CO_2 Sounder Lidar for ASCENDS Mission & Airborne Measurement Demonstrations from 3-13 km Altitudes

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ABSTRACT

We have developed a pulsed lidar technique for measuring the tropospheric CO2 concentrations as a candidate for NASA's planned ASCENDS space mission. We have developed an airborne lidar to demonstrate the CO2 column measurement from aircraft. In 2009 we measured atmospheric CO2 column absorption and line shapes on a series of flights at altitudes from 3-13 km.

1. INTRODUCTION

The US NRC Decadal Survey for Earth Science has recommended an orbital laser-based CO_2 measuring mission called ASCENDS. We have developed a laser technique as a candidate for the remote measurement of the tropospheric CO_2 concentrations from orbit. Our initial goals are to demonstrate a lidar technique and instrument technology that will permit measurements of the CO_2 column abundance in the lower troposphere from aircraft at the few ppm level under typical surfaces and realistic atmospheric scattering conditions.

2. APPROACH

Our approach for ASCENDS, shown in Figure 1, is to use the 1570nm band and a pulsed dual channel laser absorption spectrometer, a direct detection DIAL lidar used the altimeter (IPDA) mode. It continuously measures at nadir from a near polar circular orbit. The 1570 nm CO_2 band shown in Figure 2 is well suited for this measurement. It is largely free from interference, has absorption lines with the needed temperature insensitivity and strengths [1], and can be accessed by suitable high power lasers and sensitive photon counting detectors.

We have developed a wavelength stepped lidar technique for this measurement. It uses two pulsed laser transmitters allowing simultaneous measurement of a CO2 absorption line in the 1570 nm band, O2 extinction in the Oxygen A-band [2] and surface height and backscatter. The lidar measures the energy and time of flight of the laser echoes reflected from the atmosphere and surface. The lasers are rapidly and precisely stepped in wavelength across a single CO2 line and an O2 line pair during the measurement. The direct detection receiver uses photon-counting detectors and measures the background light and laser backscatter profiles from the atmosphere and surface at both wavelengths.

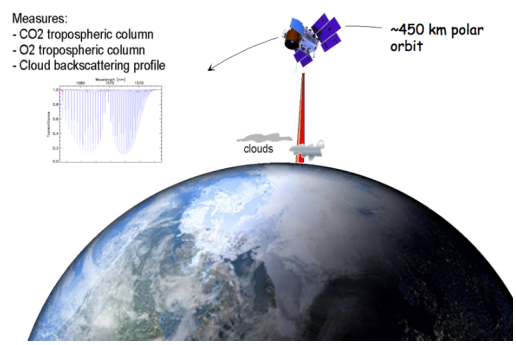

Figure 1- Measurement concept for a space-based CO_2 Laser Sounder.

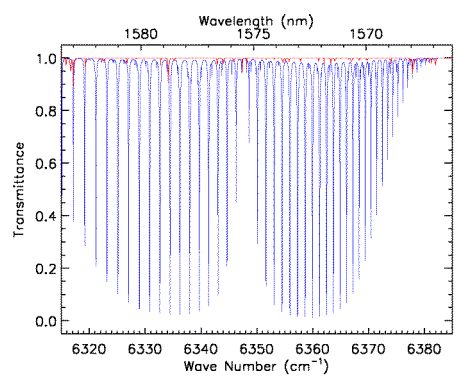

Figure 2 – Two-way atmospheric absorption from space for the 1570 nm CO_2 band in blue (computed from HITRAN). Water vapor absorption is shown in red.

The gas extinction and column densities for the CO2 and O2 gases are estimated from the ratio of the on- and off- line signals via the IPDA technique. Time gating is used to isolate the laser echo signals from the surface, and to reject laser photons scattered in the atmosphere. The time of flight of the laser pulses are also used to estimate the height of the scattering surface and to identify cases of mixed cloud and

ground scattering. Using multiple wavelength sampling across the line allows a much more accurate estimate of the instrument response and allows an additional mid-troposphere CO2 weighting profile.

