Development of Evaluating Method for sink/source of CO2 in a regional scale

(Abstract of the Interim Report)

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1. Introduction

The carbon exchange between the forest ecosystems and the atmosphere is one of the key processes that need to be assessed for the estimation of CO_2 budget in compliance to the Kyoto Protocol. The accurate assessment of the global CO_2 budget largely depends on regional observation and estimation of regional CO_2 fluxes. The forest CO_2 uptake plays an important role in controlling the global CO_2 budget between the anthropogenic CO_2 emission and various CO_2 sinks. The net production of forest ecosystems is ultimately the result of equilibrium between photosynthesis and respiration processes which has strong diurnal, seasonal and annual variabilities. .

Because of the possibility of large errors in estimating CO_2 budget based on limited number of inventory data and insufficient understanding of CO_2 fluxes, there is an urgent need to enhance measurements of background atmospheric CO_2 and to monitor forest CO_2 uptake. Some of the European and America countries are beginning to use atmospheric observations to increase the accuracy of inventory-based estimates of carbon emission. This report presents our development of observation systems and evaluation methods for the CO_2 budget estimation.

2. Research Objective

This study focuses on the carbon budget in an area west of Hokkaido where urban regions distribute patchily in 100 km scales. It is assumed that fossil fuel is consumed heavily by industries and by large cities such as Sapporo and Tomakomai, while carbon dioxide can be absorbed by large-scales of croplands and forests. It is relatively easy to measure the absorption/emission of CO_2 in this area by measuring the transport of CO_2 into and off the Island because the area faces the sea and is surrounded by mountains; Our main objective is to validate and improve atmospheric transport models by comparing model output with the direct estimates of CO_2 budget so that eventually we can use the model to inversely estimate temporal and horizontal variation of CO_2 budget.

3. Research Method

Regional CO_2 budget in this area can be estimated by the following procedures:

a) Collection of the inventory data of CO_2 source, and GIS mapping;
b) CO_2 flux measurement over the archetypal forest and GIS mapping for the forest type;

c) Estimation of the distribution of CO_2 concentration using atmospheric transportation model and GIS data under typical climate condition;
d) Direct measurements of horizontal and vertical profiles of the atmospheric CO_2 concentrations using air plane near the land-sea boundary;
e) Comparison between the results of airplane measurements and modeling, and the re-estimation using the improved model;

CO2 sink data were collected from the results of Tomakomai Flux Research Site (40-years-old larch plantation; 42-44'N 141-31'E, Tomakomai, Hokkaido, Japan) and Teshio CC-LaG (Carbon **C**ycle and **La**rch **G**rowth Experiment) Site (natural conifer-hardwood mixed forest; 45-03'N 142-07'E, Horonobe, Hokkaido, Japan) which are managed by National Institute for Environmental Studies collaboratively. Basic inventory data of anthropogenic CO2 source was collected from public statistical data. All data was classified into seasonal and hourly categories mapped to geographical grid by 1 km resolution. Using an atmospheric transportation model based on the dynamic equation and hydrostatic equation was used, CO2 advection and diffusion were calculated from wind-fieldsand potential temperature simulated using the model. The simulation were run for a typical meteorological condition, especially weather and geostrophic wind direction and speed. Campaign observations were made in summer and in winter. Both CO2 source and sink exist within the plain in summer, so flight course was set to observe 2-dimensional vertical profiles of CO2 concentration in upwind and downwind. In contrast, only CO2 source exists because of snow cover and defoliated tree in winter. Thus, we planed the flight course to circle over Sapporo to observe CO2 emission mainly from the commercial and residential region.

4. Results

(1) Data collection and GIS mapping

In this study, there are important that data accuracy and simple source, so that public statistical data were used purposely. Data collection was enhanced according to the priority of CO_2 emission ratio: manufacturing industries (31%), residential sector (18%), road transportation (18%), and commercial/institutional sector (12%). The data was classified into seasonal and hourly categories and mapped to the geographical grid of 1 km by 1 km resolution.

(2) Observations in ground monitoring sites

As the foundation of this monitoring program, CO_2 flux, vertical profiles of CO_2 concentrations and basic meteorological elements have been observed in Tomakomai Flux Research Site since 2001. Moreover, with the cooperation of Hokkaido University, CO_2 flux measurements in Teshio Experimental Forest of Hokkaido University started in August 2002.

