Evaluation of the ACME Land Model using the ILAMB Prototype

ACME Accelerated Climate Modeling for Energy

Forrest M. Hoffman[1], Daniel M. Ricciuto[1], William J. Riley[2], and Peter E. Thornton[1]

[1]Oak Ridge National Laboratory (ORNL) and [2]Lawrence Berkeley National Laboratory (LBNL)

Oak Ridge National Laboratory

Berkeley Lab

Abstract

Assessment of overall model fidelity requires a comprehensive comparison of model results with a wide variety of observational data spanning multiple space and time scales. The International Land Model Benchmarking (ILAMB) activity has developed an open source benchmarking software system that employs a growing collection of laboratory, field, and remote sensing data sets for systematic evaluation of terrestrial biogeochemical and biogeophysical processes. The ACME Project is leveraging the ILAMB metrics and diagnostics prototype system, developed by the Biogeochemistry–Climate Feedbacks Scientific Focus Area (SFA), and extending the system to assess the overall performance of the ACME Land Model (ALM), both coupled and uncoupled, as it evolves over time. Here we show how the performance of the latest version of ALM, run offline and forced with CRU-NCEP reanalysis, compared with the performance of the Community Land Model (CLM) versions CLM4.0-CN (forced with CRU-NCEP), CLM4.5-BGC (forced with CRU-NCEP), and CLM4.5-BGC (forced with GSWP3) on the full suite of metrics currently contained in the ILAMB system. Diagnostics highlighting key model response differences attributable to new model structures implemented in ALM will be presented. Additional proposed metrics important for evaluating new process representations in ALM will also be discussed.

International Land Model Benchmarking (ILAMB) Project

The objective of the ILAMB Project is to improve the performance of land models and, in parallel, improve the design of new measurement campaigns to reduce uncertainties associated with key land surface processes. An open source software diagnostics package, called the ILAMB Prototype, has been developed for use in benchmarking land model performance through comparison with contemporary observations. The ILAMB Prototype evaluates and scores model performance on eight Ecosystem and Carbon Cycle variables, five Hydrology Cycle variables, seven Radiation and Energy Cycle variables, and four Atmospheric Forcing variables. In addition, variable-to-variable relationships from models are compared with those functional relationships from observations. We leveraged this prototype and developed plans to extend it for routine evaluation of the ACME Land Model.

Model Description and Experimental Design

The ACME Land Model (ALM) started as a branch off the Community Land Model version 4.5 (CLM4.5-BGC), employing vertically resolved soil carbon and nitrification/denitrification. However, the initial version of ALM is utilizing the Convergent Trophic Cascade (CTC) instead of the CENTURY decomposition submodel, and it has a new phosphorus cycle that implements P-limitation on vegetation growth.

To test the fidelity of this model configuration, we performed an offline simulation at 1° resolution over the past 50 years (1970–2010) using CRU-NCEP reanalysis as forcing. Land use change was disabled in this test simulation. The results of this simulation were benchmarked with the ILAMB Prototype diagnostics package and compared with similar simulation results from CLM4.0-CN, CLM4.5-BGC, and CLM4.5-BGC forced with the Global Soil Wetness Project version 3 (GSWP3) reanalysis.

Ecosystem and Carbon Cycle Performance

Details for a few example variables in the Ecosystem and Carbon Cycle category are presented here to demonstrate the utility of the evaluation metrics and show how ALM compares with prior versions of CLM.

Aboveground Live Biomass

Three different biomass datasets are currently available in ILAMB:

- Pan-tropical forest biomass [GLOBAL.CARBON] (Saatchi et al., 2011),
- Contiguous U.S. (Kellendorfer et al., 2000), and
- Contiguous U.S. and Alaska (Blackard et al., 2008).

