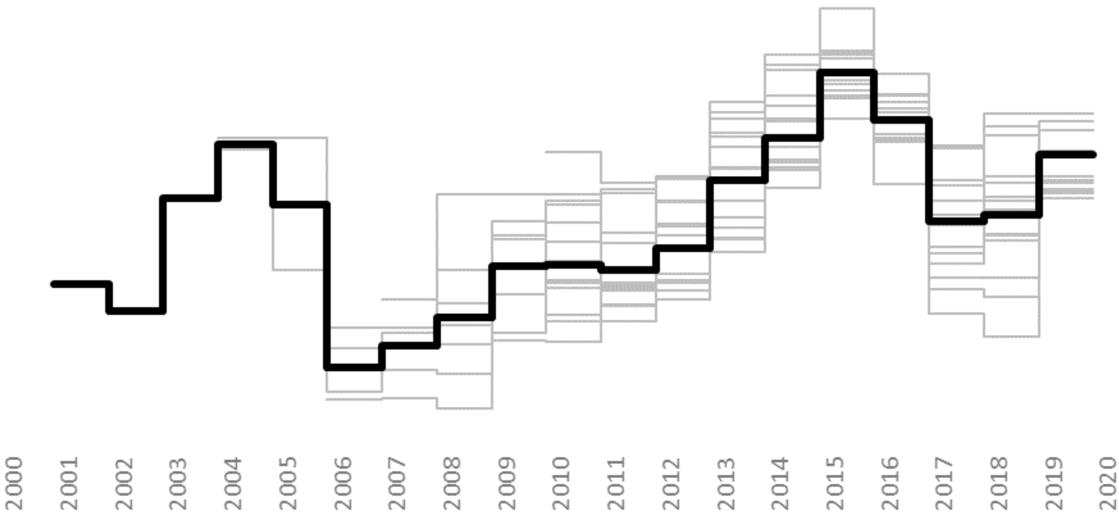
IPA Action Group Rock glacier inventories and kinematics

Rock glacier kinematics as an associated parameter of ECV Permafrost

(Version 1.0)



https://www3.unifr.ch/geo/geomorphology/en/research/ipa-action-group-rock-glacier *(Action Group website)*

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Authors and contributions

This version has been edited by the scientific committee of the Action Group Workshop II: Chloé Barboux (University of Fribourg, Switzerland), Line Rouyet (NORCE, Norway), Tazio Strozzi (Gamma Remote Sensing, Switzerland), Xavier Bodin (University of Savoie Mont-Blanc, France) and Reynald Delaloye (University of Fribourg, Switzerland).

Workshop II will be held on 11-13 February 2020 in Fribourg (Switzerland). A part of the workshop will focus on exploring the feasibility of preparing "products" which could serve for monitoring *rock glacier kinematics as an associated parameter of the ECV Permafrost*. The results of the workshop will be integrated in the next version of this document.

The purpose of this document is to serve as a baseline for the establishment of practical guidelines permitting to derive from kinematical time series of regionally selected rock glaciers an associated parameter of the ECV Permafrost in a climate-oriented perspective.

Preamble

Task 2 of the IPA (International Permafrost Association) Action Group *Rock glacier inventories and kinematics* (2018-2022) aims to **explore the feasibility of preparing "products" which could serve for monitoring rock glacier kinematics as an associated parameter of the ECV (Essential Climate Variable) Permafrost** in a climate-oriented perspective.

The development of such products has been divided in three sub-tasks, namely:

- the promotion of the use of satellite SAR interferometry, e.g. based on Sentinel-1 data, but more generally of remote sensing data for monitoring the rock glacier activity at a regional to global scale, and the definition of the appropriate standards and guidelines;
- the integration, as far as possible, of local-scale monitoring data based on aerial and terrestrial geodetic surveys;
- the setting up of standard guidelines for selecting an appropriate number of rock glaciers per region that can be then used to assess temporal trends of climatic significance with decadal to intra-decadal time steps (product for ECV Permafrost)

The present document (**version 1.0**) sets the necessary concepts for standardizing the production and exploitation of rock glacier kinematical time series in a climate-oriented perspective. It results from a preparatory work performed by the scientific committee of the Action Group Workshop II. It aims at being a provisory document, which has to be finalized during the dedicated workshop in February 2020.

