Evaluating aerosol-cloud interactions in E3SMv3 using a perturbed parameter ensemble

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Breakout Session J: Strengthening EESM Integrated Modeling Framework – Towards a Digital Earth

PROCEED

Perturbed physics ensemble regression optimization center for ESM evaluation and development

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Our focus: aerosol-cloud interactions from pre-industrial (PI) to present-day (PD) conditions in the Nd-LWP relationship

- Increases in cloud drop number concentration (Nd) lead to changes in cloud macrophysics, especially liquid water path (LWP)
- "Inverted-v" relationship between LWP and Nd
    - Precipitation suppression. (+ correlation) vs. size-dependent entrainment (- correlation)
- Where does this relationship come from in earth system models? Can we constrain it with observations?

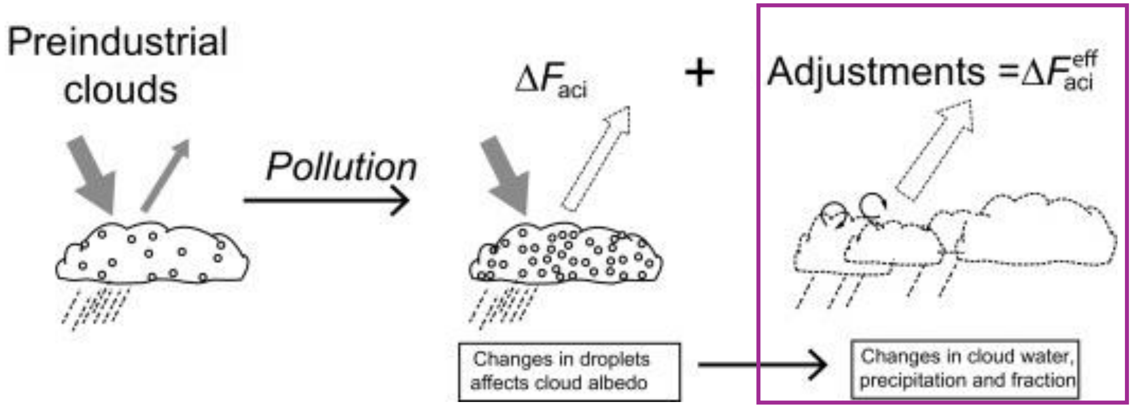


Fig., 2.9, K. Carslaw (2022), *Aerosols and Climate*

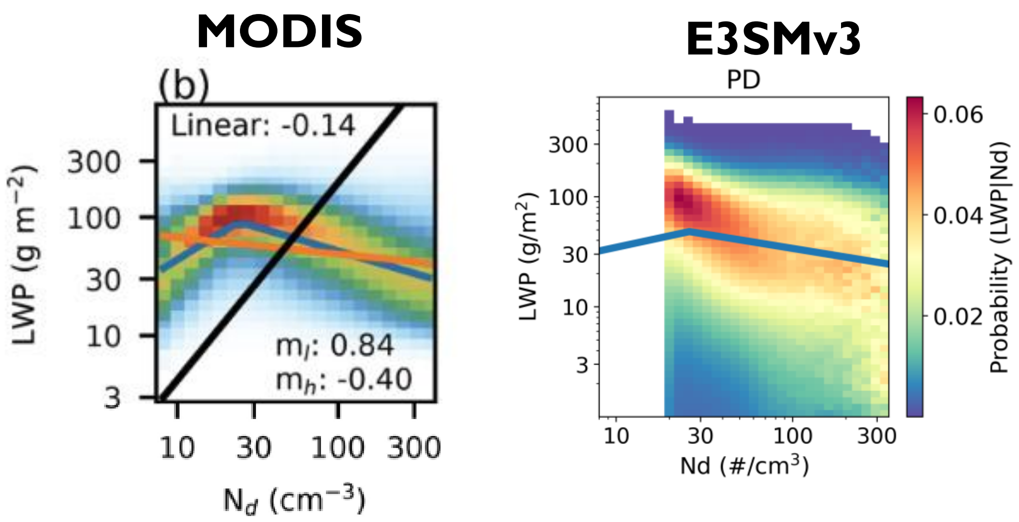
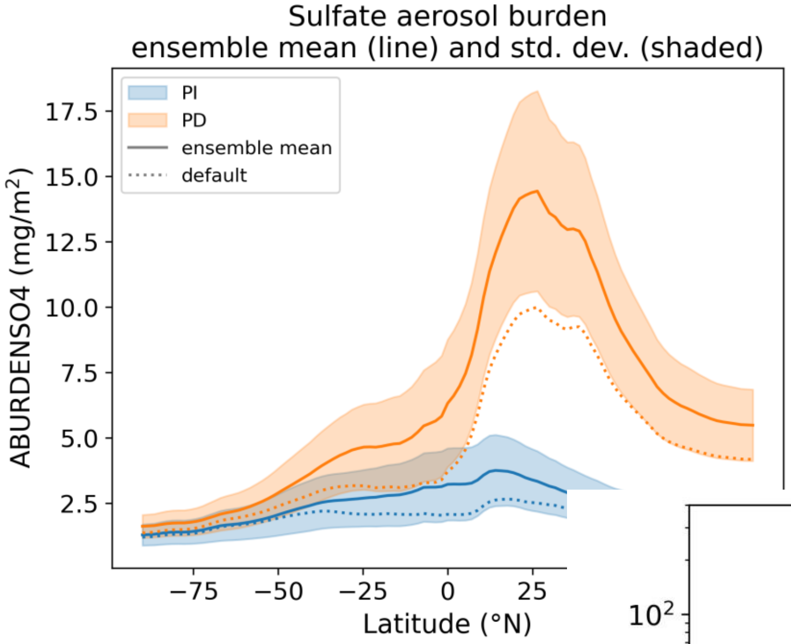


