Airborne Lidar Measurements of Atmospheric Column CO2 Concentration to Cloud Tops during ASCENDS Science Campaigns

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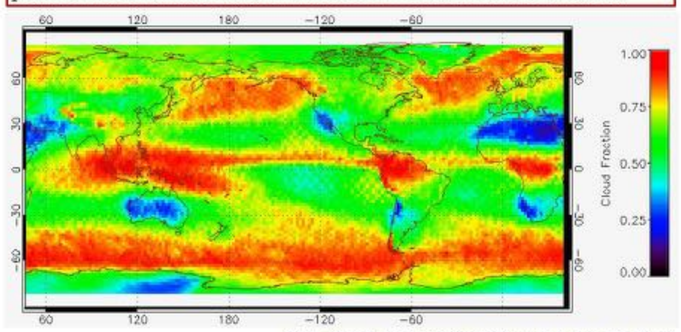
Introduction

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 scenes and have limited global data coverage and poor data 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 column CO_2 concentration to cloud tops, providing much higher spatial coverage and some information about vertical structure of CO2. This is expected to benefit atmospheric transport process studies, carbon data assimilation in models, and global and regional carbon flux estimation.

Annual mean total cloud fraction

2/3 of the Earth's surface is typically covered by clouds and space-based passive missions are unable to make CO2 measurements over clouds

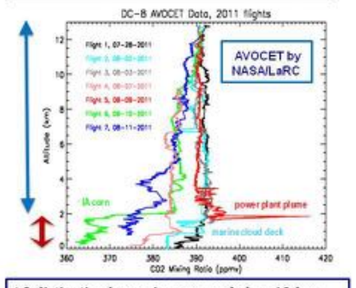


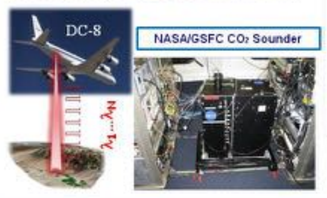
from CloudSat and CALIPSO (contributed by Jen Kay)

In-situ CO_2 Vertical Profiles – Summer 2011

Spirals

2-layer: boundary and free troposphere



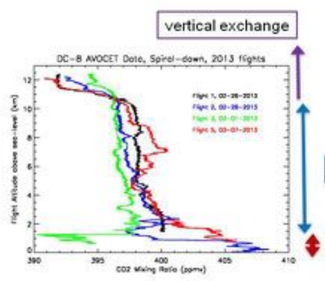


- 2 distinctive layers in summer below 13-km
- PBL: power plant plume, marine sink and ecological drawdown
- Free-troposphere: significant gradient

In-situ CO_2 Vertical Profiles – Winter 2013

3-layer: boundary, troposphere and stratosphere

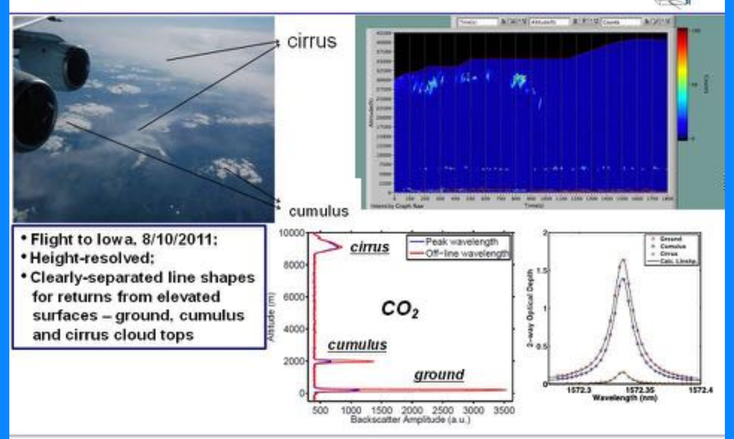
Feb./March 2013 Flights on-board AVOCET gas analyzer



- 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

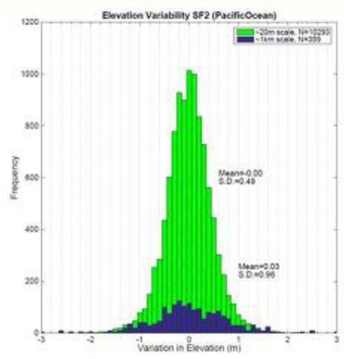
Column CO_2 measurements to cloud tops help resolve vertical structure and physical processes of CO_2 !

