Development of a Robust CO_2 Sensing Platform for Fixed Wing or Multirotor UAS

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Abstract

Carbon dioxide (CO_2) concentrations in the atmospheric boundary layer (ABL) have been demonstrated to have strong seasonal and diurnal fluctuations that are influenced by industry, crop health, land usage, and fossil fuel consumption. These local and regional variations in CO_2 are often overlooked in current climate modeling because traditional sampling methods such as aircraft, ground stations, and satellites, do not provide data with adequate vertical resolution in the atmospheric boundary layer. Advances in unmanned aerial systems (UAS) make them an appealing option for a low-cost, rugged vehicle to probe the ABL. This presentation will highlight the development and implementation of a robust CO_2 sampling system designed to be carried by small UAS. First, the response of commercially available near-infrared gas sensors were thoroughly characterized on the benchtop to asses their capabilities and limitations. Afterward, reported CO_2 values were then validated against a non-dispersive infrared (NDIR) CO_2 gas analyzer that corrects for water vapor (LI-840A) and found to have agreement within 2-3 ppm. After optimizing airflow, placement, and operating parameters, and the sensing units were integrated into a fixed-wing UAS (Tuffwing UAV Mapper) for field deployment.

The presented results come from observations made during the Innovative Strategies for Observations in the Arctic Atmospheric Boundary Layer (ISOBAR) campaign in Hailuoto, Finland in February 2018. Future experiments at the Kessler Atmospheric and Ecological Research Farm (KAEFS) in Washington, Oklahoma over the course of several months will explore diurnal and seasonal variability as well as examine the role of land usage and precipitation on CO_2 flux.

Motivation

CO_2 concentrations and fluxes in the atmospheric boundary layer have seasonal and diurnal fluctuations that are influenced by weather systems, industry, crop health, land usage, and fossil fuel consumption. Present monitoring methods such as tower based gas analyzers, satellites, and gas flask collection are limited in vertical and temporal resolution, especially in the ABL, and are time- and resource-intensive. In order to reduce the high uncertainty in regional emissions estimates and understand the pathways CO_2 takes from emission source to the atmosphere or carbon reservoirs, a flexible, portable measurement system with enhanced spatio-temporal monitoring capabilities must be developed.

We propose that using validated miniaturized NDIR sensors onboard UAS systems can provide increased spatio-temporal resolution in the ABL to supplement current observing techniques.

