Recent Interannual Variations of Rock Glacier Creep in the European Alps

Reynald Delaloye, Eric Perruchoud
Department of Geosciences, Geography, University of Fribourg, Switzerland
Michael Avian, Viktor Kaufmann
Institute of Remote Sensing and Photogrammetry, Graz University of Technology, Austria
Xavier Bodin
Institute of Alpine Geography, Joseph Fourier University, Grenoble, France
Helmut Hausmann
Institute of Geodesy and Geophysics, Vienna University of Technology, Austria
Atsushi Ikeda
Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan
Andreas Kääb
Department of Geosciences, University of Oslo, Norway
Andreas Kellerer-Pirklbauer
Institute of Geography and Regional Science, University of Graz, Austria
Karl Krainer
Institute of Geology and Paleontology, University of Innsbruck, Austria
Christophe Lambiel
Institute of Geography, University of Lausanne, Switzerland
Dragan Mihajlovic, Benno Staub
Institute of Geography, University of Bern, Switzerland
Isabelle Roer
Department of Geography, University of Zurich, Switzerland
Emmanuel Thibert
Cemagref, Grenoble, France

Abstract

Recent interannual variations of rock glacier surface motion are compared for 16 landforms monitored for a few years in various parts of the European Alps. Large fluctuations have been observed particularly since 2002. Most investigated rock glaciers have shown a similar behavior whatever their location in the Alpine arc, their size, or their velocity. The observed interannual variations appear to be primarily related to external climatic factors rather than to internal characteristics. They are mostly well correlated with mean annual ground surface temperature shifts with a delay of a few months, reflecting the thermal wave propagation deeper into permafrost. Seasonal factors may also play a significant role: a lower intensity of winter ground freezing and/or a larger winter snow accumulation appear to facilitate a higher rate of rock glacier surface motion.

Keywords: creep; European Alps; interannual variations, rock glaciers; surface motion.

Introduction

Rock glaciers act as sediment conveyors in cold periglacial mountain environments. Where a rock glacier is perched on a steep valley side, it may be the source of slope instability processes (mainly rock falls and debris flows). Any change in the rate of permafrost creep may modify the delivery of loose materials at the rock glacier snout and affect the frequency, the magnitude, and even the type of related slope instabilities (e.g., Roer et al. 2008). In this context, and paying regard to the ongoing climate warming trend, there is an increasing request in the densely inhabited European Alps for precise and up-to-date data documenting the evolution of the high-altitude permafrost environment. In addition to the assessment of longer term (decadal to pluri-decadal) changes affecting rock glacier dynamics, which can be precisely determined by airborne photogrammetric analysis (Kääb et al. 2003), documentation of the short-term (interannual and even seasonal) variations is needed. Two decades after the pioneer work on the Gruben rock glacier (Haeberli 1985), the systematic survey of annual velocities was reinitiated a few years ago by several research teams by means of terrestrial measurements. This paper provides a first comparison of time series that have been measured since 1999/2000 or later on a sample of 16 rock glaciers located in six regions of the Alpine arc.

Background

Mostly located in the lower half of the mountain discontinuous permafrost belt, Alpine rock glaciers are rather warm. They may move relatively fast and are highly sensitive to small temperature changes (Kääb et al. 2007).

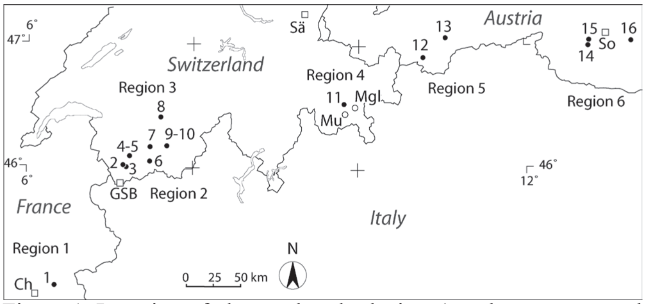

Figure 1. Location of observed rock glaciers (numbers correspond to Table 1). Other cited rock glaciers : Mu: Murtèl; Mgl : Muragl. Regions: 1. southwestern Alps (France), 2. western Swiss Alps (Valais), 3. northwestern Swiss Alps (Bernese Alps), 4. eastern Swiss Alps (Upper Engadine), 5. western Austrian Alps, 6. central Austrian Alps. Weather stations : Ch: St.-Christophe-en-Oisans; GSB : Grand-St-Bernard; Sä : Säntis; So : Sonnblick.

