The Community Terrestrial Systems Model (CTSM)

Facilitating the Transition of Land Model Research to Operations for Applications Spanning Weather to Climate

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https://github.com/escomp/ctsm

NCAR

NSF

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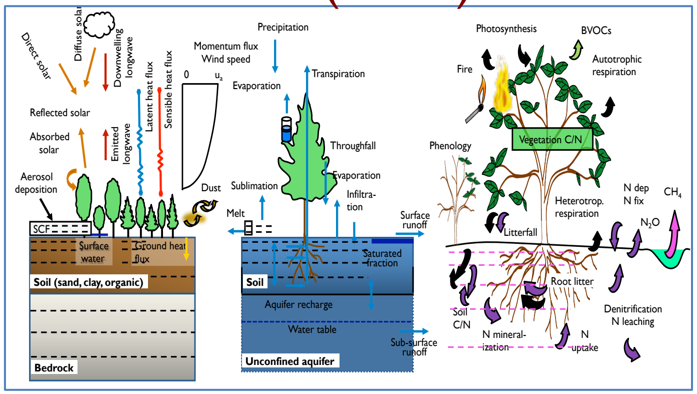
The Community Terrestrial System Model

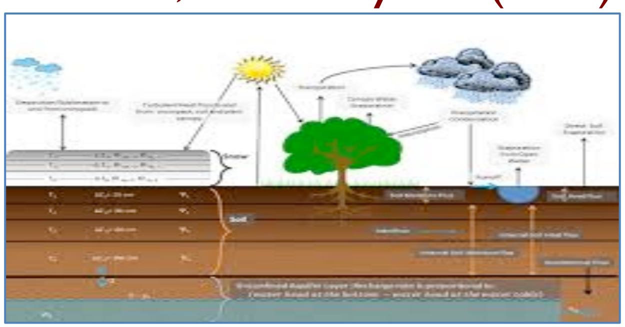
a unified model for research and prediction in climate, weather, water, and ecosystems

CLM (CGD)



SUMMA concepts → CTSM

Noah-MP, WRF-Hydro (RAL)



CTSM (unification) benefits:

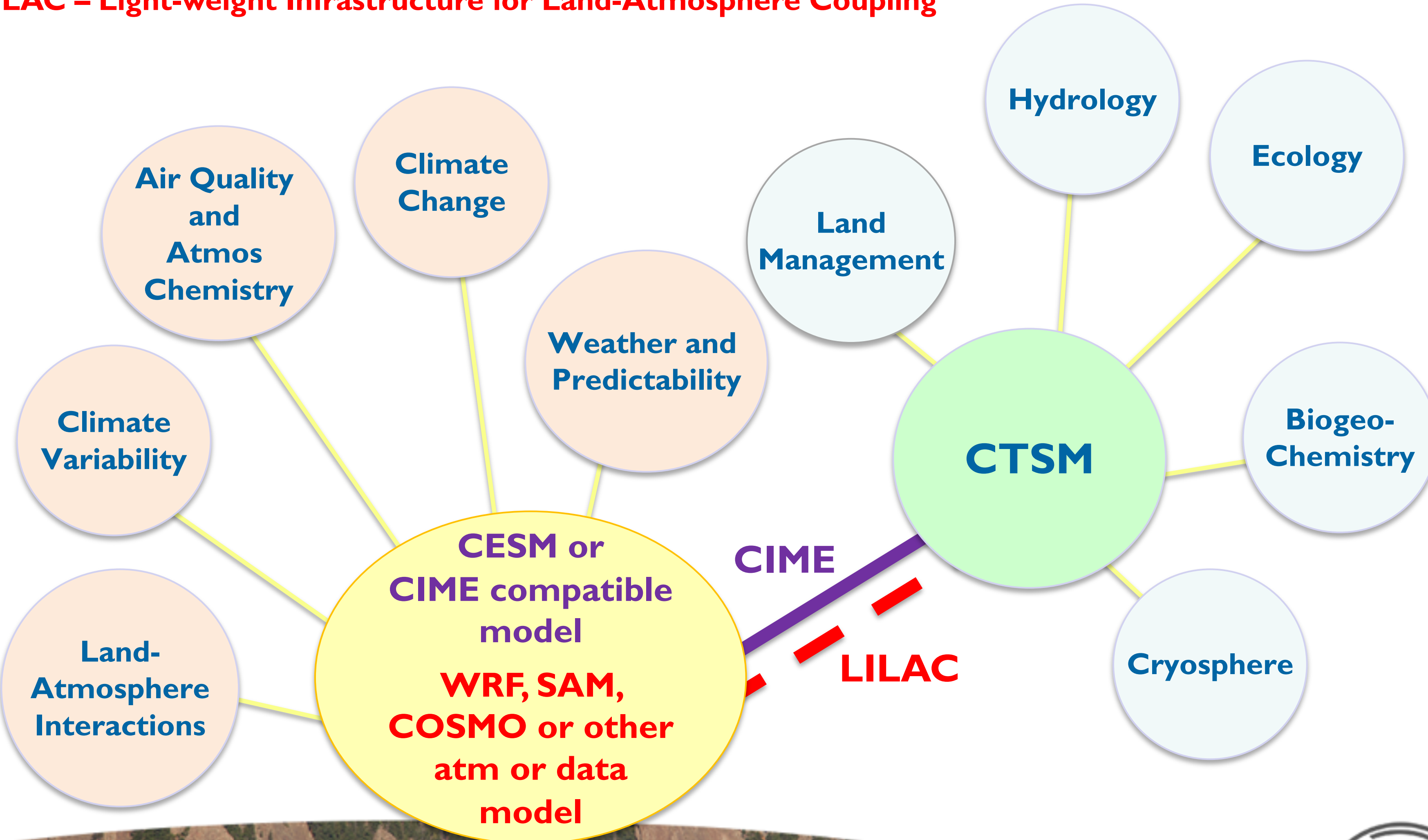
- extend leadership in community modeling
- reverse trends of model proliferation and shantytown syndrome
- more efficient use of NCAR and community model development resources
- accelerate advances, improve science through multiple hypothesis testing
- facilitate transfer of land model advances to operations

