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Exploring the Use of Ultra-Low Resolution E3SM Simulations to Predict Sea Ice – Free Summers, and to Elucidate the Role of Arctic Sea Ice in Polar Amplification

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Motivation

- Sea Ice extent is a critical control in global climate stability, because sea ice reflects ~ 80% of incoming sunlight
- Sea Ice cover is significantly reduced since the advent of satellite – based monitoring (1979)
- Tight coupling of Arctic subsystems – sea and land ice, permafrost, ocean and boreal forests,
- Tipping of one subsystem (e.g., sea ice), potentially rapidly cascading to others
- Strategic and ecological importance of the Arctic cannot be overstated

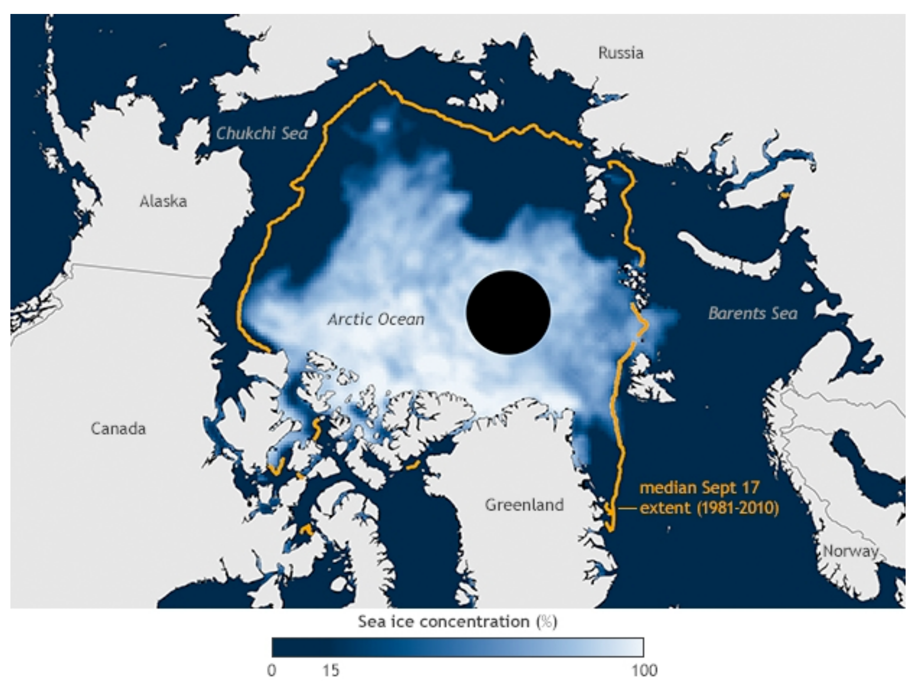


Figure 1) 2019 September Sea Ice Minimum. September minimum is on track to be significantly less than the 1981-2010 median (yellow outline). Anomalous warming during the previous winter and spring, drove the dramatic melt, nearly eclipsing the previous record in 2012. Evidence indicates that sea ice is in a downward spiral, with, melting now exceeding ice formation, and young ice representing outsized fraction of the total ice, relative to historical norms (Witze, 2019). Satellite image adapted from the NOAA Environment Visualization Lab archive.

GOALS

- Develop an ultra low resolution (ULR) E3SM fully coupled configuration by "pre-tuning" the model to published values for important parameters in the atmosphere component (EAM) to avoid "one at a time" parameter-tuning inefficiencies (Qian, et al. 2018)
- Run E3SM fully-coupled simulations using key component sets (Pre-Industrial Control, 4XCO2 – forcing) (Golaz et al., 2019, Rasch et al., 2019)
- Compare sea ice-relevant quantities of interest (QoI, *e.g.*, sea ice extent, top-of-atmosphere energy flux) in the ULR simulations *vs.* those in the publicly-available, E3SM 1-degree resolution reference datasets to assess model fidelity
- Understand which key physical processes and feedbacks are meaningfully represented at ULR (~ 250 km2 /cell sea ice and ocean grid) in fully-coupled climate models
- Explore large-scale interacting physical processes (including anthropogenic forcing) and internal drivers (*e.g.*, low-frequency Arctic atmospheric variability), main controls on sea ice evolution (Ding et al., 2019; Olonscheck et al., 2019)
- Estimate parametric uncertainty in sea ice – related phenomena

