THE ORBITING CARBON OBSERVATORY MISSION

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ABSTRACT

The Orbiting Carbon Observatory (OCO) mission was selected by NASA's Office of Earth Science as the fifth mission in its Earth System Science Pathfinder (ESSP) Program. OCO will make the first global measurements of atmospheric CO_2 with the precision, resolution, and coverage needed to characterize sources and sinks of this important greenhouse gas on regional scales. These measurements will improve our understanding of the processes that regulate CO_2, enabling more reliable forecasts of climate change. During its 2-year mission, OCO will fly in a 1:15 PM sun-synchronous orbit, sharing its ground track with the Earth Observing System (EOS) Aqua platform. It will carry a single instrument that incorporates three high-resolution spectrometers to measure reflected sunlight in the molecular oxygen (O_2) A-band at 0.76-microns and the CO_2 bands at 1.61 and 2.06 microns. These data will be analyzed to retrieve the column-averaged CO_2 dry air mole fraction with precisions of 0.3% (1ppm) on regional scales. A comprehensive validation and correlative measurement program has been incorporated into this mission to ensure the accuracy of the space-based X_{CO2} measurements.

1. INTRODUCTION

Over the past 40 years, measurements from a global network of ground-based sites indicate that only about half of the CO_2 that has released by human activities has remained in the atmosphere. The rest has apparently been absorbed by the oceans and by land-based ecosystems. However, the existing measurements do not provide the coverage or spatial resolution needed to resolve these CO_2 sinks. In particular, while they provide strong evidence for a northern hemisphere sink, they cannot discriminate the relative roles of the North American and Asian continents and the ocean basins. These uncertainties complicate efforts to predict future atmospheric CO_2 concentrations or their effects on the climate, because they limit our ability to predict how these processes might change as the climate evolves. They also complicate efforts to monitor compliance to proposed CO_2 emission treaties that give credit for CO_2 sinks. To address these issues, NASA has selected the Orbiting Carbon Observatory (OCO) as the fifth mission in Earth System Science Pathfinder (ESSP) Program. This mission will acquire global, space-based measurements of atmospheric CO_2 with the spatial resolution and accuracy needed to identify and characterize surface sources and sinks of this important greenhouse gas. This paper summarizes the factors that drove the design of the OCO mission, and provides a brief description of the implementation approach.

2. MISSION OBJECTIVES

Global simulations with source-sink inversion models [1] indicate that our understanding of CO_2 sources and sinks could be improved substantially if data from the existing ground-based CO_2 monitoring network were augmented by global, space-based measurements of the column-integrated dry air mole fraction (X_{CO2}) with accuracies of ~1ppm (0.3% of 370 ppm). The OCO mission was designed to address this need. The OCO satellite will fly in a polar, sun-synchronous orbit, providing global coverage every 16 days. It will fly just ahead of Earth Observing System (EOS) Afternoon Constellation (A-Train), with a 1:15 PM equator crossing time. This orbit facilitates direct comparisons of OCO observations with complementary data taken by Aqua (e.g. AIRS temperature, humidity, and CO_2 retrievals; MODIS clouds, aerosols, and ocean color), Aura (TES CH_4 and CO), and other A-Train missions. This orbit's 16-day repeat cycle also facilitates monitoring X_{CO2} variations on semi-monthly time scales.

The OCO spacecraft will carry a single instrument that incorporates three high-resolution grating spectrometers to measure reflected sunlight in the 0.76-micron (μm) O_2 A-band, and the CO_2 bands at 1.58 and 2.06 μm. A simultaneous retrieval algorithm will be used to retrieve time-dependent estimates of the column-averaged CO_2 dry air mole fraction, X_{CO2}. The OCO mission incorporates a comprehensive ground-based validation and correlative measurement program to ensure the accuracy of the space-based X_{CO2} measurements have precisions of 0.3% (1-ppm CO_2) on regional scales. Once validated, the space-based X_{CO2} measurements will be combined with ground-based and aircraft measurements and incorporated into sophisticated source-sink inversion and data assimilation models to characterize the geographic distribution of CO_2 sources and sinks over two annual cycles.

3. MEASUREMENT APPROACH

The measurement requirements for OCO were derived from end-to-end observation system simulation experiments [2]. The weak CO_2 band near 1.61 μm was selected for CO_2 column measurements because this spectral region is relatively free of absorption by other gases. Measurements in this band are also ideal for studying near-surface CO_2 sources and sinks because most of the spectral lines produce measurable absorption, but do not saturate for the range of observing paths considered here. The absorption depth of these lines therefore increases almost linearly with the CO_2 number density and path length, such that high-resolution spectroscopic measurements yield their greatest information content near the surface. Bore-sighted measurements in the 0.76μm O_2 A-band provide direct constraints on the total (dry-air) atmospheric pressure of the reflecting surface. This information must be combined with the CO_2 column estimates to derive the column-averaged CO_2 dry air mole fraction, X_{CO2}. Aircraft studies show that A-band observations can provide surface pressure estimates with accuracies of ~1 millibar (O'Brien and Mitchell, 1992). A-Band spectra also provide a sensitive indicator of clouds and optically thick aerosols, which preclude full column measurements of CO_2. Finally, spectra of the strong 2.06 μm band will provide independent constraints on the aerosol optical properties at near-infrared wavelengths, dramatically improve the accuracy of X_{CO2} retrievals in aerosol-laden conditions [2]. Bore-sighted measurements in this band also provide direct constraints on the atmospheric temperature and humidity along the optical path, minimizing systematic errors associated with uncertainties in these parameters. The OCO instrument therefore includes spectral channels centered within in the 0.76 μm O_2 A-band and the CO_2 bands at 1.61 and 2.06 μm. A single ***sounding*** consists of bore-sighted spectra in these 3 channels.