CTSM software improvement goals:

- reduce accumulated technical debt
- clean separation of flux params and numerical solution
- modularity; alternative hypotheses
- hierarchy of complexity (climate, NWP, water, and ecology applications)
- flexibility of spatial disaggregation

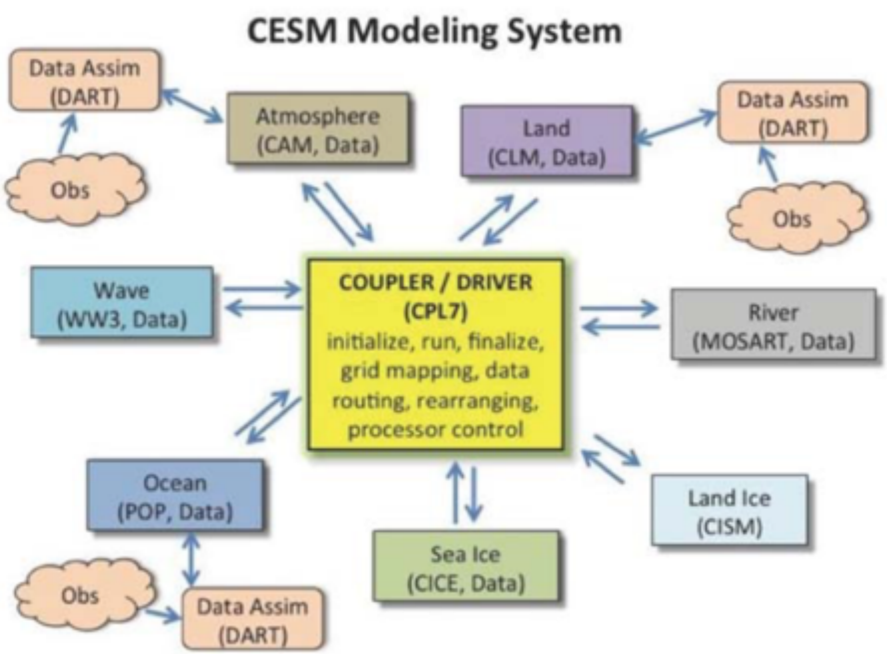
Community Terrestrial Systems Model (CTSM) as a community modeling tool

