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Numerical simulations of glacier evolution performed using flow-line models of varying complexity

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Glaciers are generally thought to be good indicators of a global climate change on time scales of decades to centuries. Records of glacier fluctuations and changes in climatic conditions can be used to project future changes in glacier size and spatial distribution. For a correct simulation of glaciers, their bed characteristics and flow mechanics along with the spatial and temporal distribution of surface mass balance must be taken into account. Over the last few decades, glaciers have been a subject of many studies relying on different complexities of the used numerical models. But the performance of models of different complexity, and therefore the applicability of these models to simulate future glacier volume and length evolution is still under debate.

In this study, we focus on differences in glacier volume and length evolutions simulated using two numerical models of different complexity. We systematically build up the problem by applying several configurations of climatic forcing and glacier bed characteristics. The climatic forcing is imposed by means of variation in the equilibrium line altitude in the mass balance equation. The bed characteristics are changed from a simple glacier bed with a constant slope and uniform width to a longitudinally varying bed slope and width. The applied models are quite different with respect to their mathematical formulation. The first model is a full-Stokes model (FSM) using the finite element code Elmer/Ice, while the second model is based on the shallow-ice approximation (SIA) which is a highly simplified description of the glacier flow.

Our results show that glaciers in the two models do not develop identically. The steady state is reached 60, 30 and 10 years, respectively faster for large, medium and small glacier, when simulations are performed using SIA compared to FSM. Glaciers time response is studied by using step and periodic changes, and natural variability in the equilibrium-line altitude. Glacier length response time is up to 15 years longer when FSM is used compared to SIA. However, when periodic and natural variability is enforced, glaciers lag in phase (up to 17°) for length and lead in phase (up to 20°) for volume in FSM compared to SIA.