

Wave – Sea Ice Interactions (and other critical Wave developments) in E3SM

International Waves Workshop

October 1–6, 2023

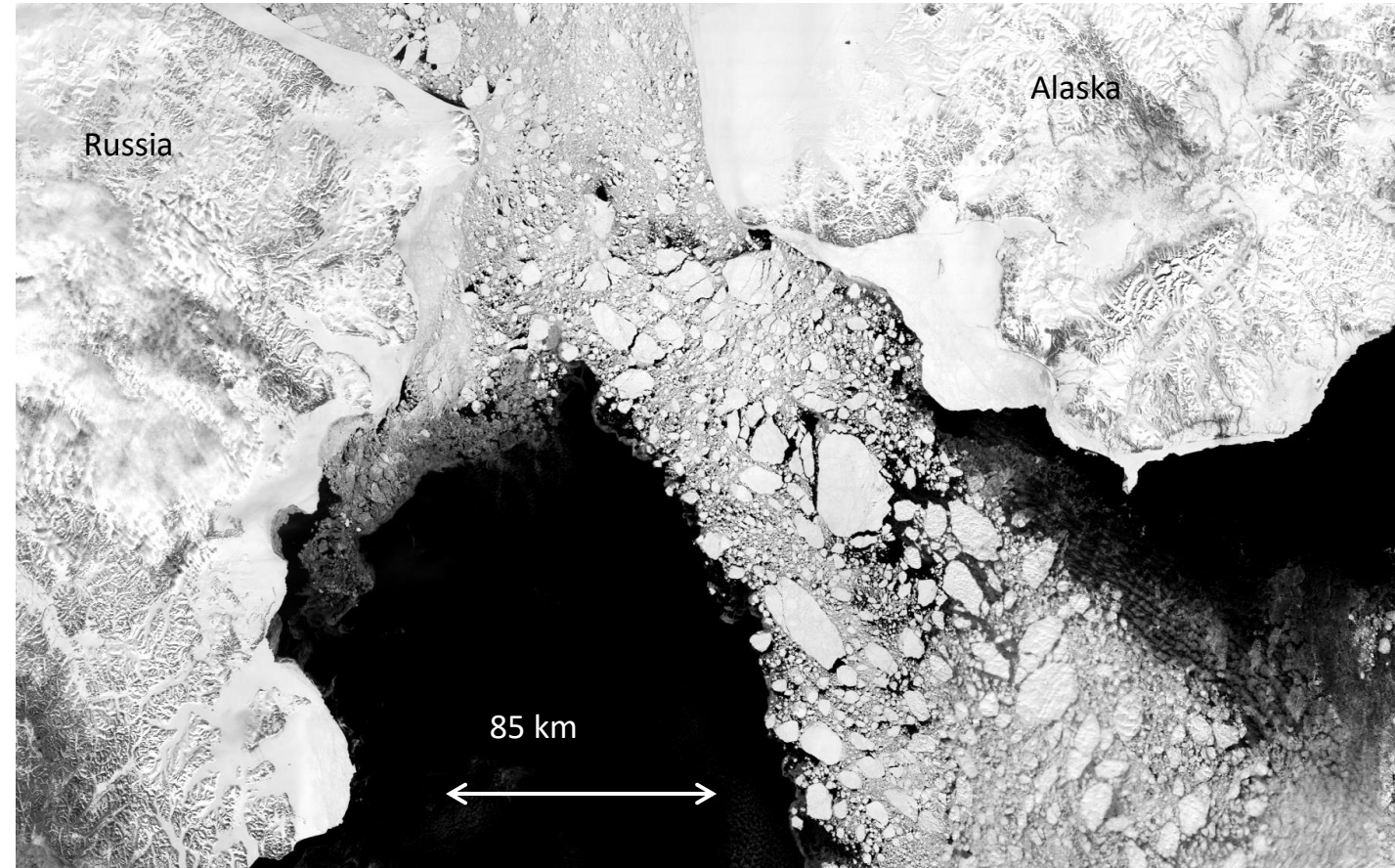
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1 Los Alamos National Lab

2 Argonne National Lab

Outline

- Background + Current Capabilities
- New Wave-Ice Coupling Framework in E3SM
- Floe Size Distribution
- Ice Floe Breaking from Waves
- Preliminary Results + Future efforts



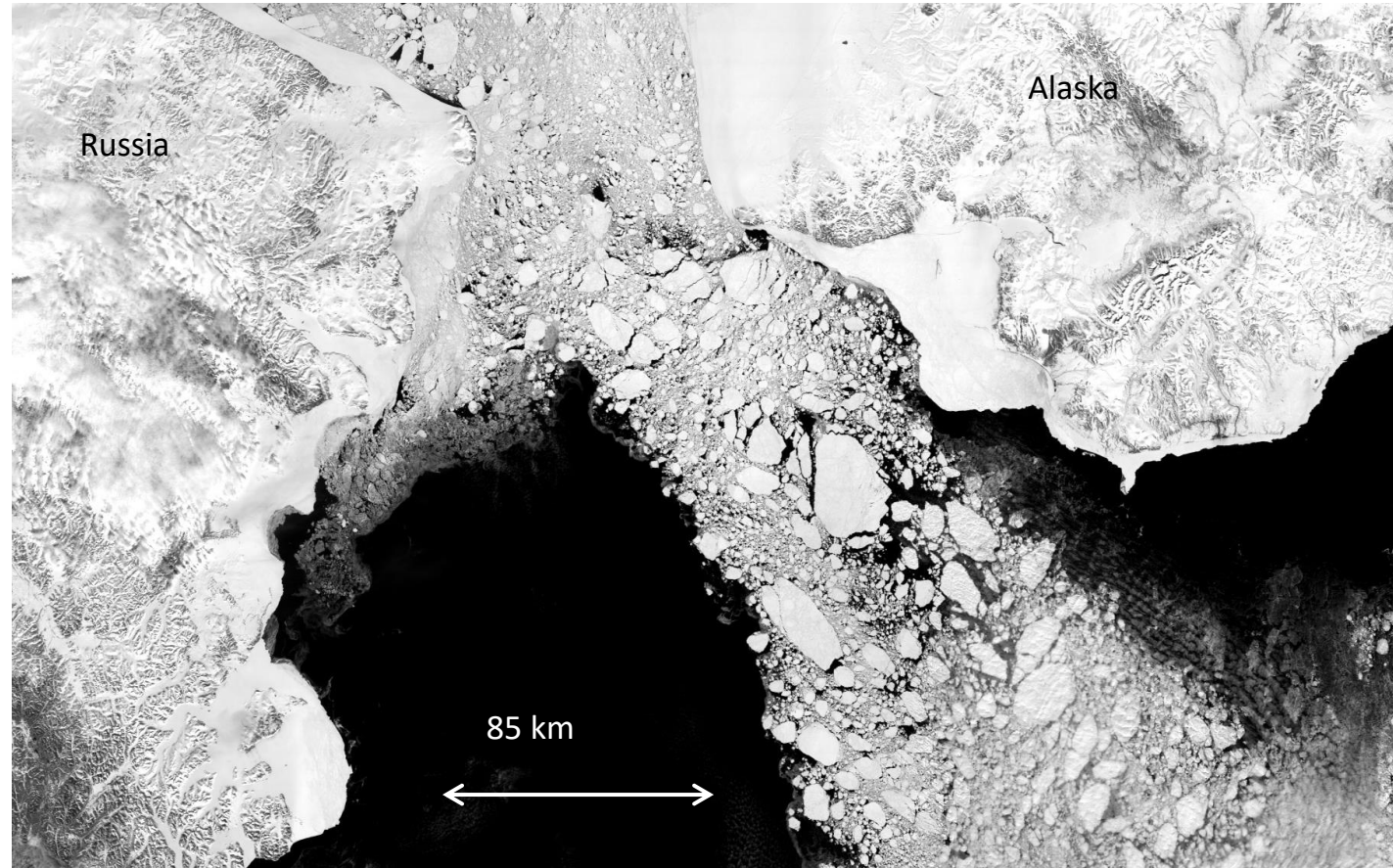
Floes in the Bering Sea (MODIS)

