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

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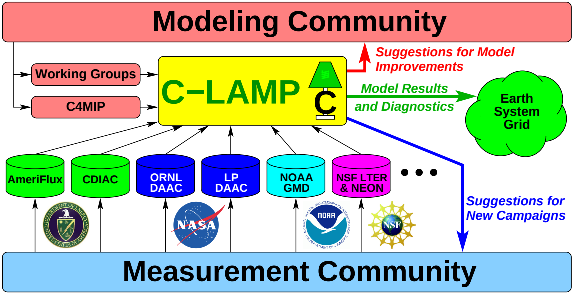
- The **Carbon-Land Model Intercomparison Project (C-LAMP)** began as a CCSM Biogeochemistry Working Group project to assess model capabilities in the coupled climate system and to explore processes important for inclusion in the CCSM4/CESM1 for use in the IPCC Fifth Assessment Report (AR5).
- Unlike traditional MIPs, C-LAMP was designed to confront models with observational datasets, develop metrics for evaluation of biosphere models, and build a general-purpose biogeochemistry diagnostics package for model validation and verification (V&V).



- C-LAMP was a 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

Model Configurations

- Biosphere models coupled to the Community Climate System Model version 3.1
  - CLM3-CASA′ — Carnegie/Ames/Stanford Approach Model previously run in CSM1.4 (Fung)
  - CLM3-CN — coupled carbon and nitrogen cycles based on the Biome-BGC model (Thornton)
- 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).

C-LAMP Protocol Overview

- Experiment 1: Models forced with 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.
- All forcing and observational datasets are being shared, and model results are available through Earth System Grid (ESG).
- Experimental protocol, output fields, and metrics described at `http://www.climatemodeling.org/c-lamp/`.

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 of output.

C-LAMP Common Model Output - Mozilla Firefox

File Edit View History Bookmarks Tools Help

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

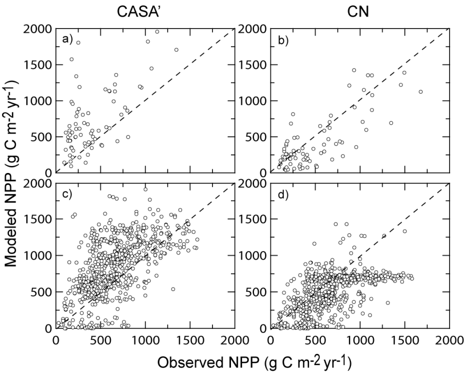
Atmospheric forcing				
Variable Name	**Long Name and CF Standard Name**	**Units**	**Comment**	**Statistics**
husf	Specific humidity at atmospheric forcing height specific_humidity‡	kg kg-1		MHM, MHS, MM
prra	Rainfall precipitation flux rainfall_flux‡	kg m-2 s-1	Rainfall includes all liquid types (rain, 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

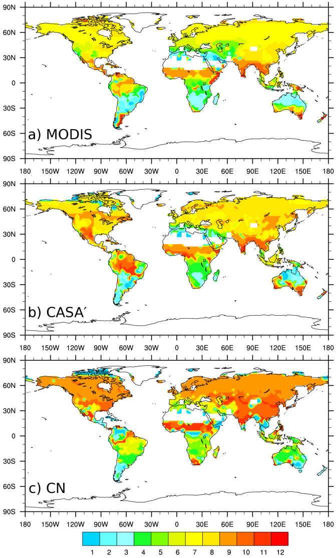
- An evolving document on metrics for model evaluation was developed by the CCSM Biogeochemistry Working Group.
- Each model was scored with respect to its performance compared with best-available observational datasets.
- Examples included:
  - leaf area index (LAI): comparison of phase and spatial distribution using MODIS
  - net primary production (NPP): comparison with EMDI and correlation with MODIS
  - CO_2 seasonal cycle: comparison with NOAA/Globalview flask sites after combining fluxes with impulse response functions from TRANSCOM
  - regional carbon stocks (Saatchi *et al.*, 2006; Batjes, 2006)
  - carbon and energy fluxes (AmeriFlux/Fluxnet sites)
  - other transient dynamics: β factor, fire emissions

- Comparisons with field observations included 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).

