International Land Model Benchmarking (ILAMB) Update

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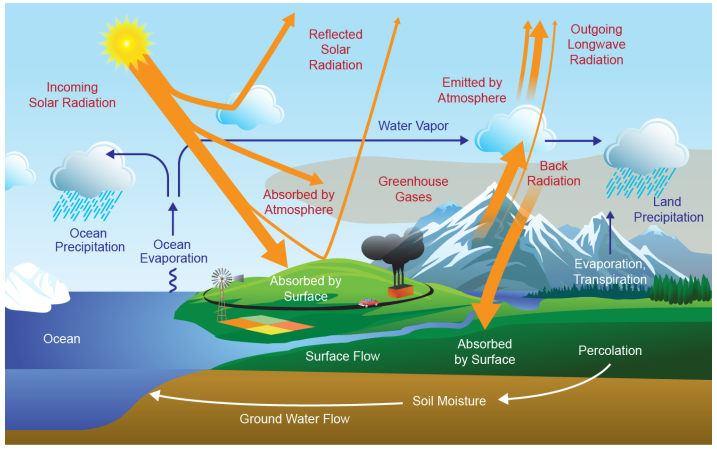
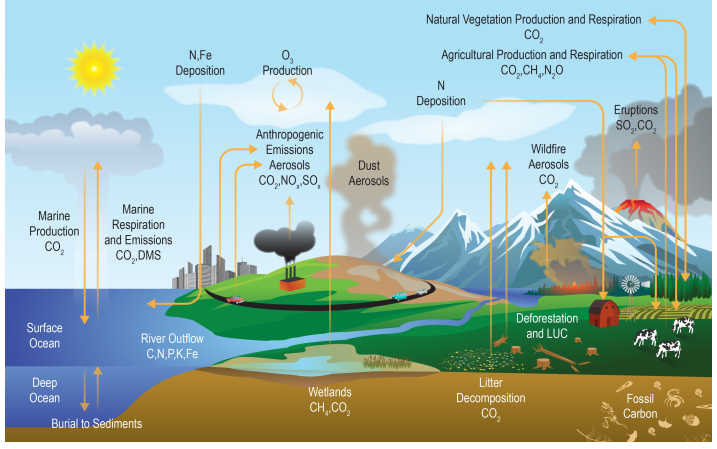
What is ILAMB?

A community coordination activity created to:

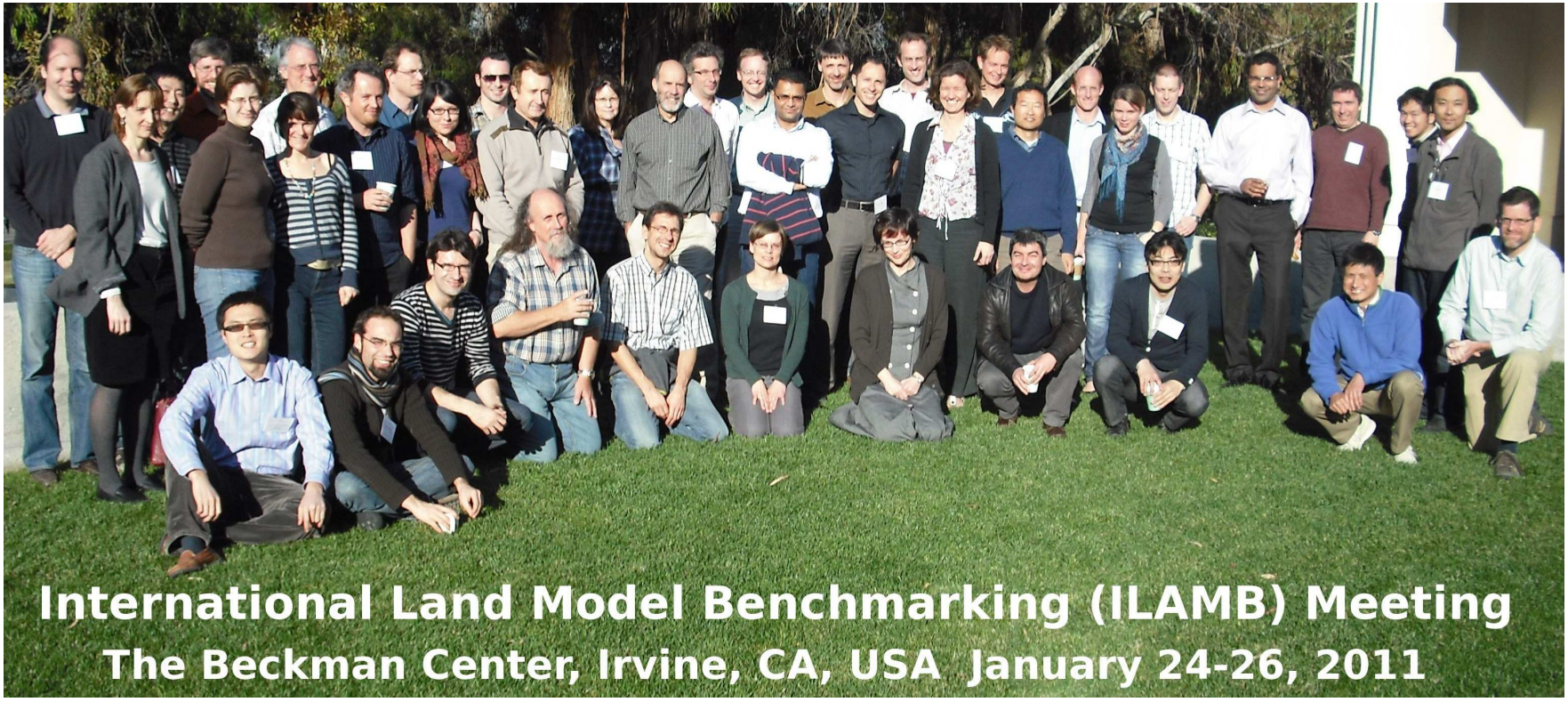
- **Develop internationally accepted benchmarks** for land model performance by drawing upon collaborative expertise
- **Promote the use of these benchmarks** for model intercomparison
- **Strengthen linkages between experimental, remote sensing, and climate modeling communities** in the design of new model tests and new measurement programs
- **Support the design and development of open source benchmarking tools** (Luo et al., 2012)



Energy and Water Cycles

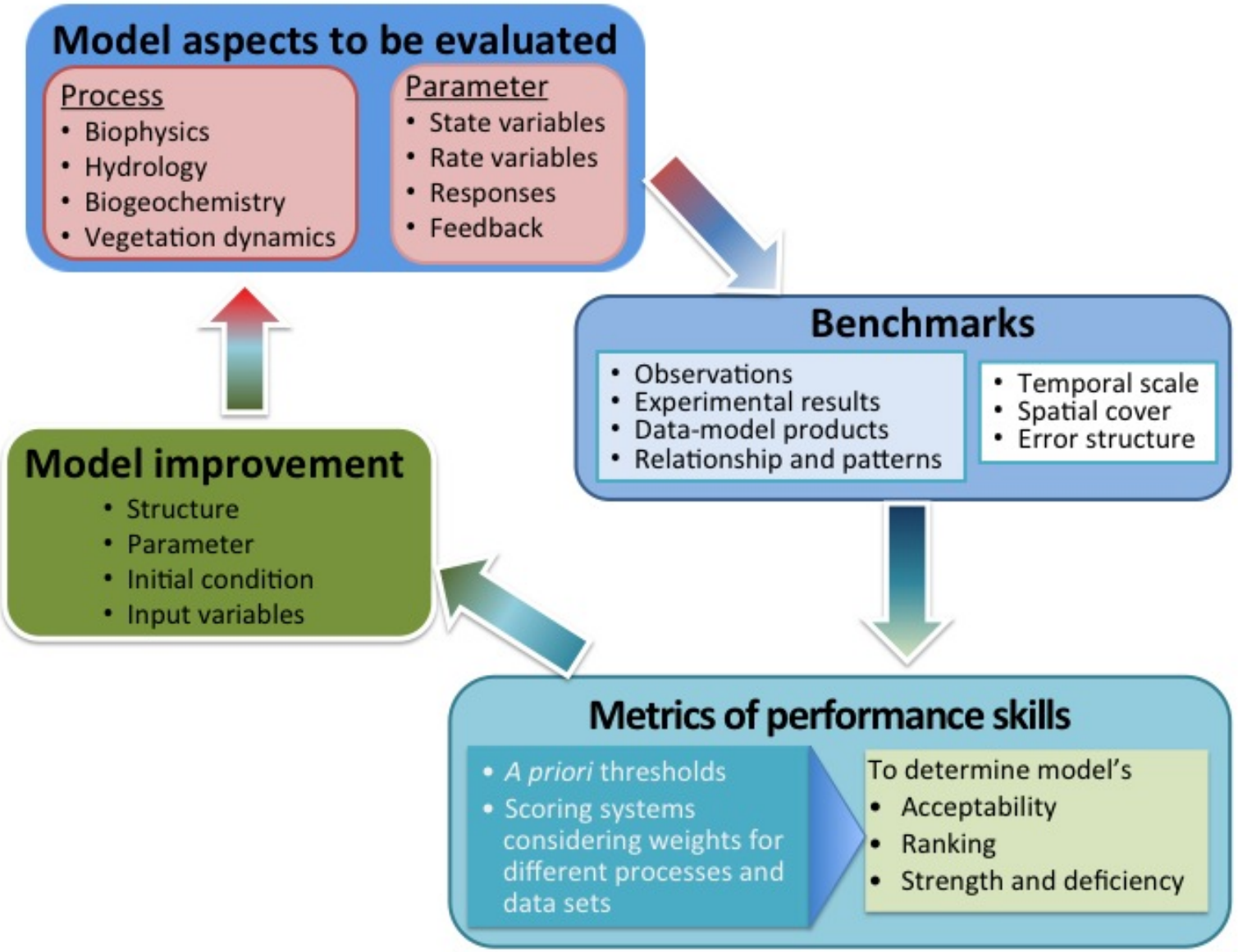


Carbon and Biogeochemical Cycles



- First ILAMB Meeting was held in Exeter, UK, on June 22–24, 2009.
- Second ILAMB Meeting was held in Irvine, CA, USA, on January 24–26, 2011.
  - ∼45 researchers participated from the United States, Canada, the United Kingdom, the Netherlands, France, Germany, Switzerland, China, Japan, and Australia.
  - *Initial focus on CMIP5 models.*
  - Developed methodology for model–data comparison and baseline standard for performance of land model process representations (Luo et al., 2012).

