The Polar Climate of E3SM Versions 1 and 2

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DOE ESMD-E3SM PI Meeting, October 26-29, 2020

U.S. DEPARTMENT OF ENERGY | Office of Science

E3SM Energy Exascale Earth System Model

Outline

1. Introduction: Improvements in Ocean-Sea Ice-Atmosphere Coupling in E3SM
2. E3SM Version 1 sea ice performance in brief
3. Sea Ice improvements introduced in E3SM Version 2
4. The Current State of Sea Ice in E3SM V2 alpha
5. Impact of Ocean improvements in E3SM Version 2
6. The Way Forward

E3SM Science Drivers

1. Water Cycle: How do the hydrological cycle interact with the rest of the human-Earth system on local to global scales to determine water availability and water cycle extremes?
2. Biogeochemistry: How do the biogeochemical cycle interact with other Earth system components to influence energy-sector decisions?
3. Cryosphere Systems: How do rapid changes in cryospheric systems evolve with the Earth system and contribute to sea level rise and increased coastal vulnerability?

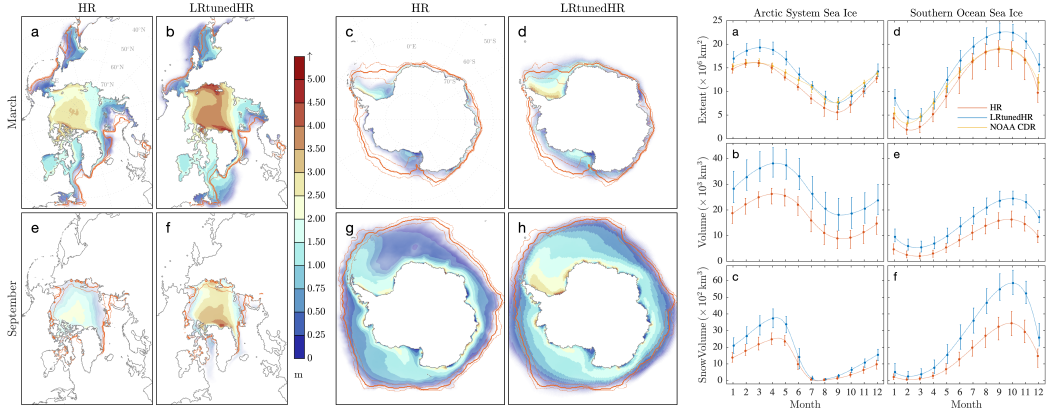
Most E3SM marine polar improvements addressing these core drivers are focused on the need for advanced coupling methods. That is, careful consideration of the physics and biogeochemistry across component boundaries, not just coupling infrastructure.

Straw man says this is where the largest improvements are likely to be made in the coming five years.

Transfer	Coupling	Focus of Potential Improvements
Radiation	Shortwave	Bare Ice, Snow, Melt Ponds, Aerosols
		Atmospheric Shortwave Radiation Scheme
	Longwave	Emissivity
		Atmospheric Longwave Radiation Scheme
Heat & Momentum	Barotropic Mode	Geostrophy
		Inertial Oscillations
	Turbulence	Length Scale vs. $g(h)$ Resolution
		Form Drag vs. Skin Drag
Mass	Sea Water	Sea Water Freezing
		Ocean Stratification
		Flooding
	Snow and Rain	Enthalpy
		Metamorphosis
	Salt and Freshwater	Sublimation and Evaporation
		Drainage and Melt

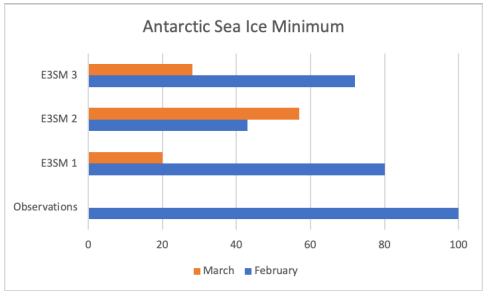
Various physics being improved or considered for improvements over E3SM V2 to V4.

