Long-term Measurement of Atmospheric Greenhouse Gases by Observational Network using Commercial Airliners (Abstract of the Final Report)

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1. Introduction

There still remain substantial uncertainties of feedback mechanism in global carbon cycle against the climate change when we predict the future global warming. To understand the global carbon cycle quantitatively, we need to observe temporal and spatial variations of atmospheric greenhouse gases for long time. But the atmospheric observation network for greenhouse gases is still sparse, especially in upper atmosphere.

Commercial airliner is one of the ideal platforms to measure atmospheric CO_2 and other trace gases in the upper air. By the study of "Observation of Atmospheric Greenhouse Gases over Asian-Pacific Region using Commercial Airliners" founded by Global Environment Research Account for National Institutes in FY2006-FY2010, steady and reliable observational methods for greenhouse gases using passenger aircraft were established[1][2] and a research project named CONTRAIL (Comprehensive Observation Network for TRace gases by AirLiner) was started. Some of the important characteristics in 3-D spatial distribution of greenhouse gases are revealed by the CONTRAIL project until 2010. However, the dataset obtained by aircraft is still not enough in the sense of the coverage of both space and time. Long-term and dense records to be analyzed for capturing the secular change in atmospheric greenhouse gases are necessary in many areas in the world.

2. Research Objective

The purpose of this study is to extend the observation by the CONTRAIL project to catch the year-to-year variations of greenhouse gases along with ENSO events and their differences in space. We will also construct the 3-D dataset for greenhouse gases in 10 years and distribute these data as high-quality information of global atmospheric watching.

3. Research Method

We use Continuous CO_2 Measuring Equipment (CME) and improved Automatic Air Sampling Equipment (ASE). CME is installed on boeing 777-200ER and 777-300ER aircraft. CME continuously measures CO_2 during 2 months onboard and obtain vertical profiles during ascending and descending, and horizontal distributions in the upper air during the cruises. ASE obtains air samples over the pacific during the flights from Sydney to Narita twice a month. Air samples are analyzed to obtain concentrations of CO_2, CH_4, CO, N_2O, SF_6 and H_2 and stable isotope ratios of CO_2 and CH_4[1)2)]. Global carbon cycle models are prepared to investigate atmospheric transport of CO_2 and to estimate CO_2 fluxes at the earth's surface by using aircraft data. Two models, NICAM-TM and NIES TM, are used in this study.

4. Results and Discussion

During the period from November 2005 to February 2016, more than 24,200 vertical profiles have been obtained. Figure 1 shows the flight routes, airport code for flight destination and the numbers of vertical profiles obtained by CME.
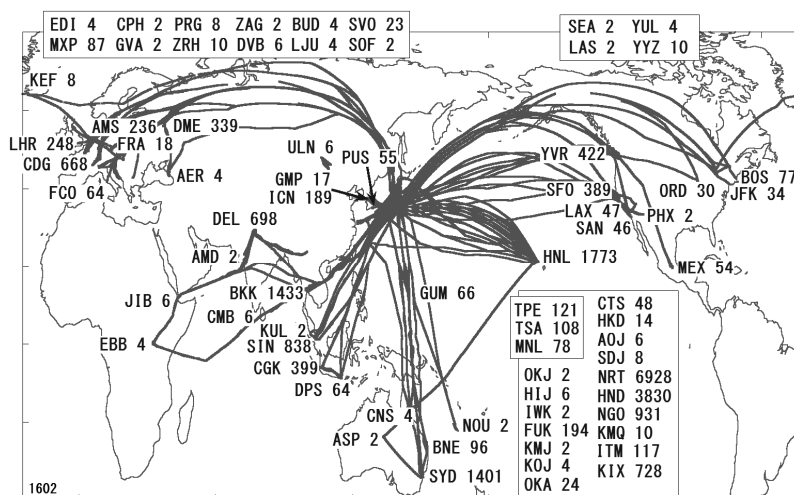

Figure 1. Flight routes of CME observation and
numbers of vertical profile measurement over each airport.

