Committed Sea-level Rise for the Next Century from Greenland Ice Sheet Dynamics

Stephen Price, T-3; Antony Payne, University of Bristol, UK; Ian Howat, Ohio State University; Ben Smith, University of Washington

The Antarctic and Greenland ice sheets are losing mass at rates contributing a total of ~1 mm per year to global sea level rise [1]. This contribution is expected to increase in the future but, as noted in the recent Intergovernmental Panel on Climate Change climate assessment report [2], current ice sheet models are too crude to provide a best estimate, or even an upper bound, for 21st century sea level rise due to changes occurring on ice sheets. This failing is due in large part to poor representation of ice dynamical processes, from which most of the future increase in sea-level rise is expected to come. For example, recent observations indicate that over the past decade, one half of the sea-level contribution from Greenland was the result of dynamical thinning [3].

The Climate, Ocean and Sea Ice Modeling (COSIM) project has recently begun building an ice sheet model with improved dynamics and physics. The initial model is based on the model of Payne and Price [4,5], which includes an improved treatment of ice dynamics. Continuing advances to this model made under the Department of Energy ISICLES (Ice Sheet Initiative for Climate Extremes) project will soon allow for efficient large-scale, high-resolution simulations on massively parallel architectures. The model has been coupled to the Community Earth System Model and will soon be coupled to COSIM's existing world-class sea ice and ocean circulation models. This will allow for the investigation of a wide range of possible feedbacks among these climate components.

The model is now being used to estimate how recent, short-lived perturbations to the fronts of Greenland's outlet glaciers, as a result of warm ocean water incursions [6], translate to long-term mass loss within the larger ice sheet (Fig. 1). These past dynamic perturbations are currently propagating into the ice sheet interior and will result in some amount of "committed" sea-level rise that can be quantified using the current model constrained by observations. Based on a moderate (5 km) resolution model of Greenland, experiments indicate a minimum sea-level rise from Greenland ice sheet dynamics of ~6 mm by 2100 [7] (Fig. 2, black curve). By making reasonable assumptions about the recurrence of similar dynamic perturbations in the future [8], the modeling can also be used to obtain middle- and upper-bound estimates for the future dynamic sea-level rise from Greenland (Fig. 2, blue and red curves, respectively). The upper-bound estimate of ~45 mm of sea-level rise by 2100 from this work [7] is about one-half of a recent upper-bound estimate based purely on kinematic constraints [9]. The smaller magnitude is largely due to the fact that our dynamic modeling accounts for the decaying and periodic nature of the perturbations driving long-term ice sheet mass loss, whereas the kinematic modeling does not.

Ongoing and future work will include revision of the current estimates for Greenland using a higher-resolution (1–2 km), fully parallel model, and extension of the method to areas of Antarctica that are currently undergoing similar changes.

For more information contact Stephen Price at sprice@lanl.gov.

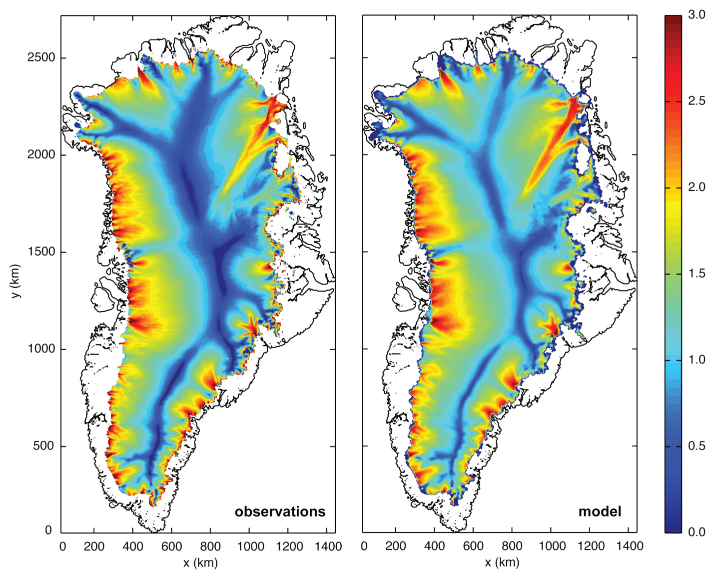

Fig. 1. Steady-state velocity field (log10 scale) for the Greenland ice sheet based on modern-day observations of geometry and surface mass balance (left panel) and modeled velocity field with basal sliding tuned to match the velocity field inferred from observations (right panel). The model results are being used as initial and boundary conditions for high-resolution experiments to examine the susceptibility of particular outlet glaciers to dynamic mass loss induced by perturbations at their marine calving fronts.

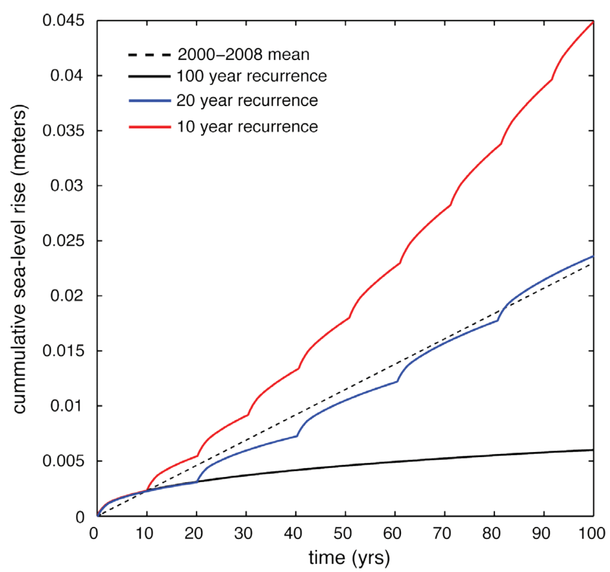

Fig. 2. Estimated future sea-level rise as a result of Greenland ice sheet dynamics. The lower-, middle-, and upper-bound estimates are given by the black, blue, and red solid lines, respectively. The cumulative sea-level rise inferred by assuming a constant dynamic contribution at 2000-2008 levels (from [3]) is shown by the black dashed line.

[1] Cazenave, A., et al., *Global Planet Change* **65,** 83 (2009).
[2] "Summary for Policymakers," in *Climate Change 2007: The Physical Science Basis*, Eds. S. Solomon, et al., Cambridge University Press, NY (2007).
[3] van den Broeke, M., et al., *Science* **326,** 984; doi:10.1126/science1178176 (2009).
[4] Payne, A.J. and S.F. Price, "A Three-dimensional, First-order Model of Ice Flow," in preparation.
[5] Price, S.F., et al., *EOS Trans AGU* **88,** 52; Abstract C43A-06 (2007).
[6] Holland, D.M., et al., *Nat Geosci* **1,** 659 (2008).
[7] Price, S., et al., *PNAS,* submitted.
[8] Murray, T., et al., *J Geophys Res* **115**; doi:10.1029/2009JF001522 (2010).
[9] Pfeffer, T., et al., *Science* **321**; doi:10.1126/science.1157638 (2008).

Funding Acknowledgments
DOE, Office of Biological and Environmental Research, Climate Change Prediction Program; DOE, Office of Science, Scientific Discovery through Advanced Computing Program