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Title: The Arctic in E3SM: Progress, Opportunities, and Challenges

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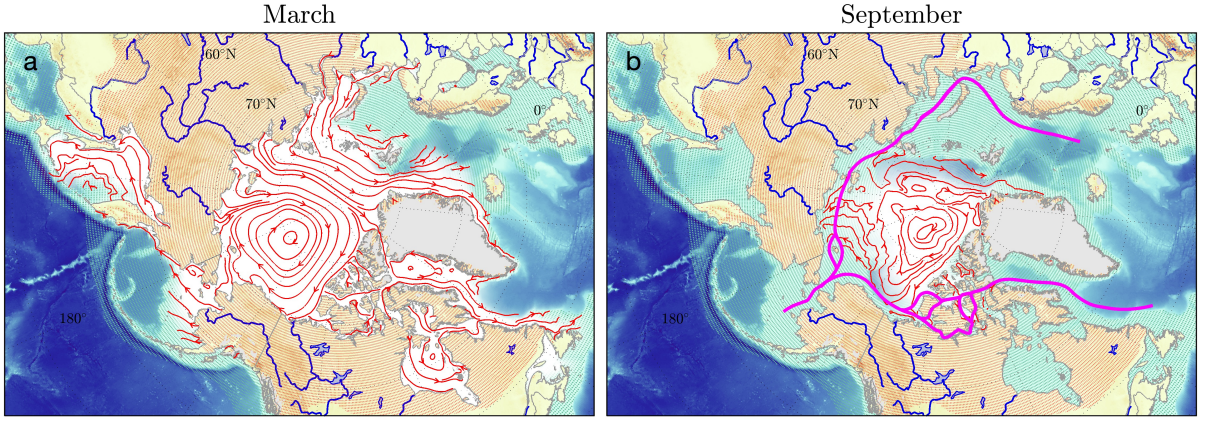
The Arctic in E3SM

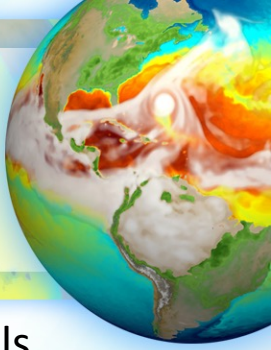
Progress, Opportunities, and Challenges

Luke Van Roekel and Andrew Roberts | Los Alamos National Laboratory

With contributions from Elizabeth Hunke, Adrian Turner, Nicole Jeffery, Matt Hoffman, Qi Tang, Wuyin Lin, Nairita Pal, Steve Brus, Mark Petersen, and Brian Arbic



Arctic Research in a E3SM's global context

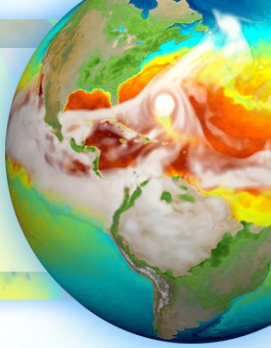


Water Cycle: What are the moisture sources for precipitation over land? Do models converge with increasing resolution, and what controls this behavior? How will the moisture sources and precipitation over land change in the future?

Biogeochemistry: What are the impacts of different energy and land use on the biogeochemical cycle and water availability? How might terrestrial-aquatic processes influence terrestrial and marine biogeochemistry?

Cryosphere: What processes and their model representations contribute to key uncertainties in projecting regional sea level rise? What are the implications to coastal inundation that result from interactions between sea level rise and extreme storms?