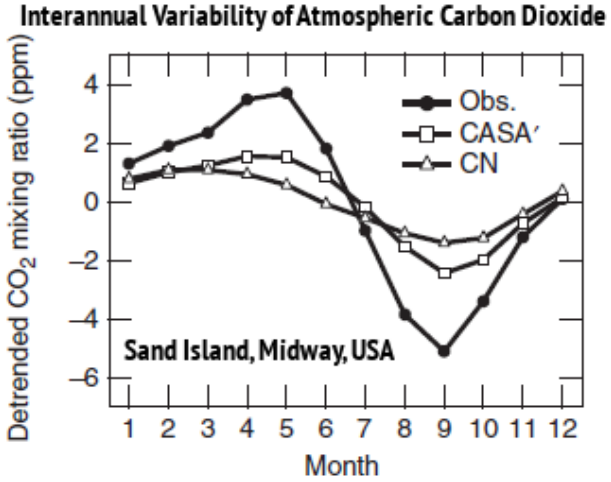
General Benchmarking Procedure



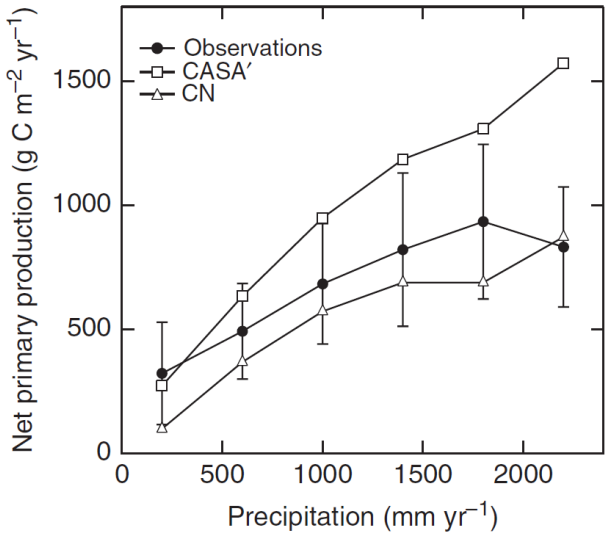
(Luo et al., 2012)

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 benchmarks **is a necessary but not sufficient condition** for a fully functioning model.
- **Functional 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 on **multiple temporal and spatial scales**.



Models often fail to capture the amplitude of the seasonal cycle of atmospheric CO_2.



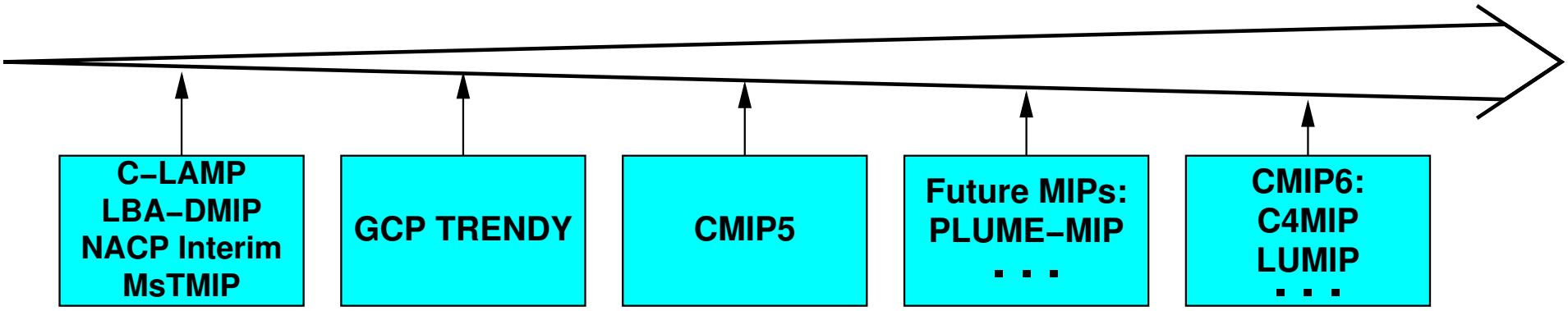
Models may reproduce correct responses over only a limited range of forcing variables.

(Randerson et al., 2009)

Why Benchmark?

- **To demonstrate model improvements** in representation of coupled climate and biogeochemical cycles
- **To quantitatively diagnose impacts of model development** in related fields on carbon cycle processes
- **To guide synthesis efforts**, such as the Intergovernmental Panel on Climate Change (IPCC), in assessing model fidelity
- **To increase scrutiny of key datasets** used for model evaluation
- **To identify gaps in existing observations** needed for model validation
- **To accelerate incorporation of new measurements** for rapid and widespread use in model assessment
- **To offer a quantitative, application-specific set of criteria** for participation in model intercomparison projects (MIPs)
- **To inform a model weighting system** for multi-model estimates of future changes in the carbon cycle

An Open Source Benchmarking Software System



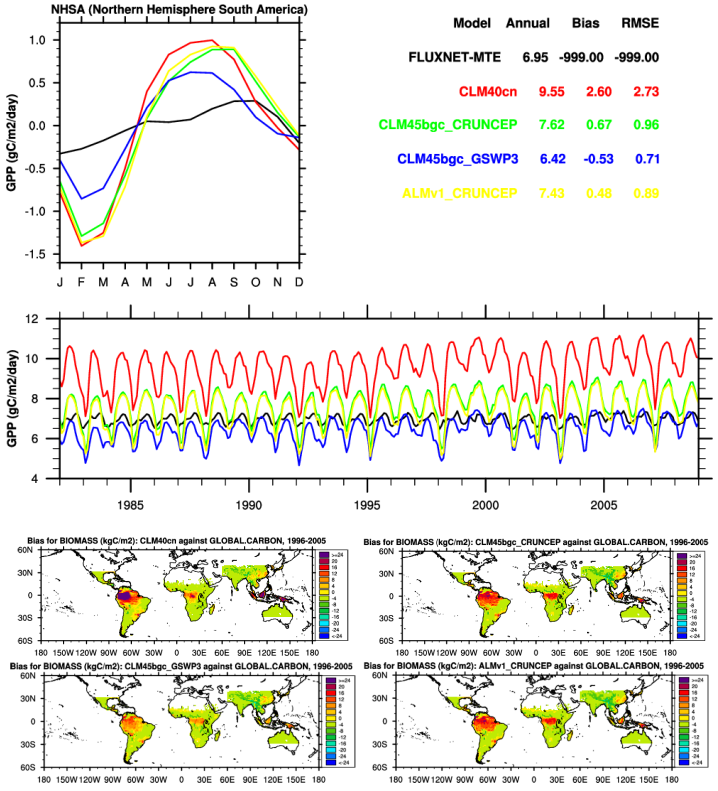
- Human capital costs of making rigorous model–data comparisons is considerable and constrains the scope of individual MIPs.
- Many MIPs spend resources "reinventing the wheel" in terms of variable naming conventions, model simulation protocols, and analysis software.
- **Need for ILAMB:** Each new MIP has access to the model–data comparison modules from past MIPs through ILAMB (*e.g.*, MIPs use one common modular software system). Standardized international naming conventions also increases MIP efficiency.