Any **feedback** regarding the content of the document is nevertheless warmly welcome in advance until **2 February 2020** using exclusively the dedicated boxes inserted at the end of each section.

Greyish inserts in the text have to be discussed/developed in particular during Workshop II.

Provisional timeline

- Comments on the present document (version 1.0) are expected until 2 February 2020 and will be discussed during the Workshop II.
- A post-workshop version (2.0) will be submitted as soon as possible after the workshop and again opened to comment in March/April 2020.
- The final version (3.0) is intended to be made available in June 2020.

Workshop II will be the opportunity to discuss/decide about the technical issues regarding the preparation of *practical guidelines* for producing/exploiting rock glacier kinematical time series in a climate-oriented perspective.

If you have any comment about the previous section, please use this box.

Comment box 0

1. Purpose of associating rock glacier kinematics to ECV Permafrost

On a global scale, the evolution of mountain permafrost is scarcely observed by temperature monitoring in a few boreholes, whose long-term maintenance is particularly challenging. A large majority of periglacial mountain areas worldwide are thus lacking permafrost monitoring data. Therefore, the response of mountain permafrost to ongoing climate evolution cannot be depicted in most regions on Earth.

Several studies conducted in the European Alps for the last two decades have shown that there is dependency of rock glacier interannual behavior to permafrost temperature, the latter particularly impacting the rheological and hydrological properties of the frozen ground. It has been observed that rock glaciers tend to accelerate on an interannual basis under warmer conditions as long as the permafrost degradation has not become too severe to counter it. In addition, rock glaciers tend to display a concomitant regional behavior: namely, interannual acceleration and deceleration are occurring at almost the same time and in the same proportion in a given region, independently of the activity rate and the morphological characteristics of the rock glaciers. Finally, continuous or seasonal monitoring has shown that the observed rock glaciers develop a landform-specific but repetitive intra-annual behavior, whose inter-annual variations do not significantly alter the pluri-annual trends.

Between the 1980s and the 2010s, a majority of rock glaciers in the European Alps have increased their annual velocity rate by a factor 2 to 10. A similar evolution can be expected to have occurred or to occur in the future in many other mountain ranges depending on their specific climatic settings.

Rock glaciers are widespread. Remote sensing data allow the producing of kinematical information on many rock glaciers. The increasing emergence of open-access and high-resolution satellite imagery (e.g. optical, SAR) facilitates the set-up of regional survey worldwide. The current increasing availability of SAR data (e.g. Sentinel-1 SAR images) makes possible the build-up of rock glacier kinematics time series, to investigate the occurrence of concomitant regional behaviors, and to evaluate their climatic significance.

Exploiting the availability of remote sensing data on tens of thousands of rock glaciers, and even more, to explore the concomitance of their kinematical behavior and to develop a regional index (or parameter) evidencing the evolution of mountain permafrost based rock glacier kinematics is the challenge raised by the Action Group in its Task 2.

If you have any comment about the previous section, please use this box.

Comment box 1

2. Rock glaciers kinematics

2.1. Generalities

1^{rst}-level data consist of individual kinematical time series having an annual or pluri-annual resolution expressing a velocity.

2nd-level data consist of individual kinematical time series having an annual or pluri-annual resolution expressing a relative velocity to a reference time. A regional index (or parameter) would then be an assemblage (e.g. mean) of selected 2nd-level time series. An example is given in Figure 1.

The following sections are fixing the necessary requirements for building up both the individual time series and the regional index.

If you have any comment about the previous section, please use this box.

Comment box 2

2.2 Individual time series

2.2.1 Generalities

There are two sets of approaches for measuring rock glacier surface velocities: in situ terrestrial survey (e.g. repeated GNSS field campaigns, permanent GNSS stations) and remote sensing based approaches (e.g. InSAR, satellite-/air-/UAV-borne photogrammetry). In all cases and in the aim of producing a regional index (see 2.3), the resulting individual time series consist of velocity values that can be expressed in m/yr, and whose time resolution (frequency) is annual or pluri-annual.

