IM-CW Fiber Laser Lidar

In Situ Measurements

Atmospheric CO_2 Variability Observed from ASCENDS Flight Campaigns

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Introduction

• Atmospheric CO_2 is the major climate forcing for the changing climate. Its concentration (or volume mixing ratio XCO_2) has significantly increased from about 280 ppm in pre-industrial era to ~ 395 ppm at present.

• There is a lack of quantitative knowledge of atmospheric CO_2 variability in various spatiotemporal scales. A large part of carbon amounts within the Earth's carbon cycle cannot be accounted for even in observed global annual means.

Lidar and In-Situ CO_2 Measurements

• U.S. National Research Council has identified the need of a future NASA Active Sensing of CO_2 Emissions during Nights, Days, and Seasons (ASCENDS) mission for improved determination of atmospheric carbon sources and sinks. NASA Langley Research Center (LaRC) and Harris Corp are jointly assessing the space measurement capability using airborne CO_2 laser absorption lidars [1-2].

• The CO_2 lidars are intensity-modulated continuous-wave (IM-CW) multi-channel instruments operating on a CO_2 absorption line in the 1.57-µm band with both online and offline wavelengths. A total of 14 flight campaigns have been conducted with lidar and in-situ CO_2 measurement systems.

• This effort analyzes the measurements of atmospheric CO_2 from the lidar and in-situ instruments during recent flight campaigns. Significant atmospheric CO_2 variations on various spatiotemporal scales were observed during these campaigns. Discussed cases include CO_2 drawdown by cornfields, large CO_2 variations within small regions, vertical CO_2 variability during the growing season and biologically dormant conditions, and urban impacts on CO_2 distributions.

• Lidar remotely sensed CO_2 column values are also evaluated under both clear and cloudy conditions and within atmospheric boundary layer and above clouds[3].

Measurement Characteristics

❖ Multifunctional Fiber Laser Lidar (MFLL):

Laser power:	5 W
Telescope diameter:	0.203 m
Detector dark current (cryogenic cooling):	45 pA
Sampling rate:	2 MHz
Signal integration time:	0.1-s
Modulation scheme:	swept sine with 30-km unambiguous range
Normalization and calibration:	reference channels

❖ ASCENDS CarbonHawk Experiment Simulator (ACES):

Laser power:	3×10 W
Telescope diameter:	3×0.178 m diameter
Detector dark current (vacuum cooling):	45 pA
Others:	same as MFLL

❖ In Situ Sensor (AVOCET):

Atmospheric CO_2:	XCO_2
Meteorological state:	T/p/q and winds

Lidar CO_2 Retrieval

❖ Integrated path differential absorption

$$\tau_d = -\frac{1}{2} Ln\left(\frac{P_{on}}{P_{off}} \times \frac{P^r_{off}}{P^r_{on}}\right)$$

(online : on)
(offline: off)

(r: normalization signal from reference channels)

CO_2 differential absorption optical depth (DAOD): τ_d

❖ CO_2 volume mixing ratio (XCO_2)

In situ atmospheric state profile: XCO_2, T/p/q

DAOD calculations based on radiative transfer model

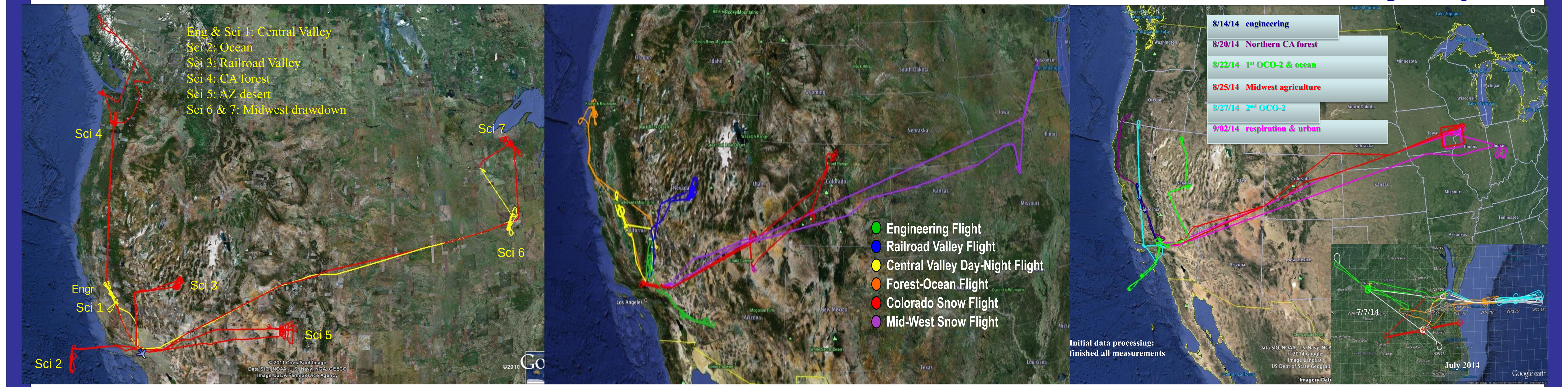
XCO_2 calculated from observed DAOD and meteorological state measurements

