IPA Action Group Rock glacier inventories and kinematics

Towards standard guidelines for inventorying rock glaciers

Baseline concepts

(Version 4.1)

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The document has been edited by Reynald Delaloye and Thomas Echelard (University of Fribourg, Switzerland) with the contribution of the participants at the workshop held in Evolène (Switzerland) on 23 - 27 September 2019 as well as further members of the Action Group.

The purpose of this document is to serve as a baseline for the establishment of practical guidelines permitting to inventory rock glaciers on a global scale.

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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. 4.0.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 minor content changes appear to be necessary, they will be adopted by the dedicated committee named in Evolène in September 2019, including Xavier Bodin (France), Francesco Brardinoni (Italy), Reynald Delaloye (Switzerland), Christophe Lambiel (Switzerland), Shelley MacDonell (Chile), Line Rouyet (Norway) and Lucas Ruiz (Argentina). The second digit of the versioning will be changed (4.x) and an information will be sent to the Action Group subscribers.

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

Contents

Preamble

Rock glacier inventories have been set up for decades all around the world, yet without any real coordination, making their global assemblage and uniform completion impossible. In the meantime, quantitative information about kinematics has been made available for numerous rock glaciers, particularly with the development of remote sensing techniques. The IPA (International Permafrost Association) Action Group *Rock glacier inventories and kinematics* (2018–2022) aims at **exploring the feasibility of developing widely accepted standard guidelines for inventorying rock glaciers on a global scale, including information on their kinematics**.

Defining standard guidelines for inventorying rock glaciers constitutes Task 1 of the Action Group. It has been divided into three Sub-Tasks, namely:

- 1.1: definition of the *main concepts and principles* (present document),
- 1.2: establishment of *practical inventorying guidelines* (including worldwide examples),
- 1.3: establishment of a *technical (operational) manual*, on how to implement a rock glacier inventory in an open-access database.

The present document intends to set the necessary **baseline concepts** for inventorying rock glaciers on a global scale (Sub-Task 1.1). Its content is the result of a preparatory workshop held in Chambéry (France) on 23 March 2019, comments received about the workshop wrap-up, further informal meetings and discussions between participants of the Chambéry meeting, comments received on version 1.0 until 15 August 2019, the revision of version 2.0 during the international workshop held in Evolène (Switzerland) on 23-27 September 2019 and comments received on version 3.0 (post-workshop I).

Provisional timeline

The current document is the final version and is submitted for approbation until 31 December 2020.

The practical guidelines for inventorying rock glaciers (Sub-Task 1.2) will be compiled in a next stage starting in spring 2020 on the basis of the present version of the baseline concepts. A number of technical aspects, which have been discussed during the Workshop I, will be integrated and further detailed in these *practical inventorying guidelines*.

1. Purpose of standardized guidelines

Today, although many (published and unpublished) regional rock glacier inventories exist, they are not exhaustive worldwide. Existing rock glacier inventories have various ages and have been compiled using different methodologies, which mainly depend on the experience of the cartographer, review process and availability of appropriate source data (e.g. satellite imagery), as well on the varying objectives that motivated each single study. For these reasons, merging all existing inventories in a fully coherent way is presently not possible.

The increasing emergence of open-access satellite imagery (e.g. optical, SAR) facilitates the development of new inventories and/or the update of existing ones. The growing availability of remotely sensed data (e.g. Sentinel-1 SAR images) makes also the systematic detection of rock glacier surface motion, and consequently, the integration of kinematic information in standardized rock glacier inventories potentially feasible.

Previous glacier-oriented initiatives, such as the World Glacier Inventory (WGI) or Global Land Ice Measurements from Space (GLIMS), tried to include rock glaciers but have not succeeded in being systematic and homogeneous. It has been particularly difficult to properly include rock glaciers due to the complexity of detecting them automatically by remote sensing (GLIMS methodology).

