Atmospheric CO2 Concentration Measurements with Clouds from Airborne Lidar Measurements during ASCENDS Science Campaigns

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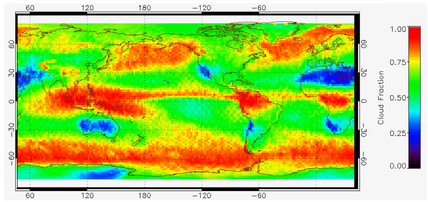
Introduction

Globally distributed atmospheric CO_2 measurements with high-precision, low-bias and full seasonal sampling are crucial to advance carbon cycle sciences. However, passive remote sensing approaches from space are limited to cloud-free pixels and have limited global data coverage and sampling in cloudy regions, even though some cloudy regions have active carbon surface fluxes.

NASA Goddard Space Flight Center is developing an integrated-path, differential absorption (IPDA) lidar approach to measure atmospheric CO_2 concentrations from space as a candidate for NASA's *ASCENDS* mission. Measurements of time-resolved laser backscatter profiles from the atmosphere also allow this technique to estimate column CO_2 and range to cloud tops in addition to those to the ground with precise knowledge of the photon path-length. This allows retrievals of CO_2 column above clouds and ground, improving data coverage and sampling. This is expected to benefit atmospheric transport process studies, carbon data assimilation and thus help global and regional carbon flux estimates.

Annual mean total cloud fraction

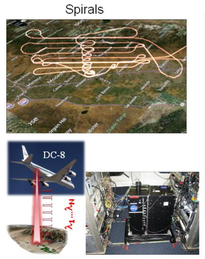
2/3 of the Earth's surface is typically covered by clouds!!!



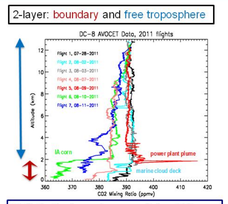
from CloudSat and CALIPSO (contributed by Jen Kay)

In-situ CO_2 Vertical Profiles – Summer 2011

Spirals



2-layer: boundary and free troposphere

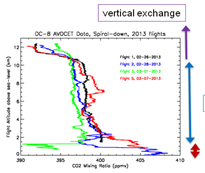


- 2 distinctive layers in summer below 13-km
- PBL: power plant plume, marine sink and ecological drawdown
- Free-troposphere: significant gradient

In-situ CO_2 Vertical Profiles – Winter 2013

3-layer: boundary, troposphere and stratosphere

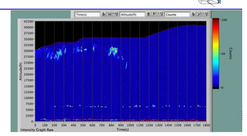
Feb./March 2013 Flights on-board AVOCET gas analyzer



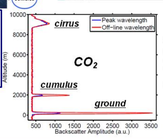
- 3 distinctive layers
- High CO_2 in PBL: respiration exceeds photosynthesis in winter and pollutants
- Shallower PBL and troposphere
- Low CO_2 in the tropopause/stratosphere

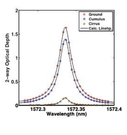
Column CO2 measurements to cloud tops help resolve vertical structure and physical processes of CO2 !

CO_2 Sounder Lidar Backscatter Profiles



- Flight to Iowa, 8/10/2011;
- Height-resolved;
- Clearly-separated line shapes for returns from elevated surfaces – ground, cumulus and cirrus cloud tops

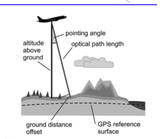


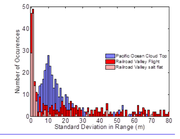


CO_2 Sounder provides Pulsed, Time-resolved Range Measurements

Analysis of Range Measurements From a Pulsed Airborne CO_2 Integrated Path Differential Absorption Lidar

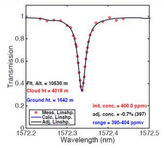
Accuracy ~1.2 m (for flat surface and no aircraft tilt)

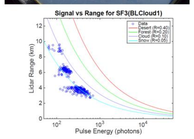




Measurements to cumulus cloud tops Iowa 2014

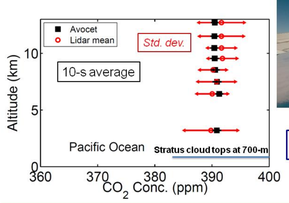
- CO_2 measurements to cloud tops is now a standard part of our analysis.
- We are the first group to do this.
- Clouds cover ~2/3 of the Earth's surface - this allows much more data coverage.