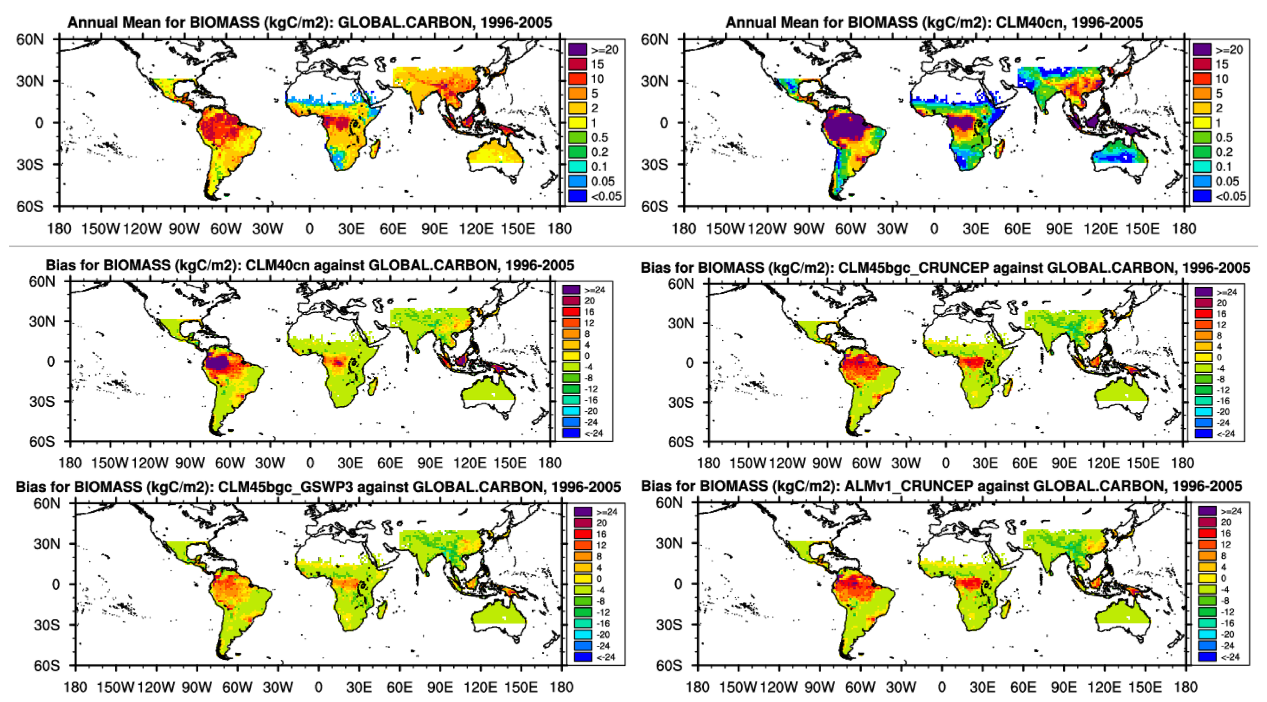

Figure 1: *Shown here are the year 2000 pan-tropical forest biomass benchmark data (Saatchi et al., 2011) (top row left) and the ALMv1 annual mean biomass for years 1996–2005 (top row right). Below the horizontal line are maps of the bias from all four models computed by subtracting the benchmark from the model annual mean biomass for years 1996–2005.*

Table 1: *Diagnostic Summary for Aboveground Live Biomass: Models versus the GLOBAL.CARBON benchmark.*

	Global Patterns		Scoring (Info)		
	Annual Mean (PgC)	Bias (PgC)	Global Bias	Spatial Distribution	Overall
Benchmark [Saatchi et al. (2011)]	351.4	-	-	-	-
CLM40cn	483.9	132.4	0.48	0.50	0.49
CLM45bgc_CRUNCEP	437.2	85.8	0.47	0.58	0.52
CLM45bgc_GSWP3	354.6	3.2	0.56	0.73	0.64
ALMv1_CRUNCEP	416.0	64.6	0.48	0.61	0.55

Soil Carbon

The ILAMB Prototype includes metrics for two different soil carbon data sets: Global top 1 m of soil carbon from the Harmonized World Soil Database (HWSD) (Todd-Brown et al., 2013) and Northern circumpolar top 1 m soil carbon (Hugelius et al., 2013).