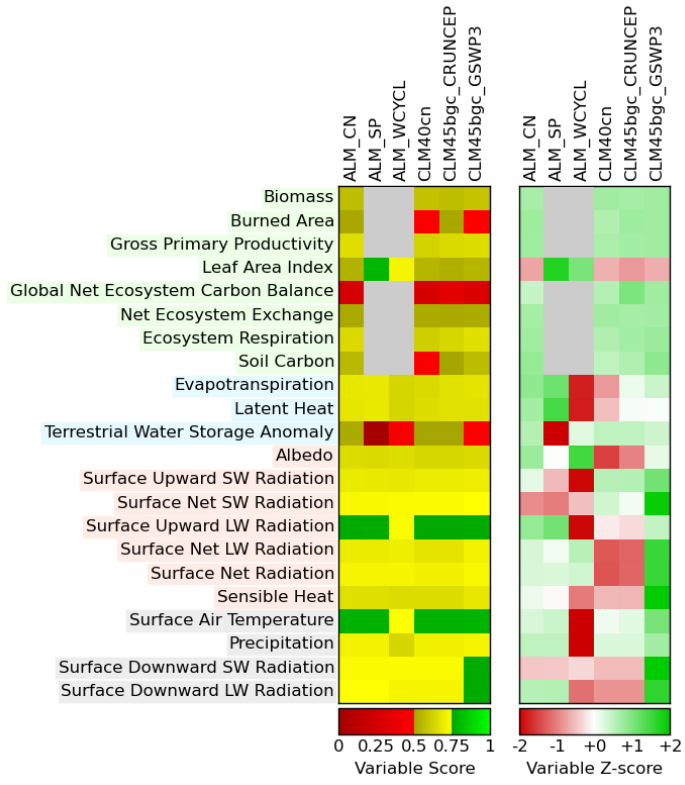
What is ILAMB Now?

- **Community:** global group of modelers and scientists enthusiastic about benchmarking
- **Datasets:** curated collection of datasets formatted for easy comparison
- **Methods:** innovative assembly of techniques for benchmarking models
- **Software:** open-source python package which you can use or tailor
- **Results:** catalog of comparisons which you can access and peruse

Current Status of the ILAMB Packages

- **ILAMBv1** released at 2015 AGU Town Hall, doi:10.18139/ILAMB.v001.00/1251597
- **ILAMBv2** released at 2016 ILAMB Workshop, doi:10.18139/ILAMB.v002.00/1251621
- Used routinely for E3SM and CESM evaluation during development





ILAMBv2 Diagnostics Package

- Current variables:

  Aboveground live biomass (Contiguous US, Pan Tropical Forest), Burned area (GFED3), CO_2 (NOAA GMD, Mauna Loa), Gross primary production (Fluxnet, MTE), Leaf area index (AVHRR, MODIS), Global net land flux (GCP, Khatiwala/Hoffman), Net ecosystem exchange (Fluxnet, GBA), Ecosystem Respiration (Fluxnet, GBA), Soil C (HWSD, NCSCDv2), Evapotranspiration (GLEAM, MODIS), Latent heat (Fluxnet, MTE), Soil moisture (ESA), Terrestrial water storage anomaly (GRACE), Albedo (CERES, GEWEX, MODIS), Surface up SW/LW radiation (CERES, GEWEX.SRB, WRMC.BSRN), Sensible heat (Fluxnet, GBA), Surface air temperature (CRU, Fluxnet), Precipitation (Fluxnet, GPCC, GPCP2), Surface down SW/LW radiation (Fluxnet, CERES, GEWEX.SRB, WRMC.BSRN),

- Graphics and scoring systems:
  - Annual mean, Bias, RMSE, seasonal cycle, spatial distribution, interannual coeff. of variation and variability, long-term trend scores
  - Global maps, variable to variable, and time series comparisons

- Software:

  Freely distributed, designed to be user friendly and to enable easy addition of new variables


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
Biomass
Burned Area
Gross Primary Productivity
Leaf Area Index
Global Net Ecosystem Carbon Balance
Net Ecosystem Exchange
Ecosystem Respiration
Soil Carbon
Evapotranspiration
Evaporative Fraction
Latent Heat
Runoff
Sensible Heat
Terrestrial Water Storage Anomaly
Snow Water Equivalent
Permafrost
Albedo
Surface Upward SW Radiation
Surface Net SW Radiation
Surface Upward LW Radiation
Surface Net LW Radiation
Surface Net Radiation
Surface Air Temperature
Precipitation
Surface Relative Humidity
Surface Downward SW Radiation
Surface Downward LW Radiation
0
0.25
0.5
0.75
1
Absolute Score
-2
-1
+0
+1
+2
Relative Score

Mean State Scores

	bcc-csm1-1-m	BNU-ESM	CanESM2	CESM1-BGC	GFDL-ESM2G	HadGEM2-ES	inmcm4	IPSL-CM5
Biomass	0.61	0.48	0.65	0.61	0.65	0.71	0.63	0.66
Burned Area	~	~	~	0.38	~	~	~	~
Gross Primary Productivity	0.56	0.59	0.53	0.57	0.51	0.53	0.18	0.53
Fluxnet (37.5%)	0.61	0.65	0.58	0.61	0.58	0.60	0.29	0.58
GBAF (62.5%)	0.53	0.56	0.51	0.54	0.46	0.49	0.12	0.49
Leaf Area Index	0.48	0.33	0.45	0.39	0.37	0.48	0.13	0.49
Global Net Ecosystem Carbon Balance	~	0.77	0.66	0.64	0.63	~	0.67	0.63
Net Ecosystem Exchange	0.49	0.46	0.38	0.49	0.51	0.47	0.16	0.55
Ecosystem Respiration	0.60	0.59	0.56	0.53	0.57	0.52	0.60	0.53
Soil Carbon	0.58	0.47	0.66	0.24	0.59	0.61	0.66	0.67
Ecosystem and Carbon Cycle Summary	~	~	~	0.49	~	~	~	~
Evapotranspiration	0.57	0.56	0.54	0.58	0.52	0.58	0.51	0.61
Evaporative Fraction	0.66	0.69	0.71	0.71	0.68	0.67	0.67	0.66
Latent Heat	0.56	0.56	0.56	0.56	0.54	0.56	0.50	0.58
Runoff	0.63	0.66	0.61	0.71	0.66	~	0.66	0.60
Sensible Heat	0.56	0.57	0.59	0.62	0.59	0.63	0.53	0.59
Terrestrial Water Storage Anomaly	0.46	0.19	0.55	0.59	0.55	~	0.53	0.55