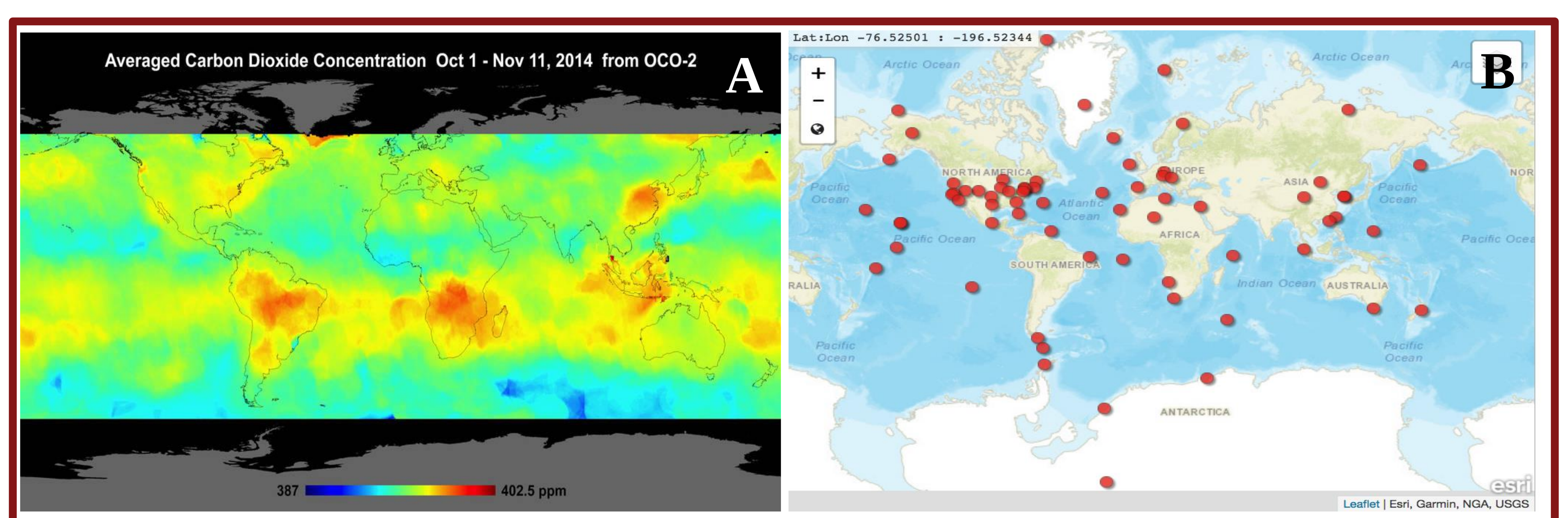

Figure 1: (A) Satellite retrievals and (B) ground based measurement stations represent two CO_2 monitoring systems.

Objective

The aim of this project is to (1) characterize the accuracy and behavior of miniature CO_2 sensors, (2) construct a platform agnostic CO_2 payload and integrate it into a UAV, and (3) conduct measurements using the integrated UAS system in the field.

Results

Figure 2 shows the response of two K30 NDIR CO_2 analyzers operated for 6 hours on a laboratory benchtop alongside a LI-840A CO_2/H_2O analyzer. The miniaturized devices were observed to accurately track the LiCOR instrument after a warm up period of 60 min. Longer calibration runs demonstrated that each K30 has a unique offset that remained constant. Once applied, measured values were within 2-3 ppm of the [CO_2] reported by the continuous analyzer.