RESULTS AND DISCUSSION

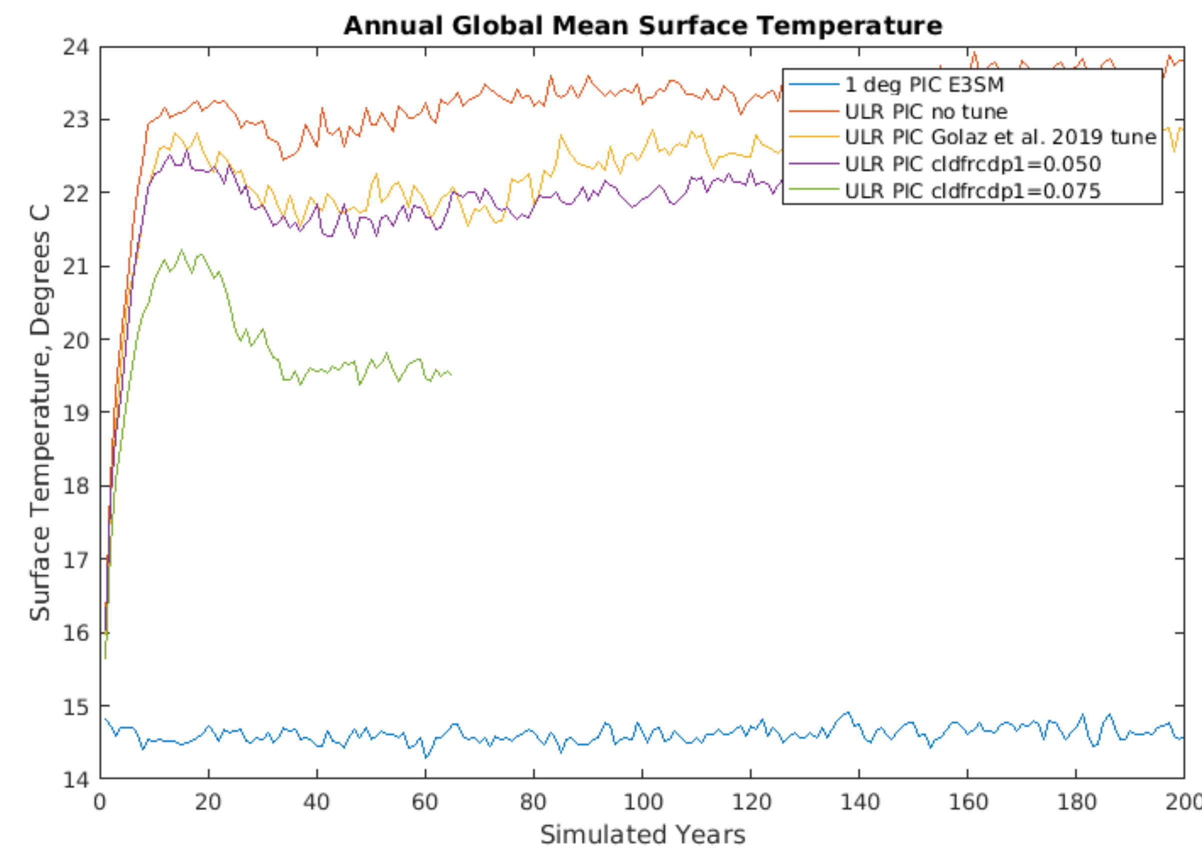


Figure 3) Diagnostic Quantities of Interest (QoI) to Assess Model Fidelity, Towards Developing Spun Up Compsets for Ultralow Resolution Simulations. To engineer an ULR tuning predictive of climate reality, we used several recently published E3SM QoI (Golaz et al., 2019; Rasch et al., 2019). Our initial efforts have focused on the E3SM Atmospheric Component (EAM, Rasch et al., 2019). Here, we show annual global mean surface temperature for four ULR simulations, *vs.* scientifically – validated E3SM data (blue). This QoI in all of our differently tuned E3SM ULR runs was significantly higher than the scientifically validated mean (E3SM 1- degree resolution). In contrast, the