

ESS Cyberinfrastructure Working Groups

Common tools and approaches for constraining models, quantifying uncertainty, and performing big (and little!) data analytics supporting MoDEx:

- Modeling workflows, model–data comparison, model evaluation and benchmarking
- Uncertainty quantification and data assimilation
- Management and fusion of model output and observational data (Data Management)
- Geospatial and remote sensing data analysis
- Data analytics methods and techniques, e.g., data mining, machine learning, genetic algorithms, visual analytics
- Hybrid ML/process-based models & data-driven models (Software Engineering & Integration)

Working Group on Model-Data Integration Co-Leads

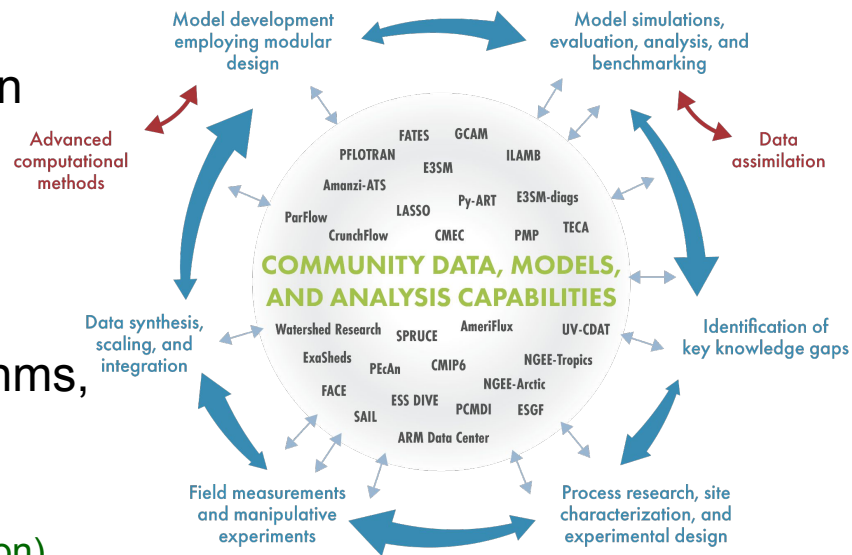


Xingyuan Chen
(PNNL)



Forrest Hoffman
(ORNL)

EESSD's Model-Data-Experiment Enterprise

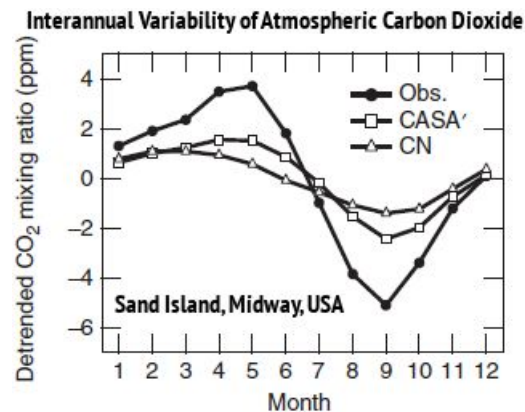


Virtual Hackathon for E3SM Land Model (ELM) Watershed Simulation

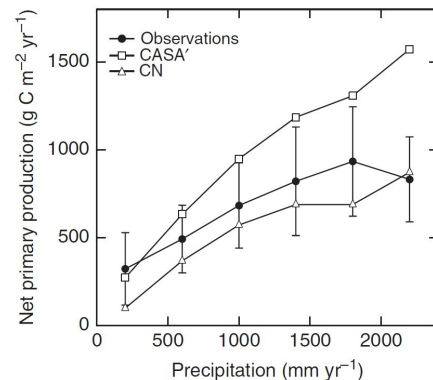
- GitHub Link: https://github.com/doe-ess-community/elm_hackathon_20230413
- Video Recording: <http://www.youtube.com/watch?v=WgkX2QWKBF4>

What is a Benchmark?

