IPA Action Group Rock glacier inventories and kinematics

Optional kinematic attribute in standardized rock glacier inventories

(Version 3.0)

http://www.rgik.org *(Action Group website)*

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Authors and contributions

The document has been edited by the scientific committee of the Action Group Workshop II held in Fribourg (Switzerland) on 11-13 February 2020, namely and in alphabetical order Chloé Barboux (University of Fribourg, Switzerland), Aldo Bertone (University of Fribourg, Switzerland), Xavier Bodin (CNRS, France), Reynald Delaloye (University of Fribourg, Switzerland), Line Rouyet (NORCE, Norway) and Tazio Strozzi (Gamma Remote Sensing, Switzerland). It includes the contributions of the participants to the workshop and of further members of the Action Group after electronic consultation.

The purpose of this document is to serve as baseline for the establishment of practical guidelines permitting the integration of an optional kinematic attribute in standardized rock glacier inventories.

The content of this document has been approved by (in alphabetical order):

Do you approve the content of this document and want your name to appear in the approval list above? *Please fill in this online form*.

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Updated versions including the renewed approval list and possibly very small changes and edits could be released at any time during the lifetime of the Action Group and renamed by adding a third digit in the versioning (e.g. 3.0.x). The last version will always be the one hosted on the Action Group website. There will be no specific information sent to the Action Group subscribers.

If major changes are required, a thorough revision of the document must be undertaken and the Action Group community will be questioned.

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Acronym:

RGI_ KAv3.0

Content

Preamble

Task 1 of the IPA (International Permafrost Association) Action Group *Rock glacier inventories and kinematics* (2018-2023) aims at exploring the feasibility of developing widely accepted standard guidelines for inventorying rock glaciers on a global scale, including information on their kinematics. *Baseline* and *practical concepts* for inventorying rock glaciers have been developed in a common contribution of the Action Group members. The present, complementary document intends to set the necessary concepts for including kinematics as an optional attribute in standardized rock glacier inventories. **It must be read and applied in conjunction with the general inventorying *baseline* (RGI_BC) and *practical* (RGI_PC) *concepts***.

The content of the current document (version 3.0) results from a preparatory work performed by the scientific committee of the Action Group Workshop II (version 1.0), comments received on it, discussions with the participants to the workshop held in Fribourg (Switzerland) on 11-13 February 2020, and later the comments from the Action Group community made on the post-workshop version 2.1 until 31 May 2020.

The main text is complemented with some illustrations. Numbers in brackets (e.g. (**1**)) are active links to these illustrations.

Provisional timeline

Version 3.0 is submitted for approbation until **30.06.2022**.

The integration of the present document (RGI_KA) with the baseline (RGI_BC) and practical concepts (RGI_PC) for inventorying rock glaciers into one single document is foreseen at a later stage before the completion of the current Action Group phase in June 2023.

1. Purpose of integrating kinematics in rock glacier inventories

Although many rock glacier inventories are available worldwide, they have been compiled using different methodologies, which make their comparison difficult. The increasing emergence of open-access satellite imagery facilitates the development of new rock glacier inventories and/or the update of existing ones. It also makes the systematic detection of rock glacier surface motion, and consequently, the integration of kinematic information in standardized rock glacier inventories, feasible. In the *Baseline concepts towards standard guidelines for inventorying rock glaciers*, the IPA Action Group has defined that the attribution of an activity category to a rock glacier unit is primarily based on geomorphological indicators, but, if available, can also depend on any measured and adequate kinematic data. It has therefore been specified that an **optional kinematic attribute** could be included in the inventories.

Within the framework of rock glacier inventories and due to their regional-global scale, only **surface velocities** can be taken into consideration. There are basically two sets of techniques for measuring surface velocity on rock glaciers: terrestrial surveys (e.g. repeated GNSS field campaigns, permanent GNSS stations) and remote sensing methods (e.g. InSAR, photogrammetry). Whereas some of these techniques allow only for the measurement at single location(s) on a rock glacier, others permit to upscale the analysis and map surface velocity in a uniform way at a regional scale. The exploitation of such data offers the possibility to **refine the activity categorization** (active, transitional or relict) by adding a **semi-quantitative variable documenting the magnitude order of the creep rate** of the inventoried rock glacier units, i.e. a kinematic attribute[1].

