B-4.6 Estimation of Carbon Sink Distribution Using Inverse and Forward Models

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Abstract We aim at establishing methods of estimating carbon sink distribution on a continental scale from carbon dioxide concentration measurement network and from meteorological data using global tracer transport models. Global tracer transport models are thus developed. We use recent carbon dioxide concentration observations over Asia and the inverse models participating in the inverse model intercomparison project of TransCom to improve estimates of the Asian carbon dioxide sources and sinks. The inclusion of the carbon dioxide concentration data in West and Central Siberia, in Japan, and on the Tokyo-Sydney route in addition to the TransCom standard observation data set reduces uncertainty of the estimated regional carbon dioxide fluxes for Boreal Asia (Siberia), Temperate Asia, and Southeast Asia. The largest effect is observed for emission/sink estimate for Boreal Asia region where introducing the added observations in Siberia reduces the source uncertainty by almost half. The addition of the Siberian airborne observations leads to extra sinks on Boreal Asia of 0.2 GtC/year. The local carbon dioxide circulation model with horizontal resolution of 60 km is integrated over the Asian Continent for 1 year to evaluate carbon dioxide exchange rate between the atmosphere and land surface ecosystems. It is necessary to evaluate a precision of the estimated carbon dioxide exchange rate by the model in comparison with observed data of atmospheric carbon dioxide concentration and flux. Using a land ecosystem model, a global mapping of carbon dioxide exchange rate between the atmosphere and land surface ecosystem is made mainly on forests. Furthermore, interannual variations of responses of the carbon dioxide exchange rates are investigated using three kinds of meteorological re-analysis data, and the results depend quantitatively on the selection of the re-analysis data.

Key Words Carbon Sink Distribution, Carbon Budget, Tracer Transport Model, Local Carbon Dioxide Circulation Model, Land Ecosystem Model

1. Introduction

The carbon source/sink strength and its horizontal distribution over the content by forest are uncertain, and should be pursued by various methods. The methods not only include field measurements of carbon storage in ecosystems, soil respiration, photosynthesis of plant, eddy correlation measurement of carbon dioxide flux, and altitude profile measurements of carbon dioxide, etc. but also inversion estimate on a continental scale from carbon dioxide concentration measurement network using 3-dimensional global tracer transport models. The present sub-theme research is concerned with the latter of the inverse models while other sub-theme researches are with the former studies. A component of the research participated in the TransCom (Atmospheric Tracer Transport Model Intercomparison Project), a project under International Geosphere-Biosphere Program (IGBP)/Global Analysis, Interpretation, and Modeling Project (GAIM). Other related model studies are also carried out in the research.

2. Research Objective

We aim at establishing methods of estimating carbon sink distribution on a continental scale from carbon dioxide concentration measurement network and from meteorological data using tracer transport models.

3. Research Method

As for the 3-dimensional global tracer transport model (hereafter referred to as 3-D global transport model), two groups develop different models in the framework of this research to exchange ideas, and try to contribute to the model development because the status of the 3-D global transport model development is still on the way of requiring more refinements. One research component made an emphasis on the model development itself (See Section 4.1). Another research component develops an inverse model to estimate carbon sink/source horizontal distribution from a given horizontal distribution of carbon dioxide concentration by using a different 3-D global transport model through participating in the TrancCom project and by utilizing our own data of carbon dioxide concentration in addition to the standard data set (See Section 4.2). In the 3-D global transport models, global objective analysis data of meteorological parameters based on meteorological observations are used as input data to the models, e.g., wind data for calculating advection of carbon dioxide. A so-called forward model of a local carbon dioxide circulation model with a scheme of plant physiology and plant ecology to directly estimate carbon dioxide exchange rate (i.e., sink/source strength) between the atmosphere and land surface ecosystems over the Asian Continent is developed (See Section 4.3). The meteorological data such as winds and temperature used in the local circulation model are those calculated by the model itself. Moreover, a land ecosystem model, where surface meteorological data from global objective analysis data are inputted into the model as external parameters, is developed to estimate the carbon budgets between the atmosphere and land ecosystem (See Section 4.4).

