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U.S. DEPARTMENT OF ENERGY | Office of Science

FY 2016 Second Quarter Performance Metric: Develop, Test, and Integrate Necessary Coupling between Ice Sheet and Climate Models into DOE Earth System Models

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DISCLAIMER

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1.0 Product Definition

To simulate changes in sea levels, dynamic ice sheet models need to be developed and incorporated into climate models. Models also need to accurately capture various processes by which the surrounding climate model components cause the ice sheet to lose or gain mass (e.g., through melting or freezing). The primary couplings that need to be accounted for include (1) heat and precipitation fluxes between the atmosphere and the ice sheets upper-surface, (2) heat and freshwater fluxes between the lower surface of floating ice sheets and the ocean, (3) liquid (meltwater runoff) and solid (icebergs) freshwater fluxes from the lateral margins of ice sheets into the oceans; and (4) changes in surface albedo resulting from snowpack evolution and ice sheet advances or retreats (snow versus ice versus bare land). Changes in sea level occur when there is an imbalance between the amount of mass gained and lost over a given time period; if net melting, sublimation, and calving exceed net accumulation, ice sheets loose mass and sea level increases (and vice versa). At present, surface melting and iceberg calving are estimated to contribute approximately equally to the annual sea-level rise from Greenland, with melting beneath floating ice contributing a small fraction of the total. For Antarctica, iceberg calving and basal melting of ice shelves are estimated to contribute approximately equally to the annual sea-level rise, with surface melting being a small fraction of the total.

2.0 Product Documentation

The U.S. Department of Energy (DOE) has funded efforts to include the coupling between ice sheets and other climate components in advanced Earth System Models (ESMs), including the Community Earth System Model and, more recently, DOE’s Accelerated Climate Model for Energy. Coupling between the land ice and the atmosphere models is responsible for passing heat and moisture fluxes between the two components and for evolving the land ice surface brightness. Coupling between the land ice model and the ocean model is responsible for the passing of heat and freshwater fluxes between the two components, both at the base of floating ice shelves and at its margins. Gain or loss of mass from the ice sheet model component via these couplings dictates the rate of ice sheet growth or decay and, in turn the rate at which that ice sheet detracts from, or contributes to, global sea-level rise. These new couplings, described in further detail in the report, have all been developed, integrated, and tested within DOE ESMs. Ongoing testing as part of fully coupled ESM simulations is currently active as part of Accelerated Climate Model for Energy, version 1.0, development and tuning.

3.0 Results

In its Fourth Assessment Report (AR4), the Intergovernmental Panel on Climate Change highlighted ice sheet models of the time as being deficient at simulating or explaining contemporary observations of rapid ice sheet change (IPCC, 2007) and, as a result, neglected to speculate on the potential dynamic contribution of ice sheets to future sea-level rise. After publication of the AR4, several workshops provided recommendations towards improved ice sheet model simulation capabilities (e.g., Little, 2007; Lipscomb et al., 2009). High on the list of recommendations was an improved representation of climate forcing on ice sheets through improved coupling between ice sheet and climate models. A schematic of the ways in which ice sheets couple to the rest of the climate system is shown in Figure 1.