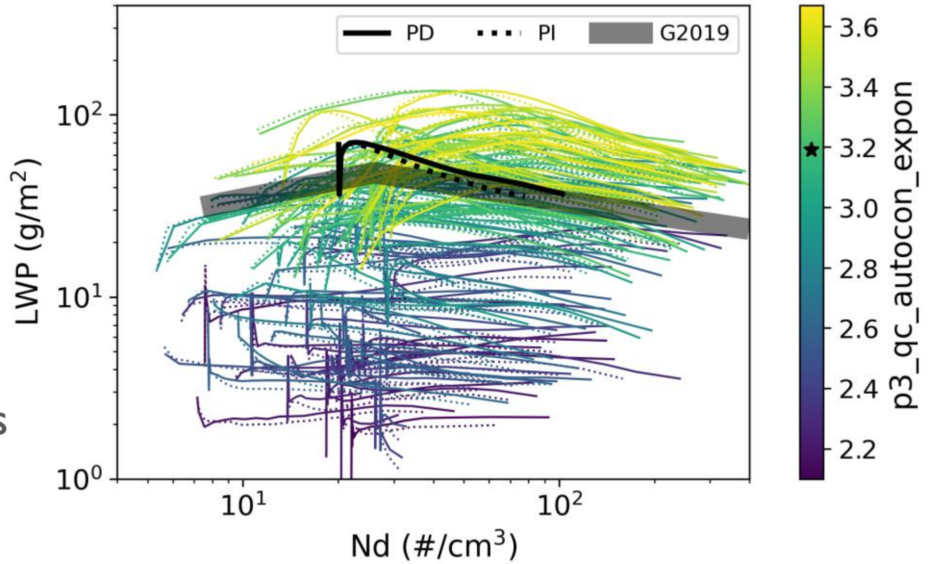
Fig. 2b, Gryspeerdt et al. 2019, *ACP*

We develop a perturbed parameter ensemble (PPE) in E3SMv3 to address parametric uncertainty and causality

- PI and PD versions
  - 126 ensemble members (default + 125 parameter combinations perturbed with Latin Hypercube sampling)
  - 2-year nudged simulations, atmosphere-only configuration
- Varied 25 parameters: 7 microphysics, 7 convective microphysics, 11 aerosol



