

# LASER SOUNDER FOR GLOBAL MEASUREMENT OF CO<sub>2</sub> CONCENTRATIONS IN THE TROPOSPHERE FROM SPACE

*Haris Riris, James B. Abshire, Graham Allan\*, Xiaoli Sun, S. Randy Kawa, Jian-Ping Mao\*\*, Mark Stephen, Emily Wilson, Michael A. Krainak*

NASA-Goddard Space Flight Center Science and Technology Directorates  
Codes 690, 610, and 554, Greenbelt MD 20771

Haris.Riris-1@nasa.gov

\*Sigma Space Inc., NASA Goddard Code 694, Greenbelt MD 20771

\*\* - RSIS Inc. 1651 Old Meadow Road McLean VA 22102

## 1. INTRODUCTION

Measurements from ice cores show that atmospheric CO<sub>2</sub> concentrations are higher now than they have been in the past 400,000 years. It is becoming increasingly important to understand the nature and processes of the CO<sub>2</sub> sinks and sources, on a global scale, in order to make predictions of future climate change.

Accurate measurements of tropospheric CO<sub>2</sub> abundance with global-coverage, 300 km spatial and monthly temporal resolution are needed to quantify processes that regulate CO<sub>2</sub> storage by the land and oceans [1].

The NASA Orbiting Carbon Observatory (OCO) is the first space mission focused on atmospheric CO<sub>2</sub> for measuring total column CO<sub>2</sub> and O<sub>2</sub> 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<sub>2</sub> distributions. However there are unavoidable limitations imposed by its measurement approach. These include best accuracy only during daytime at moderate to high sun angles, interference by cloud and aerosol scattering, and limited signal from CO<sub>2</sub> variability in the lower tropospheric CO<sub>2</sub> column. The recent NRC Decadal Survey for Earth Science [2] has recommended addressing these un-met needs in a laser-based CO<sub>2</sub> measuring mission called ASCENDS.

We have been in developing a laser technique for the remote measurement of the tropospheric CO<sub>2</sub> concentrations from orbit [3-6]. Our goal is to develop a space instrument and mission approach for active CO<sub>2</sub> measurements.

## 2. APPROACH

Previous and some ongoing efforts to develop laser instruments for measuring atmospheric CO<sub>2</sub> have used the 4.88 um [7] and 2 um [8-11] bands. Our approach uses the 1570nm band and a dual channel laser absorption spectrometer (ie DIAL lidar used an altimeter mode), which continuously measures at nadir from a near polar circular orbit.

It uses tunable fiber laser transmitters allowing simultaneous measurement of the absorption from a CO<sub>2</sub> absorption line in the 1570 nm band [12] and O<sub>2</sub> extinction in the oxygen A-band, and aerosol backscatter in the same measurement path. It 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.

The lasers use a Master Oscillator Power Amplifier (MOPA) architecture using tunable diode seed lasers and 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 [13], and measures the background light and energies of the laser echoes from the surface along with scattering from any clouds and aerosols in the path. The gas extinction and column densities for the CO<sub>2</sub> and O<sub>2</sub> gases are estimated from the ratio of the on- and off-line signals via the differential optical absorption technique. Pulsed laser signals and time gating are used to isolate the laser echo signals from the surface, and to exclude photons scattered from clouds and atmospheric aerosols.

The 1570 nm CO<sub>2</sub> band [13] is well suited for this measurement. It is largely free from interference, and is within the spectral range of high power lasers and sensitive photon counting detectors.

Our technique uses the on-line wavelengths tuned to the sides of the gas absorption line. This exploits the atmospheric pressure broadening of the gas lines to weight the measurement sensitivity to the atmospheric column below 5 km. This maximizes sensitivity to CO<sub>2</sub> changes in the boundary layer where variations caused by surface sources and sinks are largest. Simultaneous measurements of O<sub>2</sub> column are planned using a selected region in the Oxygen A-band. Laser altimetry and atmospheric backscatter profiles are also measured simultaneously, which permits determining the surface height and measurements made to thick cloud tops and through aerosol layers.

The laser sounder approach has some fundamental advantages over measurements with passive sensors using reflected sunlight. It measures gas absorption in a common nadir/zenith path and the narrow laser divergence produces small laser footprints. The laser sources allow measurements in sunlight and darkness allowing global coverage. It can measure continuously over the ocean, to cloud tops and through broken clouds. The lasers are pulsed and potential measurement errors from scattering from clouds and aerosols are greatly reduced by using time gating in the receiver. Nonetheless, the optical absorption change due to a few ppm change in CO<sub>2</sub> is quite small, <1%, which makes achieving measurement sensitivity and stabilities challenging. Signal-to-noise ratios and measurement stabilities of > 700:1 are needed to allow CO<sub>2</sub> mixing ratio estimates at the few ppm level.

We have calculated several characteristics of the technique, and have demonstrated key aspects of the laser, detector and receiver approaches in the laboratory. We have also measured O<sub>2</sub> in an absorption cell, and CO<sub>2</sub> over 206 and 400m long open horizontal paths [6] using a breadboard version of the sensor.

## 11. REFERENCES

1. R.J. Engelen et al., *J. of Geophysical Res.-Atmospheres* **106** (D17): 20055 (2001).
2. National Research Council, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," Jan. 2007, available from <http://www.nap.edu/>.
3. J.B. Abshire, et al. "Laser Sounder Technique for Remotely Measuring Atmospheric CO<sub>2</sub> Concentrations", *Eos Trans. AGU*, 82(47), Fall Meet. Suppl., Abstract GC32A-0221, December 2001.
4. M.A. Krainak, et al., "Measurements of atmospheric CO<sub>2</sub> over a horizontal path using a tunable-diode-laser and erbium-fiber-amplifier at 1572 nm," *CLEO '03*, June 2003.
5. J.B. Abshire, et al., "Laser Sounder for Global Measurement of CO<sub>2</sub> Concentrations in the Lower Troposphere from Space: Progress," Fall AGU 2004, Paper SF43A-0783, December 2004.
6. J.B. Abshire et al., "Laser Sounder for Global Measurement of CO<sub>2</sub> Concentrations in the Troposphere from Space," 2007 EGU General Assembly, Abstract 2007-A-10014, Vienna Austria, April 2007.
7. J.L. Bufton et al., *Appl. Optics* **22** (17), 2592 (1983).
8. N. Sugimoto et al., *Appl. Optics* **32** (33), 6827 (1993).
9. Ismail, S., et al., "A 2-micron DIAL system for profiling atmospheric CO<sub>2</sub>", *International Laser Radar Conference, Proceedings*, (2002).
10. Ismail, S. et al., "Technology development for tropospheric profiling of CO<sub>2</sub> and ground-based measurements", *International Laser Radar Conference, Proceedings*, (2004)
11. Koch, G., et al., "Coherent differential absorption lidar measurements of CO<sub>2</sub>", *Appl. Opt.*, 43(26), 5092, (2004)
12. J. Henningsen et al., *J. Mol. Spectrosc.* **203** (1), 16 (2000).
13. X. Sun et al., *CLEO 2002*, paper CFF3 (2002).
14. J. Mao et al., "Sensitivity Studies for a Space-based CO<sub>2</sub> Laser Sounder Development", 2007 EGU General Assembly, Abstract 2007-A-11150, Vienna Austria, April 2007.