We will focus on these three aspects of E3SM



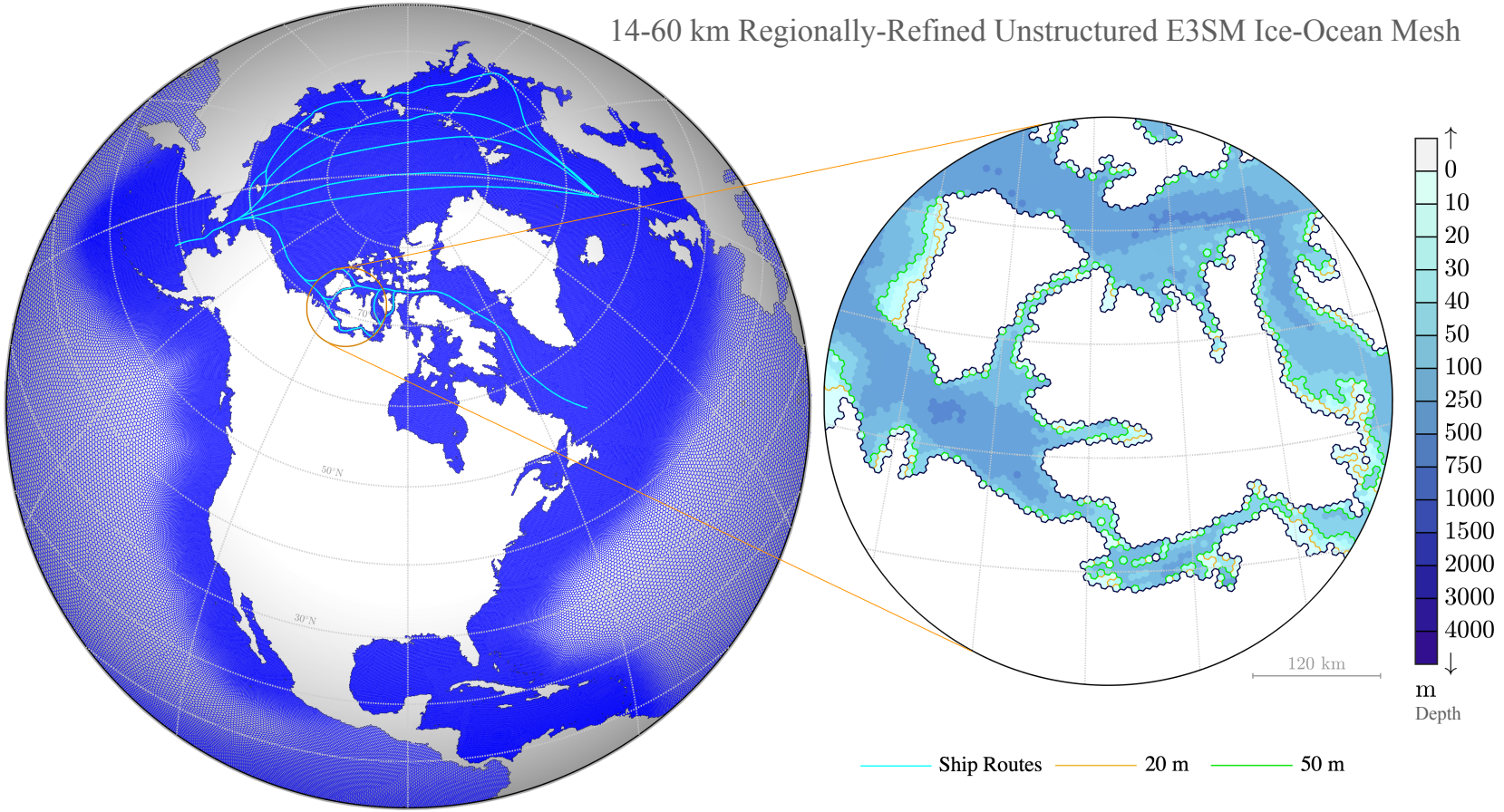
1. Regional refinement and scale-aware physics and biogeochemistry

2. Coastal interactions and sea level rise

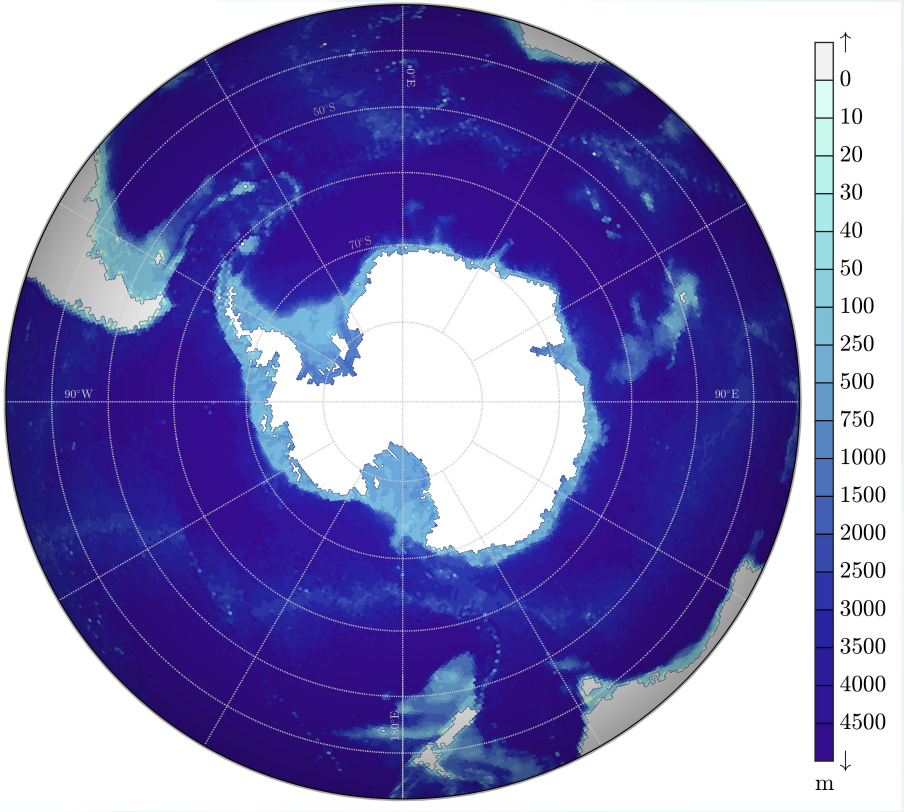
3. Developing model-observation data fusion

Projects: E3SM, InteRFACE, HiLAT-RASM, DEMSI, ICoM, Creating a Sea-level enabled E3SM (M. Hoffmann)

