20 years of mountain permafrost monitoring in the Swiss Alps: key results and major challenges

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Permafrost is a widespread thermal subsurface phenomenon in polar and high mountain regions and was defined as an essential climatic variable (ECV) by the Global Climate Observing System (GCOS). The Swiss Permafrost Monitoring Network was started in the year 2000 as an unconsolidated network of sites from research projects and as the first national long-term observation network for permafrost it is an early component of the Global Terrestrial Network for Permafrost (GTN-P). After 20 years of operation, development and evaluation, PERMOS holds the largest and most diverse collection of mountain permafrost data worldwide and has a role model regarding its structure and organization. PERMOS aims at the systematic long-term documentation of the state and changes of mountain permafrost in the Swiss Alps. The scientific monitoring strategy is now based on three observation elements: ground-surface and subsurface temperatures, changes in subsurface ice content, and permafrost creep velocities. These three elements complement each other in a landform-based approach to capture the influence of the topography as well as the surface and subsurface conditions of different landforms on the ground thermal regime. These influences are considered to be more relevant than regional climatic conditions in the small country.

Over the past 20 years, all observation elements indicate a clear warming trend of mountain permafrost in the Swiss Alps. Borehole temperatures generally increase at 10 and 20 m depth. This warming trend was intensified after 2009 and temporarily interrupted following winters with a thin and late snow cover, particularly winter 2016. Further, the trend is more pronounced at cold permafrost sites like rock glacier Murtèl-Corvatsch, where an increase of +0.5°C has been observed at 20 m over the past 30 years. For permafrost temperatures close to 0 °C, climate warming does not result in significant temperature increase but is masked by phase changes and latent heat effects. These result in significant changes in ice content, which can be registered by electrical resistivity tomography (ERT). Further, the warming trend of mountain permafrost in the Swiss Alps is corroborated by increasing creep rates of rock glaciers, which follow an exponential relationship with ground temperatures. In this contribution, we present and discuss the key results from two decades of mountain permafrost monitoring within the PERMOS network. In addition to the measurement data, we identified considerable challenges for long-term monitoring network of mountain permafrost based on experience collected over two decades. The acquisition of reliable data at a limited number of stations in extreme environments with difficult access...
requires robust strategies, standards and traceability for the entire data acquisition chain: installation > measurement > raw data > processing > archiving and, finally, reporting.