International LAnd Model Benchmarking (ILAMB) Project

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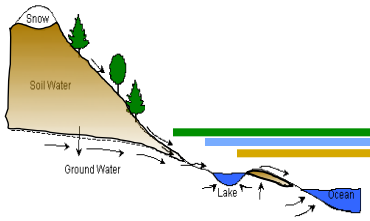
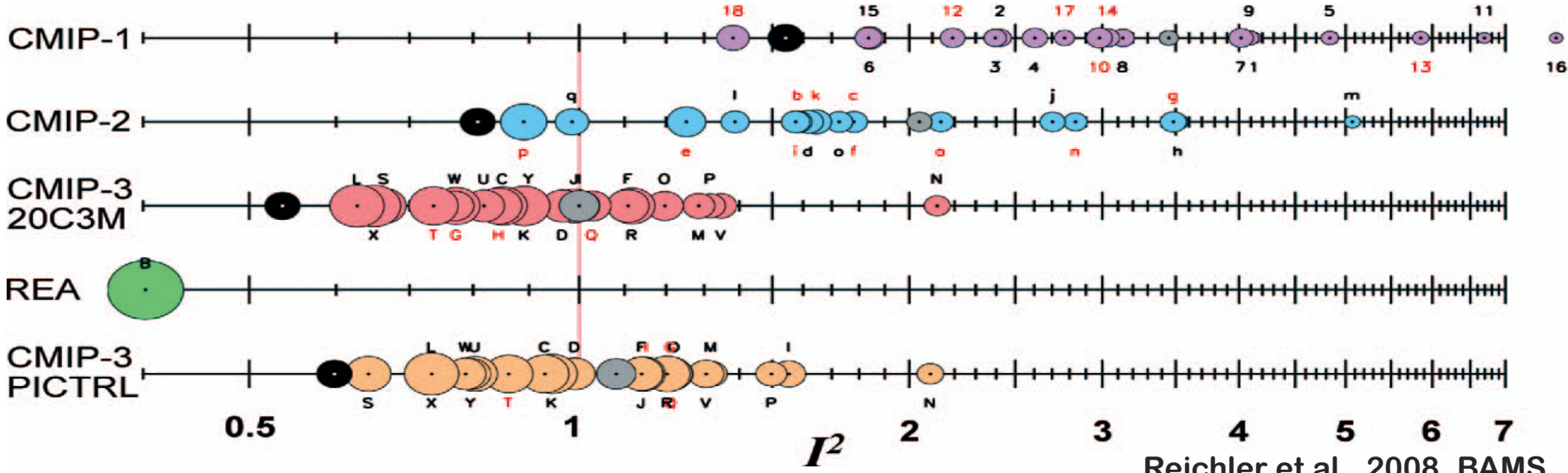
U.S. DEPARTMENT OF ENERGY

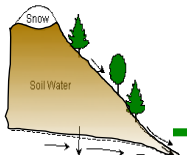


ILAMB Goals

- Develop benchmarks/metrics for land model performance, with emphasis on breadth (carbon cycle, ecosystem, surface energy, and hydrological processes)
- Support the design and development of a new, open-source, benchmarking software system for diagnostics and MIPs
- Strengthen linkages between experimental, monitoring, remote sensing, and climate modeling communities in design of model tests and new measurement programs

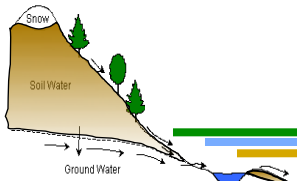


Reichler et al., 2008, BAMS



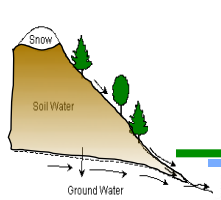
Potential metrics for inclusion in a comprehensive land benchmarking/metric system

- Large-scale state and flux estimates
  - LH, SH, total water storage, albedo, river discharge, SCF, LAI, soil and veg C stocks, GPP, NEE, ER, burnt area, permafrost distribution, T_{2m}, P, …
  - RMSE, spatial pattern corr, interannual variance, annual cycle phase, trends
- Functional relationships and emergent properties
  - soil moisture – ET, soil moisture – runoff, precip – GPP, stomatal response to VPD, precip – burnt area, transient carbon storage trajectory, runoff ratio, spring albedo transition
- Experimental manipulation (testing model functional responses)
  - Nitrogen additions, FACE, artificial warming, rainfall exclusion, ecosystem response to disturbance



International LAnd Model Benchmarking (ILAMB) project
Variables and Visualization within ILAMB

- Currently integrates analysis of 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, variable-to-variable
  - Global maps, time series plots averaged over specific regions, individual measurement sites, functional relationships



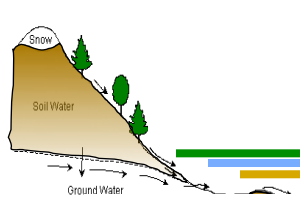
Global Variables

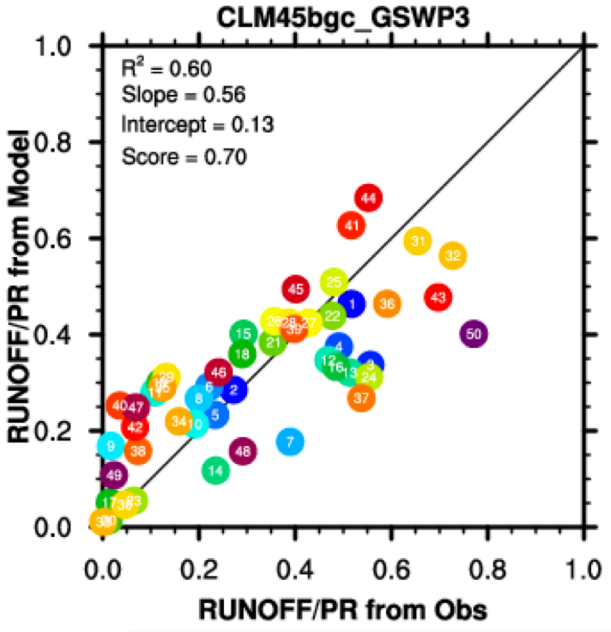
Global Variables (Info for Weightings)

	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

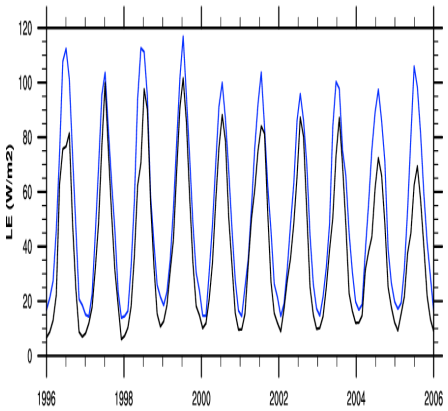
Notes: 4 Categories are divided: Ecosystem and Carbon Cycle, Hydrology and Turbulent Flux, Radiation and Energy Cycle, and Forcings.

