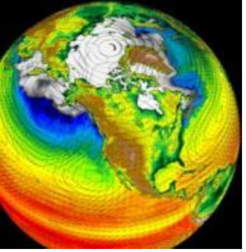
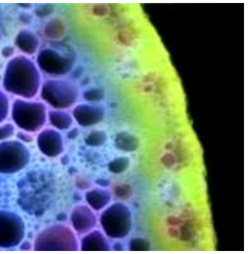
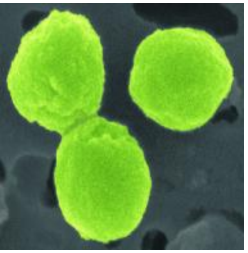


DOE scientific successes as part of the International LAnd Model Benchmarking (ILAMB) Project

AGU FALL MEETING
San Francisco | 14–18 December 2015

December 14, 2015

Outline

1. Introduction to DOE-CESD and the BGC Feedbacks Science Focus Area

   Renu Joseph

2. Introduction and History of ILAMB

   Forrest Hoffman and Nathan Collier

3. ILAMB Prototype for Model Development

   Dave Lawrence

4. ILAMB Prototype for CMIP5 and CMIP6 Evaluation

   Jim Randerson and Mingquan Mu

5. Discussion and Q/A

   Bill Riley and Gretchen Keppel-Aleks

DOE Office of Science

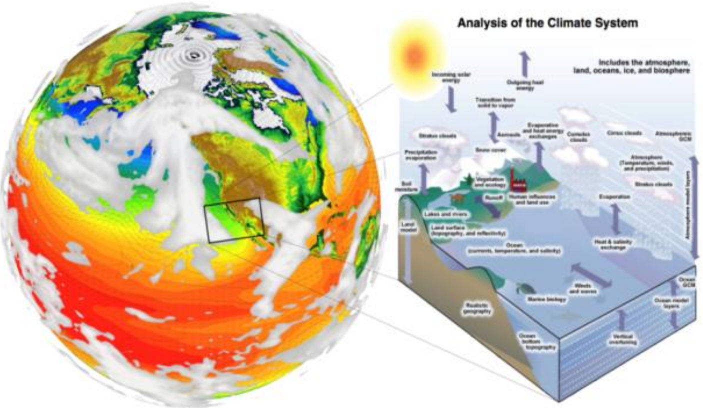
Patricia Dehmer
Director

"…Energy, Environmental and Nuclear Security…"
"…Transformative Science…"

- Basic Energy Sciences
- **Biological and Environmental Research (BER)**
  S. Weatherwax
  - **Climate and Environmental Sciences**
    Gary Geernaert
  - **Biological System Sciences**
    Todd Anderson
- High Energy Physics
- Nuclear Physics
- Fusion Energy Sciences
- Advanced Scientific Computing Research

CESD is the intellectual home for fundamental research to understand the energy-environment-climate connections and their implications for energy production, use, sustainability, and security.

Climate and Environmental Sciences Division



Atmospheric Science

- Atmospheric Radiation Measurement Climate Research Facility
- Atmospheric System Research

Modeling

- Earth System Modeling
- Regional and Global Climate Modeling
- Integrated Assessment Research

Environmental System Science

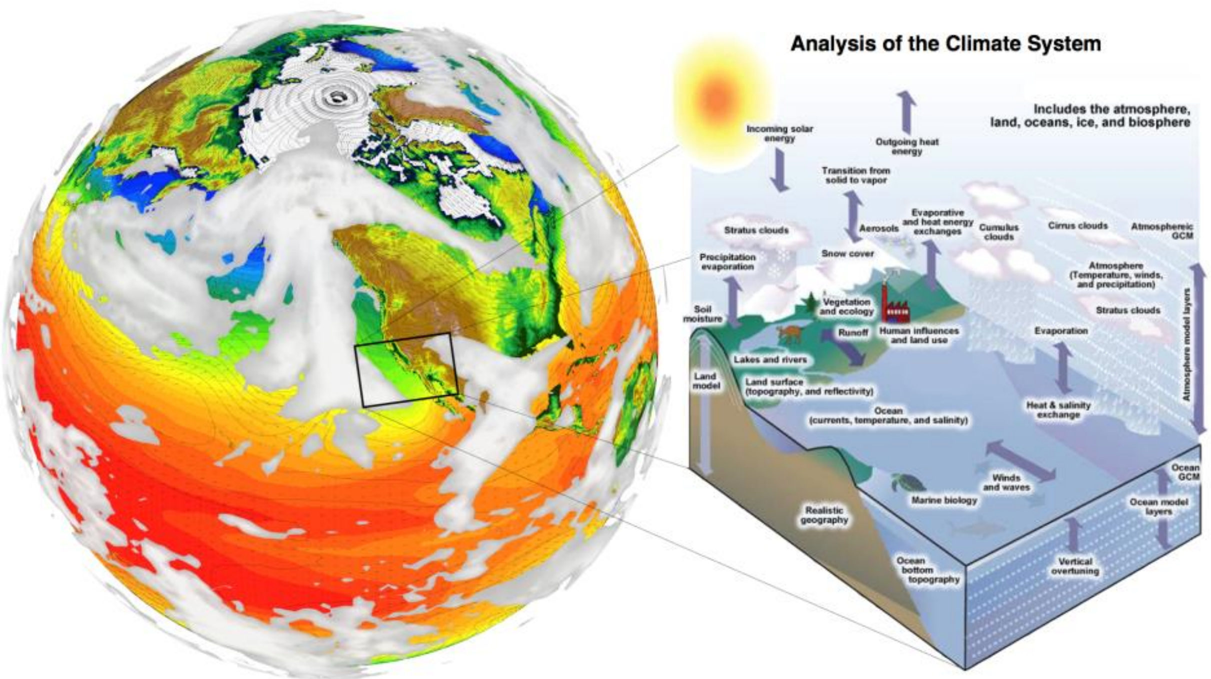
- Terrestrial Ecosystem Science
- Subsurface Biogeochemical Research
- Environmental Molecular Sciences Laboratory

Data Informatics

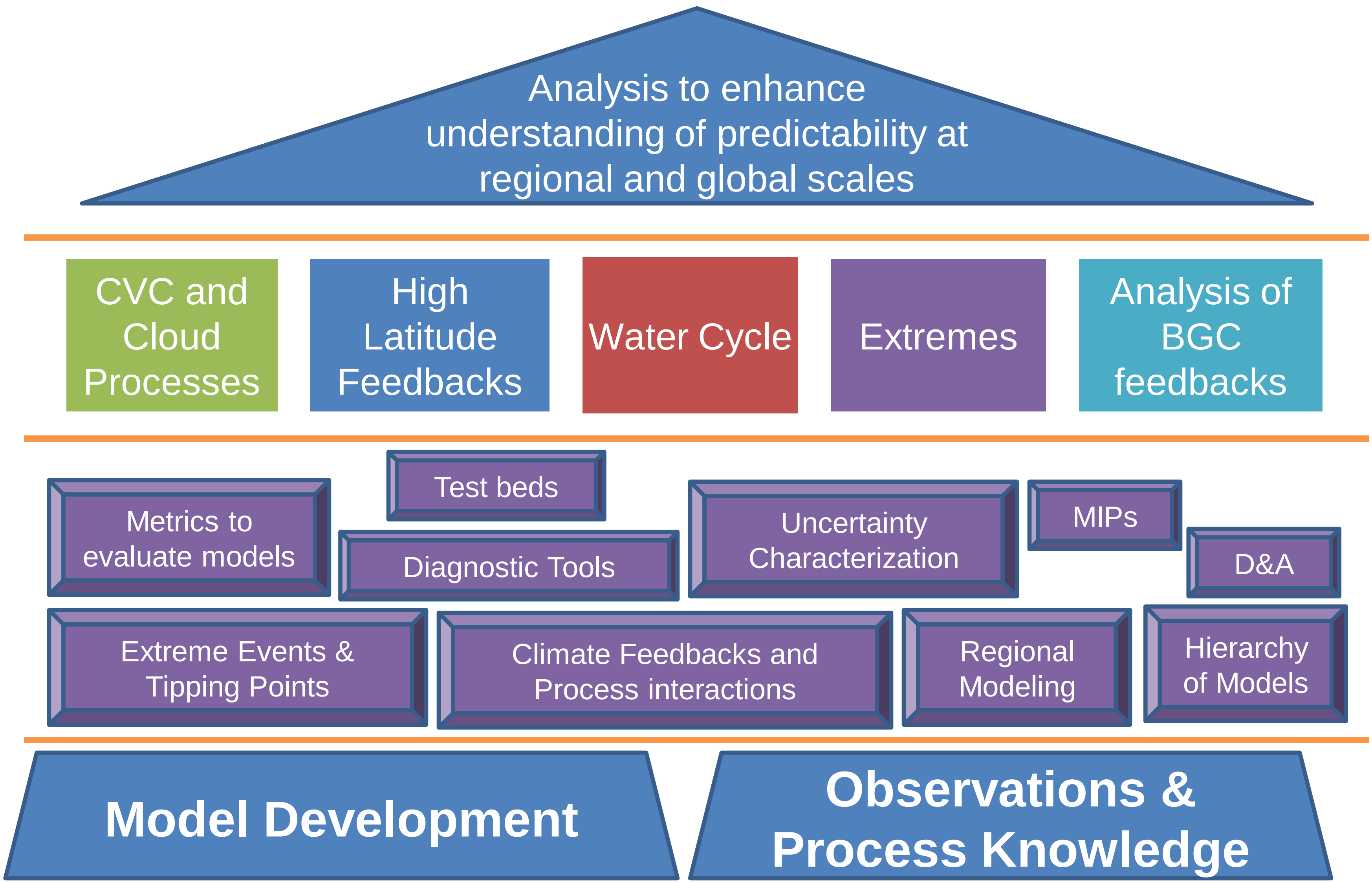
Regional and Global Climate Modeling

Strategic Goal

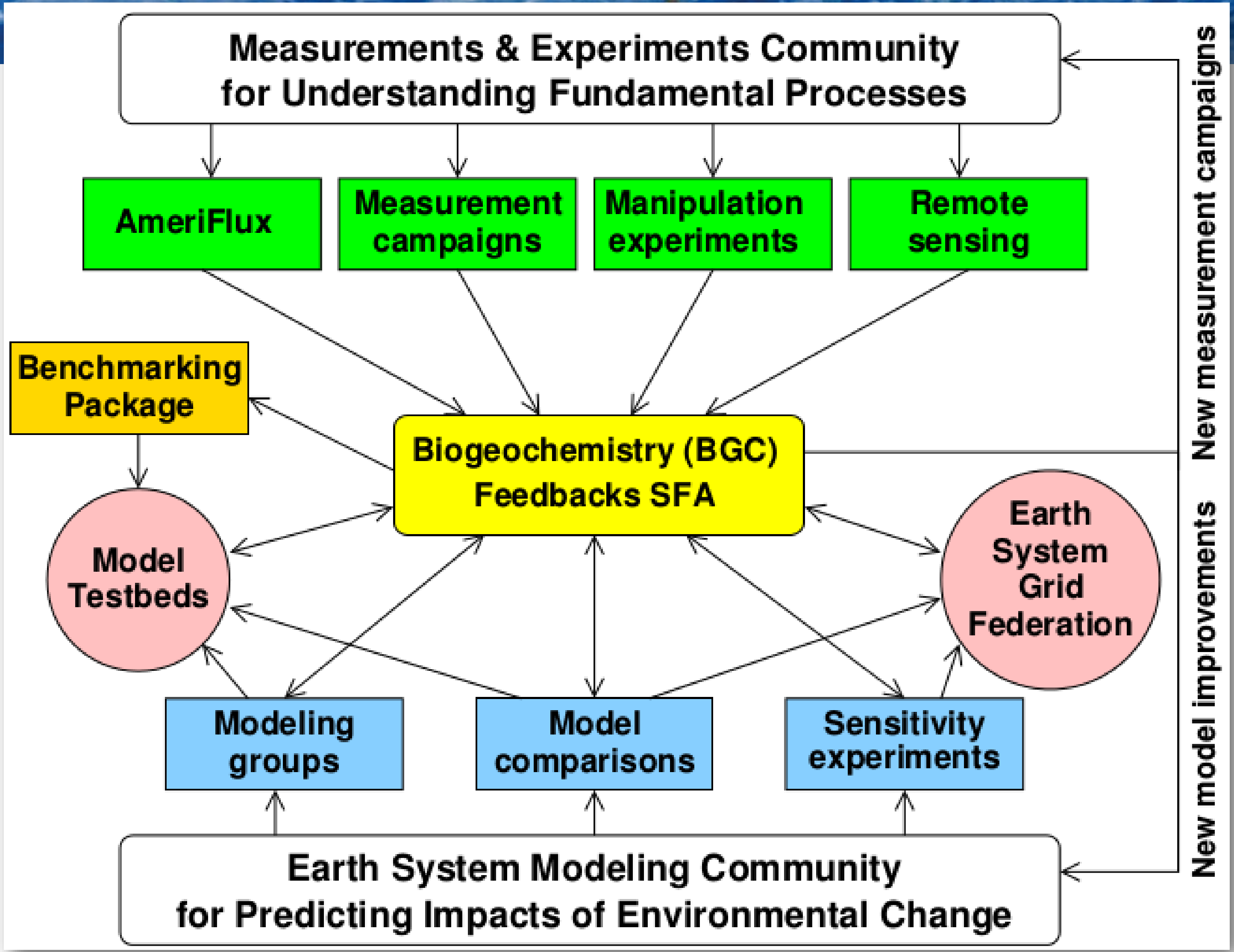
- To enhance a predictive understanding of climate variability and change by analyzing global and regional earth system models in conjunction with observations

