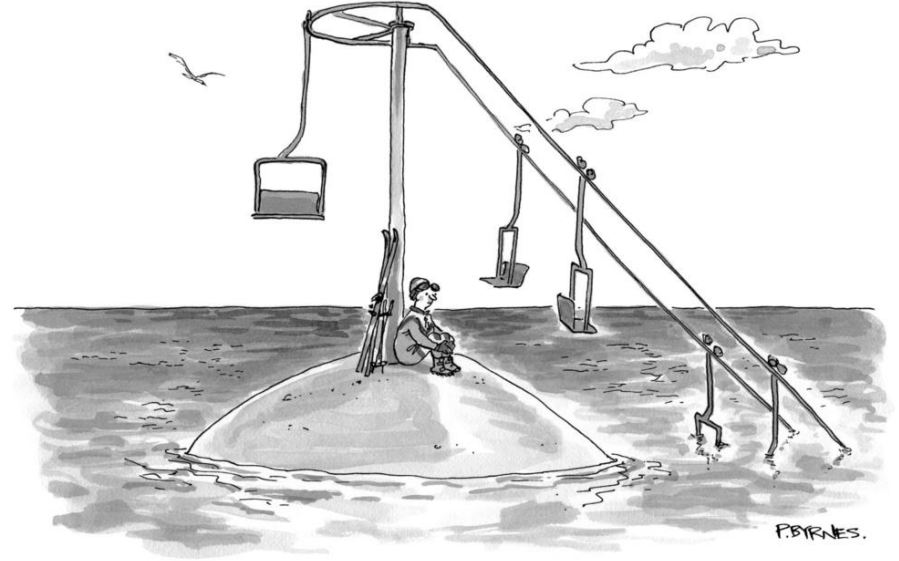# State of CLM

## David Lawrence and the LMWG

What's New for CLM5

Hydrology: dry surface layer, variable soil depth with deeper (8.5m) max depth, revised GW and canopy interception, adaptive time-stepping, increased soil layer resolution

Snow: canopy snow, wind and T effects on snow dens., firn model (12 layers), glacier MEC

Rivers: MOSART (hillslope → tributary → main channel)

Nitrogen: New C-N coupling (flexible leaf C:N ratio, leaf N optimization, C cost for N)

Vegetation: plant hydraulics and hydraulic redist, deep roots tropical trees, Medlyn stomatal cond, Ecosystem Demography (FATES), prognostic roots, ozone damage

Fire: updates, trace gas and aerosol emissions

Crops: global crop model with transient irrigation and fertilization (9 crop types), grain product pool, revised irrigation scheme

Carbon: revisions to carbon allocation and soil carbon decomposition

Land cover/use: dynamic landunits, updated PFT-distribution, wood harvest by mass

Isotopes: carbon and water isotope enabled
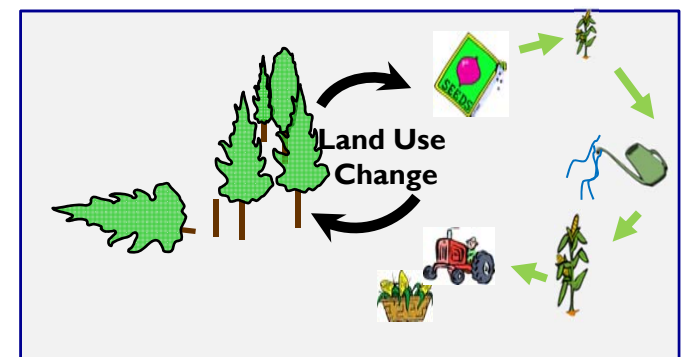
CLM5 default configuration
CLM5 optional feature

Rosie Fisher   Erik Kluzek
Keith Oleson   Bill Sacks
Sean Swenson   Peter Lawrence
Will Wieder   Yaqiong Lu
Charlie Koven   Fang Li
Danica Lombardozzi   Daniel Kennedy
Ben Sanderson

More than 50 scientists and software engineers from 16 different institutions involved in development of CLM5

CLM4.5   June 2013 (CESM1.2)

- vertically-resolved soil BGC and revised nitrification-denitrification, N-fixation

- cold region hydrology updates, incl perched water table

- new snow cover fraction parameterization

- revised canopy radiation scheme

- co-limitation and temperature acclimation on photosynthesis

- updated lake model

- multiple urban density classes

- updated fire model with natural and anthropogenic triggers and suppression

- BVOC updated to MEGAN2.1

- CH_4 emissions

- prognostic wetlands and flooding (optional)

- Conversion of glacier snow-capped snow from ice to liquid

  - Resolves unphysical sea ice build up (10's of m thick) in closed ocean channels

- Nitrogen deposition

  - Prescribed annually in CLM4/4.5

  - Prescribed monthly or instantaneous from the coupler

- Revised inundation inversion parameters

- Fixed processing error with soil albedos

- Isotope bugs with crop model resolved (?)

Land-only simulations for release and CLM5 documentation papers*

Forcing	CLM4			CLM4.5			CLM5			
	CN	SP	+N	BGC	SP	+N	BGC crop	SP	+N	no LULCC
GSWP3v1	✓		✓	✓		✓	✓		✓	✓
CRUNCEPv7	✓			✓			✓			

* Note that these simulations do not include new N-deposition and aerosol deposition that will be generated from WACCM runs

CLM5 documentation papers for CESM2 special issue

CLM5 model overview and technical description	Lawrence et al.	JAMES
CLM5 C-N coupling	Fisher et al.	JGR-Biogeosciences
Plant Hydraulic Stress	Kennedy et al.	JAMES
CLM5 Hydrology	Swenson et al.	WRR
Land use and land cover change	Lawrence et al.	JAMES
CLM5 Crop	Lombardozzi, Lu et al.	JGR-Biogeosciences
Stomatal conductance	Bonan et al.	JGR-Biogeosciences
Urban model	Oleson et al.	JAMES
N and CO_2 fertilization	Wieder et al.	GBC
Land-atmosphere interactions	Tawfik et al.	JAMES

Assessment in ILAMB

Metrics for RMSE, bias, spatial pattern corr, interannual variability, funct relationships

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

Assessment of CLM5 (land-only) with ILAMB

ILAMB = Land diagnostics package (25 variables, 60 datasets) with metrics for RMSE, bias, spatial pattern corr, interannual variability, funct relationships

-2 -1 +0 +1 +2
worse model — better model

CLM4 CLM4.5 CLM5

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
Albedo
Surface Upward SW Radiation
Surface Net SW Radiation
Surface Upward LW Radiation
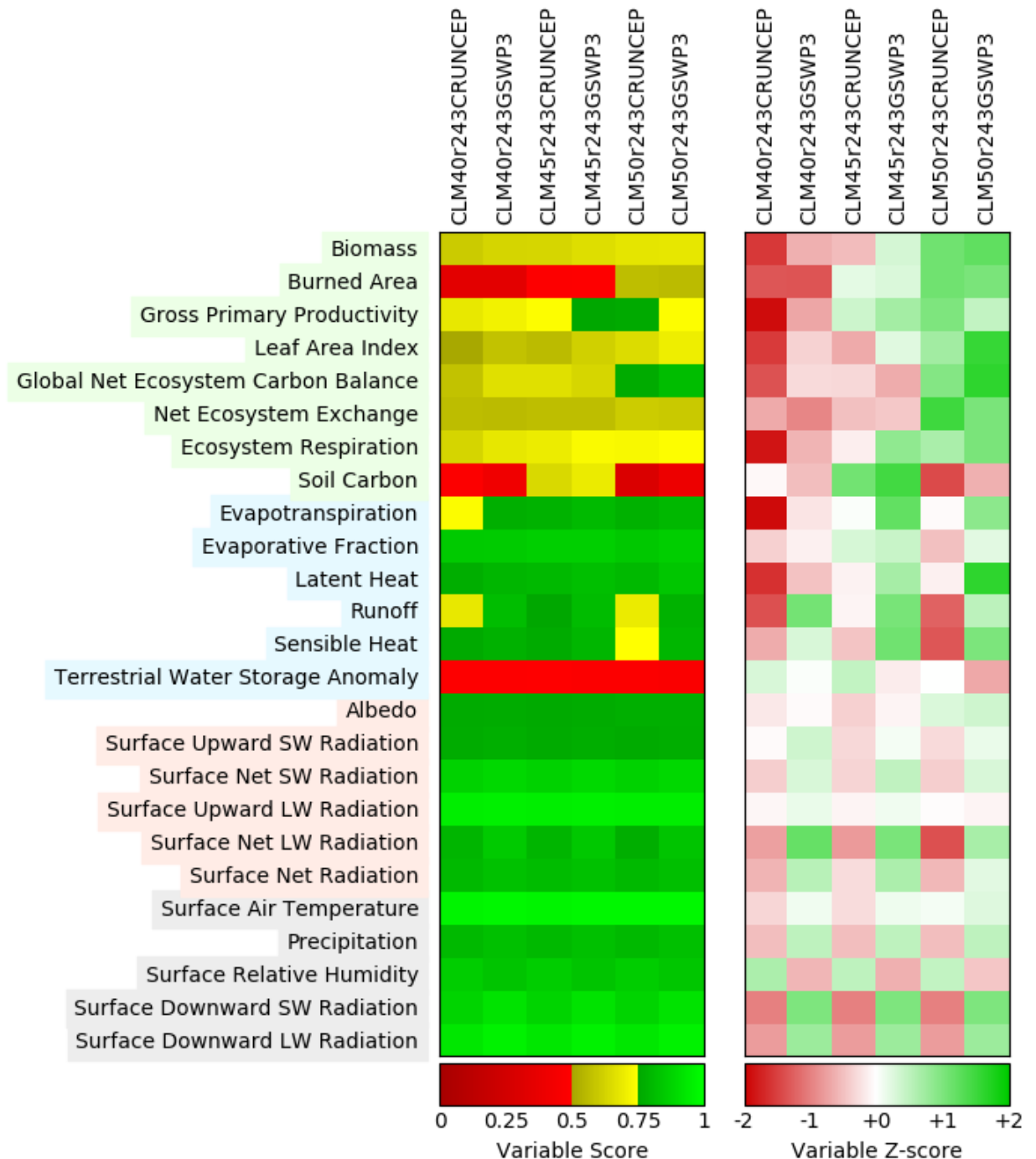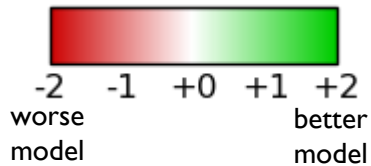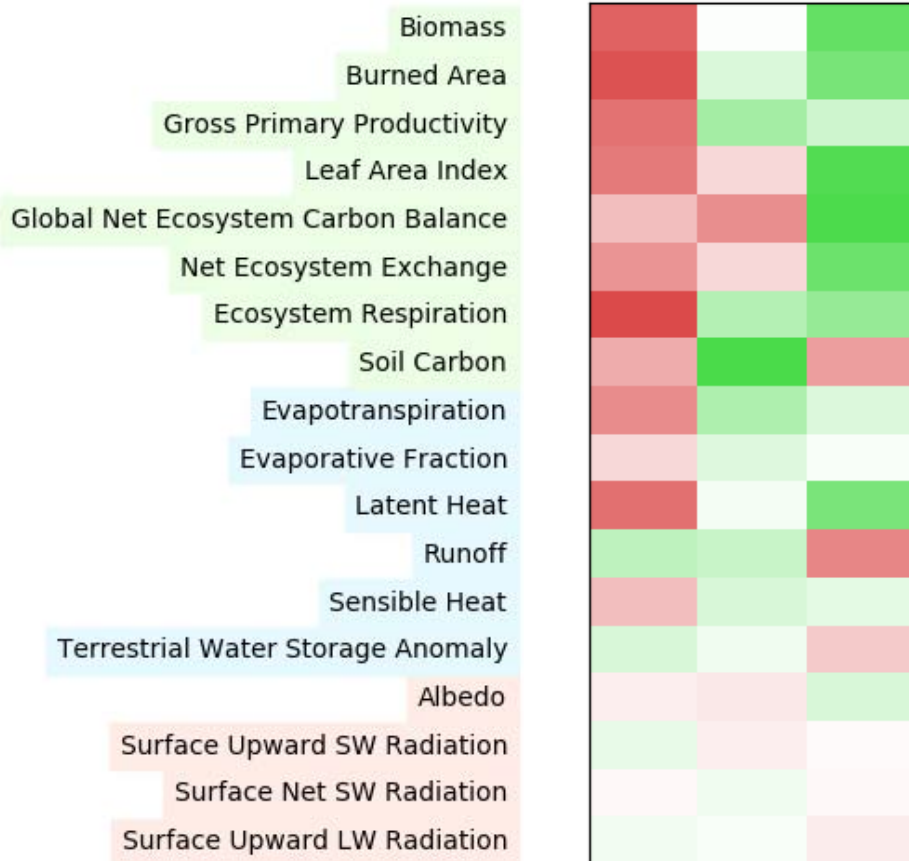
- Improvements in mechanistic treatment of hydrology, ecology, and land use