GrossPrimaryProductivity / GBAF / 1982-2008 / global / CESM1-BGC

Mean State | Relationships | All Models | Data Information

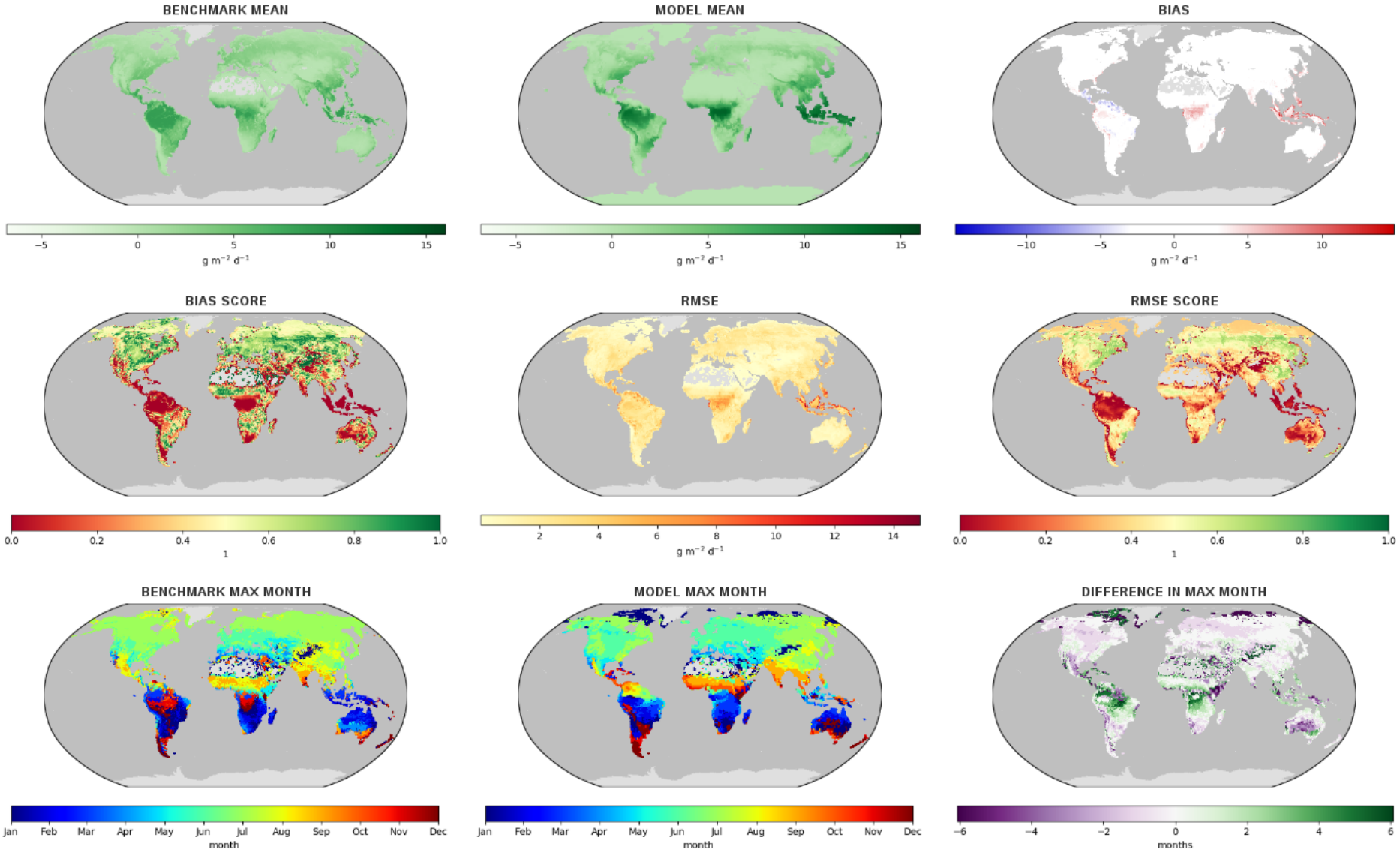
Globe

	Download Data	Period Mean (original grids) [Pg yr-1]	Model Period Mean (intersection) [Pg yr-1]	Model Period Mean (complement) [Pg yr-1]	Benchmark Period Mean (intersection) [Pg yr-1]	Benchmark Period Mean (complement) [Pg yr-1]	Bias [g m-2 d-1]	RMSE [g m-2 d-1]	Phase Shift [months]	Bias Score [1]	RMSE Score [1]	Seasonal Cycle Score [1]	Spatial Distribution Score [1]	Overall Score [1]
Benchmark	[.]	119.												
bcc-csm1-1-m	[.]	115.	110.	4.90	118.	0.684	-0.0636	1.97	1.39	0.42	0.26	0.79	0.94	0.53
BNU-ESM	[.]	102.	93.1	9.06	118.	0.245	-0.302	1.77	1.37	0.40	0.36	0.77	0.92	0.56
CanESM2	[.]	129.	119.	10.6	119.	0.00	-0.00850	2.26	2.10	0.36	0.35	0.66	0.83	0.51
CESM1-BGC	[.]	130.	126.	4.92	118.	0.802	0.343	1.76	1.39	0.39	0.35	0.76	0.87	0.54
GFDL-ESM2G	[.]	175.	161.	14.3	119.	0.00	1.33	3.35	1.46	0.35	0.18	0.72	0.87	0.46
HadGEM2-ES	[.]	146.	139.	6.78	118.	0.909	0.718	2.38	1.24	0.36	0.25	0.78	0.81	0.49
inmcm4	[.]	-112.	-104.	-7.19	113.	5.90	-4.93	5.76	4.62	0.057	0.12	0.23	0.055	0.12
IPSL-CM5A-LR	[.]	167.	152.	14.5	118.	0.548	1.08	2.69	1.29	0.32	0.25	0.77	0.89	0.49
MIROC-ESM	[.]	132.	124.	8.18	108.	10.5	0.367	2.10	1.39	0.42	0.32	0.75	0.92	0.55
MPI-ESM-LR	[.]	170.	162.	8.16	110.	9.08	1.22	2.36	1.43	0.38	0.29	0.70	0.92	0.52

GrossPrimaryProductivity / GBAF / 1982-2008 / global / CESM1-BGC

Mean State | Relationships | All Models | Data Information

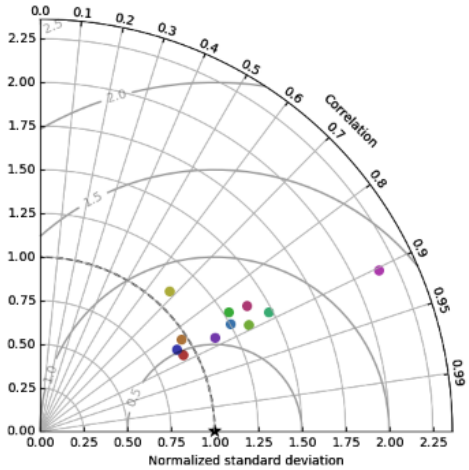
Temporally integrated period mean



GrossPrimaryProductivity / GBAF / 1982-2008 / global / CESM1-BGC

Mean State | Relationships | All Models | Data Information

SPATIAL TAYLOR DIAGRAM



MODEL COLORS

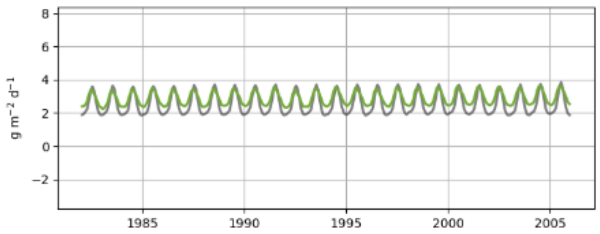
- Benchmark
- bcc-csm1-1-m
- BNU-ESM
- CanESM2
- CESM1-BGC
- GFDL-ESM2G
- HadGEM2-ES
- inmcm4
- IPSL-CM5A-LR
- MIROC-ESM
- MPI-ESM-LR
- MRI-ESM1
- NorESM1-ME

Spatially integrated regional mean

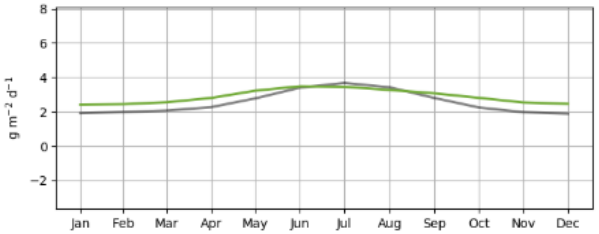
MODEL COLORS

- Benchmark
- 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

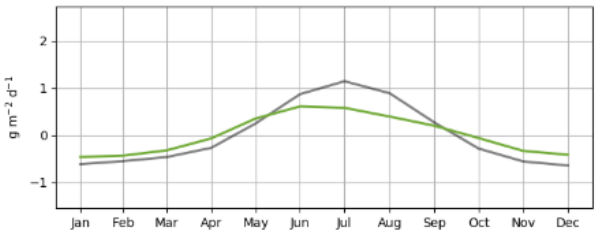
REGIONAL MEAN



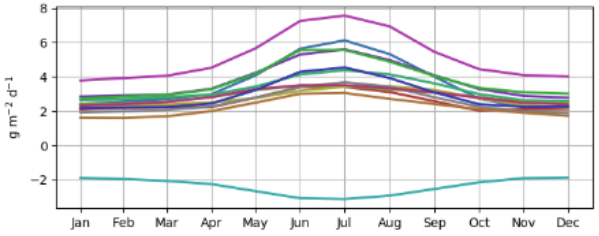
ANNUAL CYCLE



MONTHLY ANOMALY



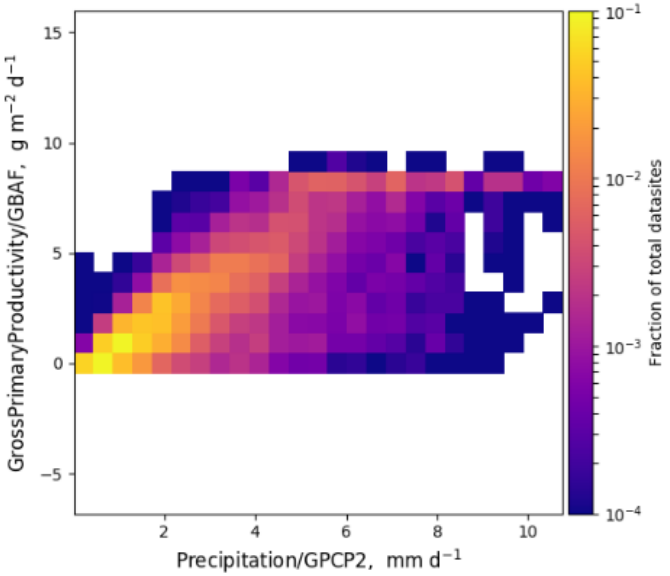
ANNUAL CYCLE

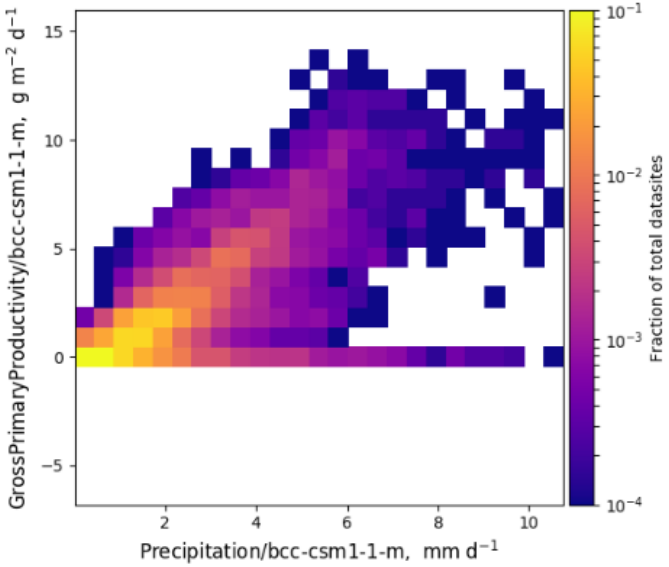


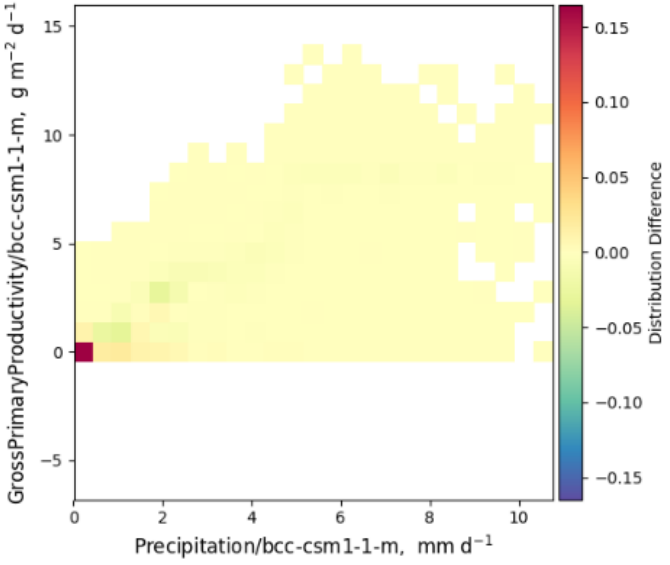
GrossPrimaryProductivity / GBAF / 1982-2008 / global / bcc-csm1...