Large spread across the PPE in both PI and PD aerosols



"inverted v" across all PPE members

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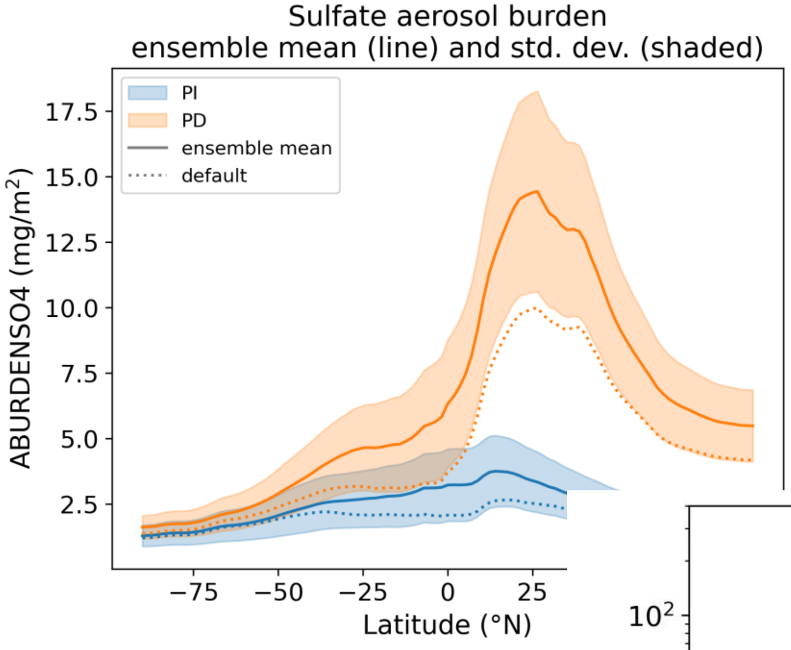

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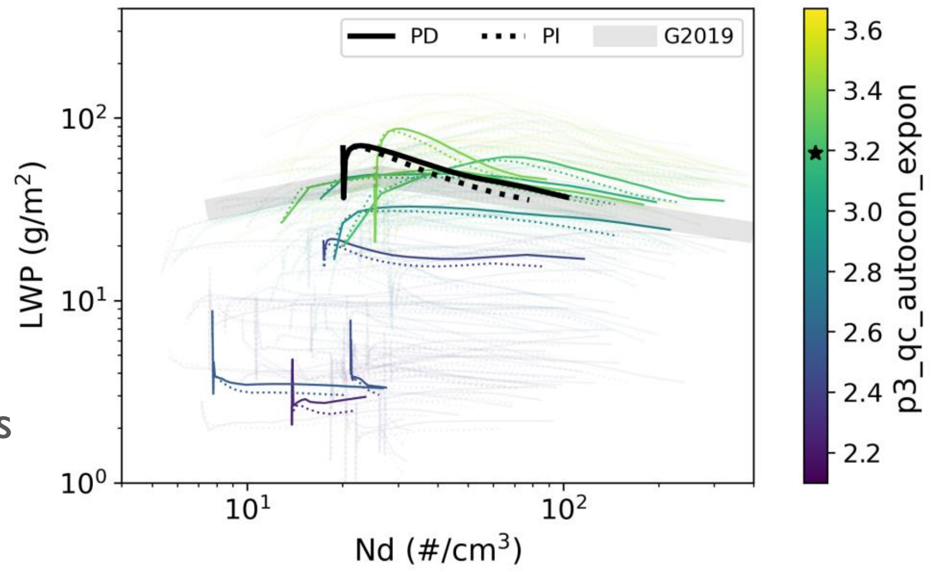
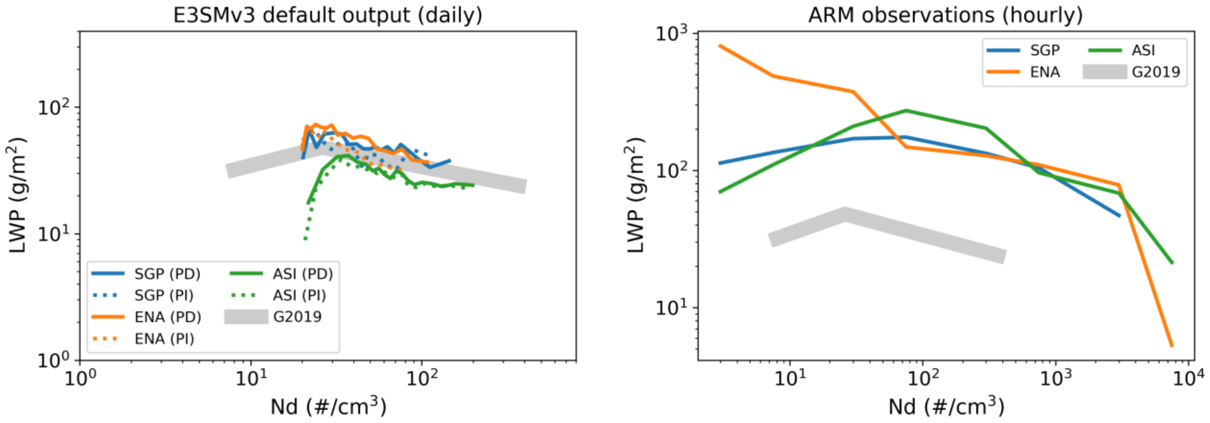
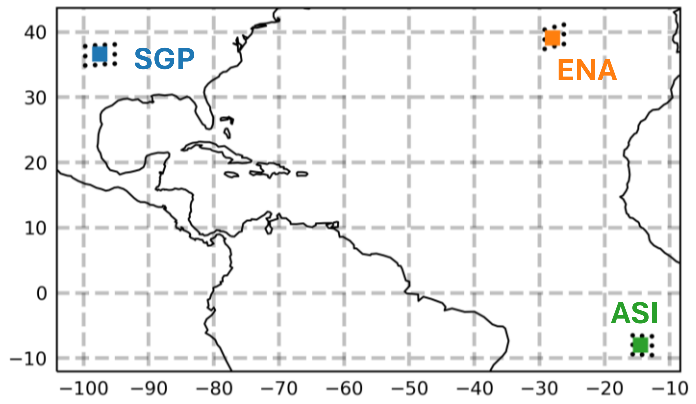