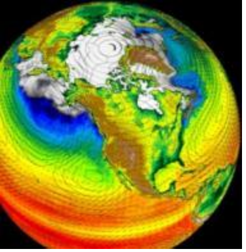


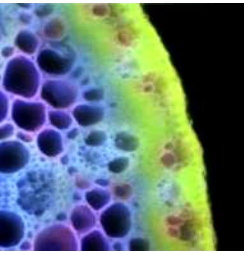
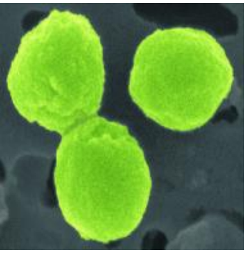
Regional and Global Climate Modeling



Biogeochemistry–Climate Feedbacks Scientific Focus Area





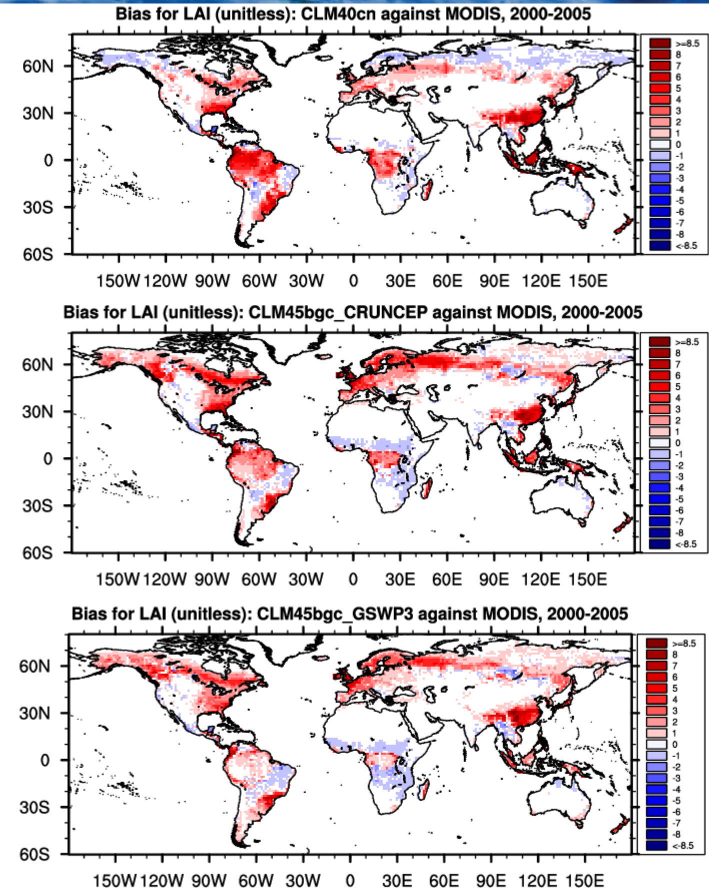




Introduction and History of ILAMB

Forrest Hoffman and Nathan Collier

What is ILAMB?

- The **International Land Model Benchmarking (ILAMB)** project seeks to develop internationally accepted standards for land model evaluation.
- Model **benchmarking** can diagnose impacts of model development and guide synthesis efforts like IPCC.
- **Effective benchmarks** must draw upon a broad set of independent observations to evaluate model performance on multiple temporal and spatial scales.
- A free, **open source analysis and diagnostics software package** for community use will enhance model intercomparison projects.



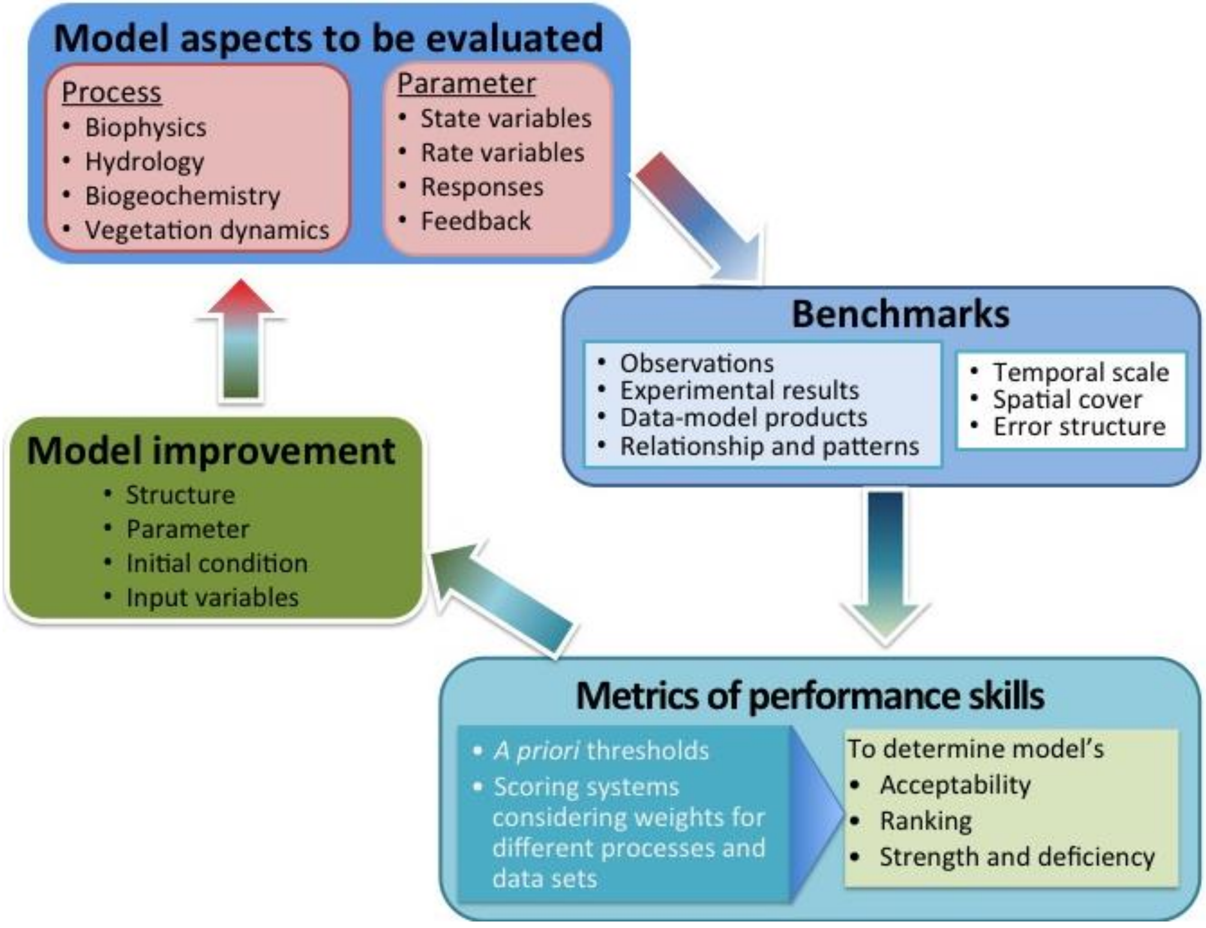
Bias in mean annual leaf area index from comparison of three versions of CLM with MODIS.

BGC Feedbacks

- We co-organized inaugural meeting of ~45 researchers from U.S., Canada, United Kingdom, Netherlands, France, Germany, Switzerland, China, Japan, Australia.
- **ILAMB Goals**: Develop an internationally accepted set of benchmarks for model performance; advocate for design of open-source software system; and strengthen linkages between experimental, remote sensing, and climate modeling communities.
- Methodology for model–data comparison and baseline standard for performance of land model process representations (Luo et al., 2012).

Benchmark Methodology (Luo et al., 2012)

- Based on this methodology and prior work in C-LAMP, we developed a new model benchmarking package for ILAMB.
- Prototype is ready for use in NCL and a new version is under development using python.



ILAMB Prototype developed by Mingquan Mu

- Assesses 24 variables in 4 categories from ~45 datasets
  - aboveground live biomass, burned area, carbon dioxide, gross primary production, leaf area index, global net ecosystem carbon balance, net ecosystem exchange, ecosystem respiration, soil carbon
  - evapotranspiration, latent heat, terrestrial water storage anomaly
  - albedo, surface upward SW radiation, surface net SW radiation, surface upward LW radiation, surface net LW radiation, surface net radiation, sensible heat
  - surface air temperature, precipitation, surface relative humidity, surface downward SW radiation, surface downward LW radiation
- Graphics and scoring system
  - annual mean, bias, RMSE, seasonal cycle, spatial distribution, interannual coefficient of variation, spatial distribution, long-term trend
- Software is available at http://redwood.ess.uci.edu/mingquan/www/ILAMB/index.html

ILAMB Prototype: Global Variables for 12 Models

Global Variables (Info for Weightings)

	MeanModel	bcc-csm1-1-m	BNU-ESM	CanESM2	CESM1-BGC	GFDL-ESM2G	HadGEM2-ES	inmcm4	IPSL-CM5A-LR	MIROC-ESM	MPI-ESM-LR	MRI-ESM1	NorESM1-ME
Aboveground Live Biomass	0.68	0.52	0.50	0.61	0.65	0.58	0.67	0.54	0.68	0.52	0.51	0.67	0.65
Burned Area	0.38	-	-	-	0.37	-	-	-	-	-	0.38	-	0.38
Carbon Dioxide	0.85	-	0.65	0.65	0.78	0.65	-	-	-	0.79	0.68	0.68	0.75
Gross Primary Productivity	0.77	0.72	0.73	0.64	0.70	0.67	0.68	0.70	0.67	0.69	0.69	0.53	0.70
Leaf Area Index	0.66	0.66	0.41	0.60	0.53	0.49	0.59	0.68	0.66	0.62	0.68	0.43	0.50
Global Net Ecosystem Carbon Balance	0.58	-	0.38	0.27	0.38	0.18	-	0.46	0.25	0.38	0.42	0.27	0.40
Net Ecosystem Exchange	0.49	0.47	0.47	0.39	0.48	0.49	0.46	0.44	0.53	0.48	0.50	0.48	0.48
Ecosystem Respiration	0.75	0.72	0.72	0.65	0.67	0.71	0.66	0.70	0.67	0.68	0.68	0.47	0.66
Soil Carbon	0.55	0.50	0.42	0.56	0.38	0.51	0.51	0.53	0.57	0.53	0.41	0.53	0.39
Summary	0.64	0.59	0.54	0.54	0.55	0.53	0.59	0.57	0.57	0.58	0.54	0.51	0.55
Evapotranspiration	0.75	0.73	0.72	0.72	0.73	0.70	0.74	0.69	0.75	0.70	0.73	0.73	0.72
Latent Heat	0.80	0.76	0.77	0.77	0.78	0.74	0.77	0.72	0.77	0.75	0.76	0.78	0.76
Terrestrial Water Storage Anomaly	0.53	0.45	0.35	0.54	0.48	0.43	-	0.52	0.45	0.52	0.55	0.47	0.45
Summary	0.69	0.65	0.61	0.68	0.66	0.62	0.75	0.64	0.65	0.66	0.68	0.66	0.64
Albedo	0.72	0.71	0.61	0.71	0.73	0.69	0.74	0.67	0.71	0.67	0.73	0.64	0.72
Surface Upward SW Radiation	0.78	0.73	0.67	0.74	0.78	0.74	0.77	0.74	0.74	0.72	0.78	0.67	0.76
Surface Net SW Radiation	0.84	0.86	0.84	0.85	0.85	0.86	0.85	0.84	0.82	0.83	0.87	0.85	0.85
Surface Upward LW Radiation	0.90	0.91	0.91	0.91	0.92	0.91	0.92	0.89	0.90	0.91	0.92	0.92	0.92
Surface Net LW Radiation	0.81	0.82	0.81	0.79	0.82	0.81	0.83	0.79	0.78	0.78	0.81	0.82	0.81
Surface Net Radiation	0.78	0.79	0.76	0.80	0.80	0.80	0.79	0.74	0.77	0.76	0.80	0.78	0.80
Sensible Heat	0.76	0.69	0.70	0.71	0.75	0.69	0.75	0.66	0.69	0.69	0.69	0.72	0.72
Summary	0.79	0.78	0.75	0.78	0.80	0.78	0.80	0.75	0.76	0.76	0.79	0.77	0.79
Surface Air Temperature	0.87	0.87	0.85	0.85	0.88	0.85	0.87	0.85	0.87	0.85	0.88	0.88	0.87
Precipitation	0.70	0.67	0.66	0.67	0.70	0.68	0.72	0.68	0.68	0.68	0.70	0.69	0.69
Surface Relative Humidity	0.81	-	0.80	0.76	0.82	-	-	0.79	0.82	-	-	0.83	0.81
Surface Downward SW Radiation	0.86	0.88	0.87	0.87	0.88	0.87	0.87	0.87	0.83	0.86	0.88	0.86	0.88
Surface Downward LW Radiation	0.90	0.92	0.91	0.91	0.92	0.92	0.92	0.90	0.89	0.91	0.93	0.91	0.91
Summary	0.82	0.82	0.81	0.80	0.83	0.82	0.84	0.81	0.81	0.81	0.84	0.83	0.82
Overall	0.69	0.51	0.59	0.60	0.64	0.56	0.49	0.57	0.57	0.59	0.61	0.59	0.63

