Demonstration of an Ocean Model Simulation at 20km Resolution

1.0 Product Definition

A simulation of the global ocean was developed and completed. The simulation was configured with a grid spacing of 11km at the equator, decreasing to 4 km at high latitudes, in preparation for a high resolution atmosphere-ocean coupled simulation using the Community Earth System Model (CESM). Simulations were performed with the Parallel Ocean Program (POP), the current CESM ocean component.

2.0 Product Documentation

In preparation for a fully coupled atmosphere-ocean high-resolution simulation using the CESM, we have prepared the ocean component and tested it in a number of high-resolution simulations. This effort is meant to devise the best possible configuration for the coupled simulation as well as the best ocean initial condition.

2.1 Model Configuration and Forcing

In order to avoid singularities, the horizontal grid employs a tripole layout with the North Pole split and moved into land regions in Canada and Russia. The tripole grid matches up with a standard latitude-longitude Mercator grid at 20ºN (figure 1). The 42 level vertical grid spacing varies from 10m at the surface to 250m at depth. Atmospheric state and flux variables are provided by the CORE (Coordinated Ocean Reference Experiments) "Normal Year" data set averaged to monthly values (see References for link). No explicit sea ice model was included for most of the simulations; instead, a strong restoring of climatological temperature and salinity was applied in areas of prescribed sea-ice.

2.2 Simulation Results

Much effort has been spent comparing the simulation results with observations, with an emphasis on processes that are explicitly resolved by the "eddy-permitting" grid. Analyses range from essentially descriptive, such as the location of boundary current detachment (figure 2), to quantitative comparisons with, for example, satellite altimetry data (figure 3).

Simulations in ocean-only mode have been the subject of two projects over the past year. One project examined the effect of enhanced fresh water flux from Greenland (due to likely increases in melting, iceberg calving and precipitation in the future) on the strength of the Atlantic Meridional Overturning Circulation (AMOC). In particular, we have focused on the role of model grid resolution on the results by comparing the solutions from the 1/10º configuration and the nominally 1º setup used for coupled climate simulations (Weijer et al., 2011). We have found that the

high resolution model has a stronger response (as measured by the strength of the AMOC) so results in the literature using much coarser resolution may be underestimating the possible consequences of significant increases in Greenland runoff (figure 4). It is also worth noting that the inclusion of a passive dye tracer that marks the extra fresh water played an important role in the process of understanding the differences in the high versus low resolution runs (figure 5).

The second project has involved extending the original model grid further southward to prepare for high resolution coupling of the ocean with Antarctic ice shelves. The standard model treats ice shelves as a solid land boundary. In reality, the ocean can transport heat under the ice and strongly affect the melt rate and grounding line movement. Thus, the new configuration uses the bedrock depth (up to the current grounding line) to define the land mask (figure 6). This new setup has been run for 2 years (without ice sheets) to demonstrate the capability of the ocean to transport heat up to the grounding lines of the important Antarctic ice shelves.