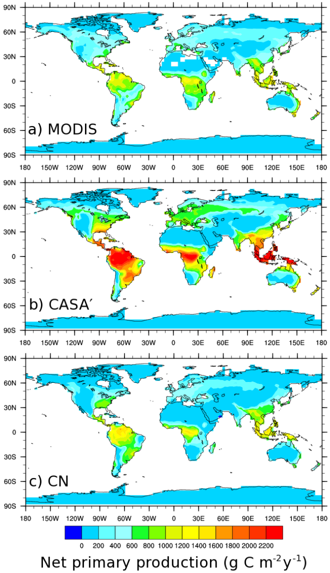


Data provided by NASA Distributed Active Archive Center (DAAC) at ORNL

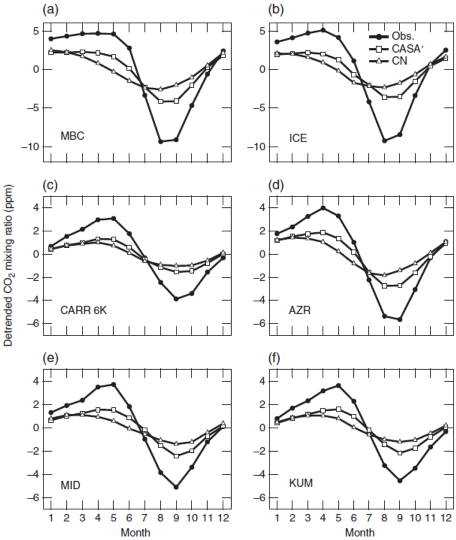
- Comparisons with satellite "modeled observations" must be made carefully because of high uncertainty.
- This comparison with MODIS leaf area index (LAI) focused on the month of maximum LAI (phase), a measurement with less uncertainty than the "observed" LAI values.
- C-LAMP accounted for such uncertainties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



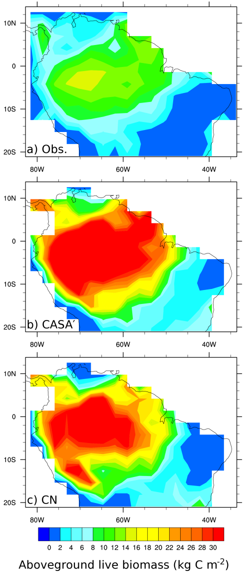
- MODIS net primary production (NPP) "observations" have even higher uncertainty.
- Comparison with MODIS NPP focused on correlation of spatial patterns.
- CLM-CASA′ scored 1.6/2.0 while CLM-CN scored 1.4/2.0; however, CN compared better with respect to mean values.



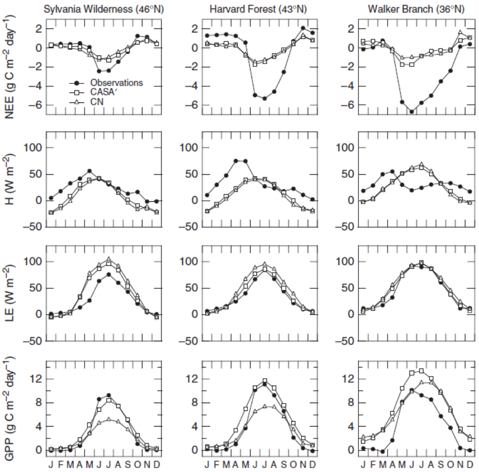
- Comparisons with Globalview flask sites were made by combining model fluxes with impulse response functions from TRANSCOM.
- Shown are annual cycles of atmospheric CO_2 at a) Mould Bay, Canada (76°N), b) Storhofdi, Iceland (63°N), c) Carr, Colorado (41°N), d) Azores Islands (39°N), e) Sand Island, Midway (28°N), and f) Kumakahi, Hawaii (20°N).
- CLM-CASA′ scored 10.4/15.0 while CLM-CN scored 7.7/15.0 for this metric.



- 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) showed 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.