- Many more moving parts

- Simulation improved even with enhanced complexity

- Obs datasets not always self-consistent (improved LH, degraded runoff?)

Soil carbon turnover time

Observation-based estimate
(1350 Pg C)
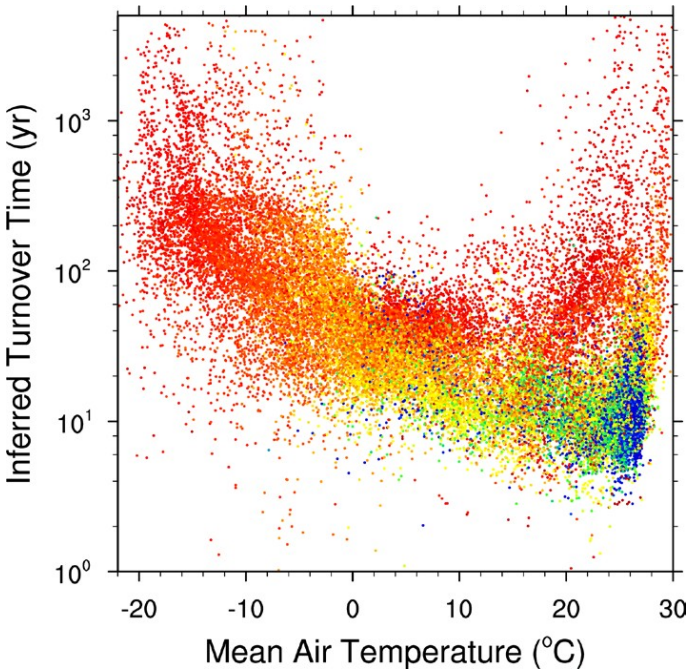
CLM5 (1250 PgC)
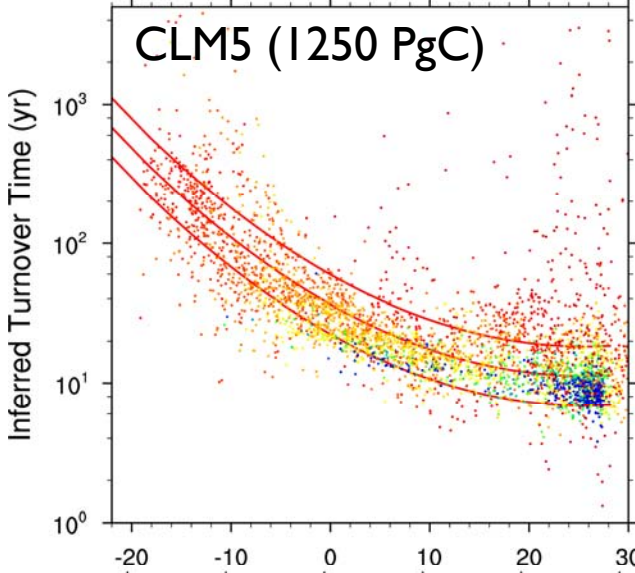
CLM4 (500 PgC)
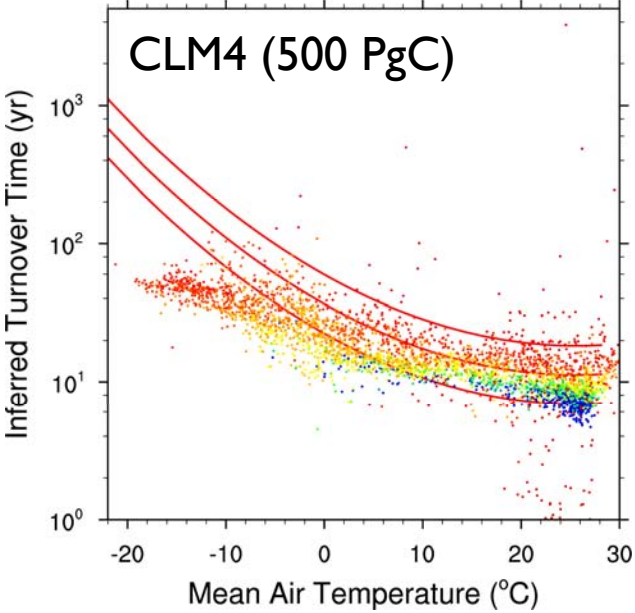
Koven et al., *in review*

Precipitation (mm/yr)

Amazon river discharge
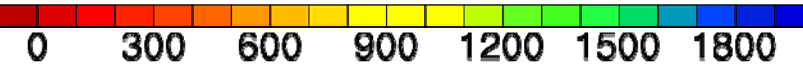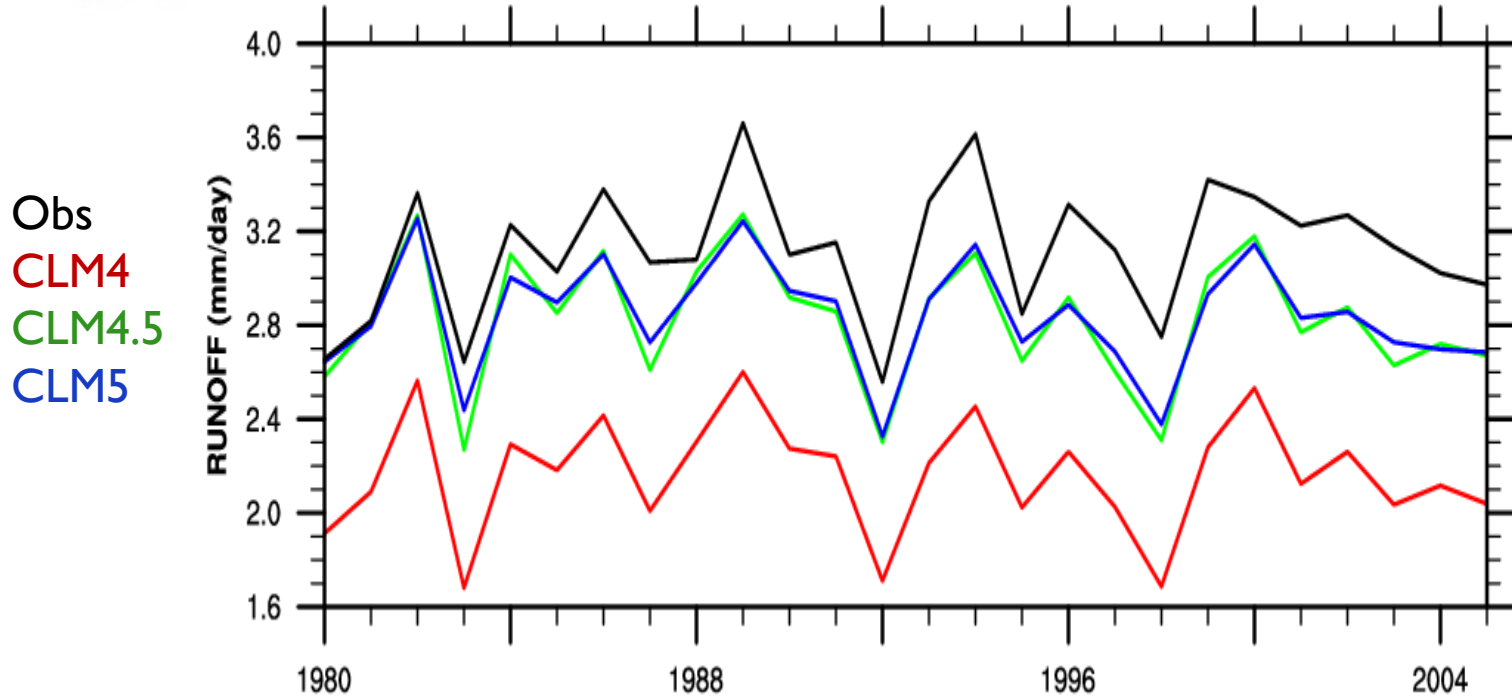
Accumulated land carbon fluxes