The development of widely accepted standard guidelines for inventorying rock glaciers, including kinematic information, is becoming an urgent task to be fulfilled by the scientific community of concern. It will serve the compilation of new regional inventories and the adaptation of existing ones, hence leading – as a final objective – to the merging of all inventories in a more homogeneous open-access worldwide database. Standard guidelines should also help to avoid, or at least minimize, potential discrepancies between various usages of rock glacier datasets.

Inventorying rock glaciers is a manual (visual) procedure, which cannot be automatized yet and requires geomorphological expertise by the operators. Identifying and characterizing rock glaciers has often led to various and sometimes controversial opinions due to the complexity of morphologies (e.g. multiple generations, coalescent landforms, heterogeneous dynamics, interaction with glaciers) and the diversity of environments in which rock glaciers have developed. In order to overcome any endless discussion, it must be accepted that subjectivity is part of the process of rock glacier mapping. Establishing standard guidelines aims at minimizing its impact. It could even be envisaged that an increasing number of manually identified rock glaciers based on a widely accepted standard would support the development of automatic techniques (e.g. deep learning) as a complementary tool to compile inventories.

2. Inventorying rock glaciers

Rock glaciers are characteristic landforms associated to mountain periglacial landscapes. They are prevalent periglacial items of the Earth's geomorphological heritage, whose identification (detection and delineation) can be nevertheless challenging. Motivations for producing rock glacier inventories and approaches to create them are various.

a) Motivations for producing a rock glacier inventory

Basic and applied scientific motivations for producing an exhaustive rock glacier inventory at various scales can be summarized as follows:

- **Geomorphological mapping**: rock glaciers are identified and mapped as functional[1] or inherited[2] (relict) landforms of the geomorphological landscape: they are part of the mountain sediment cascade and as such contribute to control the pace of periglacial mountain landscape evolution. Enhancing the value of geomorphological heritage could also be the main motivation to compile a rock glacier inventory.

- **Proxy for permafrost occurrence**: functional rock glaciers are geomorphological indicators of the occurrence of permafrost. Even if it is accepted that functional rock glaciers may export perennially frozen ground outside of a permafrost prone area, they can be used to approximate the regional lower limit of the mountain permafrost belt and to validate spatial models of permafrost extent. Conversely, inherited (relict) rock glaciers are discriminative landforms of currently permafrost-free areas. Although functional rock glaciers attest to the occurrence of permafrost at depth, it must be considered that given the ongoing climate change, these features may gradually no longer reflect surface conditions favorable to permafrost occurrence.

- **Paleo-permafrost studies**: inherited (relict) rock glaciers can be used as proxies for various paleo-permafrost extents. Discrimination between inherited and functional state is often difficult, making integration of inherited landforms in a global inventory indispensable.

- **Climate relevant variable**: rock glacier movement is particularly sensitive to changing permafrost temperature. Updating and comparing inventories of functional rock glaciers, which include temporally well-constrained kinematic information, can be used to assess the impact of ongoing climate change on the mountain periglacial environment over regions.

- **Hydrological significance**: functional rock glaciers are, by nature, ice (and water) storage features, which may play a prominent role in the hydrological regime of mountain catchments, especially in dry areas. Rock glacier inventories have been developed and/or used in particular for estimating their regional water-equivalent significance. In addition to being ice storage features, rock glaciers can affect water transit time and water chemistry in a catchment.

- **Geohazards**: functional rock glaciers may be the source of direct or indirect geohazards (e.g. destabilization, conveying of loose debris into a debris flow prone gully) that may pose risk to human activities and/or facilities (e.g. transport infrastructures, buildings, livelihoods). Rock glacier inventories and related kinematic data can be used to locate and assess some potential geohazards at local to regional scales. It must be noted that in the context of infrastructure construction/maintenance, using a rock glacier inventory will not be sufficient to fully understand the issues related to permafrost degradation. However, it may provide clues for assessing the occurrence (or absence) of permafrost in the study area.