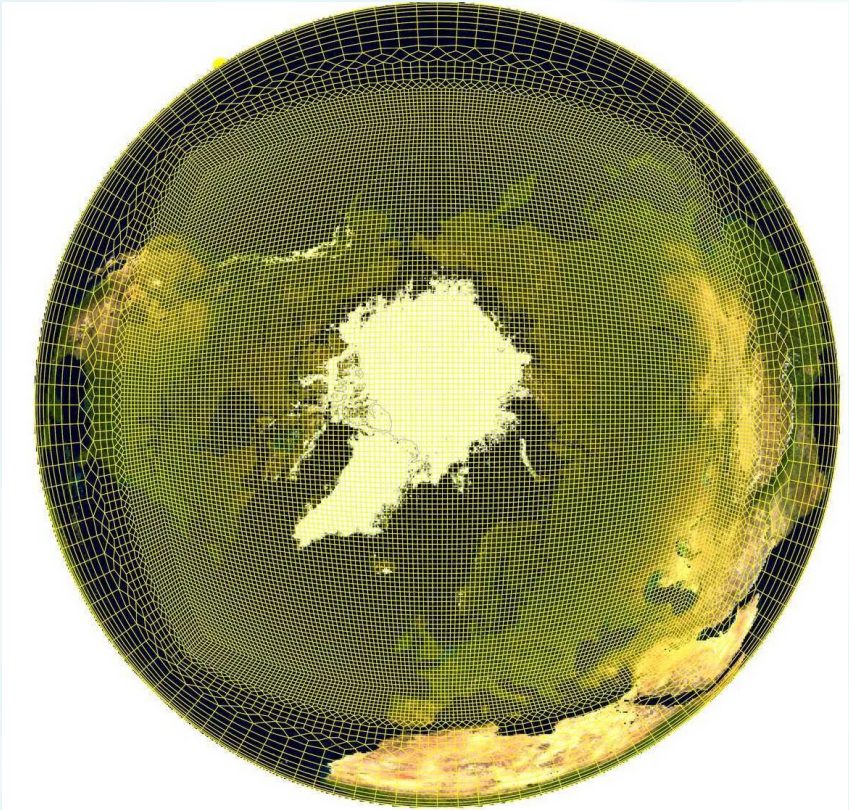
Arctic mesh refinement with a global focus: E3SM V2



Arctic mesh refinement with a global focus: E3SM V2



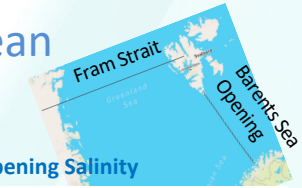
Ice shelf capability for global sea level studies



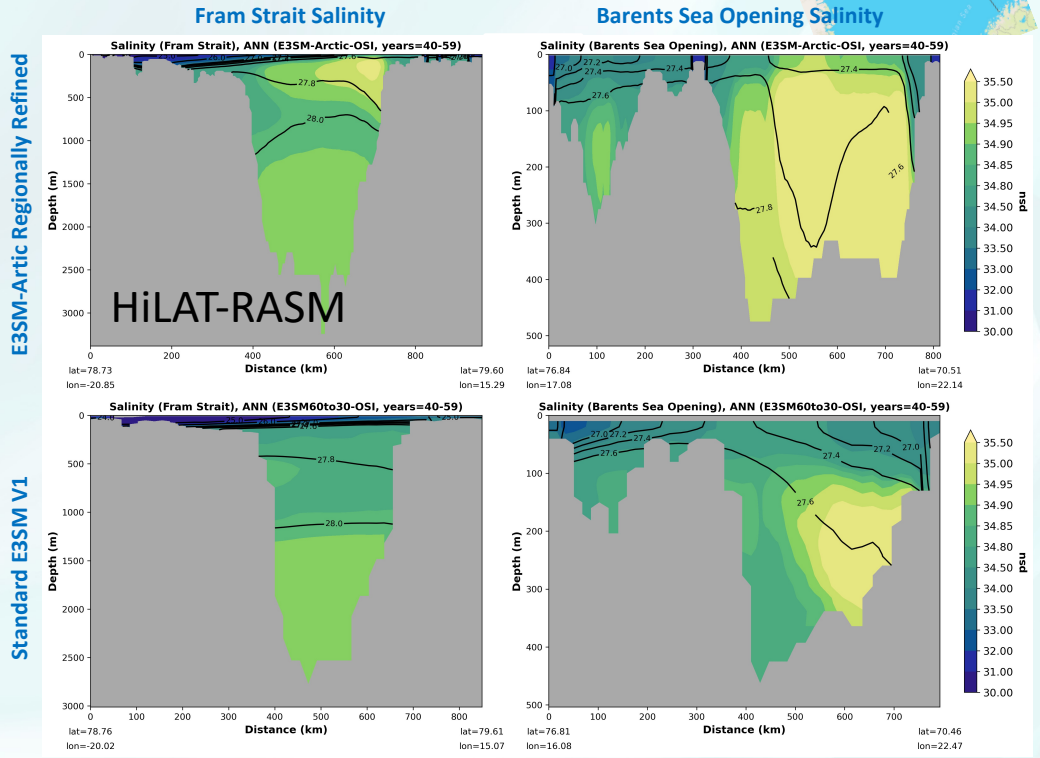
Global atmospheric model with regional refinement