We estimated that the capacity of CO_2 fixation in larch forest at Tomakomai research site was 250-350gC m^{-2} $year^{-1}$ in this period and that the capacity at the Teshio site was less than 100 gC m^{-2} $year^{-1}$ in this period, which is less than 40% of the capacity at Tomakomai site. This difference may be attributed to the more mature forest and heavier snow cover in winter at Teshio.

At Teshio site, CO_2 efflux from the snow surface to the atmosphere was reported in winter, about 68gC m^{-2} $year^{-1}$ or about 70% of the annual carbon fixation. Obviously, the CO_2 efflux at the leafless period is not negligible, even when the ground level is covered with deep snow.

(3) Simulation of the horizontal and vertical distribution of CO_2 concentration

Using an atmospheric transportation model based on the dynamic equation and hydrostatic equation was used, CO_2 advection and diffusion were calculated from wind-fieldsand potential temperature simulated using the model. The simulation were run for a typical meteorological condition, especially weather and geostrophic wind direction and speed.

Fig.1 shows a distribution of air CO_2 concentration estimated using the model for geostrophic southernly wind of 10 m s-1, total cloud amount of 3. The clearly high CO_2 concentration in the center of the Ishikari Plain originates in the Tomakomai Industrial Area.

According to the simulated results, the surface airflow and CO_2 distribution behave intricately when the geostrophic wind direction is SE or W in summer. To have a good campaign observation of air CO_2, the geostrophic wind direction is should be S, SW or NE.

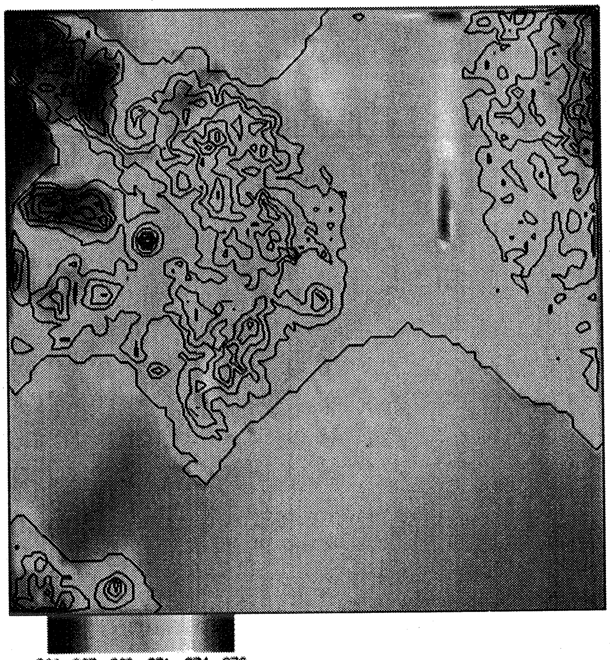

Fig.1 simulated result of air CO_2 concentration near the surface

(4) Campaign observations

For the measurement of CO_2 concentration on the same air mass at different point, accurate and small CO_2 airborne analyzer is needed. Existing analyzer developed by CGER/NIES was improved using back-pressure valve, two standard gases and et al. Additionally, all components were placed in the small box less than 0.1 $m^3$for its portability. (Photo1) Measurements of 2-dimensional distribution and vertical profiles of CO_2concentrations in upwind and downwind are necessary for the estimation of CO_2 budget. If measured for a different condition, the results cannot be used for budget calculation. Because an aerial measurement by airplane needs the permission from the aeronautical administration, we have to plan a flight carefully based on the minute weather forecast.

