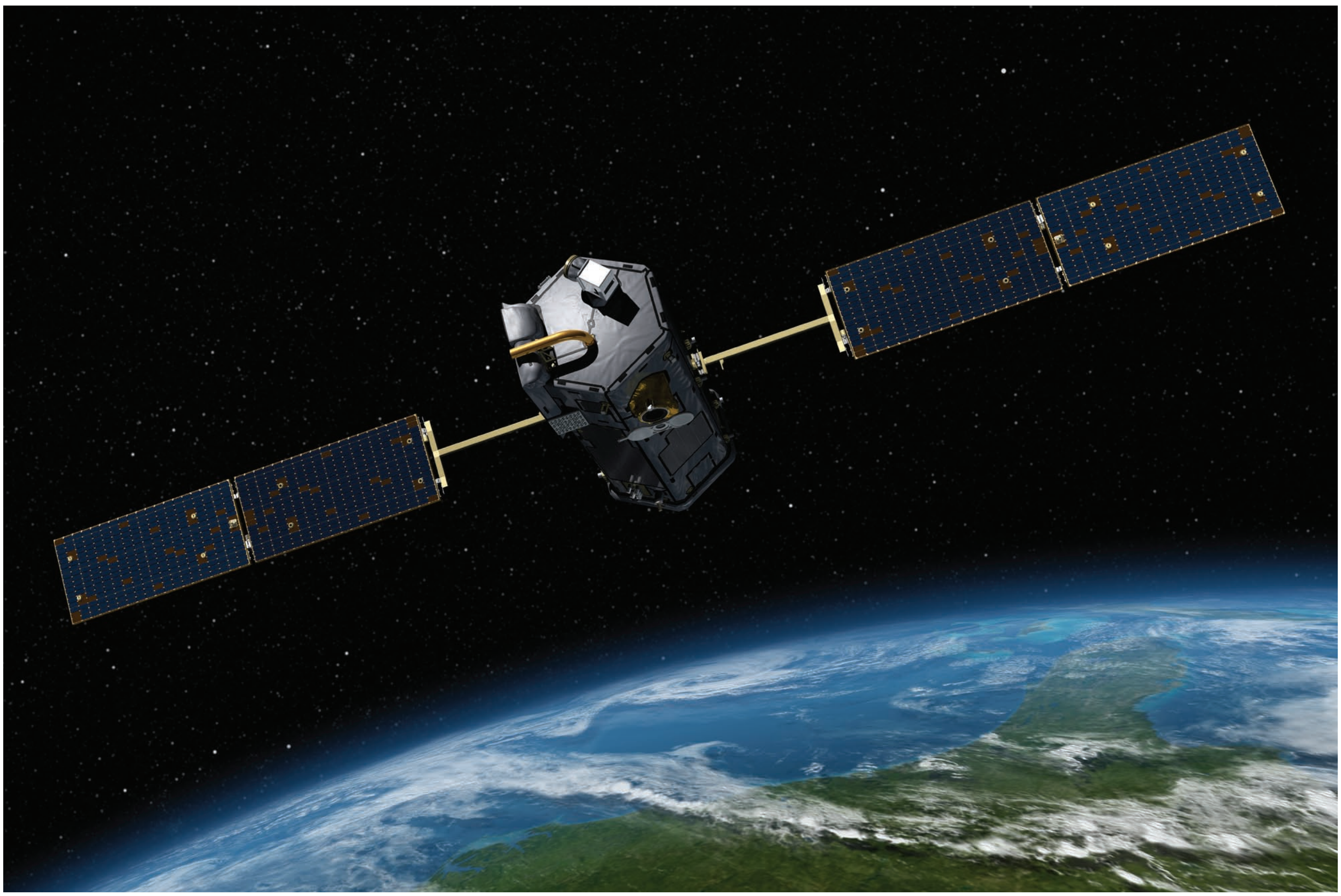
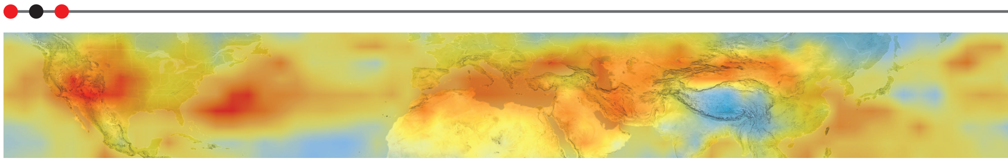
National Aeronautics and Space Administration

Orbiting Carbon Observatory

SCIENCE WRITERS' GUIDE





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Cover image credit: NASA

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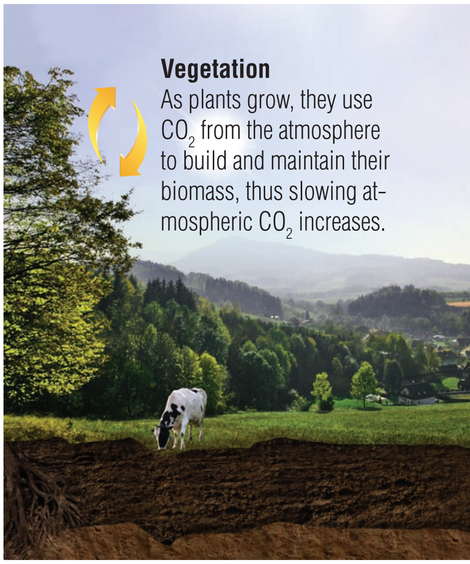
SCIENCE OVERVIEW

The Orbiting Carbon Observatory is the latest mission in NASA's ongoing study of the global carbon cycle. It is the first spacecraft dedicated to studying atmospheric carbon dioxide, the most significant human-produced greenhouse gas and the principal human-produced driver of climate change.

This experimental NASA Earth System Science Pathfinder Program mission will measure atmospheric carbon dioxide from space, mapping the globe once every 16 days for at least two years. It will do so with the accuracy, resolution and coverage needed to provide the first complete picture of the regional-scale geographic distribution and seasonal variations of both human and natural sources of carbon dioxide emissions and their sinks—the reservoirs that pull carbon dioxide out of the atmosphere and store it.

Mission data will be used by the atmospheric and carbon cycle science communities to improve global carbon cycle models, reduce uncertainties in forecasts of how much carbon dioxide is in the atmosphere, and make more accurate predictions of global climate change.



The Orbiting Carbon Observatory is the latest mission in NASA's ongoing study of the global carbon cycle—the cycling of carbon between its various storage reservoirs (the ocean, atmosphere, terrestrial biosphere and geologic fossil fuel reserves). The mission provides a key new measurement that can be combined with other ground and aircraft measurements and satellite data to answer important questions about the processes that regulate atmospheric carbon dioxide and its role in the carbon cycle and climate. Credit: Jennifer Mottar

The mission provides a key new measurement that can be combined with other ground and aircraft measurements and satellite data to answer important questions about the processes that regulate atmospheric carbon dioxide and its role in the carbon cycle and climate. This information could help policymakers and business leaders make better decisions to ensure climate stability and retain our quality of life. The mission will also serve as a pathfinder for future long-term satellite missions to monitor carbon dioxide.

Scientists want to better understand the processes responsible for regulating the amount of carbon dioxide in the atmosphere, because the increasing concentrations of this efficient greenhouse gas are warming our planet and changing its climate. The concentration of carbon dioxide in our atmosphere is determined by the balance between its sources, which emit carbon dioxide into the atmosphere, and sinks, which remove this gas from the atmosphere. While natural sources roughly balance out natural sinks, human activities have thrown the natural carbon cycle out of balance.