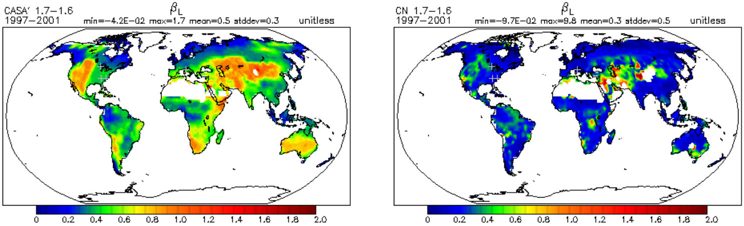


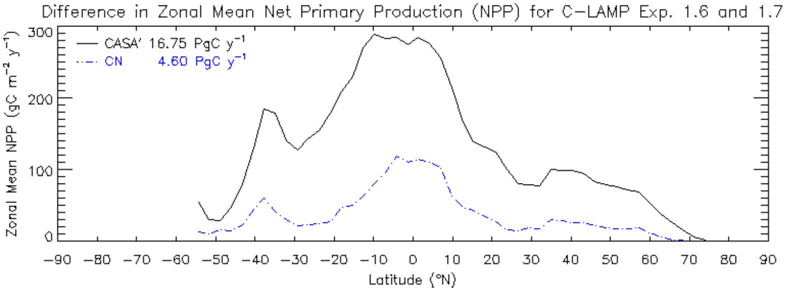
- Comparisons with AmeriFlux eddy correlation CO_2 flux tower sites included net ecosystem exchange (NEE), gross primary production (GPP), respiration, shortwave incoming radiation, and latent and sensible heat.
- Shown here is a comparison of model estimates with eddy covariance measurements from Sylvania Wilderness, Harvard Forest, and Walker Branch.
- Level 4 data were used.



Data provided by ORNL Carbon Dioxide Information Analysis Center (CDIAC).

- Additional field measurement comparisons included 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 ($^\circ$E)	Lat ($^\circ$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 more recently reported reduced NPP enhancement at the ORNL FACE site due probably to N limitation!

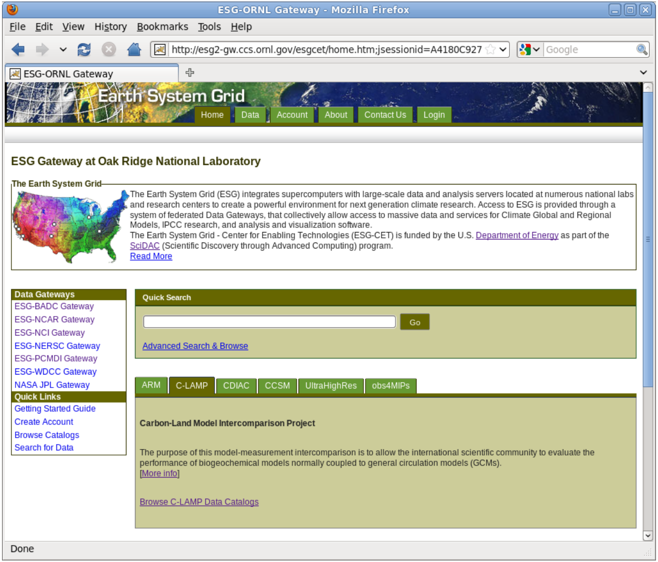
C-LAMP Score Sheet for CLM3-CASA′ and CLM3-CN

Models

BGC Datasets

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**	

C-LAMP Output on ESG Gateway at ORNL



Global Change Biology

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Systematic assessment of terrestrial biogeochemistry in coupled climate–carbon models

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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 comparisons, we used this framework to evaluate two biogeochemistry models that are integrated within the Community Climate System Model (CCSM) – Carnegie-Ames-Stanford Approach′ (CASA′) and carbon–nitrogen (CN). Both models underestimated the magnitude of net carbon uptake during the growing season in temperate and boreal

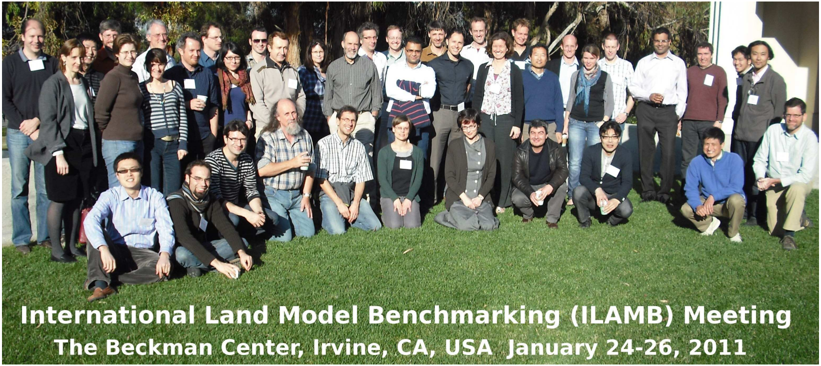
Recent Progress

- C-LAMP helped drive model improvements in terrestrial biogeochemistry for the Community Land Model (CLM4).
- Subsequent C-LAMP analyses of six model configurations using CLM3.6 (a pre-release version of CLM4) with CASA′ and CN demonstrated much improved performance by CN.
- Physical model changes must be tested using C-LAMP to ensure these changes do not negatively impact biogeochemistry model performance.
- C-LAMP helped launch an international community effort to develop land model benchmarks and an open source model evaluation system to support future MIPs, like LBA-MIP, NACP Syntheses, TRENDY, MsTMIP, and CMIP5.

