ILAMB System Overview

Design and Application of a Community Benchmarking System for Land Models

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Variables and Visualization within ILAMB

- Integrates 25 variables in 4 categories from ~60 datasets
  - Above ground 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, sensible heat, runoff, evaporative fraction, terrestrial water storage anomaly
  - 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
- Graphics and scoring system
  - annual mean, bias, relative bias, RMSE, seasonal cycle phase, spatial distribution, interannual variability
  - Global maps, time series plots averaged over specific regions, individual measurement sites

ILAMB versions 1 and 2 are available

- Version 1 – written in NCL
  - http://redwood.ess.uci.edu/mingquan/www/ILAMB/index.html
  - Tuned and vetted versions working with CMIP5 historical, CMIP5 esmHistorical, and CLM development branches

- Version 2 – written in Python and is parallel
  - Hosted in a git repository: https://bitbucket.org/ncollier/ilamb
  - Tutorial:: http://climate.ornl.gov/~ncf/ILAMB/docs/index.html
  - Sample output: http://www.climatemodeling.org/~nate/ILAMB/index.html

- Both versions have the following features:
  - constructed with a modular structure, so that new models, variables or benchmarks can be easily added
  - High quality output files (encapsulated postscript files) can be used directly for publications or proposals.

Global Variables

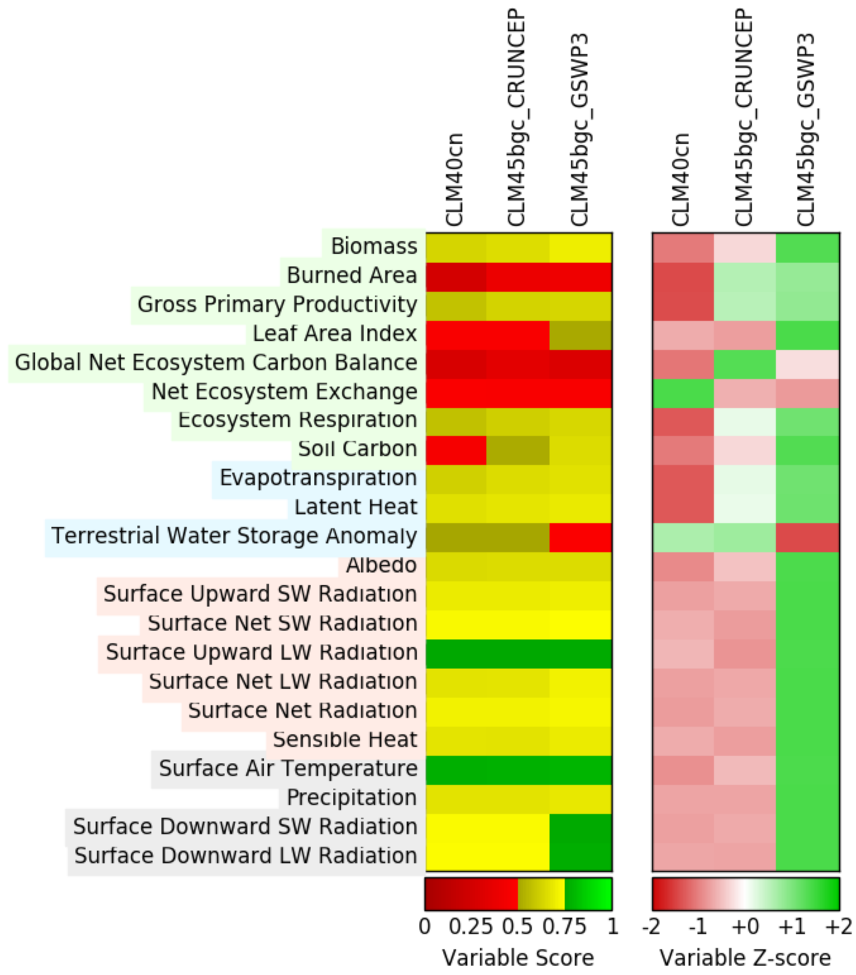
Global Variables (Info for Weightings)

	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
Live Biomass Carbon	0.73	0.68	0.33	0.65	0.60	0.62	0.72	0.50	0.56	0.62	0.58	0.56	0.57
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	0.62	0.51	0.55	0.55	0.54	0.60	0.56	0.55	0.59	0.55	0.50	0.54
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
Evaporative Fraction	0.84	0.76	0.77	0.81	0.81	0.75	0.81	0.81	0.72	0.75	0.75	0.80	0.79
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
Runoff	0.61	0.59	0.60	0.58	0.64	0.59	-	0.62	0.57	0.56	0.66	0.70	0.62
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
Terrestrial Water Storage Anomaly	0.38	0.37	0.36	0.38	0.38	0.38	-	0.38	0.37	0.38	0.38	0.38	0.38
Summary	0.68	0.65	0.65	0.66	0.67	0.64	0.77	0.64	0.64	0.63	0.66	0.68	0.66
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	0.77	0.74	0.67	0.74	0.78	0.74	0.77	0.74	0.73	0.72	0.78	0.67	0.76
Surface Net SW Radiation	0.84	0.86	0.84	0.85	0.86	0.86	0.86	0.84	0.82	0.83	0.87	0.85	0.85
Surface Upward LW Radiation	0.89	0.91	0.91	0.91	0.92	0.91	0.92	0.89	0.90	0.91	0.92	0.91	0.91
Surface Net LW Radiation	0.81	0.82	0.81	0.79	0.81	0.81	0.83	0.80	0.78	0.78	0.81	0.81	0.81
Surface Net Radiation	0.78	0.79	0.76	0.80	0.80	0.81	0.80	0.74	0.77	0.77	0.81	0.78	0.80
Summary	0.80	0.80	0.77	0.80	0.81	0.80	0.82	0.77	0.78	0.78	0.82	0.78	0.81
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	0.71	0.69	0.67	0.69	0.72	0.69	0.73	0.69	0.69	0.69	0.72	0.70	0.70
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	0.89	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	0.83	0.81	0.80	0.83	0.82	0.84	0.81	0.81	0.82	0.84	0.83	0.82
Overall	0.69	0.54	0.59	0.61	0.64	0.57	0.48	0.58	0.57	0.59	0.61	0.59	0.63

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

ILAMB System

Global Variables – Interface to Version 2



Variable to Variable Relationships

Variable to Variable Relationships (Info for Weightings)