CLM4 CRUNCEPv7
CLM5 CRUNCEPv7
CLM4 GSWP3v1
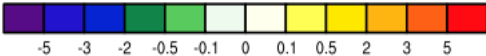CLM5 GSWP3v1
Obs (Hoffman)
CLM4.5 GSWP3v1
CLM4.5 CRUNCEPv7
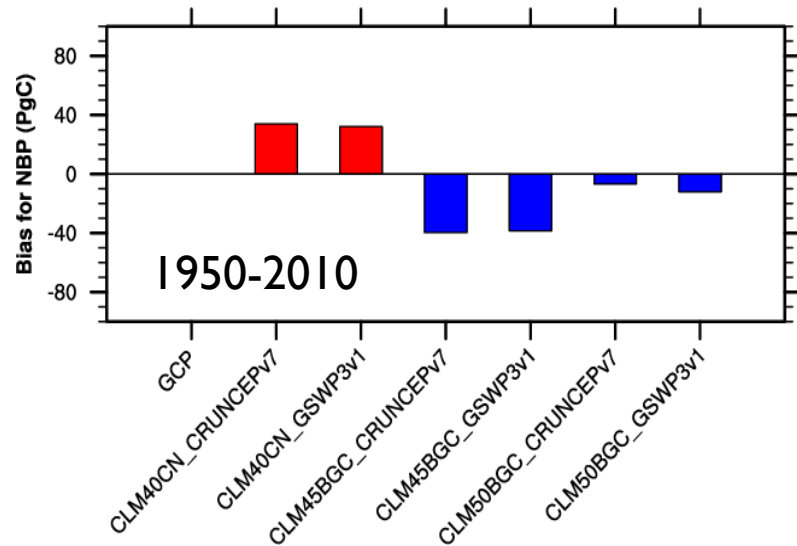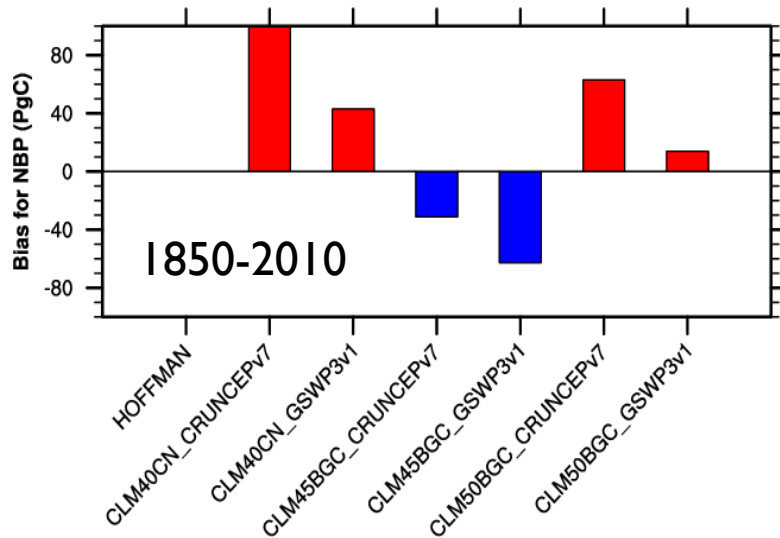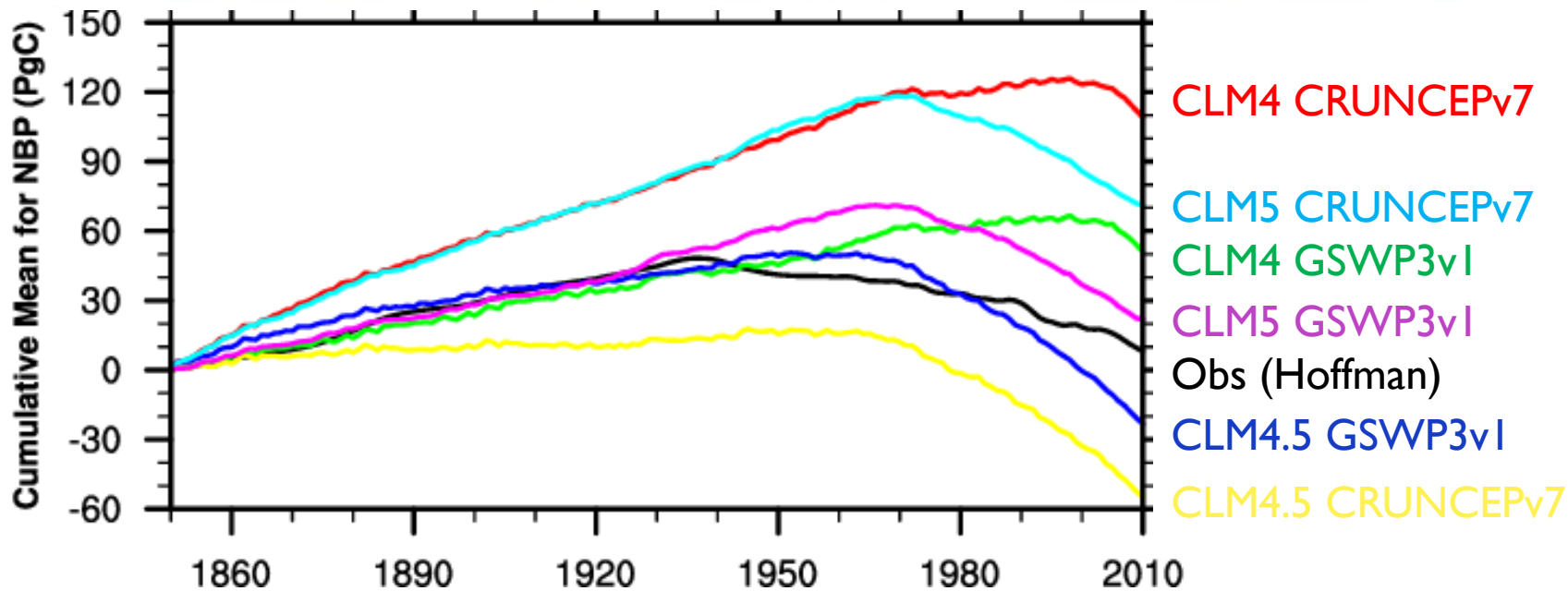
LAI bias by PFT

CLM4CN

rmsd= 2.7
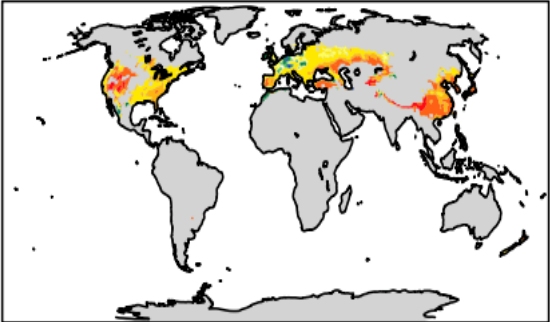
NL Evergreen Temperate Tree

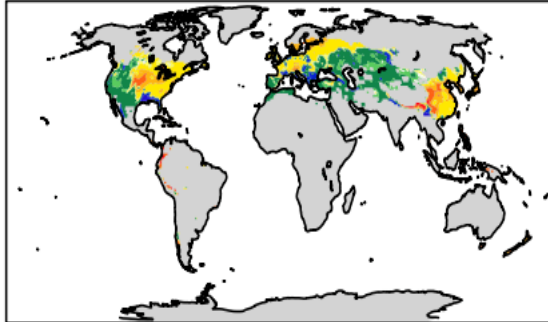-5 -3 -2 -0.5 -0.1 0 0.1 0.5 2 3 5

rmsd= 5.1

C4 grass

-5 -3 -2 -0.5 -0.1 0 0.1 0.5 2 3 5

CLM4.5BGC
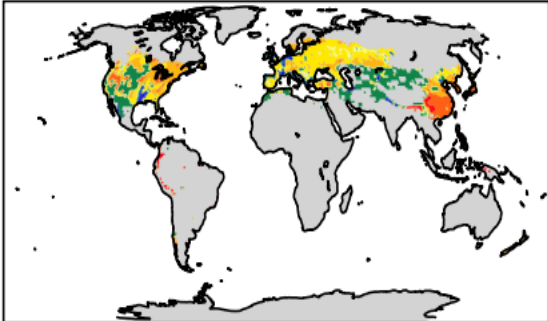
rmsd= 2.6

rmsd= 5.9

CLM5BGCcrop

rmsd= 2.1
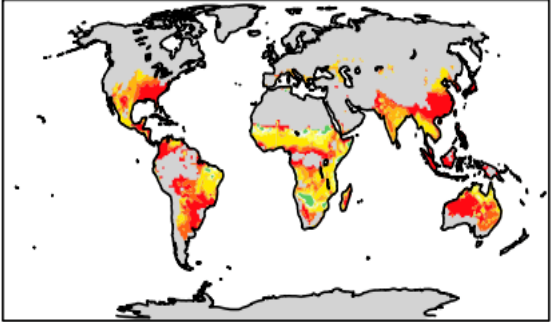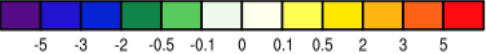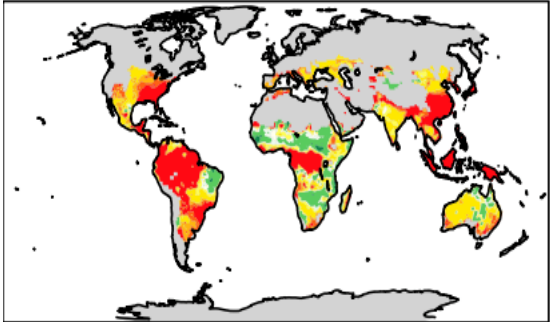
rmsd= 1.2
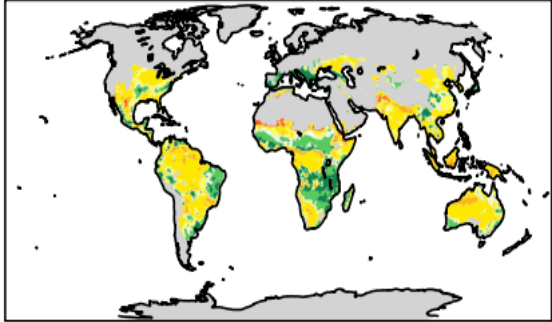
LAI bias by PFT