International Land Model Benchmarking (ILAMB)

Why Benchmark?

- to show the broader science community and the public that the representation of the carbon cycle in climate models is improving;
- to provide a means, to quantitatively diagnose impacts of model development on carbon cycle and land surface processes;
- to guide synthesis efforts, such as the IPCC, in review of mechanisms of global change in models that are broadly consistent with available contemporary observations;
- to increase scrutiny of key datasets used for model evaluation;
- to identify gaps in existing observations needed for model validation;
- to provide a quantitative, application-specific set of minimum criteria for participation in model intercomparison projects (MIPs);
- to provide an optional weighting system for multi-model mean estimates of future changes in the carbon cycle.



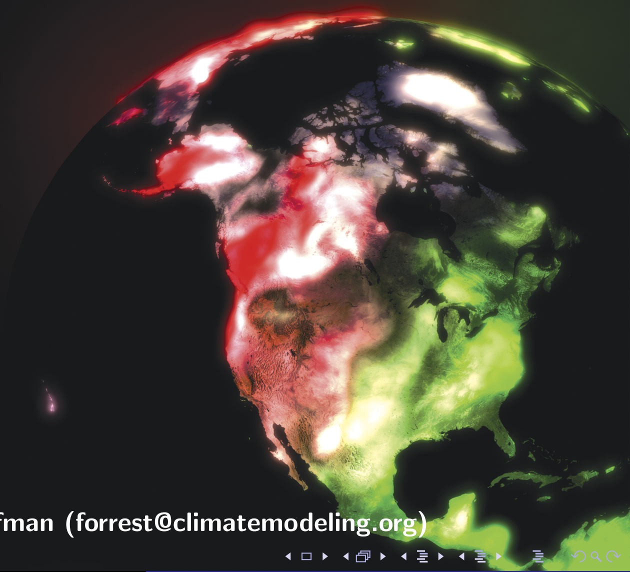
- Meeting Co-organized by Forrest Hoffman (UC-Irvine and ORNL), Chris Jones (UK Met Office Hadley Centre), Pierre Friedlingstein (U. Exeter), and Jim Randerson (UC-Irvine).
- About 45 researchers participated from the United States, Canada, the United Kingdom, the Netherlands, France, Germany, Switzerland, China, Japan, and Australia.

	Annual Mean	Seasonal Cycle	Interannual Variability	Trend	Data Source
Atmospheric CO_2					
Flask/conc. + transport		✓	✓	✓	NOAA, SIO, CSIRO
TCCON + transport		✓	✓	✓	Caltech
Fluxnet					
GPP, NEE, TER, LE, H, RN	✓	✓	✓		Fluxnet, MAST-DC
Gridded: GPP	✓	✓	?		MPI-BGC
Hydrology/Energy					
river flow	✓		✓		GRDC, Dai, GFDL
global runoff/ocean balance	✓				Syed/Famiglietti
albedo (multi-band)		✓	✓		MODIS, CERES
soil moisture		✓	✓		de Jeur, SMAP
column water		✓	✓		GRACE
snow cover	✓	✓	✓	✓	AVHRR, GlobSnow
snow depth/SWE	✓	✓	✓	✓	CMC (N. America)
T_{air} & P	✓	✓	✓	✓	CRU, GPCP and TRMM
Gridded: LE, H	✓	✓			MPI-BGC, dedicated ET
Ecosystem Processes & State					
soil C, N	✓				HWSD, MPI-BGC
litter C, N	✓				LIDET
soil respiration	✓	?	✓	✓	Bond-Lamberty
FAPAR	✓	✓			MODIS, SeaWIFS
biomass & change	✓			✓	Saatchi, Pan, Blackard
canopy height	✓				Lefsky, Fisher
NPP	✓				EMDI, Luyssaert
Vegetation Dynamics					
fire — burned area	✓	✓	✓		GFED3
wood harvest	✓			✓	Hurtt
land cover	✓				MODIS PFT fraction

Next Steps

- Five benchmarks will be implemented initially and used to evaluate existing model results from TRENDY and CMIP5.
- A draft document proposing additional new netCDF Climate and Forecast (CF) conventions, beyond those created for CMIP5, is available for comment.
- Model results will be shared on the Earth System Grid (ESG).
- Future: New protocols and forcing data comparisons.
- A development Wiki is coming soon.
- ILAMB Town Hall meeting at AGU in December.
- Next ILAMB meeting in Beijing, China, in early 2012.

International Land Model Benchmarking (ILAMB) Project
http://www.ilamb.org/



Thank you!

Contact: Forrest Hoffman (forrest@climatemodeling.org)