Global Environment Research Coordination System

Long-term 3-D Measurement of Atmospheric Greenhouse Gases by Commercial Airliner and Development of their Data Providing System
(Abstract of the Interim Report)

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1. Introduction

A Commercial airliner is one of the ideal platforms to measure atmospheric carbon dioxide (CO2) and other trace gases in the upper air. Through the studies of “Observation of Atmospheric Greenhouse Gases over the Asia-Pacific Region using the Commercial Airliners” founded by the Global Environment Research Account for National Institutes in FY2006-10, and “Long-term Measurement of Atmospheric Greenhouse Gases by Observational Network using Commercial Airliners” in FY2011-15, steady and reliable observational methods for greenhouse gases using the passenger aircraft had been established[1)2)] and a research project named CONTRAIL (Comprehensive Observation Network for Trace gases by AirLiner) started. However, dense datasets in both space and time are not available yet. Long-term and dense records to be analyzed for capturing the secular change in atmospheric greenhouse gases are necessary in many areas of the world.

2. Research Objectives

The purpose of this study is to extend the observations by the CONTRAIL project to catch the year-to-year variations of greenhouse gases associated with or without ENSO events and their changes influenced by huge emissions especially from Asian countries. We will also construct the 3-D datasets from the CONTRAIL observations and distribute these data to the public.

3. Research Methods

We use the Continuous CO2 Measuring Equipment (CME), improved Automatic Air Sampling Equipment (ASE) and the Manual air Sampling Equipment (MSE). CME is installed on the Boeing 777-200ER and -300ER aircraft. CME continuously measures CO2 during 2 months onboard and obtains vertical profiles while an airplane is ascending and descending, and horizontal distributions in the upper air during the cruises. ASE and MSE collect air samples in the upper atmosphere. Air samples are analyzed to obtain concentrations of CO2, methane (CH4), carbon monoxide (CO), nitrous oxide (N2O), sulfur hexafluoride (SF6) and Hydrogen (H2) and stable isotope ratios of CO2 and CH4[1)2)]. Global carbon cycle models are developed to investigate transport of atmospheric CO2 and to estimate CO2 fluxes at the earth’s surface using aircraft data.

4. Results and Discussions

During the research period from 2016 to 2020, the CMEs have observed atmospheric CO2 mole fractions successfully, whose data amount is as much as 3,912,825. Those data were taken by 6,583 flights, which ranges from Japan to Europe, Oceania, North America and Asia.

The CME data obtained during 2005-2015 were analyzed to calculate climatological seasonal and altitudinal variations of CO2 over the Asia-Pacific region. In particular, in August-September, the upper tropospheric CO2 is noticeably low within the Asian summer monsoon anticyclone associated with the convective transport of strong biospheric CO2 uptake signal over South Asia. It was demonstrated that atmospheric CO2 in the Asia-Pacific region shows considerable variations under the monsoon circulation.

Vertical profiles of atmospheric CO2 in proximity to 36 airports worldwide were analyzed. Significant flight-to-flight variations of CO2 enhancements downwind of neighboring cities were observed, and the observed variability were generally increased with decreasing altitude. It was found that the magnitude of CO2 variability near the ground at an airport was correlated with the intensity of CO2 emissions from a nearby city (Figure 1). This demonstrates usefulness of commercial aircraft data for city-scale anthropogenic CO2 emission studies.

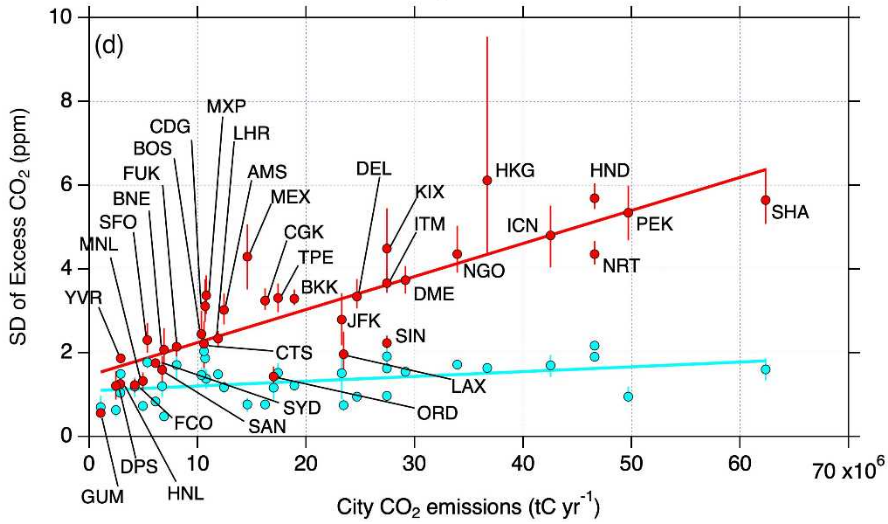

Figure 1. Relationship of the SD of excess CO2 at 1.0-1.5 km (red) and 4.0-4.5 km (light blue) altitude bins with city CO2 emissions based on the ODIAC dataset.

Using the CONTRAIL-CME data, inverse analysis was performed with NISMON-CO2 to estimate fire carbon emissions in Equatorial Asia induced by the big El Niño event in 2015. By comparisons with independent shipboard observations (NIES VOS), especially carbon monoxide (CO) data, the validity of the estimated fire-induced carbon emission was demonstrated. The best estimate, which used both CONTRAIL-CME and NIES VOS CO2 observations, indicated 273 Tg C for fire emissions during September-October 2015. The continuation of aircraft and shipboard observations is fruitful for reliable monitoring of carbon fluxes in Equatorial Asia.