LILAC – Light-weight Infrastructure for Land-Atmosphere Coupling

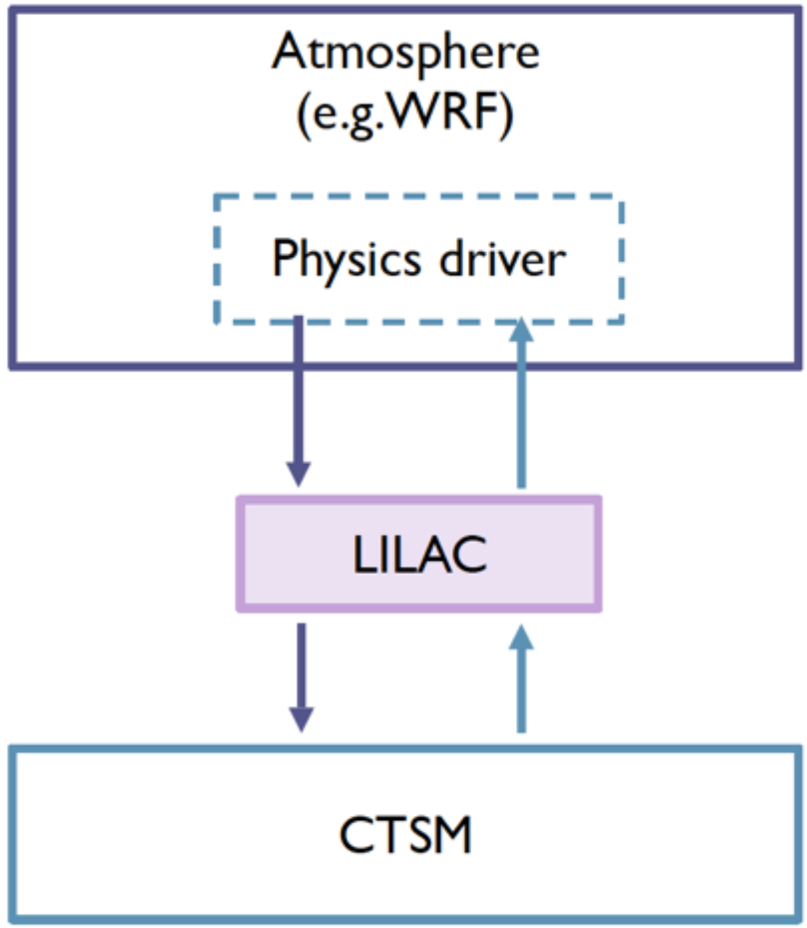


CESM vs LILAC coupling architecture

CESM hub and spoke architecture



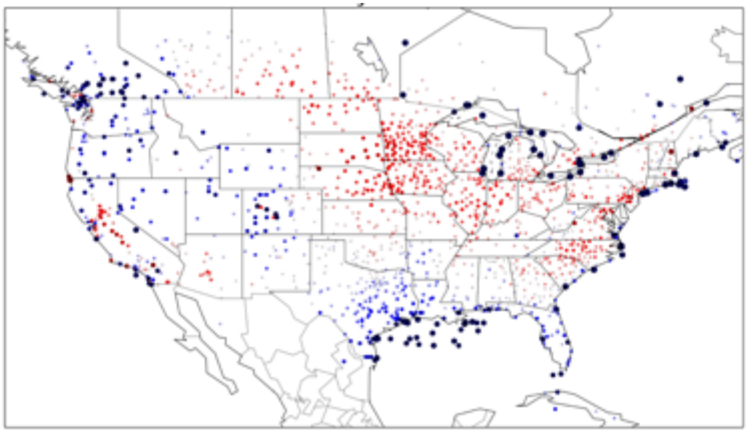
LILAC architecture



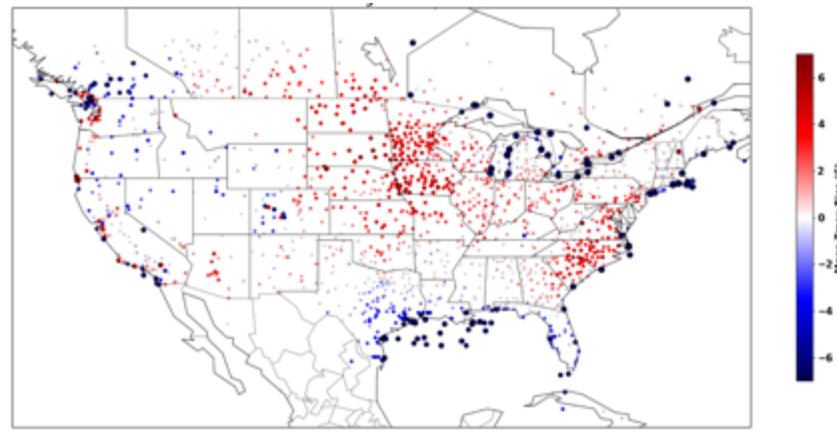
WRF-CTSM5(NWP) Test Simulations (27km)

