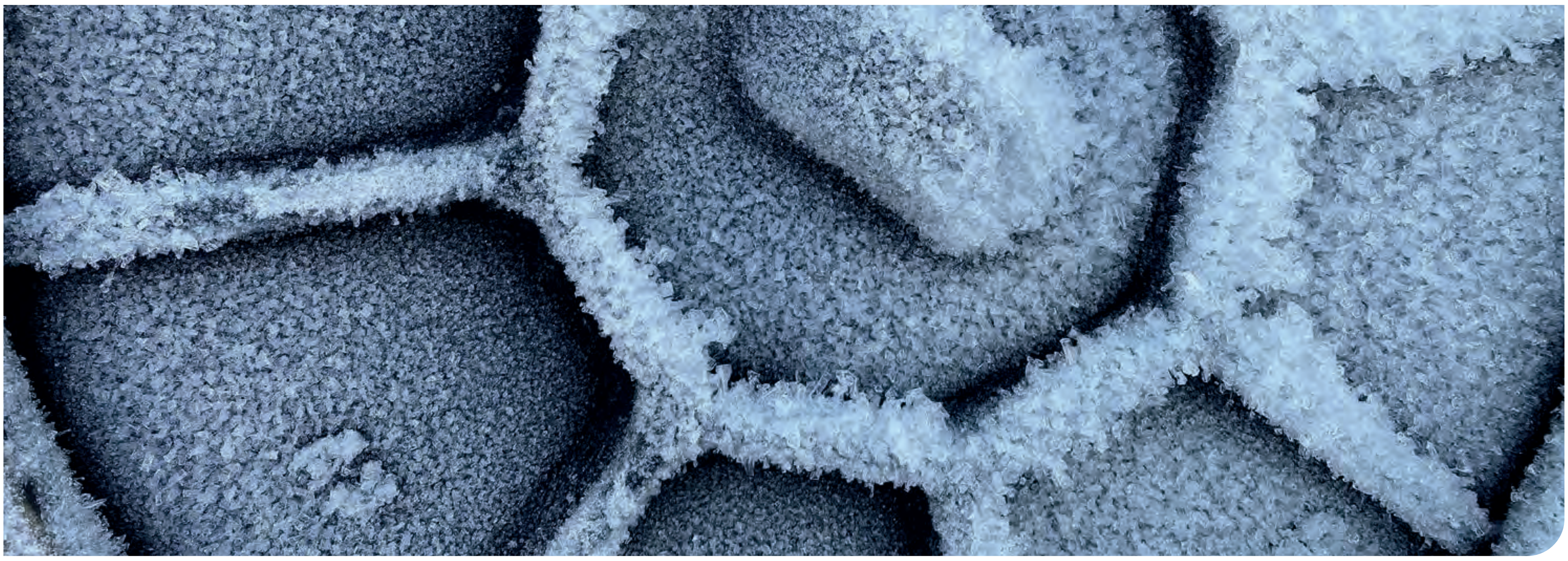
MEASURING MOUNTAIN PERMAFROST USING BOREHOLE PIEZOMETER DATA



Up until now, researchers have not been able to research seasonal changes in ice-rich mountain permafrost, or have only been able to do so in imprecise terms. The Schafberg rock glacier in the eastern Swiss Alps is being monitored to a depth of 12 metres using a new combination of borehole temperature, borehole piezometer and cross-borehole electrical resistivity tomography (ERT) data in order to give researchers a better understanding of accelerating rock glacier kinematics and future water availability.

An acceleration of ice-rich rock glaciers is being recorded in the Alps, caused by global warming and increasing water content. This widespread acceleration increases the likelihood of mass movements, such as debris flows.

At the moment, there is little information available about the internal hydrology of rock glaciers, whilst borehole temperature data does not enable a differentiation between ice and water. Many Alpine rock glaciers are close to their melting points. Depending on the soil properties, salinity and pore-water pressure, then, a substantial unfrozen water content can persist well below 0°C. Although pore-water pressure is routinely monitored in other environments, up until this point no piezometer data has been obtained in ice-rich mountain permafrost. Now the WSL Institute for Snow and Avalanche Research SLF can present the first data snapshots resulting from a novel combination of borehole temperature, borehole piezometer and cross-borehole electrical resistivity tomography (ERT) measurements. This new method is designed to investigate changes occurring in ice-rich rock glaciers - particularly changes in the ice-to-water ratio - through continuous measurements.

Two KELLER ARC-1 boxes and 4G data loggers, wich contain a barometer.

