Dynamics of the Aget back-creeping push-moraine from 1998 to 2017

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Abstract

Electrical resistivity measurements, which were carried out in 1998 to understand the impact of the advance of a small cirque glacier during the Little Ice Age (LIA) on pre-existing frozen debris, allowed to evidence the frozen state of an active back-creeping push-moraine, morphologically similar to an active rock glacier. These measurements were repeated in 2017 to assess the evolution of permafrost and ground ice in the push-moraine and its immediate surroundings. In combination with respectively 20-year and 15-year time series of surface temperature and displacement, data comparison indicates an overall permafrost degradation, which corroborates with the decelerating trend of the push-moraine kinematics and some local subsidence.

Keywords: permafrost, ground ice, push-moraine, glacier forefield, evolution, electrical resistivity

Introduction

In the Alps, the shrinkage of small glaciers since the Little Ice Age (LIA) has often occurred in areas located within the belt of discontinuous permafrost, that is above about 2500 m a.s.l. Permafrost conditions and ground ice – interstitial ice or buried glacier ice – are commonly encountered in the margins of these deglaciated areas, whereas they are often absent in the central zones. Such distribution dominantly reflects both thermal (e.g. warming in case of temperate-based glacier) and mechanical (e.g. build-up of push-moraines) impacts of the LIA glacier advance (Delaloye, 2004; Bosson *et al.*, 2014).

As a consequence of the glacier retreat, the heat fluxes between the ground surface and the atmosphere are more direct and ground cooling may have been expected to occur where the former glacier was temperate-based. Nevertheless, the recent 30-year strong increase in air temperature could have counterbalanced this cooling effect. Morphodynamic readjustments such as the back-creeping of formerly displaced frozen sediments (push-moraines) or the development of subsidence features (thermokarst) driven by ice melt at depth are likely to occur.

The study site and previous works

The LIA Aget glacier forefield (46°00'32" N, 7°14'20" E, western Swiss Alps) extends north-east of the Grand Aget summit from about 3000 m down to 2760 m a.s.l. (Fig. 1). The morphology of its orographic left side suggests the occurrence of an active back-creeping push-moraine whose ice content was investigated by means of geoelectrical measurements in 1998 (Reynard *et al.*, 2003). Ground ice was found in the active zone at larger depth (Ag-S06, Ag-S08), as well as in its margins (Ag-S07, Ag-S09), but not elsewhere (Ag-S03, Ag-S04). Surface temperature and surface displacement have been monitored since 1998 and 2001 respectively.

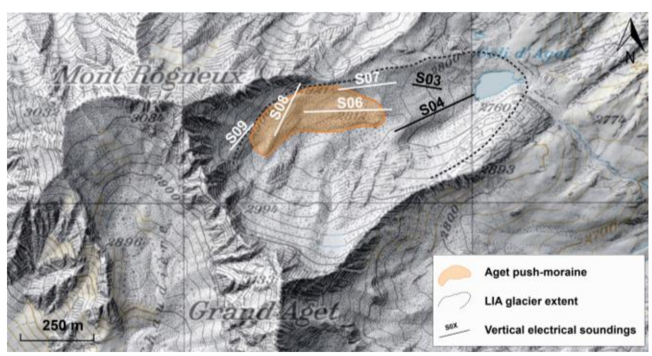

Figure 1: Location of the Aget active back-creeping push-moraine within the LIA glacier forefield and the repeated vertical electrical soundings (white: permafrost; black: no permafrost) (basemap Swisstopo).

Over the past 20 years, the mean annual ground surface temperature (MAGST) was +0.6°C, increasing by 0.15°C per decade, essentially due to warmer summers (Fig. 2). Both the high MAGST value and the temperature rise have supposedly contributed to a thermal degradation of permafrost during that time.

