

Pulsed Lidar Measurements of XCO₂ made during the 2017 ASCENDS Airborne Campaign show Capabilities for a Space Mission

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Overview & Summary

- Airborne CO₂ Sounder lidar was developed as demonstrator for a space mission
- Multiwavelength lidar approach samples the CO₂ line shape for accurate retrievals
- Sensitive detector minimizes needed laser power & random errors in retrievals

Measurements in the 2017 ASCENDS airborne campaign showed:

- Better than 1-ppm agreement between most lidar & in situ measurements at spiral-down locations
- Typically 1-ppm random error with 1-sec integration time
- North-south and east-west XCO₂ gradients, XCO₂ drawdown caused by growing cropland
- Changes in XCO₂ caused by change in wind directions (i.e. changes in transport)
- Measurements through wildfire smoke showed enhanced XCO₂
- Measurements to cloud tops allow isolating XCO₂ in lower atmosphere via cloud slicing

Technologies for CO₂ Sounder lidar are ready for small-to-medium sized space mission:

- Fiber laser and detector components are at or near TRL-6
- Measurement model shows ~1-ppm random error in 1-sec (7-km along track) averaging

July 27, 2017 flight from California to Alaska via Nebraska

- Very strong (~15 ppm) ND gradient from Nevada to Nebraska, AK
- Strong XCO₂ drawdown over growing cropland in Nebraska & North Dakota
- Stable & useful XCO₂ measurements when flying over Rocky Mountains
- XCO₂ to cloud tops leaving Grand Island NE

Lidar Measured XCO₂ change over south-central Alaska for flights on August 5 & 6, 2017

- Close timing average of 4 sec retrievals
- Atmospheric state in retrievals from GEOS-5

Dashed region showed significant change in XCO₂ from August 5 to 6

Recent results from Airborne CO₂ Sounder Lidar

Abstract: Lidar measurements of atmospheric CO₂ column concentration in cloud top view during the 2017 ASCENDS ABoVE airborne campaign.

Airborne CO₂ Sounder Lidar

- Pulsed Direct Detection IPDA lidar
- Airborne Lidar samples the CO₂ line with 15 to 30 laser wavelengths
- Scanning line shape allows retrieval's line fit to reduce biases
- Typical areas are from instrument artifacts, such as laser wavelength drift & receiver's non-uniform spectral response
- Others can be from Doppler shift, & from WV residual interference
- The number of wavelengths is programmable

XCO₂ Measured to Cloud Tops in ascent after Grand Island Spiral down

Lidar Backscatter from Cloud tops

1-sec XCO₂ measurements

Flight Altitude

Cloud Top Altitude

CO₂ (ppm)

Change in XCO₂ in southern Alaska caused by change in Wind Direction (in transport)

Winds from South, primarily from over ocean

Winds from Northeast, primarily from over land - primarily central AK

CO₂ Sounder Lidar - Approach for Space Mission

- Nadir pointing from ~400 km polar LEO orbit
- Measure a single CO₂ absorption line with 10 wavelengths
- Continuous measurements of ODE column absorption, range, backscatter profiles
- Measure XCO₂ & range to ground, water surfaces & cloud tops
- Random measurement error < 1 ppm in 1 sec (7km) over deserts
- Bias < 0.4 ppm

How this lidar measures XCO₂ to ground & cloud tops

- Lidar measures height resolved backscatter profiles for all 30 wavelengths
- The ground, clouds & range to both are clear strong signals in backscatter profiles
- Allows CO₂ absorption line shapes to be computed every 1-sec for strong signals to ground & cloud tops (ODR)
- Retrievals (black lines) use lidar samples, range & atmospheric model (or measured state) to compute XCO₂

August 6, 2017 flight over northern & western Alaska

- Lidar shows horizontal and vertical gradients in XCO₂
- Clear gradient in XCO₂ in southwest Alaska
- Lower XCO₂ near surface in northwest Alaska
- Higher XCO₂ at beginning of flight, lower during last spiral over Fairbanks

Lidar Measured XCO₂ Enhancements from Wildfire Plumes on August 8, 2017 Flight

- Lidar allows retrievals of XCO₂ to ground even in presence of dense smoke plumes from wildfires
- Demonstrated this in overflight on Vancouver Island and Washington State
- Satellites using passive spectroscopy (i.e., GOSAT, OCO-2) are unable to measure in these conditions

CO₂ Sounder Lidar - Approach for Space using 80 cm diameter telescope

Parameter	Value	Parameter	Value	Parameter	Value
Orbit altitude	400 km	Laser wavelength	1560 nm	Detector quantum efficiency	20%
Laser pulse energy	2.5 J	ODR line absorption fraction	50%	Detector offset gain	0%
Laser pulse rate	2.5 Hz	Receiver efficiency	30%	Detector ODR gain	50%
Laser pulse width	1.0 nsec	Telescope diameter	80 and 1.8 m	Detector dark current	1 nA
Laser alignment	100 arc	Telescope FWHM	22 arc	Detector bandwidth	< 0.5 MHz

Airborne measurements during 2017 ASCENDS/ABoVE Airborne Campaign July 20-August 8, 2017

Comparison from on NASA DC-8 during:

- Grounded PDR retrievals
- Grounded PDR in situ
- LAIC ABoVE & DLR in situ

Flights & Legend:

Date	Name	Duration (hr:min)	Spiral/Descent
20-Jul	Calibration	4.4	0
21-Jul	Calibration	5.6	0
22-Jul	Northbound science/transit	9.4	4
23-Jul	Northbound	1.0	0
24-Jul	Northbound	1.0	0
5-Aug	South-Central Alaska	6.2	5
6-Aug	Southbound science/transit	1.1	0
7-Aug	Southbound	5.3	4

Lidar XCO₂ vs in situ XCO₂ in Spiral Down Maneuvers for Aug 6, 2017 flight

- Blue - In situ measured XCO₂, averaged to 1-km bins
- Gray dots - 1-sec lidar measurements during spiral
- Red - Lidar measured XCO₂, averaged to 1-km bins

Comparison of Lidar XCO₂ retrievals in Spirals: Beginning & end of campaign

Retrieved atmospheres based on ODR-8 met and OLR WV data

July 20, 2017 Spiral over Edwards AFB CA

Aug 8, 2017 Spiral over Edwards AFB CA

Where:

- Red: Lidar 1-sec retrievals (mean ±1-1 std dev)
- Blue line - in situ CO₂ measured by AVOICET
- Blue dots - Column XCO₂ from AVOICET using lidar's vertical weighting function

Note:

- < 0.5 ppm difference between Lidar & in situ XCO₂ at altitudes >4 km
- No detectable change in Lidar vs in situ (in bias) over campaign's 19 days

Comparing Lidar measurement Model with Airborne Data Scaling the Model Results for a Space Mission

Comparison of the predicted XCO₂ error from the measurements for the 2016 airborne measurements over Edwards CA using 1-sec averaging.

Model shows space lidar measurements to vegetation under clear conditions have ~1ppm random error with 1-sec (7km along track) averaging