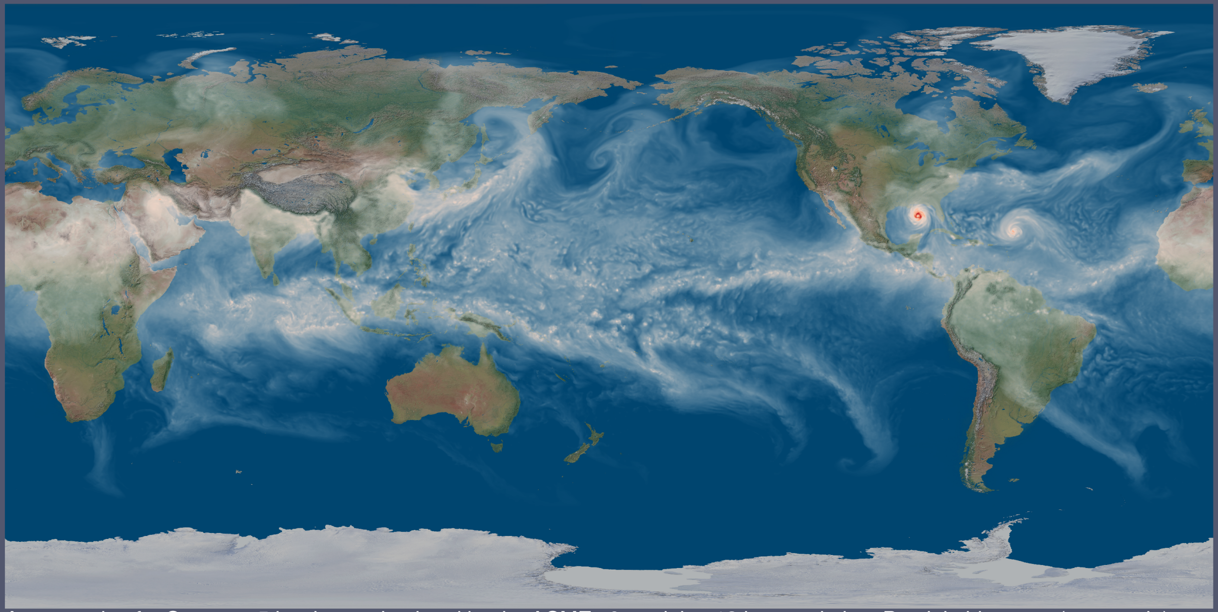
A DOE CESD perspective on the Success, Limitations, Gaps and Low-Hanging Fruits in Arctic Modeling

LA-UR-17-23734

Science objectives for DOE's Climate and Environmental Science Division (CESD)

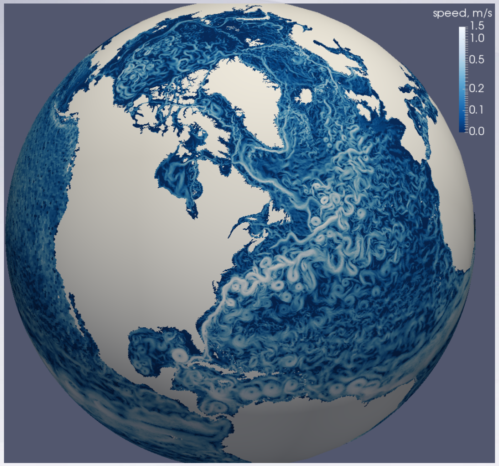
Conduct pioneering work in high-resolution climate modeling methodologies to produce robust regional climate projections, including information on extremes, feedbacks, variability and change, and thresholds and tipping points with a focus toward regions vital to the Nation's interests, such as the Arctic.



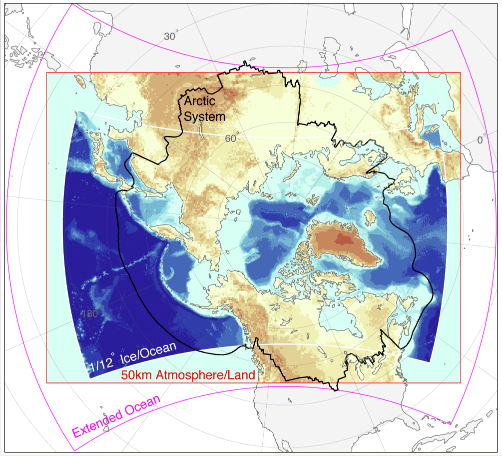
An example of a Category 5 hurricane simulated by the ACME v0 model at 13 km resolution. Precipitable water (grey scale) shows the detailed dynamical structure in the flow. Strong precipitation is overlaid in red. High resolution is necessary to simulate reasonable numbers of tropical cyclones including Category 4 and 5 storms.

Core DOE activities with significant Arctic model development, analysis and evaluation capability:

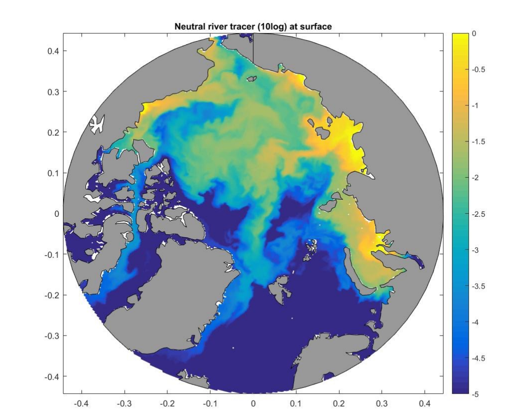
Accelerated Climate Model for Energy



Regional Arctic System Model



Next Generation Ecosystem Experiment - Arctic

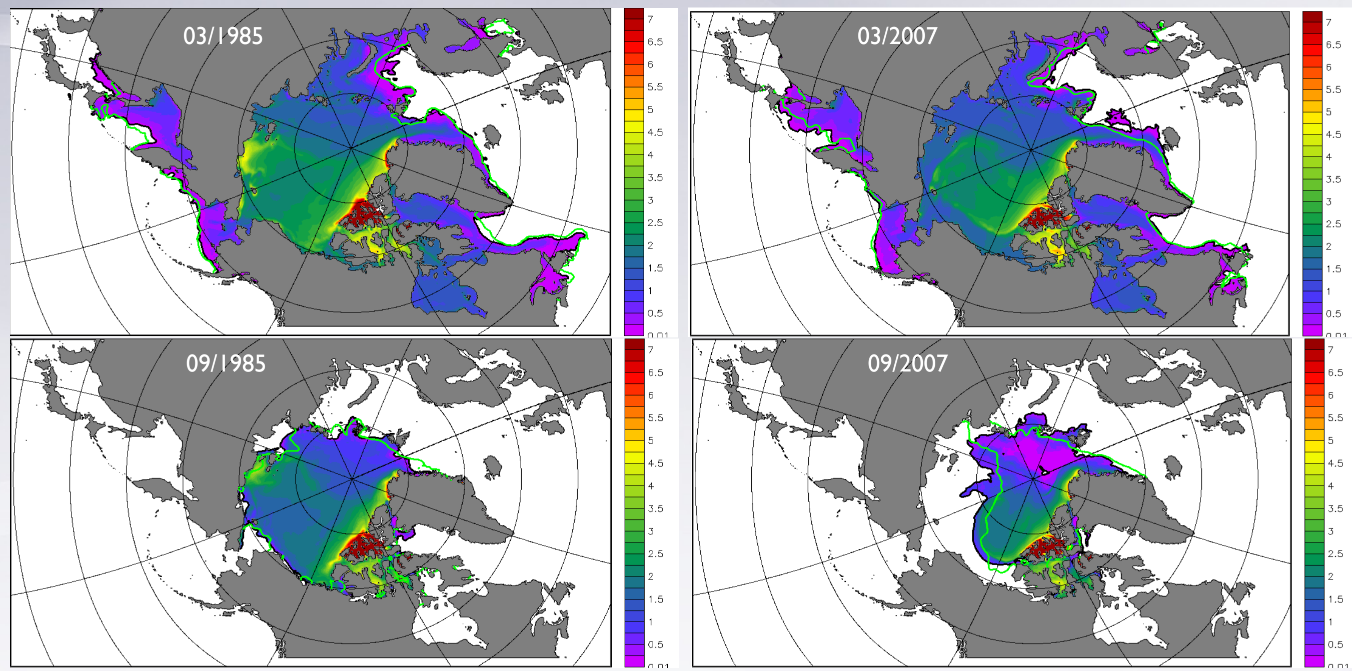


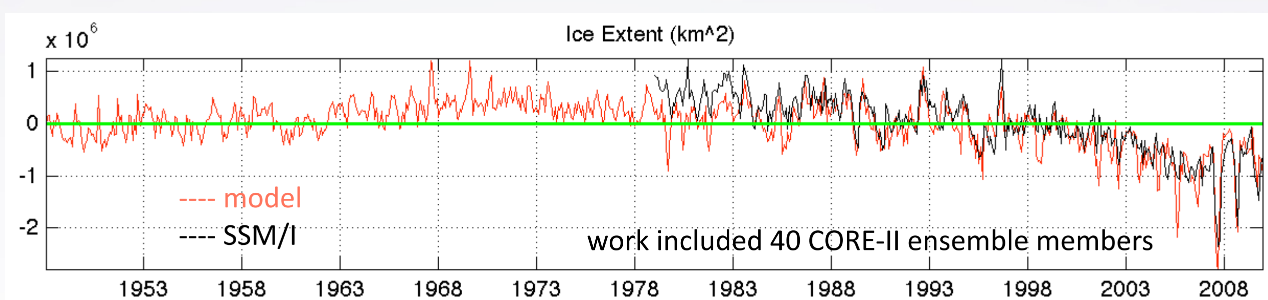
High-Latitude Application and Testing of Global and Regional Climate Models

RASM: Increasing fidelity of Arctic simulations through improved representation of important processes.

Limited-area domain allows computational resources to be focused toward the Arctic region.

Hierarchy of resolutions are utilized with highest resolutions of 2.4 km in the ocean and 25 km in the atmosphere.



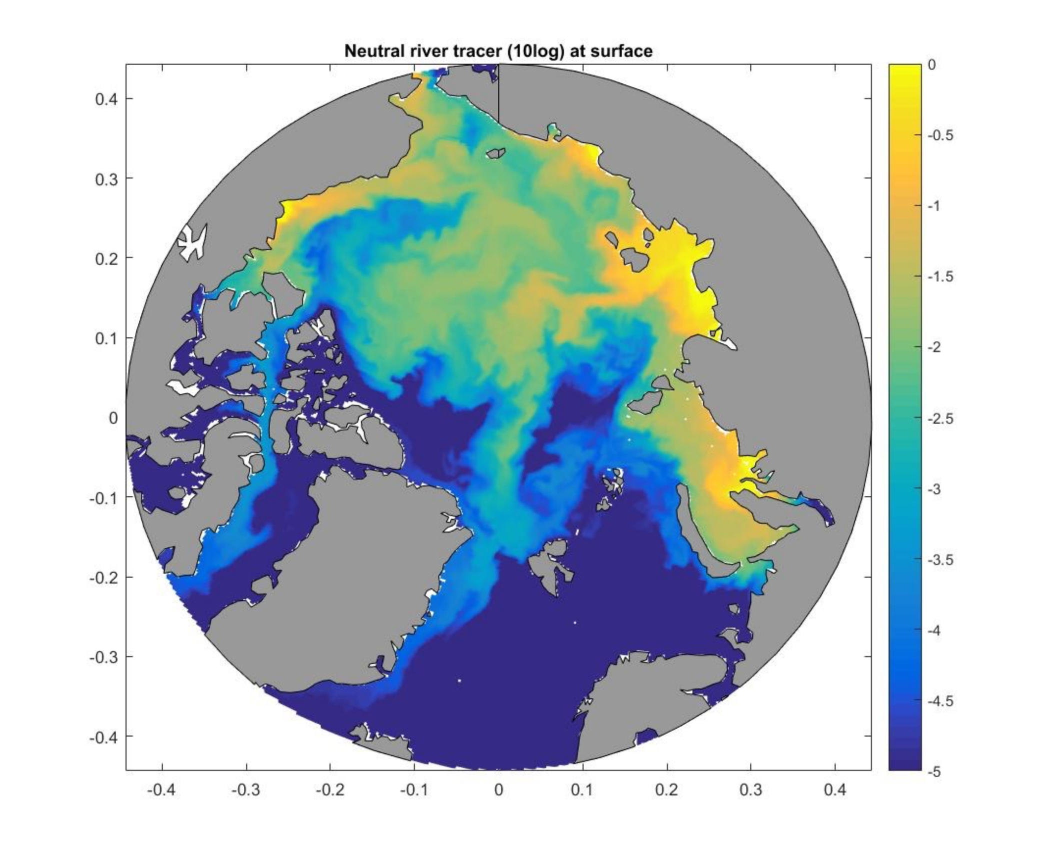


from Wieslaw Maslowski and the RASM Team

HiLAT: Quantifying feedbacks between the cryospheric changes in the Arctic and the Earth's heat and water budget.

Using global models at eddy permitting resolution (POP 0.3 degree grid) allows much of the intrinsic variability to be captured while maintaining connection to the global climate system.

To the right we see the transport and diffusion of river-input fresh water across the Arctic system.

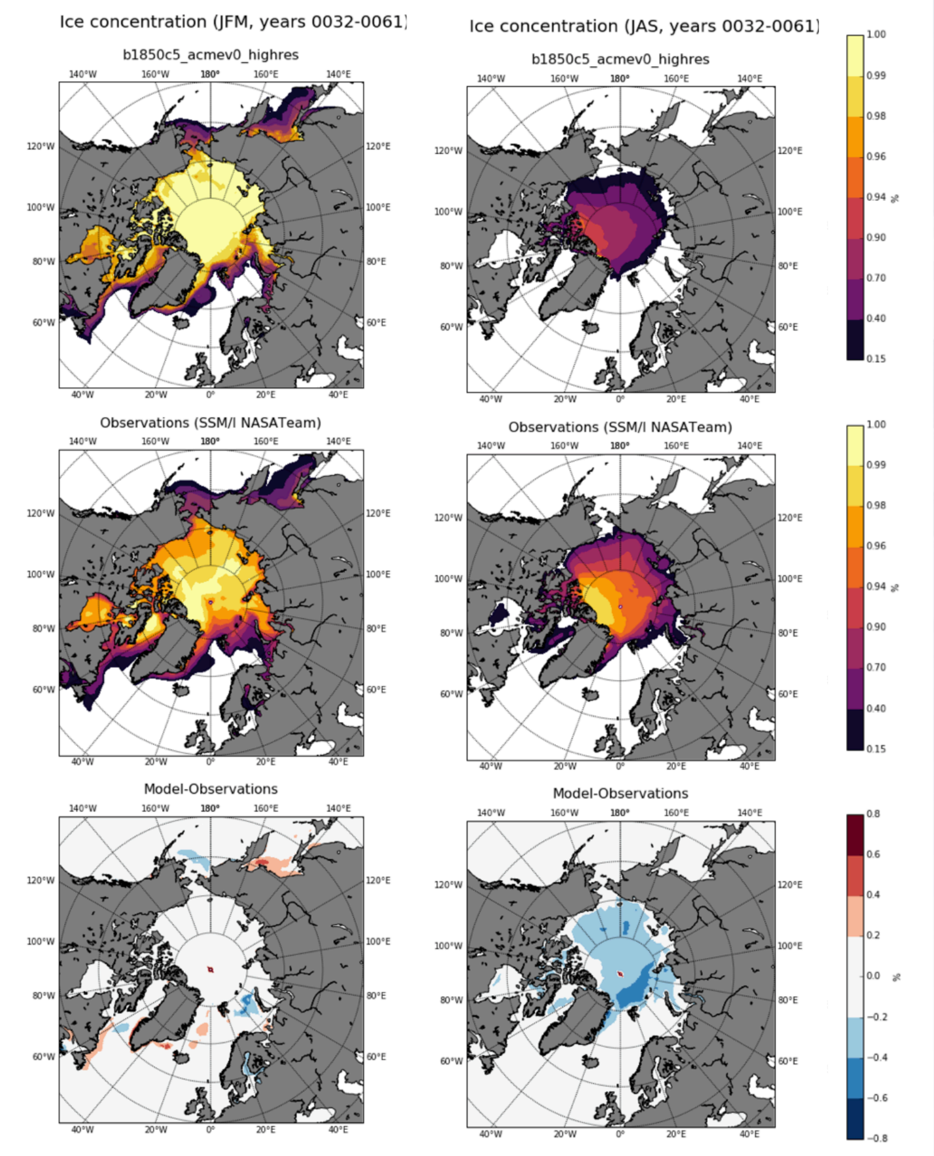


From Wilbert Weijer, Phil Rasch and the HiLAT team

ACME: "How do the hydrological cycle and water resources interact with the climate system on local to global scales?"

