Community Terrestrial Systems Model (CTSM) Update and CTSM5.1(CLMBGC) Perturbed Parameter Experiment

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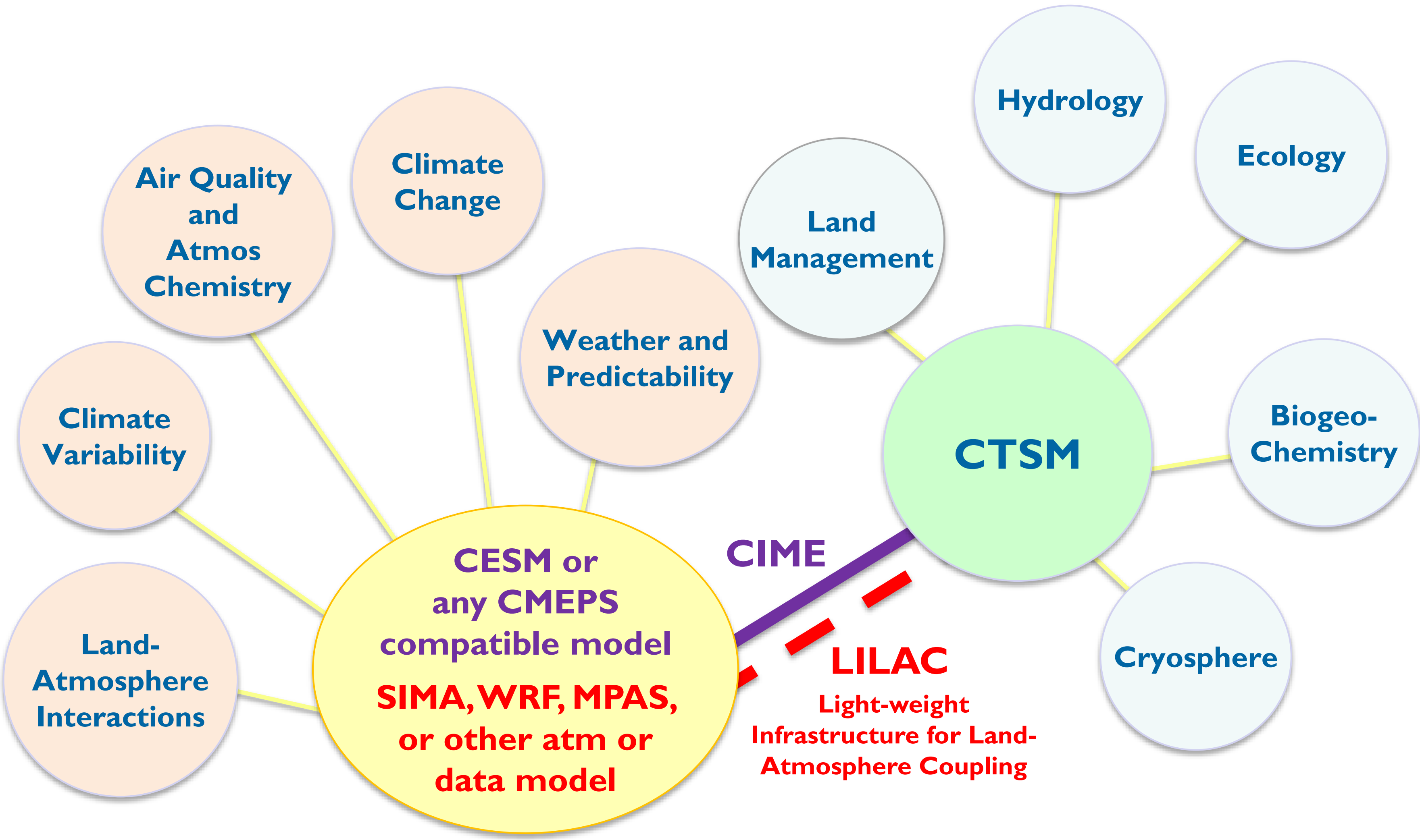
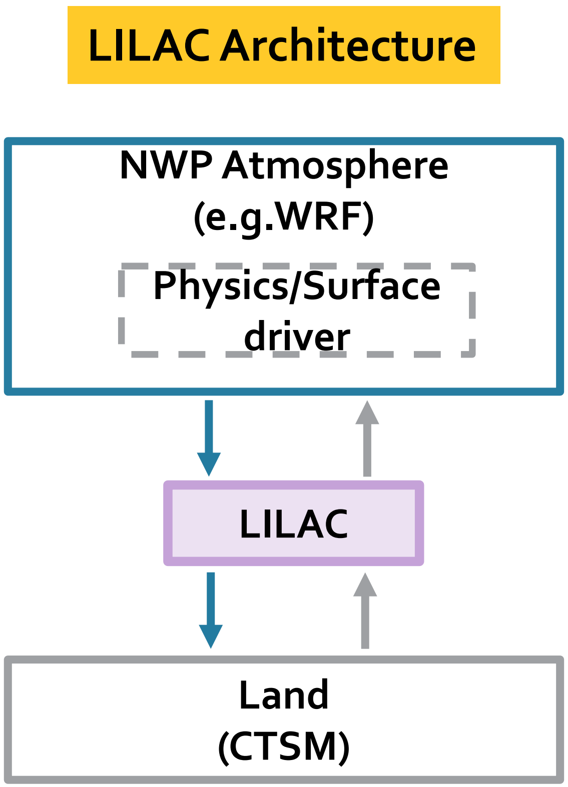
The Community Terrestrial System Model

a unified model for research and prediction in climate, weather, water, and ecosystems



