New Pulsed Airborne Broadband Lidar for Greenhouse Carbon Dioxide Gas Sensing in the Earth's Atmosphere

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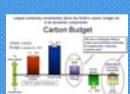
ABSTRACT

We report laboratory, field and initial airborne measurements of atmospheric CO2 using our novel broadband LIDAR operating at 1.5 microns spectral region and developed as a candidate for NASA's ASCENDS mission. It is based on innovative new techniques employing a spectrally broad OPO laser source and using a Fabry-Perot interferometer in the detector part. The broadband lidar is capable of mitigating inaccuracy associated with atmospherically induced variations in CO2 absorption line shape and strength while demonstrating precision, sensitivity robustness / ruggedness, and stability. The Fabry-Perot solid etalon in the receiver part is tuned to match the wavelength of several CO2 absorption lines simultaneously. The receiver itself has been in development over the last few years at GSFC as a passive sensor to measure atmospheric CO2 column. It was tested during two successful flight campaigns. This new active approach reduces the number of individual different wavelength lasers required from three or more to only one, considerably reducing the risk of failure associated with multiple laser systems. The broadband technique also tremendously reduces the requirement for source wavelength stability, instead putting this responsibility on the Fabry- Perot based receiver. Laboratory, ground based and recent airborne results of the lidar system will be discussed. For the laboratory experiments we were using the OPO based system for 1.57 µm that has demonstrated pulse energies as high as 14.6 mJ per pulse, rep. rate of 15 Hz, 4 ns pulse duration over 2 nm spectral range. The fielded laser operates with ~60 mJ pulse energy in 5 ns pulses over a 1 nm spectral range. The instrument technology we are developing has a clear pathway to space and realistic potential to become a robust, simple and stable, low risk space measurement system.

THE CHALLENGE

There is great need for global high spatial- and temporal-resolution remote sensing of atmospheric CO_2 concentration for global and regional studies of the carbon cycle. The biggest challenge for CO_2 remote sensing is to achieve high measurement precision (~ 1 ppmv) so that such a measurement is valuable in reducing uncertainties about carbon sources and sinks.



Active Sensing of CO_2 Emissions (ASCENDS)

- The goal of Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission is to significantly enhance the understanding of the role of CO_2 in the global carbon cycle.
  Science themes addressed by ASCENDS include:
  - Shifts in terrestrial carbon sources and sinks
  - Identifying processes controlling biospheric carbon fluxes
  - Understanding the evolving nature of oceanic carbon fluxes
- Planned to be launched in the 2013-2016 time frame - http://cce.nasa.gov/ascends/index.htm

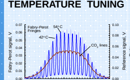
ADVANTAGES OF BROADBAND APPROACH

- SIMPLER LASER OUTPUT IN SINGLE DEVICE, NO HIGH PRECISION WAVELENGTH CONTROL
- RATIOING PROTECTS AGAINST INSTRUMENTAL DRIFTS IN DETECTOR AND IN LASER SOURCE
- OUT OF BAND LASER EFFECTS DIMINISHED BY BANDPASS FILTER
- SOURCE BASED UPON HIGH TRL ND:YAG AND NONLINEAR CRYSTAL TECHNOLOGY

RECEIVER EVOLUTION: LABORATORY / GROUND BASED/ AIRBORNE TESTS

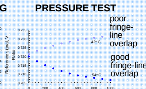
Passive CO_2 Instrument developed under a previous ESTO contract and successfully tested in the lab, in the field and from DC-8 airplane

TEMPERATURE TUNING



Fringe-CO_2 line overlap compared at two Fabry-Perot temperatures

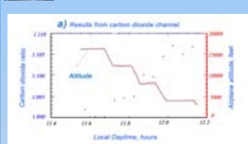
PRESSURE TEST



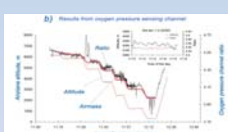
Change in ratio as a function of CO_2 pressure in an absorption cell compared at two Fabry-Perot temperatures

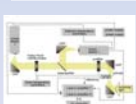
Aircraft instrument on DC-8

Aircraft data:



Changes in the CO_2 ratio (top) and pressure-sensitive O_2 ratio (bottom) are compared with varying aircraft altitude Both clearly track changes in altitude. CO_2 ratio is inversely proportional to the CO_2 in the column, while O_2 ratio is directly proportional to O_2 in the column.





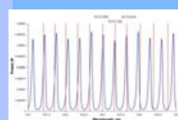
Schematic of one channel of the FP radiometer:

The mechanical setup of the improved Fabry-Perot detector for the broad band lidar.

Fiber-coupled incoming light from a telescope is divided into two channels:
- Fabry-Perot channel measures changes in CO_2 absorption (detector 2).
- Reference channel measures changes in solar flux (detector 1).

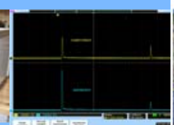
Ratio of these signals is proportional to changes in the CO_2 column.