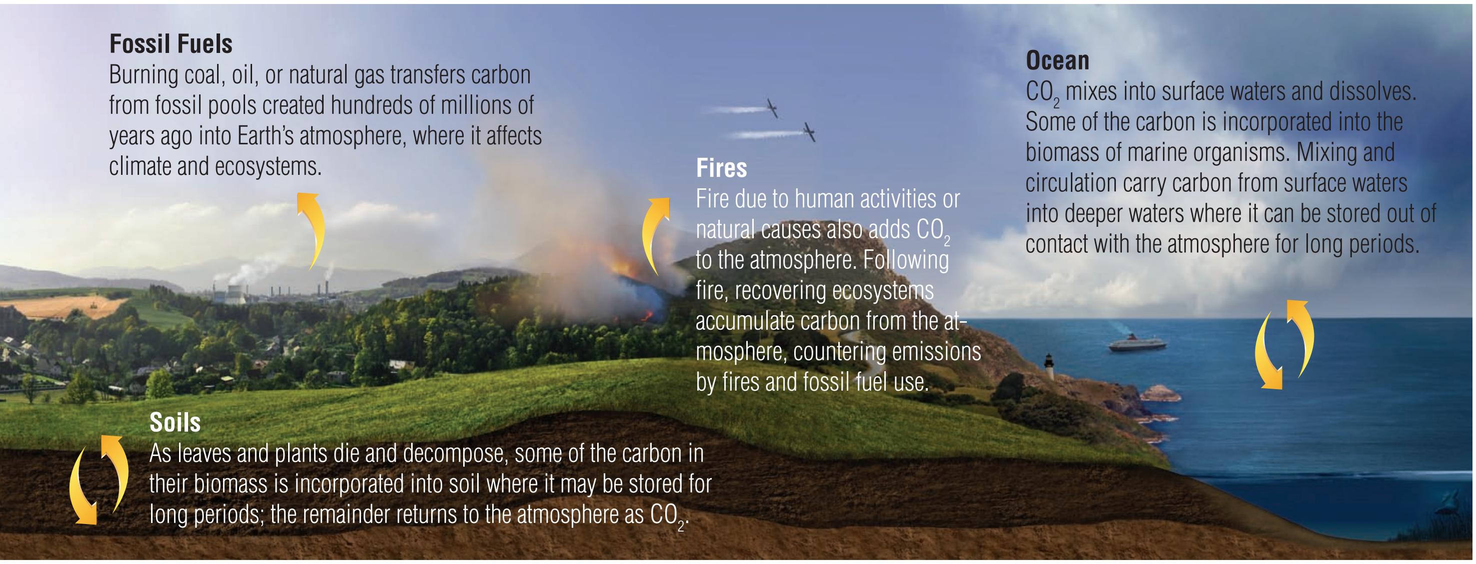
In the 10,000 years before the Industrial Revolution in 1751, carbon dioxide levels rose less than one percent. Since then, they've risen 37 percent. Between 1751 and 2003, human activities added about 466 billion tons of carbon to the atmosphere as carbon dioxide. The burning of fossil fuels, and cement manufacturing, account for about two-thirds of these emissions, while land use changes (primarily forest clearing) make up the rest. Humans are currently adding almost 30 billion tons of carbon dioxide to the atmosphere each year, and this rate of emission is increasing dramatically. In fact, carbon dioxide levels have risen by 30 parts per million in just the last 17 years, and are now increasing at about two parts per million by volume per year. The current globally averaged concentration is about 384 parts per million.

Of all the carbon emitted by human activities between 1751 and 2003, only about 40 percent has remained in the atmosphere. The remaining 60 percent has been apparently absorbed (at least temporarily) by the ocean and continents. Recent inventories of the ocean can account for about half of this missing carbon. The remainder must have been absorbed somewhere on land, but scientists don't know where most of the land sinks are located or what controls their efficiency over time.

An improved understanding of carbon sinks is essential to predicting future carbon dioxide increases and making accurate predictions of carbon dioxide's impact on Earth's climate. If these natural carbon dioxide sinks become less efficient as the climate changes, the rate of buildup of carbon dioxide would increase—in fact, today's carbon dioxide levels would be about 100 parts per million higher were it not for them.

Scientists monitor carbon dioxide concentrations using a ground-based network consisting of about 100 sites all over the world. But the current network does not have the spatial coverage, resolution or sampling rates necessary to identify the natural sinks responsible for absorbing carbon dioxide, or the processes that control how the efficiency of those sinks changes from year to year.

The Orbiting Carbon Observatory will dramatically improve measurements of carbon dioxide over space and time, uniformly sampling Earth's land and ocean and collecting about 8,000,000 measurements of atmospheric carbon dioxide



concentration over Earth's entire sunlit hemisphere every 16 days.

Scientific models have shown that we can reduce uncertainties in our understanding of the balance of carbon dioxide in our atmosphere by up to 80 percent through the use of precise, space-based measurements. Data from the existing ground-based monitoring network can be augmented with high-resolution, global, space-based measurements of atmospheric carbon dioxide concentration accurate to 0.3 to 0.5 percent (about one to two parts per million out of the background level of about 385 parts per million) on regional to continental scales. This level of precision is necessary because atmospheric carbon dioxide concentrations rarely vary by more than two percent from one pole of Earth to the other. The Orbiting Carbon Observatory will have this level of precision.

Scientists hope to use Orbiting Carbon Observatory data to address a number of questions about carbon dioxide and the carbon cycle. Among them:

- What natural processes absorb carbon dioxide from human emissions?
- Will those processes continue to limit increases in atmospheric carbon dioxide in the future, as they do now? Or will they stop or even reverse and accelerate the atmospheric increases?
- Is the missing carbon dioxide being absorbed primarily by land or the ocean and in what proportions? Which continents absorb more than others?
- Why does the increase in atmospheric carbon dioxide vary from one year to the next while emission rates increase uniformly?
- How will carbon dioxide sinks respond to changes in Earth's climate or changes in land use?
- What are the processes controlling the rate at which carbon dioxide is building up in Earth's atmosphere?
- Where are the sources of carbon dioxide?
- What is the geographic distribution and quantity of carbon dioxide emitted through both fossil fuel combustion and less well understood sources, such as ocean outgassing, deforestation, fires and biomass burning? How does this distribution change over time?

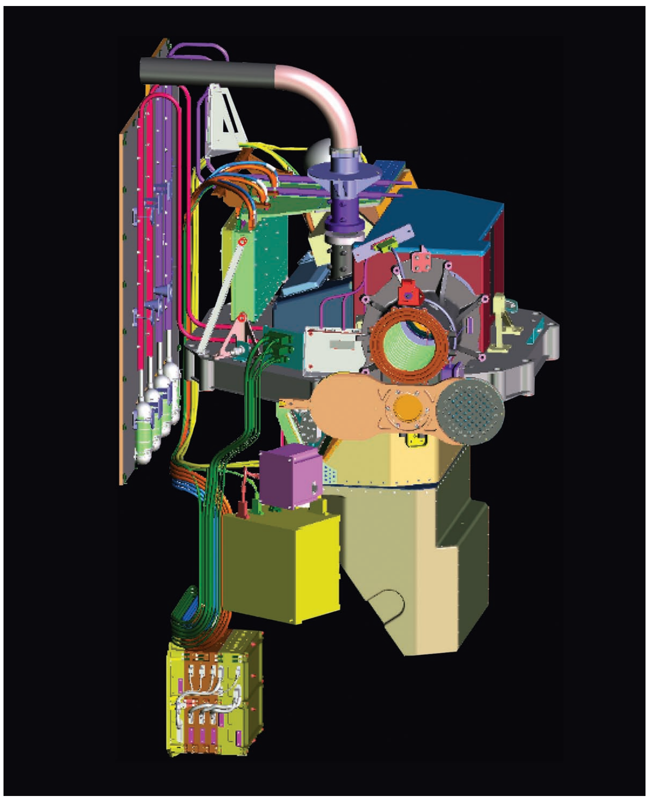
Following launch from California's Vandenberg Air Force Base aboard an Orbital Sciences Corporation Taurus XL rocket, the Orbiting Carbon Observatory will be placed in a near-polar Earth orbit at an altitude of 438 miles (705 kilometers), orbiting once every 98.8 minutes and repeating its orbit track every 16 days. It will fly in a loose formation with the other Earth-observing satellites of NASA's Afternoon Constellation, or "A-Train": Aura, Glory, Parasol, Calipso, CloudSat and Aqua. Flying in the A-Train will complement the mission's science return and facilitate observatory calibration and validation.

The Orbiting Carbon Observatory is managed by NASA's Jet Propulsion Laboratory, Pasadena, Calif., for NASA's Science Mission Directorate, Washington. Orbital Sciences Corporation, Dulles, Va., built the spacecraft and launch vehicle and provides mission operations under JPL's leadership. Hamilton Sundstrand, Pomona, Calif., designed and built the observatory's science instrument. NASA's Launch Services Program at NASA's Kennedy Space Center in Florida is responsible for launch management.

INSTRUMENT

The Orbiting Carbon Observatory's single science instrument consists of three parallel, high-resolution spectrometers, integrated into a common structure and fed by a common telescope. The spectrometers will make simultaneous measurements of the carbon dioxide and molecular oxygen absorption of sunlight reflected off the same location on Earth's surface when viewed in the near-infrared part of the electromagnetic spectrum, invisible to the human eye.

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 dark lines. Different gases absorb different colors, so the pattern of absorption lines provides a telltale spectral "fingerprint" for that molecule. The Orbiting Carbon Observatory's spectrometers have been designed to detect these molecular fingerprints.



The Orbiting Carbon Observatory's science instrument consists of three high-resolution spectrometers integrated into a common structure and fed by a common telescope. The spectrometers measure how carbon dioxide and molecular oxygen absorb sunlight reflected off the Earth's surface, as viewed in the near-infrared part of the electromagnetic spectrum. Each spectrometer focuses on a different, narrow range of colors to detect the "fingerprints" of carbon dioxide and molecular oxygen. Credit: OCO Team.

