Space based measurements of Atmospheric Carbon Dioxide: A New Tool for Monitoring our Environment

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Abstract: The NASA Orbiting Carbon Observatory-2 (OCO-2) was launched in July 2014. This satellite is designed to characterize the sources emitting carbon dioxide into the atmosphere and the natural processes absorbing it at the surface.

1. Introduction

Fossil fuel combustion, deforestation, and other human activities are now adding almost 40 billion tons of carbon dioxide (CO_2) to the atmosphere each year. Interestingly, as these emissions have increased over time, natural "sinks" in land biosphere and oceans have absorbed roughly half of this CO_2, reducing the rate of atmospheric buildup by a half. Measurements of the increasing acidity (pH) of seawater indicate that the ocean absorbs one quarter of this CO_2. Another quarter is apparently being absorbed by the land biosphere, but the identity and location of these natural land CO_2 "sinks" are still unknown. The existing ground-based greenhouse gas monitoring network provides an accurate record of the atmospheric buildup, but still does not have the spatial resolution or coverage needed to identify or quantify CO_2 sources and sinks.

2. Space Based Measurements – the Pioneers

One way to improve the spatial and temporal sampling of CO2 is to retrieve precise, spatially-resolved, global estimates of the column-averaged CO2 dry air mole fraction (XCO2) from space. Surface weighted XCO2 estimates can be retrieved from high resolution spectroscopic observations of reflected sunlight in near infrared CO2 and O2 bands. This is a challenging space based remote sensing observation because even the largest CO2 sources and sinks produce changes in the background XCO2 distribution no larger than 2%, and most are smaller 0.25%. The European Space Agency (ESA) EnviSat SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY) and Japanese Greenhouse gases Observing SATellite (GOSAT) Thermal And Near infrared Sensor for carbon Observation - Fourier Transform Spectrometer (TANSO-FTS) were the first satellite instruments designed to exploit this measurement approach. SCIAMACHY collected column averaged CO2 and methane (XCH4) measurements over the sunlit hemisphere from 2002 to 2012. TANSO-FTS has been collecting XCO2 and XCH4 observations since April 2009. These data have provided an excellent proof of concept, and are beginning to yield new insights into the carbon cycle, but improvements in sensitivity, resolution, and coverage are still needed.

3. The NASA Orbiting Carbon Observatory-2 (OCO-2) Mission

OCO-2 is the first NASA satellite designed to measure atmospheric CO_2 with the precision, accuracy, resolution and coverage needed to characterize the sources emitting this gas into the atmosphere, and the natural sinks that currently absorb over half of all CO_2 emissions from human activities. OCO-2 is a "carbon copy" of the Orbiting Carbon Observatory, which was lost in 2009, when its launch vehicle malfunctioned and failed to reach orbit. OCO-2 carries and points a 3-channel, imaging, grating spectrometer. This instrument collects high resolution spectra of reflected sunlight in the 0.765 μm O_2 A-band and in the 1.61 and 2.06 μm CO_2 bands with unprecedented sensitivity. Each channel collects 24 spectra per second over the sunlit hemisphere. Coincident measurements from the three channels are combined and analysed with a "full-physics" retrieval algorithm to yield estimates of X_{CO2} and other geophysical quantities.

OCO-2 was successfully launched from Vandenberg Air Force Base in California on 2 July 2014. After completing a series of spacecraft check-out activities and orbit raising maneuvers, OCO-2 joined the 705 km Afternoon Constellation (A-Train) on August 6, 2014. Its 3-channel imaging grating spectrometer was then cooled to its operating temperatures and a series of calibration and validation activities was initiated. This instrument's rapid sampling, small (< 3 km^2) sounding footprint, and high sensitivity, combined with an optimized observing strategy, are expected to provide improved coverage of the ocean, partially cloudy regions, and high latitude continents than earlier missions.

In early October, OCO-2 started routinely collecting almost one million soundings over the sunlit hemisphere each day. Around 25% of these soundings (250,000/day) are sufficiently cloud free to yield full column estimates of X_{CO2}. For routine science operations, the instrument's bore sight is pointed to the local nadir or at the "glint spot," where sunlight is specularly reflected from the Earth's surface. Nadir observations provide the best spatial resolution and yield more cloud-free X_{CO2} soundings over land. Glint observations have much more signal over dark, ocean surfaces, yielding much more complete coverage of the globe. The initial observation sequence alternates between glint and nadir observations on consecutive 16-day ground-track repeat cycles, so that the entire sunlit hemisphere is sampled in both modes at 32-day intervals. OCO-2 can also target selected surface calibration and validation sites to collect thousands of soundings as the spacecraft flies overhead. The primary surface targets include well calibrated surface sites, such as Railroad Valley, Nevada, and Total Carbon Column Observing Network (TCCON) stations, which make precise measurements of CO_2 and other trace gases from the ground.

The OCO-2 team started releasing calibrated, geo-located, spectra to the science community through the NASA Goddard Earth Sciences Data and Information Services Center (GES-DISC) on 30 December, 2014. Deliveries of a preliminary Level 2 product, including estimates of X_{CO2}, surface pressure, and solar-induced chlorophyll fluorescence (SIF), were initiated on 30 March 2015. These data are now being used the scientific community to address the questions described above..

4. Acknowledgements

Part of the research described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.