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Recent accumulation rates of an Alpine glacier derived from repeated airborne GPR and firn cores

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The topmost areas of glaciers contain a valuable record of their past accumulation rates. The water equivalent of annual firn layers can be used to initiate or extend existing time series of local mass balance and, ultimately, to consolidate the knowledge on the response of glaciers to changing climatic conditions. Measurements of the thickness and density of firn layers typically involve drilling in remote areas and core analysis and are thus expensive in terms of time and effort.

Here, we discuss measurements from 2012 on Findelengletscher, Switzerland, a large Alpine valley glacier, using two in-situ firn cores and airborne Ground-Penetrating Radar (GPR). The firn cores were analysed regarding their density, major ions and deuterium concentration. The ammonium (NH_4^+) concentration is known to show seasonality due to a higher source activity and pronounced vertical transportation in the atmosphere in summer. The deuterium concentration serves as a proxy for air temperature during precipitation formation. Together, they provide depth and dating of annual summer surfaces.

GPR has previously been used for a non-destructive assessment of internal layers in snow, firn and ice. Signal reflections indicate changes in the dielectric properties of the material, e.g. density changes at former summer surfaces. Airborne surveys allow measurements to be taken in remote and inaccessible areas. However, to transfer information from the GPR pulse travel time to the depth domain, the dielectric permittivity of the material is required, that changes with density of the firn. We observed a good agreement of the GPR signal with pronounced changes in the density profile, ice layers and peak contents of major ions. This underlines the high potential of GPR for detecting firn layers. However, not all peak-densities and thick ice layers represent a former glacier summer surface but can also be due to melting and refreezing during winter.

We show that up to four years of annual accumulation on Findelengletscher can be reconstructed from repeated GPR measurements alone. A simple transient spatial model for firn compaction is calibrated based on a comparison with GPR data of 2013 at positions were profiles intersect. Density and water equivalent of firn layers can then be extracted along the measured GPR profiles. However, if no in-situ information from firn cores is available, the dating of reflectors as former annual summer surfaces must be verified by external information such as modelled mass balance to avoid misinterpretations. We show that helicopter-borne GPR is an effective method to derive several years of past accumulation rates of mountain glaciers. It benefits but does not depend exclusively on the time-matched availability of firn cores when overlapping profiles are mapped in subsequent years.