Background

Accurately representing the processes of wave-sea ice interactions is critical to simulating the changing wave climate in polar regions.

Sea ice floe sizes span a wide range of scales, described statistically by their floe size distribution (FSD).

Waves are critical to simulating FSD in the marginal ice zone

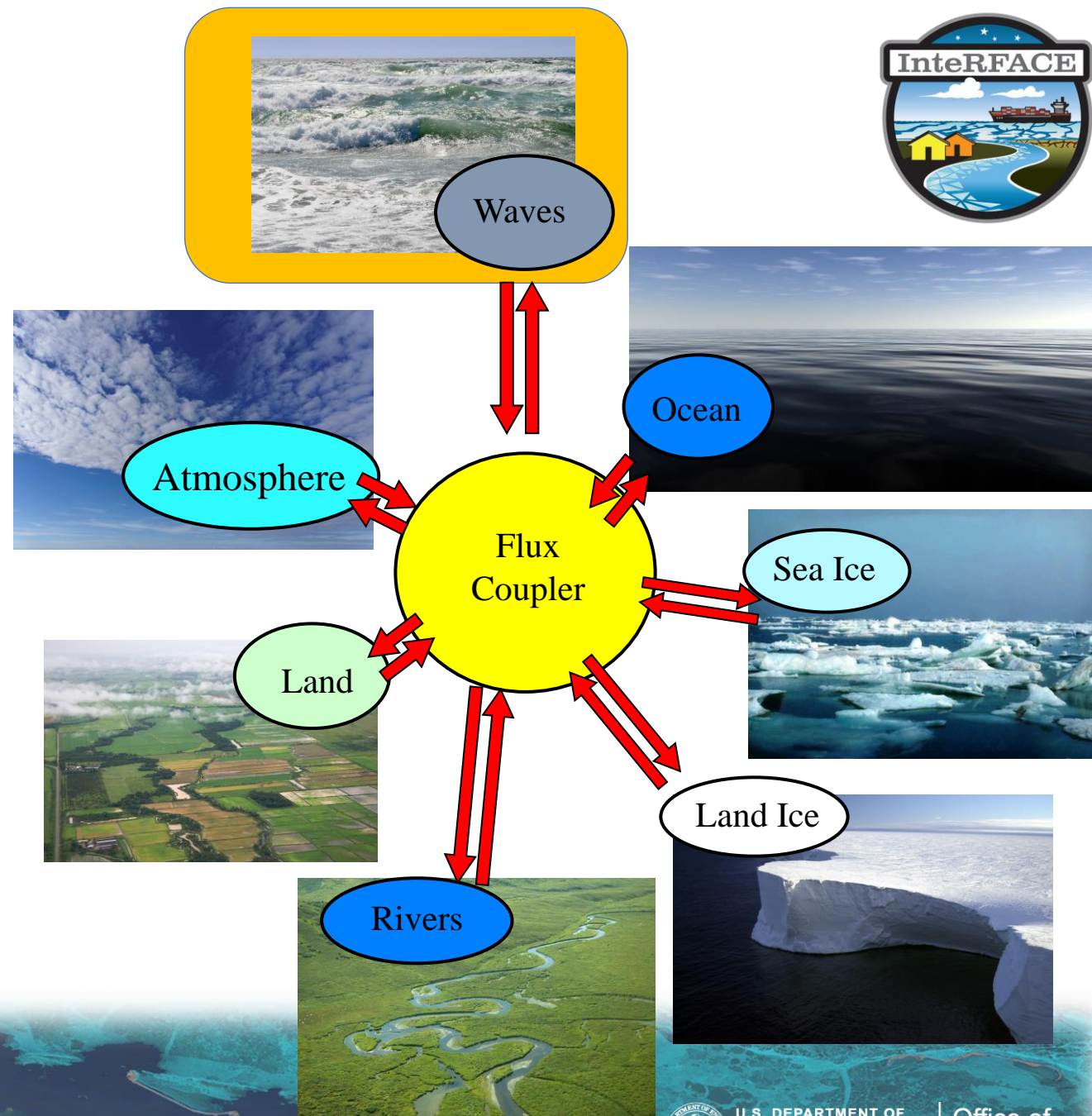


Floes in the Bering Sea (MODIS)

Current Capabilities in E3SM:

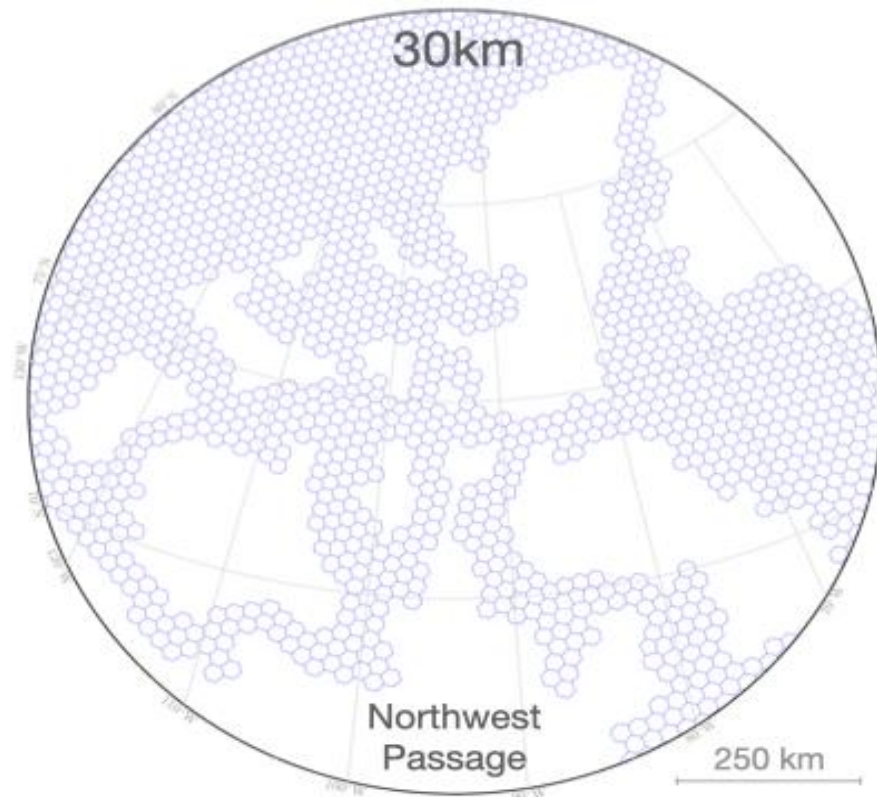
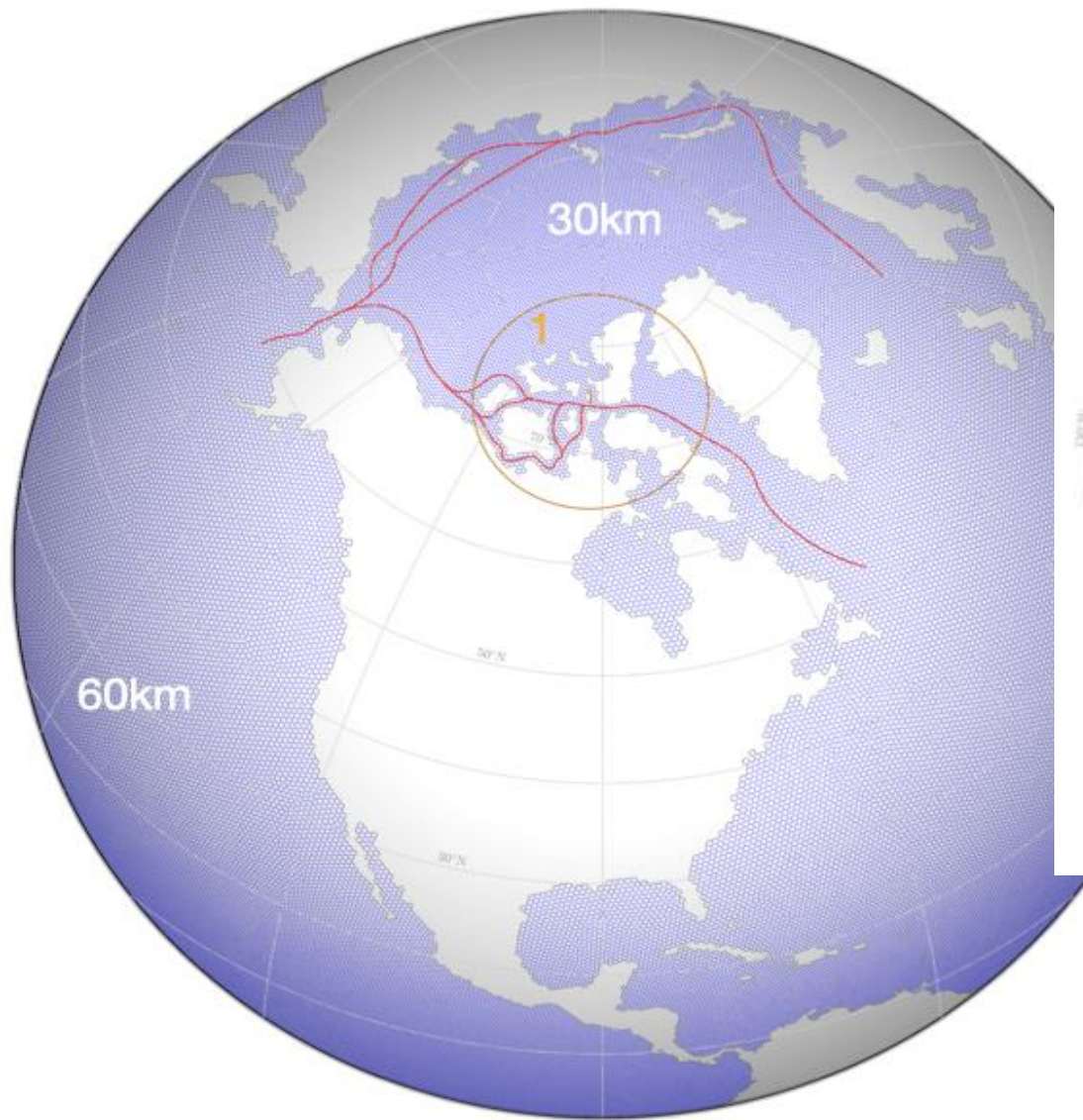
E3SM is a fully coupled global Earth system model targeting exascale computing.

- Intended for DOE's advanced architectures, and high resolution
- **Includes atmosphere, land, runoff, ocean, sea ice and WAVE coupled components**
- Includes Antarctic ice shelves, soon to include the Greenland ice sheet
- **Capable of regional refinement, using unstructured sea ice, ocean, and wave meshes**



