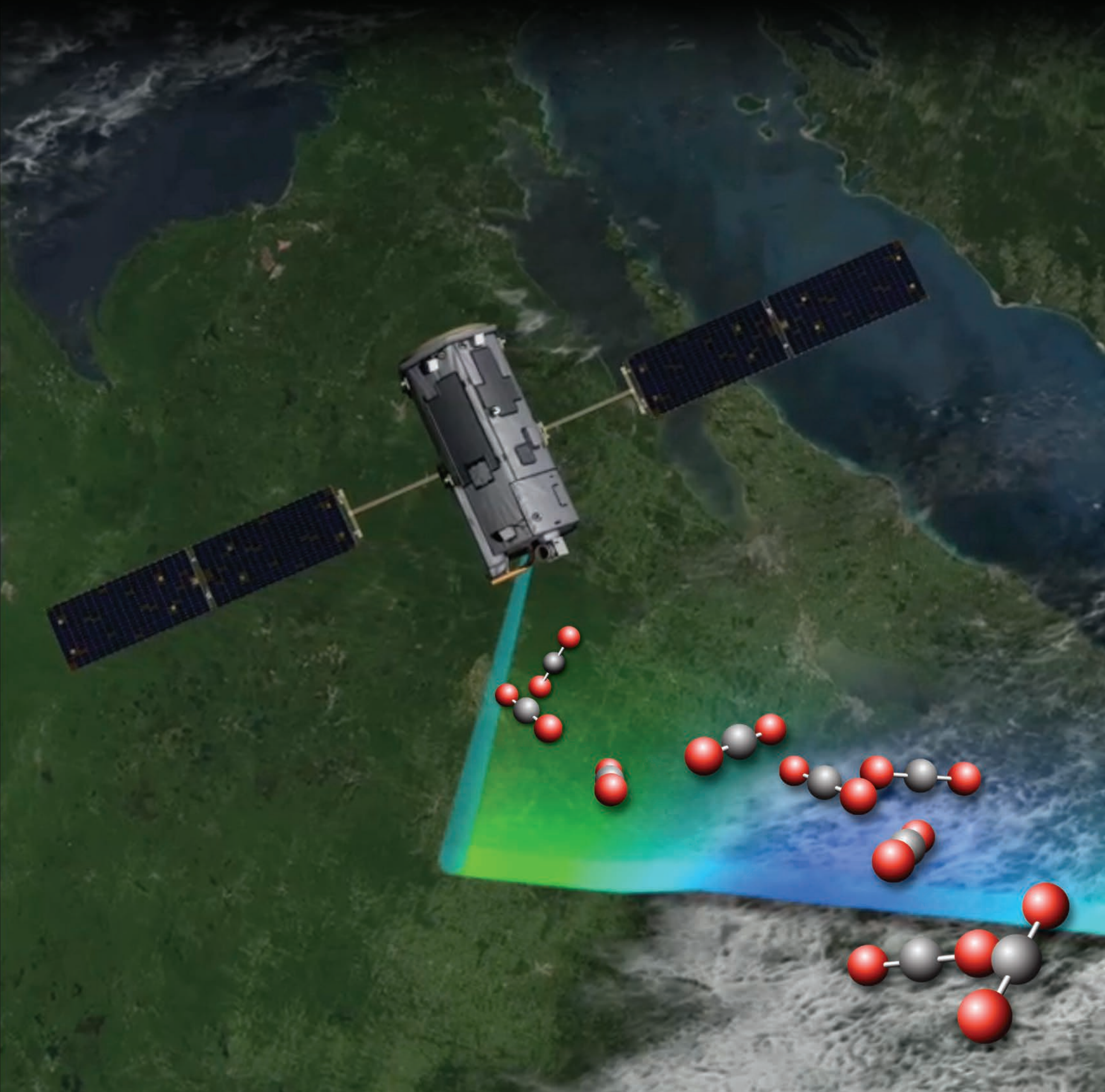
National Aeronautics and Space Administration

Orbiting Carbon Observatory-2 (OCO-2)

Watching the Earth Breathe…Observing CO_2 from Space



Acknowledgements

OCO-2 Websites
www.nasa.gov/oco2
oco.jpl.nasa.gov

Special thanks to the Orbiting Carbon Observatory-2 Science Team for making this publication possible.

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Carbon Dioxide in the Earth System

Photo credit: pfly

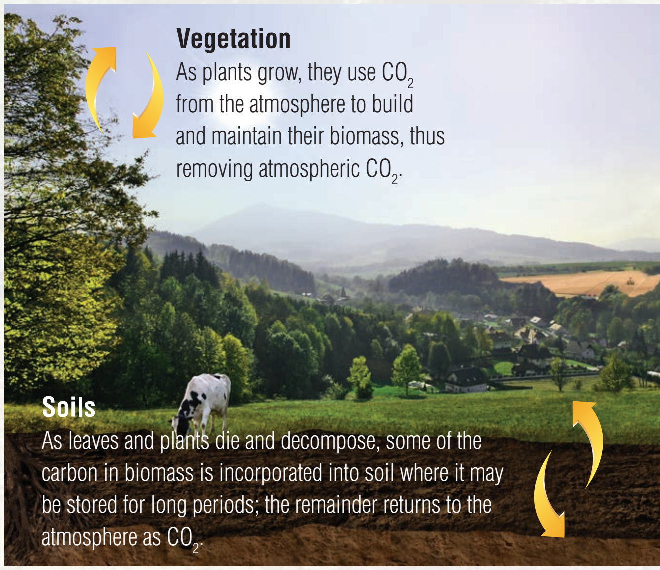
Life as we know it would not exist without carbon. All living and once-living things (i.e., biomass) are made of carbon, the fourth most abundant element in our universe. Carbon—in its many forms (e.g., carbon, carbon dioxide, carbon monoxide)—can be released into the atmosphere or absorbed from the atmosphere by processes at the surface. The continual exchanges of carbon between the atmosphere, oceans, and terrestrial ecosystems define Earth's global *carbon cycle*. Carbon moves more quickly through some parts of the carbon cycle than others. For example, respiration is a rapid process compared to the lifetimes of trees, carbonate rocks, or fossil fuels.

All living and once-living things (i.e., biomass) are made of carbon, the fourth most abundant element in our universe. Carbon—in its many forms (e.g., carbon, carbon dioxide, carbon monoxide)—can be released into the atmosphere or absorbed from the atmosphere by processes at the surface.

Carbon dioxide, also known by its chemical formula as CO_2, is the most abundant carbon bearing gas, and plays a special role in the carbon cycle. From an atmospheric perspective, *sources* emit or release carbon into the atmosphere, primarily as CO_2, while *sinks* remove CO_2 from the atmosphere. For example, plants act as CO_2 sinks when they absorb sunlight and CO_2 from the atmosphere to produce carbohydrates through *photosynthesis*. As plants grow, they accumulate carbon within their roots, stems, and leaves. When plants die, they become sources as their biomass begins to decay, returning an almost equal amount of carbon to the atmosphere as CO_2. The ocean also exchanges CO_2 with the atmosphere, absorbing more CO_2 where surface waters are cold, and re-emitting it back to the atmosphere where the surface waters are warmer. As CO_2 dissolves in seawater, it forms carbonic acid and carbonate for the shells and bones of sea creatures. Cold, dense, CO_2-rich water that forms at high latitudes can sink and be transported great distances to lower latitudes before ascending to the surface again where it can release CO_2 back to the atmosphere. These physical, chemical, and biological processes cause carbon to accumulate within the oceans, much of it away from surface exchange with the atmosphere for centuries and longer. Collectively, these natural processes are roughly balanced, absorbing about as much CO_2 as they emit.

