Interannual variability of rock glacier flow velocities in the European Alps

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Abstract

The monitoring of surface flow velocities at active rock glaciers has a long tradition in the European Alps with first surveys in the 1920s. Since the 1990s annual to seasonal flow velocity monitoring activities have been substantially expanded and partly institutionalized. In this article, we present and compare annual rock glacier surface flow velocity data from 35 rock glaciers in Austria (6), France (1), Italy (2) and Switzerland (26) spanning a time period of up to two decades. Results indicate a strong correlation of relative interannual velocity changes attributed to climate forcing.

Keywords: rock glacier monitoring, surface flow velocity, climate forcing, long-term evolution

Introduction and context

Rock glaciers are widespread periglacial landforms in the European Alps as revealed by several inventories. Monitoring of surface flow velocities at active rock glaciers has a long tradition with first terrestrial photogrammetric surveys in the Swiss and Austrian Alps already in the 1920s (Krainer *et al.*, 2012).

Since the 1990s velocity monitoring activities have been substantially expanded but also institutionalized (e.g. Delaloye *et al.*, 2010). In many cases, kinematic monitoring is carried out jointly with meteorological, hydrological and temperature monitoring in order to better understand the rock glacier-climate relationships and the reaction of rock glacier behavior to climatic changes (e.g. Kellerer-Pirklbauer & Kaufmann, 2012).

In this short contribution, we compare the relative changes of the surface velocities measured at 35 rock glaciers with at least annually-repeated data in four different Alpine countries. Similarities and differences of the movement patterns at different sites are described, while the spatio-temporal pattern of the surface velocity is compared with the climate context. This joint research effort is based on multi-annual velocity data and is a continuation of an earlier activity (Delaloye *et al.*, 2008).

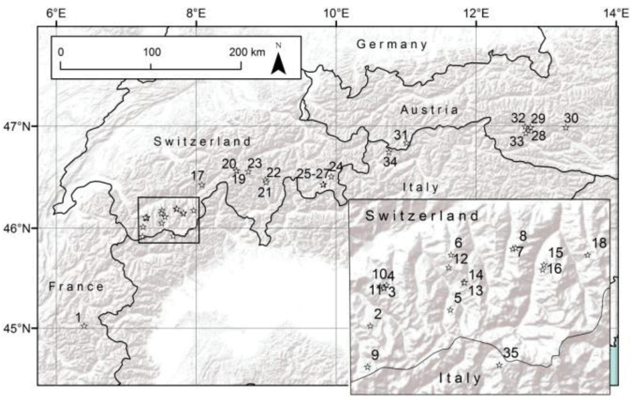

Figure 1. Location of the 35 rock glaciers in the European Alps where annual surface velocity data were used in this study. Inset map refers to S-Switzerland (numbers *cf.* Table 1).

Rock glacier monitoring sites

Table 1 lists the 35 rock glacier kinematic monitoring sites with some overview data. The sites cover a west-east distance of *c.*530 km and a north-south distance of *c.*220 km. Figure 1 depicts the monitoring locations.

Table 1. List of the rock glaciers relevant for this study

Nr.	Name	Nat.	Start	Inst.[1]	16/17[3]
1	Laurichard	FR	1984	8,9,13	115
2	Aget-Rogneux (median)	CH	2001	2	18
3	Yettes Condjà B	CH	2000	3	92
4	Yettes Condjà C	CH	2000	3	10
5	Tsarmine	CH	2004	2,3	429
6	Becs-de-Bosson / Réchy	CH	2004	2	114
7	HuHH1 / Hungerlitälli 1	CH	2001	4	91
8	HuHH3 / Hungerlitälli 3	CH	2002	4	166
9	Petit-Vélan	CH	2005	2	74
10	Lac des Vaux B	CH	2005	3	63
11	Lués Rares	CH	2006	3	36
12	Les Cliosses	CH	2006	3	25
13	Tsaté-Moiry 1	CH	2005	3	103
14	Tsaté-Moiry 2	CH	2005	3	96
15	Grosse Grabe	CH	2007	2	158
16	Gugla-Bielzug	CH	2007	2	249
17	Grosses Gufer	CH	2007	2	138
18	Gruben	CH	2012	2	81
19	Monte Prosa A	CH	2009	2	34
20	Monte Prosa B	CH	2009	2	14
21	Stabbio di Lagrario	CH	2008	6	32
22	Piancabella	CH	2008	6	16
23	Ganoni di Schenadüi	CH	2009	6	10
24	Muragl	CH	2009	4	119
25	Murtèl	CH	2009	4	14
26	Marmugnun	CH	2009	4	25
27	Chastelets	CH	2009	4	62
28	Weissenkar	AT	1997	5,1	10
29	Hinteres Langtalkar (low)	AT	1999	5,1	460
30	Dösen	AT	1995	5,1	43
31	Äußere Hochebenkar	AT	1938[2]	10	239
32	Tschadinhorn	AT	2014	5	177
33	Leibnitzkopf	AT	2010	5	321
34	Lazaun	IT	2006[2]	7,12	89
35	Gran Sometta	IT	2012	2,11	95

[1]Institutions according to the affiliation list; [2]with gaps; [3]mean annual horizontal flow velocity (cm/a) in 2016/17

Preliminary results

Rock glacier surface flow velocities in the European Alps have been relatively low in the 1980s-1990s. A first maximum was reached in 2003/04 followed by a drastic drop until *c.*2007/08. Since then, velocities increased again with new velocity maxima at most of the observed rock glaciers in 2015/16. The velocity maxima mentioned correlate with warm permafrost temperatures recorded in boreholes (e.g. PERMOS 2018) and are likely a result of the continuously warm conditions in the ground during the last years. The 35 rock glacier monitoring sites do not only differ substantially in location but also in elevation, topographical conditions and lithology. The surface velocity during the most recent monitoring year varied substantially between the rock glaciers with 10-460 cm/a (Table 1). The type of field measurement setup, the time of the measurements and the approach to calculate a "mean" annual surface velocity value differs also substantially between the sites. However, the relative change of the annual horizontal surface velocity (reference year 2016/17) shows high correlation between the sites (Figure 2).

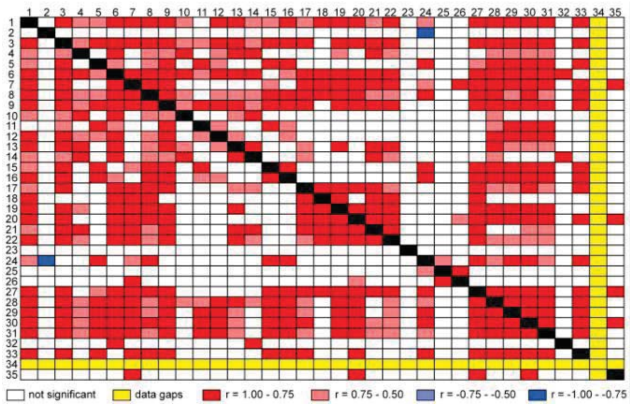

Figure 2. Correlation matrix for all 35 rock glaciers based on the relative change of the surface flow velocities (reference period 2016/17). Correlations: significant at the <0.05 level.

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