WRF-CTSM coupling via LILAC



Released to community in September, 2020

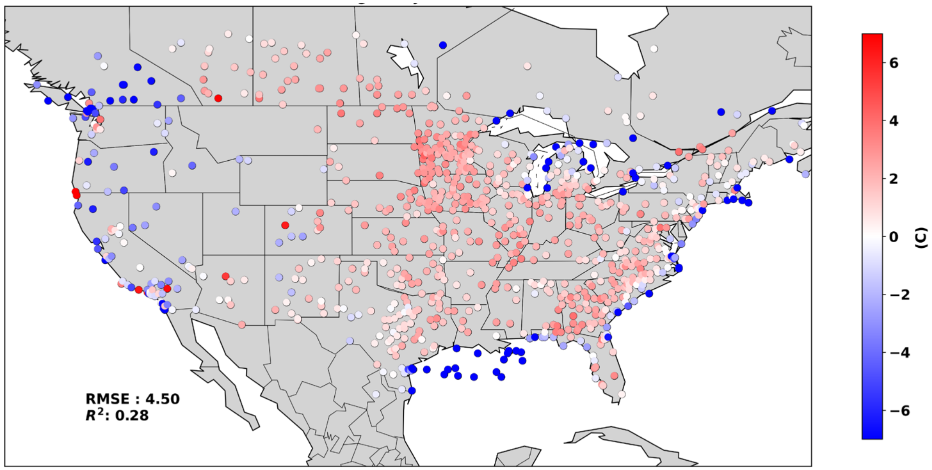
User's guide: Accessible from CTSM github wiki page

escomp.github.io/ctsm-docs/versions/master/html/lilac/specific-atm-models/wrf.html

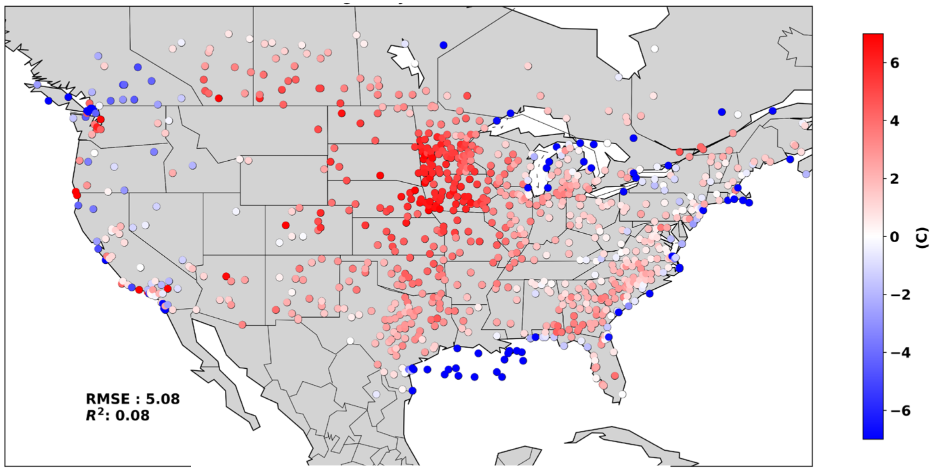
WRF Test Simulations (27km): Spectral nudged runs

Tmax bias July 2013

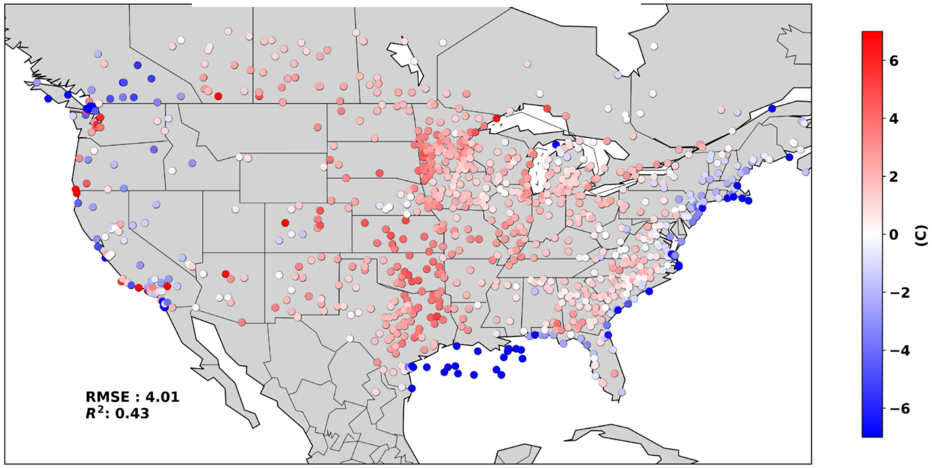
WRF-Noah



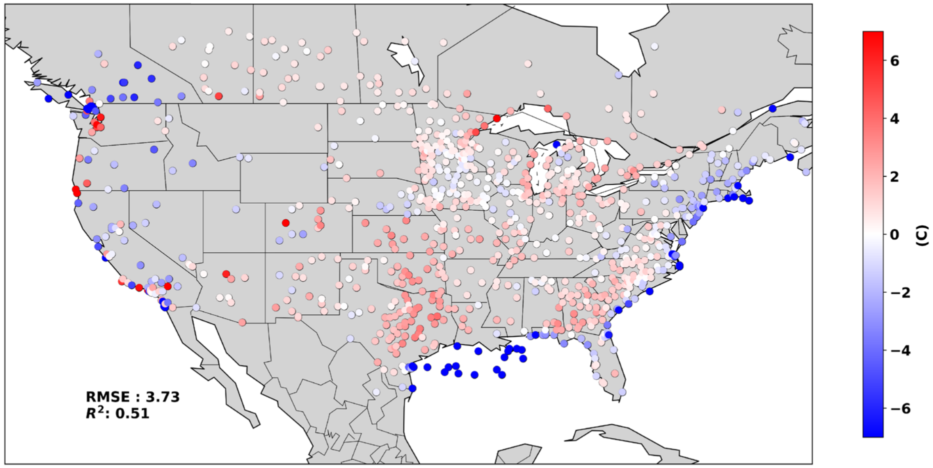
WRF-NoahMP



WRF-CTSM5(NWP)

