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FY 2012 Fourth Quarter Performance Metric: Demonstration of Coupled Climate Simulation at 20km Resolution

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Demonstration of Coupled Climate Simulation at 20km Resolution

1.0 Product Definition

A series of simulations of the global climate system were performed using high resolution for all components using the Community Earth System Model (CESM). All of the runs were configured as follows:

1. The ocean model (POP) employs a tripolar grid with a horizontal spacing of 11 km at the equator, decreasing to 4 km at high latitudes
2. The sea ice model (CICE) uses the same grid as POP
3. The atmosphere uses the spectral dynamical core (CAM-EU) at T341 resolution. Although this corresponds to colocation points with approximately 30 km resolution, the characteristics of the scheme make it similar to the finite volume dynamical core (CAM-FV) with finer spacing. For column physics, the CAM4 package is used
4. The land model (CLM) employs the 1/8º CAM-FV grid, which has a resolution of slightly over 20 km.

Initial conditions for POP and CICE were obtained from year 1 of the coupled ocean-ice simulation being performed by the Scripps Institution of Oceanography group led by Dr. Julie McClean. For CAM and CLM, initial conditions were provided by Dr. Kate Evans (ORNL) from year 10 of an atmosphere-land run. Over a dozen test runs were performed to assess specific configuration options, such as coupling frequency and the sea ice radiation scheme. One particular setup was of sufficiently high quality to warrant pursuing a multi-decadal run.

2.0 Product Documentation

As is the standard procedure, the model has been run with pre-industrial conditions (e.g., 284.7 ppm of atmospheric CO_2) in order to document the non-perturbed state of the system. At the time of this report, 40 years of simulated time have been completed. While this is not sufficient for true equilibrium of the full system, much can be learned from examining the solution. The remainder of this milestone will describe a few aspects of the model state as reflected by individual components, since an exhaustive detailing of the results is beyond the scope of the report.

2.1 Simulation Results

One of the most sensitive indicators of model fidelity is sea ice. For example, the so-called "LLNL Grand Challenge" run (McClean et al.) had extremely extensive Arctic sea ice due to poor polar atmospheric dynamics that made the simulation unusable for long timescale studies. Figure 1 shows the sea ice area fraction averaged over the most recent 5 years of the simulation. Based on the extent derived from late 20th century satellite observations (thick black line), the simulated distribution is clearly too

extensive in the western Labrador Sea, in the western Greenland-Iceland-Norwegian Seas, in the northern Bering Sea, and in the eastern Sea of Okhotsk. However, the extent around Antarctica is essentially indistinguishable from the data.

One contributor to this discrepancy is an apparent cold bias of several degrees Celsius in the atmosphere near the poles (which is also present in atmosphere-only runs). While this doesn't affect the Southern Ocean very much because of the Antarctic land mass, the Arctic can be very sensitive to this bias. Figure 2 shows a time series of the Arctic sea ice volume compared to a late 20th century estimate PIOMAS, 2011). While this comparison shows there is too much ice in the simulation, it appears to have reached a quasi-equilibrium with a decadal-scale oscillation superimposed. Note also that the sea ice in 1850 may have, in fact, been thicker and more extensive than in the late 20th century, which may account for part of the differences when compared to observations.

Figure 3 shows the detail that can be resolved with such a fine-scale atmospheric model. The simulation has also demonstrated the spontaneous formation of tropical cyclones in the North Atlantic (as well as in the Pacific and Indian Oceans), which did not occur in the McClean et al. run. A wide variety of diagnostics (not shown) indicate that some aspects of the atmospheric state are improved compared to the CAM-FV dynamical core, though many deficiencies are more directly tied to the CAM4 column physics and are essentially independent of the specific dynamical core.