net top-of-atmosphere energy flux long – term average QoI for the different ULR tunings did approach the scientifically-accepted mean of near zero (data not shown).

METHODOLOGY

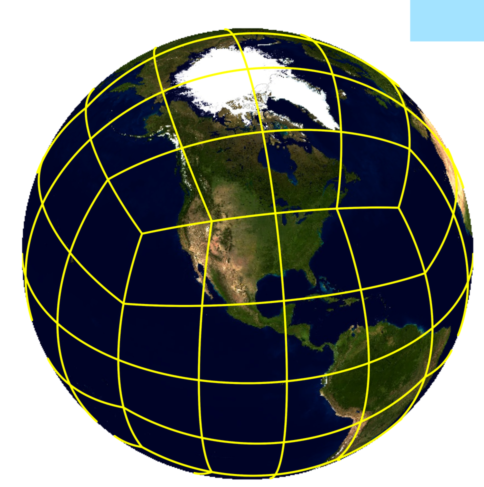


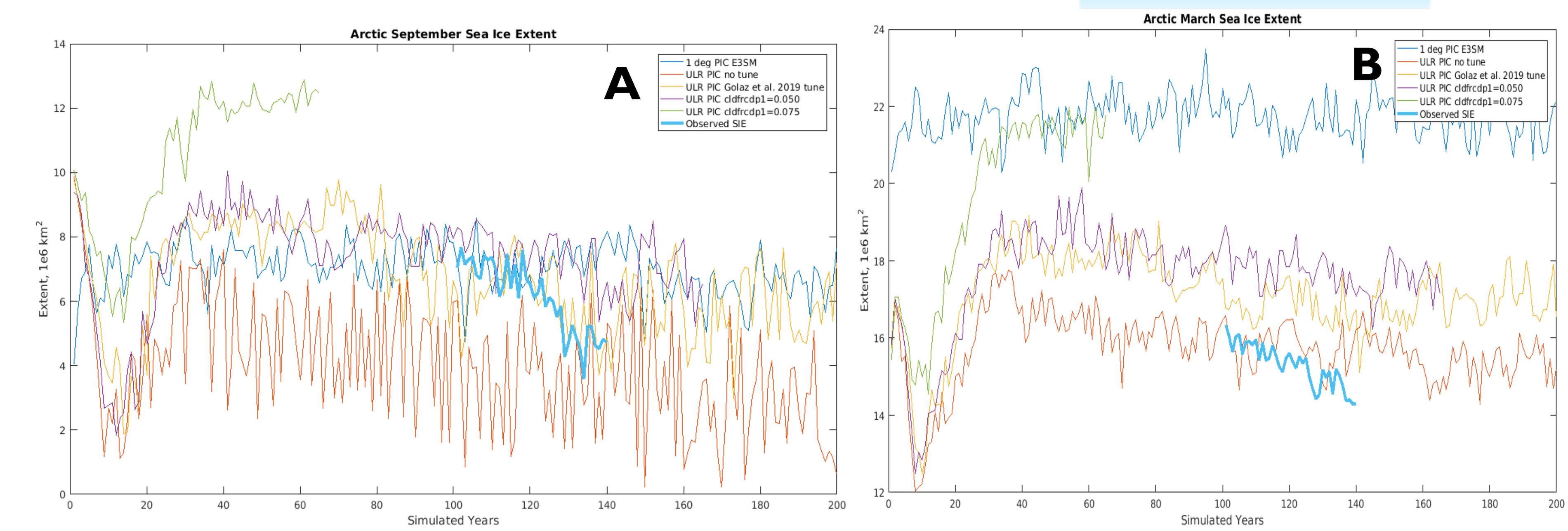
Figure 2). Ultralow Resolution Grid for E3SM Climate Simulations. Ultra low resolution (ULR) simulations were originally developed to facilitate software testing. Simulations at ULR have not yet been scientifically validated. Our goal is to develop scientifically -validated ULR configurations as an enabling capability for: 1) rapidly testing physical parameters, 2) multi-fidelity modeling, 3) comprehensive uncertainty quantification, 4) focusing high-resolution Arctic simulations.

