Lidar Remote Sensing Technologies for ACT - America

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12 – 13 August 2015, Newport News, VA

Outline

- Introduction
  - Carbon science requirements
  - Lidar CO_2 measurement approach
  - Instrumentation
- Lidar Measurements
  - CO_2 column measurements
  - Accuracy and precision
  - CO_2 column measurements with clouds
  - Ranging measurements
- Summary

Mission Goals

- Quantify and reduce atmospheric transport uncertainties
- Improve regional-scale, seasonal prior estimates of CO_2 and CH_4 fluxes
- Evaluate the sensitivity of OCO-2 column CO_2 measurements to regional variability in tropospheric CO_2

These goals address the three primary sources of uncertainty in atmospheric inversions – transport error, prior flux uncertainty and limited data density

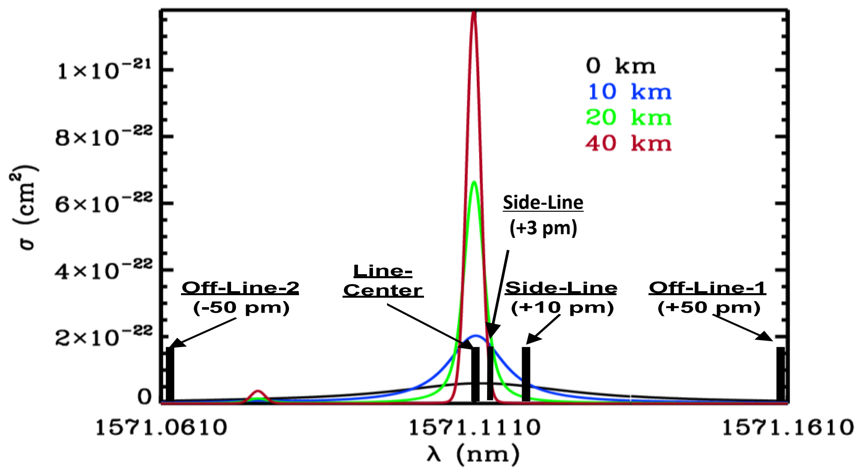
Needs: column CO_2 and boundary layer measurements

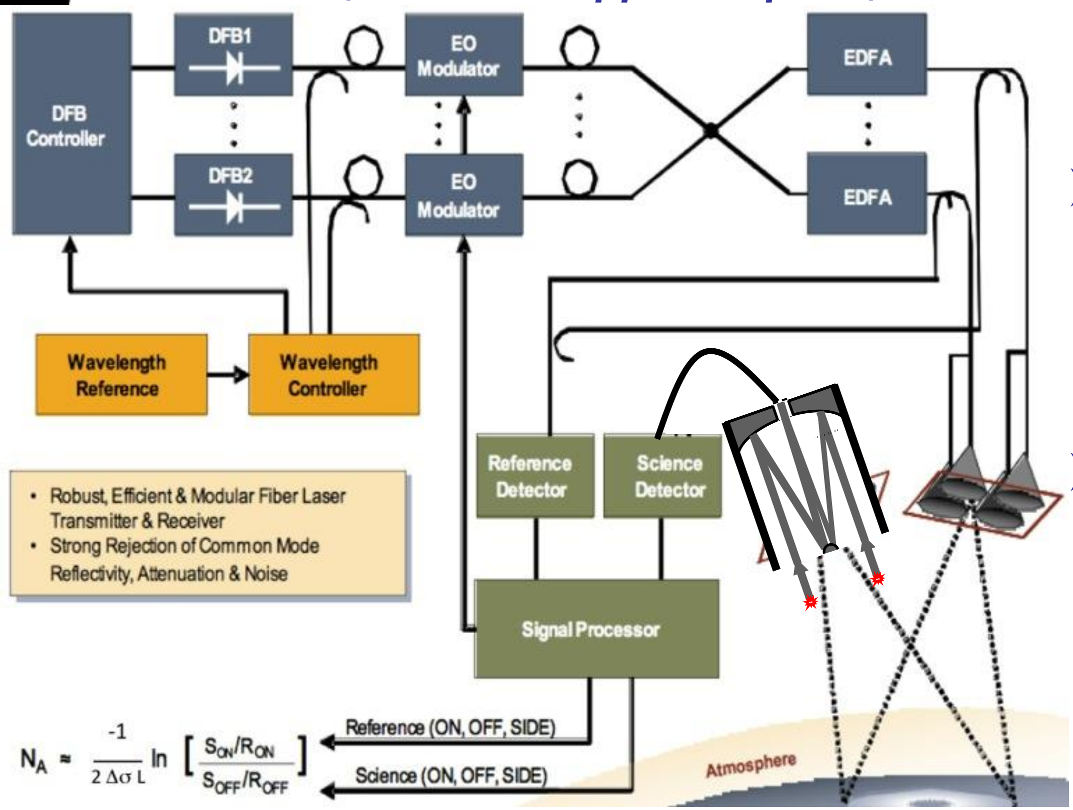
→ **CO_2 and backscatter lidars**

CO_2 Measurement Architecture

Exelis Multi-functional Fiber Laser Lidar (MFLL) and LaRC ASCENDS CarbonHawk Experiment Simulator (ACES) architecture:

Dobler et al., Lin et al. *Applied Optics*, 2013





- Simultaneously transmits λ_{on} and λ_{off} reducing noise from the atmosphere and eliminating surface reflectance variations.
- Approach is independent of the system wavelength and allows simultaneous CO_2 & O_2 (1.26 μm) number density measurements, combining them to derive XCO_2.