"inverted v" across all PPE members

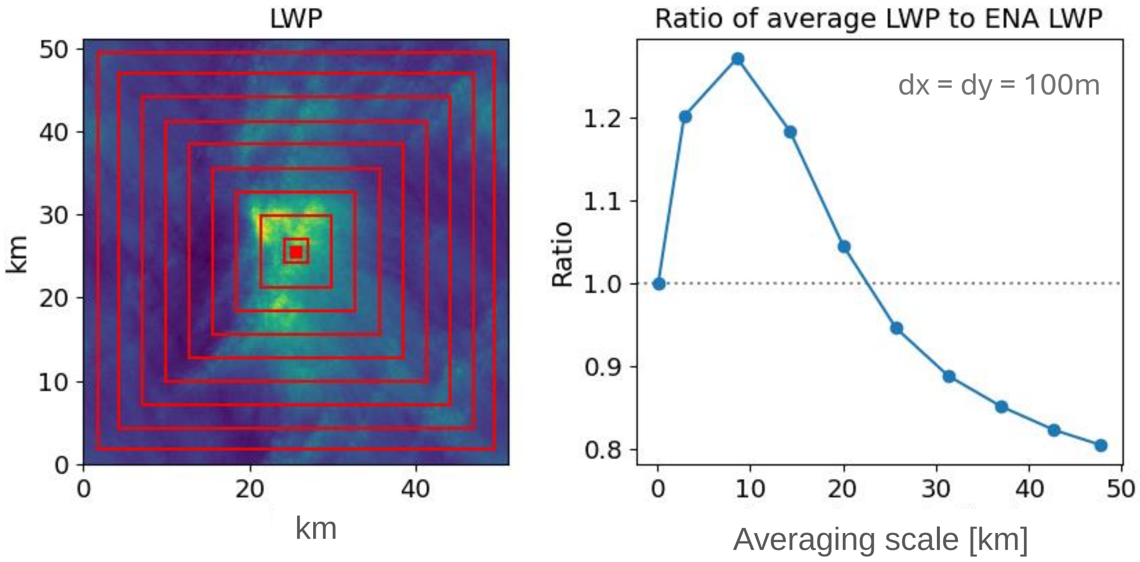
Multiscale issue: we need to constrain the (relatively) coarse E3SMv3 PPE to reality