Rock glaciers on which a climate-oriented monitoring is feasible is strongly dependent on site accessibility and safety for in situ measurements and on favorable configuration for investigation with remote sensing methods.

The *connection to the upslope unit* of the rock glacier (unit) of concern must be known according to the baseline concepts for inventorying rock glaciers.

If you have any comment about the previous section, please use this box.

Comment box 3a

2.2.2 Horizontal surface velocity values

The velocity value of individual series refers to horizontal (2D) surface velocity.

If the methodology does not allow the distinction between horizontal and vertical flow values, the horizontal value is extracted assuming that the movement develops downwards along the slope.

When the velocity rate is measured on a selected point of the rock glacier, the location should be consistent over time, and be spatially representative of the landform, i.e. located within a recognized *moving area* (see definition under 2.3.1 in *Kinematics as an optional attribute of standardized rock glacier inventories*).

When the velocity value is computed over a targeted moving part of the rock glacier, the way of computing the value (e.g. from discrete available measurement points or from a velocity flow field) must be consistent over the time. The targeted moving part should be spatially representative of the landform, i.e. located within a recognized *moving area.*

How to be technology independent (point measurement and field measurement, orientation of the movement)?
How to be spatially representative for the selected rock glacier?

If you have any comment about the previous section, please use this box.

Comment box 3b

2.2.3 Time resolution:

The velocity value is computed at an annual frequency or a multiple of it.

2.2.4 Time observation window:

The velocity value is calculated on the basis of the effective displacement of a target (or an ensemble of targets) over a year.

However, depending on the applied technique, this velocity value could only be obtained for a shorter *time observation window* than an annual one, but at an annual (or pluri-annual) frequency. The time observation window should be as constant as possible in time. The obtained velocity values are infra-annual, but the time series keeps an annual resolution.

How to be technology independent (how to deal with methods providing summer velocity (gaps during snow-affected period) and the one providing multi-annual velocity)?
Can the time window be modified for an individual time series? Under which conditions?

If you have any comment about the previous section, please use this box.

Comment box 3c

2.2.5 Required measurement uncertainty

This section refers to the maximal measurement uncertainty, which can be accepted in order to provide reliable individual time series exploitable in a climate-oriented perspective. The uncertainty is given by the applied methodology, the specificities of the sensor or the algorithm used in the data processing.

The uncertainty should be evaluated relatively to the magnitude of the velocity that is observed. It is required to insure a relative measurement uncertainty below 20% in order to allow the integration of an individual time series in trend analysis. For instance, a methodology characterized by measurement uncertainty of 2 cm is not recommended to be used for deriving individual series over a rock glacier slower than 10 cm/yr.

If you have any comment about the previous section, please use this box.

Comment box 3d

2.3 Regional index

2.3.1. Generalities

A region is an (almost) continuous area in which a large number of the observed rock glaciers displays a similar behavior pattern (similarity of the relative kinematical time series). A region is not defined by a size.

The regional relative velocity time series (regional index) synthetizes the relative behavior of individual velocity time series acquired by terrestrial or remote sensing survey to a reference time (Figure 1). In principle, a regional index cannot be derived from an individual time series only.

Individual time series that show abnormal behavior should be removed from the regional trend, at least from the moment the behavior no longer corroborates with the regional trend (see 2.3.2).