Three types of temporal variability in surface motion are superimposed on a secular time scale in response to ground surface temperature variations (e.g., Kääb et al. 2007, Perruchoud & Delaloye 2007): a decadal to pluri-decadal trend, interannual variations, and a seasonal rhythm. Non-thermally induced changes in rock glacier dynamics (e.g., topography effect) may also influence the creep rate particularly at longer time scales, whereas the infiltration of snowmelt water (Ikeda et al. 2008) and the influence of subpermafrost groundwater (Haeberli 1985, Krainer & Mostler 2006) are also advanced as controlling factors at shorter time intervals. The early measurements on the Gruben rock glacier already indicated that strong short-term velocity variations occur where the permafrost base is above bedrock, and that these variations can be different in lower and upper rock glacier parts (Haeberli 1985).

Studies carried out in various parts of the Alps (e.g., Roer et al. 2005, Kääb et al. 2007, Kaufmann et al. 2007) have shown that the motion of alpine rock glaciers has drastically accelerated since the 1980s, probably in response to an increase in permafrost temperature consecutive to warmer air temperatures. For the past 15 years or so, however, no clear further warming trend has been visible in the borehole temperatures time series on the Murtèl rock glacier in the eastern Swiss Alps (Vonder Mühll et al. 2007).

Seasonal variations have been reported for several rock glaciers (Haeberli 1985, Kääb et al. 2003, Hausmann et al. 2007a, Perruchoud & Delaloye 2007), whereas almost constant annual velocities have also been observed (Krainer & Mostler 2006), particularly where permafrost is reaching into bedrock as on the Murtèl rock glacier (Haeberli et al. 1998). Where existing, seasonal fluctuations can be large, reaching up to 50 % from the annual mean. They occur every year more or less at the same time but are not fully synchronous for all rock glaciers. Highest velocities are reached in most cases between summer and early winter, whereas the lowest values are usually observed in spring or early summer. The seasonal increase in velocity can be rapid and connected to the snowmelt process (Perruchoud & Delaloye 2007) or slower and delayed (Kääb et al. 2007). On the Muragl rock glacier (eastern Swiss Alps), the annual amplitude of the seasonal rhythm varies significantly, the winter/spring decrease being reduced by warmer winter ground surface temperature (Kääb et al. 2007).

Interannual Velocity Survey and Dataset

Interannual velocities are surveyed by terrestrial measurements (geodetics or real-time kinematic GPS) with accuracy in the mm to cm range. The annual campaign at each rock glacier is carried out as closely as possible on the same date - ideally by late summer - in order to avoid an effect of potentially strong seasonal variations on the reliability of the data. Ten to more than 100 marked points, covering part or the whole of the rock glacier or disposed along longitudinal and/or transversal profiles, are surveyed. The compared value is then the mean horizontal velocity for all moving points with uninterrupted series. This value is considered to be a proxy for the activity of a whole rock glacier, keeping in mind that local differences in flow rates and amplitudes of annual changes are probable.

The 16 observed rock glaciers (Fig. 1) are located in six distinct regions and are briefly described hereafter and in Table 1. There is a distance of 600 km between Laurichard (southwest) and Dösen (east) rock glaciers.

Region 1: Southwestern Alps (France)

Laurichard is a tongue-shaped rock glacier which displays longitudinal furrows in its steepest part and transversal ridges near the edge. Surface velocities have been measured since 1983 (Francou & Reynaud 1992) along a 420 m long longitudinal profile of 17 painted blocks. Mean horizontal velocity over the 1983–2007 period is 0.75 ma^{-1}.

Region 2: Western Swiss Alps (Valais)

Mille is a rock glacier looking inactive on morphological criteria (Delaloye 2004), however moving slowly in its steeper lower half (0.02 to 0.05 ma^{-1}).

Aget-Rogneux is a low active back creeping push-moraine located in the Little Ice Age forefield of a small vanished glacier (Lambiel & Delaloye 2004).

Mont-Gelé B and C are two coalescent small rock glaciers. Whereas Mont-Gelé B is moving faster, the deformation of Mont-Gelé C is much reduced despite an apparently higher ice content (Lambiel & Delaloye 2004).