Clearly, the Arctic is a primary driver of the hydrologic system across local, regional and global scales.

To the right we see sea-ice concentration from the high-resolution ACME v0 configuration using the 25 km CAM-SE atmosphere model, the 1/10 degree POP and the v4 CICE model.



from Dave Bader and the ACME team

Gaps (or, rather, opportunities) within the DOE climate modeling activity with respect to the projection of the Arctic system over the next 40 years:

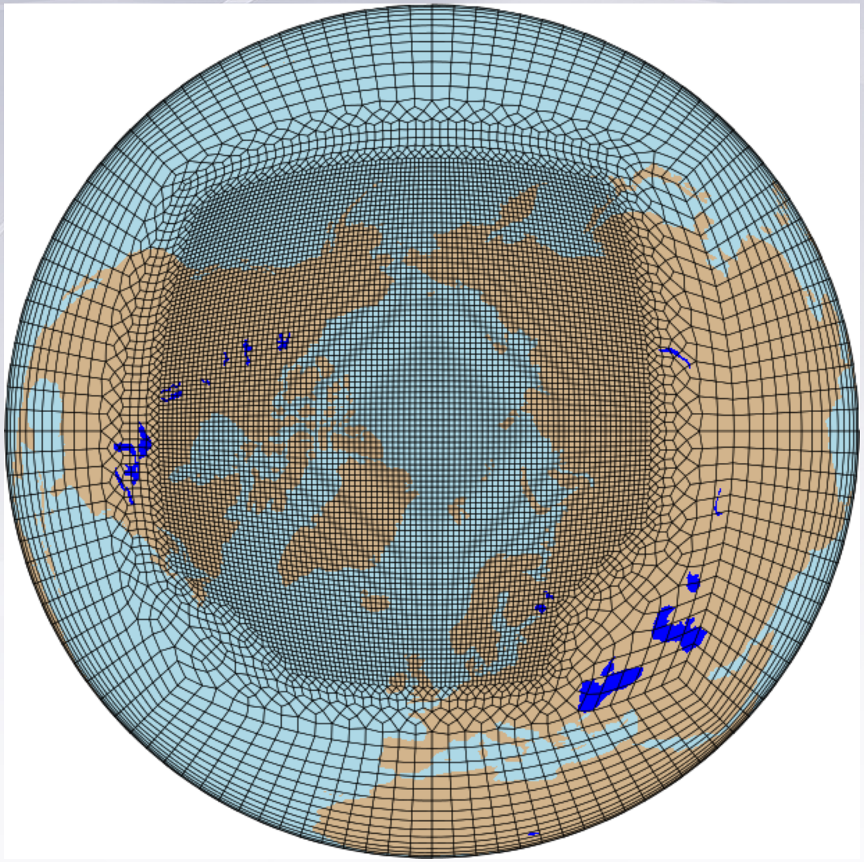
problem: tension between resolution and ensemble size

RASM	HiLat	ACME
highest-resolution	moderate-resolution	high-resolution
many ensembles	some ensembles	no ensembles
no global connectivity	includes global connectivity	includes global connectivity

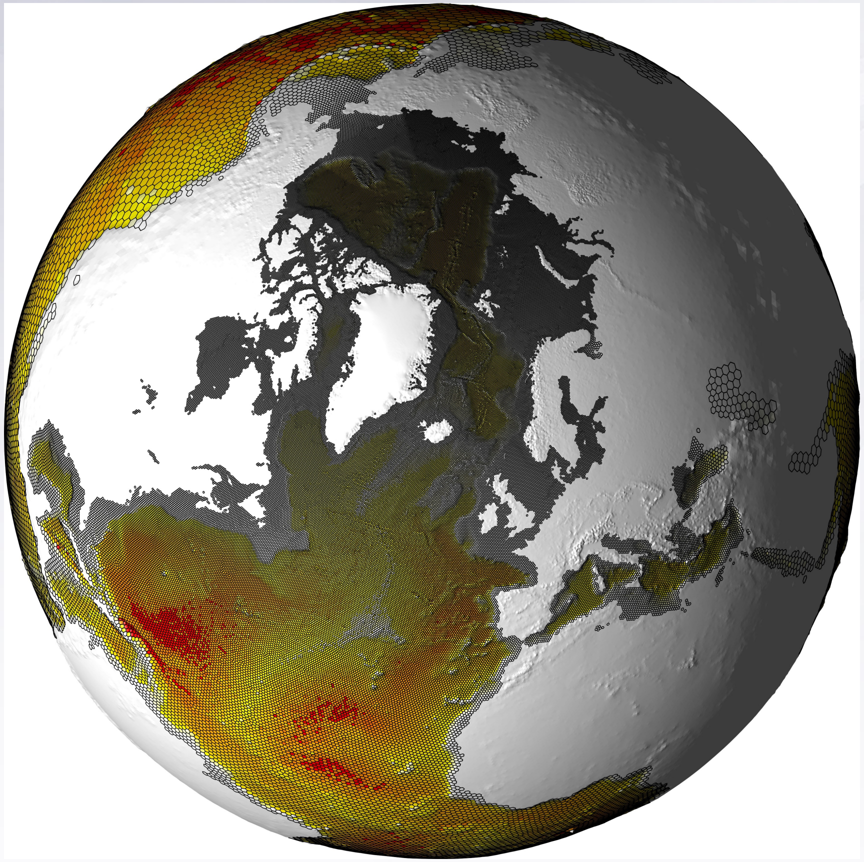
possible solution: multi-resolution ESM w/ focus toward the Arctic

Note: the lowest hanging fruit for demonstrating value of a fully-coupled, multi-resolution ESM configuration is probably in the Arctic region.

ACME v1 can address some of the tension between resolution and ensemble size ….

