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Assessments of climate change impacts on the terrestrial ecosystem in Japan using the Bio-Geographical and GeoChemical (BGGC) Model

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Summary. This study assessed the future impacts of global climate change on the distribution and functioning of terrestrial ecosystems in Japan using the Bio-Geographical and GeoChemical model (BGGC model). The model enables us to simulate the carbon and nitrogen cycles within ecosystems on the basis of estimated potential natural vegetation distribution. In this study, changes in net primary productivity (NPP) and the distribution of potential natural vegetation were evaluated for assessments of climate change impacts. The GCMs experimental data used for future climate conditions were the CSIRO-Mk2 and ECHAM4/OPYC3 for each of A2 and B2 scenarios in the SRES. Comparison of the averages of simulated NPP under each scenario with the average NPP under current climate conditions showed that the average NPP could increase about 19 to 33 percent by the year 2050s and 25 to 53 percent by the year 2080s with changes in potential natural vegetation type.

Key words. BGGC model, Japan, Potential natural vegetation, NPP

1. Introduction

Vegetation in terrestrial ecosystems provides not only an important habitat for animals but most importantly it plays a significant role in the cycle of carbon and nutrients. IPCC reports indicated that the changes in global climate caused by the continual increase in greenhouse gases will affect the ecosystem in future. For evaluation of the impact, there are several process-based models to simulate vegetation distribution, carbon and nutrient cycle (Haxeltine and Prentice 1996; Neilson et al. 1998; Ishigami et al. 2002, 2003; Levy et al. 2004; Hajima et al. 2005). The process-based model includes knowledge on the physiological responses of plants to environmental change. This is a suitable model for predicting the effect of climate change on the ecosystem because the plant's physiological and ecological functions must be considered. The objective of this study is to assess the future impacts of global climate change on the distribution and functioning of terrestrial ecosystems in Japan using the Bio-Geographical and GeoChemical model. We evaluated changes in net primary productivity (NPP) and the distribution of potential natural vegetation for assessments of climate change impacts. NPP denotes the net production of organic matter by plants in an ecosystem, and is one of important indicators to provide information on the carbon budget of terrestrial ecosystem.

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2. Model structure

The BGGC model consists of two types of process-based model. The one is the bio-geographical model, which puts emphasis on the determination of what kind of vegetation could live in a given location. The other is the bio-geochemical model, which simulates the carbon and nutrient cycles within ecosystems on the basis of given vegetation distribution.

Most of the basic structures of some modules in the model were borrowed from the modified BIOME3 (Ishigami et al. 2002) and sub-model of CENTURY4 (Parton et al. 1993). The BGGC model is divided into two sub-models, the vegetation competition sub-model and the soil organic matter sub-model. The vegetation competition sub-model contains the photosynthesis model and the canopy model. The photosynthesis model estimates the optimized net primary productivity (NPP) and leaf area index (LAI) for each plant functional type (PFT) to satisfy annual moisture and the soil nitrogen. In order to consider the effect of CO_2 and nitrogen on photosynthesis, the model contains the Farquhar photosynthesis model as simplified by Collats et al. (1991) and canopy photosynsynthesis model developed by Hikosaka (2003). The PFTs were determined by differences in phenological type (evergreen or deciduous), leaf type (broad-leaved or conifer) and the rooting depth. Competition among PFTs is simulated by using the estimated NPP of each PFT as an index of competitiveness. The PFT with the highest NPP is selected as the dominant type. The canopy model takes account of the effect of difference in the canopy structure of the forest vegetation on calculation of daily net photosynthesis. The distribution of potential natural vegetation types was determined by the selected PFT and the estimated NPP and LAI. On the other hand, the soil organic matter sub-model simulates carbon, nitrogen, and water dynamics in the soil ecosystem. The model includes three soil organic matter pools with different potential decomposition rates. The model is linked to the vegetation competition model by the exchange of soil nitrogen and NPP. Fig. 1 shows the schematic diagram of the BGGC model.