Examples of ILAMB metrics / plots

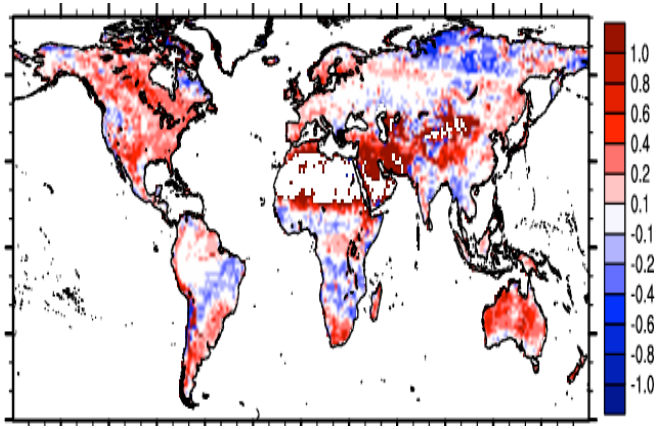




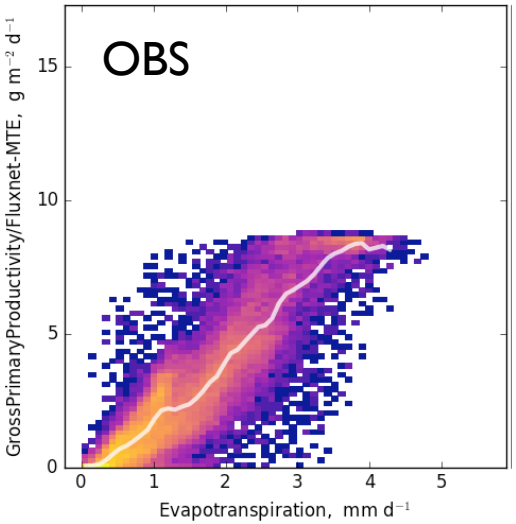
Tower Site

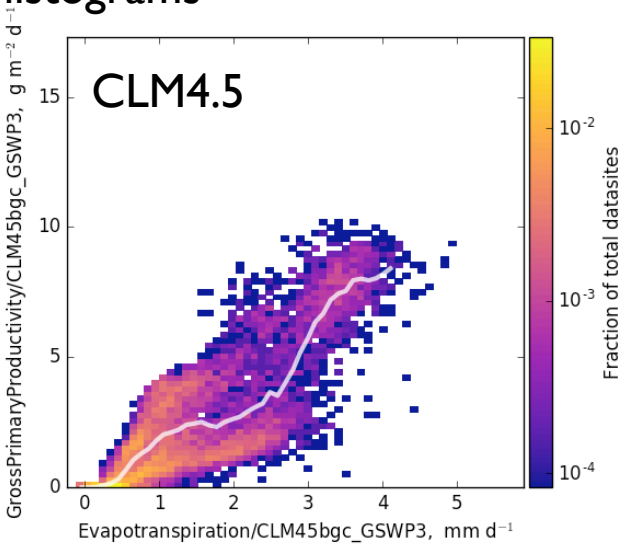


Global bias, relative bias, RMSE

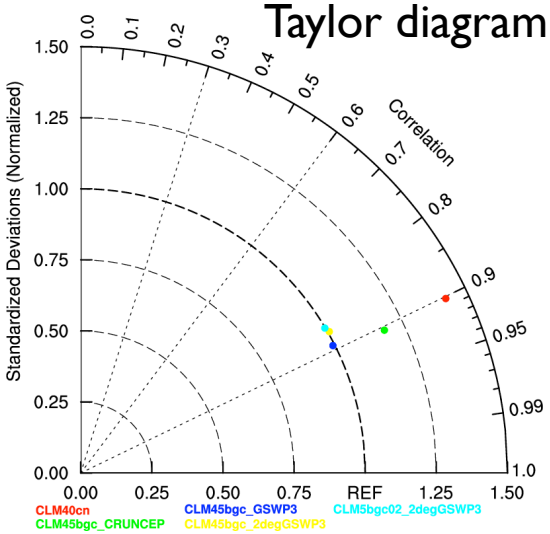


2-d histograms



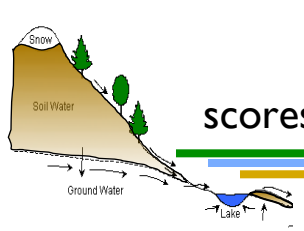


Taylor diagram



International LAnd Model Benchmarking (ILAMB) package

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



Potential permafrost-related metrics

Permafrost distribution

Snow and soil heat transfer

Soil C stocks

Soil C quality with depth

CH_4 emissions

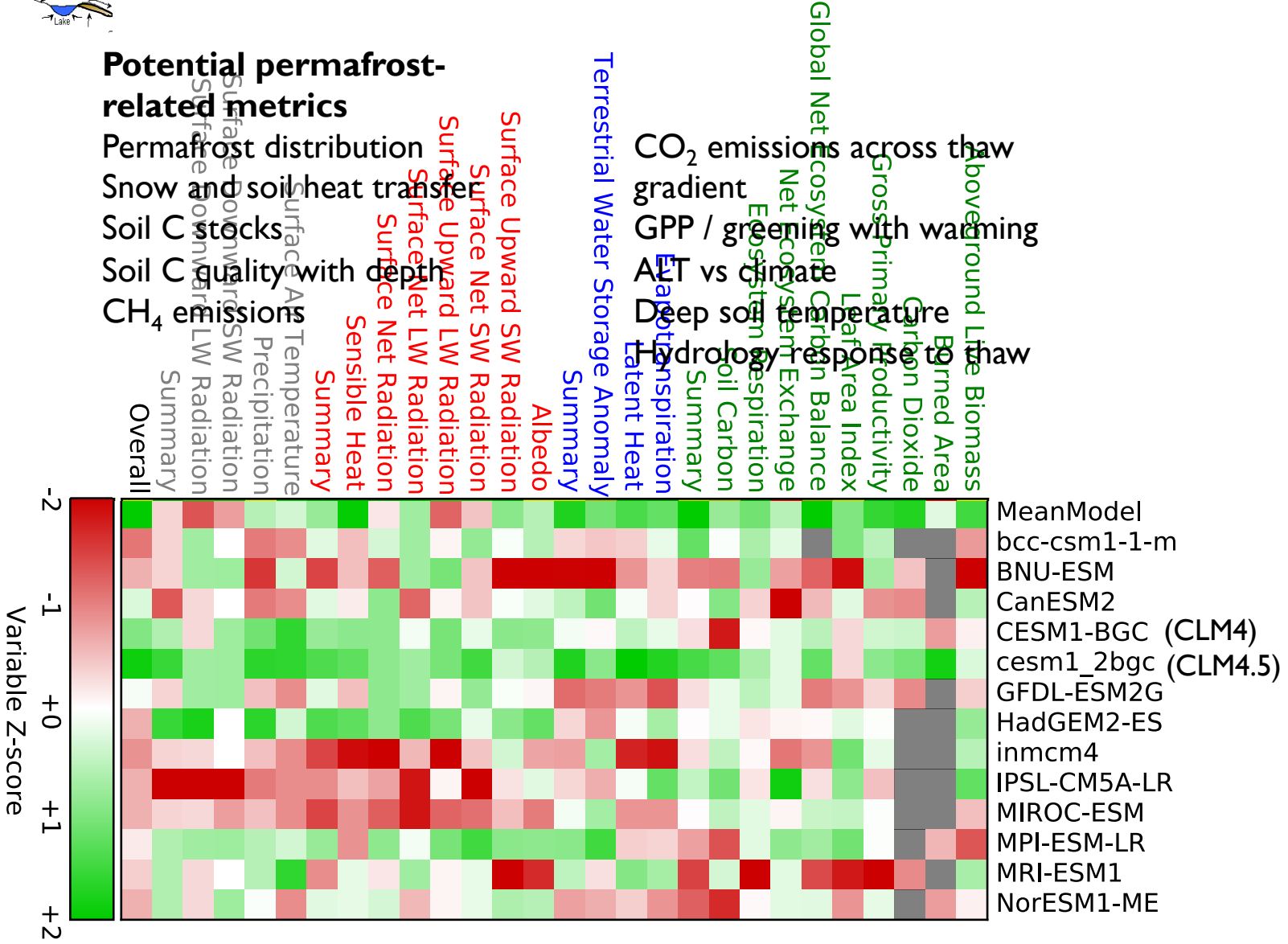
CO_2 emissions across thaw gradient