	Relationship	Benchmark	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
Evapotranspiration vs. Gross Primary Productivity	function_bar	1	0.81	0.79	0.61	0.84	0.73	0.90	0.85	0.69	0.87	0.74	0.88	0.62	0.69
Precipitation vs. Burned Area	function_bar	1	0.45	-	-	-	0.46	-	-	-	-	-	0.43	-	0.47
Precipitation vs. Evapotranspiration	function_bar	1	0.71	0.81	0.77	0.79	0.70	0.76	0.68	0.68	0.75	0.72	0.74	0.78	0.67
Precipitation vs. Gross Primary Productivity	function_bar	1	0.89	0.91	0.72	0.79	0.87	0.76	0.69	0.85	0.71	0.83	0.68	0.40	0.84
Precipitation vs. Leaf Area Index	function_bar	1	0.62	0.68	0.34	0.58	0.55	0.42	0.47	0.84	0.60	0.67	0.76	0.24	0.56
Surface Downward SW Radiation vs. Gross Primary Productivity	function_bar	1	0.74	0.80	0.77	0.64	0.72	0.60	0.65	0.75	0.47	0.66	0.53	0.31	0.68
Surface Net SW Radiation vs. Gross Primary Productivity	function_bar	1	0.77	0.83	0.63	0.67	0.77	0.64	0.76	0.78	0.60	0.62	0.59	0.44	0.73
Surface Air Temperature vs. Burned Area	function_bar	1	0.42	-	-	-	0.44	-	-	-	-	-	0.44	-	0.47
Surface Air Temperature vs. Evapotranspiration	function_bar	1	0.68	0.75	0.63	0.82	0.64	0.65	0.65	0.59	0.74	0.65	0.76	0.72	0.60
Surface Air Temperature vs. Gross Primary Productivity	function_bar	1	0.78	0.77	0.65	0.75	0.70	0.67	0.76	0.62	0.62	0.73	0.56	0.38	0.63
Precipitation vs. Evapotranspiration	function_ratio	-	0.77	0.75	0.70	0.75	0.73	0.77	0.73	0.69	0.73	0.72	0.75	0.71	0.71
Precipitation vs. Runoff	function_ratio	-	0.73	0.66	0.68	0.71	0.70	0.61	-	0.69	0.66	0.70	0.75	0.70	0.68
