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C-LAMP Subproject Description:Climate Forcing by the Terrestrial Biosphere During the Second Half of the 20th Century

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1. Introduction

This project will quantify selected components of climate forcing due to changes in the terrestrial biosphere over the period 1948-2004, as simulated by the climate / carbon-cycle models participating in C-LAMP (the Carbon-Land Model Intercomparison Project; see http://www.climatemodeling.org/c-lamp). Unlike other C-LAMP projects that attempt to close the carbon budget, this project will focus on the contributions of individual biomes in terms of the resulting climate forcing. Bala et al. (2007) used a similar (though more comprehensive) model-based technique to assess and compare different components of biospheric climate forcing, but their focus was on potential future deforestation rather than the historical period.

To the extent that its effects benefit humanity, climate forcing by natural ecosystems can be termed a "climate service" (Bonan 2008, Malhi et al. 2008), one component of ecosystem services. Bonan notes that the primary influence of forests on climate arise from albedo, evaporative cooling and carbon sequestration. He concludes, "The net climate forcing from these and other processes is not known." Similar statements could be made for other biomes (grassland, tundra, . . .).

As we discuss below, comparing different types of biogenic climate forcing is not straightforward. Also, radiative forcing at the top of the atmosphere due to increased atmospheric carbon dioxide is defined to be the change in net energy flux that would occur immediately after an instantaneous increase, before the climate below the stratosphere responds. Obviously this requires a theoretical model in order to be "measured."

This project will examine climate forcing simulated by two different models, each running three different numerical experiments. None of our quantities of interest are comprehensively observed. Therefore, although we will check whether or not the model simulations are consistent with available observations, our main focus we be comparing the models with each other. Our results will provide information about how the simulated climate forcing depends on assumptions in the models and assumptions underlying the numerical-experiment scenarios (boundary conditions). To the extent that the results are consistent across models and scenarios, our results may also identify aspects of biogenic climate forcing that are theoretically "robust."

2. Methods

The current phase of C-LAMP employs Version 3 the Community Climate System Model (CCSM3) coupled to either the CASA-prime (Fung et al. 2005) or CN (P. Thornton et al., submitted manuscript) terrestrial biogeochemistry module. The main difference between the biogeochemistry modules is that only CN explicitly includes the effects of nitrogen limitation on plant growth.

Input data for this project will be taken from C-LAMP Experiments 1.3 – 1.5 (http://www.climatemodeling.org/c-lamp/protocol/protocol.html). All three of these numerical experiments use observed meteorology from NCEP / NCAR reanalysis for the years 1948-2004 as input, thereby incorporating global warming since the mid-20th century. Model output includes land surface fluxes of energy, water vapor and carbon dioxide. Atmospheric CO2 content, however, is not calculated from the CO2 fluxes; instead it is part of the prescribed input to the models. Experiment 1.3 uses pre-industrial atmospheric CO2, nitrogen deposition and land cover. Experiment 1.4 uses observed values of atmospheric CO2 and nitrogen deposition over the period of interest but keeps pre-industrial land cover. Experiment 1.5 uses observed atmospheric CO2, nitrogen deposition *and* land cover changes over the period of interest. Output from Experiments 1.3 – 1.4 is now available on the Earth System Grid (http://esg2.ornl.gov). Experiment 1.5 is planned but not yet done for C-LAMP.

We define, for each biome, the change in climate forcing from 1948 to time *t* as consisting of three components, each in units of Watts per square meter:

1. Change in absorbed solar (visible and near-infrared) energy flux at the surface
2. Change in latent heat flux at the surface
3. Change in radiative forcing at the top of the atmosphere due to CO2 lost from the atmosphere by sequestration in the biosphere

We may also consider secondary biogenic effects, such as organic aerosol production or changes in cloudiness due to Component (2), but our top priority will be examining Components (1) – (3).

Our sign convention for each of Components (1) – (3) is that positive values indicate a warming effect. Components (1) – (2) are standard output fields in AMIP, CMIP, etc., and presumably available from C-LAMP. Appropriately comparing Component (1) with Component (3)—e.g., in a global average as given in Figures 2.21 and 2.22 of Forster et al. 2007)—requires an estimate of cloud masking effects on surface albedo changes (Covey et al. 1991) so that we are comparing "apples with apples" (top-of-atmosphere fluxes with top-of-atmosphere fluxes). Evaporative cooling from Component (2) is local to the surface: apart from changes in atmospheric water vapor content, what goes up as evaporation comes down as precipitation with release of the latent heat somewhere in the atmosphere. Accordingly, Component (2) cannot be compared with (1) or (3). Nevertheless it may be important regionally.

Component (3) may be obtained by time-integrating net ecosystem exchange (NEE). This C-LAMP standard output field is defined as the difference between net primary productivity and respiration of dead plant matter (see http://www.climatemodeling.org/c-lamp/protocol/common_fields.html). Time-integrating NEE over the period of interest and multiplying by the area of the biome gives the decrease in atmospheric carbon due to that biome's sequestration, apart from changes due to ocean carbon storage and release. This may be converted to a change in atmospheric CO2 concentration, which in turn gives a change in climate forcing via the standard expression

$$\Delta F_{2\times} \cdot \frac{\ell n([CO2]/[CO2]_0)}{\ell n(2)} \approx \frac{\Delta F_{2\times}}{\ell n(2)} \cdot \frac{\Delta[CO2]}{[CO2]}$$

where $\Delta F_{2\times}$ = 3.7 Watts per square meter, $[CO2]$ is atmospheric carbon dioxide concentration (a function of *t*) and $[CO2]_0$ is the initial (1948) value of $[CO2]$ (Forster et al. 2007).

Inherent differences among the components defined above limit their comparison with each other. Because CO2 is long-lived and thus well-mixed in the atmosphere, each biome's input of carbon is spread globally for its contribution to $\Delta[CO2]$ and thus Component (3). In contrast, Components (1) and (2) are local. Also, as noted above, Component (2) should not be compared directly with (1) or (3).

3. Summary

The end product of this project will be Components (1) – (3) of climate forcing, taken from each C-LAMP simulation over the period 1948-2004, for each model-defined biome (actually for each model-defined land surface type, with the understanding that Component (3) is zero for surface types that don't sequester carbon). The primary question to be addressed in analysis of this product is how different assumptions regarding CO2-induced "greening," land use changes and nitrogen limitation of plant growth affect the climate forcing.

A second question is what (if any) aspects of the forcing are consistent across different models and scenarios. Such aspects may indicate the real-world situation if they are also consistent with available observations; if inconsistent with observations, they will indicate common problems that require attention in future model development.

We will publish our results in an appropriate peer-reviewed journal, probably *Global Biogeochemical Cycles*.

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