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Sensitivity analysis using the variational data assimilation software DassFlow-Ice

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To be confident in the accuracy of the modelling of free surface ice-flows requires to confront numerical experiments to actual observations. This type of geophysical flows is strongly sensitive to their input parameters and boundary conditions and shows multiscale behaviours. Thus, sensitivity analysis is a useful tool to improve our understanding of ice-flows. To achieve this goal, we are developing at the Mathematical Institute of Toulouse a computational software named DassFlow (*cf.* N. Martin et al., *Internal Report IMT*, 2011 and M. Honnorat et al., *RR INRIA*, 2007) following several rules of implementation and algorithmic structure. Then, the direct computational code has been algorithmically differentiated in order to obtain its adjoint part.

The direct component of the code is an ice-flow modelling tool implementing the full-Stokes equations with ALE (Arbitrary Lagrangian Eulerian) representation of the free-surface. It is based on an order 2 high-precision finite-element kernel. It allows computations of 2D-flowline domains and a 3D version is currently under development. Some of the features are friction boundary condition on the bedrock, imposed lateral flux, non-linear rheology solver and general steady or quasi-static free-surface simulations can be performed. The software has been validated on analytical test-cases and successfully compared with the results published in the Ice-Sheet Model Intercomparison Project (cf. F. Pattyn et al., *The Cryosphere Discuss*, 2008).

Using the Automatic Differentiation tool *Tapenade*, we obtained the adjoint code of DassFlow-Ice (including non-newtonian rheology solver). The code has been derivated according to several control variables such as imposed lateral flux, exponent and rheological parameter of Glen's law, accumulation at the free surface, friction coefficient, shape factor for 3D friction effects. The performance has been optimized to reach a time of computation around 4 times a direct run for an adjoint run.

We present an application of our tool on the *Variegated Glacier* in Alaska. This glacier has been monitored for many years because of its surge behaviour which occurs more or less periodically. The computation is made on a 2D-domain where topography of the bedrock and of the surface has been measured along the central flowline. The specific behaviour of this glacier is mainly driven by its basal conditions and quantifying the sensitivity of the friction coefficient along the bedrock could be of primary interest.

First runs confirmed that the main driving parameters of the flow are the basal conditions and specific area of the glacier has been highlighted. These first sensitivity tests are a first step toward a complete data assimilation procedure which would allow to infer the basal drag coefficient from the knowledge of surface velocities.