A Coupled Climate-Carbon Cycle Model Evaluation Methodology for IPCC AR5

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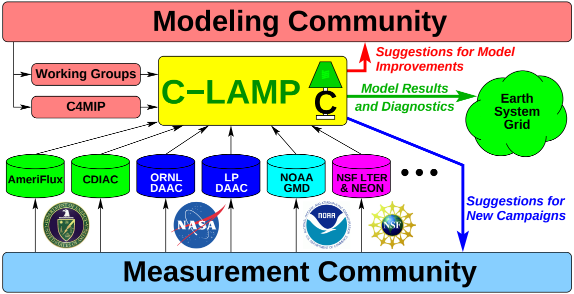
- The **Carbon-Land Model Intercomparison Project (C-LAMP)** began as a CCSM Biogeochemistry Working Group project to assess model capabilities in the coupled climate system and to explore processes important for inclusion in the CCSM4 Earth System Model for use in the IPCC Fifth Assessment Report (AR5).
- 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.



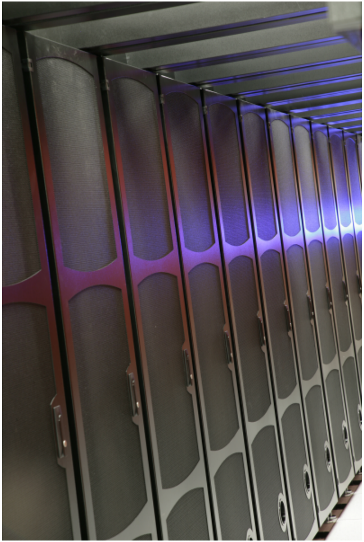
- C-LAMP is a Biogeochemistry Subproject of the **Computational Climate Science End Station** (Warren Washington, PI), a U.S. Dept. of Energy INCITE Project.
- Models were initially run on the Cray X1E vector supercomputer in ORNL's **National Center for Computational Sciences (NCCS)**.

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^4MIP, and iLEAPS

- C-LAMP Experiment 2 is patterned after C^4MIP (Coupled Climate-Carbon Cycle Model Intercomparison Project, http://www.c4mip.cnrs-gif.fr/) Phase 1, which few modeling groups performed.
- At the C^4MIP 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 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 (beta 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 biomass in South	obs amazon	model amazon	amazon map	10.00	[illegible]	[illegible]

Done

Score Sheet for CLAMP - Mozilla Firefox

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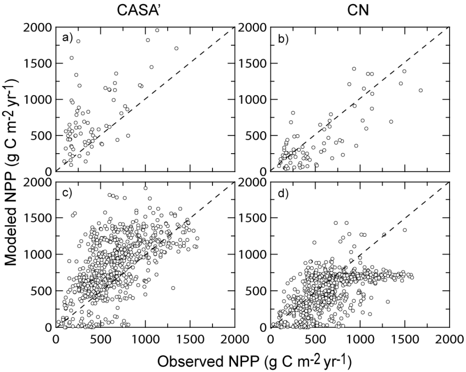
http://www.climatemodeling.org/c-lamp/results/diagnostics/CN_vs_CA

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**

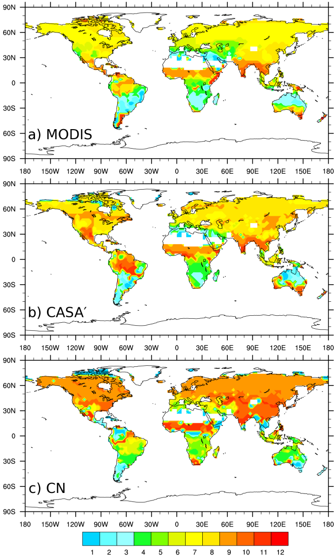
Done

- 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).

