A Study on Variation and Transport of Atmospheric CO_2 in Planetary Boundary Layer by High-frequency Measurements

Contact person MACHIDA,Toshinobu
Center for Global Environmental Research
National Institute for Environmental Studies
Onogawa 16-2,Tsukuba 305-8506, Japan
Tel:+81-298-50-2525 Fax:+81-298-58-2645
E-mail: tmachida@nies.go.jp

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1. Introduction

The inverse method for atmospheric transport model is one of the most reliable ways to estimate a carbon flux on the subcontinent scale. But the CO_2 exchange between planetary boundary layer (PBL) and free troposphere (FT) cannot be expressed sufficiently in most of the transport model.

The theoretical expression on CO_2 transport at the top of PBL is hard for quantitative discussion. In addition, there is quite limited observation to evaluate the CO_2 behavior around the PBL in high quality and high frequency.

In this study, we carry out the vertical CO_2 measurements using a small aircraft in and above the PBL frequently. Diurnal changes in CO_2 profile are observed to understand the CO_2 transport in daily PBL growth. We also measure stable isotope ratio in CO_2 to evaluate both CO_2 flux by photosynthesis and respiration.

2. Methods

Frequent measurements of atmospheric CO_2 are conducted using a small aircraft at the forest area in Berezorechka, West Siberia (56°N, 84°E) and Yakutsk, East Siberia (62°N, 130°E). Observation sites are shown in Figure 1.

The aircraft observation has carried out using An-2 aircraft between 3 km and 0.15 km over the site at two or three times per month. CO_2 mixing ratios are measured continuously using small CO_2 observation system based on single-cell NDIR (LI-COR, LI-800).

We developed an air sampling system optimized for on-board operation in a small aircraft. To improve the operation efficiency, glass flasks with pneumatically operated valves and electric switches and timers were used.

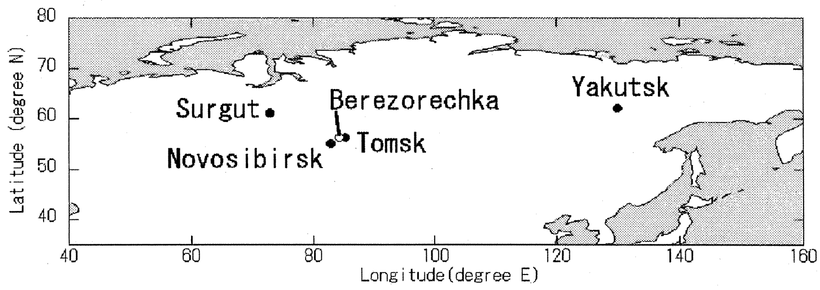

Figure 1. Map of observation site

3. Results and discussion

During the period from April 2004 to April 2007, we have been obtained 138 vertical profiles in CO_2 mixing ratio. Examples of CO_2 profiles observed in 2006 are shown in Figure 2. The vertical variability as well as day-to-day variability in CO_2 mixing ratio are rather large in summer, while vertical profiles are quite stable in winter and spring.

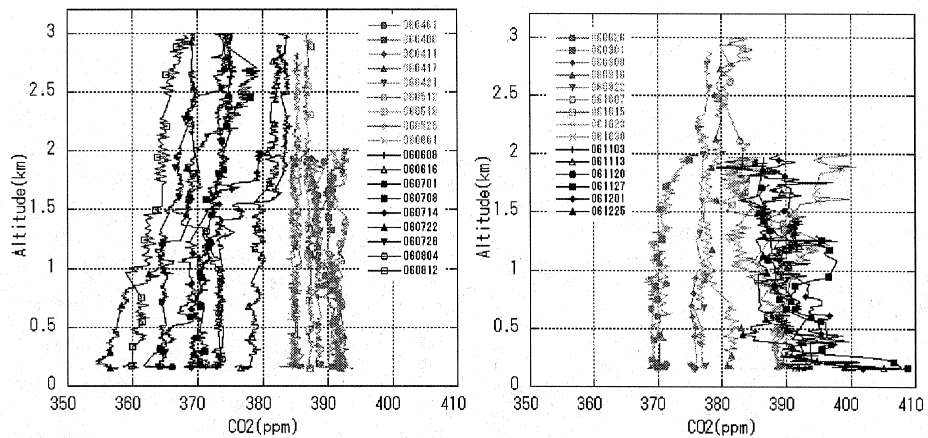

Figure 2. Vertical CO_2 profiles over Berezorechka.

