The Carbon-Land Model Intercomparison Project (C-LAMP)

Forrest M. Hoffman[1], James T. Randerson[2], Peter E. Thornton[3,1], Natalie M. Mahowald[3,4], Keith Lindsay[3], Yen-Huei Lee[3], Cynthia D. Nevison[5,3], Scott C. Doney[6], Gordon B. Bonan[3], Reto Stöckli[7,8], Curtis C. Covey[9], Steven W. Running[10], and Inez Y. Fung[11]

[1]Oak Ridge National Laboratory, [2]University of California-Irvine, [3]National Center for Atmospheric Research, [4]Cornell University, [5]University of Colorado-Boulder, [6]Woods Hole Oceanographic Institute, [7]Colorado State University, [8]MeteoSwiss, [9]Lawrence Livermore National Laboratory/PCMDI, [10]University of Montana, and [11]University of California-Berkeley

SMC-IT Workshop on IT for Climate Research

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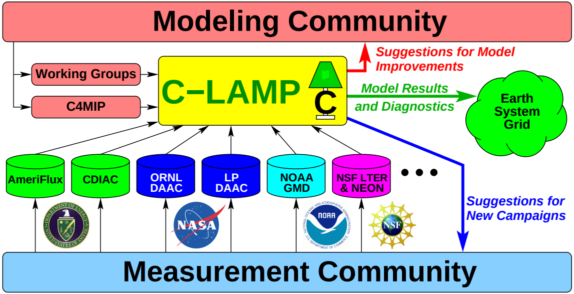
- The **Carbon-Land Model Intercomparison Project (C-LAMP)** began as a CCSM Biogeochemistry Working Group project to assess model capabilities in the coupled climate system and to explore processes important for inclusion in the CCSM4 Earth System Model for use in the IPCC Fifth Assessment Report (AR5).
- Unlike traditional MIPs, C-LAMP was designed to confront models with best-available observational datasets, develop metrics for evaluation of biosphere models, and build a general-purpose BGC diagnostics package for model evaluation.



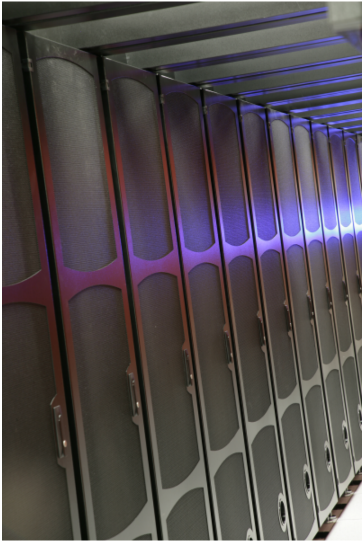
- C-LAMP is a Biogeochemistry Subproject of the **Computational Climate Science End Station** (Warren Washington, PI), a U.S. Dept. of Energy INCITE Project.
- Models were initially run on the Cray X1E vector supercomputer in ORNL's **National Center for Computational Sciences (NCCS)**.

Cray X1E (phoenix)

1024 processors (MSPs), 2048 GB memory, and 18.08 TFlop/s peak

DECOMMISSIONED September 30, 2008

Present Jaguar: 250 TFlop/s



New Jaguar: Second Fastest in the World at 1.059 PFlop/s

C-LAMP Protocol Overview

- Experiment 1: Models forced with an improved NCEP/NCAR reanalysis climate data set (Qian, *et al.* 2006) to examine the influence of climate variability, prescribed atmospheric CO_2, and land cover change on terrestrial carbon fluxes during the 20th century (specifically 1948–2004).
- Experiment 2: Models coupled with an active atmosphere (CAM3), prescribed atmospheric CO_2, prescribed sea surface temperatures and ocean carbon fluxes to examine the effect of a coupled biosphere-atmosphere for carbon fluxes and climate during the 20th century.
- CCSM3.1 partially coupled ("I" & "F" configurations) run at T42 resolution ($\sim 2.8^\circ \times 2.8^\circ$), spectral Eulerian dycore, $1^\circ \times 0.27^\circ$–$0.53^\circ$ ocean & sea ice data models (T42gx1v3).
- Experimental protocol, output fields, and metrics are available at http://www.climatemodeling.org/c-lamp/