GPP / greening with warming

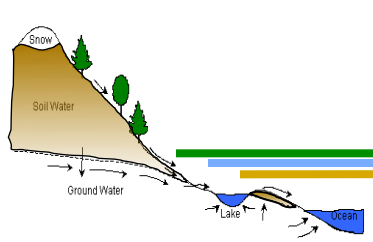
ALT vs climate

Deep soil temperature

Hydrology response to thaw

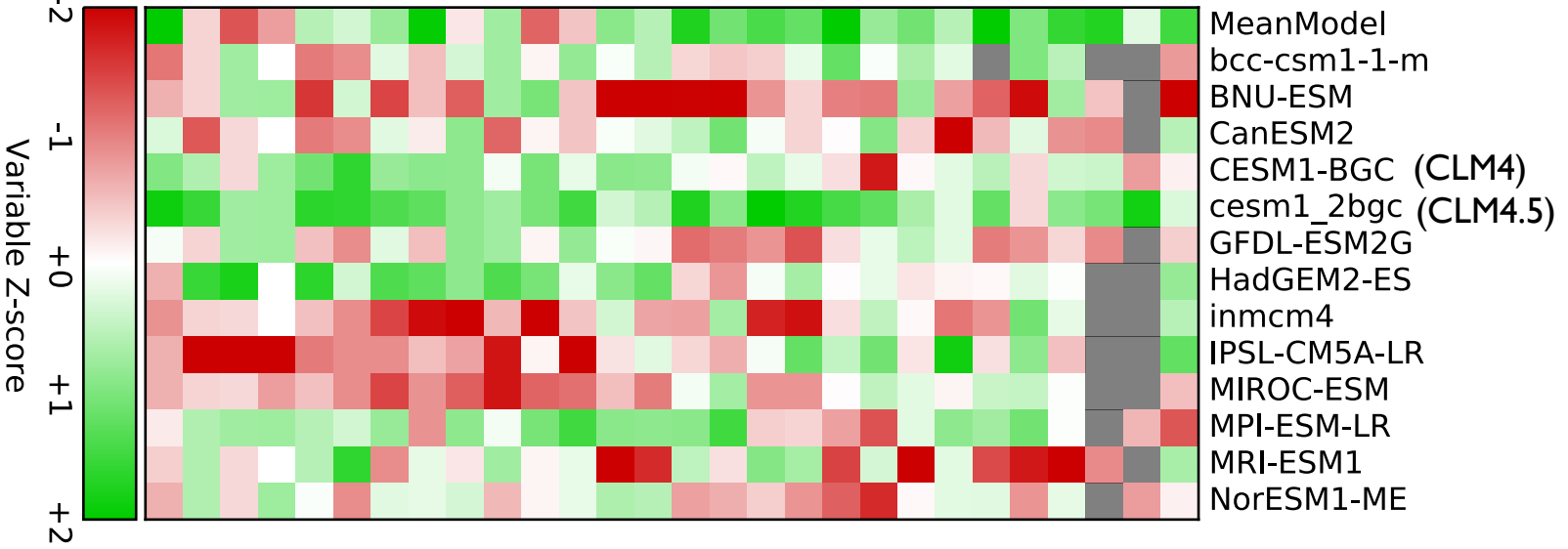


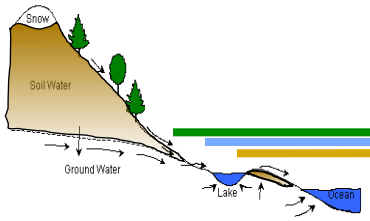
Permafrost-metrics package
potentially added to ILAMB



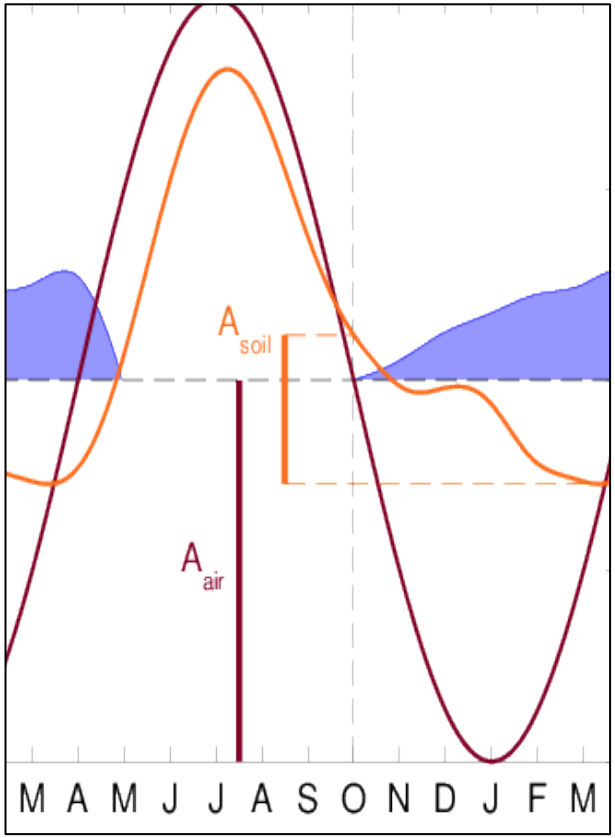
Permafrost-related metrics

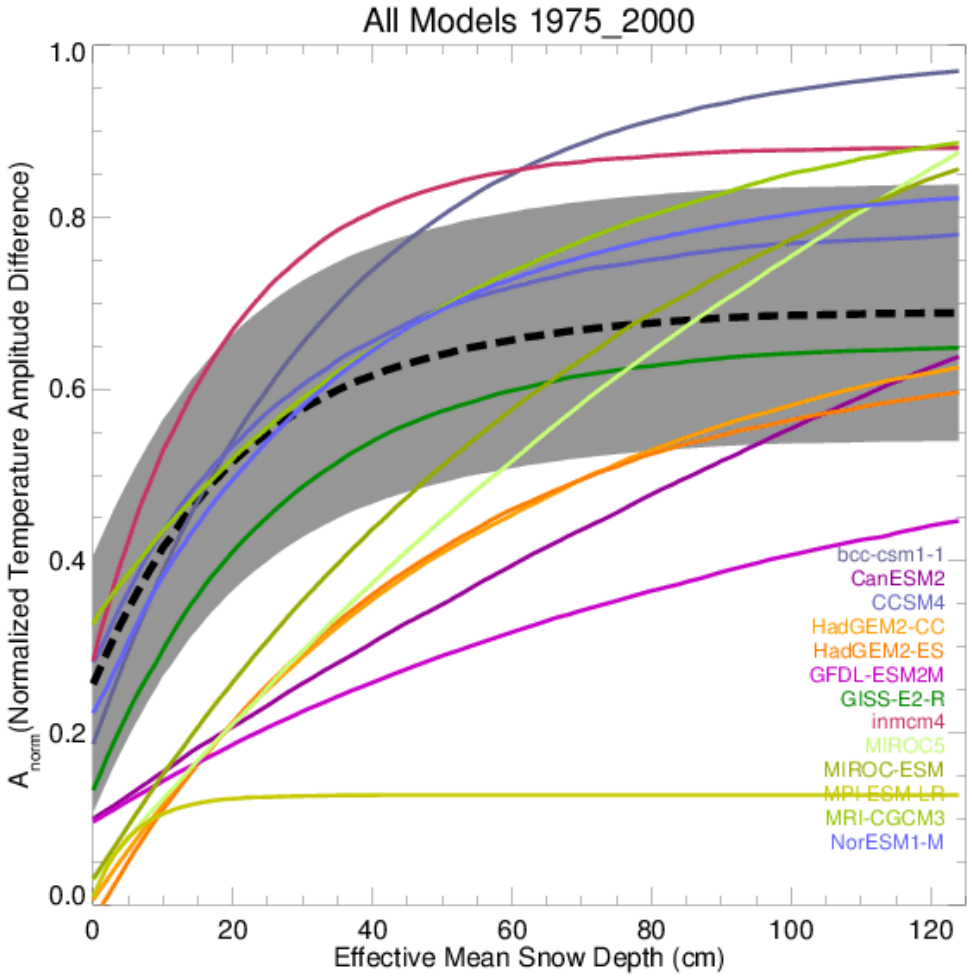
- Permafrost distribution
- Snow and soil heat transfer
- Deep soil temperature
- Soil C stocks
- Soil C quality with depth
- CH_4 emissions
- CO_2 emis across thaw gradient
- GPP / greening with warming
- ALT vs climate
- Hydrology response to thaw
- …





