permafrost
cci

CCI+ PHASE 1 – NEW ECVS
PERMAFROST

CCN1 & CCN2
ROCK GLACIER KINEMATICS AS NEW ASSOCIATED PARAMETER OF ECV PERMAFROST

D1.1 User Requirement Document (URD)

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EUROPEAN SPACE AGENCY CONTRACT REPORT

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Executive summary

Within the European Space Agency (ESA), the Climate Change Initiative (CCI) is a global monitoring program which aims to provide long-term satellite-based products to serve the climate modelling and climate user community. Permafrost has been selected as one of the Essential Climate Variables (ECVs) which are elaborated during Phase 1 of CCI+ (2018-2021). As part of the Permafrost_cci baseline project, ground temperature and active layer thickness were considered the primary variables that require climate-standard continuity as defined by GCOS. Permafrost extent and zonation are secondary parameters, but of high interest to users. The ultimate objective of Permafrost_cci is to develop and deliver permafrost maps as ECV products primarily derived from satellite measurements. Algorithms have been identified which can provide these parameters ingesting a set of global satellite data products (Land Surface Temperature LST, Snow Water Equivalent SWE, and landcover) in a permafrost model scheme that computes the ground thermal regime. Annual averages of ground temperature and annual maxima of thaw depth (active layer thickness) were provided at 1km spatial resolution during Year 1 of Permafrost_cci. The data sets were created from the analysis of lower level data, resulting in gridded, gap-free products.

CCN1 and CCN2 options address the need for additional regional cases in cooperation with dedicated users in characterising mountain permafrost as a local indicator for climate change and direct impact on the society in mountainous area. Started in October 2018, CCN1 is led by a Romanian team focusing on case studies in Carpathians. The specific objective of CCN1 is to develop and deliver maps and products, such as rock glacier inventories, kinematical time series of selected rock glaciers and a permafrost distribution model for Southern Carpathians, primarily derived from satellite measurements. Started in September 2019, CCN2 consists of two options led by Swiss and Norwegian teams focusing on the investigation and definition of a new associated ECV Permafrost variable related to rock glacier kinematics through the two products “regional rock glacier inventory” and “kinematical time series of selected rock glacier”. Actually, inventories and monitoring of rock glaciers are not explicitly mentioned as being an ECV associated parameter. But in mountainous terrain, the frozen ground is often continuously moving and considerable volumes of debris or fractured rocks are transferred. Rock glaciers are the best visual expression of the creep of mountain permafrost and constitute an essential geomorphological heritage of the mountain periglacial landscape. Their dynamics is largely depending on climatic factors and may locally interact with human activities (e.g. debris flow initiated from a rock glacier snout). Observing changes in rock glacier kinematics, which is primarily feasible by means of processing remote sensing data at landscape scale, provides information about the climatic impact on mountain permafrost and has the potential to become a key parameter of cryosphere monitoring in mountain regions. Conversely, rock glacier monitoring also forms a unique validation dataset for climate models in mountain regions, where direct permafrost (thermal state) measurements are very scarce or even totally lacking. The Permafrost_cci CCN2 team and users are thus proposing that a proper rock glacier monitoring adapted to climate issues should be integrated as a new associated parameter to the ECV permafrost in order to: 1) assess impacts related to the baseline proposal results for mountain regions and 2) validate baseline proposal permafrost modelling results on a regional scale. The specific objective of CCN2 is to provide additional regional cases in the European Alps, Northern Norway, Svalbard and four selected sites in different climatic contexts, as well as tools and standards for providing homogeneous inventories and kinematical time series of rock glaciers at global scale.

This document describes the user requirements for the case of mountain permafrost. The specific activities of the user requirement analysis include in particular the results of two user questionnaires that were made available in 2018 for CCN1 and online in September 2019 for CCN2. Collected answers from the research community (regional permafrost modellers in mountain areas, remote sensing scientists, and field scientists in mountain permafrost areas) were analysed. The review further covers user survey results from ESA DUE GlobPermafrost, workshop reports, from discussions with representatives of the International Permafrost Association (IPA) and the IPA Action Group 'Rock glacier inventories and kinematics', and a consultation with the Climate Modelling User Group (CMUG) and the Climate Research Group (CRG) of the permafrost baseline project.