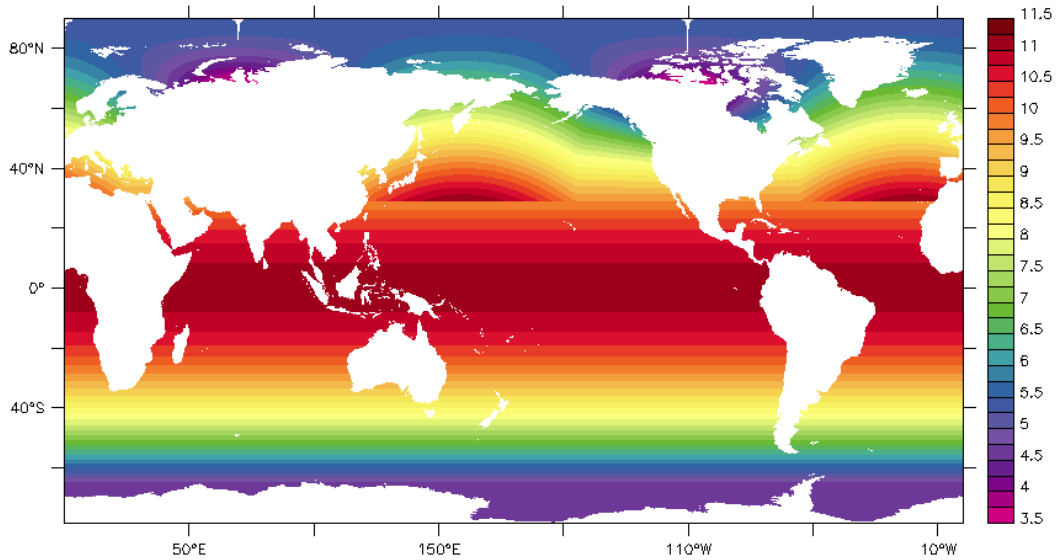

Figure 1. Maximum grid cell length (km) for the 1/10º tripole configuration. From 78ºS to 30ºN the grid is a regular latitude-longitude layout. North of 30ºN, the grid becomes distorted with respect to latitude and longitude as the grid becomes tripolar to allow for full resolution of the Arctic. The two Northern poles are located in Canada and Russia near the regions of smallest grid cell length.

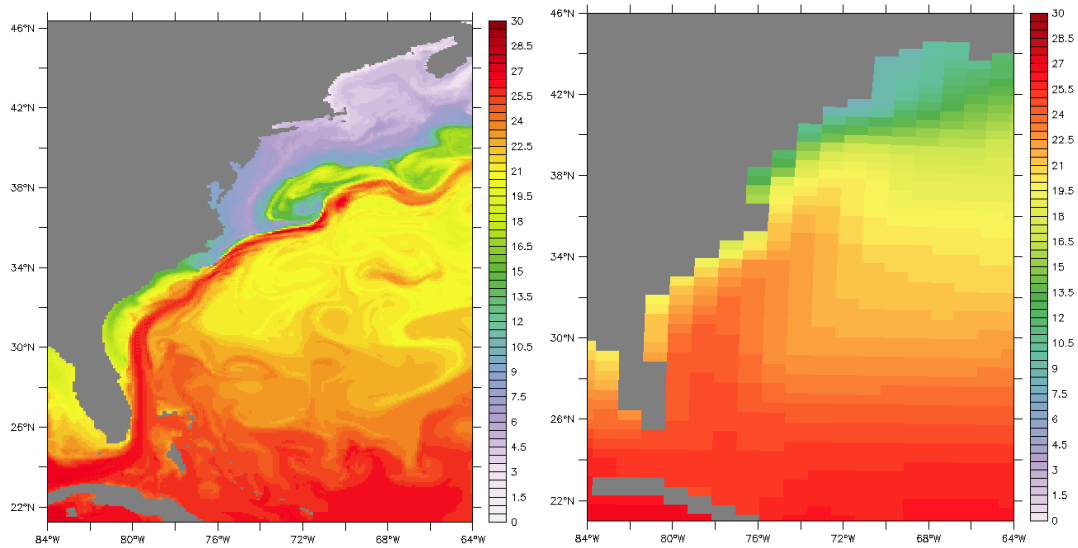

Figure 2. Snapshot of January 1 sea surface temperature (ºC) from the 1/10º model (left) and 1º model (right) showing that the high resolution Gulf Stream has a much more realistic structure, including a well-defined jet structure and separation from the coast at Cape Hatteras.