It is very important to note that the original motivation for producing a rock glacier inventory may differ from that of a subsequent third-party user. Therefore, standardized guidelines should help to avoid, or at least minimize, potential discrepancies.

b) Inventory compilation

Two main approaches have been commonly used for compiling a rock glacier inventory:

- **Geomorphological approach**: rock glaciers are recognized by a systematic visual inspection of the (imaged) landscape and DEM-derived products. To this purpose, surface texture and morphometric analysis could also be used. This is the classical approach, locally complemented by field visits. It

[1] In a geomorphological slope sequence, a functional rock glacier is a landform, which is currently conveying sediments from a rooting zone towards its front.

[2] In a geomorphological slope sequence, an inherited rock glacier is a landform, which today no longer conveys sediments from a rooting zone towards its front, due to permafrost exhaustion.

allows the production of exhaustive inventories of presumed moving and non-moving landforms, whose discrimination (activity classes) is primarily based on geomorphological characteristics. Photogrammetry and LiDAR DEM surveys, when available, facilitate the identification of rock glaciers in forested areas.

- **Kinematic approach**: moving areas, which may be temporally and spatially heterogeneous, are detected using multi-temporal remotely sensed data (e.g. SAR-derived products, multi-temporal airborne LiDAR, high resolution optical satellite and aerial images). The association of a moving area to a rock glacier is then mainly performed by the geomorphological assessment of optical images (geomorphological approach). This approach is limited to the non-exhaustive identification and delimitation of moving areas on rock glaciers, whereas non-moving rock glaciers, for instance, are missed. It provides quantitative data for evaluating the motion rate of rock glaciers. It also allows the identification of moving areas, which cannot be geomorphologically related to rock glaciers.

Whereas the two approaches are complementary and can be used in an integrated and iterative process, a rock glacier inventory is by definition a geomorphological inventory.

3. Rock glaciers

The following section defines rock glaciers in the perspective of generating a standardized inventory and details various significant aspects related to their characterization.

a) Technical definition of rock glaciers

The present technical definition (also called working definition) is exclusively addressed to frame rock glacier inventorying and lies beyond any outstanding controversy, for example about rock glacier genesis and ice origin. The following technical definition relies on the most common geomorphological evidences allowing the identification of rock glaciers in the landscape:

Rock glaciers are debris landforms generated by a former or current creep of frozen ground (permafrost)[3], detectable in the landscape with the following morphologies: front, lateral margins and optionally ridge-and-furrow surface topography. In a geomorphological slope sequence, rock glaciers are (or were) landforms conveying debris from an upslope area (source area or rooting zone) towards their front. The debris grain size is not specified.

Geomorphological criteria:

- **Front** (mandatory criterion): a discernable talus delimiting the terminal part of a (former) moving area overriding a non- or less-moving terrain and, when non-eroded, drawing a convex morphology perpendicular to the principal (former) flow direction. For a rock glacier developing on a steep slope, the front may be difficult to recognize.
- **Lateral margins** (mandatory criterion): discernible lateral continuation of the front. Lateral margins may nevertheless be absent in particular in the upper part of the landform.
- **Ridge-and-furrow topography** (optional criterion): pronounced convex downslope or longitudinal surface undulations associated with current or former compressive flow.

In coherence with global glacier inventories standards, and given the technical limitations (that may evolve in the future), it is recommended that the minimum rock glacier size applied for an inventory

[3] Rock glacier (or permafrost) creep has to be understand here as a generic term referring to the variable combination of both internal deformation within the crystalline structure of the frozen ground (creep stricto sensu) and shearing in one or several discrete layers at depth

to be included into a global compilation should be 0.01 km^2. Nevertheless, inventories at higher resolution are encouraged.

Discriminating rock glaciers from other landforms

Without the knowledge of the environmental context and/or limited mapping experience, some landforms may express rock glacier-like morphology (e.g. solifluction lobe, earth flow, and lava flow) leading to inconsistent mapping.

