AIRBORNE CARBON DIOXIDE LASER ABSORPTION SPECTROMETER FOR IPDA MEASUREMENTS OF TROPOSPHERIC CO2: RECENT RESULTS

Gary D. Spiers, Robert T. Menzies

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109
gary.spiers@jpl.nasa.gov

Abstract

The National Research Council's decadal survey on Earth Science and Applications from Space[1] recommended the Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission for launch in 2013-2016 as a logical follow-on to the Orbiting Carbon Observatory (OCO) which is scheduled for launch in late 2008 [2].

The use of a laser absorption measurement technique provides the required ability to make day and night measurements of CO_2 over all latitudes and seasons. As a demonstrator for an approach to meeting the instrument needs for the ASCENDS mission we have developed the airborne Carbon Dioxide Laser Absorption Spectrometer (CO2LAS) which uses the Integrated Path Differential Absorption (IPDA) Spectrometer [3] technique operating in the 2 micron wavelength region.. During 2006 a short engineering checkout flight of the CO2LAS was conducted and the results presented previously [4]. Several short flight campaigns were conducted during 2007 and we report results from these campaigns.

Overview of the Airborne CO_2 LAS Instrument

The CO2LAS instrument was jointly developed by JPL and Lockheed Martin Coherent Technologies under funding from the NASA Earth Science Technology Office Instrument Incubator Program [5].

The instrument uses three continuous-wave (c.w.) Th:Ho:YLF lasers, one of which is used as an absolute frequency reference and is locked to a carbon dioxide absorption line in an internal gas cell using a phase modulation spectroscopy scheme. The remaining two lasers are offset frequency locked from the reference laser to provide the online and offline beams that are propagated through the atmosphere. The online and offline beams are expanded to an eye-safe level and transmitted to the ground where they are reflected back to the instrument, collected by the receive optics and detected. The use of the offset frequency-locking scheme together with the absolute frequency reference enables the absolute frequency of the online and offline lasers to be held to within 200 kHz of the desired values. The CO2LAS transceiver uses separate co-axial transmit/receive paths for each of the on-line and off-line channels.

A Doppler frequency shift is induced between the outgoing and return signals by pointing the transmit beams slightly off nadir. This frequency offset, together with a polarization transmit/receive architecture, ensures the receive signals are separated from the transmit signals by both polarization and frequency. The nominal Doppler offset is 15 MHz but this will vary as the aircraft attitude changes. The return signals on each channel are digitized and stored during flight for post-processing. Throughput of the data collection system was increased from ~8% to >20% between 2006 and 2007.

In order to ensure the instrument remains stable, the output power and frequency of all three lasers are monitored. The output power values for the online and offline lasers are used in the determination of the on-line and off-line absorption as part of the LAS measurement. The output power value for the reference laser is used primarily as a laser health status to check the integrity of the CO2 line center lock.

During operation there are real-time diagnostics of the environment within the instrument. Additional diagnostics include the status of the lasers, tracking of the ground Doppler frequency and a capability to do quick look processing on a subset of the signal data. During flight an external Doppler target can be inserted into the beam path outside of the instrument. This enables a measurement of the relative stability of the overall instrument to be determined between data collections.

There are four major parts to the instrument installation on the aircraft, the lidar transceiver itself, the control and data collection electronics, a ground motion simulator and a mounting frame.

The transceiver optical head contains all of the optics and lasers mounted on a double sided optical bench supported vertically inside a canister. The optical bench is mounted to the support structure using vibration isolators. The optical head is insulated, hermetically sealed and backfilled with dry nitrogen. Multiple temperature sensors, a pressure sensor and a humidity sensor are used to monitor the environment within the canister.

The electronics for the CO2LAS are mounted in two racks that typically mount to the seat rails of the host aircraft. One rack contains the control electronics for the transceiver system, laser controller, frequency locking electronics and provides the user interface for the overall system.

The second rack houses the chiller that supplies the optical transceiver with coolant and the signal processor which receives housekeeping data from the electronics rack, and digitizes, stores and analyzes the lidar return signal. The CO2LAS uses a Gigabit Ethernet system to distribute data across the system and to other computers that can be connected into the gigabit hub located in the back of one of the racks.

The ground motion simulator consists of a modified commercial belt sander that is periodically inserted into the beam path. The surface of the belt sander provides a Lambertian surface that permits drift in the ratio of the online/offline signals due to instrumental changes to be assessed independent of any systems internal to the instrument.

The support frame is a custom designed structure that holds the sander and the instrument over a nadir viewing aircraft port. The angle of the frame is selected to obtain the correct Doppler return frequency from the ground at cruising velocity.

