Geophysical Research Abstracts, Vol. 9, 10014, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-10014

Laser Sounder for Global Measurement of CO2 Concentrations in the Troposphere from Space

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Atmospheric CO_2 concentrations are higher now than they have been in the past 25 million years. It is becoming increasingly important to understand the nature and processes of the CO2 sinks, on a global scale, in order to make predictions of future atmospheric composition. Accurate measurements of tropospheric CO2 abundance with global-coverage, a few hundred km spatial and monthly temporal resolution are needed to quantify processes that regulate CO2 storage by the land and oceans. The NASA Orbiting Carbon Observatory (OCO) is the first space mission focused on atmospheric CO_2 for measuring total column CO_2 and O_2 by detecting the spectral absorption in reflected sunlight. The OCO mission is a key first step, and will yield important new information about atmospheric CO_2 distributions. However they are some unavoidable limitations imposed by its measurement approach. These include best accuracy only during daytime at moderate to high sun angles, sensitivity to errors from cloud and aerosol scattering, and limited signal from CO_2 variability in the lower tropospheric CO_2 column.

We have been developing a new laser-based technique for the remote measurement of the tropospheric CO_2 concentrations from orbit. Our initial goal is to demonstrate a lidar technique and instrument technology that will permit measurements of the CO_2 column abundance in the lower troposphere from aircraft. Our final goal is to

develop a space instrument and mission approach for active measurements of the CO_2 mixing ratio at the 1-2 ppmv level. Our technique is much less sensitive to cloud and atmospheric scattering conditions and would allow continuous measurements of CO_2 mixing ratio in the lower troposphere from orbit over land and ocean surfaces during day and night.

Our approach is to use the 1570nm CO_2 band and a 3-channel laser absorption spectrometer (ie lidar used an altimeter mode), which continuously measures at nadir from a near polar circular orbit. The approach directs the narrow co-aligned laser beams from the instrument's lasers toward nadir, and measures the energy of the laser echoes reflected from land and water surfaces. It uses several tunable fiber laser transmitters which allowing measurement of the extinction from a single selected CO_2 absorption line in the 1570 nm band. This band is free from interference from other gases and has temperature insensitive absorption lines. During the measurement the lasers are tuned on- and off- a selected CO_2 line near 1572 nm and a selected O_2 line near 768 nm in the Oxygen A band at kHz rates. The lasers use tunable diode seed lasers followed by fiber amplifiers, and have spectral widths much narrower than the gas absorption lines. The receiver uses a 1-m diameter telescope and photon counting detectors and measures the background light and energies of the laser echoes from the surface. The extinction and column densities for the CO_2 and O_2 gases are estimated from the ratio of the on and off line surface echo via the differential optical absorption technique.

Our technique rapidly alternates between several on-line wavelengths set to the sides of the selected gas absorption lines. It exploits the atmospheric pressure broadening of the lines to weight the measurement sensitivity to the atmospheric column below 5 km. This maximizes sensitivity to CO_2 in the boundary layer, where variations caused by surface sources and sinks are largest. Simultaneous measurements of O_2 column will use an identical approach with an O_2 line. The laser frequencies are tunable with narrow (MHz) line widths. In combination with sensitive photon counting detectors these enable much higher spectral resolutions and precisions than are possible with passive spectrometers. Laser backscatter profiles are also measured, which permits identifying measurements made to cloud tops and through aerosol layers.

The measurement approach using lasers in common-nadir-zenith path allows retrieving CO_2 column mixing ratios in the lower troposphere irrespective of sun angle. Pulsed laser signals, time gated receiver and a narrow receiver field-of-view are used to isolate the surface laser echo signals and to exclude photons scattered from clouds and aerosols. Nonetheless, the optical absorption change due to a change of a few ppm CO_2 is small, $<1\%$, which makes achieving the needed measurement sensitivities and stabilities quite challenging. Measurement SNRs and stabilities of $>600:1$ are needed to estimate CO2 mixing ratio at the 1-2 ppm level. We have calculated several characteristics of the technique, and have demonstrated aspects of the laser, detector and receiver approaches in the laboratory. We have also measured O2 in an absorption cell, CO2 over a 206 m long (one way) horizontal path using a breadboard version of the sensor. We will describe these measurements and more details about our approach in the paper.