Permafrost creeping areas that can be detected as moving in a kinematic approach but that do not express the morphology typical of a rock glacier (as it is for many push-moraines and for frozen debris lobes) are also excluded from this definition. Therefore, a rock glacier inventory is an inventory of rock glaciers only, but is neither an inventory of any ground ice occurrences, nor of any other mountain permafrost-related landforms.

Rock glaciers should also not be mistaken with debris-covered glaciers, which are glaciers partially or completely covered by supraglacial debris. In some cases, the downslope transition from glacier to debris-covered glacier and possibly to a rock glacier is extremely challenging to define (cf. Section 3c).

b) Rock glacier morphological system and units

Rock glaciers with a complex morphology (e.g. multiple generations, multiple lobes, coalescent lobes and heterogeneous dynamics) are common and difficult to characterize unequivocally. To address this issue the following hierarchical **classification scheme** is adopted:

- **Rock glacier system**: landform identified as a rock glacier according to the technical definition provided in Section 3.a, which is composed of either a single or multiple *rock glacier unit(s)* that are spatially connected, either in a topo-sequence or through coalescence.

- **Rock glacier unit**: single rock glacier landform that can be unambiguously discerned according to the technical definition provided in Section 3.a and, in case of a spatial connection, can be differentiated from other (adjacent or overlapping) rock glacier units according to the following criteria:

    - Geomorphological and land cover attributes suggest a distinct generation of formation (e.g. overlapping lobes),
    - Connection to the upslope unit can be discriminated (see Section 3.c),
    - Activity is clearly different (see Section 3.d).

  A rock glacier **unit** consists of a single lobate structure. More complex structures of multiple lobes are classified as **composite**. Composite rock glaciers consists of **sub-units**, which in turn could be single or composite ones. The structure of a rock glacier (sub-)unit can be **simple** or **complex**. Overridden (sub-)units are only partially visible and must be considered as such when characterized.

c) Spatial connection of the rock glacier to the upslope unit

The geomorphological unit located directly upslope of a rock glacier system can hold implications for the characterization of the latter (e.g. internal structure and composition, ice origin, ice content) as well as the designation of attributes (e.g. landform outlining, definition of the rooting zone). The focus is set on the spatial (structural) connection because it is generally discernable in optical images. The spatial connection of the rock glacier to an upslope unit does not necessarily mean that there is a dynamic and/or genetic connection. The term “derived” is not used because it implies an interpretation of the origin of both debris and/or ice.

- **Talus-connected**: The rock glacier is part of a downslope sequence including headwall – talus slope – rock glacier (sometimes the talus slope is almost lacking). The rock glacier unit is subjacent and connected to a talus slope unit, which is dominantly fed by rock fall activity, but may also be fed by surface runoff, debris flow and/or avalanche events from the headwall unit. Sediment transfer across the talus slope unit can be operated by a number of interrelated processes. The area connecting the talus slope and rock glacier is often characterized by a concave morphology, where the episodic to frequent development of long-lasting avalanche cones, snow/ice patches or even small glaciers (relative to the rock glacier size) may occur. In the latter case, although the episodic disappearance of a glacier may imply the lack of an efficient sedimentary connection with the relevant upslope unit, the rock glacier is still classified as talus-connected.

  Protalus ramparts are included in this category as "embryonic" rock glaciers if they are related to permafrost creep. They should not be confused with protalus-looking landforms related to (former or present) snow accumulation (i.e. pronival ramparts).

- **Debris-mantled slope-connected**: The rock glacier lacks of any (significant) headwall. The debris is dominantly produced by in-situ bedrock weathering (debris mantle) and gradually put into motion by shallow, surficial mass movement processes (e.g. solifluction) before developing into a rock glacier feature.

- **Landslide-connected**: The rock glacier is located in direct downslope spatial connection to a landslide (i.e. rock or debris slide) or lies on a large deep-seated gravitational slope deformation. In these situations, the talus slope unit is usually lacking.

