In recent decades, permafrost has warmed up in Switzerland. Numerous signs of degradation were observed, and most rock glaciers are moving faster. This is shown by long-term measurements of the Swiss Permafrost Monitoring Network PERMOS. PERMOS was established in 2000 as the world’s first national permafrost monitoring network and is now a recognized part of the international community. It provides the largest data collection on permafrost in mountain regions, with the longest time series covering more than 30 years.

The period 2000–2019 was marked by numerous extreme weather situations, such as the hot summers of 2003, 2015, 2017, 2018 and 2019 or the extremely snow poor winter of 2016/2017. Above all, these were the two decades with the highest air temperatures ever measured in Switzerland. The five warmest years were all recorded after 2010.

More water, less ice
During the same period, the high air temperatures also led to significant changes in permafrost in the Swiss Alps: Permafrost temperatures measured in boreholes increased at all 15 observation sites. The 32-year-old and longest series of measurements from Corvatsch-Murtel in the Upper Engadine shows that the permafrost warmed up by about 1 degree Celsius at a depth of 10 metres and by about 0.5 degree Celsius at 20 metres depth since the beginning of the measurements. The active layer – the layer that experiences positive temperatures in summer – also became several metres deeper at the borehole locations. In addition, the water content in the permafrost increased significantly.

Rock glaciers creep faster
The movement of the 15 surveyed rock glaciers (debris masses consisting of boulders and ice creeping down the valley) accelerated considerably. Their speed is now in the order of several metres per year – compared to several decimetres per year at the beginning of the measurements in the 1990s. The trend has increased over the last 10 years, although the general trend has been interrupted by temporary fluctuations at some measurement sites. For example, the winter 2016/2017 with little snow led to a short-term cooling down to greater depths, as the ground was able to cool down without the insulating snow cover.

Close to the surface, the annual average temperatures have remained above 0 degrees Celsius at most locations over the last 10 years. This means that the permafrost of the Alps is not in balance with the current climatic conditions. This imbalance is also reflected in a warming of the permafrost that is smaller than the increase in air temperatures over the same period. This indicates that the trend observed today will continue for a long time and to large depths.
**Warming patterns and better process understanding**

In addition to the trends observed, the data analyses of the past 20 years also show clear spatial patterns in the long-term development of permafrost in the high mountains of Switzerland. The cold permafrost in the highest peaks, where permanent ice is only found in rock pores and fissures, is currently warming the fastest. In the ice-rich talus slopes, which covers largest parts of the permafrost and where the permafrost temperatures are only slightly below the melting point – the temperatures change only slightly. This is due to the large amount of energy required to melt the ice. Nevertheless, the ground ice content has continuously decreased and the unfrozen water content has increased.

The measurements show that the snow conditions are important. For example, they can interrupt the warming trend for a short period of time, even at large depths. Heat waves lasting several days or weeks have only a limited effect in this case. Finally, the measurements show that changes in the creep velocity of rock glaciers generally follow the development of permafrost temperatures and unfrozen water content. This is true even if the warming trend is interrupted by snow poor winters.

Observations and knowledge about permafrost in high mountains are of great importance for the management of mountain areas with regard to natural hazards, infrastructure and land use. However, in view of the rapid evolution of permafrost, many changes are still to come. PERMOS is committed to continue collecting, interpreting and communicating the best possible data also for the next 20 years.

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**Swiss Permafrost Monitoring Network (PERMOS)**

PERMOS celebrates its 20th anniversary this year. It is financed by MeteoSwiss within the framework of GCOS Switzerland, the Swiss Federal Office for the Environment and the Swiss Academy of Sciences and is carried by six Swiss research institutions: Universities of Lausanne, Fribourg and Zurich, ETH Zurich, SUPSI University of Applied Sciences Southern Switzerland and the WSL Institute for Snow and Avalanche Research SLF.

To document the state and changes of permafrost in the Swiss Alps, temperatures near the surface and at depth are measured, changes in ground ice content are determined and the creep velocity of rock glaciers is observed.

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