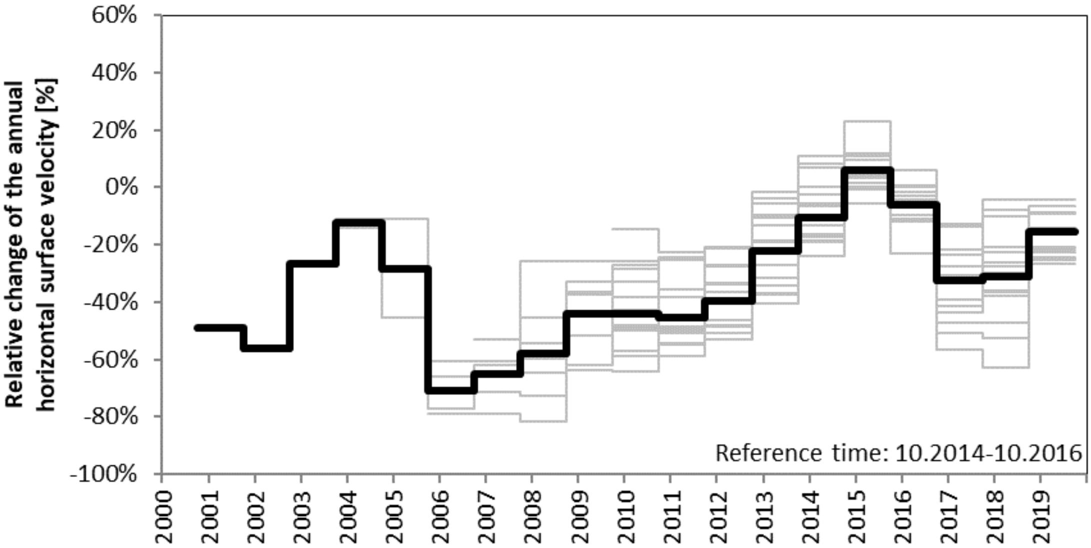

Figure 1: Relative change of the rock glacier surface velocity in the western Swiss Alps (data source : University of Fribourg, University of Lausanne, PERMOS): the regional index (black curve) is the mean of selected individual rock glacier time series, which are derived from annual GNSS multi-point survey.

How to define a reference time ?

If you have any comment about the previous section, please use this box.

Comment box 4a

2.3.2 Rock glacier selection

Only talus-connected rock glaciers and possibly debris-mantled slope-connected rock glaciers are of concern, whereas glacier-connected and glacier forefield-connected rock glacier are not or must be considered separately.

Ideally, at least 10% of the active talus-connected rock glaciers, but not less than 10 rock glaciers, should be selected in a region to build up a reliable regional index. The number of available individual time series must be large enough in order to allow the identification of "abnormally" behaving time series.

Figure 2 is illustrating the detection of individual time series accelerating or decelerating abnormally and which are omitted from the calculation of the regional index.