Tuning Parameter	Run Value
zmconv_ke	5e-6
so4_sz_thresh_icenuc	0.05e-6
clubb_c14	1.06
l_ieflx_fix = .true.	.true.
ieflx_opt	2
cldfrc_dp1	(0.5, 0.1, 0.045, 0.05, 0.075)

Table 1A) Tuning Parameters Varied to Develop Scientifically Valid Ultra Low Resolution E3SM Configuration. The "A_WCYCL1850" compset, representing Pre-Industrial Control (PIC) forcing, was used to prototype ULR datasets to compare with the scientifically – validated CMIP Low Resolution (1-degree) PIC. This compset does not include a "spun up" oceans component, and thus required empirical exploration and diagnostic quantities of interest testing to assess the model's estimation of climate reality.

Resolution	Grid Spacing (equator, km)	Latitude & Longitude Approximation	Physics timestep (s)
ne4	834	7.5 ° x 7.5 °	7200
ne30	111	1 ° x 1 °	1600

Table 1B) Ultra Low Resolution *vs.* Low Resolution Climate Simulation Attributes. ULR configuration is coarser than that for low resolution, but the physics and coupling in both are the same. Resolving certain physical phenomena (e.g., Baroclinic Instability) can be problematic at ULR, however,



Figures 4A-B) September and March Sea Ice Extent (SIE) Under Different E3SM ULR Tunings. For both September (annual historical minimum) and March (annual historical maximum), our ULR E3SM "no tune" (red) and "Golaz et al., 2019" (orange) tunings better model the observed data (thick blue) than the scientifically – validated projections in the E3SM 1-degree resolution simulations. (blue) At values greater than 0.045 (Golaz et al., 2019), the deep convective cloud fraction tuning parameter (cldfrc_dp1), SIE model projections (green and purple) are markedly higher than the observed sea ice data (thick blue).