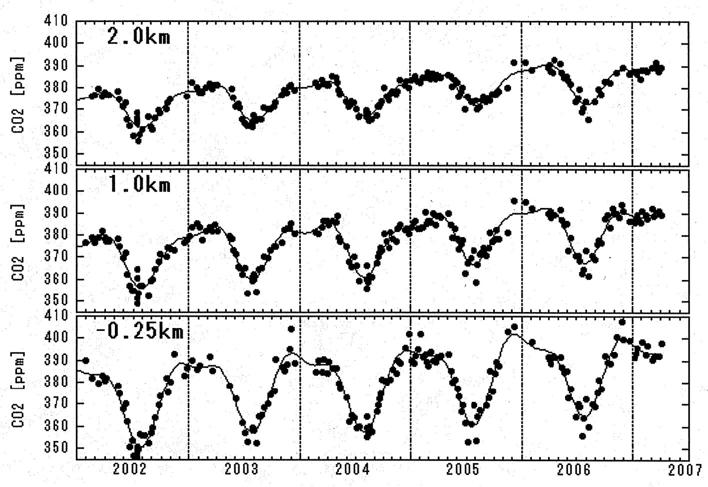

Figure 3. Time series of CO_2 mixing ratio over Berezorechka.Seasonal CO_2 variations observed over Berezorechka are compared with those calculated my NICAM 3D transport model with vegetation model (Figure 4). The model successfully expressed CO_2 seasonality as well as the synoptic change in CO_2 mixing ratio. This fact indicated the

vertical transport process around PBL in the model was reasonably expressed real atmosphere.

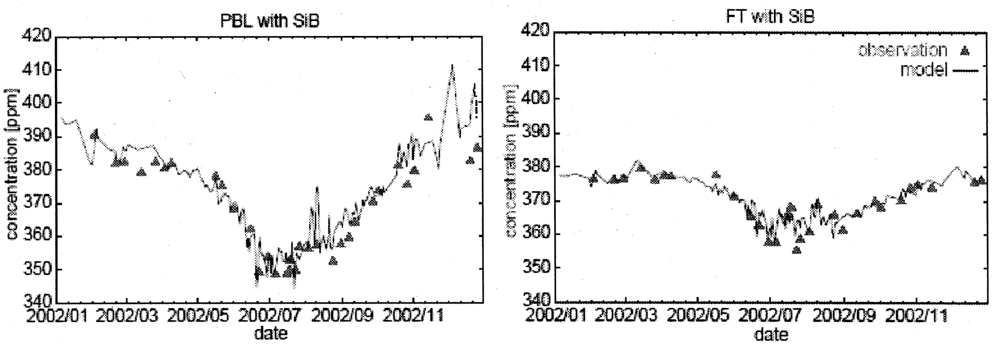

Figure 4. Comparison of CO_2 seasonal variation obtained from observation and model.

Diurnal variation in CO_2 profile showed various characters day by day in relation to the PBL structure. The variability of diurnal growth and the daily maximum height of PBL were caused not only radiative effect but also atmospheric condition which was governed by synoptic pressure pattern.

Several noticeable interrelation characters between the CO_2 change and the PBL dynamics were found and categorized as follows, (1) diurnal PBL growth and CO_2 concentration drawdown in the PBL (Figure 5a), (2) squall-like rain event occurred by diurnal developed cumulus, (3) cloud layer formed aloft of PBL in daytime, (4) suppressed PBL growth by subsidence (Figure 5b).