Process-oriented metrics: heat transfer through snow





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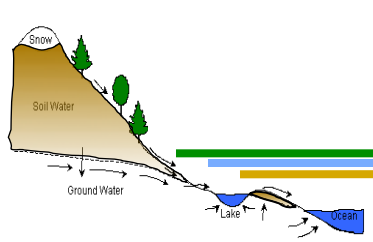
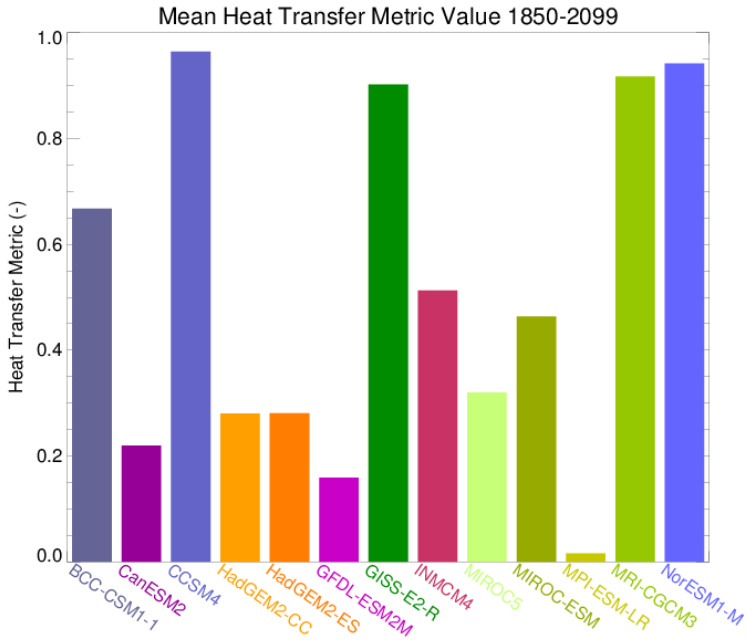
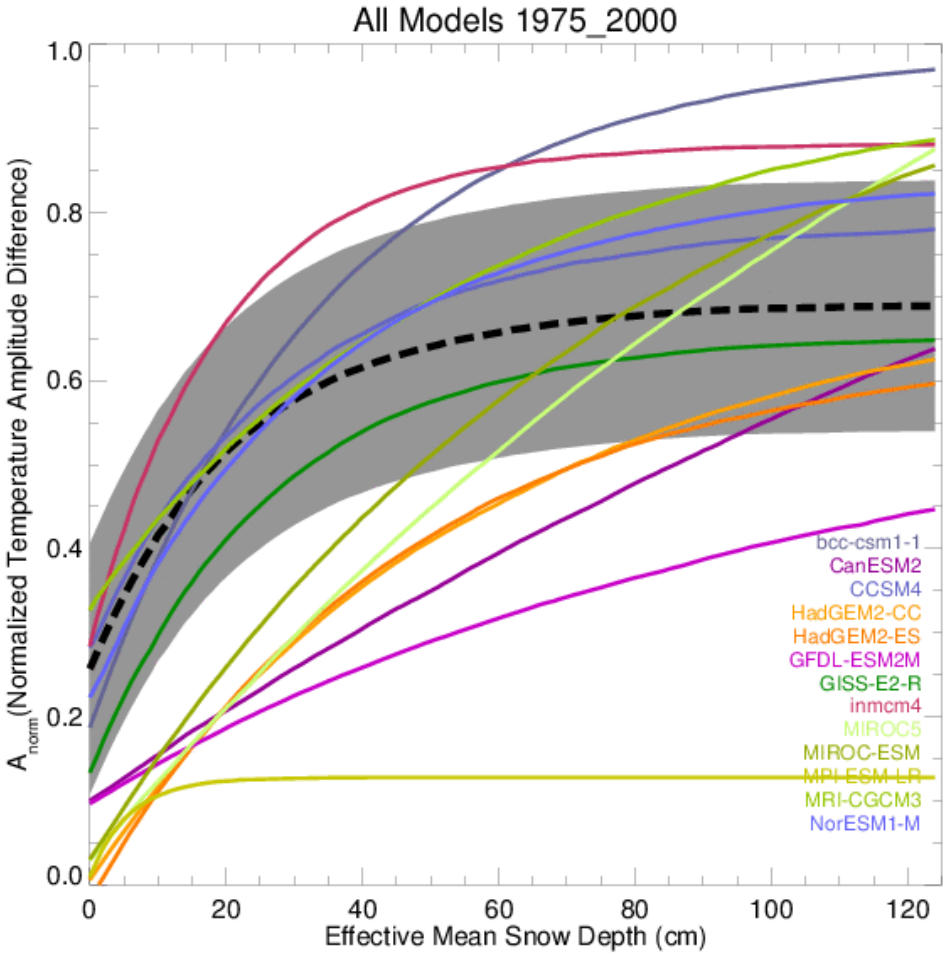
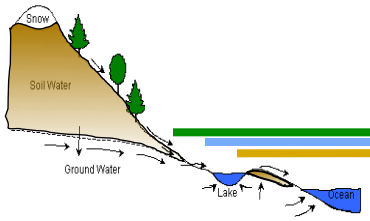


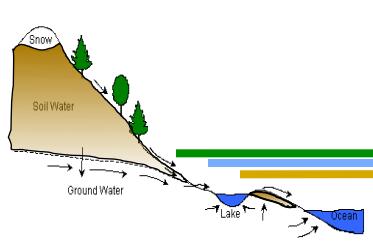






Summary

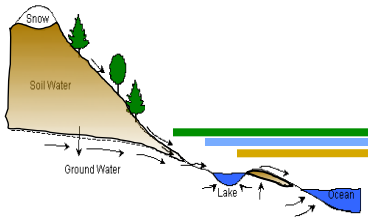
- ILAMB useful tool for model development and assessment
  - Along with tower site simulations, other diagnostics packages, scientific insight and intuition, case studies, etc.
- Provides quick and comprehensive comparison against growing set of observations and metrics
- Future development of ILAMB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



Utilizing ILAMB in model development and assessment process

Global Variables (Info for Weightings)