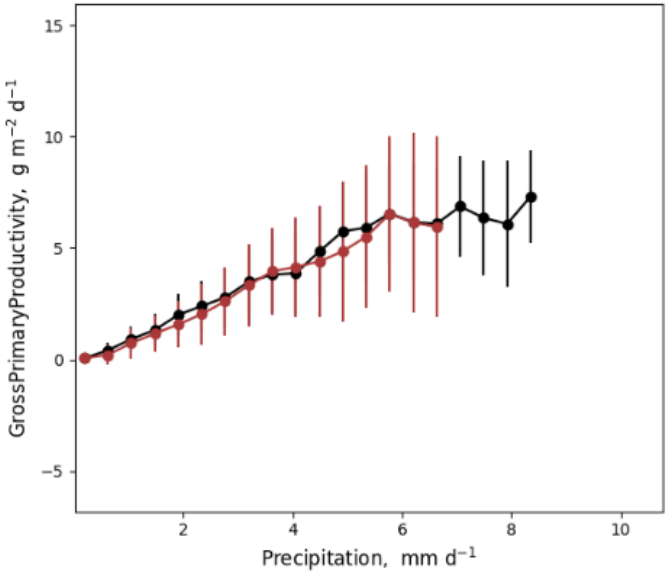
Mean State | Relationships | All Models | Data Information

Precipitation/GPCP2









Dataset Weighting Rubric

Score	Certainty of data	Scale appropriateness and coverage	Overall important of constraint or process
1	No uncertainty, significant methodological issues affecting quality	Site level observations with limited space/time coverage	Observations that have limited influence on the targeted Earth system dynamics
2	No uncertainty, some methodological issues affecting quality	Partial regional coverage, up to 1 year	Observations have direct influence on the targeted Earth system dynamics
3	No uncertainty, methodology has some peer review	Regional coverage, at least 1 year	Observations useful to constrain processes that contribute to the targeted Earth system dynamics
4	Qualitative uncertainty, methodology accepted	Important regional coverage, at least 1 year	Observations well-suited to constrain important processes
5	Well-defined and relatively low uncertainty	Global scale spanning multiple years	Observations well-suited for discriminating critical processes among models

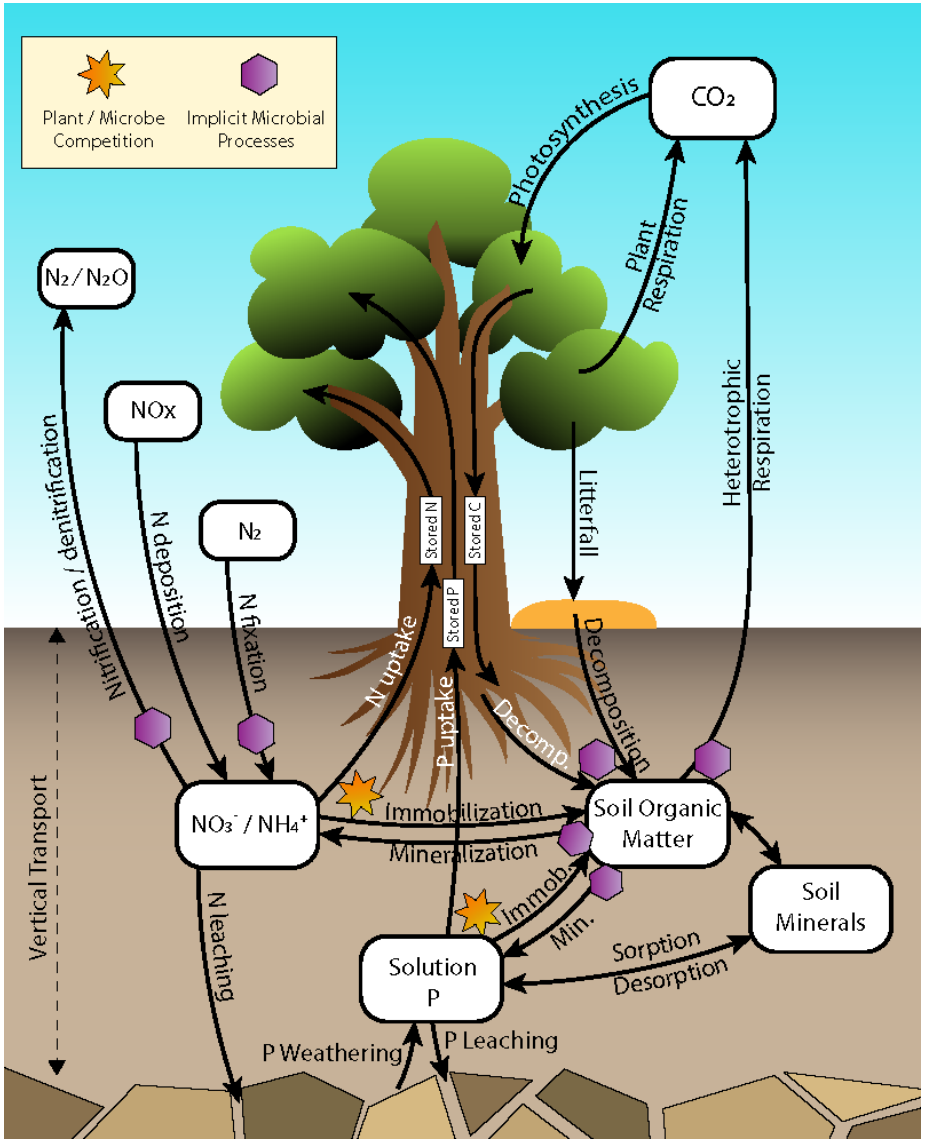
What is in the Overall Score?

$$S_{overall} = \frac{S_{bias} + 2S_{rmse} + S_{phase} + S_{iav} + S_{dist}}{1 + 2 + 1 + 1 + 1}$$

Scores are based on the:

- S_{bias} - normalized bias
- S_{rmse} - normalized central RMSE
- S_{phase} - timing of the maximum of the annual cycle
- S_{iav} - interannual variability
- S_{dist} - spatial distribution of the period mean

E3SM Land Model (ELM) v1



- Built from the Community Land Model Version 4.5 (CLM4.5);
- Introduce prognostic phosphorus cycle and C-N-P interactions;
- Characterize dynamic storage pools for C, N and P;
- Produce global P maps for model initialization;
- Simulate the competition between plants and microbial process for available soil N and P;
- Include many other new developments, evaluations and applications

