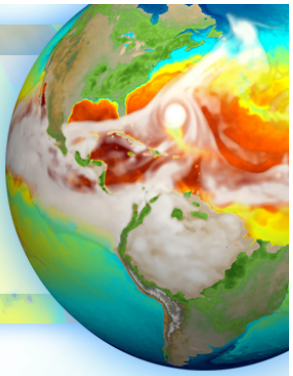
Development of Regionally Refined Ocean/Sea Ice Meshes for E3SMv2



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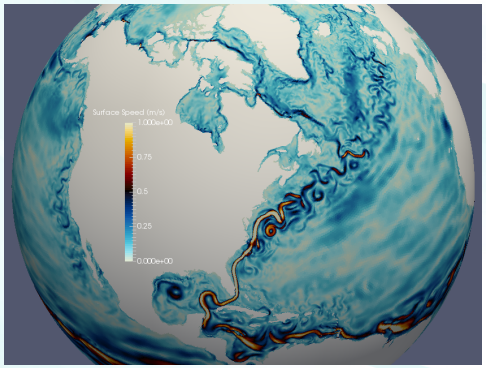

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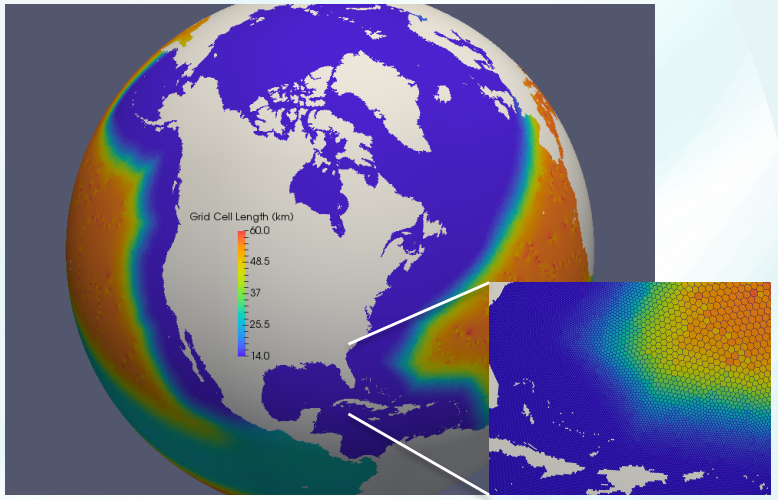
E3SM Energy Exascale Earth System Model

U.S. DEPARTMENT OF ENERGY

MPAS Framework based on unstructured meshes

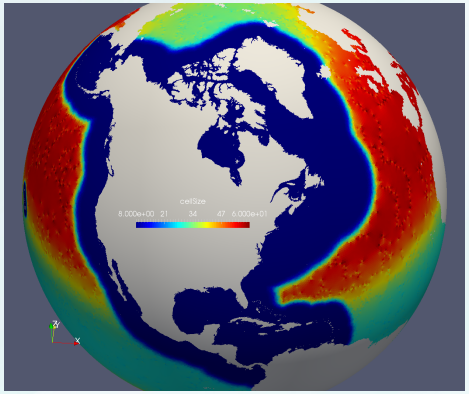
- We have tested ~10 different ocean/sea-ice meshes with refined resolution in the vicinity of North America and Greenland
- All have a background global mesh similar to the E3SMv1 low resolution mesh that varies from 30km at the equator to 60km at mid latitudes, then back to 30km near the poles
- Grid scale is smoothly transitioned between background and refined regions
- Horizontal mixing parameterizations are linearly grid scale dependent, including GM eddy advection and Redi isopycnal mixing which transition from full strength at scales > 30km to zero for scales < 20km
- Better resolution of bathymetry and coastlines such as in the Canadian Archipelago, Florida-Bahamas Strait, and Bering Strait



