# Observation of Atmospheric Greenhouse Gases over Asian-Pacific Region using Commercial Airliners

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## 1. Introduction

The inverse approach by atmospheric transport model is one of the most reliable way to estimate the temporal and spatial variations of $CO_2$ fluxes. Major limitation of the inverse approach is the low density of atmospheric $CO_2$ concentration measurement. Substantial efforts are made to measure atmospheric $CO_2$ in the world. In comparison with the surface air observations, $CO_2$ measurements above the planetary boundary layer (PBL) are sparse due to the limited number of aircraft observations. Research aircraft campaigns using on-board measuring systems provided a detailed $CO_2$ distribution in the free troposphere[1)2)]. But expense and the snap-shot nature of research aircraft campaigns mean that the climatology in spatial and temporal $CO_2$ variabilities above the PBL have not been well defined in comparison with surface air measurements. Commercial airliner is one of the ideal platform to measure atmospheric $CO_2$ and other trace gases in the upper air in high frequency and wide area-coverage.

## 2. Research Objective

Regular air sampling using Boeing 747 commercial airliner has been carried out since 1993 to observe $CO_2$, $CH_4$ and CO mixing ratios between Japan and Australia[3)]. We extend the observation to conduct the in-situ $CO_2$ measurement onboard the aircraft operated by Japan Airlines (JAL) and reveal the spatial and temporal variation of $CO_2$ over South East Asia and East Asia as well as Europe, North America, Pacific and Australia. Obtained data are useful not only for solving global carbon cycles but also for understanding atmospheric air transport and for validating satellite $CO_2$ measurements such as GOSAT.

## 3. Research Method

We use Continuous $CO_2$ Measurement Equipment (CME) and improved Automatic Air Sampling Equipment (ASE). CME can be installed on two 747-400 aircraft and three 777-200 aircraft. CME continuously measure $CO_2$ during 1-1.5 months onboard and obtain vertical profiles during ascending and descending, and horizontal distributions in upper air during the cruise. ASE can be installed on two 747-400. ASE get air samples over the pacific during the flight from Sydney to Narita twice a month. Air sample is analyzed for concentrations of $CO_2$, $CH_4$, CO, $N_2O$, $SF_6$ and $H_2$ and stable isotope ratio of $CO_2$ and $CH_4$[4)5)].

4. Results and Discussion

During the period from November 2005 to March 2011, more than 10000 vertical profiles have been obtained. Figure 1 shows the flight routes, airport code for flight destination and the number of vertical profiles obtained.

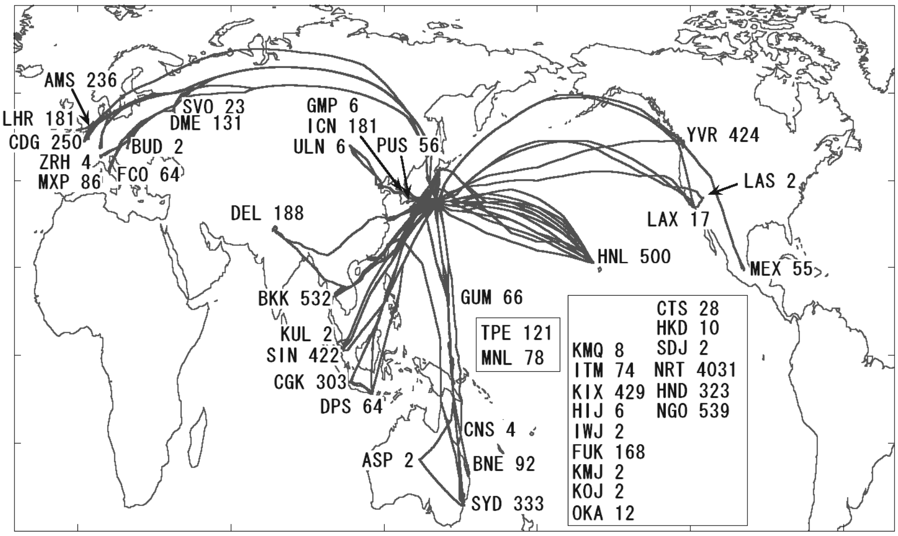


Figure 1. Flight routes of CME observation.