Overall			0.71	0.66	0.56	0.63	0.68	0.59	0.54	0.61	0.59	0.60	0.67	0.46	0.65

Notes: 2 Categories are divided: normal variable to variable relationship (Function Bar) and Ratio.

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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)	Relative Bias	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	0.2	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	-0.0	6.0	-0.2	access to plots	0.72	0.64	0.80	0.89	0.74
BNU-ESM	102.0	-16.4	-0.1	6.2	0.1	access to plots	0.69	0.66	0.78	0.84	0.73
CanESM2	129.2	10.8	0.1	7.3	0.8	access to plots	0.64	0.60	0.68	0.70	0.64
CESM1-BGC	130.3	11.9	0.1	5.8	0.5	access to plots	0.69	0.65	0.76	0.87	0.72
GFDL-ESM2G	175.1	56.7	0.5	9.8	0.5	access to plots	0.66	0.54	0.73	0.83	0.66
HadGEM2-ES	145.9	27.5	0.2	7.4	0.3	access to plots	0.65	0.58	0.78	0.79	0.68
inmcm4	111.4	-7.0	-0.1	5.6	0.3	access to plots	0.71	0.66	0.78	0.83	0.73
IPSL-CM5A-LR	166.6	48.2	0.4	8.8	0.4	access to plots	0.63	0.56	0.77	0.84	0.67
MIROC-ESM	131.7	13.3	0.1	6.2	0.2	access to plots	0.72	0.66	0.74	0.86	0.73
MPI-ESM-LR	169.9	51.5	0.4	7.4	0.3	access to plots	0.67	0.62	0.70	0.89	0.70
MRI-ESM1	236.1	117.7	1.0	12.5	0.2	access to plots	0.45	0.43	0.79	0.59	0.54
NorESM1-ME	130.4	12.0	0.1	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.

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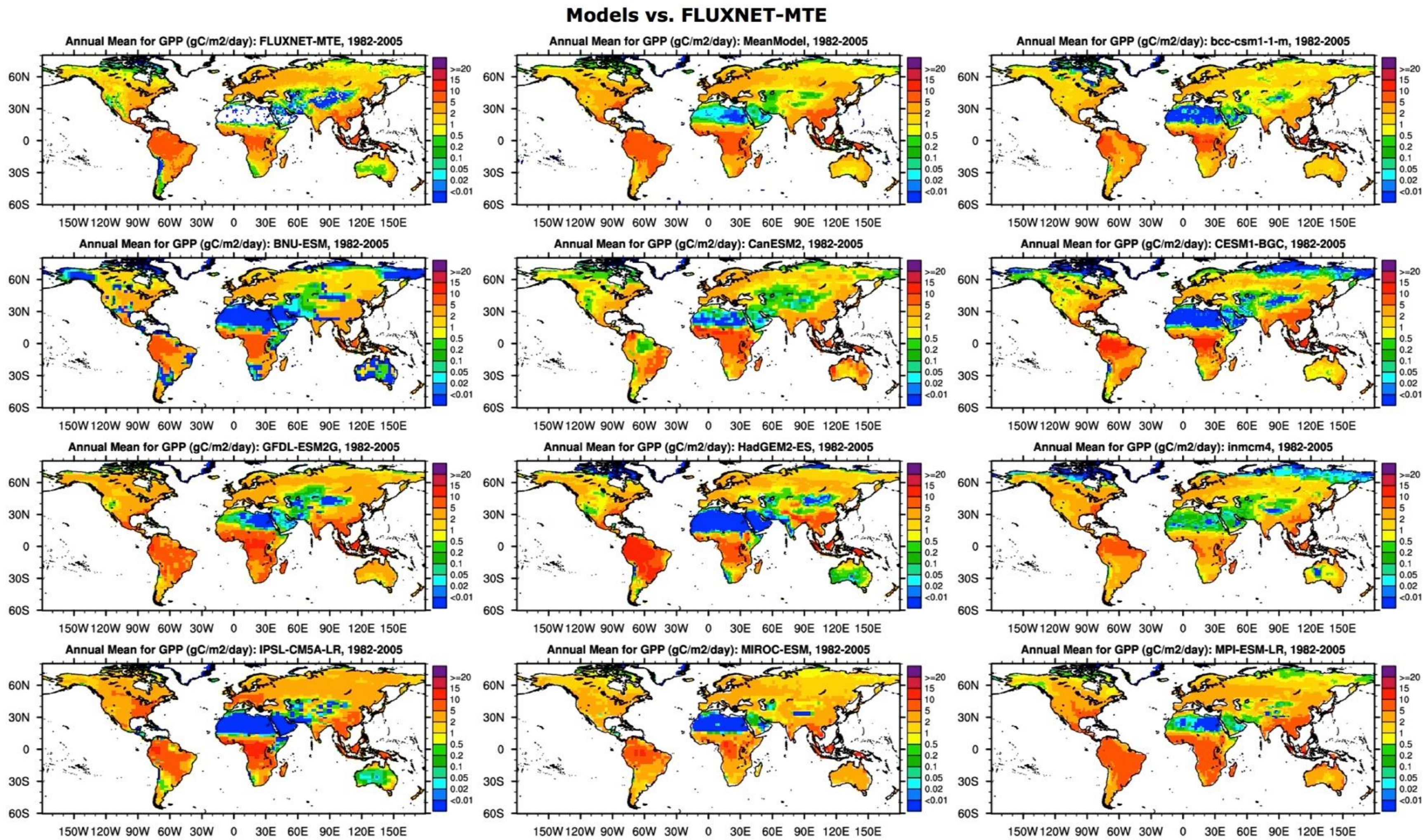
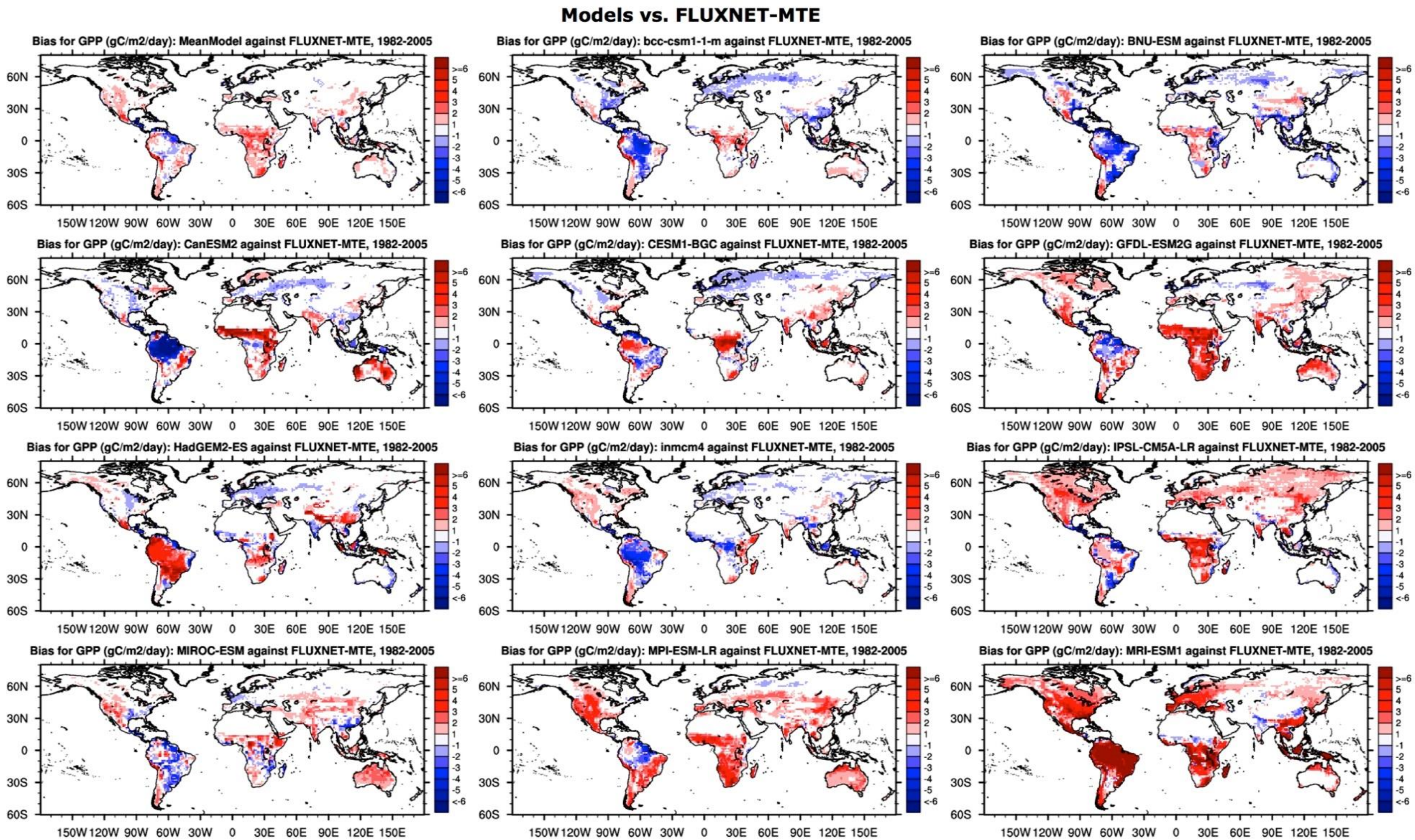
Annual Mean Global GPP