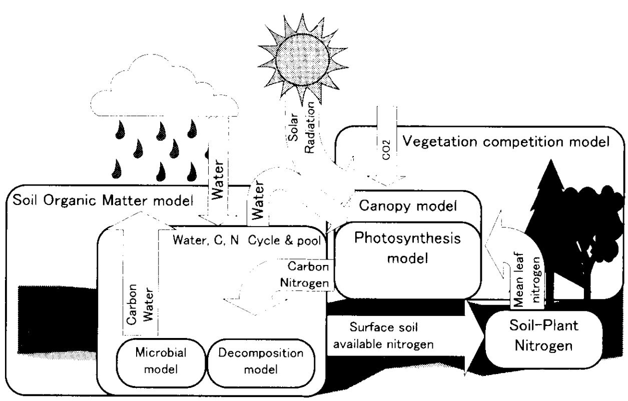


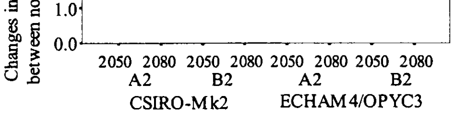
Fig. 1. Schematic diagram of BGGC model.

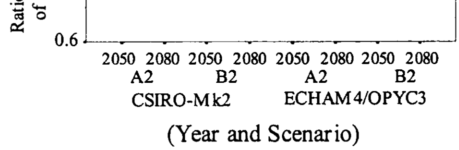
3. Data

3.1 Climate and soil data

Monthly climate normals data (average for 30 years; 1971 to 2000) and GCMs experimental data prescribed by IPCC-SRES (The Intergovernmental Panel on Climate Change, Special Report on Emissions Scenarios) were used in this study. Current and future climate input data consist of monthly mean temperature, monthly precipitation and solar radiation. The GCMs experimental data were the CSIRO-Mk2 and ECHAM4/OPYC3 for each of A2 and B2 scenarios in the SRES. Since each scenario has different assumptions on global population, gross world product, and technological change, future greenhouse gas (GHG) emissions are different. Although high-spatial resolution GCMs are required to assess the regional climate impacts, grid resolutions of current GCMs are roughly 3° longitude x 3° latitude. Yokozawa et al. (2003) statistically interpolated the GCMs data (based on the IS92a emission scenario) to a 10 x 10 sq. km grid data. This study applied the same method to GCMs data based on SRES scenarios. The number of grids is 4,691. Soil texture data was obtained from Haxeltine and Prentice (1996). All data were arranged in the form of a 10 x 10 sq. km grid system.

Fig. 2 shows boxplots of changes in annual mean temperature between normals and GCMs experimental data (CSIRO-Mk2 and ECHAM4/OPYC3) and those of ratios of





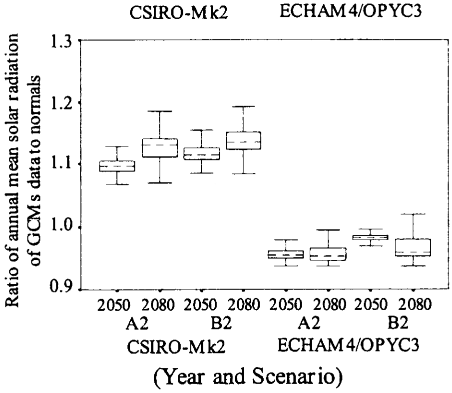


Fig. 2. Boxplots of changes in annual mean temperature, annual precipitation and mean solar radiation between normals and GCMs data. The central box indicates the interquartile range, and the dotted line in the box is the 50th percentile.

GCMs annual precipitation and mean solar radiation to normals. In both GCMs data, projected temperatures in the 2080s under the A2 scenario are higher than under the B2. Annual precipitation and solar radiation projected by CSIRO-Mk2 increased over Japan.

3.2 CO_2 concentration data

CO_2 concentration data for A2 and B2 scenarios were obtained from the IPCC WG-1 report (IPCC 2001). CO_2 concentrations in 2050 and 2080 for A2 scenario are 537 and 713 ppm respectively, Those for B2 scenarios are 476 and 570 ppm, respectively.

