TEST RESULTS for the
BROADBAND CARBON DIOXIDE
LIDAR

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OUTLINE OF TALK

1. INTRODUCTION - MOSTLY ABOUT ASCENDS
2. BROADBAND LIDAR - THEORY
3. BROADBAND LIDAR - OUR IMPLEMENTATION
4. SOME EARLY RESULTS
5. PLANS AND CONCLUSIONS
THE ASCENDS MISSION

• 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
• The National Academy of Sciences recommended in its decadal survey that NASA put in orbit a CO$_2$ lidar to satisfy this long standing need.

• Existing passive sensors suffer from two shortcomings.
  • Their measurement precision can be compromised by the path length uncertainties arising from scattering within the atmosphere.
  • Also passive sensors using sunlight cannot observe the column at night.

• Both of these difficulties can be ameliorated by lidar techniques.
LIDAR SYSTEMS

• Lidar systems will present global measurement of carbon dioxide column with the aim of discovering and quantifying unknown sources and sinks - a high priority for the last decade.

• Spectroscopy data is a major challenge to $CO_2$ remote sensing. Uncertainties in line intensity and line pressure broadened width parameters, inadequate line position knowledge, incomplete knowledge or measurement of spectrum for isotopes, and pressure shift are large $CO_2$ retrieval error sources.

  • Temperature changes in the atmosphere alter the cross section for individual $CO_2$ absorption features.

  • Different atmospheric pressures encountered passing through the atmosphere broaden the absorption lines.

• Currently proposed lidars require multiple lasers operating at multiple wavelengths simultaneously in order to untangle these effects.
SPECTROSCOPY-PRESSURE EFFECTS

At the top of the atmosphere the width of a spectral line is dominated by the Doppler effect. Proceeding lower into the atmosphere collisional (pressure) broadening begins to manifest itself to a greater and greater extent. A shift in the center frequency also occurs as the result of collisions. There is only a minimal contribution to the absorption in the wing from the upper atmospheric $CO_2$ the effect of a surface source or sink will be a larger perturbation on the overall column absorption at these wavelengths.
The line strengths change with the temperature of the atmosphere. This can introduce errors in the column as large as 1ppm for a 2 degree K change in temperature. This means that using a single absorption line and relying on meteorological measurements or models to provide the temperature correction may not suffice for the CO₂ column measurement. Small changes in strengths and widths affect CO₂ retrievals at high airmass.
Major LIDAR Contenders for ASCENDS Mission

1. LaRC-ITT Team—“Lock-In” LIDAR -- simultaneous, continuous transmission of 3 wavelengths at different positions on CO2 absorption line

2. JPL—2.0 micron Heterodyne LIDAR -- continuous transmission detected using local oscillator mixer. Operates in wings of very strong absorption features

3. NASA (Abshire Team)—Conventional pulsed LIDAR cycles rapidly through 3 or more wavelengths

4. NASA (Heaps Team)—Broadband LIDAR-simultaneous pulsed transmission of “ON” and “OFF” wavelengths.
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Our current goal is to develop an ultra precise, inexpensive new lidar system for precise column measurements of CO$_2$ changes in the lower atmosphere that uses a Fabry-Perot interferometer based system as the detector portion of the instrument.

- We replace the narrow band laser commonly used in lidars with a laser like source that emits over a wider spectrum—a number of ways to do this.
- This approach reduces the number of individual lasers used in the system from three or more to one—considerably reducing the risk of failure.
- It also tremendously reduces the requirement for wavelength stability in the source putting this responsibility instead on the Fabry-Perot subsystem.
DIFFERENTIAL ABSORPTION LIDAR

BEER’S LAW

\[ I = I_0 \exp (-n \, s \, z) \]

\[ I = I_0 \exp (-n \, s \, z) \]

\[ \log(I/I_0) = -n \, s \, z \]

\[ \log(I/I_0) - \log(I/I_0) = -n(s-s)z. \]
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The output of the SLED increases with increasing drive current. The spectral output is quite broad covering almost 100 nm. We only use a narrow region 2-3 nm wide centered around 1571 nm. The OPA is designed to amplify this region in particular.

This figure shows a scan of the output of the OPA made using the same monochromator. The spectral width has been reduced to about 2 nm. All of the photons coming out of the OPA are within the bandpass of our lidar receiver.
There are CO$_2$ absorption lines located at
1571.7, 
1572.0, 
1572.3, 
1572.65, 
and 1573.0 nm
that will absorb light from this transmitter.
TYPICAL LIDAR RETURNS
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Test Flight May 4, 2011
THE REAL UNKNOWN IN THE DEVELOPMENT PATH OF THE BROAD BAND LIDAR IS THE DEGREE TO WHICH FLUCTUATIONS IN THE LASER OUTPUT SPECTRUM CAN GENERATE NOISE THAT LIMITS THE PRECISION
FABRY-PEROT WITH CAMERA SERVES A LASER DIAGNOSTIC TOOL
CAMERA WAVELENGTH CALIBRATION

1574.0 nm

1572.5 nm
2 HOUR TEST OF LASER SPECTRUM STABILITY

VERTICAL SEPARATION OF TRACES IS ~6 MINUTES
I_0 THROUGHOUT MAY4 FLIGHT

INITIAL FLUX (FP AND REF) V. TIME

RATIO INITIAL FLUX V. TIME
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Conclusions

• Innovative active system using advanced source technology development—will enable daytime or nighttime measurements of column CO$_2$

• Directly responds to NRC DS ASCENDS mission

• Number of lasers is reduced compared to competing technologies 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

• Plan to participate in lidar intercomparison flights on DC-8 next month.

• Laser power poor during first engineering test flights—at present power is ~ 30-60 times greater

• Shot to shot ratio stability 3.5% needs to be improved. Can be improved by better broadband laser source and ameliorated by improved receiver that discriminates wavelength. Funds requested from ESTO to build this receiver.
Great thanks to ESTO for their continued support in our efforts to develop a high precision sensor for the carbon dioxide column