SIMULATING CARBON SEQUESTRATION IN COUPLED CLIMATE-CARBON MODELS

A.W. King[1] and W.M. Post III[2]

[1]*Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6335; kingaw@ornl.gov*

[2]*Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6335; postwmiii@ornl.gov*

ABSTRACT

Prognostic simulation of carbon sequestration and carbon management must provide for the influence of potential changes in future atmospheric CO_2 concentrations and climate on carbon cycle processes. The conventional approach is to use various scenarios of changes in atmospheric CO_2 and climate as external inputs to carbon cycle models. However, this approach decouples potentially important feedbacks between the carbon cycle and climate, and thus contributes uncertainty to the simulation of future carbon sequestration and the evaluation of carbon management options. Here we describe modeling results that analyze components of this uncertainty. We describe how coupling a carbon management model with a climate model in fully coupled climate-carbon simulations influences the analysis and interpretation of terrestrial ecosystem sequestration as an option for future carbon management.

INTRODUCTION

Carbon sequestration in vegetation and soils occurs in unmanaged ecosystems as the result of changes in atmospheric CO_2 concentrations and climate variables that regulate terrestrial ecosystem carbon storage and exchange with the atmosphere. Carbon sequestration may also result from intentional effort in managed terrestrial ecosystems, but the carbon dynamics of these managed systems are also influenced by changes in atmospheric CO_2 and climate. Simulations of terrestrial sequestration and carbon management over the 21st century must include the forcings from a changing climate accompanying a future of elevated atmospheric CO_2 and other greenhouse gases as well as the direct intervention by humans on the biogeochemistry of managed ecosystems. However, the future climate forcing used in these carbon management simulations are usually derived from climate models that do not include an interactive carbon cycle, and thus they miss the important climate-carbon cycle feedbacks that have been recently revealed by coupled climate-carbon model simulations. In the context of carbon management analyses, in particular, such analyses miss the feedbacks among purposeful carbon management, its influence on atmospheric CO_2, the influence of atmospheric CO_2 on climate, and the subsequent influence of climate on managed and unmanaged ecosystem carbon sequestration. This decoupling is a source of uncertainty in evaluating potential carbon management options. To address these uncertainties, and to provide for a more comprehensive analysis of carbon management in a future of potentially changing climate, we have coupled a model of global carbon management with a global climate model providing for prognostic modeling and analysis of carbon sequestration and management in fully coupled climate-carbon simulations. We first present simulations using a scenario of future climate change from an independent decoupled climate model. These runs indicate that future carbon management must compensate for carbon released in response to climate change as well as the emissions from energy utilization. We then describe how coupling the carbon management model with the climate in fully coupled climate-carbon simulations influences the analysis and interpretation of these results.

THE MODEL

The coupled climate-carbon management model is a coupling of the CarMan global carbon management model [*King et al*., 2001] with the current release of the Community Climate System Model (CCSM3.0). CCSM3.0 is a fully coupled (atmosphere, ocean, land surface, and sea ice) model for simulating the earth's climate system (http://www.ccsm.ucar.edu). The coupling between CarMan and CCSM is relatively straightforward. The daily integral of canopy photosynthesis calculated by the land-surface model of CCSM (Community Land Model, CLM) is passed to CarMan's terrestrial ecosystem biogeochemistry module (the Global Terrestrial Ecosystem Model GTEC V2.0 of *Post and King* [2005]) as daily gross primary production (GPP). The ecosystem biogeochemistry module then simulates the allocation of that gross carbon uptake to plant parts and the respiratory loss of carbon for both growth and maintenance of these parts, as well as litter production and litter and soil decomposition, to calculate daily net ecosystem exchange of carbon (NEE) with the atmosphere through the CCSM flux coupler. Importantly, CarMan includes an energy emissions model (the ER model of *Edmonds and Reilly* [1993]) that predicts CO_2 emissions based on the input of an energy-economics scenario, which can include carbon management technologies and practices. Similarly, scenarios of land-use/land-cover change (e.g., deforestation, expansion of no-till agriculture, establishment of biomass-energy plantations, or management for terrestrial carbon sequestration) are inputs to the land-use emissions module of CarMan (the model of *King et al*. [1995]) that predicts CO_2 emissions resulting from changes in land-use. As a consequence, the coupled CCSM3-CarMan model is forced by energy-economics and land-use change scenarios rather than the anthropogenic emissions scenarios characteristically used to force coupled climate-carbon models.

