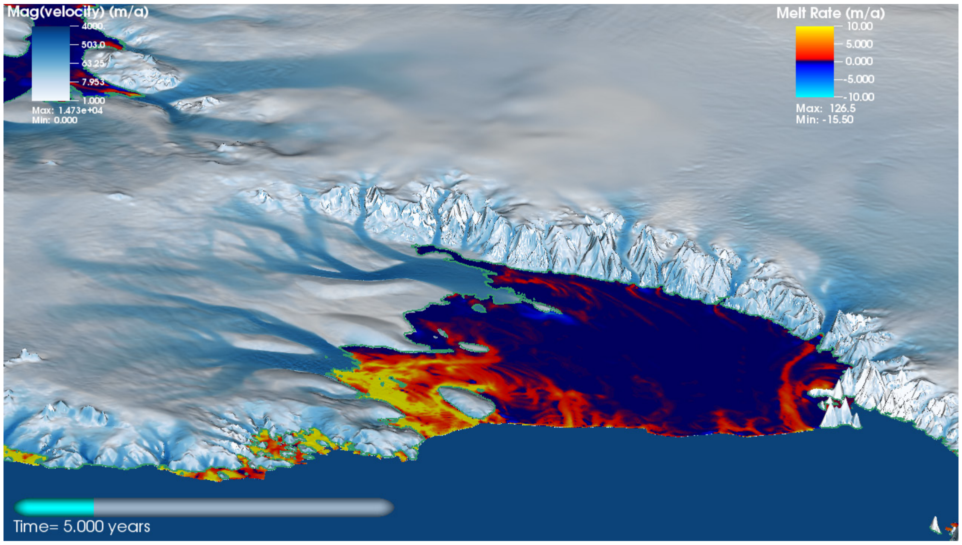
BISICLES: ADAPTIVE MESH REFINEMENT FOR ICE SHEETS

BISICLES is an ice-sheet model that uses adaptive mesh refinement (AMR) to enable fully resolved modeling of the marine ice-sheet dynamics found in Antarctica and Greenland.

On average, Earth's glaciers and ice sheets are shrinking. It is estimated that Antarctica holds about 70 percent of the world's freshwater and 90 percent of the total global ice mass, while Greenland contains much of the remaining 10 percent. Understanding how these huge ice reserves respond to changing earth systems is critical for projections of sea-level rise in the 21st century and beyond.

Because they extend as a shelf over the ocean, marine ice sheets are particularly vulnerable to rapid change. In these ice sheets, ice flows in relatively fast-moving ice streams from the interior toward the ocean and into large floating ice shelves, which in turn push back against ("buttress") the flow of the ice streams. The point at which the ice separates from the land and begins to float is known as the "grounding line."

As ice shelves weaken and collapse due to mechanisms like warm-water incursions or surface melting that leads to crevassing and hydrofactures, the buttressing effect is lost and their feeder ice streams accelerate and thin. This can lead to dramatic grounding line retreat, a greater rate of ice loss—and amplified contributions to sea-level rise.



Movie frame from a coupled ice-ocean model simulation of the Antarctic ice sheet and the Southern Ocean: The white-light blue colors indicate highest velocities of the grounded ice, while red-yellow indicates the highest melt rates.

There is substantial evidence that accurately modeling the relevant ice-sheet dynamics requires very fine spatial and temporal resolution. Using the AMR technique, the BISICLES (Berkeley Ice Sheet Initiative for CLimate ExtremeS) ice-sheet model dynamically applies high resolution only to where it is needed to resolve the dynamics of the ice sheet. This allows accurate and efficient projections of ice-sheet response to climate forcing and the resulting contributions to sea-level rise.

