A Systematic Assessment of Terrestrial Biogeochemistry Models in the Community Climate System Model (CCSM)

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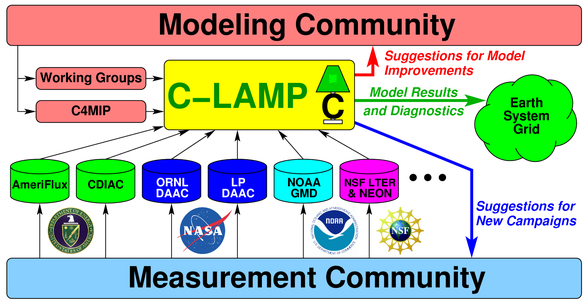
Introduction

As general circulation models (GCMs) evolve and improve, there is increasing interest in applying them to understand the potential for global climate change. The global carbon cycle is of particular importance since it may create a significant positive feedback on global warming. A wide array of carbon models have been coupled to GCMs, and recent work has shown that coupled interactive biogeochemical models can yield useful, but wide-ranging, results for climate change studies (*e.g.*, Friedlingstein *et al.* 2006).

Described here are model-data intercomparison experiments of general use for measuring the scientific performance of global biosphere models. Originally designed to test the performance of three such models coupled to the Community Climate System Model Version 3 (CCSM3), the Carbon-Land Model Intercomparison Project (C-LAMP) has evolved into an international protocol and a growing set of metrics for scoring the performance of models by comparison with best-available observational datasets, from satellite-based to leaf-scale measurements. C-LAMP is expected to serve as a prototype for biosphere model benchmarking for IPCC AR5.



By making use of the wide variety of mesaurements made, collected, and distributed by government agencies, C-LAMP identifies areas in which improvements can be made to models as well as identifying needs for new kinds of measurements. In addition, all the C-LAMP model output is distributed via the Earth System Grid (ESG), and model diagnostics are available on the Web for use by the wider scientific community.

C-LAMP Protocol

Experiment 1: "off-line" biosphere model runs forced with new NCEP/NCAR Reanalysis meteorological datasets (Qian *et al.* 2005)
1.1 Spin-up run
1.2 Control run (1798–2004)
1.3 Climate varying run (1948–2004)
1.4 Climate, CO_2, and N deposition varying run (1798–2004)
1.5 Climate, CO_2, N deposition, and land use varying run (1798–2004)

Experiment 1.4 results from CLM3-CASA´ and CLM3-CN models are being used for the North American Carbon Program (NACP) Regional Interim Synthesis

Experiment 2: partially coupled land-atmosphere model runs with prescribed sea surface temperatures (SSTs) and sea ice cover
2.1 Spin-up run
2.2 Control run (1800–2004)
2.3 Climate varying run (1800–2004)
2.4 Climate, CO_2, and N deposition varying run (1800–2004)
2.5 Climate, CO_2, N deposition, and land use varying run (1800–2004)

C-LAMP has produced a standard set of common output quantities for climate-carbon cycle models and recommendations for carbon accounting. These are being proposed as additions to the NetCDF Climate and Forecast (CF) Metadata Convention for output field names and units to be produced by terrestrial biogeochemistry components of Earth System Models for IPCC AR5.

The complete protocol, metrics for evaluation, and output approach are described at http://www.climatemodeling.org/c-lamp