C-LAMP, C^{4}MIP, and iLEAPS

- C-LAMP Experiment 2 is patterned after C^{4}MIP (Coupled Climate-Carbon Cycle Model Intercomparison Project, http://www.c4mip.cnrs-gif.fr/) Phase 1.
- At the October 2006 C^{4}MIP Workshop at the UK Met Office in Exeter, there was strong interest in Experiment 1 and validation experiments using Fluxnet observations.
- At the Marie Curie/iLEAPS Workshop in Hyères, a number of modeling groups expressed interest in consistent model validation and model-data comparisons for their coupled biosphere models, but best-available observations from ground and satellite measurements are difficult to manipulate.
- C-LAMP is sharing forcing and observational datasets, and model results are available through the Earth System Grid (ESG), just like for CMIP3 (the IPCC AR4 model results).

Offline Forcing with NCEP/NCAR Reanalysis		
Exp.	**Description**	**Time Period**
1.1	Spin Up	∼4,000 y
1.2	Control	1798–2004
1.3	Varying climate	1948–2004
1.4	Varying climate, CO_2, and N deposition	1798–2004
1.5	Varying climate, CO_2, N deposition and land use	1798–2004
1.6	Free Air CO_2 Enrichment (FACE) Control	1997–2100
1.7	Free Air CO_2 Enrichment (FACE) Transient	1997–2100

Coupled Land-Atmosphere Forcing with Hadley SSTs		
Exp.	**Description**	**Time Period**
2.1	Spin Up	∼2,600 y
2.2	Control	1800–2004
2.3	Varying climate	1800–2004
2.4	Varying climate, CO_2, and N deposition	1800–2004
2.5	Varying climate, CO_2, N deposition and land use	1800–2004
2.6	Varying climate, CO_2, N deposition, seasonal FFE	1800–2004

All but the land use experiments were run with CCSM3.1 using CLM3-CASA′ and CLM3-CN biogeochemistry models yielding >16,000 y and ∼50 TB

C-LAMP Common Model Output - Mozilla Firefox

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http://www.climatemodeling.org/c-lamp/protocol/model_output.php

C-LAMP Common Model Output

While all models participating in the Carbon Land Model intercomparison Project (C-LAMP) will output their own "native" fields, a common set of fields is needed to facilitate head-to-head comparison of the models to each other and to available observational datasets. Model results transmitted to the Earth System Grid for redistribution to the community will use common field names, netCDF long names, CF Standard Names and units. Contained below is a table of the common output fields required for the C-LAMP and consistent with the metadata conventions used for CMIP3, formerly called the IPCC 4th Assessment Model Output database. Corrections and suggestions are solicited on this information. Software is available for rewriting model output into netCDF files following the Climate and Forecast (CF) Metadata Convention.

Version 2.1 - Aug 30, 2008

Variable Name	Long Name and CF Standard Name	Units	Comment	Statistics
Atmospheric forcing				
husf	Specific humidity at atmospheric forcing height `specific_humidity`‡	kg kg-1		MHM, MHS, MM
prra	Rainfall precipitation flux `rainfall_flux`‡	kg m-2 s-1	Rainfall includes all liquid types (rain, large-scale, convective, etc.)	MHM, MHS, MM
prsn†	Snowfall precipitation flux `snowfall_flux`‡	kg m-2 s-1	Snowfall includes all frozen types (snow, hail, ice, etc.)	MHM, MHS, MM
Biogeochemistry				
Variable Name	**Long Name and CF Standard Name**	**Units**	**Comment**	**Statistics**
agbc*	Above-ground biomass carbon `above_ground_biomass_carbon_content`	kg m-2	Total carbon content in above-ground live and dead carbon pool(s)	MM
aglbc*	Above-ground live biomass carbon `above_ground_live_biomass_carbon_content`	kg m-2	Total carbon content in above-ground live carbon pool(s)	MM
agnpp	Above-ground net primary production `above_ground_net_primary_productivity_of_carbon`	kg m-2 s-1	Component of net primary production attributable to above-ground live biomass	MM
ar	Autotrophic respiration `autotrophic_respiration_of_carbon` alias(es): `plant_respiration_carbon_flux`	kg m-2 s-1	Sum of maintenance respiration and growth respiration of vegetation	MHM, MHS, MM
bco	Biogenic carbon monoxide flux `biogenic_carbon_monoxide_flux`	kg m-2 s-1	Total biogenic carbon monoxide flux out of biosphere	MM

