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Sensitivity of very small glaciers in the Swiss Alps to future climate change

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Very small glaciers ($<0.5 km^2$) currently account for up to 80% of the total number of glaciers in mountain ranges around the globe. Although their total area and volume is small compared to larger glaciers, they are a relevant component of the cryosphere contributing to landscape formation, local hydrology and sea-level rise. Very small glaciers have generally shorter response times than valley glaciers and their mass balance is strongly dependent on snow redistribution processes. Worldwide glacier monitoring has focused on medium-sized to large glaciers leaving us with a relatively limited understanding of the behavior of very small glaciers. With warming climate there is an increasing concern that very small glaciers might be the first to disappear. Already in the next decades this might result in the complete deglaciation of mountain ranges with glacier equilibrium lines close to the highest peaks.

Here, we present a comprehensive modeling framework to assess past and future changes of very small glaciers at the mountain-range scale. Among other processes our model accounts for snow redistribution, changes in glacier geometry and the time-varying effect of supraglacial debris. It computes the mass balance distribution, the englacial temperature regime and proglacial runoff. The past evolution of 1'133 glaciers in the Swiss Alps is individually constrained based on geodetic ice volume changes, and the model is validated against an extensive data base of in-situ measurements on very small glaciers. Our results indicate that 52% of all very small glaciers in Switzerland will completely disappear within the next 25 years. However, a few avalanche-fed glaciers at low elevation might be able to survive even substantial atmospheric warming. We find highly variable sensitivities of very small glaciers to air temperature change, gently-sloping, low-elevation, and debris-covered glaciers being most sensitive.