Instrument Development
(joint effort of LaRC and Exelis)

ASCENDS CarbonHawk Experiment Simulator (ACES developed at Langley with support from Exelis)

Multifunctional Fiber Laser Lidar (MFLL) (developed by Exelis in 2004 Exelis and Langley since 2005)

3×10W amplifier integration

Instrument-aircraft integration

advancing key technologies for spaceborne measurements of CO_2 column mixing ratio

Development & Demonstration

21-25 May 2005, Ponca City, OK (DOE ARM)
5 Lear Flts: Land, Day & Night (D&N)

20-26 June 2006, Alpena, MI
6 Lear Flts: Land & Water (L&W), D&N

20-24 October 2006, Portsmouth, NH
4 Lear Flts: L&W, D&N

20-24 May 2007, Newport News, VA
8 Lear Flts: L&W, D&N

17-22 October 2007, Newport News, VA
9 Lear Flts: L&W, D&N, Clear & Cloudy

22 Sept. – 30 Oct. 2008, Newport News, VA
10 UC-12 Flts: L&W, D&N, Rural & Urban

10-16 July 2009, Newport News, VA
5 UC-12 Flts: L&W

31 July – 7 Aug. 2009, Ponca City, OK
5 UC-12 Flts: L&W, D&N

10-20 May 2010, Hampton, VA
6 UC-12 Flts: L&W, D&N

5-11 May 2011, Hampton, VA
5 UC-12 Flts: L&W, D&N, Clear and Cloudy

6-18 July 2010, Palmdale CA
6 DC-8 Flts: L&W, D

28 July – 11 Aug. 2011, Palmdale CA
8 DC-8 Flts: L&W, D

February 19 – March 9, 2013, Palmdale CA
7 DC-8 Flts: L&W, D&N

August 13 – September 3, 2014, Palmdale CA
5 DC-8 Flts: L&W, D

ranging capability enabled


MFLL on Lear-25

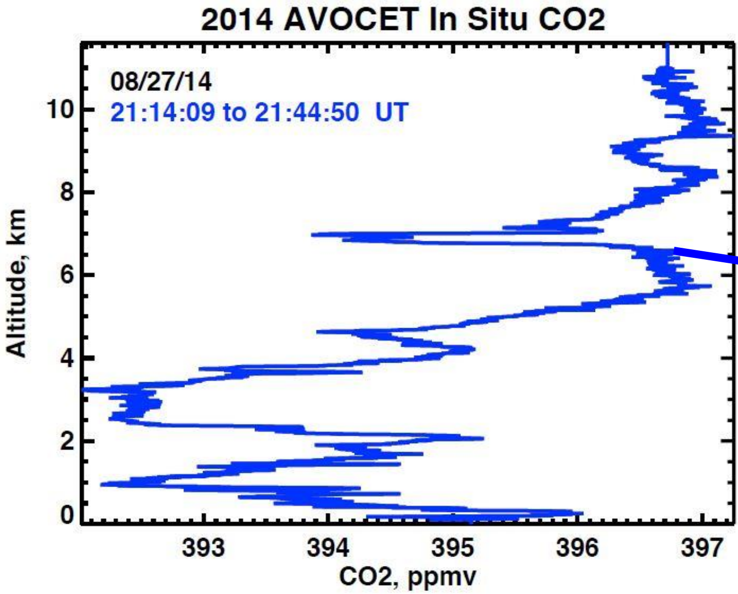

MFLL on UC-12

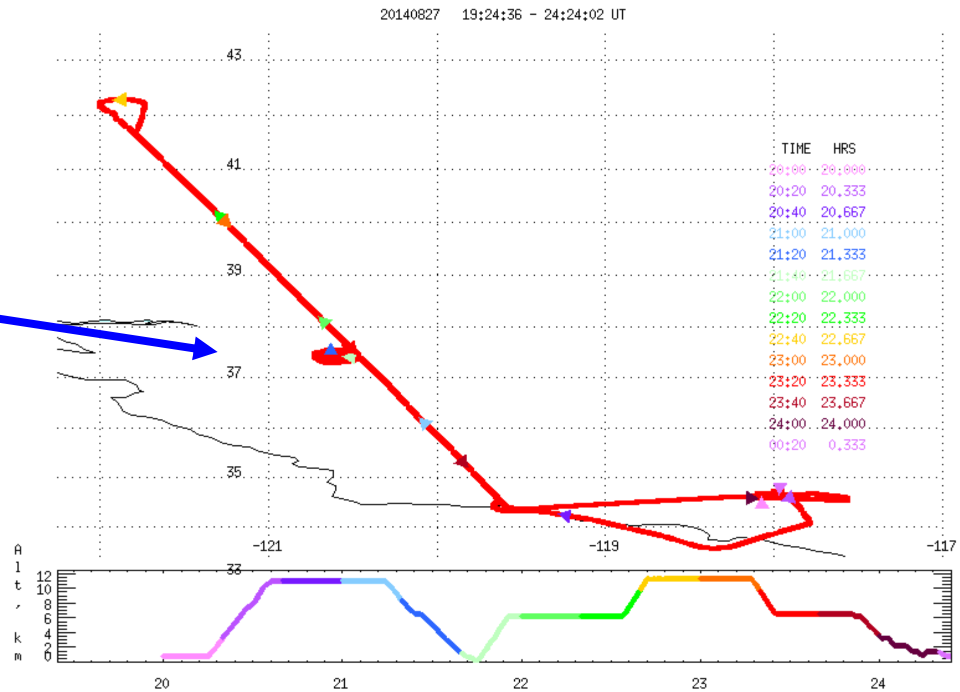

MFLL on DC-8

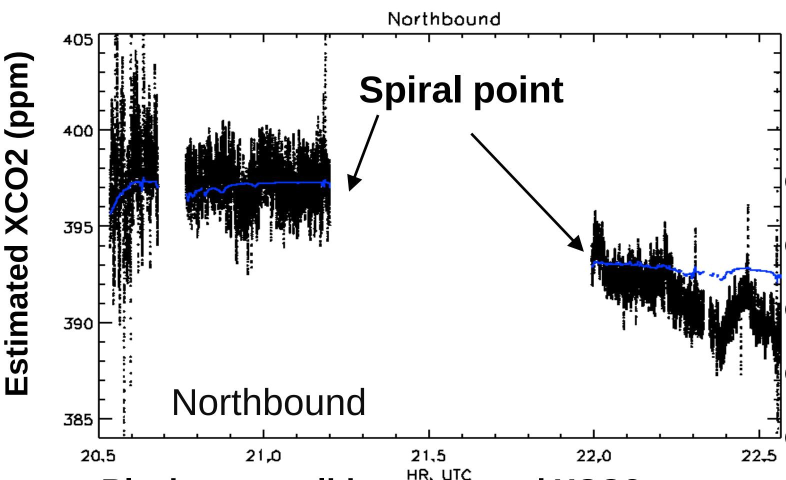
various lab, ground range, and flight tests

total 14 MFLL flight campaigns since 2005, plus 1 ACES in Hampton, 2014

In Situ and Lidar Comparision
(MFLL OCO-2 Under Flight: 20140827)