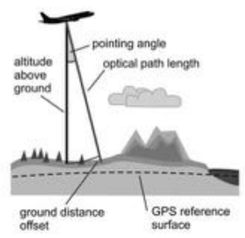
CO_2 Sounder measured Lidar Backscatter Profiles



- 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

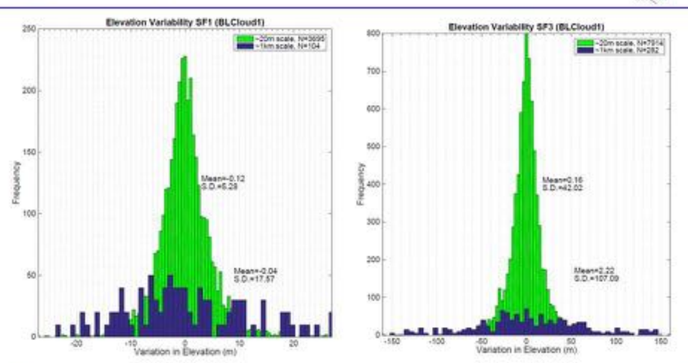




Accuracy ~0.5 m

Histogram of range measurement standard deviation with regard to GPS altimeter data over Pacific Ocean near California coast on Aug. 22 during 2014 ASCENDS airborne science campaign

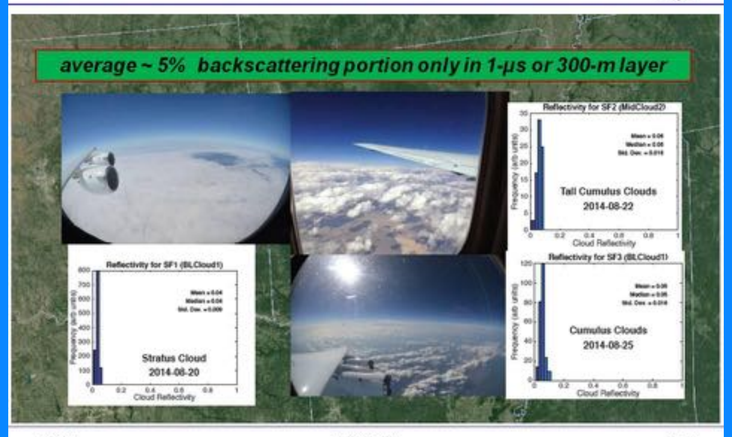
CO_2 Sounder measured roughness of cloud tops



flat marine stratus (left) vs ***bumpy*** cumulonimbus (right)

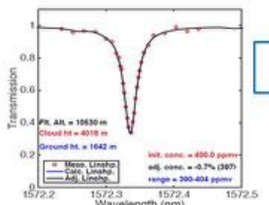
CO_2 Sounder measured cloud reflectivity

average ~ 5% backscattering portion only in 1-μs or 300-m layer

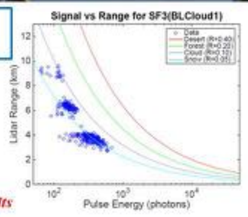


Column CO_2 Retrievals to all cloud tops

- Column CO_2 measurements to cloud tops is now a standard product of our analysis.
- We are the first group to do this.
- This capability allows much more data coverage and sampling and provides more information of CO_2 vertical structure.