Since the beginning of the industrial age, however, humans have disrupted this balance. For example, each time humans use coal or natural gas (e.g., methane) to generate electricity, drive a petroleum-powered car, cut down a forest, or ignite a forest fire, CO_2 is released into the atmosphere—and unlike the natural processes described above, these human activities absorb little or no CO_2 in return. Such activities have and continue to produce rapid increases in atmospheric CO_2, currently adding approximately 36 billion tons of CO_2 to the atmosphere each year. Fossil fuel combustion is the largest and most rapidly growing source of CO_2 emission into the atmosphere, with global growth rates of 2.2% per year. Since the turn of the century, the

The Carbon Cycle



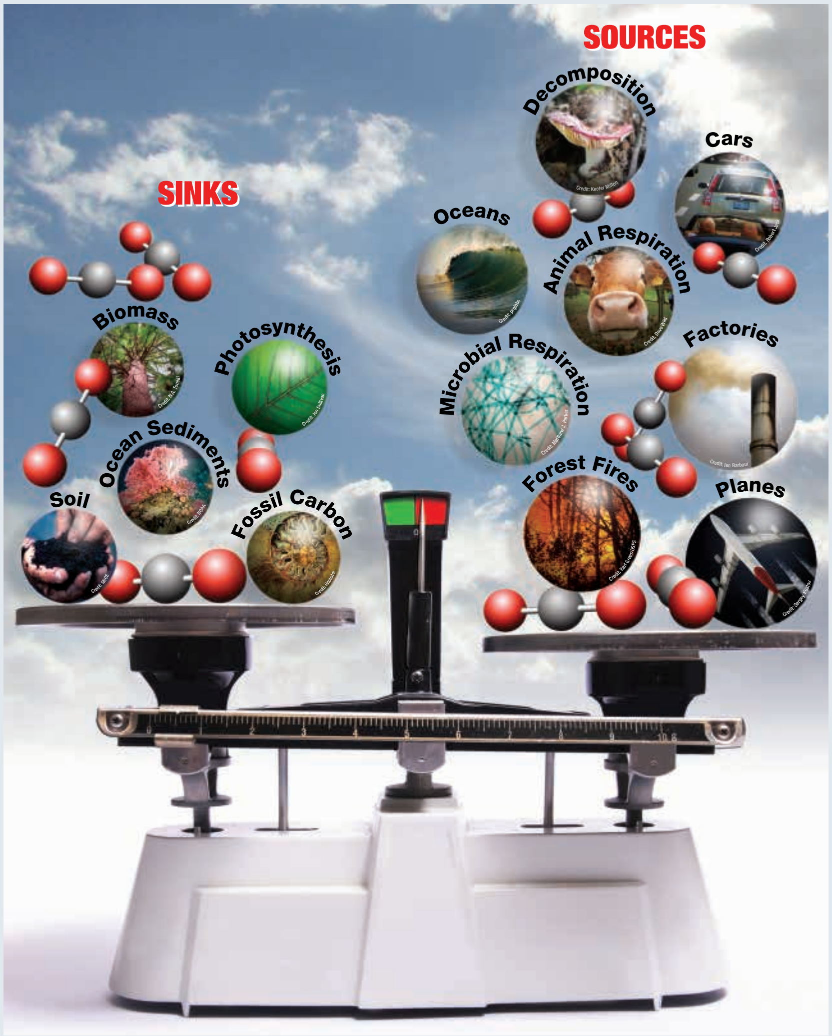
Vegetation

As plants grow, they use CO_2 from the atmosphere to build and maintain their biomass, thus removing atmospheric CO_2.

Soils

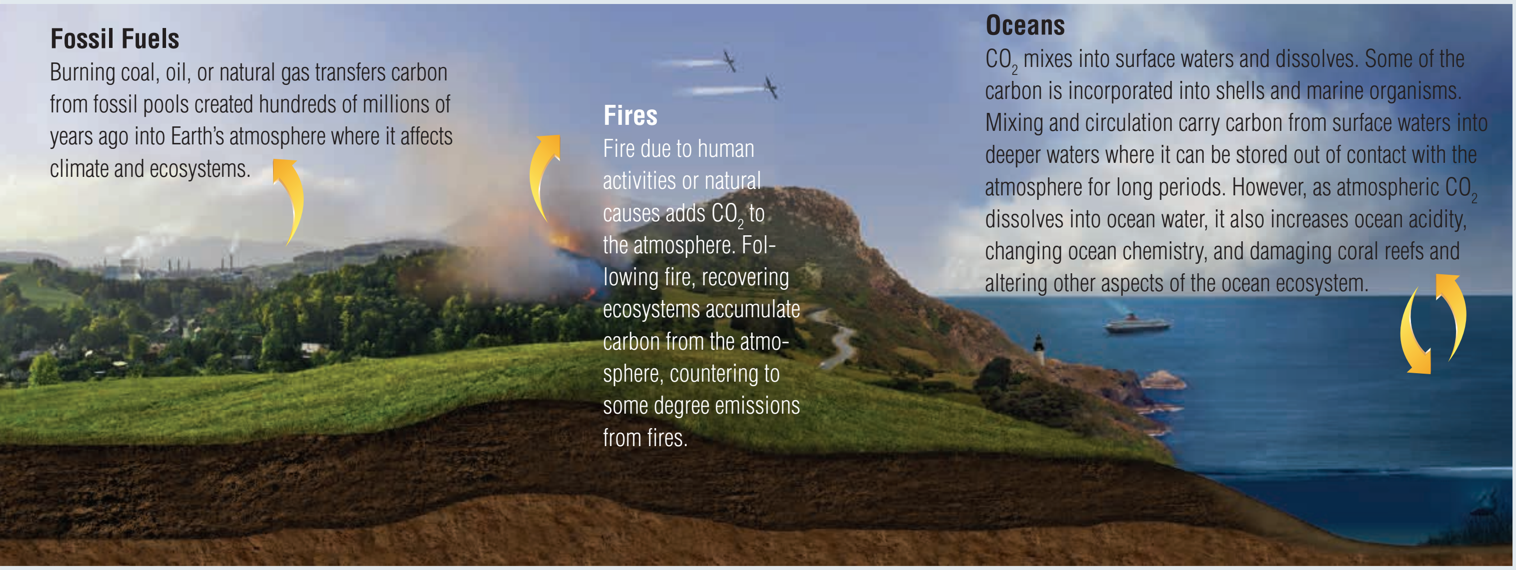
As leaves and plants die and decompose, some of the carbon in biomass is incorporated into soil where it may be stored for long periods; the remainder returns to the atmosphere as CO_2.

largest increases have occurred in the developing world, which is now responsible for 57% of all CO_2 emissions. Changes in land use (e.g., clearing forests) are the second largest source; however, this source has decreased from almost 17% of the total emissions in 1990, to about 8% today. In many instances, forests and other vegetated land areas previously harvested for wood or to grow crops will experience natural (or intentional) regrowth, called *reforestation*. This allows an area cleared for wood or crops multiple decades ago to act as a carbon sink again, removing CO_2 from the atmosphere. However, not all carbon sinks are replenished, and large-scale fluctuations in these reservoirs affect the global carbon cycle, ultimately impacting Earth's climate system.



