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Data assimilation of surface altimetry on the North-Easter Ice Stream using the Ice Sheet System Model (ISSM)

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Extensive surface altimetry data has been collected on polar ice sheets over the past decades, following missions such as Envisat and IceSat. This data record will further increase in size with the new CryoSat mission, the ongoing Operation IceBridge Mission and the soon to launch IceSat-2 mission. In order to make the best use of these
dataset, ice flow models need to improve on the way they ingest surface altimetry to infer: 1) parameterizations of poorly known physical processes such as basal friction; 2) boundary conditions such as Surface Mass Balance (SMB).
Ad-hoc sensitivity studies and adjoint-based inversions have so far been the way ice sheet models have attempted to
resolve the impact of 1) on their results. As for boundary conditions or the lack thereof, most studies assume that they are a fixed quantity, which, though prone to large errors from the measurement itself, is not varied according to the simulated results.

Here, we propose a method based on automatic differentiation to improve boundary conditions at the base and surface
of the ice sheet during a short-term transient run for which surface altimetry observations are available. The method relies on minimizing a cost-function, the best fit between modeled surface evolution and surface altimetry observations, using gradients that are computed for each time step from automatic differentiation of the ISSM (Ice Sheet System Model) code. The approach relies on overloaded operators using the ADOLC (Automatic Differentiation by OverLoading in C++) package. It is applied to the 79 North Glacier, Greenland, for a short term transient spanning a couple of decades before the start of the retreat of the Zachariae Isstrom outlet
glacier. Our results show adjustments required on the basal friction and the SMB of the whole basin to best fit surface altimetry observations, along with sensitivities each one of these parameters has on the overall cost function. Our approach presents a pathway towards assimilating multiple datasets in transient ice flow models of Greenland and Antarctica, which will become increasingly important as the amount of available observations becomes
too large to assess on a case by case basis.

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