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3D Spectral Induced Polarization survey to evaluate a thawing permafrost endangered hut in the Italian Alps

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Due to generally rising air temperatures in the European Alps in context of climate change, large areas of mountain permafrost are thawing, and subsurface pore ice is melting. Consequently, the cohesion of rock masses decreases which can constitute a threat for infrastructure like mountain huts in alpine areas. One directly affected building is the Guide Val d'Ayas al Lambronecca, a hut on a rock ledge in the Italian Alps at 3400 m above sea level. During the last decade the ground directly underneath the hut sank of about 2 m, probably due to the melting of pore ice in the subsurface below the hut. In this study, we investigate the subsurface properties beneath the hut using a 3D geophysical survey. In particular, we deploy the spectral induced polarization (SIP) method, which has emerged as a promising tool to discriminate between ice-rich and ice-poor regions in the subsurface. Our investigation is built on the hypothesis that ice can be identified in electrical images due to its high electrical resistivity and polarization (i.e., capacitive) properties at frequencies above 10 Hz. In our survey, we conducted 2D SIP measurements in summer 2020 (between 0.5 and 225 Hz) along three profiles near the hut, while real 3D SIP measurements (in the range between 1 and 240 Hz) were conducted in summer 2021. For the 3D measurements, we deployed two parallel lines, one on the southern and one on the northern rock wall of the summit where the hut is located. To improve the data quality, we used coaxial cables for the 2D measurements in 2020, while data collected in 2021 were based on the actual separation of the transmitter and receiver (i.e., instrument and cables) to reduce the contamination of the data due to parasitic electromagnetic fields. Processing of the data was based on the statistical analysis of normal and reciprocal misfits. Inversion of the data was performed in 3D using ResIPy which uses complex calculus to simultaneously resolve for the conductive and capacitive properties. Our imaging results evidence a core of ice-filled pores corresponding to high resistivity values (>10 kΩm) directly underneath the hut, this structure is overlain by lower values (<1 kΩm) in near-surface areas representing the active layer. Images of the polarization effect confirm an anomaly due to high values at frequencies above 10 Hz in the center of the rock ledge. Our study demonstrates that 3D SIP measurements can be used to differentiate between ice-rich and ice-poor areas in high mountain permafrost sites with complex topography. Moreover, 3D SIP approaches enable a detection of electrical anomalies in all three dimensions and not only along

one certain direction in the case of 2D profiles. This information can be used to assess the impact of permafrost degradation on infrastructure stability in mountain regions and to support restoration actions.