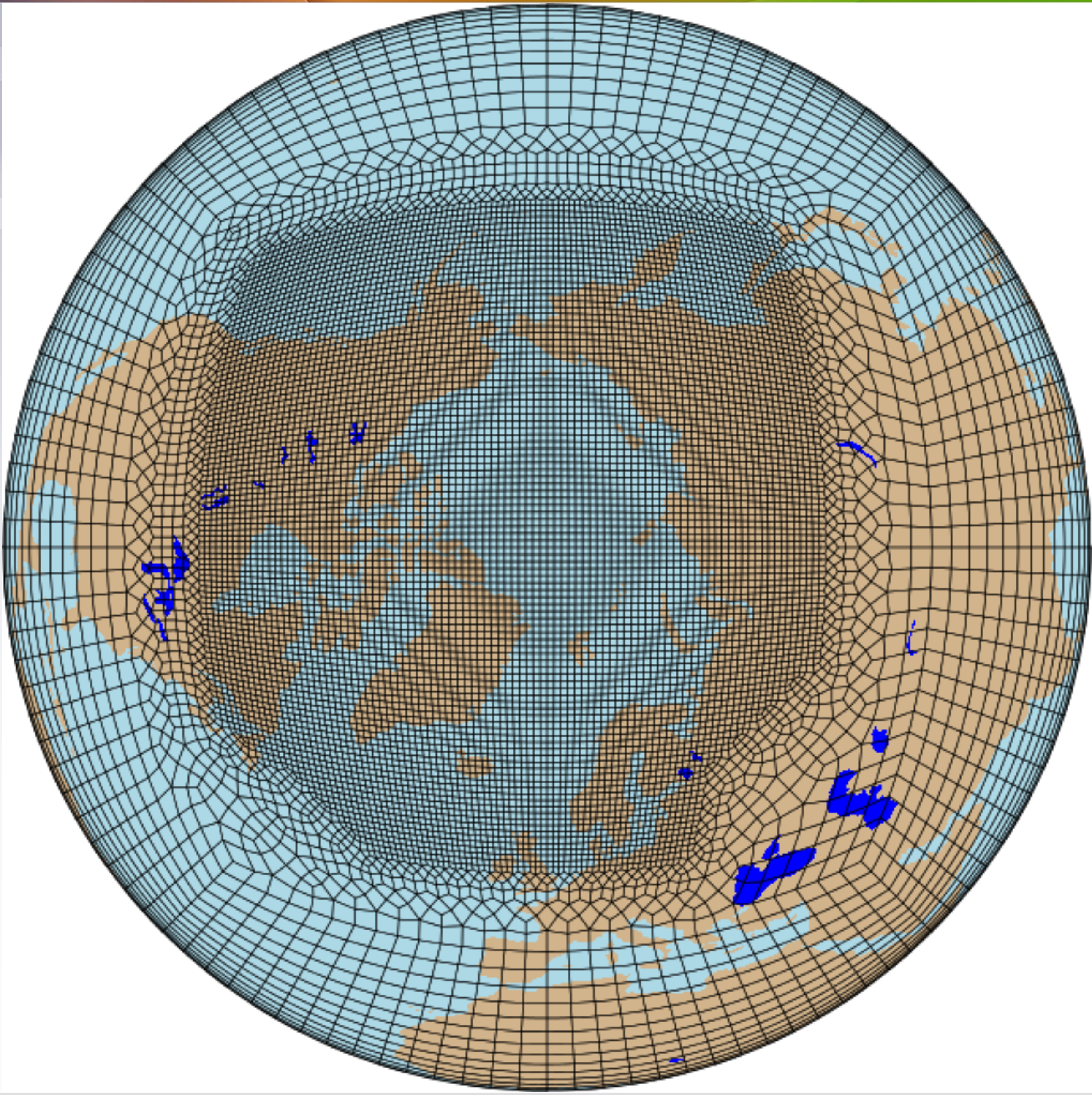


ACME Spectral Element Atmosphere Model
25 km resolution in Arctic
~7X saving in compute over global high-res



ACME Model for Prediction Across Scales - Ocean
6 km resolution in Arctic
4X saving in compute over global high-res

A (rough draft) multi-resolution atmosphere mesh for Arctic science applications.



This mesh is a hybrid of the ACME v1 high- and low-resolution water cycle meshes.

Circumpolar Arctic atmosphere domain resolved at 25 km with 100 km resolution elsewhere.

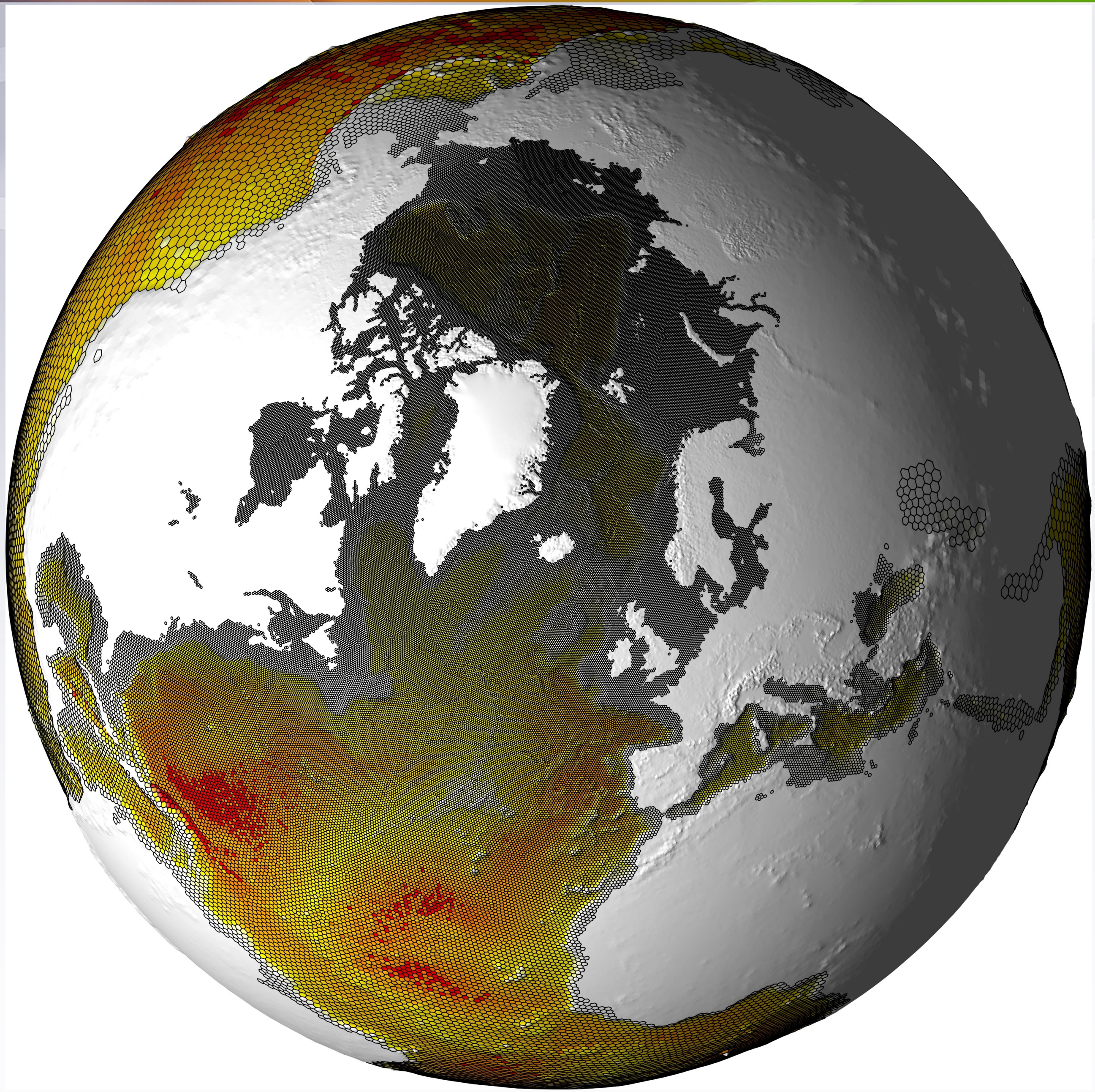
Mesh produced Erika Roesler

A (rough draft) multi-resolution ocean/sea-ice mesh for Arctic science applications.