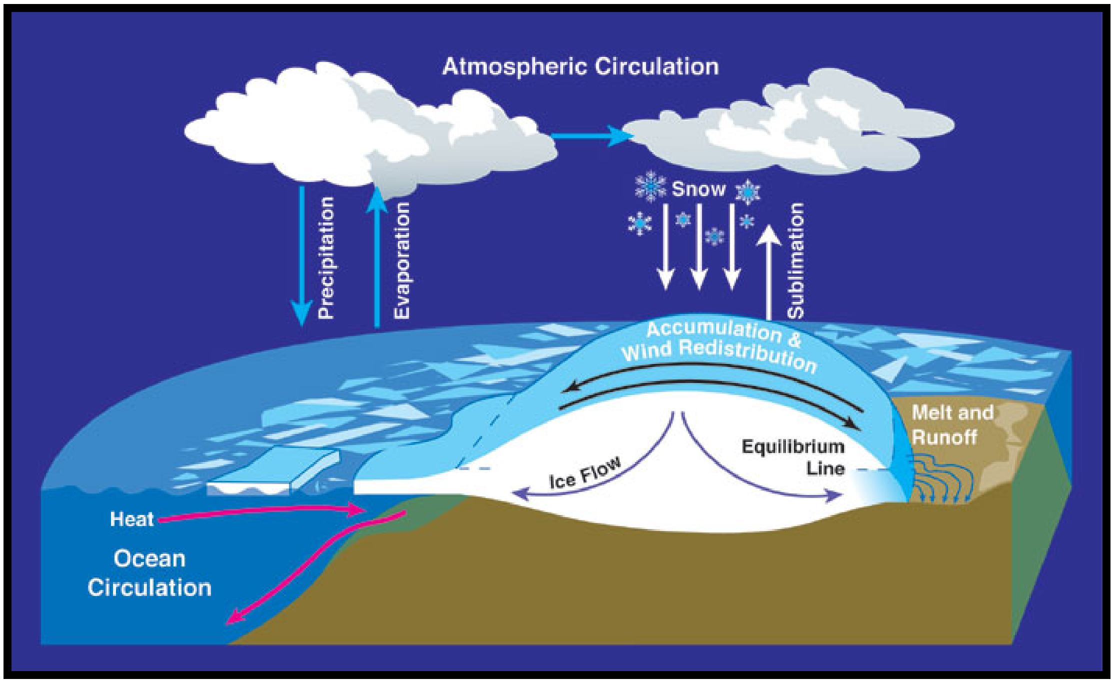

Figure 1. Schematic Showing Primary Ways in which Ice Sheets are coupled to the Rest of the Climate System. (http://www.nasa.gov/images/content/53743main_atmos_circ.jpg)

Coupling between land ice and atmosphere models is responsible for passing heat and moisture fluxes between the two components and for evolving the land ice surface albedo. Changes in the atmospheric, near ice sheet surface temperature are passed to the land ice model, providing the upper-surface boundary condition for temperature calculations in the land ice model. Heat and moisture fluxes are used to calculate the ice sheet surface mass balance—accumulation from snow and re-frozen rain, minus ablation from melting and sublimation—which in turn adds to, or subtracts from, the land ice model thickness and/or changes its areal extent. This coupling relies on the energy and snowpack evolution models from the land surface model as intermediaries, which is necessary for energy conservation and consistency in snow physics across different model components. It also is needed to allow snow-covered land surfaces to become glaciated, or for glaciated regions to transition back to snow-covered land surfaces. To allow for a more realistic simulation of the formation of glacier ice from snow, the snowpack model over ice sheets is allowed a larger maximum thickness and number of layers, relative to snow-covered land surfaces. The atmosphere and land models generally run at much coarser spatial resolution than the land ice model (on the order of hundreds of kilometers versus <10 km, respectively), and to account for the sensitivity of precipitation to orography over ice sheets, a coupler-based downscaling scheme uses the high-resolution land ice topography when calculating precipitation over ice sheets. Additional details of the surface mass balance scheme and its validation are discussed in detail in Lipscomb et al. (2013) and Vizcaíno et al. (2013). Figure 2 demonstrates validation of modeled surface mass balance calculations for the Greenland ice sheet. Figure 1 schematically displays a number of these coupling mechanisms, the net effect of which is to drive changes in ice sheet thickness and extent, add or remove freshwater to/from the oceans, and alter the Earth's energy balance.