Example of the impact of Arctic mesh refinement

Eddy and boundary-dependent seawater exchange with the Arctic Ocean

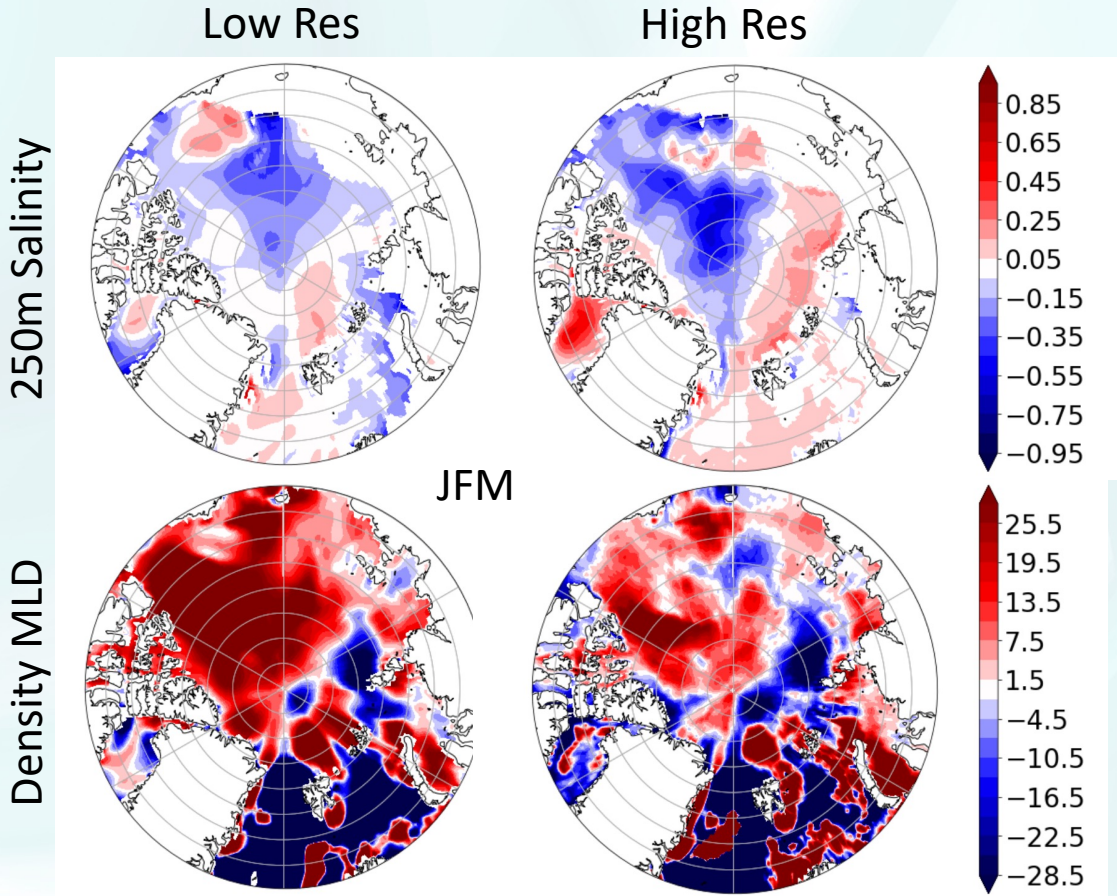


- Regional refinement Reproduces subarctic ocean processes of relevance, such as the inflows of Atlantic and Pacific Waters and the meridional overturning circulation
- Captures the Arctic and Antarctic ice edge with much greater accuracy than standard resolution
- Challenges exist in accurately representing mixing



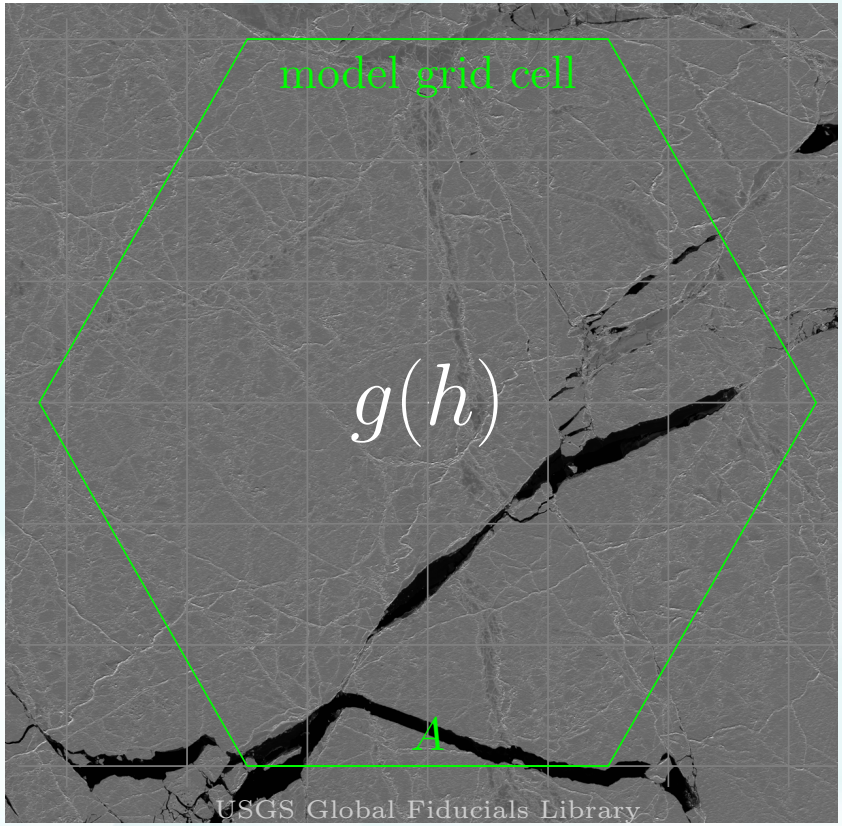
Accurate representation of turbulent mixing remains elusive for the Arctic