The requirements related to the ECV permafrost variables ground temperature and active layer thickness (baseline project) demand a regional geographical coverage in mountain regions, high spatial resolution (target resolution 0,1km) including representation of sub-grid variability, high temporal resolution (monthly data), and long temporal coverage (one to several decades back in time). These requirements go considerably beyond the state-of-the-art in remote permafrost ECV assessment, based on published studies and recently demonstrated progress [RD-2]. The requirements for rock glacier inventories and kinematical time series indicate that global scale data set would be valuable information. Rock glacier inventories must be made on the basis of mountain ranges whatever the national boundary, and should illustrate the current situation. They should identify each rock glacier at least by a point and include, when possible, the extended or restricted geomorphological footprint as described in the "baseline concepts" document of IPA Action Group. Additional information regarding activity and kinematics are useful (required qualitative information with defined classes of activity, optional information regarding kinematics). An update of a rock glacier inventory should be performed every 10 years. Kinematical time series should be derived for a minimum of 30% of rock glaciers that are representative of a specific region and should indicate the mean annual velocity with a 1-year time step and a precision/accuracy of at least 5cm/yr. An update of kinematics should be performed every 5 years. Users stress that the quality of the results will be dependent on the remote sensing-based methods used and request flexible and feasible solutions for the development of products at global scale.

1 Introduction

The user requirement document ascertains specific user requirement for the use of EO derived kinematical rock glacier products and permafrost distribution models in mountain permafrost area. It provides an overall summary of main findings. User requirements are established by the clear definition of a number of attributes.

The document benefits from a close cooperation with the IPA Action Group *Rock glacier inventories and kinematics* engaged on integrating rock glacier kinematics in GTN-P (Global Terrestrial Network for Permafrost) as a new parameter characterizing the evolution of mountain permafrost.

1.1 Purpose of the document

This document provides the user requirements for CCN 1 (option led by the Romanian team focusing on case studies in Carpathians) and CCN 2 (options led by Swiss and Norwegian research teams working on case studies in the European Alps, Northern Norway and Svalbard as well as 4 selected sites in different climatic context). The URD assesses the requirements of relevant organisations from the Climate Research Community and the international mountain permafrost community. The requirements will be used to guide the product specifications of the Permafrost_cci project. In this document, where specific user requirements are identified they are concisely stated and assigned a requirement ID reference code named 'URq_XX'. This allows cross-referencing and traceability between multiple CCI documents.

1.2 Structure of the document

In Section 1.7, this document contains a glossary of terms specific to mountain permafrost. Section 2 of this document details the user community and potential use of the Permafrost_cci service in mountainous regions. Results from user survey and related documents are summarized in Section 3. This also includes the results of the Permafrost_cci baseline survey, which targeted climate modellers and specific use cases. Key issues to fulfil these requirements are discussed in Section 4. A summary of the requirements is presented in Section 5.

1.3 Applicable documents

[AD-1] ESA. 2017. Climate Change Initiative Extension (CCI+) Phase 1 – New Essential Climate Variables - Statement of Work. ESA-CCI-PRGM-EOPS-SW-17-0032.

[AD-2] Requirements for monitoring of permafrost in polar regions - A community white paper in response to the WMO Polar Space Task Group (PSTG), Version 4, 2014-10-09. Austrian Polar Research Institute, Vienna, Austria, 20 pp.

[AD-3] ECV 9 Permafrost: assessment report on available methodological standards and guides, 1 Nov 2009, GTOS-62.

[AD-4] GCOS-200. 2016. The Global Observing System for Climate: Implementation Needs. GCOS Implementation Plan, WMO.

1.4 Reference Documents

[RD-1] Bartsch, A., Matthes, H., Westermann, S., Heim, B., Pellet, C., Onacu, A., Kroisleitner, C., Strozzi, T. 2019. ESA CCI+ Permafrost User Requirements Document, v1.0

[RD-2] National Research Council. 2014. Opportunities to Use Remote Sensing in Understanding Permafrost and Related Ecological Characteristics: Report of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/18711

[RD-3] GlobPermafrost team. 2016. Requirements Baseline Document. ESA DUE GlobPermafrost project. ZAMG, Vienna

[RD-4] Bartsch, A., Westermann, Strozzi, T., Wiesmann, A., Kroisleitner, C. 2019. ESA CCI+ Permafrost Product Specifications Document, v1.0

[RD-5] van Everdingen, Robert, ed. 1998 revised May 2005. Multi-language glossary of permafrost and related ground-ice terms. Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology. (http://nsidc.org/fgdc/glossary/; accessed 23.09.2009)

[RD-6] IPA Action Group Rock glacier inventories and kinematics. 2019. Towards standard guidelines for inventorying rock glaciers. Baseline concepts, v3.0.

1.5 Bibliography

A complete bibliographic list that support arguments or statements made within the current document is provided in Section 6.1.

1.6 Acronyms

A list of acronyms is provided in section 6.2.

1.7 Glossary

The list below provides a selection of terms relevant for the parameters addressed in Permafrost_cci [RD-5]. A comprehensive glossary is available as part of the Product Specifications Document [RD-4].

active layer

The layer of ground that is subject to annual thawing and freezing in areas underlain by permafrost.

