CLM5!

David Lawrence and the Land Model Working Group

What is new or improved in CLM5?

How did we ever get to the stage of a finalized model? *

Is the model any good?

What's next: CTSM / CLM6?

* Finalized should be in " "s

What's New for CLM5

A LOT!

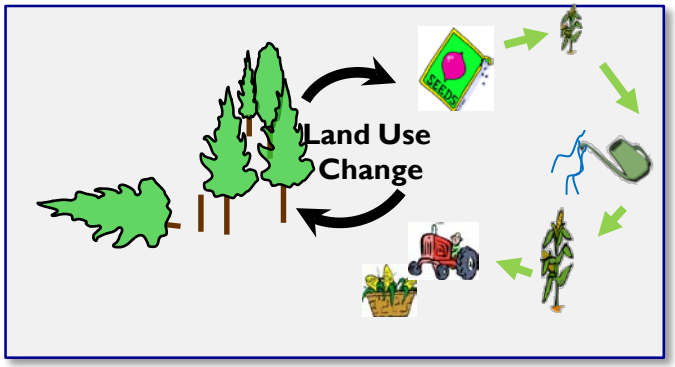
More than 50 scientists and software engineers from 15 different institutions involved in development of CLM5

What's New for CLM5

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

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 effects, firn model (12 layers), glacier MEC, fresh snow dens.
Rivers:	MOSART(hillslope → tributary → main channel)
Nitrogen:	flexible leaf C:N ratio, leaf N optimization, C cost for N (FUN)
Vegetation:	plant hydraulics and hydraulic redistr, deep roots tropical trees, Medlyn photosynth, 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, shifting cultivation
Isotopes:	carbon and water isotope enabled



CLM5 default configuration

CLM5 optional feature

2nd CLM Tutorial **September 12-16, 2016**

- **Lectures** on underlying model physics, hydrology, biogeochemistry, ecology, etc
- **Practical sessions** about how to run, modify, and analyze CLM simulations
- Presented science and software of **CLM5 / CESM2**
- More than 85 applicants, 46 accepted plus 8-10 auditors
- All tutorial material including lectures and practical sessions **http://www.cesm.ucar.edu/events/tutorials/2016-clm/**

CLM versions and configurations

CLM2 May 2002 (CCSM2)

CLM3 June 2004 (CCSM3)

CLM3.5 June 2007 (CCSM Distinguished Achievement Award to LMWG)

CLM4 June 2010 (CCSM4 and CESM1; CMIP5)

- carbon-nitrogen cycling
- prognostic vegetation phenology, LAI, and height
- transient land cover change
- urban model
- updated hydrology including groundwater
- updated snow incl. dust and black carbon dep.
- organic soil + deep ground column (permafrost)

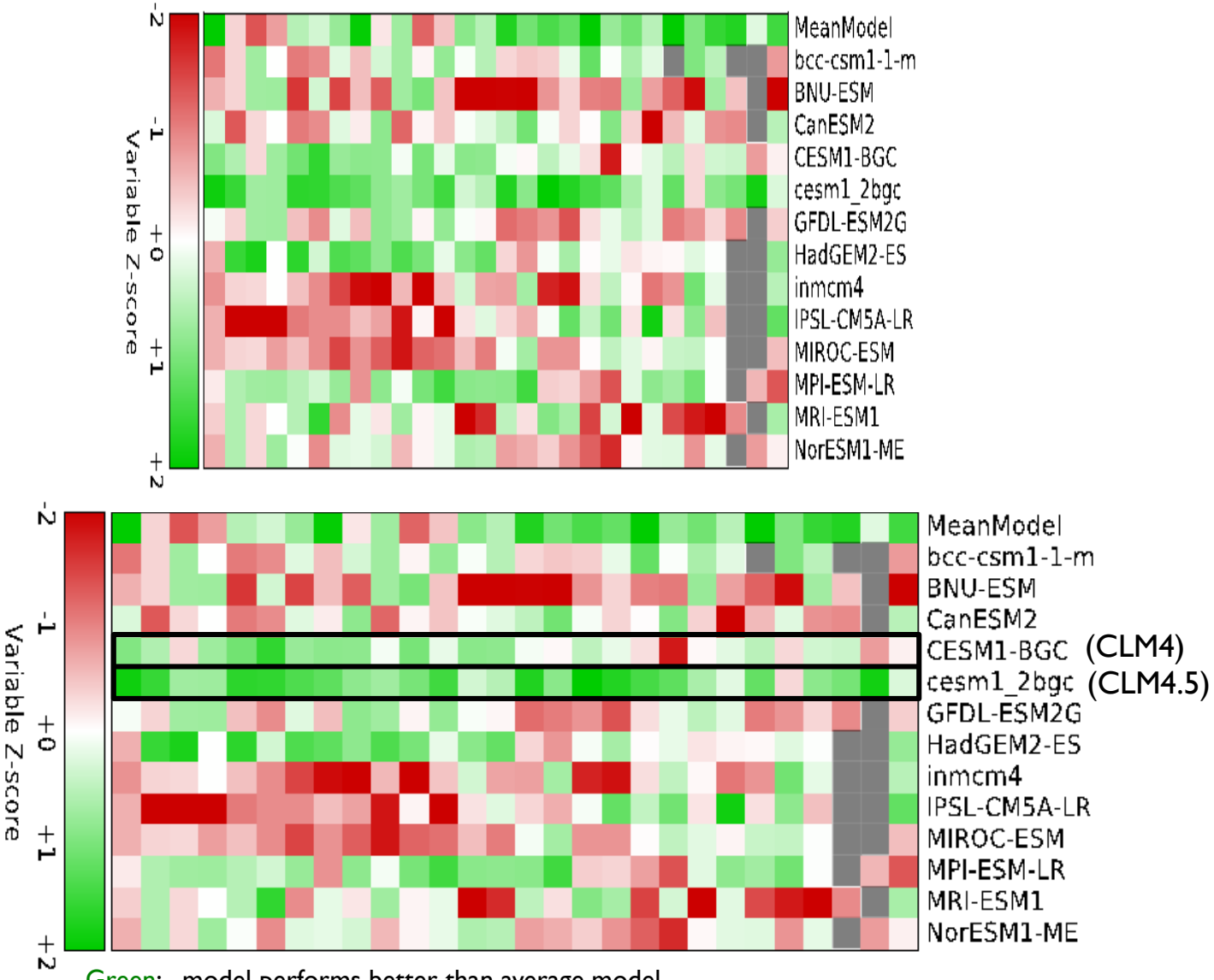
CLM versions and configurations

CLM4.5 June 2013 (CESM1.2)

- vertically-resolved soil BGC and revised nitrification-denitrification, N-fixation
- cold region hydrology updates incl perched water table, VIC option
- snow cover fraction updates
- revised canopy radiation scheme
- co-limitation and temperature acclimation on photosynthesis
- updated lake model
- prognostic wetlands and flooding (optional)
- updated fire model with natural and anthropogenic triggers and suppression
- BVOC updated to MEGAN2.1
- CH_4 emissions

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

What's New for CLM5

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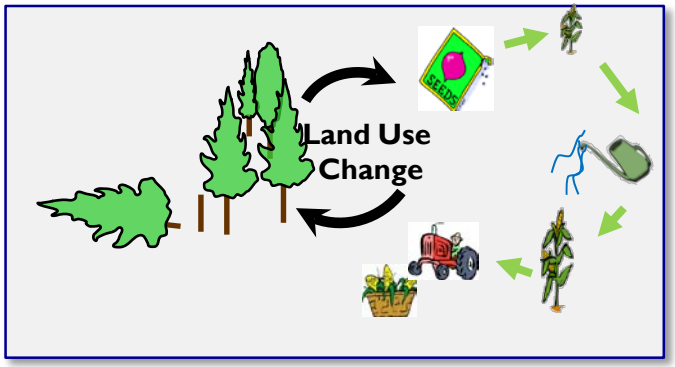

CLM5 default configuration

CLM5 optional feature

How did we get here?

Hydrology:	dry surf. layer, var. soil depth w/ deeper (8.5m) max soil, revised GW and canopy interc
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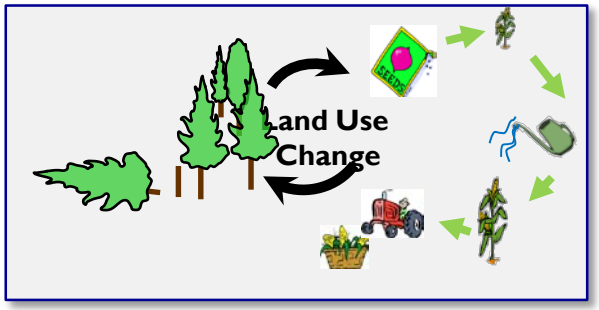
Implemented CLM5 default configuration

CLM5 optional feature

Not yet implemented



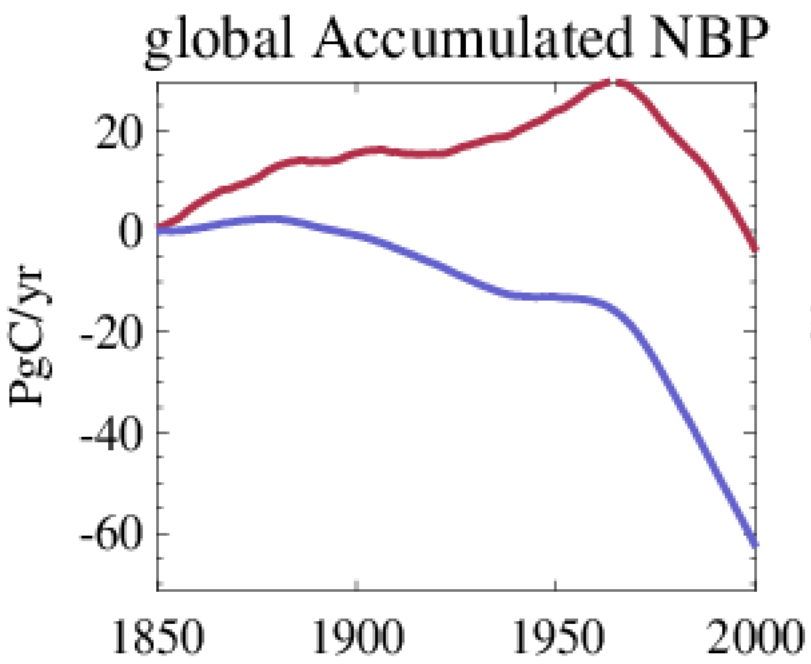
How did we get here?