Done

C-LAMP Performance Metrics and Diagnostics

- An evolving draft document on metrics for model evaluation is available at http://www.climatemodeling.org/c-lamp/
- Each model is scored with respect to its performance on various output fields compared with best-available observational datasets.
- Examples include:
  - net primary production (NPP) from EMDI and MODIS
  - leaf area index (LAI) using MODIS spatial distribution and phase
  - CO_2 seasonal cycle (NOAA/Globalview flask sites, after running fluxes through an atmospheric transport model for Experiment 1)
  - regional carbon stocks (Saatchi *et al.*, 2006; Batjes, 2006)
  - carbon and energy fluxes (Fluxnet sites)
  - transient dynamics (β factor, etc.)
- More diagnostic or metric ideas? Please contribute them!

Score Sheet for CLAMP - Mozilla Firefox

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http://www.climatemodeling.org/c-lamp/results/diagnostics/CN_vs_CA

C-LAMP Score Sheet for Biogeochemical Model Evaluation

Metric	Metric components	Observations & comparison protocol	Model CASA'	Model CN	Score (points) Possible	CASA'	CN
LAI	MODIS Phase	global map	global map model vs obs	global map model vs obs	6.00	5.11	4.24
	MODIS Maximum	global map	global map model vs obs	global map model vs obs	5.00	4.60	4.26
	MODIS Mean	land class obs land class model global map	model vs obs table global map model vs obs	model vs obs table global map model vs obs	4.00	3.75	3.53
NPP	EMDI NPP observations	Class A table	table scatter plot	table scatter plot	1.00	0.68	0.73
		Class B table	table scatter plot	table scatter plot	1.00	0.83	0.82
	EMDI NPP normalized by PPT	Class A histogram	Class A histogram	Class A histogram	2.00	1.50	1.74
		Class B histogram	Class B histogram	Class B histogram	2.00	1.51	1.65
	Correlation with MODIS	global map	model map model vs obs	model map model vs obs	2.00	1.64	1.44
	Correlation with MODIS-zonal mean	zonal mean obs	zonal mean model vs obs plot	zonal mean model vs obs plot	2.00	1.88	1.84
CO_2 Seasonal Cycle — Comparison with Globalview phase and amplitude	60°N–90°N	—	—	—	6.00	4.11	2.77
	30°N–60°N	—	—	—	6.00	4.23	3.23
	0°N–30°N	—	—	—	3.00	2.07	1.71
Energy and C Fluxes from Fluxnet	NEE	line plot	model vs obs	model vs obs	—	—	—
	Net radiation				—	—	—
	Latent heat				—	—	—
	Sensible heat				—	—	—
Energy and C Fluxes from Ameriflux	NEE	line plot	model vs obs timeseries plot	model vs obs timeseries plot	6.00	2.46	2.13
	Shortwave Incoming				—	—	—
	Latent heat				9.00	6.38	6.39
	Sensible heat				9.00	4.90	4.64
	GPP				6.00	3.39	3.46
	ER				—	—	—
	Aboveground live		model amazon	amazon map			

Done

Score Sheet for CLAMP - Mozilla Firefox

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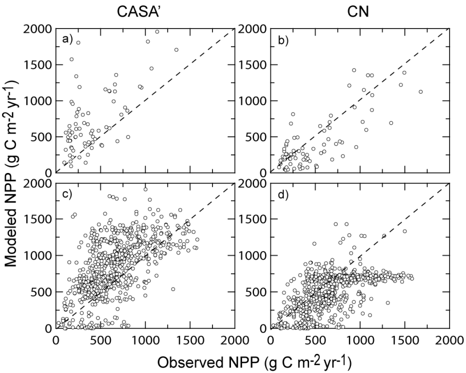
http://www.climatemodeling.org/c-lamp/results/diagnostics/CN_vs_CA

