Estimation of CO_2 and CH_4 fluxes in Siberia using tower observation network
（Abstract of the Interim Report）

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1. Introduction

Inverse method for atmospheric transport model is one of the most reliable ways to estimate a carbon flux on the continental scale1) 2). To improve the spatial resolution for the flux estimation in the continent, more dense and reliable CO_2 measurements are needed.

In this study, we carry out the continuous measurements of atmospheric CO_2 and CH_4 using existing towers in Siberia to reveal the spatial and temporal variation of these gases in the continental interior. Siberia is one of the blank region for CO_2 and CH_4 observation in the world. The data obtained in this study are used for estimating regional CO_2 and CH_4 fluxes and their year-to-year variations in Siberia.

2. Methods

The network of towers (JR–STATION: Japan-Russia Siberian Tall Tower Inland Observation Network)3) consists of eight towers located in West Siberia and one tower in Yakutsk in East Siberia (Fig. 1). Atmospheric air was delivered via a decabon tube by a diaphragm pump into the freight container with insulators to reduce temperature variation and dried with (1) adiabatic expansion in a glass water trap, (2) a semi-permeable membrane dryer, and (3) magnesium perchlorate. The dehumidified air was then introduced into a non-dispersive infrared analyzer (model LI-820, LI-COR, USA) and a CH_4 semiconductor sensor4) at a constant flow rate of 35 cm^3 min^{-1} using a mass flow controller. Three standard gases were prepared from pure CO_2 and CH_4 diluted with purified air, and their concentrations were determined against the NIES 95 CO_2 scale5) and NIES 94 CH_4 scale6).

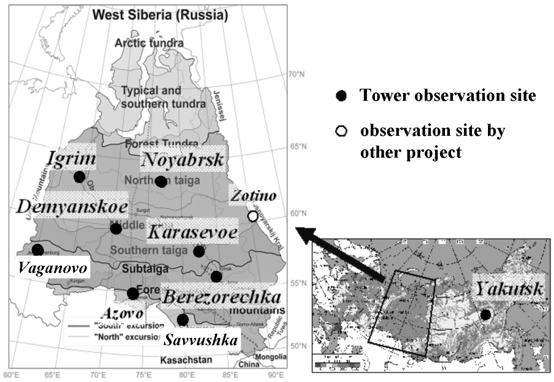

Figure 1. Location of JR–STATION.

We conducted first inversion analyses to estimate monthly carbon fluxes focused on Siberia by using measurements from the Siberia observation network consists of JR-STATION and four aircraft sites in addition to surface background flask measurements from NOAA/GMD. The inversion analyses were performed for 68 regions of the globe for four cases using different observation datasets and two different regularization methods for the period of 2000 - 2009 by using NIES TM and a fixes-lag Kalman Smother approach.

3. Results and Discussions

The fitted line from the daytime (13:00–17:00 GLT) mean CO_2 data showed stagnant increase trend in the summer of 2009 then increase trend in the summer of 2010 (Fig.2). ENSO summer in 2009 may affect the photosynthesis of vegetation in Siberia. The stagnation and restart in CO_2 increase was observed in NOAA coastal sites as well. The time lag of seasonal minimum between the data from JR–STATION and NOAA sites was 1–2 months. This implies that lower CO_2 air due to photosynthesis in Siberia gradually spread to the same latitudinal zone.