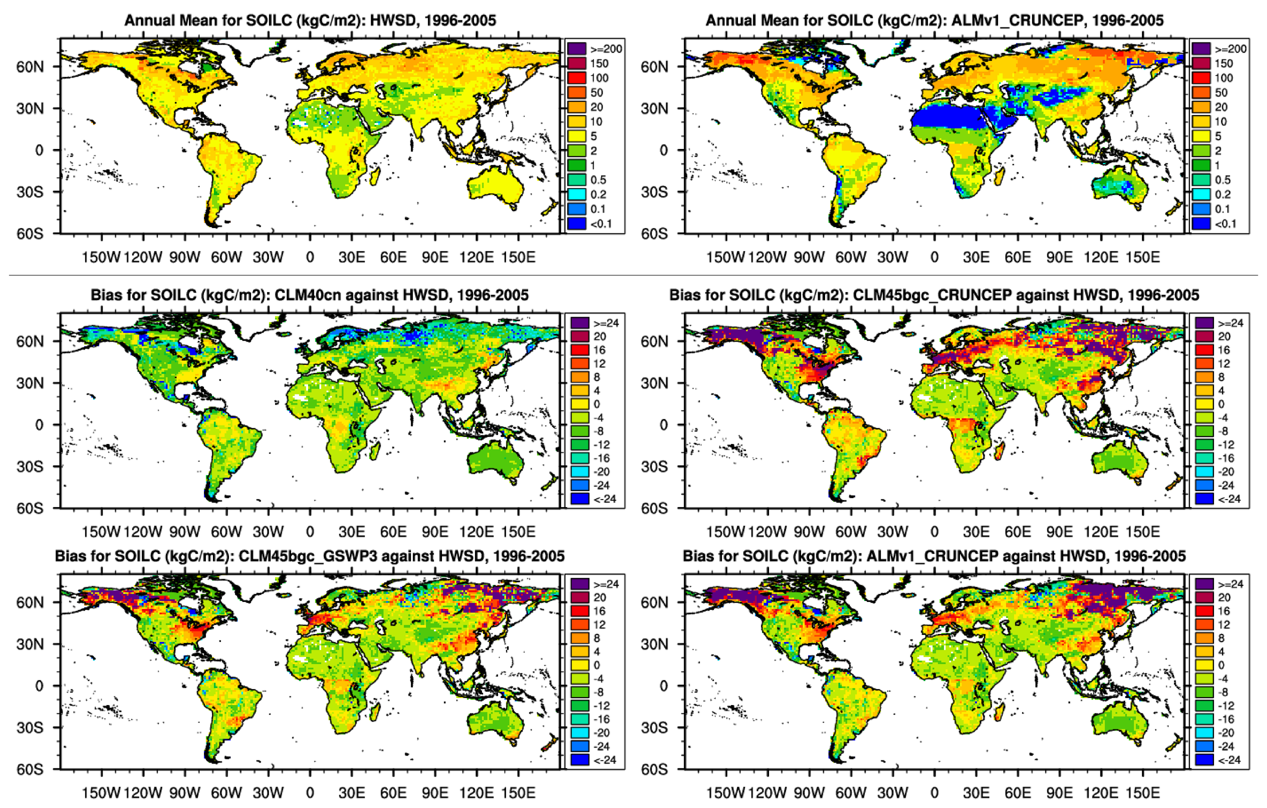

Figure 2: *Shown here are the year 2000 global top 1 m of soil carbon from HWSD benchmark data (Todd-Brown et al., 2013) (top row left) and the ALMv1 annual mean soil carbon for years 1996–2005 (top row right). Below the horizontal line are maps of the bias from all four models computed by subtracting the benchmark from the model annual mean biomass for years 1996–2005.*