Process-level ARM observations help us ground the model to the real world





LES output to address sampling bias from averaging over the E3SM grid

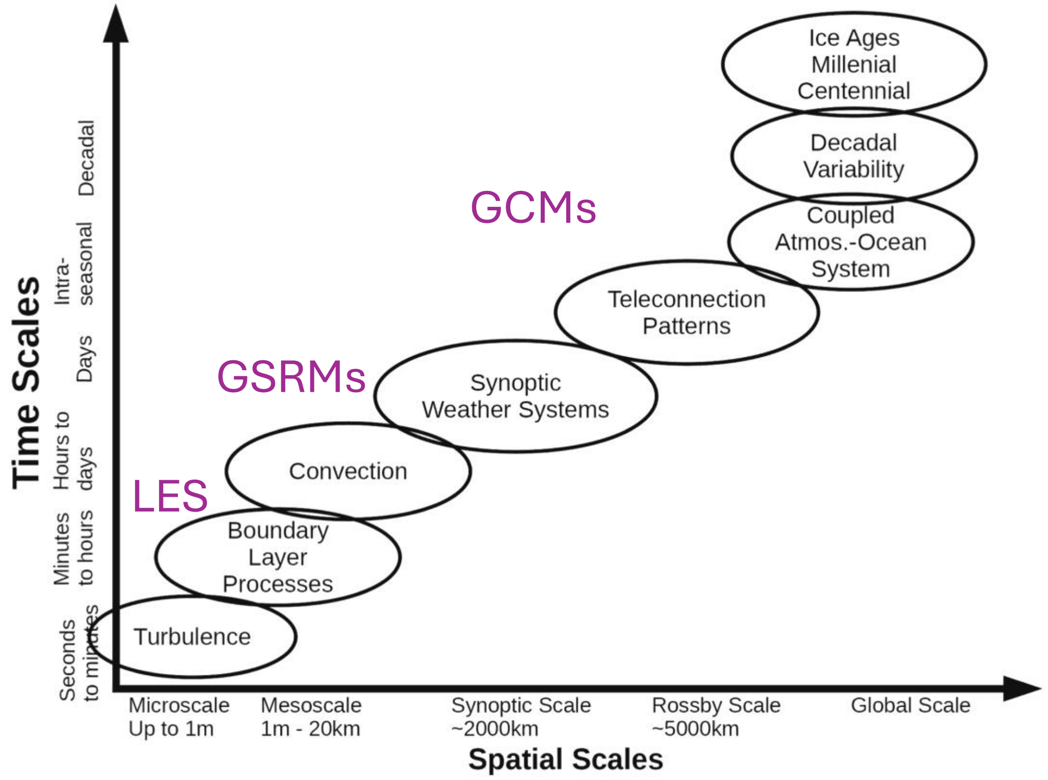


ACE-ENA LES simulations from McCoy et al. (2024), *JGRA*
doi: 10.5281/zenodo.8088444