ILAMB Prototype: Global Variables for 12 Models

Global Variables (Info for Weightings)

	MeanModel	bcc-csm1-1-m	BNU-ESM	CanESM2	CESM1-BGC	GFDL-ESM2G	HadGE
Aboveground Live Biomass	0.68	0.52	0.50	0.61	0.65	0.58	0.6
Burned Area	0.38	-	-	-	0.37	-	-
Carbon Dioxide	0.85	-	0.65	0.65	0.78	0.65	-
Gross Primary Productivity	0.77	0.72	0.73	0.64	0.70	0.67	0.6
Leaf Area Index	0.66	0.66	0.41	0.60	0.53	0.49	0.5
Global Net Ecosystem Carbon Balance	0.58	-	0.38	0.27	0.38	0.18	-
Net Ecosystem Exchange	0.49	0.47	0.47	0.39	0.48	0.49	0.4
Ecosystem Respiration	0.75	0.72	0.72	0.65	0.67	0.71	0.6
Soil Carbon	0.55	0.50	0.42	0.56	0.38	0.51	0.5
Summary	0.64	0.59	0.54	0.54	0.55	0.53	0.5
Evapotranspiration	0.75	0.73	0.72	0.72	0.73	0.70	0.7
Latent Heat	0.80	0.76	0.77	0.77	0.78	0.74	0.7
Terrestrial Water Storage Anomaly	0.53	0.45	0.35	0.54	0.48	0.43	-
Summary	0.69	0.65	0.61	0.68	0.66	0.62	0.7
Albedo	0.72	0.71	0.61	0.71	0.73	0.69	0.7
Surface Upward SW Radiation	0.78	0.73	0.67	0.74	0.78	0.74	0.7
Surface Net SW	0.84	0.86	0.84	0.85	0.85	0.86	0.8

BGC Feedbacks

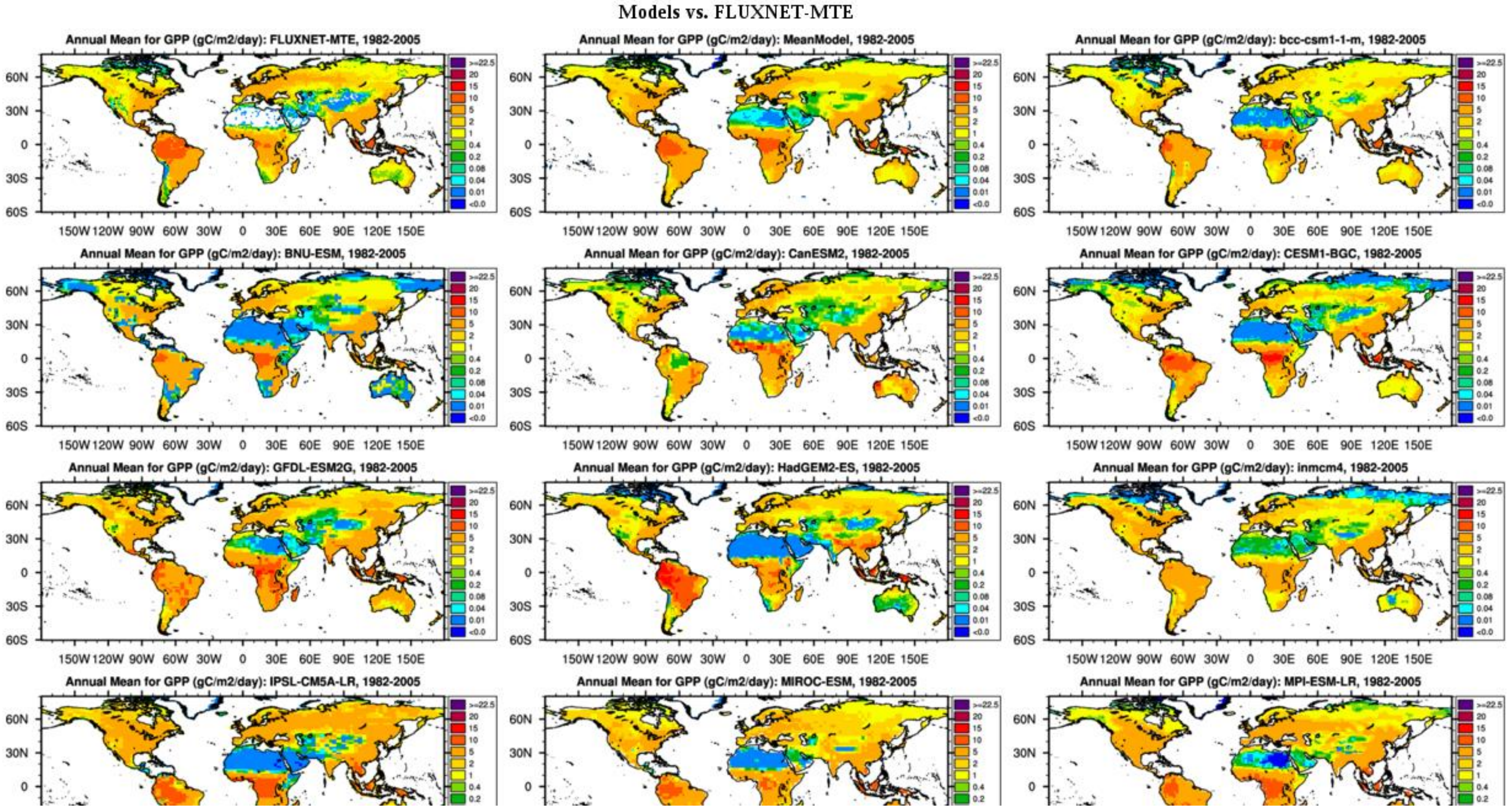
Scoring for Global GPP from Fluxnet-MTE

Diagnostic Summary for Gross Primary Productivity: Model vs. FLUXNET-MTE

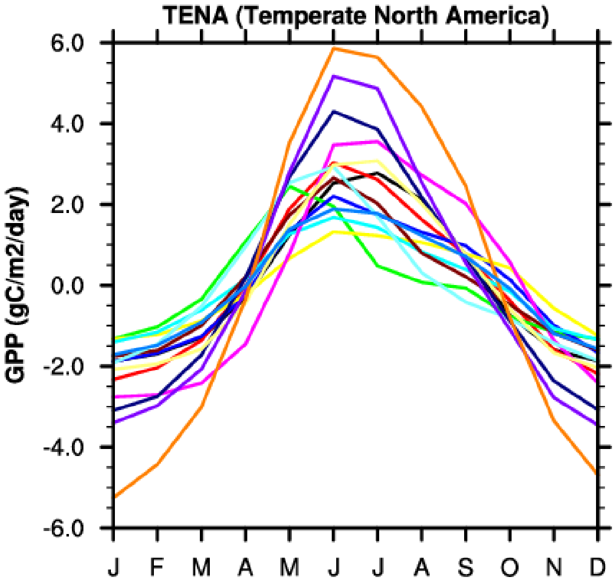
	Global Patterns				Regional and Seasonal Patterns	Scoring (Info)				
	Annual Mean (PgC/yr)	Bias (PgC/yr)	RMSE (PgC/mon)	Phase Difference (months)	Regional Means	Global Bias	RMSE	Seasonal Cycle	Spatial Distribution	Overall
Benchmark [Jung et al. (2009)]	118.4	-	-	0.0	access to plots	-	-	-	-	-
MeanModel	145.3	26.9	4.7	0.6	access to plots	0.77	0.73	0.78	0.94	0.79
bcc-csm1-1-m	114.4	-4.0	6.0	-0.2	access to plots	0.72	0.64	0.80	0.89	0.74
BNU-ESM	102.0	-16.4	6.2	0.1	access to plots	0.69	0.66	0.78	0.84	0.73
CanESM2	129.2	10.8	7.3	0.8	access to plots	0.64	0.60	0.68	0.70	0.64
CESM1-BGC	130.3	11.9	5.8	0.5	access to plots	0.69	0.65	0.76	0.87	0.72
GFDL-ESM2G	175.1	56.7	9.8	0.5	access to plots	0.66	0.54	0.73	0.83	0.66
HadGEM2-ES	145.9	27.5	7.4	0.3	access to plots	0.65	0.58	0.78	0.79	0.68
inmcm4	111.4	-7.0	5.6	0.3	access to plots	0.71	0.66	0.78	0.83	0.73
IPSL-CM5A-LR	166.6	48.2	8.8	0.4	access to plots	0.63	0.56	0.77	0.84	0.67
MIROC-ESM	131.7	13.3	6.2	0.2	access to plots	0.72	0.66	0.74	0.86	0.73
MPI-ESM-LR	169.9	51.5	7.4	0.3	access to plots	0.67	0.62	0.70	0.89	0.70
MRI-ESM1	236.1	117.7	12.5	0.2	access to plots	0.45	0.43	0.79	0.59	0.54
NorESM1-ME	130.4	12.0	6.5	0.5	access to plots	0.66	0.62	0.76	0.84	0.70