Each of the three spectrometers is tuned to measure the absorption in a specific range of colors. Each of these ranges includes dozens of dark absorption lines produced by either carbon dioxide or molecular oxygen. The amount of light absorbed in each spectral line increases with the number of molecules along the optical path. The Orbiting Carbon Observatory spectrometers measure the fraction of the light absorbed in each of these lines with very high precision. This information is then analyzed to determine the number of molecules along the path between the top of the atmosphere and the surface.

If the amount of carbon dioxide varies from place to place, the amount of absorption will also vary. To resolve these variations, the Orbiting Carbon Observatory's instrument records 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. This information is then transmitted to the ground, where carbon dioxide concentrations are retrieved in four separate footprints for each image collected. These spatially varying carbon dioxide concentration estimates are then analyzed using global transport models, like those used for weather prediction, to infer the locations of carbon dioxide sources and sinks.

The instrument views Earth through a telescope mounted in the side of the spacecraft. Reflected sunlight is first focused at a field stop (a rectangular aperture at the focus of the telescope that limits the field of view) and then realigned before entering a transfer optics assembly that ensures all three spectrometer channels view the same scene. A beam splitter selects specific ranges of colors of light to be analyzed by each spectrometer, which is then refocused on a narrow slit that forms the entrance to each spectrometer.

Once light passes through the spectrometer slits, it is aligned, and then divided into its component colors by a diffraction grating. This is similar to the way light shined through a prism creates a rainbow.

The light is then refocused by a camera lens onto each spectrometer's focal plane array—image sensing devices designed to detect very fine differences in the intensity of the light within its spectrometer's spectral range. There, it forms a two-dimensional image of a spectrum and is recorded.

The instrument measures the absorption of reflected sunlight by carbon dioxide in two color ranges. The first absorbs carbon dioxide relatively weakly, but is most sensitive to the concentration of carbon dioxide near Earth's surface. The second absorbs carbon dioxide more strongly, and provides a totally independent measure of carbon dioxide in the atmosphere. That color range provides critical information about the pathway the light has taken and can detect clouds, aerosols and variations in atmospheric pressure and humidity, all of which can interfere with accurate measurements of carbon dioxide.

The third range of colors, within the molecular oxygen A-band, is used to measure how much molecular oxygen is present in the light's pathway. To accurately derive the atmospheric concentration of carbon dioxide using instrument data, scientists first need to compare them to measurements of a second atmospheric gas. Because the concentration of molecular oxygen is constant, well-known and uniformly distributed throughout the atmosphere, it provides an excellent reference measurement. The molecular oxygen A-band spectra can also assess the effects of clouds, aerosols and the atmospheric pressure at Earth's surface.

The observatory will continuously collect 12 soundings per second while over Earth's sunlit hemisphere. At this rate, the instrument will gather between 33,500 and 35,500 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). Over the course of each 16-day ground repeat cycle, it will collect about 8,000,000 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.

To enhance the quality and verify the validity of mission data, the observatory will collect science observations in three standard observational modes: nadir, glint and target.

In nadir mode, the satellite points the instrument straight down to the ground. 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. Nadir observations may not be suitable over dark ocean surfaces or in areas covered by snow.

In glint mode, the spacecraft points the instrument at the spot on Earth's surface where the sun's reflection is most intense. Glint mode provides up to 100 times more signal than nadir mode, improving observations over dark ocean surfaces.

Target-tracking mode is used primarily for validating the observatory data against ground calibration sites. The observatory locks its view onto a single specific surface location while it flies overhead.

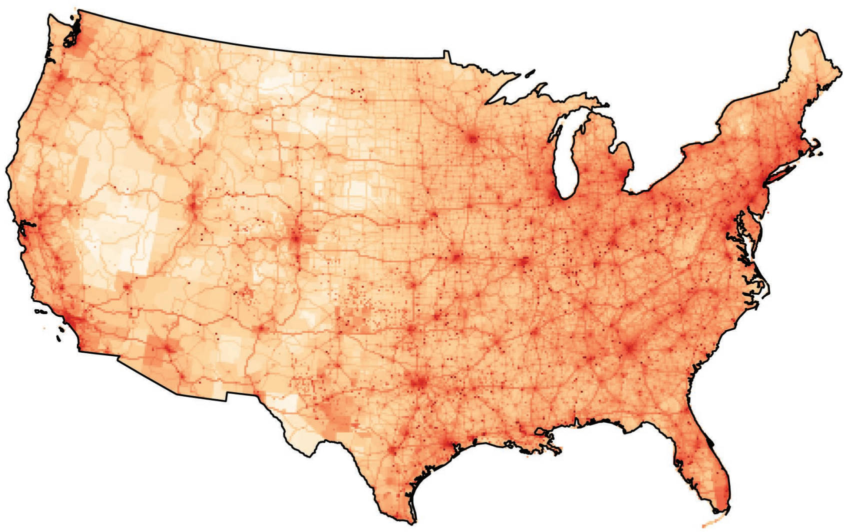
The mission plans to alternate between nadir and glint modes over each sequential 16-day global ground track repeat cycle, so the entire Earth is mapped in each mode on roughly monthly time scales. Up to one target observation can be taken each day to validate the data.

FEATURE STORIES

THE HUMAN FACTOR: UNDERSTANDING THE SOURCES OF RISING CARBON DIOXIDE

Every time we get into our car, turn the key and drive somewhere, we burn gasoline, a fossil fuel derived from crude oil. The burning of the organic materials in fossil fuels produces energy and releases carbon dioxide and other compounds into Earth's atmosphere. Greenhouse gases such as carbon dioxide trap heat in our atmosphere, warming it and disturbing Earth's climate.

Scientists agree that human activities have been the primary source for the rise in atmospheric carbon dioxide observed since the beginning of the fossil fuel era in the 1860s. Eighty-five percent of all human-produced carbon dioxide emissions come from the burning of fossil fuels like coal, natural gas and oil, including gasoline. The remainder results from the clearing of forests and other land use, as well as some industrial processes such as cement manufacturing. The use of fossil fuels has grown rapidly, especially since the end of World War II and continues to increase exponentially. In fact, more than half of all fossil fuels ever used by humans have been consumed in just the last 20 years.



The Vulcan Project maps American carbon dioxide emissions. The map shows annual emissions in 2002 (in kilotons of carbon, with 1 kiloton equivalent to about two million pounds) from urban centers (larger red patches), widely scattered point sources like remote power stations or smelters (small red dots), and highways. Credit: Jesse Allen, NASA/Earth Observatory, based on data from the Vulcan Project

Combined, these human activities add a worldwide average of almost 1.4 metric tons of carbon per person per year to the atmosphere. Before industrialization, the concentration of carbon dioxide in the atmosphere was about 280 parts per million. By 1958, it had increased to around 315 parts per million, and by 2007, it had risen to about 383 parts per million. These increases were due almost entirely to human activity.

Yet while we are able to accurately measure the amount of carbon dioxide in the atmosphere, much about the processes that govern its atmospheric concentration remains a mystery. Scientists still do not know precisely where all the carbon dioxide in our atmosphere comes from and where it goes. They want to learn more about the magnitudes and distributions of carbon dioxide's sources and the places it is absorbed (sinks). This will help improve critical forecasts of atmospheric carbon dioxide increases as fossil fuel use and other human activities continue. Such information is crucial to understanding the impact of human activities on climate and for evaluating options for mitigating or adapting to climate change.

But scientists soon expect to get some answers to these and other compelling carbon questions, thanks to the Orbiting Carbon Observatory, a new Earth-orbiting NASA satellite set to launch in early 2009. The new mission will allow scientists to record, for the first time, detailed daily measurements of carbon dioxide, making more than 100,000 measurements around the world each day. The new data will provide valuable new insights into where this important greenhouse gas is coming from and where it is being stored.

In the absence of significant carbon dioxide emissions by human activities, atmospheric uptake and loss approximately balance. "Carbon dioxide in the atmosphere remained pretty stable during the pre-industrial period," said Gregg Marland of Oak Ridge National Laboratory in Oak Ridge, Tenn. "Carbon dioxide generated by human activities amounts to only about four percent of yearly atmospheric uptake or loss of carbon dioxide, but the result is that the concentration of carbon dioxide in the atmosphere has been growing, on average, by four-tenths of one percent each year for the last 40 years. Though this may not seem like much of an influence, humans have essentially tipped the balance of the global cycling of carbon. Our emissions add significant weight to one side of the balance between carbon being added to the atmosphere and carbon being removed from the atmosphere.

"Plant life and geochemical processes on land and in the ocean 'inhale' large amounts of carbon dioxide through photosynthesis and then 'exhale' most of it back into the atmosphere," Marland continued. "Humans, however, have altered the carbon cycle over the last couple of centuries, through the burning of fossil fuels that enable us to live more productively. Now that humans are acknowledging the environmental effects of our dependence on fossil fuels and other carbon dioxide-emitting activities, our goal is to analyze the sources and sinks of this carbon dioxide and to find better ways to manage it."