The approach to decadal-scale equilibrium can be seen in the Atlantic Meridional Overturning Circulation (AMOC) simulated by the ocean model. Figure 4 shows the maximum annual AMOC below the shallow (upper couple hundred meters) wind-driven cells. As is always the case in a simulation that begins with the ocean at rest, there is an initial period of strong variation followed by a longer adjustment phase. It appears that the model is approaching an average overturning of about 17 Sv, which may be a bit lower than typical values, but not outside the range of uncertainty. At least another decade of simulation will be required to more fully assess the state of the AMOC.

In summary, the fully coupled high resolution version of the CESM is in full production mode and producing realistic, interesting results. Simulation throughput varies considerably (between 0 to 3 model years per wallclock week) on the ORNL JaguarPF platform due to workload, stability, and availability of the resource. Our plan is to run at least one more decade followed by extensive analysis, including comparison with standard low-resolution CESM.

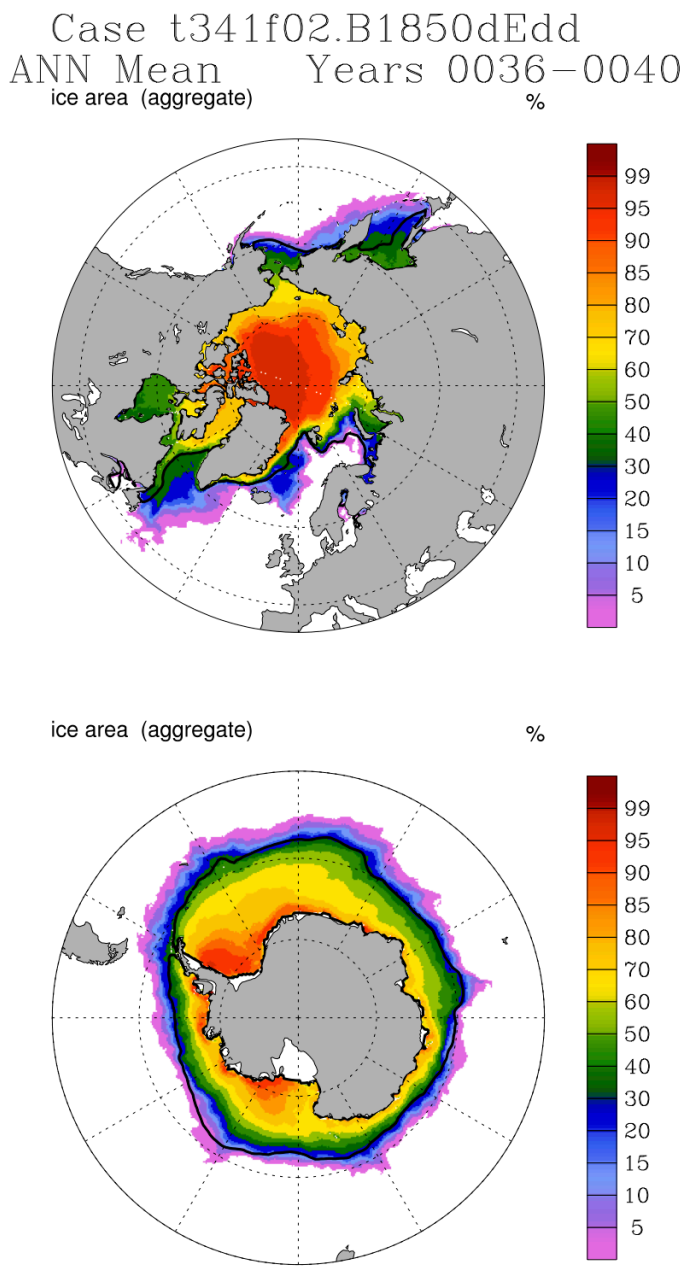

Figure 1. Five year average of model sea ice concentration (percent). The thick black line denotes the extent derived from 1979-2000 satellite observations. Note that the observational extent is based on a threshold of 15%, thus for direct comparison, model values denoted by magenta and light blue should be ignored.