Tsarmine is a tongue-shaped, currently very active rock glacier ending at the top of a steep gully and providing large amounts of loose materials. Local disturbances of the block surface point to a recent drastic acceleration of the rock glacier movement (Lambiel et al. 2008).

The Becs-de-Bosson rock glacier is an active feature consisting of two adjacent lobes. There is no permafrost—and no creep—in the rooting zone of the rock glacier due to the former development of a local glacier during the Little Ice Age. Significant seasonal variations are observed on the whole rock glacier (Perruchoud & Delaloye 2007).

HuHH1 and HuHH3 are two adjacent multilobate rock glaciers situated below cirques. Both landforms are of similar size and showed maximum horizontal velocities up to 4 ma^{-1} in 2003/04 (Roer 2007).

Region 3: Northwestern Swiss Alps (Bernese Alps)

Furggentälti is a small, tongue-shaped rock glacier with annual surface displacement currently 5 to 10 times larger than during the period 1960–1974 (Mihajlovic et al. 2008). Seasonal fluctuations were observed in 1998/99.

Table 1. Alpine rock glaciers with annual surface velocity survey.

N°	Name	Coordinates	Elevation m a.s.l.	Area km^2	Aspect	Available data	Mean horizontal velocity (2003/04) ma^{-1}	Relative drop (2004-2006) %
1	Laurichard	45°01'N, 06°24'E	2424-2644	0.08	N	1999-...	1.03	-40
2	Mille	46°01'N, 07°12'E	2340-2430	0.02	NE	2003-...	0.05	-61
3	Aget-Rogneux	46°01'N, 07°14'E	2810-2890	0.03	SE	2001-...	0.20	-50
4	Mont-Gelé B	46°06'N, 07°17'E	2600-2740	0.02	NE	2000-...	1.20	-81
5	Mont-Gelé C	46°06'N, 07°17'E	2620-2820	0.05	N	2000-...	0.22	-42
6	Tsarmine	46°03'N, 07°30'E	2480-2650	0.04	W	2004-...	-	-
7	Becs-de-Bosson/Réchy	46°10'N, 07°31'E	2610-2850	0.10	NW	2001-…	0.97	-36
8	Furggentälti/Gemmi	46°24'N, 07°38'E	2450-2650	0.03	N	1994-...	3.08	-52
9	HuHH1	46°11'N, 07°43'E	2630-2780	0.04	NNW	2001-2005	1.26	-
10	HuHH3	46°11'N, 07°43'E	2515-2650	0.05	NW	2002-...	1.78	-52
11	Büz North (Trais Fluors)	46°32'N, 09°49'E	2775-2840	0.02	NE	1998-2005	0.74	-
12	Ölgrube	46°54'N, 10°45'E	2380-2810	0.21	W	2000-2005	1.50	-
13	Reichenkar	47°03'N, 11°02'E	2310-2750	0.27	NE	1998-2006	3.15	-9
14	Weissenkar	46°57'N, 12°45'E	2610-2720	0.15	W	1999-...	0.08	-41
15	Hinteres Langtalkar	46°59'N, 12°46'E	2455-2700	0.15	NW	1999-...		
	(upper part)		>2655	0.06			0.18	-28
	(lower part)		<2655	0.09			2.22	-21
16	Dösen	46°59'N, 13°17'E	2340-2650	0.19	W	1995-...	0.26	-19

Region 4: Eastern Swiss Alps (Upper Engadine)

The Büz North (Trais Fluors) pebbly rock glacier comprises two superimposed lobes, 70 and 90 m long. At the beginning of the survey in 1998, no pronounced morphological expression of flow was noticed. However, the movement turned out to be in the order of 1 ma^{-1} and more (Ikeda et al. 2008, Kääb et al. 2007).

Region 5: Western Austrian Alps

Ölgrube rock glacier consists of two lobes of varying activity. Maximum annual velocities (1.5 ma^{-1}) occur in the central lower part. Seasonal variations were observed with a velocity decrease of about 50% during winter 2003 (Krainer & Mostler 2006, Hausmann et al. 2007a).

Reichenkar is a 1400 m long, very active tongue-shaped rock glacier. Highest velocity (up to 3 ma^{-1}) occurred in 2003/04. No seasonal variation was noticed in 2002 and 2003 (Krainer & Mostler 2006, Hausmann et al. 2007a, b).