Table 2: *Diagnostic Summary for Soil Carbon: Models versus the HWSD benchmark.*

	Global Patterns		Scoring (Info)		
	Annual Mean (PgC)	Bias (PgC)	Global Bias	Spatial Distribution	Overall
Benchmark [Todd-Brown et al. (2013)]	1372.7	-	-	-	-
CLM40cn	582.9	-789.8	0.57	0.54	0.56
CLM45bgc_CRUNCEP	1711.1	338.4	0.55	0.46	0.50
CLM45bgc_GSWP3	1306.3	-66.4	0.60	0.66	0.63
ALMv1_CRUNCEP	1415.8	43.1	0.59	0.55	0.57

Gross Primary Production

Table 3: *Diagnostic Summary for Gross Primary Production: Models versus the FLUXNET-MTE benchmark (Jung et al., 2009).*

	Global Patterns				Regional Patterns	Scoring (Info)				
	Annual Mean (PgC/yr)	Bias (PgC/yr)	RMSE (PgC/mon)	Phase Difference (months)	Regional Mean	Global Bias	RMSE	Seasonal Cycle	Spatial Distribution	Overall
Benchmark [Jung et al. (2009)]	118.5	-	-	0.0	access to plots	-	-	-	-	-
CLM40cn	134.4	15.9	5.7	0.4	access to plots	0.67	0.64	0.78	0.82	0.71
CLM45bgc_CRUNCEP	122.1	3.5	5.0	0.4	access to plots	0.73	0.69	0.79	0.93	0.77
CLM45bgc_GSWP3	110.9	-7.6	4.9	0.4	access to plots	0.73	0.70	0.78	0.92	0.77
ALMv1_CRUNCEP	121.1	2.5	5.0	0.4	access to plots	0.74	0.70	0.80	0.93	0.77

Notes: In calculating overall score, rmse score contributes double in comparison with all other scores.

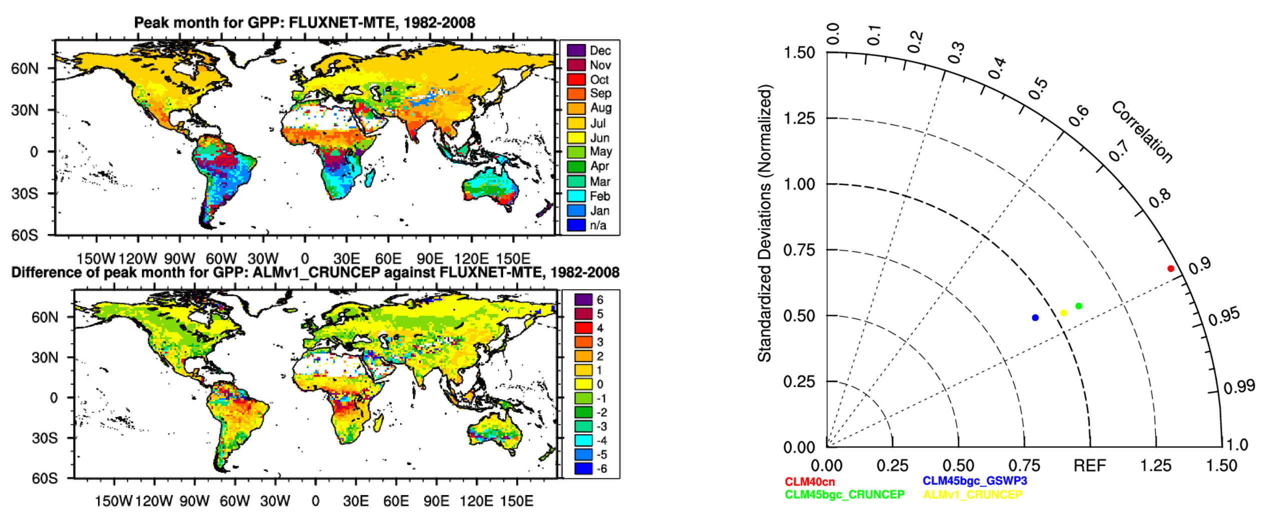

Figure 3: *The peak month of GPP from FLUXNET-MTE (top left) and the difference in peak month for GPP from ALMv1_CRUNCEP (bottom left). The Taylor Diagram (right) shows that the spatial distribution of GPP is slightly better in ALMv1_CRUNCEP than in the other models.*