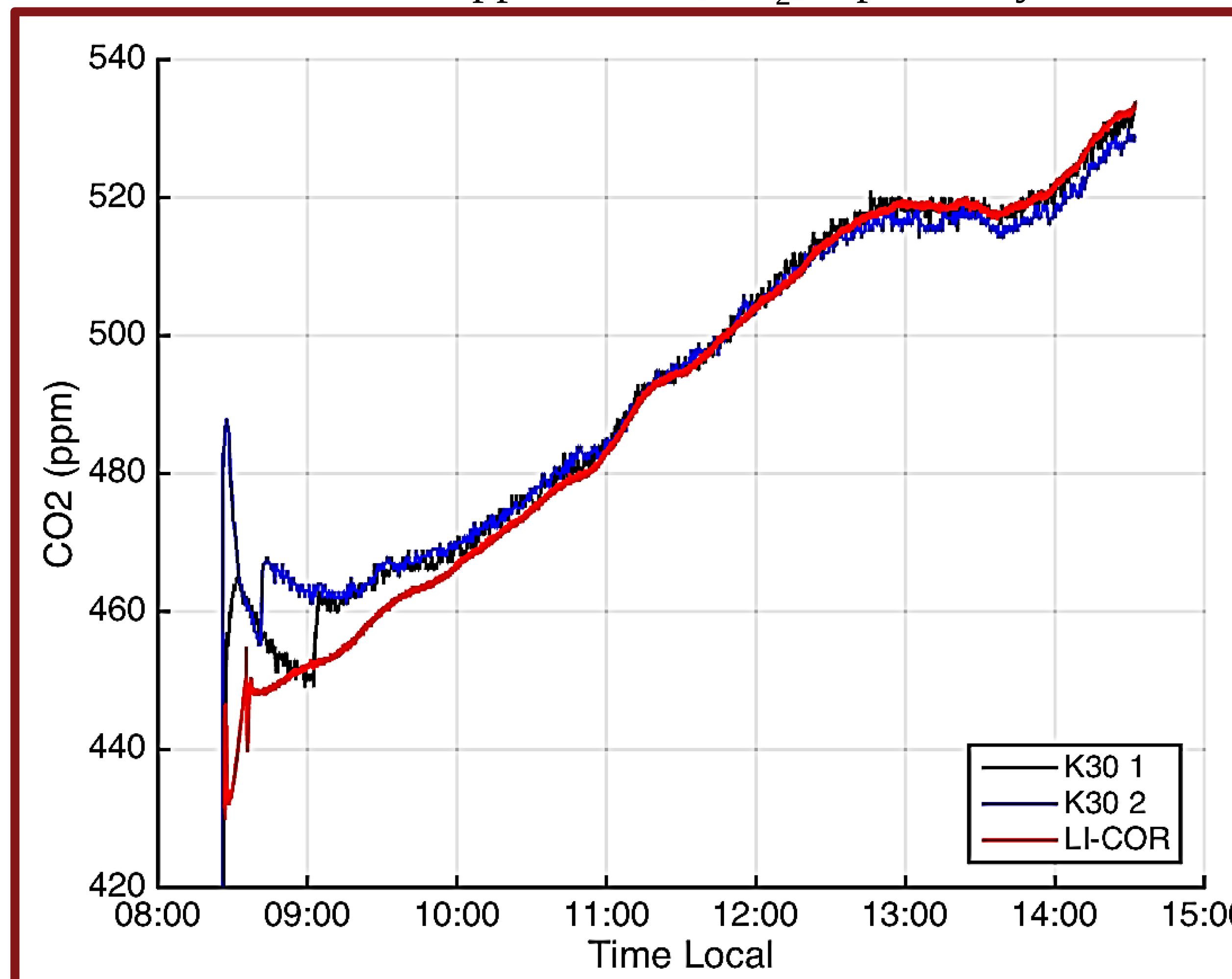

Figure 2: Observed [CO_2] during bench test for K30 1(black), K30 2 (blue) and the Li-COR gas analyzer (red). Offsets of -7 ppm and -14 ppm were applied to K30 1 and K30 2 respectively during post processing.

After characterizing sensor response, the flow-through system, sensor placement, and operating parameters were optimized. The final sensor payload included two flow-through systems (K30 (Figure 3B), diaphragm pump and tubing), a microcontroller, a real time clock chip, and a dedicated datalogger (Figure 3A). This payload was integrated into a fixed wing UAV (Figure 3C) by securing the case in the instrument bay and connecting inlet tubes to the nose of the UAV and exhaust lines to the motor mount at the rear of the platform.

