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Prospecting alpine permafrost with Spectral Induced Polarization in different geomorphological landforms

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Permafrost regions are highly sensitive to climate changes, which has significant implications for the hydrological regimes and the mechanical state of the subsurface leading to natural hazards such as rock slope failures. Therefore, a better understanding of the future evolution and dynamics of mountain permafrost is highly relevant and monitoring of the thermal state of permafrost has become an essential task in the European Alps. Geophysical methods have emerged as well-suited to support borehole data and investigate the spatial distribution and temporal changes of temperature and the degradation of permafrost. In particular, electrical resistivity tomography (ERT) has developed into a routine imaging tool for the quantification of ice-rich permafrost, commonly associated with a significant increase in the electrical resistivity. However, in many cases, the interpretation of the subsurface electrical resistivity is ambiguous and additional information would improve the quantification of the ice content within the subsurface. Theoretical and laboratory studies have suggested that ice exhibits a characteristic induced electrical polarization response. Our results from an extensive field programme including many morphologically different mountain permafrost sites now indicate that this IP response may indeed be detected in the field suggesting the potential of the Induced Polarization (IP) method to overcome such ambiguities. We present here Spectral IP (SIP) mapping results conducted over a broad range of frequencies (0.1-225 Hz) at four representative permafrost sites of the Swiss-, Italian- and Austrian Alps. The mapping results have been used to install long-term permafrost monitoring arrays for a better understanding of subsurface variations associated to climate change. All SIP study sites are located at elevations around 2600 - 3000 m and include comprehensive geophysical and temperature data for validation. We focus on the spatial characterization of each site to address different research questions: to (i) reproduce and improve the mapping of the spatial permafrost extent inferred from previous investigations in the Lapires talus slope,Western Swiss Alps, to (ii) improve the geophysical characterization of the Sonnblick monitoring site located in the Austrian Central Alps, to (iii) determine the transition between permafrost and non-permafrost at the Schilthorn site, Bernese Alps, Switzerland, and to (iv) find the best-suited location for a SIP monitoring profile and conduct year-round measurements at the Cime Bianche site, Western Italian Alps. Our various field applications demonstrate the potential of the IP method for characterizing and monitoring permafrost systems in high-mountain environments.