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# Unveiling cooling, drying and deceleration of a rock glacier during a warm period through ground temperature, piezometer and cross-borehole ERT data

**Alexander Bast**[1,2], Robert Kenner[1,2], and Marcia Phillips[1,2]
[1]WSL Institute for Snow and Avalanche Research SLF, Alpine Environment and Natural Hazards / Permafrost, Davos Dorf, Switzerland (alexander.bast@slf.ch)
[2]Climate Change, Extremes and Natural Hazards in Alpine Regions Research Center CERC, Davos Dorf, Switzerland

Rock glacier monitoring has revealed a long-term increase in rock glacier surface velocity in the European Alps, often associated with increased air and ground temperatures as well as water content. The long-term acceleration of rock glaciers is superimposed by high interannual variability of their velocity, and there is still a gap in the quantitative assessment of the role of water in rock glaciers and the factors leading to the short-term deceleration of rock glaciers.

To address this research gap, we drilled and documented the stratigraphy of three vertical boreholes in the Schafberg Ursina III rock glacier, Swiss Alps (46°29'50.391" N, 9°55'34.779" E; 2’750m asl), in August 2020. One of the boreholes was instrumented with ten *Keller PAA-36XiW* piezometers, which measure pore water pressure (www.keller-druck.ch) at depths ranging from 2 m to 8.5 m depth. In addition, each piezometer is equipped with a PT 1000 temperature sensor. The other two boreholes were equipped with a permanently installed cross-borehole electrical resistivity tomography (ERT) setup consisting of 24 electrodes in each borehole, spaced at 0.5 m, to a depth of 11.5 m, reaching the top of the shear horizon of the rock glacier. We used a *Syscal Pro Switch 48* resistivity meter and a *Syscal monitoring unit* to automatically collect, record and transmit the acquired data (www.iris-intruments.com). ERT monitoring provides information on relative changes in ice water content. Rock glacier velocities were determined from terrestrial laser scans taken in July each year using a Riegel VZ6000 long-range scanner (www.riegl.com). Using data from nearby weather stations of the *Intercantonal Measurement and Information System* (IMIS network) and ground surface temperature sensors, we analysed the interplay between meteorological and subsurface conditions during a rock glacier deceleration period from January 2021 to June 2023, which included two snow-poor winters (2021-2022, 2022-2023) and a summer heat wave in 2022.

Our results show that a reduction of the water content of rock glaciers is crucial for intermittent, interannual rock glacier deceleration. The influence of snow cover on rock glacier kinematics is significant, both as an insulator and as a water source. Winters with little snow and relatively dry summers are ideal for cooling and drying rock glaciers, leading to deceleration. Summer heat waves have a limited effect if preceded by dry winters. The importance of rainfall and snow melt water infiltration from the entire catchment remains to be determined. High-resolution GNSS data and information on water contents in rock glacier shear horizons is needed to improve our understanding of the role of water on rock glacier kinematics.

Our contribution highlights an innovative combination of borehole data to gain insight into an alpine rock glacier's ground temperature and water content, allowing us to detect relative changes in ice/water content in ice-rich permafrost.