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

Yonghoon Choi1,2, Melissa Yang3,4, Susan A. Kool1,2, Edward V. Browell3, Joshua P. DiGangi2

1Space Systems and Applications Inc., 2NASA Langley Research Center, 3STARSS Affilate, 4National Suborbital Research and Technology Center

Contact Information: Yonghoon.choi-1@nasa.gov

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 powerful way to quantify spatial and temporal variability, by displaying differences with average evaluations, 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 compared 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

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).

Structure Function and Data Filtering

The 2-way optical depth Τ of a gas is calculated as

\[ \tau = \frac{2}{\pi} \ln \left( \frac{1}{1 - z(x + \Delta x)} \right) \]

where, \( z(x + \Delta x) \) denotes the averaged value for data pairs separated by distance \( x \), and \( z(x) \) is the variable of interest (CO₂ in this analysis) at a given location \( x \). This represents the expected gradient (average difference) for a given resolution (distance) \( \Delta x \).

For the airborne data analysis here, the distance \( x \) 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

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

Basic Concept

\[ \text{CO}_2^{\text{fossil}} = \text{CO}_2^{\text{total}} - \text{CO}_2^{\text{biog}} \]

where, \( \text{CO}_2^{\text{fossil}} \) is the fossil fuel CO₂ concentration, \( \text{CO}_2^{\text{total}} \) is the total column CO₂ concentration, and \( \text{CO}_2^{\text{biog}} \) is the biogenic CO₂ concentration.

During the highway run, the observed CO₂ values are shown with higher than background values at Morning and Noon, but its lower than background value at Afternoon. FF CO₂ are almost consistent at different time period, but the biogenic uptake signal, which is shown much lower during afternoon, result in the lower observed CO₂ even in the highway.