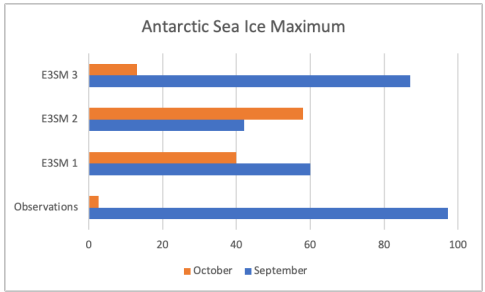
Sea Ice Volume, Extent and Annual Cycle



Comparison of E3SM Version 1 High Resolution (HR) and equivalent standard resolution (LR) simulations from Caldwell et al. (2019). Seasonality is skewed late at low resolution.

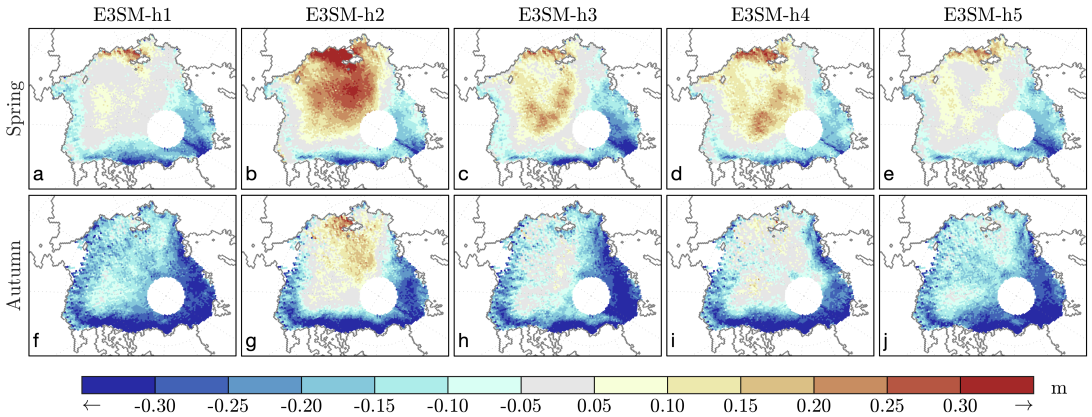
Sea Ice Volume, Extent and Annual Cycle





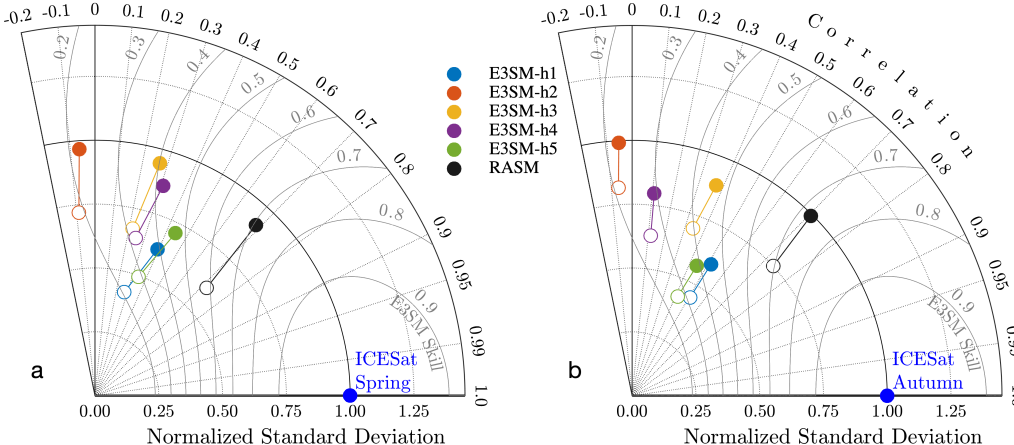
Minimum and maximum extent at standard resolution is lagged relative to observations (frequencies on the abscissa are as a percentage of a 30-year period, from Comeau et al. 2020, in progress),

