Seasonal variations of rock glacier creep: time series observations from the Western Swiss Alps

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The observed velocity of active rock glaciers, as well as other permafrost-related creep features (landslides), is changing from year to year in a relatively homogeneous and simultaneous way at the regional scale. The inter-annual changes may be large, exceeding sometimes 50 % of acceleration or deceleration in one year. They are often well congruent to changes in temperature of the creeping frozen ground particularly at the depth of the main shear horizon (> 15 m depth), except when a destabilization phase (dramatic change of velocity, opening of crevasses and/or scars) is occurring. Seasonal (intra-annual) variations of rock glacier surface velocity have also been observed and so far mainly attributed to the influence of hydrological (changing water content and/or pore pressure by snow melt or rain periods) and/or thermal factors (delayed response to seasonal changes of the ground surface temperature). This poster contribution aims at presenting and discussing results on the seasonal rhythm of creeping permafrost landforms based on observational data from the Western Swiss Alps.

Annual surface displacement rates have been measured by our group on about 30 active rock glaciers in the Swiss Alps for various monitoring purposes and since the early 2000s for the longest time series. On 8 rock glaciers, which are located in the Valais Alps (western Swiss Alps) and were moving between about 1 and 20 ma^{-1} in 2014/15, we dispose now of monitoring data which can be used to document and discuss seasonal variations of displacement rates. Considered seasonal time series are 2 to 10 years long, comprising at least 6 positions per year. They consist of either real-time kinematics GNSS measurements (10-year time series of the Becs-de-Bosson/Réchy rock glacier, 80 points surveyed 6 – 8 times per year), total station measurements (6-year time series for one point on the destabilized Grabengufer rock glacier) or permanent mono-frequency GNSS time series of hourly to monthly resolution depending on the site and the year (rock glaciers Becs-de-Bosson/Réchy, Tsavolires, Tsarmine, Gugla/Bielzug, Péterey, Tracuit, Jegi, Gruben). We investigate here the patterns (annual amplitude, type and time of changes, inter-annual regularities) of the seasonal variations of the observed velocities in order to detect possible responsible processes, especially a potential influence of the snow melt in early summer.

We can state on the basis of our observations that seasonal variations are occurring on all monitored rock glaciers. The seasonal velocity pattern roughly resembles a sinusoidal curve and is characteristic for each rock glacier or even for each rock glacier part. On all rock glaciers velocity minima were reached every year at the end of the winter (April-May) and acceleration occurred then during the snow melt season, with an onset between the end of April and the end of May (Fig. 1). The spring acceleration differed notably from a rock glacier to another, but not essentially from a year to the next one. It was either rapid and strong, or of medium intensity, or gentle. Moreover, the character of the spring acceleration did apparently not depend on the rock glacier velocity level. On most rock glaciers, velocity maxima were observed every year in autumn or early winter (September-December) and followed by a deceleration phase, which was often but not systematically stronger in the second half of the winter. The transition between the spring acceleration and the velocity maximum in autumn/early winter showed a large diversity among the different rock glaciers (Fig. 1). Some rock glaciers underwent an interim stagnation (e.g. Tsarmine) or deceleration (e.g. Becs-de-Bosson) in mid-summer after the snow melt period, whereas the velocities of other rock glaciers increased continuously until November (e.g. Grabengufer).

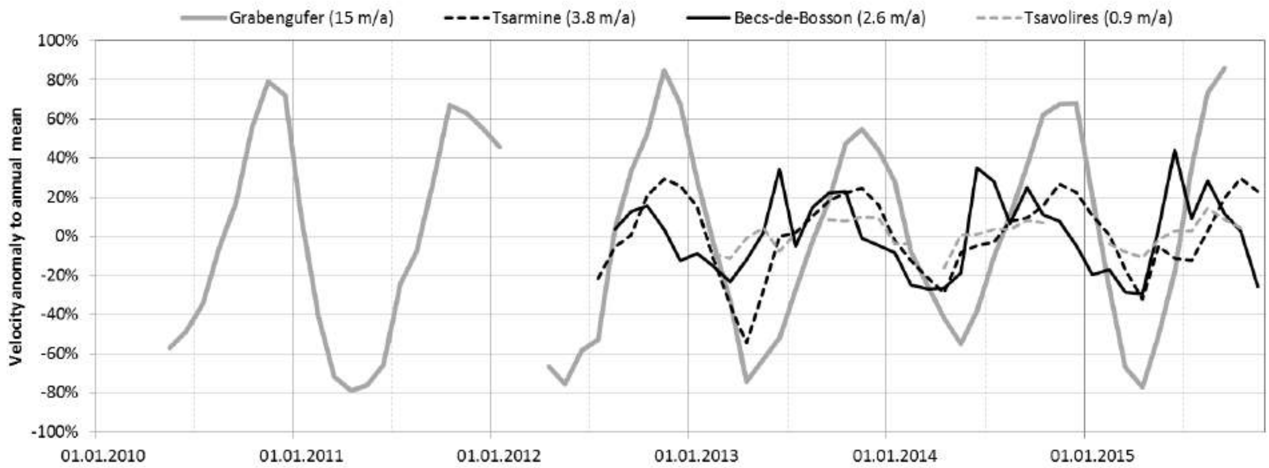

Figure 1: Various types of year-round surface velocity anomalies behavior observed at 4 rock glaciers in the Western Swiss Alps. Illustrated values are anomalies of the monthly velocity relative to the annual mean.

The behavior of the seasonal variations relatively to the annual mean velocity stayed almost similar over the years (rhythmic behavior), whereas the annual velocity amplitude varied strongly depending on the rock glacier (Fig. 1). The largest seasonal variations were observed on the extraordinary rapid Grabengufer rock glacier (1 : 9 ratio between minimal and maximal monthly values) and the smallest on the Tsavolires rock glacier (1 : 1.2). The longest time series measured on the Becs-de-Bosson rock glacier also showed that the intensity (amplitude) of the deceleration in winter time was depending on the intensity of the winter ground surface cooling (ground freezing index) and was usually following the behavior of the monthly mean surface temperature with a delay of 2 – 3 months.

The temporal regularity of the seasonal variations implies that the processes which control the kinematic behavior of the rock glaciers did not significantly change over the years, even though absolute creep velocities are in 2015 by factors (1.5 – 4) larger than during the slowest (and in the ground, coldest) period between 2005 and 2007. It appears that especially the wintertime may cause a significant inter-annual variability of the seasonal kinematic behavior, which nevertheless contributes only partly to observed changes in annual velocity. Significant summer acceleration phases have been occasionally observed on short term (a few hours to a few days, up to 30 cm total displacement) but only on steep, unstable and rapidly moving features. They were for most of them occurring in connection with strong rain events or intense snow melt phases and were obviously caused by the single movement of the boulder on which the GNSS device was installed or by movement affecting the active layer (or a part of it) in the surroundings. Significant behavior changes (from year to year) due to a possible influence of water (snow melt phase, rain events) have not been observed. Therefore, inter-annual variations in the water input during the summertime (including the snow melt phase) have not contributed significantly to the changes in annual velocities observed during the period of investigation.

In our point of view, two main questions are now rising up and require in-depth investigation:

1. the causes of the acceleration in spring, which are obviously connected to the snow melt, should be investigated at the process level;
2. the velocity maxima in late autumn/early winter and the effect of the ground cooling on the velocity decrease during winter time have to be explained.

For all these phenomena, seasonal temperature changes at the main shear horizon at > 15 m depth are certainly not the key controlling factor, because they may either not exist at all or occur with a timing which is different as those observed for the velocity changes.