A review of 10 years of CO2LAS flights

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Abstract: The CO2LAS Laser Absorption Spectrometer has been flying for 10 years measuring the weighted, column averaged carbon dioxide concentration between an aircraft and the ground using a continuous-wave heterodyne technique operating at a wavelength of 2.05 microns. Initially flying on a Twin Otter the instrument now flies on the NASA DC-8. We provide an overview of the instrument development and changes that have occurred over that time, review the results of the flights undertaken to date and discuss the practical challenges of making an accurate integrated column measurement of carbon dioxide. We conclude by looking forward to future improvements for the instrument and approach.

Keywords: Laser, Lidar, Coherent, Differential Absorption, Airborne

1. Introduction

The CO2LAS instrument was conceived and developed in the 2000-2006 time frame with the goal of demonstrating an approach to measuring CO_2 mixing ratios from Earth orbit, primarily in the lower and middle troposphere with measurement precision equivalent to 1– 2 parts per million by volume (ppmv) or better. These precisions were desired in order to define the spatial gradients of CO_2, from which sources and sinks could be estimated with much reduced uncertainty than was attainable at the time on a spatial grid scale of order 10^3 km x 10^3 km [1–3]. Atmospheric CO_2 is a long-lived gas, with sources and sinks primarily at the surface. Consequently, a remote sensing technique that could emphasize the lower tropospheric component or provide vertical profiles within the troposphere was preferred.

The laser absorption spectrometer (LAS) approach offered the potential to provide the high-accuracy CO_2 mixing ratio measurements with the vertical and horizontal spatial resolution that was desired by the carbon cycle research community. The LAS approach probes a well-characterized pressure-broadened absorption line profile with one or more laser frequencies in order to provide weighting functions suitable for retrieving vertical profile information [4]. An LAS approach to global-scale CO_2 measurement from Earth orbit utilizes differentially attenuated multi-wavelength backscatter from the Earth surface along the suborbital track, with subsequent analysis of the backscatter intensities at each wavelength to retrieve CO_2 mixing ratios. This is a form of the technique referred to as integrated path differential absorption (IPDA). An airborne LAS system utilizing the IPDA technique can obtain mixing ratio information on a regional scale with higher spatial resolution than can be obtained from low Earth orbit (LEO).

Flying the airborne CO2LAS instrument over a variety of sites offered the opportunity to demonstrate the suitability of the LAS IPDA technique, to evaluate the instrument technology, and to develop and refine the high-precision CO_2 retrieval algorithms that would be the predecessors to the LEO retrieval analogues. With an airborne platform, multiple overpasses at different altitudes provide vertical profile information in addition to the inherent weighting functions.

2. Instrument Development

The CO2LAS instrument developed jointly by the Jet Propulsion Laboratory (JPL) and Lockheed Martin Coherent Technologies consists of five key subsystems: (1) the optical assembly, (2) the control electronics unit, (3) the control software unit, (4) the thermal management assembly, and (5) the signal processing/data acquisition electronics.
The CO2LAS transceiver approach utilizes heterodyne detection, implementing a narrow bandwidth receiver, with frequency-stabilized narrow linewidth laser transmitters and local oscillators. The lasers are diode-laser-pumped rare-earth ion doped crystal lasers, specifically yttrium lithium fluoride (YLF) crystal with thulium (Tm) and holmium (Ho) dopants. These lasers are designed for efficient lasing in the 2**:**05 **μ**m spectral region. The transceiver consists of two separate transmit/receive channels for the on-line and off-line components of the LAS measurement. The beam expander off-axis telescopes for each channel are identical in size and configuration, with the input optics designed to optimize the truncated Gaussian beam parameters for maximum heterodyne photomixing efficiency. The transmitter frequencies are carefully stabilized with respect to a selected CO2 absorption line. Each channel has a dedicated heterodyne detector and a cw single-frequency laser, which acts both as the transmit laser and the local oscillator for heterodyne detection of the return signal. The transceiver also includes a separate low-power cw laser that provides a reference for frequency offset locking of the on-line and off-line lasers. A summary of the instrument parameters is given in Table 1 and the instrument is described in more detail in reference [5].

Parameter	Value
CO2 Line Center	4875.747 cm^{-1}
Offline Laser	4875.225 cm^{-1}
Online Laser	4875.882 cm^{-1}
Transmitted Laser Power	<100 mW/channel
Transmit/Receive Aperture	10 cm Diameter
Receiver FOV	60 μrad
Photomixer Type	InGaAs
Receiver Heterodyne Frequency Window	10-25 MHz
Signal Digitization	14 bit/ 60 MHz

Table 1 Key Instrument Parameters

Modifications to the instrument over the years have mostly been refurbishment of the lasers and upgrades to the data system throughput duty cycle which has gone from 8% in 2006 to 20% in 2007, 40% in 2009 and 100% in 2014. In 2014 the thermal control subsystem was replaced and the analog front end for the detection electronics renovated. In 2015 a 1W fiber amplifier was added to the online channel however this has yet to be tested in a field campaign.