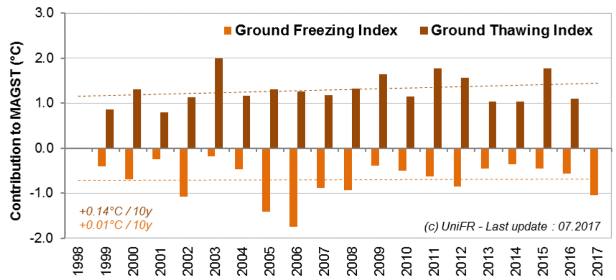

Figure 2: Contribution of the ground thawing and freezing index to the MAGST on the Aget push-moraine (mean on 7 monitoring stations).

For the last decade, displacement velocities have decreased compared to the regional trend: in particular the 2012-16 peak activity was not observed on the push-moraine in contrast with the 2003-04 event (Fig. 3). This behaviour suggests an ongoing permafrost degradation process. Therefore, electrical resistivity measurements, both the former vertical electrical soundings (VES) and resistivity mapping were repeated in 2017 to gain further insight on the driving factors contributing to the decelerating creep rate.

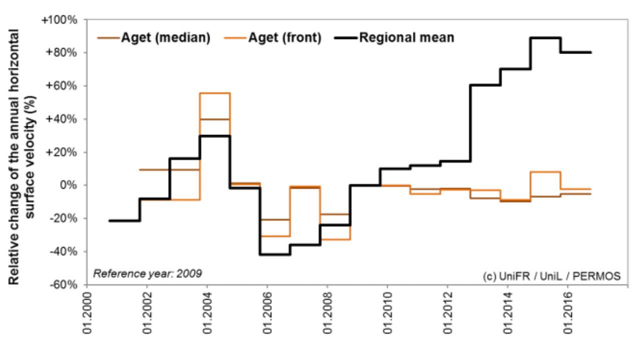

Figure 3: Relative change of the annual horizontal surface velocity (%) of the Aget push-moraine in comparison to the regional mean behaviour of active rock glaciers (n = 3-8 depending on year).

Repetition of geoelectrical measurements

VES repetition has successfully provided similar structures in 1998 and 2017 on all permafrost sites, but a significant decrease of the maximal apparent resistivity has been systematically observed (Fig. 4). On the actively back-creeping part of the push-moraine (Ag-S06 and Ag-S08) the active layer has deepened from about 5 to 7 m and the specific resistivity of the underlying frozen layer has decreased from approximately 60-70 to 40-60 kΩm. The section of the push-moraine, which is not moving, has subsided 1.9 m since 2001, reflecting a significant melt of underlying ground ice, which is accordance with the dramatic decrease in resistivity (from 30 to 10 kΩm) of the (shallower) frozen layer observed in Ag-S07. The maximal subsidence occurred in the hot summer 2003 (-27 cm), but vertical displacement has tended to diminish in the recent past.

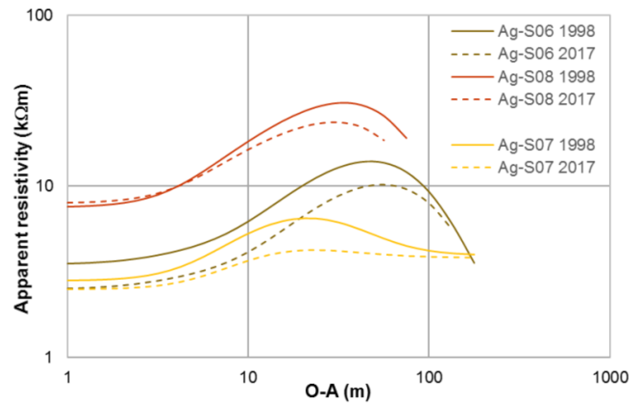

Figure 4: Modelled apparent resistivity in 1998 and 2017.

Preliminary statements

The comparative analysis of electrical resistivity values asserts a 20-year degradation of permafrost, which could explain the decelerating behaviour of the push-moraine. However, this relationship is discussable as lower resistivity means higher relative water content favouring faster creep rates. Conversely the deepening of the active layer has supposedly reduced the water column within the frozen ground above the shear horizon, contributing to lower the creep rate.

Permafrost degradation has also been observed between 1998 and 2017 in the Creux de la Lé (Sanetsch) glacier forefield, another investigated LIA glacier forefield distant of 50 km (ongoing research work), confirming the observations made at Aget.

References

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