EARTH SYSTEM RESPONSE TO GLOBAL WARMING INFERRED BY SIMULATION USING A ONE-DIMENSIONAL ENERGY AND CARBON CYCLE COUPLED MODEL

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ABSTRACT

The coupled feedback processes of energy and carbon cycles are an essential mechanism for understanding global environmental change. We developed a simplified one-dimensional carbon and energy cycle coupled model to quantify the feedback processes between energy and carbon cycles. The model was calibrated to reproduce the historical variations in temperature and atmospheric CO_2 concentration. The model results of vertical ocean temperature profiles, and latitudinal NPP and NEP distributions were in good agreement with the observation data and terrestrial biosphere model results. The regional difference of terrestrial ecosystem response by climate feedback appeared in the middle and high latitudes. The north-south distribution is important to investigate the terrestrial ecosystem because the opposite response appeared in the middle and high latitude. The future change of carbon cycle and climate was also simulated up to the year 2100 based on the IPCC scenario. The atmospheric CO_2 concentration reaches 735 ppmv in 2100 and global average temperature increases 1.9 K for 2000-2100.

INTRODUCTION

Global warming due to increased greenhouse gases attributed to industrial activities and deforestation is a serious problem. Its mechanism includes the coupled feedback processes of energy and carbon cycles. Uncertainties in the feedback processes lead to a wide range of future projections of carbon cycle and climate change, and thus temperature variation. Recently many models incorporating the energy and carbon coupled cycles have been used to estimate the future global warming [*Cox et al.,* 2000; *Friedlingstein et al.,* 2001]. However, the terrestrial ecosystems in these models exhibit large differences in the land carbon fluxes (e.g. one responded as sink, and the other as source) and its regional responses by climate change are inexplicit because of uncertainties of its mechanism. Thus it is essential to evaluate the feedback processes by various sensitivity studies using a simplified earth system model that is suitable to analyze many feedback processes easily.

The purpose of this study is to analyze the effects of feedback processes and the regional response caused by global warming. In order to understand regional differences, we modified the original zero-dimensional earth system model [*Ichii et al.,* 2003] to the north-south one-dimensional model, quantified the feedback processes by sensitivity analyses, and investigated future projection based upon the IPCC scenario.

MODEL DESCRIPTION

We developed a simplified one-dimensional carbon and energy cycle coupled model, which consists of a north-south one-dimensional zonally averaged atmosphere-ocean energy balance model (EBM), and a box-type one-dimensional carbon cycle model. The atmosphere model is based on the EBM by Sellers [1969], and the ocean model includes energy and carbon cycles, and ocean circulation consisting of three advections based on INK model [Ishizawa et al., 2002]. The carbon cycle model includes atmosphere, terrestrial biosphere (vegetation and soil), ocean, and their interactive feedback processes. The following feedback processes of energy and carbon cycles are included in the model; (1) biospheric CO_2 fertilization on net primary production (NPP), (2) temperature dependency of NPP, (3) temperature dependency of soil decomposition, and (4) temperature dependency of ocean surface chemistry.

RESULT

The model was forced with total greenhouse gas emissions from industrial activities from 1750 to 1990, and was calibrated to reproduce the historical variations in temperature and atmospheric CO_2 concentration. We assumed that carbon cycle and climate were in steady state in pre-industrial era before 1750. Each model component was spun up based on pre-industrial greenhouse gas concentration, carbon cycle, and climate until the model reached steady state. The model results of the vertical ocean temperature profiles and latitudinal NPP / NEP distributions were in good agreement with the observation data and terrestrial biosphere model results. The atmospheric CO_2 concentration trend was reproduced well, and the atmospheric temperature rise of 0.9 K from 1850 to 2000 was in good agreement with observations.

The future status of the global carbon cycle and climate was also simulated up to the year 2100 based on the IPCC IS92a emission scenario. The atmospheric CO_2 concentration reaches 735 ppmv in the coupled simulation in 2100 (370ppm in 2000) and 658ppmv in the offline (without coupling) simulation, and global average temperature increases 1.9 K for 2000-2100 (Fig. 1 (a)).

The regional difference of terrestrial ecosystem response by climate feedback appeared more significantly in the coupled model particularly in the middle and high latitudes (Fig. 1 (b)). The north-south distribution is important to investigate the terrestrial ecosystem because the opposite response appeared in the middle and high latitudes. The sensitivity studies showed that temperature dependency of NPP and soil decomposition has large uncertainties in carbon uptake between atmosphere and terrestrial ecosystem that greatly influences global carbon balance.

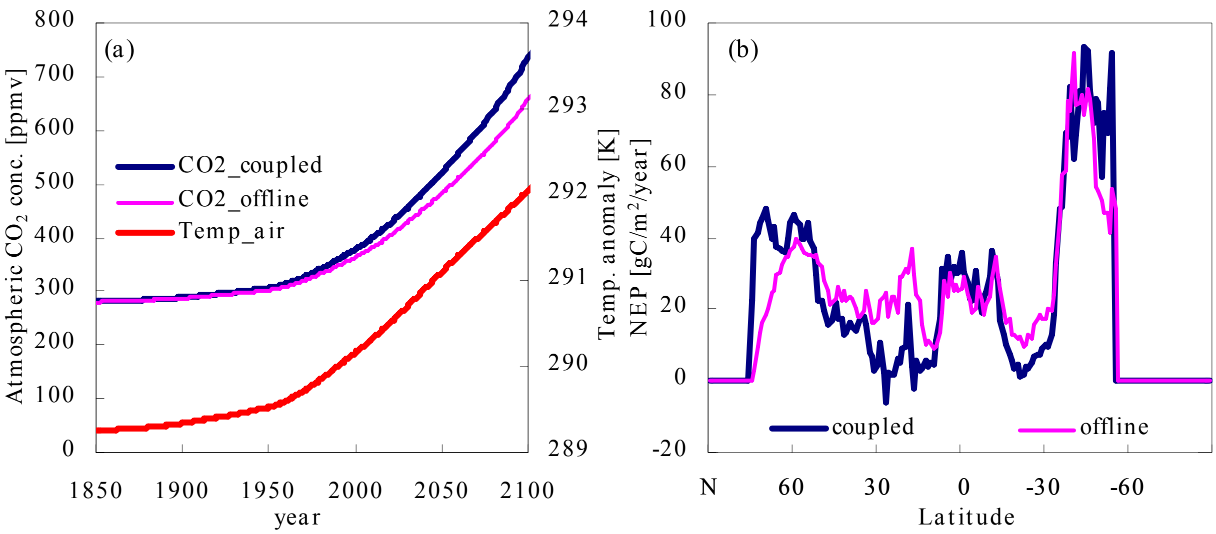

Fig. 1 (a) Future projections of atmospheric CO_2 concentrations in the coupled and offline (without coupling) simulations, and global averaged temperature change. (b) Latitudinal NEP change from 2000 to 2100 in the coupled and offline simulations.

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