Marland said the Orbiting Carbon Observatory will help us pin down where the carbon dioxide that's tipping the balance is coming from, such as from the burning of fossil fuels, mineral production facilities and forest burning.

The mission's highly sensitive instrument will measure the distribution of carbon dioxide, sampling information around the globe from its space-based orbit. Though the instrument will not directly measure the carbon dioxide emissions from every individual smokestack, tailpipe or forest fire, scientists will incorporate the observatory's global measurements of varying carbon dioxide concentrations into computer-based models. The models will infer where and when the sources are emitting carbon dioxide into the atmosphere. Current estimates of human-produced carbon dioxide emissions into the atmosphere are based on inventories and estimates of where fossil fuels are burned and where other carbon dioxide-producing human activities are occurring. However, the availability and precision of this information is not uniform around the world, not even from within developed countries like the United States.

"The Orbiting Carbon Observatory data differ from that of other missions like the Atmospheric Infrared Sounder instrument on NASA's Aqua satellite by having a relatively small measurement 'footprint,'" said Kevin Gurney, associate director of the Climate Change Research Center at Purdue University in West Lafayette, Ind. "Rather than getting an average amount of carbon dioxide over a large physical area like a state or country, the mission will capture measurements over scales as small as a medium-sized city. This allows it to more accurately distinguish movements of carbon dioxide from natural sources versus from fossil fuel-based activities."

"Essentially, if you visualize a column of air that stretches from Earth's surface to the top of the atmosphere, the Orbiting Carbon Observatory will identify how much of that vertical column is carbon dioxide, with an understanding that most is emitted at the surface," said Marland. "Simply, it will act like a plane observing the smoke from forest fires down below, with the task of assessing where the fires are and how big they are. Compare that aerial capability with sending a lot of people into the forest looking for fires. In this vein, the observatory will use its vantage point from space to peer down and capture a picture of where the sources and sinks of carbon dioxide are, rather than our cobbling data together from multiple sources with less frequency, reliability and detail."

Gurney believes the Orbiting Carbon Observatory will also complement a NASA/U.S. Department of Energy jointly-funded project he is currently leading called Vulcan.

"Vulcan estimates the movement of carbon dioxide through the combustion of fossil fuels at very small scales. Vulcan and the Orbiting Carbon Observatory together will act like partners in closing the carbon budget, with Vulcan estimating movements in the atmosphere from the bottom-up and the Orbiting Carbon Observatory estimating sources from the top-down," he said. "By tackling the problem from both perspectives, we'll stand to achieve an independent, mutually-compatible view of the carbon cycle. And the insight gained by combining these top-down and bottom-up approaches might take on special significance in the near future as our policymakers consider options for regulating carbon dioxide across the entire globe."

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Related Links:

NASA's OCO Mission Web sites:
http://oco.jpl.nasa.gov
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FEATURE STORIES

THE ORBITING CARBON OBSERVATORY AND THE MYSTERY OF THE MISSING SINKS

Picture a tree in the forest. The tree "inhales" carbon dioxide from the atmosphere, transforming that greenhouse gas into the building materials and energy it needs to grow its branches and leaves.

By removing carbon dioxide from the atmosphere, the tree serves as an indispensable "sink," or warehouse, for carbon that, in tandem with Earth's other trees, plants and the ocean, helps reduce rising levels of carbon dioxide in the air that contribute to global warming.

Each year, humans release more than 30 billion tons of carbon dioxide into the atmosphere through the burning of fossil fuels for powering vehicles, generating electricity and manufacturing products. Up to five-and-a-half additional tons of carbon dioxide are released each year by biomass burning, forest fires and land-use practices such as slash-and-burn agriculture. Between 40 and 50 percent of that amount remains in the atmosphere, according to measurements by about 100 ground-based carbon dioxide monitoring stations scattered across the globe. Another estimated 30 percent is dissolved into the ocean, the world's largest sink.

But what about the rest? The math doesn't add up. For years, scientists have sought to find the answer to this mystery. Though scientists agree the remaining carbon dioxide is also "inhaled" by Earth, they have been unable to precisely determine where it is going, what processes are involved, and whether Earth will continue to absorb it in the future. A new NASA satellite scheduled to launch in early 2009 is poised to shed a very bright light on these "missing" sinks: the Orbiting Carbon Observatory.

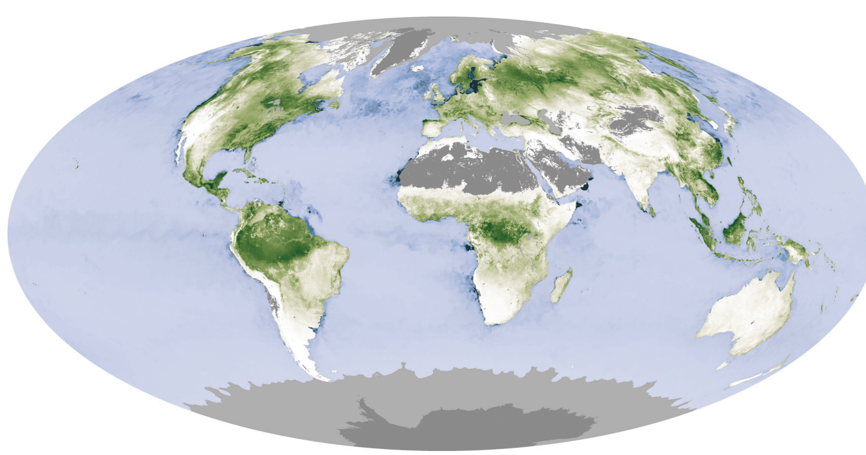
"It's important to make clear that the 'missing' sinks aren't really missing, they are just poorly understood," said Scott Denning, a professor of atmospheric sciences at Colorado State University in Fort Collins, Colo. "We know the 'missing' sinks are terrestrial, land areas where forests, grasslands, crops and soil are absorbing carbon dioxide. But finding these sinks is like finding a needle in a haystack. It would be great if we could measure how much carbon every tree, shrub, peat bog or blade of grass takes in, but the world is too big and too diverse and is constantly changing, making such measurements virtually impossible. The solution is not in measuring carbon in trees. The solution is measuring carbon in the air."

The Orbiting Carbon Observatory will do just that: measure carbon in the air, from Earth's surface to the top of the atmosphere.

"NASA's Orbiting Carbon Observatory satellite will work as a detective from space, measuring the distribution of carbon dioxide thousands of times daily as it orbits the planet, providing the data to create very precise carbon dioxide maps that will help us confirm the whereabouts, nature and efficiency of the sinks absorbing the 30 percent of carbon dioxide that disappears each year from the atmosphere," said Steve Wofsy, a professor of atmospheric and environmental chemistry at Harvard University in Cambridge, Mass., and a co-investigator for the mission.

Carbon, a chemical element that is the basis of all known life and part of the chemical compound carbon dioxide, is the basic "currency" of the carbon cycle. It is "inhaled" by sinks to fuel photosynthesis in plant life. It is "exhaled" by natural sources when plant life dies or burns, and through human activities like the burning of fossil fuels, crops and forests.

If we think of Earth as "breathing," the balance between photosynthesis, or "inhaling," and respiration, or "exhaling," was about equal until humans began mining and burning large amounts of fossilized organic matter like coal, oil and natural gas a couple of hundred years ago.



Global measurements of the carbon stored by plants (net primary productivity) during photosynthesis are an important piece of the climate change puzzle. Scientists need to know how much of the carbon dioxide released by burning fossil fuels can be absorbed by the biosphere and how much will linger in the atmosphere, a dilemma the Orbiting Carbon Observatory is expected to help resolve. Credit: NASA map by Robert Simmon and Reto Stöckli, based on MODIS data

Until about 1990, most scientists believed land was primarily a source of carbon dioxide to the atmosphere because forests are continuously being destroyed by human activities like deforestation in tropical areas, urban and suburban development and land clearing for farming.

"The amazing truth is that on a global scale, photosynthesis is greater than decomposition and has been for decades," said Denning. "Believe it or not, plant life is growing faster than it's dying. This means land is a net sink for carbon dioxide, rather than a net source."