In the zone of continuous permafrost, the active layer generally reaches the permafrost table; in the zone of discontinuous permafrost it often does not. The active layer includes the uppermost part of the permafrost wherever either the salinity or clay content of the permafrost allows it to thaw and refreeze annually, even though the material remains cryotic ($T < 0°C$).

The active layer is sometimes referred to as the "active zone"; the term "zone," however, should be reserved for the zones of discontinuous and continuous permafrost.

In Russian and Chinese literature, the term active layer covers two distinct types: (1) the seasonally thawed layer overlying permafrost, and (2) the seasonally frozen layer overlying unfrozen ground inside or outside permafrost areas.

REFERENCES: Muller, 1943; Williams, 1965; Brown, 1971; van Everdingen, 1985.

active-layer thickness

The thickness of the layer of the ground that is subject to annual thawing and freezing in areas underlain by permafrost.

The thickness of the active layer depends on such factors as the ambient air temperature, vegetation, drainage, soil or rock type and total water content, snowcover, and degree and orientation of slope. As a rule, the active layer is thin in the High Arctic (it can be less than 15 cm) and becomes thicker farther south (1 m or more).

The thickness of the active layer can vary from year to year, primarily due to variations in the mean annual air temperature, distribution of soil moisture, and snowcover.

The thickness of the active layer includes the uppermost part of the permafrost wherever either the salinity or clay content of the permafrost allows it to thaw and refreeze annually, even though the material remains cryotic ($T < 0°C$).

Use of the term "depth to permafrost" as a synonym for the thickness of the active layer is misleading, especially in areas where the active layer is separated from the permafrost by a residual thaw layer, that is, by a thawed or noncryotic ($T > 0°C$) layer of ground.

REFERENCES: Muller, 1943; Williams, 1965; van Everdingen, 1985

ground ice

A general term referring to all types of ice contained in freezing and frozen ground.

Ground ice occurs in pores, cavities, voids or other openings in soil or rock and includes massive ice. It generally excludes buried ice, except in Russian usage. Ground ice may be epigenetic or syngenetic, contemporaneous or relict, aggrading or degrading, perennial or seasonal. It may occur as lenses, wedges, veins, sheets, seams, irregular masses, or as individual crystals or coatings on mineral or organic particles. Perennial ground ice can only occur within permafrost bodies.

REFERENCES: Mackay, 1972b; Pollard and French, 1980.

ice content

The amount of ice contained in frozen or partially frozen soil or rock.

Ice content is normally expressed in one of two ways:

1. on a dry-weight basis (gravimetric), as the ratio of the mass of the ice in a sample to the mass of the dry sample, expressed as a percentage, or

2. on a volume basis (volumetric), as the ratio of the volume of ice in a sample to the volume of the whole sample, expressed as a fraction.

The volumetric ice content cannot exceed unity whereas the gravimetric ice content can greatly exceed 100 percent.

REFERENCES: Penner, 1970; Anderson and Morgenstern, 1973; Johnston, 1981.

isolated patches of permafrost

Permafrost underlying less than 10 percent of the exposed land surface.

Individual areas of permafrost are of limited areal extent, widely separated, and are completely surrounded by unfrozen ground.

SYNONYMS: (not recommended) insular permafrost; island perma-frost; scattered permafrost.

REFERENCES: Heginbottom and Radburn, 1992.

mean annual ground-surface temperature (MAGST)

Mean annual temperature of the surface of the ground.

Permafrost exists if the mean annual ground-surface temperature is perennially below 0°C. Although the mean annual surface temperature may be below 0°C, the surface temperature will fluctuate during the year, causing a layer of ground immediately beneath the surface to thaw in the summer and freeze in the winter (the active layer). Small changes in the annual range of surface temperature and in the mean annual surface temperature from year to year, or over a period of a few years, may cause a layer of ground between the bottom of the active layer and the permafrost table to remain at a temperature above 0°C, creating a talik or residual thaw layer. [RD-1]

mean annual ground temperature (MAGT)

Mean annual temperature of the ground at a particular depth.

The mean annual temperature of the ground usually increases with depth below the surface. In some northern areas, however, it is not un-common to find that the mean annual ground temperature decreases in the upper 50 to 100 metres below the ground surface as a result of past changes in surface and climate conditions. Below that depth, it will increase as a result of the geothermal heat flux from the interior of the earth. The mean annual ground temperature at the depth of zero annual amplitude is often used to assess the thermal regime of the ground at various locations [RD-1]

mountain permafrost

Mountain permafrost is simply permafrost in mountain areas. It can be situated at low or at high latitudes and in the Arctic or Antarctic – we define mountain permafrost based on the influence that mountain topography has on its properties. Many other terms that are commonly used to classify certain types of permafrost, such as Arctic, Antarctic, polar, or plateau, can be applicable at the same time. The dominating characteristic of mountain areas and mountain permafrost is their extreme spatial variability with respect to nearly all surface and near-surface characteristics and properties

REFERENCES: Gruber and Haeberli, 2009

periglacial environments

Those environments in which cold, non glacial processes dominate.

