Phyton (Austria) Special issue: "APGC 2004"	Vol. 45	Fasc. 4	(55)-(59)	1.10.2005

Developing a New Model to Simulate Net CO_2 Exchange at AsiaFlux Sites

By

A. ITO[1)]

Key words: AsiaFlux site, global change, modelling, net ecosystem CO_2 exchange.

Summary

ITO A. 2005. Developing a new model to simulate net CO_2 exchange at AsiaFlux sites. - Phyton (Horn, Austria) 45 (4): (55)-(59).

Elucidating the atmosphere–ecosystem CO_2 exchange in Asia is the final goal of the GERF-S1 project, for which intimate collaboration between modeling and observation is essential. To this end, I have developed a new model to simulate the CO_2 exchange at flux measurement sites on the basis of a process-based carbon cycle model used for some global studies. The new model has 12 carbon compartments (tall trees (leaf, stem, and root), floor plants (leaf, stem, and root), litter (leaf, stem, and root), and humus (active, intermediate, and passive)) and operates at daily or 30-minute time steps. Canopy photosynthesis is simulated with a 2-and-2-layer model (upper/lower and sunny/shade), including a biochemical model and stomata model, allowing us to capture diurnal variation. A simple 6-compartment model is used for soil carbon dynamics, allowing us to capture seasonal and long-term variability of soil organic carbon. Preliminarily, the model was applied to an AsiaFlux sites, a cool temperate deciduous broad-leaved forest in Takayama, central Japan. The simulation results were compared with observed data with the eddy covariance method in the GERF-S1 project, in terms of diurnal, seasonal, and interannual changes. Then, discussions will be made on scaling-up from the site-level to broad scales, probably in conjunction with remote sensing and other components of the GERF-S1 project.

Introduction

Elucidation of the terrestrial carbon budget (including productivity) is one of the focal points of the Global Environmental Research Fund (GERF) S-1 Project and the International Geosphere-Biosphere Program (IGBP). The Asian network of flux measurement (AsiaFlux) was established to collect observational evidences

1) Frontier Research Center for Global Change, Japan Agency for Marine-Earth Science and Technology, 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001, Japan. FAX: +81-45-778-5706, e-mail: itoh@jamstec.go.jp

concerning the net carbon budget of Asia region, which is composed of a wide variety of ecosystems. Therefore, modeling approach should play a vital role in conjunction with observational studies, especially for regional and long-term evaluation of the carbon budget. In this study, a process-based carbon cycle model (Sim-CYCLE) is modified and applied to an AsiaFlux site in central Japan. Seasonal and interannual variability of gross and net carbon dioxide (CO_2) exchange is mainly addressed, in relation to the variability of environmental conditions.

Material and Methods

Model simulation was performed at a cool-temperate deciduous broad-leaved forest in Takayama, central Japan (36°08'N, 135°25'E, 1420 m ASL), where many collaborative studies are being carried out. Since 1994, atmosphere–ecosystem CO_2 exchange flux was observed with the aerodynamic and eddy covariance methods (SAIGUSA & al. 2002). Annul mean temperature is 7.3°C and annual precipitation is about 2400 mm. Overstory (tree canopy) is composed of *Quercus*, *Betula*, and *Magnolia* species, and understory (forest floor) is dominated by Japanese bamboo grass species. The site has been disturbed by timber exploitation during the last decades.

