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Functional Inversion of Glacier Rheology from Ice Velocities using ODINN.jl

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Inversion methods play an important role in glacier models, both to calibrate and estimate parameters of interest (e.g. Glen's coefficients). However, inversions are usually made for each glacier individually, without using any global information, i.e. without deriving general laws governing the spatiotemporal variability of those parameters. The reason behind this limitation is twofold: the statistical challenge of making constrained inferences with multiple glaciers, and the computational limitation of processing massive glacier datasets. Machine learning powered with differential programming is a tool that can address both limitations.

We introduce a statistical framework for functional inversion of physical processes governing global-scale glacier changes. We apply this framework to invert a prescribed function describing the spatial variability of Glen's coefficient (A). Instead of estimating a single parameter per glacier, we learn the parameters of a regressor (i.e. a neural network) that encodes information related to each glacier (i.e. long-term air temperature) to the parameter of interest. The inversion is done by embedding a neural network inside the Shallow Ice Approximation PDE - resulting in a Universal Differential Equation - with the goal of minimizing the error on the simulated ice surface velocities. We previously had shown that this hybrid model training is possible thanks to the use of differential programming, enabling differentiation of a PDE, a numerical solver and a neural network simultaneously. In this work we upscale this approach to include larger datasets and with the goal of learning real empirical laws from observations.

This framework is built inside ODINN.jl, an open-source package in the Julia programming language for global glacier evolution modelling using Universal Differential Equations. ODINN exploits the latest generation of ice surface velocities and geodetic mass balance remote sensing products, as well as many preprocessing tools from the Open Global Glacier Model (OGGM).