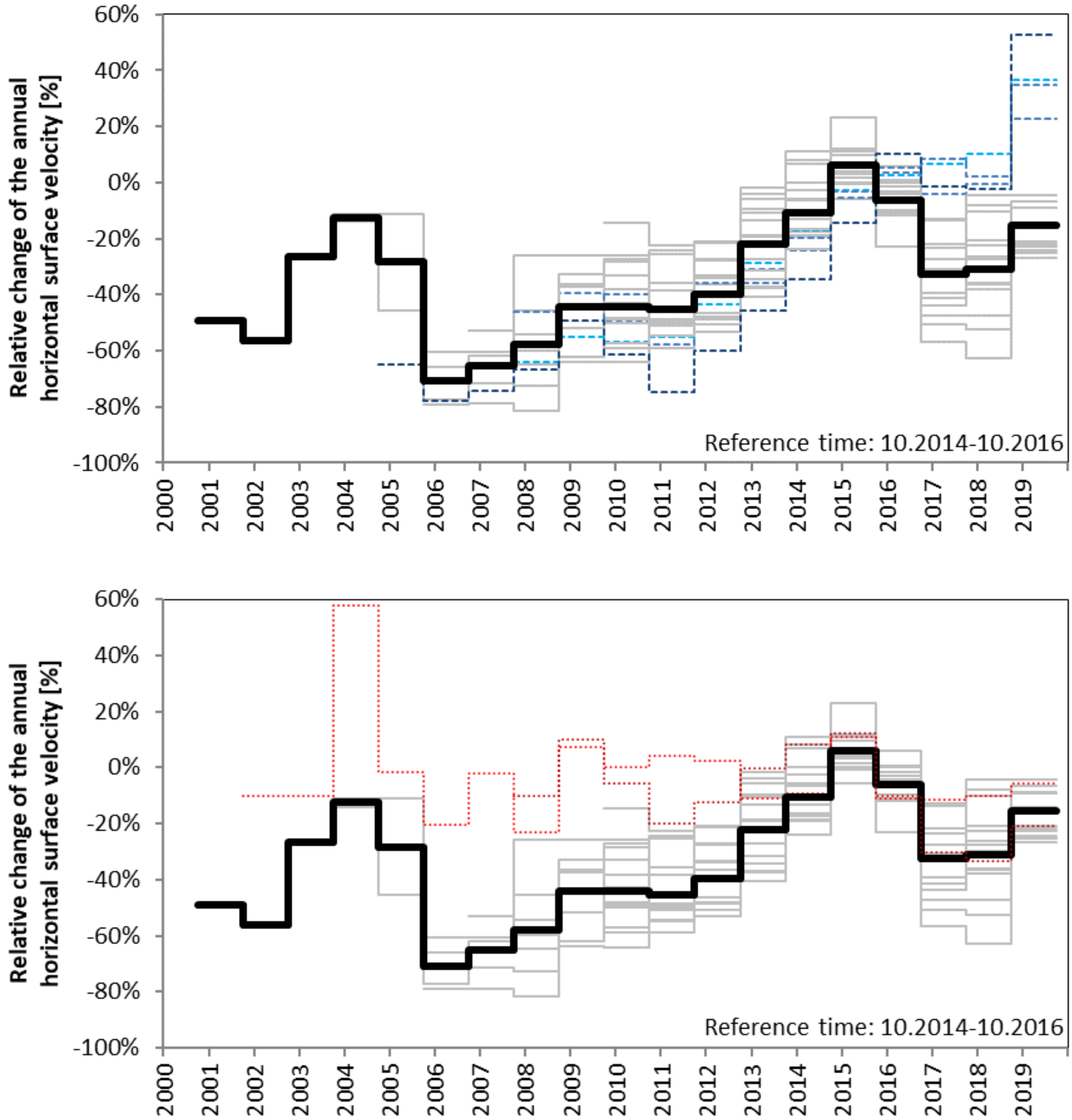

Figure 2: Same as Figure 1, but with the illustration of individual time series, which are not retained for the calculation of the regional index (black curve) due to an "abnormal" acceleration (up, blue dotted lines) or deceleration (down, red pointed lines).

How to define the selection based on rock glacier characteristics. What is a representative rock glacier in a regional context?

What does "sufficient sites" in a defined regional context mean?

"Abnormality" to be defined (deviation thresholds ?).

How to be technology independent? How to deal with the bias in aspect in removing N-S facing slopes from InSAR based results.

…

If you have any comment about the previous section, please use this box.

Comment box 4b

3. Integration of RGK in the next GCOS Implementation Plan

3.1. Project status

GCOS (Global Climate Observing System) is currently renewing its new implementation plan (IP). This IP is under public review from January to March 2020. Rock Glacier Kinematics (RGK) has been provisionally submitted by GTN-P in December 2019 as a new associated parameter (product) to the variable ECV Permafrost. RGK would consist of collected individual 1st-level kinematical time series, which are fulfilling standardized requirements (2.2 in the present document) in order to provide the basis for producing regional indices (2.3 in the present document).

The GCOS strategy and the new Rock Glacier Kinematics associated parameter to the ECV Permafrost will be presented and discussed at the Workshop 2

After the workshop, a review of the integration of RKG in the IP has to be written to GCOS on behalf of the IPA Action Group and GTN-P.

3.2. RGK Scientific Committee

A scientific committee should be nominated to manage data and provide regional annual trends of selected/reference rock glaciers to GCOS and other international programs.

If you have any comment about the previous section, please use this box.

Comment box 5

General open questions:

- Integration of multi-methods at one site: if both GNSS and InSAR are available, how to integrate the results?
- Metadata – how to deal with initial datasets (e.g. complete time series)
- Integration of past data (locally going back up to prior 1950) ?