Sea Ice Volume, Extent and Annual Cycle



Arctic freeboard compared to ICESat for the DECK ensemble, 2003-2008, using a satellite emulator. (from Roberts et al. 2020, in progress)

Sea Ice Volume, Extent and Annual Cycle



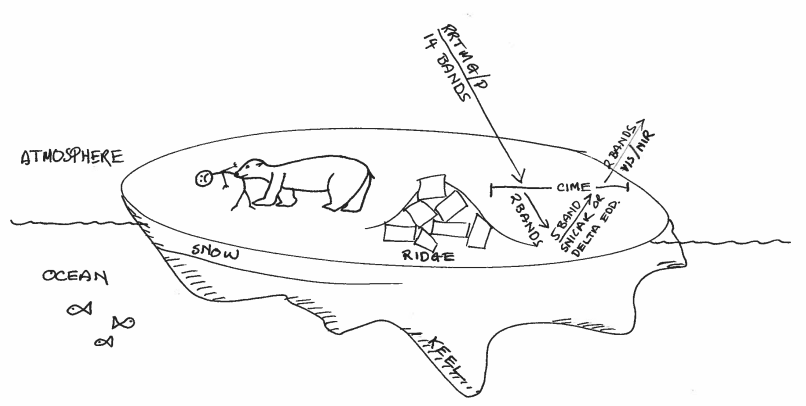
Arctic freeboard skill compared to ICESat for the DECK ensemble, 2003-2008, using a satellite emulator (from Roberts et al. 2020, in progress). The Regional Arctic System Model (RASM) is shown for comparison. Empty bubbles indicate where snow is not included in freeboard calculations.

Sea Ice improvements introduced in E3SM Version 2

Transfer	Coupling	Focus of Potential Improvements
Radiation	Shortwave	SNICAR_AD Radiative Transfer Scheme
		No Change
	Longwave	No Change
		No Change
Heat & Momentum	Barotropic Mode	No Change
		No Change
	Turbulence	No Change
		No Change
Mass	Sea Water	Sea Water Freezing Temperature
		No Change
		No Change
	Snow and Rain	No Change
		Improved Snow Layers and Redistribution
	Salt and Freshwater	No Change
		No Change

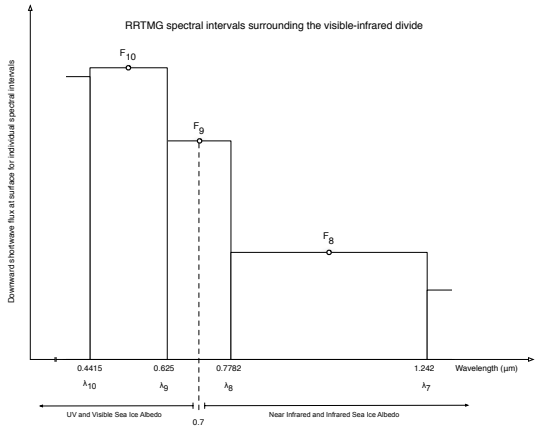
Various physics addressed just in E3SM V2.

Radiation Changes on Sea Ice – SNICAR_AD



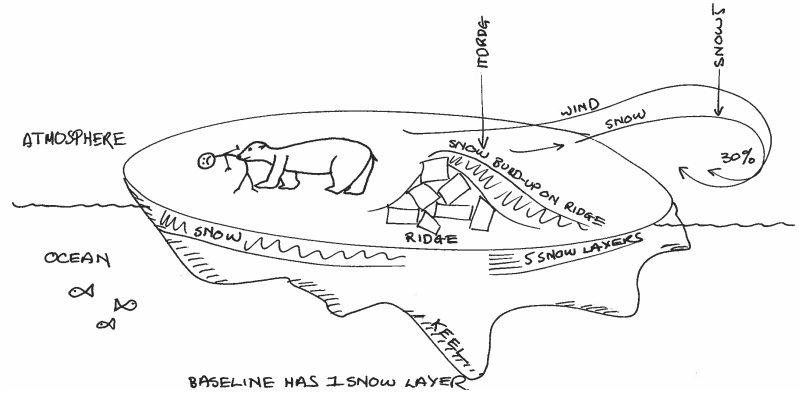
SNICAR brings homogeneous coupling and methods to sea ice, land and ice sheets,
but requires further improvements in coupling E3SM Version 3 (NOT version 2) to fix band discrepencies.
Implementation by Cheng Dang, Charles Zender, and Mark Flanner