4. Results and Discussion

4.1 Development of a 3-dimensional global tracer transport model

(1) Model outline

A 3-D global transport model is developed to examine scenarios of atmospheric carbon dioxide budget. The model divides the atmosphere into a large number of grid boxes and calculate fluxes between the boxes so as to conserve total mass of tracers. The spatial distribution of carbon dioxide is simulated using the wind data of ECMWF/TOGA objective analysis and NASA/GISS Fung's carbon dioxide exchange data set of surface flux. The initial condition is given by interpolating WDCGG/WMO monthly averaged data of January 1990, and the integration is made for one year from the initial condition.

(2) Results and Discussion

A simulation was carried out with the Fung's original dataset of carbon dioxide flux. Annually and zonally averaged carbon dioxide concentration in the simulation was higher in the Northern Hemisphere and lower in the Southern Hemisphere than that of the 1990 observational data. As a result of model sensitivity study to the carbon dioxide flux data, we modified the Fung's carbon dioxide flux data so as for the carbon dioxide budget to be within the error of the IPCC (1996)'s estimation. With the modified carbon dioxide flux data, the model reproduced well the observed carbon dioxide distribution in the sense that the latitudinal gradient and the horizontal distribution of the annual mean of the simulation are similar to those of the observation.

4.2 Development of an inverse model

(1) Background

Inverse models of global carbon dynamics use 3-D global transport models to estimate terrestrial and oceanic carbon fluxes from the observations of spatial and temporal distributions of the atmospheric carbon dioxide concentration. These estimates of the annual average flux of carbon usually indicate that the northern hemispheric land is a carbon sink (e.g., Tans et al, 1990). However, the attempts to deduce the annual average fluxes for large terrestrial and oceanic regions from spatial structure of the observed concentrations resulted in large spread of the estimations for regions such as North America and Eurasia (Fan et al, 1998; Rayner et al, 1999; Bousquet et al, 2000). The reasons for the differences among inverse model results are believed to originate in model transports and inverse modeling approaches. Another factor limiting the application of the inverse modeling to discrimination of the carbon fluxes among land regions is the lack of the observations close to the target areas. We add some observations to the standard data set of the TransCom project, and investigate the impact of the addition on the estimate of carbon source/sink (Maksyutov et al., 2001).

(2) Inverse model analysis

A3-D global transport model incorporated with a cumulus parameterization scheme and a boundary layer turbulent diffusion scheme (Maksyutov and Inoue, 2000) was used in addition to other models participating in the TransCom project. We follow a basic inverse model analysis by Transcom-3 project of TranCom (Gurney et al, 2001) as a base for our analysis, so that we can use the basic inversion as a reference. The difference between the basic inversion and our procedure is in the data preparation for additional sites, and in the time periods for which the annual averages are calculated. We use a Bayesian synthesis inversion (Rayner et al, 1999) to derive the estimates for surface fluxes of carbon dioxide. Results from 14 transport models are used in the inversion. The transport models calculate annual average atmospheric carbon dioxide responses to the carbon dioxide fluxes from fossil fuel combustion, terrestrial biosphere, and ocean-atmosphere exchange given as global, seasonally varying fields. Moreover, the annual average responses to fluxes from 22 large regions, 11 in the land and 11 in the ocean, are prepared in order to model the effects of the regional sources and sinks (Gurney et al, 2001). In addition to the basic observation dataset for Transcom-3 inversion (Globalview, 2000), we include airborne and tower observations in West and Central Siberia, continuous monitoring and airborne observations in Japan, and the airborne monitoring on regular flights on Tokyo-Sydney route. The time period we use (1992-1998) does not always match with that of the basic Transcom-3 estimation, which uses data from Globalview sites for the period of 1992-1996. The reason for selecting wider time frame for our data is that we need to average over larger time period to compensate for strong day-to day variability that adversely affects results of the low frequency aircraft sampling, which is conducted once a month (Machida et al, 2001).