Since April 2009, a manual sampling equipment (MSE) was used to continue flask sampling observations for measuring $CO_2$, $CH_4$, CO, $N_2O$, $SF_6$ and $H_2$ at about 10 km altitude between Australia and Japan.

A new ASE and MSE were used to conduct atmospheric measurements of $CO_2$, $CH_4$, CO, $N_2O$, $SF_6$ and $H_2$ at about 10km altitude by using JAL airliner between Australia and Japan during December 2005 – December 2010. On the basis of these measurements, the time-series data analyses for 12 latitudinal bands between 30N and 30S were made. The recent long-term trends during the past 5 years were well captured in the both hemispheres over the western Pacific. In addition, seasonal cycles and their latitudinal changes of $CO_2$, $CH_4$ and CO were clearly observed, although very small amplitudes of the seasonal cycles were found in $N_2O$ and $SF_6$. The long-term trends and seasonal cycles of $CO_2$, $CH_4$ and CO from the new ASE were consistent with those from the climatology of previous observations since 1993 (Figure 2). These results demonstrate the consistency in the continuity of the $CO_2$, $CH_4$ and CO records extended by the present study. All of the present and past measurements were re-calculated based on the same standard scales, and then combined to make high-quality integrated databases for the past 18 years from 1993 to 2010. The $CO_2$ dataset was posted on the world data centers operated by the WMO/JMA and NOAA/ESRL. The data were used for validating model transports and satellite observations, and their results were published by collaborative studies.