Current approximation for both SNICAR and Delta-Eddington coupling



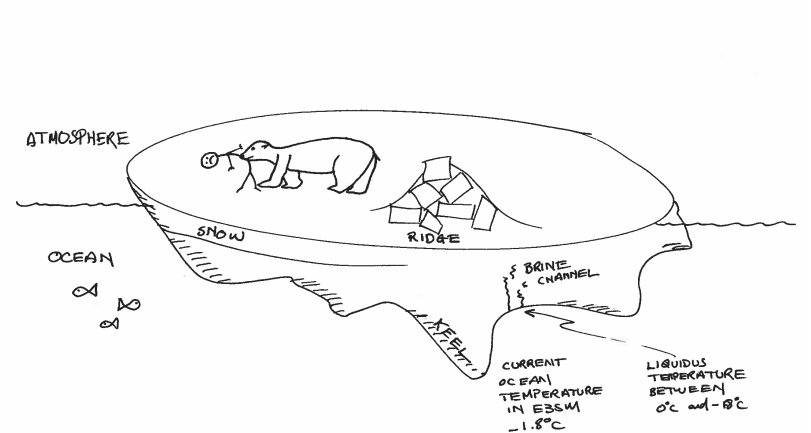
A 50/50 split is applied over the intervening RRTMG VIS band, where 700nm was previously used in CCSM with the CAM scheme. Working group being set up in the CICE Consortium is addressing this along with improvements from MOSAiC observations.

Snow Changes on Sea Ice



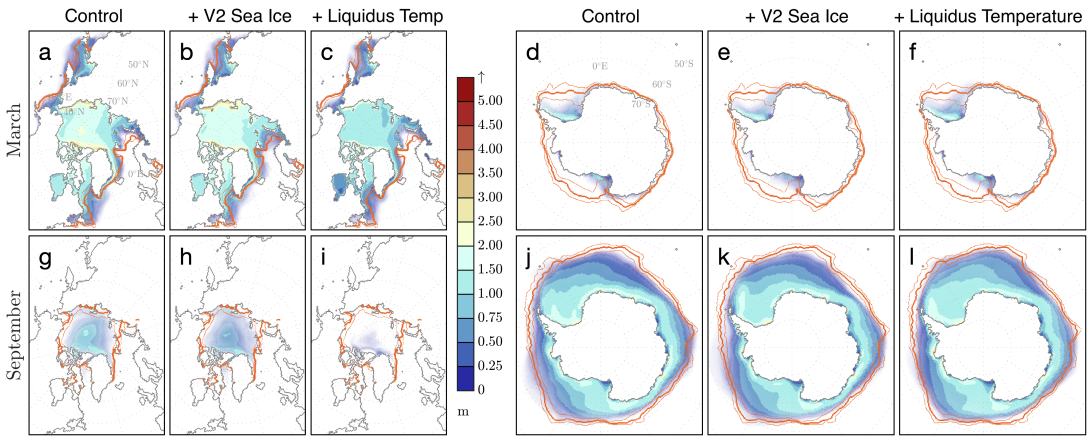
The snow changes include increasing the number of snow layers in sea ice from 1 to 5. The proceeding 'snow5' simulation includes this change, as well as the '30% rule' where 30% of snow is distributed into leads (the ocean). The 'ITDRdge' simulations includes snow accumulation against ridges following Lecomte et al. (2013), also using 5 snow layers (default).
Implementation by Nicole Jeffery and Elizabeth Hunke

