Profiling CO_2 within the Planetary Boundary Layer

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1. ABSTRACT

This paper describes the development of a differential absorption lidar designed to make range resolved measurements of CO_2 at a precision of 1 ppmv within the planetary boundary layer (typically <3000 meters above the surface during the day).

2. INTRODUCTION

There is widespread agreement within the scientific community about the significant impact that the increasing concentration of greenhouse gases will have on global climate. The most important greenhouse gas, CO_2, is rapidly increasing due to anthropogenic activity (the use of fossil fuels and burning of the tropical biomass in Africa, Asia and South America). Current CO_2 mixing ratios are ~30% higher than at the start of the industrial revolution and increasing at the rate of approximately 1.5 parts per million volume (ppmv) per year. Although the sources for CO_2 are well characterized there is a great deal of uncertainty about current sinks. Recent data at continental scale resolution strongly suggests that there are substantial terrestrial sinks for CO_2 in North America whose location and mode of operation are not understood. In order to better understand the long term impact that CO_2 will have on climate and develop effective mitigation strategies it is important to identify and understand how these sinks behave and how their uptake of CO_2 might change in the future in response to anthropogenic activities. These sinks betray their presence by modifying the spatial and temporal distribution of CO_2 within the boundary layer; range resolved CO_2 measurements when combined with a transport model can be used to characterize the resulting fluxes and ultimately locate sinks whose spatial extent is only several square kilometers hundreds of kilometers distant [1] [2] [3]. The strongest signatures are typically found in the planetary boundary layer (PBL) - typically <3000 meters above ground level during the day and less than several hundred meters at night. As more powerful lasers are employed signal returns will be acquired from the first kilometer within the free troposphere – this will allow the study of transport processes across the PBL free troposphere interface. Although diurnal changes in CO_2 can be quite large the perturbation in the CO_2 field caused by small terrestrial sinks will require a measurement precision of approximately 1 ppmv to identify (the current mixing ratio of CO_2 is ~380 ppmv). At NASA's Goddard Space Flight Center we are using the differential absorption lidar technique in an effort to make range resolved measurements of CO_2 both within the PBL and into the lower part of the free troposphere. This work is driven by measurements requirements laid out in the North American Carbon Program to make range resolved measurements of CO_2 within the PBL to a precision of better than 1 ppmv (part per million volume) with a range resolution of from 10-250 meters [4]. The DIAL technique derives the number density as a function of altitude by measuring how rapidly two signals, closely spaced in wavelength, fall off with altitude with one laser tuned to a strong absorption line and the second laser tuned so that there is no absorption by the specie of interest. Signal returns within the PBL are generated by aerosol backscattering, a process that is typically several orders of magnitude stronger than Rayleigh scattering at this wavelength. Within the free troposphere the atmosphere is usually much cleaner with signal returns rapidly falling off with altitude.

3. INSTRUMENT

This effort is focused on the development of a small, compact and self-contained unit that is capable of autonomous operation at a remote site over many months. Its final cost will be significantly under $100,000 allowing for their large-scale global deployment. The instrument is a differential absorption lidar (DIAL) operating in the near IR that employs direct detection. Its operational configuration consists of a transmitter, receiver and the associated electronics (figure 1). We have chosen to utilize CO_2

