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A new approach for estimating ice thickness distribution of 90'000 mountain glaciers around the globe

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Mass loss of mountain glaciers and small ice caps is an important component of eustatic sea-level rise. The ice volume of these more than 100'000 glaciers is normally estimated using volume-area scaling relationships. Volume-area scaling does, however, not account for the characteristics of individual glaciers, and does not yield any information about the spatial distribution of the ice thickness, which is required e.g. for the transient modelling of glacier ice flow dynamics.

Here, we propose and apply a new method for adding the third dimension to glacier inventories by inverting global digital elevation model (DEM) data to distributed ice thickness. The method to estimate ice thickness distribution of mountain glaciers and small ice caps around the globe is based on glacier mass turn-over and the principles of ice flow mechanics. Using glacier elevation bands evaluated from a digital elevation model, volume balance flux is calculated and transformed into local ice thickness using Glen's flow law. In an iterative procedure, the basal shear-stress distribution and the shape factor is determined. Finally, mean thickness in each elevation band is extrapolated transversal to the topographic gradient based on local surface slope. Thus, for each glacier ice thickness on a regular grid can be calculated. The only input requirements are a glacier outline and a DEM.

DEMs between 60°N and 60°S are available from the Shuttle Radar Topographic Mission (SRTM) with a spatial resolution of about 90 m. North and South of 60° the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM (30 m resolution) is used. Glacier outlines are provided by the Global Land Ice Measurement from Space (GLIMS). Based on these readily available data sets, thickness distribution and ice volume of all 90'000 glaciers currently contained in the GLIMS database are evaluated. Application of the method to all mountain glaciers and small ice caps around the globe provided by a recently completed world glacier inventory is planned for estimating global glacier ice volumes.

Inferred thickness distribution is validated against in-situ measurements (radio-echo sounding) for about 50 glaciers across all continents, and against additional ice volume data. Calculated ice thickness agrees well with field observations which supports the worldwide applicability of the approach. Uncertainties are quantified, and we discuss the potential of the new approach in comparison to traditional volume-area scaling.