Frost action and either seasonally or perennially frozen ground dominate in these environments. Around 20% of the Earth`s land surface currently experiences periglacial conditions.

SYNONYMS: (not recommended): cold, non glacial processes

REFERENCES: French, 2007

permafrost

Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years.

Permafrost is synonymous with perennially cryotic ground: it is defined on the basis of temperature. It is not necessarily frozen, because the freezing point of the included water may be depressed several degrees below 0°C; moisture in the form of water or ice may or may not be present. In other words, whereas all perennially frozen ground is permafrost, not all permafrost is perennially frozen. Permafrost should not be regarded as permanent, because natural or man-made changes in the climate or terrain may cause the temperature of the ground to rise above 0°C.

Permafrost includes perennial ground ice, but not glacier ice or icings, or bodies of surface water with temperatures perennially below 0°C; it does include man-made perennially frozen ground around or below chilled pipelines, hockey arenas, etc.

Russian usage requires the continuous existence of temperatures below 0°C for at least three years, and also the presence of at least some ice.

SYNONYMS: perennially frozen ground, perennially cryotic ground and (not recommended) biennially frozen ground, climafrost, cryic layer, permanently frozen ground.

REFERENCES: Muller, 1943; van Everdingen, 1985; Kudryavtsev, 1978.

permafrost degradation

A naturally or artificially caused decrease in the thickness and/or areal extent of permafrost.

Permafrost degradation may be caused by climatic warming or by changes in terrain conditions, such as disturbance or removal of an insulating vegetation layer by fire, or by flooding caused by a landslide-blocked stream, or by human activity. It may be expressed as a thickening of the active layer, a lowering of the permafrost table, a raising of the permafrost base, or a reduction in the areal extent or the complete disappearance of permafrost. [RD-1]

rock glaciers

Rock glaciers are cryo-conditioned landforms. They are the visible expression of former or current cumulative deformation by long-term gravity-driven creep of ice/debris mixtures under permafrost conditions, often characterized by a distinctive surface topography of transversal and longitudinal ridges and furrows.

They have been described either as periglacial features resulting from the downslope creep of rock-ice matrix, but some authors state that the deforming ice in within rock glaciers may be of glacial origin. These outstanding landforms are common features in alpine environments and their specific characteristics enable conclusions to be drawn about past and present environmental conditions in high mountain ranges.

REFERENCES: Barsch, 1996; Haeberli, 1985, Bertling 2011.

2 Users of mountain permafrost data and related initiatives

2.1 Users of rock glacier inventories and kinematics in mountain permafrost areas

In mountainous terrain, permafrost is occurring above an altitude rising from the sea level in the polar regions to >4'500 m a.s.l. in the intertropical zone. The regional lower altitudinal limit of the so-called discontinuous permafrost belt is heterogeneous already over short distances because of the extreme variability of both the topographical setting and ground constitution. The combination of both gravity and (steep) slope topography makes the frozen ground susceptible to continuous moving deformation building up for instance rock glaciers as one of the most typical landform of these permafrost-related environments. Rock glaciers are often moving at a rate closely depending on the temperature profile between the permafrost table and a main shear horizon at depth. Monitoring rock glaciers velocities at the regional scale, which is primarily feasible by means of processing remote sensing data, provides information on the transfer rate of sediments along mountain slopes and on the impact of climate change on mountain slope stability. Conversely, rock glacier monitoring also builds up a unique validation dataset for climate models of mountain regions, where direct permafrost (thermal state) measurements are very scarce or even totally lacking. A sound rock glacier monitoring adapted to climate issues could be integrated as a new associated parameter to the ECV permafrost.

Two different targeted communities have been identified in mountain permafrost areas: producers of the rock glacier inventories, and users of the inventories and rock glaciers velocity time series. Initiatives have risen for decades in many high-altitude regions for inventorying rock glaciers as a proxy for permafrost occurrence, but also for instance in the perspective of ice (water) storage estimation, geohazards management as well as climate reconstruction. However, these efforts often rely on different methodologies based on the unequal availability of source datasets and on variable local skills and institutional support. In a context where open access to high-quality remotely sensed data is constantly increasing, there is a need for the scientific community to promote international cooperation and develop standard guidelines. In 2018, the international initiative IPA Action Group *Rock glacier inventories and kinematics* was launched to support the production of consistent and comparable global observations of rock glaciers. CCN2 is foreseen as supporting this Action Group on integrating rock glacier kinematics in GTN-P (Global Terrestrial Network for Permafrost) as a new parameter characterizing the evolution of mountain permafrost.