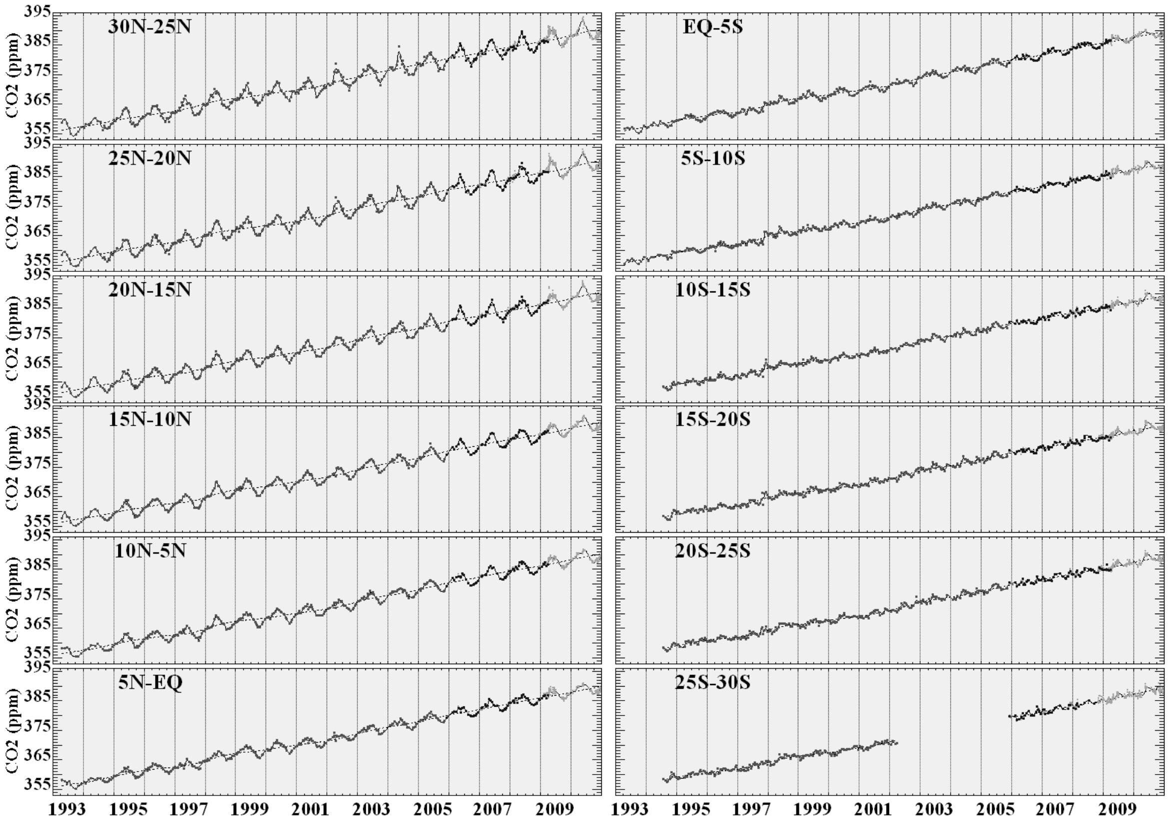


Figure 2. Time variations of $CO_2$ divided into 12 latitudinal bands at 10 km over the western Pacific from April 1993 to December 2010 based on the high-quality database integrated by the present and past JAL airliner observations.

Figure 3 shows the seasonal variations of $CO_2$ over North Europe, Moscow, Vancouver, Delhi, Narita, Honolulu, Bangkok, Singapore and Sydney. Large seasonal amplitudes were observed over Moscow, due to direct influence of biospheric activities around there. Seasonal variations in free troposphere are almost constant along the altitude over Honolulu, which located on small island in the Pacific ocean. Higher $CO_2$ were found at lower altitude over Bangkok from January to March. Biomass burnings around Bangkok might enhance $CO_2$ mixing ratios in that season. Small but clear seasonal variations with the phase in Northern Hemisphere were found over Singapore even though it is located near Equator. The seasonal variations over Sydney were opposite in phase with those in Northern Hemisphere.

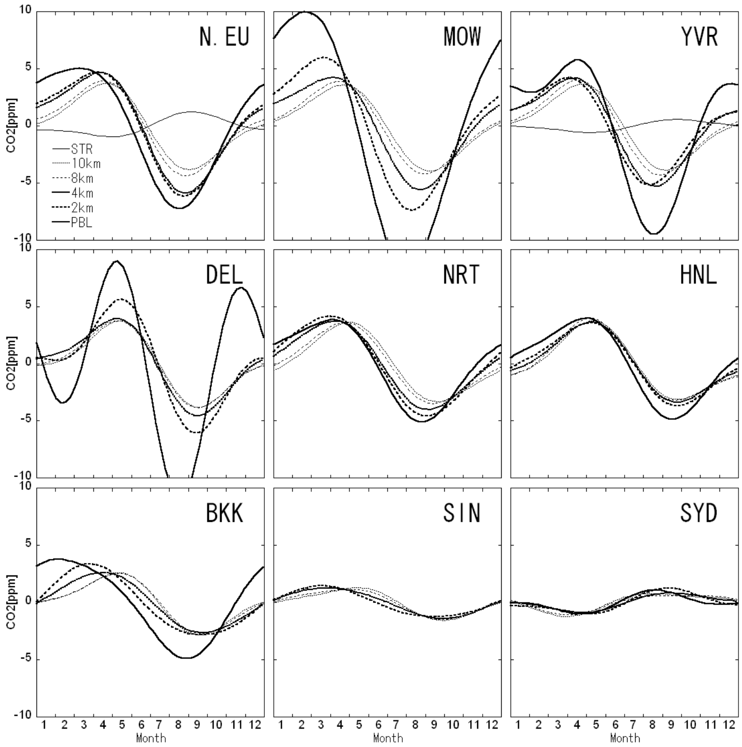


Figure 3. Seasonal variations of $CO_2$ over North Europe, Moscow, Vancouver, Delhi, Narita, Honolulu, Bangkok, Singapore and Sydney.