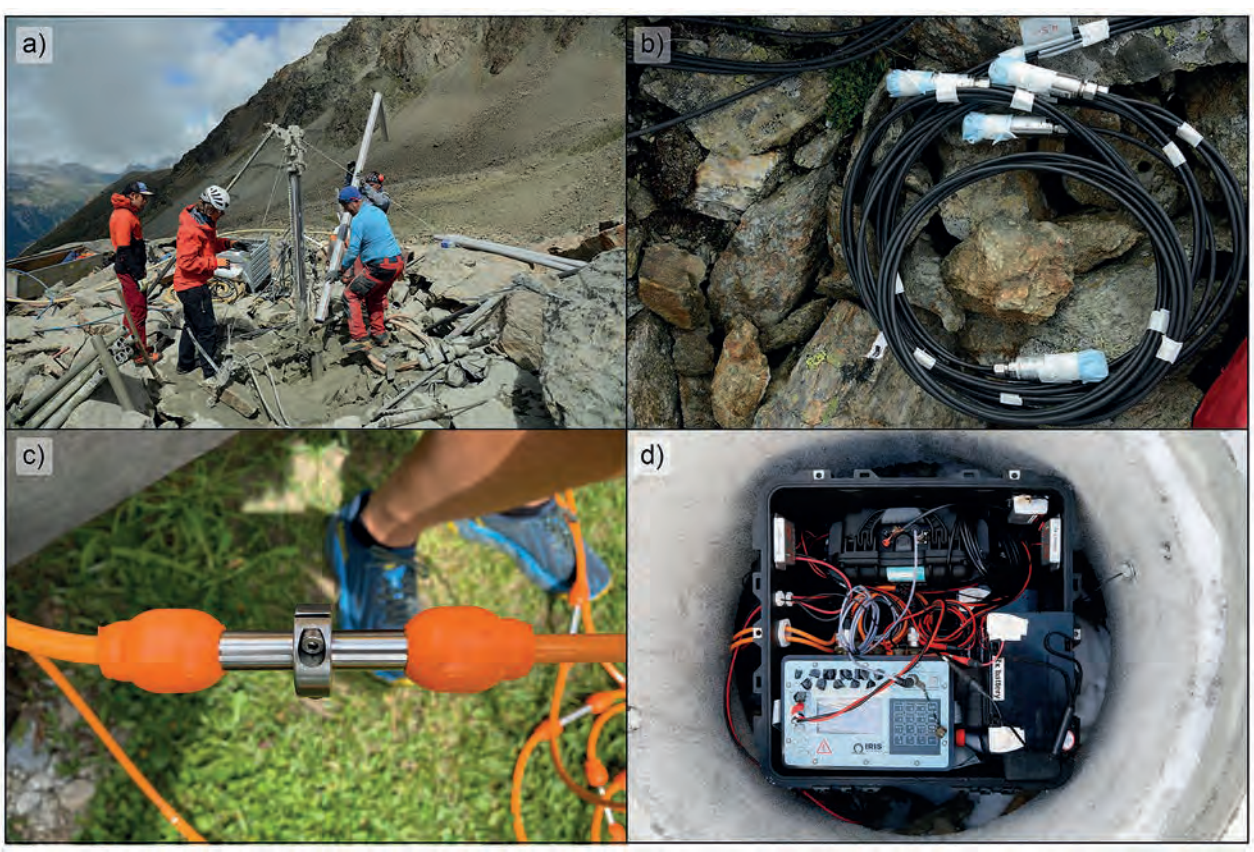


Figure (a) Drill and protective PVC pipe used to drill boreholes B3, B4 and B5 on Schafberg rock glacier in August 2020. (b) Piezometer and temperature sensors ready to be installed in B5. (c) Stainless steel ring mounted on the cross-borehole ERT electrode to improve contact with the ground. (d) Cross-borehole ERT logging system for B3 and B4 in a concrete chamber.