The overall purpose of the present document is to define the baseline concepts allowing for the integration of specified kinematic information as an optional attribute in standardized rock glacier inventories.

2. Basic concepts, limitations and requirements

Because the rock glacier motion mechanism (permafrost creep) primarily takes place at large depth, related surface displacements build up consistent flow fields. Consequently, areas presenting rather homogeneous surface movement patterns occur on any moving rock glacier unit. They can be detected, characterized and exploited to assign a kinematic attribute.

Several limitations, however, must be acknowledged and taken into consideration:

- Surface velocity is expected to be principally dependent on the rock glacier downslope movement, but various processes can alter this relationship and even dominate the measured surface displacement (e.g. melt-induced subsidence).
- Surface velocity is generally faster than the effective mean motion rate occurring within the rock glacier body down to the main shear horizon (by a factor of up to approximately 1.5), but in the absence of borehole deformation measurements the difference is not known.
- Surface velocity usually displays a certain degree of spatial heterogeneity over a rock glacier unit, in relation to the landform (e.g. internal structure) and terrain (e.g. slope) characteristics.

[1] According to the results of the User Survey provided during the Action Group Workshop I in September 2019, the kinematic attribute should be a semi-quantitative optional information in rock glacier inventories. It should represent the overall multi-annual downslope movement rate of a rock glacier unit at the time of an inventory, and express velocities with an order of magnitude (e.g. cm/yr, dm/yr, m/yr and higher), rather than with absolute values.

For instance, the terminal part (front), lateral margins and rooting zone are often slower than the central part.

- Temporal variations of the surface velocity can occur, for example:
    - the velocity may change significantly from year to year (inter-annual to decennial variations) as a response to changing environmental factors.
    - the velocity often oscillates within a year. It is usually faster during or after the warm season, due to higher ground temperature and increased water inputs from snowmelt and liquid precipitation. A large amplitude is possible within a year. Thus, when observing rock glacier velocity during summertime only, generally faster values are noted than when considering a time period of one year (**1**).
    - the velocity may vary within a season. There is usually a decreasing trend during the colder season and an accelerating trend during the warmer season, and thus a large amplitude is possible. Ground temperature and water content appear to be the main drivers of these velocity variations.
    - other changes over various time scales could occur (e.g. destabilization, short-term peaks).

Hence, the kinematic attribute has to be, as far as possible, representative of the **multi-annual movement rate of the rock glacier unit at the time of an inventory** (snapshot). It should provide a generic velocity information about the inventoried rock glaciers, that allows comparisons within and between rock glacier inventories at regional and global scales. The kinematic attribute should be derivable from in situ or remote sensing measurements. Contrary to the velocity time series (see "Rock glacier velocity (RGV) as an associated parameter of ECV Permafrost"), it has no monitoring purpose.

3. Determination of the kinematic attribute

Rock glacier kinematics are defined as the surface movement rate related to the downslope creep. The kinematic attribute is a semi-quantitative (order of magnitude) velocity information.

A two-step procedure, possibly iterative, is proposed to assign a kinematic attribute to inventoried rock glacier units. It consists of:

a) identifying **moving areas** on rock glaciers (3.1) and assigning a **velocity class** based on adequate kinematic data (3.2);

b) categorizing the inventoried **rock glacier units** with a **kinematic attribute** based on the previously identified moving area(s) (3.3).

The identification and characterization of moving areas (a) is an initial step, after which it is recommended to subsequently assign a kinematic attribute to a rock glacier unit (b) (**2**).

3.1 Moving areas

The identification of **moving areas (MAs)** can be performed using a single technique or a combination of techniques providing surface velocity maps over entire mountain slopes or ranges. The MAs may document processes other than rock glacier creep. To focus on rock glaciers in the absence of any already existing inventory, a simultaneous thorough analysis of aerial images is necessary, and a sufficient knowledge of geomorphology is therefore required.