CO_2 Seasonal Cycle — Comparison with Globalview phase and amplitude	60°N–90°N	—	—	—	6.00	4.11	2.77
	30°N–60°N	—	—	—	6.00	4.23	3.23
	0°N–30°N	—	—	—	3.00	2.07	1.71
Energy and C Fluxes from Fluxnet	NEE	line plot	model vs obs	model vs obs	—	—	—
	Net radiation				—	—	—
	Latent heat				—	—	—
	Sensible heat				—	—	—
Energy and C Fluxes from Ameriflux	NEE	line plot	model vs obs timeseries plot	model vs obs timeseries plot	6.00	2.46	2.13
	Shortwave Incoming				—	—	—
	Latent heat				9.00	6.38	6.39
	Sensible heat				9.00	4.90	4.64
	GPP				6.00	3.39	3.46
	ER				—	—	—
Carbon Stocks and Transient Dynamics	Aboveground live biomass in South America	obs amazon	model amazon model vs obs	amazon map model vs obs	10.00	5.28	4.99
	Aboveground live biomass within Amazon Basin (sum within Legal Amazon)	mask obs masked 68.90 (Pg C)	model masked model vs obs 198.87 (Pg C)	model masked model vs obs 160.61 (Pg C)	—	—	—
	NPP Stimulation from elevated CO_2	—	FACE Site table biome table	FACE Site table biome table	10.00	7.87	4.11
	Interannual variability of global carbon fluxes - comparison with TRANSCOM	—	—	—	5.00	3.55	3.00
	Turnover times and pool sizes	—	Leaf Wood Fine Root Litter Coarse Woody Debris Soil	Leaf Wood Fine Root Litter Coarse Woody Debris Soil	—	—	—
	Carbon Sinks (1990–2004)	—	biome mean biome total	biome mean biome total	—	—	—
	Fire Variability (1997–2004)	—	—	global spatial comparison temporal dynamics	5.00	—	1.70
				Total Score	**100.00**	**65.74**	**58.38**

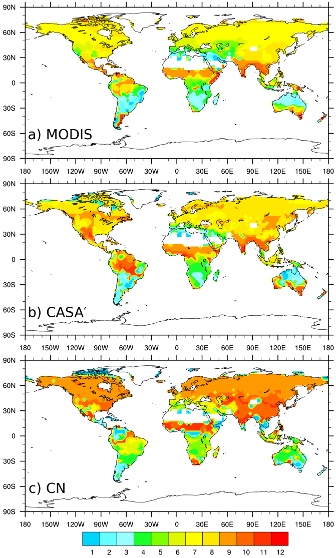
Done

- Comparisons with field observations include net primary production (NPP) from the Ecosystem Model-Data Intercomparison (EMDI).
- Measurements were performed in different ways, at different times, and by different groups for a limited number of field sites.
- Shown here are comparisons of NPP with EMDI Class A observations (Figures a and b) and Class B observations (Figures c and d).

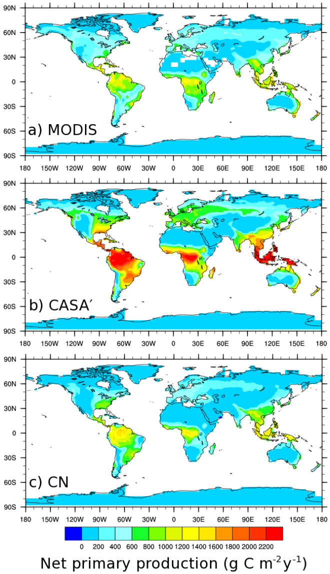


Data provided by NASA Distributed Active Archive Center (DAAC) at ORNL

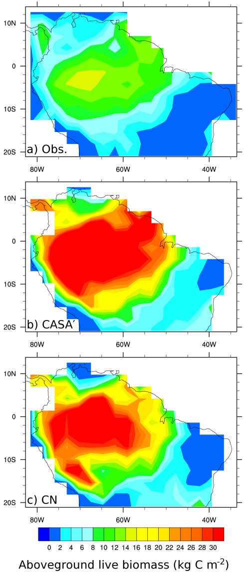
- Comparisons with satellite "modeled observations" must be made carefully because of high uncertainty.
- This comparison with MODIS leaf area index (LAI) focuses on the month of maximum LAI (phase), a measurement with less uncertainty than the "observed" LAI values.
- C-LAMP accounts for this uncertainty by weighting scores accordingly.
- CLM-CASA′ scored 5.1/6.0 while CLM-CN scored 4.2/6.0 for this metric.