Standard “Low Resolution” Ocean - Sea Ice Mesh

Current
Capabilities:
E3SM
Unstructured
Meshes

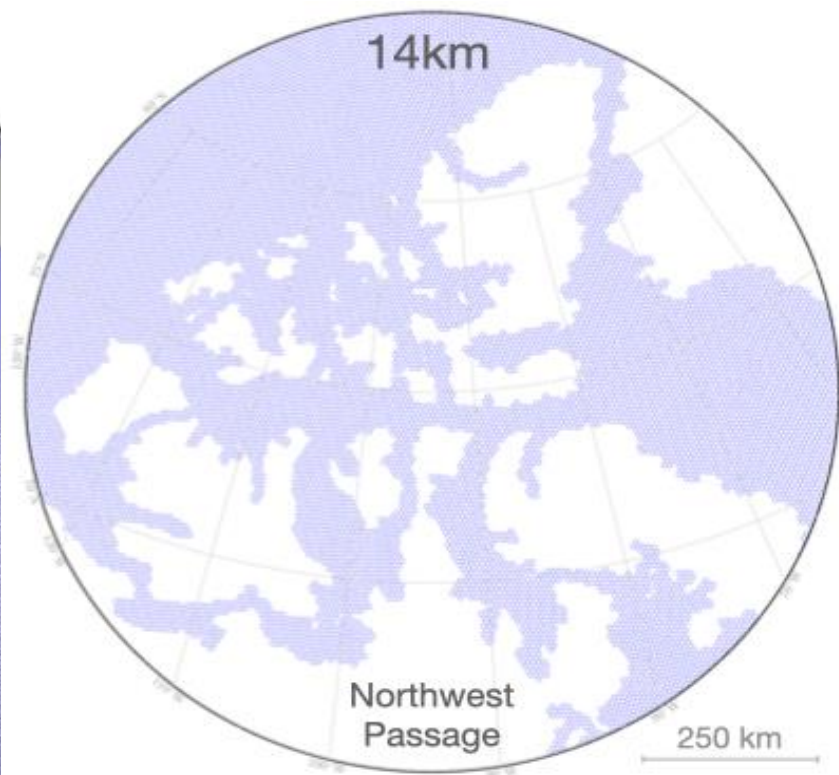
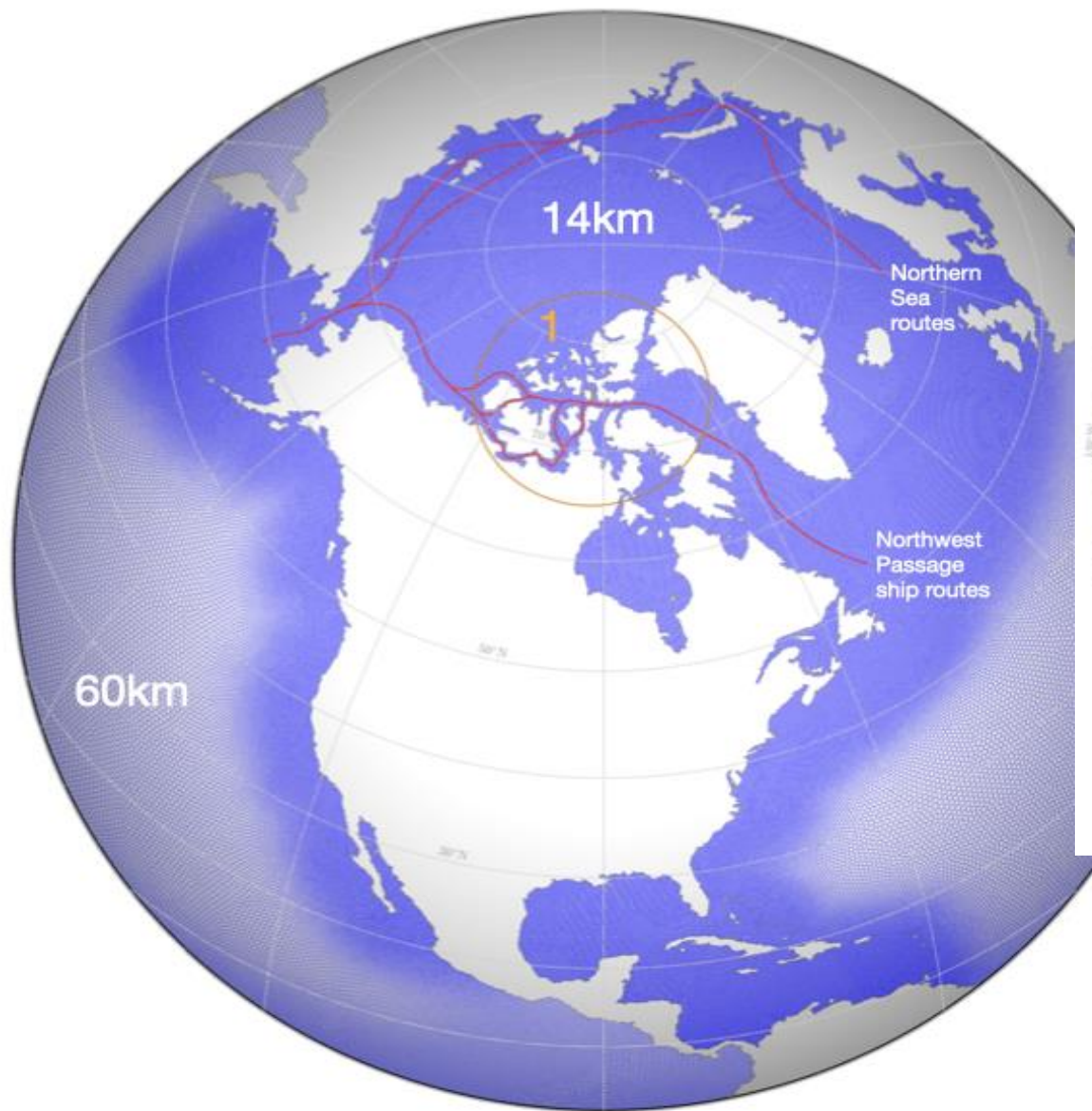