Annual Mean TLAI RMSD (1991-2010)

Several PFT / landunit level vars archived by default

Legend: CLM50GSWP3 (orange), CLM45GSWP3 (purple), CLM40GSWP3 (red)
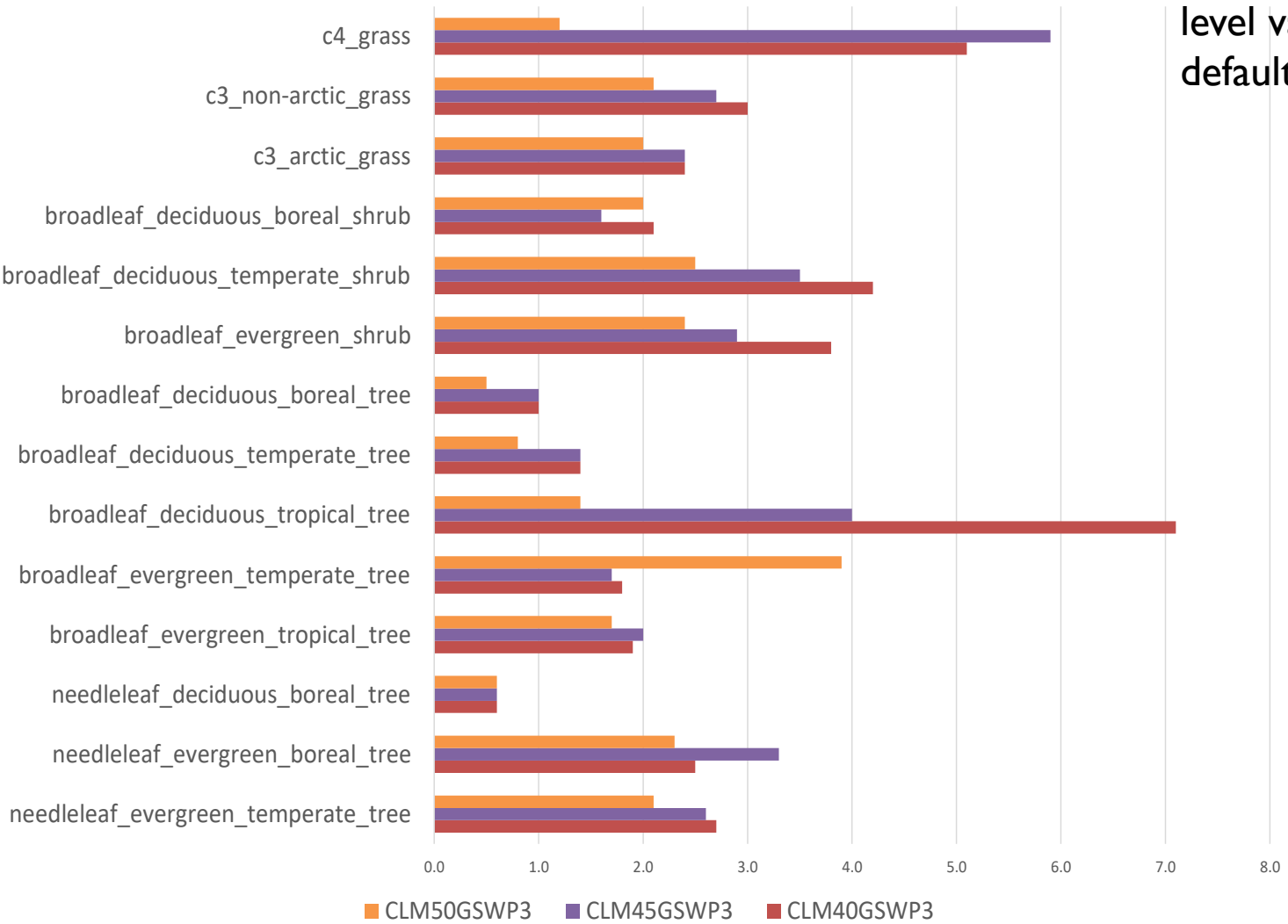
Gross primary production vs Evapotranspiration

Permafrost Distribution
~15-16 million km² (obs)

CLM4.5 CRUNCEP

CLM4.5 GSWP3

Max ALT 2000: 19.6

Max ALT 2000: 14.5
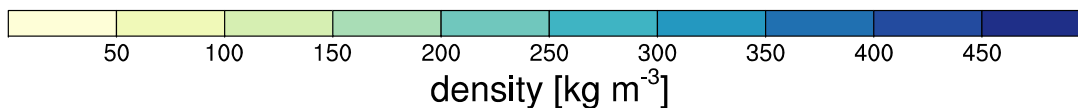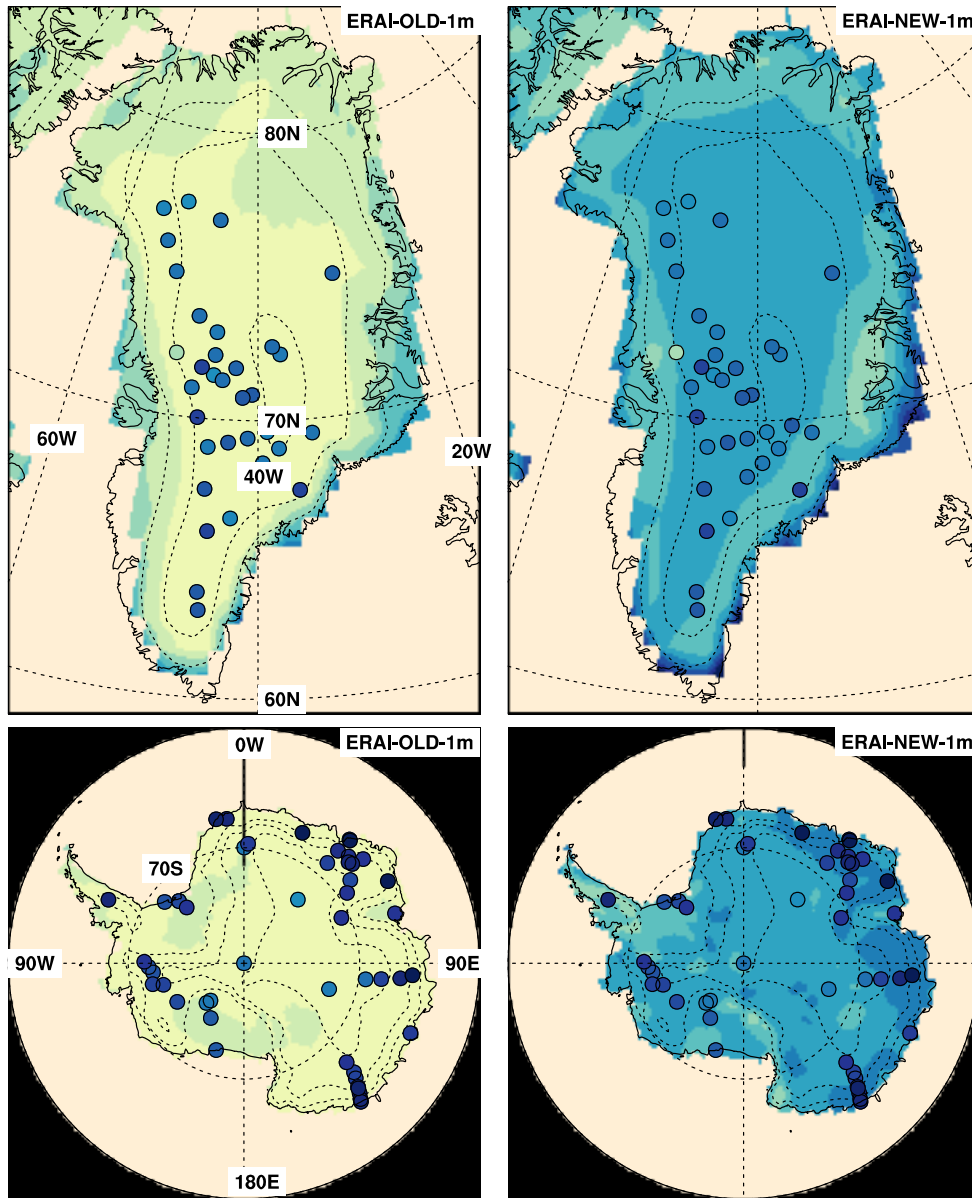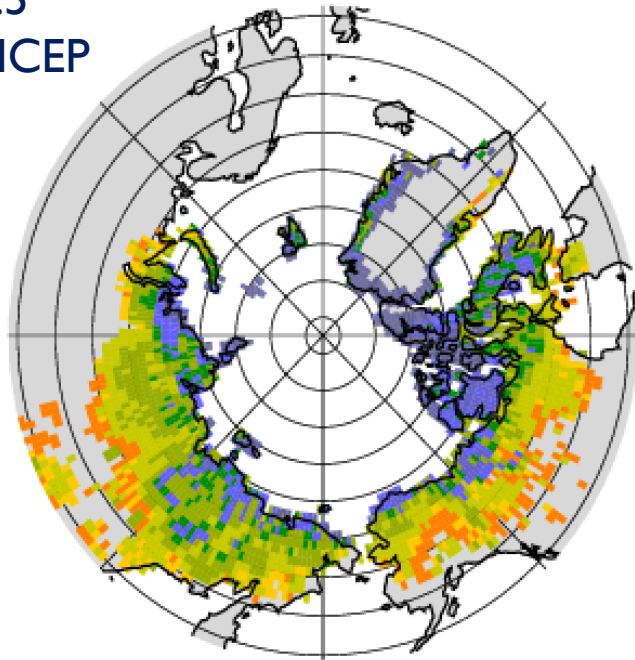
Slater et al. 2017