- **Glacier-connected:** Continuity from a (debris-covered) glacier or ice patch to a rock glacier feature ("debris-covered glacier to rock glacier" transition). Delimitation between the glacier or the ice patch section and the rock glacier section is not feasible without further direct or geophysical prospection. Embedded glacier ice within the rock glacier is likely to occur. Geomorphological indices evidencing the presence of a debris-covered glacier upslope of the apparent rock glacier feature may be observed (e.g. crevasses, thermokarst, meltwater channels).

- **Glacier forefield-connected:** Interaction between a glacier or ice patch and the rock glacier feature is prevalent, but essentially restricted to phases of glacier advance (e.g. Little Ice Age). Embedded glacier ice within the rock glacier is possible. When receding, which is a common pattern nowadays, the glacier has disconnected from the rock glacier or may have completely disappeared. This category includes till-derived rock glaciers, which correspond to the classical debris rock glacier definition and push-moraines (glacitectonized frozen sediments).

- **Other**: Other type of geomorphological sequence related to a rock glacier landform.

- **Poly-connected:** Two or more upslope connections (e.g. talus- and glacier-connected). The use of poly-connected should be restricted to cases where there is no large dominance of one type of upslope connection.

An attribute value, defining whether the rock glacier is currently connected to the upslope unit or not, must be added.

d) Rock glacier activity

Background

The activity of rock glaciers was conceptually and classically categorized regarding the presumed flow behavior and, in relation to this, the ice occurrence. Primarily based on the visual observation of geomorphological (e.g. front slope angle) and vegetation-related indicators, which differ locally and regionally due to lithological and climatic settings, rock glaciers have been most commonly classified into the following categories of activity:

- Intact:
    - Active: rock glaciers bearing excessive ice that are in effective motion.
    - Inactive: rock glaciers that remain (almost) motionless yet still contain ice.
- Relict: rock glaciers that have stopped moving, often several hundreds to thousands of years ago, due to the loss of (almost) all their ice.

Historically, regional inventories of rock glaciers have been based on a *geomorphological approach*. In-situ or remotely sensed kinematic data as well as field visualizations have remained occasional. Activity attribution based on the geomorphological approach is a highly subjective task depending on the operators' skills. As a result of the continuous development of remote sensing techniques (e.g. photogrammetry, satellite-borne InSAR), kinematic information on surface motion can henceforth be obtained for a large majority of rock glaciers. This could allow the refinement of rock glacier activity categories.

Whereas the classical categorization may have considered the activity of rock glaciers as almost constant over time at a scale of decades to centuries, observations of rock glacier kinematic behavior, in particular in the European Alps, show that an acceleration by a factor 2 to 10 of the surface velocities between the 1980s and 2010s has been a common feature in many sites, probably in response to increased permafrost temperature resulting from warmer air temperature. Whereas a significant majority of the rock glaciers follow this regional trend, some single features manifest singular behaviors (e.g. reactivation, rapid acceleration, destabilization or decrease in velocity). In cold permafrost regions (e.g. Arctic or high altitude Andes), rock glaciers, which are almost stationary or moving only very slowly, may accelerate in response to warming.

These scientific observations have revealed the need of refining and/or redefining the categorization of rock glacier activity.

Updated categorization of activity

The following conceptual categorization of rock glacier activity refers exclusively to the efficiency of the sediment conveying (expressed by the surface movement) at the time of observation, and should not be used to infer any ground ice content. The categories are still based on geomorphological indicators, which have to be adapted regionally or contextually. If areal or point kinematic data are available, they should be integrated as a supplementary attribute and must be considered in order to assign the category of activity, which is defined as:

- **Active**: rock glacier moving downslope over most of its surface.
    - If no kinematic data is available: an active rock glacier shows geomorphological evidence of downslope movement such as a steep front (steeper than the angle of repose) and possibly lateral margins with freshly exposed material on top.
    - If adequate kinematic data is available: an active rock glacier shows coherent downslope movement over most of its surface. As an indication, the displacement rate can range from a decimeter to several meters per year.
- **Transitional:** rock glacier with low movement only detectable by measurement and/or restricted to areas of non-dominant extent. According to the topographic and/or climatic context, transitional rock glaciers can either evolve towards a relict (degraded) or an active state.