Denning outlined the six different ways carbon dioxide sinks can develop on land:

- Carbon dioxide fertilization, a process often prominent in land areas, happens when more carbon dioxide in the air stimulates photosynthesis to produce a temporary "bump" in the growth rates of plant life.
- Agricultural abandonment occurs where once-deforested land formerly used as family farms is abandoned, allowing forests to re-grow into terrestrial carbon dioxide sinks.
- Forest fire suppression, the aggressive extinguishing of forest fires that has led to preservation of more wooded areas than existed 100 years ago, saves trees that pull carbon dioxide from the air for growth.
- Woody encroachment occurs when cattle graze on grass but leave behind carbon dioxide-absorbing woody shrubs that accumulate over land ranges throughout the western U.S. and elsewhere.
- Boreal, or northern, warming takes place in northern latitude forests that are experiencing longer frost-free growing seasons due to global warming, allowing more woody growth and more absorption of carbon dioxide.
- Lastly, carbon dioxide sinks are created when nitrogen in agricultural fertilizer or nitrogen oxide from car emissions dissolves into clouds, spreads for hundreds of miles on vegetation with rainfall, and acts in tandem with carbon dioxide fertilization to accelerate plant growth.

The Orbiting Carbon Observatory will help scientists locate and characterize areas experiencing these biological processes.

"The future behavior of carbon dioxide sinks is one of the most uncertain things in predicting climate in the 21st century," said Denning. "Mapping today's sinks will allow us to measure how much of the carbon budget is controlled by carbon dioxide intake from ocean mixing, versus carbon dioxide fertilization, versus forest re-growth, etcetera. If we can determine that current land sinks are dominated by carbon dioxide fertilization, it would buy us more time to develop alternative energy and other mitigation measures."

Past attempts by researchers to measure terrestrial carbon dioxide were limited by an inability to account for the different ages of forests or how disturbances to the forests have affected their ability to absorb carbon dioxide. Similar attempts to measure carbon dioxide in human-managed ecosystems like cropland, pastures, golf courses and suburban landscapes are also difficult because such areas are so varied and numerous.

"We're expecting the Orbiting Carbon Observatory to allow us to identify the precise geographic locations of these 'missing' carbon dioxide-absorbing areas as well as the make-up of the sinks and the rate at which they soak up carbon dioxide," said Wofsy. "The efficiency of a sink and its location with respect to that of sources emitting carbon dioxide has critical implications for our ability to regulate carbon dioxide in global efforts to offset the well-documented global climate warming trend. We're anticipating a big step forward on this front with the Orbiting Carbon Observatory's help."

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Related Links:

NASA's OCO Mission Web sites
http://oco.jpl.nasa.gov
http://www.nasa.gov/oco

Forests Damaged by Hurricane Katrina Become Major Carbon Source
http://www.nasa.gov/mission_pages/hurricanes/archives/2007/katrina_carbon.html

NASA Study Illustrates How Global Peak Oil Could Impact Climate
http://www.nasa.gov/centers/goddard/news/topstory/2008/peakoil.html

NASA Study Finds World Warmth Edging Ancient Levels
http://www.nasa.gov/vision/earth/environment/world_warmth_prt.htm

Additional Web sites that might be of interest:

North American Carbon Program
http://www.nacarbon.org/nacp/

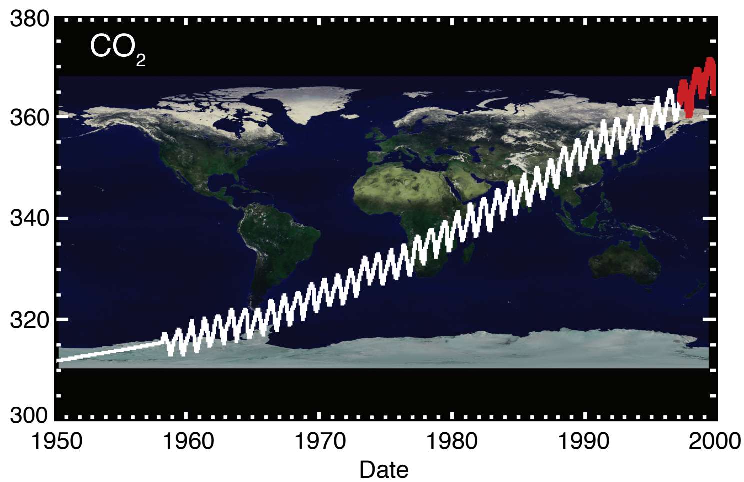
NASA Carbon Cycle and Ecosystems Focus Area
http://cce.nasa.gov/cce/index.htm

FEATURE STORIES

TOWARD A NEW GENERATION OF CLIMATE MODELS

Recent years have seen an increase in events related to climate change. For example, 2005 was the warmest year globally in more than a century, and in 2007, Arctic sea ice retreated more than any other time in recorded history. A new NASA mission is poised to help scientists better understand the most important human-produced greenhouse gas contributing to climate change—carbon dioxide. The knowledge gained may help us better predict how our climate may change in the future.

Scientists rely on models to forecast future impacts of carbon dioxide on Earth's climate. When the carbon dioxide concentrations used in, or predicted by, these models are not accurate, the resulting climate projections can have a large degree of uncertainty. To accurately predict atmospheric carbon dioxide concentrations in the future, we need to understand natural and human sources of carbon dioxide, as well as the natural "sinks" that remove this gas from our atmosphere.



This image shows the past half-century of carbon dioxide trends, beginning in 1950 when global industrialization took off. A more complete understanding of Earth's carbon cycle gained from the Orbiting Carbon Observatory will help researchers arrive at models that better predict future trends. Credit: NASA

The rapid buildup of carbon dioxide from the burning of fossil fuels is a relatively well understood and predictable source. Other impacts, however, such as forestry and agricultural practices which can act as either sources or sinks, are far harder to predict with confidence. More importantly, measurements from a global network of greenhouse gas monitoring stations indicate that more than half of the carbon dioxide emitted by human activities is currently being absorbed by the ocean and by plants on land. But the current ground-based carbon dioxide monitoring network does not have the coverage or resolution needed to identify sufficiently the natural sinks responsible for absorbing this carbon dioxide. In addition, the amount of carbon dioxide absorbed by these natural sinks varies dramatically from year to year, for reasons that are largely unknown. Because the nature, location and processes controlling these natural sinks are not well understood, it is impossible to accurately predict how much carbon dioxide they might absorb in the future as the climate changes. NASA's new Orbiting Carbon Observatory aims to help resolve these and other open carbon-cycle questions.

"The Orbiting Carbon Observatory will provide the initial steps in the journey of measuring carbon dioxide from space, and the discoveries will be profound—we'll gather basic information about the distribution of carbon that we wouldn't have been able to do any other way," says Graeme Stephens of Colorado State University, Fort Collins, and a co-investigator on the Orbiting Carbon Observatory science team.

Researchers have shown that warming, particularly from greenhouse gases including carbon dioxide, is driving Earth's climate toward "tipping points." Those are the points at which temperatures could set in motion processes that are very difficult to reverse. One potential example is the runaway disintegration of Arctic sea ice and of the West Antarctic ice sheet. In this scenario, warmer temperatures melt more ice and create more open water, which absorbs more heat. This, in turn, melts more ice, in a process that feeds upon itself.

Research by James Hansen of NASA's Goddard Institute for Space Studies in New York, and colleagues suggests that to avoid dangerous tipping points, Earth's atmosphere should be limited to a carbon dioxide concentration of 450 parts per million at the most, and potentially much lower. Today, the level of carbon dioxide is about 384 parts per million, and over the last few decades that number has been rising by about two parts per million per year. But arriving at models that accurately predict how carbon dioxide levels will change in the future depends, in part, on whether researchers can collect enough data to untangle the mysteries of the carbon cycle.

The Orbiting Carbon Observatory's measurements throughout Earth's atmosphere, from the surface to the top, will give researchers the means to indirectly track where carbon dioxide is emitted and absorbed.

"As human-caused emissions change, what will happen to the carbon budget (the contribution of carbon dioxide's various sources)?" Stephens asked. "There's a gross lack of understanding as to where the re-absorbed carbon is going because it's currently impossible to make global observations to see how carbon dioxide varies on both global and regional scales."

Currently, a sparse network of ground stations across the globe collects precise measurements of carbon dioxide, but is mostly limited to remote locations, far away from power plants, automobiles and other sources of carbon dioxide. The Atmospheric Infrared Sounder instrument on NASA's Aqua satellite now provides some carbon dioxide measurements in the atmosphere, but they are limited to the atmosphere miles above where we live and where emissions occur.

Measurements from ground stations and the Atmospheric Infrared Sounder have already shown that the level of carbon dioxide is more varied throughout the atmosphere than was previously believed. The levels fluctuate with weather and temperature and are influenced by land plants and the ocean. It's the goal of carbon cycle models to explain and ultimately predict the response of this complex system.

"It's like a domino effect," Stephens said. "The climate system is so interconnected, and the carbon dioxide system is an integral part of that system."