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

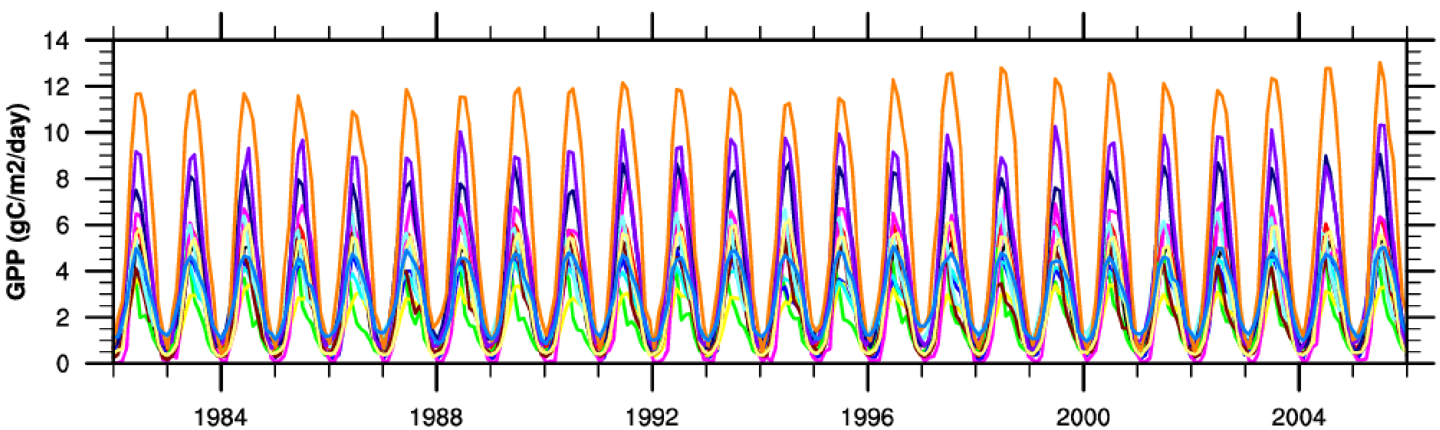
Annual Mean Global GPP



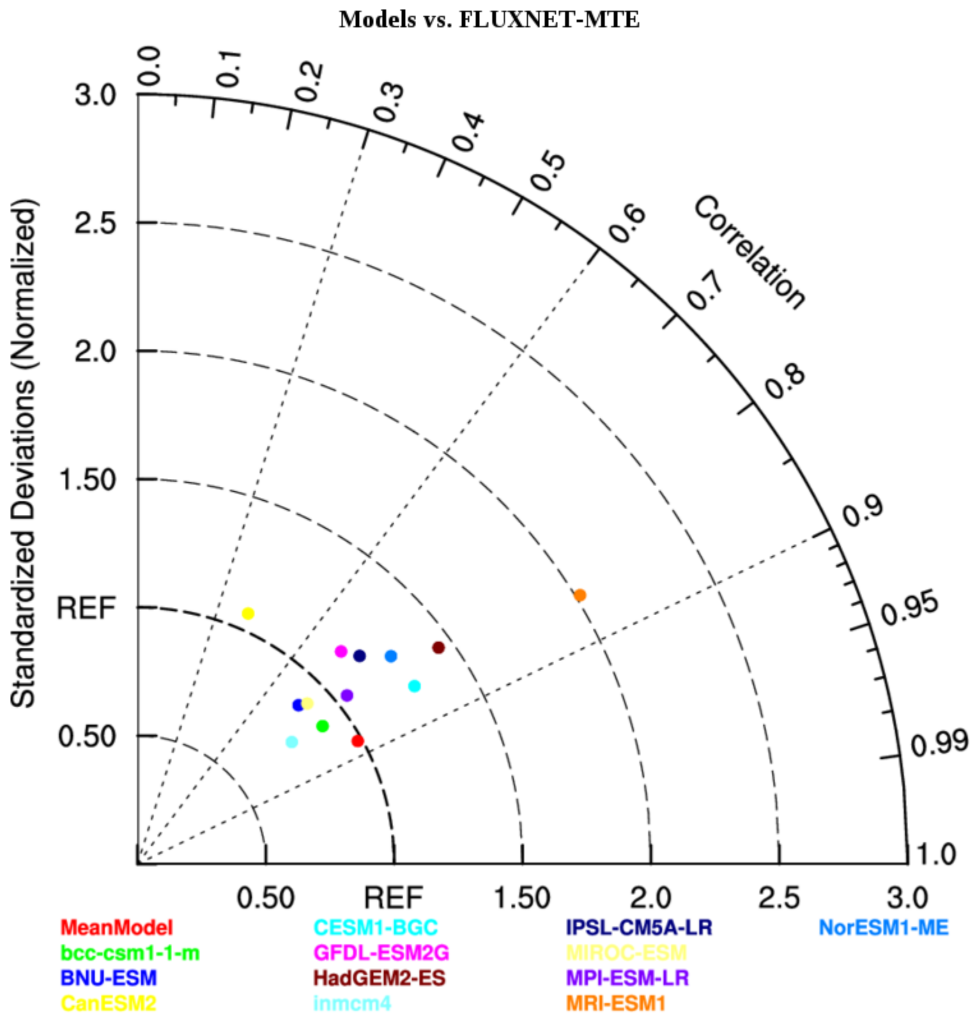
Seasonal Cycle of Regional GPP



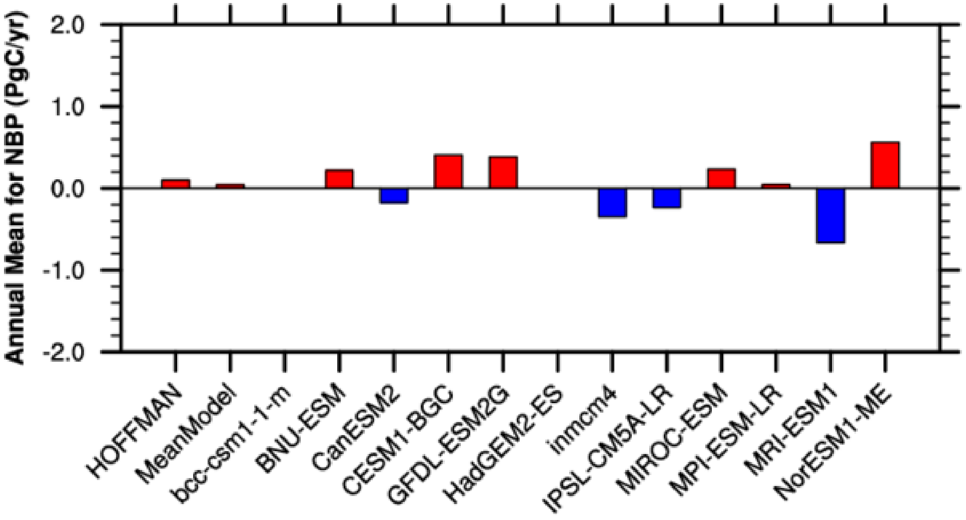
Model	Annual	Bias	RMSE
FLUXNET-MTE	2.36	-999.00	-999.00
MeanModel	2.99	0.63	0.74
bcc-csm1-1-m	1.82	-0.54	1.31
BNU-ESM	2.17	-0.19	0.62
CanESM2	1.76	-0.60	1.08
CESM1-BGC	2.45	0.08	0.78
GFDL-ESM2G	2.85	0.49	1.16
HadGEM2-ES	2.12	-0.24	0.72
inmcm4	3.06	0.70	1.20
IPSL-CM5A-LR	3.95	1.59	1.90
MIROC-ESM	2.48	0.12	0.35
MPI-ESM-LR	4.27	1.91	2.38
MRI-ESM1	6.13	3.76	4.46
NorESM1-ME	2.84	0.48	0.74



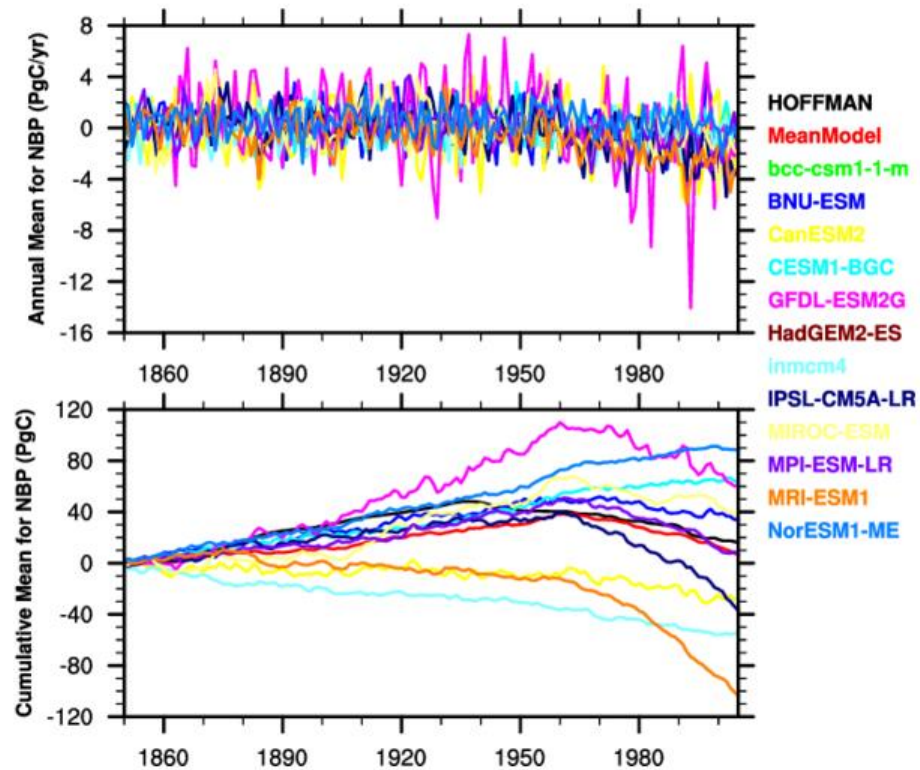
Global Annual Mean GPP Spatial Correspondence



Global Net Ecosystem Carbon



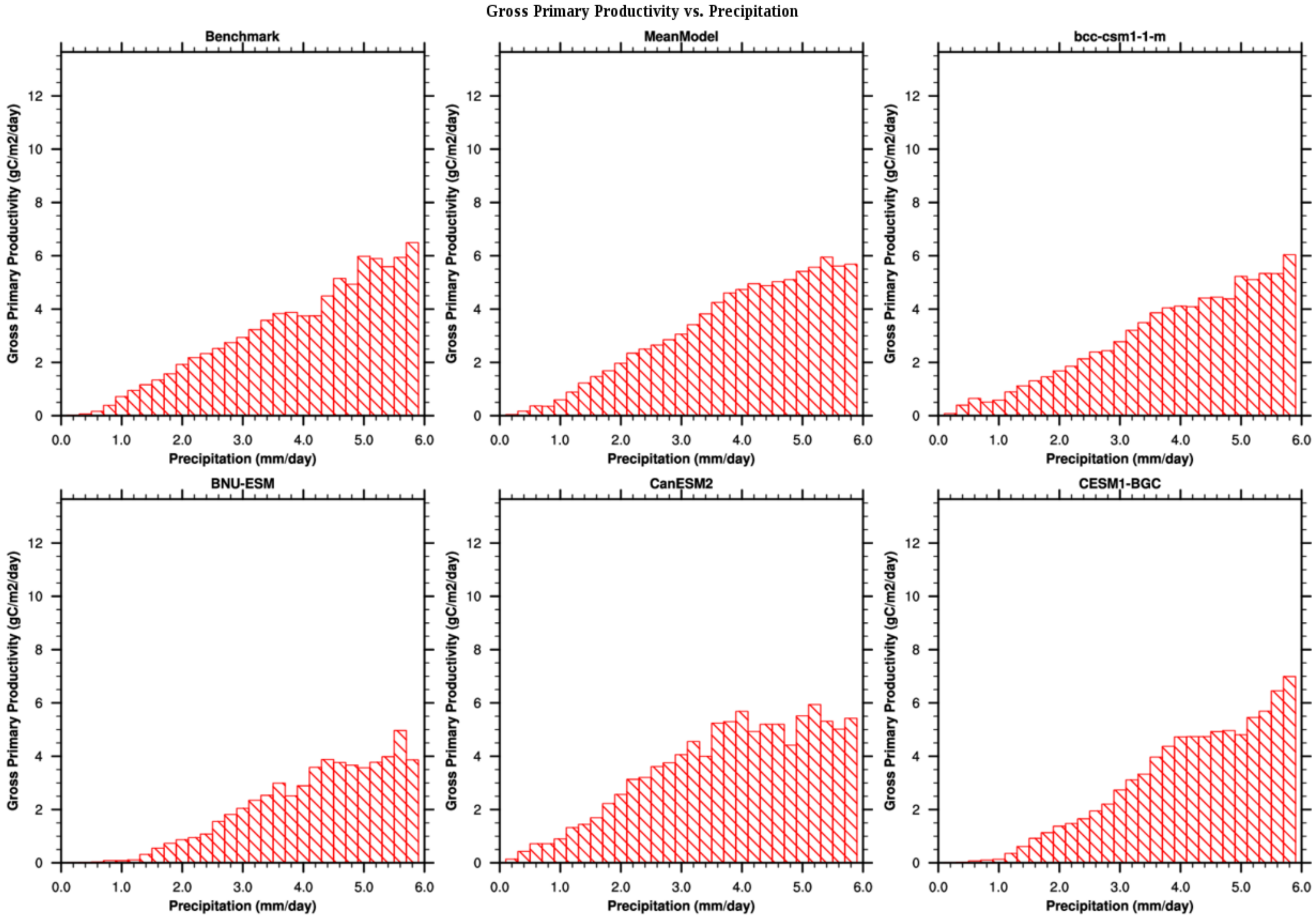
Global Net Ecosystem Carbon Balance



Long term carbon storage

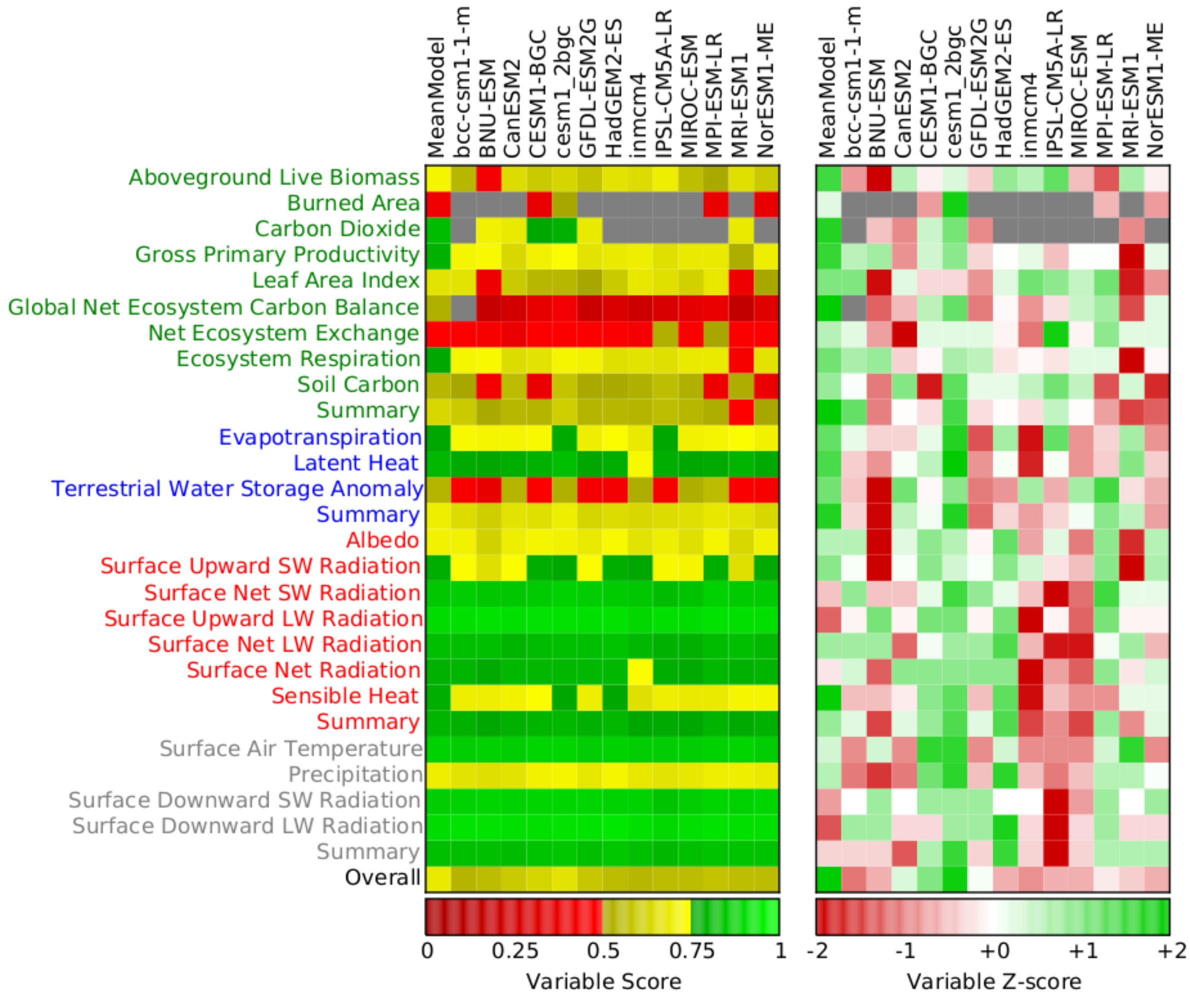
BGC Feedbacks

Functional Relationships: GPP vs. Precipitation



BGC Feedbacks

ILAMB Model Scoring by Variable



BGC Feedbacks

Argonne NATIONAL LABORATORY · BERKELEY LAB · Los Alamos NATIONAL LABORATORY · NCAR · OAK RIDGE National Laboratory · UCI · MICHIGAN

