Computational Methods in Ice Sheet Modeling for Next-Generation Climate Simulations

Abstract:

In its fourth assessment report (AR4), the Intergovernmental Panel on Climate Change (IPCC) declined to include estimates of future sea-level rise from ice sheet dynamics due to the inability of ice sheet models to mimic or explain observed dynamic behaviors, such as the acceleration and thinning then occurring on several of Greenland's large outlet glaciers [1]. In recent years, there has been a push to develop "next generation" community-supported ice sheet models and codes: codes that (1) are able to perform realistic, high-resolution, continental scale simulations, (2) are robust, efficient and scalable on high-performance hybrid (CPU+GPU) architectures, and (3) possess built-in advanced analysis capabilities (e.g., sensitivity analysis, optimization, uncertainty quantification), in particular, the capability to provide uncertainty ranges for future sea-level rise due to ice sheet mass loss.

This talk will give an overview of the Albany/FELIX (Finite Elements for Land Ice eXperiments) [5] next-generation land-ice dynamical core (dycore) that is currently under development at Sandia National Laboratories as a part of the PISCEES (Predicting Ice Sheet and Climate Evolution at Extreme Scales) project. This dycore is currently being integrated into the U.S. Department of Energy's (DOE's) new global Earth System Model (ESM), which will be used to calculate anticipated sea-level rise predictions during the twenty-first century, including uncertainty bounds. It is widely accepted that ice sheets behave like an incompressible non-Newtonian fluid, modeled by the Stokes equations with a nonlinear viscosity. The Albany/FELIX dycore implements an approximation to these equations, known as the "First-Order Stokes" model [2], an attractive alternative to the full Stokes model because of its reduced computational cost. Following a description of the PISCEES project, the First-Order Stokes model for ice sheets and its implementation within the Albany [4] code base using Trilinos [3] components will be detailed. Also discussed will be the coupling of Albany/FELIX to other land ice dycores, which enables dynamic simulations of ice sheet evolution, and facilitates the integration of the Albany/FELIX dycore into global ESMs. Results for some steady-state as well as dynamic Greenland and Antarctica simulations obtained on both structured and unstructured meshes will be presented. Convergence of the code on a realistic Greenland geometry will be demonstrated. It will be shown that the Albany/FELIX code is scalable, robust and portable to new architecture machines (multi-core, many-core and GPUs), and some algorithms for achieving these properties will be described. Finally, attention will be turned from forward to inverse ice sheet problems. These problems are solved for the optimal Greenland/Antarctica initial state and basal sliding coefficient, and entail minimizing a merit functional involving the mismatch between measured and computed fields (e.g., surface mass balance, surface velocities) [6], either in a deterministic or stochastic (Bayesian) setting.

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