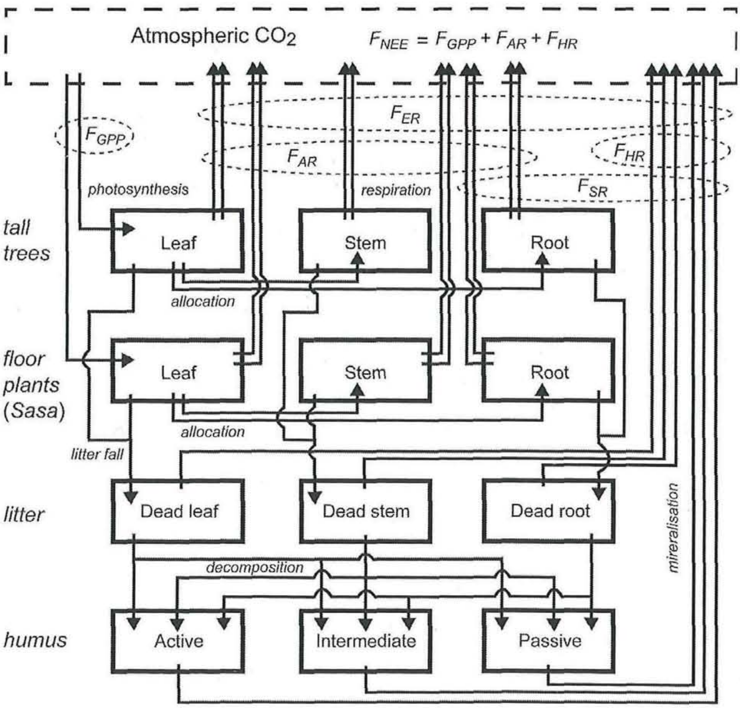

Fig. 1. Schematic diagram of the carbon cycle model. F_{GPP}, F_{AR}, F_{HR}, F_{SR}, F_{ER}, and F_{NEE} denote gross primary production, autotrophic respiration, heterotrophic respiration, soil respiration, ecosystem respiration, and net ecosystem exchange, respectively.

Model description

A process-based carbon cycle model, Sim-CYCLE (Simulation model of Carbon cYCle in Land Ecosystems), is used to simulate gross and net CO_2 exchange between the atmosphere and terrestrial ecosystem (Fig. 1). The original simple model (ITO & OIKAWA 2002), used in large-scale simulation studies, was revised here. The new model (ITO & al. in press) consists of 12 carbon compartments, and net ecosystem exchange (F_{NEE}) is defined by the following: $F_{NEE} = F_{GPP} + F_{AR} + F_{HR}$ (a positive value indicates a release to the atmosphere, vise versa). The component CO_2 fluxes (gross photosynthesis, F_{GPP}; autotrophic respiration, F_{AR}; and heterotrophic respiration, F_{HR}) are calculated for the period from Jan.1, 1948 to Dec.31, 2002, based on physiological relatinships with solar radiation, ambient CO_2 concentration, temperature, vapor pressure deficit, and soil water content. For the recent years, F_{GPP} is calculated with a 30-min step model, in which light condition is different between the overstory and understory and between sunny and shaded layers (i.e., beam and diffuse components of solar radiation). Model parameters were calibrated on the basis of field observations concerning the carbon pools and flows (e.g., JIA & AKIYAMA 2003, LEE & al. 2003).

Results and Discussion

In the last 12 years of simulation (1991–2002), the annual gross CO_2 fluxes, F_{GPP} and F_{ER} (= $F_{AR} + F_{HR}$, ecosystem respiration), were estimated to be –1095 ± 83 and 889 ± 45 g C m^{-2} yr^{-1} (average ± standard deviation), respectively. This means that the Takayama forest was a net carbon sink of –206 ± 45 g C m^{-2} yr^{-1}. This sink is largely owing to the disturbance (biomass removal by human logging) in 1960s, as well as the historical atmospheric CO_2 increase and climatic change. The estimated net ecosystem exchange is sufficiently close to an observation by the eddy covariance method in 1998–1999, –214 g C m^{-2} yr^{-1} (YAMAMOTO & al. 1999, SAIGUSA & al. 2002), although the magnitude of the gross fluxes were slightly smaller than their empirical estimates (–1146 and 984 g C m^{-2} yr^{-1}, for F_{GPP} and F_{ER}, respectively). The seasonal and interannual changes in the CO_2 fluxes were very clear (Fig. 2).

As to the net sink, the model simulation indicated that 185 g C m^{-2} yr^{-1} was stored in plant biomass and 21 g C m^{-2} yr^{-1} was stored in soil organic matter; further observations are required to confirm these results. Tree biomass, floor plant biomass, and soil-carbon storage were estimated as 8.1, 0.76, and 33.0 kg C m^{-2}, respectively. These values are consistent with biometric observations by OHTSUKA 2003 (tree biomass, 7.6 kg C m^{-2}) and a soil survey by JIA & AKIYAMA 2003 (soil carbon, 33.4 kg C m^{-2}). Apparently, humus (32.3 kg C m^{-2}) was the largest carbon pool of the ecosystem (total, 43.6 kg C m^{-2}). The CO_2 emission through the soil surface (F_{SR}, soil respiration by microbes and plant roots) was estimated as 697 ± 33 g C m^{-2} yr^{-1}; this value agrees well with the observation, 701 g C m^{-2} yr^{-1} (SAIGUSA & al. 2002, MO & al. in press). Root respiration accounted for 45.2 ± 0.6 % of F_{SR}; this ratio is also consistent with an experimental evaluation, 45 %, by LEE & al. 2003.

