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Methodological approaches to inferring end-of-winter snow distribution on alpine glaciers

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End-of-winter snow distribution is a key variable in terms of glacier mass balance. However, such measurements are typically rare and not adequately represented in today's mass balance models. A better understanding of processes governing preferential snow deposition and redistribution on glacierized surfaces is a prerequisite for a more reliable impact assessment of climate change on glaciers.

We present measurements of snow accumulation distribution from the 2009/2010 season on Findelengletscher, Valais, Switzerland, a large alpine valley glacier (13.4 km^2). Field data were obtained simultaneously in April 2010 from (a) manual snow probing, (b) airborne Ground Penetrating Radar (GPR) and (c) surface elevation changes given by two LIDAR (Light Detection and Ranging) Digital Elevation Models (DEM). In this study, we aim at combining and comparing these data sources of point, line and area type. In-situ snow probings serve as ground reference. This data set consists of 463 point values covering the entire glacier elevation range. Additionally, snow density was measured in 13 snow pits across the glacier. The 500 MHz GPR survey was carried out from helicopter along 12.7 km of linear tracks providing about 10,000 evaluated traces. The surface elevation change based on LIDAR DEMs of Oct. 2009 and Apr. 2010 is corrected for the glacier dynamics using ice emergence velocity estimated with the 5-year average surface mass balance and observed geometry changes. This data source provides fully distributed spatial information on snow depth on a 1x1 m resolution grid over the entire glacier.

The LIDAR-derived snow depth distribution differs from in-situ snow probings and the GPR-based data particularly in crevassed areas and due to difficulties in the spatial correction of glacier dynamics. These deviations are assessed by localizing error magnitudes and by their dependency on elevation. The GPR-based measurements reveal general problems of scale when comparing them with point-based snow probings on a rough surface such as on a glacier. This is addressed by a variogram analysis to detect possible systematic biases. Further, we compute the winter mass balance from the raw LIDAR surface elevation change and snow density measurements as 0.620 m water equivalent (w.e.). Extrapolating the snow distribution from the in-situ snow probings yields a higher winter balance of 0.780 m w.e. and allows a cross-validation with the GPR- and LIDAR-based data sets.

Our results show that surface elevation change from LIDAR DEMs provides valuable information on end-of-winter snow distribution but has to be carefully corrected for glacier dynamics. Although not being truly distributed, the GPR-based data is reliable and unaffected by glacier dynamics. Thus, helicopter-borne GPR offers a straightforward and efficient tool for mapping the snow distribution on alpine glaciers. Cross-comparison of the three data sets indicates that the conventional method of extrapolating snow distribution from point probings might be subject to a systematic bias.