CLM5 snow density

Revised fresh snow density with improved temperature and wind effects
Lead to increased and more realistic snow density and less thermal insulation

density [kg m^{-3}]
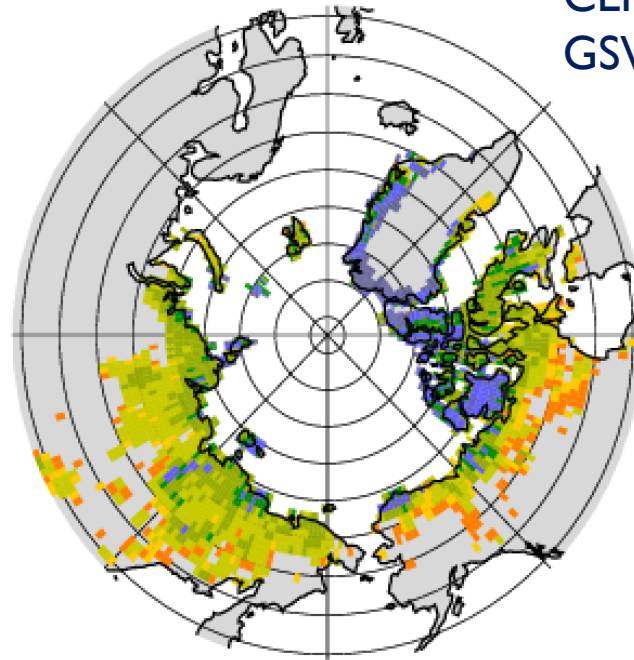
Figure courtesy L. Van Kampenhout

Permafrost Distribution
~15-16 million km² (obs)

CLM4.5 CRUNCEP — Max ALT 2000: 19.6

CLM4.5 GSWP3 — Max ALT 2000: 14.5

CLM5 CRUNCEP — Max ALT 2000: 18.1

CLM5 GSWP3 — Max ALT 2000: 15.1

m
2.50
2.00
1.50
1.00
0.75
0.50
0.25
0.000

FAO Rice

CLM5 Rice

Global Harvested Food

*UNFAO Equiv Crops

clm50_n18clm5r229 food

Millions of Tonnes

6000

5000

4000

3000

2000

1000

0

1850   1870   1890   1910   1930   1950   1970   1990
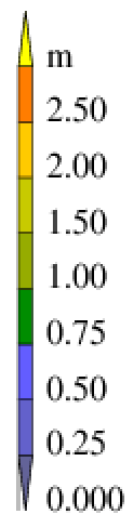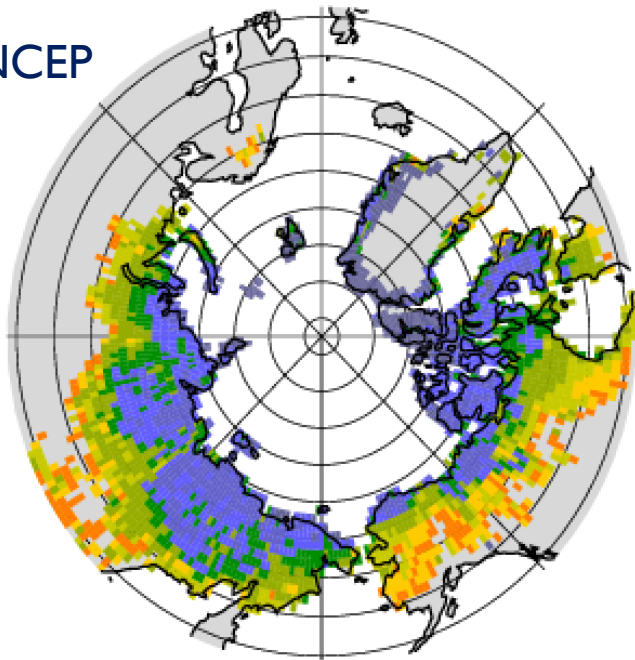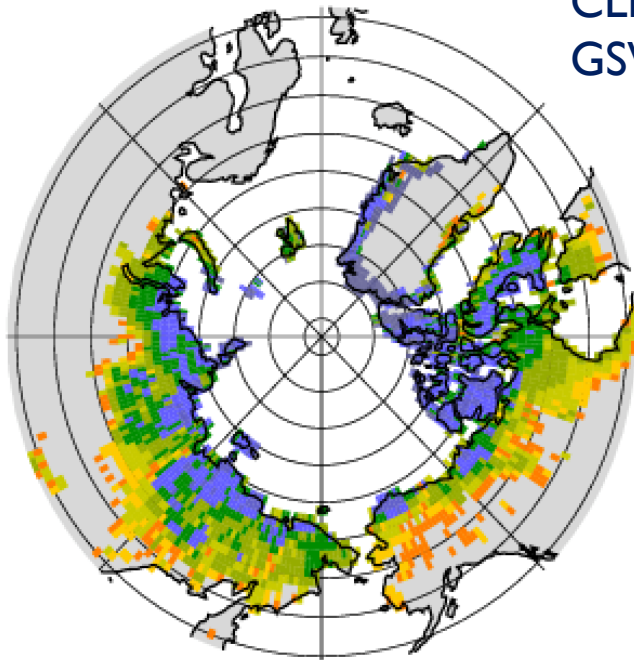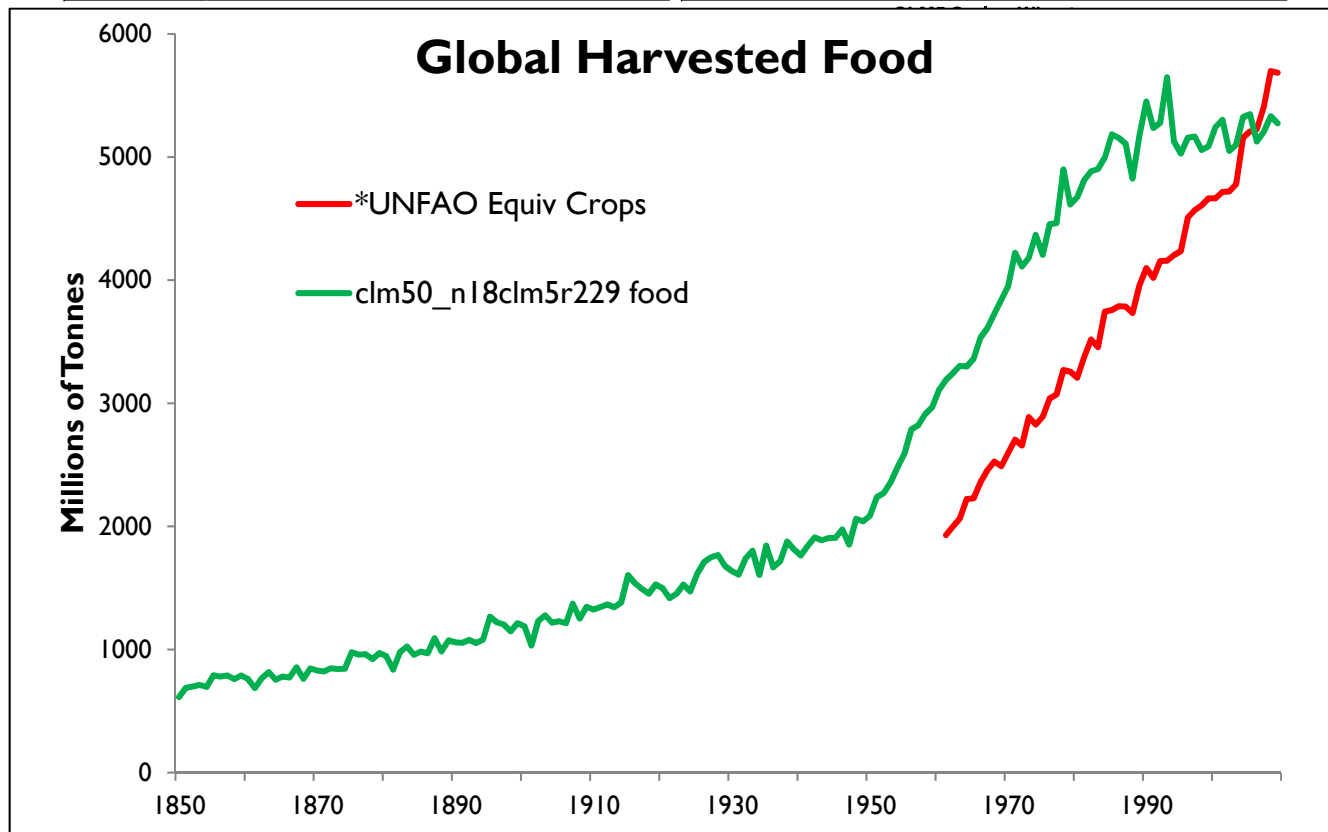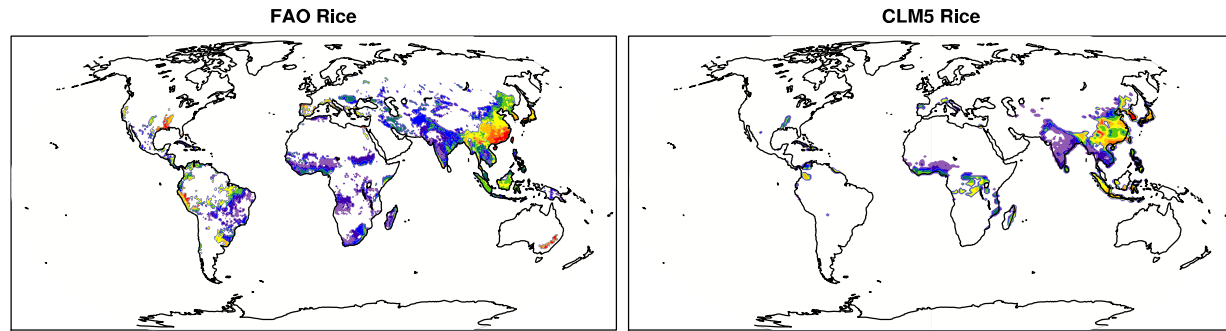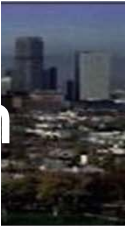
Irrigation