The involvement of the climate research community as stated in the Executive Summary of the Baseline Proposal also applies to this option. In addition, research communities involved in the assessment and monitoring of mass wasting processes in cold mountain environments are also targeted by this option. But more generally, providing tools and standards for monitoring rock glaciers will serve any instance involved with the management of cold mountain slopes and related hazards in particular.

It is intended to develop regional rock glacier inventories in the CCN2 Swiss option on at least five different climatic regions (European Alps, Andes, Brooke Range in northern Alaska, Tien Shan in central Asia and New Zeland) as a continuation of the outcomes of the ESA GlobPermafrost project. In the CCN2 Norwegian option, three regions have been selected for the same purpose (Troms County and Finnmark Countries in Northern Norway, and Nordenskiöld Land in Svalbard). This selection

encompasses a wide range of climatic, topographical and periglacial conditions, within the continuous, discontinuous and sporadic permafrost zones. These sites will be specified in the PSD. Will the CCN2 be successful, wider development can be immediately envisaged in many other mountain regions around the world. Results will be used to validate and assess the impact of the baseline permafrost models in mountains regions.

Finally, CCN1 and CCN2 also addresses the need for additional regional cases in cooperation with dedicated users in characterising mountain permafrost and are specified below.

2.2 Users of permafrost data and related initiatives in Romania (CCN1)

The Southern Carpathians are located in a marginal periglacial environment, the permafrost occurrence is patchy and the preservation of permafrost is controlled by site-specific conditions. The existing database is in some cases incomplete or has gaps in some years. Thus, there is a necessity to set up a systematic monitoring network that will integrate the existing measurements. In Romania there are a number of scientific groups that are interested and could potentially use the data from a permafrost monitoring database. They are mainly related to projects/initiatives interested in using the database in relation to climate change.

From the research community, the regional permafrost modellers in mountain areas and remote sensing scientists (who use the ECV parameters for validation purpose and investigate permafrost areas at landscape scale), and field scientists (e.g from the Romanian Ministry of the Environment and Climate Change, the National Meteorological Administration, the University of Bucharest, the Babes-Bolyai University) might find the database useful. In the climate research community, the climate change working group within the Romanian National Meteorological Administration (NMA) has an interest in using the database, one of their main goals being to evaluate the environmental impacts of climate change in Romania. Within NMA there is also a growing interest in the understanding of long-term evolution of GST, this being in accordance with some of the goals of this project. The CCI+ Permafrost initiative also supports the production of consistent and comparable global observations of permafrost and addresses the GCOS Action T33. In addition, the generated products are useful for international initiatives such as Mountain Research Initiative (MRI), Science for the Carpathians (S4C), IPA Action Group Rock glacier inventories and kinematics, and DENUCHANGE Working Group from International Association of Geomorphologists (IAG).

2.3 Users of permafrost data and related initiatives in Switzerland (CCN2)

The products of CCN2 in Switzerland will be valuable for users concerned with the evolution of permafrost in general in the Swiss Alps and the related mass movements:

- PERMOS as the national permafrost monitoring network in Switzerland,
- any national (e.g. BAFU, ProClim, SCNAT) or regional (e.g. cantonal offices) service of concern with hazards and environmental issues,
- private (environmental) companies involved in hazard mitigation projects,
- research and education institutions (e.g. universities),
- and a large public (e.g. mountaineers, Swiss Alpine Club) having any interest in mountain stability issues.

2.4 Users of permafrost data and related initiatives in Norway (CCN2)

The products of CCN2 Norway will be valuable for various users within the permafrost, geohazard and climate community. It includes:

- Research and education institutions, involved in geoscience and climate programmes: Universities (e.g. UiO, UNIS, UiT, NTNU, UiB, HVL Sogndal, NMBU) and research institutes/centres (e.g. NORCE Norwegian Research Centre, Bjerknes Centre for Climate Research, NGI Norwegian Geotechnical Institute);
- National (the Geological Survey of Norway NGU, the Norwegian Water Resources and Energy Directorate NVE, the road and rail authorities, etc.) and the local authorities (municipalities in mainland Norway, The Governor of Svalbard and Longyearbyen Lokalstyre) interested in the identification of destabilized and potentially hazardous rock glaciers, and the relation between permafrost landforms and unstable rock slopes.
- The National Meteorological Institute (MET Norway) conducting research in climatology and permafrost-climate interactions in the Earth System.
- A large public (e.g. mountaineers, local community) having an interest in mountain stability issues and relations with climate change.

