Spatial and Temporal Variability of Carbon Dioxide using Structure Functions in Urban Areas: Insights for Future Active Remote CO₂ Sensors

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Introduction

High resolution in situ CO₂ measurements were recorded onboard the NASA P-3B during the DISCOVER-AQ (Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality) Field Campaigns during July 2011 over Washington DC/Baltimore, MD, January – February 2013 over the San Joaquin Valley, CA; September 2013 over Houston, TX; and July-August 2014 over Denver, CO. Each of these campaigns have approximately two hundred vertical soundings of CO₂ within the lower troposphere (surface to about 5 km) at 6-8 different sites in each of the urban area. In this study, we used structure function analysis, which is a useful way to quantify spatial and temporal variability, by displaying differences with average observations, to evaluate the variability of CO₂ in the 0-2 km range (representative of the planetary boundary layer). These results can then be used to provide guidance in the development of science requirements for the future ASCENDS (Active Sensing of CO₂ Emissions over Nights, Days, and Seasons) mission to measure near-surface CO₂ variability in different urban areas. We also compare the observed in situ CO₂ variability with the variability of the CO₂ column-averaged optical depths in the 0.1 km and 0.3-5 km altitude ranges in the four geographically different urban areas, using vertical weighting functions for potential future ASCENDS lidar CO₂ sensors operating in the 1.57 and 2.05 μm measurement regions. In addition to determining the natural variability of CO₂ near the surface and in the column, radiocarbon method using continuous CO₂ and CO measurements are used to examine the variation of emission quantification between anthropogenic and biogenic in the DC/Maryland urban site.

Sample Site – DISCOVER-AQ

To improve the interpretation of satellite observations in order to diagnose near surface conditions relating to air quality, low altitude in situ measurements on the NASA P-3B aircraft were performed at four urban sites: DC/Baltimore (July 2011), San Joaquin Valley, CA (Jan-Feb 2013), Houston, TX (Sep., 2013), and Denver, CO (July – August, 2014).

Structures and Function Data Filtering

\[ f(Z, y) \propto |Z(x + y) - Z(x)| \]

where, \( \langle \rangle \) denotes taking the average for data pairs separated by distance \( y \), \( Z \) is the variable of interest (CO₂ in this analysis) at a given location \( x \), it represents the expected gradient (average difference) for a given resolution (distance \( y \)).

For the airborne data analysis here, the distance \( y \) is considered to represent satellite resolution and the average difference could represent the expected variability for given resolution.

Data Filtration

High resolution 1 Hz data (roughly 100 m resolution), below 2km AGL, data pairs taken less than 60 minutes to minimize the differences by chemistry and transport, and data pairs with distance up to 100 km were used with the assumed well-mixed boundary layer.

OPTICAL DEPTH CALCULATION

The 2-way optical depth \( T \) of a gas is calculated as

\[
T = 2 \int_{z_0}^{z_f} \frac{\text{C} \cdot \text{N}}{\text{C} \cdot \text{N} + \text{C} \cdot \text{N}} \text{dr}
\]

where

- \( \alpha \) = absorption cross section
- \( \pi \) = number density of the gas
- \( \beta \) = vertical bin size

Quantification of Fossil Fuel CO₂ using continuous CO₂ and CO measurement with Radiocarbon

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