SYNERGISM OF TERRESTRIAL CARBON CYCLE FEEDBACKS IN SIMULATIONS OF FUTURE CLIMATE CHANGE

H.D. Matthews

Department of Geography, University of Calgary, 2500 University Drive N.W., Calgary, Alberta, T2N 1N4, Canada; dmatthew@ucalgary.ca

ABSTRACT

This paper examines two key feedbacks that operate between the terrestrial carbon cycle, atmospheric carbon dioxide (CO_2) and climate: the positive carbon cycle-climate feedback and the negative CO_2 fertilization feedback. Both feedbacks affect strongly the growth rate of future atmospheric CO_2, and interact in such a way that the effect of one is notably modified in the absence of the other.

INTRODUCTION

Terrestrial carbon cycle feedbacks have the potential to either slow or accelerate the rate of accumulation of carbon dioxide in the atmosphere. A negative feedback involving the stimulation of vegetation growth by increased CO_2 (CO_2 fertilization), is thought to be an important contributor to the present terrestrial carbon sink, and has the potential to significantly slow the rate of increase of future atmospheric CO_2 [*Prentice et al.*, 2001]. A positive feedback resulting from decreased terrestrial carbon uptake as a result of climate changes has been highlighted in recent model simulations as an important potential amplifier of future climate change [e.g., *Cox et al.*, 2000; *Matthews et al.*, 2005]. In this paper, I quantify the effect of each of these feedbacks using a coupled climate-carbon cycle model, and examine their interactions in a series of model simulations.

MODEL AND METHODS

The model used for this research is the University of Victoria Earth System Climate Model (UVic ESCM), comprised of an intermediate complexity physical climate model coupled to inorganic ocean and terrestrial carbon cycle components [*Weaver et al.*, 2001; *Matthews et al.*, 2005]. The model was forced by observed and future (SRES A2) anthropogenic CO_2 emissions from 1750 to 2100. Four runs were performed: (1) a fully coupled simulation with both positive and negative feedbacks active (COU); (2) an uncoupled-climate simulation in which climate changes did not affect the carbon cycle, and thus only the negative CO_2 fertilization feedback was active (UNC-CL); (3) an uncoupled-CO_2 simulation in which modeled CO_2 increases did not affect the terrestrial carbon cycle, and thus only the positive carbon cycle-climate feedback was active (UNC-CO_2); and (4) a fully uncoupled simulation in which neither positive nor negative feedbacks were active (UNC).

RESULTS

The model reproduced well the observed CO_2 concentration (shown in the inset of Fig. 1, left panel), with a small (~5 ppmv) overestimate of present-day CO_2 in the COU simulation. Simulations without CO_2 fertilization (UNC-CL and UNC) resulted in large overestimates of present-day CO_2, emphasizing the important contribution of CO_2 fertilization in the model to the present terrestrial carbon sink.

The effects of positive and negative feedbacks on simulated CO_2 are shown in the right panels of Fig. 1. Panel (a) represents the magnitude of the positive carbon cycle-climate feedback: the difference between the COU and UNC-CL runs resulted in an increase in simulated CO_2 of 130 ppmv at the year 2100 which can be attributed to this positive feedback. The positive carbon cycle-climate feedback in the absence of CO_2 fertilization is shown in panel (b); when the UNC-CO_2 and UNC runs were compared, the magnitude of the positive carbon cycle-climate feedback was found to be amplified, leading to a 200 ppmv CO_2 increase at the year 2100. The magnitude of the negative CO_2 fertilization feedback is shown in panels (c) and (d) for the case with (COU – UNC-CO_2: –300 ppmv CO_2 difference at 2100) and without (UNC-

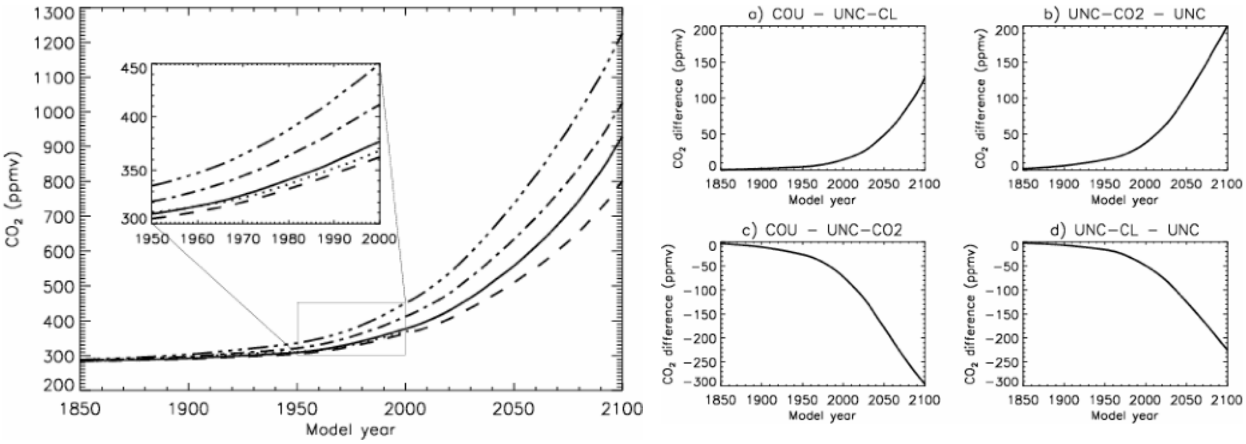

Fig. 1. Left Panel: simulated atmospheric CO_2 for the four model runs: COU (solid line), UNC-CL (dashed line), UNC-CO_2 (dash-triple dot) and UNC (dash-dot), with observed CO_2 shown from 1850 to 2004 (dotted line). Right Panels: effect of the carbon cycle-climate feedback on atmospheric CO_2 with (a) and without (b) CO_2 fertilization; effect of CO_2 fertilization with (c) and without (d) climate changes.

CL – UNC: –200 ppmv CO_2 difference at 2100) the positive carbon cycle-climate feedback. The magnitude of each feedback is dependent on the strength of the other, revealing a synergism of feedbacks in the terrestrial carbon cycle.

DISCUSSION

Numerous recent modeling studies have demonstrated a positive carbon cycle-climate feedback, though the magnitude of this feedback has varied substantially between models [e.g. *Friedlingstein et al.*, 2003]. The finding here that weak CO_2 fertilization amplifies positive carbon cycle feedbacks can be used to understand in part this spread in model-simulated feedbacks, given that different carbon cycle models have been shown to differ in the strength of their respective CO_2 fertilization effects [*McGuire et al.*, 2001]. The dependence of the CO_2 fertilization feedback on the magnitude of climate changes in the model demonstrates the sensitivity of photosynthesis processes in the model to changes in climatic conditions; in particular, CO_2 fertilization was enhanced at higher temperatures in the model.

These results highlight the strong association between climate and the carbon cycle and the importance of including a dynamic carbon cycle in simulations of future climate change. Further, the complexity of the terrestrial carbon cycle is evident here, emphasizing the need to improve our understanding of how present and future climate changes will affect the role of the terrestrial carbon cycle in the climate system.

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