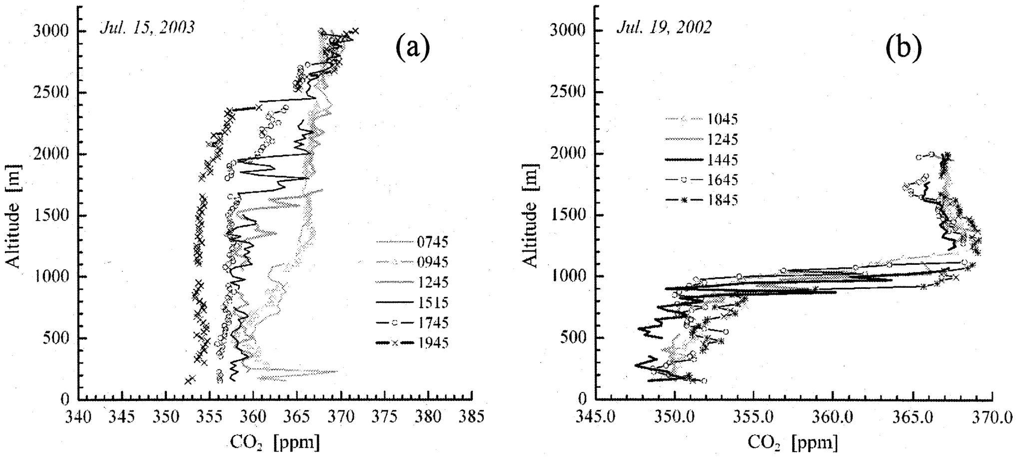

Figure 5. Diurnal variation in vertical profile of CO_2 over Berezorechka on 15 July in 2003 (a) and on 19 July in 2002 (b)

Over the forest in East Siberia near Yakutsk city, we collected air samples semimonthly by using a small aircraft at different altitudes between 100m and 3000m throughout year. Time series of CO_2 mixing ratio and carbon stable isotope ratio ($\delta^{13}C$) of CO_2 showed regular seasonal cycle at all the altitudes. The sign of vertical gradients of CO_2 mixing ratio and $\delta^{13}C$ ratio of CO_2 changed between summer and winter. In the vertical profiles, we found distinct gap usually in lower altitude in winter but could find only slight differences between upper and lower altitudes in summer. We calculated net isotopic signature (δ_{net}) from individual vertical profiles of CO_2 mixing ratio and $\delta^{13}C$ ratio of CO_2 from two-component simple mixing approach. Values of those apparent source signatures showed significant seasonal variability. In summer, the signatures ranged around –25‰PDB with wide dispersion. Narrow range in CO_2 mixing ratio made it difficult to give accurate estimates in summer. After defoliation period (from late August to mid September at the area), the apparent source isotopic signatures declined gradually to about –32‰PDB. This excessive depletion of isotopic signatures was formed most likely from extremely ^{13}C-depleted CO_2 originated from fossil fuels.

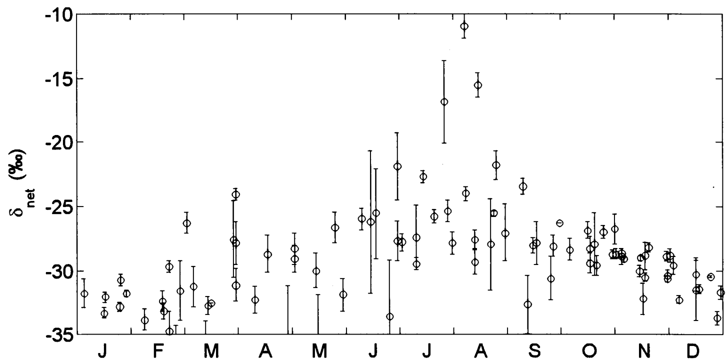

Figure 6. Seasonal variation in δ_{net} observed over Yakutsk