Region 6: Central Austrian Alps

Weissenkar is a slowly moving, tongue-shaped rock glacier consisting of an upper lobe overriding a lower one, and characterized by well developed furrows and ridges at the entire lower half. Weissenkar rock glacier moves on average 0.02 to 0.11 ma^{-1} (Kaufmann et al. 2006).

Hinteres Langtalkar houses a highly active, tongue-shaped rock glacier advanced over a prominent terrain ridge into steeper terrain most likely in 1994 (Avian et al. 2005). Several transverse crevasses have developed since (e.g., Roer et al. 2008). The current movement pattern differentiates a faster lower part and a substantially slower upper part.

Dösen is a tongue-shaped rock glacier. Displacement measurements started in 1995—including photogrammetric work of the preceding period until 1954—revealing mean velocity rates of 0.13–0.37 ma^{-1} (Kaufmann et al. 2007).

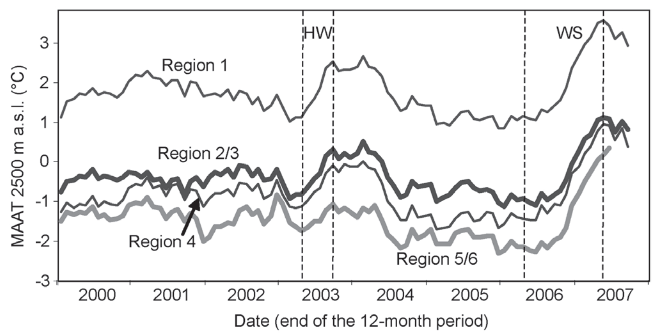

Figure 2. Mean annual air temperature (12-month running mean) standardized at 2500 m a.s.l. (gradient: -0.56°C/100 m). HW: heat wave 2003; WS: warm swell 2006/07. Region 1: St. Christophe, 1570 m a.s.l. (Météo-France). Region 2/3: Grand-St-Bernard, 2472 m a.s.l. (MeteoSwiss). Region 4: Säntis, 2490 m a.s.l. (MeteoSwiss). Region 5/6: Sonnblick, 3105 m a.s.l. (ZAMG –Central Institute for Meteorology and Geodynamics).

MAAT and MAGST in 2000–2007

Air temperature

The 1987–2007 mean annual air temperature (MAAT) in the Alps was on average 1°C to 2°C warmer than during the preceding decades. Since 2000, two extreme, warm climatic events affected the Alpine region: the heat wave of summer 2003 and the 2006/07 warm swell, namely 15 months of quasi continuous, large, positive temperature anomaly between April 2006 and June 2007 (except August 2006). The 2003 heat wave induced a rapid warming of MAAT towards values exceeding those of earlier and later years (except in the Austrian Alps), and the 2006/07 event resulted in an exceptionally high MAAT, which exceeded everywhere the 2003 value by 0.5°C to 1.5°C (Fig. 2).

Ground surface temperature

There are no boreholes on the 16 observed rock glaciers, except a shallow one (6 m) at Trais Fluors. Ground surface temperature is nevertheless monitored on several of them. Variations of the mean annual ground surface temperature (MAGST)

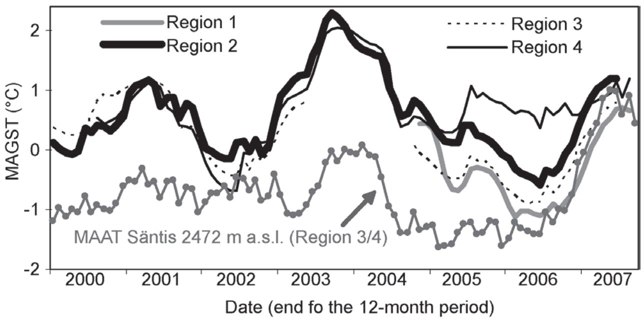

Figure 3. Interregional comparison of MAGST behavior in the western and central Alps (12-month running mean). Region 1: Laurichard rock glacier (average of 2 sites of measurement). Region 2: Becs-de-Bosson/ Réchy (2). Region 3: Furggentälti/ Gemmi (1). Region 4: Trais Fluors (1).