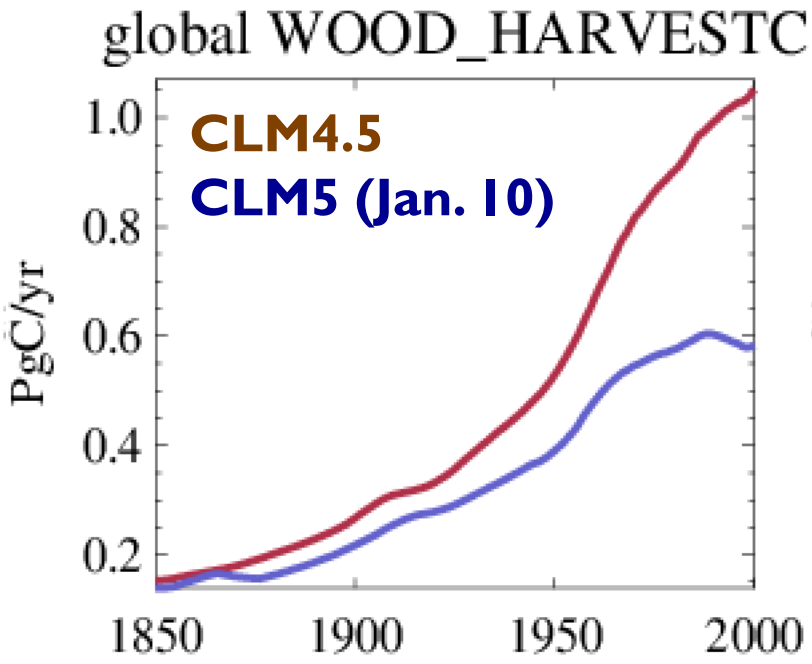
How did we get here?

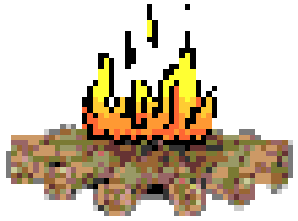
July to December, 2016

- Integrating new features
- Fixing problems
- Dealing with edge cases
- Assembling datasets
- CLM Tutorial
- Multiple false starts, trials, and tribulations with optimized parameter calibration

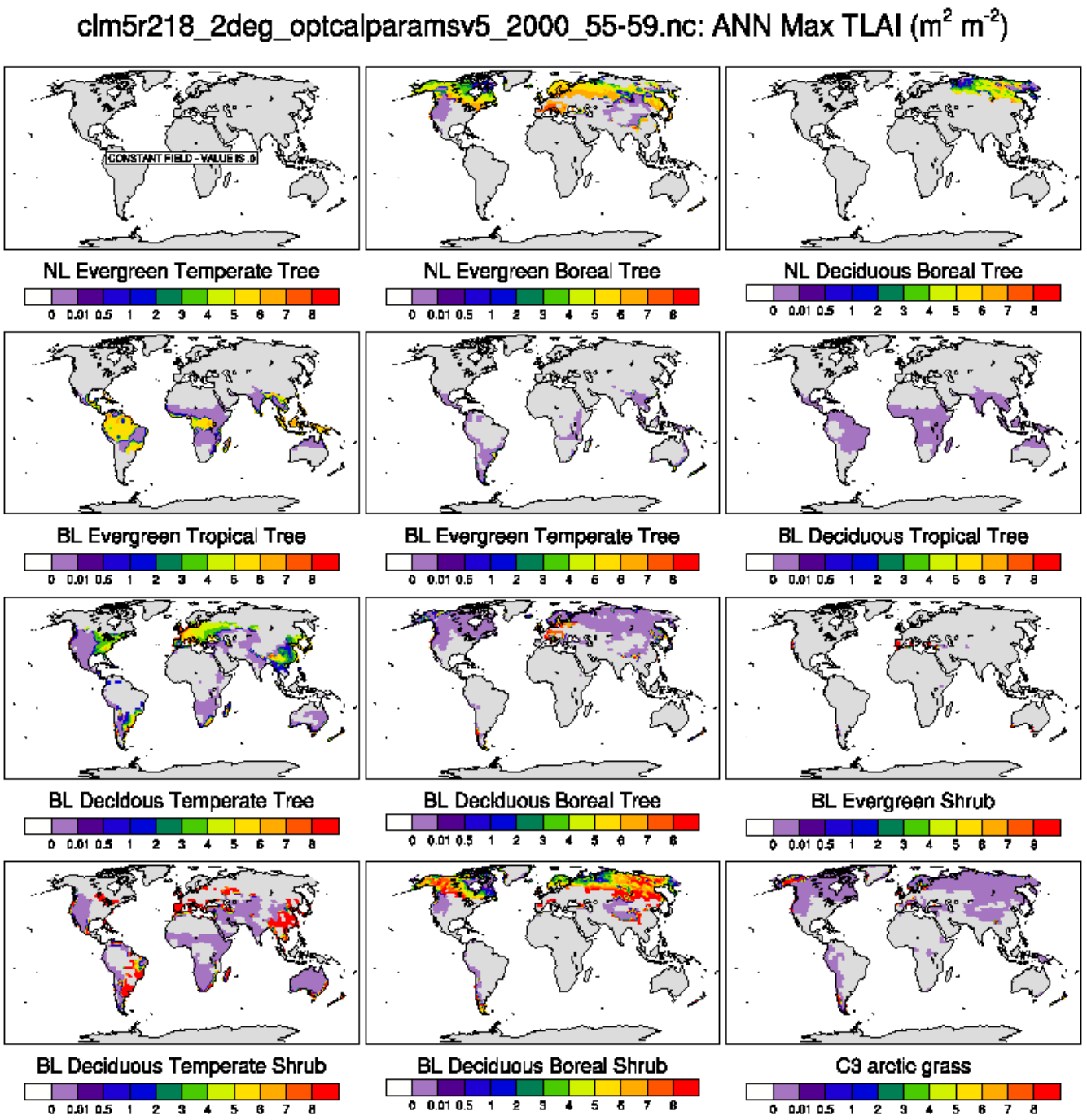
Problem with wood harvest





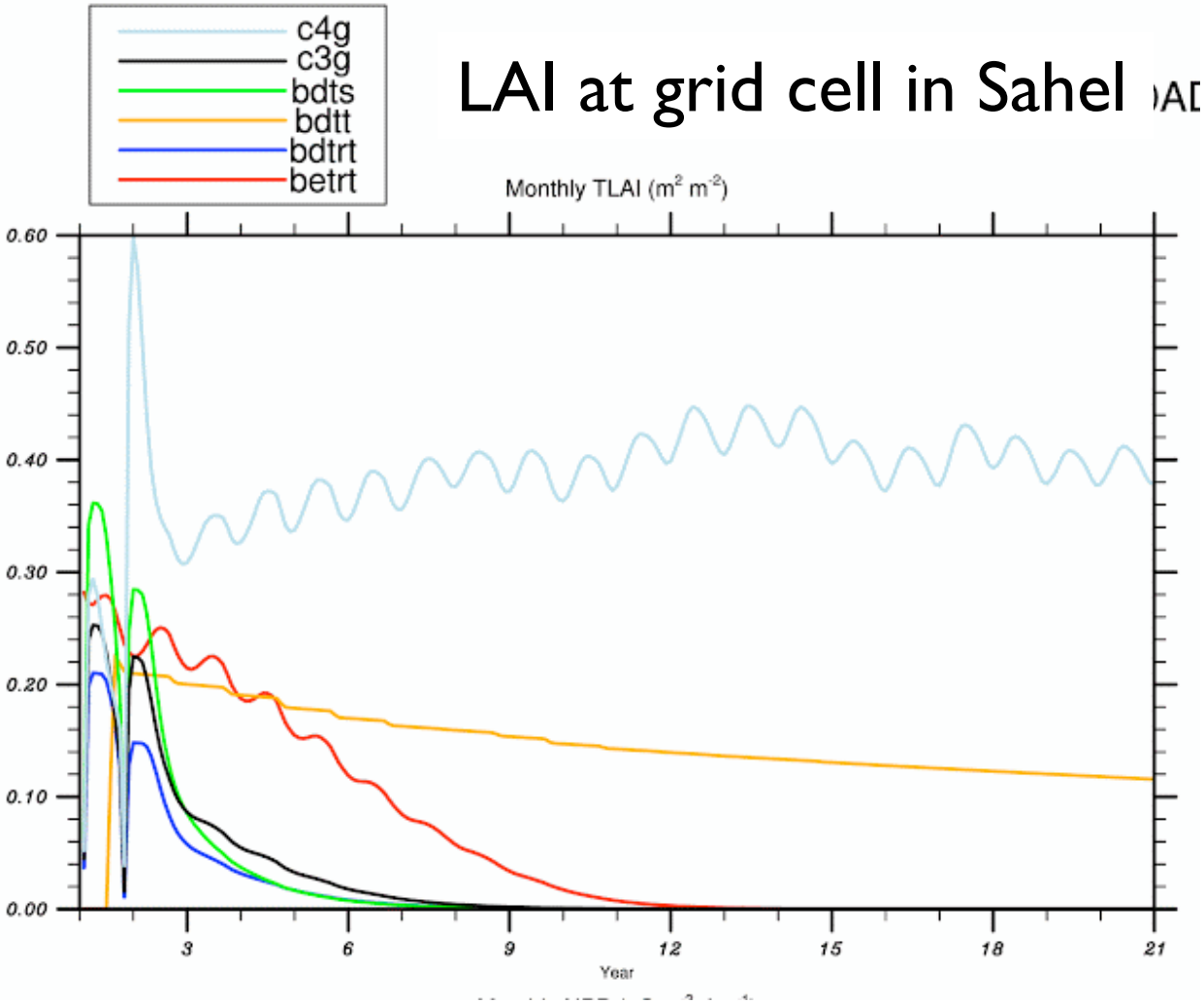


CLM Annual Max LAI (from some run circa Jan 10)



CLM Safety Tip:
Once a PFT in a grid cell dies, it ***stays*** dead for the remainder of simulation