Black curves: lidar measured XCO2
Blue curves: in-situ derived XCO2

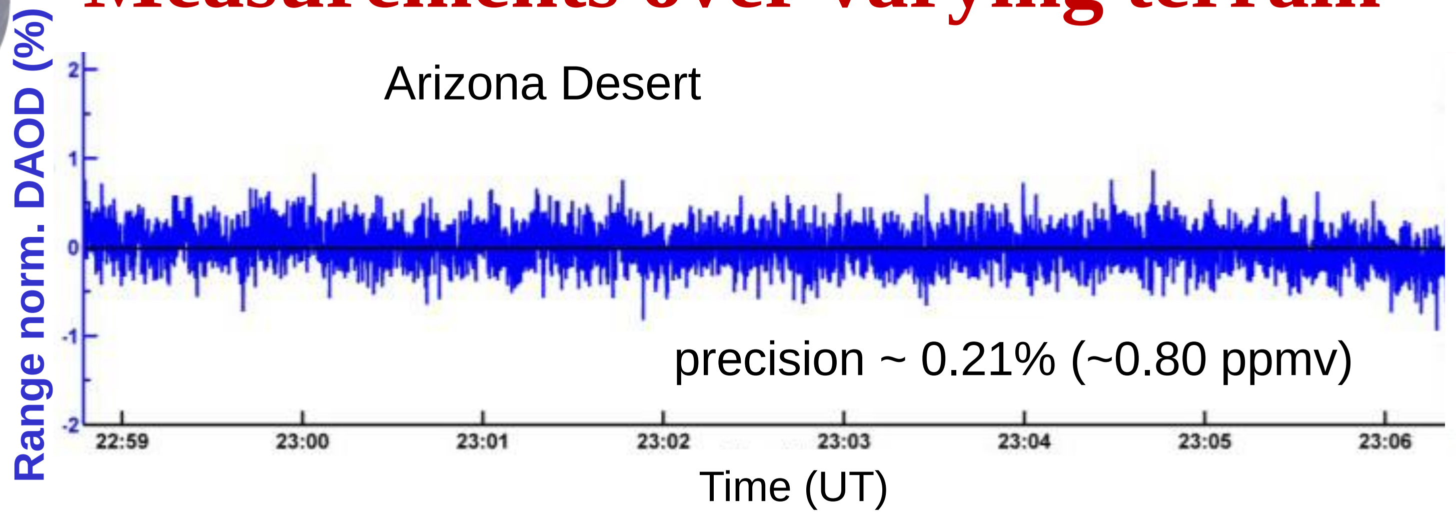
In-situ derived (or modeled) Value

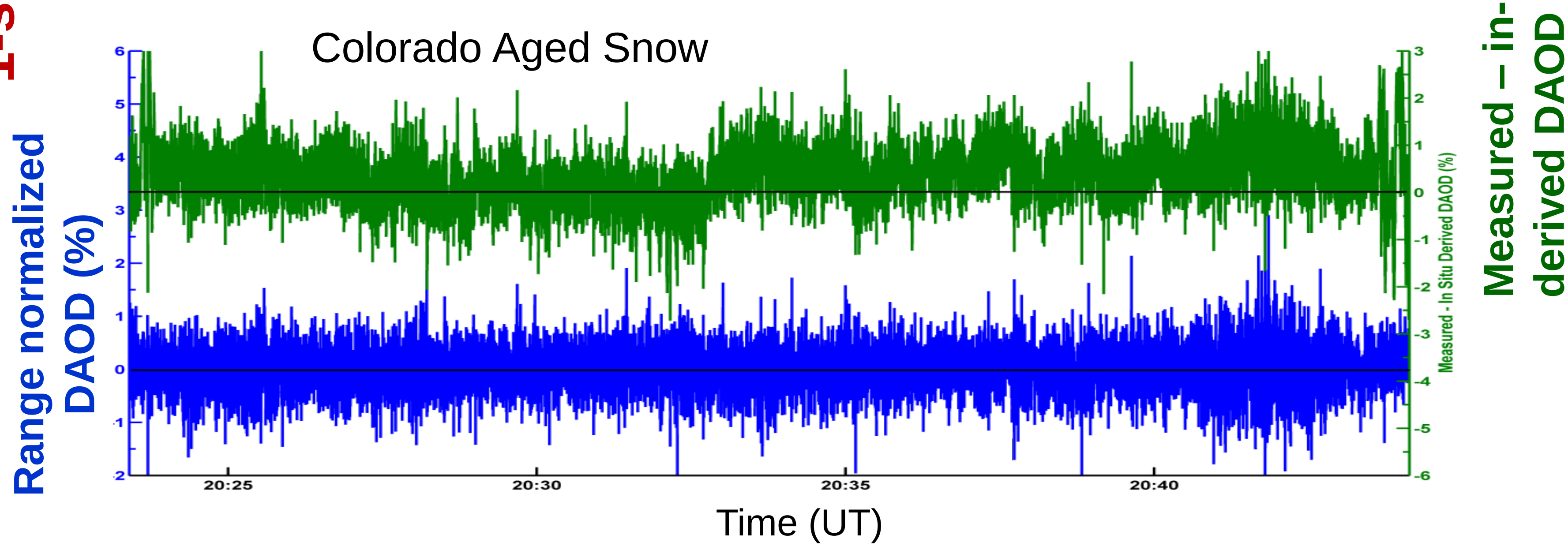
- In-situ from Spiral: CO_2, T/p/q profiles
- Radiative transfer model
- Ranging correction with lidar range data
- In-situ derived (or modeled) DAOD
- In-situ derived (or modeled) XCO_2