are used as a proxy for the permafrost thermal regime at shallow depth, even if the intensity of the winter cooling and summer warming (freezing and thawing index) should not be neglected. The snow cover buffers the ground-atmosphere heat exchanges for a long part of year, varying annual snow cover conditions alter the behavior of MAGST in comparison with MAAT: both are not evolving in a parallel way (Fig. 3). Despite the effect of snow, a homogeneous MAGST behavior is observed at the regional scale (e.g., Delaloye & Monbaron 2003). The larger variations of MAGST are also similar at the interregional scale in the Alps with, however, some differences in 2005–2006—colder values in the western regions 1–3 (Fig. 3). Three periods of warmer MAGST occurred in 2001, 2003/04 and 2007, with the 2003/04 event as the warmest.

Both 2003 and 2006/07 warm climatic events did not affect MAGST in the same way. In 2003 a strong MAGST increase already had occurred during the winter due to earlier snow insulation (e.g., Vonder Mühll et al. 2007); a second phase of warming succeeded in summer and was caused by the heat wave. An extremely high MAGST value was reached by the end of 2003. In 2006/07, the situation was the reverse. Later and lesser snowfalls in early winter favoured the cooling of the ground surface in spite of the persistence of mild air temperature. The extremely high MAAT was strongly attenuated in MAGST.

Results

Despite variable size, morphology, complexity of flow field, mean annual velocity, seasonal rhythm, etc., the compared rock glaciers have shown a rather homogeneous and synchronous behavior (Fig. 4). Three phases of higher creep rate can be quoted in 2000/01, 2003/04, and 2006/07. They all followed immediately a period of warmer MAGST.

Every rock glacier reached an absolute or relative maximal creep rate in 2003/04 before a drastic drop occurred for most of them between 2004 and 2006 (up to -81%, Table. 1). The drop was generally stronger to the west (Regions 1–3) than to the east (Regions 5–6). Stationary or slightly increased velocities were observed everywhere in 2006/07.

The situation in 2000/01 was more contrasted. A peak rate of deformation occurred in Region 4 and was also almost reached in Region 1. Relative maxima are reported from Regions 3 and 6 (no data in Region 2) whereas no maximum is documented in Region 5. Neighboring regions did not display similar behavior in rock glacier movement.

Discussion

Neglecting small differences in interannual variations that may be due to either internal and topographical characteristics of the rock glaciers or to the variability of the seasonal rhythm or to a shift in the measurement date, the rather homogeneous behavior of Alpine rock glaciers allows us to state that: (1) the driving processes are likely to be the same for all observed rock glaciers; (2) there should be a common climatic control of the permafrost creep rate; (3) a dominant effect of active layer solifluction or surface boulder creep can be excluded, as corroborated, for instance, by borehole deformation measurements on the Trais Fluors rock glacier (Ikeda et al. 2008).

As the interannual changes of surface motion appear to be mostly correlated to the evolution of the MAGST with a delay of a few months (Fig. 4) - the warmer the MAGST, the larger the velocity, - one can infer that they should be caused by a thermally induced process. The delay being not long enough for the surface thermal signal to penetrate deeply into permafrost, interannual changes would thus be primarily caused by shifts in the deformation rate of shallow permafrost layers mostly located—if existing—above the shear horizon.

Higher creep rates should also be caused by the development of a thick winter snow cover, which during early summer provides more meltwater to penetrate into a warm rock glacier system. This process is evoked by Ikeda et al. (2008) to explain the high activity of the Trais Fluors rock glacier in 2001. In that region, the snow cover in winter 2000/01 was much deeper than for both the previous and the following winters. The unusually high amount of meltwater in early summer 2001 is advanced as a factor which facilitated permafrost creep. A similar situation occurred in the Laurichard area in the French Alps. The snow accumulation (2.42 m we) recorded that winter on the Sarennes glacier at a distance of 24 km was 0.65 m we above the 1984–2007 mean and the only value exceeding 2 m we since 1995 (Fig. 5). Among the six regions defined in this study, both Laurichard and Trais Fluors regions are the most exposed to southerly precipitations, a situation which prevailed in winter 2000/01.