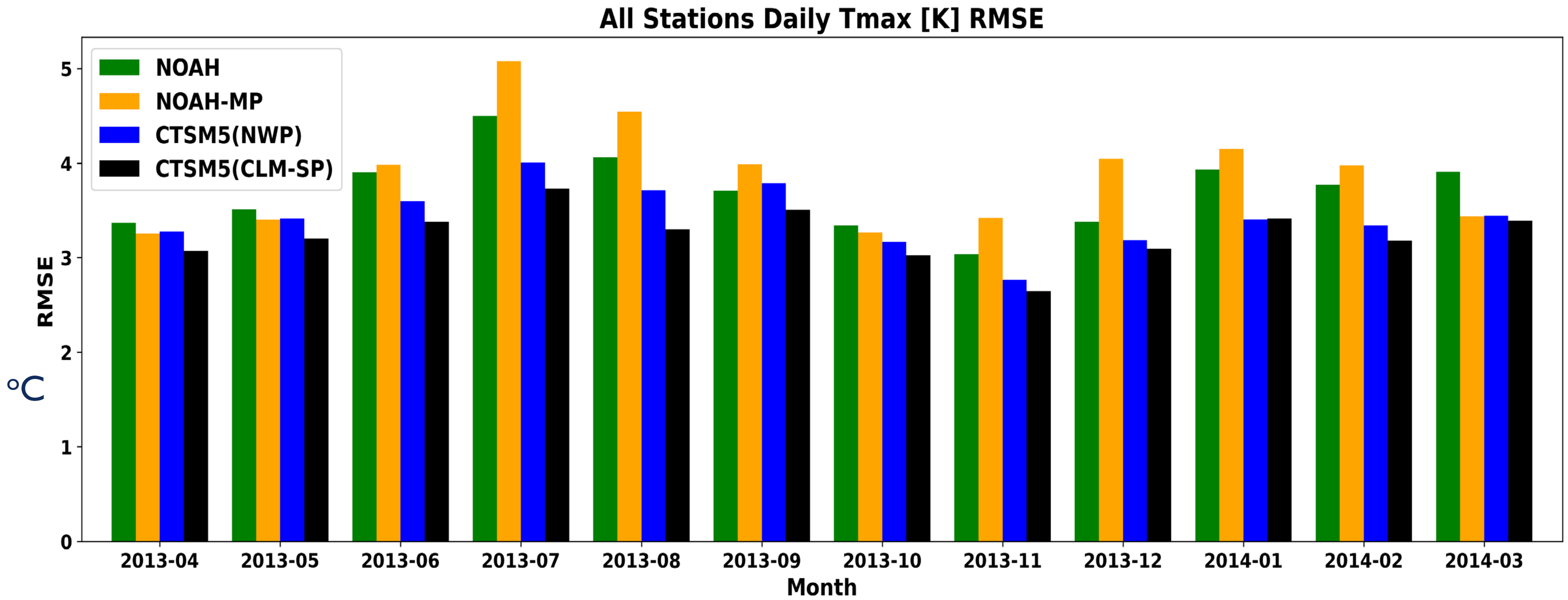


WRF-CTSM5(CLMSP)



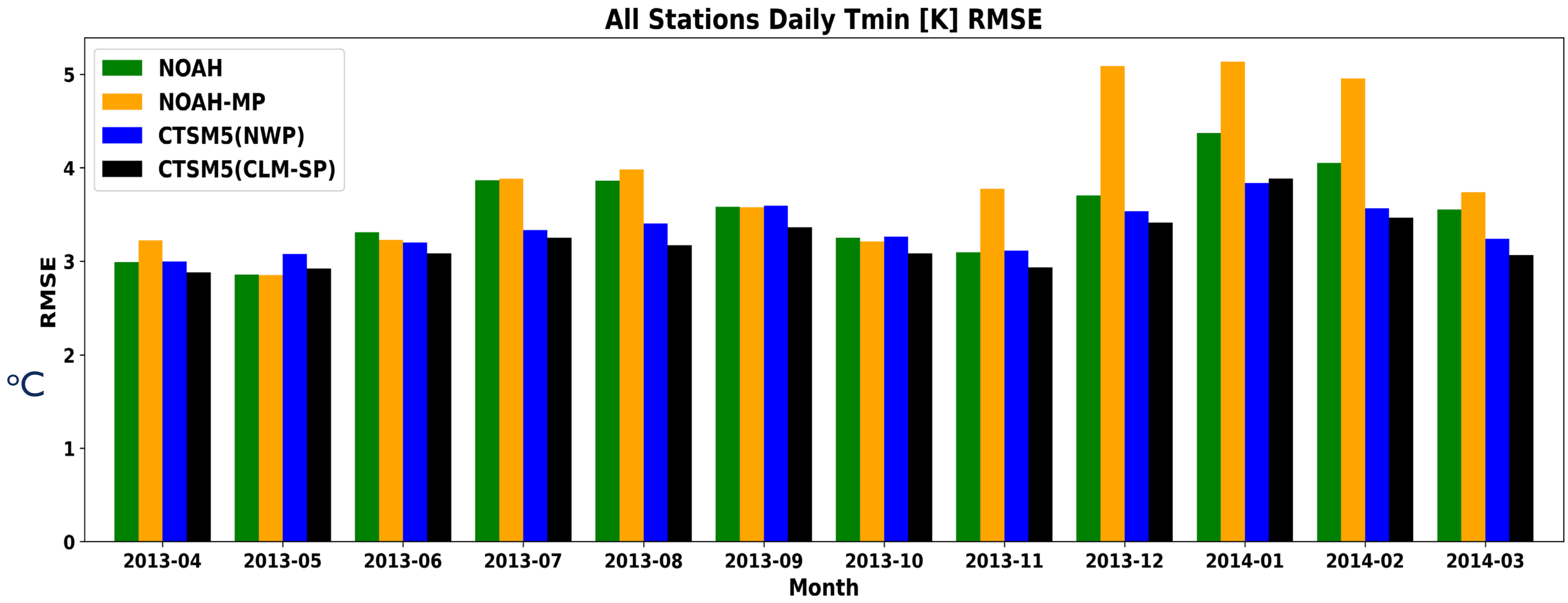
Note: WRF-CTSM5(NWP) ~15-20% more expensive than WRF-Noah

WRF Simulations (27km)