Airborne Flight Campaigns

2011 Summer: 29 July – 11 Aug

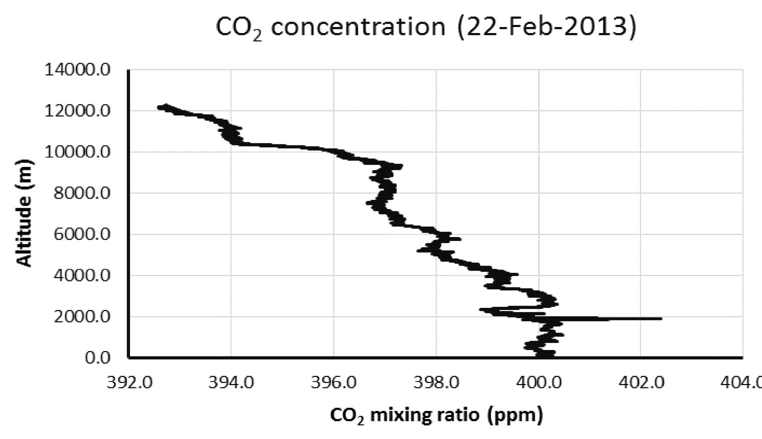
2013 Winter: 18 Feb – 5 March

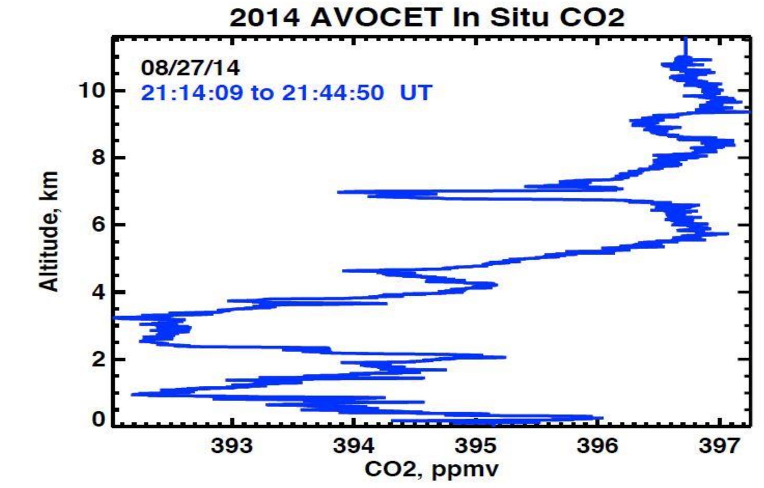
2014 Summer: 14 Aug – 2 Sept



Observations

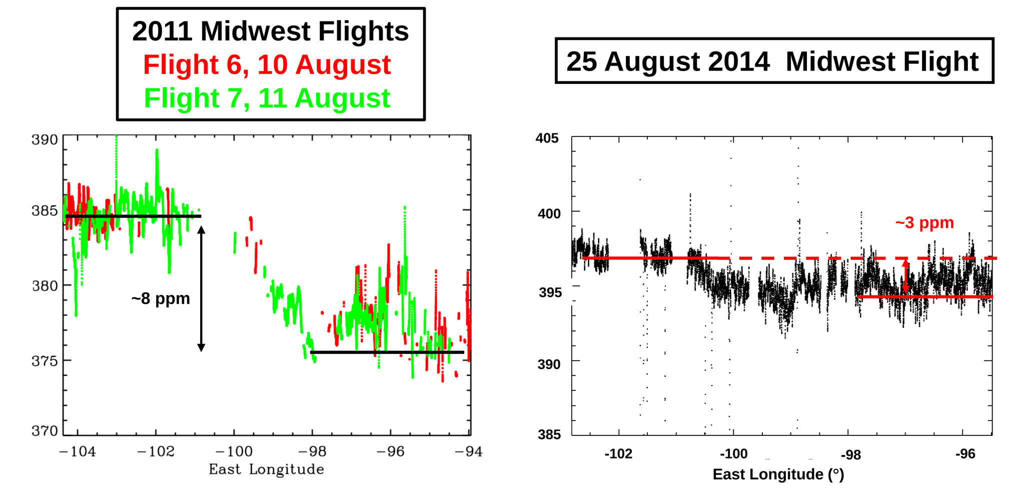
Vertical profiles: CA





Atmospheric CO_2 profiles measured during the winter 2013 and summer 2014 ASCENDS flight campaigns over California. Winter buildup and summer drawdown of CO_2 around 3 ~ 5 ppm within low atmosphere were observed. During winter times, vegetation normally shuts its evapotranspiration process down and nearly stops its CO_2 uptake. Thus, relatively uniform CO_2 distributions, especially over snow/ice surfaces, were observed (not shown). However, surface soil, animals, and human activities continuously release CO_2, which, along with