Location and methods

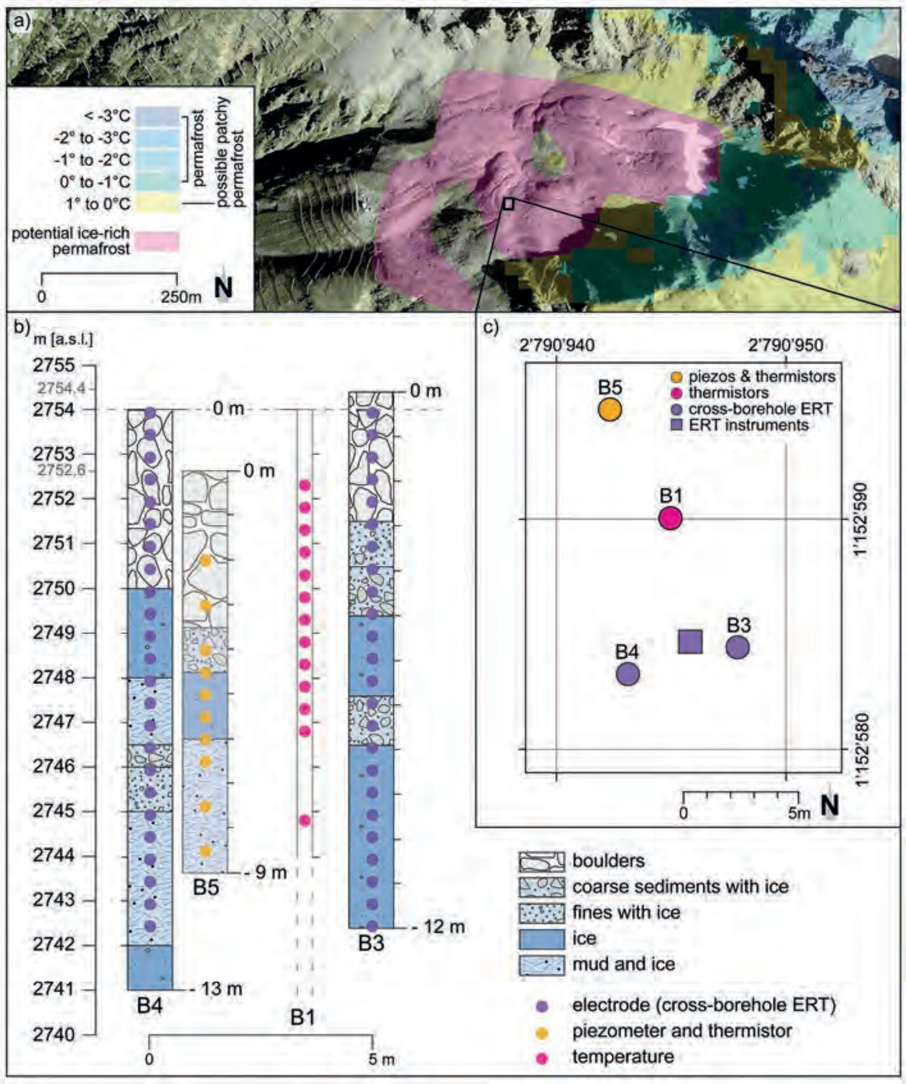
The measurement site is located on the ice-rich Schafberg rock glacier, 2750 m above sea level and above Pontresina in the Engadine in the eastern Swiss Alps. In August 2020, three additional vertical bores were drilled into the existing temperature sensor bore, allowing the new sensors to be inserted. The boreholes were filled with a sand-gravel mixture in order to establish contact between the sensors and the borehole walls, and to minimise air circulation. At ground surface level, the boreholes and instrument boxes are protected by concrete chambers with iron lids.

Borehole B5 is located 10 m north-west of B3 and was equipped with 10 KELLER PAA-36iW piezometers. The piezometer data indicate the development over time of the effective pressure as measured at the sensor diaphragm (measured relative to a vacuum; pressure range 60-230 kPa, accuracy ±1.7 kPa), combined with 10 PT1000 temperature sensors (accuracy ±0.1°C) between 2.0 and 8.5 m in depth. To protect against glaciation, the sensors were coated with Vaseline and wrapped in a thin material (Fig. b). They are connected to two KELLER ARC-1 boxes and 4G data loggers, which contain a barometer. Data is collected hourly and transmitted to a cloud-based data platform daily via a mobile phone network.

First results

The multi-method approach presented here is an innovative combination of techniques for ice-rich rock glaciers and has delivered some encouraging initial results.