- A **benchmark** is a quantitative test of model function achieved through comparison of model results with observational data
- Acceptable performance on a benchmark **is a necessary but not sufficient condition** for a fully functioning model
- **Functional relationship benchmarks** offer tests of model responses to forcings and yield insights into ecosystem processes
- Effective benchmarks must draw upon **a broad set of independent observations** to evaluate model performance at multiple scales



Models often fail to capture the amplitude of the seasonal cycle of atmospheric CO₂

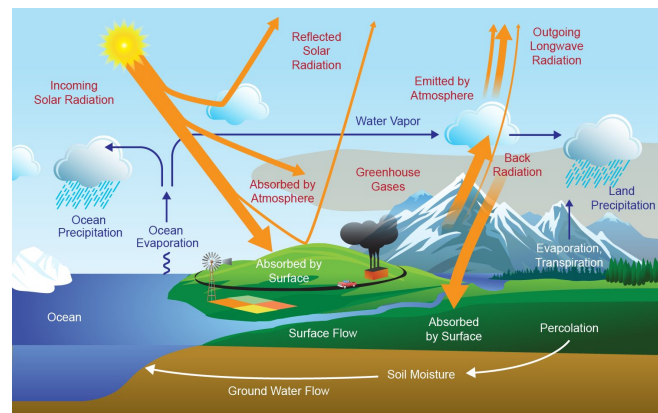


Models may reproduce correct responses over only a limited range of forcing variables

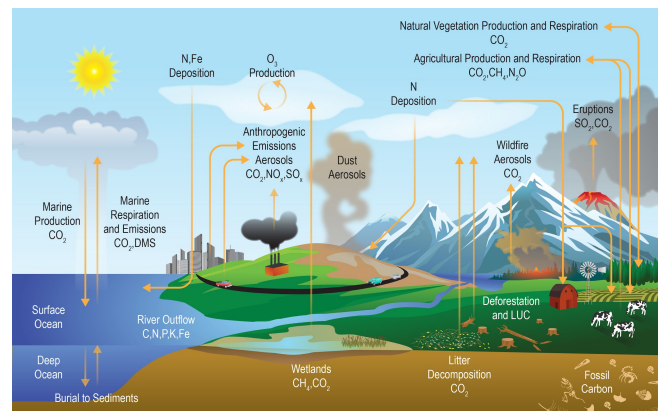
What is ILAMB?

A community coordination activity created to:

- **Develop internationally accepted benchmarks** for land model performance by drawing upon collaborative expertise
- **Promote the use of these benchmarks** for model intercomparison
- **Strengthen linkages between experimental, remote sensing, and Earth system modeling communities** in the design of new model tests and new measurement programs
- **Support the design and development of open source benchmarking tools**



Energy and Water Cycles



Carbon and Biogeochemical Cycles

ILAMB Produces Diagnostics and Scores Models

- ILAMB generates a top-level **portrait plot** of models scores
- For every variable and dataset, ILAMB can automatically produce
 - Tables** containing individual metrics and metric scores (when relevant to the data), including
 - Benchmark and model **period mean**
 - Bias** and **bias score** (S_{bias})
 - Root-mean-square error (RMSE)** and **RMSE score** (S_{rmse})
 - Phase shift** and **seasonal cycle score** (S_{phase})
 - Interannual coefficient of variation** and **IAV score** (S_{iav})
 - Spatial distribution score** (S_{dist})
 - Overall score** (S_{overall}) $\longrightarrow S_{\text{overall}} = \frac{S_{\text{bias}} + 2S_{\text{rmse}} + S_{\text{phase}} + S_{\text{iav}} + S_{\text{dist}}}{1 + 2 + 1 + 1 + 1}$
 - Graphical diagnostics**
 - Spatial contour maps
 - Time series line plots
 - Spatial Taylor diagrams (Taylor, 2001)
- Similar **tables** and **graphical diagnostics** for functional relationships