Changing interannual creep rates may finally be related to the intensity of winter ground freezing. Where data is available, the maximal activity of rock glaciers appears to be linked to lower freezing index values. In the western and eastern Swiss Alps, the highest annual velocities occurred after the warmest winters on the ground surface, in 2001 and 2003 (Fig. 6). On the Muragl rock glacier, close to Trais Fluors, seasonal velocity surveys carried out between 1998 and 2003 (Kääb et al. 2007) showed that, contrary to other winters, the velocity of the rock glacier did not decrease during winter 2000/01. The higher annual velocity was caused by the absence of a winter deceleration.

Conclusions and Perspectives

Rapid and slow rock glaciers have shown mostly a similar kind of annual velocity variations in the whole arc of the

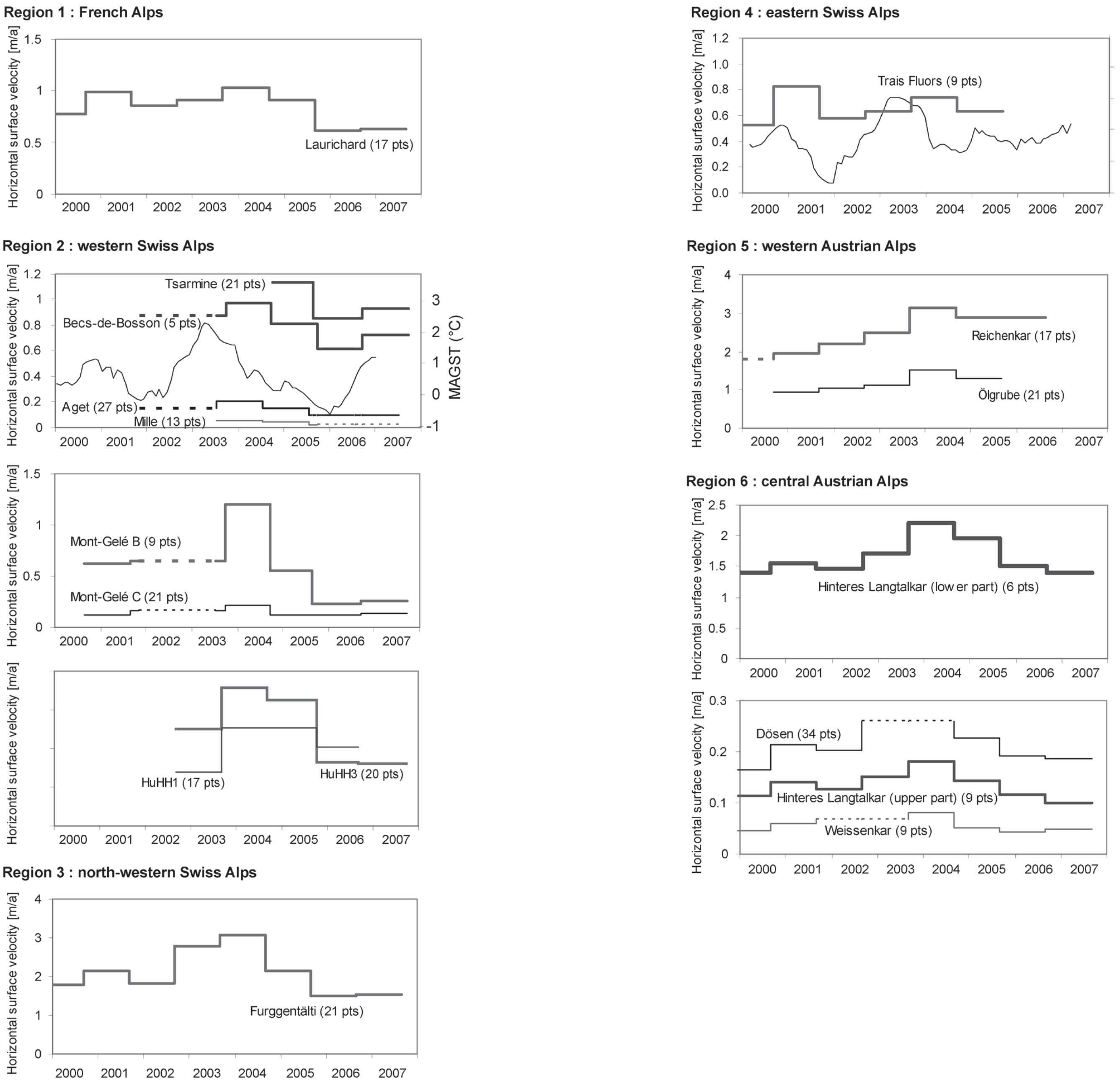

Figure 4. Annual horizontal velocities of alpine rock glaciers. The velocity scale is not identical on every graph. Dotted lines indicate a 2-year interval of measurement. Mean annual ground surface temperature (MAGST) at Becs-de-Bosson and Trais Fluors rock glaciers are inserted in the respective chart with date corresponding to the median of the 12-month period.

