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Adjoint-based sensitivities and data assimilation with a time-dependent marine ice sheet model

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To date, assimilation of observational data using large-scale ice models has consisted only of time-dependent inversions of surface velocities for basal traction, bed elevation, or ice stiffness. These inversions are for the most part based on control methods (Macayeal D R, 1992, A tutorial on the use of control methods in ice sheet modeling), which involve generating and solving the adjoint of the ice model. Quite a lot has been learned about the fast-flowing parts of the Antarctic Ice Sheet from such inversions. Still, there are limitations to these "snapshot" inversions. For instance, they cannot capture time-dependent dynamics, such as propagation of perturbations through the ice sheet. They cannot assimilate time-dependent observations, such as surface elevation changes. And they are problematic for initializing time-dependent ice sheet models, as such initializations may contain considerable model drift.

We have developed an adjoint for a time-dependent land ice model, with which we will address such issues. The land ice model implements a hybrid shallow shelf-shallow ice stress balance and can represent the floating, fast-sliding, and frozen bed regimes of a marine ice sheet. The adjoint is generated by a combination of analytic methods and the use of automated differentiation (AD) software. Experiments with idealized geometries have been carried out; adjoint sensitivities reveal the "vulnerable" regions of ice shelves, and preliminary inversions of "synthetic" observations (e.g. simultaneous inversion of basal traction and topography) yield encouraging results.