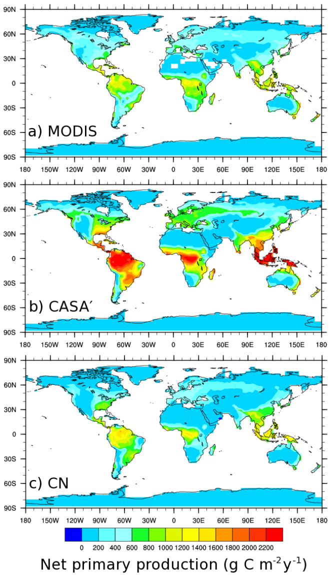


Data provided by NASA Distributed Active Archive Center (DAAC) at ORNL

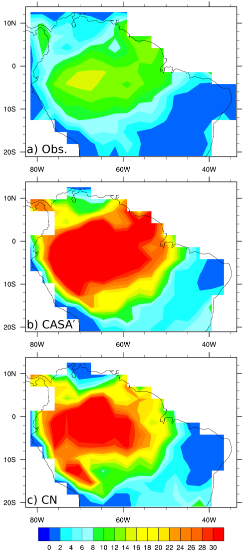
- Comparisons with satellite "modeled observations" must be made carefully because of high uncertainty.
- This comparison with MODIS leaf area index (LAI) focuses on the month of maximum LAI (phase), a measurement with less uncertainty than the "observed" LAI values.
- C-LAMP accounts for this uncertainty by weighting scores accordingly.
- CLM-CASA′ scored 5.11/6.00 while CLM-CN scored 4.24/6.00 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 1.64/2.00 while CLM-CN scored 1.44/2.00.

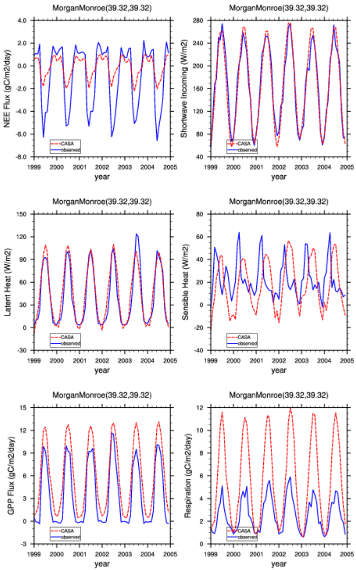


- Estimates of carbon stocks are very difficult to obtain.
- This comparison with estimates of aboveground live biomass in the Amazon by Saatchi *et al.* (2006) shows that both models are too high by about a factor of 2.
- Using a score based on normalized cell-by-cell differences, CLM-CASA′ scored 5.28/10.00 while CLM-CN scored 4.99/10.00.

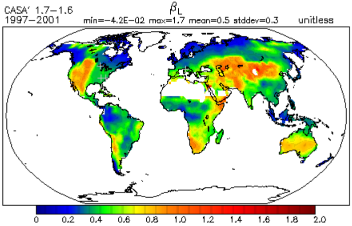


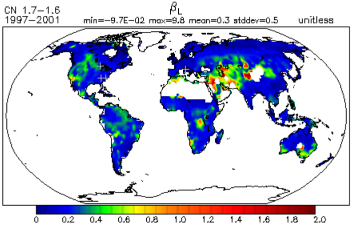
Aboveground live biomass (kg C m^{-2})

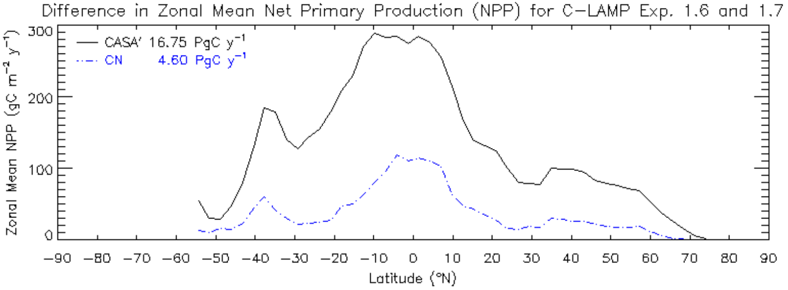
- Comparisons with AmeriFlux eddy correlation CO_2 flux tower sites include net ecosystem exchange (NEE), gross primary production (GPP), respiration, shortwave incoming radiation, and latent and sensible heat.
- Shown here is a comparison of CLM-CASA′ results with the Morgan Monroe L4 time series data.
- 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.