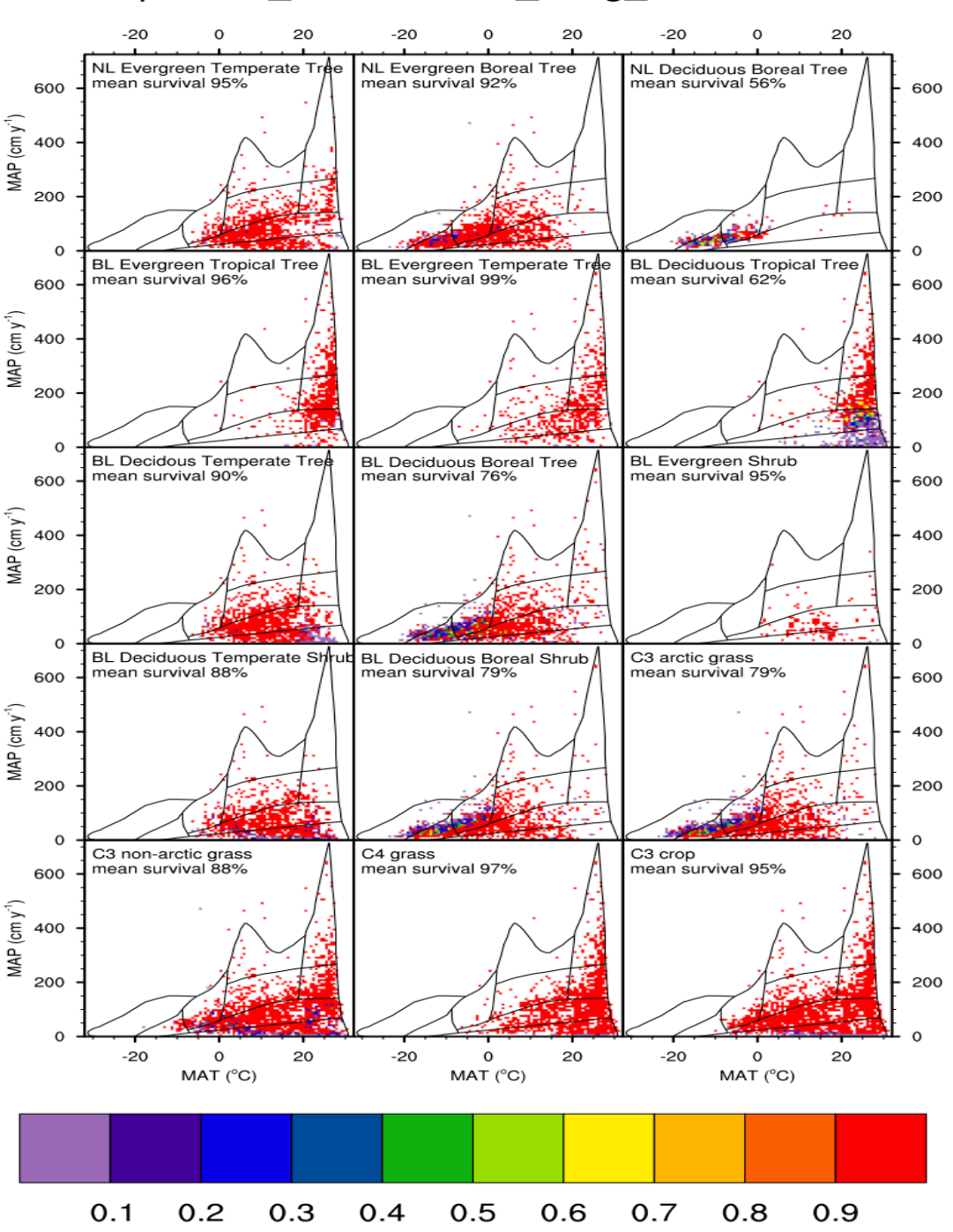
Why are plants dying?



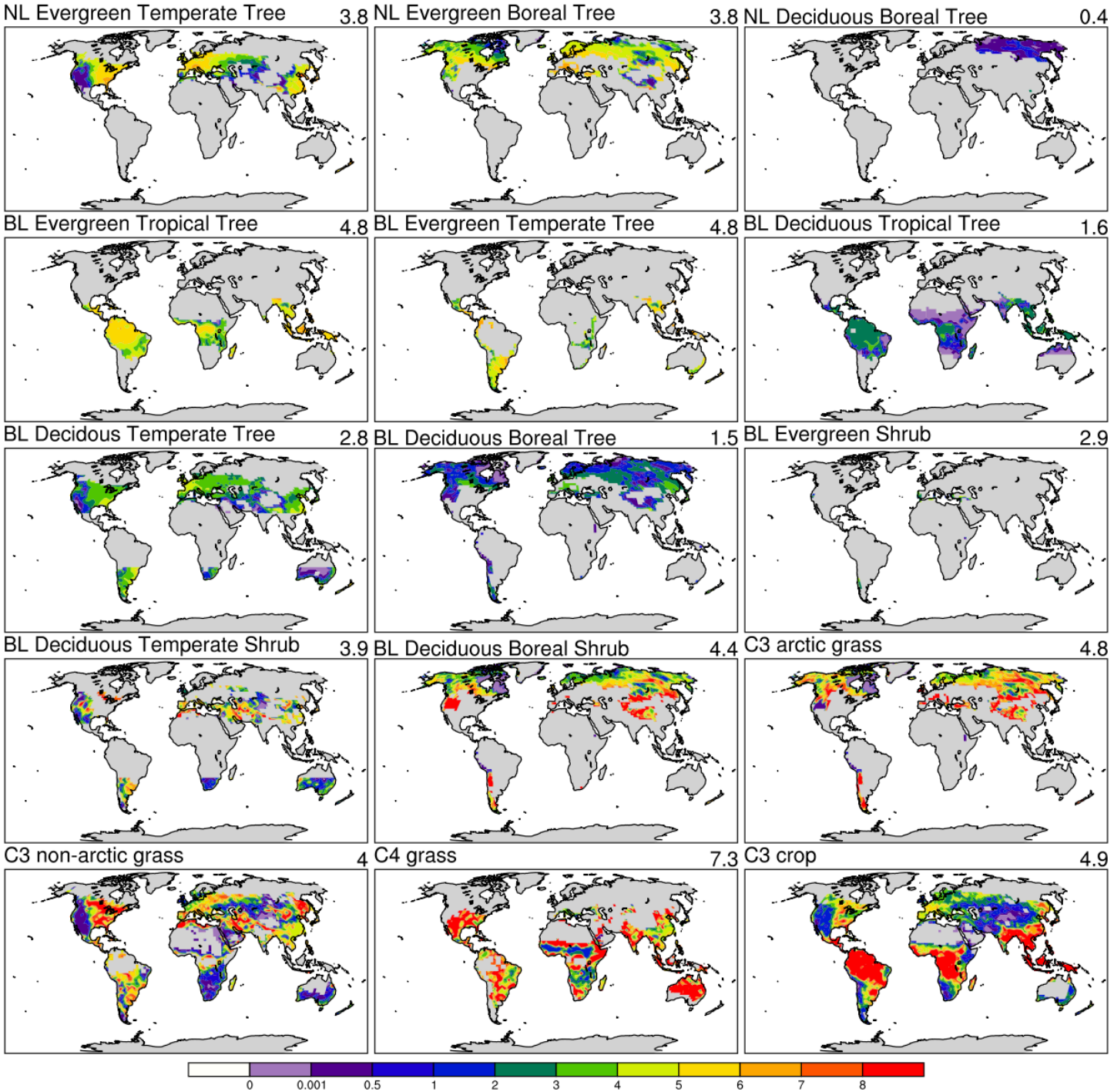
→ Reworked initialization strategy, with more initial C/N in veg and soil