air-mass exchange and transport at the top of and within PBL, causes elevated CO_2 in the lower atmosphere. In summer, free tropospheric CO_2 values were generally >395 ppm, and reached about 397 ppm above 10 km. The low values below ~4 km reflected the impact of active growing season of ecosystem during this flight campaign on atmospheric CO_2.

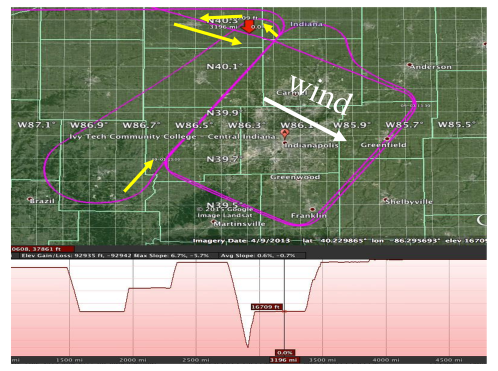
Cornfield CO_2 drawdown

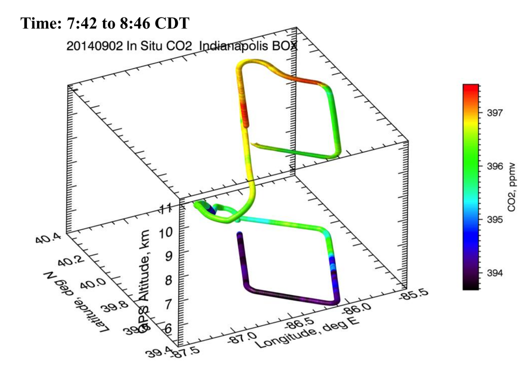


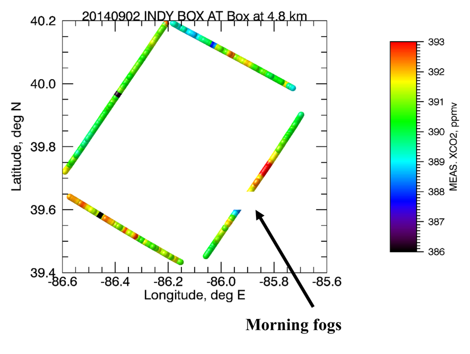
Column CO_2 measurements over Midwestern farm fields showed much larger drawdown signal in 2011 (~8 ppm) compared with measurements in 2014 (~3 ppm)

- Resulting from differences in meteorological states and phases of growing season
- Certain variability due to inter-annual changes in meteorological and biological conditions