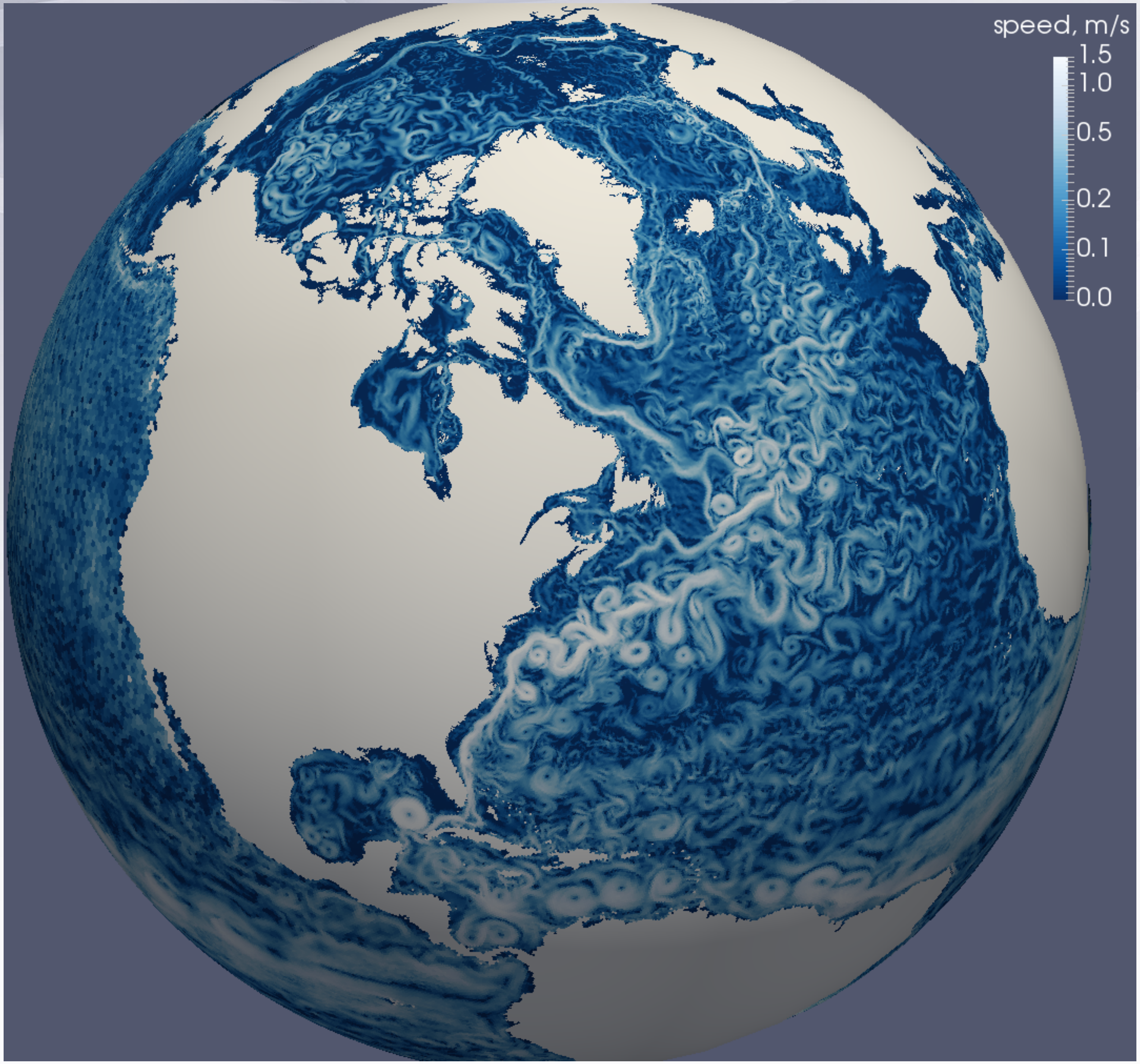
This mesh is a hybrid of the ACME v1 high- and low-resolution water cycle meshes.

North Atlantic / Arctic ocean domain scales from 18 km at Equator to 6 km in the Arctic.

Mesh produced by Darren Engwirda (GISS) using his JIGSAW-GEO software.

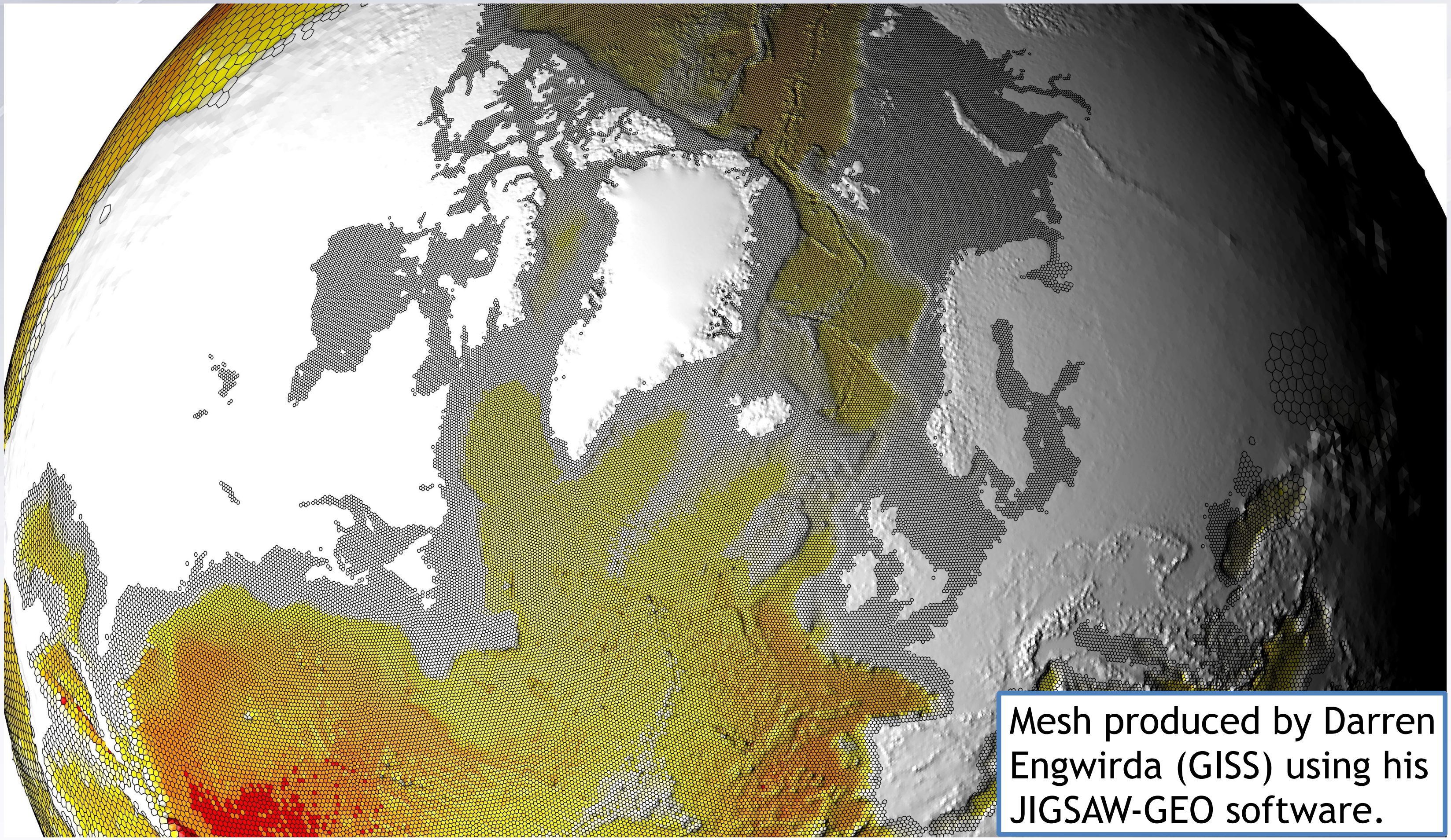


Snap-shot (after 2 years of spin up from rest) of ocean surface current speed using a NA-Arctic focused mesh.



(CORE-II wind stress, no sea-ice)

Thank you!