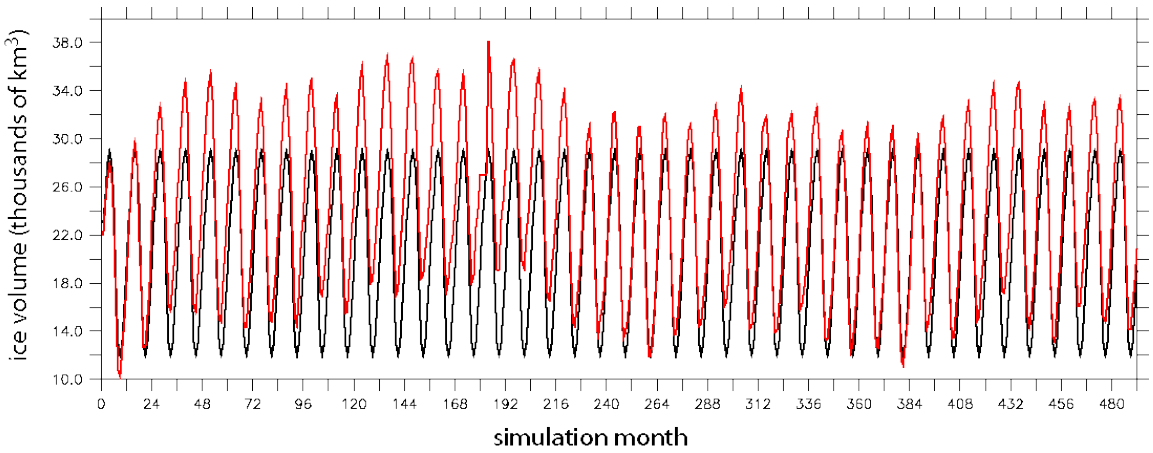

Figure 2. Time series of total Arctic sea ice volume (thousands of cubic km). Model output is in red, and an estimate of the real world mean over 1979-2011 (PIOMAS, 2011) is in black.

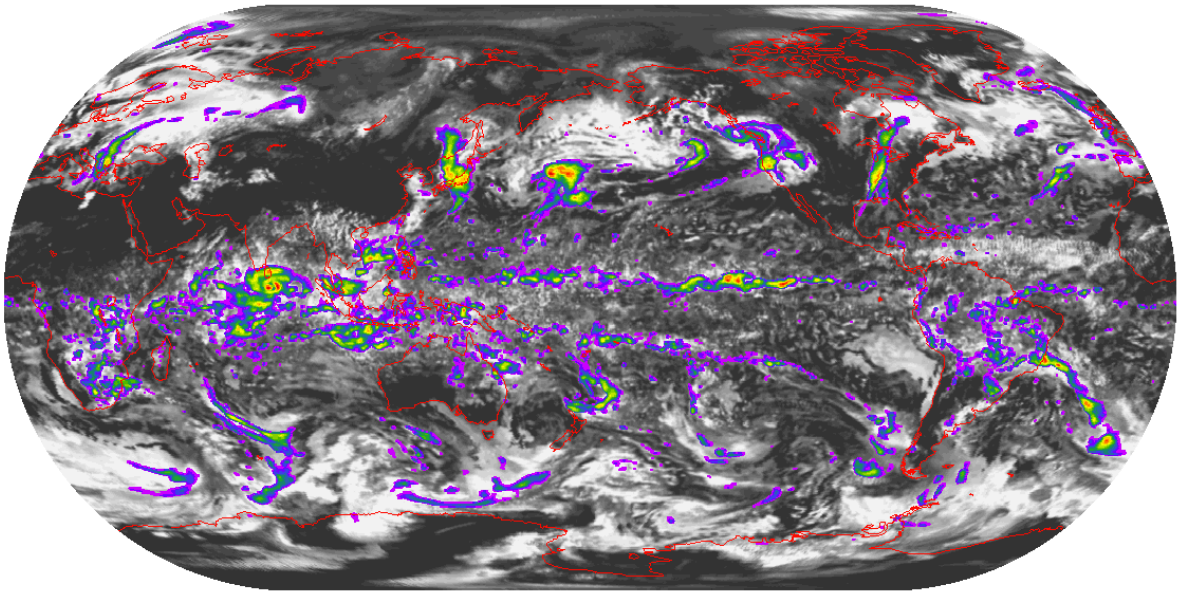

Figure 3. Snapshot of total vertically integrated cloud fraction (grey scale) and precipitation (colors, with purple corresponding to low values and red to high values) from January 4 of year 41 of the coupled simulation.