Precip   ET Obs   ET Model
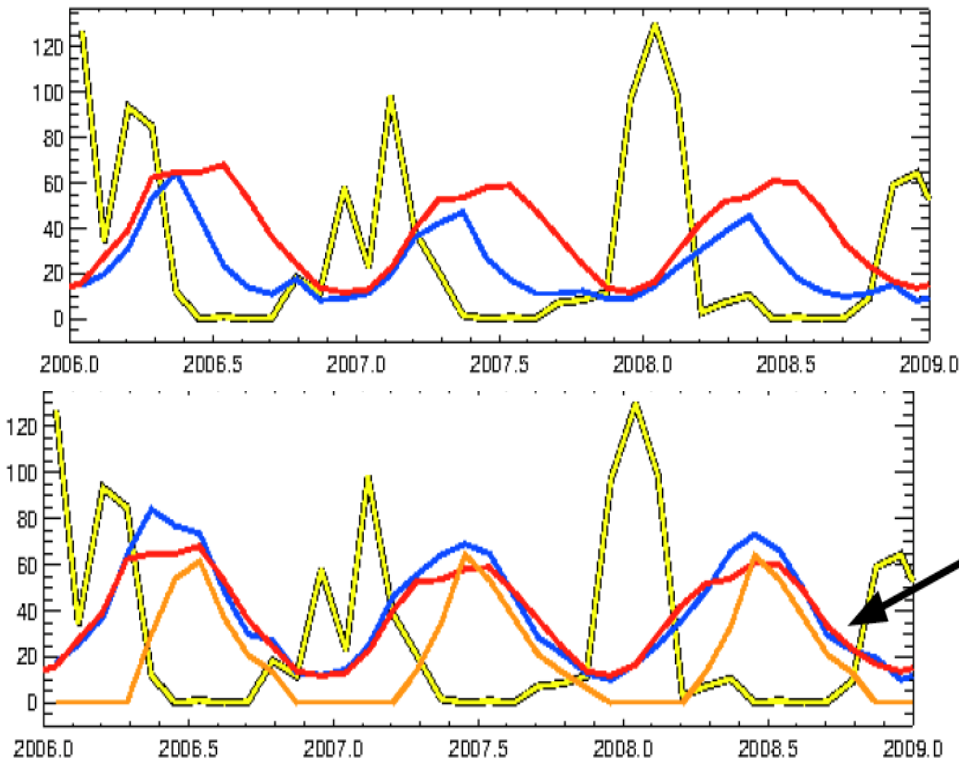
CLM Irrigation

Irrigation fulfills ET demand

Regional Irrigation Amounts (Target)
Global: 650 km3/yr (1000 - 2400)
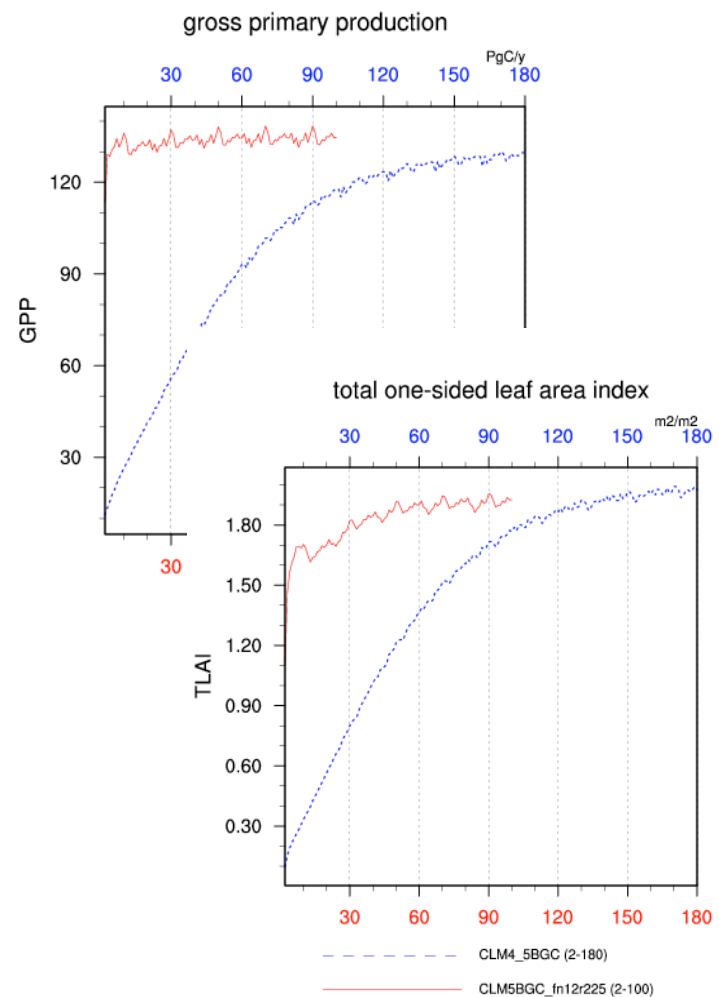US: 55 km3/yr (110 - 180)
China: 60 km3/yr (120 - 350)
India: 365 km3/yr (220 - 650)

- Online initial condition interpolation (use_init_interp = .true.)
- Much faster accelerated spin-up (biogeophysical land state comes into equil quickly)
  - CLM4, 2000+ years; CLM5, ~700 years
- Lots of namelist control
  - lnd_in: ~240 lines CLM5; 18 lines CLM4
  - Towards multi-hypothesis model
- Anomaly forcing
  - Mode to force CLM with monthly climate anomalies
- PFT / landunit level variables archived by default

Configuration	Cost (pe-hrs/yr)
CLM4.0 CN	20
CLM4.5 BGC	80 (4x)
CLM5.0 BGC	120 (6x)
CLM5.0 BGC-crop	175 (8x)
CLM5.0 SP	50

gross primary production

total one-sided leaf area index

CLM4_5BGC (2-180)
CLM5BGC_fn12r225 (2-100)

Terrestrial Processes in CMIP6

Collection of coordinated activities to assess land role in climate and climate change

- **Land Only** simulations forced with obs historical climate (joint GSWP3, TRENDY, ISI-MIP protocol)

- **Land Use = LUMIP** land use forcing on climate, biogeophysics and biogeochemistry with policy relevance, coupled and land-only land management factorial simulations

- **Carbon Cycle = C4MIP** land biogeochemical feedbacks on climate change

- **Land = LS3MIP** land systematic biases and biogeophys feedbacks including soil moisture and snow feedbacks, prescribed soil moisture and snow coupled simulations
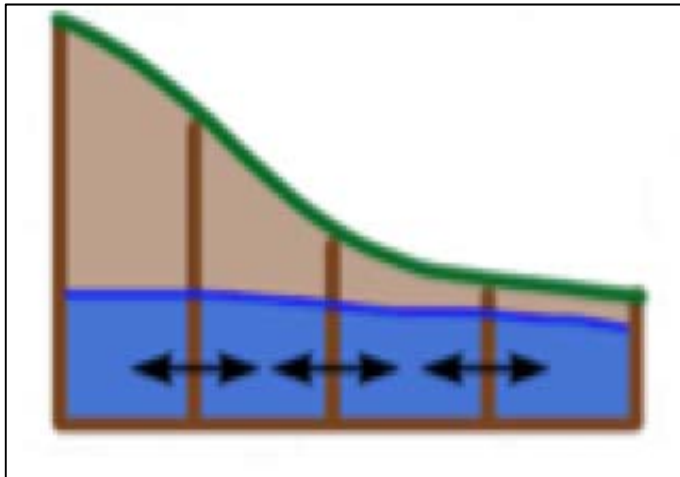
Other MIP activities

- **Soil Parameter MIP = SP-MIP** lland-only simulations to assess impact of uncertainties in soil texture/hydraulic parameters

- **Agriculture MIP = AgMIP** global gridded crop model evaluation and applications