Comeau et al. 2022, JAMES

10/23/2023

Arctic and North American RRM

Current Capabilities:
E3SM
Unstructured Meshes

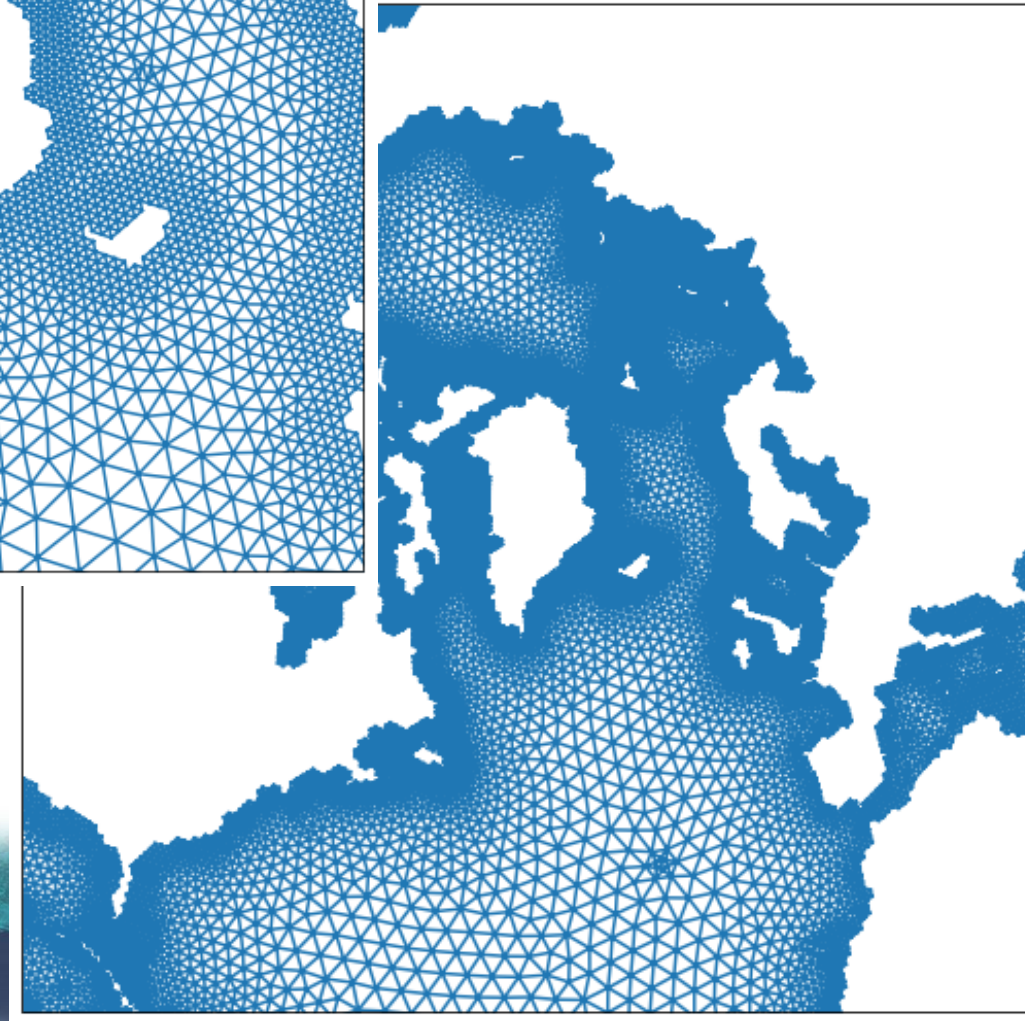
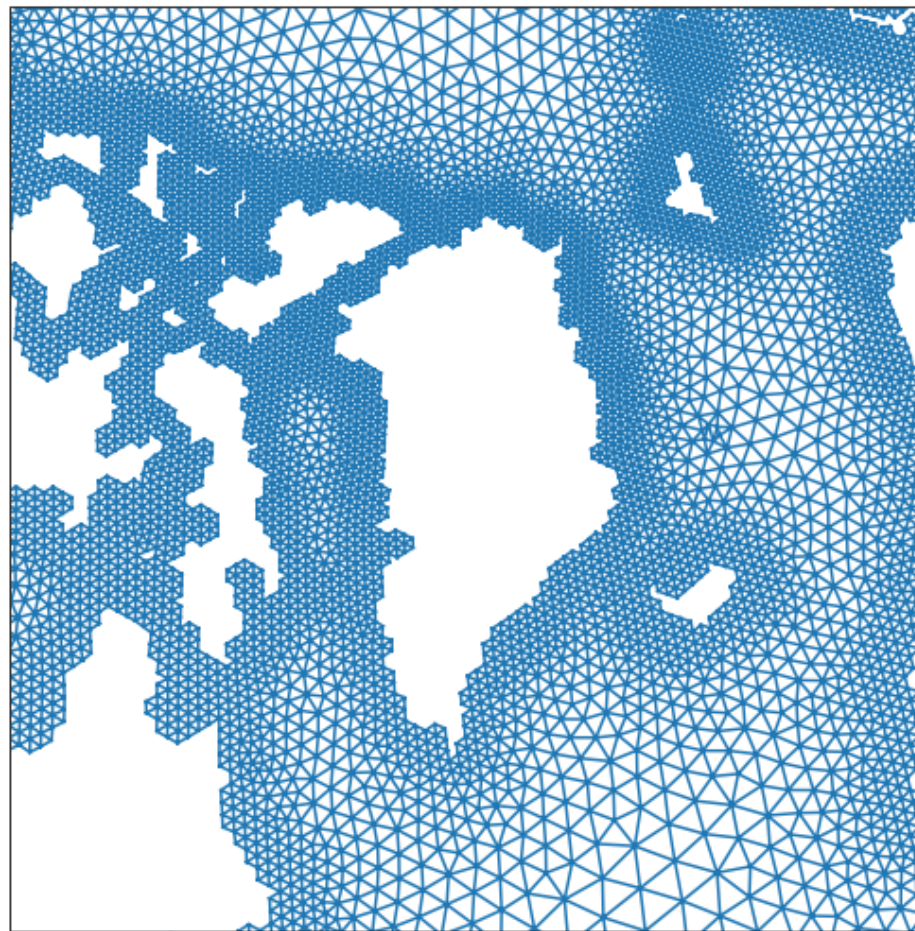


Comeau et al. 2022, JAMES

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New Developments in E3SM: WW3

1. **WAVEWATCH III on an unstructured mesh** in E3SM, resolution ranges from >200km open ocean but **matching the coastal shape and resolution of the ocean and sea ice models at the coast** – here 30-60 km (*Brus et al. 2021 GMD*)
2. Large economies achieved by a **porting WW3 Source Terms to GPUs** but still consumes similar resources to an entire ocean model, depending on the architecture (*Ikuyajolu et. al. 2022 JAMES*)
3. **WW3 coupling with Sea Ice Model**, includes estimate of Sea Ice Floe Size Distribution and Ice Floe-breaking due to waves



New Developments for Wave - Sea Ice Coupling: Sea Ice Floe Size Distribution

Ice Floe Size depends on:

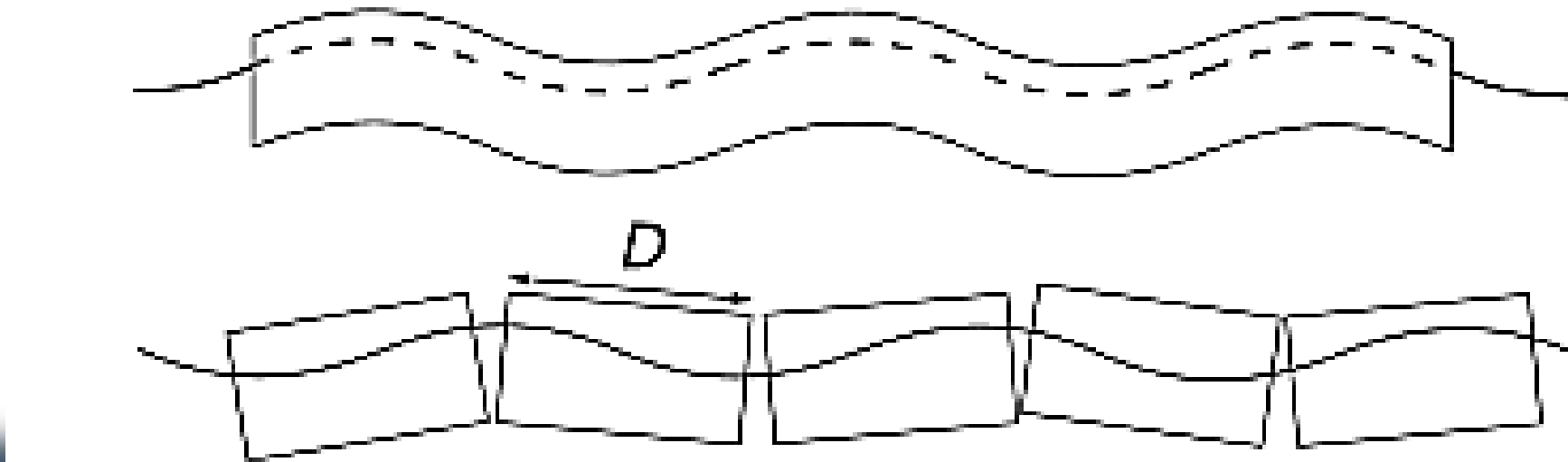
- Advection of floes
- Thermodynamics
 - growth due to freezing
 - loss due to melting
- Mechanical processes
 - collisions (welding)
- **Breaking due to waves**

$$\frac{\partial f(r, h)}{\partial t} = - \overbrace{\nabla \cdot (f(r, h)\mathbf{v})}^{\text{Advection}} + \underbrace{\mathcal{L}_T}_{\text{Thermodynamics}} + \underbrace{\mathcal{L}_M}_{\text{Mechanical}} + \underbrace{\mathcal{L}_W}_{\text{Waves}}$$



New Developments for Wave - Sea Ice Coupling: Floe Breaking due to Waves in MPAS-SI

- Assumes sea ice flexes with the sea surface height field
- Ice Floe breaks if 'strain' exceeds critical threshold
- Resulting floe diameter = distance between the extrema in sea surface height field



New Developments for Wave - Sea Ice Coupling:

WAVEWATCH III

Wave Variables Sent to coupler:

- Significant Wave Height (H_s)
- Wave Spectra
 - function of wave frequencies

Red = New infrastructure for wave-ice coupling



Ice Vars received from Coupler :

- Ice Fraction
- Ice Thickness
- Mean Ice Floe Diameter



MPAS – Sea Ice

Wave Variables Received from Coupler:

- Significant Wave Height (H_s)
- Wave Spectra
 - function of wave frequencies

Ice Variables sent to coupler:

- Ice Fraction
- Ice Thickness
- Mean Ice Floe Diameter

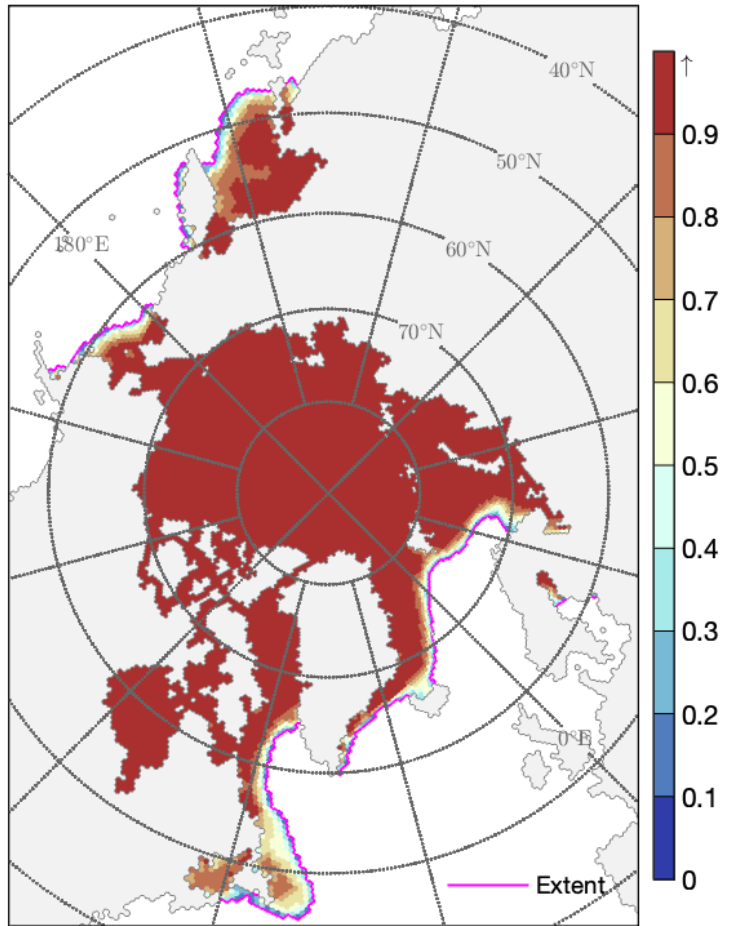
Preliminary Results

Experimental Design Plan

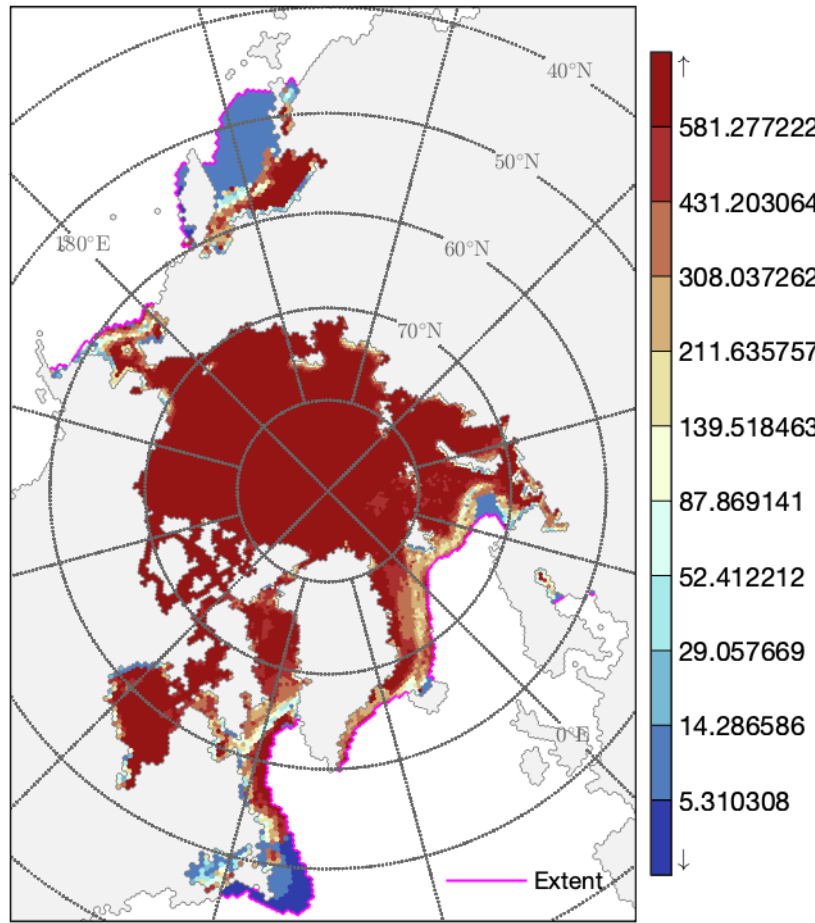
1. MPAS-SI + FSD (no waves)
2. MPAS-SI + FSD + Idealized Data-Waves (ongoing development for Data-Wave Component)
3. MPAS-SI + FSD + Fully Active WW3 (ongoing testing)