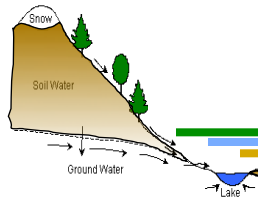
	CLM45bgc_2degGSWP3	CLM5bgc01_2degGSWP3
Aboveground Live Biomass	0.71	0.64
Burned Area	0.51	0.42
Gross Primary Productivity	0.75	0.72
Leaf Area Index	0.57	0.58
Global Net Ecosystem Carbon Balance	0.47	0.45
Net Ecosystem Exchange	0.49	0.51
Ecosystem Respiration	0.73	0.70
Soil Carbon	0.56	0.58
Summary	0.60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



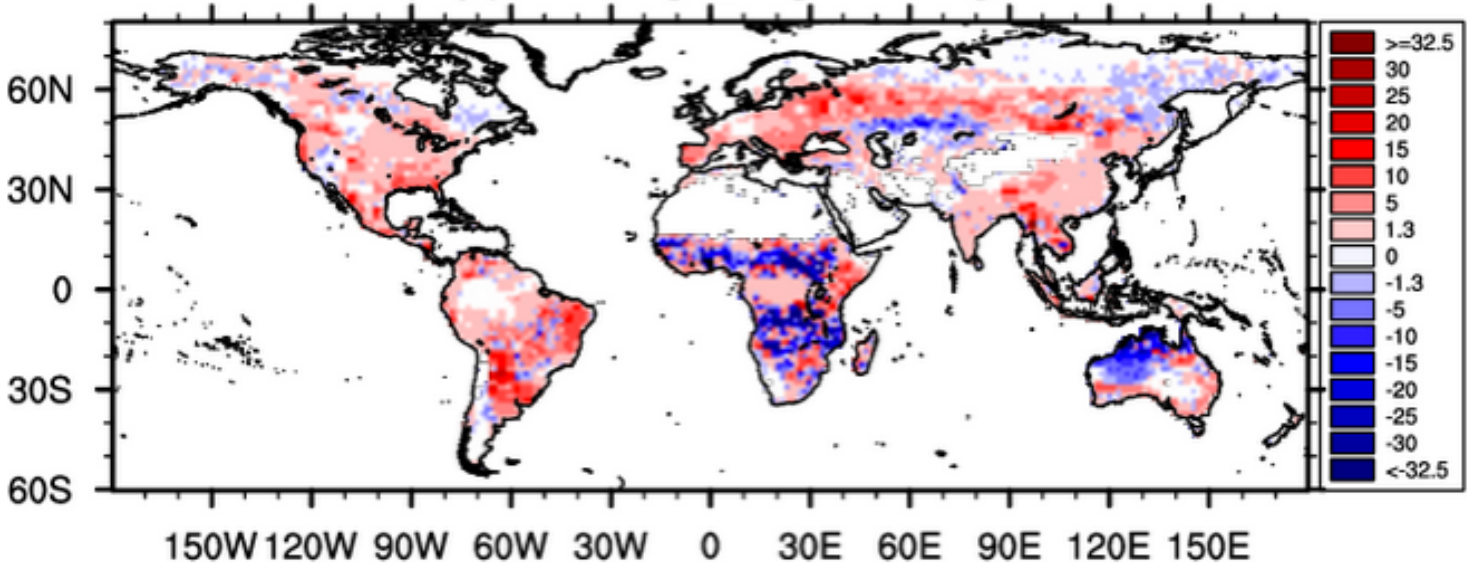
Diagnostic Summary for Burned Area: Model vs. GFED3

	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

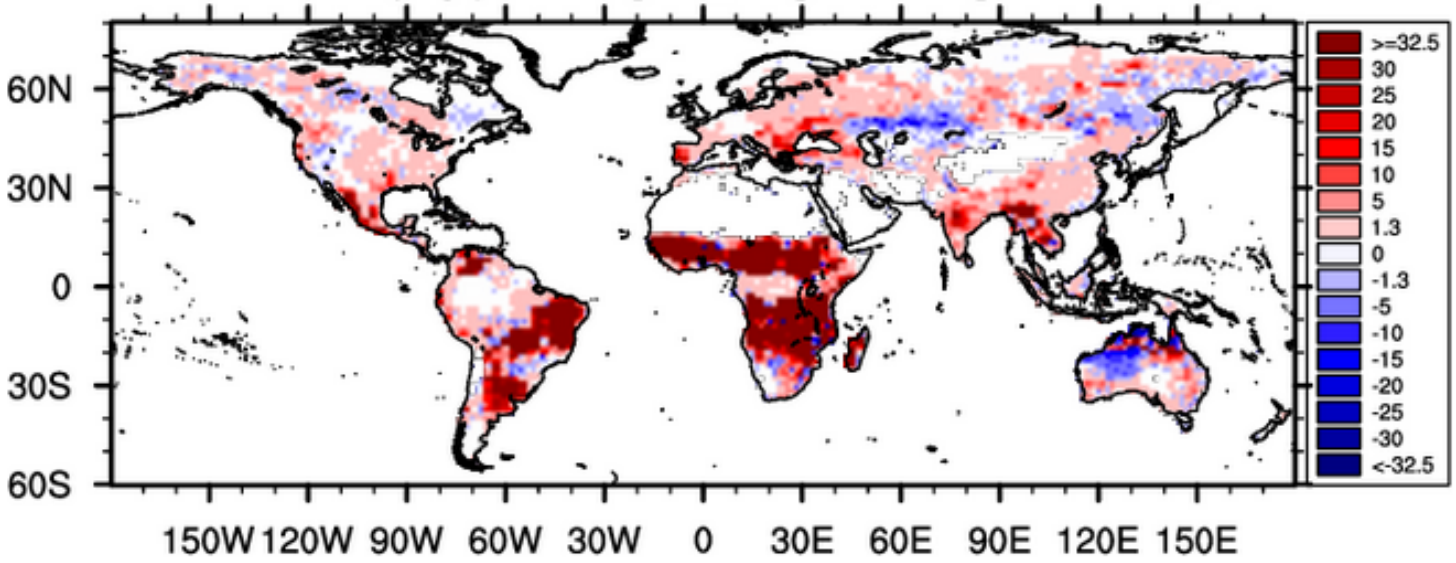
Notes: In calculating overall score, rmse score contributes double in comparison with all other scores.