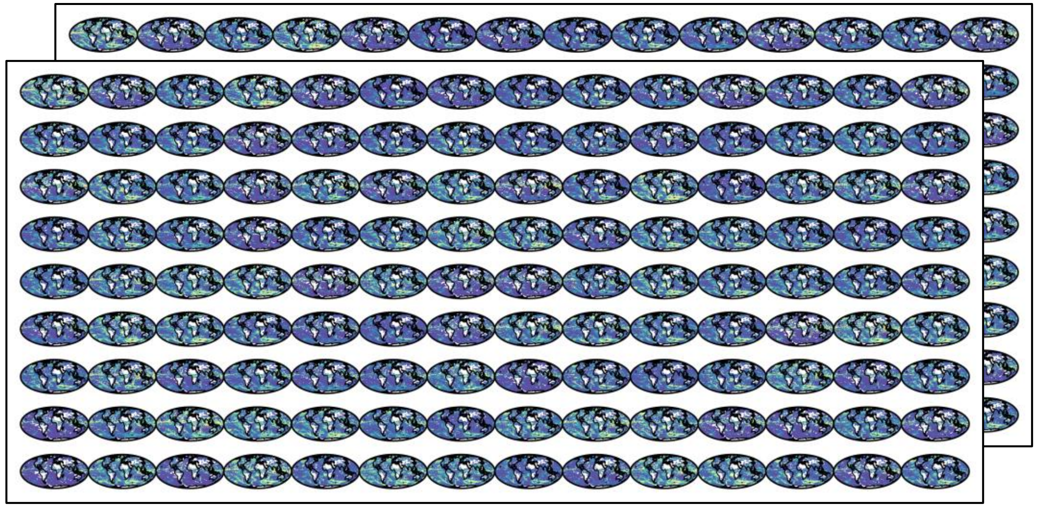
Digital Earth – Where We Might Go

E3SM
Energy Exascale
Earth System Model

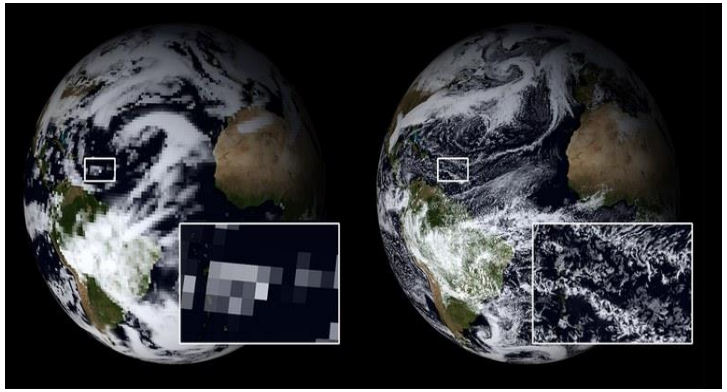
Development across scales: earth system models in the "model hierarchy" serve different (but equally important) purposes



Franzke et al. (2020), *Rev. Geophys.*



E3SMv3 PPE: 2x126 simulations, ~2.2 million core hours

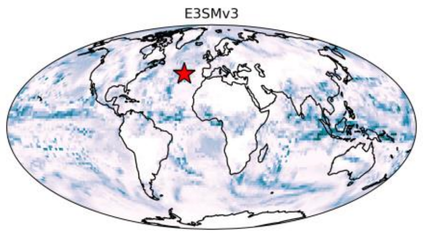


80 km vs. 2.5 km horizontal resolution (ESiWACE)

Ongoing challenge: effective model-observation intercomparisons

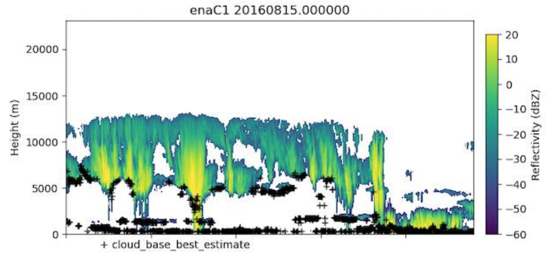
- Prioritize keep simulators up to pace with the latest & greatest models
- Develop more unified ways to compare models to observations in situations where existing simulators won't work?