difference (ppm): 0.18

2013 ASCENDS Campaign: Measurements over varying terrain

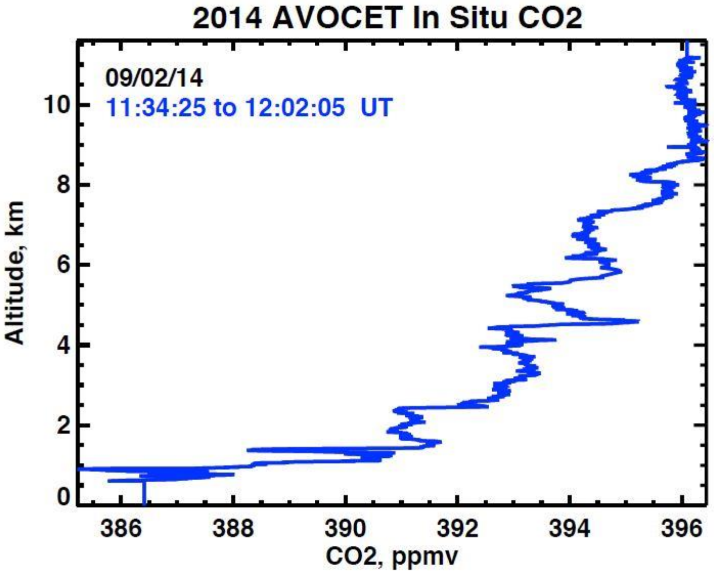
1-s average

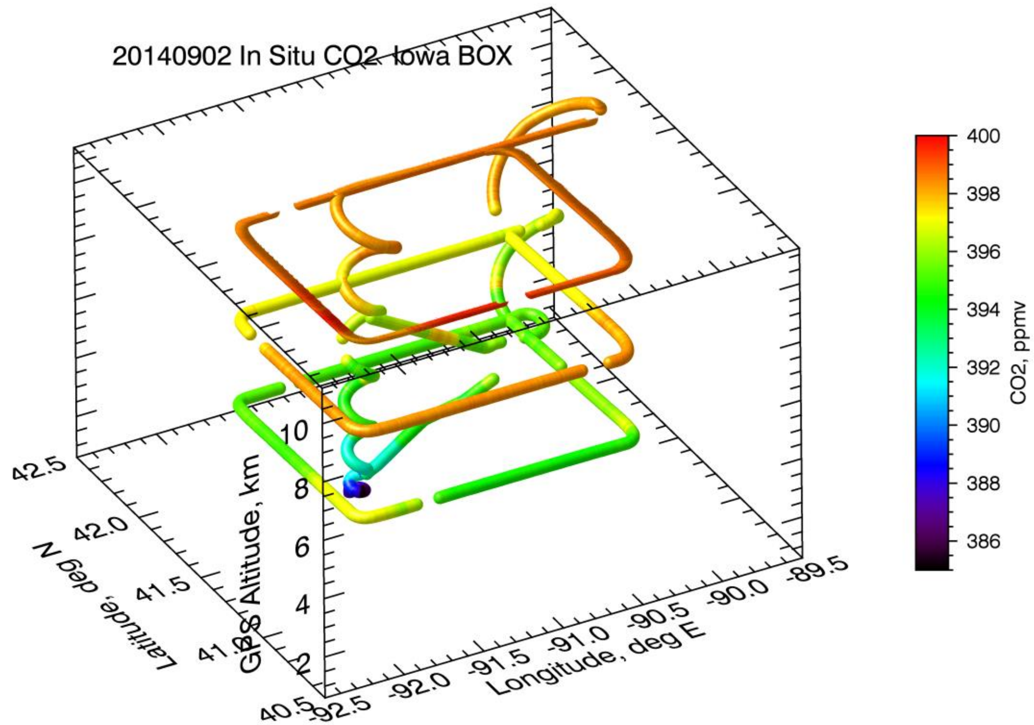


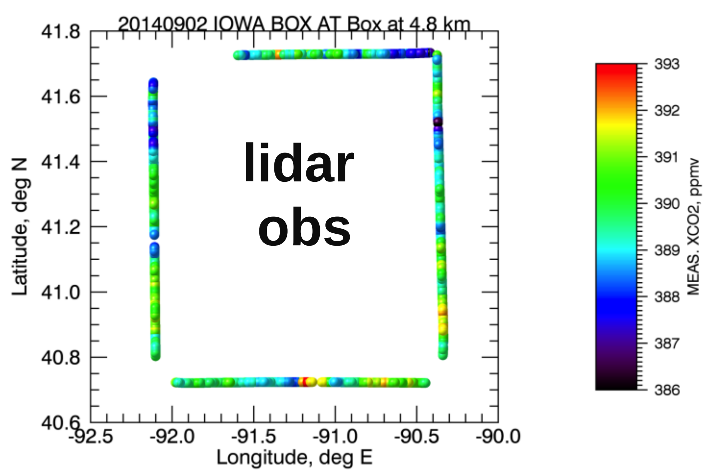


difference ~ 0.26% (~0.99 ppmv); Precision ~ 0.42% (~1.6 ppmv)

Natural Variability
(lidar and in-situ measurements)
(Mid-West Flight: Iowa Box; 02 Sept 2014)