A new generation of climate modelers already considers the interactions of carbon between land, ocean and atmosphere. These models predict that the growth rate of atmospheric carbon dioxide and of global warming will accelerate, as Earth's land and ocean show a decreased capacity to absorb carbon dioxide. But with the current scant observations of the carbon system, the magnitude and timing of such model predictions are highly uncertain. The next generation of carbon-climate models will better represent these systems, thanks to more abundant global carbon dioxide data from the Orbiting Carbon Observatory and other future satellite missions. And while the data from these new satellites may not be as precise as data from ground stations, the models will nonetheless improve due to the tremendous volume of data from across the globe and throughout the atmosphere.

Researchers expect the volume of carbon dioxide data to increase dramatically. "This is tremendous," says Inez Fung of the University of California, Berkeley, and a co-investigator on the Orbiting Carbon Observatory science team. "There is much horizontal and vertical variation of carbon dioxide in the atmosphere due to sources and sinks and turbulent mixing processes that vary between day and night, from place to place, and from season to season. The Orbiting Carbon Observatory will give scientists a much more complete global picture of how the carbon cycle works."

The observatory will measure the percentage of carbon dioxide present within columns of the atmosphere that span less than 1.6 square miles (4.1 square kilometers) on the surface and extend all the way up to the satellite 438 miles (705 kilometers) above. "This is a major advance over the traditional surface observations, which are sparse and which sample only at fixed heights and mostly near the ground," Fung said.

The Orbiting Carbon Observatory information will allow researchers to "see" for the first time carbon dioxide sources and sinks. The information will allow researchers to assess or "rank" the performance of carbon-climate models and will help to flag areas that need additional study. Researchers also expect the observatory to turn up surprises where little or no carbon dioxide data have been taken, such as over Africa, Eurasia and the open ocean.

"I am extremely excited—I have been working on the carbon cycle for over 25 years and have been hampered by the data scarcity," Fung said. "Christmas is coming."

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Links:

NASA's Orbiting Carbon Observatory Mission Web sites:
http://oco.jpl.nasa.gov
http://www.nasa.gov/oco

Research Finds That Earth's Climate is Approaching 'Dangerous' Point
http://www.giss.nasa.gov/research/news/20070530/

Uncertainties in Understanding Low- and High-Latitude Climate Sensitivity Affect Ability to Predict Climate Change Impacts
http://www.giss.nasa.gov/research/briefs/rind_02/

NASA Study Illustrates How Global Peak Oil Could Impact Climate
http://www.giss.nasa.gov/research/news/20080910/

FEATURE STORIES

NASA MISSION MEETS THE CARBON DIOXIDE MEASUREMENT CHALLENGE

The challenge: very precisely measure carbon dioxide in Earth's atmosphere all over the world, especially near Earth's surface.

For Orbiting Carbon Observatory Principal Investigator David Crisp of NASA's Jet Propulsion Laboratory, Pasadena, Calif., and his team, the logical solution was an Earth-orbiting spacecraft. But shopping for a science instrument that could accomplish these objectives was no easy task.

In this case, "shopping" meant finding the right technology to meet the mission's demanding requirements. The observatory contains a custom-built instrument designed to make what Deputy Principal Investigator Charles Miller of the Jet Propulsion Laboratory calls "the most difficult atmospheric trace-gas measurement that's ever been made from space." To put that measurement challenge into perspective, consider that all of Earth's trace gases combined, including carbon dioxide, make up less than one percent of Earth's atmosphere. In addition, carbon dioxide levels vary by only about two percent from pole to pole. To substantially increase our understanding of how carbon dioxide sources (places where carbon dioxide is emitted) and sinks (places where it is absorbed, or stored) are geographically distributed on regional scales and study how their distribution changes over time, the new mission needed to be able to resolve differences in atmospheric carbon dioxide as small as 0.3 percent on regional scales every month.

The dark lines of the solar spectrum are produced as atoms and molecules in the sun's atmosphere absorb specific colors of the spectrum. Molecules in Earth's atmosphere also absorb specific colors, but these colors are primarily in the ultraviolet and infrared portions of the spectrum, beyond the left and right ends of this spectrum. Credit: The Institute for Astronomy, University of Hawaii

While one spaceborne instrument can already make carbon dioxide measurements from space—the Atmospheric Infrared Sounder on NASA's Aqua satellite—it sees the gas high up in the atmosphere, not near the surface, where it is emitted and where some of it is absorbed into land systems and the ocean. A different technology was clearly needed.

Enter NASA's team of experts in atmospheric science, remote sensing instrumentation and the optical properties of the atmosphere's components.

The principle behind the observatory's measurement is relatively simple. Carbon dioxide, like all molecules, has an affinity for certain colors, or wavelengths, of light that have exactly the right energy to make the molecule vibrate or rotate at specific frequencies. A good analogy would be how a radio broadcasts sounds when it is tuned to a specific channel. So, if you could shine a light through Earth's atmosphere and see how the different colors that are sensitive to carbon dioxide respond, you could use that information to calculate how much carbon dioxide is present. Do this precisely enough and often enough and it would be possible to see changes in carbon dioxide levels over time—the key to identifying carbon dioxide sources and sinks.

The observatory uses the sun as its light source. To measure changes in sunlight as it passes through the atmosphere, its instrument incorporates a trio of high-resolution grating spectrometers, which divide light from the sun into a very fine rainbow of colors called a spectrum. They are known as grating spectrometers because they use a grate, or grid, to partition light into different wavelengths.

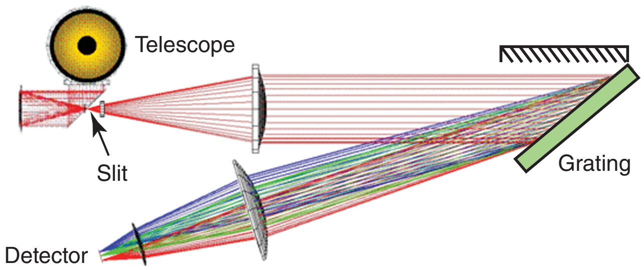
"You can see a good example of how a grating spectrometer works by looking at the back of a compact disc illuminated by a bright light," said Crisp. "The narrow circular tracks that record the information on the disk are very effective at splitting light into different colors."

As the Orbiting Carbon Observatory satellite circles the globe, the telescope on its instrument captures sunlight reflected by the surface below—light that has traveled from the sun, down through Earth's atmosphere and back up again to space. It sends the light to the three spectrometers, each of which looks at a different range of colors and breaks that spectral range down even further into more than 1,000 discrete colors. Two of the three spectral ranges that the spectrometers target are sensitive to carbon dioxide, and one responds to molecular oxygen.

The resulting spectra look something like bar codes, with dark lines showing where carbon dioxide or oxygen have absorbed specific colors. "By measuring the fraction of the light that has been absorbed in each of these dark lines, we can count the number of carbon dioxide or oxygen molecules in the atmosphere," said Crisp.

Three separate digital detectors, one for each spectrometer, record a spectrum three times each second as the observatory flies above Earth's surface. Fast exposures are essential because the spacecraft moves at more than four miles per second along its orbit track. "We don't want long exposures that could include clouds as well as clear sky within individual exposures," says Crisp. "We also want to take the data fast and get more clear views to the surface."

While similar to the digital detectors in an ordinary camera, the observatory's detectors take advantage of advances from the world of astronomy to achieve the greatest possible sensitivity. "These detectors were originally developed to measure objects that are faint, fuzzy and far-away," said Crisp. "Here, we use them to measure very fine details in the spectrum of sunlight reflected from Earth."



The optical path of each spectrometer channel, showing the locations of the telescope, slit, grating and detector. Credit: OCO Team

The three spectral ranges measured by the observatory's spectrometers are in the near-infrared part of the electromagnetic spectrum, invisible to the human eye. Each provides a critical piece of information. One provides precise information about changes in the amount of carbon dioxide present in the atmosphere, while the others show just how much of the atmosphere is being measured. "We need all three of these measurements to do the job," said Crisp.

One spectral range absorbs carbon dioxide relatively weakly, but it measures carbon dioxide the most precisely, especially near Earth's surface.

The second spectral range absorbs carbon dioxide much more strongly, so much so that almost all of the light in this part of the spectrum is absorbed completely as it traverses the atmosphere. Adding more carbon dioxide produces little additional absorption, so this wavelength is less useful for showing changes in carbon dioxide amounts. However, it does provide needed information about the pathway the light has taken. It helps determine whether the observatory is looking at light coming up all the way from the surface, or if clouds or aerosols, such as particles of smog or smoke, have gotten in the way and reflected the light back to space before it can be absorbed by carbon dioxide.

The third spectral range shows how much oxygen is present in the light's pathway, another way to determine how much atmosphere the light has passed through.

"Oxygen makes up about 21 percent of the atmosphere," explained Crisp. "Because we know the concentration, we know how much sunlight it should absorb over any particular surface elevation. If the sunlight penetrates all the way to sea level before it is reflected back to the spacecraft, it will produce more absorption than if it penetrates only to the top of a mountain or to the top of a cloud before it is reflected to space. We can even use measurements of the oxygen absorption to infer the surface pressure differences associated with elevation changes as small as 100 feet (30 meters). We can also detect scattering by very thin clouds or hazes that reflect less than one percent of light back to space. These precise measurements of the atmospheric optical path are essential for accurate carbon dioxide measurements."