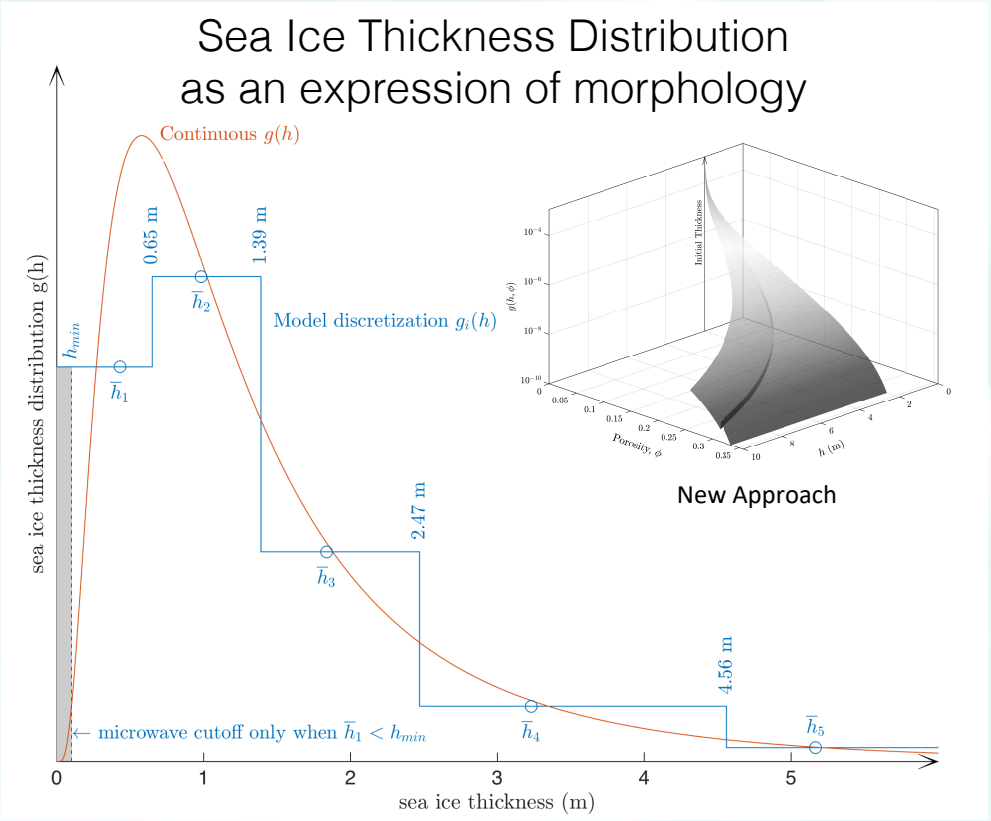
- Moving from E3SM-LR to HR does not improve subsurface salinity and mixed layer depth biases suggesting vertical mixing biases
- Current schemes are sensitive to either timestep, horizontal, or vertical resolution
- Representation of mixed layer entrainment is poor
- Work underway on new closure with improved physics (including entrainment)



Scale Awareness: A limitations being addressed for future E3SM

Many sub-grid scale parameterizations are unaware of the scale of a model grid cell