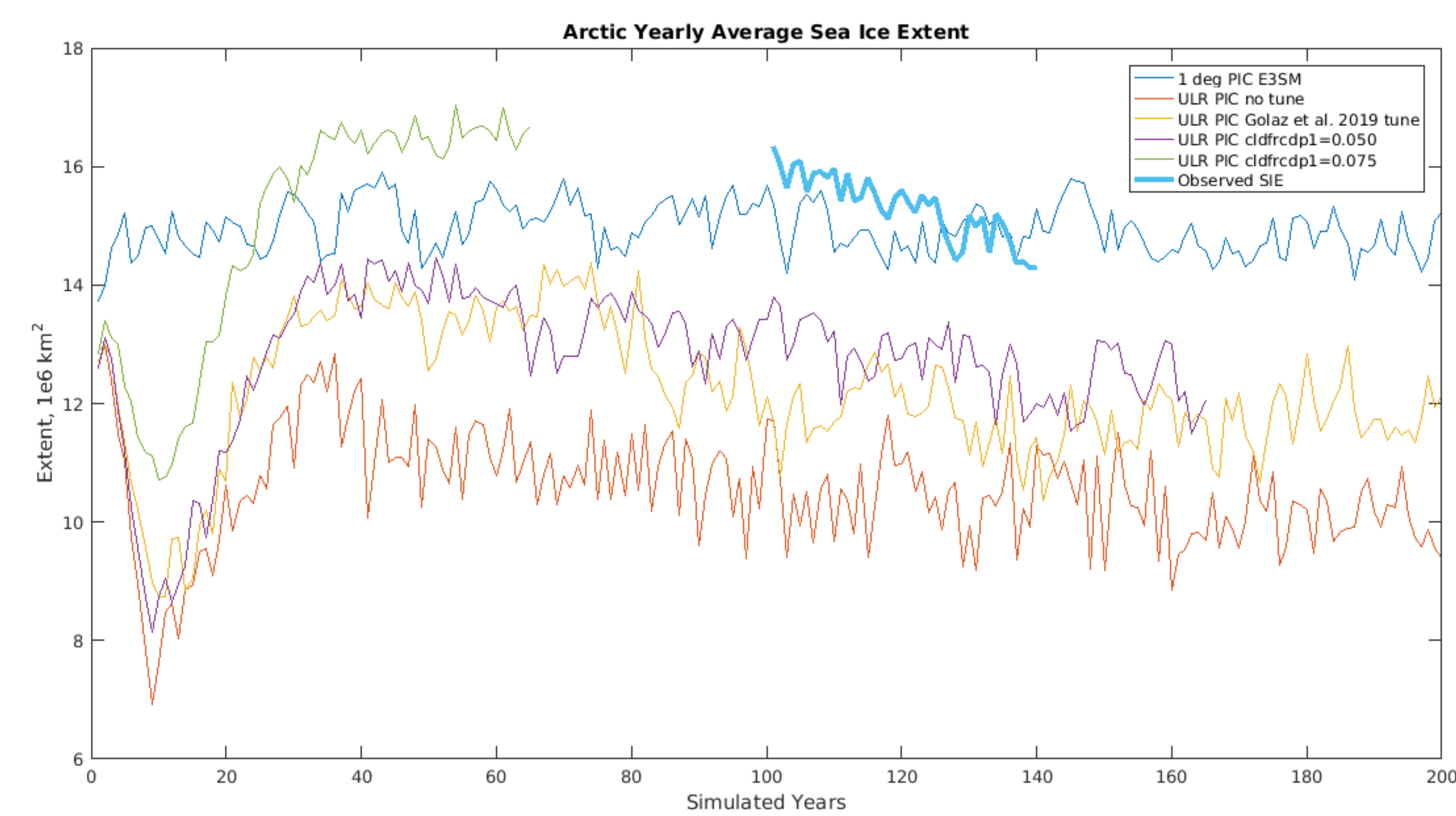


Figure 5) Arctic Yearly Average Sea Ice Extent Under Different E3SM ULR Tunings. All (green, purple, orange, red) of our ULR tunings modeled average annual SIE poorly, relative to the observed SIE (thick blue). The E3SM scientifically – validated 1-degree resolution simulation (blue) showed relatively stronger trending towards observed SIE. These results suggest that tuning the deep convective cloud fraction tuning parameter (cldfrc_dp1).To values between 0.05 and 0.075 could result in reliable ULR projections of average annual SIE.

NEXT STEPS

- Analyze key QoI for 200-year simulations with the the deep convective cloud fraction tuning parameter (cldfrc_dp1) adjusted to values between 0.05 and 0.075
- Identify additionally potentially useful tuning parameters from other E3SM components for studies to deliver a scientifically – valid ULR configuration

REFERENCES

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- Qian *et al.* (2018) "Parametric Sensitivity and Uncertainty Quantification in the Version 1 of E3SM Atmosphere Model Based on Short Perturbed Parameter Ensemble Simulations"
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