Hot off the Press: Preliminary Results: MPAS-SI + FSD (no waves)

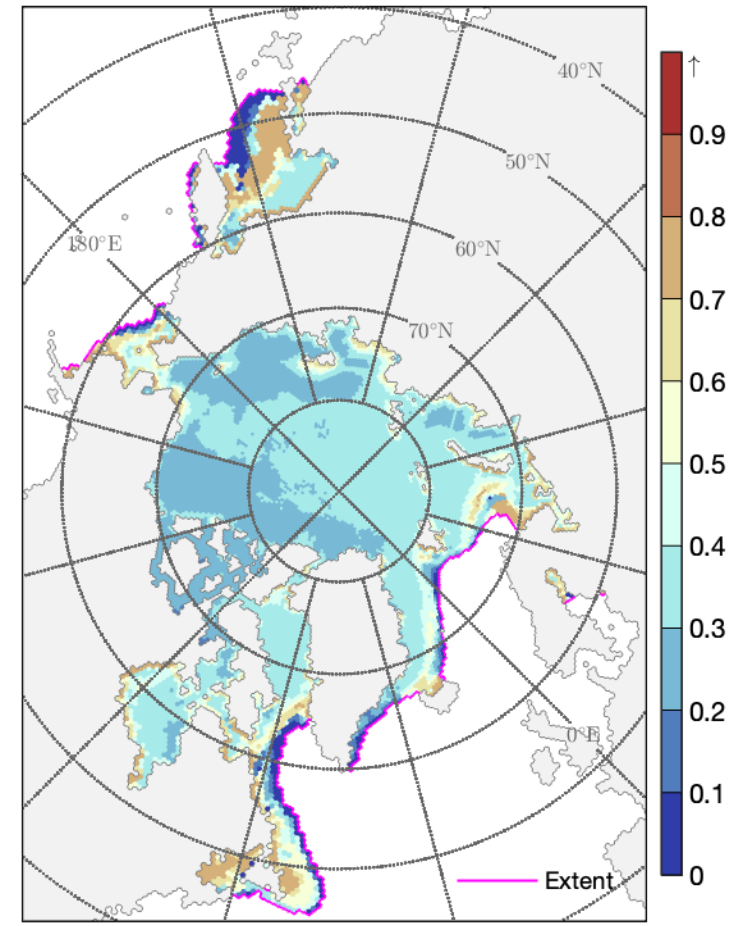
Feb
Ice Fraction



Feb
Mean Floe Size Diameter



Feb
Mean Floe Perimeter per unit area



Future Directions:

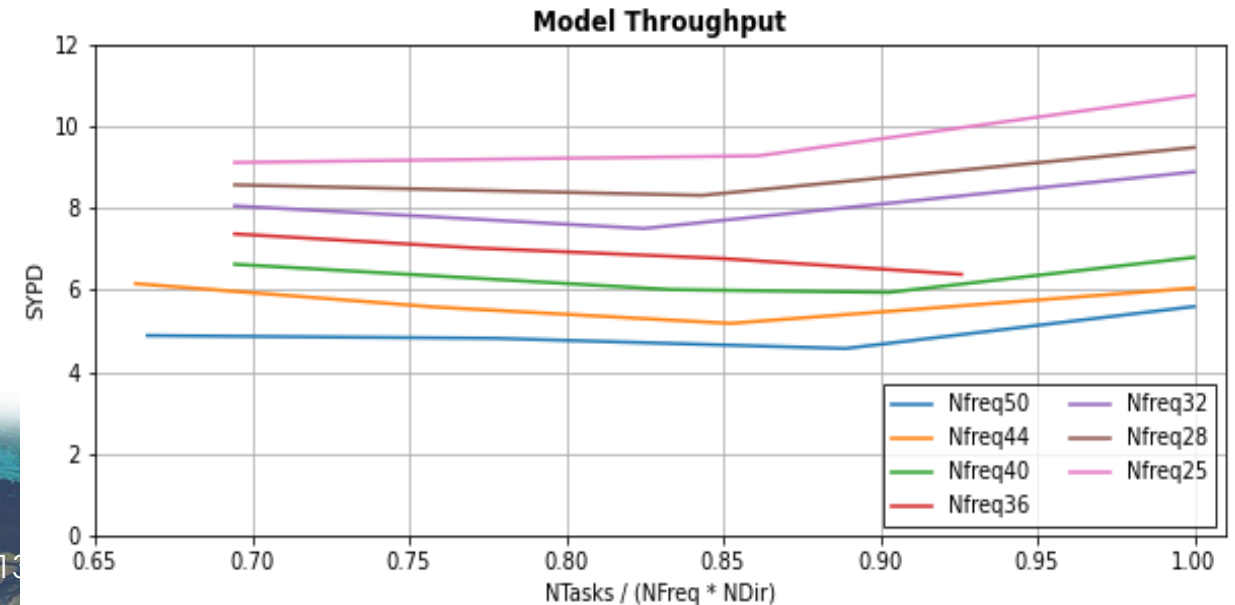
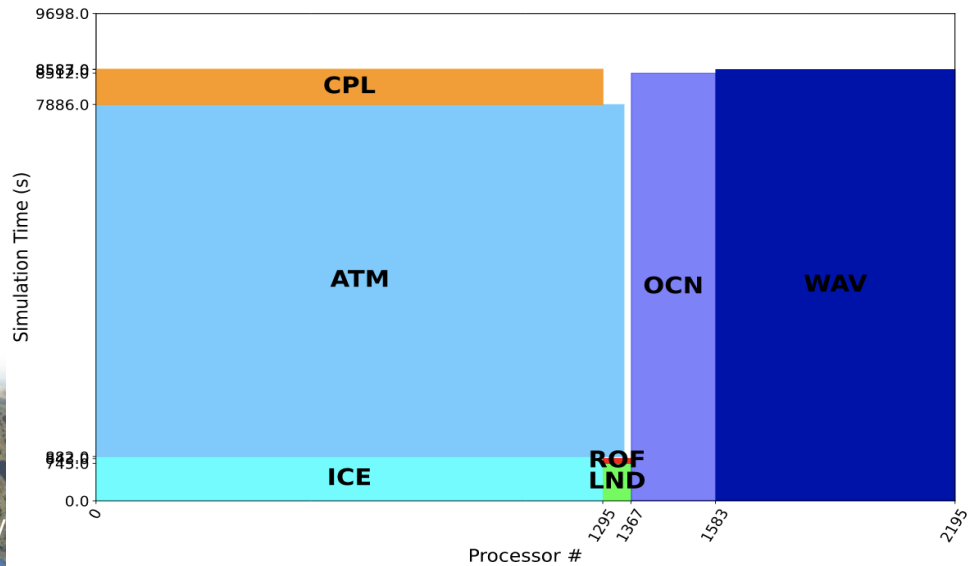
Global Climate Sensitivity to Spectral Resolution of Waves