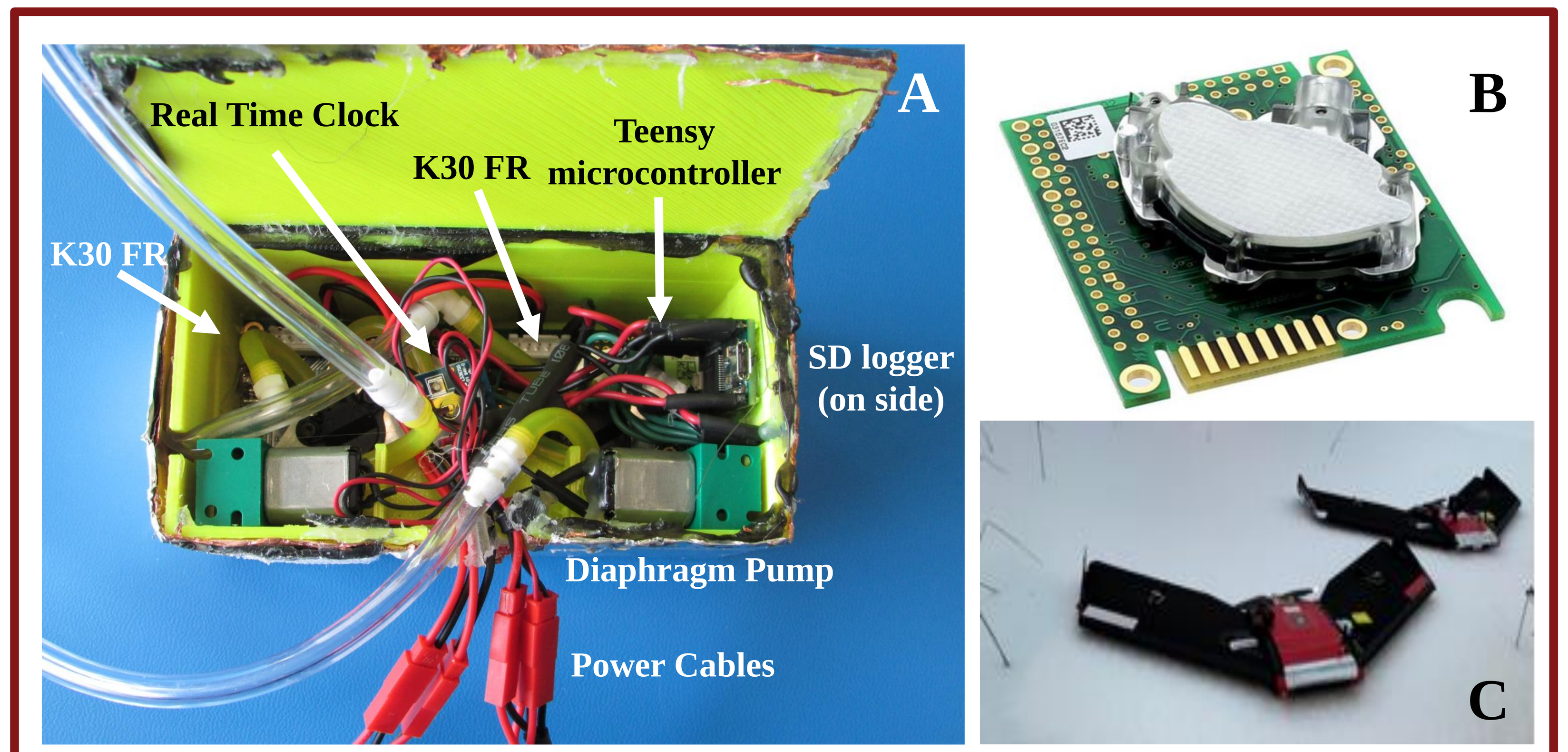

Figure 3: (A) Schematic of the CO_2 sensing payload, (B) close-up of the Sensair K30 FR, and (C) picture of the fixed wing (Tuffwing UAV Mapper) used to carry the CO_2 payload during the ISOBAR campaign in Hailuoto, Finland during February 2018.

Acknowledgements

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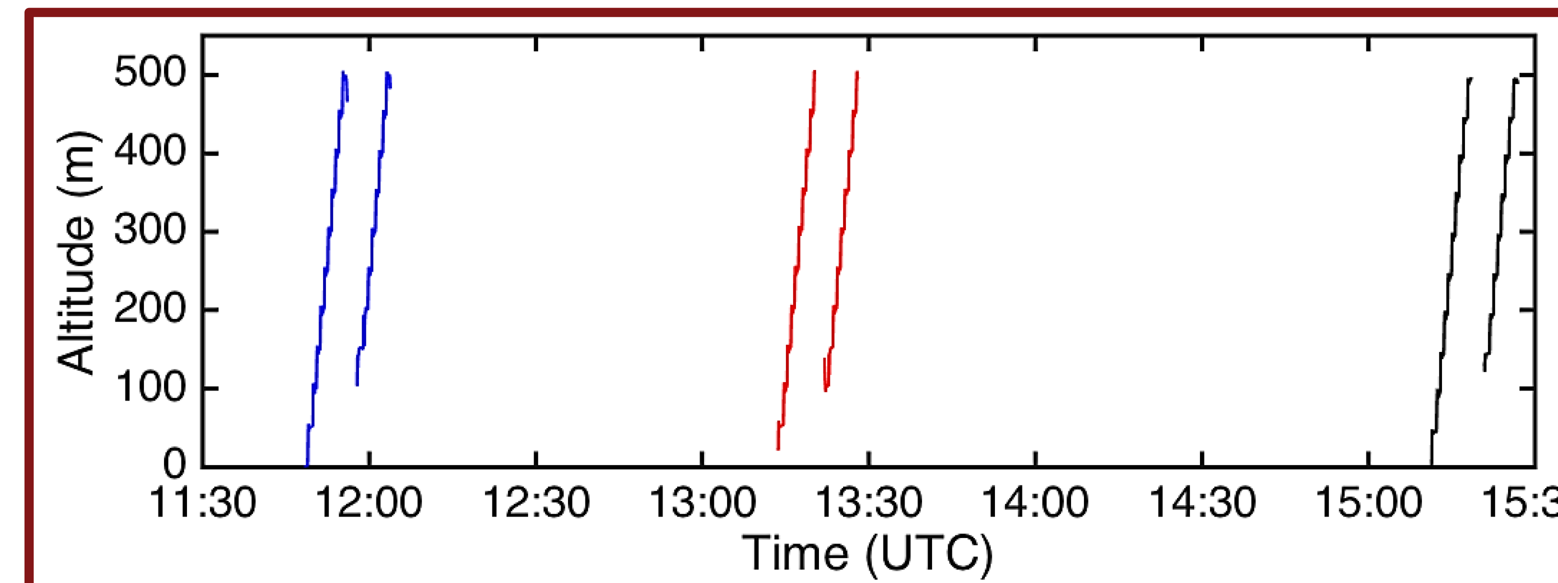

Figure 4: Temporal distribution of CO_2 profiles captured on 21 Feb 2018 in Hailuoto, Finland. Each flight consisted of two vertically ascending profiles, excluding descending legs.