Helped, but majority of issue seems to be with parameters

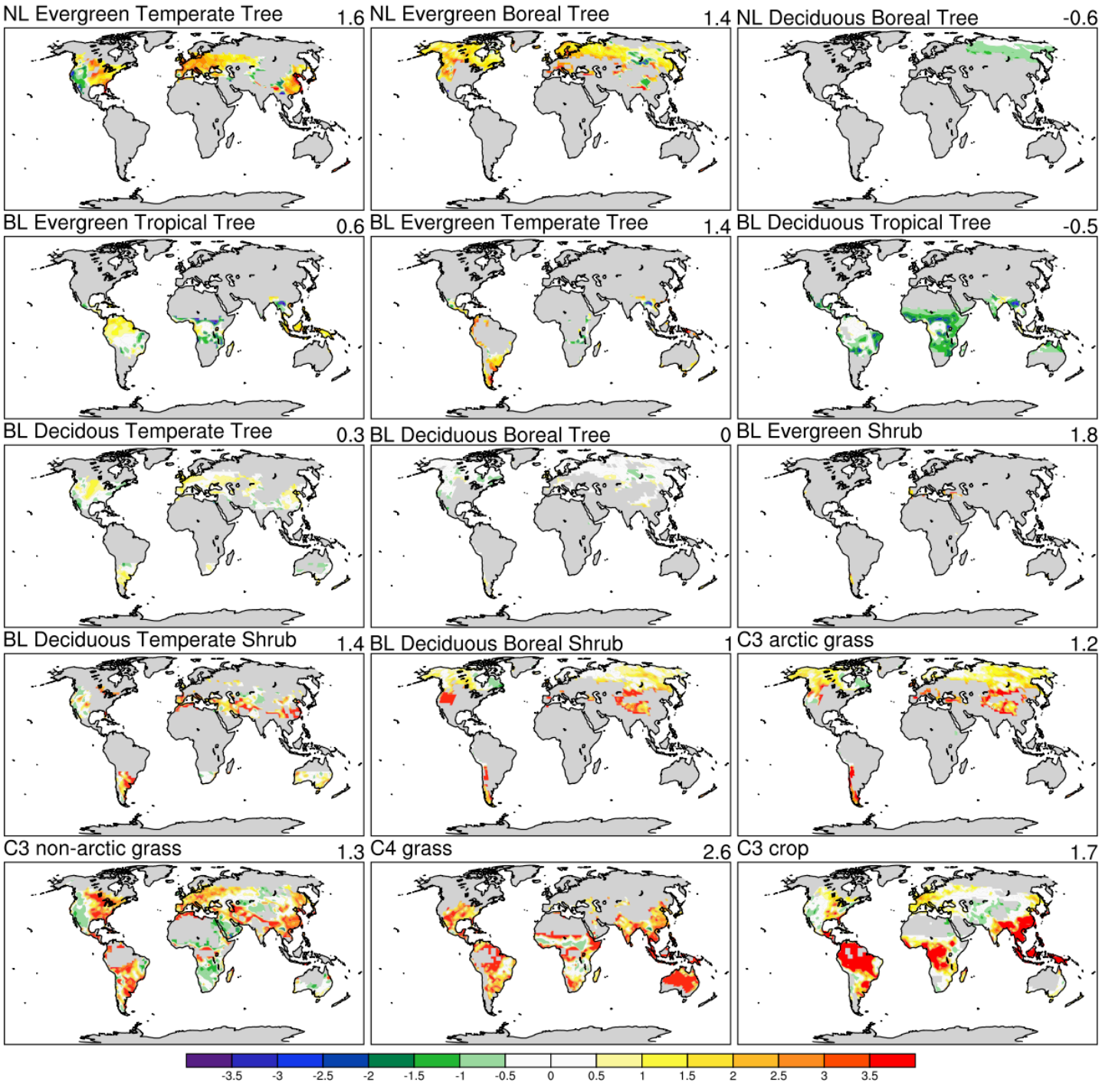
Survival Probability



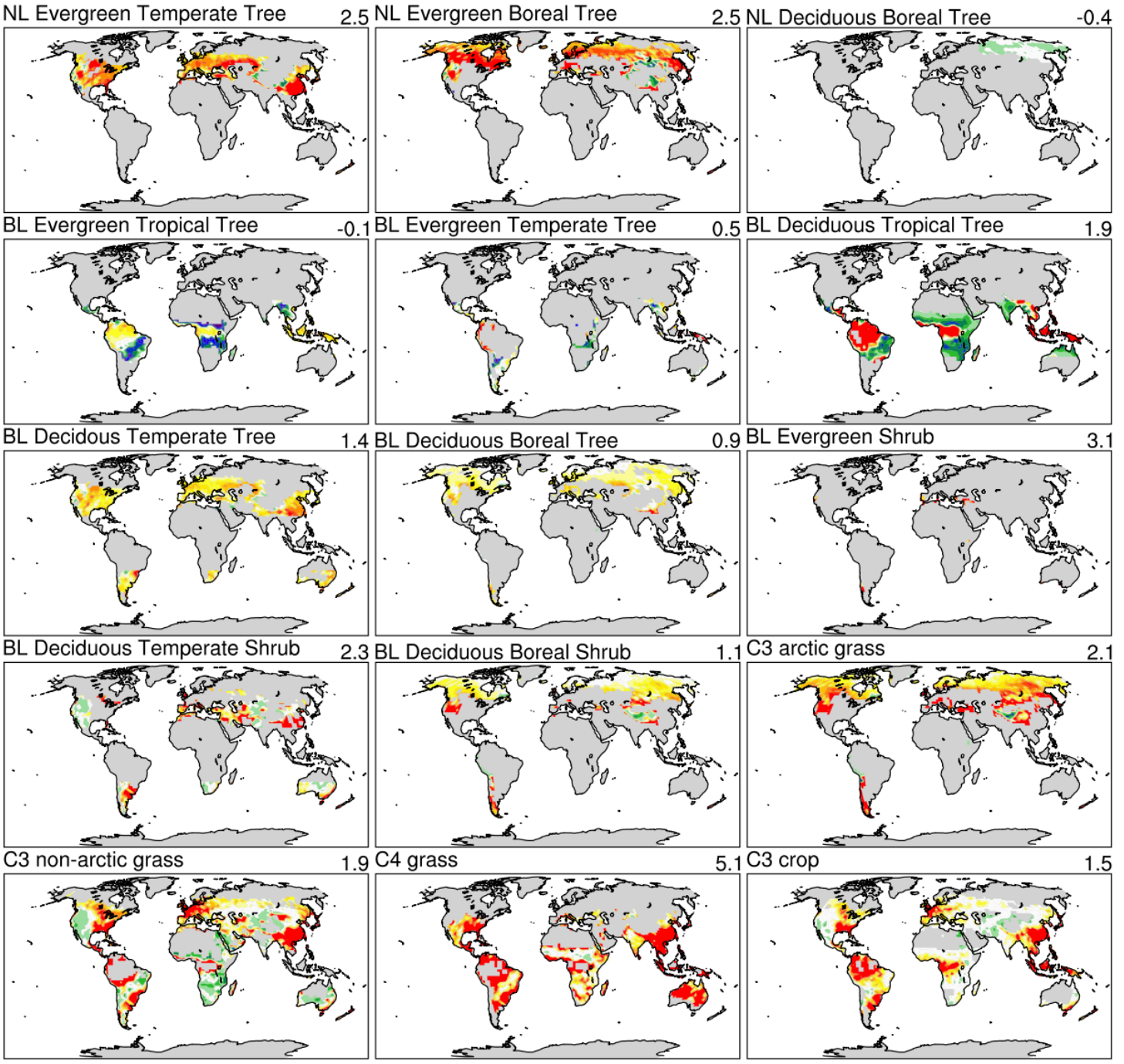
CLM5 Annual max LAI



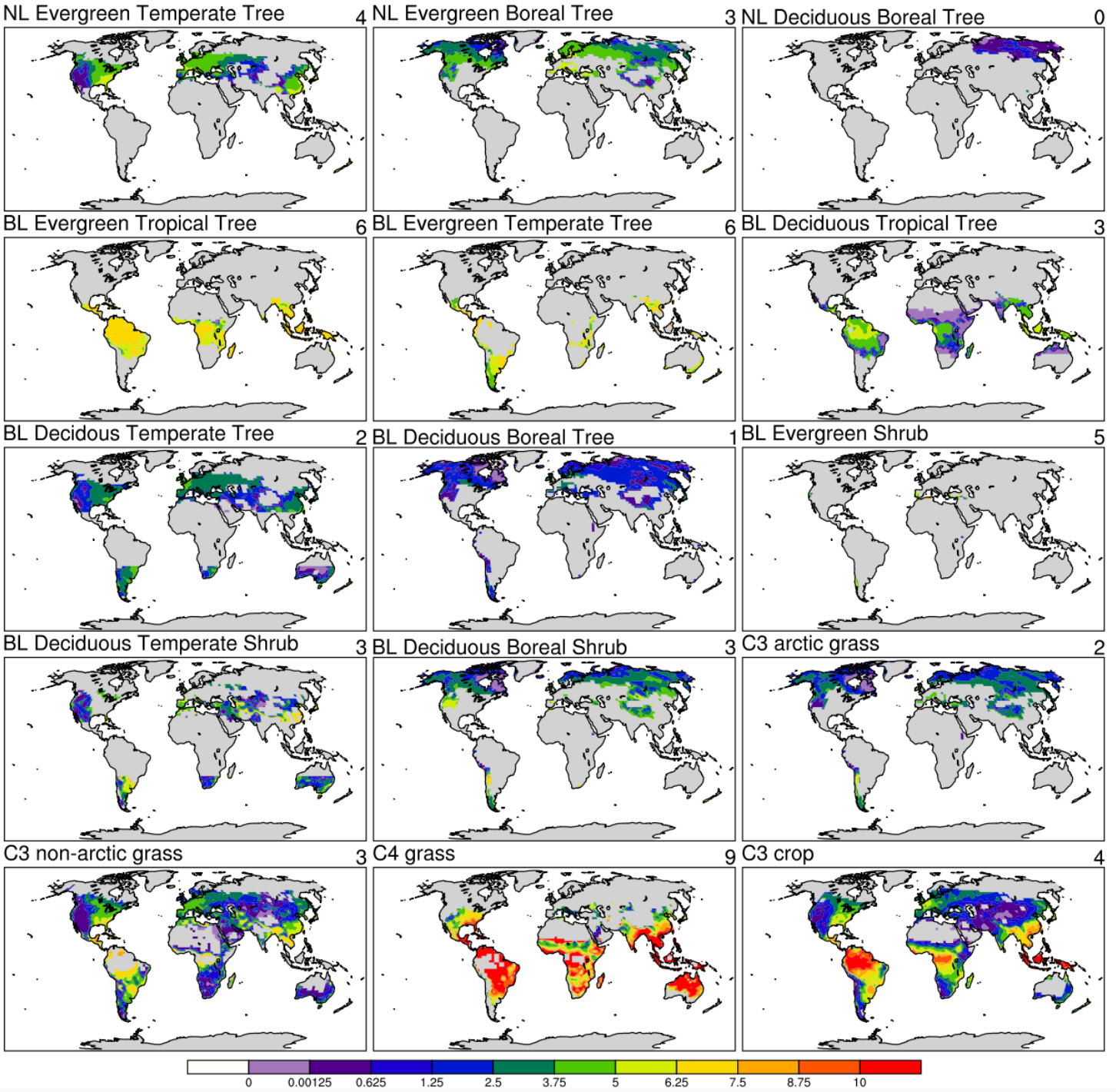
CLM5 bias in annual mean LAI



CLM4.5 bias in annual mean LAI



CLM5 Daily mean GPP



Is CLM5 in improvement over CLM4.5?

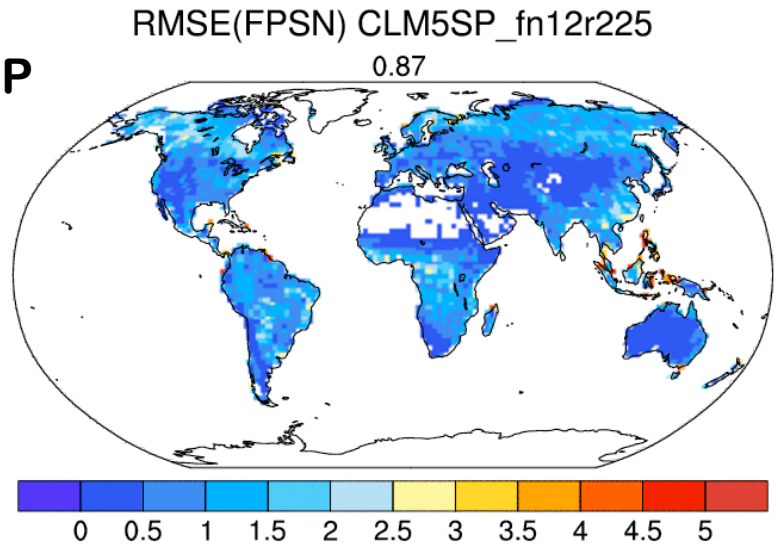
- Mechanistically and capability-wise, definitely yes
- Model skill against observations?

  TBD, some fields like GPP, LH, LAI, river discharge, albedo, fire either not degraded or improved

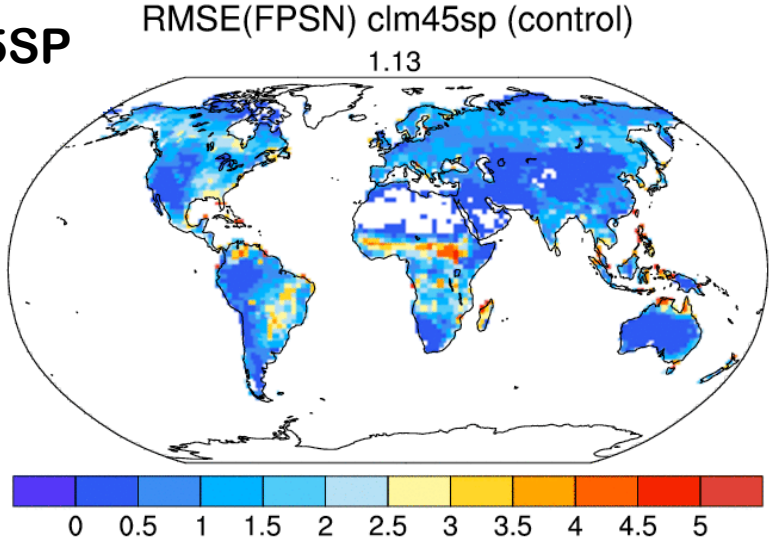
  Carbon flux interannual variability lower
- Some more details in talks today and tomorrow
- Will take some time to be able to fully characterize and understand the model