  - If no kinematic data is available: a transitional rock glacier has less distinct geomorphological evidences of current downslope movement than active rock glaciers in the same regional context.
  - If adequate kinematic data is available: a transitional rock glacier shows little to no downslope movement over most of its surface. As an indication, the average displacement rate is less than a decimeter per year in an annual mean over most of the rock glacier. Downslope movement must not be confused with subsidence.
- **Relict***:* rock glacier with no detectable movement and no geomorphological evidence of recent movement.
  - If no kinematic data is available: a relict rock glacier shows no geomorphological evidence of recent movement. The relict state could also be indicated by vegetation and soil cover (e.g. lichen, grass, forest), subdued topography, and smoothed lateral and frontal slopes/margins. Relict rock glaciers are generally found at lower elevations than the active ones.
  - If adequate kinematic data is available: a relict rock glacier shows no detectable downslope movement over most of its surface and the geomorphological characteristics are as described above.
- **Undefined***:* inadequate data for discriminating between the activity classes.

Any activity assessment must be dated and defined (i.e. based on geomorphological identifiers only or supported by kinematic data).

The details about the use of kinematic data in a standardized inventory will be developed in a separated document and implemented in the *practical inventorying guidelines*.

e) Rock glacier destabilization

The motion rate of some rock glaciers may be characterized by a drastic acceleration that can lead the landform, or a part of it, to behave abnormally fast (i.e. no longer following the regional trend) for a minimum of several years. The term ***destabilization*** has been progressively used since the 2000s to refer to rock glaciers with obvious signals of abnormally fast displacement, often matched by the opening of large cracks and/or scarps.

Destabilized rock glaciers generally display an initial acceleration phase, followed by a high velocity phase and finally a deceleration phase. The morphology of destabilized rock glaciers, characterized by large scarps and/or cracks, can be preserved for a long time after the high-velocity phase has ended. Whereas this surface expression can be documented in an inventory as evidence of a current or past destabilization phase, an actual state of destabilization can only rely on kinematic data. Multiannual time series showing displacement rates of several meters per year and departing from the regional trend (if known) attest to the actual destabilization phase. Rock glaciers experiencing an ongoing destabilization phase constitute a sub-category of active rock glaciers and must be inventoried as such.

It is worth noting that destabilization is not used here in a geotechnical, slope stability context, but solely to describe the above described temporal variability in rock glacier deformation.

f) Outlining rock glaciers

Technically defining a rock glacier as a landform implies setting a distinct outline, and for various practical issues (e.g. area calculation) this outline has to be a polygon. Mapping an outline retains some degree of subjectivity, i.e. it is dependent on the “operator”. Recent work shows that the operators’ mapping styles may highly differ and significantly impact the exploitation of any rock glacier inventory data. For example: i) a rock glacier specific area directly affects a first-order assessment of inherent water content; ii) maximum and minimum rock glacier elevations directly influence altitudinal thresholds derived for modelling past or present occurrence of mountain permafrost. Therefore, “outlining rules” must be clearly defined in order to minimize subjectivity as much as possible. Nevertheless, if boundaries are uncertain, this uncertainty should be specified and highlighted in the database.

In order to address all inventorying motivations (c.f. Section 2.a), two ways of delineating rock glacier boundaries are recommended to be included as standards: the ***extended*** and the ***restricted geomorphological footprints***. If only one footprint is chosen, it must be clearly specified.

- **Extended geomorphological footprint**: the outline embeds the entire rock glacier up to the rooting zone and includes the external parts (front and lateral margins).
- **Restricted geomorphological footprint**: the outline embeds the entire rock glacier up to the rooting zone and excludes the external parts (front and lateral margins).