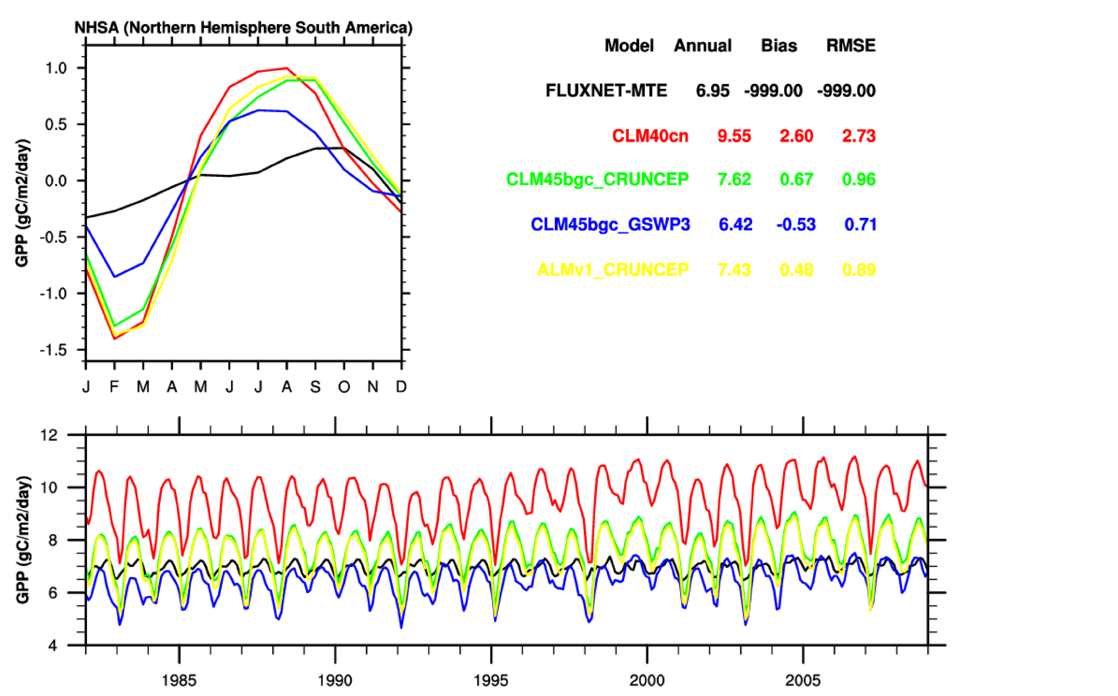

Figure 4: *The ILAMB Prototype compares the model and FLUXNET mean GPP annual cycle (amplitude and phase) (top left); computes the annual mean, bias, and RMSE (top right), and compares the full time series of GPP for prescribed regions.*

Variable-to-Variable (Functional) Relationships

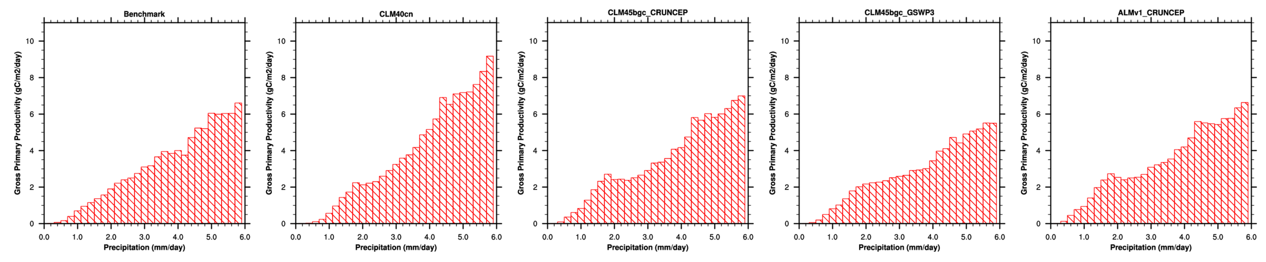

Figure 5: *These histograms show the variable-to-variable relationship between gross primary production and precipitation globally in the observations (left) and all four models. Such functional relationship evaluations highlight overall model responses even when biases may exist in the atmospheric forcing.*