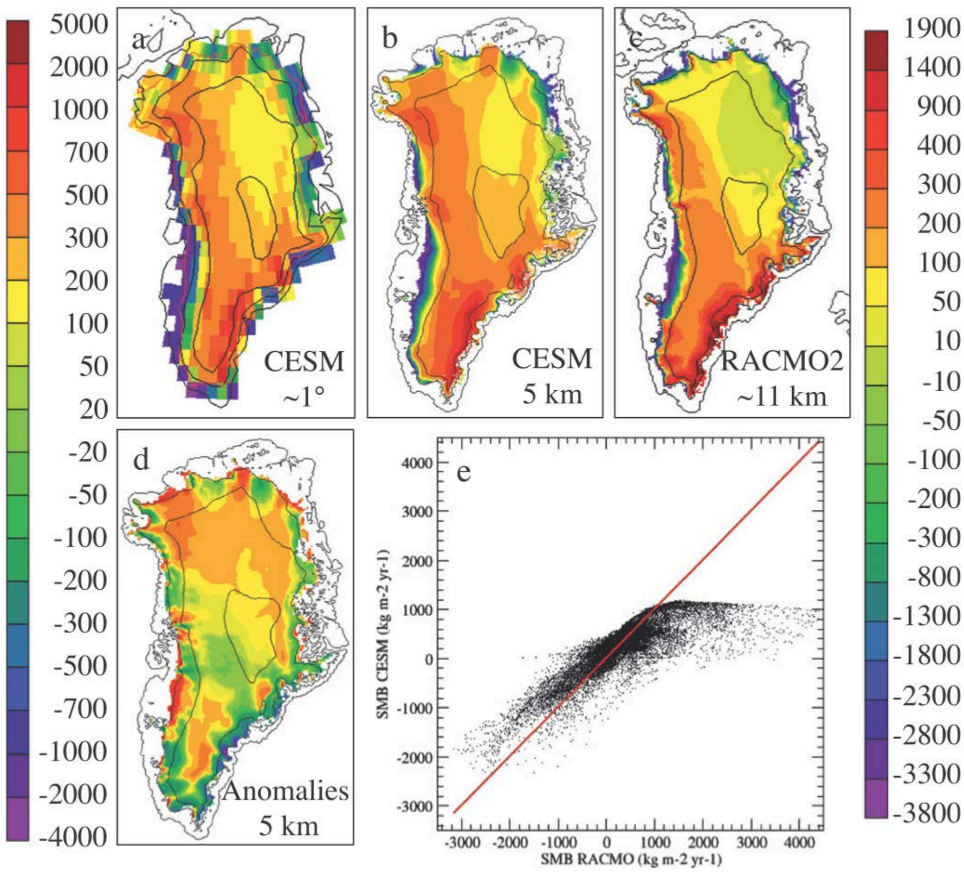

Figure 2. Simulated Mean Surface Mass Balance (accumulation, via snowfall and refreezing of rain, minus ablation, via melting and sublimation, in kilograms per square meter per year) for the Greenland Ice Sheet over the Time Period from 1960 to 2005 (figure after Vizcaíno et al., 2013).

Shown are values that were not downscaled (upper left), values downscaled onto a 5-km land ice mesh (upper center), and values from the Regional Atmospheric Climate Model, version 2.1 (Ettema et al., 2010), a high-resolution, regional climate model that has undergone extensive validation using observations. A detailed comparison of differences between the downscaled surface mass balance and the model results are shown in the lower row of the plot. This scheme, first implemented in the Community Earth System Model, has been ported to the Accelerated Climate Model for Energy, version 1.0.

Coupling between the land ice model and the ocean model is responsible for the passing of heat and freshwater fluxes between the two components, both at floating ice sheet basal boundaries (beneath ice shelves via basal melting and freezing) and at the ice sheet lateral margins (via meltwater runoff and iceberg calving). Solid and liquid freshwater fluxes are either passed to, or calculated in, the model coupler, which mediates the changes from one component to another. Meltwater runoff and iceberg mass flux are passed to the ocean model through the coupler, and use standard land model "runoff-streams" as entry points to the ocean model. Submarine melting (freezing) and the resulting transfer of freshwater to/from the ice shelf base are calculated in the coupler using a standard boundary layer physics scheme (Holland and Jenkins, 1999) that has been validated using standard benchmarking test cases (Figure 3). Interface temperatures provided by the boundary layer physics scheme supply an additional boundary condition for temperature calculations within the land ice model. As when coupling to the atmosphere, changes in the land ice thickness (because of submarine melting or freezing) and extent (because of iceberg calving) are accounted for when evolving the land ice model at each time step. For coupled land ice and ocean model simulations using realistic ice sheet and ocean geometries, new variable resolution ocean grids that include sub-ice shelf bathymetry have been created. In addition, new techniques have been developed to initialize global ocean circulation models with ice shelf cavities in a stable manner. Figure 4 shows an example for a limited-region, variable-resolution ocean mesh that allows ocean circulation beneath Antarctic ice shelves.