3. AIRBORNE LIDAR

We have developed an airborne lidar to demonstrate the CO2 column measurement from the NASA Glenn Lear-25 aircraft. Photographs of the aircraft and instrument are shown in Figure 3.

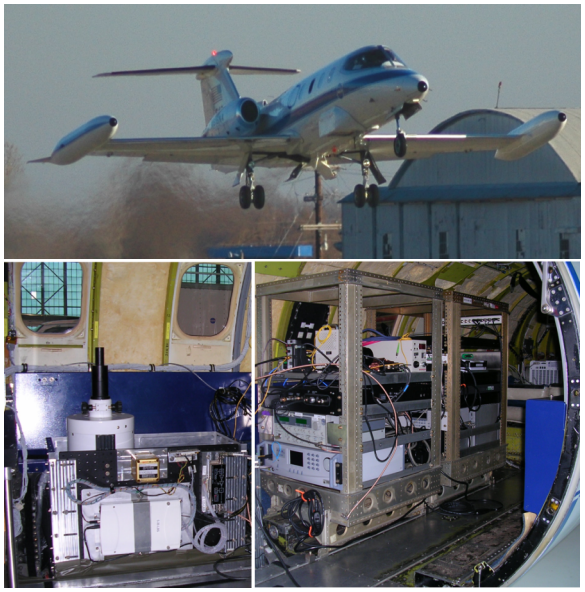

Figure 3- Photo of the NASA Glenn Lear-25 aircraft and CO2 Sounder lidar installed inside. The white receiver telescope is mounted over the aircraft's nadir optical window assembly, which is visible in the upper photo.

The laser uses a MOPA architecture with a single frequency DFB diode laser followed by pulsed AOM modulator a commercial EDFA fiber amplifier. The airborne lidar steps the diode laser's wavelength across the selected CO2 line with 20 steps per scan. Figure 4 shows a sketch of the laser wavelength stepping approach. The time resolved laser backscatter is collected by the receiver telescope, detected by a commercial photomultiplier and is recorded by a photon counting multi-channel scalar and computer. The lidar parameters are summarized in Table 1.

We made initial airborne CO2 column measurements on flights during fall 2008. Laser backscatter and absorption measurements were made over a variety of land and water surfaces and through thin clouds. Two flights were made above the US Department of Energy's SGP ARM site from 3-8 km altitudes. The increasing CO2 line absorptions with altitudes were evident. Comparison with in-situ measurements showed agreements to 6 ppm, but their quality was limited by etalon fringes caused by the aircraft's nadir window.

Table 1 – Parameters of the Airborne Pulsed CO2 Lidar

CO2 line center wavelength:	1572.33 nm
Wavelength scan # across line:	20 wavelengths
CO2 line scan rate:	450 Hz
Laser pulse energy & rate:	24 uJ, 10 KHz
Laser beam divergence:	100 urad
Telescope diameter:	20 cm
Receiver FOV diameter:	200 urad
Receiver optical transmission:	~64%
Receiver optical bandwidth:	800 pm
Detector quantum efficiency:	2%
PMT dark count rate:	~500 kHz
Receiver time bin resolution:	8 nsec
Receiver integr time/record:	1 sec
Data system recording fraction:	50%

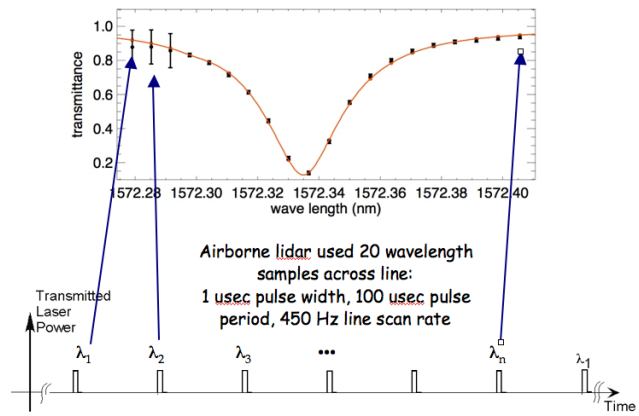

Figure 4- Sketch of the pulsed, wavelength stepped approach used for the laser and a CO2 line shape.