3. Field Campaigns

Early flights of the instrument were carried out on a Twin Otter aircraft over desert dry lake beds in order to evaluate the performance characteristics of the instrument. Results from these experiments led to the CO2LAS being included as one of the instruments flown by the NASA ASCENDS Decadal Survey Study on board the NASA DC-8. A summary of the flight campaigns is given in Table 2.

Date	Aircraft	Location	Description
2006	Twin Otter	California El Mirage Dry Lake Bed and Pacific Ocean	Checkout Flights
2007	Twin Otter	Virginia	Joint flights with LaRC/ITT instrument
2009	Twin Otter	El Mirage Dry Lake Bed, California	Calibration Flights
2009	Twin Otter	ARM SGP Site	ASCENDS Joint flights with LaRC & GSFC
2010	DC-8	California, Pacific, Oklahoma	ASCENDS Joint flights with LaRC & GSFC
2011	DC-8	Multiple Flights	ASCENDS Joint flights with LaRC & GSFC
2013	DC-8	Multiple Flights	ASCENDS Joint flights with LaRC & GSFC
2014	DC-8	Multiple Flights	ASCENDS Joint flights with LaRC & GSFC

Table 2 CO2LAS Field Campaigns

The instrument has measured CO_2 drawdown over active vegetation, small scale source emissions such as individual smoke stack emissions at power plants and has demonstrated the ability to conduct retrievals over low reflectivity surfaces such as snow and ice (Figure 1).

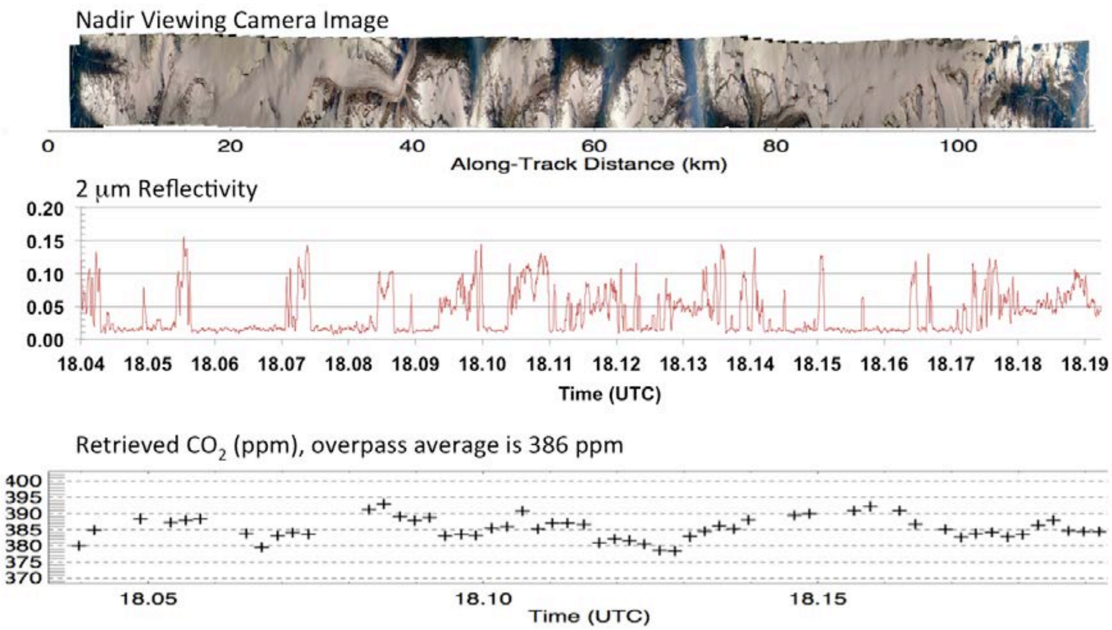

Figure 1 Simultaneous reflectivity and CO_2 retrieval during a portion of the northbound flight segment over the British Columbia Coastal Mountains, August 7, 2011. The imagery shows a mixture of snow covered areas (low backscatter), glacier segments (the blue streaks), and patches of bare rock, dirt, alpine flora. The lidar footprint track is centered in the imagery. Time duration from left to right: 9 min.

Additional results from other campaigns will be presented and details of the retrieval algorithms used will be discussed at this conference in the companion presentation by Menzies [6].

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4. References

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