The ASE observation in our CONTRAIL project re-started from May 2011 using Boeing 777-200ER aircraft operated by Japan Airlines (JAL), after the retirement of Boeing 747-400 aircraft in March 2009. We obtained CO_2, CH_4, CO, N_2O, SF_6 and H_2 measurements at about 10km altitude between Australia and Japan by 164 flights for the past 10 years from December 2005 to December 2015. On the basis of these measurements, the time-series data analyses for 12 latitudinal bands between 30°N and 30°S were made (Figure 2). The continuous increasing trends of CO_2, CH_4, N_2O and SF_6 were well captured in the upper troposphere of both the Northern and Southern Hemispheres. The mean growth rates for the past 10 years were determined to be about 2 ppm/yr for CO_2, 6ppb/yr for CH_4, 0.9 ppb/yr for N_2O, and 0.3 ppt/yr for SF_6. These growth rates well agree with the recent trends observed from the ground-based stations. In addition, seasonal cycles and their latitudinal

changes of CO_2, CH_4 and CO were clearly observed, while the N_2O and SF_6 show very small amplitudes of their seasonal cycles. The CONTRAIL datasets in the upper troposphere from the ASE plus MSE observations provide a useful constraint on model estimations of global and regional fluxes of these trace gases.
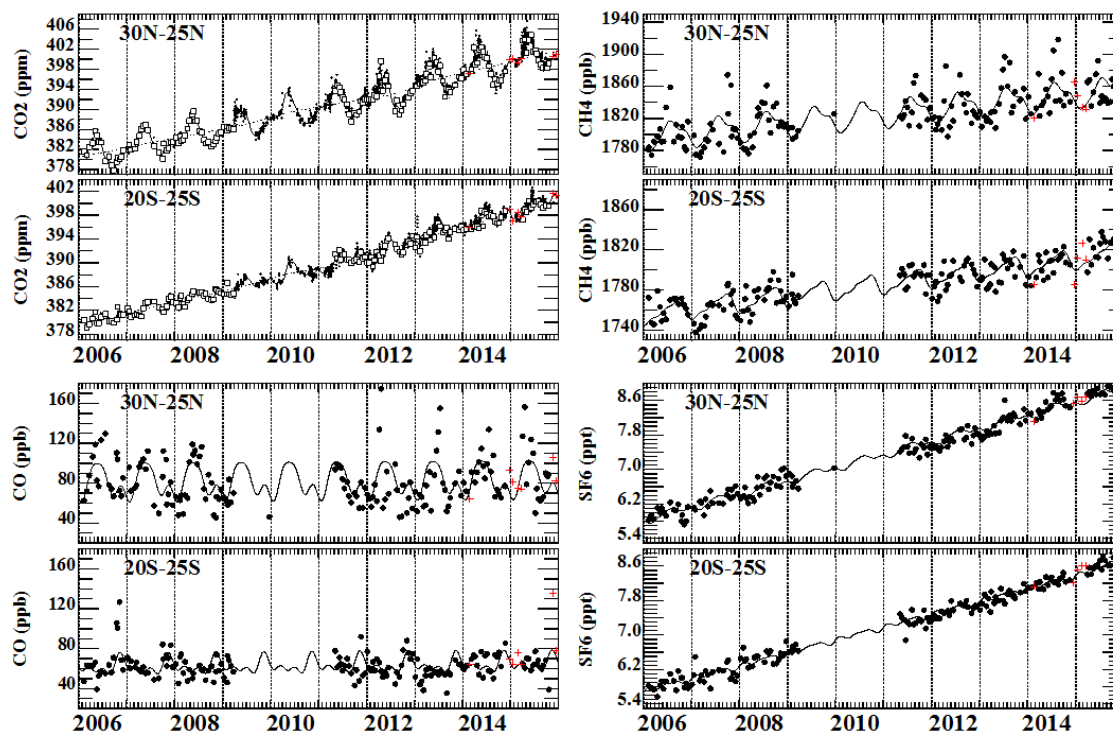

Figure 2. Time variations of CO_2, CH_4, CO and SF_6 for 2 latitudinal bans at about 10 km over the western Pacific from January 2006 to December 2015

The CME observation covers wide areas of the world over the Eurasian continent, the North Pacific, Southeast Asia, and Oceania since 2005. We obtained more than 4 million CO_2 data from about 8000 flights from 2011 to 2015. Several modifications for CME in the study period contributed to get more frequent and wide observations of CO_2 with high precisions. The observed CO_2 mixing ratios by CME agreed well with those determined by the ASE during the same flights.