WRF-CTSM5(CLMSP) performs as well or better in all months in this test

WRF Simulations (27km)



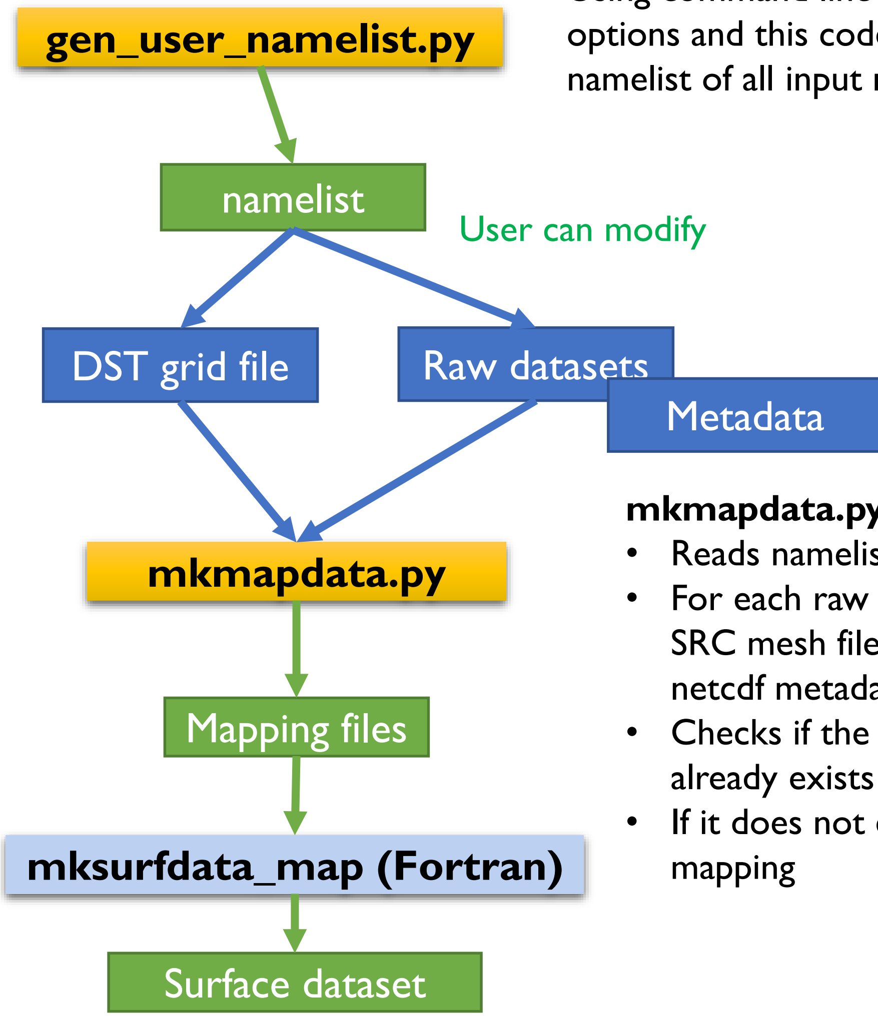
WRF-CTSM5(CLMSP) performs as well or better in all months in this test

But, it IS more expensive: WRF-CTSM5(NWP) is 5% slower than WRF-NoahMP
WRF-CTSM5(CLMSP) is **40%** slower than WRF-NoahMP

CTSM: Refactor of surface dataset generation toolchain

Benefits:

- Two clear steps for creating the surface dataset
- User has option to stop at making namelist, mapping files, or sfc dataset
- User need not be aware of intermediate (a) mapping files, (b) fortran namelist, (c) landuse.txt file
- No need for separate SRC mesh file paths; script chooses appropriate path for each raw dataset



gen_user_namelist.py
Using command line arguments the user sets options and this code creates a user-friendly namelist of all input raw datasets

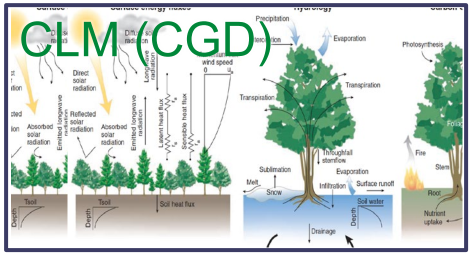
Metadata from raw datasets include SRC grid files

mkmapdata.py

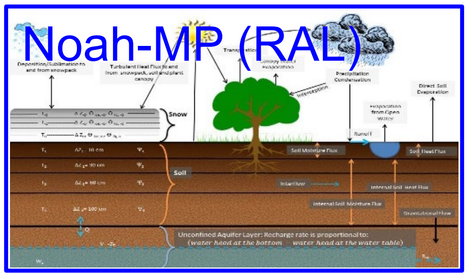
- Reads namelist for DST mesh file
- For each raw dataset in namelist, finds SRC mesh file and mask from the netcdf metadata
- Checks if the weight (mapping file) already exists or not (creates if not)
- If it does not exist, it creates the mapping

The Community Terrestrial Systems Model

CLM (CGD)

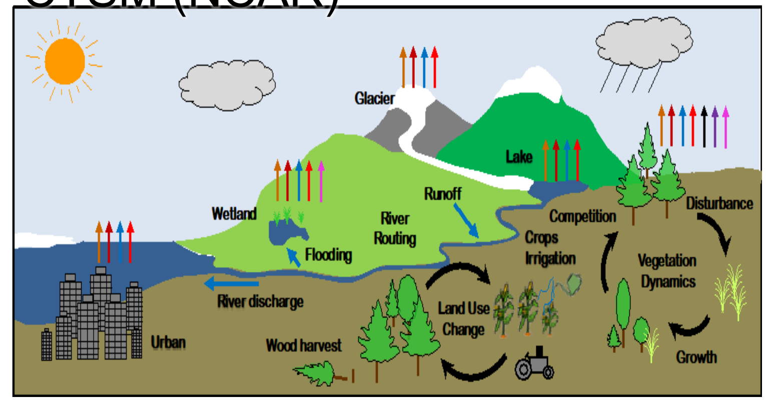


Noah-MP (RAL)



unified design

CTSM (NCAR)



for research and prediction in climate, weather, water, and ecosystems

Next steps (not necessarily in order)