[*Right*] Although natural and anthropogenic (i.e., human-induced) sources and sinks can be found almost anywhere in the world, human activities are causing the sources of carbon to outweigh the sinks. Such activities are contributing to a rise in atmospheric CO_2, which impacts Earth's climate system. Note that this diagram does not include all carbon sources and sinks.

This diagram [*below*] depicts the different ways carbon is cycled through Earth's environment, called the global carbon cycle.



Fossil Fuels

Burning coal, oil, or natural gas transfers carbon from fossil pools created hundreds of millions of years ago into Earth's atmosphere where it affects climate and ecosystems.

Fires

Fire due to human activities or natural causes adds CO_2 to the atmosphere. Following fire, recovering ecosystems accumulate carbon from the atmosphere, countering to some degree emissions from fires.

Oceans

CO_2 mixes into surface waters and dissolves. Some of the carbon is incorporated into shells and marine organisms. Mixing and circulation carry carbon from surface waters into deeper waters where it can be stored out of contact with the atmosphere for long periods. However, as atmospheric CO_2 dissolves into ocean water, it also increases ocean acidity, changing ocean chemistry, and damaging coral reefs and altering other aspects of the ocean ecosystem.

Photo credit: NASA/Jenny Mottar

Where is the Carbon Going?

> Scientists need to understand the processes that are controlling the buildup of CO_2 in Earth's atmosphere today so they can predict how fast CO_2 will accumulate in the future.

Because CO_2 reacts very slowly with ultraviolet radiation and other atmospheric gases, most of the CO_2 that we emit today will remain in the atmosphere for several hundred years. As this long-lived gas mixes in Earth's atmosphere and is transported around the globe and throughout the carbon cycle, it will continue to impact our planet. Scientists need to understand the processes that are controlling the buildup of CO_2 in Earth's atmosphere today so they can predict how fast CO_2 will accumulate in the future.

Scientists have estimated the amount of CO_2 emitted into the atmosphere from inventories of fossil fuel use, forest clearing, and industrial activity. These studies show that between 1750 and 2003, human activities have released between 1900 and 2460 billion tons of CO_2 to the atmosphere[1]. Fossil fuel combustion and cement manufacturing (building new neighborhoods and infrastructure) account for approximately 65% of the accumulated emissions over that period. Most of the rest has been attributed to land-use changes such as deforestation.

To monitor the impact of these emissions on the atmosphere, scientists rely on more than 150 ground-based measurement stations around the world to collect precise measurements of atmospheric CO_2. These measurements show that the atmospheric CO_2 concentration has grown by more than 40%, from approximately 280 parts

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[1] C. Le Quéré, G. Peters, *et al.* "Global Carbon Budget 2013," Earth System Science Data Discussions (in review), www.earth-syst-sci-data-discuss.net/6/689/2013, DOI:10.5194/essdd-6-689-2013.