Installation of all of the above equipment into a Twin Otter can be completed in less than 4 hours and de-installation and packing for shipping can be accomplished in the same or less time.

Field Experiments

Following a short series of engineering checkout flights conducted in 2006 the CO2LAS instrument was flown twice in 2007. A Twin Ottter aircraft was used for both campaigns and ancillary instrumentation consisting of an INS/GPS, an in-situ Licor CO2 sensor, pressure, temperature and humidity sensors. During August of 2007 a short 3 day campaign was conducted over the Southern Great Plains ARM site. .A second flight campaign was conducted in conjunction with NASA LaRC[5] and ITT in October 2007. ITT supplied a second Laser Absorption Spectrometer operating in the 1.57 micron band [6]operating from a second aircraft. The campaign was based out of the Newport News/Williamsburg International Airport in Virginia. Flights of the CO2LAS were conducted between October 18th and Oct. 23rd over a variety of terrain types. Weather was humid with thunderstorms and some flight opportunities were lost due to poor weather conditions.

The data shown here were collected on October 21st 2007 during an early evening flight. All times referenced in the data are UTC. The flight profile is shown in figures 1 and 2 and consisted of three passes over land at altitudes of 10, 7.5 and 5 kft.

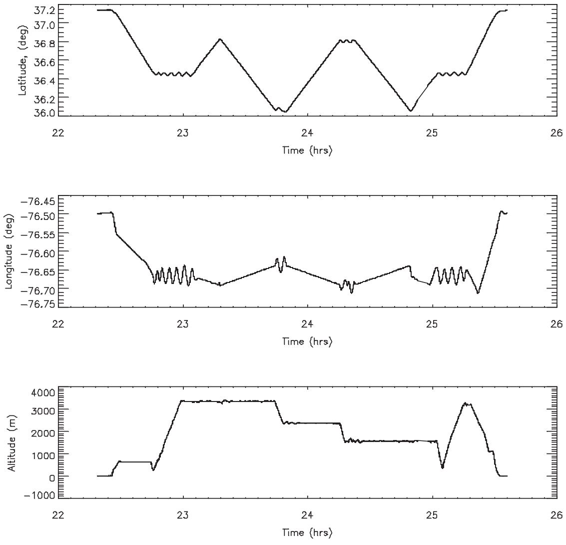

Figure 1. The flight profile for October 21st 2007. Data were collected at 10, 7.5 and 5 kft.

Digitization of the raw signals gives us the flexibility to process the data in multiple ways. For the example shown here we used 2048 pt FFTs summed over 130 ms to process each channel. For each summed FFT the location of the frequency peak is determined and the energy under the peak calculated. This data is then passed through a quality control filter to identify suspect data before summing over 2.5 seconds of data. Finally the log intensity ratio between the two channels is calculated.

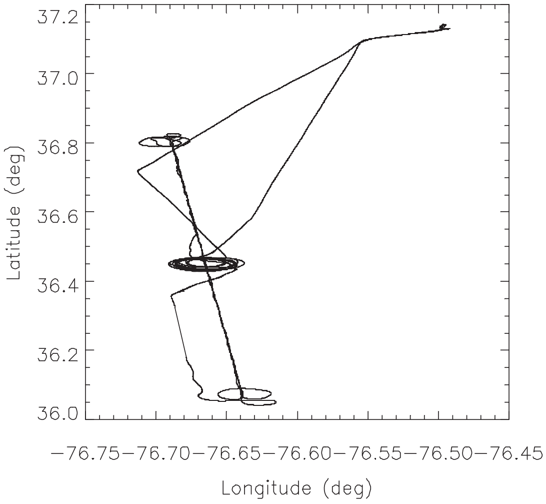

Figure 2. Aircraft flight track showing the racetrack pattern flown and the location of the descent/ascent spirals flown.

One of the benefits of the data collection and processing scheme used is that it provides detailed information on the health of the instrument. We use the Doppler frequency shift from both channels (Figure 3) together with the measured linewidth (figure 4) as part of a quality control scheme to assess that the instrument was behaving correctly.

