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Ice thickness measurements and volume estimates for glaciers in Norway

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Whereas glacier areas in many mountain regions around the world now are well surveyed using optical satellite sensors and available in digital inventories, measurements of ice thickness are sparse in comparison and a global dataset does not exist. Since the 1980s ice thickness measurements have been carried out by ground penetrating radar on many glaciers in Norway, often as part of contract work for hydropower companies with the aim to calculate hydrological divides of ice caps. Measurements have been conducted on numerous glaciers, covering the largest ice caps as well as a few smaller mountain glaciers. However, so far no ice volume estimate for Norway has been derived from these measurements. Here, we give an overview of ice thickness measurements in Norway, and use a distributed model to interpolate and extrapolate the data to provide an ice volume estimate of all glaciers in Norway. We also compare the results to various volume-area/thickness-scaling approaches using values from the literature as well as scaling constants we obtained from ice thickness measurements in Norway.

Glacier outlines from a Landsat-derived inventory from 1999-2006 together with a national digital elevation model were used as input data for the ice volume calculations. The inventory covers all glaciers in mainland Norway and consists of 2534 glaciers (3143 glacier units) covering an area of 2692 km2 $\pm$ 81 km2. To calculate the ice thickness distribution of glaciers in Norway we used a distributed model which estimates surface mass balance distribution, calculates the volumetric balance flux and converts it into thickness using the flow law for ice. We calibrated this model with ice thickness data for Norway, mainly by adjusting the mass balance gradient. Model results generally agree well with the measured values, however, larger deviations were found for some glaciers. The total ice volume of Norway was estimated to be 275 km3 $\pm$ 30 km3.

From the ice thickness data set we selected glacier units or entire ice caps with sufficient data to interpolate mean ice thickness. Scaling constants c and γ were fitted by least square regression for totally 86 glacier units and 8 ice caps. The ice volume results from scaling were sensitive to how the glaciers are divided and scaling applied to glaciers divided into glacier units gave best results. Scaling laws for ice caps did not work well, as the mean thickness of the ice caps varies less than their areas and the sample of ice caps with sufficient measurement coverage was small. Calculated ice volumes range from 280 to 305 km3, much higher than values obtained from the literature (134-184 km3). As measurements are biased towards outlets from the largest and thickest ice caps, more measurements are needed for a better estimate of the present ice volume of the smaller glaciers.