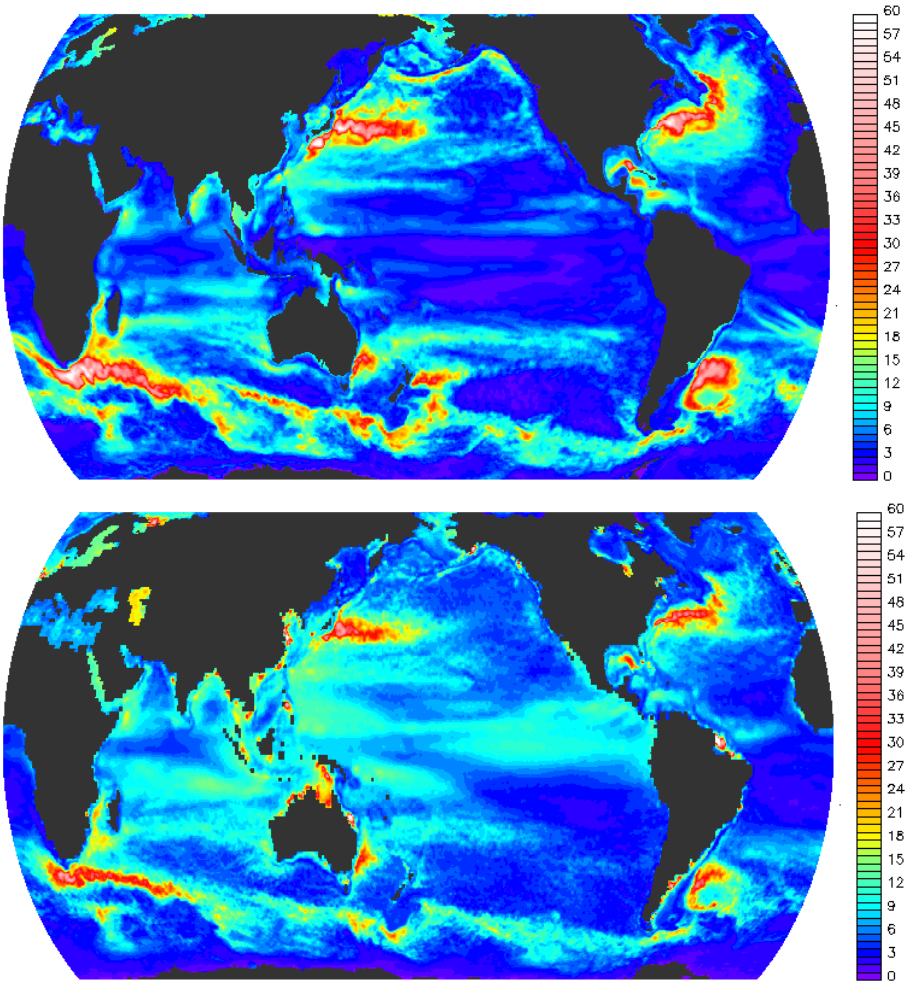

Figure 3. Sea surface height variability (cm) from POP (top) and from satellite altimetry (courtesy of AVISO). This is a quantitative measure of eddy activity. Since 1º simulations don't exhibit significant eddying behavior, a comparable figure from such a configuration would be almost uniformly blue.