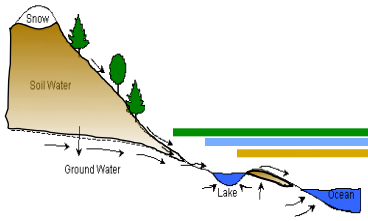


Bias for BURNTAREA (%/yr): CLM45bgc_2degGSWP3 against GFED3, 1997-2010



Bias for BURNTAREA (%/yr): CLM5bgc01_2degGSWP3 against GFED3, 1997-2010





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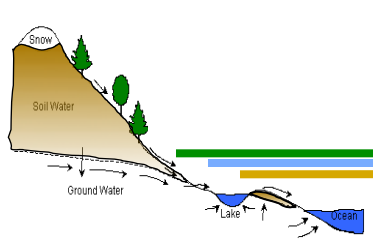
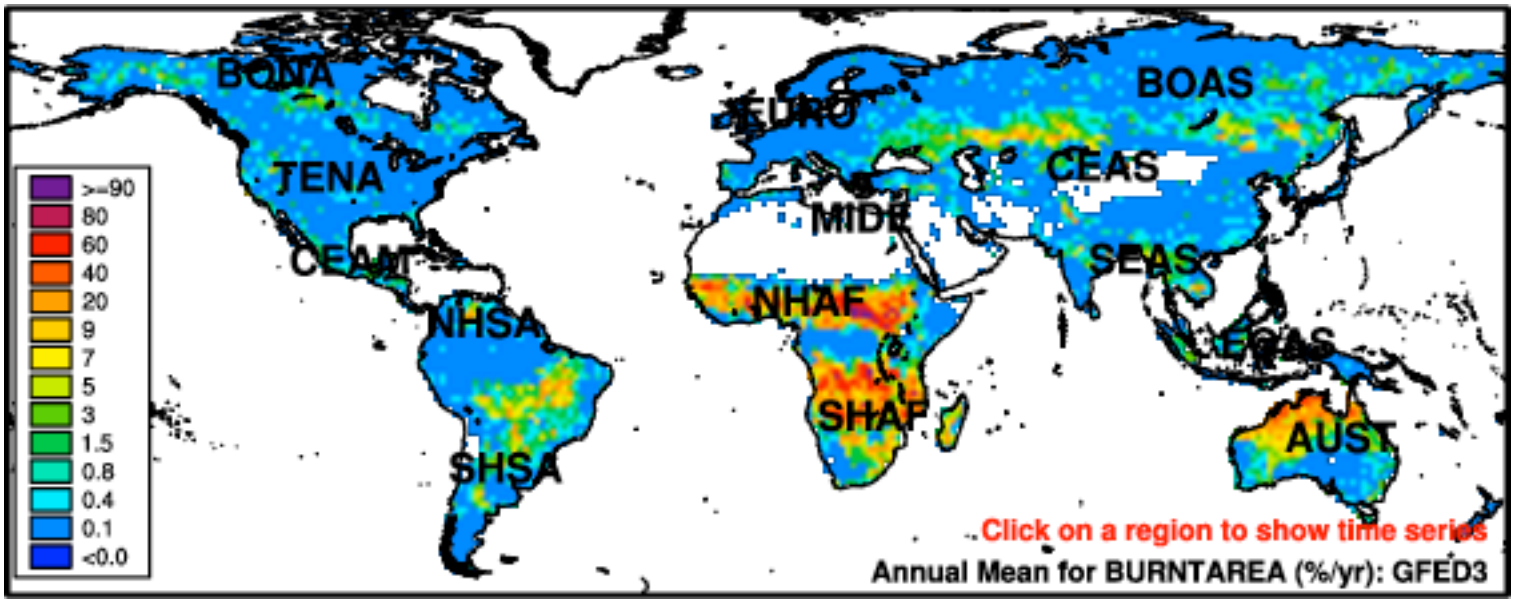
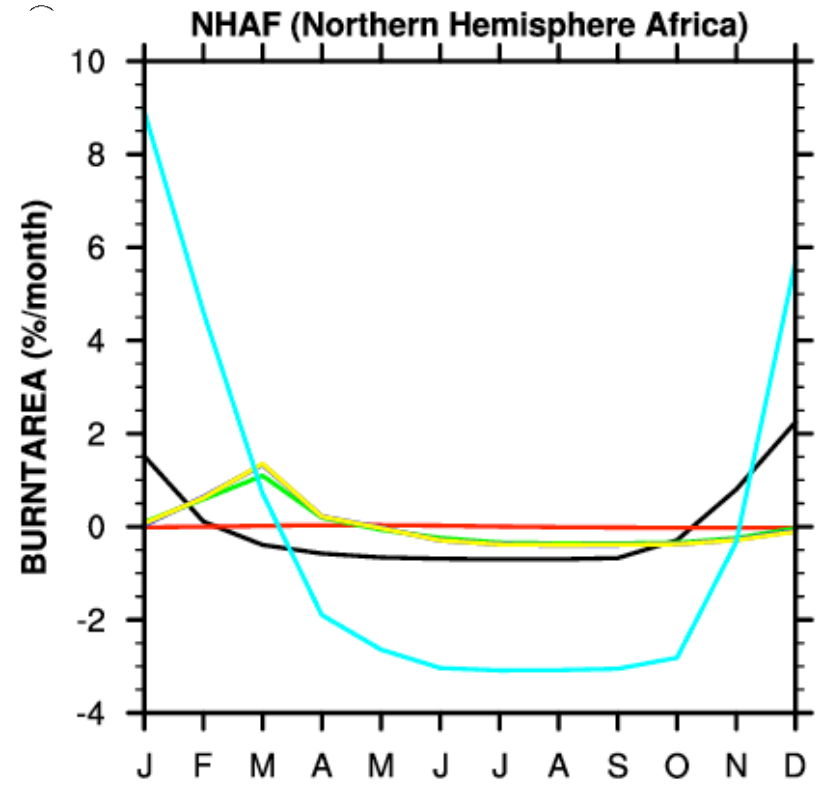
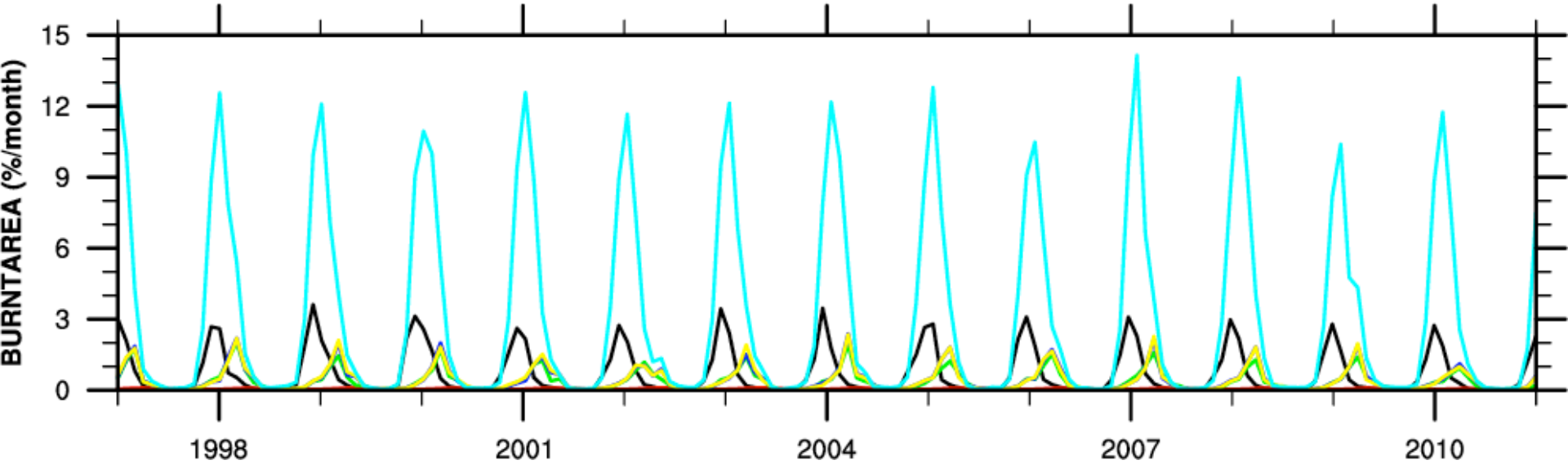
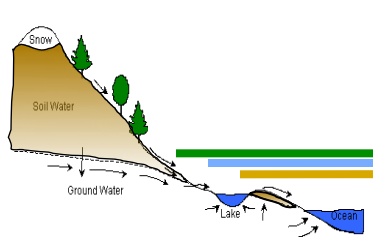