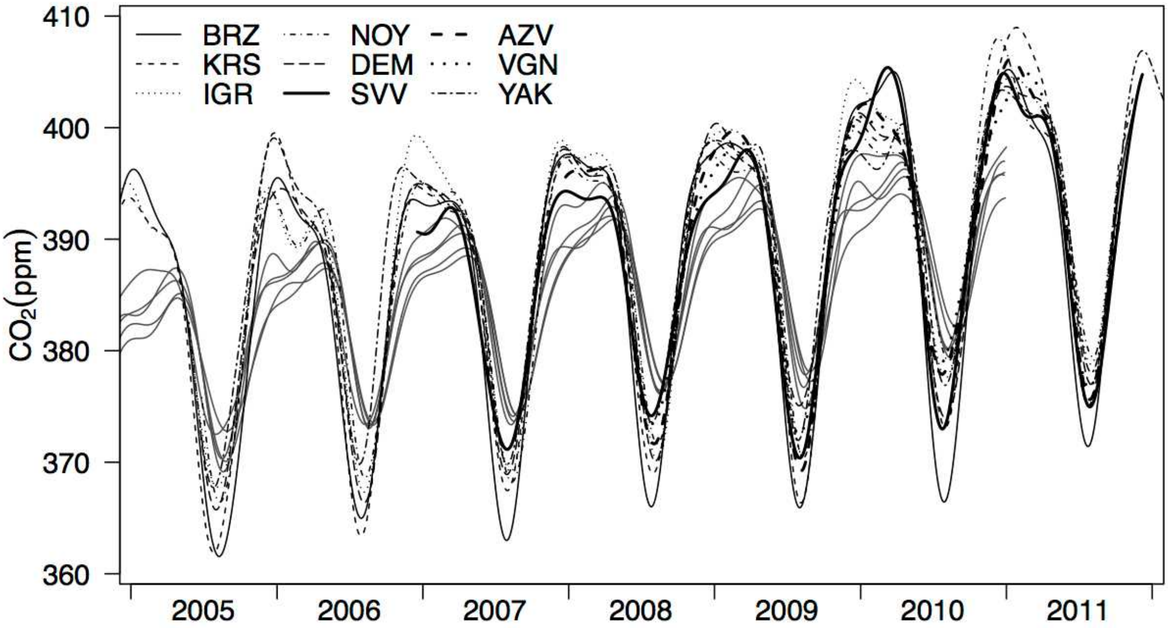

Figure 2. Fitted line from the daytime (13:00–17:00 GLT) mean CO_2 data. Gray lines indicate NOAA flask data[7)] from the same latitudinal zone (CBA, ICE, MHD, PAL, SHM).

Although both CH_4 and CO_2 accumulation (ΔCH_4 and ΔCO_2) during nighttime (duration of 7 h beginning 21:30 LST) at Karasevoe (KRS) in July 2007 showed an anomalously high concentration, higher ratios of $\Delta CH_4/\Delta CO_2$ compared with those in other years indicate that a considerably more CH_4 flux occurred relative to the CO_2 flux in response to a large precipitation recorded in 2007 (~2.7 mm d^{-1} higher than the climatological 1979–1998 base). In order to estimate the actual daily CH_4 flux from the CASA (Carnegie–Ames–Stanford Approach ecosystem model) 3-hourly CO_2 flux normalized with the observed CH_4 and CO_2 accumulation on a certain day (day x), we used the average of three midnight data [21:30 LST (day x), 0:30 LST (day x+1), and 3:30 (day x+1)] over the targeted area (±3° latitude, ±1° longitude) around the towers as CO_2 flux (F_{CO2}). Daily CH_4 flux was then calculated with the following Equation:

$$F_{CH4} = F_{CO2} \times \Delta CH_4/\Delta CO_2.$$

Estimated seasonal CH_4 fluxes (F_{CH4}) for the 2005–2009 period exhibited a seasonal variation with maximum in July at both sites (Fig. 3). Methane fluxes in June and July 2007 around KRS were noticeably higher than those in other years (Fig. 3a). Generally CH_4 fluxes around Demyanskoe (DEM) were lower than those around KRS, and no anomalous high flux in July 2007 appeared (Fig. 3b). It should be noted that the anomaly in CH_4 flux was quite different between the two sites, although both sites were placed in the middle taiga in West Siberian Lowland.

Annual values of the CH_4 emission from the forested bogs around KRS (approx. 7.8×10^4 km^2) calculated from a process-based ecosystem model, VISIT (Vegetation Integrative Simulator for Trace gases), showed an inter-annual variation of 0.54, 0.31, 0.94, 0.44, and 0.41 Tg CH_4 yr^{-1} from 2005 to 2009, respectively, with the highest value in 2007. It was assumed in the model that the flooded area is proportional to the cumulative anomaly in monthly precipitation rate. Although the emission in 2007 was 2~3 times higher than those in other years, the anomalous CH_4 emission from the targeted area around KRS by itself does not appear to explain all the recently observed variability in the global CH_4 concentration growth.

The strength of the calculated CH_4 flux could be refined if anomalous weather condition leads to an extreme increase/decrease in CO_2 flux from vegetation respiration, but an assessment of this bias requires a better CO_2 flux distribution that includes yearly variation. A further research is required for evaluating CH_4 flux map more precisely in the future.