4. Results

Fig. 3 shows the estimated NPP and the distribution of potential natural vegetation type under current climatic conditions and CO_2 concentration (367 ppm). Comparing with the NPP distribution estimated by our previous model (Ishigami et al. 2002) on the basis of the simulation by Chikugo model (Uchijima and Seino 1985), the BGGC model could simulate it more successfully. The model has correctly estimated the vegetation distribution except for the broad-leaved evergreen forest in the Hokkaido region.

Fig. 4 shows the estimated NPP under CSIRO-Mk2 and ECHAM4/OPYC3 experimental data for each of A2 and B2 scenarios. The simulated NPP under CSIRO-Mk2 was larger than under ECHAM4/OPYC3. It depends on the difference in climatic conditions

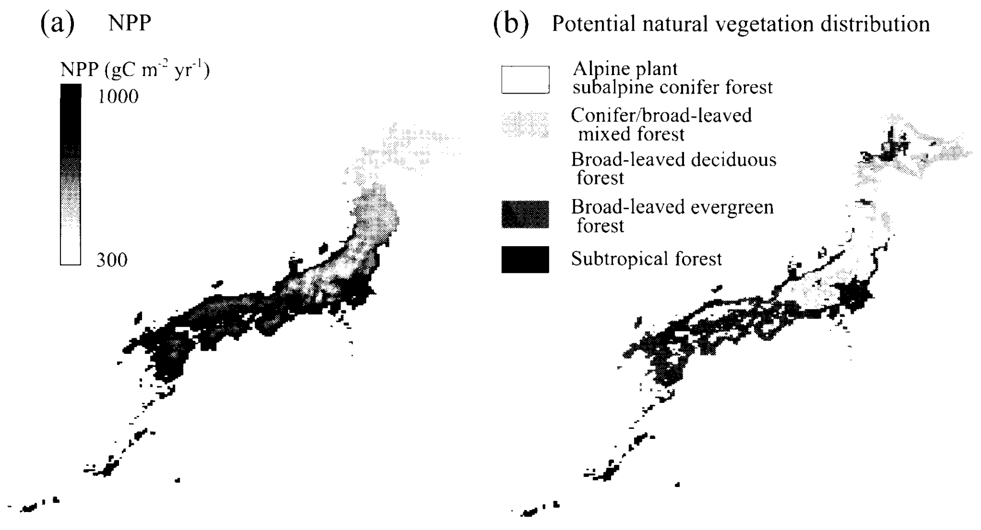


Fig. 3. Estimated (a) NPP and (b) distribution of potential natural vegetation type under current climatic conditions and CO_2 concentration.

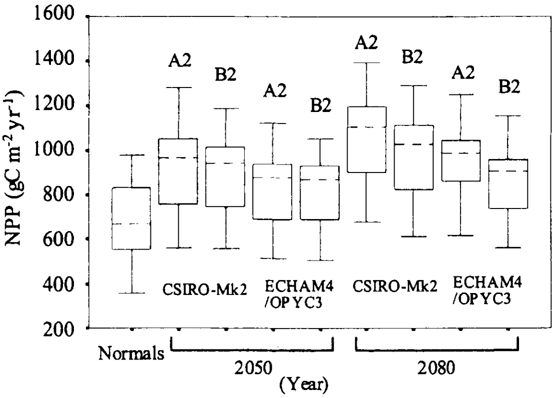


Fig. 4. Comparison of simulated NPP under each SRES scenario.

as shown in Fig. 2. Comparing the averages of simulated NPP for each scenario with the average NPP under current climatic conditions, an increase of 19 to 33 percent in the average NPP for year 2050s and about 25 to 53 percent for year 2080s can be observed with changes in potential natural vegetation type.

This study assessed the future impacts of global climate change on the distribution and functioning of terrestrial ecosystems in Japan using the BGGC model. The model has the characteristics of both a bio-geographical model and a bio-geochemical model which enable estimation of the potential distribution of natural vegetation using NPP under future climate conditions.

The model included the processes of CO_2 effect on NPP, the responses of NPP to climate that specifically considered plant functional type, and competition among PFTs for light and water. The model is also capable of determining which vegetation type is most suited for given climatic conditions. In order to improve characteristics as a bio-geochemical model, however, there is still a need to consider the dynamic processes involved in vegetation structure due to climate and CO_2 effects.

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