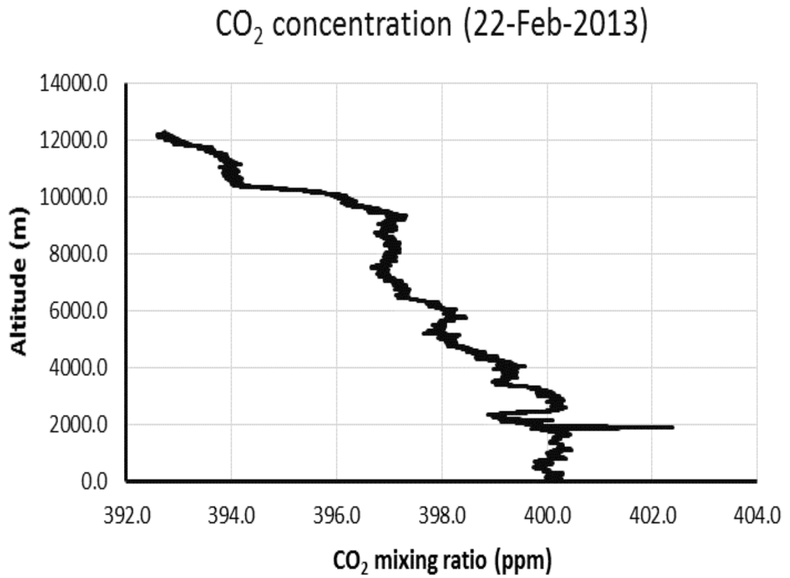


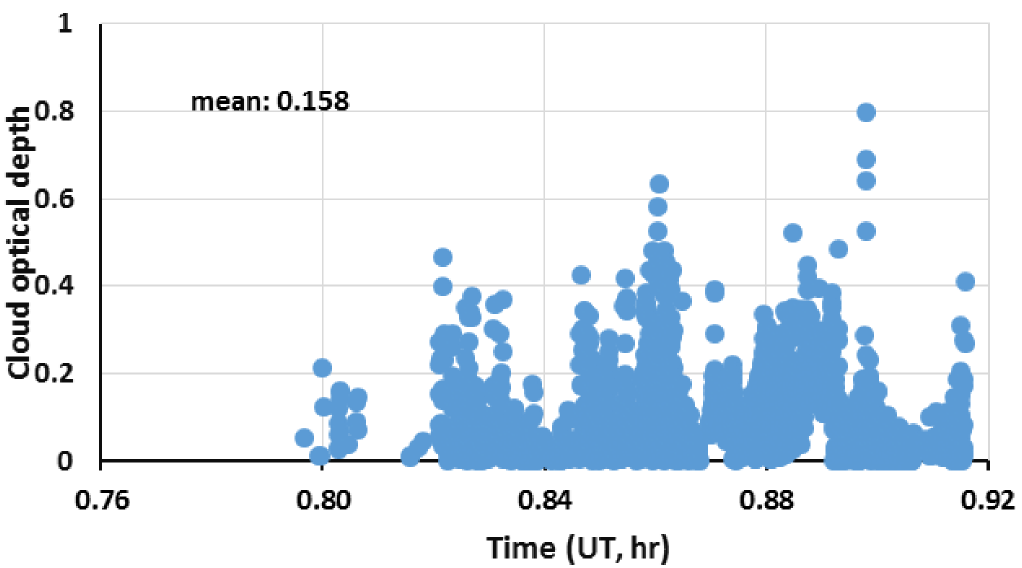


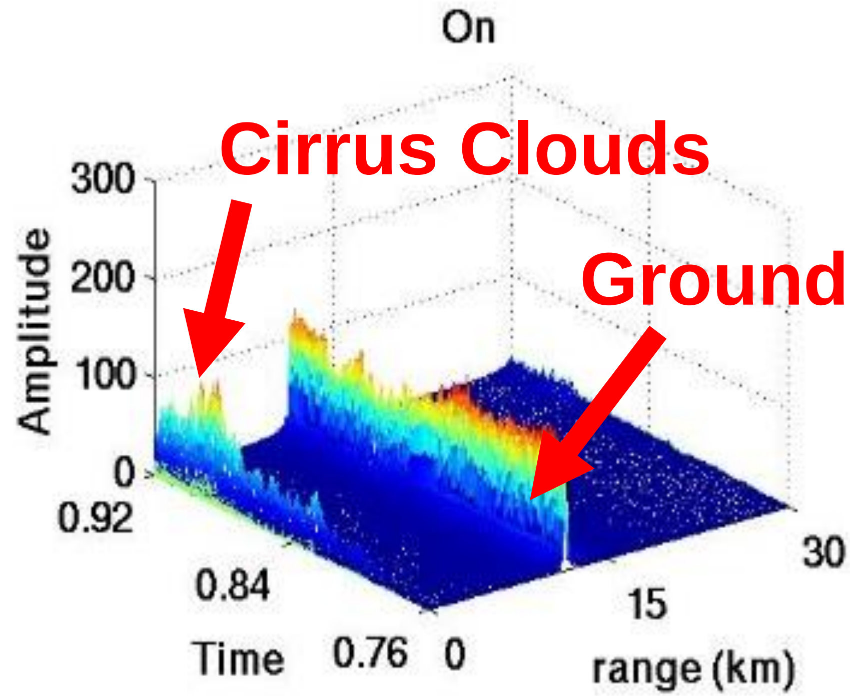


Significant spatiotemporal variations (a few ppm) found from lidar observations and when comparing spiral with non-spiral in-situ observational data

CO_2 Column Measurements Through Thin Cirrus (22 Feb 2013)