European Alps since 2000. Interannual variations of rock glacier dynamics appear so far—with probably a few exceptions—to be primarily related to external climatic factors rather than to the internal characteristics of the rock glaciers. They are mostly well related to shifts in mean annual ground surface temperature with a few months of time lag reflecting the delay in propagation of corresponding anomalies deeper into permafrost. Seasonal factors may also play an important role. A lower intensity of winter ground freezing and/or a larger amount of winter (October–May) snowfall facilitate a higher rate of annual rock glaciers surface motion.

The set of 16 rock glaciers is representative of six alpine regions. It establishes a pioneer network for the observation of short-term variations of rock glacier activity. The first synthetic results strongly encourage the continuation of the monitoring effort and the extension of the network to further regions, particularly in the southern Alps for which such data is still mostly lacking. The availability of uninterrupted series, complemented by ground surface temperature and snow data acquired on the rock glaciers or in their close vicinity, will serve a more precise identification and quantification of the factors driving the short-term behavior of permafrost creep rate in temperate mountain areas.

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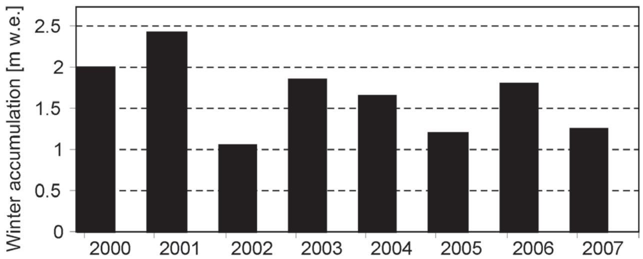

Figure 5. Winter snow precipitations (cumulative amount from October to April in meters of water equivalent, m we) recorded at Sarennes Glacier (French Alps).

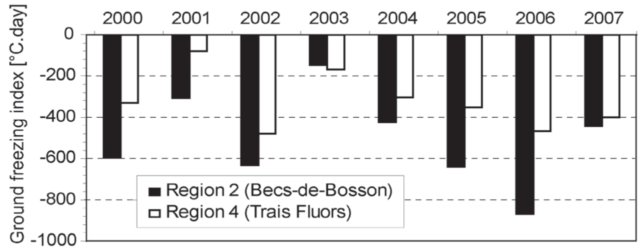

Figure 6. Interregional comparison of ground freezing index in the Swiss Alps.

References

Avian, M., Kaufmann, V. & Lieb, G.K. 2005. Recent and Holocene dynamics of a rock glacier system – the example of Langtalkar (Central Alps, Austria). *Norwegian Journal of Geography* 5: 149-156.

Delaloye, R. & Monbaron, M. 2003. Snow effects on recent shifts (1998-2002) in mean annual ground surface temperature at alpine permafrost sites in the western Swiss Alps. *Eighth Conference on Permafrost, Zurich 2003, Extended Abstracts*: 23-24.

Delaloye, R. 2004. *Contribution à l'étude du pergélisol de montagne en zone marginale*. Ph.D. Thesis, University of Fribourg, Switzerland, *GeoFocus* 10.

Francou, B. & Reynaud, L. 1992. 10 years of surficial velocities on a rock glacier (Laurichard, French Alps). *Permafrost and Periglacial Processes* 3: 209-213.

Haeberli, W. 1985. Creep of mountain permafrost: internal structure and flow of Alpine rock glaciers. *Mitteilung VAW/ETH Zurich* 74.

Haeberli, W., Hoelzle, M., Kääb, A., Keller, F., Vonder Mühll, D. & Wagner, S. 1998. Ten years after drilling through the permafrost of the active rock glacier Murtèl, eastern Swiss Alps: answered questions and new perspectives. *Proceedings of the Seventh International Conference on Permafrost, Yellowknife,* Nordicana 57: 403-410.

