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The dark zone of an alpine glacier - considering albedo impacts of firn loss

Lea Hartl[1,2], Martin Stocker-Waldhuber[1], Federico Covi[3], Anna Baldo[4], and Kathrin Naegeli[5]
[1]Institute for interdisciplinary Mountain Research, Austrian Academy of Sciences, Innsbruck, Austria
[2]Alaska Climate Research Center, University of Alaska Fairbanks, Fairbanks, USA
[3]British Antarctic Survey, Cambridge, United Kingdom
[4]Department of Atmospheric and Cryospheric Sciences, University of Innsbruck, Innsbruck, Austria
[5]Department of Geography, University of Zurich, Zurich, Switzerland

As the decline of alpine glaciers continues and accelerates, many glaciers are losing their firn area. Former accumulation zones are increasingly seeing melt conditions and mass loss. The loss of brighter snow and firn surfaces lowers albedo locally and at the glacier scale, impacting surface energy balance and leading to an albedo-mass balance feedback effect.

We assess the recent progression of firn loss into the (former) accumulation zone of Gepatschferner, Austria, focusing particularly on ice surfaces that have newly become exposed. Broadband albedo in the visible and near-infrared generally shows an altitudinal gradient in early summer from the darker, bare-ice glacier tongue to the snow covered region at higher elevations. As the melt season progresses and ablation of multi-year firn at higher elevations begins, albedo decreases substantially in areas that lose their firn cover. We find that these areas can become darker than ice in the ablation zone where no firn was present in previous years. In the extreme summer of 2022, the glacier surface of Gepatschferner was darkest in parts of the former accumulation zone where the firn-line shifted upwards. Newly exposed ice surfaces formed a “dark zone” between the remaining firn and previously exposed bare-ice areas. This zone of minimal albedo at relatively high elevations of the glacier persisted until the first snow falls in autumn and reemerged during the 2023 ablation season.

Time series of satellite imagery show melt patterns as well as trends and variability of homogenized broadband albedo in the study region. In addition to remote-sensing based observations, multiple in-situ datasets are available for the summit region of Gepatschferner (i.e. on-ice weather station, ablation stakes, automatic camera, ice thickness measurements). Combining these datasets provides a unique opportunity to explore the impact of firn loss and albedo decrease on energy and mass balance, generate calibration and validation data for point scale and distributed modeling, and generally improve understanding of processes related to firn loss at different spatial and temporal scales. However, each observational dataset comes with uncertainties related to the scale and method of observation and the parameter being observed. Leveraging the potential of the rich available data basis requires careful consideration of the

characteristics of the different data types and, when combined with energy and mass balance modeling approaches, the forcing requirements of the model. We present preliminary results from a project addressing the above for Gepatschferner and hope to connect with the community regarding the observation, modeling, and impacts of darkening mountain glaciers.