The spectral range each channel includes the complete molecular absorption band as well as some nearby continuum to minimizes biases due to uncertainties in atmospheric temperature and provide constraints on the optical properties of the surface albedo and aerosols. The spectral resolving power for each channel was selected to maximize the sensitivity to variations in the column abundances of CO_2 and O_2, and to minimize the impact of systematic measurement errors. A spectral resolving power, $\lambda/\Delta\lambda$ ~21,000 separates individual CO_2 lines in the 1.61 and 2.06 μm regions from weak H_2O and CH_4 lines and from the underlying continuum. For the O_2 A-band, a resolving power of 17,500 is needed to distinguish the O_2 doublets from the continuum. With these resolving powers, the OCO retrieval algorithm can characterize the surface albedo throughout the band and solve for the wavelength dependence of the aerosol scattering, minimizing X_{CO2} retrieval errors contributed by uncertainties in the continuum level.

While many soundings must be collected to adequately characterize the CO_2 abundance on regional scales, contiguous spatial sampling is not required because CO_2 diffuses over a large area as it is mixed through the column. However the full atmospheric column must be sampled to provide constraints on surface CO_2 sources and sinks. Clouds and optically thick aerosols preclude measurements of the complete column. Preliminary studies by the OCO team indicate that probability of viewing a cloud-free scene increase as the size of the footprint decreases. To obtain an adequate number of soundings on regional scales, even in the presence of patchy clouds, each OCO spectrometer will have a 10 km-wide cross-track field of view (FOV) at nadir that is divided into ten or more cross-track elements. Soundings are collected at a rate of 45 soundings per second as the spacecraft moves along its ground track at 6.78 km/sec. This yields ~740 soundings per degree of latitude along the orbit track, such that thousands of samples are collected on regional scales during each 16-day ground repeat cycle.

Three different observing modes were defined for OCO. In Nadir mode, the satellite points the instrument to the local nadir, so that data can be collected along the ground track just below the spacecraft. This mode provides the highest spatial resolution on the surface, but may not provide adequate signal to noise over dark ocean surfaces. The Glint mode was designed to address this concern. In this mode, the spacecraft points the instrument toward the bright "glint" spot, where solar radiation is specularly reflected from the surface. Glint measurements should provide much higher signal to noise rations over the ocean. OCO will switch from Nadir to Glint modes on alternate 16-day global ground track repeat cycles such that the entire Earth is mapped in each mode on roughly monthly time scales. Finally, a Target mode will be used to track specific surface targets as the satellite flies overhead. This mode will provide up to 27,000 samples over sites that include ground-based OCO calibration assets at monthly intervals.

The OCO instrument will be manufactured by Hamilton Sundstand Sensor Systems, in Pomona California, the same organization that supplied the last 4 Total Ozone Mapping Spectrometer (TOMS) instruments. It incorporates independent bore-sighted, long-slit, imaging grating spectrometers for the 1.61 μm and 2.06 μm CO_2 bands and the 0.76 μm O_2 A-band. These 3 spectrometers are integrated into a common structure to improve rigidity and thermal stability. They use similar optical designs, consisting of an optimized 100 mm diameter, f/2 telescope that focuses light on a long, narrow slit that is aligned perpendicular to the orbit track. Behind the slit, the light is collimated, dispersed by a grating, and focused by a camera lens, forming an image of a spectrum on a focal plane array (FPA). The spectrum is dispersed across the FPA in the direction orthogonal to the slit, and (cross-track) spatial information is recorded along the slit.

OCO will use a 3-axis stabilized spacecraft based on the Orbital LEOStar-II bus (Fig. 3a). This bus was used previously for OrbView-4 (OV-4), Galaxy Explorer (GALEX), and Solar Radiation and Climate Explorer (SORCE). For OCO, the bus will be used to point the instrument to nadir, glint, specific ground targets, or the limb, or to orient the calibration target toward the sun. It will also be used to point the body-mounted X-band antenna at the ground station twice each day. The estimated pointing accuracy is better than 900 arc seconds (arcsec), and pointing knowledge is better than 200 arcsec.

4. CONCLUSIONS

The OCO mission is in the process of completing a risk reduction phase and preparing for its System Requirements Review. We anticipate that it will enter Formulation Phase before October 2003, in preparation for a launch in late 2007 and a two-year operational lifetime as an ESSP mission. After that, if the observatory is still working well, it is our hope that it will be maintained as the first operational CO_2 monitoring satellite.

5. REFERENCES

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