The Carbon-Land Model Intercomparison Project (C-LAMP) and an International Land-Biosphere Model Benchmarking Activity for the IPCC AR5

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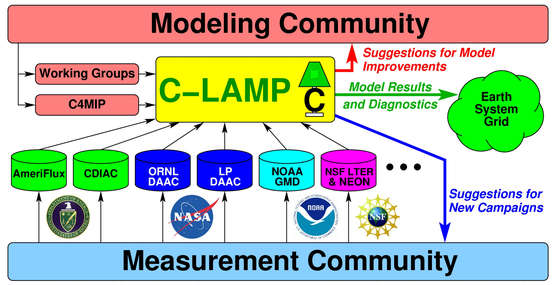
Introduction

The need to capture important climate feedbacks in general circulation models (GCMs) has resulted in new efforts to include atmospheric chemistry and land and ocean biogeochemistry into the next generation of production climate models, now often referred to as Earth System Models (ESMs). While many terrestrial and ocean carbon models have been coupled to GCMs, recent work has shown that such models can yield a wide range of results (Friedlingstein *et al.*, 2006), suggesting that a more rigorous set of offline and partially coupled experiments, along with detailed analyses of processes and comparisons with measurements, are warranted. The Carbon-Land Model Intercomparison Project (C-LAMP) provides a simulation protocol and model performance metrics based upon comparisons against best-available satellite- and ground-based measurements (Hoffman *et al.*, 2007). C-LAMP provides feedback to the modeling community regarding model improvements and to the measurement community by suggesting new observational campaigns.



By using the wide variety of measurements made, collected, and distributed by researchers and data centers, 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.

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.

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)

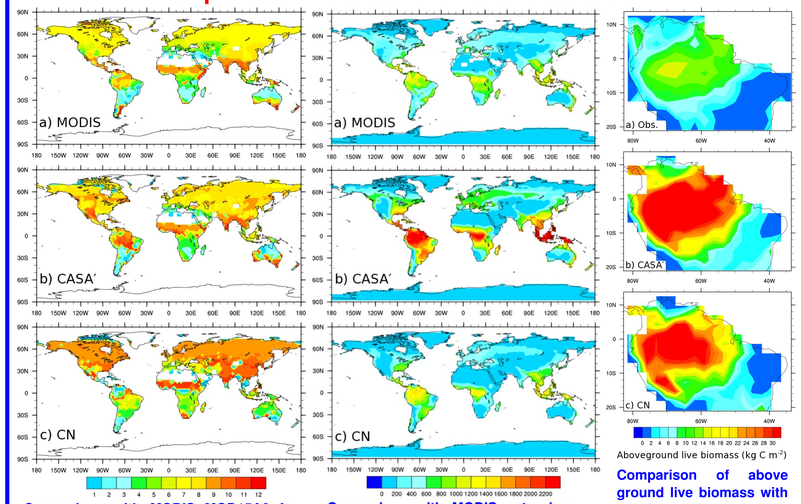
Experiment 2: partially coupled land-atmosphere model runs with prescribed sea surface temperatures (SSTs) and sea ice cover

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

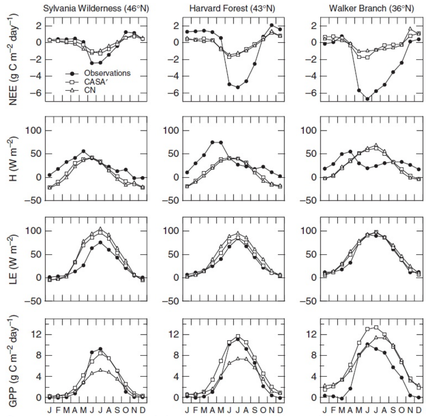
Experiment 1 Results for CASA´ and CN



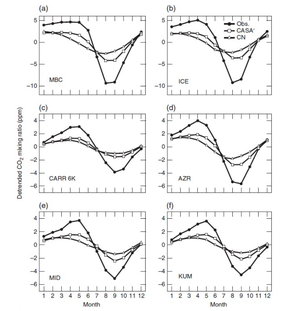
Comparison with MODIS MOD15A2 for month of maximum leaf area index (LAI). While direct comparison of model results with MODIS LAI values is problematic, it is expected that the month of maximum LAI from MODIS has a much lower uncertainty. Both models exhibited a 1–3 month delay in maximum LAI.

