Airborne Demonstration of Atmospheric CO2 Concentration Measurements with a Pulsed Multi-wavelength IPDA Lidar

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2017 ASCENDS/ABoVE Airborne Science Campaign in Alaska

Support from NASA’s:
ASCENDS Pre-formulation Activity,  ABoVE Science Investigation,  Airborne Science Program
Information Content of CO2 Sounder

- Multiple-wavelength approach for low-bias retrievals
- Returns from elevated surfaces with accurate ranging capability and weighting functions peaking at different altitudes contain vertical information of CO2 distribution
Timeline of Measurement Progress

Detector
InGaAs PMT
HgCdTe APD
Laser Source
Free Scanning
Step-Locked

Year
0
2
4
6
XCO₂ scatter (ppm) 10s ave
1s ave

clear-sky
XCO₂ ~ 0.8 ppm 1-s
~ 0.4 ppm 10-s
Overview of the Airborne Campaign  
July 20 – Aug. 8, 2017

<table>
<thead>
<tr>
<th>Dates</th>
<th>Name</th>
<th>Duration (hrs)</th>
<th># Spirals/Descents</th>
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</thead>
<tbody>
<tr>
<td>20-Jul</td>
<td>Engineering</td>
<td>4.4</td>
<td>3</td>
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<tr>
<td>21-Jul</td>
<td>Calibration</td>
<td>5.6</td>
<td>10</td>
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<tr>
<td>27-Jul</td>
<td>Northbound science/transit</td>
<td>9.4</td>
<td>4</td>
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<tr>
<td>31-Jul</td>
<td>Western NWT</td>
<td>8</td>
<td>6</td>
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<tr>
<td>2-Aug</td>
<td>Northern NWT</td>
<td>6.6</td>
<td>4</td>
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<tr>
<td>5-Aug</td>
<td>South-Central Alaska</td>
<td>6.2</td>
<td>5</td>
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<tr>
<td>6-Aug</td>
<td>Central Alaska</td>
<td>7</td>
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<tr>
<td>8-Aug</td>
<td>Southbound science/transit</td>
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<td><strong>Totals:</strong></td>
<td><strong>55.3</strong></td>
<td><strong>47</strong></td>
</tr>
</tbody>
</table>

Flights & Legend:

- Alaska
- Canada
- California
- Pacific

6/5/2019
Validation with AVOCET

Eng(EdwardsAFB)

1st flight

7/20/2017

S6 (EDW)

last flight

8/8/2017

1-s average
Validation with AVOCET

- Low bias and high precision
- Good responses to vertical gradient

7/27/2017

Drawdown~30 ppm
Validation with AVOCET

Northernmost spiral Deadhorse ~ 70N

Flight Altitude (km)

8/1/2017

NWT1 (Deadhorse)
Validation with AVOCET

8/5/2017

Westernmost spiral
Nome

Flight Direction

SF4 (Nome)

in situ CO2
in situ XCO2
Lidar XCO2

XCO2 (ppm)

Flight Altitude (km)

380 390 400 410

0 2 4 6 8 10 12

in situ CO2
in situ XCO2
Lidar XCO2

6/5/2019

Example: 8/5/2017
Validation with AVOCET

S5 (McGrath)

8/6/2017

S5 (Fort Yukon)
Lidar Measurements to Cloud Tops

- 8/6/2017, last flight in Alaska
- Both returns from ground and PBL cloud tops
- Opportunity for cloud slicing
XCO2 retrievals to both surfaces

- Low bias for both full and partial column XCO2
- Greater RMS error in XCO2 to cloud tops due to lower cloud reflectivity and soft cloud tops

8/6/2017, 1-s average
Transit south flight, 8/8/2017

Significant vertical and horizontal gradients from onboard Picarro
Transit south flight, 8/8/2017

Enhancement:
Measurements when flying over western Washington state, measuring XCO₂ thru smoke plume from Canadian wildfires.
Summary

• Large, stable, rich and valuable data set!
• High precision: < 1 ppm for 1-s average and < 0.5 ppm for 10-s average
• Low bias: lidar XCO2 agrees with in-situ profiles
• Lidar XCO2 clearly shows north-south gradients and CO2 enhancement from forest fires
• CO2 Sounder is ready to participate in future airborne campaigns
  – scale up to spaceborne – see poster #55 by Abshire et al
  – status and future of ASCENDS – Ken Jucks talk
• Lidar XCO2 data will be released to public this summer

Acknowledgement: This work was funded by the NASA ESTO IIP-10 program and the NASA ASCENDS pre-formulation activity, ABoVE science investigation and airborne science program. We also thank the NASA DAOF DC-8 team for help conducting the flight campaigns.
Backup slides
Measurement Approach - *highlights*

**Measurement Approach**

- Pulsed laser and time-gated receiver
  - Height-resolved backscatter measurements
  - High spectral resolution, high measurement sensitivity
- Multiple-wavelength measurement cross one CO$_2$ absorption line
  - Lineshape-resolved w/ 30 wavelengths
  - Very narrow spectral coverage (< 0.15 nm)
- Fixed nadir-pointed

**Measurement Parameters**

- 1-μs laser pulse width
- 10 kHz pulse rate ~ a step of 100-μs
- 300 Hz laser scan rate cross 30 wavelengths on the 1572.335 nm CO$_2$ line
- 10 Hz receiver data recording rate for all wavelengths ~ 0.1 s raw data reporting interval
- 10 ns receiver bin width ~ up to 1.5 m vertical resolution
Surface Reflectance Measurements

8/25/2014 ASCENDS flight above *cumulus clouds* in Iowa

Mao et al., 2018

Kuze et al., 2010

1 μs ~ 150-m vertical layer
Validation with AVOCET

8/1/2017

NWT1 (Inuvik1) 00Z

NWT1 (Inuvik2) 05Z