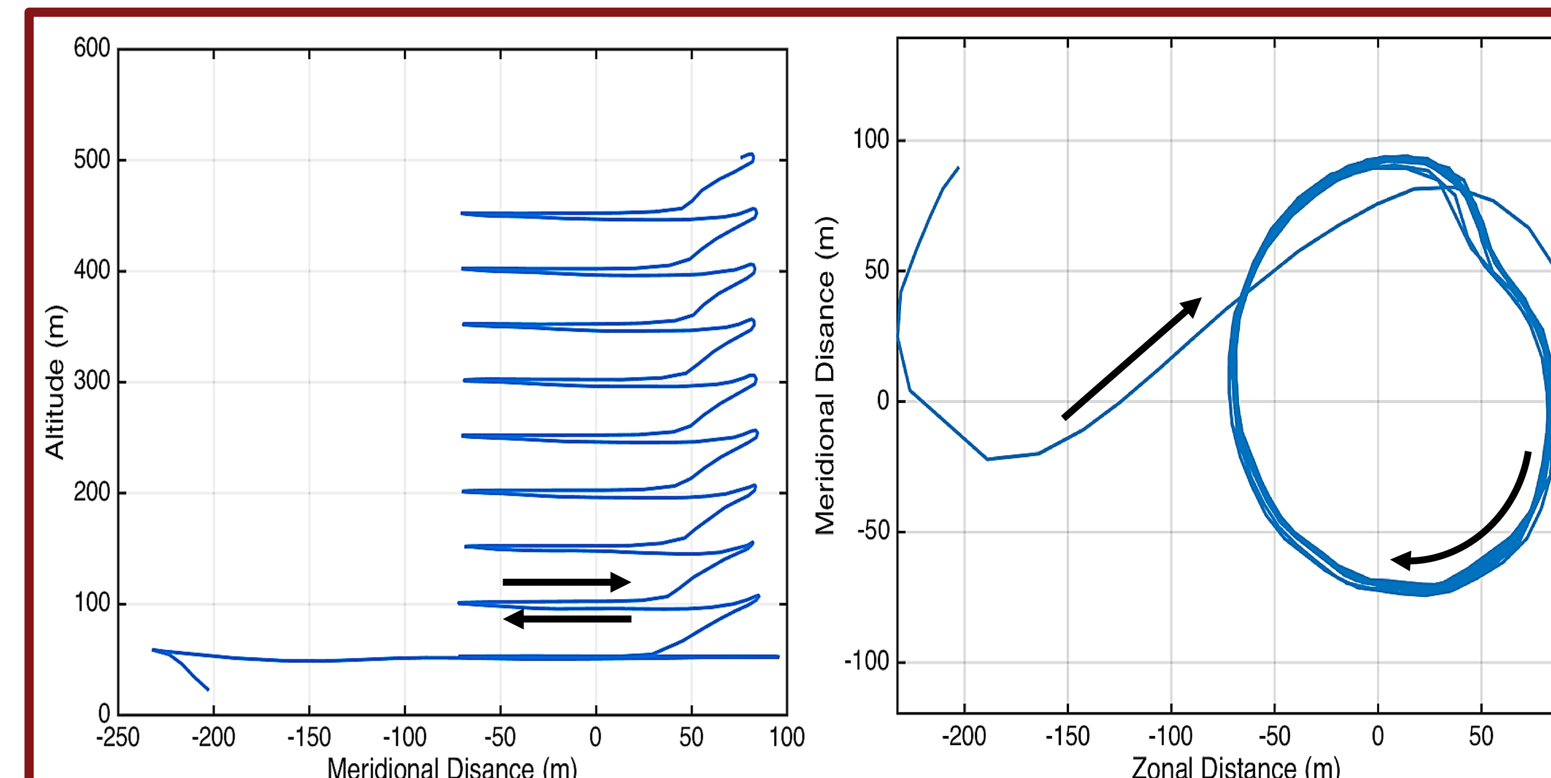

Figure 5: Visualization of 21 Feb 2018 13:13 – 13:20 UTC flight path.