The high-resolution grating spectrometers and the digital detectors make it possible to make these measurements from a space-based instrument, according to Crisp.

Another technological challenge for the mission was designing the instrument to meet the strict size and energy requirements of an Earth-orbiting spacecraft.

"One of the most challenging aspects of the mission was not inventing components, but fitting a big instrument into a small spacecraft about the size of a phone booth and designing it to use very little power," said the Jet Propulsion Laboratory's Randy Pollock, the mission's instrument systems engineer. The observatory's instrument uses only about 100 watts of electricity, while the entire spacecraft uses only 400-500 watts, about half the amount used by most microwave ovens.

Once received back on Earth, the observatory's data will be analyzed to yield estimates of the carbon dioxide concentration over Earth's sunlit hemisphere at spatial resolutions as small as one square mile using complex mathematical algorithms. Scientists will then analyze these carbon dioxide estimates using global transport models similar to those used for weather prediction to quantify carbon dioxide sources and sinks.

"Carbon dioxide is the primary human-produced greenhouse gas and, therefore, the primary human-caused driver of global warming," said Crisp. "To estimate the rate of global warming, we have to understand the processes controlling the buildup of carbon dioxide in Earth's atmosphere. Global, space-based monitoring systems like the Orbiting Carbon Observatory are essential tools for this task. The technology we validate on this mission will be used to develop future carbon dioxide monitoring missions."

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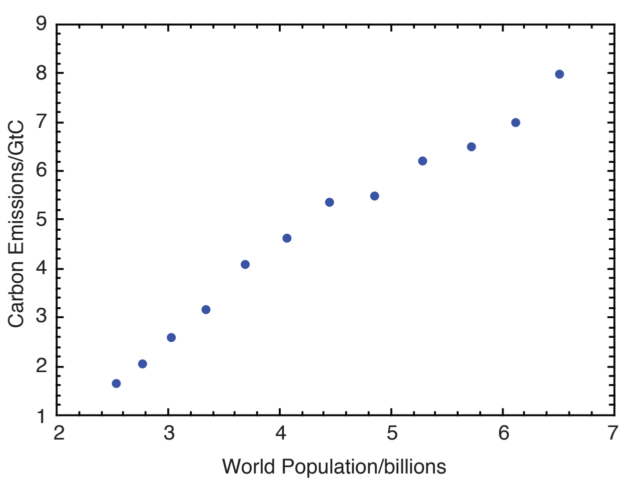
FEATURE STORIES

ORBITING CARBON OBSERVATORY AIMS TO BOOST CARBON MANAGEMENT OPTIONS

As the concentration of heat-trapping carbon dioxide in Earth's atmosphere continues to rise, so also does public awareness, as well as efforts to find solutions to this global problem. Increasing concentrations of this potent greenhouse gas threaten to alter Earth's climate in ways that will have profound impacts on the welfare and productivity of society and Earth's ecosystems.

This year marks the 50th anniversary of Scripps Institution of Oceanography scientist Charles David Keeling's Mauna Loa carbon dioxide record, the longest continuous record of atmospheric carbon dioxide measurements. Until now, precise ground-based measurements such as these have been the main tool for scientists monitoring the rise of atmospheric carbon dioxide concentrations.

Comparisons of this data with carbon dioxide emission rates from fossil fuel combustion, biomass burning and other human activities tell us that only about half of the carbon dioxide released into the atmosphere during this period has remained there. The rest has apparently been absorbed by surface "sinks" in the land biosphere or oceans (see "The Orbiting Carbon Observatory and the Mystery of the Missing Sinks," page 8). These measurements also show that, despite the steady long-term growth of carbon dioxide in the atmosphere, the buildup varies dramatically from year to year, even though emissions have increased smoothly. However, the ground-based carbon dioxide monitoring network is too sparse to identify the locations of these sinks or tell us what controls changes in their efficiency from year to year.



Since 1900, increases in global carbon dioxide emissions have been strongly correlated with increases in global human population. Expected increases in world population, together with the desire for economic development, guarantee a growing demand for the products and services that energy enables. The extent to which fossil fuels and other energy sources continue to be used will determine future human influences on the global climate and whether the rapid increase in greenhouse gas concentrations will continue. Credit: NASA

NASA's new Orbiting Carbon Observatory is designed to help meet this need. It will measure the amount of carbon dioxide in the atmosphere over any spot on Earth's surface and establish a record of how carbon dioxide concentrations change over time. Observations from the mission will improve our understanding of the carbon cycle—the movement of carbon among its "reservoirs" in the Earth system—and help us understand the influence of the carbon cycle on climate.

The observatory's ability to locate and monitor changes in carbon sources (places where carbon is generated) and sinks (places where carbon is absorbed or stored) will provide valuable information to support decision making by those responsible for managing carbon in the environment. It will assist them in developing effective strategies for managing global carbon dioxide and monitoring the effectiveness of those strategies.

Phil DeCola, a senior policy analyst in the White House Office of Science and Technology Policy, and former Orbiting Carbon Observatory program scientist at NASA Headquarters in Washington, said solving the scientific mystery of the missing sinks and their curious variability is likely to have large policy and economic impacts.

"If the nations of the world take serious action to limit the use of fossil fuels, the right to emit carbon dioxide will become scarcer, and emission rights would become an increasingly valuable traded commodity," DeCola said. "Observations of the location, amount and rate of carbon dioxide emission into the air, as well as the stock and flow of all forms of carbon on land and in the ocean, will be needed to manage such a world market fairly and efficiently."

Two commonly discussed strategies for reducing the amount of atmospheric carbon dioxide are a carbon tax and a "cap-and-trade" system. A carbon tax is a fee imposed on activities, such as burning of fossil fuels, which emit carbon compounds into the atmosphere. The carbon tax reduces carbon emissions by encouraging efficiencies of use, or by alternative, non-carbon emitting processes.

Cap-and-trade systems establish limits on the carbon emissions that a company, industry or country is allowed to produce. Those who exceed their established limits must compensate by either purchasing emissions rights from those whose carbon dioxide emissions fall below their established limits, or by arranging, through contracts, for sequestration (i.e., storage) of their excess emissions in plants, soils or beneath Earth's surface. Effective use of either strategy requires more accurate information on the existing sources, sinks and fluxes of carbon dioxide, information that the Orbiting Carbon Observatory can help provide.

"The new mission will provide information to help develop and implement domestic policies and international collaborations to control the movement of carbon in the environment," said Edwin Sheffner, deputy chief of Earth Science at NASA's Ames Research Center, Moffett Field, Calif. "By identifying and monitoring carbon sources and sinks within a given region, the Orbiting Carbon Observatory will enable comparisons of net carbon dioxide emission sources among regions and counties, and will improve annual reporting of carbon budgets by industrial countries in northern latitudes, and by tropical states with large forests."

"Future monitoring systems based on Orbiting Carbon Observatory technology could report on regional carbon sources and sinks to verify carbon reporting for many countries as well," he added.

Use of Orbiting Carbon Observatory data in ecosystem models may reduce uncertainties about carbon uptake, a required part of any carbon management effort. The mission will help clarify the quantity of carbon dioxide being removed from the atmosphere in different geographic regions. For example, more carbon appears to be taken up by coastal and terrestrial ecosystems in North America than in many other parts of the world. Orbiting Carbon Observatory observations will help determine the specific roles that Alaska, Canada, the contiguous United States and Mexico play in this North American carbon sink. Understanding the relative roles of different regions will help policymakers develop the most efficient carbon dioxide sequestration and reduction policies.

The observatory's measurements may also have direct applications for a variety of current efforts to reduce carbon dioxide in the atmosphere. While the mission will not be able to identify small, individual sources of carbon dioxide emissions, it will likely be able to detect high-emission events such as gas flares, where unwanted gas or other materials are burned in large quantities. This ability could allow it to verify adherence to policies aimed at reducing such flares.

Orbiting Carbon Observatory data will also have implications for land management and agricultural practices. Plants take carbon dioxide out of the atmosphere as they grow—a natural type of carbon sequestration. By repeating its measurements over multiple seasons and over regions with different types of vegetation, such as cornfields or grasslands, the observatory will help identify how changes in land use affect the amount of carbon being sequestered.

Agencies such as the U.S. Department of Agriculture may base policies for crop production and land conservation, in part, on information from Orbiting Carbon Observatory observations, according to Sheffner. Similar observations can be used by the Department of Energy to help evaluate the carbon-capture potential of various biofuels and to assess their impacts on the environment and the carbon cycle. "These findings will influence both near- and long-term policy decisions related to alternative energy," Sheffner added. In regions with large-scale agricultural land cover, Orbiting Carbon Observatory-type observations over several growing seasons could help quantify the relative roles of different types of crops and assess the effectiveness of rangeland management strategies in statewide carbon budget management.