Earth System Model Output

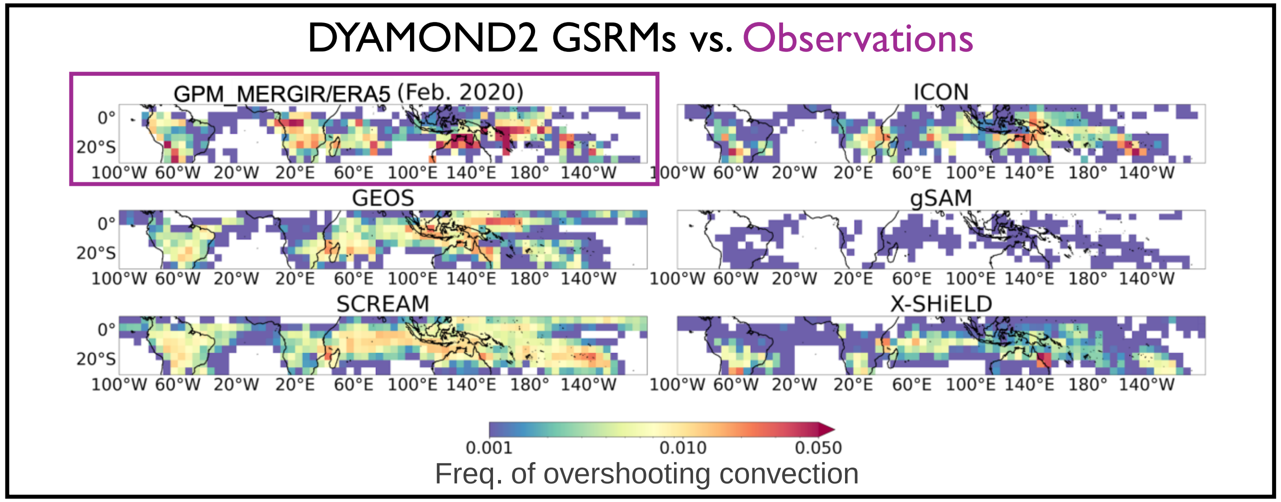


instrument/satellite simulators, proxies, etc.

Observations



(ARM)



Overshooting convection proxy based on brightness temperature: compare GSRM output to observations at the km scale

(Nugent et al., in prep)

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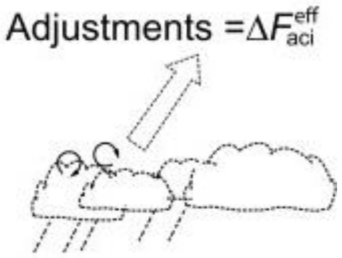
Summary

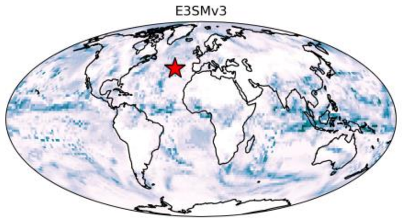
Ongoing work: E3SMv3 PPE

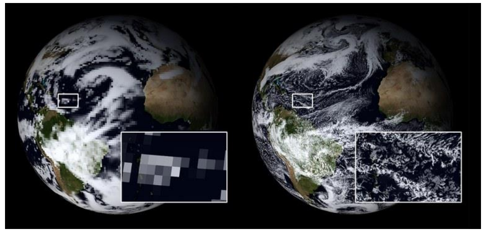
- Study the Nd-LWP relationship in E3SMv3 across a perturbed parameter ensemble
  - Parametric uncertainty
  - Causality (PI-PD)
- Constrain with observations from ARM sites
- LES output: resolve coarse grid with fine-scale observations

“Where we might go”

- Synchronous development across the model hierarchy
- Prioritize effective ways to compare models with observations







Bonus Slides

Parameter Ranges

Scheme	Parameter	Min	Max	v3 default
Microphysics *(P3)*	p3_mincdnc	5e6	30e6	20e6
	p3_nc_autocon_expon	-2	0	-1.1
	p3_qc_autocon_expon	2.10	3.67	3.19
	p3_autocon_coeff	15250	45750	30500
	p3_accret_coeff	58	235	117.25
	p3_wbf_coeff	0.1	1	1
	p3_embryonic_rain_size	1.50e-5	4.00e-5	2.5e-5
Convective microphysics *(Zhang-McFarlane)*	zmconv_accr_fac	0.1	10	1.5
	zmconv_auto_fac	0.1	10	7
	zmconv_micro_dcs	50e-6	1000e-6	150e-6
	zmconv_autocon_coeff	15250	45750	30500
	zmconv_accret_coeff	58	235	67
	zmconv_nc_autocon_expon	-2	0	-1.2
	zmconv_qc_autocon_expon	2.10	3.67	3.19
Aerosol	n_so4_monolayers_pcage	1	8	3
	seasalt_emis_scale	0.5	2.5	0.55
	sol_facti_cloud_borne	0.5	1	1
	dms_emis_scale	0.5	3	2
	microp_aero_wsubmin	0	0.5	0.001
	microp_aero_wsub_scale	0.1	5	1
	POM_hygroscopicity_param	0	0.1	0.04
	aer_sol_factb	0.03	0.1	0.1
	so2_oh_gprx_scale	0.3	3	1
	so2_o3_aqrx_scale	0.5	2	1
	so2_h2o2_aqrx_scale	0.5	2	1

Many ranges borrowed from the CAM6 PPE

(Eidhammer et al. 2024, doi:10.5194/egusphere-2023-2165)