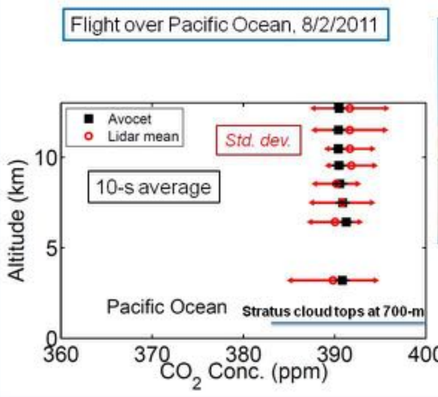
Iowa 8/25/2014



Please see posters A23B-294 295 for more measurement results

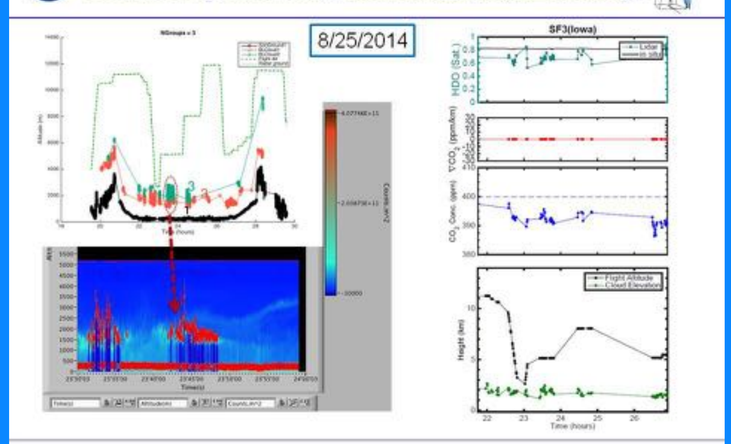
Column CO_2 Retrievals *to marine stratus cloud tops*

Flight over Pacific Ocean, 8/2/2011

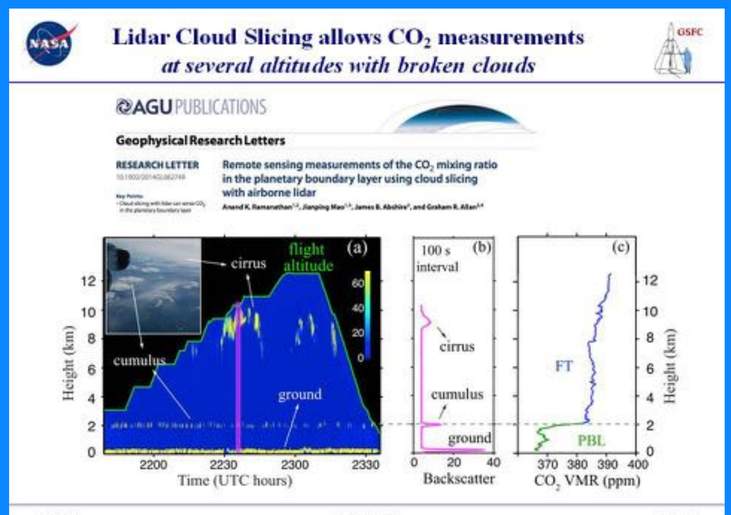


- flatter cloud tops
- smaller retrieval std. dev.

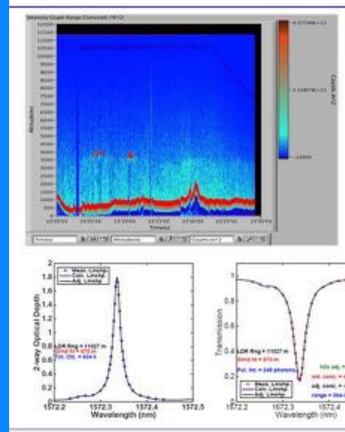
Column CO_2 Retrievals *to the boundary layer cloud tops*



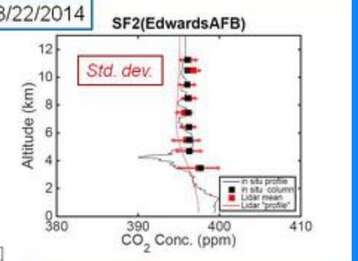
Lidar Cloud Slicing allows CO_2 measurements *at several altitudes with broken clouds*



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) minimize retrieval errors over rough surfaces (terrains, tree covers & clouds)

CO_2 Sounder measured Lidar Backscatter Profiles

- Flight to Iowa, 8/10/2011;
- Height-resolved;
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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 fluxes;
- 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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