Tmax bias over US for July 2013

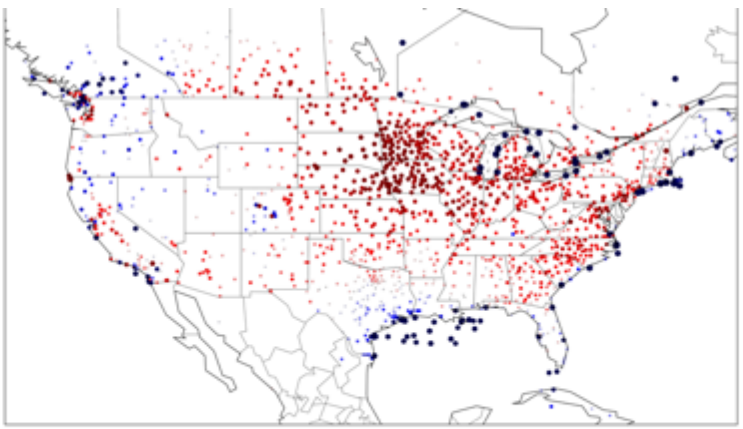
WRF-Noah

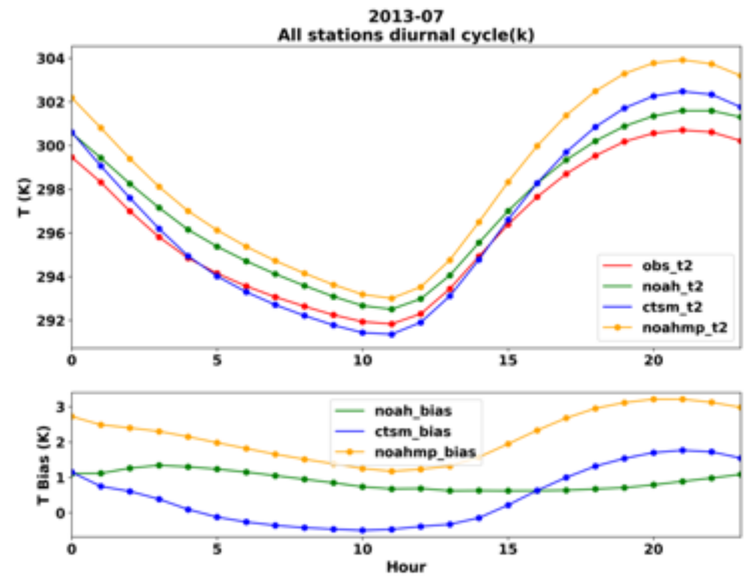


WRF-CTSM5(NWP)