Historical ELMv1 Simulations for LS3MIP

Preliminary Look at Initial LS3MIP Simulations with ELMv1

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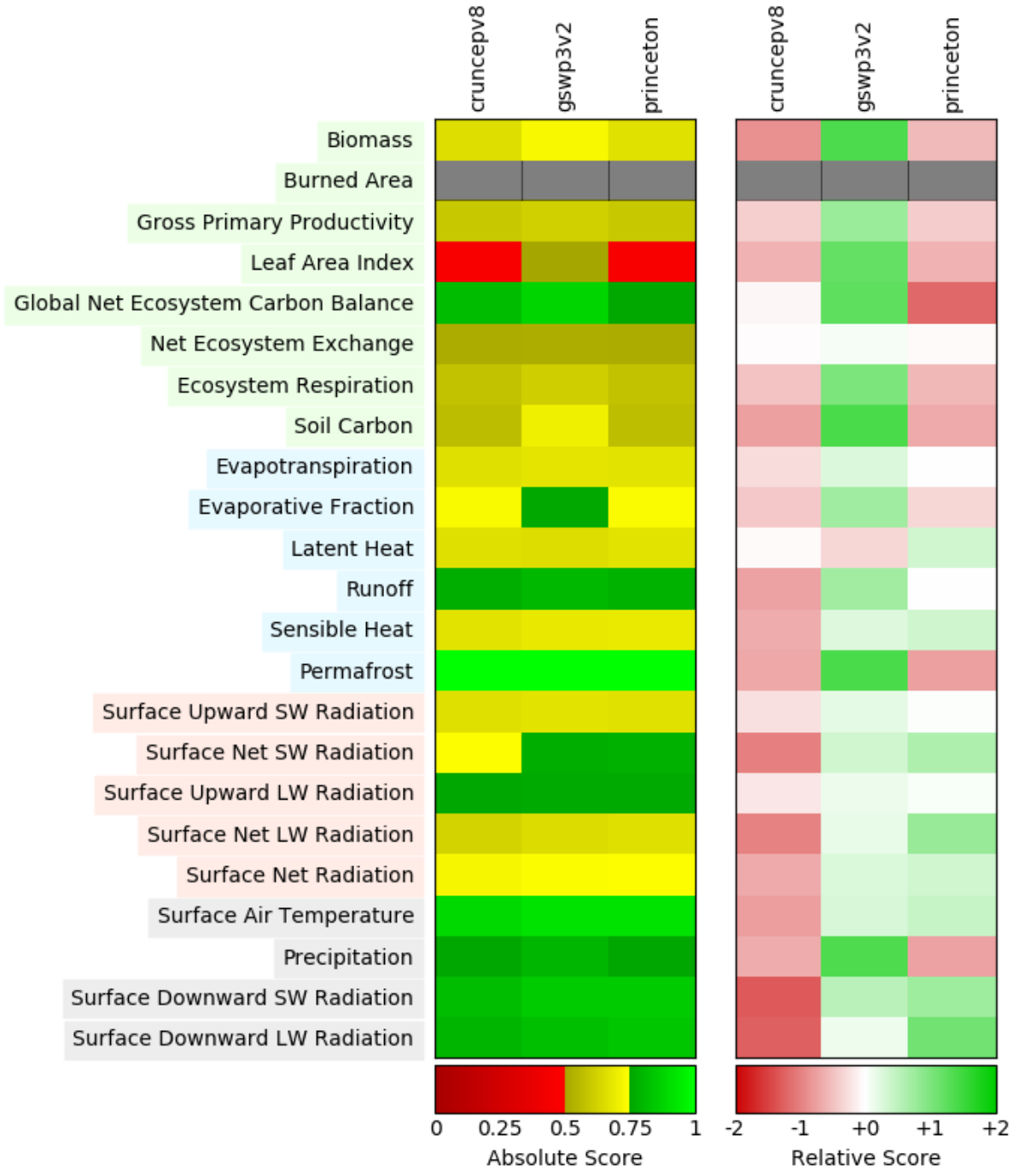
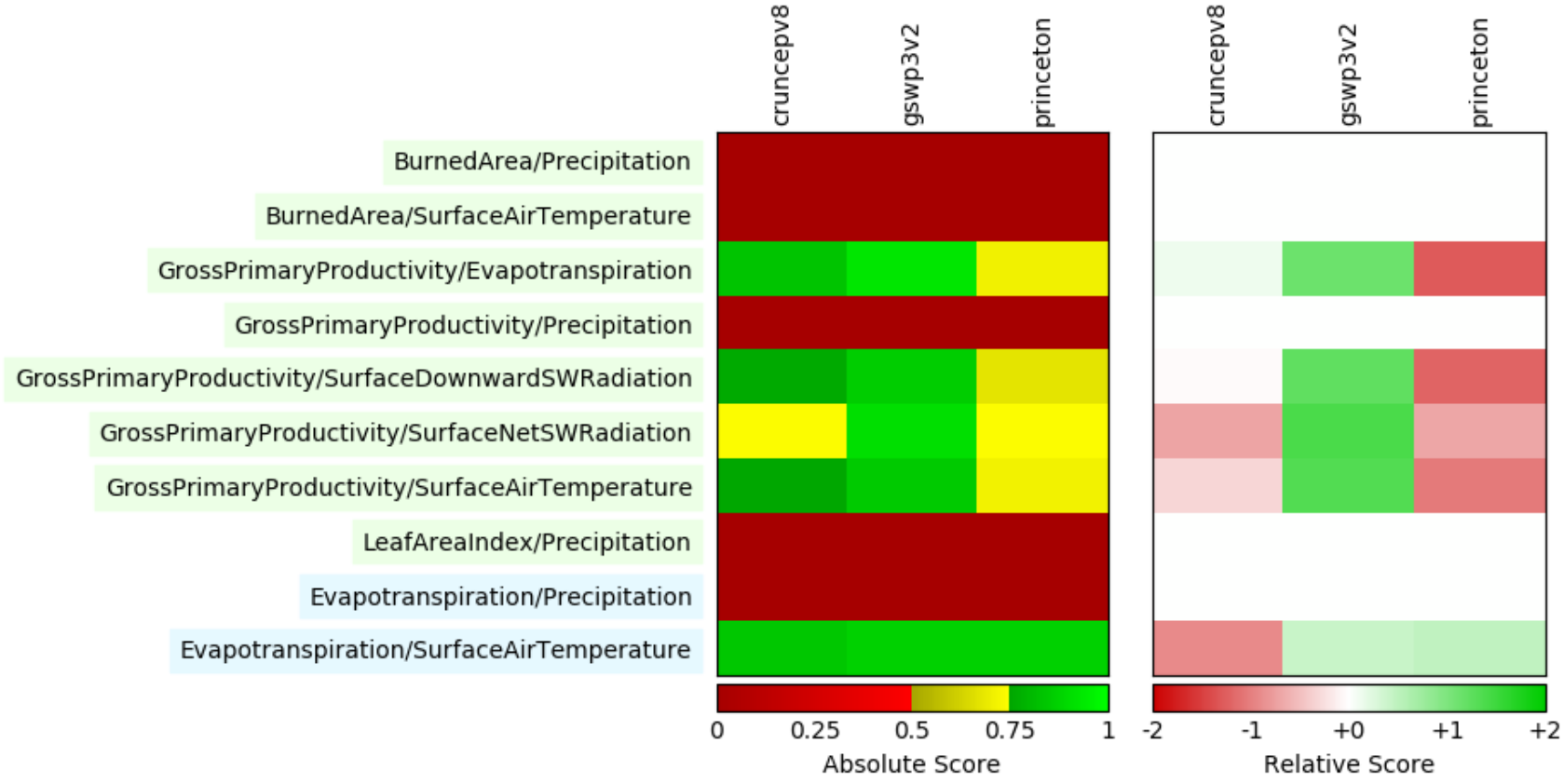
Oak Ridge National Laboratory
*Correspondence to maoj@ornl.gov

Domain	Experiment Name	Time Period	Climate Forcing	Spinup	Land Use	Atmospheric CO_2	Nitrogen Deposition	Aerosol Deposition
Global 0.5 by 0.5 degree	Land-Hist-gswp3	1850-2014	GSWP3_v1.06	~600	Historical Transient			
	Land-Hist-cruncep	1850-2014	CRUNCEP_v8					
	Land-Hist-princeton	1850-2010	PRINCETON					

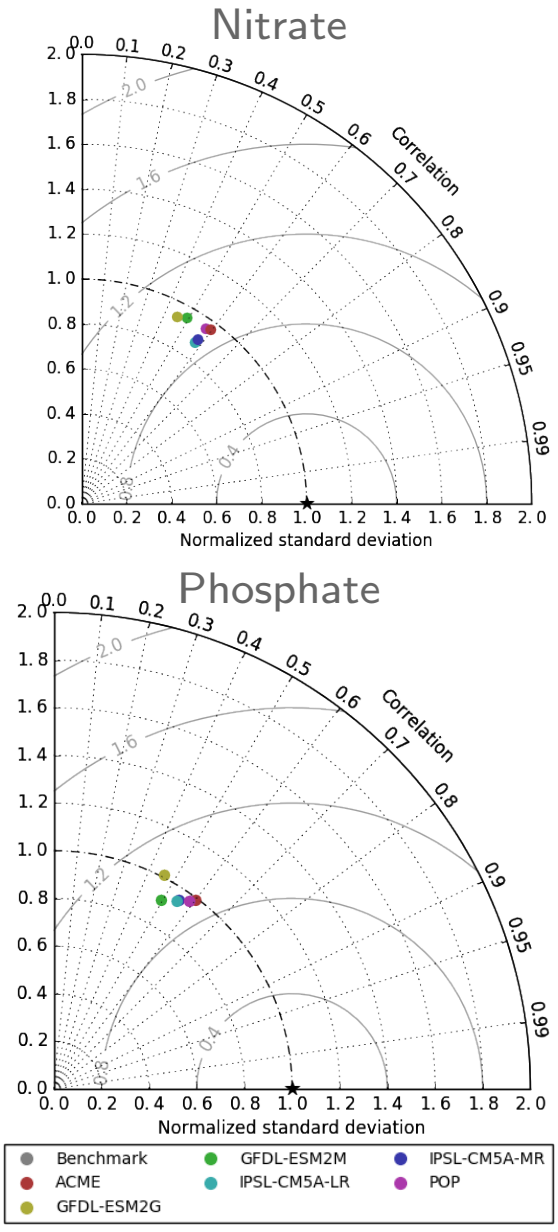

cruncepv8
gswp3v2
princeton
cruncepv8
gswp3v2
princeton
Biomass
Burned Area
Gross Primary Productivity
Leaf Area Index
Global Net Ecosystem Carbon Balance
Net Ecosystem Exchange
Ecosystem Respiration
Soil Carbon
Evapotranspiration
Evaporative Fraction
Latent Heat
Runoff
Sensible Heat
Permafrost
Surface Upward SW Radiation
Surface Net SW Radiation
Surface Upward LW Radiation
Surface Net LW Radiation
Surface Net Radiation
Surface Air Temperature
Precipitation
Surface Downward SW Radiation
Surface Downward LW Radiation
0 0.25 0.5 0.75 1
Absolute Score
-2 -1 +0 +1 +2
Relative Score