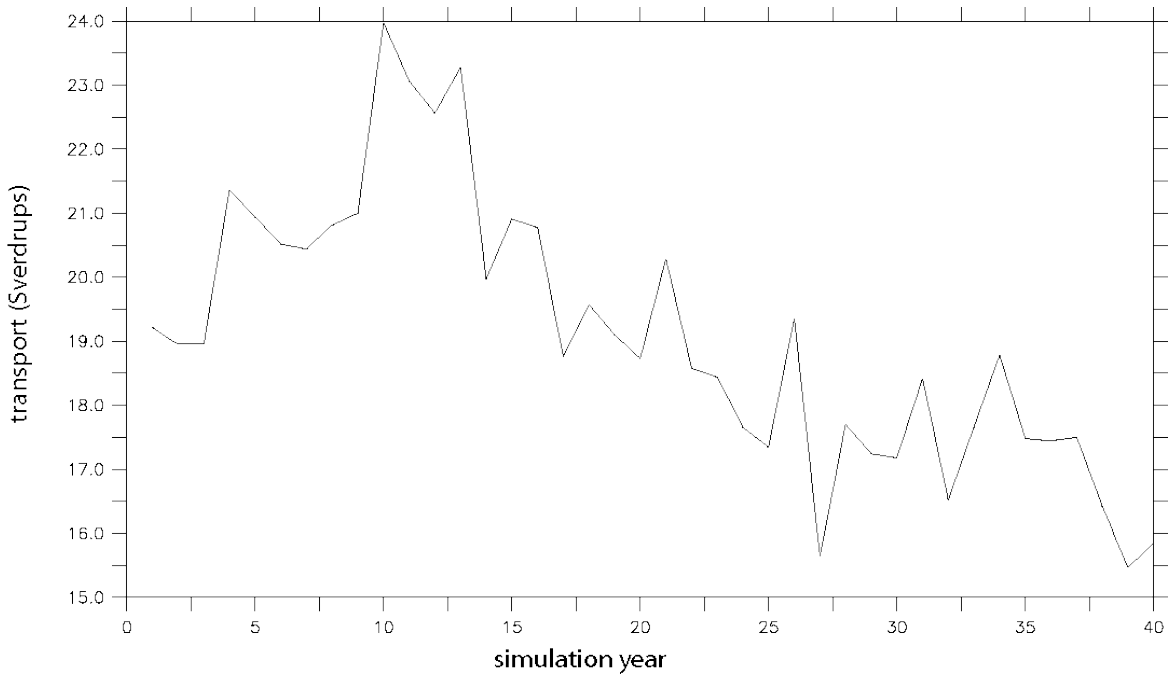

Figure 4. Maximum annual averaged Atlantic Meridional Overturning Circulation (Sverdrups; 1 Sv = 1 million cubic meters/second) from the coupled simulation. After initial increase, the transport appears to be asymptoting to a value of about 17 Sv.

3.0 References

McClean, JL, DC Bader, FO Bryan, ME Maltrud, JM Dennis, AA Mirin, PW Jones, Y-Y. Kim, DP Ivanova, M Vertenstein, J Boyle, RL Jacob, N Norton, A Craig, and PH Worley. 2011. "A Prototype Two-Decade Fully-Coupled Fine-Resolution CCSM Simulation." *Ocean Modelling* **39**(1-2):10-30. DOI: 10.1016/j.ocemod.2011.02.011.

PIOMAS. 2011. Arctic Sea Ice Volume Anomaly, Version 2. http://psc.apl.washington.edu/wordpress/research/projects/arctic-sea-ice-volume-anomaly.

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