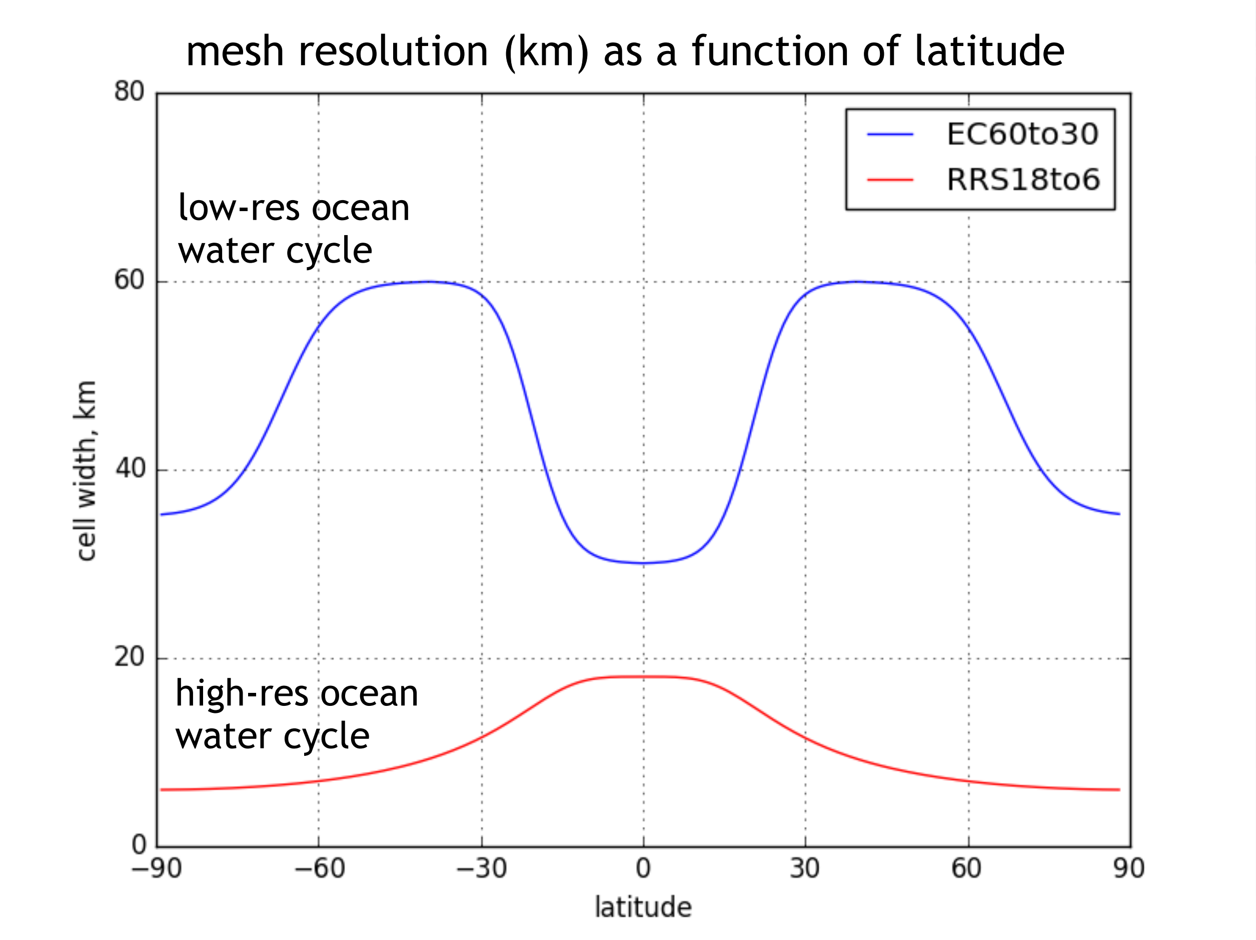
Mesh produced by Darren Engwirda (GISS) using his JIGSAW-GEO software.

Additional slides

Resolution of ACME v1 high- and low-resolution water cycle configurations:

atmosphere
- low-res: ~100 km
- high-res: ~25 km

ocean
- low-res: EC60to30
- high-res: RRS18to6



Why develop an multi-resolution, Arctic-focused ESM configuration?

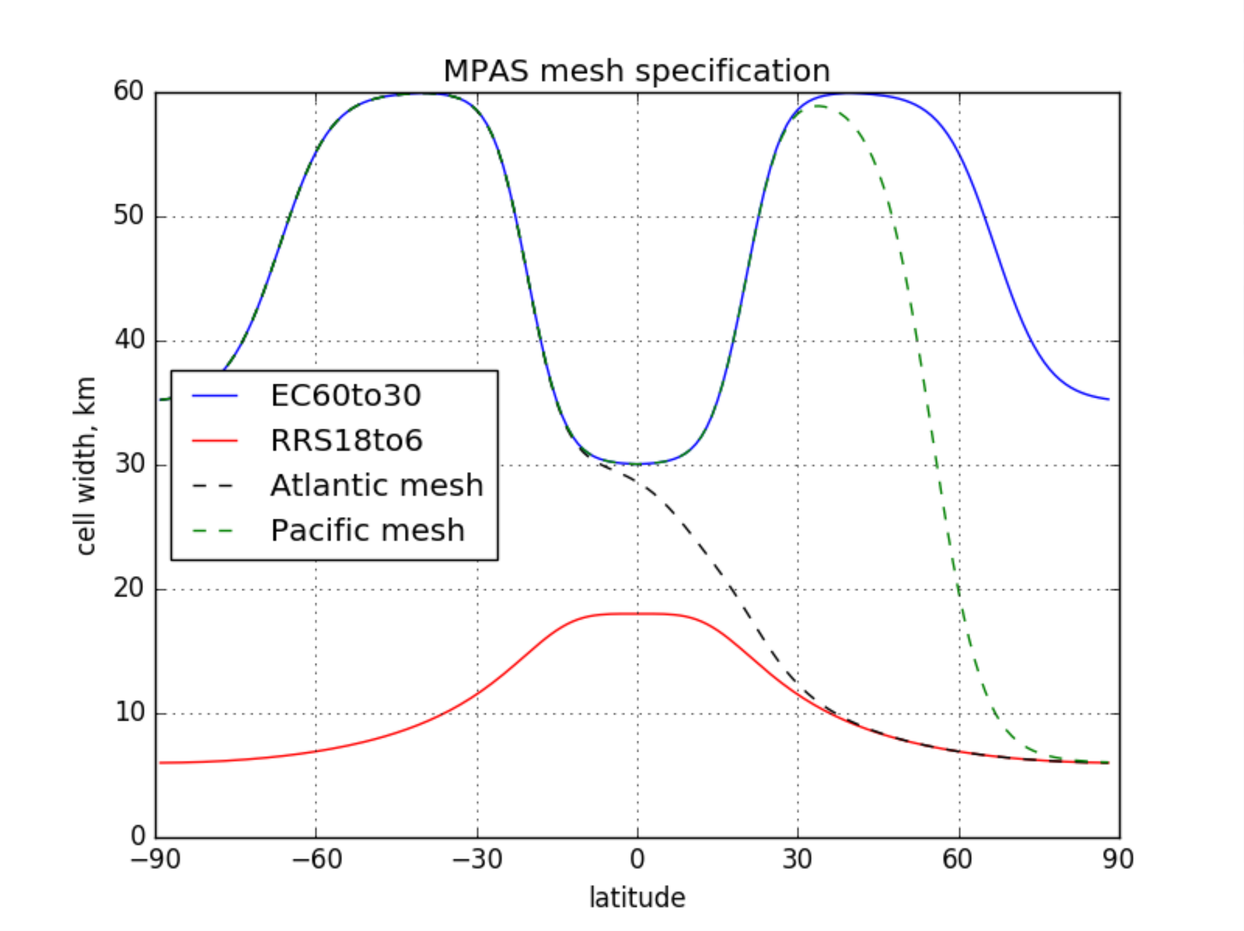
This configuration with ~5X cheaper than the ACME v1 high-resolution water cycle configuration.

We can “re-invest” our 5X savings toward increasing ensemble size.

The lowest hanging fruit for demonstrating value of a fully-coupled, multi-resolution ESM configuration is probably in the Arctic region.

NA-Arctic focused mesh is a blending of the low- and high-res water cycle meshes:

NA-Arctic focused mesh is equal to the low-res water cycle mesh everywhere except in NA and Arctic basins where it is equal to the high-res water cycle mesh.