- **ESM-SnowMIP** site reference level and global prescribed snow simulations
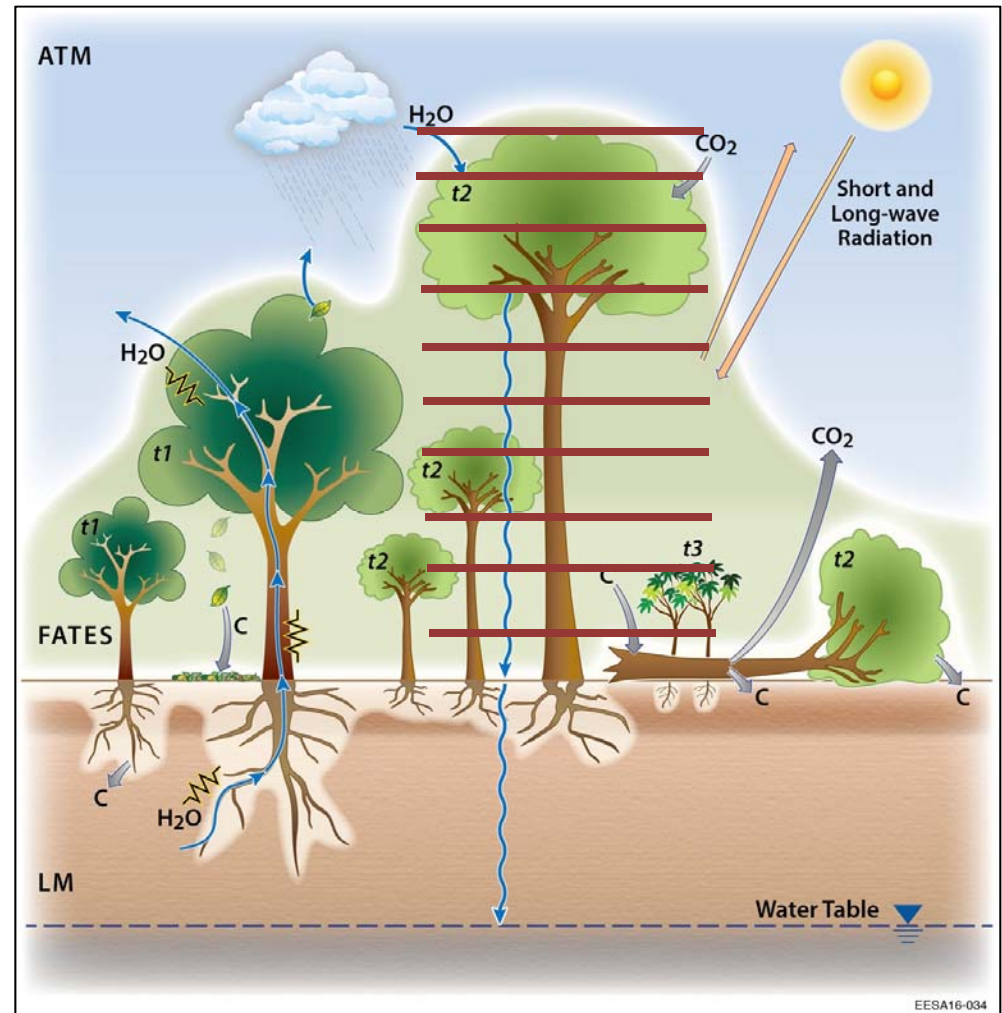
Hillslope hydrology

- Matrix approach to modeling land carbon and nitrogen cycles

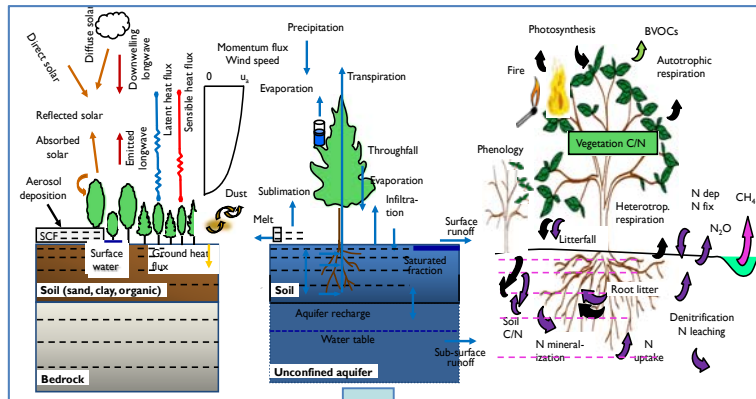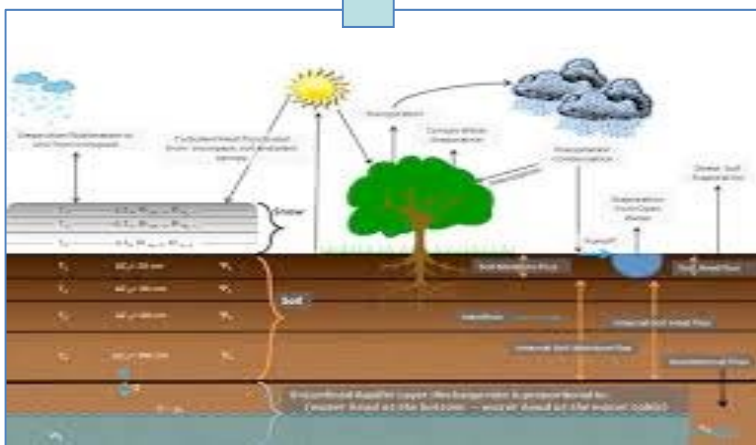## Ecosystem Demography / multi-layer canopy

The Community Terrestrial Systems Model
a model for research and prediction in climate, weather, water, and ecosystems

CLM (CGD)

CTSM

Noah-MP, WRF-Hydro (RAL)

Unify land modeling across NCAR

- More efficient use of NCAR and community resources

- Accelerate advances

- Increase flexibility and robustness of process representation, spatial disaggregation, and numerical solution (SUMMA concepts, modularization)

- Enable more hypothesis-driven science

- Integrate and expand land modeling research community

- Expand funding opportunities?

- Work is underway
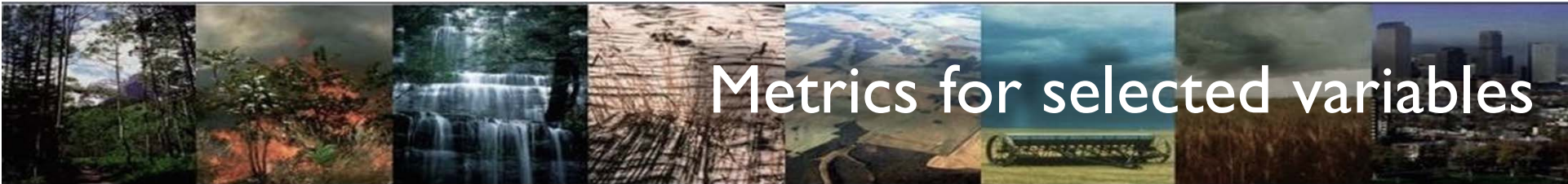 - Transition CLM/CTSM from svn to git
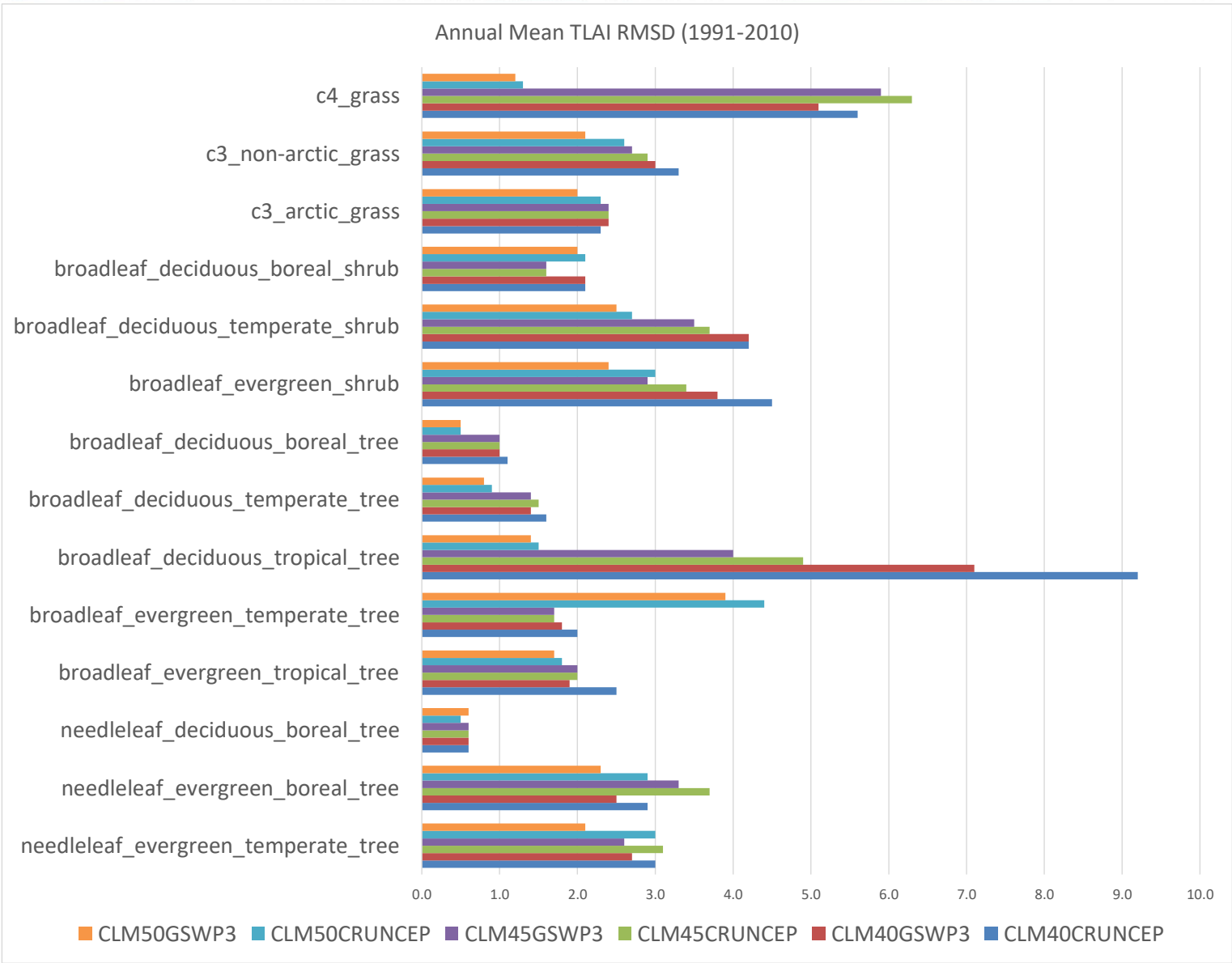
Thanks. Questions or comments?