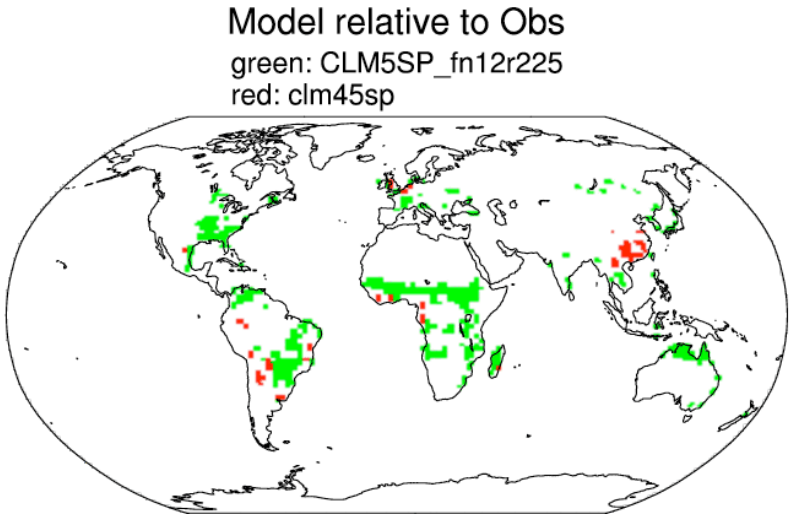
Improvements

CLM5SP

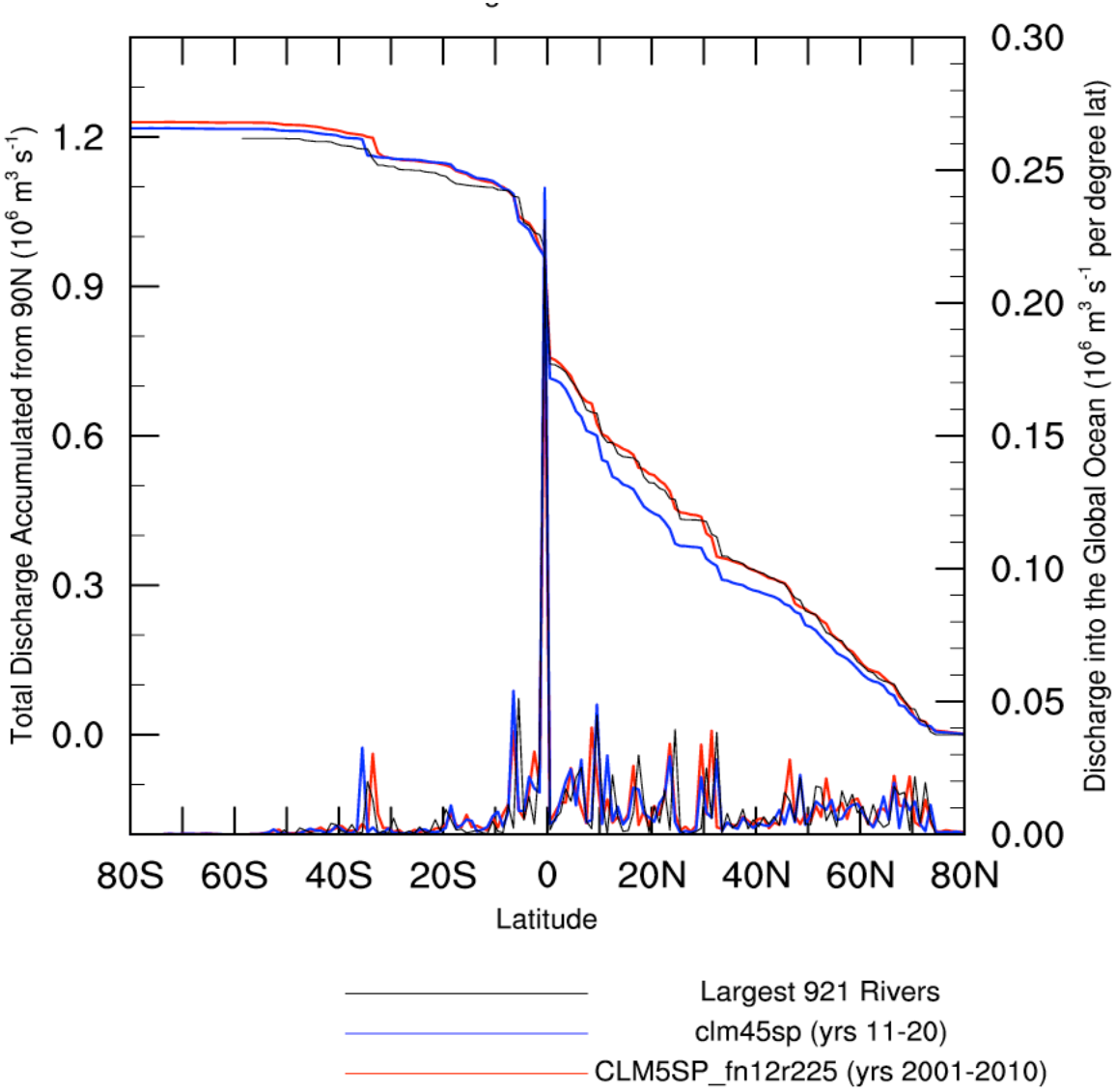


CLM4.5SP



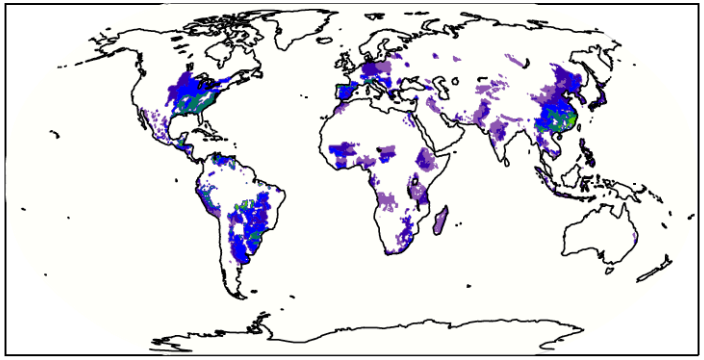


Annual river discharge

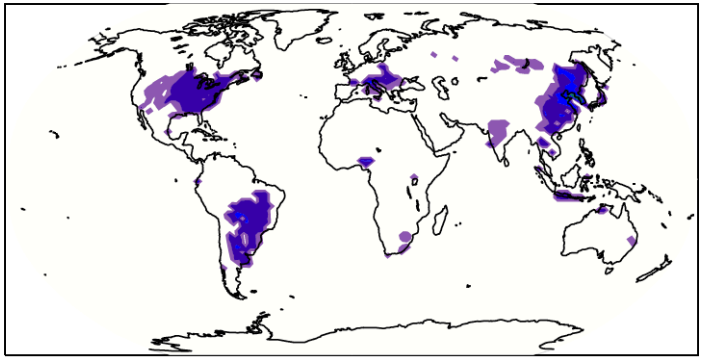


Crop yields

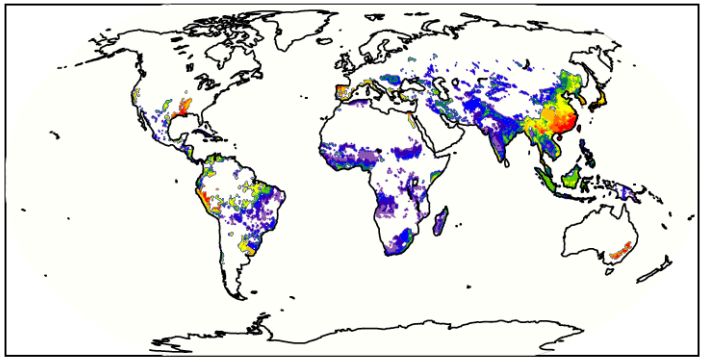
FAO Soy



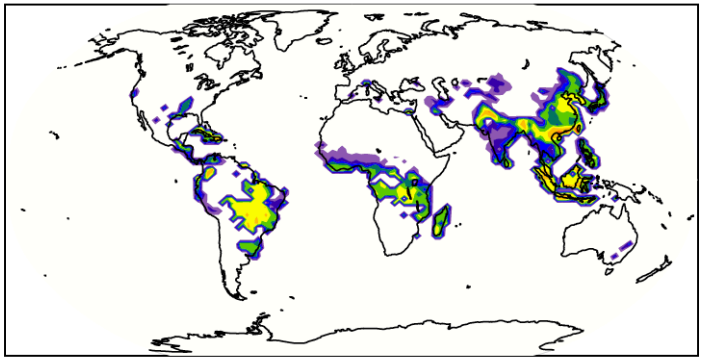
CLM5 Soy



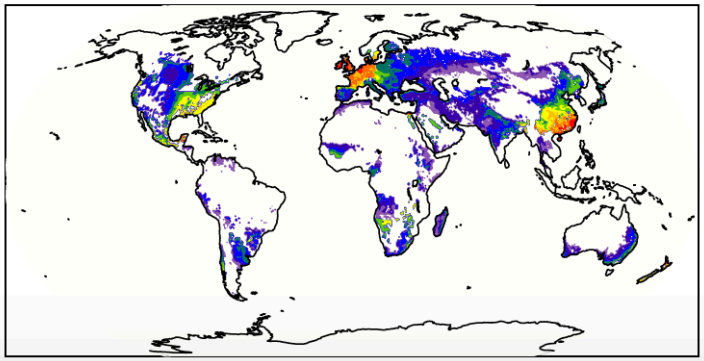
FAO RIce



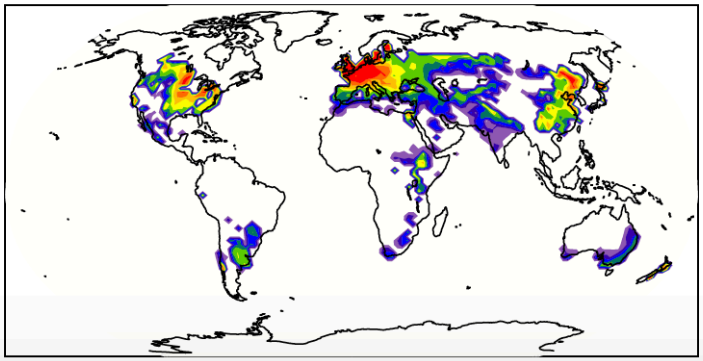
CLM5 RIce



FAO Wheat

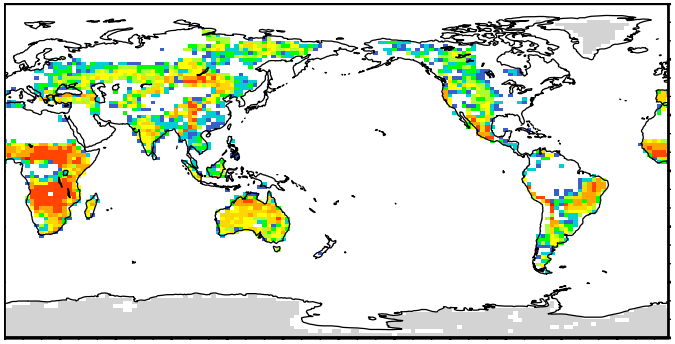


CLM5 SprIng Wheat



Burned area

)



What's next?

- Documentation
  - JAMES papers (CESM Special Collection)
  - Technical Description
  - User's guide

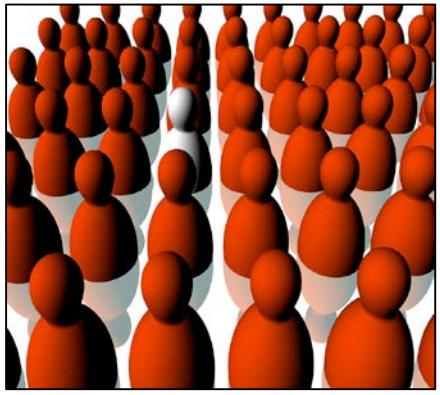
- Land-oriented CMIP6 activities
  - Rationalize CLM output streams
  - LUMIP, LS3MIP land-only runs

Beyond CLM5

- FATES
- Multilayer canopy
- Hillslope hydrology
- …

Can we move beyond "Shantytown" syndrome?

… and the proliferation of models?