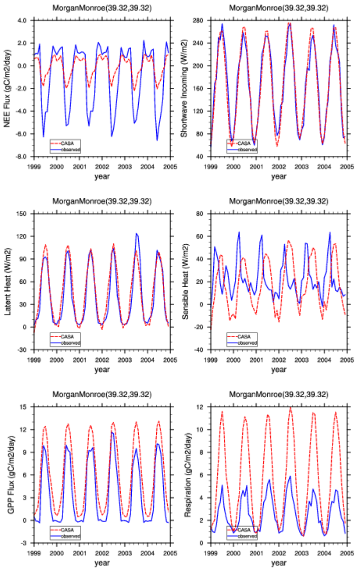
- MODIS net primary production (NPP) "observations" have higher uncertainty.
- Comparison with MODIS NPP focuses on correlation of spatial patterns.
- CLM-CASA′ scored 1.6/2.0 while CLM-CN scored 1.4/2.0.



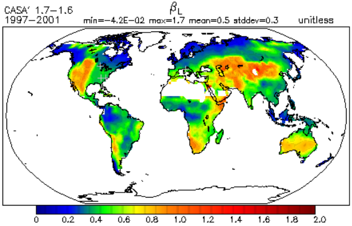
- Estimates of carbon stocks are very difficult to obtain.
- This comparison with estimates of aboveground live biomass in the Amazon by Saatchi *et al.* (2006) shows that both models are too high by about a factor of 2.
- Using a score based on normalized cell-by-cell differences, CLM-CASA′ scored 5.3/10.0 while CLM-CN scored 5.0/10.0.

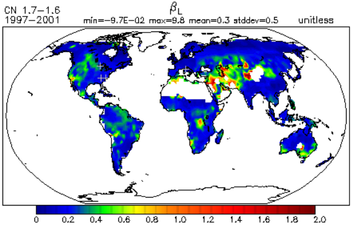


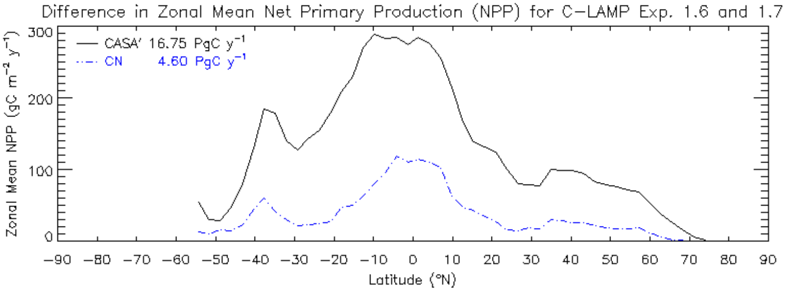
- Comparisons with AmeriFlux eddy correlation CO_2 flux tower sites include net ecosystem exchange (NEE), gross primary production (GPP), respiration, shortwave incoming radiation, and latent and sensible heat.
- Shown here is a comparison of CLM-CASA′ results with the Morgan Monroe L4 time series data.
- All AmeriFlux data are stored and distributed by ORNL's Carbon Dioxide Information Analysis Center (CDIAC).



- Additional field measurement comparisons include the Free Air CO_2 Enrichment (FACE) results, including the ORNL site.
- The Norby *et al.* (2005) synthesis of four FACE site observations suggested "response of forest NPP to elevated [CO_2] is highly conserved across a broad range of productivity, with a stimulation at the median of $23 \pm 2\%$."
- A C-LAMP experiment was added to test this result by increasing [CO_2] to 550 ppmv in 1997.







Site Name	Lon (°E)	Lat (°N)	Observations NPP↑	Observations β_L	CASA′ NPP↑	CASA′ β_L	CASA′ Score	CN NPP↑	CN β_L	CN Score
Duke	-79.08	35.97	28.0%	0.69	16.4%	0.41	0.26	6.2%	0.15	0.65
Aspen	-89.62	45.67	35.2%	0.87	15.6%	0.39	0.39	12.4%	0.31	0.48
ORNL	-84.33	35.90	23.9%	0.59	17.3%	0.43	0.16	5.2%	0.13	0.64
POP-Euro	11.80	42.37	21.8%	0.54	20.0%	0.49	0.04	5.7%	0.14	0.59
4 site mean			27.2%	0.67	17.3%	0.43		7.4%	0.18	
			Total M Score				**0.79**			**0.41**

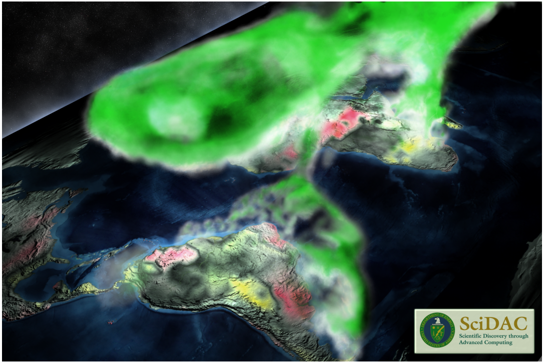
But! Norby is now reporting reduced NPP enhancement at the ORNL FACE site due probably to N limitation!