ILAMB Next Generation Layout

Ecosystem and Carbon Cycle

	bcc-csm1-1	bcc-csm1-1-m	BNU-ESM	CanESM2	CCSM4	CESM1-BGC	GFDL-ESM2G	HadGEM2-CC	HadGEM2-ES	inmcm4	IPSL-CM5A-LR	IPSL-CM5A-MR	MIROC-ESM	MIROC-ESM-CHEM	MPI-ESM-LR	MRI-ESM1	NorESM1-M	NorESM1-ME	
Biomass	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Burned Area	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Carbon Dioxide	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Gross Primary Productivity	0.53	0.57	0.52	0.47	0.52	0.52	0.52	0.51	0.51	0.05	0.50	0.52	0.55	0.55	0.55	0.45	0.54	0.54	▼
Leaf Area Index	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Global Net Ecosystem Carbon Balance	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Net Ecosystem Exchange	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Ecosystem Respiration	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Soil Carbon	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼

Hydrology Cycle

	bcc-csm1-1	bcc-csm1-1-m	BNU-ESM	CanESM2	CCSM4	CESM1-BGC	GFDL-ESM2G	HadGEM2-CC	HadGEM2-ES	inmcm4	IPSL-CM5A-LR	IPSL-CM5A-MR	MIROC-ESM	MIROC-ESM-CHEM	MPI-ESM-LR	MRI-ESM1	NorESM1-M	NorESM1-ME	
Evapotranspiration	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Latent Heat	0.39	0.39	0.43	0.36	0.44	0.44	0.41	0.42	0.42	0.40	0.44	0.42	0.43	0.43	0.40	0.41	0.45	0.45	▲
Fluxnet-MTE (75.0%)	0.27	0.26	0.31	0.28	0.31	0.31	0.29	0.28	0.28	0.28	0.31	0.30	0.34	0.34	0.28	0.27	0.34	0.33	
Fluxnet (25.0%)	0.77	0.76	0.78	0.60	0.83	0.83	0.78	0.86	0.85	0.77	0.83	0.78	0.71	0.71	0.76	0.82	0.79	0.78	
Terrestrial Water Storage Anomaly	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼

Radiation and Energy Cycle

	bcc-csm1-1	bcc-csm1-1-m	BNU-ESM	CanESM2	CCSM4	CESM1-BGC	GFDL-ESM2G	HadGEM2-CC	HadGEM2-ES	inmcm4	IPSL-CM5A-LR	IPSL-CM5A-MR	MIROC-ESM	MIROC-ESM-CHEM	MPI-ESM-LR	MRI-ESM1	NorESM1-M	NorESM1-ME	
Albedo	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Surface Upward SW Radiation	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Surface Net SW Radiation	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Surface Upward LW Radiation	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Surface Net LW Radiation	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Surface Net Radiation	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Sensible Heat	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼

Forcings

	bcc-csm1-1	bcc-csm1-1-m	BNU-ESM	CanESM2	CCSM4	CESM1-BGC	GFDL-ESM2G	HadGEM2-CC	HadGEM2-ES	inmcm4	IPSL-CM5A-LR	IPSL-CM5A-MR	MIROC-ESM	MIROC-ESM-CHEM	MPI-ESM-LR	MRI-ESM1	NorESM1-M	NorESM1-ME	
Surface Air Temperature	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Precipitation	0.36	0.35	0.36	0.36	0.37	0.37	0.35	0.36	0.36	0.34	0.35	0.35	0.36	0.36	0.35	0.35	0.36	0.36	▼
Surface Downward SW Radiation	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼
Surface Downward LW Radiation	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	▼

ILAMB Next Generation Layout

GPPFluxnetGlobalM ×

www.climatemodeling.org/~nate/ILAMB/GPP/GPPFluxnetGlobalMTE.html

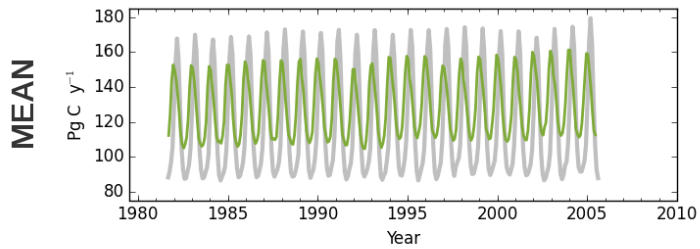
GPPFluxnetGlobalMTE / CESM1-BGC / global

global (global)

Model	Data	PeriodMean [Pg y^{-1}]	Bias [Pg y^{-1}]	RMSE [Pg y^{-1}]	PhaseShift [day]	BiasScore [-]	RMSEScore [-]	SeasonalCycleScore [-]	OverallScore [-]
bcc-csm1-1-m	[-]	112.727	-5.899	33.79	-50.776	0.951	0.758	0.409	0.719
BNU-ESM	[-]	105.936	-12.899	34.291	-53.531	0.897	0.755	0.395	0.701
CanESM2	[-]	130.126	11.341	25.989	-20.747	0.909	0.809	0.312	0.71
CESM1-BGC	[-]	129.312	10.542	30.063	-43.588	0.915	0.782	0.357	0.709
GFDL-ESM2G	[-]	169.109	50.129	66.266	-36.42	0.655	0.582	0.33	0.537
HadGEM2-ES	[-]	138.378	19.617	35.684	-42.434	0.848	0.747	0.329	0.668
inmcm4	[-]	137.359	18.594	35.237	-45.911	0.855	0.75	0.387	0.685
IPSL-CM5A-LR	[-]	168.765	49.83	76.518	-43.621	0.657	0.535	0.334	0.515
MIROC-ESM	[-]	129.69	10.816	40.742	-43.305	0.913	0.717	0.356	0.676
MRI-ESM1	[-]	244.217	125.162	138.38	-45.615	0.348	0.323	0.351	0.336
MultiModelMean	[-]	139.988	21.295	40.77	-41.101	0.836	0.716	0.305	0.643
NorESM1-ME	[-]	130.348	11.57	30.453	-39.748	0.907	0.78	0.37	0.709

Temporally integrated period mean

Spatially integrated regional mean



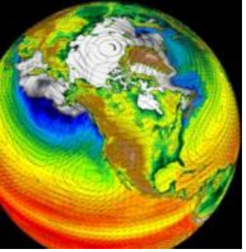
Spatial Distribution

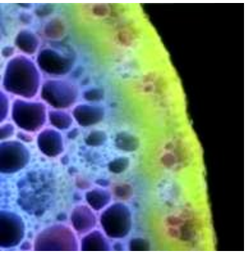
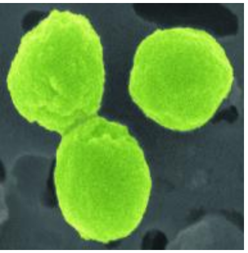
Annual cycle

Phase

Future ILAMB Development and Application

- Current ILAMB Prototype was applied to:
  - Model development of the Community Land Model (CLM)
  - CMIP5 Historical and esmHistorical simulations
  - ACME Land Model evaluation
- Within U.S. Department of Energy projects:
  - NGEE Arctic, NGEE Tropics, and SPRUCE are adopting the framework for evaluating process parameterizations & integrating field observations
  - ACME is developing metrics for evaluation of new land model features
  - BGC Feedbacks is developing the framework and benchmarking MIPs
- Future projects where we hope to apply ILAMB:
  - CMIP6, including C^4MIP, LS3MIP, and LUMIP
  - TRENDY
  - PLUME-MIP
- We will host a second ILAMB Workshop in the U.S. in the Washington, DC area May 16–18, 2016



ILAMB Prototype for Model Development

Dave Lawrence

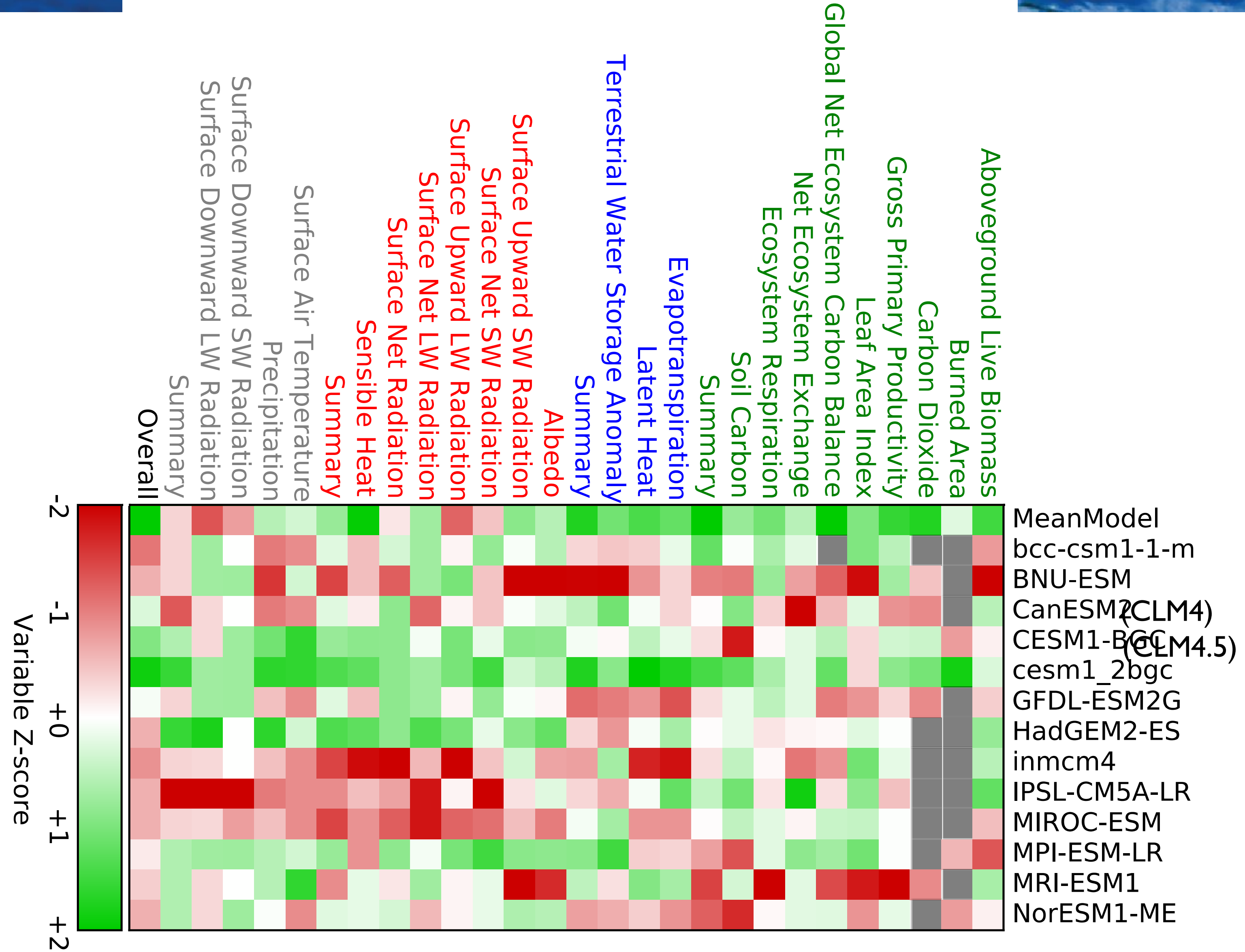
Utilizing ILAMB in model development and assessment process: Examples with Community Land Model