Orbiting Carbon Observatory data may also prove to be an important addition to the ongoing effort by the California Air Resources Board and NASA scientists to improve California's database on fluctuations in greenhouse gas emissions. "These state figures, when used to enhance NASA ecosystem carbon models, can increase our precision and confidence in the allocation of industrial sources of carbon dioxide emissions as compared to emissions caused by terrestrial events such as wildfires or crop production," Sheffner said.

Evaluation of the ocean, which takes up about one third of the carbon humans put into the atmosphere, and its role in the global carbon cycle, will also benefit from the new mission's observations. Orbiting Carbon Observatory data may help show how large-scale ocean events, such as El Niño or La Niña, affect carbon storage in the deep ocean and in coastal regions. They may also help verify the impacts of these events on carbon storage on the continents, such as reduced plant growth during an El Niño-influenced drought in the U.S. Southwest.

"As the ocean absorbs large amounts of carbon dioxide, seawater becomes more acidic, potentially threatening marine life. By monitoring changes in the ocean's carbon uptake, the mission may shed new light on ocean acidification and the resulting changes in ocean ecosystems," said Sheffner. Knowing more about how ocean carbon levels fluctuate will also help scientists evaluate the possibility of using biological or chemical processes in the ocean to sequester carbon and perhaps even mitigate ocean acidification.

Sheffner explained that the Orbiting Carbon Observatory may also aid efforts to find effective ways to store excess carbon safely underground. Combining mission data with observations from airborne and ground-based instruments will create much more accurate maps of global carbon sources and sinks than were ever possible before. "Once we have a better understanding of the 'background' fluctuations in carbon dioxide near proposed underground carbon storage sites, the observatory's data could be useful for monitoring underground carbon storage sites for leakage," he explained.

"The Orbiting Carbon Observatory will provide information needed for evaluating policy options and monitoring the effectiveness of efforts to reduce carbon emissions and increase carbon sequestration locally, regionally and globally," Sheffner said, in summing up.

Looking to the future, DeCola said the mission will serve as a prototype for the next generation of greenhouse gas space missions. "The Orbiting Carbon Observatory will be an important experiment because its results will be used to develop the future long-term, space-based missions needed to monitor carbon dioxide for science and decision support," he said.

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OCO SPOKESPERSONS

David Baker is a postdoctoral researcher at the Cooperative Institute for Research in the Atmosphere in Fort Collins, Colo. His research interests include the global carbon cycle, atmospheric data assimilation, atmospheric chemistry and climate change. He is developing a variational data assimilation system to estimate surface sources and sinks of carbon dioxide from retrieved Orbiting Carbon Observatory carbon dioxide measurements. Besides providing a "quick-look" for carbon scientists, this product will be used to help identify and remove biases in the carbon dioxide product.

David Crisp is an atmospheric physicist and a senior research scientist at NASA's Jet Propulsion Laboratory in Pasadena, Calif. As principal investigator on the Orbiting Carbon Observatory mission, he led the development of the mission science objectives, implementation approach and operational concept. Crisp is responsible to NASA for the overall success of this mission.

Phil DeCola is a senior policy analyst in the White House Office of Science and Technology Policy focusing on climate science and Earth observations. He is the former program scientist for the Orbiting Carbon Observatory at NASA Headquarters in Washington. He is interested in developing information systems that guide the formulation of plans to reduce the carbon-related effects of the world's energy supply, and that verify the efficacy of these strategies. This information system will combine Earth observations, like those from the Orbiting Carbon Observatory, together with carbon cycle and climate models to measure the stock and flow of all forms of carbon in the atmosphere, on land, and in the ocean.

Scott Denning is a professor in the Department of Atmospheric Sciences at Colorado State University in Fort Collins, Colo., where he leads a research group interested in exploring the global carbon cycle and its relationship to terrestrial ecosystems. Underpinning Denning's research is the drive to identify the "missing" carbon dioxide sinks.

Scott Doney is a senior scientist at the Woods Hole Oceanographic Institution in Woods Hole, Mass. His specialties involve data assimilation, carbon cycle modeling and the ocean carbon cycle. During the Orbiting Carbon Observatory mission, Doney will investigate ocean carbon sources and sinks of carbon on seasonal and annual average time scales, as well as air-sea gas exchange rates.

Inez Fung is a professor of atmospheric science at the University of California, Berkeley. She specializes in studying the carbon cycle and climate change. As a member of the Orbiting Carbon Observatory science team, Fung will work to infer carbon dioxide sources and sinks and quantify uncertainty.

Daniel Jacob is a professor of atmospheric chemistry and environmental engineering at Harvard University in Cambridge, Mass. Jacob's focus is using modeling of atmospheric chemistry and climate to better understand the chemical composition of the atmosphere.

Tom Livermore of NASA's Jet Propulsion Laboratory, Pasadena, Calif., is the Orbiting Carbon Observatory project manager and can address questions on mission implementation.

Charles Miller of NASA's Jet Propulsion Laboratory in Pasadena, Calif., is the Orbiting Carbon Observatory mission's deputy principal investigator and science team lead, representing the team in project activities and decisions. He is interested in finding out how well a trace gas can be measured from space. Pushing the accuracy of such measurements in the laboratory and in atmospheric remote sensing data is what drives most of the work by Miller and his colleagues.

Denis O'Brien is a senior research scientist in the Department of Atmospheric Sciences at Colorado State University in Fort Collins, Colo. His focus with the Orbiting Carbon Observatory mission is in retrieving carbon dioxide information from spectra.

Jim Randerson is an associate professor of Earth system science at the University of California, Irvine, and contributed early in the mission to its design. Randerson's specialty is the global carbon cycle, and he looks forward to using Orbiting Carbon Observatory data in modeling and analysis to better understand changes in tropical forest ecosystems, including rates of carbon loss associated with deforestation and fires.

Peter Rayner is a senior researcher at the Laboratory for the Sciences of Climate and the Environment, Saclay, France. His general research interest is the global carbon cycle, with a particular focus on determining the distribution of carbon sources and sinks using atmospheric data. He was the first to point out the potential utility of an Orbiting Carbon Observatory-like instrument for this task. He will be part of a group estimating carbon dioxide sources and sinks with Orbiting Carbon Observatory data and validating these estimates with direct measurements.

Ross Salawitch is a professor at the University of Maryland in College Park. His focus is on the uptake of carbon by the world's ocean and terrestrial biosphere and interactions between the global carbon cycle and climate change. As the Orbiting Carbon Observatory mission's validation lead and a science team member, Salawitch is focused on assuring the measurements are of high quality for addressing the science questions that drive the mission.

Graeme Stephens is a professor in the Department of Atmospheric Sciences at Colorado State University in Fort Collins. His activities include research into applying remote sensing to better understand climate change. The Orbiting Carbon Observatory mission instrument that will measure carbon dioxide is based on an approach that Stephens, the principal investigator for NASA's CloudSat mission, had first planned for CloudSat.

Pieter Tans is a senior scientist at the National Oceanic and Atmospheric Administration Earth System Research Laboratory in Boulder, Colo. Tans discovered, with Fung and Takahashi, the existence of a very large "sink" of carbon dioxide by terrestrial ecosystems at mid-latitudes in the northern hemisphere, partially offsetting the emissions caused by the burning of coal, oil and natural gas. In 2007, his group launched CarbonTracker, a data assimilation system that turns global observations of atmospheric carbon dioxide concentrations into time-varying maps of surface sources and sinks of carbon dioxide that are optimally consistent with the observations. As a member of the Orbiting Carbon Observatory science team, Tans plans to perform ongoing comparison of Orbiting Carbon Observatory retrievals with direct measurements from CarbonTracker, and explore ways to combine the information from satellite retrievals with the directly measured data.

Paul Wennberg is a professor at the California Institute of Technology in Pasadena, Calif. Through the construction of the ground-based Total Carbon Column Observing Network, Wennberg's team has built the validation system for the Orbiting Carbon Observatory. They will analyze Orbiting Carbon Observatory observations together with those from the network to assure that the final carbon dioxide products from the Orbiting Carbon Observatory are as precise and accurate as possible.

Steven Wofsy is a professor of atmospheric and environmental chemistry in the School of Engineering and Applied Science and the Department of Earth and Planetary Science at Harvard University in Cambridge, Mass. His interest is atmospheric composition and the carbon cycle. As part of the Orbiting Carbon Observatory mission, he intends to help refine the calibration of the Orbiting Carbon Observatory sensor and to use the Orbiting Carbon Observatory data to infer sources and sinks of carbon dioxide.

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