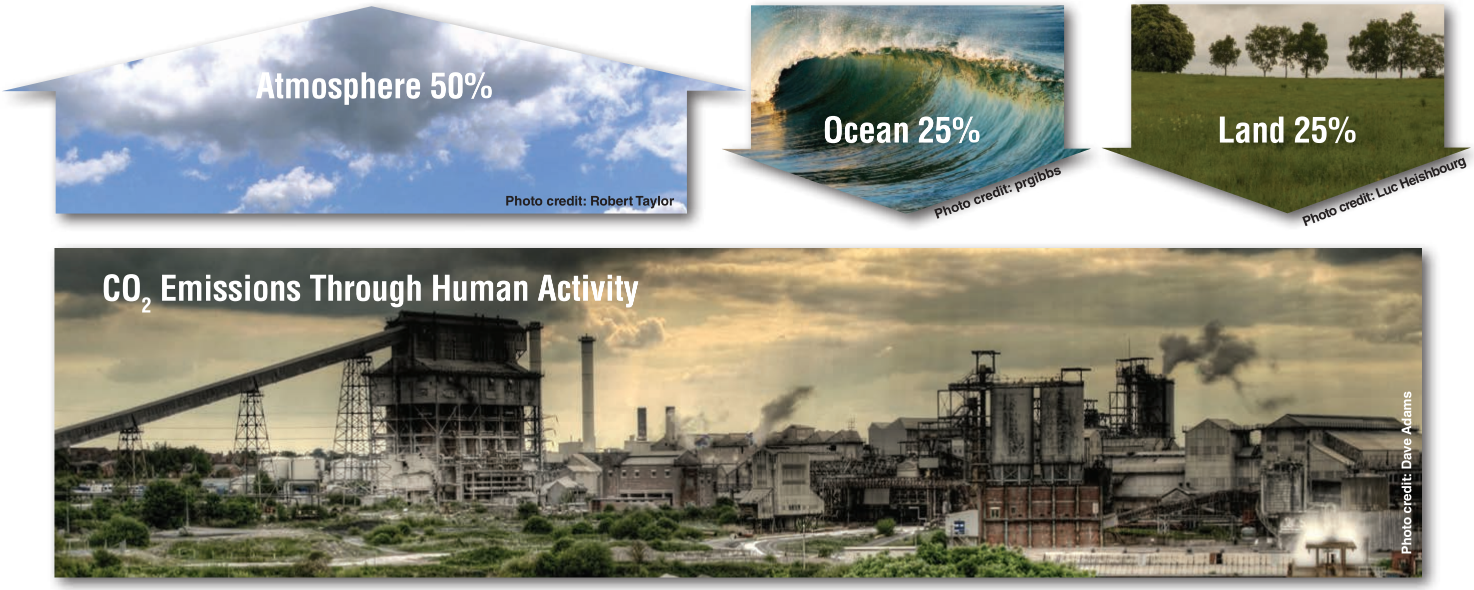


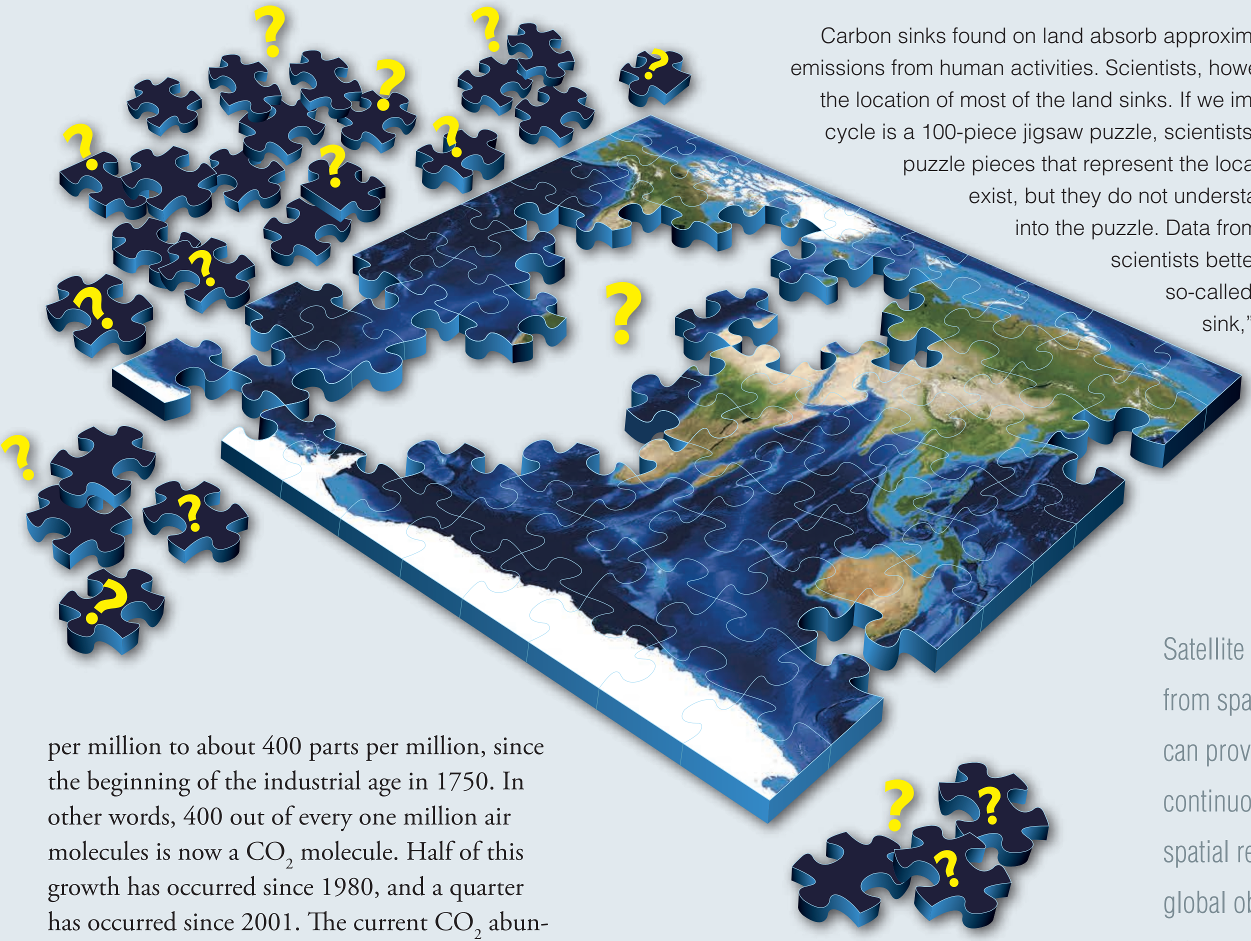
Photo credit: Robert Taylor

Photo credit: prgibbs

Photo credit: Luc Heishbourg

Photo credit: Dave Adams

Approximately half of the CO_2 emissions from human activities stay in the atmosphere, while oceans and land sinks absorb the rest. Data from OCO-2 will help scientists better understand these sinks and their locations. Note: While there is substantial year-to-year variability, these percentages reflect the long-term average.



Carbon sinks found on land absorb approximately 25% of CO_2 emissions from human activities. Scientists, however, do not know the location of most of the land sinks. If we imagine the carbon cycle is a 100-piece jigsaw puzzle, scientists know that the 25 puzzle pieces that represent the location of land sinks exist, but they do not understand where they fit into the puzzle. Data from OCO-2 will help scientists better understand this so-called "missing-carbon sink," allowing them to piece together the puzzle.

per million to about 400 parts per million, since the beginning of the industrial age in 1750. In other words, 400 out of every one million air molecules is now a CO_2 molecule. Half of this growth has occurred since 1980, and a quarter has occurred since 2001. The current CO_2 abundance is now increasing by more than 2 parts per million (0.5%) each year.

Interesting, this rapid buildup of CO_2 accounts for less than half of the 36 billion tons of CO_2 emitted into the atmosphere each year from fossil fuel use and other human activities. The remainder is apparently being absorbed by processes at the surface. Measurements of the increasing acidity of seawater indicate that at least one quarter of the CO_2 emitted by human activities is being absorbed by the ocean. The remaining quarter is presumably being absorbed by the land biosphere, but the identity, location, and processes controlling this sink are currently unknown. Scientists refer to this mystery as the "missing-carbon sink."

Despite decades of research that have steadily increased our understanding of the global carbon cycle, scientists still face tremendous challenges as they try to understand the processes controlling the increased rate of CO_2 buildup in the atmosphere. For example, characterizing intense localized sources of CO_2 associated with fossil fuel combustion is much easier than distinguishing and quantifying natural sources and sinks such as CO_2 emitted from oceans, deforestation, and biomass burning. This is due in part to large gaps between ground-based instrument sites and thus limited availability of precise measurements.

Satellite observations from space, however, can provide the continuous, high spatial resolution, global observations of CO_2 that are needed to help answer the question of where the carbon is going. That is why NASA is flying the Orbiting Carbon Observatory–2, or OCO-2 mission. OCO-2 will collect a million measurements over the sunlit hemisphere each day. Less than 20% of these measurements are expected to be sufficiently cloud free to yield precise estimates of CO_2, however, OCO-2 will still yield over a million new measurements each week. These data will help scientists understand where CO_2 is being emitted and removed from the atmosphere and how much of it is from natural processes and human activities, subsequently allowing them to make realistic projections of how Earth's climate might respond to these changes.

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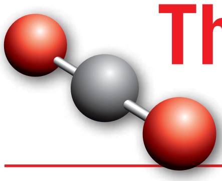


The OCO-2 Mission

Today, one of the important decisions facing scientists and governments around the world is: What can or should we do about CO_2 emissions? The answers are not simple. But OCO-2 can provide scientists and policymakers with important new data for making better-informed decisions. After all, we can only manage what we can measure!

With the launch of the OCO-2 spacecraft, NASA will have an important new tool for studying and understanding the fundamental processes that control the accumulation of CO_2 in the atmosphere now and in the future. OCO-2 is not the first satellite designed to measure atmospheric CO_2, but it is the first to provide the precision, resolution, and coverage necessary to observe regional carbon sources and sinks.

When CO_2 is emitted into the atmosphere from a source, or absorbed from the atmosphere by a sink, the resulting CO_2-rich or CO_2-poor air is rapidly mixed and transported by winds. This rapid mixing can dilute the CO_2 signature quickly, partially obscuring the sources and sinks. To account for this, the OCO-2 instrument has been optimized to collect high-precision measurements spanning all layers of the atmosphere, from the sensor to Earth's surface. Furthermore, the instrument has been designed to collect the most sensitive measurements for the layer closest to Earth's surface—where we live and breathe, and where variations in CO_2 are greatest. OCO-2's high-precision instrument is essential for this mission and data from OCO-2 will provide scientists with an unprecedented amount of new information about CO_2 emissions on regional scales.

Such data will provide scientists direct insight into the impact of land-use changes on CO_2 absorption and emission. With a better understanding of the location and contribution of natural processes involved in CO_2 absorption, decision makers will be able to more effectively manage our planet's natural resources and design and implement strategies that minimize human impact on the climbing atmospheric CO_2 rate.

Measurements from OCO-2 will also be used in conjunction with measurements from ground-based stations, aircraft, and satellites operated by NASA and its international partners to help answer important questions about Earth's climate. For example, OCO-2 data will be combined with measurements of water vapor and methane—other greenhouse gases—from NASA's Aqua and Aura spacecrafts and the Japanese Greenhouse Gases Observation Satellite (GOSAT, nicknamed, "Ibuki") mission, to more fully understand the contribution of greenhouse gases to climate change. OCO-2 data will be supplemented with measurements of other atmospheric gases—such as tropospheric ozone and nitrogen dioxide—from NASA's Aura mission to study the relationship between CO_2 and other gases associated with air pollution. By combining Earth-observation data from multiple sources, scientists can view the Earth as one interconnected system of systems; better understand how humans are contributing to climate change; and improve computer predictions of how climate will change in the future.

