Rock glacier creep as a thermally-driven phenomenon: A decade of inter-annual observations from the Swiss Alps

Benno Staub[1], Christophe Lambiel[2], & Reynald Delaloye[1]

[1]*Department of Geosciences, Geography, University of Fribourg, Fribourg, Switzerland*
[2]*Institute of Earth Surface Dynamics, University of Lausanne, Lausanne, Switzerland*

Many rock glaciers observed in the Alps show similar and synchronous relative inter-annual variations of surface velocities [Delaloye et al., 2008]. A common thermo-hydro-mechanical reaction to changes of the surface energy balance, mainly influenced by air temperature and the seasonal snow cover, is the most likely explanation for this phenomenon. To test the hypothesis of rock glacier creep rate variations being mainly a kinematic response to changes in ground temperature (GT), we analysed annual GPS data measured on 6 rock glaciers in the western and central Swiss Alps. The GPS data used for this study comprises about 200 surveying points followed over at least 10 years and covers both periods of velocity decrease between 2004 and 2006 and velocity increase since then. At most sites, new maxima were measured in the last one to three years surpassing prior velocity peaks of 2003 and 2004.

Based primarily on findings from Arenson et al. [2002] and Kannan and Rajagopal [2013] the displacement monitored at the ground surface is assumed to result mainly from deformation occurring in rather thin layer(s) of minimal viscosity within the permafrost at 10 to 30 m depth. But since the maintenance of boreholes is almost unfeasible for time periods longer than a few months to maximally a few years on fast moving landforms, active rock glaciers are usually lacking of GT time series measured within the permafrost and only ground surface temperature (GST) data are available. GST data have been used to characterise variations of the ground thermal state. Ground thermal state anomalies (GTSA) were arbitrary defined as average monthly GST anomalies over a specific time window and were validated using GT data measured in boreholes. The highest covariance between GTSA and GT data measured at 15 m depth was achieved with GST time windows of a length of ≈2 years and a delay of 2–6 months.

The relationship between relative variations of annual rock glacier velocities and GTSA has been systematically tested. A statistically significant solution was found for an ensemble of GPS points on each rock glacier or rock glacier zone in the form of an exponential regression function, as illustrated in Fig. 1 for the example of the Becs-de-Bosson rock glacier from the Valais Alps.

The comparison of different GPS points with GTSA time series clearly indicated that, within a decade, temperature changes at 10–30 m depth explain the largest part of inter-annual velocity variations. In addition, analysing the time series of the velocity residuals (namely the changes in velocity, which are not explained by the temperature function) may allow to evidence additional pluri-annual acceleration/deceleration trends. Such additional trends represent an alteration of the temperature/creep rate relationship with time as the 2010-2015 deceleration trend observed for the Aget rock glacier and could be caused for instance by the gradual change of the rock glacier geometry, a change of melt water infiltration rate at depth, or ice melt/aggradation and consecutive changing friction at the shear horizon.

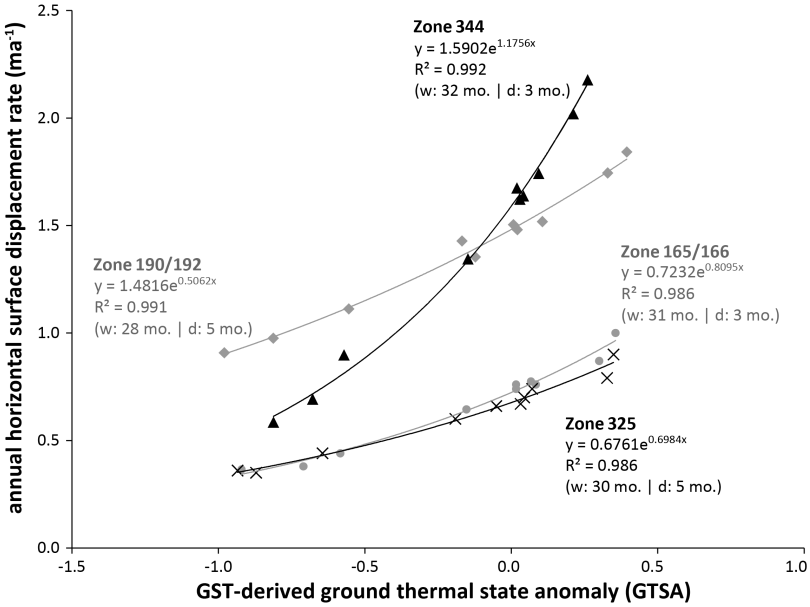

Figure 1: The influence of the ground thermal state on mean annual permafrost creep velocities illustrated using GPS and ground surface temperature (GST) monitoring data from the Becs-de-Bosson rock glacier in the Valais Alps measured between 2004 and 2014

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