Hausmann, H., Krainer, K., Brückl, E. & Mostler, W. 2007a. Creep of Two Alpine Rock Glaciers – Observation and Modelling (Ötztal- and Stubai Alps, Austria). *Grazer Schriften der Geographie und Raumforschung* 43: 145-150.

Hausmann, H., Krainer, K., Brückl, E. & Mostler, W. 2007b. Internal Structure and Ice Content of Reichenkar Rock Glacier (Stubai Alps, Austria) Assessed by Geophysical Investigations. *Permafrost and Periglacial Processes* 18: 351-367.

Ikeda, A., Matsuoka, N. & Kääb, A. 2008. Fast deformation of perennially frozen debris in a warm rock-glacier in the Swiss Alps: an effect of liquid water. *Journal of Geophysical Research* (in press).

Kääb, A., Kaufmann, V., Ladstädter, R. & Eiken, T. 2003. Rock glacier dynamics: implications from high-resolution measurements of surface velocity fields. *Proceedings of the Eighth International Conference on Permafrost, Zurich,* Balkema : 501-506.

Kääb, A., Frauenfelder, R. & Roer, I. 2007. On the response of rockglacier creep to surface temperature increases. *Global and Planetary Change* 56(1-2): 172-187.

Kaufmann, V., Ladstädter, R. & Lieb, G.K. 2006. Quantitative assessment of the creep process of Weissenkar rock glacier (Central Alps, Austria). *Proceedings of the Eighth High Mountain Remote Sensing and Cartography Symposium, La Paz, Bolivia, March 20-27, 2004*: 77-86.

Kaufmann, V., Ladstädter, R. & Kienast, G. 2007. 10 years of monitoring of the Doesen rock glacier (Ankogel group, Austria) - A review of the research activities for the time period 1995-2005. *Proceedings of the Fifth Mountain Cartography Workshop, Bohinj, Slovenia, March 29–April 1, 2006*: 129–144.

Krainer, K. & Mostler, W. 2006. Flow velocities of active rock glaciers in the Austrian Alps. *Geografiska Annaler, Series A: Physical Geography* 88(4): 267–280.

Lambiel C. & Delaloye R. 2004. Contribution of real-time kinematic GPS in the study of creeping mountain permafrost: examples from the Western Swiss Alps. *Permafrost and Periglacial Processes* 15: 229-241.

Lambiel, C., Delaloye, R., Strozzi, T., Lugon, R. & Raetzo, H. 2008. ERS InSAR for detecting the rock glacier activity. *Proceedings of the Ninth International Conference on Permafrost, Fairbanks, Alaska, June 29–July 3, 2008* (this proceedings).

Mihajlovic, D., Staub, B., Nussbaum, A., Krummenacher, B. & Kienholz, H. 2008. Twenty years of permafrost research on the Furggentälti rock glacier, Western Alps, Switzerland. *Proceedings of the Ninth International Conference on Permafrost, Fairbanks, Alaska, June 29–July 3, 2008* (this proceedings).

Roer, I. 2007. Rockglacier kinematics in a high mountain geosystem. *Bonner Geographische Abhandlungen* 117.

Roer, I., Kääb, A. & Dikau, R. 2005. Rockglacier acceleration in the Turtmann valley (Swiss Alps) - probable controls. *Norwegian Journal of Geography* 59(2): 157–163.

Roer, I., Haeberli, W., Avian, M., Kaufmann, V., Delaloye, R., Lambiel, C. & Kääb, A. 2008. Observations and considerations on collapsing active rockglaciers in the Alps. *Proceedings of the Ninth International Conference on Permafrost, Fairbanks, June 29–July 3, 2008* (this proceedings).

Perruchoud, E. & Delaloye, R. 2007. Short-term changes in surface velocities on the Becs-de-Bosson rock glacier (western Swiss Alps). *Grazer Schriften der Geographie und Raumforschung* 43: 131-136.

Vonder Muehll, D., Noeztli, J., Roer, I., Makowski, K. & Delaloye, R. (eds). 2007. *Permafrost in Switzerland.* PERMOS Reports 4 & 5 (2002/03 & 2003/04). Swiss Acad. of Sciences.