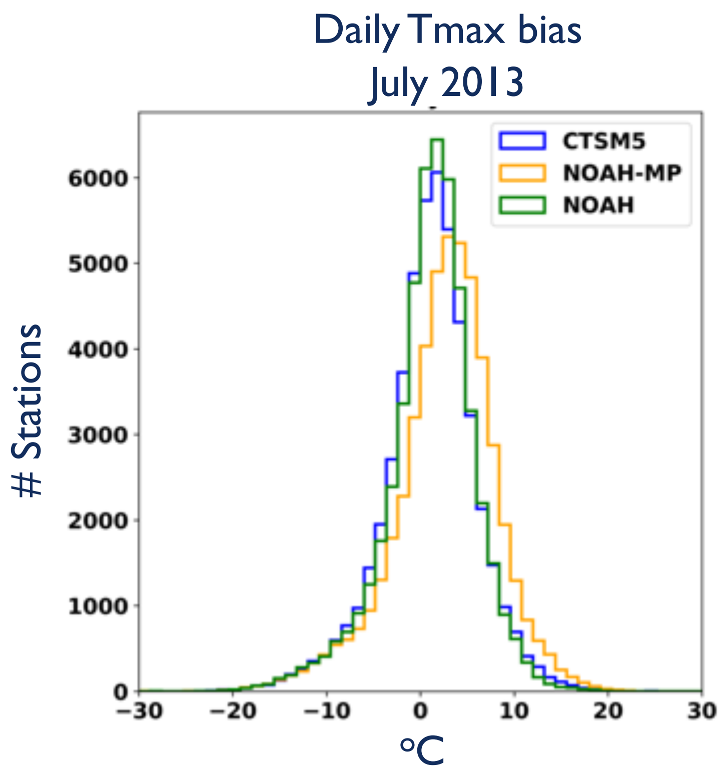
WRF-NoahMP

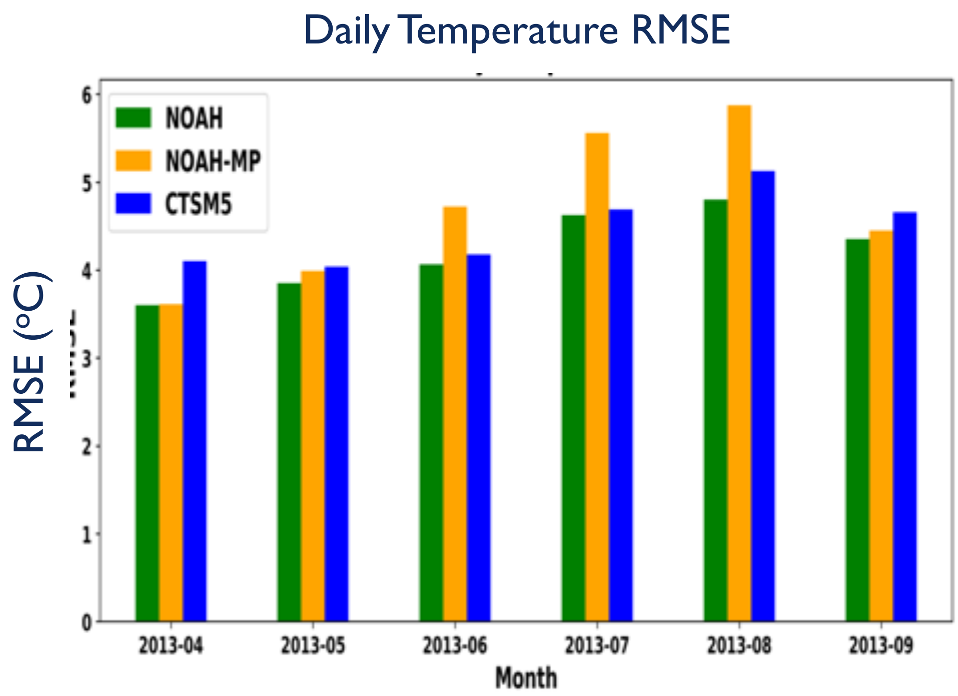




Note: WRF-CTSM5(NWP) ~15-20% more expensive than WRF-Noah

WRF-CTSM5(NWP) Test Simulations (27km)



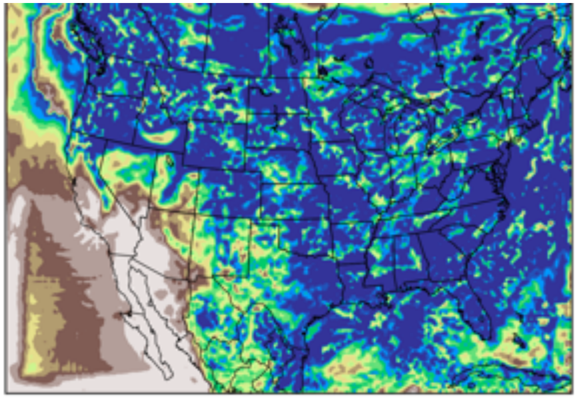


Surface air temperature simulation with different land models is roughly equivalent, with strengths and weaknesses seen for each model