RESULTS

Figure 1 illustrates prognostic runs of the uncoupled CarMan assuming no climate change (lower curve) and when forced by a future climate scenario defined by output from the Parallel Climate Model (PCM) in response to a business-as-usual scenario of future greenhouse gas concentrations and SO_2 emissions [*Dai et al*., 2001] (upper curve). With this projected climate, carbon is released as CO_2 from the terrestrial biosphere (primarily through soil response to warmer temperatures), resulting in higher future CO_2 concentrations than expected in the absence of climate change (approximately 50ppm higher by 2100). These runs suggest that future carbon management must compensate for carbon released in response to climate change as well as the emissions from energy use.

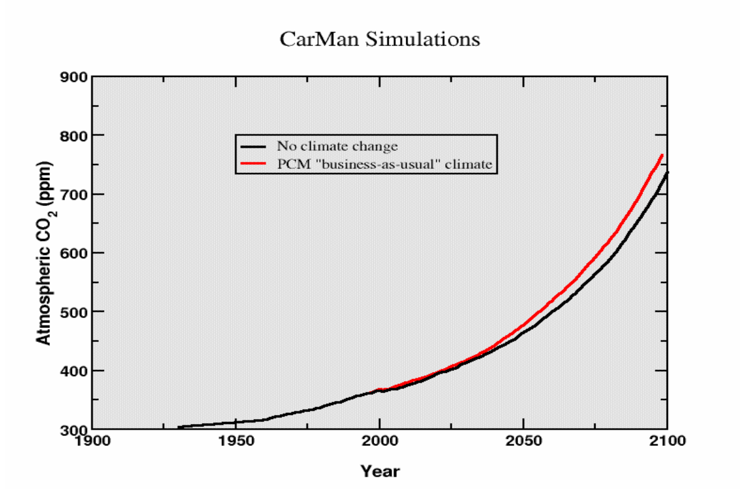

Fig.1. Simulate changes in atmospheric CO_2 concentration from the uncoupled CarMan carbon management model with and without future climate change (upper and lower curves, respectively).

Fully coupled climate-carbon simulations generally show a positive feedback between climate and carbon, with higher simulated atmospheric CO_2 concentrations and enhanced greenhouse warming. With warmer temperatures, CarMan's biogeochemistry module will likely release more carbon from the soils to the atmosphere, implying that carbon management strategies must compensate for even more climate related release of CO_2 than predicted using and independent scenario of climate change in an uncoupled analysis.

REFERENCES

Dai, A. et al., (2001), Ensemble simulation of twenty-first century climate changes: business-as-usual versus CO_2 stabilization, *Bulletin of the Am. Meteorol. Soc.* 82:2377-2388.

Edmonds, J., and J. Reilly (1993), A long-term global energy-economic model of carbon dioxide release from fossil fuel use, *Energy Economics* 5:74-88.

King, A. W., W. R. Emanuel, S. D. Wullschleger, and W. M. Post, III (1995), In search of the missing carbon sink: a model of terrestrial biospheric response to land-use change and atmospheric CO_2, *Tellus* 47B:501-519.

King, A. W., M. J. Taylor, M. P. Farrell, and K. L. Yuracko (2001), CarMan: Next-Generation Carbon Management Analysis, in *Proceedings of the First National Conference on Carbon Sequestration*, DOE/NETL-2001/1144.

Post, W. M., III, and A. W. King (2005), Climate Change and Terrestrial Ecosystem Production, in *Global Climate Change and Food Security*, edited by R. Lal, CRC Press, in press.