Sea Water Freezing Temperature Changes



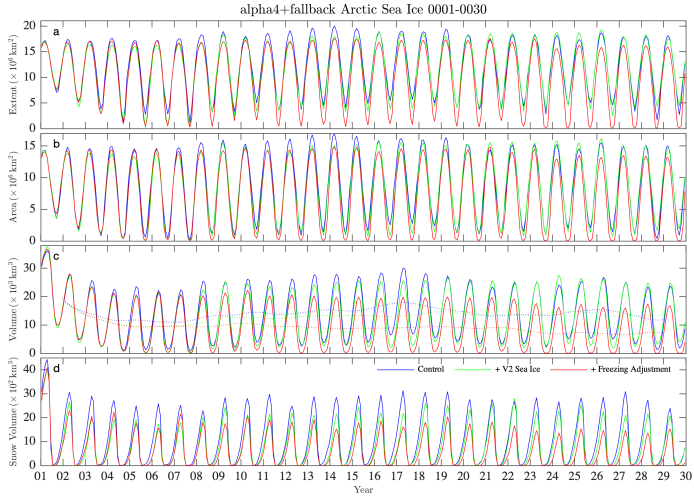
The ocean freezing temperature is set at the sea ice liquidus temperature, instead of being fixed at -1.8°.
Implementation by X. Asay-Davis

SNICAR_AD, Snow Morphology, Bug Fixes to Snow, and Freezing

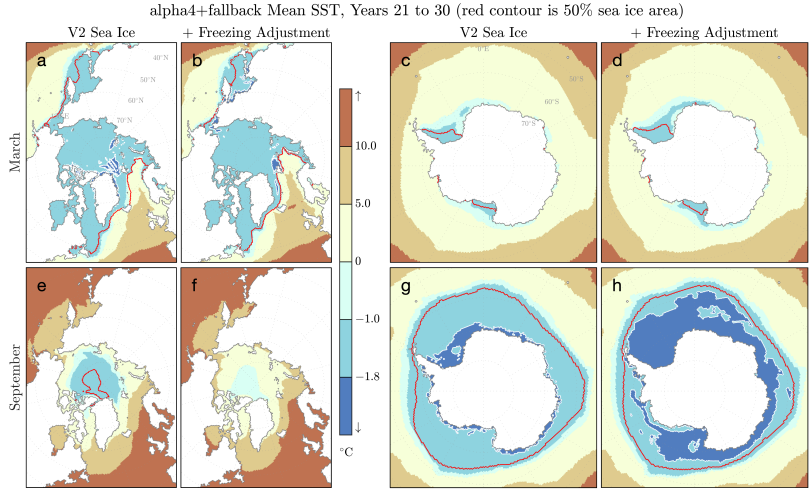


The ocean freezing temperature change has the largest impact among V2 changes.