C-LAMP Score Sheet for CLM3-CASA′ and CLM3-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 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**

Collaboration with SciDAC Visualization and Analytics Center for Enabling Technologies (VACET)

- C-LAMP and other model results are being used by members of VACET at the National Center for Computational Sciences (NCCS) to explore high performance visualization techniques.



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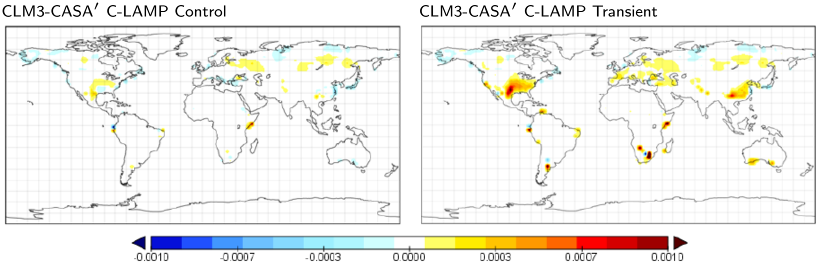
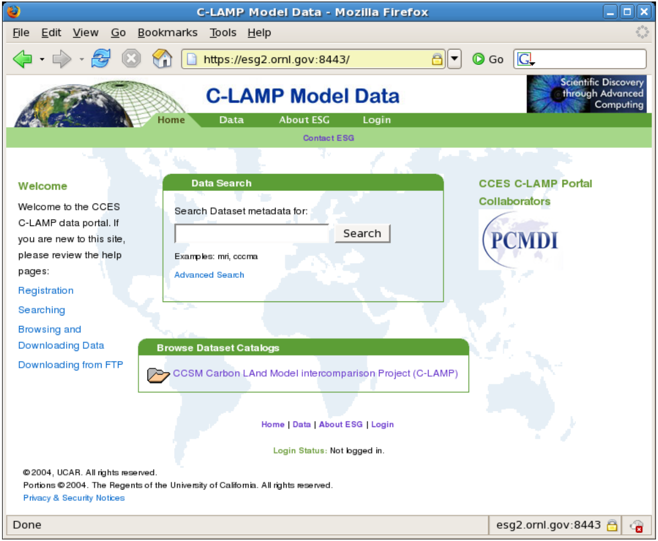
- C-LAMP model results and MODIS satellite data are being used by Jian Huang's group at the University of Tennessee, Knoxville (UTK) applying novel statistical methods to the analysis of very large climate data sets.



The slope of temporal change (λ) in exposed one-sided leaf area index (ELAI) relative to the April–May change. Red areas "green up" sooner in the year while blue areas "green up" later in the year over the 1850–2000 period.

Earth System Grid (ESG) Node at ORNL for C-LAMP



Biases and Weaknesses Exposed by the C-LAMP Analysis

- Both models had a low LAI bias in boreal and arctic regions. This bias was partially eliminated by a new hydrology model capturing freeze-thaw dynamics.

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- The models differed by a factor of two in annual carbon sinks. Both results are compatible with atmospheric budgets given other uncertainties.

Biases and Weaknesses Exposed by the C-LAMP Analysis

- Both models underestimated the amplitude of the seasonal cycle of CO_2 in the northern hemisphere. Adjustment of the Q_{10} for heterotraphic respiration from 2.0 to 1.5 in CLM3-CASA′ reduces this bias. Adoption of the same Q_{10} formulation, in place of Lloyd & Taylor, reduces this bias in CLM3-CN. The Q_{10} for maintenance respiration in CLM3-CN was also reduced from 2.0 to 1.5.

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- CLM3-CN seasonal cycle was out of phase with observations. A new day-length control on photosynthesis mechanism mitigates this bias in CLM3-CN.