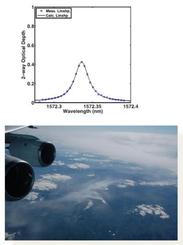
Column Retrievals *to marine stratus cloud tops*

Flight over Pacific Ocean, 8/2/2011

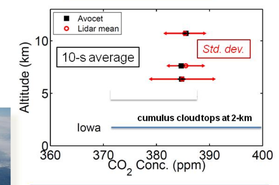


- flatter cloud tops
- smaller retrieval std. dev.

Column Retrieval *to cumulus cloud tops*

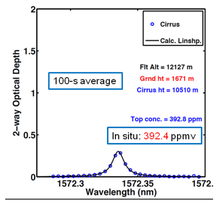


Flight to Iowa, 8/10/2011

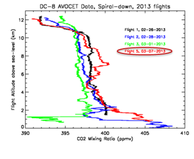


- shorter path-length, greater retrieval errors
- noisier retrievals for puffy cumulus cloud tops

Column Retrieval *to cirrus cloud tops*



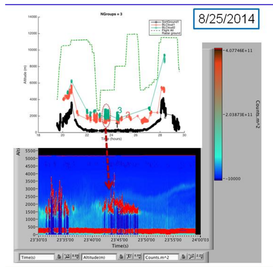
Flight to Iowa, 3/7/2013



- allow retrieval of stratospheric CO2;
- benefit retrieval of tropospheric CO2;

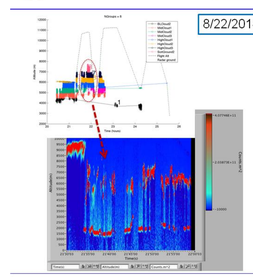
Column Retrievals *to boundary layer cloud tops*

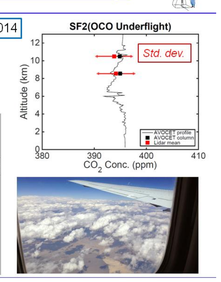
8/25/2014



Column Retrieval *to mid-altitude cloud tops*

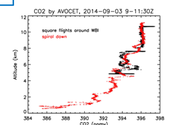
8/22/2014

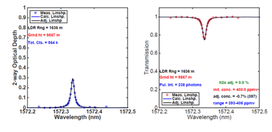




Column Retrieval *to cirrus cloud tops*

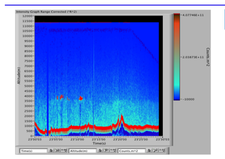
9/3/2014



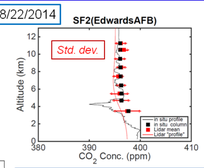


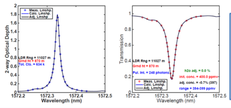
- Noisier measurements due to low reflectance and shorter pathlength but with clear absorption line-shapes
- Better measurements expected for ASCENDS with longer pathlength from space

Column Retrieval *through aerosol layers*



8/22/2014





Time-gated and range-resolved measurements: 1) minimize atmospheric scattering effect and yield low-biased retrievals; 2) minimizes retrieval errors over rough surfaces (terrains, tree covers)

Lidar Cloud Slicing allows CO_2 measurements *at several altitudes*

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

Remote sensing measurements of the CO_2 mixing ratio in the planetary boundary layer using cloud slicing with airborne lidar

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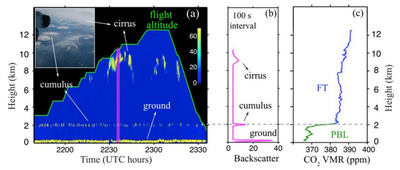

Summary

- Demonstrated CO_2 measurement capability to cloud tops and through aerosol layers using NASA/GSFC CO_2 sounder lidar;
- Demonstrated lidar cloud slicing approach to retrieve lower atmospheric CO_2;
- Resolving vertical structure of CO_2 potentially will help better separate atmospheric transport from surface processes and thus better estimate surface budgets;
- Significantly enhanced data coverage and sampling will improve carbon flux estimate
- All-sky measurement capability using NASA/GSFC CO_2 sounder lidar would provide the future space carbon mission with great values and potentials in advancing carbon cycle sciences

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