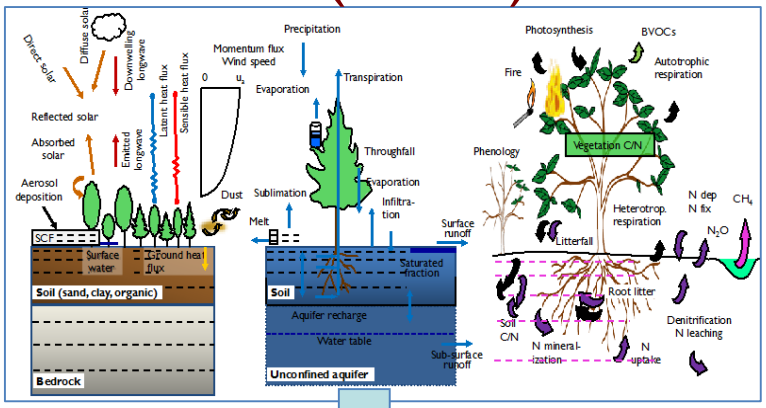


… and continue efforts to modularize and modernize the code and support tools?

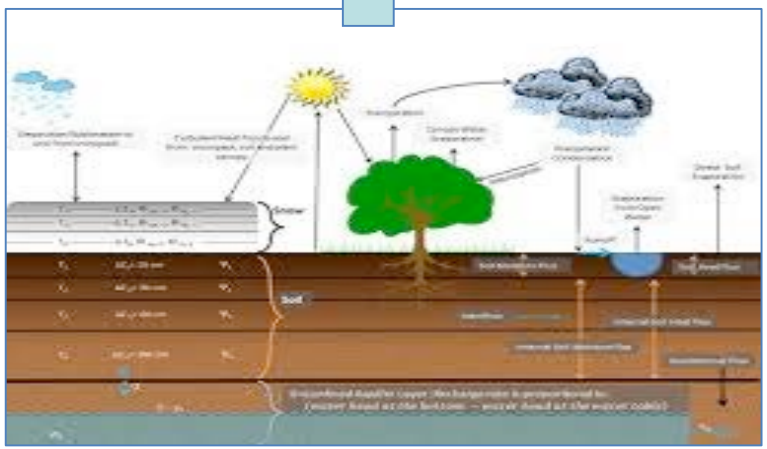
The Community Terrestrial Systems Model

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 architecture, and numerical solution (SUMMA concepts)
- Enable more hypothesis-driven science
- Integrate and expand land modeling research community
- Expand funding opportunities?

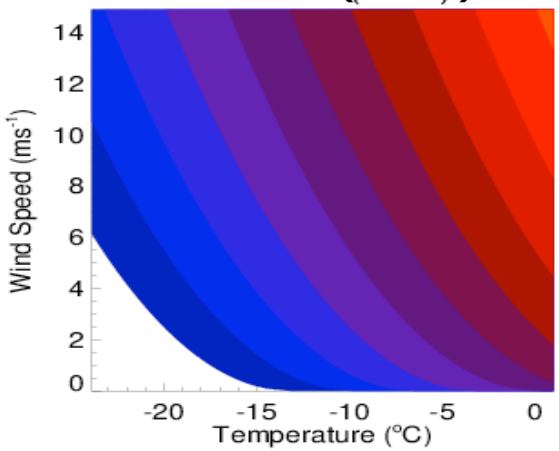
Andrew Slater, 1971-2016

Development targets for CLM5

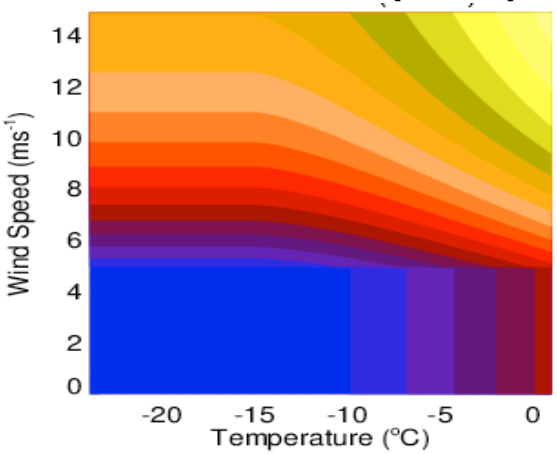
- Land cover and land use change
  - Global / transient crop capability with irrigation, fertilization, and cultivation of crops (land management) as default for historical and projection runs
  - More realistic land cover change impact on water and energy fluxes
- Carbon and nutrient cycles
  - Improved 20thC land carbon stocks and carbon stock trends
  - Address ecological stones thrown at CLM4 (plants don't get N for free , leaf N isn't static, photosynthetic capacity should respond to environment, stomatal conductance not linked to N-limitation)
- Hydrology
  - Hydrology representation closer to state-of-art hydrology understanding
  - Increase utility for use in water resource and water-carbon interaction research
- Land-atmosphere chemistry coupling
  - Enhanced interactions, fire emissions, ozone damage to plants, CH_4 emissions
- Ecosystem Demography model – future biogeochemical core of CLM
  - Functional CLM5(ED) for use in studies of biome boundaries, trait filtering, etc
  - CESM2 coupled runs with CLM(ED) within CMIP6 timeframe; will not be CESM2 default configuration

Improvements to fresh snow density and snow compaction

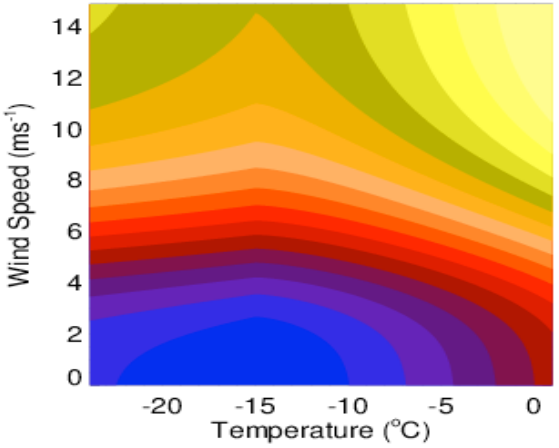
CLM4/CLM4.5
Pahaut (1976)

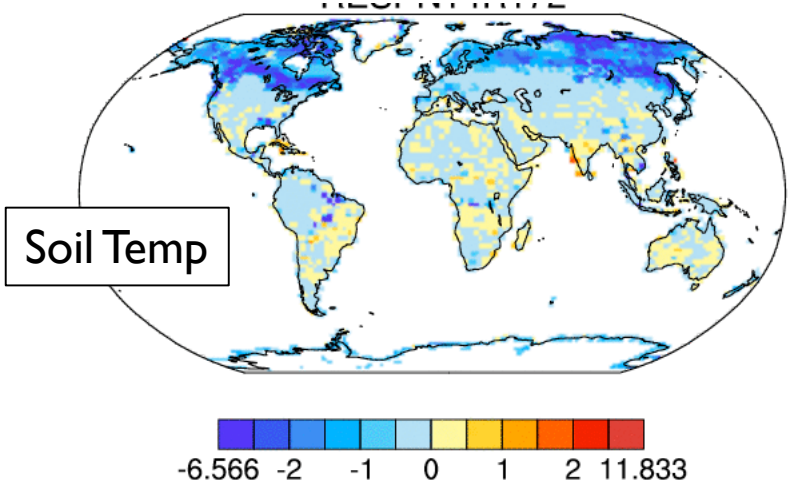


CLM5 (Feb)
Liston et al.(2007)



CLM5 (May)
Slater





- Improved snow densities
- Cooler soil temperatures
- Eliminates spurious Antarctica snow melt

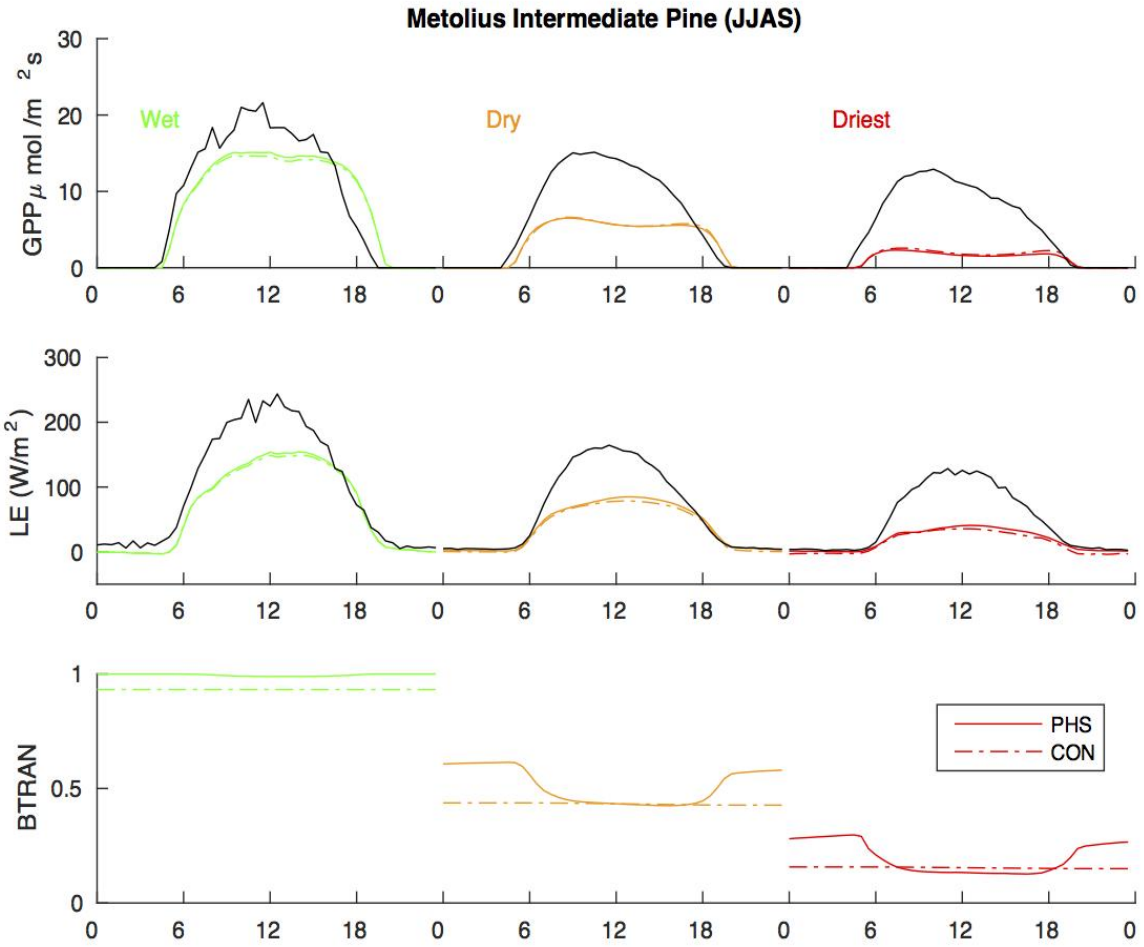
To do list: Software development

- Integrate "loose-end" projects
  - Carbon / nitrogen conservation for dynamic landunits
  - Plant hydraulics
  - Dynamic roots
  - Water isotopes (BeTR)
  - Winter wheat
  - Crop tilling
  - Dynamic local river flood stage
  - Permafrost excess ice
  - Switch for PFTs on own column
  - Prescribed soil moisture code
  - ….