Snow
Soil Water
Ground Water
Lake
Ocean


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

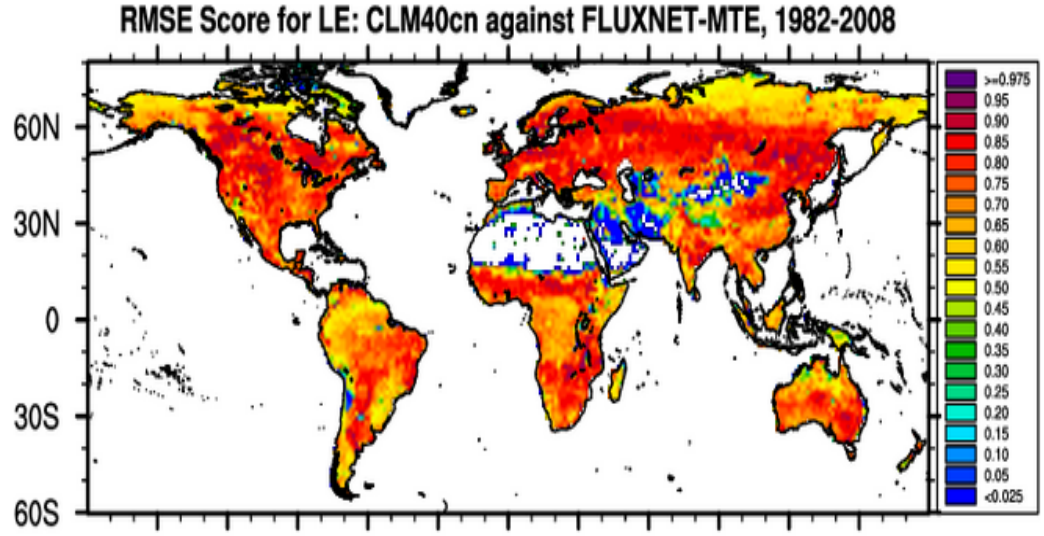


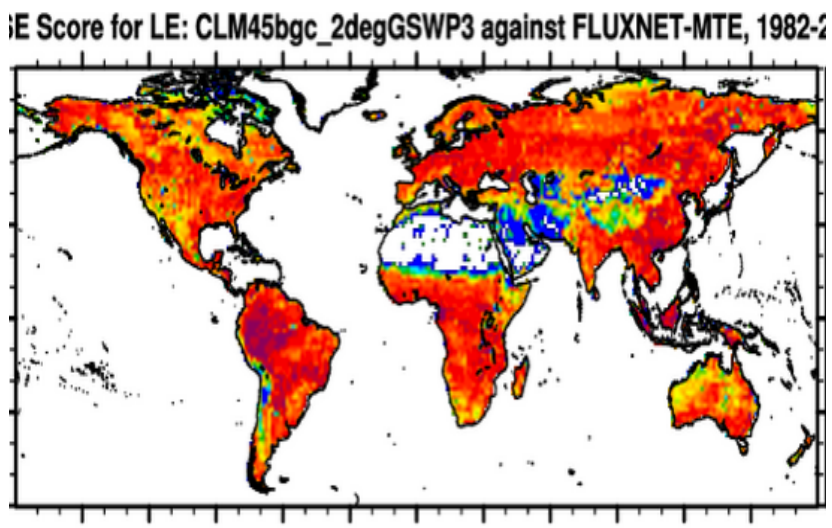
Model	Annual	Bias	RMSE
GFED3	0.71	-999.00	-999.00
CLM40cn	0.06	-0.65	1.19
CLM45bgc_CRUNCEP	0.38	-0.33	1.09
CLM45bgc_GSWP3	0.44	-0.27	1.13
CLM45bgc_2degGSWP3	0.45	-0.26	1.13
CLM5bgc01_2degGSWP3	3.18	2.47	4.10