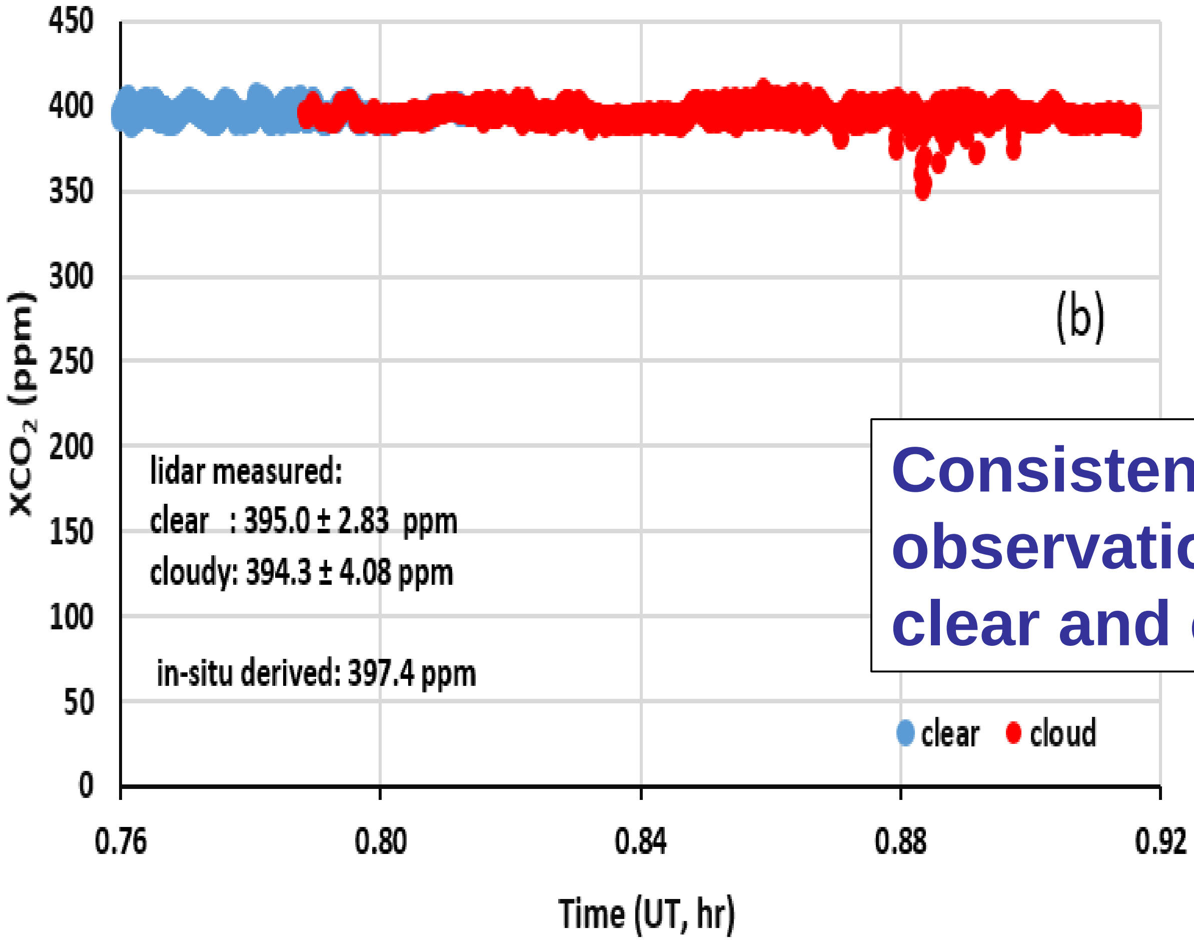


Blythe, CA

10 Hz data

Lin et al., *Optics Express*, 2015

Derived XCO_2 Column Measurements to the Surface Under Clear and Cloudy Conditions