- Code cleanup
  - Rapid code integration for science has lead to accumulation of lots of "Technical Debt"
- Performance
  - CLM5BGC-crop costs ~5-10x over CLM4CN
- Model output rationalization
  - Over 550 fields archived by default

PHS - Recent Simulations

- Using tower simulation analysis to understand and optimize parameterization for drought response



Slide courtesy Daniel Kennedy

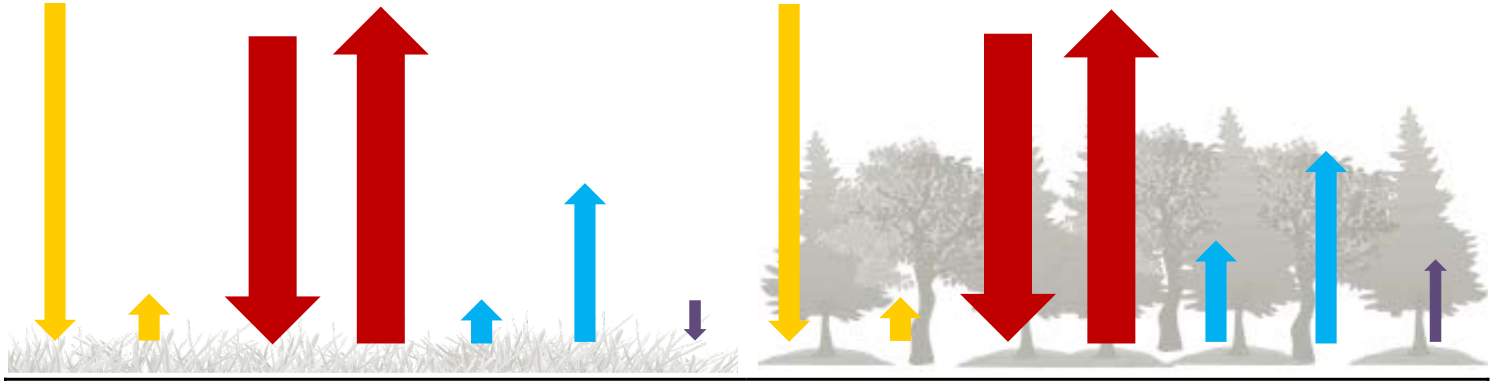
LMWG summary

- Finalizing CLM5
  - Integrate Plant Hydrodynamics and a few small code changes onto trunk
  - Parameter optimization (likely that LMWG will provide several parameter sets between now and Sept 1 as process is refined and repeated)
  - Ingest LUMIP/CMIP6 land-cover and land-use change dataset into CLM landuse timeseries file
  - Water isotopes
- Several presentations on simpler land / boundary layer models to allow for more controlled experiments in land impacts on the atmosphere
- ILAMB tutorial was well-attend, ILAMB will be integrated into CESM workflow soon

Tropical grid [6.13°N, 288.75°E]

20 year annual mean

CTRL



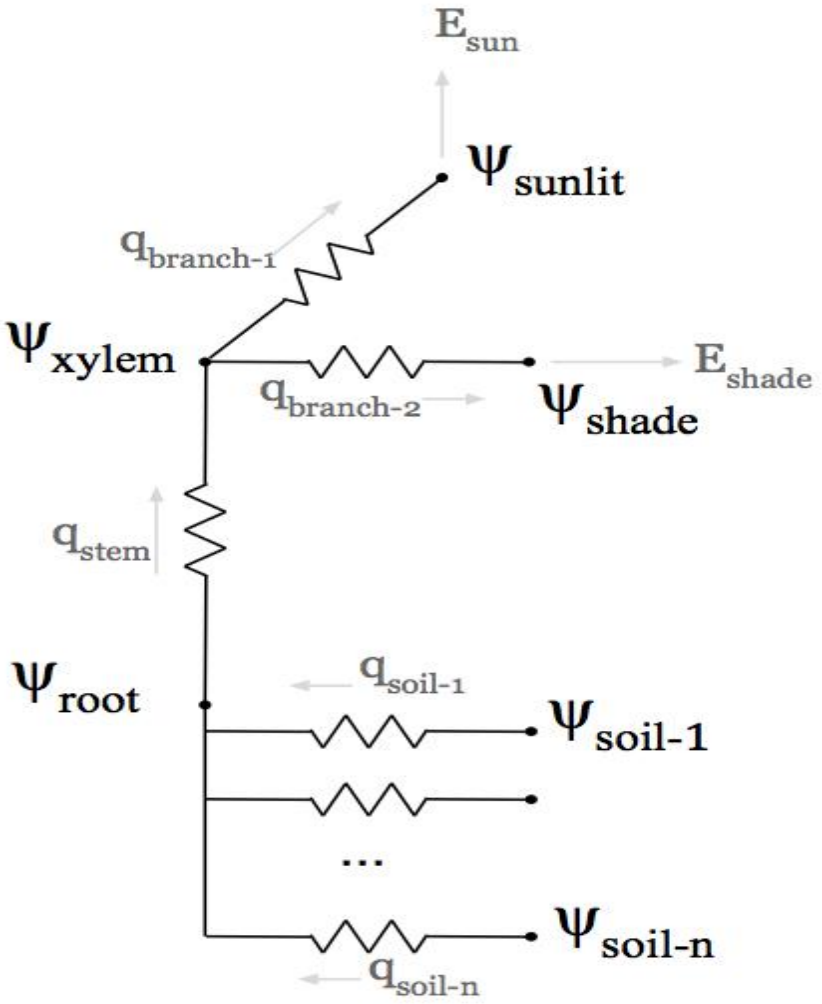
	SW↓	SW↑	LW↓	LW↑	H	λE	G	SW↓	SW↑	LW↓	LW↑	H	λE	G
[Wm^{-2}]	207.3	30.7	429.2	468.4	26.2	96.5	14.7	207.3	26.4	429.2	463.0	61.2	117.7	-31.8

PFT-COL

	SW↓	SW↑	LW↓	LW↑	H	λE	G	SW↓	SW↑	LW↓	LW↑	H	λE	G
[Wm^{-2}]	207.3	30.7	429.2	470.8	31.7	103.3	-0.04	207.3	26.4	429.2	459.3	45.2	105.6	-0.03
DIFF	--	0	--	2.4	5.5	6.8	14.74	--	0	--	3.7	16	12.1	31.77

Plant Hydraulic Stress

- Simple model to resolve water transport through the Soil Plant Atmosphere Continuum
- Water supply modeled via simple hydraulic framework
- Loss relative to unstressed transpiration modeled based on leaf-level water potential
- Water stress function used to calculate conductance, photosynthesis, and respiration



Slide courtesy Daniel Kennedy

To do list: Scientific development

Update surface dataset tool to ingest CMIP6 land use dataset

New History

- Hyde 3.2 based
- Landsat F/NF
- Multiple crop types (5)
- Multiple pasture types (2)
- Updated Forest Cover/B
- Updated Wood harvest
- Updated Shifting Cultivation
- Extended time domain (850-2015)

New Mgt. Layers

Agriculture

- Fraction of cropland irrigated
- Fraction of cropland flooded
- Fraction of cropland fertilized
- Fertilizer application rates
- Fraction of cropland tilled
- Fraction of cropland for biofuels

Crop rotations

Wood Harvest

- Fraction used for industrial products
- Fraction used for commercial biofuels
- Fraction used for fuelwood

New Future Scenarios

Six futures, SSP-based

New Resolution

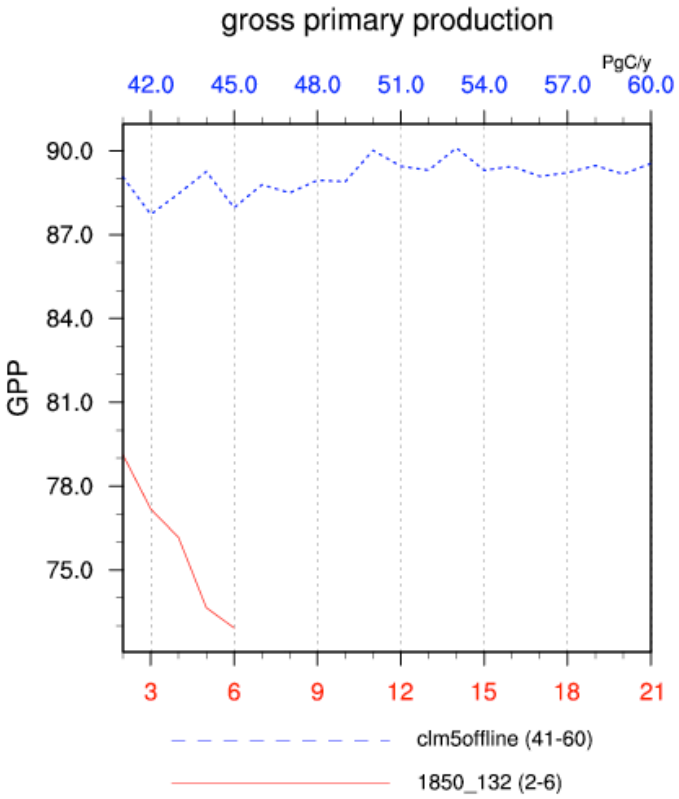
0.25°

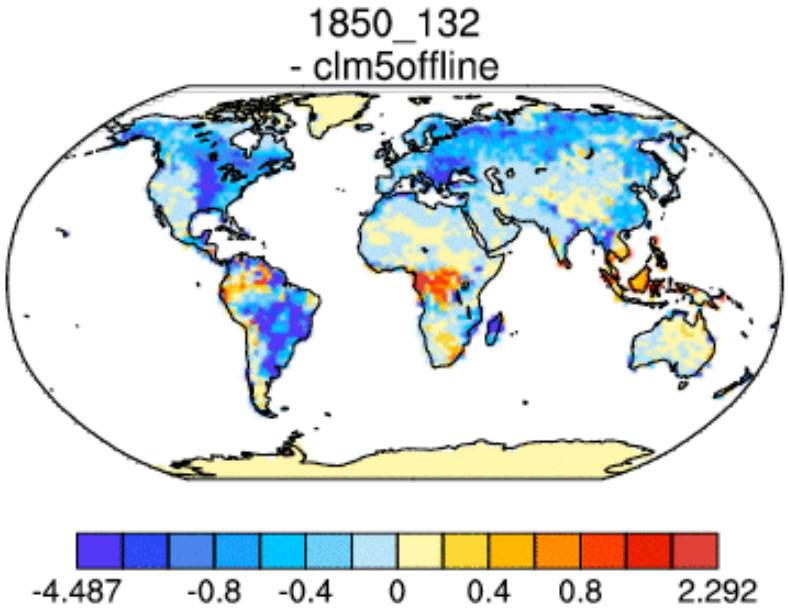
New Transition Matrix

	Pri F	Pri NF	Sec F	Sec NF	C3 Ann	C4 Ann	C3 per	C4 per	C3 N-Fix	Pasture	Rangeland	Urban
Pri F	■	■		■								
Pri NF	■	■	■									
Sec F	■	■	■	■								
Sec NF	■	■	■	■								
C3 Ann	■	■			■							
C4 Ann	■	■				■						
C3 Per	■	■					■					
C4 Per	■	■						■				
C3 N-Fix	■	■							■			
Pasture	■	■								■	■	
Rangeland	■	■								■	■	
Urban	■	■										■

~ 50x information content of CMIP5!