4. AIRBORNE MEASUREMENTS IN 2009

In spring 2009 we improved the aircraft's nadir window and during July and August we made 9 additional 2 hour long flights and measured the atmospheric CO2 absorption and line shapes. Measurements were made at stepped altitudes from 3-13 km over a variety of surface types in Nebraska, Illinois, the SGP ARM site, and near and over the Chesapeake Bay in North Carolina and eastern Virginia. Strong laser signals and clear CO2 line shapes were observed at all altitudes, and some measurements were made through thin and broken clouds. The flights over the ARM site, NC and VA were under-flown with in-situ measurements made from the NASA LaRC UC-12. The SGP ARM and east coast flights were coordinated with the NASA LaRC/ITT CO2 lidar on the LaRC UC-12 aircraft, and the SGP ARM flights also involved a JPL CO2 lidar flying on a Twin Otter aircraft.

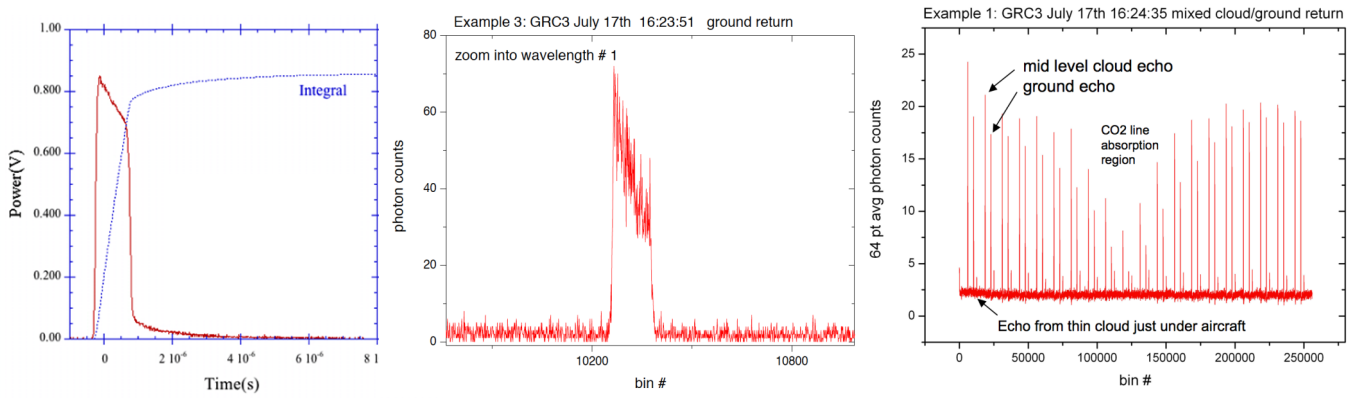

Figure 5 (*Left*) – 1 usec wide laser pulse shape from the lidar transmitter. (*Middle*) A typical single accumulated pulse shape measured from the ground echoes, with 1 second accumulation time, from the photon counting receiver with 8 nsec time bins. *(Right)* Example of a raw (uncorrected) recorded backscatter profile for measurements through 2 thin cloud layers. It shows 3 time displaced echo pulses per transmitted pulse and CO2 column absorption measured to both the ground and to the mid-level cloud layer.