The First Orbiting Carbon Observatory

Launched in February 2009, NASA's original Orbiting Carbon Observatory (OCO) spacecraft was designed to provide the most accurate atmospheric measurements of CO_2 ever made from space. Data from OCO were expected to show the location of carbon sources and sinks, and help improve scientists understanding of the global carbon cycle. Sadly, the mission was lost in a launch failure when the payload fairing of the Taurus launch vehicle failed to separate during ascent.

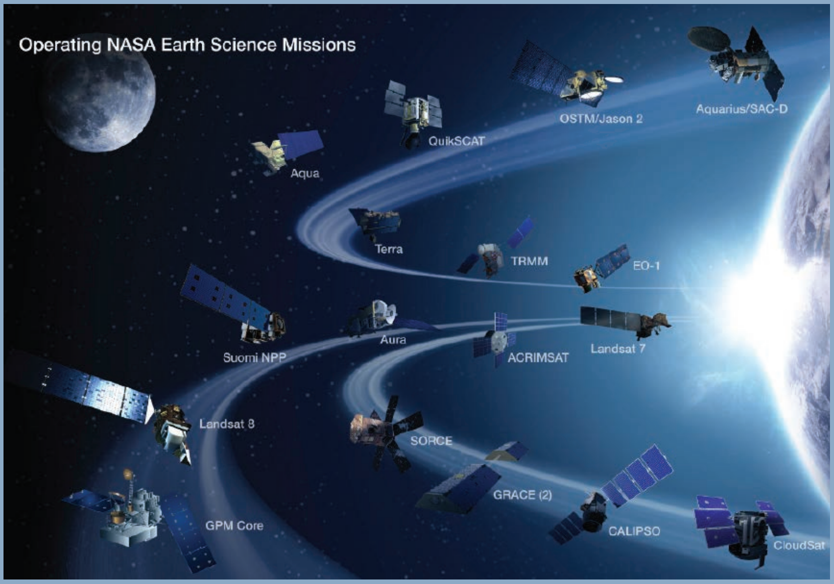
In 2010, NASA decided to support the second OCO mission, now known as OCO-2. NASA's OCO-2 mission will obtain the important scientific measurements "lost" as a result of the first OCO and is slated for launch in July 2014. OCO-2 will launch aboard a Delta II rocket from Vandenberg Air Force Base in California.

Prior to launch, the OCO and GOSAT science teams formed a close partnership to cross calibrate instruments and validate CO_2 retrievals. GOSAT was successfully launched on January 23, 2009, and has been returning routine measurements of CO_2 and methane (CH_4) since mid 2009. After the OCO launch failure in February, the GOSAT science team reached out to NASA and invited the OCO science team to participate in GOSAT data analysis, allowing them to use data from GOSAT to test the algorithms developed for OCO data. Collaboration between the two science teams has continued for many years and is expected to enhance data retrievals from OCO-2 and GOSAT-2.

Observing the Global Carbon Cycle and Earth's Changing Climate

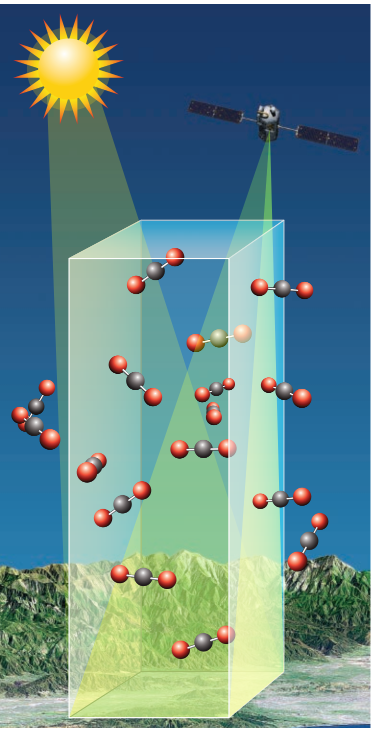
Since the 1970s NASA has played a continuous and critical role in studying the global carbon cycle and Earth's climate. Over the years, NASA has paved the way for global Earth observation through the use of satellite remote sensing technology, building a fleet of Earth-observing satellites that have helped the Agency meet specific scientific objectives for studying Earth's land, oceans, and atmosphere.

Currently there are 17 operating NASA Earth science satellite missions. OCO-2 will make 18. Each satellite has provided new perspectives and data that have helped us better understand our home planet as a complex system. The Landsat series, the oldest U.S. land surface observation system, allowed the world to see seasonal and inter-annual land surface changes. The ocean's role in the global carbon cycle and ocean primary productivity (rate of carbon fixation from the atmosphere) was first studied using data from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), which also helped to estimate the rate of oceanic carbon uptake. Ocean color and photosynthetic activity are measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments onboard the Terra and Aqua satellites, and more recently by the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite. NASA studies the atmosphere and weather with the Atmospheric Infrared Sounder (AIRS) on Aqua, which is tracking the most abundant greenhouse gas—water vapor—as well as mid-tropospheric CO_2. The launch of OCO-2 will continue these essential measurements that are needed to further our scientific understanding.



Currently, NASA operates 17 Earth-observing satellite missions. Measurements of multiple variables, across multiple scales can provide the "big-picture view" scientists need to understand our planet's ever-changing environment.

The OCO-2 Instrument



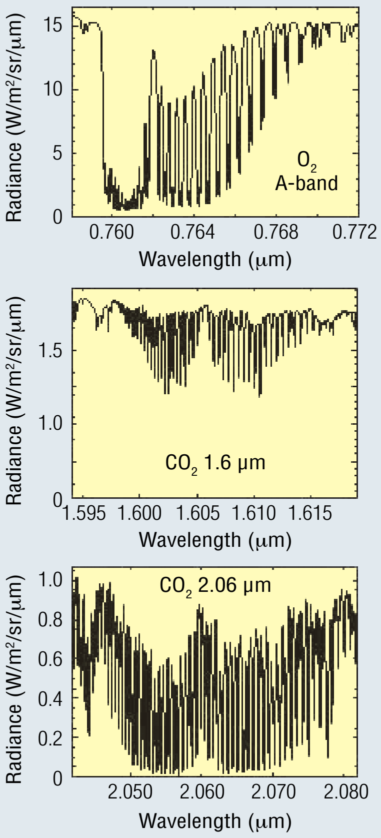
This artist illustration shows how OCO-2 will sample the CO_2 molecules in a column from the reflected sunlight, all the way down to the surface.

CO_2 is a long-lived gas that is well mixed throughout the atmosphere by winds. Because there is already a relatively large amount of CO_2 in the atmosphere, its largest known sources and sinks produce differences in its concentration no larger than a few percent on spatial scales of 1000 kilometers, and typical variations are no larger than 0.25% (1 part per million (ppm) out of the ambient 400 ppm background).