The temperature data collected from boreholes B1 and B5 are almost identical in summer; however, they differ significantly in winter in the active layer, which indicates local differences in



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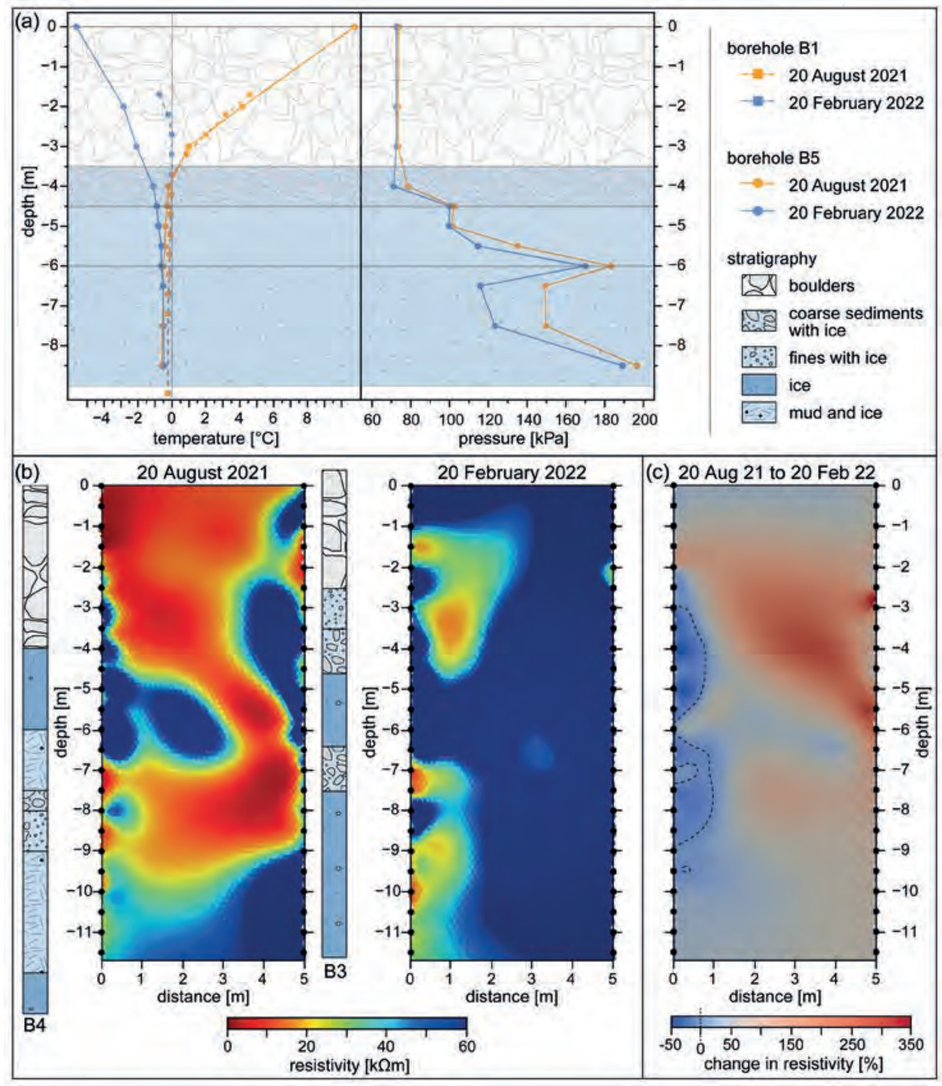

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moisture content. Below a depth of 4.5 m, ground temperatures throughout the whole year are close to 0°C, making it difficult to decipher fluctuations in the ice and/or water content using thermal data. As such, continuous, cross-borehole ERT data provides useful additional information. The data illustrate vertical and lateral changes in resistivity, which enables us to identify phase changes in the active layer, as well as variations in the ice and/or water content in the permafrost lying beneath.

In the wet sludge layers that contain ice crystals, only low levels of seasonal variation in resistivity are registered. This is likely to be due to latent heat effects. These layers confirm that mountain permafrost can contain a substantial proportion of unfrozen water. The highest seasonal changes in electrical resistance are observed in ice-rich sediments.

The piezometer data indicate the presence of air, water or ice, and register seasonal pressure fluctuations in wet layers. All data collected highlight the heterogeneous and seasonally fluctuating nature of the substrate, as also shown in the various borehole stratigraphies.

Future findings

Future analyses will indicate daily, but also medium to long-term interannual and interseasonal changes in rock glacier water content, which will be correlated with meteorological variables. This information will contribute towards closing the gap in terms of directly quantifying the water content of rock glaciers and achieving a better understanding of the effects of climate change. The innovative combination of methods presented here will provide valuable insights into the local substrate characteristics of rock glaciers and, with that, contribute to our understanding of the factors that determine the acceleration of the kinematics of rock glaciers and the future water availability from these land forms.

Acknowledgement

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