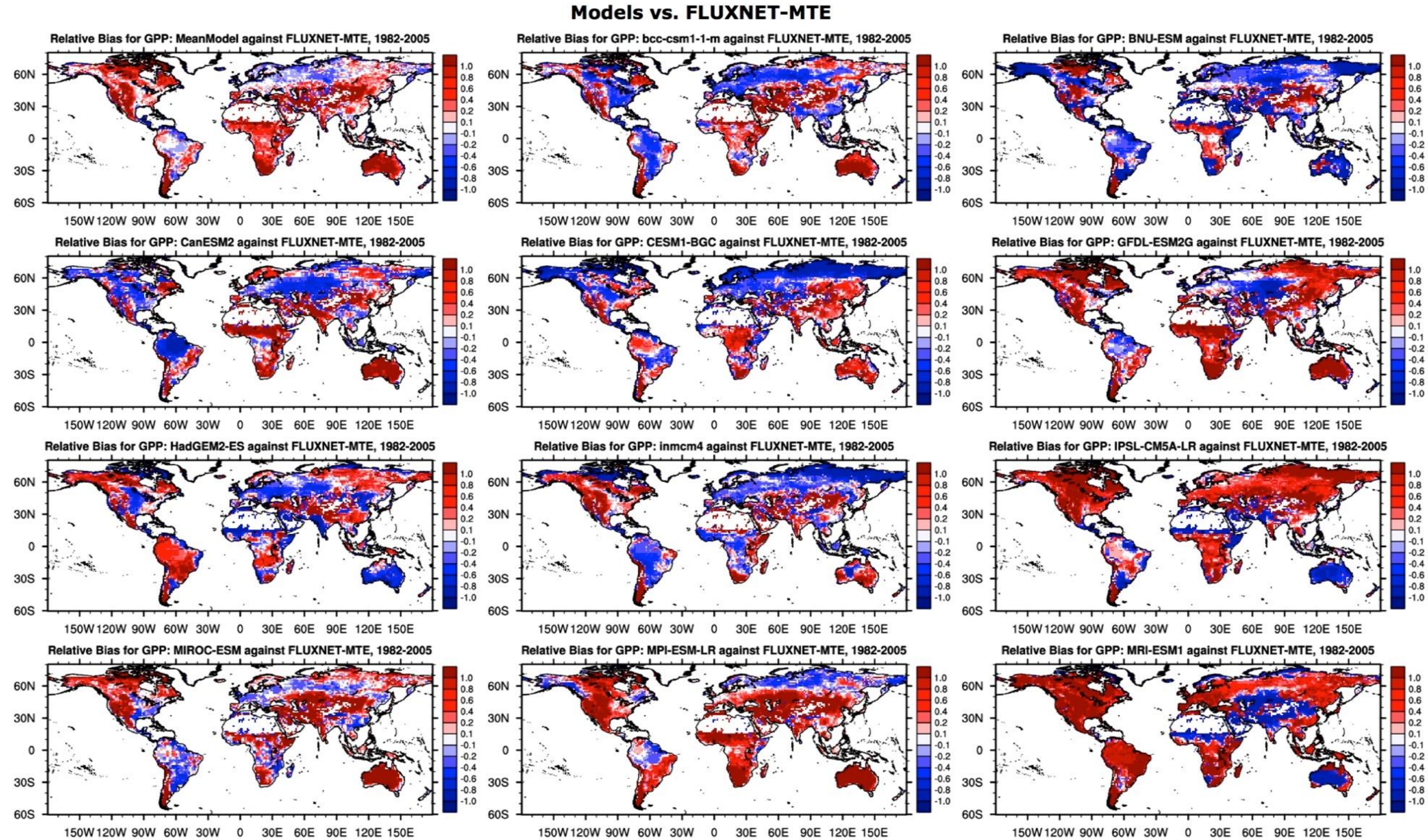


Global GPP Bias



ILAMB System

Global GPP Relative Bias



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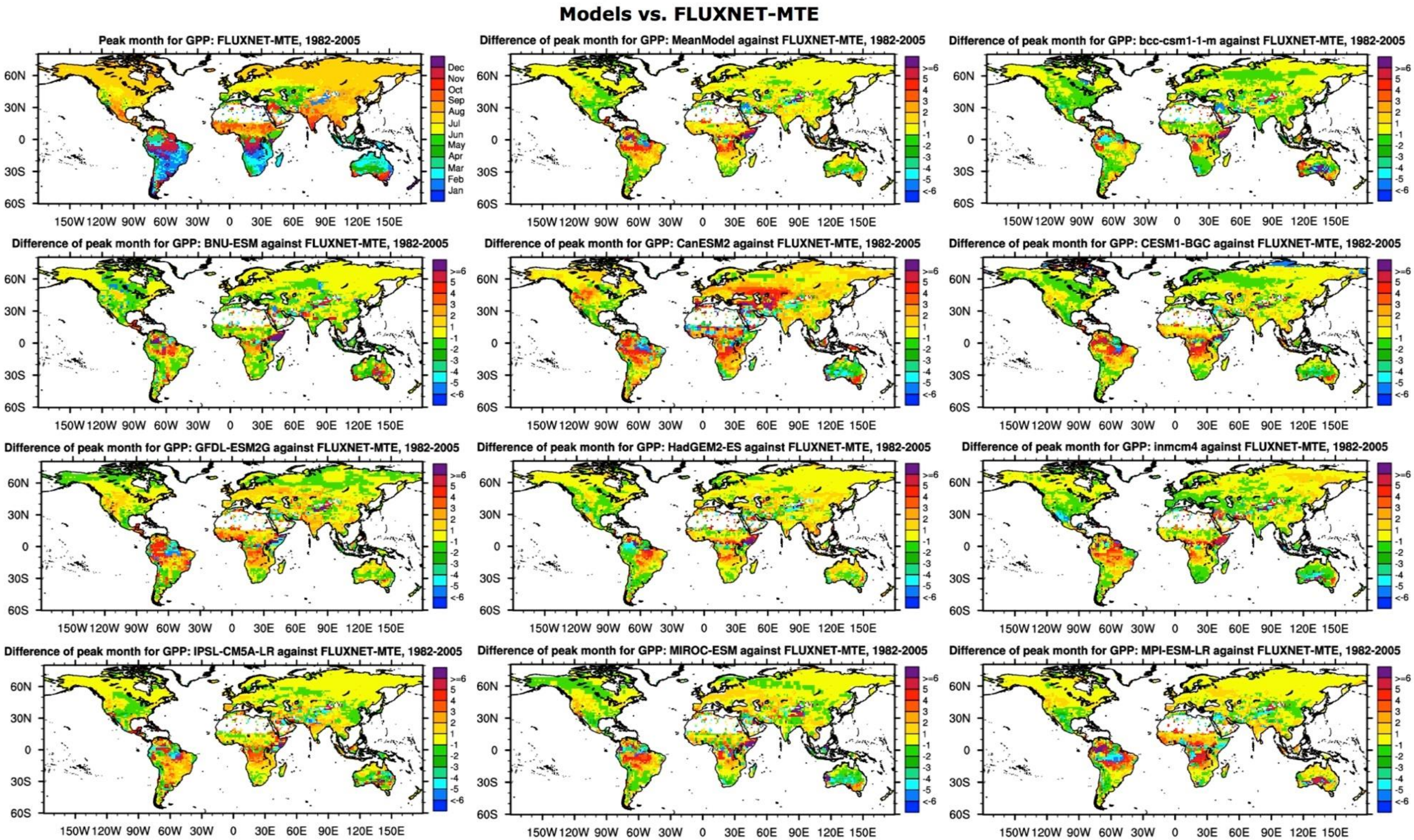
Global GPP Phase Difference



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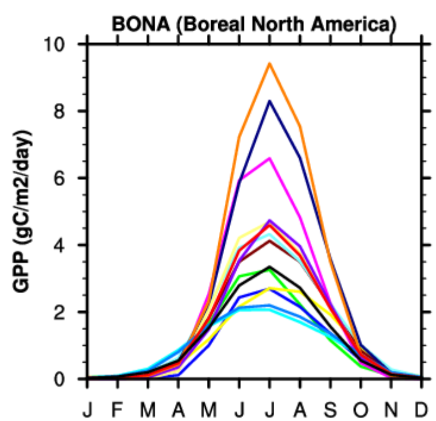
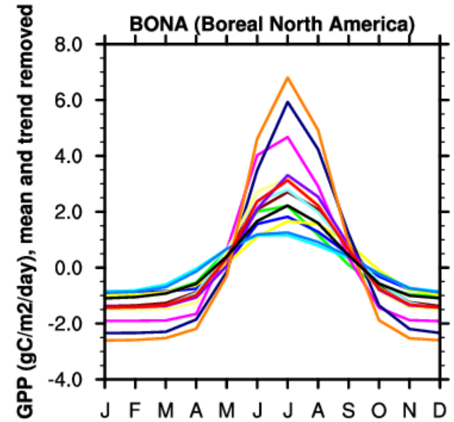
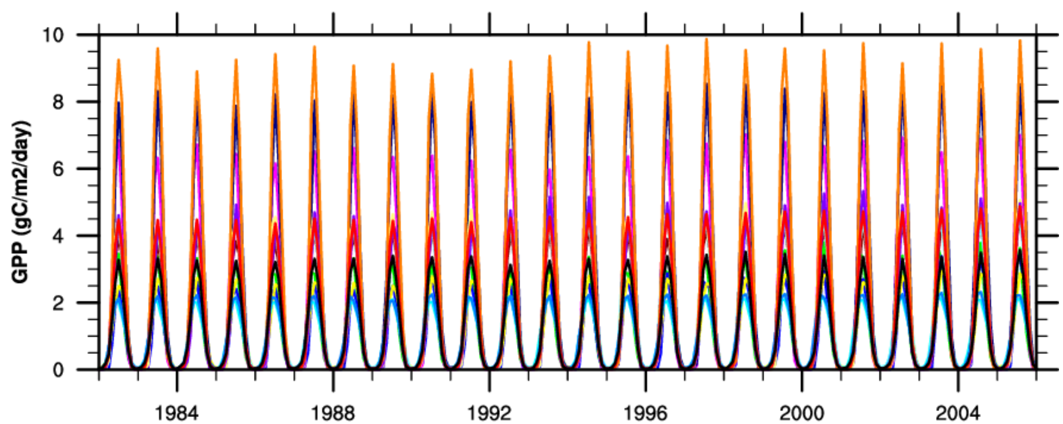
Seasonal Cycle of Regional GPP