We observed temporal variations of carbon monoxide (CO) in the upper troposphere between Japan and Australia over the period 1993-2016 (Figure 2). The seasonal CO peaks in the Southern Hemisphere showed significant interannual variability, and are proportionally associated with CO emissions from Indonesian fires. The largest CO anomaly in 1997 could be due to amplification during a strong El Niño, and enlarged human activities.

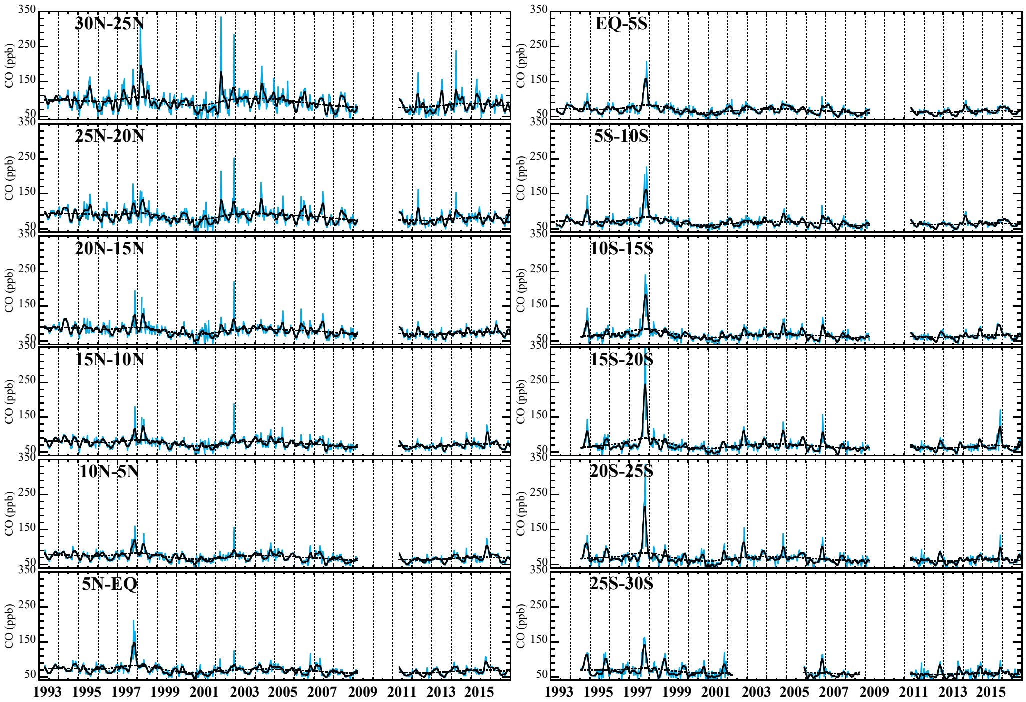

Figure 2. Temporal variations of CO (blue line) at about 10 km altitude for 12 latitudinal bands between 30 degree N-30 degree S from April 1993 to December 2016.

We have been provided CME data to the public via the global environmental database (GED) since February 2018. We released ASE data as well since August 2019. DOI (Digital Object Identifier) has been minted to each dataset and registered to the international consortium DataCite so that the dataset can be discovered from its search system. We analyze the number of data access and the locations of access users, which clearly shows the constant demand of our datasets since the data release (Figure 3).

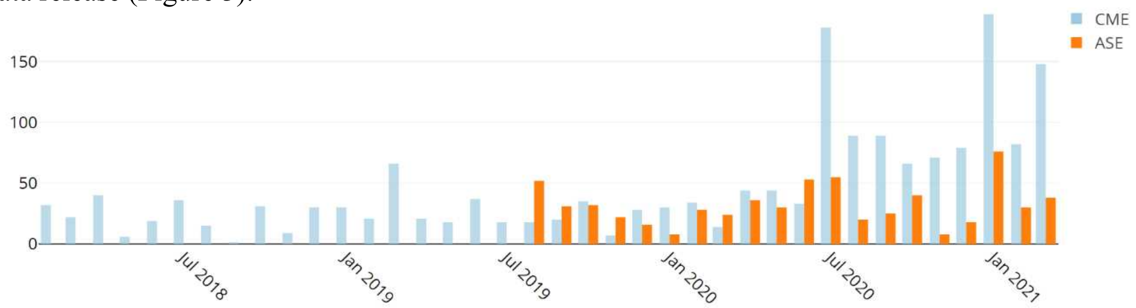

Figure 3. Number of monthly download for CME data and ASE data.

Using the atmospheric transport model NICAM-TM, we produced three-dimensional gridded data of atmospheric CO2 from the CONTRAIL-CME data. To calculate CO2 mole fractions consistently with the observations, we performed inverse analyses with the direct matrix and four-dimensional variational method to optimize surface CO2 fluxes. The three-dimensional gridded data produced by NICAM-TM were provided to several research groups. Especially, the GOSAT project leverages the provided data as a prior estimate of the SWIR retrieval of GOSAT-2 and also as a useful reference for the TIR retrievals of GOSAT and GOSAT-2.

References

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2) Matsueda, H., and Coauthors (2008), *Pap. Meteorol. Geophys*., 59, 1-17.