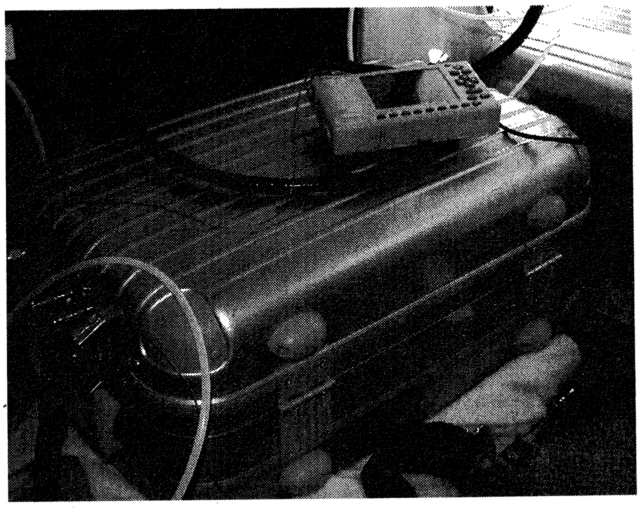

Photo1 Improved airborne analyzer

Campaign observations using airplane, pilot balloon and wind profiler were made twice in summer and once in winter. Both CO_2 source and sink exist within the Ishikari Plain in summer, so we chose the flight course to observe 2-dimensional vertical profiles of CO_2 concentrations in upwind (Tomakomai) and downwind (Sapporo). In contrast, only CO_2 source exists within the plain because of snow cover and defoliated tree. Thus, we planed the flight course to circle over Sapporo to observe CO_2 emission mainly from the commercial and residential region. Also Vertical distribution of wind direction and speed were observed by pilot balloon in Sapporo at the same time.

Fig.2 is the horizontal CO_2 distribution in winter. The flight date was Feb.25 2003, and wind direction was NW over the altitude of 300m and SE under the altitude of 300m as the consequence of radiational cooling. The flight courses of 300m and 400m were altered on the edge of urban district to keep away from mountains. The high concentrate of CO_2 observed on this altered course may be attributed to the rising air current with high CO_2 concentrate that originates from urban heat and CO_2 emission. However, high concentration of CO_2 observed at altitude of 600m above the mountain may be caused by a different mechanism, e.g., high albedo of the leafless tree and advection from urban district.

(5) Comparison between the results of airplane measurements and modeling

In summer, the CO2 flux rate estimated by the results of campaign observation on Sep. 16 and transportation model was estimated as -20.7 μmol m-2 s-1 in the daylight time. According to results at Tomakomai Flux Research Site, the rate by forest in the summer daylight time is about -5 to -30 μmol m-2 s-1, and by crop land in it is about -3 to -15 μmol m-2 s-1. From here onwards, the CO2 flux rate from grandscale CO2 source area was underestimated. It was caused by the shortage on footprint becaude the flight course was very close to grandscale CO2 source area – Sapporo.

In winter, the CO2 emission rate in the circle flight course was simulated as 580kgCO_2 s^{-1} by campaign observation, and the rate by inventory data was 220 kgCO_2 s^{-1}. It caused by the underestimation of CO2 emission rate by inventory data. The annual and monthly emission rate was rather accurate, so that hourly repartition by car transport was most possible error.