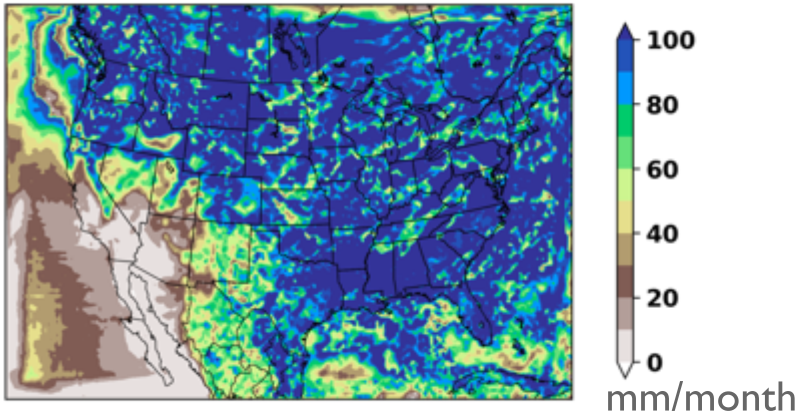
WRF-CTSM5(NWP) Test Simulations (27km)

Precipitation

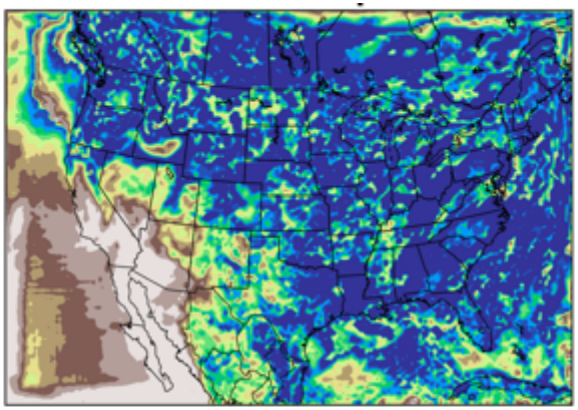
WRF-Noah



WRF-CTSM5(NWP)



WRF-NoahMP



Precipitation needs more analysis, but initial assessment does not show any clear deficiencies in WRF-CTSM5(NWP)

WRF-CTSM unsupported release

WRF 'feature branch' with CTSM, coupled with LILAC, to be released to friendly users by end of June

- Runs on Cheyenne, no guarantees about other systems
- Use at own risk
- Will include documentation about how to get the code, and how to build, configure, initialize, and execute runs
- Out-of-box support for CONUS 27km grid
- Capability to define new grids (we can help)
- Feedback from friendly users welcome and encouraged
- Targeting a full release with April 2021 WRF update

- Note: Fei Chen has run WRF-CTSM5(NWP) CONUS, so …
- More details at https://github.com/escomp/ctsm

CTSM configurations

- Climate and weather applications share same physics (currently physics version 5)
- Configurations (default, mixing and matching possible, emphasis on flexibility)
  - CTSM5(NWP) – emphasis on speed; single dominant landunit, single dominant PFT, 5 soil layers, 5 snow layers, plant hydraulics off, prescribed vegetation state, reduced canopy flux iterations
  - CTSM5(CLMSP) – full subgrid complexity, PHS on, prescribed vegetation state, land-cover change
  - CTSM5(CLMBGC-crop) – as CLMSP, but with prognostic biogeochemistry and global crop model, land-cover and land-use change
  - CTSM5(FATES) – experimental; as CLMBGC with full ecosystem demography model
  - CTSM5(HP) – hydrologic prediction; TBD

CTSM5 Parameter Perturbation Ensemble (PPE)

- Explore sensitivity of various features of land system to reasonable uncertainty in model parameter values
- Quantify parameter uncertainty effects on long-term trajectory of terrestrial carbon and water dynamics under climate change
- Generalizable enough for other CESM components

CTSM5 Parameter Perturbation Ensemble (PPE)

1. Identify full list of CTSM5 parameters
   - Scour code for 'all' CTSM5 parameters, ~200 so far
   - Move any hard coded parameters to parameter file (Keith has moved 60 parameters onto parameter file
   - List all parameters in spread sheet with reasonable ranges

CTSM5 Parameter Perturbation Experiment (PPE)