The large number of CME data enable us to well characterize spatial distributions and seasonal changes of CO_2 in wide regions of the globe especially the Asia-Pacific regions. While the mean growth rates for the past 10 years were about 2 ppm/year, large growth rates of about 3 ppm/year were found from second half of 2009 to the first half of 2010, and in 2015 over the several regions in the Northern Hemisphere, such as Southeast Asia, Japan, probably due to wide influences in El Nino year. On the other hand, the global increases in the growth rates were detected in a wide latitudinal band from 30S to 70N in the second half of 2012, suggesting the changes in the photosynthesis/respiration activity of the land biosphere. Multiyear data sets in this study have the potential to bring information to understand the global CO_2 budget.
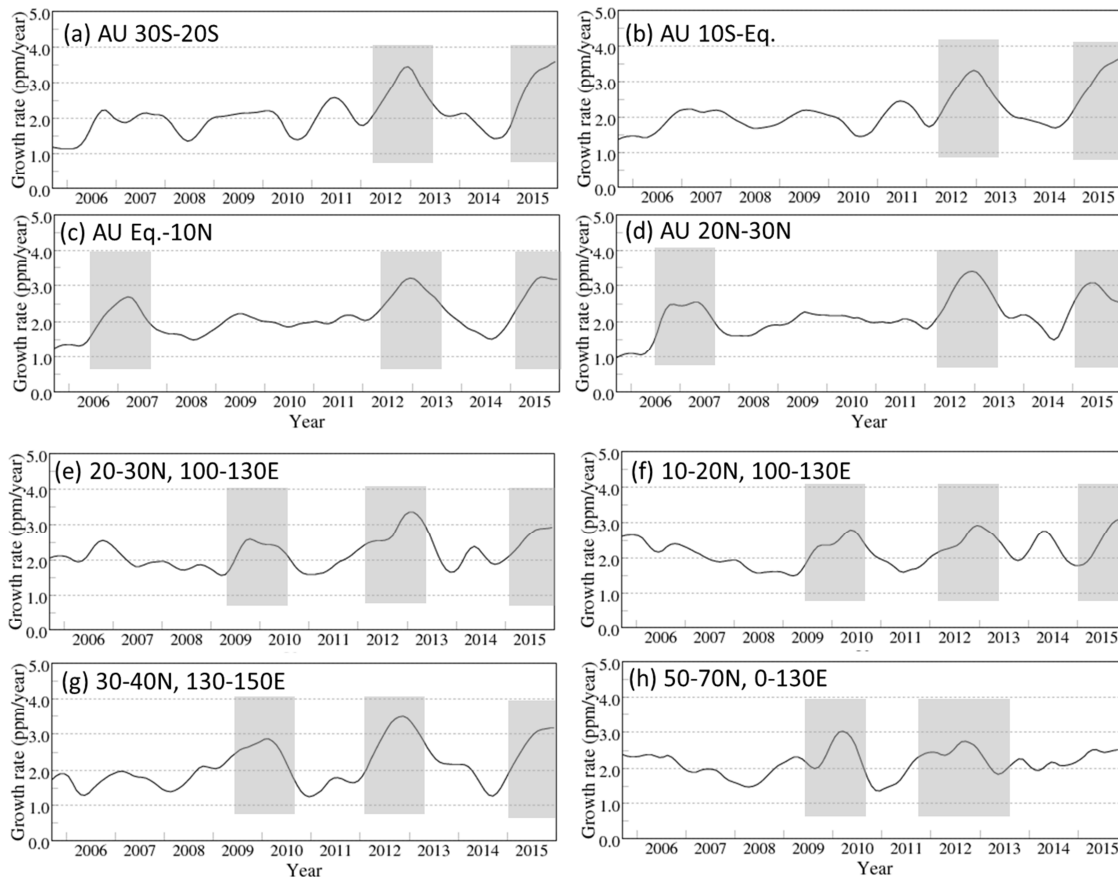
Figure 3. The growth rate of CO_2 at upper troposphere.
Gray hatches show the periods of higher growth rate.

Using the aircraft measurements of CONTRAIL-CME in conjunction with the conventionally used surface measurements, we have performed CO_2 inversion to optimize regional CO_2 fluxes focusing on 2006–2008. In the inversion, CO_2 net fluxes were optimized in 35 land and 11 ocean regions using the synthesis inversion method with the atmospheric transport model NICAM-TM. The surface data are selected from the GLOBALVIEW-CO_2 dataset. The CONTRAIL-CME data were processed according to the method of GLOBALVIEW-CO_2; data were gap-filled and smoothed out by curve-fitting for 77 horizontally and vertically dived regions. Actually, this study is the first attempt to extensively use the wide-ranging aircraft data in CO_2 inversion and has demonstrated its great utility for constraining tropical flux estimates. Specifically, error reduction rates of 64% and 31% were found respectively for equatorial and South Asia (Figure 4). This strong impact is closely related to the active vertical transport in the tropics. Therefore, fluxes for regions with strong vertical transport can be more effectively constrained by the aircraft measurements than by the surface network. The subsequent CO_2 transport simulation using the posterior fluxes and comparisons with the two aircraft data sets of CONTRAIL and CARIBIC have demonstrated the reliability of our inversion calculation. Furthermore, by atmospheric simulation with NICAM-TM and the flux data optimized by the inversion, we have constructed three-dimensional CO_2 mole fraction dataset for the long-term period of 2006–2015. The simulated CO_2 mole fractions are expected to be consistent with observations. In fact, we found that the simulated data reasonably reproduced seasonal cycles of CO_2