cloudy XCO2 – clear XCO2 = –0.7 ppm

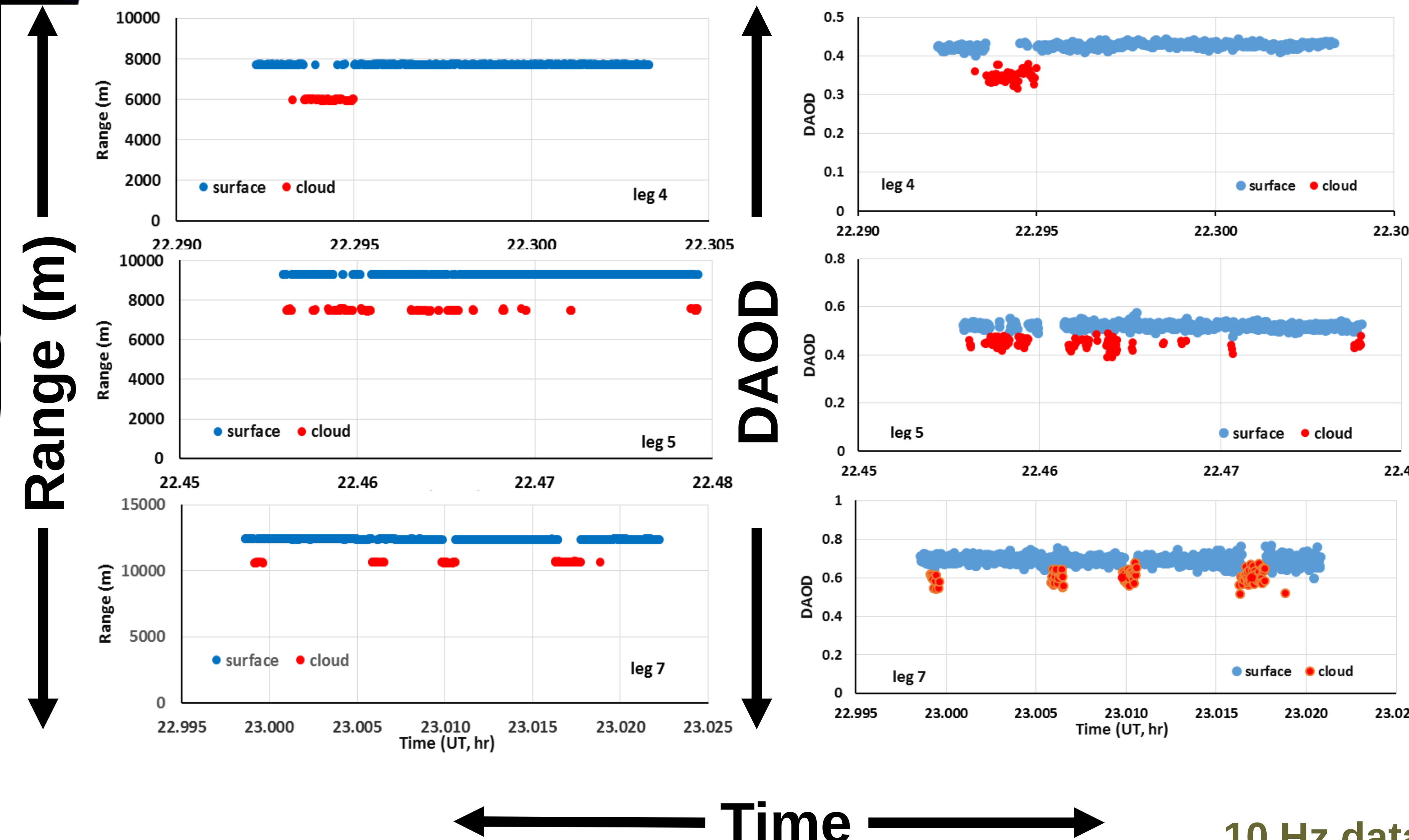
Consistent CO_2 column observations obtained for clear and cloudy conditions