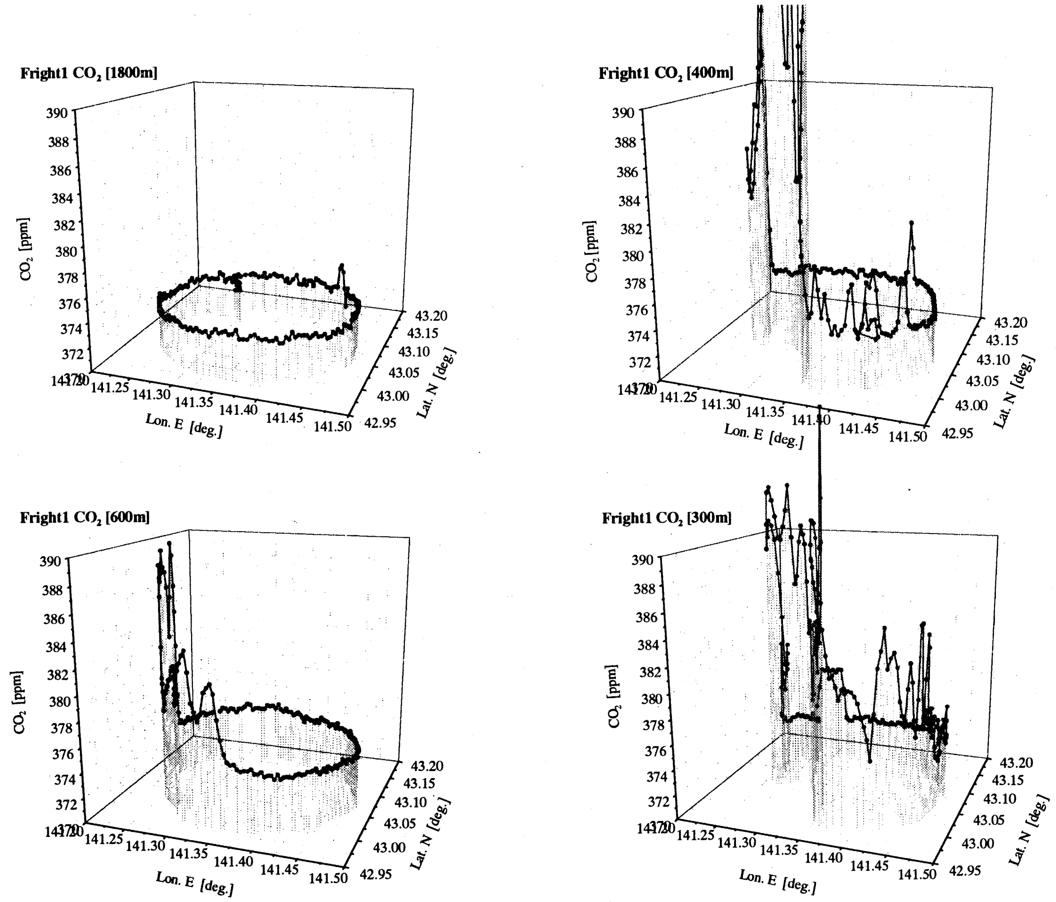

Fig.2 The horizontal distribution of CO_2 concentration on Feb.24, 2002 (altitude: 300m, 400m, 600, 1800m)

5. Discussion

This research is one of the studies for developing observation systems and evaluation methods for quantitative estimates of CO_2 budget in regional scales. First we estimated the regional CO_2 absorption/emission from inventory data with a 'unit-build up' method. We then conducted intensive in situ observations of the climatic features in the control regions and estimated CO_2 fluxes using an atmospheric transport model based on the observation data. Finally, we compared the output of the model with in situ observations and in return used the model in the planning of observations.

About CO2 inventory data, we emphasized simplified and accurate data source and spatially, temporal repartition method. Final GIS data was made from public statistical data and developed repartitioning methods, and data accuracy was almost fine except CO2 emission by car transportation. It varies temporally and spatially, so that it is indicated that more detail data is required. Airborne CO2 analyzer was improved for this study, precision and miniaturization were significantly achieved. On the atmospheric transportation model, several problems were occurred. Especially, regional behavior of air mass made an underestimation of CO2 emission.

It is forecasted that the direct estimation of regional CO2 budget from an atmospheric observation will be emphasized as an analysis for global warming and related field, especially in international relationship. In fact, this study is recognized as important task in America and Europe. In Japan, it is rather difficult due to the complex land use and surface roughness, however, the importance is increasing. In this study, we achieved the establishing of data source and processing methods to GIS data, the improvement of airborne CO2 analyzer and test production of atmospheric transportation model, moreover, this was first case to make a combined analysis through those methods in Japan. This would be helpful as a case study.

References

Kondo, H. N. Saigusa, S. Murayama, S. Yamamoto and A. Kannari, 2001: A numerical simulation of the daily variation of CO2 in the central part of Japan -summer case-, J. Meteor. Soc. of Japan, 79, 11-21.

Gambo, K., 1978: Notes on the turbulence closure model for atmospheric boundary layers, J. Meteor. Soc. of Japan, 56, 466-480.

Brummage, K.G., 1968: The calculation of atmospheric dispersion from a stack. Atmos. Environ., 2,197-224.

Schulze, E.D., F.K. Kelliher, C. Korner, J. Lloyd, and R. Leuning,1994: Relationships among maximum stomatal conductance, ecosystem surface conductance, carbon assimilation rate, and plant nitrogen nutrition, Ann. Rev. Ecol. Syst., 25, 629-660.

Saigusa, N. S. Yamamoto, S. Murayama, H. Kondo and N. Nishimura 2002: Gross primary production and net ecosystem exchange of a cool-temperate deciduous forest estimated by the eddy-covariance method, Agric. Forest Meteor., 112, 203-215.