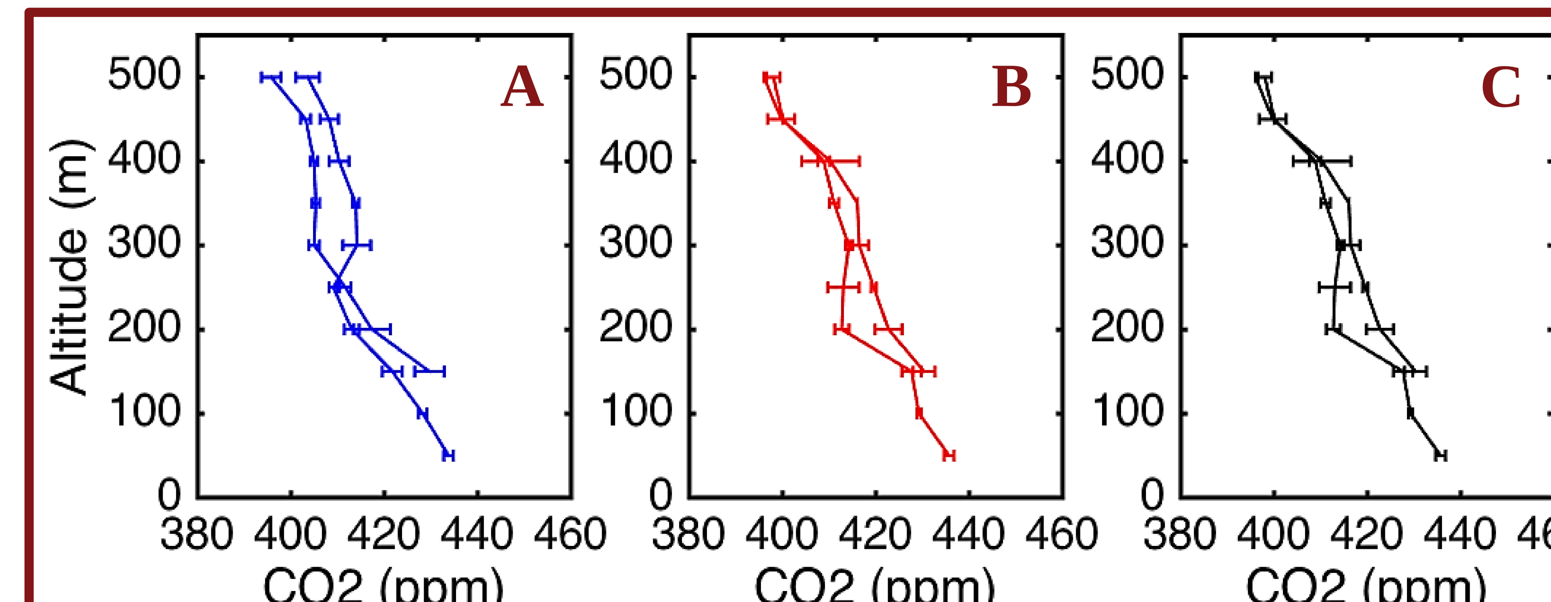

Figure 6: CO_2 profiles measured at (A) 11:48 – 12:03 UTC, (B) 13:13 – 13:27 UTC, and (C) 15:11 – 15:26 UTC. Each point represents the mean and standard deviation of [CO_2] at each altitude depicted in Figure 5.

Conclusions

These preliminary results illustrate that accurate ABL CO_2 profiles can be captured when combined with calibration/validation techniques. However, technical challenges such as datalogger malfunctions, RTC drift, and disrupted airflow were encountered during deployment. Work is underway to interface the CO_2 sensors directly with the autopilot system to sync sensor data with telemetry parameters (GPS, timestamp) and meteorological parameters (T, RH, etc). The improved system will be tested at LAPSE-RATE in July 2018.

References

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