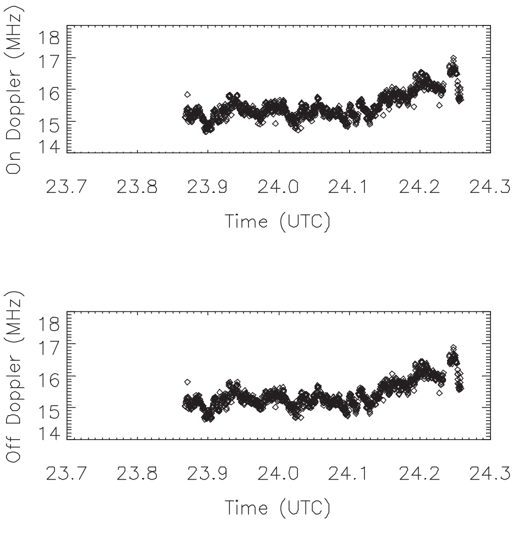

Figure 3. Doppler shifted return for each channel from the ground for the 7.5kft altitude segment.

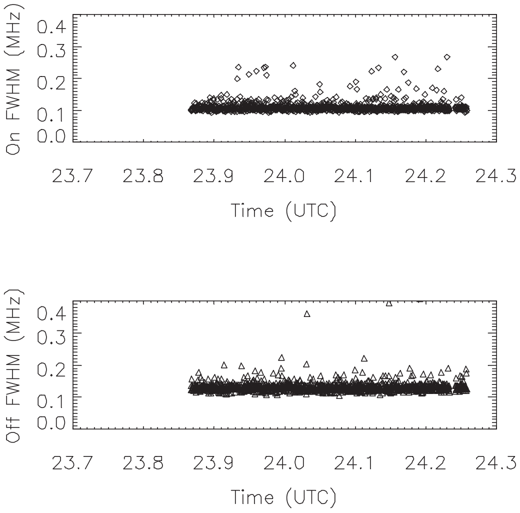

Figure 4. Linewidth of the measured return for each of the channels for the 7.5kft altitude segment.

For each altitude we determine the online and offline signal power as a function of time (figure 5). The natural log of the ratio of the online and offline power, which is proportional to the column integrated carbon dioxide concentration is then calculated (figure 6).

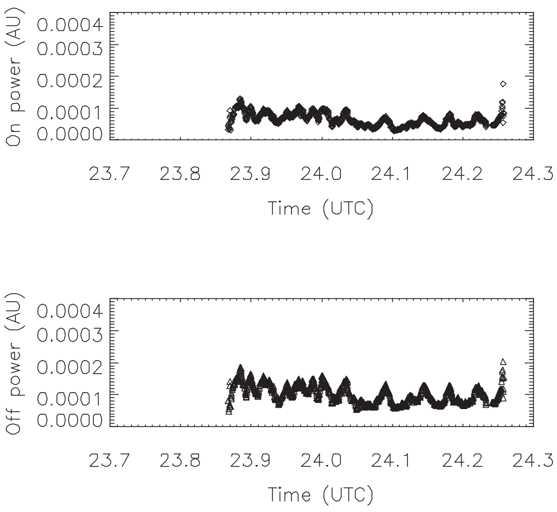

Figure 5. Speckle averaged signal return for each channel showing signal tracking of variability due to ground surface reflectivity and atmospheric variations.

We use the in-situ data together with meteorological data to model the expected column differential absorption to compare against the instrument measurements. For this particular example the variance of the log ratio for each of the altitudes flown varies between <2% (7.5kft) and up to 6%

(5kft) without accounting for terrain variation beneath the aircraft. We did have some issues with the instrument stability during these campaigns and this is being addressed.

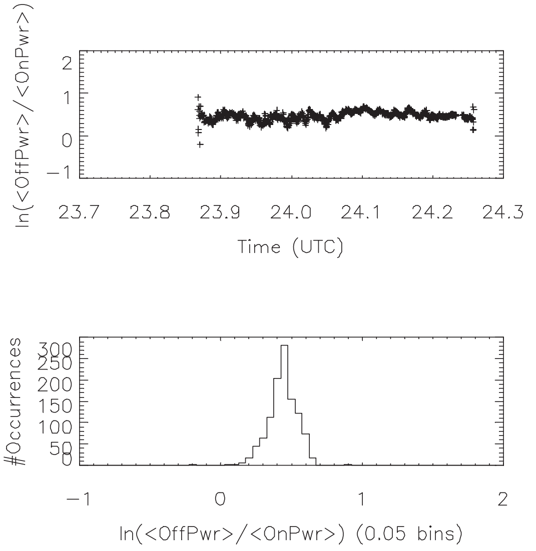

Figure 6. The natural log of the ratio of the online and offline power.

When we compare the calculated CO_2 concentration with a relatively simple model derived from the in-situ measurements the calculated value is biased high. A number of refinements to the retrieval algorithm have reduced this bias and this is still being actively worked and will be discussed.

Summary

The CO2LAS instrument has been flown on two field campaigns during 2007 and data successfully collected. A preliminary analysis of the data has been conducted.

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