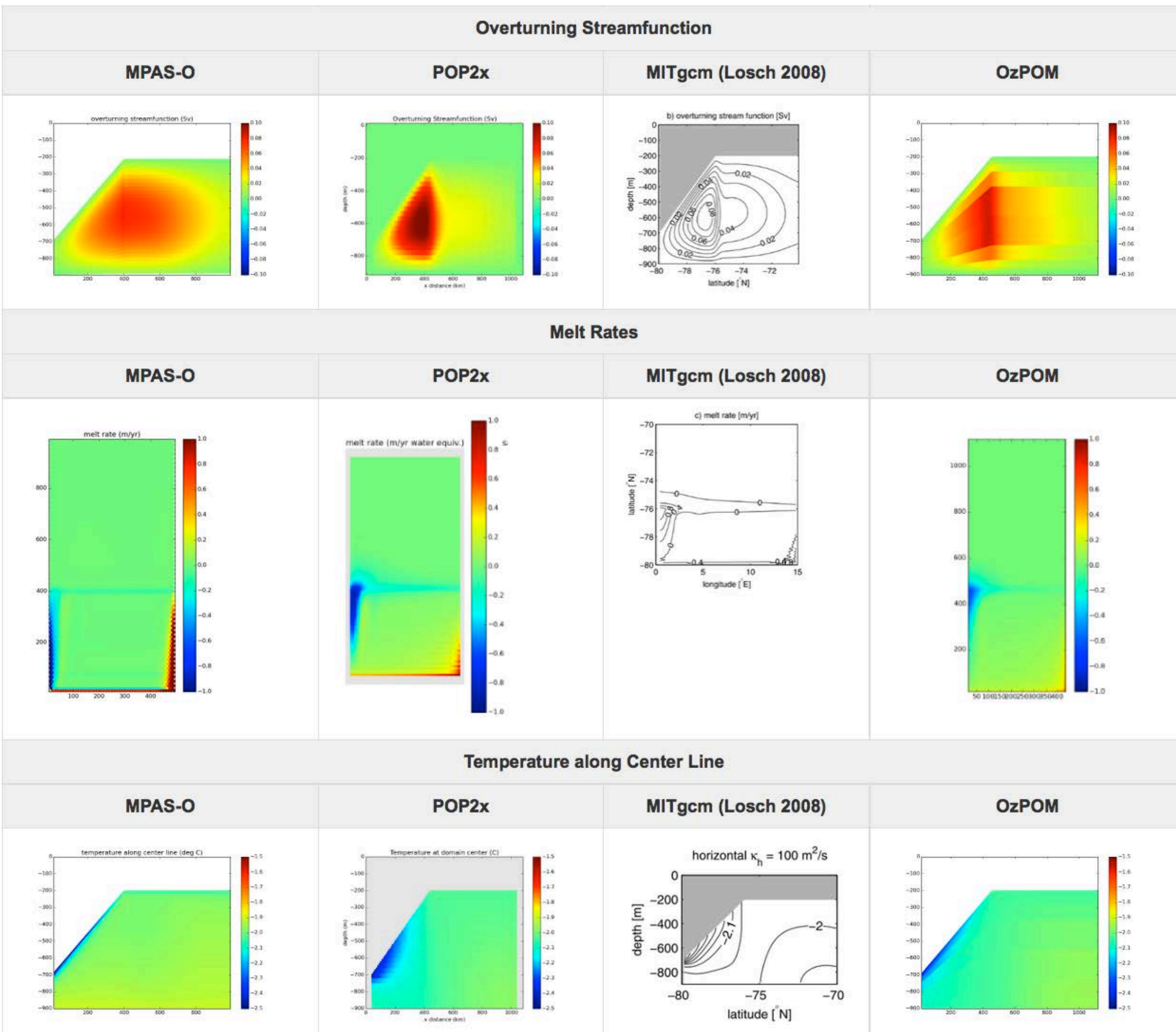

Figure 3. Validation of Boundary Layer Physics and Sub-Ice Shelf Circulation Properties in Simulations using the Model for Prediction Across Scale-Ocean (left column) applied to a Standard Benchmark Test Case (Ice Shelf-Ocean Model Intercomparison Project) (see Losch, 2008). *Figure courtesy of X. Asay-Davis (Potsdam Institute for Climate Impact Research, Potsdam, Germany).*