International LAnd Model Benchmarking (ILAMB) project
scores for RMSE, interannual variability, pattern correlation, variable-to-variable comparisons, +

Green: model performs better than average model
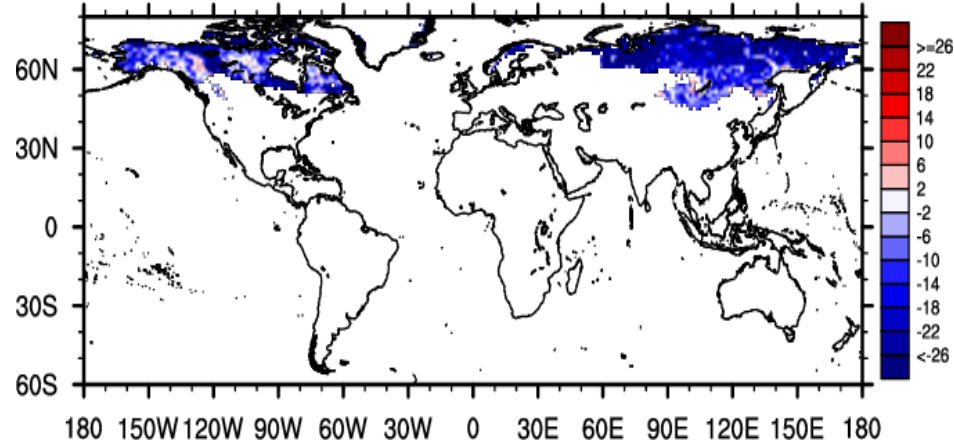Red: model performs worse than average model
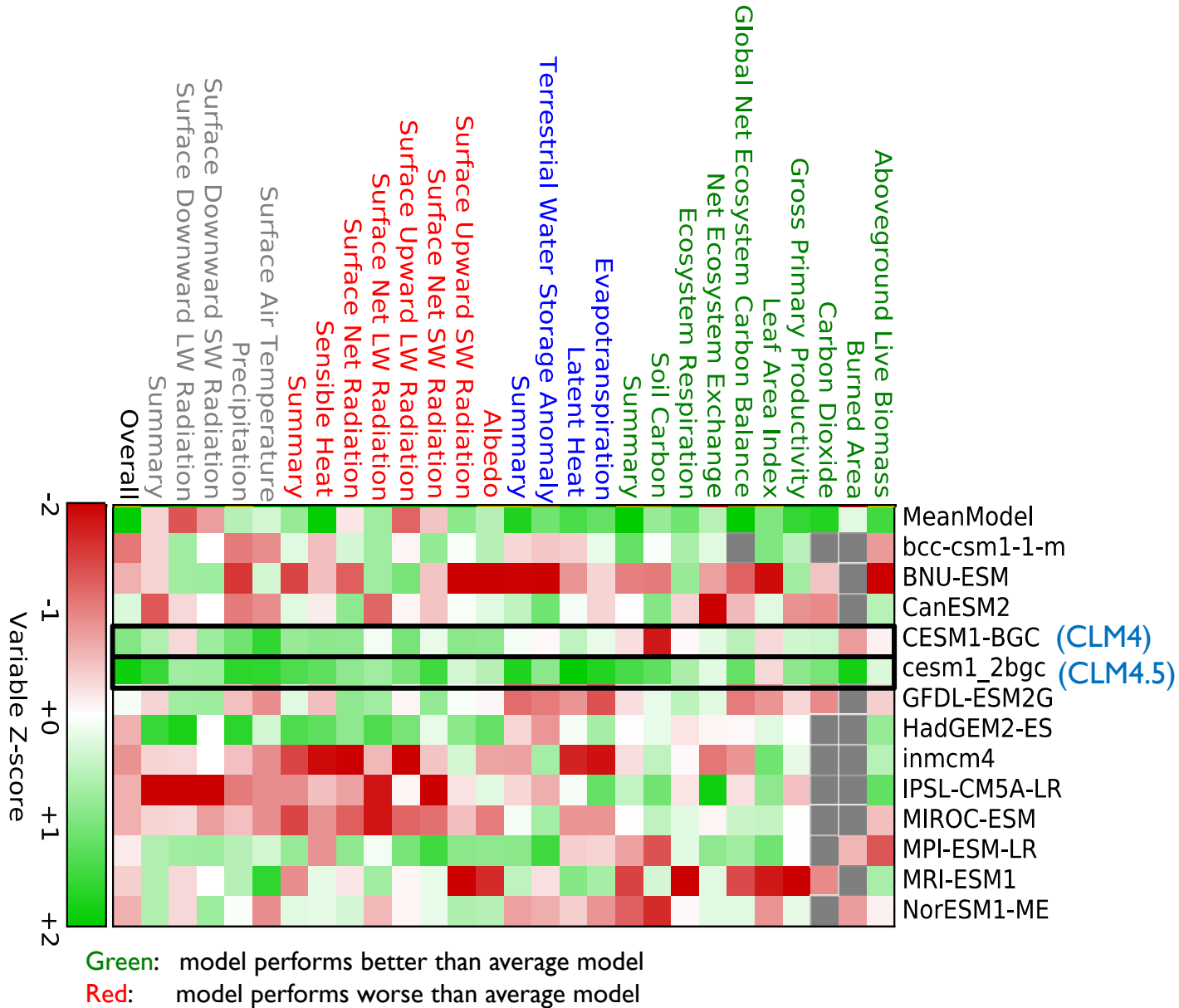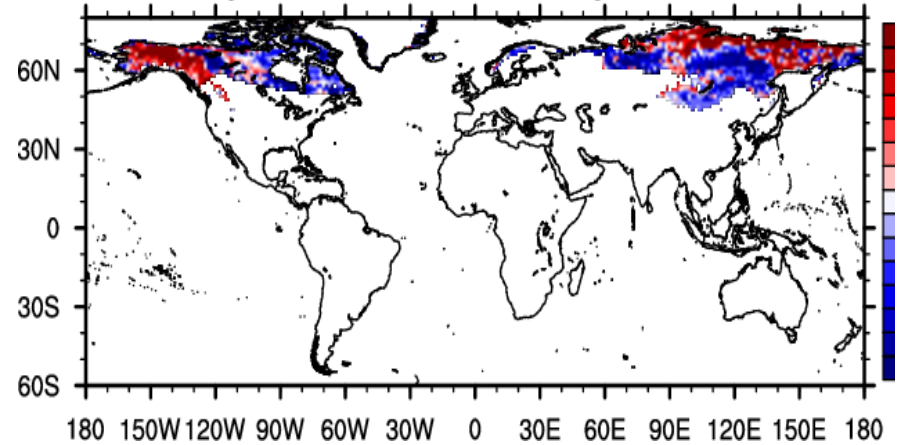
Metrics for selected variables

Assessment of CLM5 (land-only) with ILAMB

ILAMB = Land diagnostics package (25 variables, 60 datasets) with metrics for RMSE, bias, spatial pattern corr, interannual variability, funct relationships
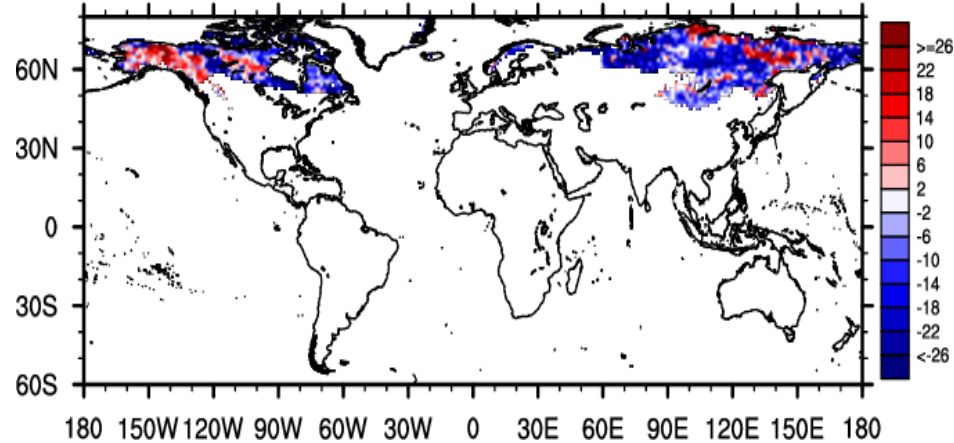
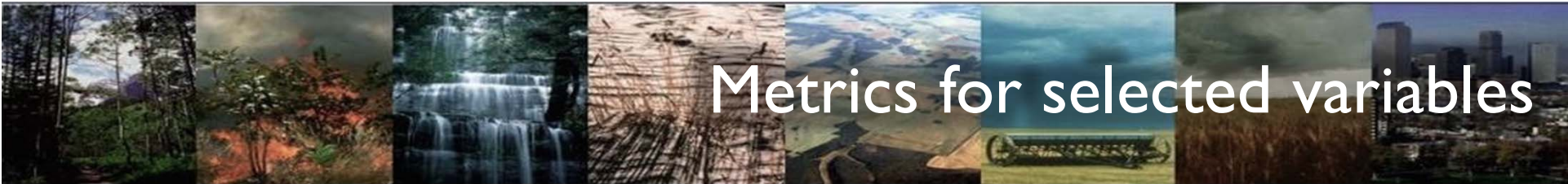Bias for SOILC (kgC/m2): CLM40CN_GSWP3v1 against NCSCDV22, 1996-2005

Bias for SOILC (kgC/m2): CLM50BGC_GSWP3v1 against NCSCDV22, 1996-200

Bias for SOILC (kgC/m2): CLM45BGC_GSWP3v1 against NCSCDV22, 1996-2005

Metrics for selected variables

Configuration	LH		GPP		LAI		Live biomass	Burned area
	RMSE	r	RMSE	r	RMSE	r	r	r
CLM4.0 CN	15.8	0.91	1.39	0.87	1.10	0.61	0.57	0.11
CLM4.5 BGC	13.6	0.95	1.17	0.94	1.04	0.72	0.67	0.38
CLM5.0 BGC-crop	12.5	0.95	1.27	0.91	0.81	0.89	0.82	0.63

ANN Bias(LHEAT) CLM50
3.55384

ANN Bias(LHEAT) CLM40
8.65885

Model relative to Obs
36.5246% - 12.625%