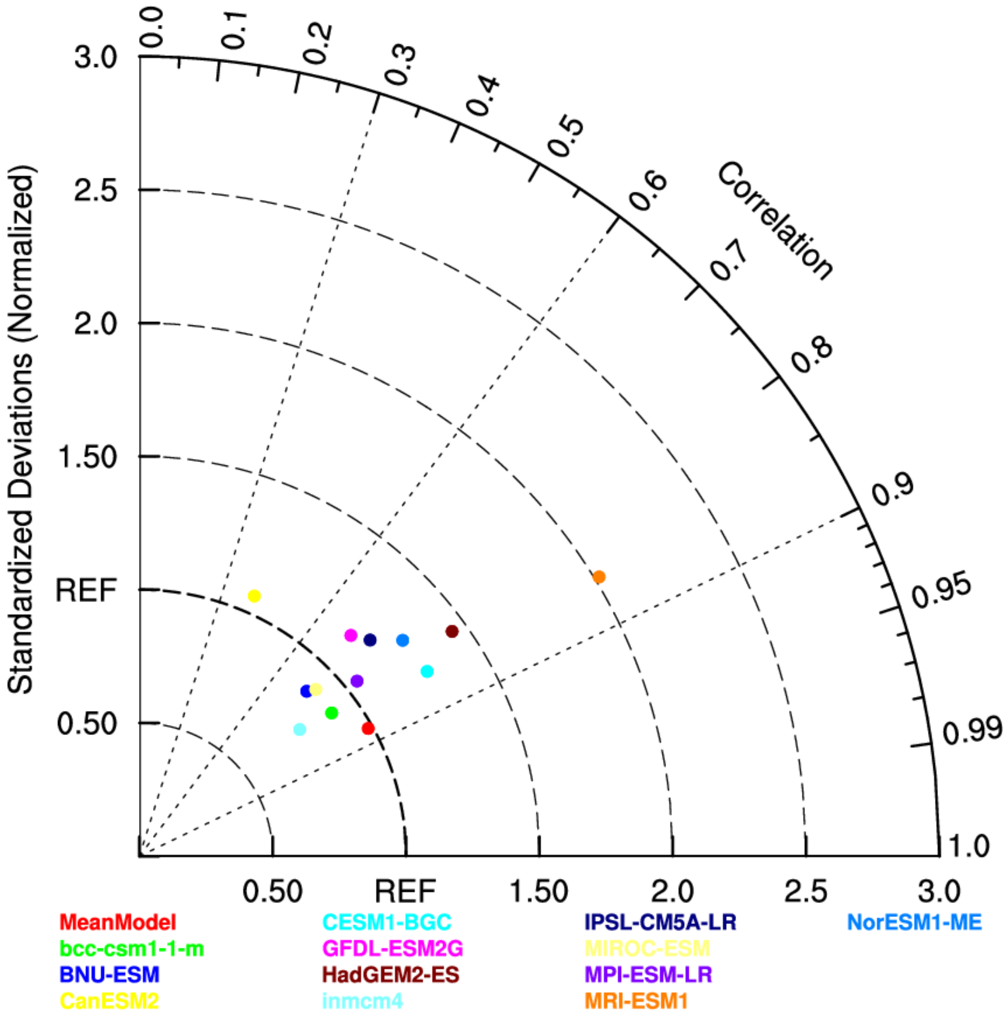






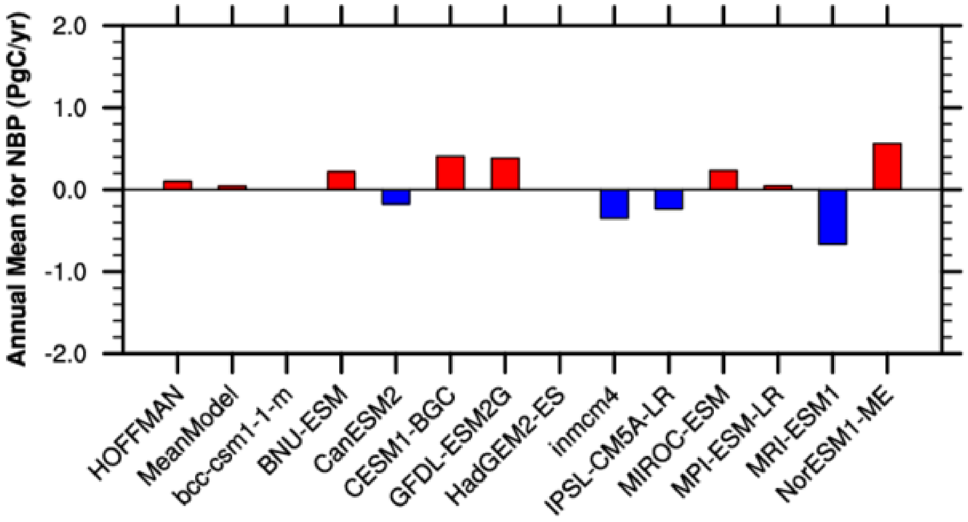
Model	Annual	Bias	RMSE	Model	Annual	Bias	RMSE	Model	Annual	Bias	RMSE
FLUXNET-MTE	1.13	-999	-999	MeanModel	1.47	0.34	0.59	bcc-csm1-1-m	1.05	-0.07	0.26
BNU-ESM	0.87	-0.25	0.39	CanESM2	1.05	-0.08	0.34	CESM1-BGC	0.91	-0.22	0.55
GFDL-ESM2G	1.91	0.79	1.50	HadGEM2-ES	1.42	0.29	0.46	inmcm4	1.54	0.41	0.60
IPSL-CM5A-LR	2.37	1.24	2.13	MIROC-ESM	1.50	0.37	0.71	MPI-ESM-LR	1.42	0.30	0.65
MRI-ESM1	2.62	1.49	2.66	NorESM1-ME	0.94	-0.18	0.48				