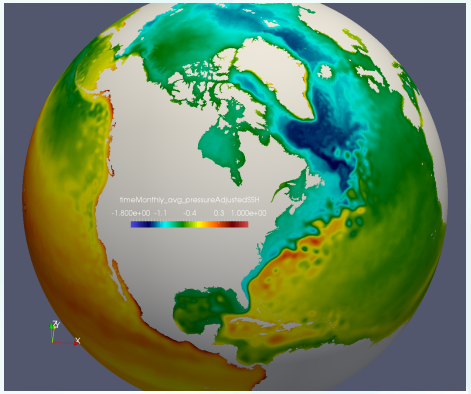
Highlight 3 top candidates

8 km refinement

- Very realistic Gulf Stream separation and Extension
- Strongly eddying in refined regions
- Grid refinement cuts through Subpolar gyre, modifying path of current
- 850k core-hours/model-century (CompyMcNodeFace)

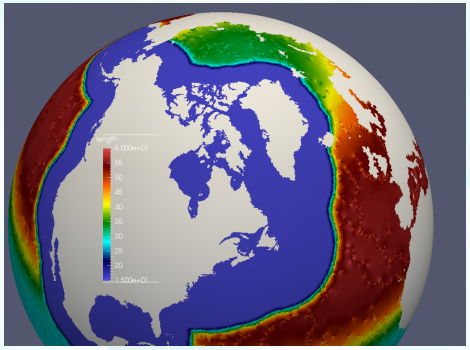


Grid scale (km)

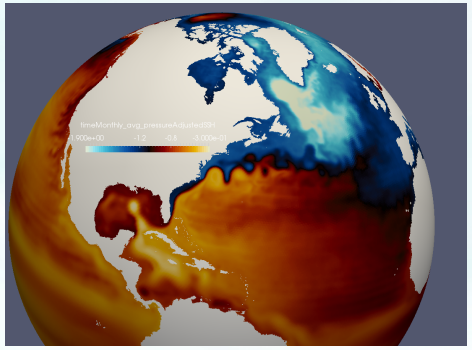


Sea Surface Height (m)

Grid scale (km)



Sea Surface Height (m)



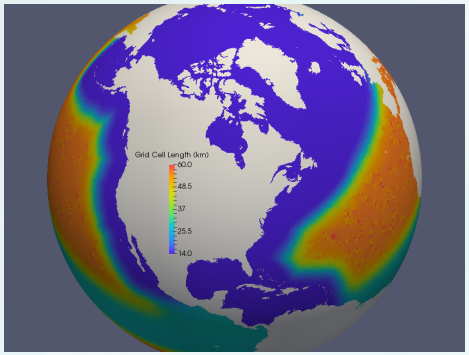
12 km refinement

- Less realistic Gulf Stream separation and Extension
- Moderate eddying in refined regions
- Grid refinement cuts through Subpolar gyre, modifying path of current
- 450k core-hours/model-century (CompyMcNodeFace)

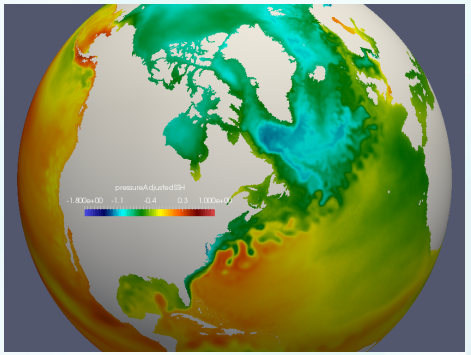
Highlight 3 top candidates (continued)

14 km refinement

- Less realistic Gulf Stream separation and Extension
- Moderate eddying in refined regions
- Grid refinement boundary is south of the Gulf Stream Extension and Subpolar gyre so doesn't artificially modify current path
- 330k core-hours/model-century (CompyMcNodeFace)



Grid scale (km)



Sea Surface Height (m)

How do we decide which candidate to use, or even create a new one?