- E3SM framework designed **to allow flexible spectra resolution in WW3**
- Current possible values: 25, 36 (default), or 50 Frequencies
- Test impact of Spectral resolution for WW3 using unstructured mesh in global climate model**

Reducing from 50 to 25 frequencies increases SYPD of the Global WW3 by ~1.8x and has very little impact on accuracy of results.

What's the impact of spectral resolution on global wave climate in our fully coupled system?

What's the impact given different horizontal and regional refined meshes?



Future Directions:

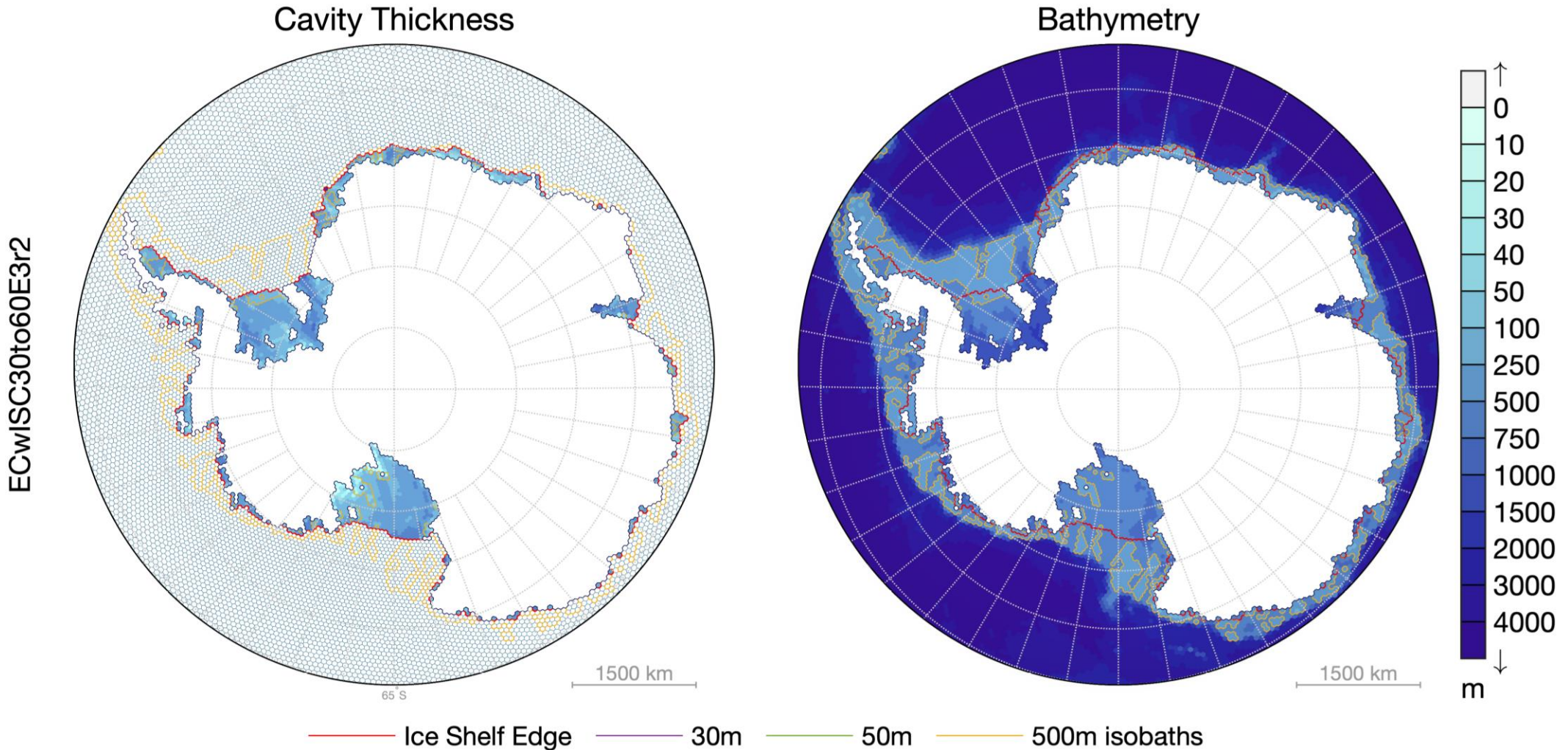
HIGH RESOLUTION
Arctic Wave Mesh:
down to ~ 2km in
Arctic



Future Directions:

ICE SHELF CAVITIES in new ocean and ice meshes

Credit to Xylar Asay-Davis, Jon Wolfe + Andrew Roberts



E3SM: a unique platform for exploring the role of waves in a fully coupled climate system

- Unstructured, Regional Refinement Wave mesh
 - spend computational resources where waves need it most: shallow, coastal regions
- New Sea Ice physics allows for fully coupled Wave-Ice interactions
 - Floe Size distribution + floe breaking due to waves

See latest
results at
AGU!

Future Efforts:

- Ongoing testing with new sea ice column physics (FSD), and Ice-Wave interactions in the next few weeks!
- Spectral sensitivity study for wave modeling on global climate scales
- New High Resolution Wave Mesh (down to 2km in coastal Arctic regions)
- New Ocean and Ice meshes with Ice shelf cavities in Antarctica - coming soon

Thank you!