To do so, the OCO-2 spacecraft carries and points a single instrument that consists of three, high-resolution *spectrometers*—instruments that separate sunlight into its component colors. As sunlight passes through Earth's atmosphere and is reflected from Earth's surface, molecules of atmospheric gases absorb very specific colors of light. If the light is divided into a rainbow of colors, called a "spectrum," the specific colors absorbed by each gas appear as narrow, dark "absorption lines." Each spectrometer uses a reflective *diffraction grating* (like the back of a compact disk) to separate the incoming light into a spectrum of colors. Different gases absorb different colors, so the pattern of absorption lines provides a telltale spectral "fingerprint" for a particular molecule.

The OCO-2 instrument will use a *diffraction grating* (like the back of a compact disk) to separate the incoming sunlight into a spectrum of multiple component colors.

OCO-2's spectrometers have been designed to detect the spectral fingerprints of CO_2 as well as molecular oxygen (O_2) in the near-infrared part of the electromagnetic spectrum, invisible to the human eye. Specifically, the spectrometers will make simultaneous measurements of the CO_2 and O_2 absorption of sunlight that has been reflected off the same location on Earth's surface. The amount of absorption observed in these spectra increases with the abundance of molecules along the optical path followed by the sunlight. If the amount of CO_2 varies from place to place, the amount of absorption will also vary.



Each of the three spectrometers onboard OCO-2 is tuned to measure the absorption in a specific range of colors that represent weak CO_2 (1.61 μm), strong CO_2 (2.06 μm), and O_2 (A-band). Each of these ranges includes dozens of dark absorption lines produced by either CO_2 or O_2. The amount of light absorbed in each spectral line increases with the number of molecules along the optical path. OCO-2's spectrometers measure the fraction of the light absorbed in each of these lines with very high precision. Scientists then analyze this information to determine the number of molecules along the path between the top of the atmosphere and the surface.

A number of factors can change the amount of CO_2 along the atmospheric path between the sun, Earth's surface, and the instrument, and only a few of these are associated with sources and sinks. For example, there are typically more CO_2 molecules above a deep valley than over an adjacent mountain range because there is a longer path and a larger atmospheric mass over the valley. Clouds and optically thick aerosols can also introduce uncertainties in the atmospheric path, as will instrument pointing errors.

One way to minimize the impact of these sources of uncertainty is to directly measure the abundance of CO_2 and that of the background atmosphere, and use these measurements to estimate the CO_2 concentration along the path. If one such measurement shows a relatively high CO_2 concentration, and another shows a relatively low CO_2 concentration, it is safe to assume that some process has enriched the first sample, indicating a source, while some process has depleted the other, indicating a sink. To estimate the CO_2 concentration along the optical path, the OCO-2 spectrometers will collect coincident measurements of CO_2 and molecular oxygen, O_2. These data will be combined to estimate the column-averaged CO_2 dry air mole fraction, XCO_2. O_2 is an ideal gas for estimating the total atmospheric dry air mass along the optical path because its concentration is constant, well known, and uniform throughout the atmosphere.

The instrument will record an image of the spectrum produced by each spectrometer three times every second as the satellite flies over the surface at more than four miles per second. Each image will be divided into eight discrete "footprints" along a ~10-kilometer wide field-of-view, and recorded for later transmission to the ground, yielding 24 "soundings" per second. At this rate, the instrument will gather between 67,000 and 71,000 individual measurements over a narrow ground track each orbit. The surface footprint of each measurement is about 1 square mile (just under 3 square kilometers).

The satellite will orbit the Earth 14.5 times each day in a 705 kilometer, sun-synchronous, 98.2-degree orbit with a 98.8 minute period and a 1:30 p.m. equator crossing time. Every 16 days, after 233 orbits, the spacecraft will return to the same ground track. Over each 233-orbit ground track repeat cycle, it will collect about 16,000,000 measurements, with orbit tracks separated by less than 1.5 degrees longitude (100 miles or 170 kilometers) at the equator. With measurement footprints of this size and density, the instrument can make an adequate number of high-quality soundings, even in regions with clouds, aerosols, and variations in topography.

Scientists will infer the location of carbon sources and sinks by analyzing OCO-2's data using computer models. The results from the models will allow them to piece together the missing-carbon puzzle and better understand the global carbon cycle.

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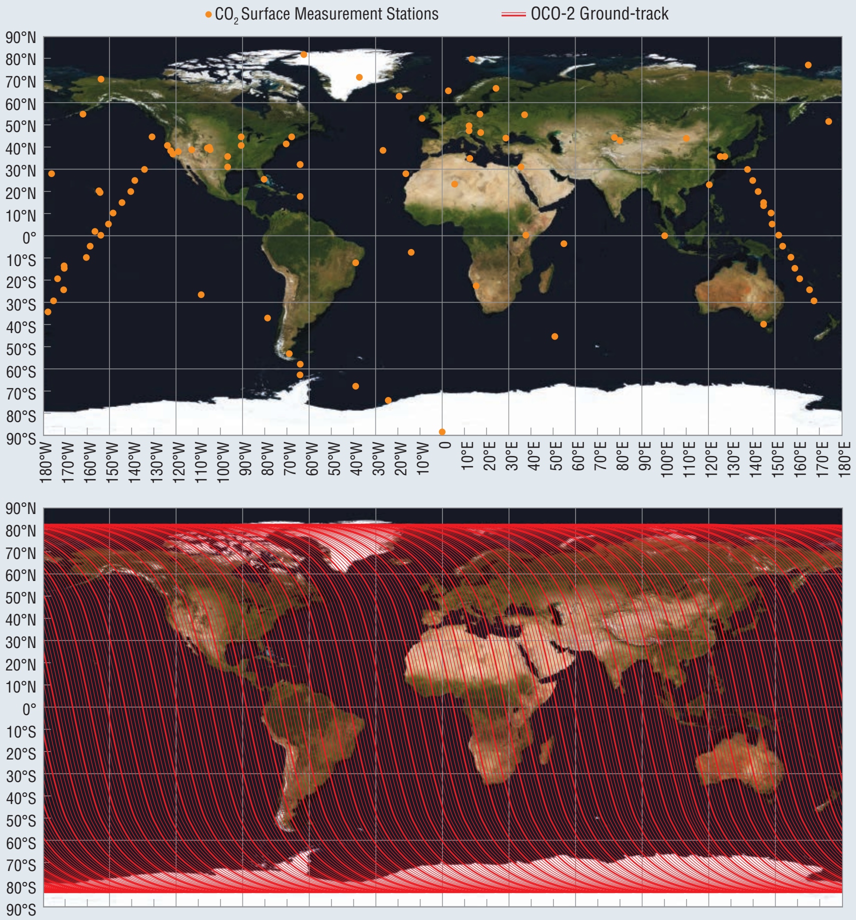
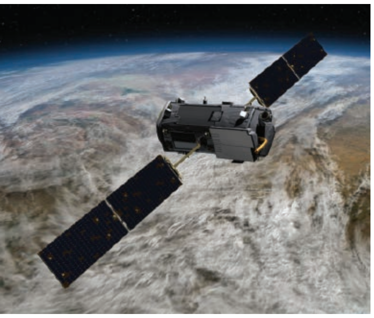


These maps compare the locations of ground-based instrument sites [*orange dots, top map*] to OCO-2's ground tracks [*red lines, bottom map*]. Data from OCO-2 will provide global observations of atmospheric CO_2 every 16 days. Scientists will use aircraft and ground-based measurements of CO_2 to validate OCO-2's data.