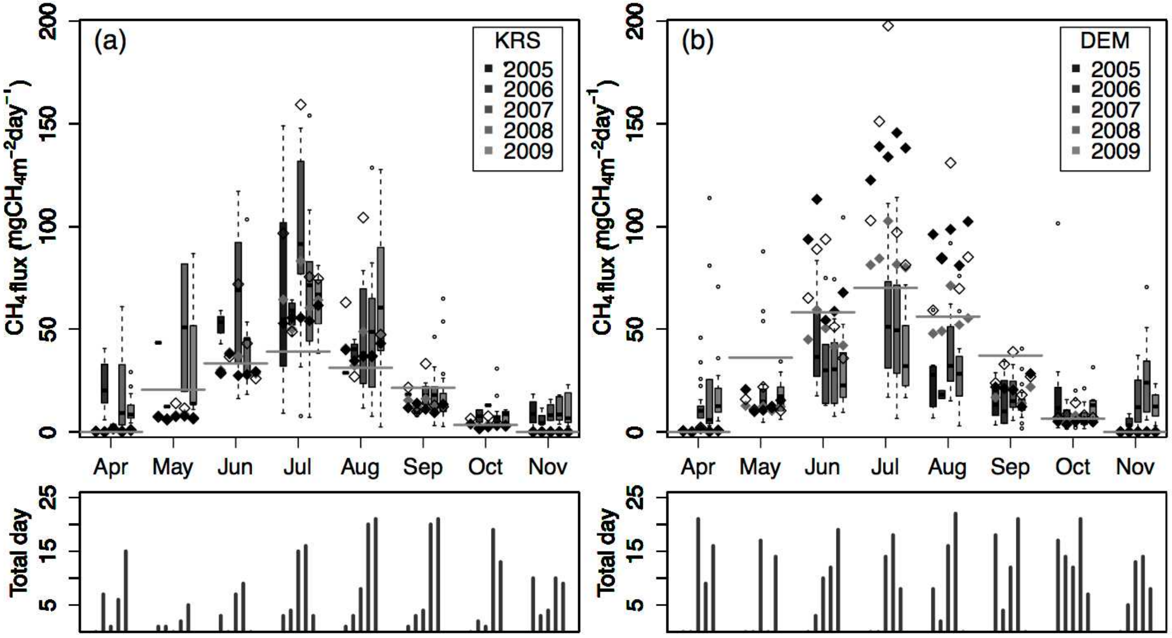

Figure 3. Box-and-whisker diagrams of daily CH_4 flux calculated with nocturnal CO_2 and CH_4 accumulation over an area (±3° latitude, ±1° longitude) around (a) KRS and (b) DEM. The diagrams are defined as follows: the median is the thick line in the box; the bottom and top of the box are the lower and upper quartiles, respectively; the whiskers extend to the most extreme data point which is no more than 1 time the interquartile range from the box; individual outliers are shown as open circles outside the whiskers. Horizontal gray lines indicate regional means of fluxes from the wetlands (bogs, swamps, and tundra) in the GISS model. Closed diamonds denote monthly CH_4 flux simulated with VISIT model. Open (gray) diamonds denote monthly CH_4 flux of high (low) response case for precipitation anomaly. The bottom figures show the number of calculated day for each month and year. It depends mostly on the number of the obtained data. No winter data are shown since there is almost no diurnal variation during winter (Sasakawa et al., 2010)[3).

We found global total fluxes of ~ -3.51 GtC/yr for the four cases averaged over the period from 2000 to 2009, which were consisted with the previous studies. Our main focus was on the Boreal Eurasia region where the Siberia network is expected to additional constraints on carbon flux estimation. When comparing the inversion results with Siberian data (Case 3) and without the Siberia data (Case 1), we clearly see the differences in the estimated fluxes over eastern Europe and northern America as well as Siberia (Fig. 4), and the Siberian network reduces regional uncertainty of 22 % in Boreal Eurasia and eastern Europe on average during the inversion period. The maximum reduction in uncertainty reached about 80 % in east Siberia and west Siberia (Fig. 5), which show effectiveness of the Siberian network to reduce uncertainty in estimated fluxes. Our Case 1 inversion with only NOAA data inferred Boreal Eurasia flux of -0.56 ± 0.79 GtC/yr, while the inclusion of the Siberia data (Case 3) estimated Boreal Eurasia flux of -0.35 ± 0.61 GtC/yr for an average over 2000-2009. We found that Case 4 inversion solved by t-SVD also resulted in -0.35 ± 0.87 GtC/yr, thus this average flux of -0.35 GtC/yr for Boreal Eurasia could be a quite robust estimate for this region against regularization methods used here. To verify performance of our inverted fluxes, we conducted forward simulations with the inverted fluxes in addition to the a priori flux dataset. Comparisons with independent observations over ZOT in central Siberia showed that the simulated CO2 concentrations with the inverted fluxes agreed better with ZOT observations than those with the a priori fluxes only. The unique Siberian network is still in operation and this should provide an additional constraint to the future inverse calculations in the flux estimate mainly over Boreal Eurasia.