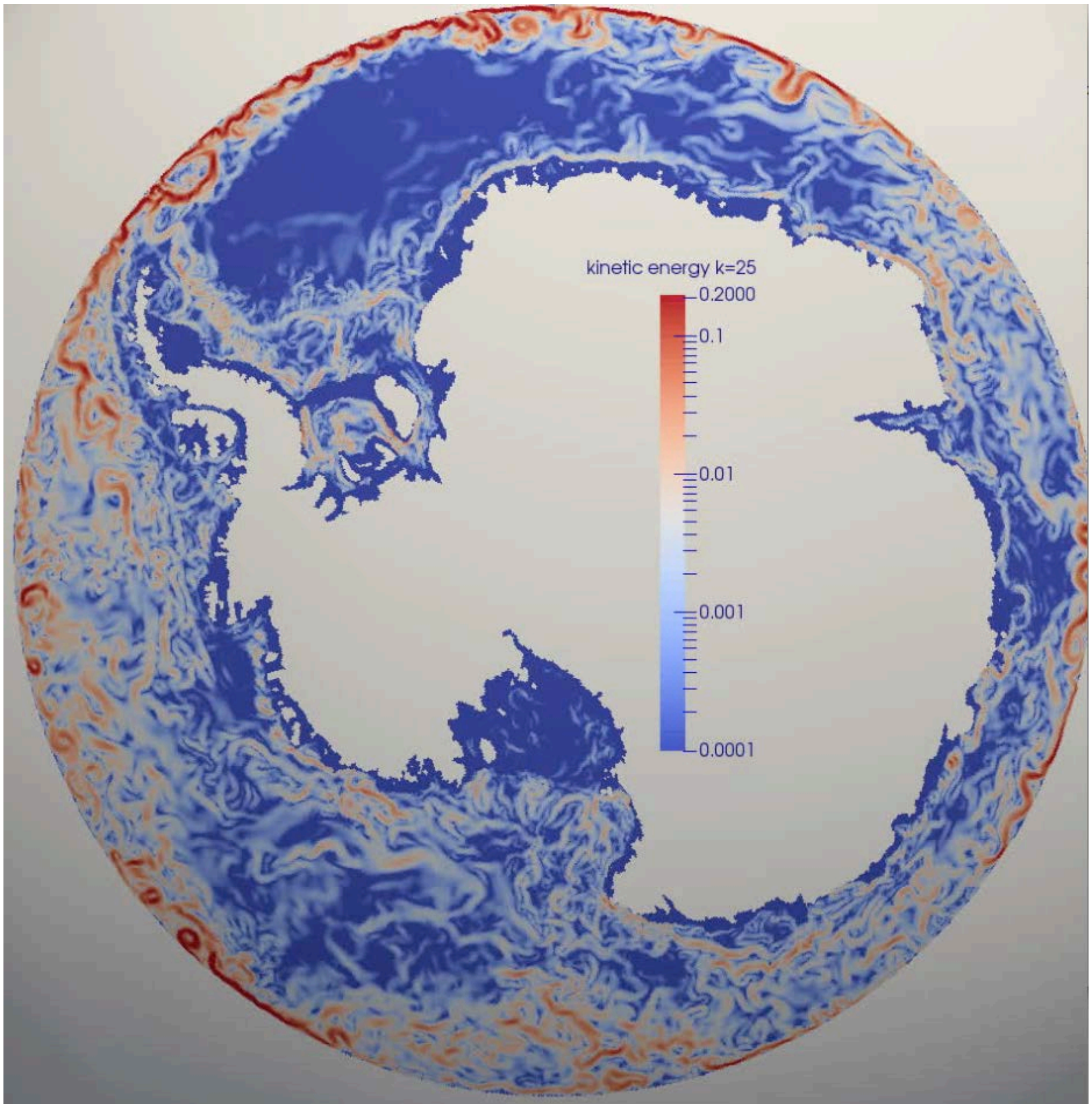

Figure 4. Ocean Kinetic Energy Calculated from the Model for Prediction Across Scale-Ocean, Limited Domain, Variable Resolution (~10 km resolution near ice shelves) Simulation With Ice Shelf Cavities beneath Antarctica. Results from this demonstrate the success of a new scheme for stable initializing of ocean simulations with ice shelf cavities, allowing for the coupling of the ocean and ice sheets in global simulations. *Figure courtesy of M. Petersen (Los Alamos National Laboratory).*

4.0 References

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