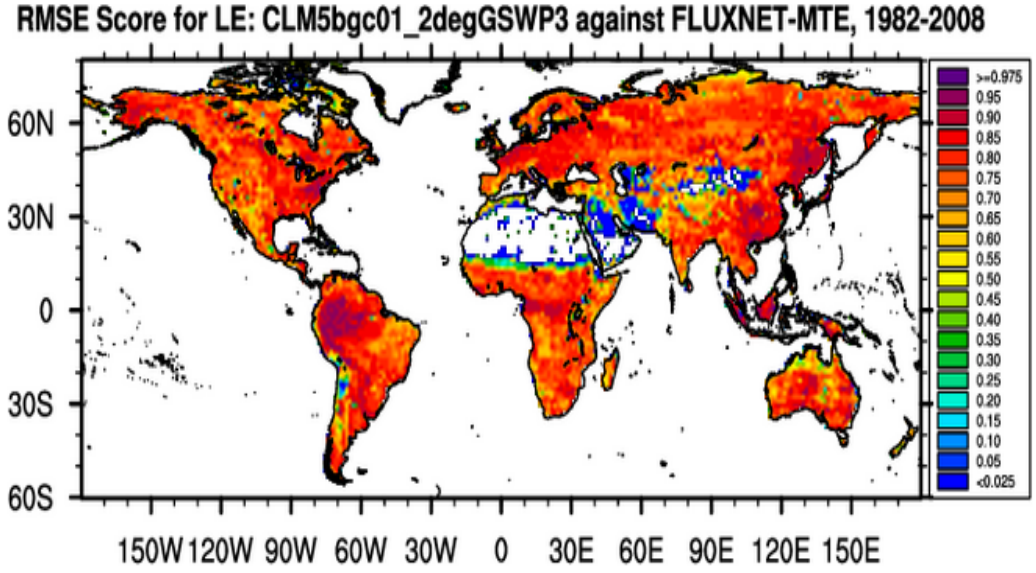


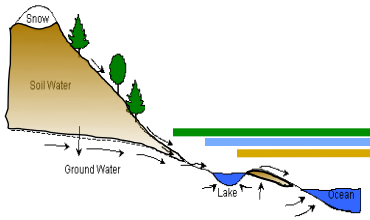


RMSE Score for Latent Heat: FLUXNET-MTE

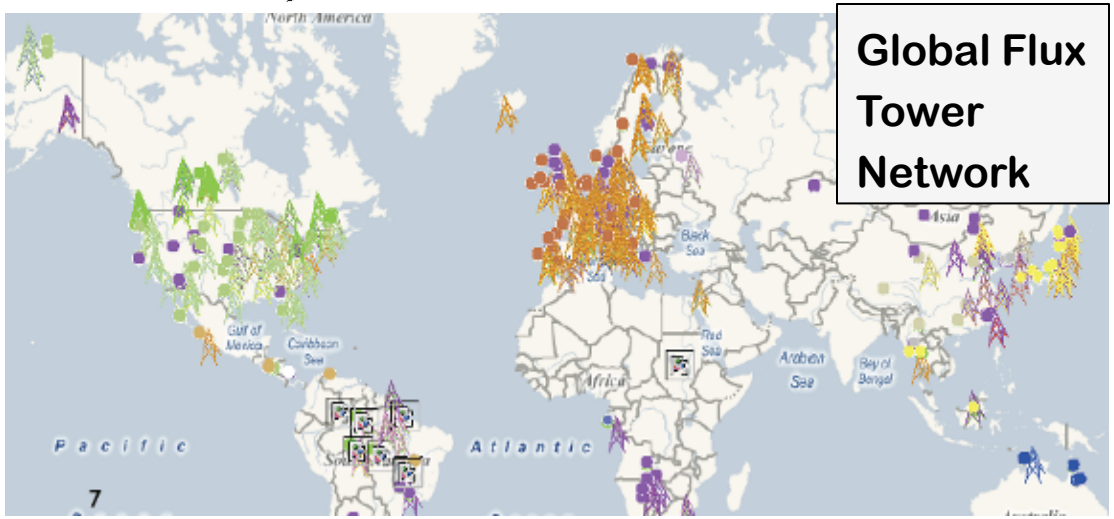




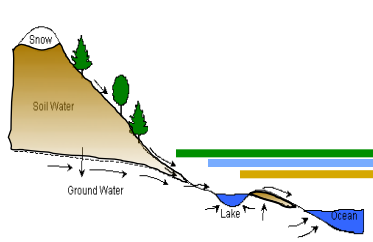




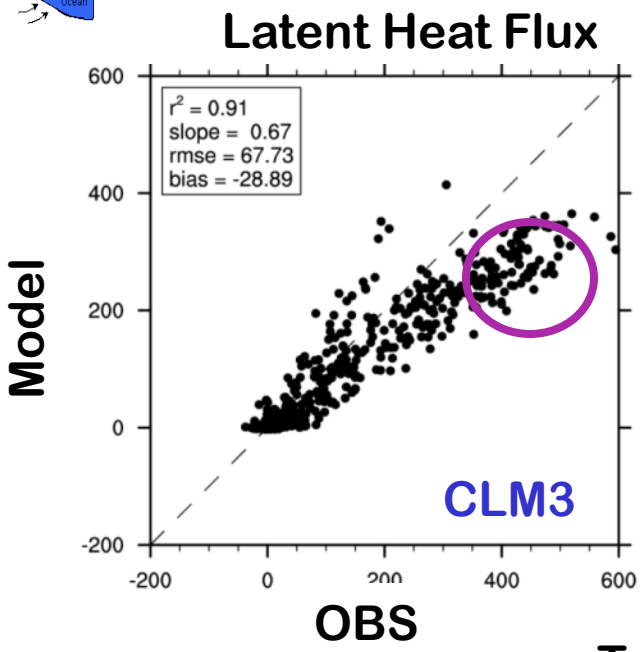
Evaluating and Improving the model with Tower Flux data

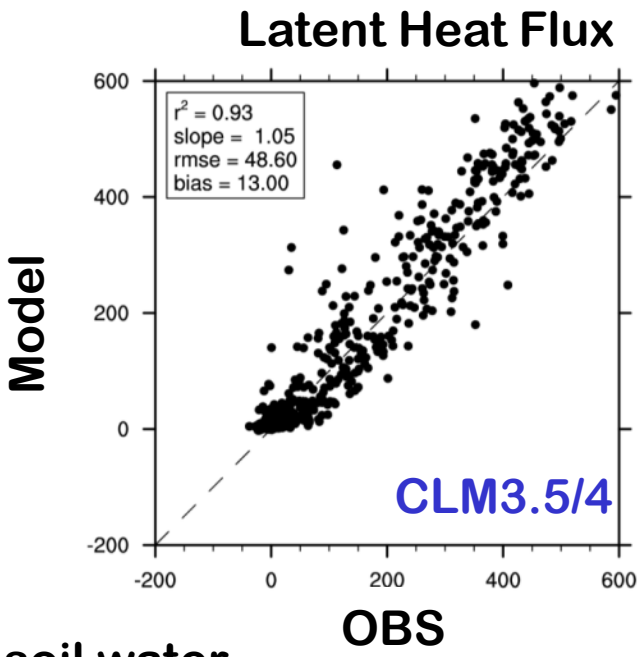


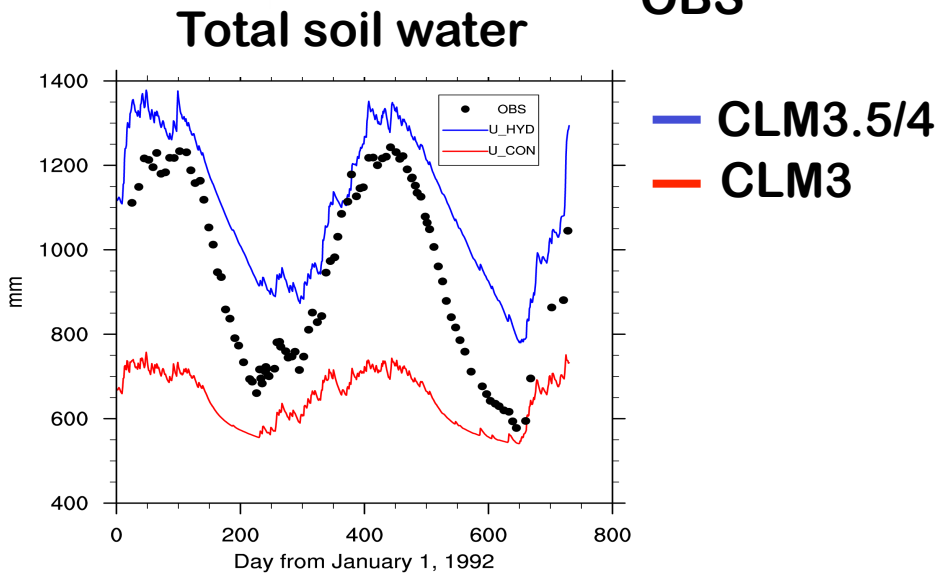
Global Flux Tower Network



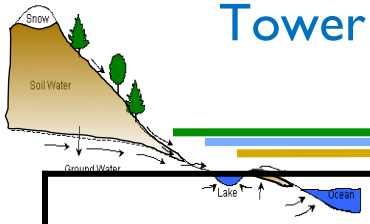
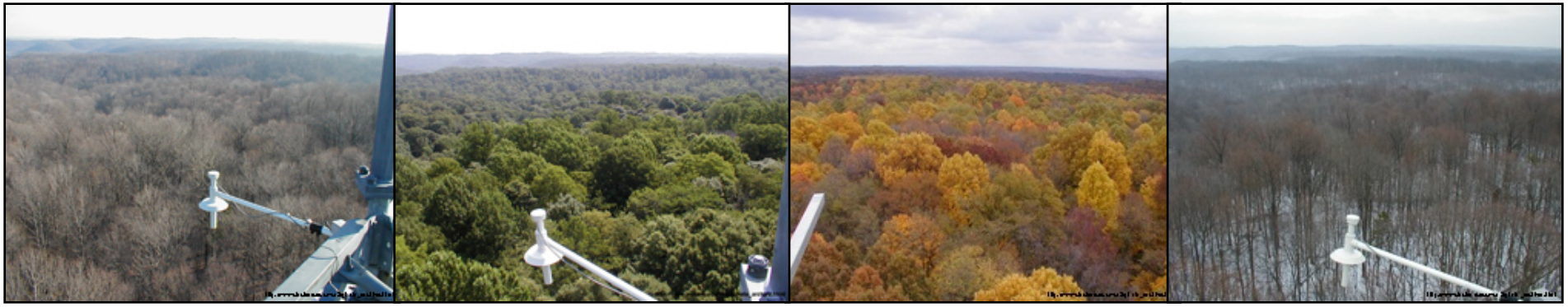
Abracos tower site (Amazon)







Tower flux statistics (15 sites incl. tropical, boreal, mediterannean, alpine, temperate; hourly)



	Latent Heat Flux		Sensible Heat Flux	
	r	RMSE (W/m^2)	r	RMSE (W/m^2)
CLM3	0.54	72	0.73	91
CLM3.5	0.80	50	0.79	65
CLM4SP	0.80	48	0.84	58