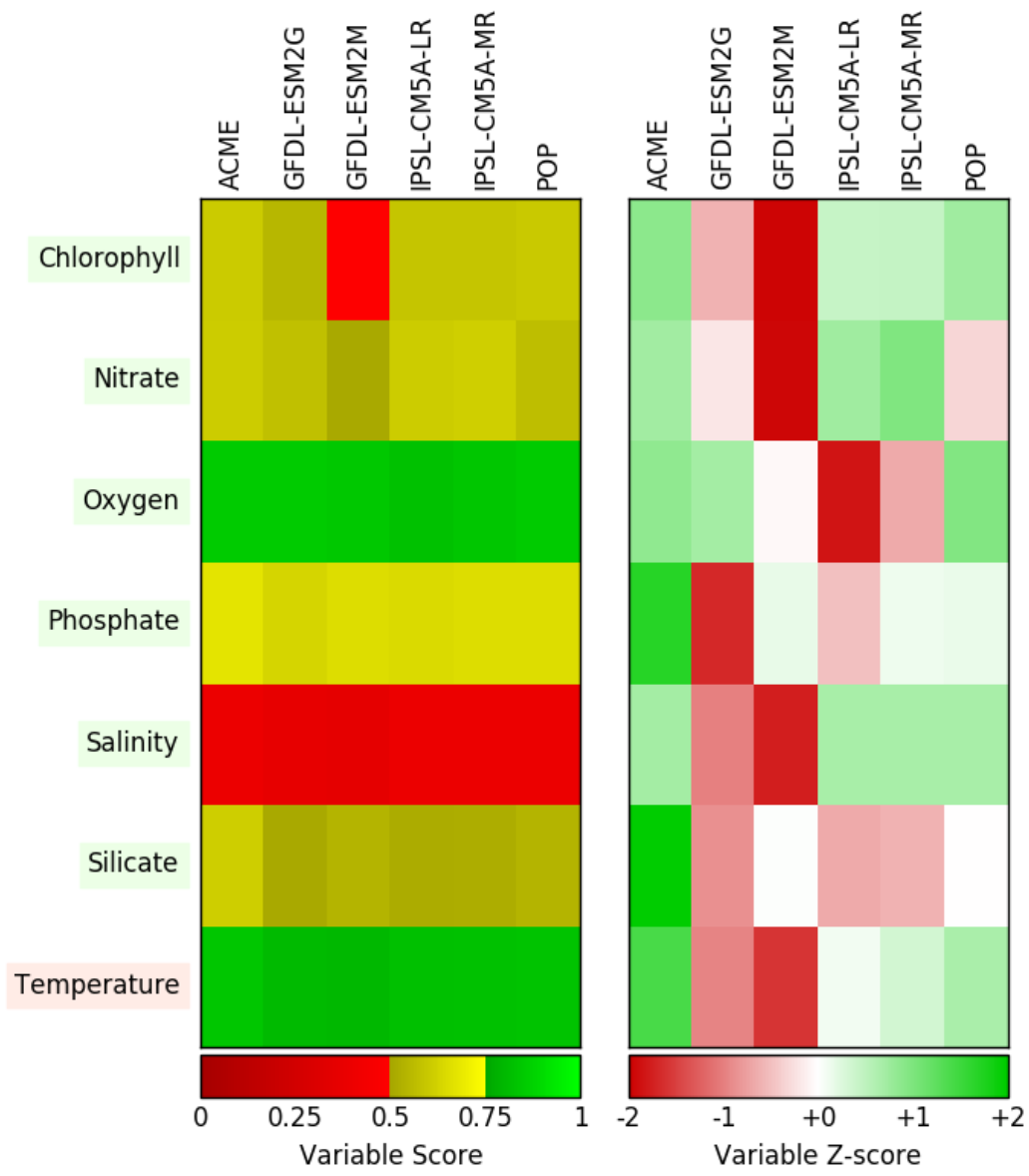

cruncepv8
gswp3v2
princeton
cruncepv8
gswp3v2
princeton
BurnedArea/Precipitation
BurnedArea/SurfaceAirTemperature
GrossPrimaryProductivity/Evapotranspiration
GrossPrimaryProductivity/Precipitation
GrossPrimaryProductivity/SurfaceDownwardSWRadiation
GrossPrimaryProductivity/SurfaceNetSWRadiation
GrossPrimaryProductivity/SurfaceAirTemperature
LeafAreaIndex/Precipitation
Evapotranspiration/Precipitation
Evapotranspiration/SurfaceAirTemperature
0
0.25
0.5
0.75
1
Absolute Score
-2
-1
+0
+1
+2
Relative Score

LS3MIP Summary and Next Steps

- Performance of the ELM is very dependent on the use of meteorological driver;
- ELM-GSWP3 has both the highest absolute and relative scores, and more detailed inter-comparisons are still ongoing;
- Selected Land Feedback MIP (LFMIP) simulations for the LS3MIP are under consideration;
- Also, factorial ELM simulations (Climate-, CO_2-, Nitrogen Deposition-, LULCC-, and aerosol-only using CN and CNP version of ELM) are under consideration for separating individual external-forcing effects on the land processes;
- More coordinated efforts for the LS3MIP are highly suggested, in terms of the inputs preparation, outputs post-processing and diagnostics, data storage, paper writing, and Fair Usage Policy.

Extending ILAMB for Ocean Model Evaluation





3rd Workshop, Washington, DC, USA, May 16–18, 2016

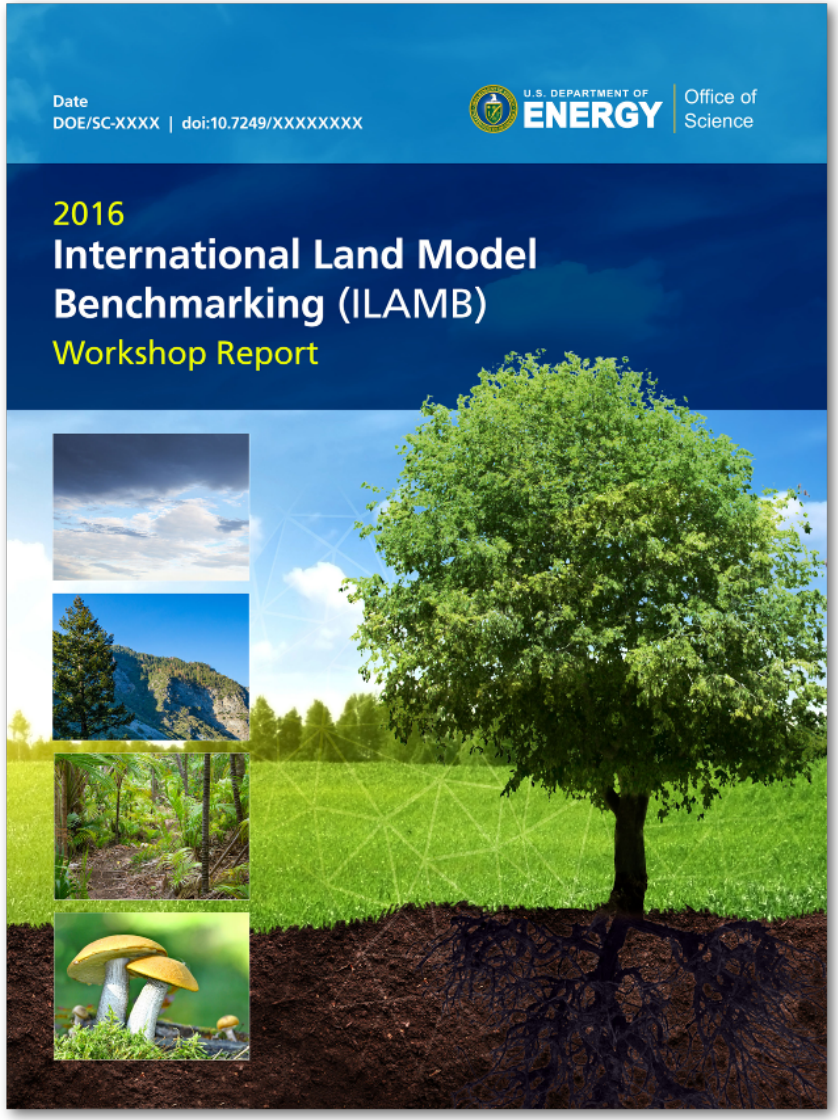
Overarching Workshop Goals

Engage the research community in defining scientific priorities for

- Design of new metrics for model benchmarking
- Model Intercomparison Project (MIP) evaluation needs
- Model development, testbeds, and workflow practices
- Observational data sets and needed measurements