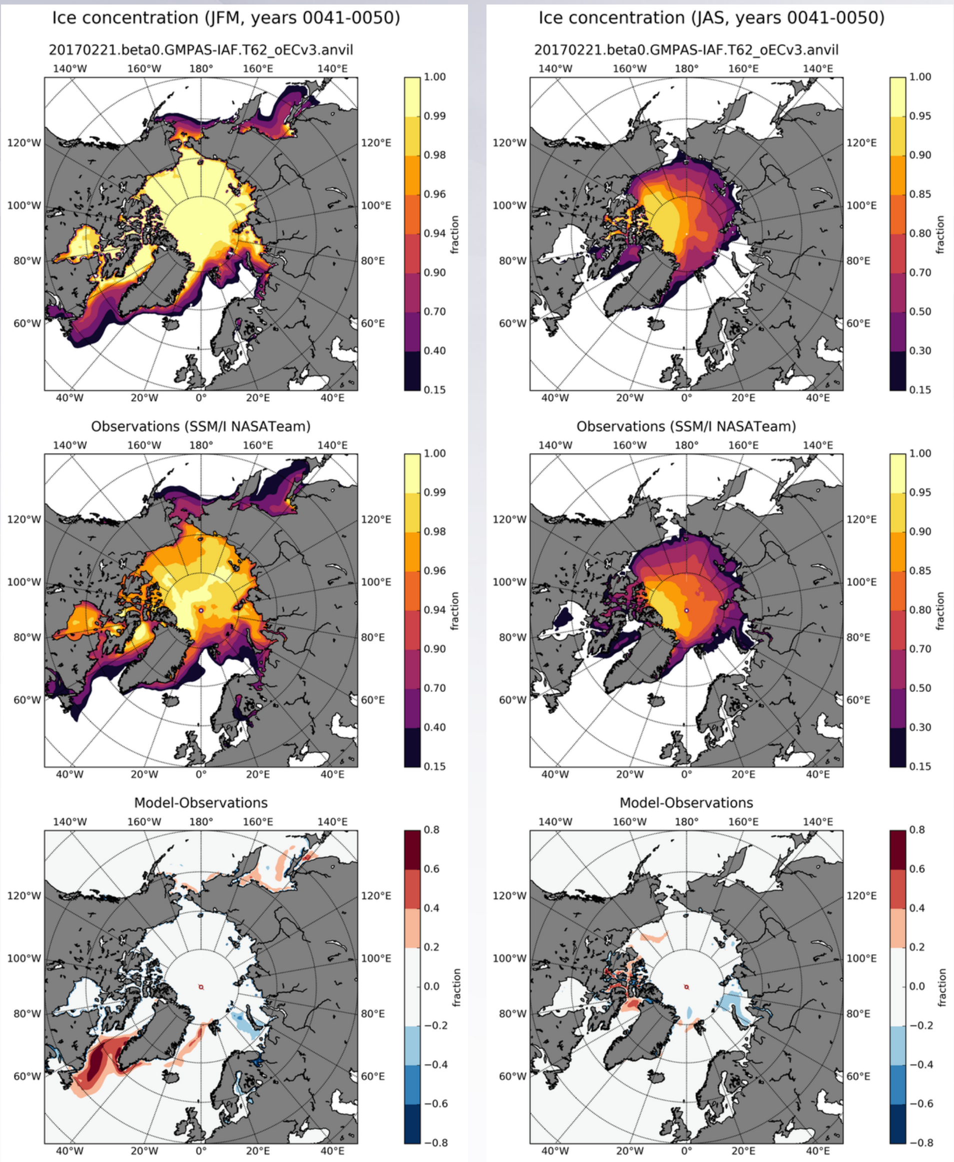


Allocation of computational resources

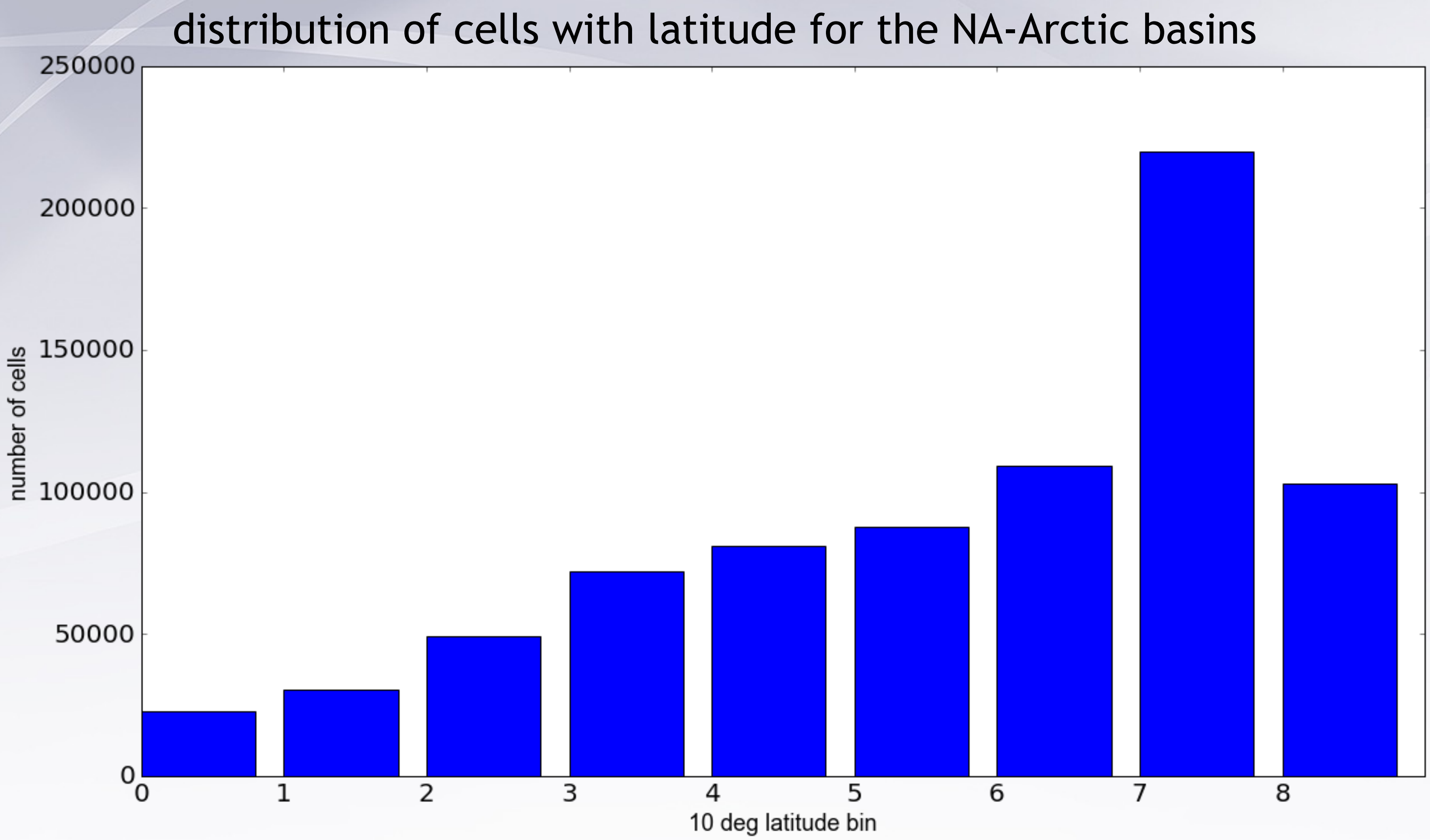
Mesh	Total number of cells	Number of cells in NA-Arctic	Faction of cells in NA-Arctic region
low-res water cycle mesh	234,988	37,196	0.16
high-res water cycle mesh	3,697,425	775,382	0.20
NA-Arctic focused mesh	973,174	775,382	0.78

We are intending to reallocate the 4X in computational savings over the high-res water cycle configuration toward increasing the ensemble size.