David Lawrence

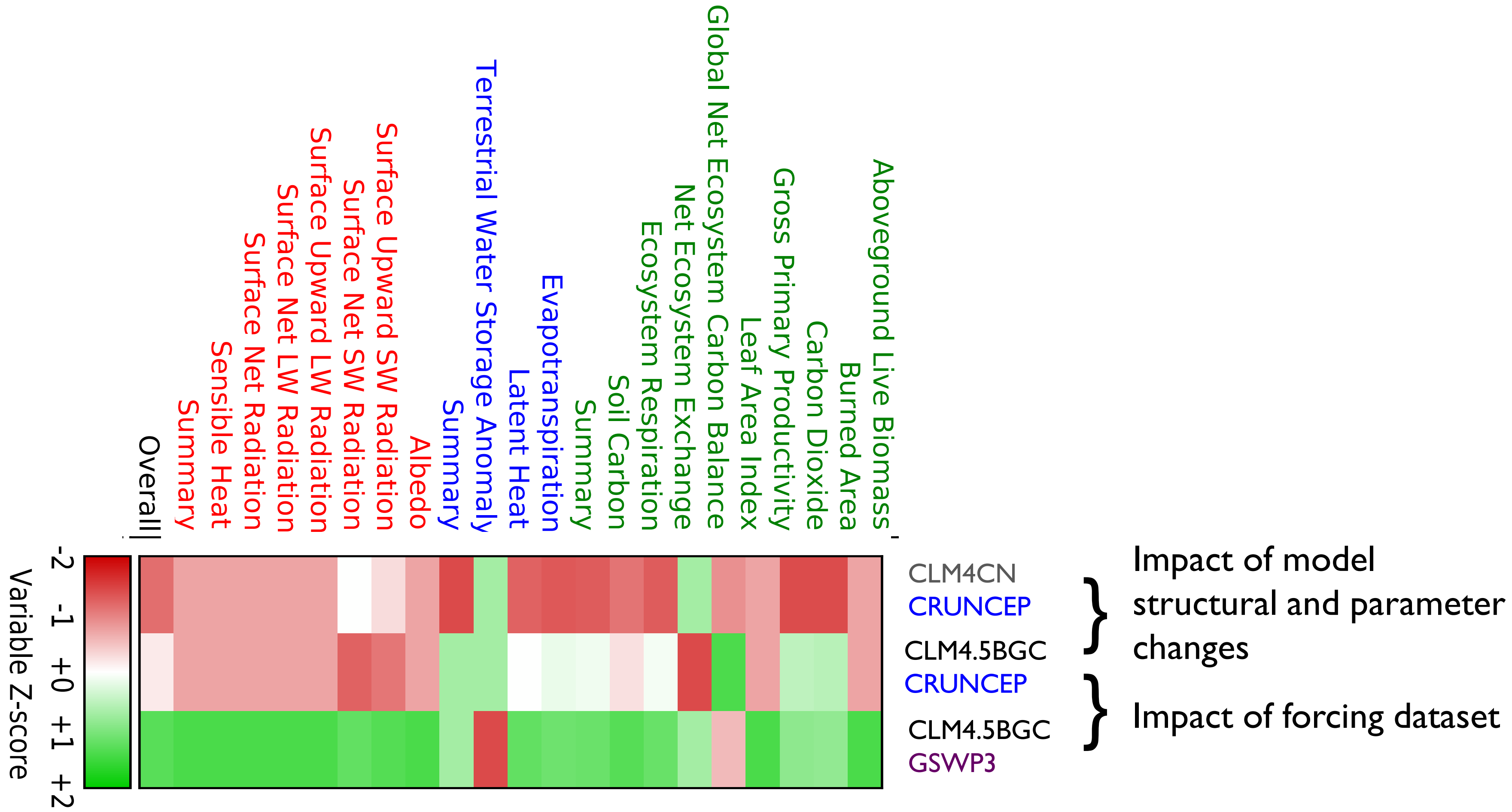
Climate and Global Dynamics Laboratory
National Center for Atmospheric Research

International LAnd Model Benchmarking (ILAMB) package

scores for RMSE, interannual variability, pattern correlation, variable-to-variable comparisons, +



Utilizing ILAMB in model development and assessment process



CLM5: to be released ~ June 2016 (CESM2; CMIP6)

Crops: global crop model with irrigation and fertilization (8 crop types)

Hydrology: dry surface layer, variable soil depth, 8.5m soil (50m ground), revised canopy interception, revised GW

Snow: canopy snow updates, wind effects, firn model (12 layers)

Rivers: Model for Scale-Adaptive River Transport (hillslope → tributary → main chan)

Nitrogen: flexible leaf C:N ratio, leaf N optimization, C cost for N

Carbon: carbon allocation revised

Fire: updates, trace gas and aerosol emissions

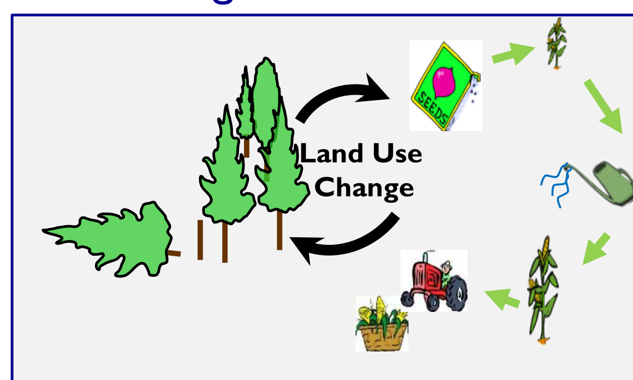
Vegetation: plant hydraulics, prognostic roots, ozone damage

Dynamic landunits

Carbon and (water) isotope enabled

Ecosystem Demography model

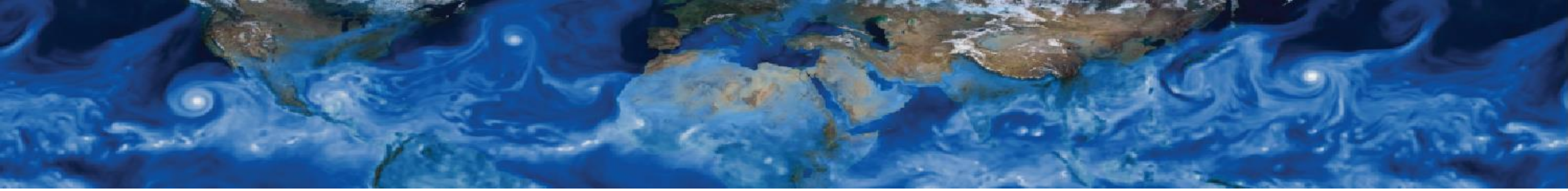
(optional, future BGC core)



Utilizing ILAMB in model development and assessment process

Global Variables (Info for Weightings)

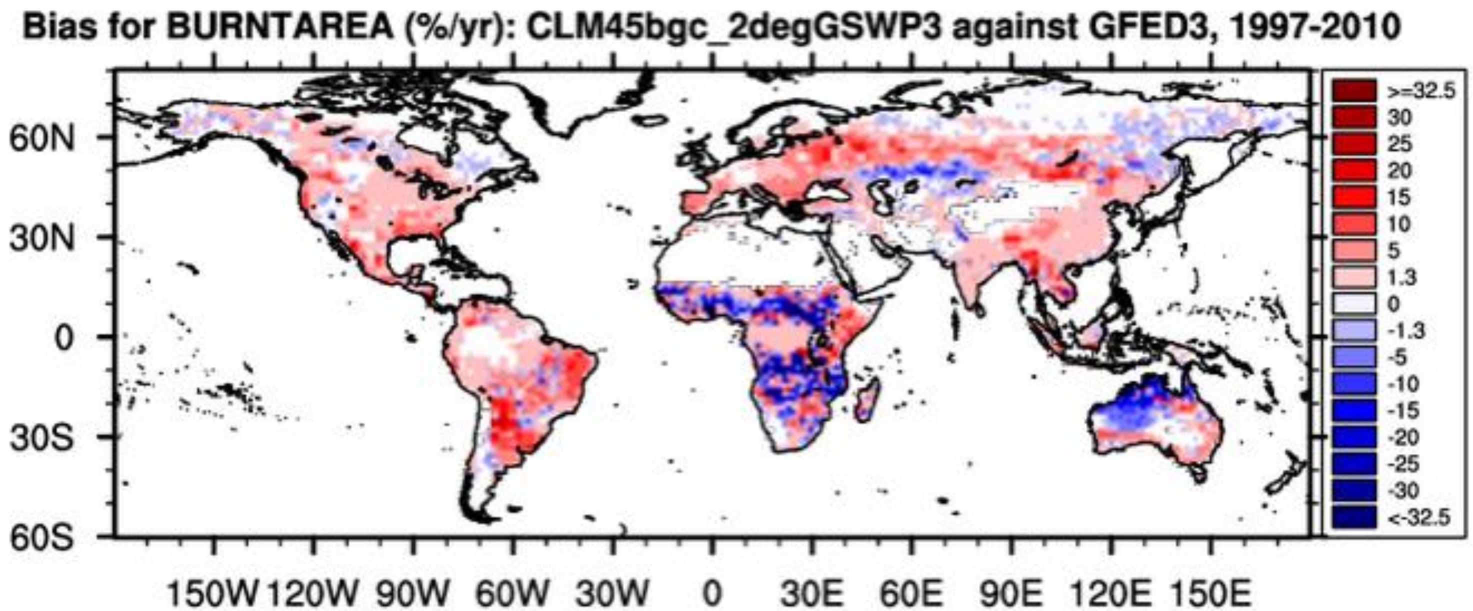
	CLM45bgc_2degGSWP3	CLM5bgc01_2degGSWP3
Aboveground Live Biomass	0.71	0.64
Burned Area	0.51	0.42
Gross Primary Productivity	0.75	0.72
Leaf Area Index	0.57	0.58
Global Net Ecosystem Carbon Balance	0.47	0.45
Net Ecosystem Exchange	0.49	0.51
Ecosystem Respiration	0.73	0.70
Soil Carbon	0.56	0.58
Summary	0.60	0.58

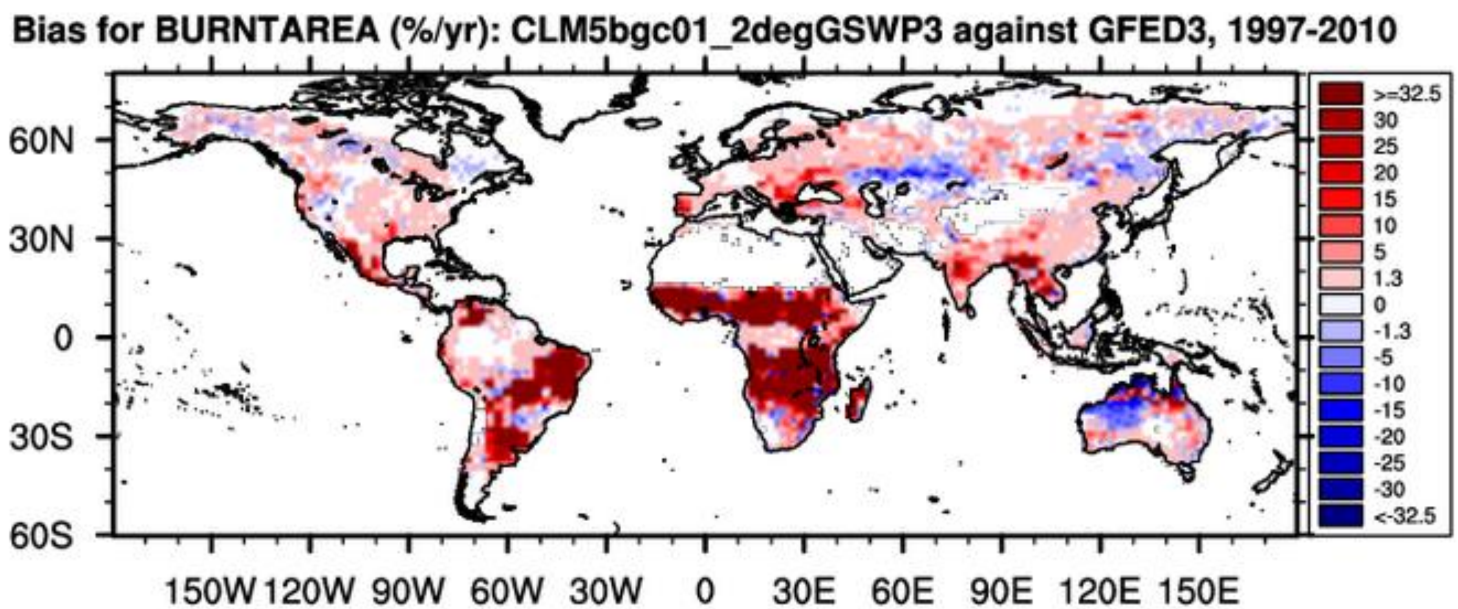


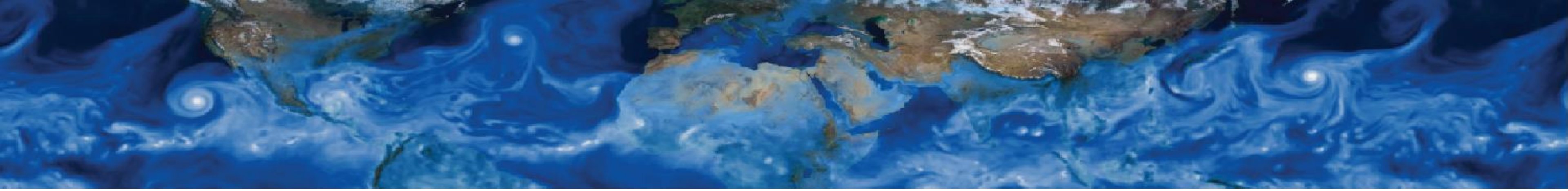
Diagnostic Summary for Burned Area: Model vs. GFED3