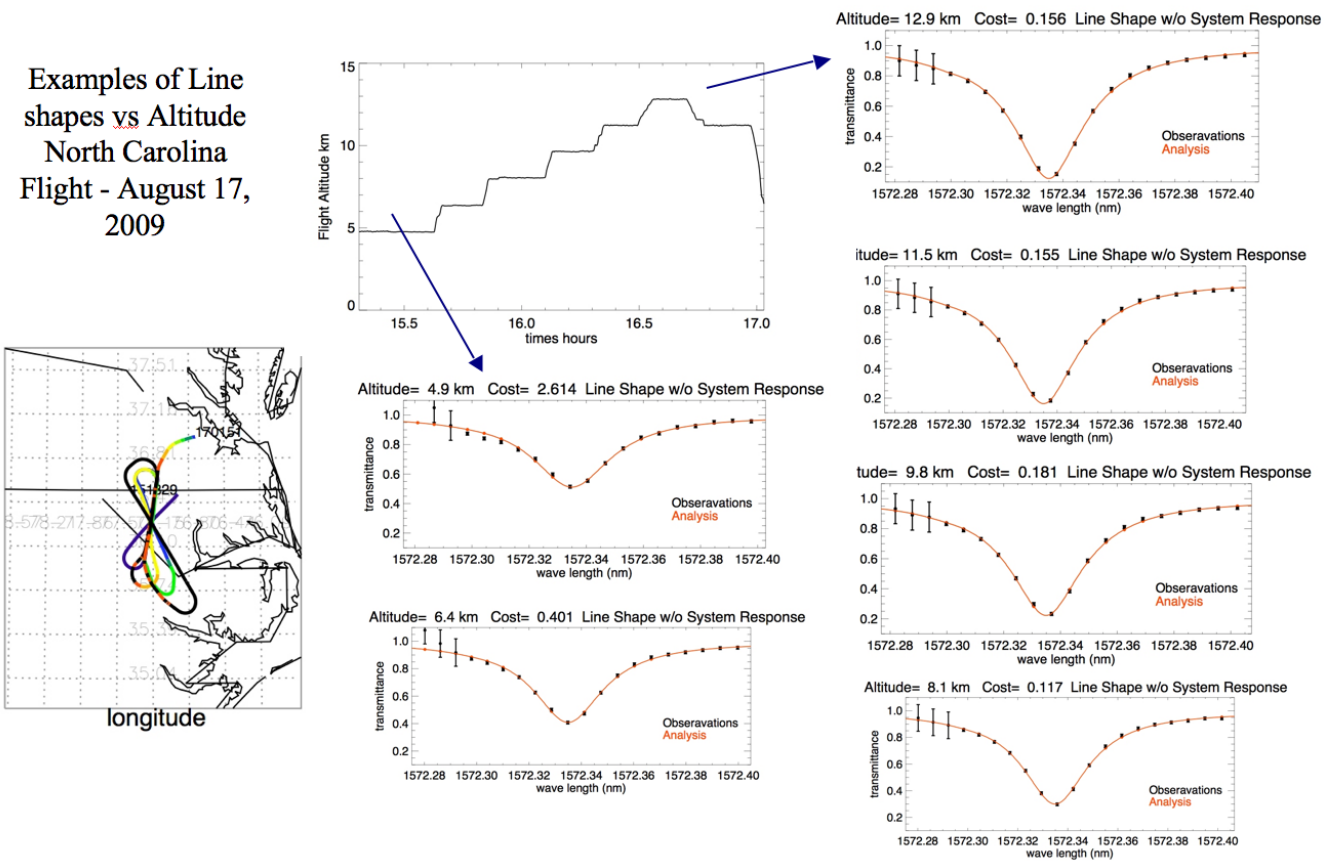

Figure 6- Outline of the flight pattern and sample measurements of the 1572.33 nm Co2 line for flight above north -central North Carolina. *Left* – map of location of "bowtie" flight patterns. The altitude changes in curved part of one bowtie, *Center top* – Altitude history of flight, showing aircraft altitude steps from 4.9 to 12.9 km, *Other plots* – measured Co2 absorption line shapes (black dots) at the constant altitude steps given and orange lines showing Co2 line shape fits through the measurements.