SNICAR_AD, Snow Morphology, Bug Fixes to Snow, and Freezing

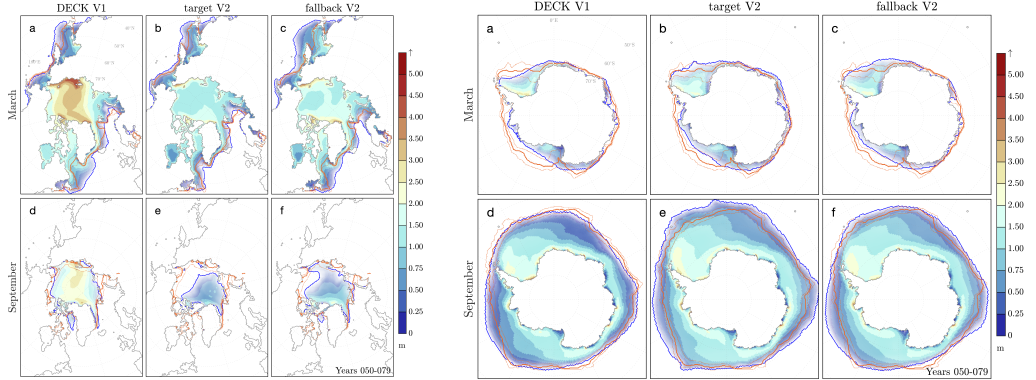


Ocean freezing with and without liquidus temperature



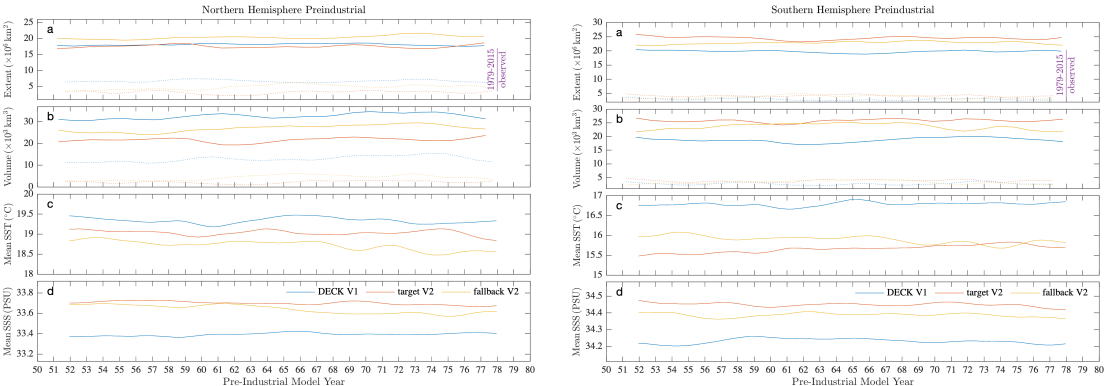
The ocean freezing temperature change has the largest impact on V1 results.

E3SM Version 2 sea ice performance in brief



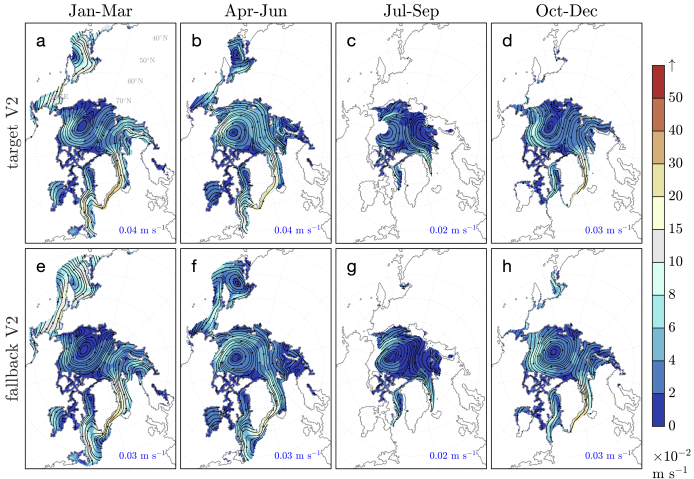
Sea ice thickness and extent as compared to the 1979-1999 observed ice edge $\pm\sigma$, 30 year mean, years 50-79 pre-industrial.

Version 2 alpha has more sea ice in the Antarctic, less in the Arctic



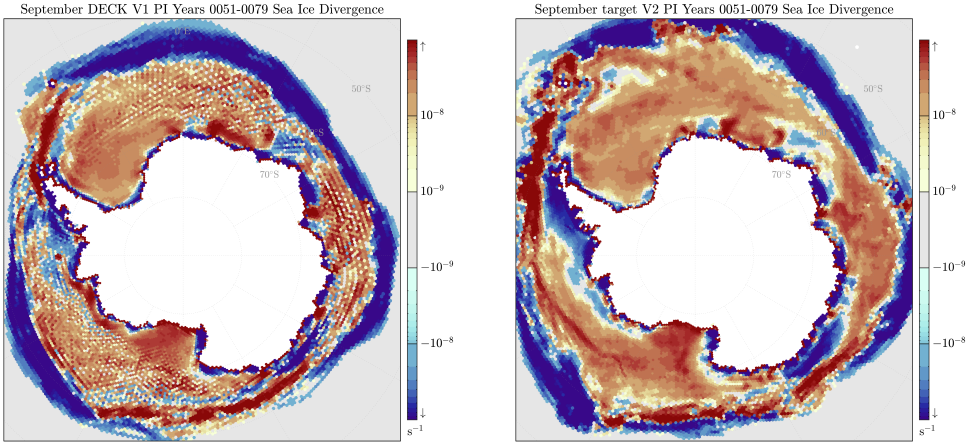
Extremes in sea ice extent and volume, and hemispheric ocean surface temperature and salinity for the 30 year period. Results are low-pass filtered at 2 years.