When related to an inventoried rock glacier, a **MA** is defined as an **area at the surface of the rock glacier in which the observed direction and velocity of the flow field are spatially consistent and homogeneous during a documented time**. It must represent its downslope motion rate (permafrost creep), where confusion with movement related to other processes (e.g. melt-induced subsidence or subjacent deep-seated landslide) should be avoided.

Identification and delineation of MAs must be performed **in accordance with the following requirements**:

- the delineation of a MA is strictly dependent on the mapped surface velocity. It is not constrained by any geomorphological feature and does not have to be adjusted to the rock glacier margins.
- any MA can override the geomorphological limits of a rock glacier unit (e.g. when two overlying/adjacent rock glacier units are moving at rates that are not significantly different, or if the rock glacier is spatially connected with another moving landform).
- the velocity range within a MA should not exceed a min/max ratio of 1:5 (i.e. half an order of magnitude). Otherwise, the MA must be split in two or more MAs with variable velocities. Thereby, several MAs can be superimposed, with a slower MA always embedding a faster one.

In addition, it should be acknowledged that:

- the minimum extent of a MA depends on the spatial resolution of the data input, but also on the size of the considered landforms. It is based on the operator's judgment.
- the delineation of a MA is often difficult to obtain with precision, depending for instance on the detection capability of the applied technique but also on the time during which the observation is performed. Therefore, the use of kinematic datasets spanning several seasons/years is recommended.
- a single point measurement is basically not a MA, but the information it provides could be taken into consideration if it can be spatially related to any MA.
- areas outside of any delineated MA refer without distinction either to a lack of movement, to a movement that may be under the detection limit, to unreliable data or to the absence of any analysis.

Any MA is always **stamped by time characteristics**, which are mostly related to the technique in use. These characteristics include:

- the *observation time window*, i.e. the period during which the detection and characterization is computed/measured (e.g. multi-annual, annual, intra-annual). When the technique does not allow for an annual or multi-annual observation time window, the minimal required duration is 1 month (which can also be obtained by aggregating observations of several shorter time windows).
- the *validity time frame*, i.e. the duration during which the periodic measurements/computations are repeated and aggregated for defining the MA (i.e. during which year(s)).

The *reliability* (or the degree of confidence) of the MA detection/delineation must be qualitatively documented (e.g. low, medium, high).

3.2 Velocity of a moving area

Assigning accurate velocity values (e.g. mean, median, amplitude, min/max) to a MA is a very challenging task, which strongly depends on the data quality, the measurement technique, and consecutively, the extent of the MA. In order to facilitate the assignment of homogeneous and simplified velocity information to MAs, the use of **velocity classes** is therefore proposed.

The velocity class documents the overall movement rate observed in a MA during a considered *time frame* and according to a specific *observation time window*. It must, as far as possible, refer to a **multi-annual surface velocity representative of the creep rate**. However, the measured/computed velocity is partly dependent on the applied technique and the conditions of observation. Some methodologies only allow for observations during summertime, meaning that the velocity cannot be measured over an annual time interval. The dimensionality (one- to three-dimensional displacement observation) also varies depending on the technique.

In consequence, various ways of classifying could be applied (e.g. range, number and limits of classes, dimensionality). The definition of the velocity classes as well as the rules for subsequently assigning the kinematic attribute to a rock glacier unit are actually dependent on the used technique and it is up to the operator to set them. An example is provided in section 4.

The exploited data, the applied method, the observation time window and the validity time frame must always be documented. The *reliability* (or the degree of confidence) *of the velocity class assignment* must be assessed (e.g. low, medium, high) in combination with the reliability of the MA detection/delineation (cf. 3.1).

3.3 Rock glacier kinematic attribute

The **kinematic attribute (KA)** is the category assigned to a rock glacier unit based on the MA characteristics (extent, velocity class, time specificities), which have been detected on its surface. It must reflect the overall kinematic state of the rock glacier unit **at the time of the inventory** (*validity time frame, cf. 3.1*). In order to minimize the potentially large inter-annual variations of rock glacier velocity, the validity time frame must be set **to minimum 2 years**, but a longer range is recommended.

