NEW COUPLED CLIMATE-CARBON SIMULATIONS WITH THE IPSL MODEL: FROM VALIDATION WITH ATMOSPHERIC CO2 AND SATELLITE DATA TO FEEDBACK ANALYSIS

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ABSTRACT

We have developed a Climate-Carbon coupled model based on the IPSL OAGCM and on two biogeochemical models, ORCHIDEE for the continent and PISCES for the ocean, to investigate the coupling between climate change and the global carbon cycle. We have performed four climate-carbon simulations over the 1860-2100 period in which atmospheric CO_2 is interactively calculated. They are :

- A control coupled simulation with no anthropogenic emissions.
- A coupled simulation with anthropogenic emissions.
- A coupled simulation with anthropogenic emissions including non-CO_2 greenhouse and sulfate aerosols.
- An uncoupled carbon simulation with the same anthropogenic emissions as second simulation but for which atmospheric CO_2 change has no impact on climate.

Compared to the first IPSL Climate-Carbon coupled model [*Dufresne, et al*., 2002], the simple carbon models have been replaced by IPSL advanced ocean and land biogeochemical models, respectively PISCES and ORCHIDEE. CO_2 is transported in the atmosphere and compared with observations. Comparison with satellite data is also done. We then analyze the coupled and uncoupled simulations, highlight the importance of the climate change both on the oceanic and biosphere sink and estimate the climate-carbon feedback. The results are also compared to the outputs of other models participating in the C4MIP inter-comparison project. Finally, off-line simulations are carried out to perform sensitivity tests (fire, dynamics of land and ocean ecosystems, soil respiration) in order to identify the key processes which govern the simulated response.

INTRODUCTION

Atmospheric CO_2 concentration is one of the most important factors likely to determine the climate of the 21st century [*Houghton et al*., 2001]. When forecasting future climate changes, the majority of experiments with comprehensive climate models (OAGCMs) still use prescribed CO_2 concentration scenarios. However the atmosphere-land and atmosphere-ocean fluxes of CO_2 are known to be sensitive to climate. For example, the growth-rate of atmospheric CO_2 responds to climatic perturbations such as El Niño. Offline carbon cycle simulations of the 21st century have indeed confirmed such large dependency of carbon fluxes to climate [*Houghton et al.,* 2001]. Since an increase in CO_2 leads to climatic change, and that climatic change, in turn, affects the CO_2 concentration, climate and CO_2 form a feedback loop. Cox et al., [2000] and Dufresne et al, [2002] found this feedback to be positive. Since these two studies, numerous models performed coupled climate-carbon cycle simulations following a similar protocol, called C4MIP. It underlined a large uncertainty in the models' responses. The climate-carbon cycle feedback leads to an addition of atmospheric CO_2 ranging anywhere between 20 and 200 ppm. Here we develop a new climate-carbon cycle model with special emphasis on experiment design and validation in order to be more confident in future projections.

MODEL AND RUNS DESCRIPTION

The IPSL coupled ocean-atmosphere general circulation model, IPSL-CM4 [*Marti et al.,* 2005] used for the IPCC-AR4 simulations, has been coupled to a carbon model composed of the PISCES biogeochemical model [*Aumont, et al.,* 2003] for the ocean part and of the ORCHIDEE model for the terrestrial part [*Krinner et al*., 2005]. ORCHIDEE is a dynamic global vegetation model which calculates for 13 PFTs, the energy and hydrology budgets, carbon assimilation, allocation and decomposition and vegetation competition. PISCES includes a simple marine ecosystem model, with 4 plankton functional groups and co-limitation of phytoplankton growth by N, P, Si and Fe. PISCES is called at each timestep of the ocean physic, and ORCHIDEE is called at each time step of the atmosphere physic.

We have performed 4 major coupled simulations to highlight the response of the land and ocean carbon cycles to atmospheric CO_2 increase and climate change. The first one is a control simulation without anthropogenic CO_2 sources. The second (coupled run) is a scenario simulation where CO_2 emissions are prescribed from historical data for 1860-2000 [*Marland et al.* 2005, *Houghton and Hackler*, 2002] and from the SRES-A2 scenario for the 21^{st} century. The third one (coupled-all forcing) is a variant of the second simulation including non-CO_2 greenhouse gases and sulfate aerosols. Finally, the fourth simulation (uncoupled run) uses the same CO_2 emissions as the second simulation but the calculated CO_2 concentration has no radiative impact.

VALIDATION AND ANALYSIS

First we analyze the control simulation, expecting no significant drift in both simulated climate and atmospheric CO_2. Then we use the control and uncoupled runs on one hand, and coupled and uncoupled runs on the other to respectively isolate the impact of atmospheric CO_2 increase and of climate change on the carbon cycle. Finally the coupled-all forcing run allows for a closer comparison with the IPCC-AR4 simulations. Also, the last run, when compared to the coupled run will show the impact of non-CO_2 GHG induced warming on the carbon cycle and therefore on the climate-carbon feedback.

We use the coupled simulation to evaluate the simulated biological fields from ORCHIDEE and PISCES (eg. productivity, chlorophyll, Leaf Area Index.) with respect to available data sets. As CO_2 (oceanic, continental and anthropogenic) is transported, we also compare the simulated atmospheric CO_2 distribution with station data in order to analyze the seasonal, inter-annual and decadal carbon budget.

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