Lin et al., *Optics Express*, 2015

10 Hz data

Range and Column CO_2 to Surface and Thick Cloud Tops

(West Bank, Iowa; 10 Aug 2011)



10 Hz data

Lin et al., *Optics Express*, 2015

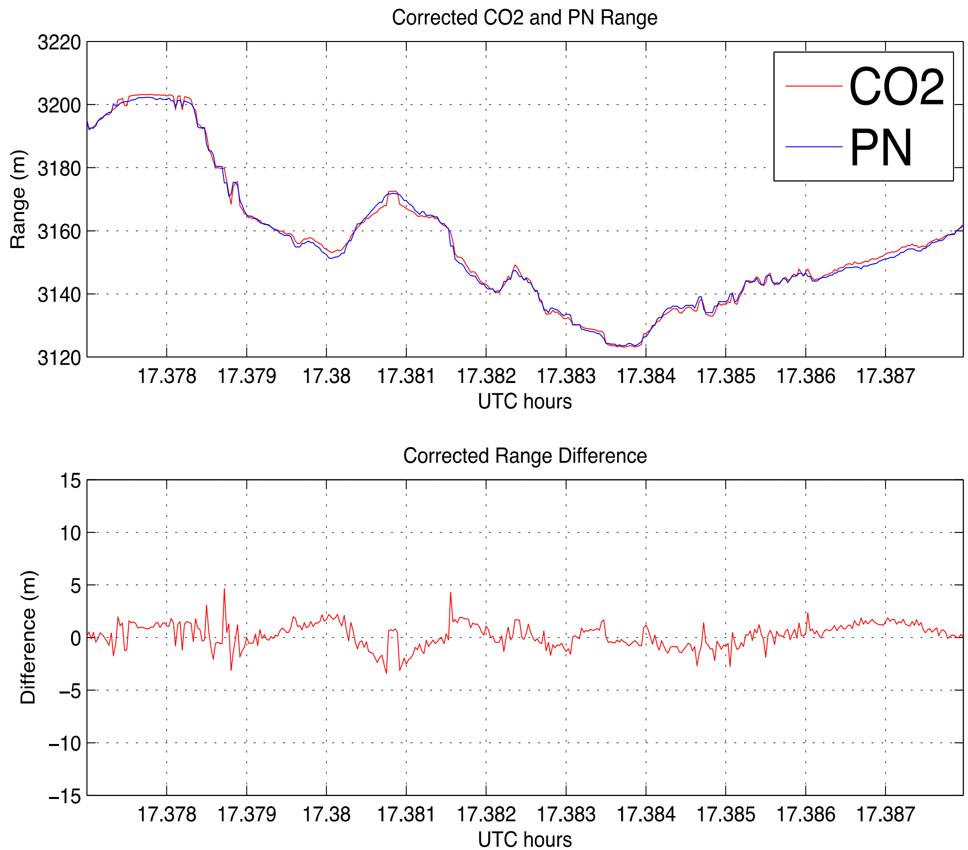
Column CO_2 Measurements to Surface and Thick Cloud Tops

	Leg 4	Leg 5	Leg 7
Lidar $DAOD_{surface}$	0.4271 ± 0.0056	0.5196 ± 0.0093	0.6902 ± 0.0155
Lidar $DAOD_{cloud}$	0.3480 ± 0.0143	0.4368 ± 0.0243	0.6007 ± 0.0339
Lidar $DAOD_{bndrylyr}$	0.0791 ± 0.0154	0.0828 ± 0.0260	0.0895 ± 0.0373
In-situ $DAOD_{surface}$	0.4243	0.5160	0.6939
In-situ $DAOD_{cloud}$	0.3417	0.4334	0.6075
In-situ $DAOD_{bndrylyr}$	0.0826	0.0826	0.0826

Lin et al., *Optics Express*, 2015

10 Hz data

Comparison of Range Determination from PN Altimeter and Off-line CO_2 Signal



Dobler et al. *Applied Optics*, 2013

RMS errors < 3 m

Range estimates obtained from the off-line CO_2 return and time coincident returns from the onboard PN altimeter over the region of Four Corners, NM from the DC-8 flight on 7 August 2011.

Summary

- Laser absorption lidars at 1.57μm with ranging-encoded IM-CW approach provide advanced capability in atmospheric CO_2 measurements and cloud/aerosol discriminations.
- IM-CW lidars have demonstrated the capabilities of precise CO_2 measurements through many airborne flight campaigns under variety of environment conditions, including CO_2 column measurements through thin cirrus clouds and to thick clouds. Over land, clear-sky CO_2 measurement precision within 1-s integration is within 1 ppm while mean bias is much smaller.
- Ranging uncertainties are shown to be below sub-meter level.
- Current lidar systems meet ACT-America observational requirements and provide precise CO_2 and ABL height measurements for carbon transport, sink and source studies.