(3) Results and discussion

The inversion model estimates for the Asian fluxes with and without the additional data were carried out. The inclusion of the aircraft data of Surgut (61N, 73E) reduces uncertainty of the estimated regional carbon dioxide fluxes for Boreal Asia (Siberia), Temperate Asia, and Southeast Asia. The largest effect is observed for emission/sink estimate for Boreal Asia region where introducing the data in Siberia reduces the source uncertainty by almost half (0.56 to 0.33 GtC/year). It also produces uncertainty reduction for Boreal North America. Inclusion of the data leads to extra sinks on Boreal Asia of 0.2 GtC/year, and smaller change for Europe. We have to pay attention to inter-annual variability in the data (Machida et al, 2001), which cannot be easily traced back to transport and biospheric variations, and which may result in large variability of the inverse model flux estimates when using data covering different periods. The Surgut observation have longest record (1993-1998) but its footprint area represents only a fraction of the Boreal Asia region. The availability of the data over Novosibirsk (55N, 82E) and Yakutsk (62N, 129E) thus gives a desired improvement in the observational coverage.

The addition of surface observation data sets at Cape Ochi-ishi (43N, 145E) and Hateruma (24N, 123E) and an aircraft observation data set over Sendai (37N, 140E) in Japan does not produce significant change in inversion flux uncertainty for Temperate Asia, because there is already a number of observations over China, Korea, Japan, and Mongolia included in Globalview dataset and the basic inversion. The Tokyo-Sydney regular flight observations (36N-34S) (Matsueda and Inoue, 1996) reduce and further constrain Southeast Asian source. The result is valuable in a sense that in the area without other observations even the observations remote from the ground (12 km altitude) are still effective in reducing the inverse model flux uncertainties. That justifies the attempts to use possible satellite remote sensing sensors of carbon dioxide measurements in the tropical troposphere even when the measurements are limited to the upper troposphere.

4.3 Development of a local carbon dioxide circulation model

(1) Model and used data

A regional climate model with a land surface hydrological model including vegetation, i.e., a local carbon dioxide circulation model, was constructed (Mabuchi et al., 1997; Mabuchi et al., 2000) to calculate carbon dioxide exchange rate between the atmosphere and land surface ecosystem under changing local weather/climate. To estimate Net Ecosystem Production (NEP) over the Asian Continent, the local carbon dioxide circulation model was designed for the Asian Continent region with its horizontal resolution of 60 km. The target period is for 1-year from March 1997 to February 1998. Land surface vegetation is prescribed on the basis of the vegetation map compiled by the Environment Agency of Japan for the Japanese lands and by Olson et al. (1983) for the Asian Continent region, respectively. As lateral boundary conditions, meteorological variables are adopted from NCEP/NCAR re-analysis data twice a day, and a standard seasonal variation of carbon dioxide concentration, which does not depend on height, was assumed on the basis of some observations.

(2) Results and Discussions

Preliminary analyses of the results over Asia for March 1997 to February 1998 by the model show reasonable results about seasonal variation of atmospheric carbon dioxide concentration at the surface and NEP rate during the year. However, further investigation shows some shortcomings, e.g., high carbon dioxide concentrations in its seasonal variation and negative NEP over the Eastern India and the Indochina Peninsula, which might mean too strong soil respiration in the model. Further verification will be needed in comparison with observed atmospheric carbon dioxide concentration and flux data at the land surface.

4.4 Development of a land ecosystem model

(1) Model

A land surface ecosystem model (Sim-CYCLE) is used to estimate the carbon budgets between the atmosphere and land ecosystem, i.e., global Net Primary Production (NPP) and Net Ecosystem Production (NEP) globally with high-resolution of 0.5-degree intervals in latitude and in longitude.

(2) Results

Using the land ecosystem model, a global simulation was made on carbon dioxide exchange processes between the atmosphere and land ecosystems, and a carbon budget between the atmosphere and land ecosystems was estimated. Further development is anticipated in comparison with observed variations of atmospheric carbon dioxide concentration and delta carbon 13. Influences of differences of three kinds of meteorological re-analysis data (NCEP/NCAR, NCEP/AMIP II DOE, ECMWF), which is used as external parameters, were investigated. The interannual variation of the estimates for NPP and NEP for the period of 15 years from 1979 to 1993 are qualitatively similar, but quantitatively different obviously among the estimate with the different meteorological data. This might be also the case for future climate projection data supplied from global climate models, i.e., atmosphere ocean global circulation model.

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