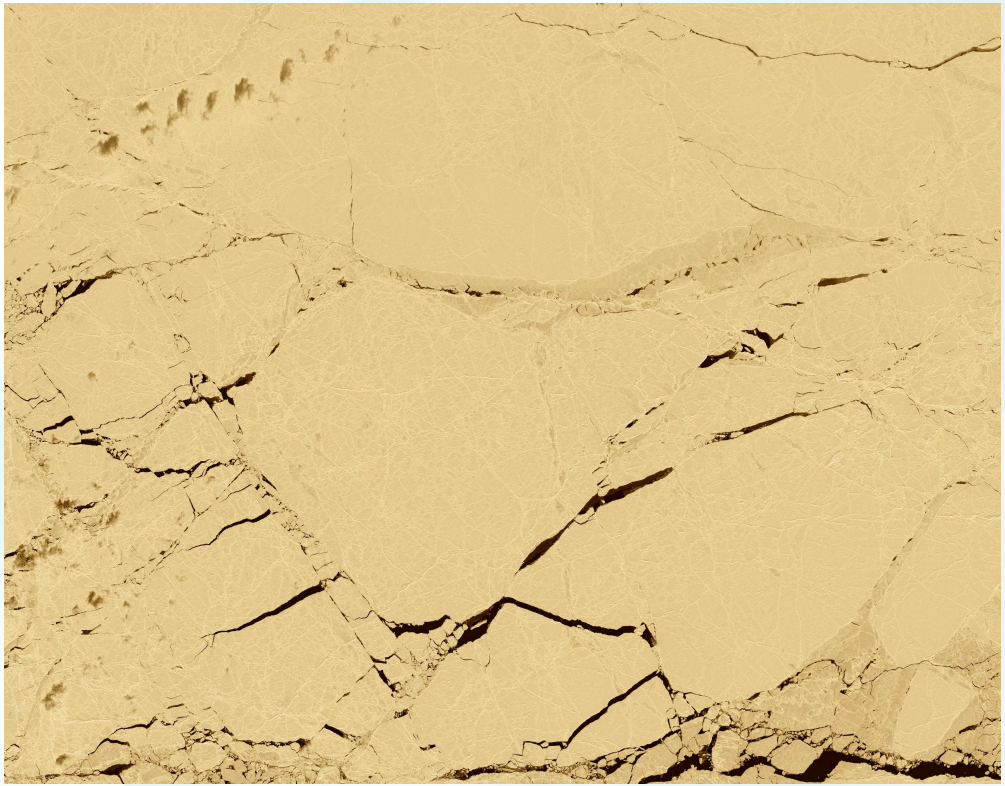




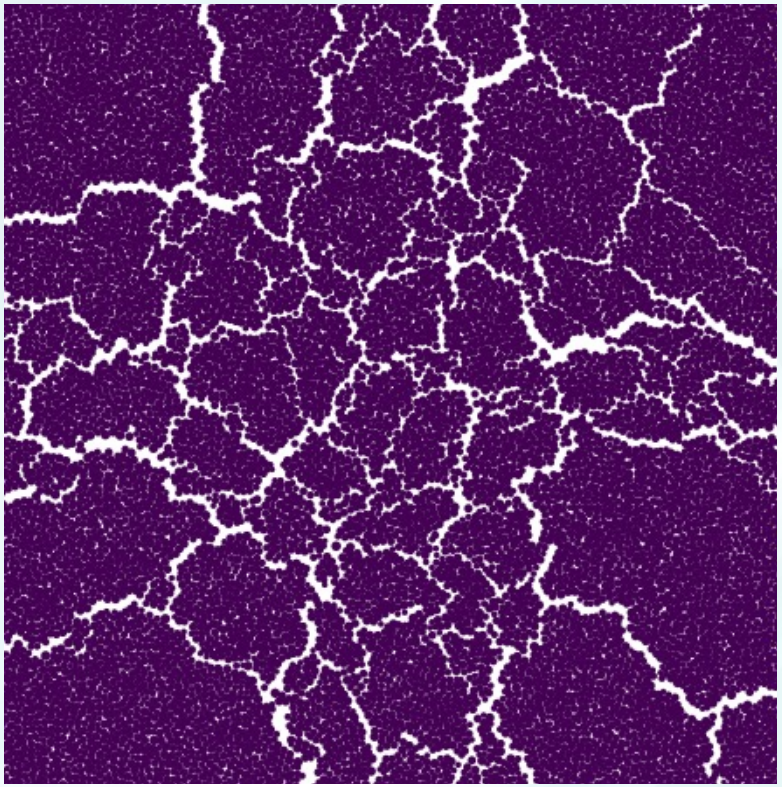
See details of new scale-aware approach to sea ice morphology in extra material

Scale Awareness: A limitations being addressed for future E3SM

Accuracy of current continuum sea ice mechanics decays with increasing resolution

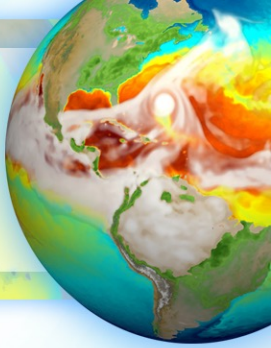


USGS Fiducial Image from the Beaufort Sea



Future: DEMSI Discrete Element Fracture

Coastal Interactions and Sea Level Rise



- InteRFACE and ICoM are E3SM ‘ecosystem’ projects, the former focusing on wave-ice interaction, oceanic mixing appropriate for coastal modeling, landfast ice implementation, benthic biogeochemistry, and land hydrology. ICoM is providing ice-tide development and spatially variable timestepping in E3SM.

- Matt Hoffman’s Early career project is creating a prognostic sea level rise capability

- Separately, full Greenland ice sheet coupling is underway in E3SM, in addition to existing work to model melt rates for Antarctic ice shelves and their contribution to global sea level rise.

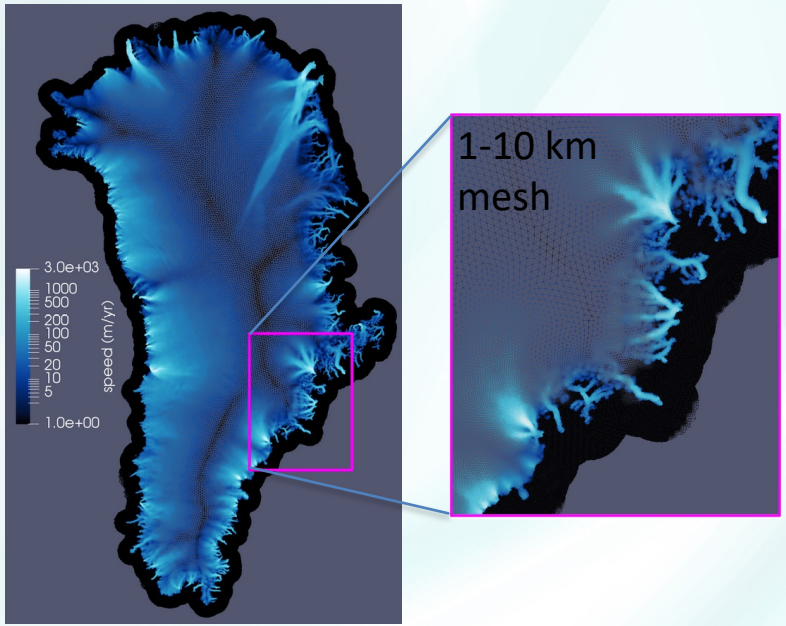
In the works: Greenland Ice Sheet Coupling to E3SM

Progress

- Dynamic higher-order ice-sheet model (MALI) with variable resolution (1-10 km GIS) with subglacial hydrology model, calving schemes, and marine melting schemes
- PDE-constrained optimization for initialization to transient climate conditions
- Surface Mass balance calculated by new firn model in Land model
- MALI's subglacial hydrology model is being applied towards improved freshwater routing to the ocean

Challenges

- Even with regionally-refined ocean model, it is not possible to fully resolve fjords
- Climate biases can lead to unrealistic ice sheet evolution and make initialization difficult