Comparison with MODIS net primary production (NPP) in gC m^{-2} y^{-1}. Models are scored with respect to their spatial correlation with MODIS NPP, not their actual values. CASA´ had a correlation coefficient of 0.91 while CN had a correlation coefficient of 0.85.

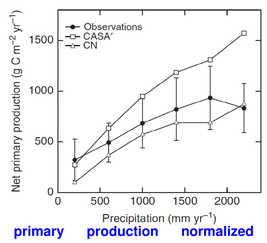
Comparison of above ground live biomass with estimates provided by Saatchi *et al.* (2006). Both models significantly over estimated carbon storage in woody biomass.



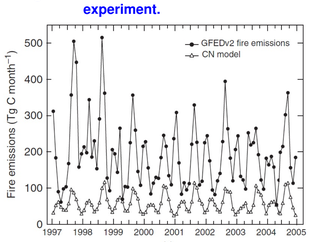
Comparison of model estimates with eddy covariance measurements from Sylvania Wilderness (Desai *et al.*, 2005), Harvard Forest (Barford *et al.*, 2001), and Walker Branch (Wilson & Baldocchi, 2001) sites from the AmeriFlux network. Both models under estimated seasonal variations in NEE and under predicted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

For more results, see

Randerson, James T., Forrest M. Hoffman, Peter E. Thornton, Natalie M. Mahowald, Keith Lindsay, Yen-Huei Lee, Cynthia D. Nevison, Scott C. Doney, Gordon Bonan, Reto Stöckli, Curtis Covey, Steven W. Running, and Inez Y. Fung. September 2009. "Systematic Assessment of Terrestrial Biogeochemistry in Coupled Climate-Carbon Models." Global Change Biology, 15(9):2462–2484. doi:10.1111/j.1365-2486.2009.01912.x.

C-LAMP Score Sheet for CASA´ and CN

Metric	Metric components	Uncertainty of obs.	Scaling mismatch	Total score	Sub-score	CASA´	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 flask 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**

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).

The C-LAMP model results are all available to the wider 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).

International Land Model Benchmarking (ILAMB) Activity

We believe that C-LAMP and Europe's ILAMB should serve as prototypes for a wider international benchmarking and carbon cycle feedback analysis activity, the results of which could contribute to IPCC AR5. Needed are

1) a well-crafted protocol that exercises model capabilities for simulating energy, water, and biogeochemical cycles;
2) model output data and metadata standards to simplify subsequent analyses;
3) best-available forcing data sets; and
4) best-available observational data sets, metrics, and diagnostics.

An international meeting of researchers is being planned for November 2010 in the U.S. to finalize the protocol, output standards, metrics, diagnostics for feedback analysis, and schedule for analysis and publication.

Office of Science
U.S. DEPARTMENT OF ENERGY
MeteoSwiss
The University of Montana
Berkeley

Acknowledgements: Research partially sponsored by the Climate and Environmental Sciences Division (CESD) of the Office of Biological and Environmental Research (OBER) within the U.S. Department of Energy's Office of Science (SC). This research used resources of the National Center for Computational Sciences (NCCS) at Oak Ridge National Laboratory (ORNL), which is managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725. The Lawrence Livermore National Laboratory is managed by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy under Contract No. DE-AC52-07NA27344. The National Center for Atmospheric Research is operated by the University Corporation for Atmospheric Research (UCAR) and receives research funding primarily from the National Science Foundation (NSF).