Spacecraft and Launch Vehicle

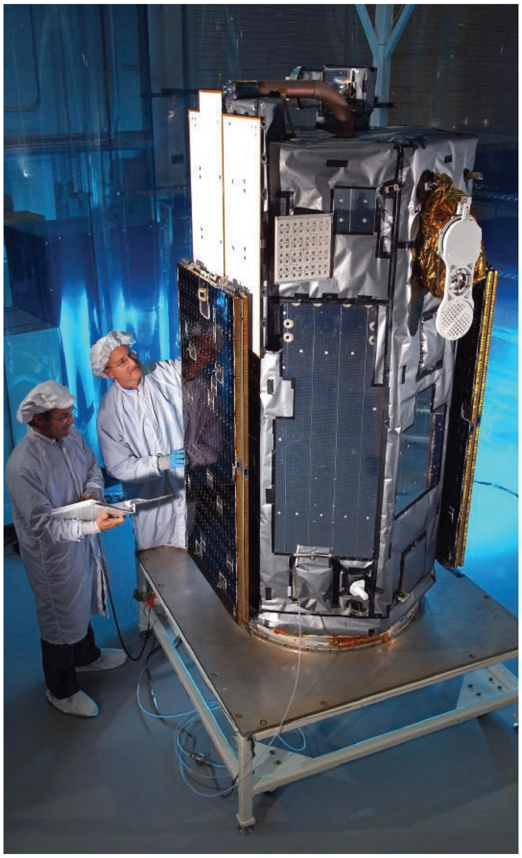


Planned to launch from Vandenberg Air Force Base in California, the spacecraft will operate in a polar orbit 705 kilometers (438 miles) above Earth's surface.

The LEOStar-2 multi-mission spacecraft bus—provided by Orbital Sciences Corporation—serves as the on-orbit service platform for OCO-2's three-channel grating spectrometer instrument. The spacecraft bus is made primarily of aluminum honeycomb panels that are both lightweight and strong, assembled to form a hexagonal structure approximately 1 meter (3.3 feet) in diameter and 2 meters (6.6 feet) tall. The structure contains most of the spacecraft bus components and much of the instrument. Measuring approximately 3 meters (10 feet) in length, the solar array wings are attached to both sides of the spacecraft by movable motors. The mass of the entire observatory, including the spacecraft bus and instrument, is approximately 450 kilograms (or 990 pounds).

An onboard computer, which was designed to operate in the harsh space radiation environment, will control both the spacecraft bus and the instrument. Special flight software running on the computer will allow the spacecraft to respond to commands stored in memory as well as those issued by ground controllers. The onboard telecommunications system will provide a link to the ground through a set of electronics and antennas that operate in the S-band—a set of frequencies that include those typically used for wireless connections in our homes and businesses. Science data will be transmitted from the observatory to the ground via the X-band antenna. Higher frequencies in the X-band region will allow the spacecraft to accommodate the quantity of data expected to be acquired by the instrument.

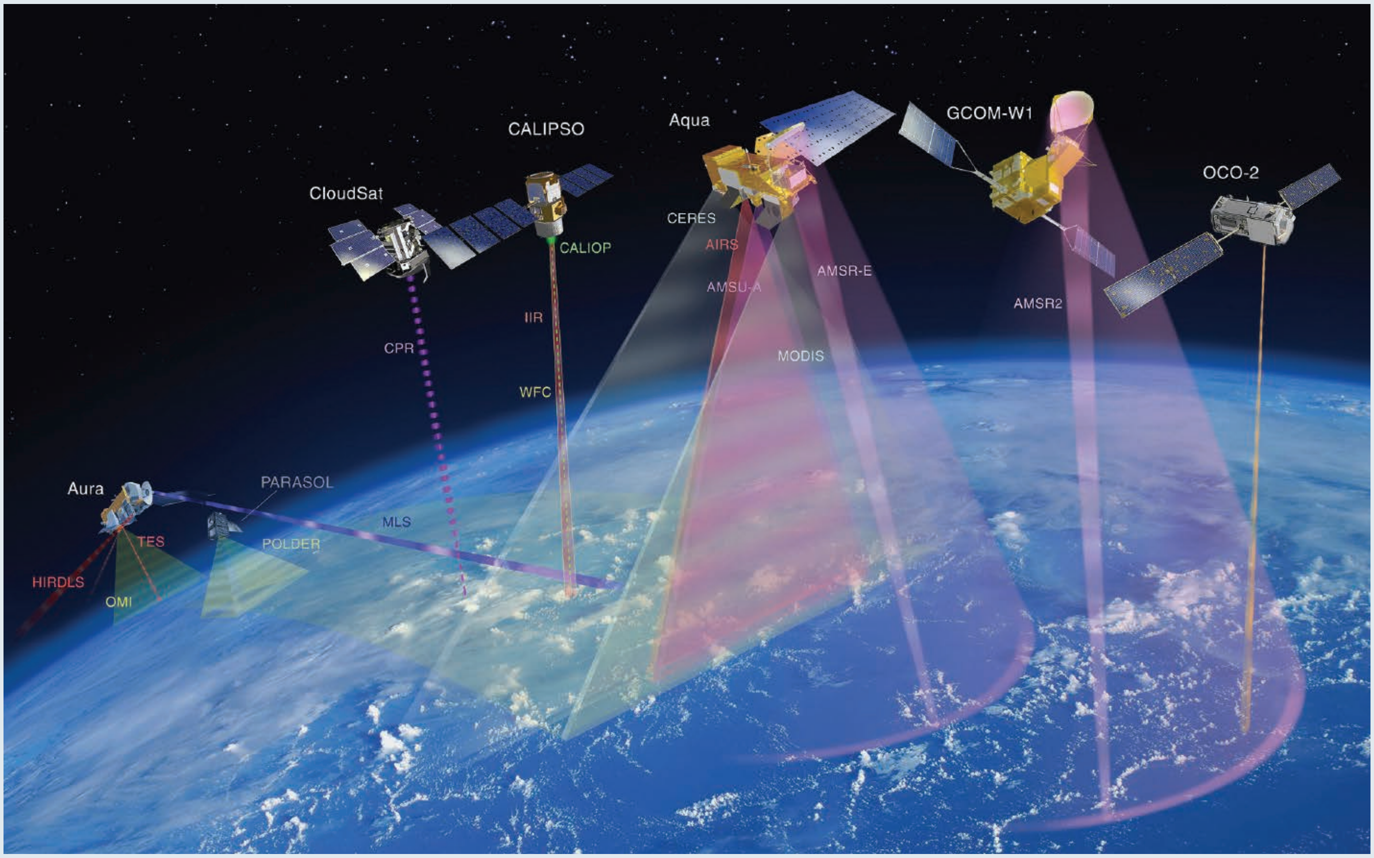
Solar array panels will provide electrical power when the observatory is operating in sunlight and a rechargeable battery (Ni-H_2) will provide power when the observatory is operating in the *umbra* (i.e., shadow of the Earth). A star tracker, inertial measurement unit, and global positioning system (GPS) will provide attitude determination (i.e., to assist the observatory in determining its orientation with respect to inertial space) and a set of momentum wheels will allow the instrument telescope to be trained in the proper direction. For example, the momentum wheels allow the telescope to look "directly downwards" in "Nadir Mode" and near the sun's reflection on the ocean in "Glint Mode."



Integration and Testing (I&T) personnel and the OCO-2 observatory (spacecraft bus and instrument) are shown in the image above. The solar array panels are in the stowed position, a configuration that allows the observatory to fit within the launch vehicle payload fairing.