Urban impact

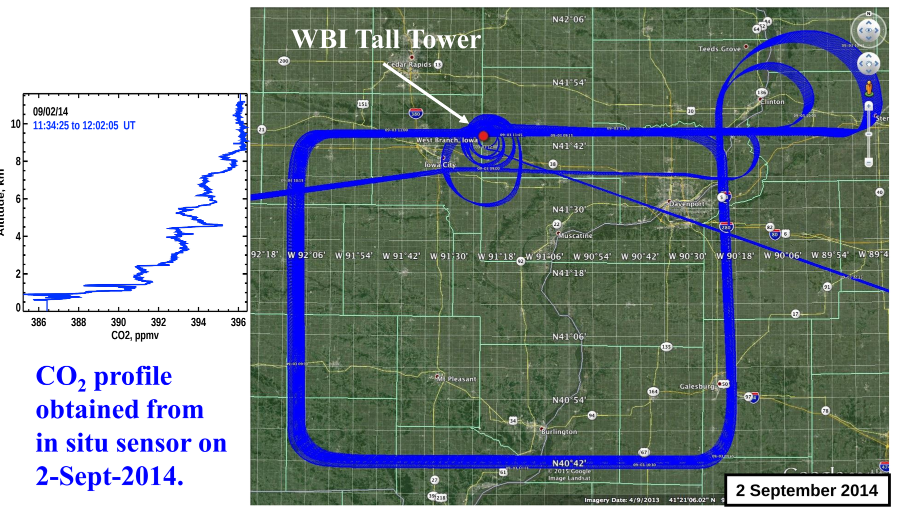




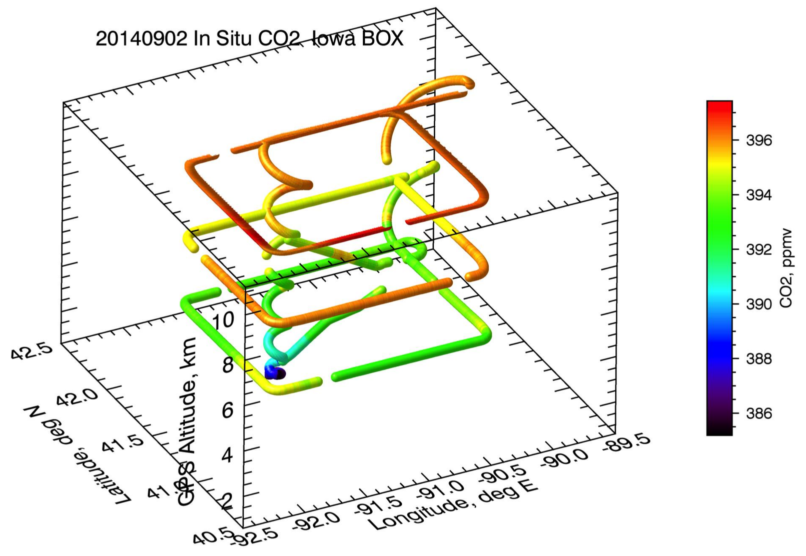


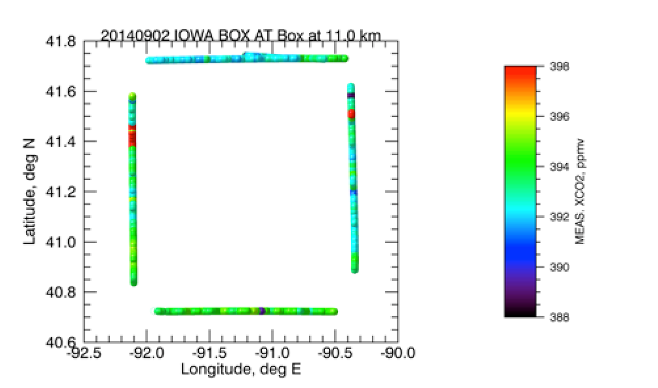
Flight pattern and measurements over Indianapolis, IN on 2 Sept 2014. Significant CO_2 variability was observed by both in situ and lidar instruments. High CO_2 values in downwind direction are likely a result of anthropogenic activities during morning rush hours.