- CTSM5.1 and 5.2 'physics' development (see Will's talk)
- CTSM overview paper, including rationale, description of capabilities, and WRF-CTSM assessment
- Finalize surface dataset creation workflow
- Initialization of BGC configurations for regional high-res models
- Evaluation in high-resolution (~3km) forecast mode
- Finish hydrology refactor
- LILAC coupling to COSMO, MPAS, LIS, and other regional models
- Distributed hydrology from NoahMP, WRF-Hydro

The CTSM5.1(CLMBGC) Perturbed Parameter Ensemble Project

Dave Lawrence, Katie Dagon, Daniel Kennedy, Keith Oleson, Rosie Fisher, Forrest Hoffman, Ben Sanderson, Charlie Koven, Erik Kluzek, Danica Lombardozzi, Nate Collier, Will Wieder, Gordon Bonan, and …

NCAR U.S. DEPARTMENT OF ENERGY | Office of Science RUBISCO NSF

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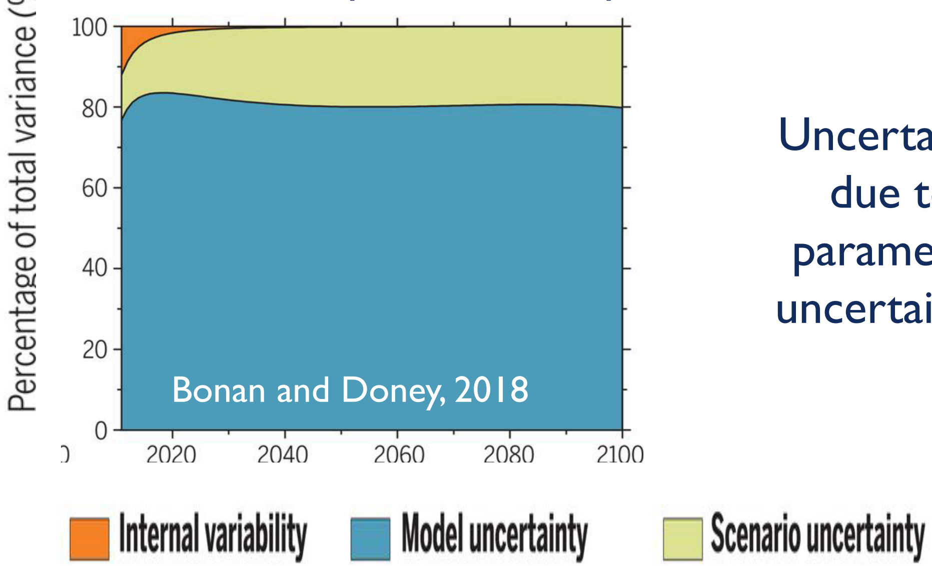
CTSM5.1(CLMBGC) Parameter Perturbation Ensemble (PPE)

Goals:

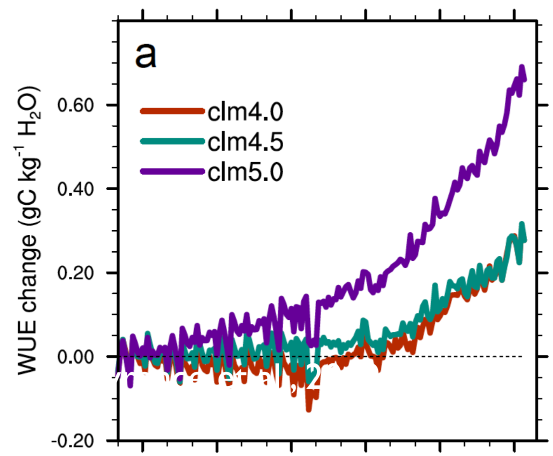
- Complete comprehensive parameter uncertainty assessment and calibration of full CLM5.1BGC model
- Develop infrastructure for easy PPEs and global parameter estimation
- Explore sensitivity of a range of features of global coupled land system to reasonable uncertainty in model parameter values

Land carbon cycle uncertainty



Uncertainty due to parameter uncertainty?

Water use efficiency trends: Structural uncertainty



Bonan and Doney, 2018

Lawrence et al, 2019

CLM5 Parameter Perturbation Ensemble (PPE): Project Phases

Phase 0: Infrastructure development

Phase 1: One-at-a-time parameter ensembles under range of environmental perturbations