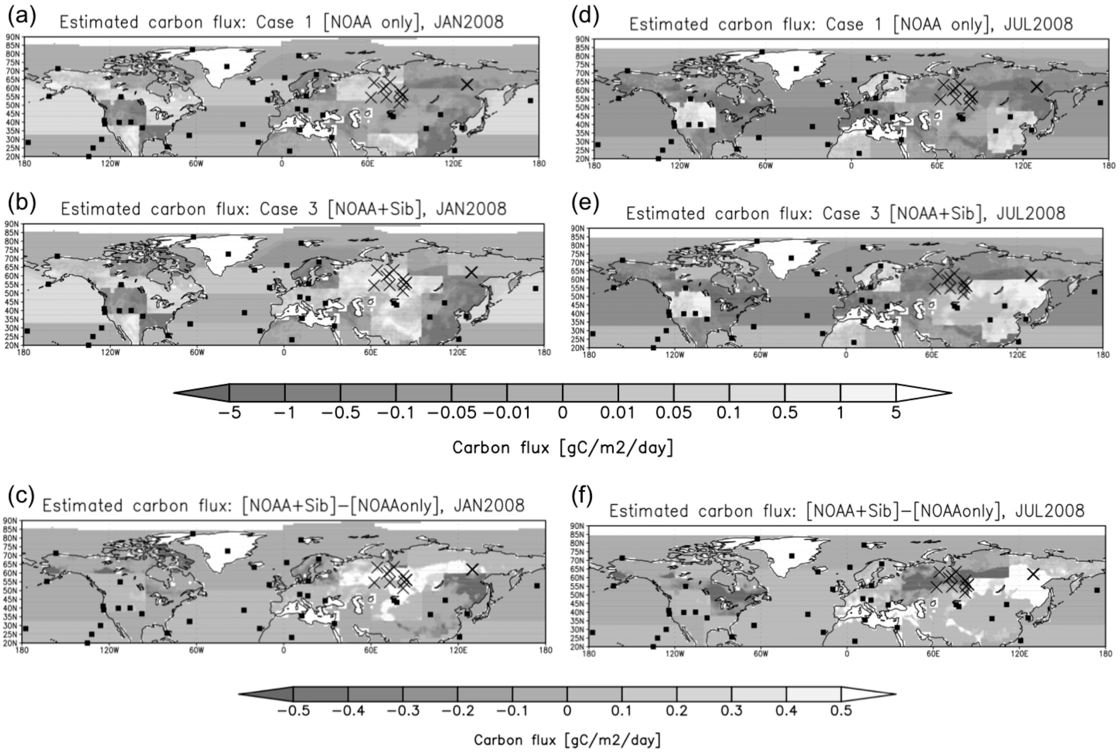

Figure 4. Estimated fluxes for Case 1 (with NOAA data) and Case 3 (with NOAA + Siberia data) and their difference in January (a)-(c) and July (d)-(f) 2008 at resolution of 1˚ x 1˚. Crosses and circles denote Siberian network sites and NOAA sites, respectively.

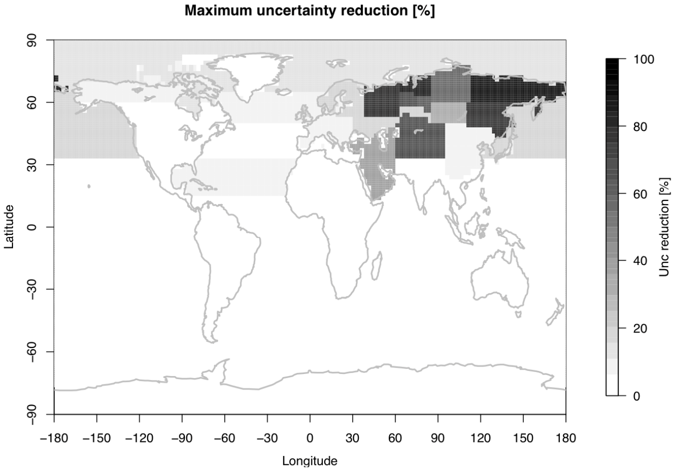

Figure 5. Maximum uncertainty reduction (%) for 68 regions in any month from January 2000 to September 2009 for the estimate uncertainty of Case 3 (with NOAA + all Siberian) data relative to that of Case 1 (with NOAA data only).

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