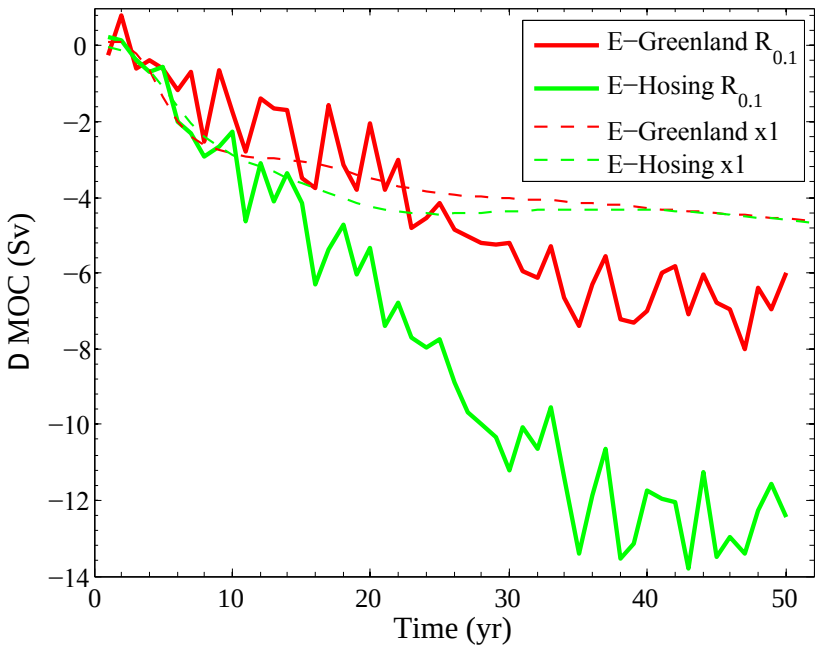

Figure 4. Change in maximum strength of the Atlantic Meridional Overturning Circulation (AMOC, in Sverdrups) for the 1/10º (solid) and 1º (dashed) model grids. The control values with which these are compared are about 24 Sv. The label "Greenland" refers to the freshwater perturbation being realistically applied around the periphery of Greenland, while 'Hosing' refers to it being applied over the entire sub-Arctic region between 50N and 70N.

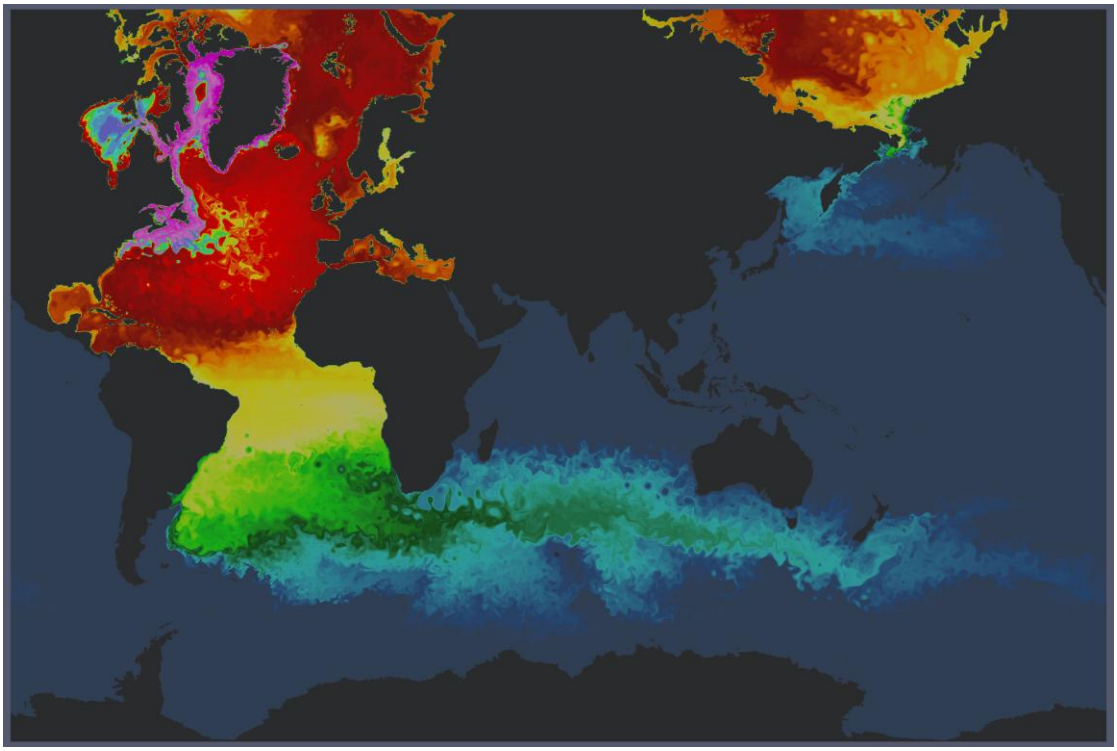

Figure 5. Depth integrated dye (logarithmic scale) 14 years after enhanced freshwater flux was introduced around the coast of Greenland. The dye demonstrates time scales and locations that are influenced by the extra runoff.

