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Transient calibration of a marine ice sheet model using an ensemble Kalman filter

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Accurate projections of the contribution of polar ice sheets to sea level rise need a good initial state.
Most ice flow models are now equipped with variational methods to constrain poorly known parameters from surface observations. However most of the studies perform “snapshot” calibrations, where the inversion is performed at a unique initial time step. The state of the model produced from this calibration is sensitive to inconsistencies between the data sets. The resulting transient artifacts are usually dissipated during a relaxation period where the model drift from the observations.
Extending the variational methods to constrain the transient model evolution by making use of the increasing temporal resolution of the observational data-sets requires important numerical developments, and their application remains limited in ice-sheet modelling.
The same problem of join state and parameters estimation can be approached with stochastic methods, and various ensemble-based Kalman filters have been successfully applied with large and non-linear geophysical models. With this method, an ensemble of simulations is propagated forward in time with the model, and the observations are used sequentially when they become available to correct the ensemble mean and covariance.

Here, we address the question of the model initialization using transient observations of a marine ice sheet that is undergoing unstable retreat. Because of the contact problem and the grounding line migration, the inversion of the basal conditions is particularly challenging.

We use the finite element ice flow modem Elmer/Ice and solve the shallow stream approximation for the force balance.
In a synthetic twin experiment of a flowline marine ice sheet, we use the error-subspace transform Kalman filter to perform the estimation of the state, represented by the surface elevation, simultaneously with the basal topography and sliding coefficients. We assume that both the surface elevation and surface velocities are observed every year with realistic noise levels.
With an ensemble size of 50 members, we show that we are able to recover accurately both the basal topography and sliding coefficients after few years of simulations. In addition, observing the surface elevation allows to keep the position of the grounding line of all the members within few grid nodes of the true grounding line position.
Using this initial state to perform century-scale forecast simulations we show that the retreat and mass loss rates are in agreement with the reference, however uncertainties in the basal conditions may lead to significant delays in the initiation of the unstable retreat.