mole fractions observed by ASE in the upper-troposphere (Figure 5) as well as by the surface station of Minamitorishima. Moreover, the simulated CO_2 are consistent even with the JMA aircraft observations in the mid-troposphere. Because the aircraft data are independent of the inversion, the result suggest the validity of the dataset. The three-dimensional CO_2 mole fraction dataset would help us to understand dynamics of atmospheric CO_2 mole fraction variations.
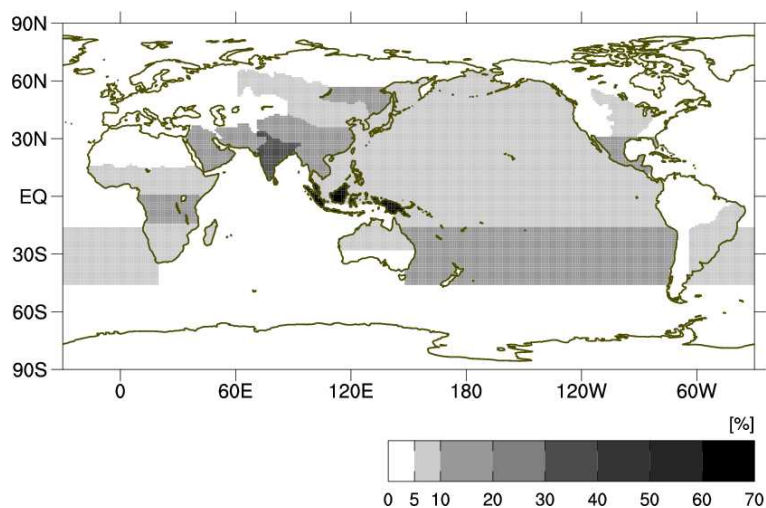

Figure 4. Reduction ratio of the posterior error obtained by adding the CONTRAL-CME data to the conventional surface data in the inversion
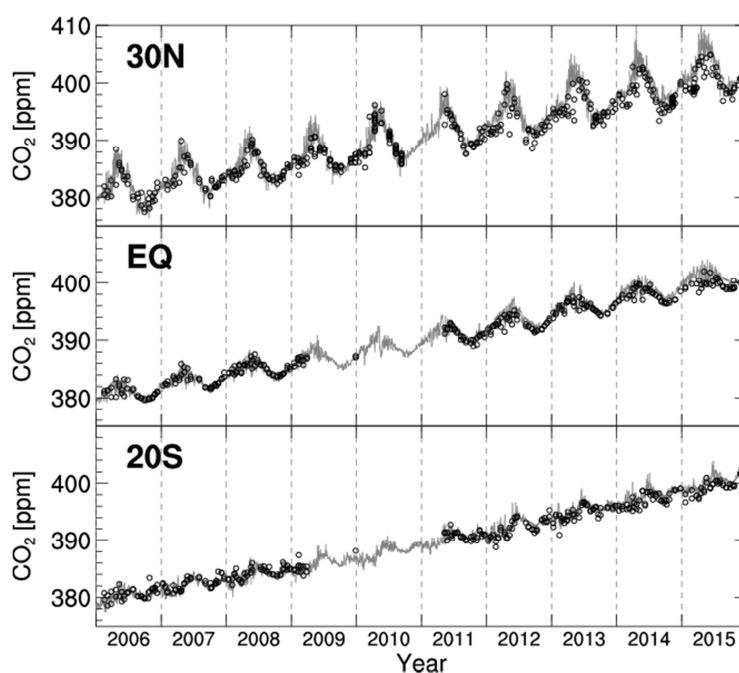

Figure 5. Times series of CO_2 mole fraction at 30°N, the equator, and 20°N observed by the ASE observation (black circle) and simulated by NICAM-TM with the inversion flux (gray line)

References

1) Machida, T., and Coauthors (2008), *J. Atmos. Oceanic. Technol*. **25** (10), 1744-1754.
2) Matsueda, H., and Coauthors (2008), *Pap. Meteorol. Geophys*., **59**, 1-17.