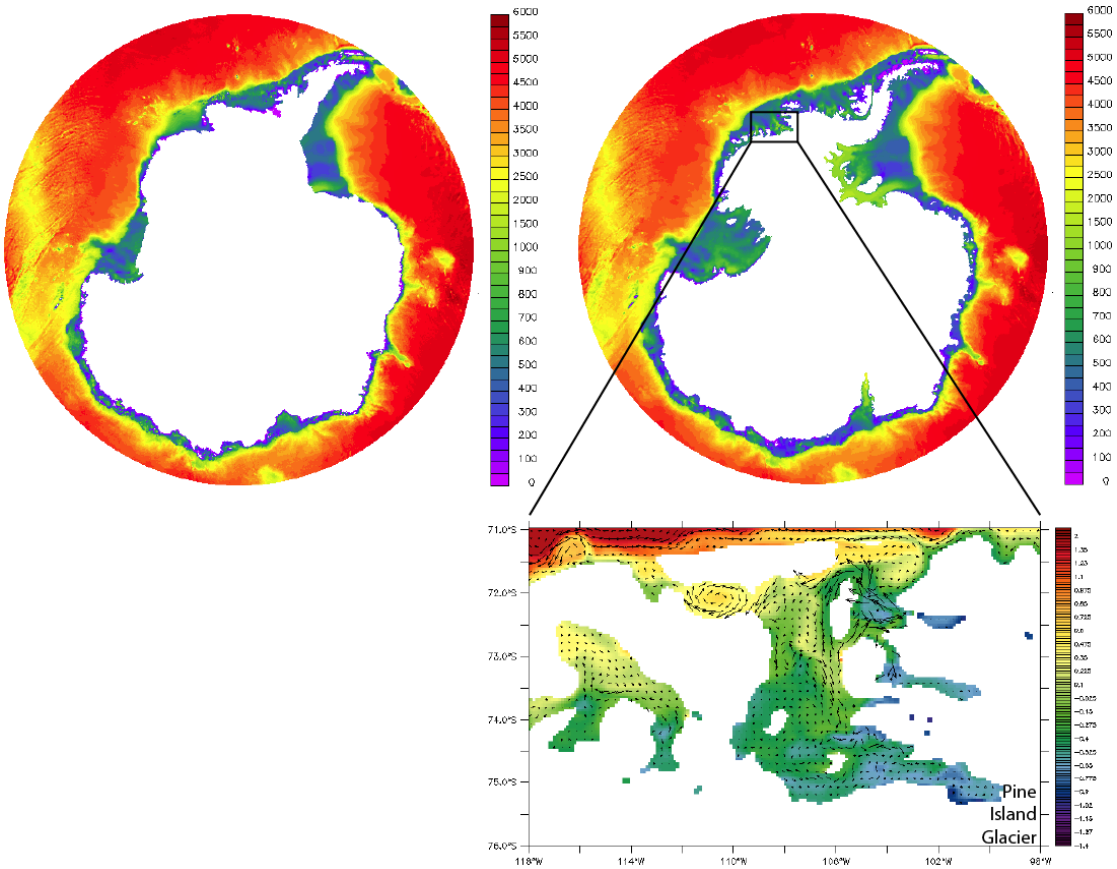

Figure 6. Model ocean depth (m) and land mask for the standard 1/10º tripole grid (left) and the new southward-extended version to be used for ocean-ice shelf interaction simulations (right). Note that the configuration on the right allows water to circulate much further inland, which is crucial for coupled ocean-ice shelf simulations. Zoomed-in region shows the temperature (ºC) and velocity vectors at 579m in the Amundsen Sea after 2 years of simulation, which demonstrates the ability of the model to transport heat to the grounding line of the Pine Island Glacier.

3.0 References

CORE forcing: http://data1.gfdl.noaa.gov/nomads/forms/mom4/CORE.html

Weijer, W, Maltrud, M. E., Hecht, M. W., Dijkstra, H. A., and Kliphuis, M. A.: Response of the Atlantic Ocean Circulation to Greenland Ice Sheet Melting, Nature-Geosciences (in review), 2011.