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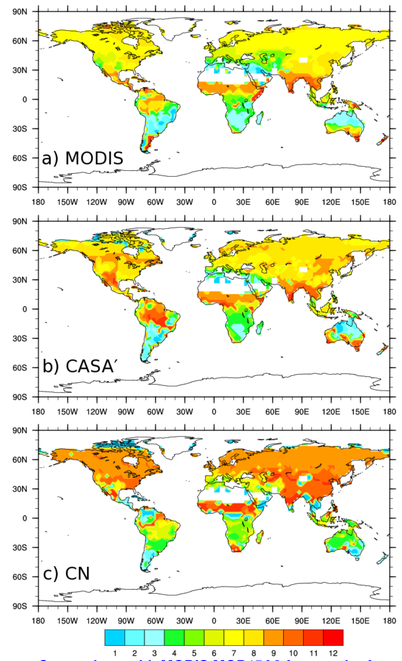
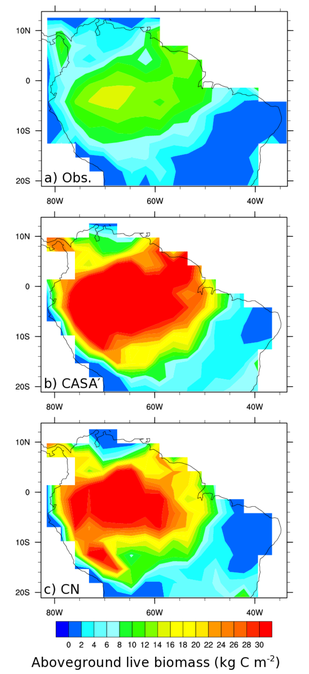
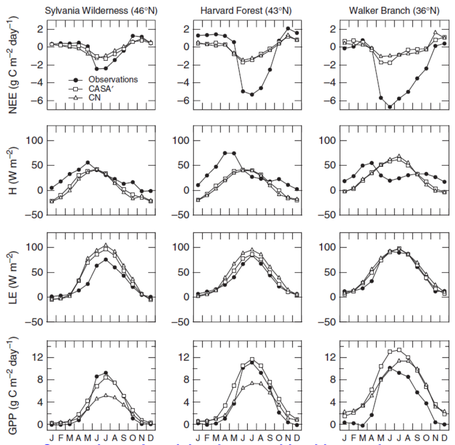
Experiment 1 Results for CASA´ and CN



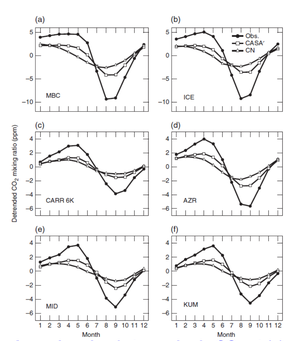
Comparison with MODIS MOD15A2 for month of maximum leaf area index (LAI). While direct comparison of model results with MODIS LAI values is problematic, it is expected that the month of maximum LAI from MODIS has a much lower uncertainty. Both models exhibited a 1–3 month delay in maximum LAI.



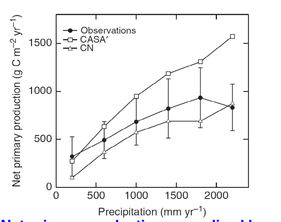
Comparison of aboveground live biomass with estimates provided by Saatchi *et al.* 2006. Both models significantly overestimated carbon storage in woody biomass.



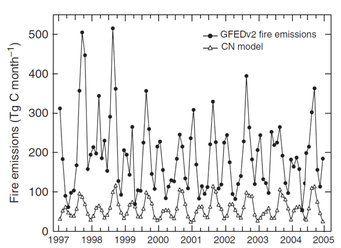
Comparison of model estimates with eddy covariance measurements from Sylvania Wilderness (Desai *et al.*, 2005), Harvard Forest (Barford, *et al.*, 2001), and Walker Branch (Wilson & Baldocchi, 2001) sites from the AmeriFlux network. Both models underestimated seasonal variations in NEE and under predicted the rate of GPP increase at the onset of the growing season.



Annual cycle of atmospheric CO_2 at (a) Mould Bay, Canada (76˚N), (b) Storhofdi, Iceland (63˚N), (c) Carr, Colorado (aircraft samples from 6 km masl; 41˚N), (d) Azores Islands (39˚N), (e) Sand Island, Midway (28˚N), and Kumakahi, Hawaii (20˚N). The observations are form Globalview and the model estimates were obtained using model fluxes from Experiment 1.4 and monthly impulse response functions from the TRANSCOM experiment.



Net primary production normalized by precipitation for EMDI NPP measurements and the models. CASA´ exhibits an increasingly high bias while CN exhibits a consistent low bias.



Global fire emissions from CN compared to the Global Fire Emissions Database version 2. The version of CASA´ analyzed here did not simulate fire emissions.