	Global Patterns				Regional and Seasonal Patterns	Scoring (Info)					
	Annual Mean (Mha/yr)	Bias (Mha/yr)	RMSE (Mha/mon)	Phase Difference (months)	Regional Means	Global Bias	RMSE	Seasonal Cycle	Spatial Distribution	Interannual Variability	Overall
Benchmark [Giglio et al. (2010)]	362.8	-	-	0.0	access to plots	-	-	-	-	-	-
CLM45bgc_2degGSWP3	378.8	16.1	85.5	1.6	access to plots	0.52	0.40	0.72	0.48	0.53	0.51
CLM5bgc01_2degGSWP3	1578.9	1216.1	208.9	0.5	access to plots	0.32	0.27	0.86	0.26	0.52	0.42

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


Bias for BURNTAREA (%/yr): CLM45bgc_2degGSWP3 against GFED3, 1997-2010
60N
30N
0
30S
60S
150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E
>=32.5
30
25
20
15
10
5
1.3
0
-1.3
-5
-10
-15
-20
-25
-30
<-32.5


Bias for BURNTAREA (%/yr): CLM5bgc01_2degGSWP3 against GFED3, 1997-2010
60N
30N
0
30S
60S
150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E
>=32.5
30
25
20
15
10
5
1.3
0
-1.3
-5
-10
-15
-20
-25
-30
<-32.5



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CLM45bgc_2degGSWP3	378.8	16.1	85.5	1.6	access to plots	0.52	0.40	0.72	0.48	0.53	0.51
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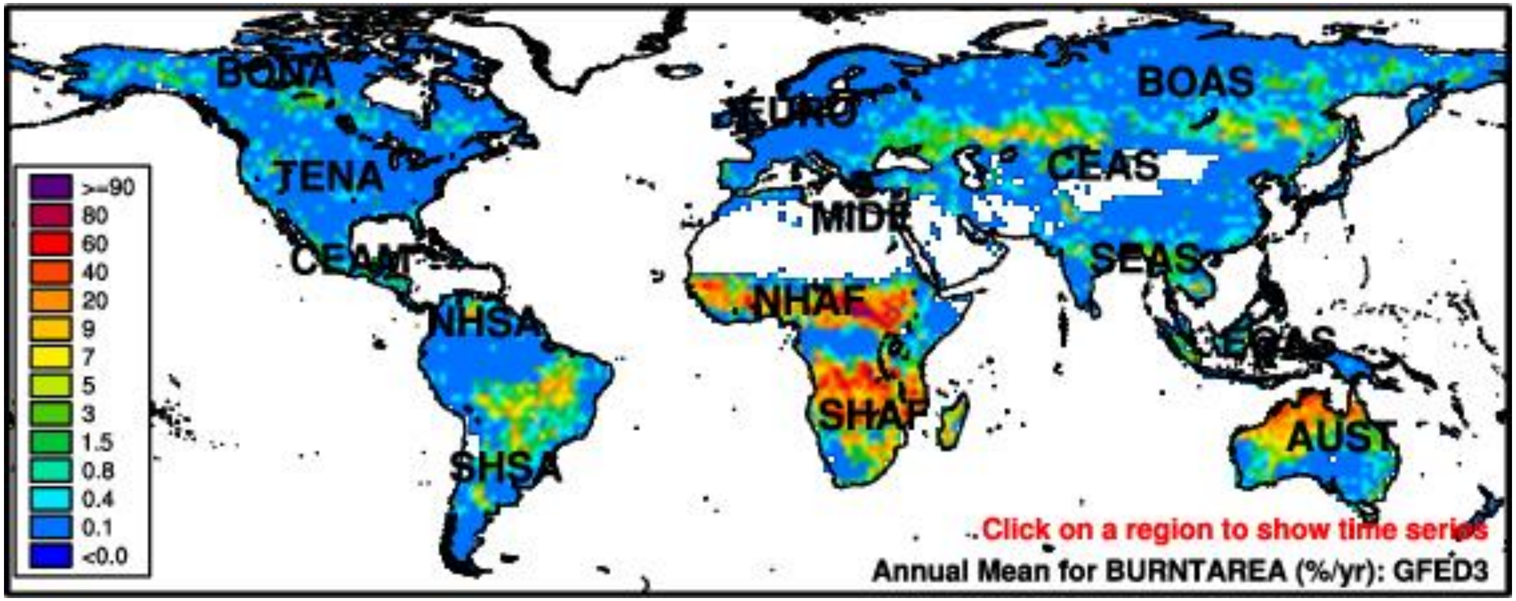
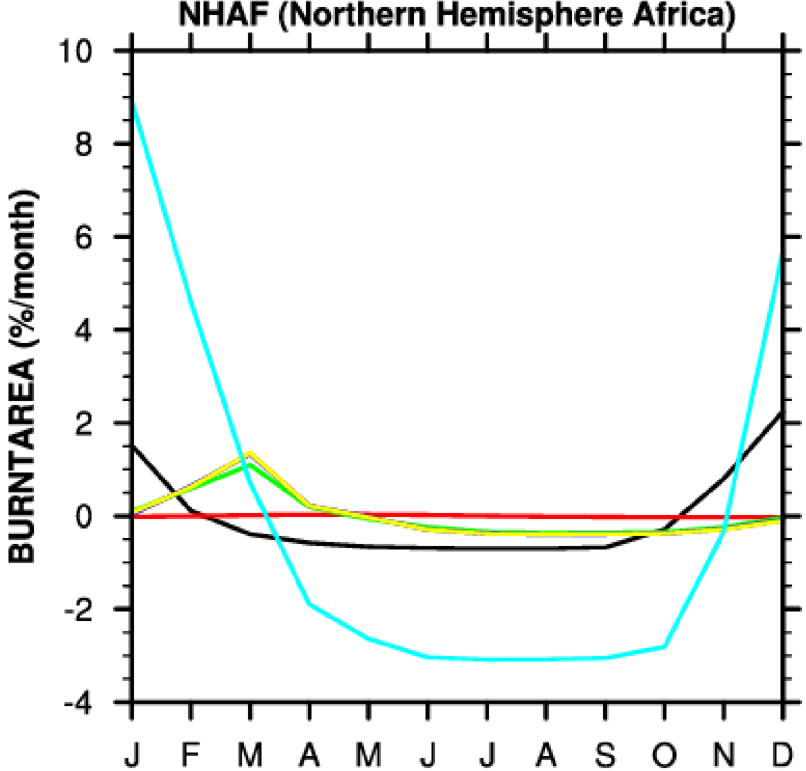
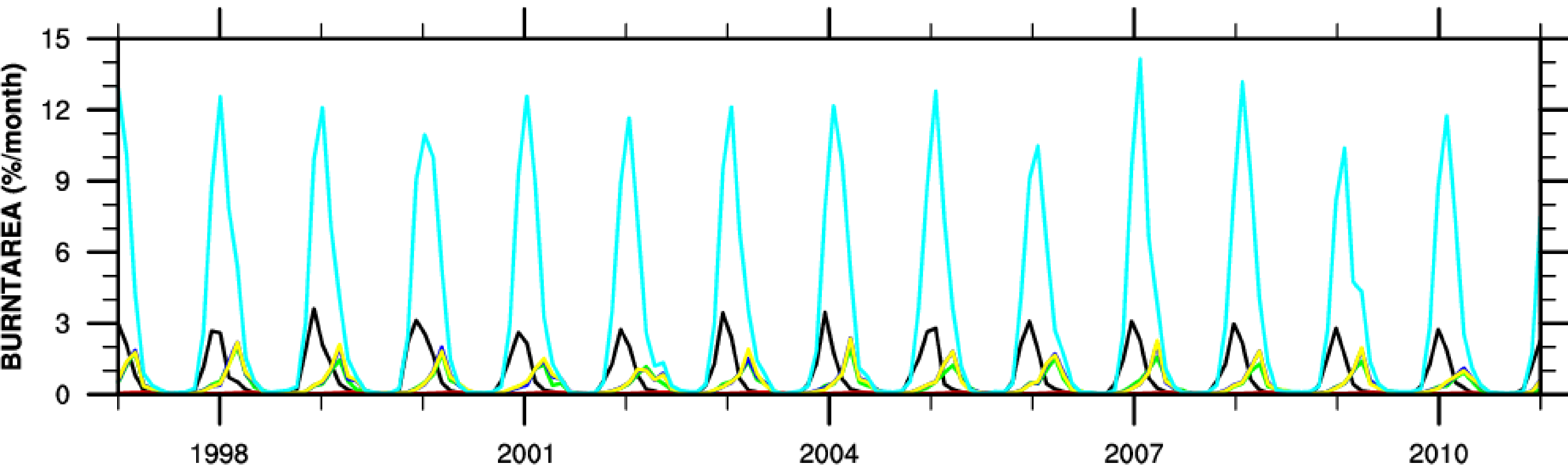
Notes: In calculating overall score, rmse score contributes double in comparison with all other scores.

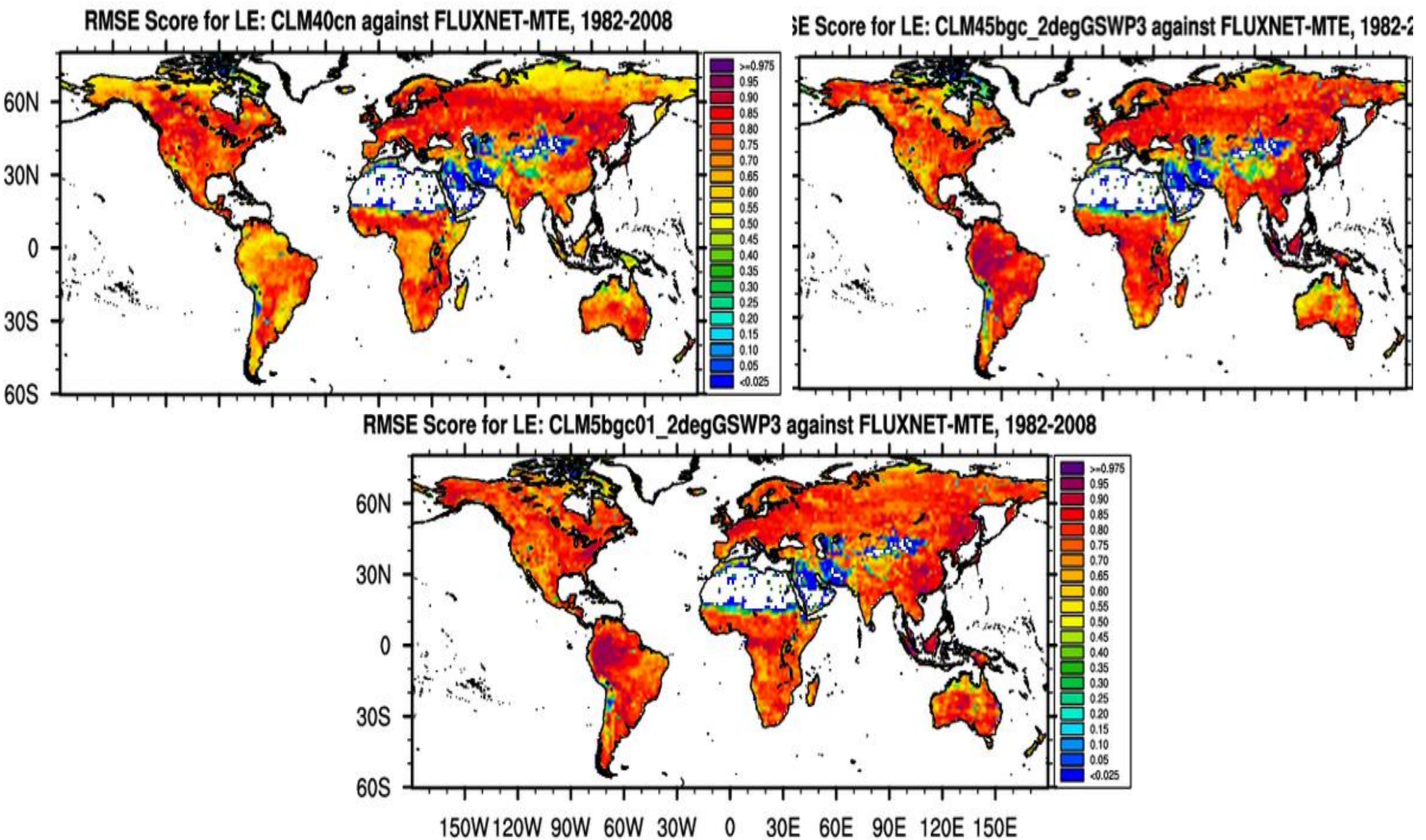

BONA
TENA
CEAM
NHSA
SHSA
EURO
MIDE
NHAF
SHAF
BOAS
CEAS
SEAS
EQAS
AUST
>=90
80
60
40
20
9
7
5
3
1.5
0.8
0.4
0.1
<0.0
Click on a region to show time series
Annual Mean for BURNTAREA (%/yr): GFED3



Model	Annual	Bias	RMSE
GFED3	0.71	-999.00	-999.00
CLM40cn	0.06	-0.65	1.19
CLM45bgc_CRUNCEP	0.38	-0.33	1.09
CLM45bgc_GSWP3	0.44	-0.27	1.13
CLM45bgc_2degGSWP3	0.45	-0.26	1.13
CLM5bgc01_2degGSWP3	3.18	2.47	4.10