Summary of ALM Performance and Conclusions

Table 4: *In the ILAMB Prototype, models are scored based on their performance with respect to best-available observational data sets in the following categories: Ecosystem and Carbon Cycle (green), Hydrological Cycle (blue), Radiation and Energy (red), and Atmospheric Forcings (gray). Compared here are simulations from CLM4.0-CN, CLM4.5-BGC with CRU-NCEP forcing, CLM4.5-BGC with GSWP3 forcing, and ALMv1 with CRU-NCEP forcing.*

Global Variables (Info for Weightings)

	CLM40cn	CLM45bgc_CRUNCEP	CLM45bgc_GSWP3	ALMv1_CRUNCEP
Aboveground Live Biomass	0.61	0.61	0.67	0.63
Burned Area	0.36	0.49	0.51	0.48
Gross Primary Productivity	0.70	0.75	0.76	0.75
Leaf Area Index	0.52	0.52	0.57	0.53
Global Net Ecosystem Carbon Balance	0.51	0.58	0.52	0.60
Net Ecosystem Exchange	0.49	0.48	0.49	0.48
Ecosystem Respiration	0.65	0.70	0.74	0.71
Soil Carbon	0.44	0.50	0.61	0.55
Summary	0.54	0.58	0.61	0.59
Evapotranspiration	0.74	0.77	0.79	0.78
Latent Heat	0.80	0.82	0.84	0.84
Terrestrial Water Storage Anomaly	0.63	0.63	0.60	0.60
Summary	0.72	0.74	0.74	0.74
Albedo	0.73	0.74	0.75	0.74
Surface Upward SW Radiation	0.77	0.76	0.79	0.75
Surface Net SW Radiation	0.86	0.85	0.87	0.85
Surface Upward LW Radiation	0.93	0.93	0.94	0.93
Surface Net LW Radiation	0.78	0.78	0.86	0.78
Surface Net Radiation	0.79	0.79	0.81	0.79
Sensible Heat	0.76	0.76	0.79	0.75
Summary	0.80	0.79	0.82	0.79
Surface Air Temperature	0.91	0.91	0.94	0.91
Precipitation	0.80	0.80	0.83	0.80
Surface Downward SW Radiation	0.87	0.87	0.90	0.87
Surface Downward LW Radiation	0.90	0.90	0.94	0.90
Summary	0.86	0.86	0.90	0.86
Overall	0.65	0.68	0.70	0.68

Notes: 4 Categories are divided: Ecosystem and Carbon Cycle, Hydrology Cycle, Radiation and Energy Cycle, and Forcings.

- ALMv1_CRUNCEP performs similarly to CLM45bgc_CRUNCEP, but has a slightly smaller tropical biomass bias and a reduced soil carbon bias.
- CLM45bgc_GSWP3 has a lower bias in tropical biomass, likely due primarily to reductions in shortwave radiation forcing.
- Comparisons of forcing variables between ALMv1_CRUNCEP and CLM45bgc_CRUNCEP in Table 4 confirm that the coupler bypass method (Ricciuto, in prep.) provides equivalent model forcing to that provided through the coupler.
- According to Table 4, ALMv1_CRUNCEP performs similarly to CLM45bgc_CRUNCEP for variables in all categories.
- Next steps are to run ALMv1 forced with GSWP3 and re-evaluate performance. This simulation will likely have a lower tropical biomass bias than any of these models.
- Since it can easily highlight changes in model performance, the ILAMB Prototype will be integrated into the standard workflow process for ACME model development and simulation.

Acknowledgements

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