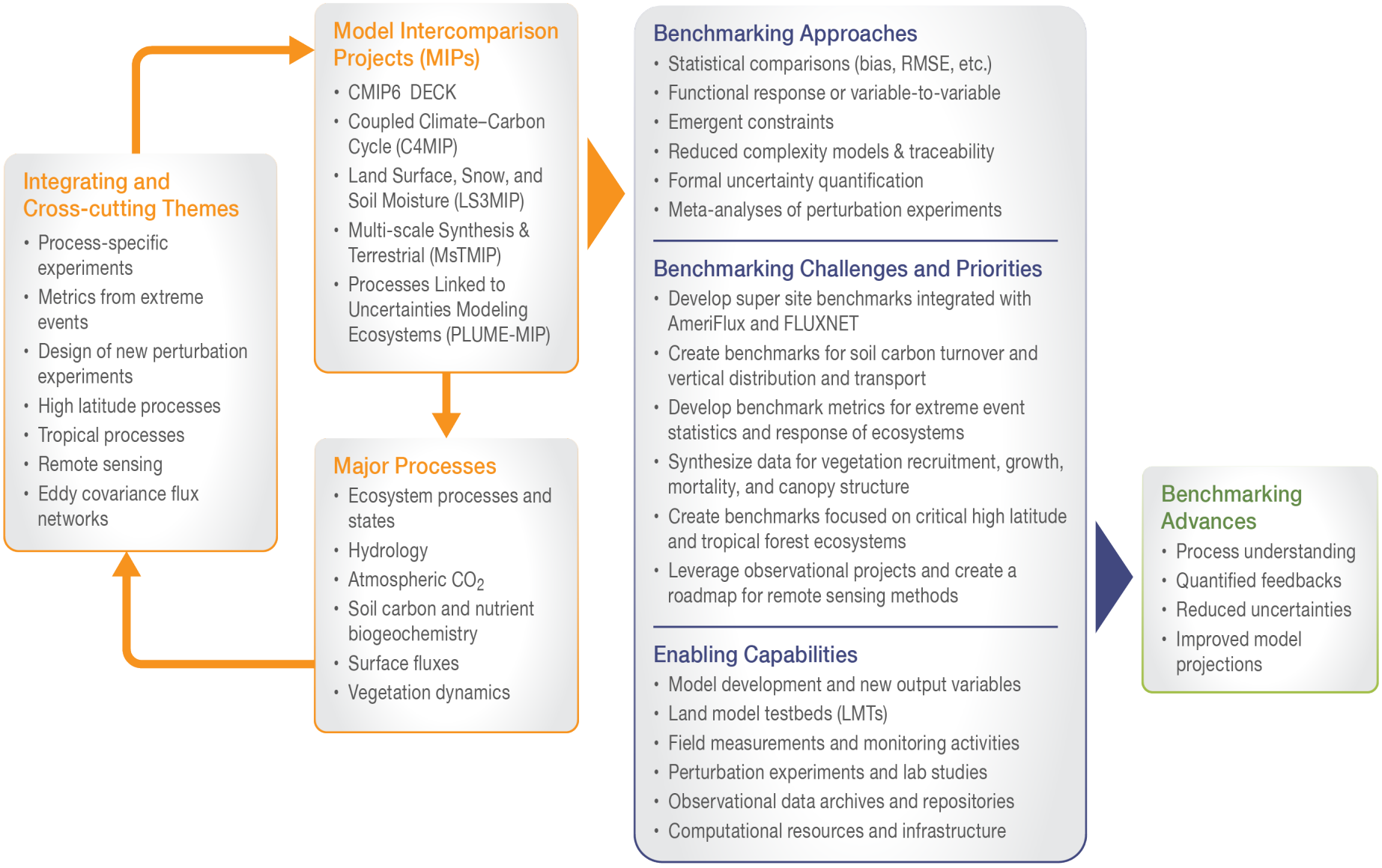
Workshop Attendance

- 60+ participants from Australia, Japan, China, Germany, Sweden, Netherlands, UK, and US
- 10 modeling centers represented
- ∼25 online attendees at any time



doi:10.2172/1330803

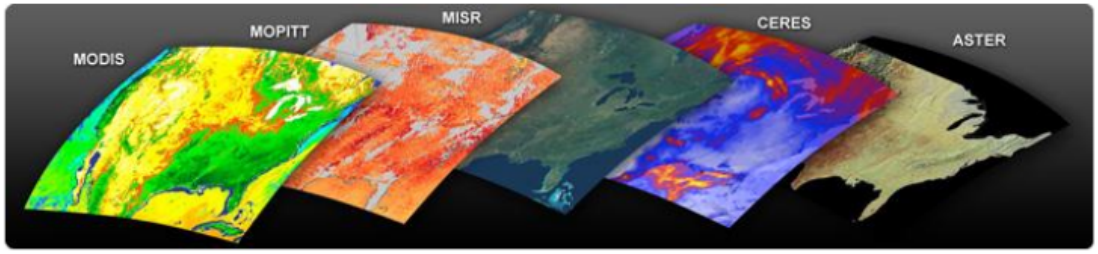
2016 ILAMB Workshop Synthesis

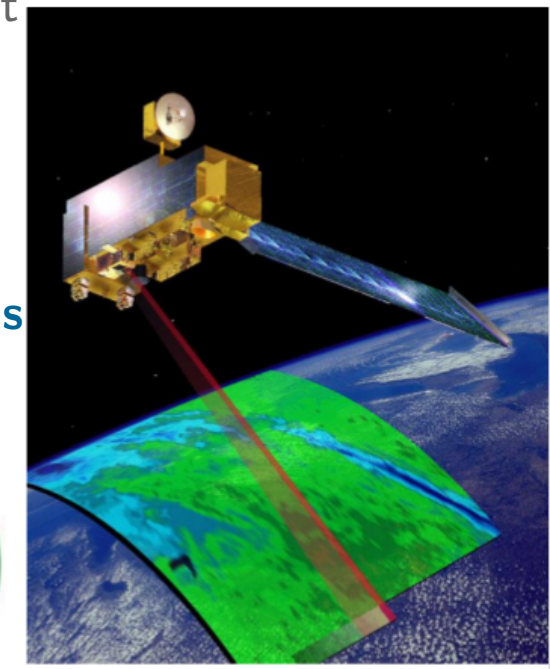


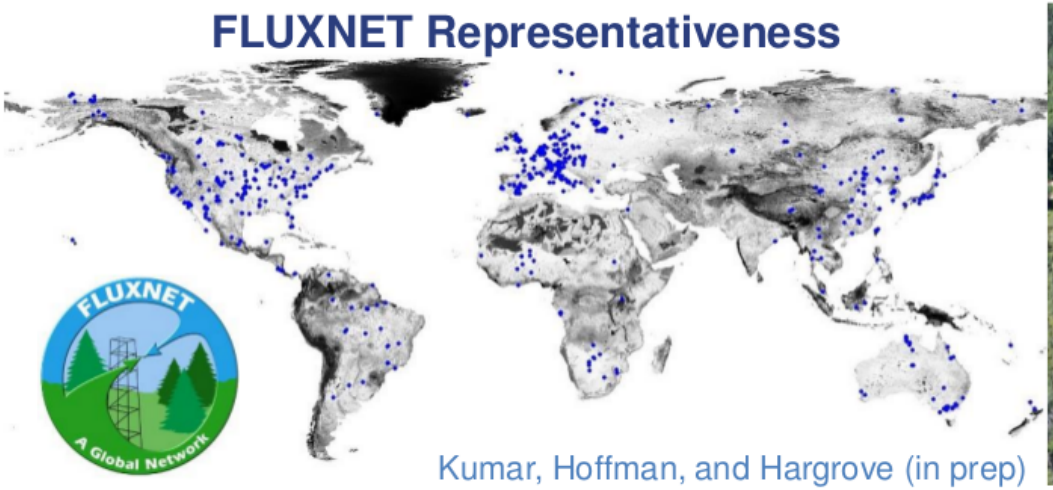
RUBISCO Argonne NATIONAL LABORATORY BROOKHAVEN NATIONAL LABORATORY BERKELEY LAB Los Alamos NATIONAL LABORATORY NCAR OAK RIDGE National Laboratory UCI MICHIGAN

Benchmarking Challenges and Priorities

- **Super site benchmarks** for AmeriFlux and FLUXNET
- **Benchmarks for soil carbon** turnover, distribution, transport
- **Metrics for extreme events** & response of ecosystems
- **Data for vegetation** recruitment, growth, mortality, phenology, canopy structure
- Benchmarks for critical **high latitude & tropical ecosystems**
- Leverage **field projects & remote sensing methods**







Kumar, Hoffman, and Hargrove (in prep)

Future ILAMB Development and Application

- ILAMBv1 and ILAMBv2 were applied to:
  - CMIP5 Historical and esmHistorical simulations
  - Model development of the Community Land Model (CLM)
  - E3SM Land Model (ELM) 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
  - E3SM uses it for evaluation of new land model features
  - RUBISCO is developing the framework and benchmarking MIPs
- Future projects where we hope to apply ILAMB:
  - CMIP6, including C^4MIP, LS3MIP, and LUMIP
  - TRENDY, MsTMIP
- Others are using and contributing to ILAMB:
  - NASA-funded Permafrost Benchmarking System
  - In-house model evaluation at various modeling centers
- ILAMB Methodology paper just accepted in JAMES (Oct 2018)

Important Links

- Open source git repository

  https://bitbucket.org/ncollier/ilamb

- CLM (4/4.5/5)

  http://ilamb.ornl.gov/CLM/

- CMIP5

  http://ilamb.ornl.gov/CMIP5/

- IOMB (Ocean benchmarking)

  http://ilamb.ornl.gov/IOMB/

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U.S. DEPARTMENT OF ENERGY

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