CLM5 Parameter List

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B	C	D	E	F
name	location	min	max	comments?
should match the name on paramfile or namelist	Location of parameter: PFT params file (P), Namelist (N), or Hard coded (H)	low side perturbation	high side perturbation	feel free to add any comments below
Radiation parameters				Table 3 of Majasalmi and Bright has uncertainty values on the optical parameters
taulnir	P	pft	pft	https://nibio.brage.unit.no/nibio-xmlui/bitstream/handle/11250/2635910/2019_10_5194_gmd_12_3923_2019.pdf?sequence=2
taulvis	P	pft	pft	These are both absolute (not relative) and PFT specific and so their interpretation depends on whether we are using their updated values or not. If we are, it is pretty trivial to implement the PFT-specific standard errors they provide (RF)
tausnir	P	20percent	20percent	
tausvis	P	20percent	20percent	
rholnir	P	pft	pft	
rholvis	P	pft	pft	
rhosnir	P	20percent	20percent	
rhosvis	P	20percent	20percent	
xl	P	pft	pft	

CTSM5 Parameter Perturbation Experiment (PPE)

CLM5 Parameter List

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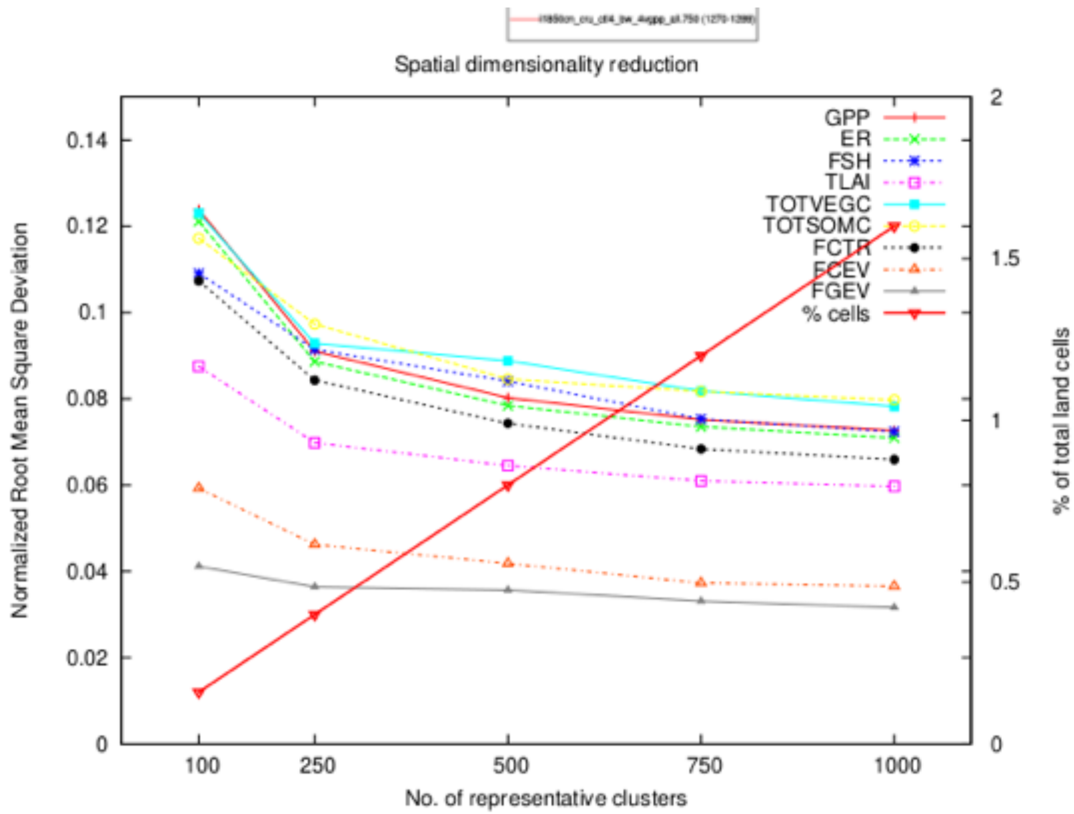
Stomatal resistance and photosynthesis				
medlynslope	P	pft	pft	
medlynintercept	P	1	200000	Range derived from Duursma et al. 2018, Figure 8a,b (note different units in fig. compared to CLM). Full range spans negative through ~300000, although most values fall between 0 and 200000.
fnps	H (moved to P branch)	0.1	0.3	BFB
theta_psii	H (moved to P branch)		0.9	BFB
theta_ip	H (moved to P branch)		0.999	BFB
theta_cj	H (moved to P branch)		0.999	BFB
kc25_coef	P	266	454	
ko25_coef	P	207	395	
cp25_yr2000	P	35	44.7	
fnr	P	7.14	7.16	max is equivalent to default
act25	P	40	120	