As a whole, the model could retrieve (at least major parts of) the ecosystem carbon cycle with an acceptable accuracy, and thus provides a useful framework for interpreting the carbon budget. In a forthcoming study, the model simulation result using the modified Sim-CYCLE will be compared with other model results.

Also, the model will be applied to other AsiaFlux sites (e.g., coniferous forest in northern Japan and tropical rain forest in Malaysia), to examine model applicability and to make inter-site comparisons. Finally, the site-scale findings will be used to improve reliability of the region-scale carbon budget estimations by the GERF-S1 project.

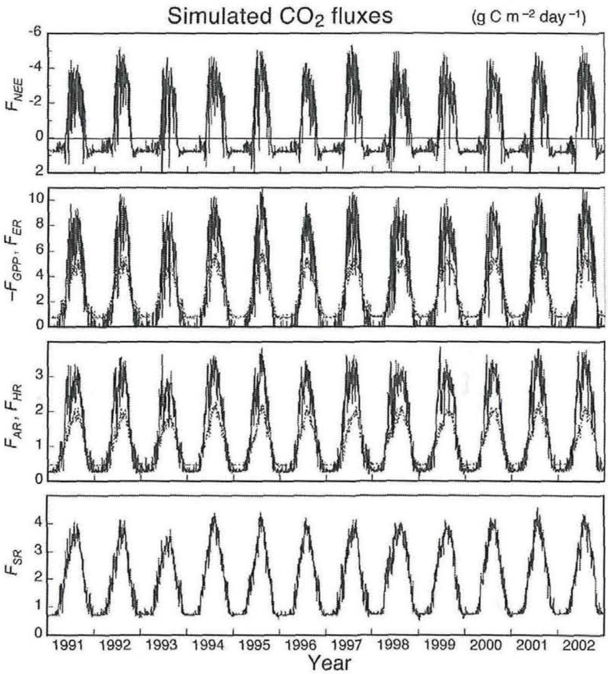

Fig. 2. Estimated daily gross and net CO_2 fluxes at the Takayama site in 1991–2002.

Acknowledgements

Observation data were provided from the National Institute of Advanced Industrial Science and Technology, Japan and by the Institute for Basin Ecosystem Studies, Gifu University, Japan. This study was partly supported by the Ministry of the Environment, Japan (Global Environment Research Fund S-1:Integrated Study for Terrestrial Carbon Management of Asia in the 21st Century Based on Scientific Advancements).

References

ITO A. & OIKAWA T. 2002. A simulation model of the carbon cycle in land ecosystems (Sim-CYCLE): A description based on dry-matter production theory and plot-scale validation. – Ecol. Model. 151: 147–179.

— , SAIGUSA N., MURAYAMA S. & YAMAMOTO S. Modeling of gross and net carbon dioxide exchange over a cool-temperate deciduous broad-leaved forest in Japan: analysis of seasonal and interannual change. – Agr. For. Meteorol. (in press)

JIA S. & AKIYAMA T. 2003. Development of a precise and unifying estimation method for forest ecosystem carbon storage and a new simple-quick survey method for soil carbon storage, in proceedings of synthesis workshop on the carbon budget in Asian monitoring network, pp. 49–52, Takayama, Japan.

LEE M.-S., NAKANE K., NAKATSUBO T. & KOIZUMI H. 2003. Seasonal changes in the contribution of root respiration to total soil respiration in a cool-temperate deciduous forest. – Plant Soil 255: 311–318.

MO W., LEE M.-S., UCHIDA M., INATOMI M., SAIGUSA N., MARIKO S. & KOIZUMI H. Seasonal and annual variations in soil respiration in a cool-temperate deciduous broad-leaved forest in Japan. – Agr. For. Meteorol. (in press)

OHTSUKA T. 2003. Biometric based estimates of annual carbon budget in a cool-temperate deciduous forest stand beneath a flux tower, in proceedings of synthesis workshop on the carbon budget in Asian monitoring network, pp. 37–40, Takayama, Japan.

SAIGUSA N., YAMAMOTO S., MURAYAMA S., KONDO H. & NISHIMURA N. 2002. Gross primary production and net ecosystem exchange of a cool-temperate deciduous forest estimated by the eddy covariance method. – Agr. For. Meteorol. 112: 203–215.

YAMAMOTO S., MURAYAMA S., SAIGUSA N. & KONDO H. 1999. Seasonal and inter-annual variability of CO_2 flux between a temperate and the atmosphere in Japan. – Tellus 51B: 402–413.