- Reduction of important biases in E3SMv1
- Better resolution of important physical processes and circulation features
- Computational cost

Labrador Sea Ice Bias

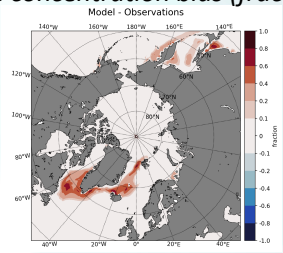
- In E3SMv1, there was too extensive sea ice in the Labrador Sea during the winter
- As a result, there was a strong fresh water bias (due to excess melt) and associated low temperature bias

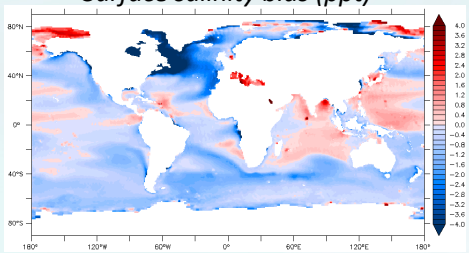
Ice concentration bias (fraction)

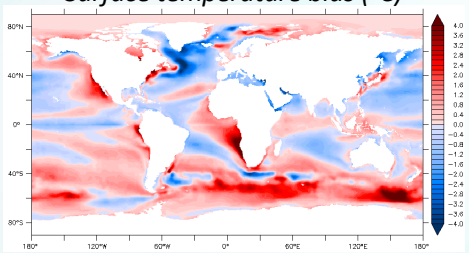
Surface salinity bias (ppt)

Surface temperature bias (°C)

E3SMv1

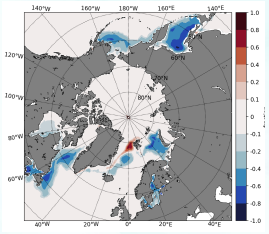


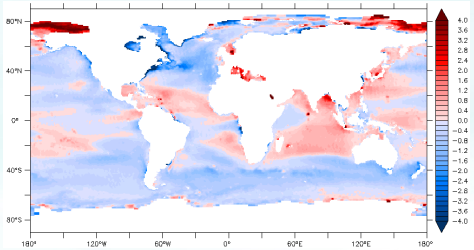


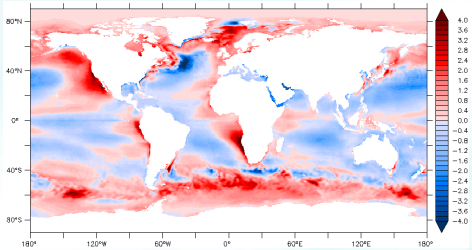


- The 3 candidates all reduced or eliminated this bias
- Better resolution of Greenland Current and eddy transport within the Subpolar gyre are responsible

14km refined

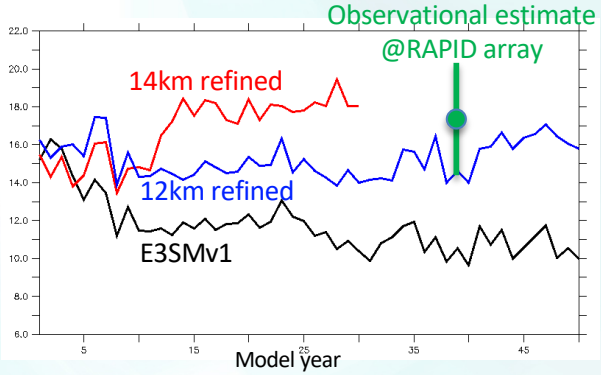




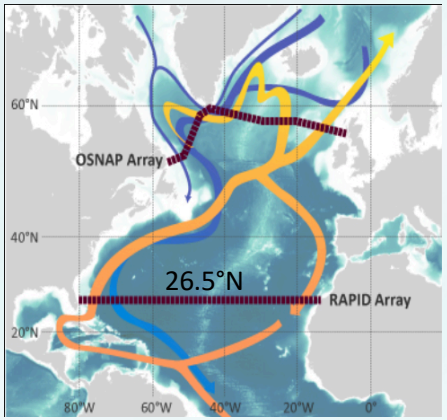


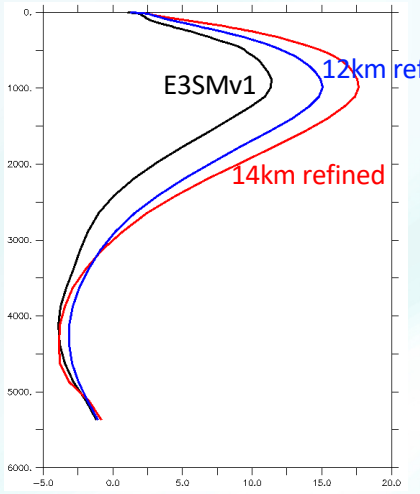
Atlantic Meridional Overturning Circulation (AMOC)