RMSE Score for Latent Heat: FLUXNET-MTE



Summary

- ILAMB useful tool for model development and assessment
  - Along with tower site simulations, other diagnostics packages, scientific insight and intuition, case studies, etc.
- Provides quick and comprehensive comparison against growing set of observations and metrics
- Future development of ILAMB to enhance utility in model development
  - Parallelization
  - Compare against years outside observational period (e.g. 1850 control)

ILAMB Prototype for CMIP5 and CMIP6 Evaluation

Jim Randerson and Mingquan Mu

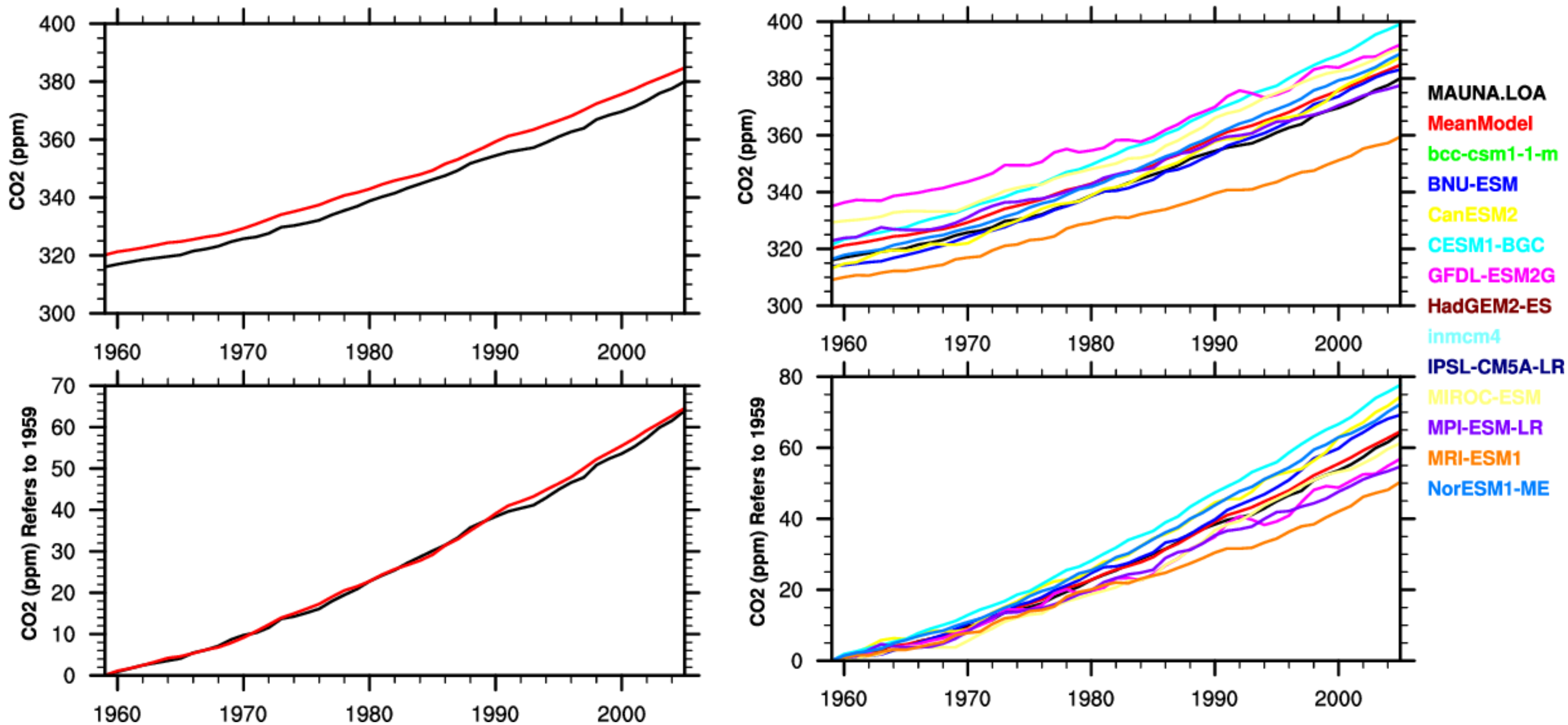
CMIP5: Evaluation of Historical ESM Simulations

Model Intercomparison Summary:

- 12 Earth system models participated, simulations retrieved from the Earth System Grid Federation
- Fossil fuel emissions are prescribed; atmospheric CO_2 is prognostic and dynamically evolving
- Spans the period from 1850–2005, enabling evaluation of long-term carbon dynamics
- Biases can be considerable in land surface “forcing variables”
  - Surface air temperature, precipitation, incoming shortwave and longwave radiation are simulated by the atmospheric model
- Land-surface coupling enables evaluation of feedbacks

CMIP5: Results

Finding #1: Atmospheric carbon dioxide has a positive bias in most models, with much of this bias originating before the Mauna Loa era

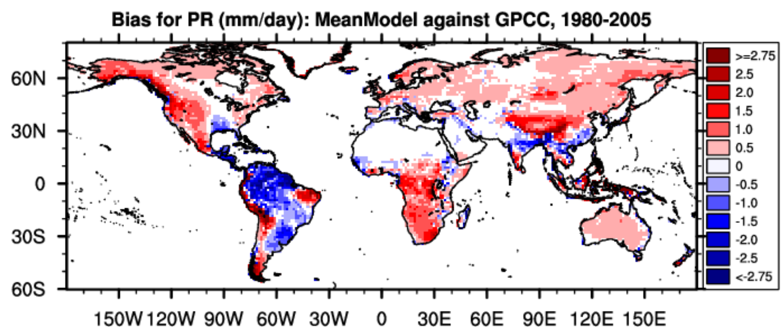


BGC Feedbacks

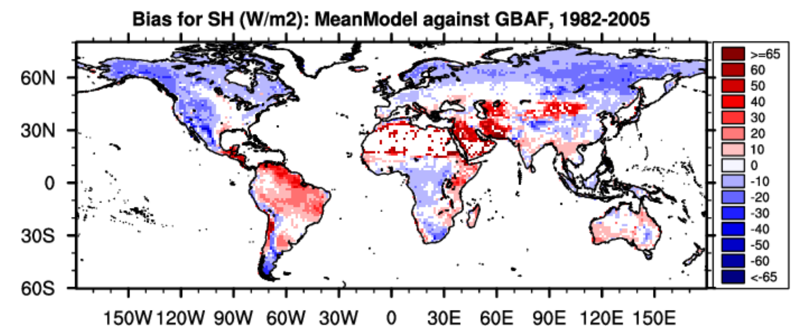
CMIP5: Results

Finding #2: Difficulties in simulating tropical atmospheric moisture transport yields biases in GPP and energy fluxes in the Amazon

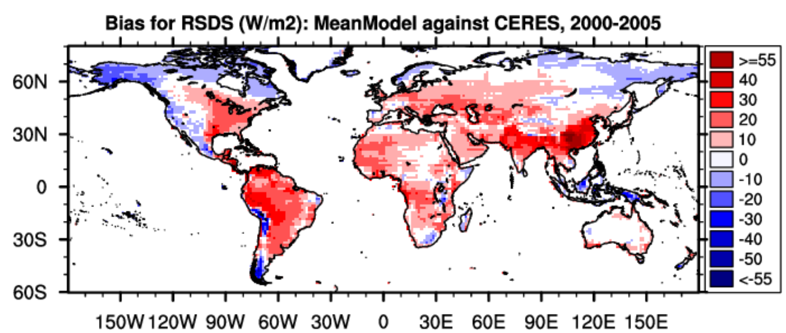
Precipitation



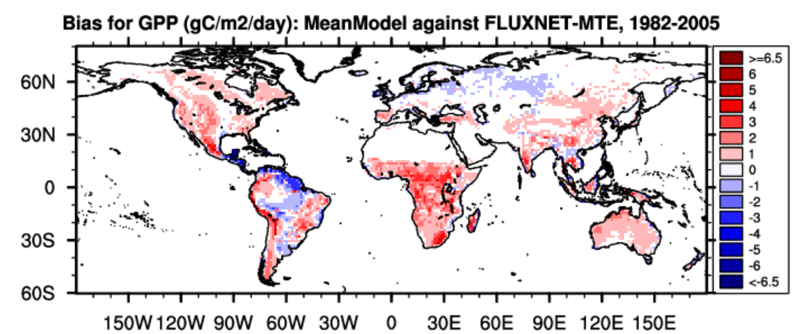
Sensible heat



Solar radiation

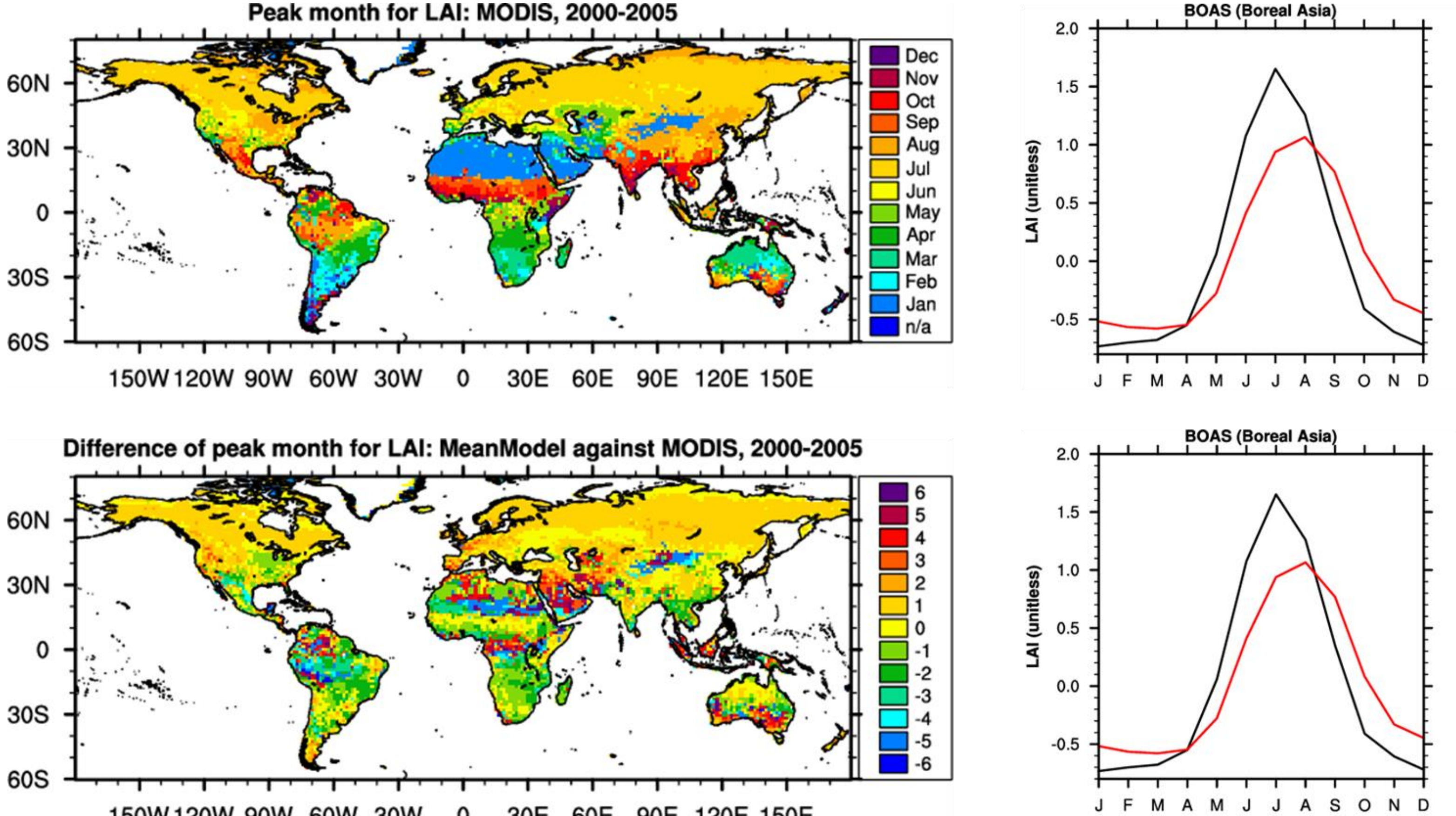


GPP



CMIP5: Results

Finding #3: Leaf area dynamics peak too late in the year at high latitudes in the northern hemisphere



CMIP5: Next Steps

- Working with data providers, complete the manuscript describing the application of ILAMB to CMIP5 ESMs
- Prepare for CMIP6 by integrating new datasets and preparing for newly available model variables
- Develop linkages between current model behavior and future predictions to 2100

Discussion and Q/A

Bill Riley and Gretchen Keppel-Aleks

Discussion and Q/A

- What are additional observations or metrics that may provide constraints at temporal or spatial scales not currently benchmarked by ILAMB?
- How can ILAMB best interface with MIPs and other model evaluation efforts?
- How can ILAMB be used to constrain future model behavior?
- What needs should we anticipate for benchmarking the next generations of ESMs with increased complexity/resolution?