Variations of $CO_2$ in the tropopause region were analyzed. The data were obtained from flights between Japan and Europe during the period November 2005 to December 2010. The local phase and amplitude of the $CO_2$ seasonal cycle varied with distance from the tropopause. In the upper troposphere and in the region just above the tropopause, a strong seasonal cycle with a springtime maximum and a relatively sharp minimum in July was observed. In the region greater than 30K in potential temperature from the tropopause, sharp $CO_2$ increases in summer followed by gradual

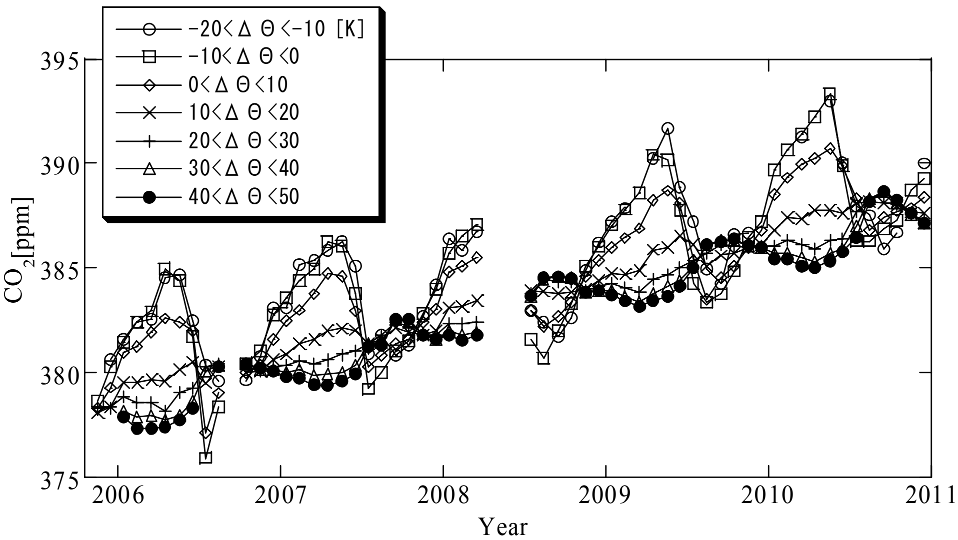


Figure 4. Seasonal cycles of $CO_2$ observed at every 10 K bin from local tropopause along the flight route between Japan and Europe from November 2005 to December 2010. $\Delta\Theta$ means the difference between the potential temperature at the flight level and at the tropopause.

decreases were found, resulting in a slightly increasing seasonal cycle amplitude with distance from the tropopause. The observed $CO_2$ distributions also showed that $CO_2$ isopleths followed the tropopause during the winter and spring, whereas in the summer they tracked potential temperature surfaces crossing the tropopause. The observed seasonal variation in $CO_2$ suggests that the lowermost stratospheric region is influenced by a combination of (1) fast meridional transport of high $CO_2$ from the tropical troposphere in the summer, (2) relatively weak vertical mixing in the winter and fall, and (3) active subsidence of low $CO_2$ from higher altitudes in the spring.

Observed mixing ratios were integrated for a reference year of 2008 to plot climatological distributions of $CO_2$ in the upper troposphere. Strong seasonal cycles with springtime maximums and relatively sharp minimums in July are found in the mid-, high latitudinal regions in the upper troposphere. Longitudinal differences of $CO_2$ mixing ratios in the mid-, high latitude were relatively small in winter season, but significant differences were found in summer. The mixing ratio begins to decrease slightly in May, reaching a minimum value in July over Eurasian continent. On the other hand, the mixing ratio over the North Pacific begins to decrease after one month delay, suggesting the transport of low $CO_2$ originated from terrestrial sinks to oceanic regions. $CO_2$ cross sections by using the flights between Japan and Australia or Southeast Asia show spread of high mixing rations from the Northern Hemisphere to the Southern Hemisphere from April in the upper troposphere. This transport brings increase of $CO_2$ of about 0.7 PgC in 600-200hPa, Eq.-30S in the Southern Hemisphere.