Global Annual Mean GPP Spatial Correspondence



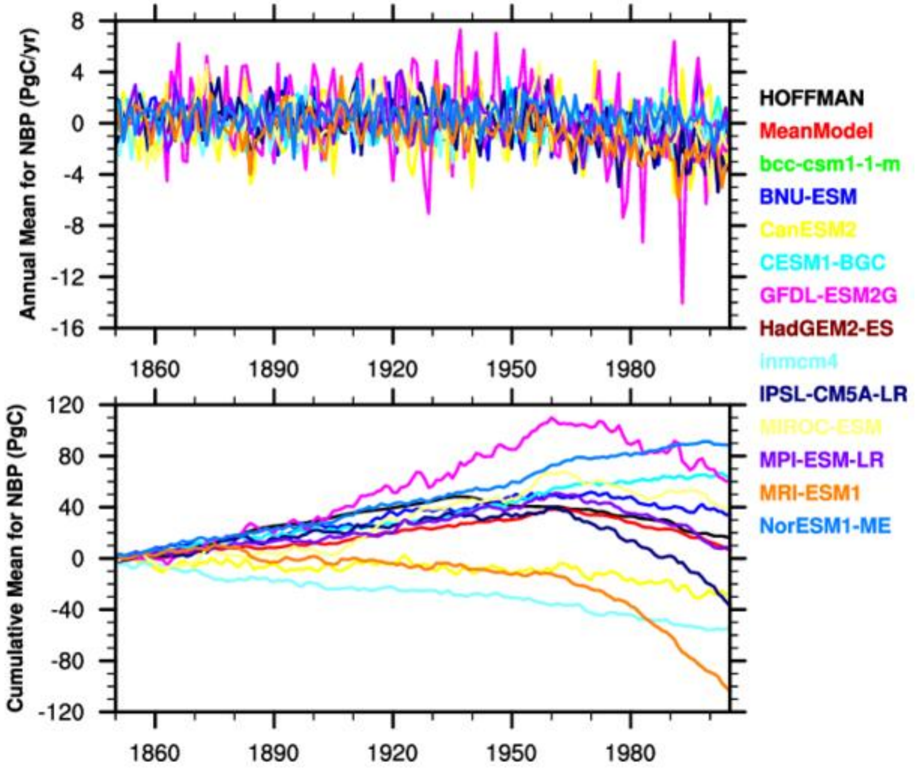
ILAMB system

Global Net Ecosystem Carbon Balance



Global Net Ecosystem Carbon Balance

Long term carbon storage

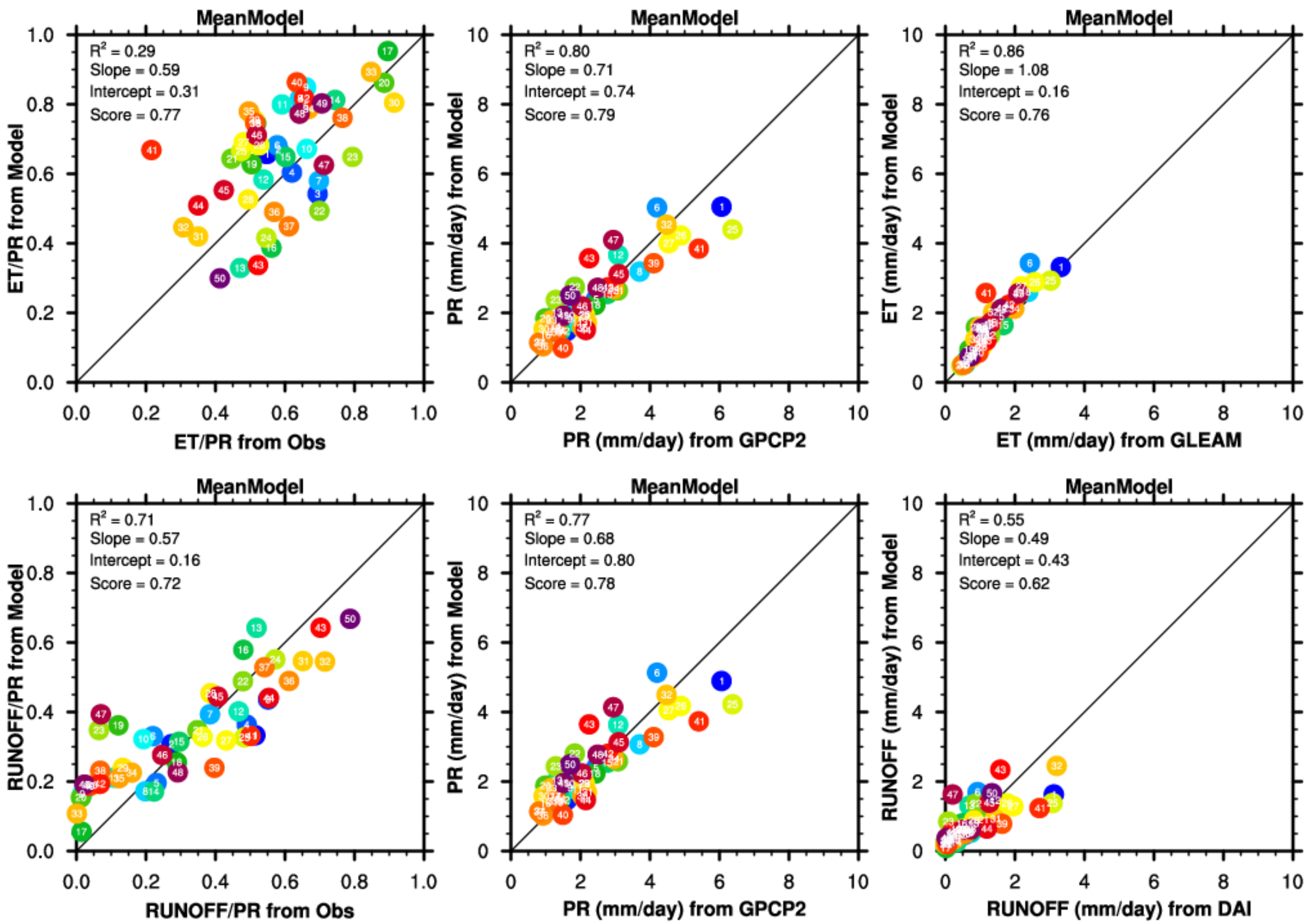