- Changes in water mass properties in the North Atlantic affect deep convection which can manifest as a change in strength of AMOC



AMOC strength at 26.5°N (Sv)





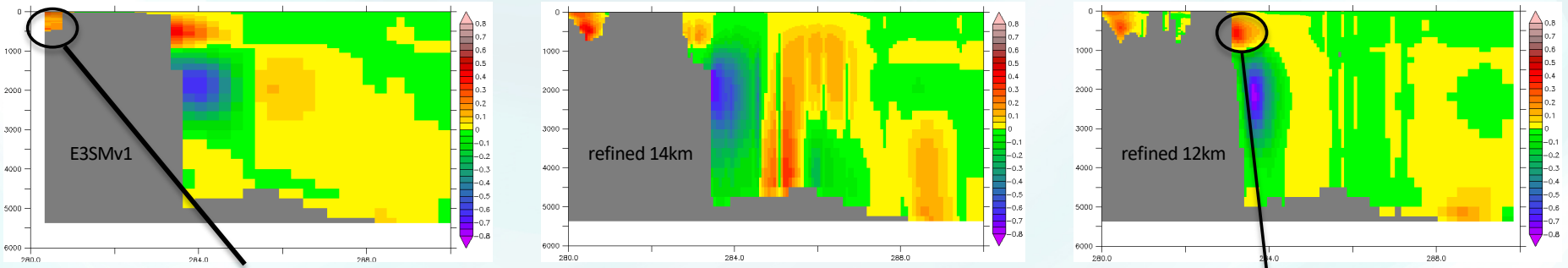
AMOC vs depth at 26.5°N (Sv)
30 year average

- Refined grid cases result in more realistic mean AMOC

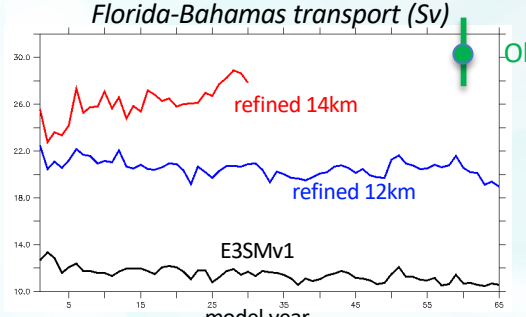
Structure of ocean circulation at 26.5°N

- Higher resolution bathymetry improves the currents that make up the Gulf Stream and Subtropical gyre

30 year average of meridional velocity (m/s) at 26.5°N

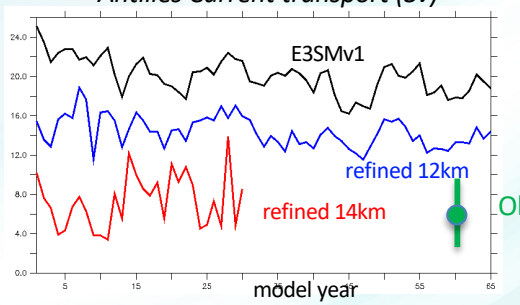


Florida-Bahamas transport (Sv)



Observational estimate (NOAA AMOL)

Antilles Current transport (Sv)



Observational estimate (NOAA AMOL)

Decision criteria and Caveats

- The most crucial feature is placing grid refinement boundary south of the Gulf Stream Extension and Subpolar gyre (14km refinement case)
- 8km refinement is too expensive, and would be even more costly after moving refinement boundary further south
- 12km refinement cost is borderline in original form, but too expensive after shifting the refinement boundary to the south
- Add refinement throughout the Arctic with nominal increase in cost
- Also used mixed layer depth, ocean heat content anomalies, and other metrics in the decision-making process
- ***As a result, we have chosen the 14km refinement as a the production version***
- Caveat: the ocean, sea ice, and atmosphere models have evolved significantly since these runs were performed and results may vary
  - Bug fixes in MPAS-Ocean turned out to have significant effects
  - Still tuning in both ocean and atmosphere