ILAMBv2.6 Package Current Variables

- **Biogeochemistry:** Biomass (Contiguous US, Pan Tropical Forest), Burned area (GFED3), CO₂ (NOAA GMD, Mauna Loa), Gross primary production (Fluxnet, GBAF), Leaf area index (AVHRR, MODIS), Global net ecosystem carbon balance (GCP, Khatiwala/Hoffman), Net ecosystem exchange (Fluxnet, GBAF), Ecosystem Respiration (Fluxnet, GBAF), Soil C (HWSD, NCSCDv22, Koven)
- **Hydrology:** Evapotranspiration (GLEAM, MODIS), Evaporative fraction (GBAF), Latent heat (Fluxnet, GBAF, DOLCE), Runoff (Dai, LORA), Sensible heat (Fluxnet, GBAF), Terrestrial water storage anomaly (GRACE), Permafrost (NSIDC)
- **Energy:** Albedo (CERES, GEWEX.SRB), Surface upward and net SW/LW radiation (CERES, GEWEX.SRB, WRMC.BSRN), Surface net radiation (CERES, Fluxnet, GEWEX.SRB, WRMC.BSRN)
- **Forcing:** Surface air temperature (CRU, Fluxnet), Diurnal max/min/range temperature (CRU), Precipitation (CMAP, Fluxnet, GPCC, GPCP2), Surface relative humidity (ERA), Surface down SW/LW radiation (CERES, Fluxnet, GEWEX.SRB, WRMC.BSRN)

Multi-Model Validation Example

Evaluation of CMIP5 vs CMIP6 with ILAMB and IOMB

- (a) ILAMB and (b) IOMB have been used to evaluate how land and ocean model performance has changed from CMIP5 to CMIP6
- Model fidelity is assessed through comparison of historical simulations with a wide variety of contemporary observational datasets
- The UN's Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) from Working Group 1 (WG1) Chapter 5 contains the full ILAMB/IOMB evaluation as Figure 5.22

(a) Land Benchmarking Results

Land Ecosystem & Carbon Cycle

	bcc-csm1-1	CanESM2	CanESM1-BGC	GFDL-ESM2G	IPSL-CM5A-LR	MIROC-ESM	MPI-ESM-LR	NorESM1-ME	HadGEM2-ES	BCC-CSM2-MR	CanESM5	CSM2	GFDL-ESM4	IPSL-CM6A-LR	MIROC-ES2L	MPI-ESM1.2-LR	NorESM2-LM	UKESM1-0-LL	Mean CMIP5	Mean CMIP6
Biomass	-0.72	-0.93	-1.95	-1.51	-0.13	0.60	-0.43	-1.11	0.19	-0.43	0.66	0.48	-1.09	0.22	0.60	-0.07	1.00	0.49	1.63	2.30
Burned Area	0.20	-0.45	-1.52	-0.40	-1.26	-1.07	-1.77	0.92	1.39	0.74	-0.20	-0.54	0.16	0.93	-0.96	-0.01	1.04	1.23	1.82	
Leaf Area Index			-0.87				0.10	-0.83			1.60									
Soil Carbon	-0.20	-0.64	-1.30	-2.53	-0.01	0.30	0.01	-1.85	-0.16	0.27	0.08	0.34	-0.70	1.19	0.82	0.46	0.37	0.69	1.04	1.81
Gross Primary Productivity	0.27	1.26	1.46	0.07	0.75	0.47	-0.03	-1.14	0.07	0.23	1.35	-0.99	-2.04	-1.55	0.90	-0.75	-0.17	0.24	1.01	1.48
Net Ecosystem Exchange	0.59	-1.23	0.01	1.81	-1.40	0.29	-0.53	-0.24	-1.04	0.77	0.04	0.59	-0.38	1.17	-1.02	-0.37	0.73	0.09	1.51	2.22
Ecosystem Respiration	-0.42	1.81	-0.21	-0.65	1.10	-0.24	0.80	0.02	-1.03	-1.02	-1.19	0.59	1.69	-0.42	0.63	-0.21	1.08	-1.43	1.28	1.43
Carbon Dioxide	0.90	-0.56	-0.86	-0.24	-1.35	0.99	-0.01	-0.94	-1.54	0.81	0.59	0.51	-0.79	0.90	-0.21	-1.24	0.43	-0.94	1.34	2.21
Global Net Carbon Balance	-1.54	-0.36	-2.02	-0.74	1.53	-0.00	0.37	0.85		0.42	-0.26	0.39	0.59	1.10	-0.87	0.21	0.69	0.09	-0.07	
Terrestrial Water Storage Anomaly	-1.64	-0.88	-1.13	0.17	-0.31	-0.38	-0.50	0.24		-0.23	1.34	-1.70	0.17	-0.74	1.45	1.56	0.26	0.92	1.40	
Permafrost	-2.65	-0.42	0.44	-0.18	-0.49	-0.52	-0.57	0.17	0.70	0.15	-0.47	1.51	-1.24	0.58	-0.72	-0.83	0.97	0.87	1.00	1.70
Evapotranspiration	-0.82	-0.99	-0.27	-1.02	0.64	-1.14	-0.62	-0.60	0.28	0.39	-1.08	1.09	0.65	0.43	-1.40	-1.01	0.82	1.05	1.41	2.20
Evaporative Fraction	-0.34	0.74	0.74	-0.14	-0.85	0.21	1.98	0.22	-0.34	0.10	0.11	1.25	-0.88	1.29	-1.65	-1.81	1.11	-0.06	0.98	1.29