In addition to the dissemination through the ESA CCI project and scientific publications, national and regional databases (NIRD, NORPERM, SIOS) and popular dissemination will be considered for sharing the products to the Norwegian users.

3 Users requirements

3.1 Permafrost_CCI specific user requirements survey in mountain permafrost areas

The ultimate objective of Permafrost_cci is to integrate rock glacier kinematics as new associated parameter of ECV permafrost.
It is foreseen to develop within CCN2 the following remote sensing-based products:
- regional rock glacier inventories
- kinematical time series for selected rock glaciers

A user consultation was carried out with a comprehensive questionnaire that was set-up by CCN2 partners and posted online until 31th of October 2019. Specific user requirements for both products have been determined. 32 international scientists working in mountain permafrost areas responded to the survey and are mainly from research organizations and higher education institutions. They are interested in using the data to get a regional overview and to compare with the own or other products. Applications are primarily geomorphological studies (41%, e.g. regional overview, relation to other geomorphological factors, physical properties of rock glaciers, etc.), followed by climate studies (32%, e.g. response of rock glaciers to climate change, understanding the permafrost evolution, etc.), hydrological studies (9%, e.g. periglacial hydrology, water intake, etc.), permafrost occurrence (6%, regional assessment of permafrost, permafrost modelling, etc.), geohazards (6%) and paleo-climate studies (6%).

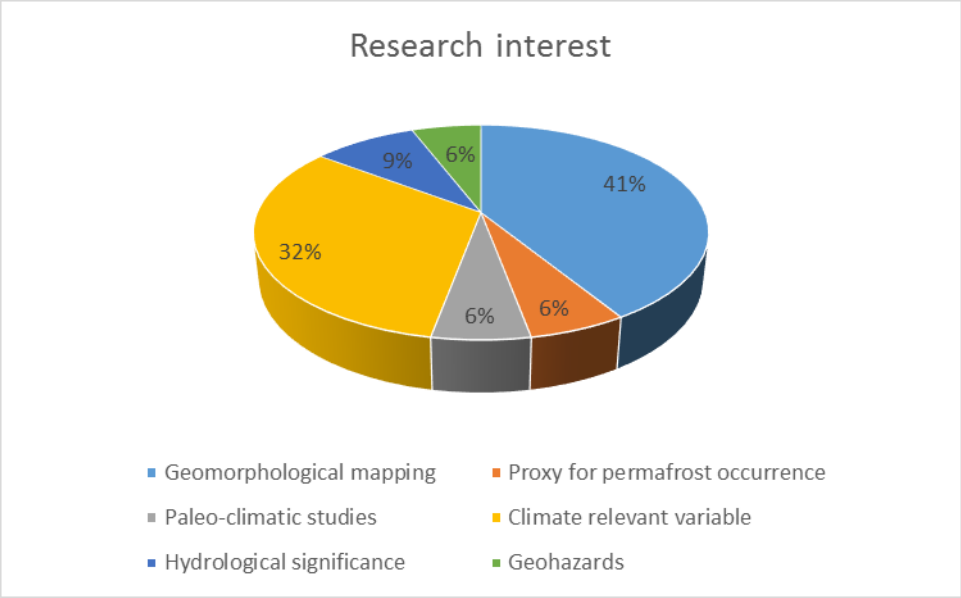

Figure 1: Research interest by users participating in the survey for rock glaciers

The survey focused on the threshold and target requirements for both regional rock glacier inventories and kinematical times series for selected rock glaciers:

- Threshold requirement (minimum: "must have"): the limit at which the observation becomes ineffectual and is not of use for your application.

- Target requirement (optimal: "nice to have"): the maximum performance limit for the observation, beyond which no significant improvement would result for your applications.

3.1.1 Regional rock glacier inventories

3.1.1.1 Summary of user requirements

Table 1. Requirements for regional rock glacier inventories in mountain permafrost areas

	Threshold requirement	**Target requirement**
	Coverage and sampling	
Geographical coverage and sampling [URq_01]	European Alps and Andes on the basis of mountain range whatever the national boundary.	Global coverage on the basis of mountain range whatever the national boundary.
Time frame and temporal extend [URq_02]	Current year	Assessed over 5-10 years and investigation in the past
	Resolution	
Rock glacier identification [URq_03]	By a point	By its geomorphological footprint
Multi-unit differentiation [URq_04]	Different generations or different dynamics	Different dynamics, different generations and different connection to the upper slope
Update [URq_5]	10 years	10 years
	Attributes	
Rock glacier activity [URq_06]	-	Extended classification [RD-6]
Rock glacier destabilization [URq_07]	Optional	Useful
Kinematics [URq_08]	Qualitative value (tbd)	Quantitative value (tbd)
Moving areas [URq_09]	Optional. Classification (tbd)	Useful. Classification (tbd)
	Error/Uncertainty	
Precision & accuracy [URq_10]	-	Up to 30% of rock glaciers in an inventory could be undefined

3.1.1.2 Coverage and sampling

a) Geographical coverage and sampling [URq_01]

Users are mainly interested in regional application (84%, threshold requirement). European Alps and Andes are in that case the primarily investigated areas. It would be optimal to have a global coverage as a target requirement (69%, target requirement). Inventories should be made on the basis of mountain ranges whatever the national boundary.