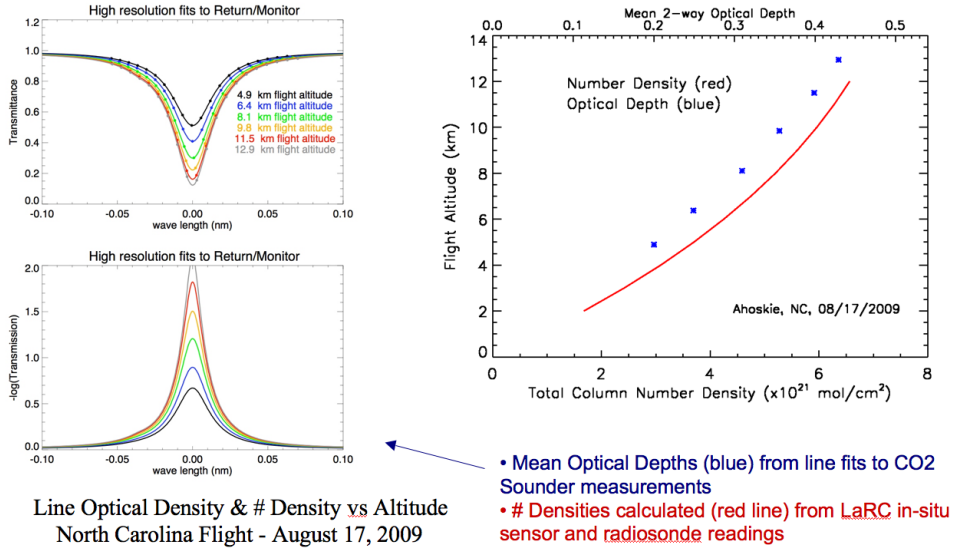

Figure 7- Initial analysis of the 1572.33 nm CO2 shape measurements for the sample flight shown in Figure 6. *Top Left* – Overlayed plot of the fitted Co2 line transmission vs wavelengths, from Figure 4, for the altitudes indicated. *Bottom Left* – Computed CO2 optical depths vs wavelength from the optical transmissions. *Right*– plot of measured Co2 absorption mean optical depths (in blue, for upper x-axis), vs altitude. The measured CO2 column density vs altitude computed from the in-situ sensor readings from the LaRC aircraft (red line, for lower x-axis).

5. SAMPLE RESULTS

Analysis of the 2009 flight measurements is ongoing [3]. To date they show the average signal levels follow predicted values [4], and that the altimetry measurements had an uncertainty of about 3 m [5]. Figure 5 shows the shape of the laser pulses, and a typical recorded echo pulse from the ground. It also shows an example of a backscatter profile recorded from a wavelength sweep made through two cloud layers, showing the echo pulses and CO2 line absorption to the middle cloud top and to the ground.

The CO2 column results are being analyzed by flight location. Figure 6 shows an outline of the flight pattern and sample measurements of the CO2 line for a flight above North Carolina. It also shows the altitude history of flight, showing the aircraft altitude steps. The plots show the CO2 absorption line shapes measured at the constant altitude steps and the CO2 line shape fits through the measurements. Figure 7 shows initial analysis of the CO2 line shape measurements for the flight shown in Figure 6. This includes a plot of the fitted CO2 line transmission vs wavelengths for the altitudes indicated. It also shows computed CO2 optical depths vs wavelength from the optical transmissions. Figure 7 also shows a plot of measured CO2 absorption mean optical depths (in blue points, upper x-axis), vs altitude. The measured CO2 column density vs altitude computed from the in-situ sensor readings from the LaRC aircraft (red line, lower x-axis). The agreement for this flight, and others, is quite good. More details from the data and related work will be described in the presentation.

6. ACKNOWLEGEMENTS

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7. REFERENCES

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