DC-8 MAJOR ASCENDS FLIGHT TEST CAMPAIGN JULY/AUGUST 2011, PALMDALE, CA; PRELIMINARY DATA

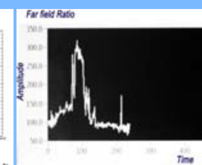


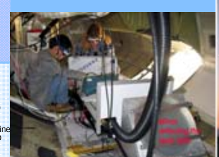
This depicts the operation of our lidar receiver.

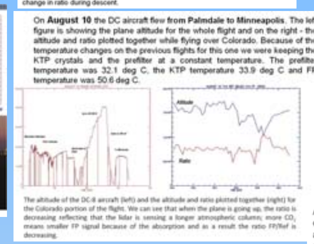
This is the instrument installed in the cargo bay of the DC-8.



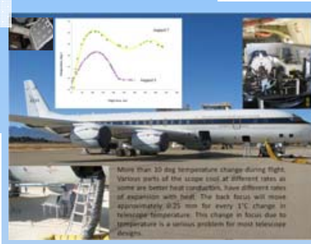
This shows typical lidar return signal.

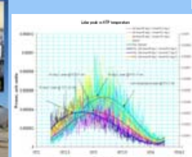


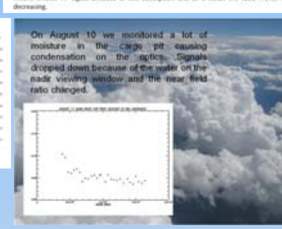


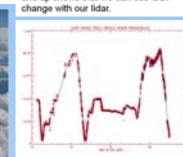


Amplitude far field ratio is a measurement of CO_2, the bell shape when going down and up shows that we can see CO_2 change with our lidar.



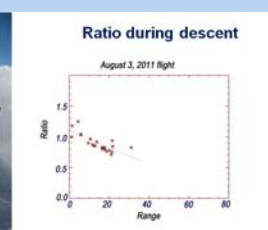






There were a lot of clouds on this flight so the analysis algorithm has to differentiate between a ground return and a cloud return. The figure shows the lidar range obtained using our custom algorithm for finding the lidar peaks and the radar altimeter range. The good agreement illustrates that the algorithm is finding the correct peak. Range is plotted in feet.

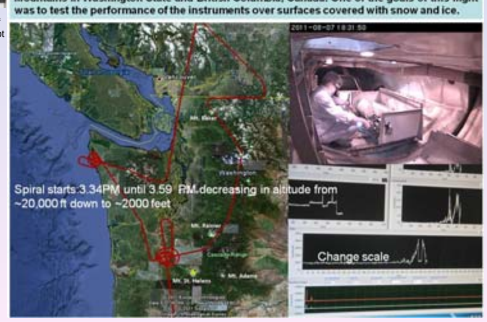
On one of the flights we monitored a lot of moisture in the cargo pit causing condensation on the optics. Signals dropped down because of the water on the nadir viewing window and the near field ratio changed. We excluded these data points from the analysis. Huge temperature changes may also affect the KTP crystals performance because the laser peak moves with temperature



When the plane is descending, ratio is going up. Means less and less absorption of carbon dioxide(Smaller atmospheric column),FP signal is getting bigger and as a result the ratio of FP/Ref is bigger.

1 microsecond is 150 m. 40 microseconds= 6000 m=6 km. 20 microseconds = 3000 m=3 km.
At 6 km the ratio is ~0.5 and at 1.5 km it change up to 1.1.

On Sunday August 7, 2011, NASA's DC-8 aircraft took off from the Dryden Aircraft Operations Facility in Palmdale, California for an eight-hour flight to the northern Cascade Mountains in Washington State and British Columbia, Canada. One of the goals of this flight was to test the performance of the instruments over surfaces covered with snow and ice.



CONCLUSIONS

- **Directly responds to NRC DS ASCENDS mission**
- **Number of lasers is reduced which reduces the complexity of sensor and thus the cost and risk of failure,**
- **Knowledge gained from previously developed passive sensor decreases the risk and cost of the present lidar system development**
- **The instrument can play a significant role as an intercomparison instrument for OCO Orbiting Carbon Observatory) as well as other laser based instruments under development for participation in ASCENDS.**
- **It can play a role as an airborne instrument in its own right in addressing the problems of scale arising from differences between point observations by the existing ground based CO2 network and wider area measurements obtained by satellites**
- **The broad band lidar has succeeded in detecting CO2 from the DC-8 aircraft. The major objective and our preliminary results show that the sensor is responding accordingly to changes of the aircraft altitude, demonstrating sensitivity, which could be scaled to a measurement from space. It exhibited strong signals at an altitude of 39,000 ft as well as while flying above snow where the reflectance at 1.57 microns is less than 5%.**

ACKNOWLEDGEMENTS

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