GPP in coupled run



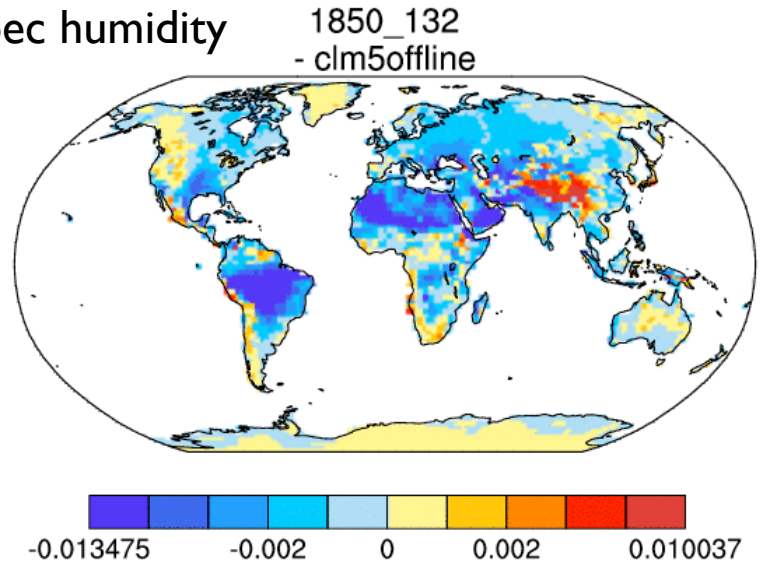


Why the systematic drop?

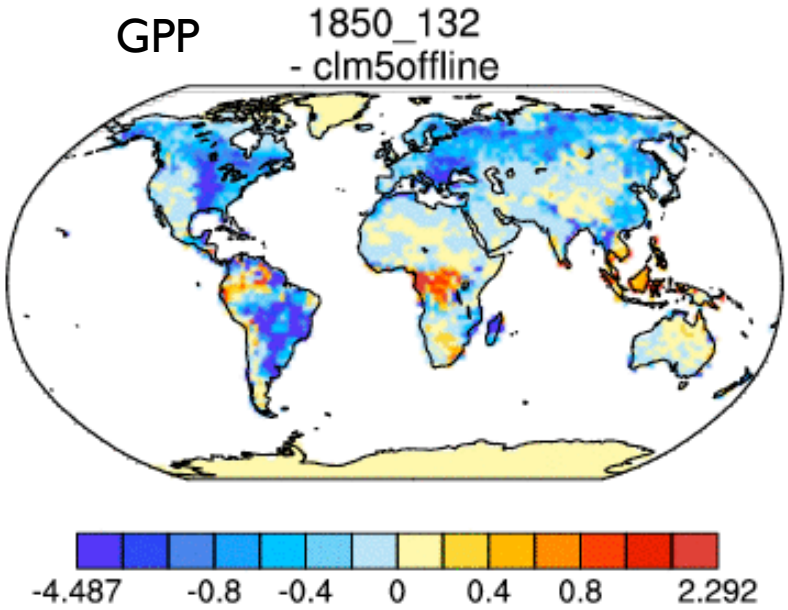
- Always a drop, but larger in this run
- Climate differences not uniform
- Forcing height
- Possibly a correlation with VPD bias in CESM
- Higher Ball-Berry or Medlyn stom conductance seem to partially alleviate

GPP in coupled run

Spec humidity



GPP

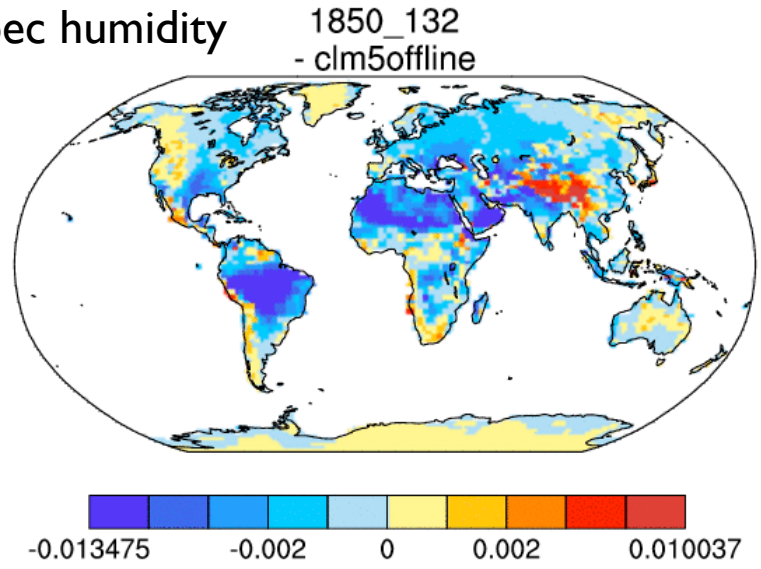


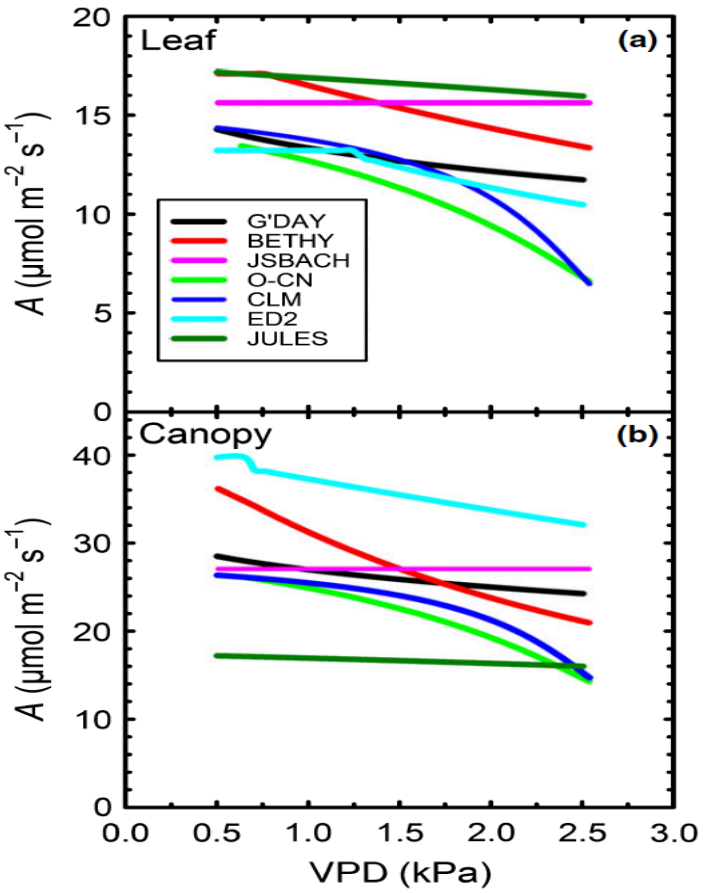
Why the systematic drop?

- Always a drop, but larger after parameter calibration
- Forcing height issues in CLM runs?
- Climate differences (T, P) generally not uniform, spec humidity more systematic lower
- Higher Ball-Berry slope params or Medlyn stom conductance seem to partially alleviate

GPP in coupled run

Spec humidity

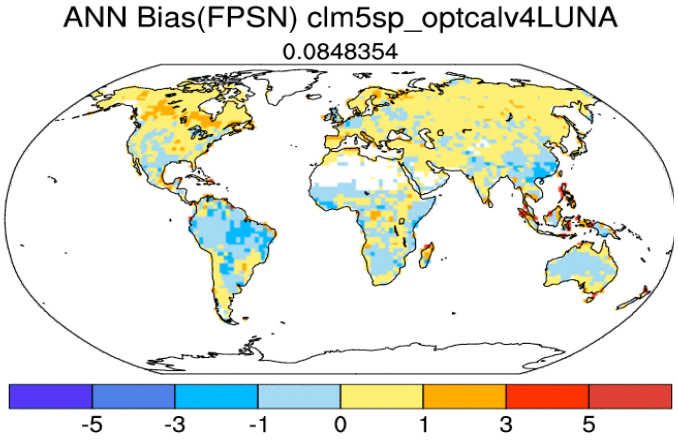


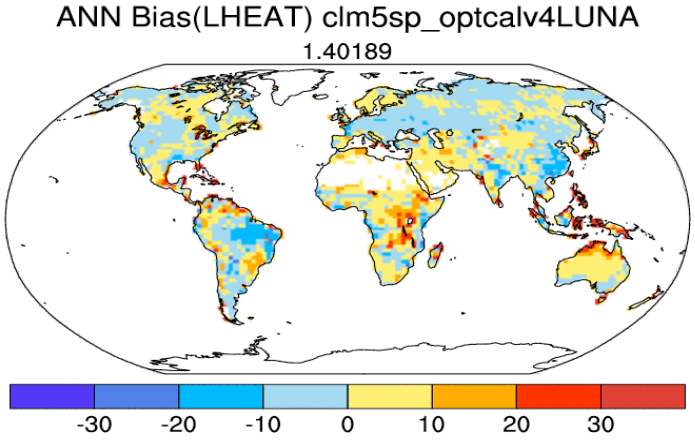


Rogers et al., 2017

CLM5SP versus CLM4.5SP

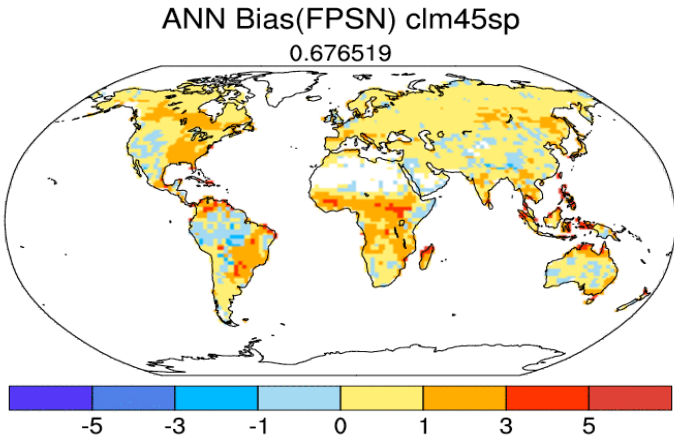
RMSE=0.78

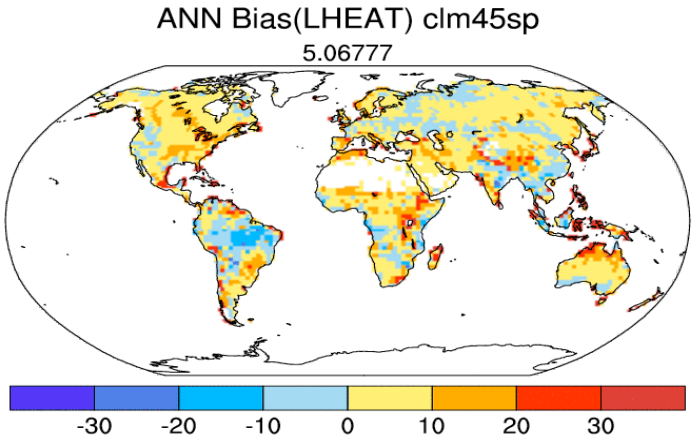




RMSE=9.52

RMSE=1.13





RMSE=12.55