C-LAMP Score Sheet for CASA´ and CN

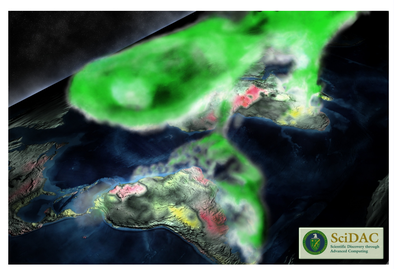
Metric	Metric components	Uncertainty of obs.	Scaling mismatch	Total score	Sub-score	CASA´	Sub-score	CN
LAI	Matching MODIS observations			15.0		13.5		12.0
	• Phase (assessed using the month of maximum LAI)	Low	Low		6.0		5.1	4.2
	• Maximum (derived separately for major biome classes)	Moderate	Low		5.0		4.6	4.3
	• Mean (derived separately for major biome classes)	Moderate	Low		4.0		3.8	3.5
NPP	Comparisons with field observations and satellite products			10.0		8.0		8.2
	• Matching EMDI Net Primary Production observations	High	High		2.0		1.5	1.6
	• EMDI comparison, normalized by precipitation	Moderate	Moderate		4.0		3.0	3.4
	• Correlation with MODIS (r^2)	High	Low		2.0		1.6	1.4
	• Latitudinal profile comparison with MODIS (r^2)	High	Low		2.0		1.9	1.8
CO_2 annual cycle	Matching phase and amplitude at Globalview flash sites			15.0		10.4		7.7
	• 60°–90°N	Low	Low		6.0		4.1	2.8
	• 30°–60°N	Low	Low		6.0		4.2	3.2
	• 0°–30°N	Moderate	Low		3.0		2.1	1.7
Energy & CO_2 fluxes	Matching eddy covariance monthly mean observations			30.0		17.2		16.6
	• Net ecosystem exchange	Low	High		6.0		2.5	2.1
	• Gross primary production	Moderate	Moderate		6.0		3.4	3.5
	• Latent heat	Low	Moderate		9.0		6.4	6.4
	• Sensible heat	Low	Moderate		9.0		4.9	4.6
Transient dynamics	Evaluating model processes that regulate carbon exchange on decadal to century timescales			30.0		16.8		13.8
	• Aboveground live biomass within the Amazon Basin	Moderate	Moderate		10.0		5.3	5.0
	• Sensitivity of NPP to elevated levels of CO_2: comparison to temperate forest FACE sites	Low	Moderate		10.0		7.9	4.1
	• Interannual variability of global carbon fluxes: comparison with TRANSCOM	High	Low		5.0		3.6	3.0
	• Regional and global fire emissions: comparison to GFEDv2	High	Low		5.0		0.0	1.7
			Total:	**100.0**		**65.9**		**58.3**

Biases and Weaknesses Exposed by the C-LAMP Analysis

- **A low LAI bias in boreal and arctic regions.** This bias was partially eliminated by a new hydrology model capturing freeze-thaw dynamics.
- **A 1–3 month delay in the timing of maximum LAI.** This bias was reduced in CLM3-CN where it was most significant.
- **Models overestimate woody biomass in the Amazon Basin.** Carbon budget comparisons with Malhi *et al.* (in press) suggest too much allocation to wood. Allocation in CLM3-CN was adjusted to reduce this bias.
- **CLM3-CASA´ and CLM3-CN differed by a factor of two in annual carbon sinks.** Both are compatible with atmospheric budgets given other uncertainties.
- **Models underestimate the amplitude of the seasonal cycle of CO_2 in the northern hemisphere.** Adjustment of Q_{10} in CLM3-CASA´ reduces the bias, and CLM3-CN adopted a similar Q_{10} formulation for heterotrophic respiration.
- **CLM3-CN seasonal cycle was out of phase with observations.** A new day-length control on photosynthesis mitigates this bias in CLM3-CN.

All C-LAMP simulations were performed as a part of the biogeochemistry subproject of the Computational Climate Science End Station Project (Dr. Warren Washington, PI), a U.S. Department of Energy Innovative and Novel Computational Impact on Theory and Experiment (INCITE) Project using resources at the National Center for Computational Sciences (NCCS) located at Oak Ridge National Laboratory (ORNL).

C-LAMP model results are being actively used by members of the SciDAC Visualization and Analytics Center for Enabling Technologies (VACET) at the National Center for Computational Sciences (NCCS) at ORNL and the University of Tennessee, Knoxville, to explore high performance visualization techniques and apply new statistical methods to climate data analysis.



The C-LAMP model results are available to the research community on a new Earth System Grid (ESG) node at Oak Ridge National Laboratory at http://esg2.ornl.gov/ provided by the SciDAC Earth System Grid Center for Enabling Technology (ESG-CET).

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