ILAMB System

Functional Relationships: Pr vs. runoff and ET

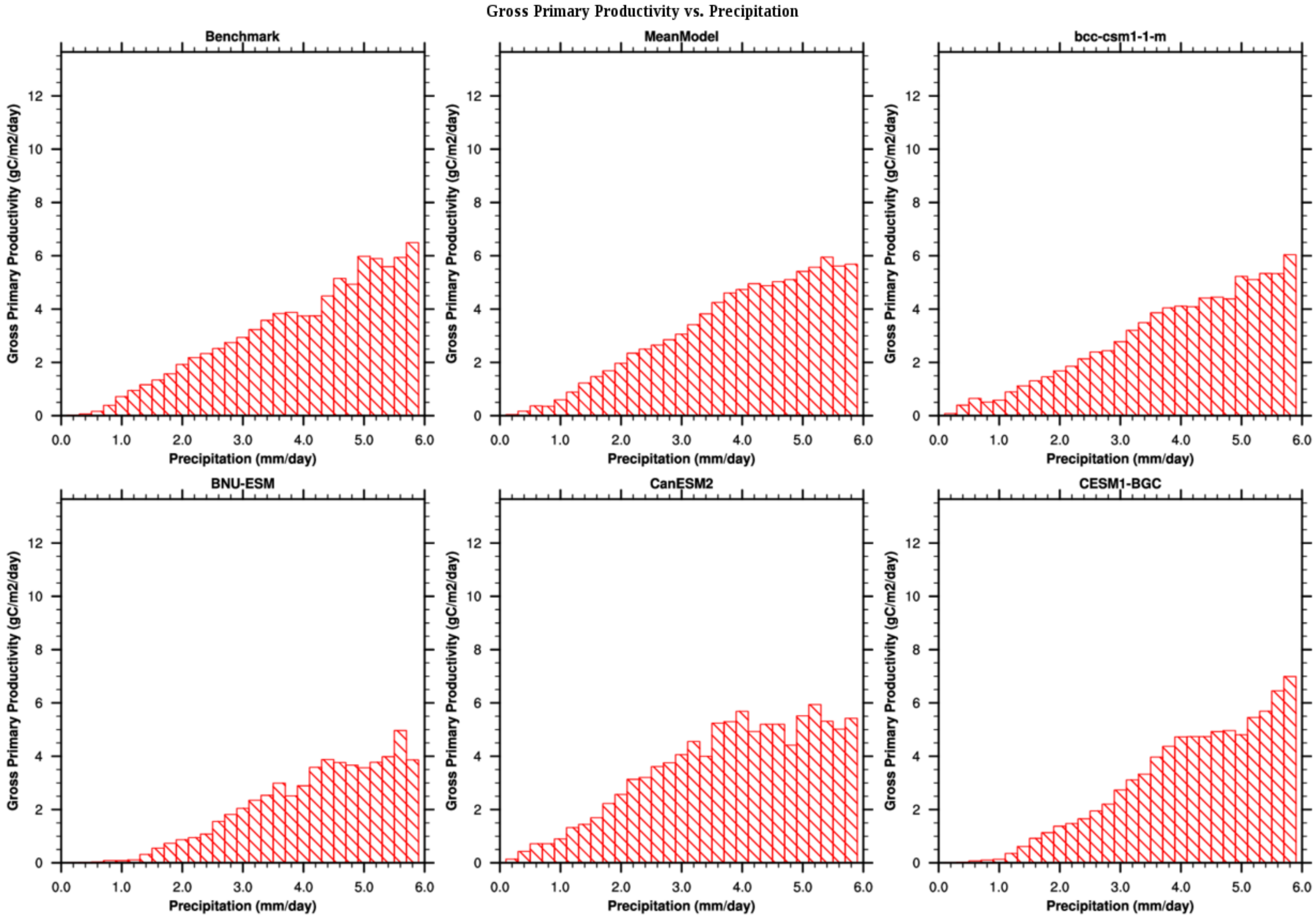
Pr vs. ET

Pr vs. runoff



ILAMB System

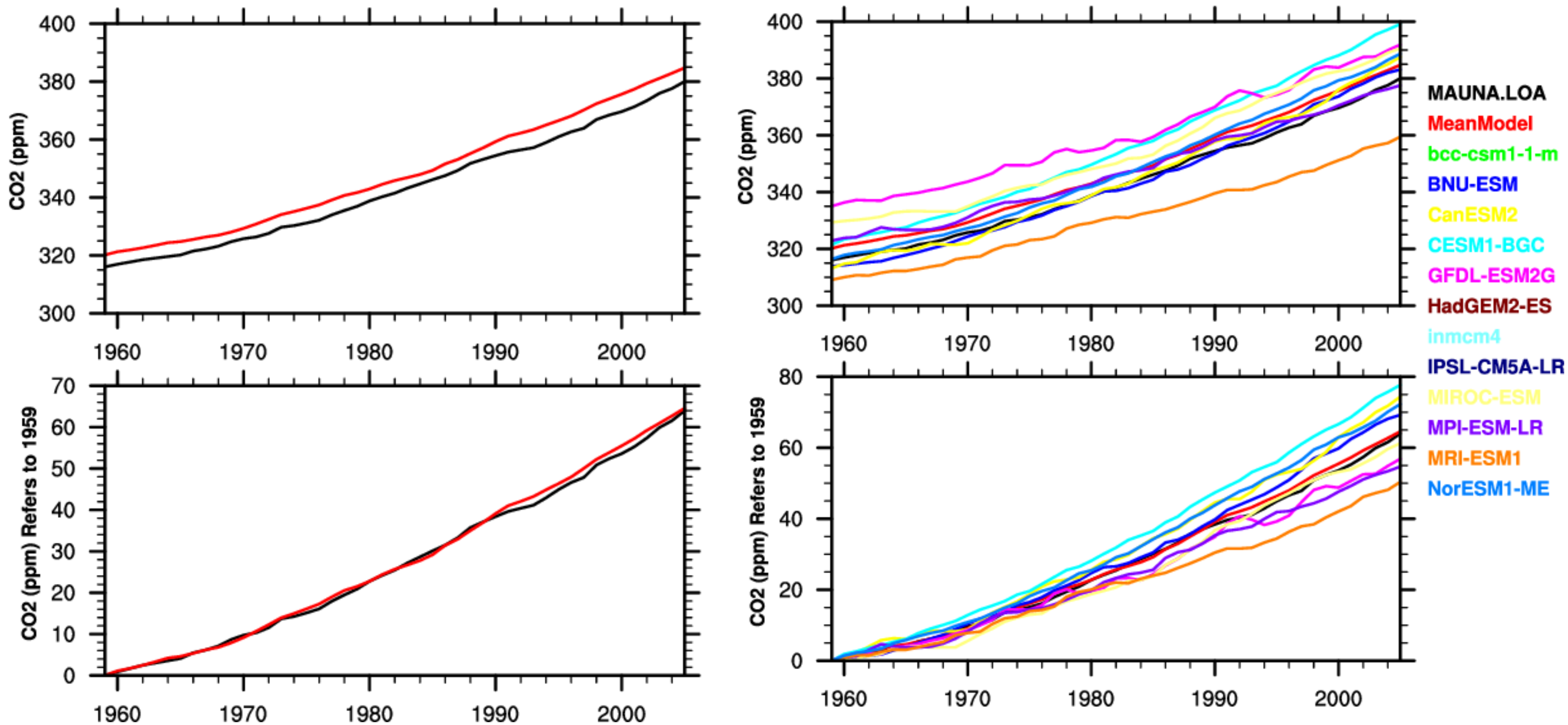
Functional Relationships: GPP vs. Precipitation