Phase 2: Latin-hypercube ensemble with most 'important' parameters

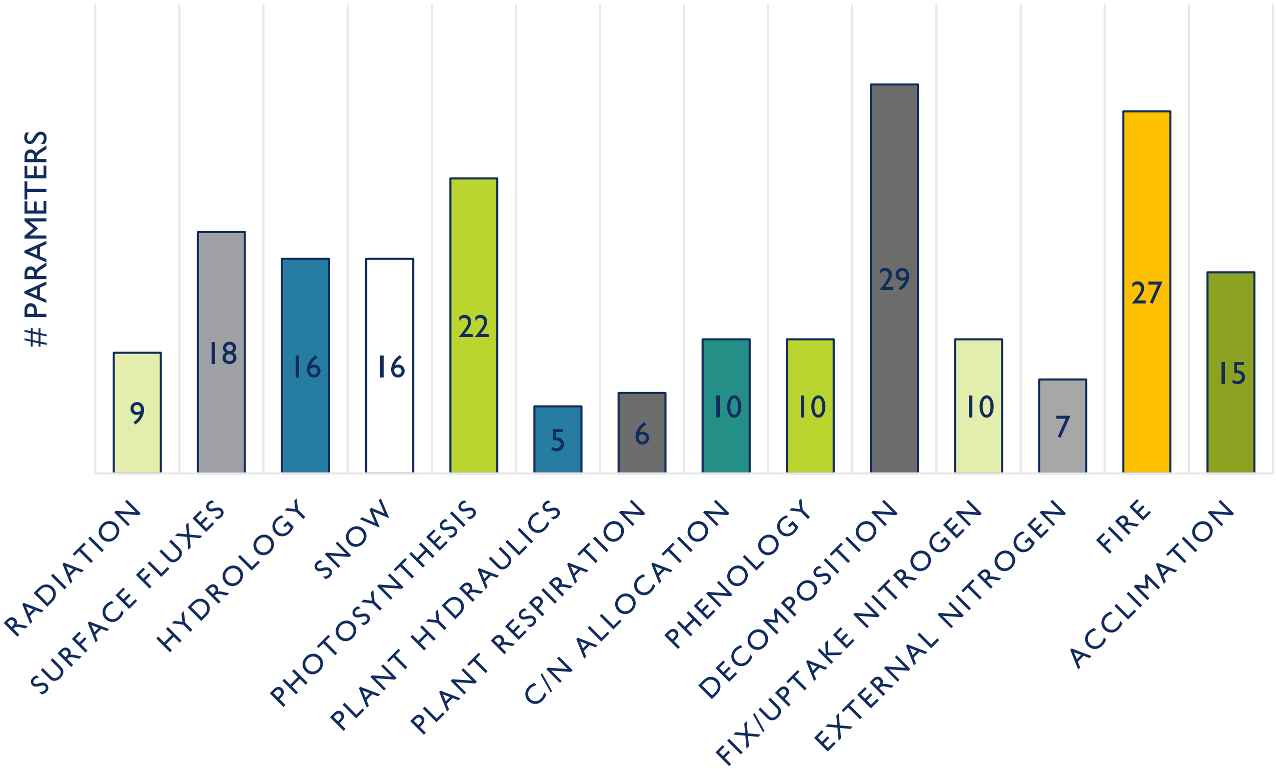
Use neural network to develop emulator of CLM output

Phase 3: Identify optimized parameter sets based on multi-objective calibration targets

Run 200-member ensemble of global transient simulations with reasonable parameter sets

Phase 0: Infrastructure development - Parameters

- Identified ‘all’ CLM5 parameters (>200)
- Extract hard coded parameters to input parameter file (>100 parameters moved to parameter file)
- Catalog all parameters and reasonable ranges in ‘living’ document



Phase 0: Infrastructure development - Parameters

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CLM5 Parameter List

File Edit View Insert Format Data Tools Add-ons Help Last edit was made 4 days ago by Keith Oleson

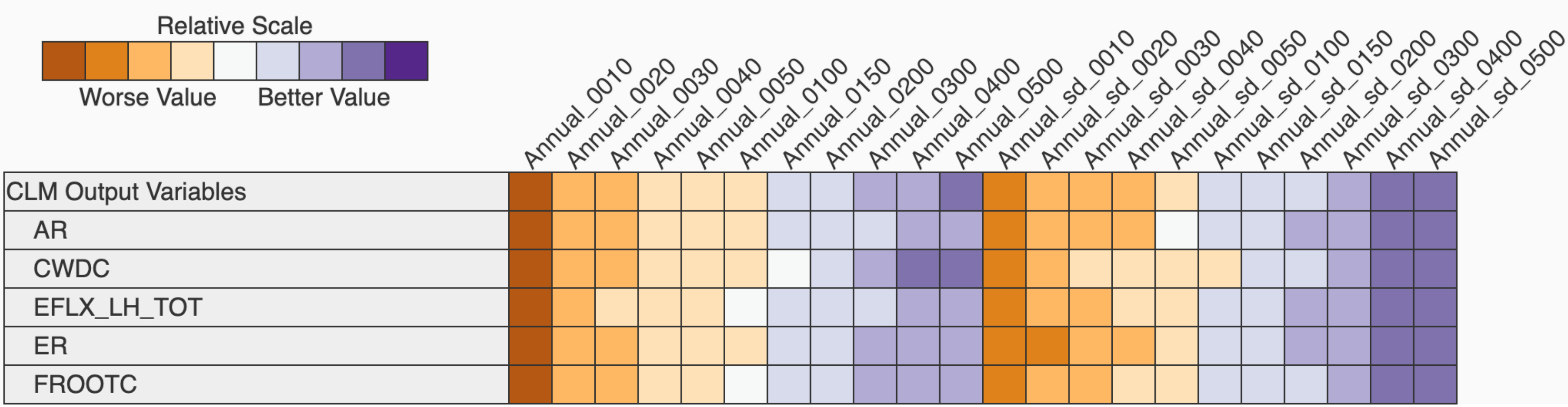
name	min	max	comments?	Description
should match the name on paramfile or namelist	low side perturbation	high side perturbation	feel free to add any comments below **ok, to write XXpercent, in lieu of absolute range**	this and the columns farther right not currently essential, but of course feel free to peruse and/or add information
Photosynthetic capacity (LUNA)				
slatop	pft	pft		specific leaf area at the canopy top
jmaxb0	0.01	0.05		the baseline proportion of nitrogen allocated for electron transport (J)
jmaxb1	0.05	0.25	This is Jmaxb1 in the code (note the capital J)	the baseline proportion of nitrogen allocated for electron transport (J)
Plant hydraulics				
kmax	pft	pft	see https://github.com/ESCOMP/CTSM/issues/1162 for how I chose kmax/krmax	Plant segment max conductance

Phase 0: Sparse grid

Cluster Analysis on transient simulation, assessed on mean and interannual s.d. for ~20 forcing and carbon, water, and energy state and flux variables

- With about 300-400 clusters, can reasonably replicate 2º global mean and transient model output
- Fast and cheap: 4 pe-hrs/yr
- Fast spinup: w/ CN Matrix (Lu et al., JAMES, 2020), full C/N spinup in ~120 years
- 1million pe-hrs = ~2000 parameter perturbation simulations, incl. spinup

Use ILAMB to assess reconstructed output against 2º simulation 'truth'



Phase 0: Scripting infrastructure

Automated scripts to:

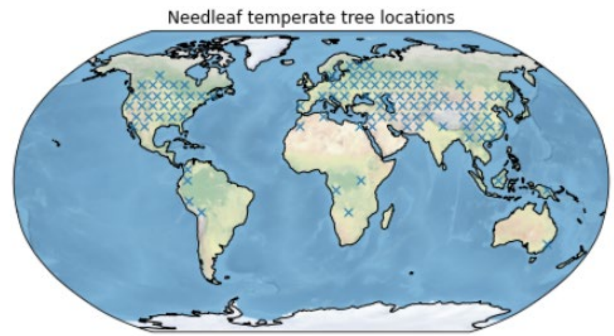
- Setup cases
- Manipulate parameter values
- Execute and check spinup
- Conduct ensembles

Scripts are generalizable enough for other CIME-based model components (e.g., components of CESM, SIMA, etc)

Analysis scripts using Jupyter notebooks in development to reduce barriers-to-entry for exploration and analysis by multiple collaborators

jupyter nbviewer

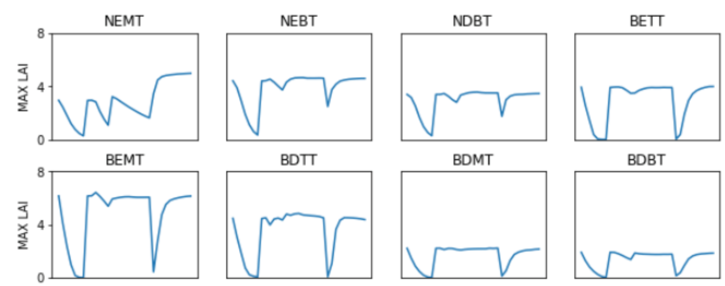
In [9]:
```
fig = plt.figure(figsize=(8, 4))
ax = fig.add_subplot(1, 1, 1, projection=ccrs.Robinson())
ax.set_global()
ax.stock_img()
ax.coastlines()
ax.plot(lons, lats, 'x', transform=ccrs.PlateCarree())
plt.title('Needleaf temperate tree locations');
```



In [8]:
```
plt.figure(figsize=[10,8])
for i in 1+np.arange(15):  #loop through the 15 pfts

    #analysis bits
    ixpft = ds['pfts1d_itype_veg']==i
    maxlai = ds['TLAI'].isel(pft=ixpft).max(axis=1).mean(axis=1)

    #plotting
    plt.subplot(4,4,i)
    plt.plot(maxlai)
    if (i==1)|(i==5)|(i==9)|(i==13):
        plt.ylabel('MAX LAI')
        plt.yticks([0,4,8])
    else:
        plt.yticks([])
    if i>11:
```

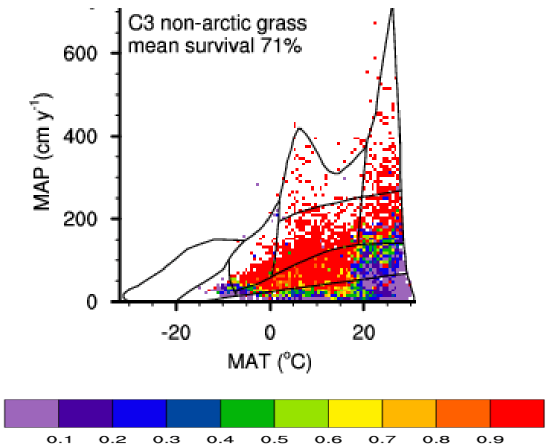


Phase 1: One-at-a-time parameter sensitivity

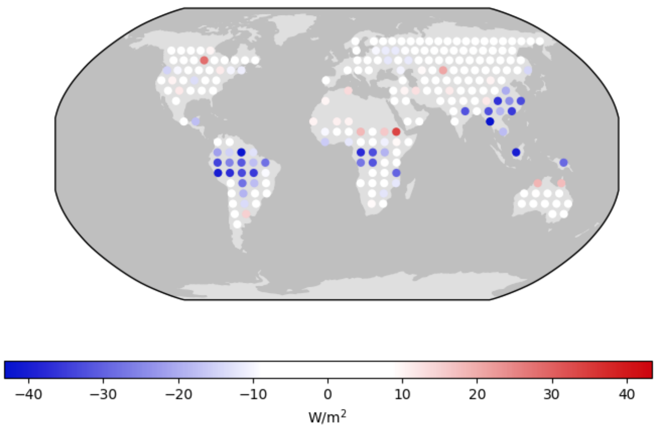
Ensemble of one-at-a-time low/high param value simulations

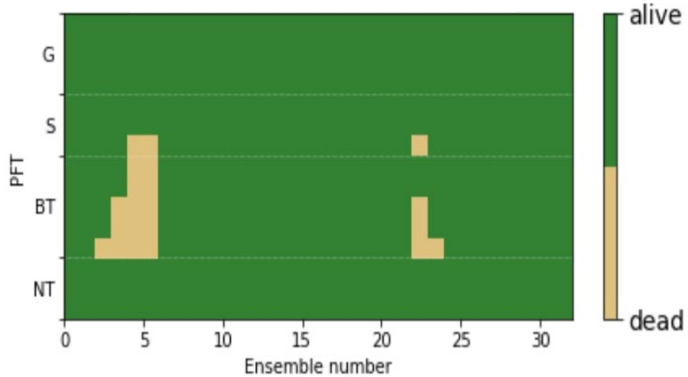
- Each simulation checked for reasonableness
  - Plant survivability rate within 30% control, reasonable max LAI
  - GPP, LH within +-30% of observed (ILAMB)
- If run with particular parameter value doesn't pass checks, constrict parameter range and run again