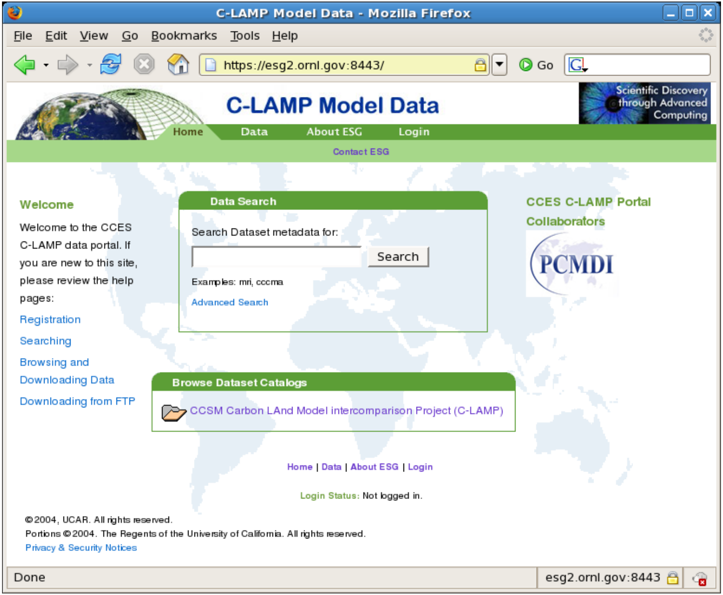






Site Name	Longitude (°E)	Latitude (°N)	Measurement		CASA' Model		CN Model	
			NPP Increase	β_L	NPP Increase	β_L	NPP Increase	β_L
DukeFACE	-79.08333	35.96666	28.0%	0.69	16.4%	0.41	6.2%	0.15
AspenFACE	-89.61666	45.66666	35.2%	0.87	15.6%	0.39	12.4%	0.31
ORNL-FACE	-84.33333	35.90000	23.9%	0.59	17.3%	0.43	5.2%	0.13
POP-EUROFACE	11.80000	42.36666	21.8%	0.54	20.0%	0.49	5.7%	0.14
4 Site Mean			**27.2%**	**0.67**	**17.3%**	**0.43**	**7.4%**	**0.18**

But! Norby is now reporting reduced NPP enhancement due probably to N limitation!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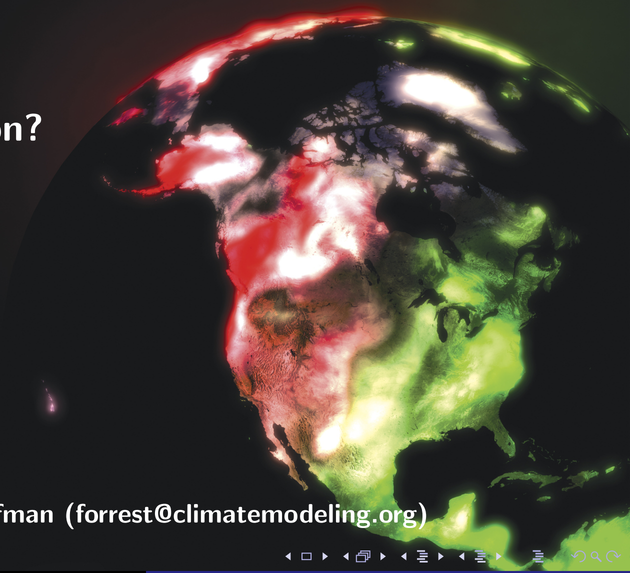
Next Steps

- Perform land use change simulations (Experiments 1.5 and 2.5) using CLM4-CASA′ and CLM4-CN.
- Add more metrics and diagnostics such as MODIS or CERES albedos, all global FluxNet sites (La Thuile dataset), etc.
- Working with both observational data centers and Earth System Grid centers, automate retrieval and processing of both the observational datasets and model results and provide web-based diagnostics interface for modelers.
- Work with the international community, and C^4MIP participants in particular, to extend the metrics and diagnostics for comparison of IPCC Fifth Assessment Report (AR5) model results.

Thank you!

Questions?

More Discussion?



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