**Atmospheric CO₂ Variability Observed from ASCENDS Flight Campaigns**

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**Introduction**

- Atmospheric CO₂ is the major climate forcing for the changing climate. Its concentration (or volume mixing ratio XCO₂) has significantly increased from about 280 ppm in pre-industrial times (~350 ppm at present).
- There is a lack of quantitative knowledge of atmospheric CO₂ variability in various spatial-temporal scales. A large part of carbon assimilated within the Earth’s carbon cycle cannot be accounted for even in observed global annual means.

**Lidar and In-Situ CO₂ Measurements**

- U.S. National Research Council has identified the need of a NASA Active Sensing of CO₂ Emissions during Nighttime, Days, and Sonsum (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 CO₂ laser absorption (3.94 μm).
- The CO₂ lidars are intensity-modulated continuous-wave (IMCW) multi-channel signal modulators operating on a CO₂ absorption line in the 1.27-μm band with both on-line and off-line wavelengths. A total of 14 flight campaigns have been conducted with lidar and in-situ CO₂ measurement systems.
- This effort analyzes the measurements of atmospheric CO₂ from the lidar and in-situ instruments during recent flight campaigns. Significant atmospheric CO₂ variations on various spatiotemporal scales were observed during these campaigns. Discussed cases include CO₂ drawdown by wildfires, large CO₂ variations within small regions, interannual variability during the growing season and biologically dormant season, and urban impacts on CO₂ distributions.
- Lidar remotely sensed CO₂ column values are also evaluated under both clear and cloudy conditions and within atmospheric boundary layer and above clouded areas.

**Measurement Characteristics**

- **Multifunctional Fiber Laser Lidar (MFLL):**
  - Laser power: 5 W
  - Telescope diameter: 629.3 mm
  - Detector dark current (cryogenic cooling): 45 pA
  - Sampling rate: 2 MHz
  - Signal integration time: 0.1 s
  - Modulation scheme: swept sine with 50-km unambiguous range
  - Normalization and calibration: same as MFLL

- **In-Situ Sensor (AVOCET):**
  - Atmospheric CO₂: XCO₂
  - Meteorological CO₂: Tpp/q and winds

**Lidar CO₂ Retrieval**

- Integrated path differential absorption
  \[ r = \ln \frac{C(t) - C(0)}{C(t) - C(0)} \]
  (online: on) and (offline: off)

- CO₂ volume mixing ratio (XCO₂) in situ atmospheric state profile: XCO₂, Tpp/q

**DAOS calculations based on radiative transfer model**: XCO₂ calculated from observed DAOS and meteorological state measurements.

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**Observed CO₂ measurements**

**Airborne Flight Campaigns**

2011 Summer: 29 July – 11 August

2013 Winter: 18 Feb – 5 March

2014 Summer: 14 Aug – 2 Sept

**Vertical profiles: CA**

CO₂ concentration (2 Feb 2013)

**Regional CO₂ changes**

- Column CO₂ measurements over Midwest farmland showed much larger drawdown signal in 2011 (~8 ppm) compared with measurements in 2013 (~3 ppm)
- Resulting differences in meteorological states and phases of growing season
- Certain variability due to inter-annual changes in meteorological and biological conditions

**Contact Information**

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**Methodology for validation**

- **Flight: 20140827**
- **In-situ derived (or modeled): Value**
  - In-situ from Spiral: CO₂ Tpp/q profiles
  - Radiative transfer model
  - Range correction with lidar range data
  - In-situ derived (or modeled): DAOD
  - In-situ derived (or modeled): XCO₂

**Future Work**

- Applying CO₂ variability from ACT-America mission data
- Evaluating of large-scale CO₂ variability utilizing colocated airborne and OCO-2 CO₂ measurements
- Understanding multi-scale integration to insights of the driving forces of CO₂ changes

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**References**