CTSM5 Parameter Perturbation Ensemble (PPE)

2. Sparse grid
   - Define representative sparse grid (~250 grid cells)
   - Fast and cheap ~3.4 pe-hrs/yr



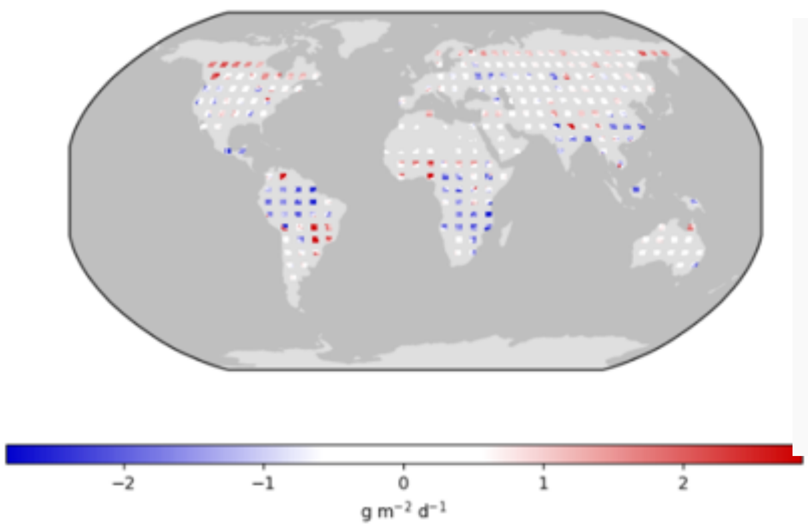
CTSM5 Parameter Perturbation Ensemble (PPE)

2. Sparse grid
   - Define representative sparse grid (~250 grid cells)
   - Fast and cheap ~3.4 pe-hrs/yr
3. Fast spinup
   - 80 years CNMatrix SASU, 40 years normal mode
4. Scripting infrastructure
   - Developing scripts that setup cases, control parameters, and execute spinup and ensembles
   - Scripting infrastructure for parameter exploration and analysis scripts will be a community resource

CTSM5 Parameter Perturbation Ensemble (PPE)

5. One-at-a time parameter sensitivity for all parameters
    - Present day climate, CO_2, N-dep
    - Check each run for survivability rate and reasonableness of GPP, ET, LAI, etc (e.g., survivability within 20% control; GPP, ET within +-30% of observed, ILAMB?)
    - If run doesn't pass checks, constrict parameter range and try again

GPP bias



	Download Data	Period Mean (original grids) [Pg yr-1]	Model Period Mean (intersection) [Pg yr-1]	Model Period Mean (complement) [Pg yr-1]	Benchmark Period Mean (intersection) [Pg yr-1]	Benchmark Period Mean (complement) [Pg yr-1]		Bias [g m-2 d-1]	RMSE [g m-2 d-1]	Phase Shift [months]		Bias Score [1]	RMSE S
Benchmark	[-]	119.											
HARDCODEP2000	[-]	10.4	10.3	0.0416	10.5	109.		-0.0546	1.52	1.39		0.431	0.403

CTSM5 Parameter Perturbation Ensemble (PPE)

5. One-at-a time parameter sensitivity for all parameters
   - Present day climate, CO2, N-dep
   - Check each run for survivability rate and reasonableness of GPP, ET, LAI, etc (e.g., survivability within 20% control; GPP, ET within +-30% of observed)
   - If run doesn't pass checks, constrict parameter range and try again
6. Environmental perturbations
   - Climate: 1850 and SSP3-7 CESM2 climate
   - CO2: 1850 and SSP3-7
   - N-dep: +- 5 gN/m2/yr
   - Restrict parameter ranges again if low-side env. pert. doesn't pass

CTSM5 Parameter Perturbation Ensemble (PPE)

7. Select ~50 parameters for full Latin hypercube sparse grid ensemble
   - Select parameters that have significant impact on mean state, response to perturbation, different aspects of system (carbon, water, veg state, etc)
   - Remove 'bad' parameter sets based on similar criteria in step 5
8. Run 'good' Latin hypercube parameter sets with environmental perturbations as in step 6
9. Global transient 2° simulations
   - Select ~100 'best' parameter sets (selection criteria TBD) and run full spinup and transient historical/projection simulations

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