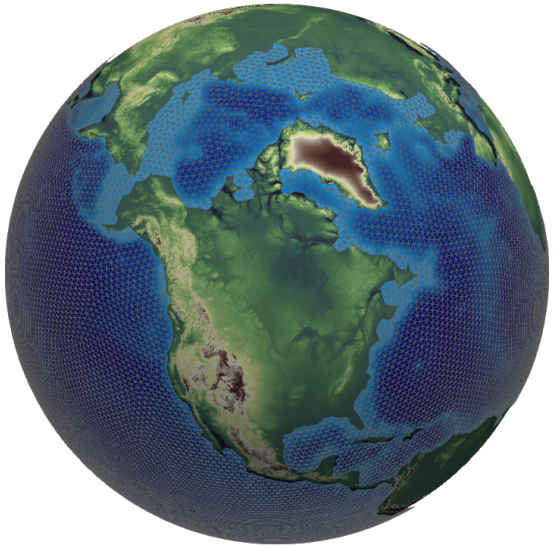


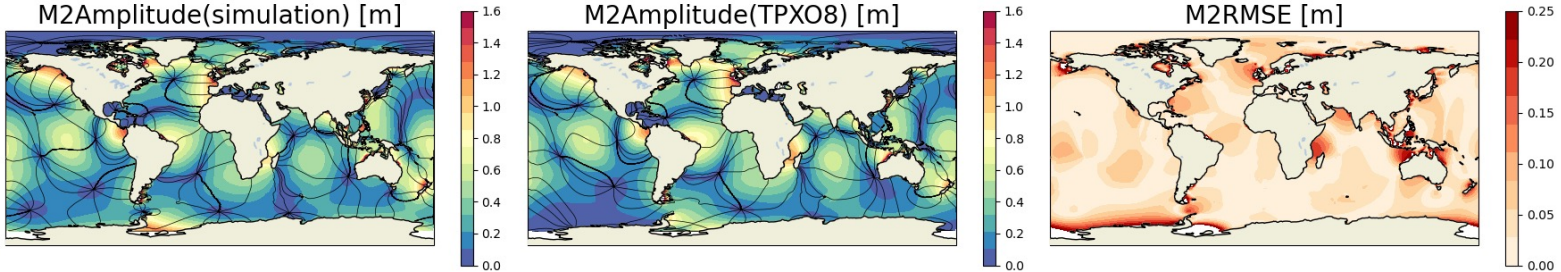
Modeled velocity in MALI

In the works: Wave-Ice and Ice-Tide interactions in E3SM

Progress:

- WaveWatch III is running on a 100km unstructured mesh with a rotated pole, suitable for Arctic simulations, costing ~3 times the ocean model.
- Mesh provides complete coverage of the Arctic suitable for coastal modeling, and conformal coastal modeling is in place to match the ice-ocean domain.
- Explicit tides running in MPAS-Ocean, currently being coupled with sea ice in E3SM as part of a collaboration between LANL and the University of Michigan





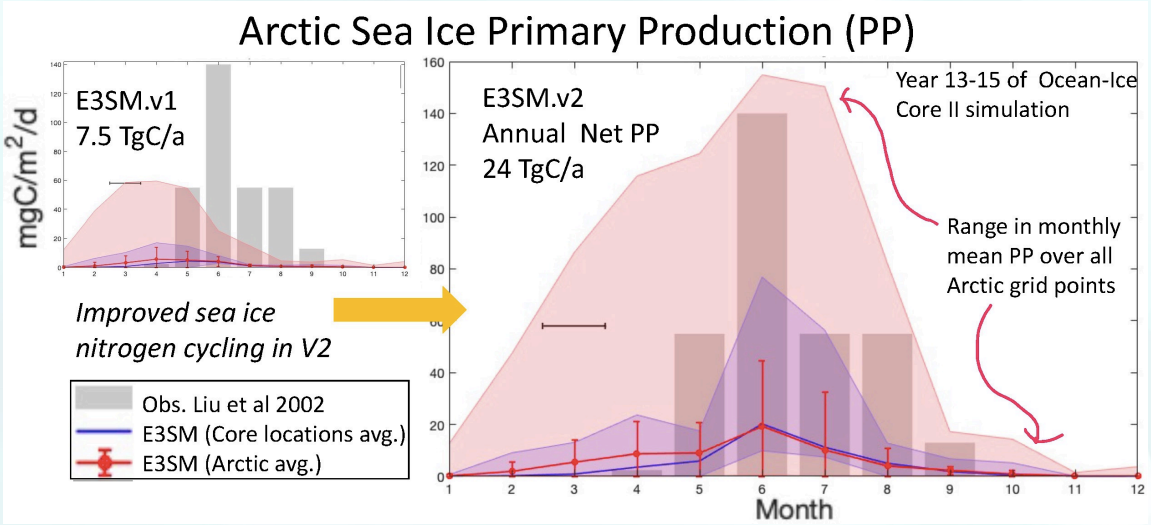
Arctic biogeochemistry in E3SM

Progress:

- 3D BGC in sea ice
- Ocean-ice BGC coupling
- Tracer supercycling
- Ocean benthos model

Challenges:

- Coastal BGC – lack resolution and processes
- Mixing in the photic zone and representation of the nitricline
- Data sparsity
- Efficient BGC codes



