Analysis of Pulsed Airborne Lidar measurements of Atmospheric CO2 Column Absorption from 3-13 km altitudes

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We have developed a pulsed lidar technique for measuring the tropospheric CO2 concentrations as a candidate for NASA's ASCENDS space mission [1]. It uses two pulsed laser transmitters allowing simultaneous measurement of a CO2 absorption line in the 1575 nm band, O2 extinction in the Oxygen A-band, surface height and backscatter profile. The lasers are precisely stepped in wavelength across the CO2 line and an O2 line region during the measurement. The direct detection receiver measures the energies of the laser echoes from the surface along with the range profile of scattering in the path. The column densities for the CO2 and O2 gases are estimated from the ratio of the on- and off- line signals via the integrated path differential absorption (IPDA) technique. The time of flight of the laser pulses is used to estimate the height of the scattering surface and to reject laser photons scattered in the atmosphere.

We developed an airborne lidar to demonstrate an early version of the CO2 measurement from the NASA Glenn Lear-25 aircraft. The airborne lidar stepped the pulsed laser's wavelength across the selected CO2 line with 20 wavelength steps per scan. The line scan rate is 450 Hz, the laser pulse widths are 1 usec, and laser pulse energy is 24 uJ. The time resolved laser backscatter is collected by a 20 cm telescope, detected by a NIR photomultiplier and is recorded on every other reading by a photon counting system [2].

During August 2009 we made a series of 2.5 hour long flights and measured the atmospheric CO2 absorption and line shapes using the 1572.33 nm CO2 line. Measurements were made at stepped altitudes from 3-13 km over locations in the US, including the SGP ARM site in Oklahoma, central Illinois, north-eastern North Carolina, and over the Chesapeake Bay and the eastern shore of Virginia. Although the received signal energies were weaker than expected for ASCENDS, clear CO2 line shapes were observed at all altitudes, and some measurements were made through thin clouds. The Oklahoma and east coast flights were coordinated with a LaRC/ITT CO2 lidar on the LaRC UC-12 aircraft, and in-situ measurements were made using its CO2 sensor and radiosondes.

We have conducted an analysis of the ranging and IPDA lidar measurements from these four flights. Most flights had 5-6 altitude steps with 200-300 seconds of recorded measurements per step. We used a cross-correlation approach to process the laser echo records. This was used to estimate the range to the scattering surface, to define the edges of the laser pulses and to determine echo pulse energy at each wavelength. We used a minimum mean square approach to fit an instrument response function and to solve for the best-fit CO2 absorption line shape. We then calculated the differential optical depth (DOD) of the fitted CO2 line. We computed its statistics at the various altitude steps, and compare them to the DODs calculated from spectroscopy based on HITRAN 2008 and the column conditions calculated from the airborne in-situ readings. The results show the lidar and in-situ measurements have very similar DOD change with altitude and > 10 segments per flight where the scatter in the lidar measurements are $\leq$ 1ppm. We also present the results from subsequent CO2 column absorption measurements, which were made with stronger detected signals during three flights on the NASA DC-8 over the southwestern US in during July 2010.

References:

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