Short-term variability of rock glacier surface velocities in the Swiss Alps revealed by continuous GPS

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In recent years, strong variations in the kinematics of rock glaciers have been detected, raising questions about the governing processes and hazard potential in a changing climate. Continuous differential L1-GPS measurements on permafrost slope movements have proved to be a suitable tool to study the intra-annual (short-term) variability of slope movements of rock glaciers (Wirz et al., 2015). Measurements with a high temporal resolution (e.g., daily measurements) allow to identify controlling factors on short-term velocity fluctuations, thus contributing to an improved process understanding of rock glacier movement and changes over time. Furthermore, continuous observations have the potential to detect relations between changes in the movement velocity observed and meteorological or snowpack factors.

We present continuous time series over three to five years of surface velocities of eleven GPS stations located on eight rock glaciers in different regions of the Swiss Alps. Each mobile GPS station consists of a low-cost single-frequency GPS receiver (u-blox LEA-6T) with active antenna (Trimble Bullet III) and a two-axis inclinometer (VTI SCA830-D07) allowing to detect the tilt of the GPS antenna mounted atop a boulder situated on each rock glacier (Wirz et al. 2013). In cases of multiple measurement points closely co-located on either the same or on adjacent rock glaciers, data is collected using a low-latency low-power wireless sensor network (Beutel et al., 2011). In the case of such online data the resulting data products are available in near real time, e.g. the daily positions and velocities used in this study are available every morning for each preceding day. For locations with offline data logging, data are collected annually and post-processed in batch mode. Where available, a local GPS reference mounted on a stable position adjacent to the rock glacier is used for differential processing of GPS data. The short baseline distance allows to reduce the position error considerably compared to the use of long baseline GPS reference data, e.g. from a national GNSS network.

Originating in an interdisciplinary research project (Wirz et al., 2013) the GPS sensor technology (Beutel et al., 2011) has been recently made available to partners on a national scale in the form of a pilot study of the Swiss Permafrost Monitoring Network (PERMOS) where further rock glaciers have been equipped with GPS-based continuous kinematic monitoring. To date the installed inventory includes the Dirruhorn, Steintälli, Grabengufer, Bielzug, Distelhorn, Ritigraben, Gruben, Jäggi (all Canton Valais, Switzerland), Schafberg, Muragl (both Canton Graubünden, Switzerland) and Largario (Canton Tessin, Switzerland) rock glaciers. The data obtained is accessible at http://data.permasense.ch. In the current study the signal-to-noise-thresholding method (SNRT, Wirz et al., 2014) is applied to obtain reliable velocity estimates based on daily GPS positions for the rock glacier inventory. Similarities and differences between the individual rock glaciers are qualitatively investigated in the following.

Average velocities between 0.2 and 6.6 m/a were observed (Fig. 1a). Most stations (eight stations) had average velocities between 0.3 and 2 m/a. Three stations moved at velocities exceeding 3.4 m/a. The observed amplitude of intra-annual variability at all stations ranged from 6 to more than 2000 % (Fig. 1b). For most stations it ranged between 30 and 90 %.

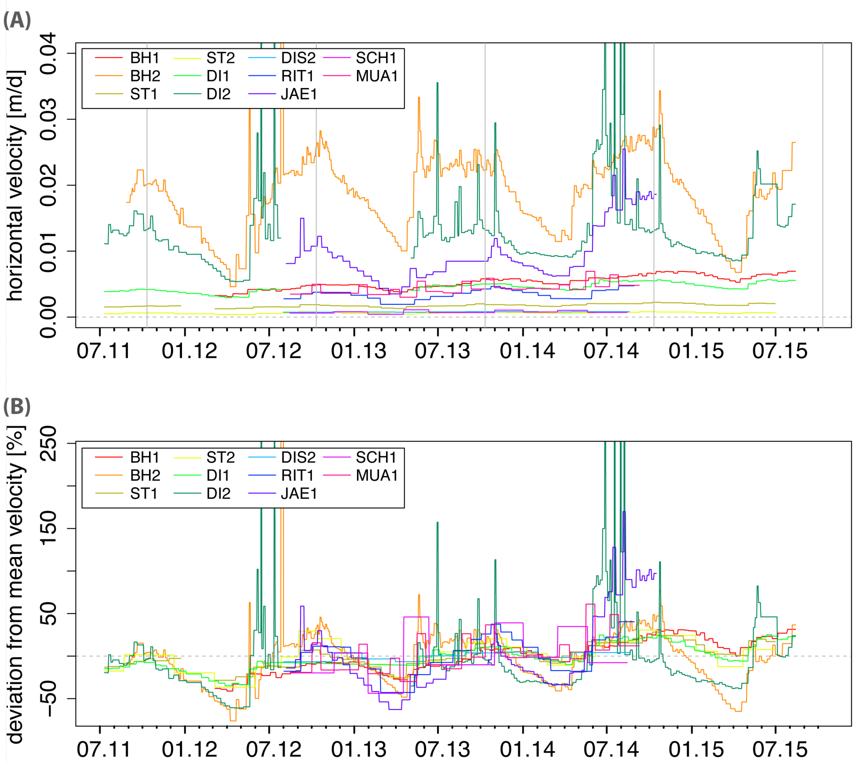

Figure 1: a) (top): Horizontal surface velocities of various rock glaciers in the Swiss Alps. Velocities were estimated based on daily GPS positions applying the SNRT method (with a threshold SNR-t of 40, Wirz et al., 2014). b) (bottom): Intra-annual variability of horizontal velocities, expressed as deviation from the corresponding average velocity. Vertical grey lines indicate individual hydrological years.

The continuous measurements with high temporal resolution revealed that all rock glaciers experience clear intra-annual variations in movement where the timing and the amplitude are rather similar between individual years (Fig. 1b). Where a seasonal cycle exists, seasonal maximum in velocities occurred between September and January, minimum in velocities between March and May. Despite these similarities also differences exists. For example, at three stations (DI2, BH2, JAE1) with velocities above 3 m/a, in addition to the seasonal cycle short-term peaks in velocity were observed. In the near future, the continuous GPS data will be compared to distributed velocity fields (with much coarser temporal resolution) as derived from remote sensing methods. Further, we will investigate the impacts of a) the geomorphological and topographical setting and of) the meteorological and snowpack factors on the observed kinematic variations.

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