Sea ice drift remains healthy (where ice exists)



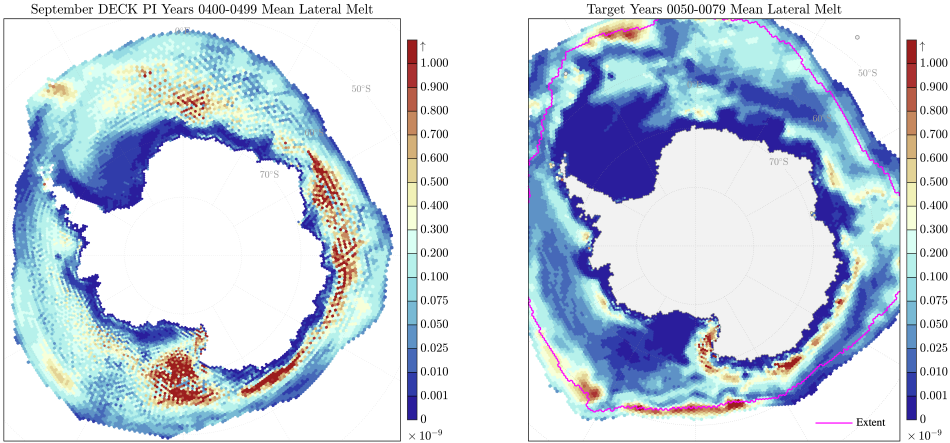
Sea ice drift streamlines, curtailed at 15% concentration over the 30-year mean period displayed in the previous few slides.

Spurious noise has been removed from sea ice divergence



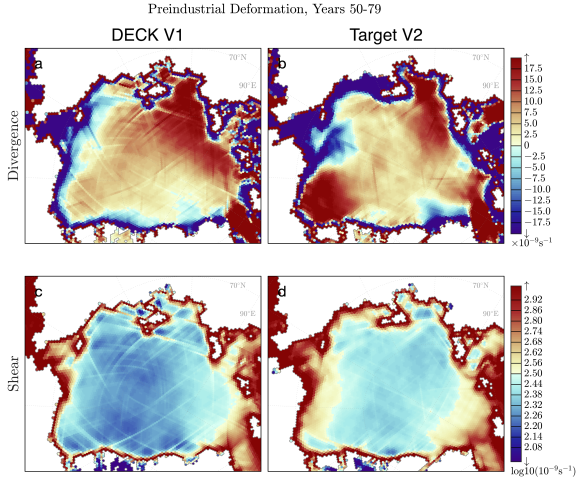
Mean climatic September divergence for V1 (left) and V2 (right).

Spurious noise has been removed from sea ice melting and freeezing



Comparison of lateral sea ice melt noise fields for V1 (left) and V2 (right).

Some noise remains in the Arctic deformation fields



Mesh imprints are far less evident in V2 Arctic deformation as compared to V1.
However, it is too early to tell if this is a diminished problem, or a product of reduced ice thickness.

Conclusions

1. We are tackling a severe Arctic thickness bias in E3SM V2
2. However, much progress has been made in removing biases in polar regions.
3. Significant problems in the Antarctic no longer appear in derivative fields.
4. The intention is to continue to target polar marine coupling in V3 and V4.

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