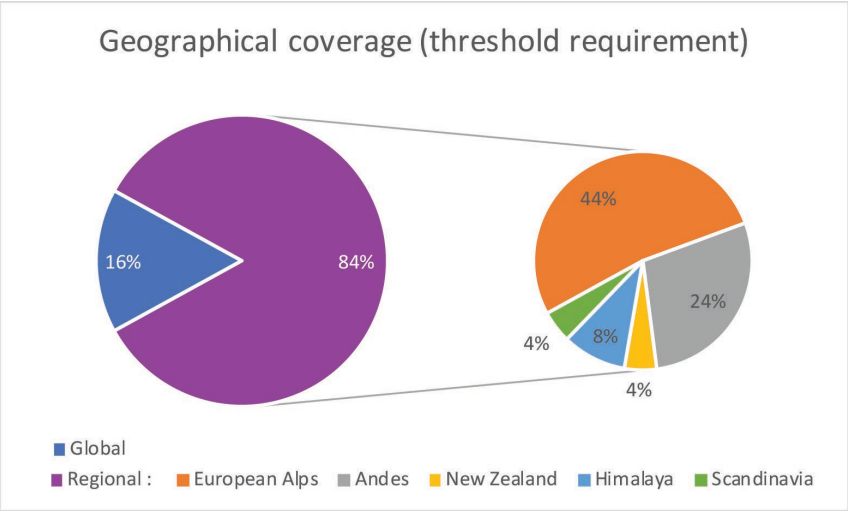

Figure 2: Required geographical coverage for rock glacier according to user survey

b) Time frame and temporal extend [URq_02]

We see some discrepancy regarding the time frame to assess attributes of rock glacier inventories (rock glacier activity, outline, etc.). In comments, users underline the fact that inventories should highlight the current situation, that the product requirements should be flexible and feasible, and that time information has to be documented in the dataset. Attributes of the inventories should be at least investigated and assessed on the current year. Assessing the attributes over a large period would be optimal (5 or 10 years) but they may be subject in that case to changes during the selected time frame and difficult to characterize homogeneously in an inventory. Investigation in the past would be also interesting.

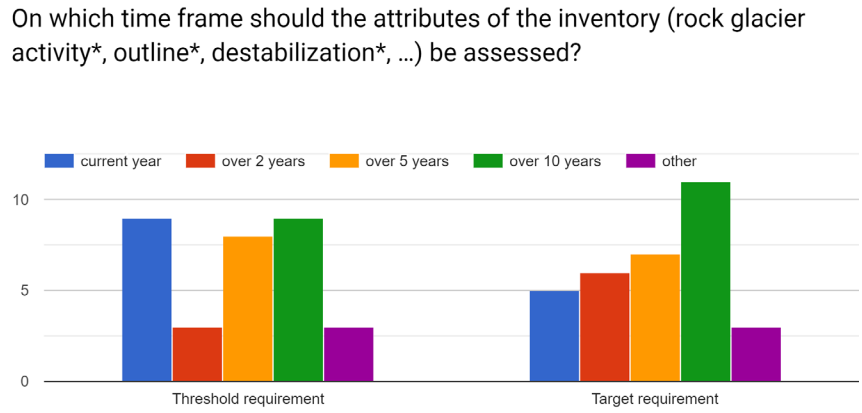

Figure 3: Required time period (duration in general) for the rock glacier inventory according to user survey

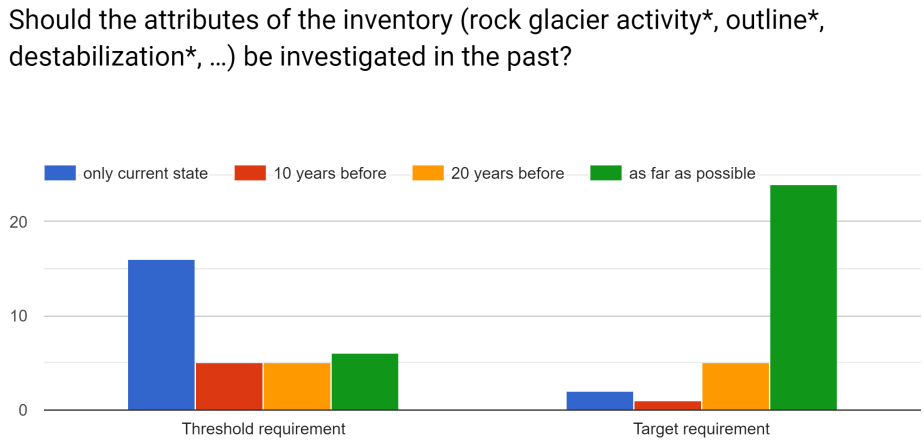

Figure 4: Required time period (start of records) for the rock glacier inventory according to user survey