The KA consists of **semi-quantitative categories expressing the multi-annual downslope velocity** of an entire rock glacier unit, as follows:

Category	Label	Comment	Related activity
0.	Undefined	default category	
1.	< cm/yr	no up to very little movement	relict
2.	cm/yr	order of magnitude ≈ 0.01 m/yr	transitional
3.	cm/yr to dm/yr	order of magnitude ≈ 0.05 m/yr	transitional
4.	dm/yr	order of magnitude ≈ 0.1 m/yr	active
5.	dm/yr to m/yr	order of magnitude ≈ 0.5 m/yr	active
6.	m/yr	order of magnitude ≈ 1 m/yr	active
7.	> m/yr	more than ≈ 3 m/yr per year	active

A KA is assigned to a rock glacier unit only when the latter is documented by **consistent kinematic information on a significant part of its surface**. There is only one kinematic category per rock glacier unit. However, as a dominant MA rarely covers an entire rock glacier unit and may not reflect a multi-annual displacement rate, a systematical translation of the velocity class of a MA to KA of a rock glacier unit is not always straightforward and has to be performed carefully. In addition to the characteristics of the MAs, the KA is highly dependent on the technique and the operator's judgment. It must also be taken into consideration that the documented surface velocities may be faster than the effective rock glacier displacement rate at depth and that intra-annual (usually summer) velocities may be faster than annual velocities (cf. 3.1).

The default category is *0. Undefined*. The rock glacier unit falls into this category when:

- no (reliable) kinematic information is available,

- the kinematic information is derived from a single point survey which cannot be related to any MA (as defined in 3.1),
- the rock glacier unit is mainly characterized by an identified MA of undefined or unreliable velocity,
- the kinematic information is too heterogeneous.

If two equally dominant, but directly adjoining KA categories (e.g. 5-6) occur on a rock glacier unit, the category of the area closer to the front is favored for the attribution. In case of a larger spread of equally dominant categories on the same rock glacier unit (e.g. 4-6), the median category (e.g. 5) should be retained, with an additional indication about the heterogeneity and the low reliability of the attribution. A large heterogeneity can also indicate the need to refine/redefine the delineation of the initial geomorphological units (iterative process combining geomorphological and kinematic approaches).

For each rock glacier unit with an assigned KA, the following additional information must be documented, depending on the supporting kinematic data (e.g. identified MAs):

- *observation time window* (e.g. multi-annual, annual, intra-annual) and multi-year *validity time frame* of the attributed category,
- *exploited data, applied technique(s) and their properties,* e.g. dimensionality of the resulting kinematic data (velocity values),
- *approximated spatial representativeness*: percentage of the rock glacier area that is documented by supporting kinematic data (e.g. < 50%, 50-75%, > 75%),
- *reliability of the assignment* of the KA (low, medium, high).

The KA is a generic parameter that can be retrieved from various measurement techniques. Conversely, the determination of velocity classes related to MAs as well as the rules for subsequently using this information to assign a KA to a rock glacier unit are dependent on the technique used to measure/compute the velocity and should be specified for each.

An example of assignment rules is provided in section 4.

4. Example of application: assigning a rock glacier kinematic attribute based on InSAR-derived moving areas

Within the framework of the European Space Agency Climate Change Initiative (ESA CCI+) Permafrost project (2018-2021) and in accordance with the present document, recommendations have been stated for a systematic procedure based on the accurate interpretation of **wrapped interferometric signals from large InSAR datasets**. The practical guidelines describe standards to locate and estimate the displacement rate of MAs related to rock glaciers and the translation rules to subsequently assign a KA to the rock glacier units. These detailed rules are provided as an example. They are described in the specific *Practical guidelines: rock glacier inventory using InSAR (kinematic approach)*. These recommendations could be applied to other InSAR methods (unwrapped interferograms, stacking, SBAS, PSI, IPTA, etc.) but they require an initial evaluation regarding the need for any specific adaptations.