論文内容の要旨

Numerical study on atmospheric transport and surface source/sink of carbon dioxide

（数値モデルを用いた二酸化炭素の大気輸送および地表面収支に関する研究）

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Accurate evaluation of the carbon budget and understanding of its mechanism are urgently demanded to perform reliable prediction of global warming. The inversion method is one approach to estimate CO_2 fluxes at the earth surface. In inversion, regional surface CO_2 fluxes are estimated from atmospheric CO_2 concentrations, using a tracer transport model. This study adopts this approach for inferring regional and temporal variations of CO_2 fluxes.

In inversion, estimated CO_2 fluxes include considerable uncertainty because of the model transport error and the lack of observations at uniform spatio-temporal coverage. Therefore, a sophisticated transport model and an expanded observation network are necessary. Recent three-dimensional CO_2 measurements by aircraft are expected to give new constraints to the surface flux estimation. In this study, a tracer transport model has been developed for an accurate CO_2 transport; prospective impacts of the upcoming three-dimensional CO_2 observations are examined in various ways.

The tracer transport model is developed based on the nonhydrostatic icosahedral atmospheric model (NICAM), which is advantageous for consistency with continuity and the feasibility of multi-resolution simulation. To improve the advection calculation, a new scheme for a three-dimensional icosahedral grid is introduced; it is found superior to the conventionally used method in terms of monotonicity and a sharper gradient. Transport simulations of SF_6 and radon verified that the newly developed model offers good performance for tracer transport processes that are closely related with CO_2 transport.

Using the NICAM, a long-term CO_2 inversion with new prior fluxes and observations has been conducted. The inversion has provided a reliable estimate of the global carbon budget. Furthermore,

the estimated results are consistent with the previous studies, indicating the possibility of wider and more intensive applications of NICAM in the inversion studies.

In the inversion, the effects of the Siberian aircraft data have been evaluated. Results show that the aircraft data introduces a new constraint on the CO_2 flux in boreal Asia. The estimated seasonal cycle and interannual variation in boreal Asia agree to some degree with those from bottom-up approaches. This fact suggests that the aircraft data provide meaningful insight into the factors related to CO_2 flux variations such as biosphere phenology, biomass burning and biosphere response to climate changes.

By comparing the simulated CO_2 from the inversion flux and the sampling aircraft measurement in the upper-troposphere over the western Pacific, contributions of regional fluxes to the concentration variations are examined. Results show that the double-peak seasonal cycles at the southern latitudes are formed by the intrusion of the large signals from the northern land biospheres with the opposite phase to those from the southern land biospheres. Results also show that the growth rate anomalies are dominated by the variations of surface fluxes rather than the meteorological changes.

Using various transport models and fluxes, three-dimensional structures of atmospheric CO_2 are investigated in comparison with the wide-ranging aircraft measurements. Results indicate that not only modeled transport but also the surface flux can affect the vertical and horizontal gradients of CO_2. This fact suggests that the CO_2 three-dimensional structures can be expected to have information that is useful to elucidate surface flux variations. Furthermore, new constraints for tropical and subtropical regions are implied. Although differences exist between simulated CO_2 and the observations arising from the unconstrained fluxes, some models (NICAM included) exhibit better performance than others in simulating three-dimensional CO_2 concentration variations.

Regarding the high quality of the model transport and the possible new constraints from the three-dimensional CO_2 measurements, it can be concluded that the uncertainty of the estimated CO_2 flux can be reduced considerably, thereby supporting better understanding of the global carbon cycle.