CO_2 UPTAKE OF THE BIOSPHERE: FEEDBACKS BETWEEN THE CARBON CYCLE AND CLIMATE CHANGE USING A DYNAMIC EARTH SYSTEM MODEL

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ABSTRACT

Different CO_2 stabilization scenarios and CO_2 emission scenarios have been carried out with an earth system model to investigate feedbacks between future climate change and carbon cycle. The model predicts a sensitivity of 1.6±0.1 K for an increase of 280 ppm in atmospheric CO_2 concentration. The decrease of the thermohaline circulation is predominantly controlled by an enhanced atmospheric moisture transport to high latitudes by global warming. Overall, the simulated effect of atmospheric CO_2 concentration on climate change reduces the total carbon uptake of the ocean and the land is reduced by 24-29%.

INTRODUCTION

The potential for two-way interactions and feedbacks between the carbon cycle and the climate system comes from the radiative properties of CO_2 and other greenhouse gases in the atmosphere. Several studies indicate overall positive feedbacks due to global warming [see e.g. *IPCC*, 2001; *Govindasamy et al*., 2005, and literature therein], but many of the processes are quantitatively not well known. In this study, feedbacks arising from continental ice sheets and the global carbon cycle are considered by using a comprehensive earth system model including all major components of the climate system. Specifically, we focus on two questions: (i) how will a polar fresh water input by integrated changes in surface circulation, continental ice sheets, and enhanced precipitation affect the thermohaline circulation on decadal-to-centennial time scales, and (ii) how may these changes in the ocean circulation affect carbon uptake in the ocean and on land.

MODEL DESCRIPTION

In this study, we apply an earth system model (ESM) developed at the Max-Planck-Institute for Meteorology and the University of Wisconsin-Madison (MPI/UW ESM) that includes the dominant climate components, which are the atmosphere, ocean, land biosphere, oceanic carbon cycle, cryosphere. The physical ocean and atmosphere components of the ESM are an improved version of the coupled atmosphere-ocean ECHAM3/LSG [*Mikolajewicz and Voss*, 2000] including a more sophisticated parameterization of the mixed-layer and eddy-induced tracer transport. The dynamic vegetation part of the ESM is the Lund-Potsdam-Jena dynamic global vegetation model (LPJ) [*Sitch et al.*, 2003], the marine biogeochemical model part is HAMOCC3 [*Maier-Reimer*, 1993], and the dynamic continental ice sheet component is the three-dimensional thermomechanical ice sheet model SICOPOLIS [*Greve*, 1997].

RESULTS

In order to study the sensitivity of the feedbacks between the carbon cycle and the climate, a control experiment and seven atmospheric sensitivity experiments with prescribed atmospheric CO_2 concentrations and with different stabilization levels (as used by IPCC, 2001) were conducted. The prescribed CO_2 concentration increases by 1% per year until it stabilizes after 70 years for $2xCO_2$, 110 years for $3xCO_2$, and 140 years for $4xCO_2$, respectively. In addition, A1B, A2, and B1 IPCC emission scenarios have been carried out.

Relatively moderate climate sensitivity to changes in the atmospheric CO_2 concentration (*IPCC*, 2001) is indicated by an increase of global mean surface temperature of 1.6±0.1 K for an increase of 280 ppm. For stabilization scenarios, the thermohaline circulation in the North Atlantic overturning cell is shallower than in the control run (not shown), and breaks almost down for scenarios above $3xCO_{fee}$. Overall, the deep Pacific circulation in the 3x and higher CO_2 concentration below 2.5 km is substantially reduced and thus prone to low oxygen or anoxic conditions. Changes in freshwater input from ice sheets by global warming have a secondary impact on variations in the thermohaline circulation and carbon cycle for the first 1000 years. However, uncertainties remain in ice sheet modeling, for example with regard to the role of ice shelves (not modeled in this approach but relevant for the evolution of the Antarctic ice sheet) and basal temperate ice layers potentially causing ice sheet instabilities.

Increased equatorial upwelling and a reduced biological pump enhance the gas exchange of carbon from the oceans to the atmosphere, lowering the CO_2 storage by the oceans (Fig. 1). On land, CO_2 fertilization of plants and carbon emissions by increase in soil temperature reducing the anthropogenic carbon uptake. Uncertainties in the feedbacks between the climate and the marine carbon cycle remain and a better representation of the important processes, like those summarized by the Joint Global Ocean Flux Study [*Fasham*, 2003], need to be subject of future investigations by the enhanced use of inverse methods.

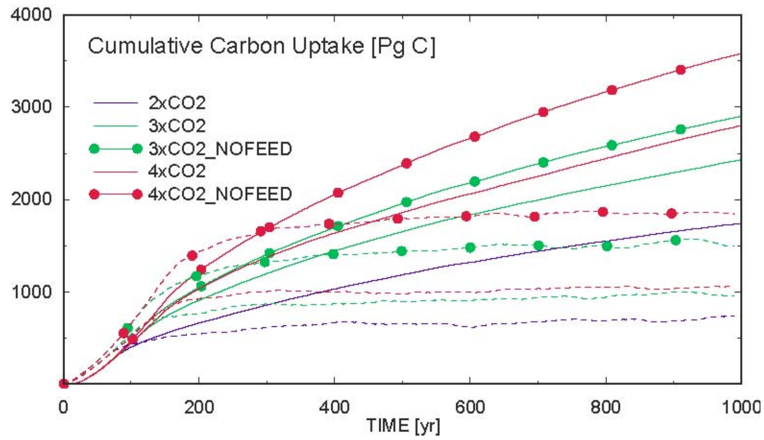

Fig. 1. Cumulative carbon uptake by the ocean (solid) and by the land (dashed). NOFEED denotes an experiment without climate change due to radiative forcing.

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