The delineation of the upper part of the rock glacier footprint and the definition of the rooting zone depend on the spatial connection of the rock glacier to the upslope unit (cf. Section 3.c). The details of this procedure will be described in the *practical inventorying guidelines*.

g) Differentiation between rock glaciers and debris-covered glaciers

Rock glaciers, as landforms resulting from a permafrost creep process, should not be confused with debris-covered glaciers. Typically, there are two main examples of misrecognition: either the entire glacier is confused with a rock glacier (or the reverse), or the rock glacier is located in front of a glacier in a “debris-covered glacier to rock glacier” sequence (c.f. Section 3.c, glacier-connected) and is difficult to be recognized/delineated unambiguously in the absence of direct observation at depth.

An arbitrary separation between rock glaciers and debris-covered glaciers can be based on morphological and textural criteria. A “checklist table” will be provided in the *practical inventorying guidelines* helping the distinction.

4. Inventorying strategy

Carrying out a rock glacier inventory requires the following steps:

- Recognition of landforms (system/units) to be inventoried *(i.e. detecting rock glaciers).*
- Attribution of a unique identifier code (ID attribution) and georeferencing *(i.e. locating rock glaciers).*
- Attribution of characteristics (attributes), including kinematic information if available *(i.e. characterizing rock glaciers).*
- Outlining *(i.e. delineating rock glaciers).*

The detailed procedure for inventorying rock glaciers will be described in the *practical inventorying guidelines*, but the baseline concepts are provided hereafter.

a) Detecting rock glaciers

Detecting rock glaciers consists **primarily of recognizing landforms** (rock glacier systems and related units) according to the technical definition proposed in Section 3a. This could be performed based on ortho-imagery, as well as DEM-derived products, but also with the help of kinematic data (e.g. InSAR) as a complementary approach.

b) Locating rock glaciers

Any rock glacier system and related unit(s) must be identified by a **primary marker** (primary ID). The marker is a **point** whose associated **primary attributes** allow to:

- Locate the rock glacier (system/units, georeferencing),
- Discriminate it clearly from other rock glacier system/units,
- Associate a rock glacier system to its constituting units and vice-versa.

Any other information related to a rock glacier system/unit can then be linked to its primary marker.

The positioning of the point on the rock glacier should avoid, as far as possible, any (frequent) temporal updating. It should not refer to anything else than the three identifying aspects listed above.

In case of a composite rock glacier system (c.f. Section 3.b), the scale of discrimination between units depends on the study motivations, the operator, the available data and the complexity of the landform (in particular for relict rock glaciers whose identification is complicated by vegetation and/or time/erosion). Thus, a **multi-level (-tiered) system of marking** has to be adopted. It is expected that 3 or 4 levels suffice for the complicated cases, but it is essentially not restricted.

c) Characterizing rock glaciers

Rock glacier characteristics are attributed to each rock glacier unit (c.f. Section 3.b) defined by a primary marker (e.g. connection to upslope unit, activity), regardless of the unit level.

The classifications “unknown” or “undefined” should be used more frequently than today in cases of obvious uncertainty in characterizing rock glaciers.

Areal or point-related kinematic data could be integrated as supplementary data associated to the primary markers, but not necessarily describing the same entire area. Specific guidelines are in preparation within the framework of the ESA project CCI+ Permafrost – Options Mountain Permafrost (2019-2021).

d) Delineating rock glaciers

Specific instructions for delineating the boundaries (outlines) of a rock glacier will be provided in the *practical inventorying guidelines*. Rules for mapping outlines of the extended and restricted footprints have to be defined specifically for each category of the *spatial connection of the rock glacier to the upslope unit* (cf. Section 3.c) and followed as strictly as possible. Any pre-existing outline which does not follow the defined rules should not be included in a standardized global inventory but should be adapted if necessary.

Acronyms

DEM	Digital Elevation Model
ESA CCI+	European Space Agency, Climate Change Initiative (link)
GLIMS	Global Land Ice Measurements from Space (link)
InSAR	Interferometric Synthetic Aperture Radar
IPA	International Permafrost Association (link)
LiDAR	Light Detection And Ranging
SAR	Synthetic Aperture Radar
WGI	World Glacier Inventory (link)