Low-resolution CORE-II ocean/sea-ice spin-up

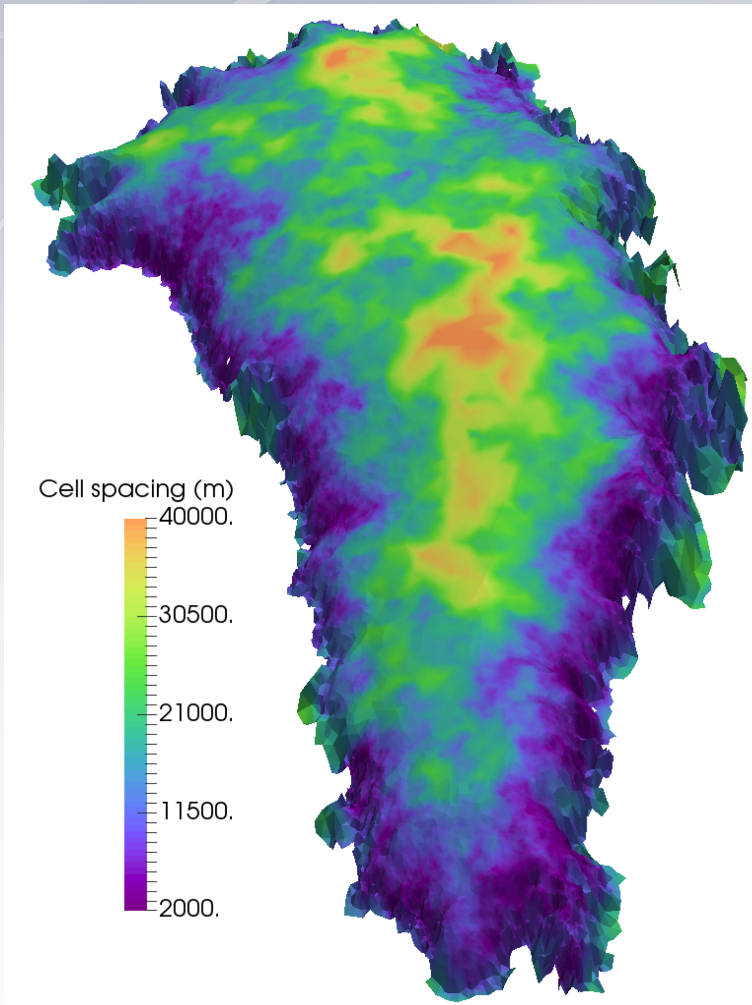


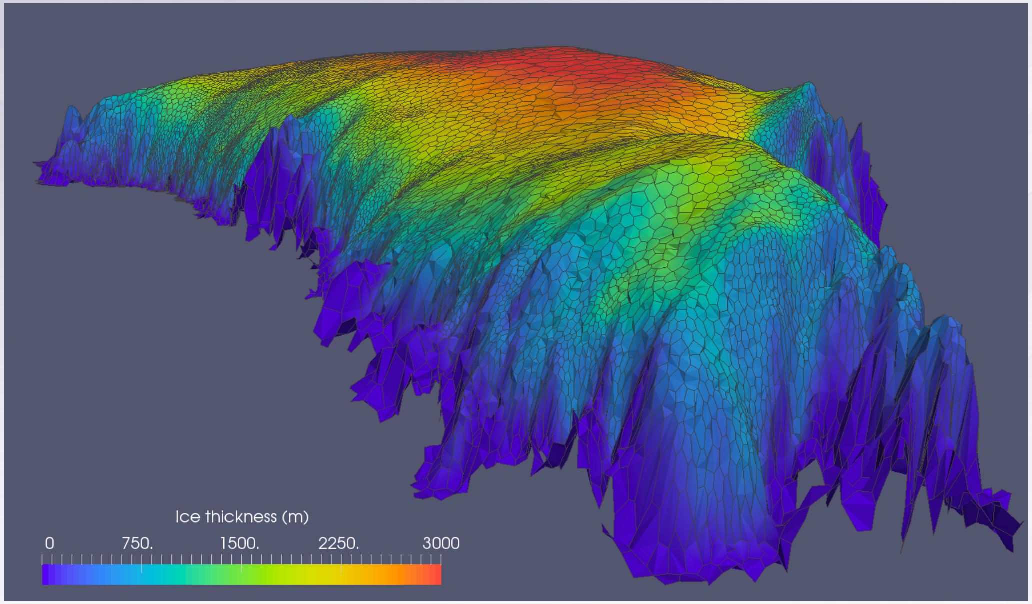
Distribution of cells in NA-Arctic focused mesh



2/3 of the cells are poleward of 50N.

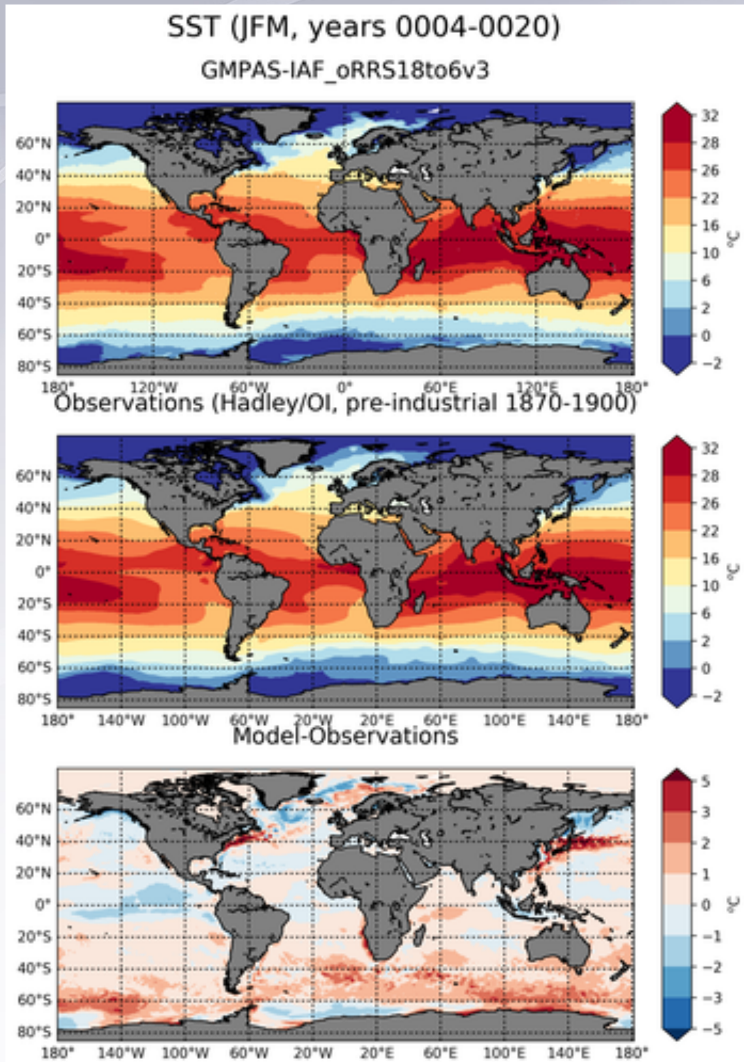
Greenland Ice Sheet resolution



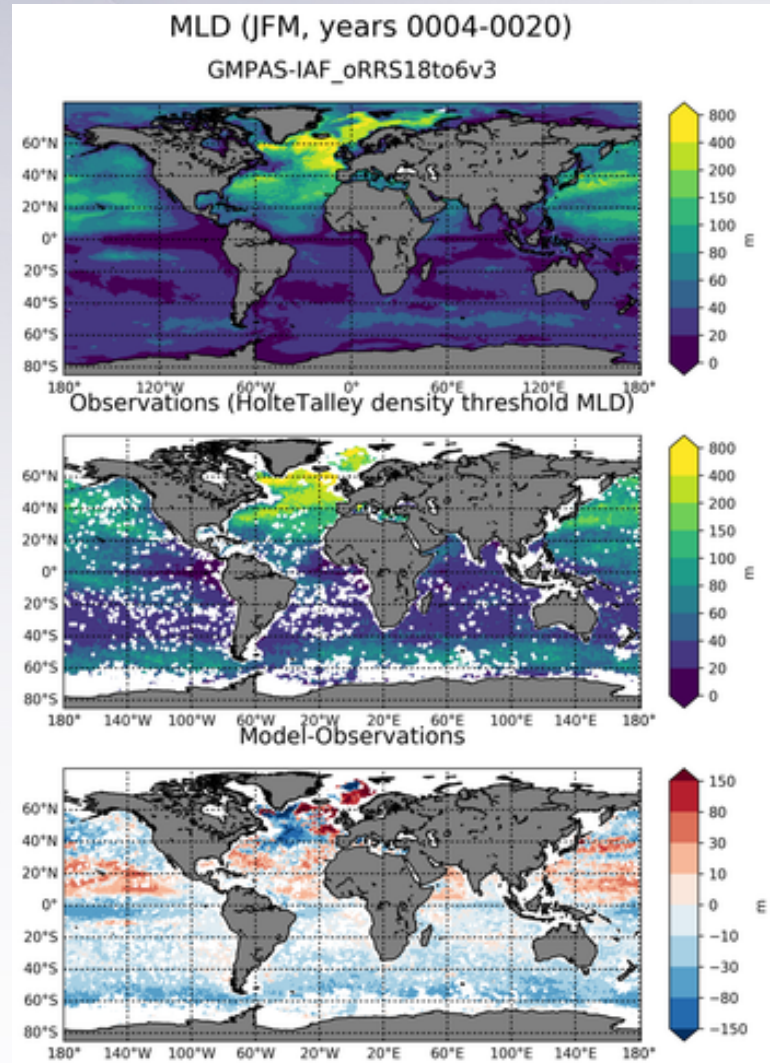


resolution ranges from 40 km in low ice-velocity regions along ridge lines to 2 km in high ice-velocity ice streams.

High-resolution CORE-II ocean/sea-ice spin-up



sea-surface temperature (C)



mixed-layer depth (m)