ILAMB System

CMIP5 ESM: Results

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

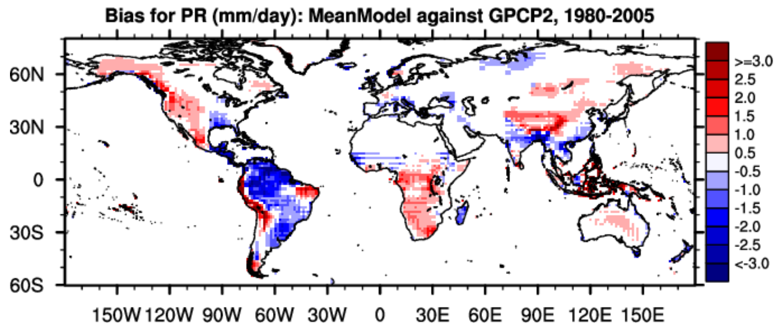


ILAMB System

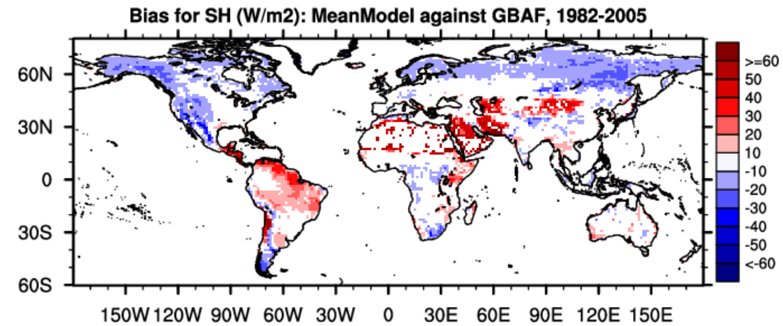
CMIP5 ESM: Results

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

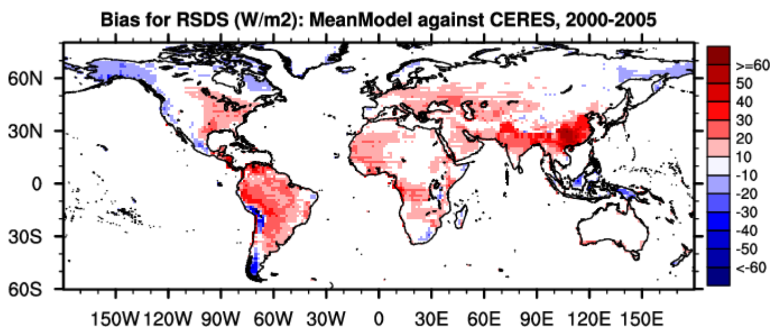
Precipitation



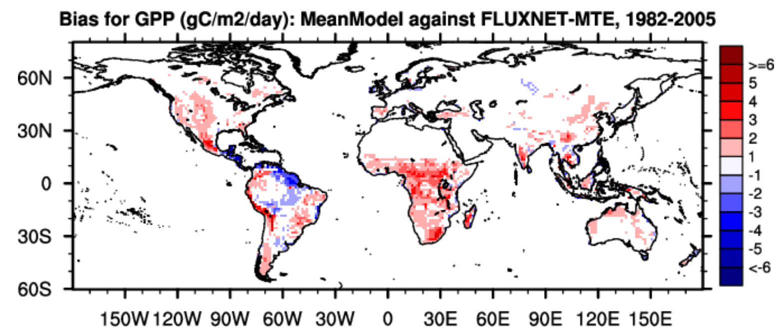
Sensible heat



Solar radiation

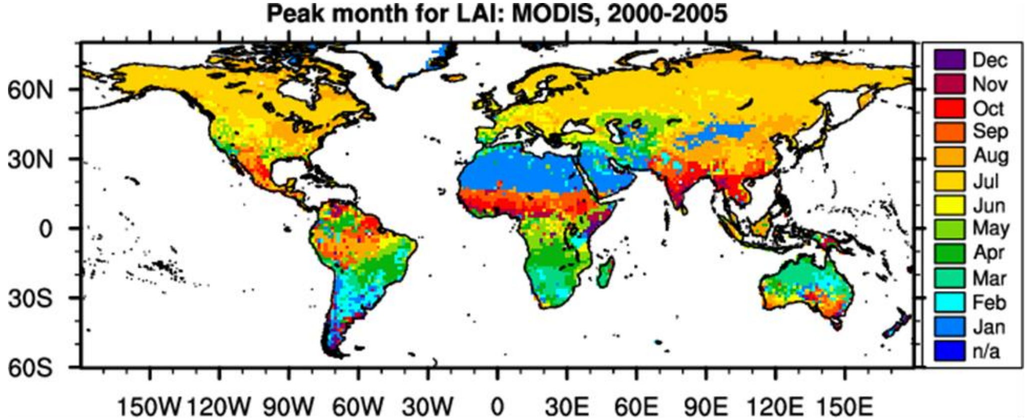


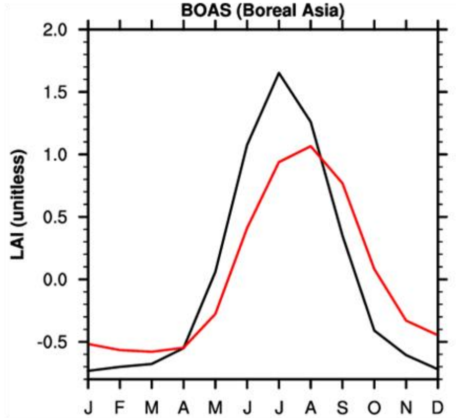
GPP

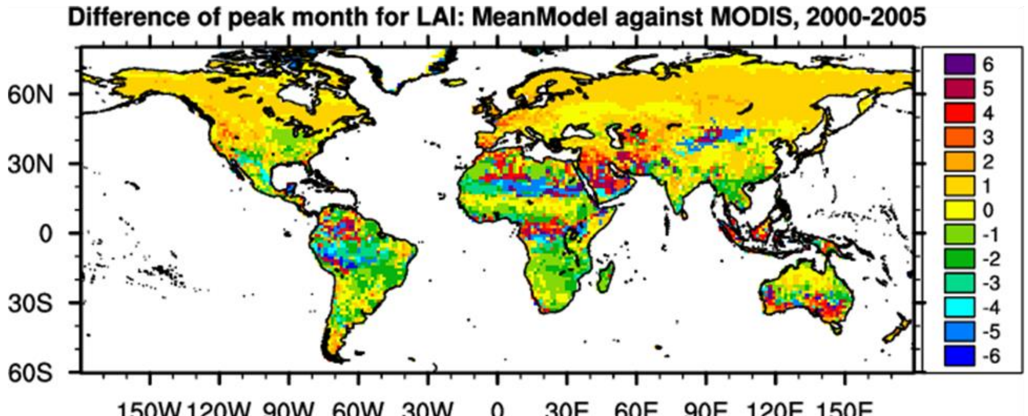


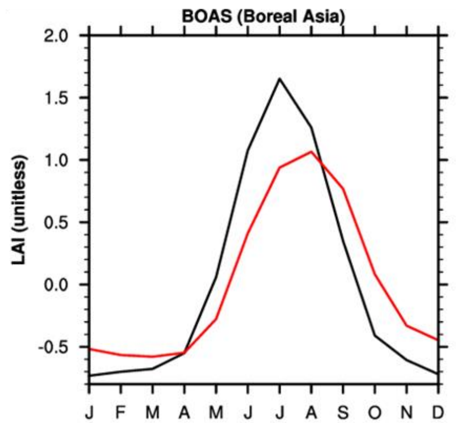
CMIP5: Results

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









Summary

- ILAMB may be a 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
  - Emergent constraints
  - Land-atmosphere coupling metrics
  - Experimental manipulations
  - Develop and integrate arctic and tropical ecosystems modules
  - Prepare for CMIP6

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

12 CMIP5 Model General Information

Table 4 Information for 12 CMIP5 Earth System Models for this study

Models	Institution/Country	Atmosphere Model	Land Model	Resolution	Dynamic Vegetation	Nitrogen Cycle	Land Use Change	Fire
bcc-csm1-1-m	Beijingl Climate Center/China	BCC_AGCM2.2	BCC_AVIM1.1	320´160	NO	NO	NO	NO
BNU-ESM	Beijing Normal University/China	CAM3.5	CoLM3+BNUDGVM	128´64	YES	YES	YES	NO
CanESM2	Canadian Center for Climate Modelling and Analysis/Canada	CanAM4	CLASS2.7	128´64	NO	NO	YES	NO
CESM1-BGC	National Center for Atmospheric Research (NCAR)	CAM4	CLM4	288´192	NO	YES	YES	YES
GFDL-ESM2G	Geosphysical Fluid Dynamics Laboratory	AM2	LM3	144´90	YES	NO	YES	NO
HadGEM2-ES	Met Office Hadley Centre/UK	HadGAM2	MOSES2+TRIFFID	192×145	YES	NO	YES	NO
Inmcm4	Insitute for Numerical Mathematics/Russia	INMCM4.0	Simplified land model	180×120	NO	NO	YES	NO
IPSL-CM5A-LR	Institut Pierre Simon Laplace/France	LMDZ4	ORCHIDEE	96×96	NO	NO	YES	NO
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology/Japan	MIROC-AGCM 2010	MATSIRO	128×64	YES	NO	YES	NO
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	ECHAM6	JSBACH	192×96	YES	NO	YES	YES
MRI-ESM1	Meteorological Research Institute/Japan	GSMUV	HAL	320×160	NO	NO	YES	NO
NorESM1-ME	Norwegian Climate Centre/Norway	CAM-Oslo	CLM4	144×96	NO	YES	YES	YES