PFT survival



LH Bias

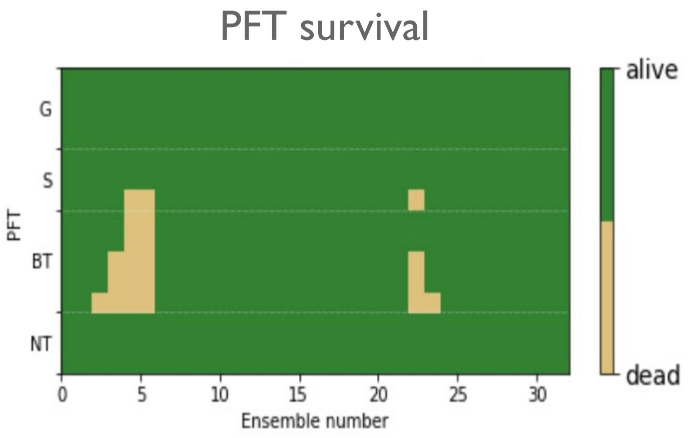




Phase 1: One-at-a-time parameter sensitivity

Parallel ensembles with environmental perturbations

- Climate: 1850 and SSP3-7 CESM2 climate
- CO_2: 1850 and SSP3-7
- N-dep: +5 gN/m2/yr
- *Last Glacial Maximum conditions*
- Restrict parameter ranges again if low-side environmental perturbation doesn't pass reasonableness checks



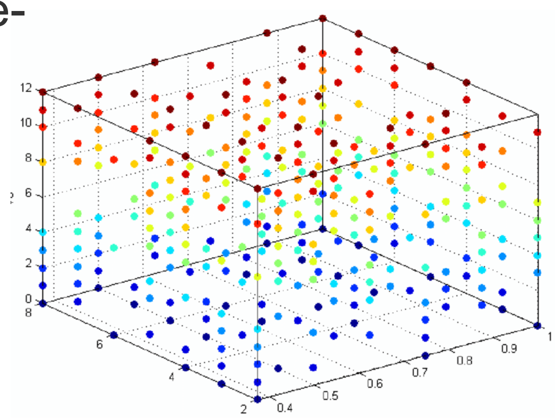
Phase 2: Latin-hypercube ensemble

1. Select ~50 ‘most important’ parameters

- Following Dagon et al., 2020, ‘objectively’ select parameters that have most significant impact on range of key carbon, water, energy flux and state variables for
    - Mean state and variability
    - Non-overlapping spatial patterns
    - Response to environmental perturbations

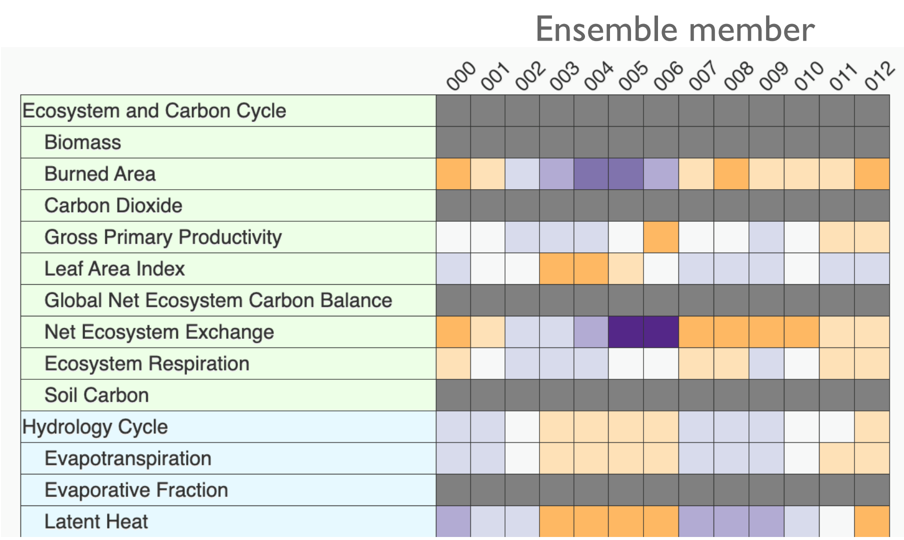
2. Run sparse grid simulations with ~2500 Latin hypercube-defined parameter sets

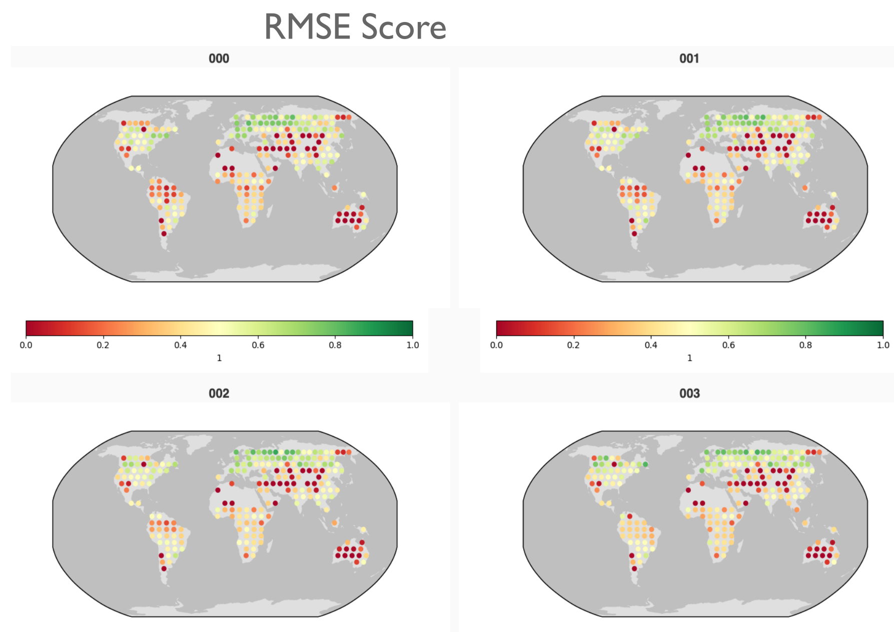
- Present-day climate (1.5 million pe-hrs)
- Environmental perturbations



Phase 3: Global transient 2° simulations

- With Phase 2 Latin Hypercube ensemble output, use neural network to develop emulator of CLM5 output based on parameter settings (Dagon et al., in review)
- Select ~200 'best' parameter sets (selection criteria TBD, ILAMB?)





- Run full spinup and transient historical/projection period 2° simulations

We need people to help analyze these ensembles!
Contact me if interested