Regional CO_2 changes



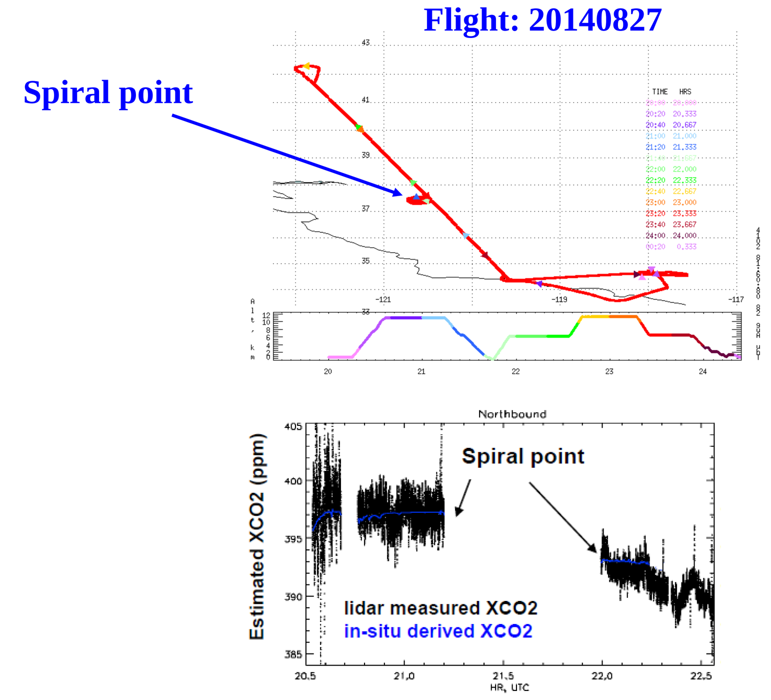
CO_2 profile obtained from in situ sensor on 2-Sept-2014.





Around 10 and 5 ppm CO_2 changes were found in vertical and horizontal, respectively, directions in a region of about 200×150 km² over Iowa during a summer 2014 flight by both remote and in situ sensors, which indicates large heterogeneity in atmospheric CO_2 distributions.

Methodology for validatation



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

Conclusions

This study evaluates the atmospheric CO_2 variability measured by in situ and active remote sensing instruments during multiple ASCENDS flight campaigns. Significant atmospheric CO_2 variations on various spatiotemporal scales were observed. For example, around 10-ppm CO_2 changes were found within free troposphere in a region of about 200×150 km² over Iowa during a summer 2014 flight. For winter times, especially over snow covered ground, relatively less horizontal CO_2 variability was observed, likely owing to minimal interactions between the atmosphere and land surface. Inter-annual variations of CO_2 drawdown over cornfields in the Mid-West were found to be larger than 5 ppm due to slight differences in the corn growing phase and meteorological conditions even in the same time period of a year. Furthermore, considerable differences in atmospheric CO_2 profiles were found during winter and summer times. In the winter CO_2 was found to decrease from about 400 ppm in the atmospheric boundary layer (ABL) to about 392 ppm in the upper troposphere, while in the summer CO_2 increased from about 390 ppm in the ABL to about 397 ppm in upper troposphere.

Future Work

- Analyzing CO_2 variability from ACT-America mission data
- Evaluation of large spatial scale CO_2 variability using collocated airborne and OCO-2 CO_2 measurements
- Model-measurement integration to obtain insights of the driving forces of CO_2 changes

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References

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[2] Bing Lin, Syed Ismail, F. Wallace Harrison, Edward V. Browell, Amin R. Nehrir, Jeremy Dobler, Berrien Moore, Tamer Refaat, Susan A. Kooi, "Modeling of intensity-modulated continuous-wave laser absorption spectrometer systems for atmospheric CO2 column measurements," Appl. Opt., 50 (29), 7062-7077 (2013).

[3] Bing Lin, Amin R. Nehrir, F. Wallace Harrison, Edward V. Browell, Syed Ismail, Michael Obland, Joel Campbell, Jeremy Dobler, Byron Meadows, Tai-Fang Fan, Susan A. Kooi, "Atmospheric CO_2 column measurements in cloudy conditions using IM-CW lidar at 1.57 micron," Optics Express, 23, A582-A593 (2015).

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