C-LAMP Paper in Press in *Global Change Biology*

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Systematic assessment of terrestrial biogeochemistry in coupled climate–carbon models

JAMES T. RANDERSON*, 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‖‖

**Department of Earth System Science, Croul Hall, University of California, Irvine, CA 92697, USA, †Oak Ridge National Laboratory, Computational Earth Sciences Group, PO Box 2008, Oak Ridge, TN 37831, USA, ‡Climate and Global Dynamics, National Center for Atmospheric Research, PO Box 3000, Boulder, CO 80307, USA, §Oak Ridge National Laboratory, Environmental Sciences Division, PO Box 2008, Oak Ridge, TN 37831, USA, ¶Department of Earth and Atmospheric Sciences, 2140 Snee Hall, Cornell University, Ithaca, NY 14850, USA, ‖Institute for Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309, USA, **Department of Marine Chemistry and Geochemistry, MS 25, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA, ††Department of Atmospheric Sciences, Colorado State University, Ft Collins, CO 80523, USA, ‡‡MeteoSwiss, Climate Service, Federal Office of Meteorology and Climatology, CH-8044 Zurich, Switzerland, §§Program for Climate Model Diagnosis and Intercomparison, 7000 East Avenue, Bldg. 170, L-103, Livermore, CA 94550-9234, USA, ¶¶Numerical Terradynamic Simulation Group, College of Forestry & Conservation, University of Montana, Missoula, MT 59812, USA, ‖‖Department of Earth and Planetary Science and Department of Environmental Science, Policy, and Management, 307 McCone, Mail Code 4767, University of California, Berkeley, CA 94720, USA*

Abstract

With representation of the global carbon cycle becoming increasingly complex in climate models, it is important to develop ways to quantitatively evaluate model performance against *in situ* and remote sensing observations. Here we present a systematic framework, the Carbon-LAnd Model Intercomparison Project (C-LAMP), for assessing terrestrial biogeochemistry models coupled to climate models using observations that span a wide range of temporal and spatial scales. As an example of the value of such

Recent Progress

- C-LAMP drove the development of model improvements in the terrestrial biogeochemistry models for the Community Land Model verison 4 (CLM4).
- Subsequent C-LAMP analyses of six model configurations using CLM3.6 (a pre-release version of CLM4) with CASA′ and CN demonstrated better performance by CN.
- Therefore, the CLM4 release will include CN. That configuration will probably be called CLM4-BGC.
- CLM4-BGC will be part of the Community Climate System Model version 4 (CCSM4), which may be called the Community Earth System Model (CESM). This model will be used for IPCC AR5 simulations.
- The physical models for CCSM4 are expected to be finalized before the end of 2009, and the full ESM configuration will follow within six months.

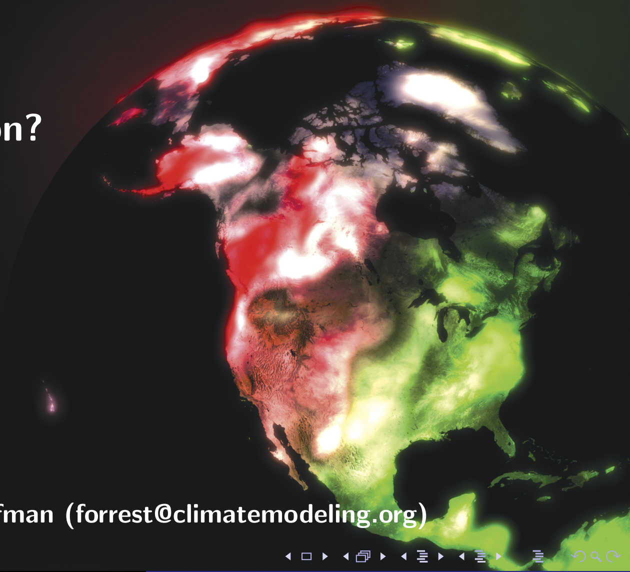
Future Directions

- Working with both observational data centers and Earth System Grid centers, we hope to automate retrieval and processing of both the observational datasets and model results, and provide a web-based diagnostics interface for modelers.
- Participate in the development of an International Land Model Benchmarking (iLAMB) activity, formulating experiments, metrics, and diagnostics for detailed comparison of land/biosphere models for the IPCC Fifth Assessment Report (AR5). The first international meeting was held in June (Exeter, UK); follow-up meetings are planned in conjunction with GEWEX/iLEAPS in August (Melbourne, Australia), with ICDC8 in September (Jena, Germany), and in Spring 2010 (California, USA).

Thank you!

Questions?

More Discussion?



Contact: Forrest Hoffman (forrest@climatemodeling.org)