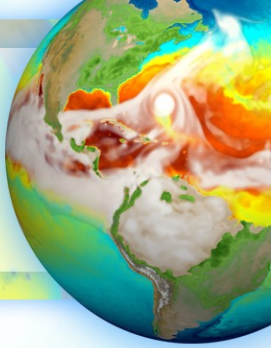
Above: Improved nitrogen cycling in v2 enhances model fidelity of sea ice primary production

Opportunities:

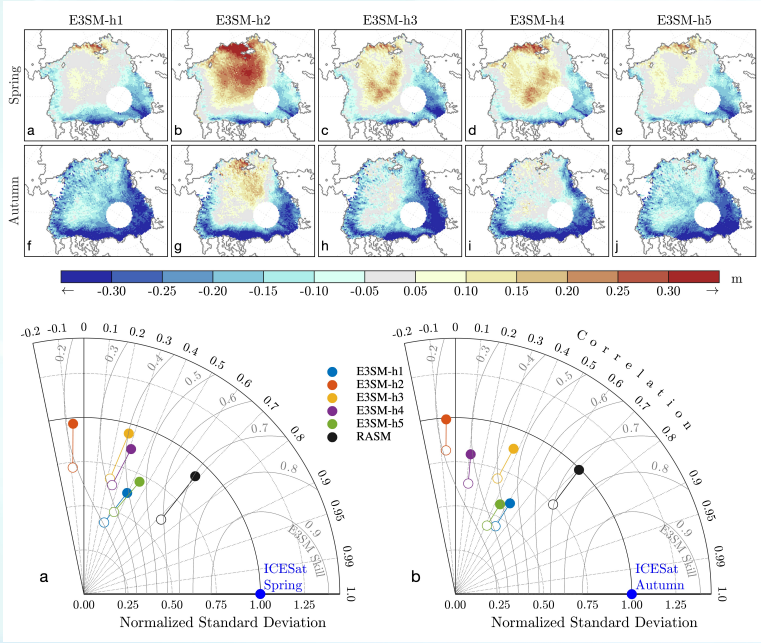
- RASM – river nutrient forcing
- UCI – implicit BGC solver
- NCAR – MARBL
- UCI and UNH – DOC
- IARC – MOSAIC data and sediment data

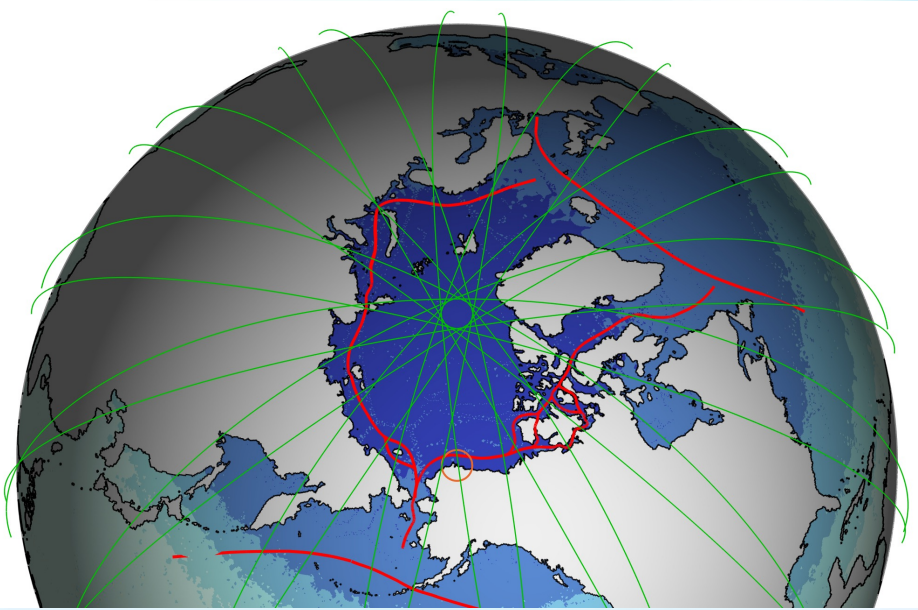
Model-Observation Data Fusion

Example: Satellite Emulation with potential for machine learning



Freeboard





E3SM CMIP6 ICESat emulation, referenced against RASM

E3SM Energy Exascale Earth System Model

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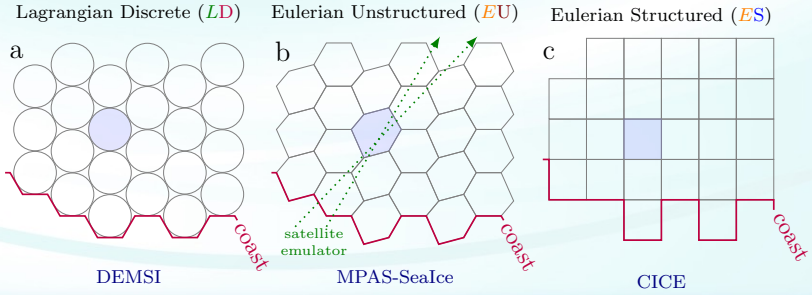
Opportunities for Collaboration

- Reach out to E3SM DOE Scientists to collaborate on solicitations (ESMD, RGMA, MSD)
- Create pathways for integration to E3SM from ICoM, InteRFACE and NGD Ocean project
- Build capabilities for Arctic predictions (Ensembles, UQ, DA, ML/AI)
- Contribute to the CICE Consortium, including integrating Icepack into MOSAiC studies
- Become part of data fusion efforts, including for BGC



E3SM Energy Exascale Earth System Model

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