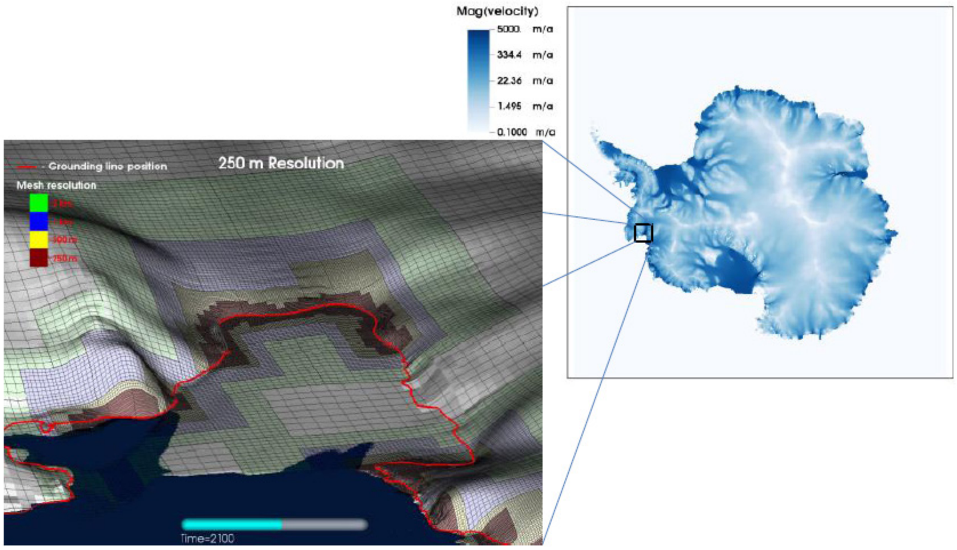
For example, Antarctica's contribution to sea-level rise is expected to be dominated by the interaction of the marine ice sheets of the West Antarctic Ice Sheet and the ocean. If the most vulnerable ice in Antarctica is lost, global sea level is projected to rise by as much as four meters, impacting worldwide populations, economies, and the environment.

FROM ISICLES TO BISICLES AND INTO E3SM

The Department of Energy's Ice Sheet Initiative for Climate Extremes (ISICLES) was initiated by the Advanced Scientific Computing Research (ASCR) Office after a 2007 international call for better projections

Get BISICLES

Instructions for downloading the BISICLES ice-sheet modeling code and software documentation are available at **http://bisicles.lbl.gov/**.



A computer rendering illustrates an Antarctic ice velocity field. The inset image at the left details adaptive mesh refinement placement of fine spatial resolution near grounding lines (red) at the Pine Island Glacier, currently the fastest melting glacier in Antarctica, responsible for about 25 percent of Antarctica's ice loss.

of potential ice sheet contribution to global sea-level rise. An extension of this effort, BISICLES today is jointly supported by DOE's Office of Advanced Scientific Computing Research (ASCR) and Office of Biological and Environmental Research (BER), and offers researchers scalable AMR ice-sheet modeling tools.

BISICLES is developed by a collaboration of computational scientists at the Lawrence Berkeley National Laboratory and the University of Swansea and earth system scientists at the Los Alamos National Laboratory and the University of Bristol. It is a scalable model built on the DOE-funded Chombo software framework, which uses block-structured AMR to dynamically refine the computational mesh needed to resolve the wide range of scales found in ice sheets. In dynamic refinement, the mesh adjusts during the simulation to place high-resolution where the sheet is changing most rapidly.

The model development team used a formulation of the momentum balance based on a mathematical analysis which simplifies the equations being solved from three dimensions down to two while preserving accuracy. This two-dimensional formulation helps reduce the computational cost of the model.

The combination of local refinement and the particular non-Newtonian, or non-linear and deformation-dependent character of ice, produces unique challenges for solving this system of equations. BISICLES developers worked closely with DOE mathematicians and computational scientists to address these challenges, greatly improving the efficiency and robustness of the code.

BISICLES will be fully coupled to DOE's **Energy Exascale Earth System Model** (E3SM) model version 3.

IN MODELING, HIGH RESOLUTION MATTERS

Because BISICLES applies high resolution only where it is needed, ice-sheet dynamics can be resolved accurately while employing computationally cheaper and coarser resolution in areas that don't need such fine detail.

Using AMR to locally deploy very fine resolution allows researchers to focus on the small regions which control the overall evolution of the ice sheet, like retreating edges and grounding lines. This allows an accurate view of processes like ice streams, grounding-line migration, and the resulting large-scale changes in the ice sheet. Importantly, the flexibility of AMR's localized accuracy allows for accurate modeling on a continental scale.

For further reading, see "***Adaptive Mesh, Finite Volume Modeling of Marine Ice Sheets***," "***Century-Scale Simulations of the Response of the West Antarctic Ice Sheet to a Warming Climate***," and "***Adaptive Mesh Refinement Versus Subgrid Friction Interpolation in Simulations of Antarctic Ice Dynamics***."

SUPPORT

- U.S. Department of Energy DOE Office of Advanced Scientific Computing Research (ASCR)
- DOE Scientific Discovery through Advanced Computing (SciDAC) program
- DOE Office of Biological and Environmental Research (BER)
- Natural Environment Research Council (United Kingdom)

CONTACTS

Daniel Martin, Ph.D.
Lead DOE Developer
Lawrence Berkeley National Laboratory
DFMartin@lbl.gov

Dorothy Koch, Ph.D.
DOE Program Manager
Earth System Modeling
dorothy.koch@science.doe.gov