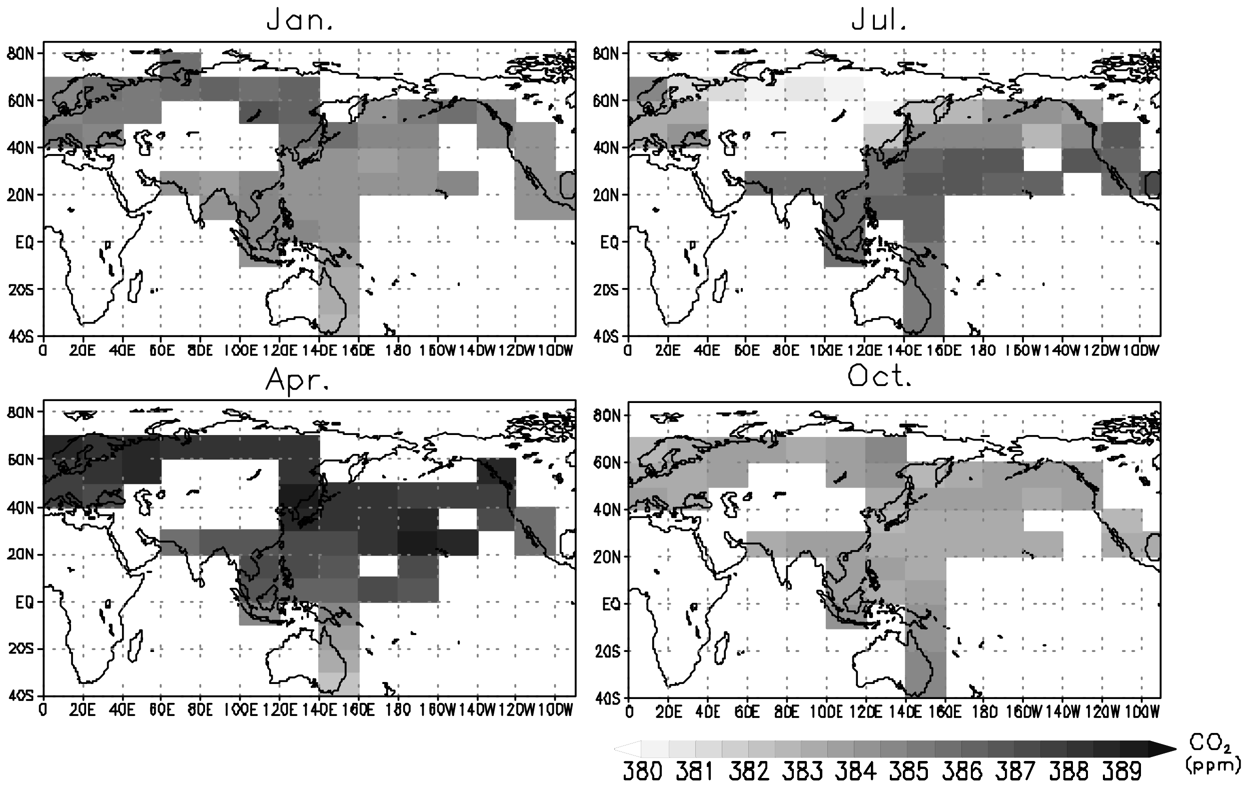


Figure 5. $CO_2$ distributions in the upper troposphere between 8 km and tropopause. $CO_2$ mixing ratios are converted to the values for a reference year of 2008 assuming the trend.

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