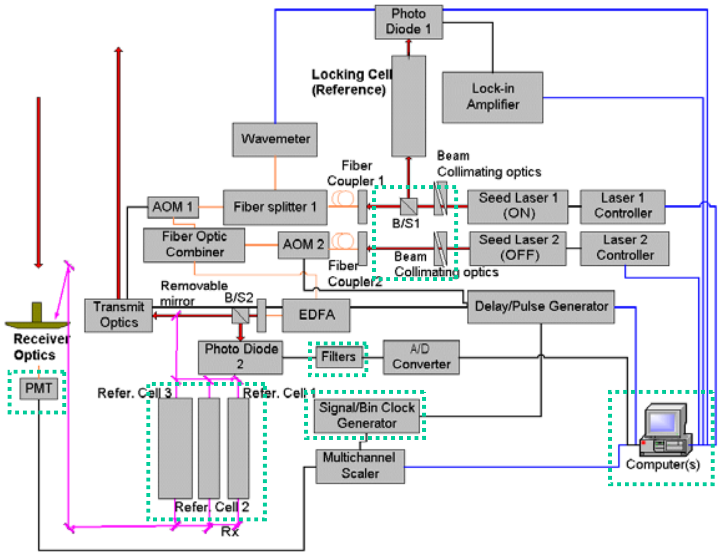

Figure 1 Schematic of CO_2 Profiling Lidar

absorption lines near 1.57 microns because of their strength, freedom from interferences originating with other molecular species, the availability of good photomultiplier tubes suitable for photon counting and excellent, well-characterized, lasers [5]. Two different transmitter concepts are being developed to support this effort. The first utilizes fiber lasers to produce the desired wavelengths. Fiber lasers have several significant advantages that are derived from the large investments in technology make by the telecommunication industry. They are compact, efficient and have been space qualified. The second approach employs a small micro pulse Nd:YAG to pump an optical parametric amplifier seeded by two distributed feedback lasers (DFBs) tuned to the proper wavelengths. This approach has an effective duty cycle of 100% meaning that all of the generated photons can be used to make a measurement as opposed to the fiber system with its low duty cycle (~0.1%) and the short pulses (~1 ns) facilitate making unambiguous range resolved measurements in the boundary layer at high resolution. We have demonstrated a conversion efficiency from 1064 nm to 1570 nm of 38% and expect to extend this to 50% in the near future. To reach the required goals for measurement precision requires that the frequency jitter be reduced to <140 MHz. This requires that the DFB lasers be temperature stabilized and that the output wavelengths be locked with a high degree of precision to predetermined values. This is accomplished by using a hollow core fiber (5 meters) filled with several hundred mbar of CO_2 (figure 2). When a fiber system is employed the CW output of the DFB lasers is modulated using an electrooptic technique to generate short 100 nanosecond pulses at a

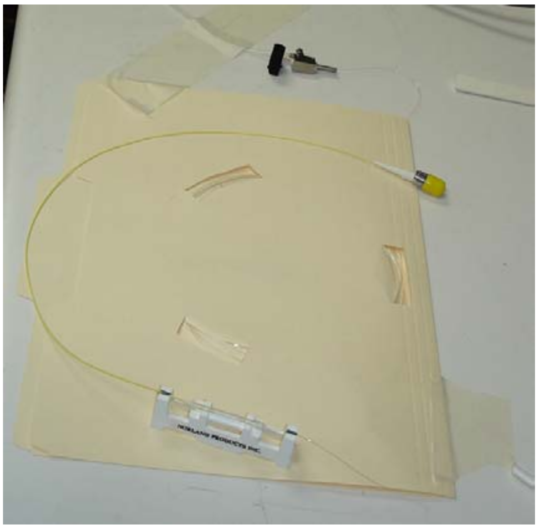

Figure 2 Fiber gas cell used to lock DFB laser. The cell is 5 meters long.

frequency repetition rate of up to 20 kHz. The temporal spacing between the on and offline wavelengths is 25 microseconds thus insuring that atmospheric fluctuations will not impact the measurement. The pulsed output is then amplified in a two-step process to produce ~10 microjoules per pulse at the desired repetition rate. The current system has the transmitted laser pulse collinear with the receiver and complete overlap occurs ~200 meters above the system. A smaller telescope is being fabricated to allow signal detection starting at 10 meters altitude. The current receiver is a 16” Meade telescope optimized for operation at 1.6 microns, fiber coupled to a box with a 1.2nm bandpass filter, etalon and an IR PMT. The PMT has a measured quantum efficiency of ~4% at 1600 nm. Data is acquired using a multi channel scalar board with a current bin size of 200 nanoseconds.

The measurement requirement is for the data to be expressed in terms of volume mixing ratio, parts per million volume. This requires that a second measurement employing molecular oxygen be made. This separate effort is being made independent of this work but as part of the same program.

4. SUMMARY

The development of a DIAL lidar to profile CO_2 at high precision within the planetary boundary layer has been described. This instrument is designed to acquire data at a precision of 1 ppmv (current CO_2 mixing ratio is 380 ppmv) in 10 minutes from the surface to the top of the PBL. The range resolved data will both help characterize fluxes within the lower troposphere and be a valuable tool for validating space based instruments designed for making total column measurements of CO_2 such as the Orbiting Carbon Observatory (OCO).

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