On July 16, 2012, NASA selected the United Launch Alliance (ULA) Delta II *7320-10C* launch vehicle to carry OCO-2 into space. Planned to launch from Vandenberg Air Force Base in California, the spacecraft will operate in a polar orbit 705 kilometers (438 miles) above Earth's surface. The Delta II is part of a launch vehicle family that first entered service in 1989 and has recorded well over 140 successful launches to date. The Delta II has also been selected to place a number of other Earth-orbiting satellites into orbit including the Soil Moisture Active Passive (SMAP) mission and second Ice, Clouds, and land Elevation Satellite (ICESat-2) mission.

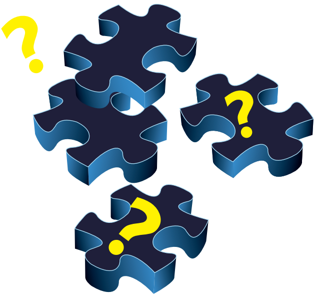
This image provides a view of the Delta II *7320-10C* launch vehicle looking into the nozzle end of one of the three Graphite Epoxy Motors that serve to double the thrust of the rocket to more than 500,000 pounds per force (thrust). Image credit: Steve Greenberg



NASA and its international partners operate several Earth-observing satellites that closely follow one after another along the same orbital "track," called the Afternoon Constellation, or A-Train. The satellites are in a polar orbit, crossing the equator northbound at about 1:30 p.m. local time, within seconds to minutes of each other. This allows near-simultaneous observations of a wide variety of parameters to aid the scientific community in advancing our knowledge of Earth-system science and applying this knowledge for the benefit of society. Five satellites currently fly in the A-Train: GCOM-W1, Aqua, CALIPSO, CloudSat, and Aura. PARASOL ceased operation on December 18, 2013. After launch, OCO-2 will join the A-Train and fly at the front of the configuration.

Serving Society and Making a Difference

The launch of OCO-2 will lead scientists down the right path in their quest to find those precious “missing pieces” of the carbon puzzle.



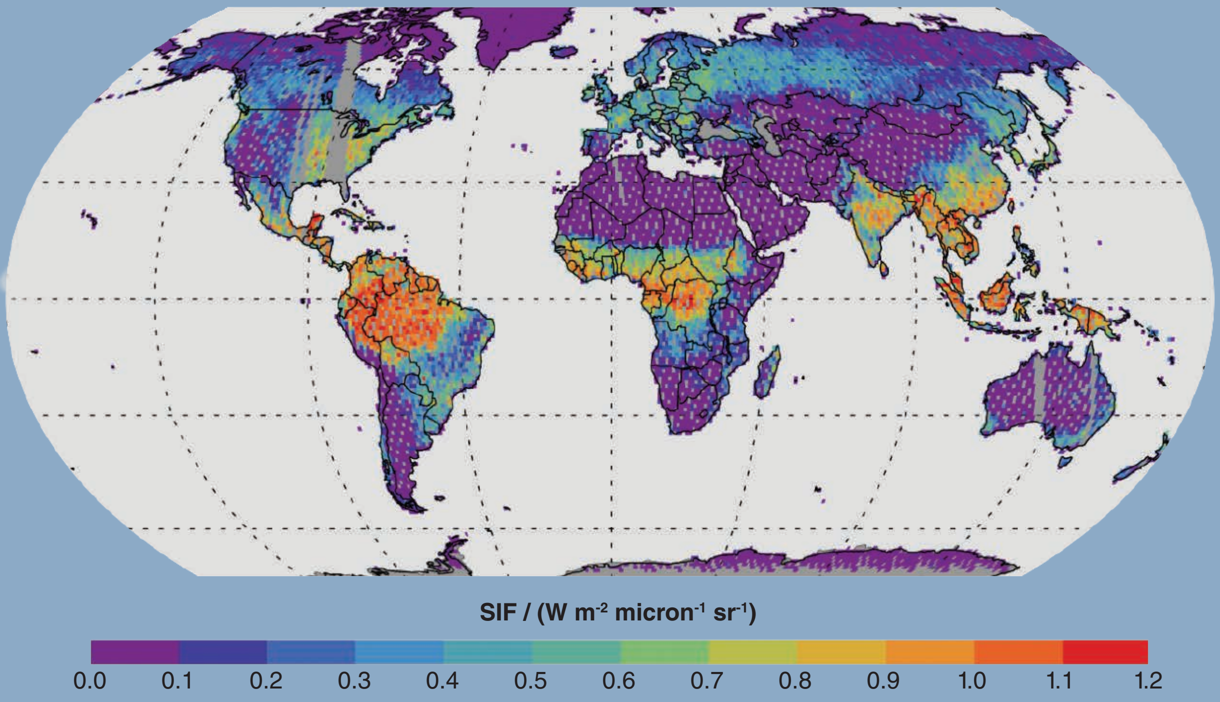
Fossil fuel combustion and other human activities are now increasing the atmospheric CO_2 abundance to unprecedented rates. In May of 2013, these emissions pushed the monthly average CO_2 concentrations above 400 parts per million (ppm), a level that has not been reached during the past 800,000 years. In March 2014, CO_2 concentrations reached 400 ppm again, and there it remained as the monthly average for all of April. These ever-increasing levels are raising concerns about greenhouse-gas-induced climate change. Data from OCO-2 will help scientists better identify how human activities, as well as the natural processes on Earth are influencing rising concentrations of atmospheric CO_2 and the global carbon cycle.

With new information comes new possibilities—scientists will discover new ways to study how plant and crop growth, deforestation, and wildfires influence the exchange of CO_2 between the atmosphere and tropical ecosystem. With OCO-2’s measurements, scientists have the improved ability to track changes in fossil fuel emissions in both hemispheres, and compare how CO_2 interacts with the land and ocean at different latitudes. These types of data will support decision and policy makers to make better-informed decisions that will provide societal benefits for years to come.

The launch of OCO-2 will lead scientists down the right path in their quest to find those precious “missing pieces” of the carbon puzzle. Piece by piece, scientists will continue reaching their goal of better understanding Earth’s complex carbon cycle and the impact humans are having on Earth’s environment.

Image credit: Trey Ratcliff

Looking Beyond CO$_2$



When plants photosynthesize, they use energy from sunlight to turn CO$_2$ from the air into sugars used to live and grow. In doing so, they give off a fluorescent light—a glow that cannot be seen with the naked eye, but that can be seen with the right instruments. This glow is known as Solar Induced Fluorescence, or SIF. More photosynthesis translates into more fluorescence, meaning that the plants are very productive in taking up CO$_2$. The amount of CO$_2$ taken up by plants is called "gross primary productivity," and is the largest part of the global carbon cycle. The ability to see this chlorophyll fluorescence from space was discovered using data from the Japanese Greenhouse Gases Observing Satellite (GOSAT). OCO-2 will also be looking in the same spectral region, and will provide global measurements of fluorescence. These maps will allow scientists to infer details about the health and activity of vegetation on the ground.

Above is a fluorescence retrieval map using a full repeat cycle (16 days) of simulated OCO-2 data in Nadir mode in September. The narrow stripes represent 1.3 to 10.5 kilometer width. Credit: NASA Earth Observatory and Frankenberg *et. al.*, Remote Sensing of Environment, 147 (2014)

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NP-2014-5-151-GSFC