Land Hydrology Cycle

Terrestrial Water Storage Anomaly	-2.79	-0.45	0.47	0.50	-0.38	0.34	0.35	0.43	0.58	0.15	-0.08	0.95	-2.91	0.43	0.37	0.15	0.39	0.51	0.49	0.50
Permafrost	-0.88	2.26	0.01	0.13	0.83	0.69	0.56	0.69	-0.56	-0.11	-3.02	0.83	0.74	-0.18	0.49	0.42	0.89	0.43	0.06	0.23

(b) Ocean Benchmarking Results

Ocean Ecosystems

Chlorophyll	-1.50	2.19	0.44	1.02		0.49	0.56	-0.67	0.88	-0.21	0.10	-1.02	-0.41	2.19	0.18	0.13	0.04			
Oxygen, surface		0.73	-0.13	-1.98		-0.53	-1.53	-0.29		0.73	0.34	-0.09	-0.41	0.35	-0.30	0.40	0.49	0.64	1.57	
Nitrate, surface		-0.84	-0.10	0.91		-0.80	-1.25			-0.02	1.00	1.98		-0.90	-1.14	-0.17	-0.16	1.60		
Phosphate, surface		0.21	-1.63	0.67	1.22		-0.18	-1.70	0.82		1.21	-0.90	0.29	1.21	1.02	0.39	-1.78	-0.56	-0.47	0.18
Silicate, surface			-0.69	-0.04	0.04		-0.45	-0.43			0.39	-0.14	0.17	-0.41	-0.98	0.00	0.02	0.88	1.63	

Ocean Carbon

TALK, surface		0.44	-0.71	0.24		-0.81	-0.20	2.16			0.50	1.24	1.60		-1.21	-0.19	0.18	-0.29	1.37	
Salinity, 700m		-0.27	1.01	0.12	0.19		0.32	-2.21	-0.22		0.06	-0.36	0.85	-0.42	0.29	2.48	1.27	0.06	1.27	0.54

Ocean Relationships

Oxygen, surface/WOA2018			-1.86	-0.36	-0.29		1.50	-0.43	0.68		-0.02	0.72	1.20	0.17	1.86	0.02	-1.12	0.39	1.25	
Nitrate, surface/WOA2018			0.27	0.23	-0.63		-0.26	-0.12	-0.38		0.29	-0.21	0.19	0.18	0.14	-0.07	0.03	-0.23	0.53	