3.1.1.3 Resolution

a) Rock glacier identification [URq_03]

Rock glacier should be at least identified by a point (53%, threshold requirement). Outlining its extended geomorphological footprint or restricted geomorphological footprint [RD-6] would be a must (48%, resp. 39%, target requirement).

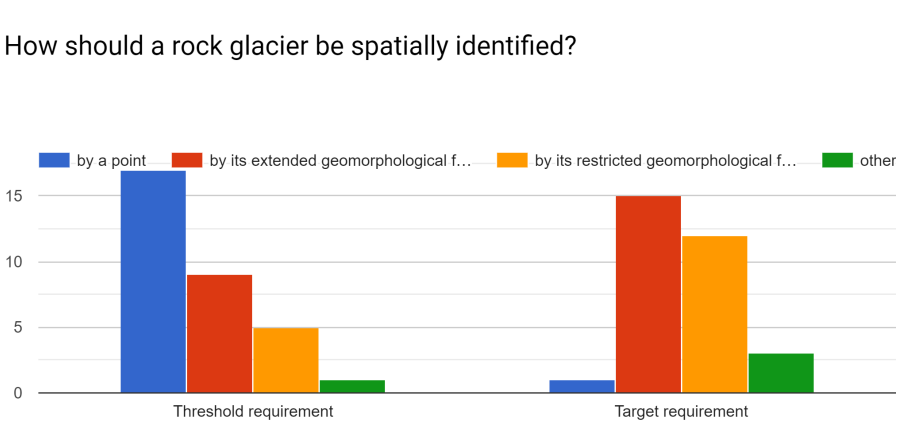

Figure 5: Required spatial information for the rock glacier inventory according to user survey

b) Multi-unit differentiation [URq_04]

In the case of multi-unit (polymorphic), the different generations or different dynamics of rock glaciers should be at least differentiated (50%, 41% respectively, threshold requirement). As noticed

by users, in most cases the different generations reflect also different dynamics. To differentiate unit using a combined analysis of the different dynamics, different generations and different connection to the upper slope would be valuable for 31% of users (target requirement). (**Urq_04**)

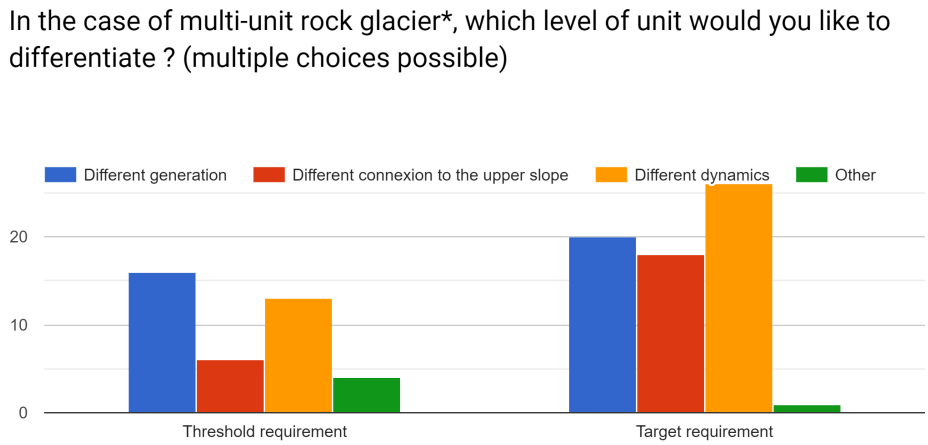

Figure 6: Required level of unit for the rock glacier inventory according to user survey

c) Update of rock glacier inventories [URq_05]

The inventories have to be updated at least every 10 years.

3.1.1.4 Attributes

a) Rock glacier activity [URq_06]

The activity of rock glaciers was conceptually and classically categorized regarding the presumed flow behaviour and in consequence the ice occurrence. The classification was primarily based on the visual observation of morphological and vegetation-related indicators (that differ locally to regionally due to lithological and climatic settings).
The IPA Action Group suggests the following renewed conceptual categorization of rock glaciers activity that refers exclusively to the efficiency of the sediment conveying (expressed by the surface movement) at a time of observation and should not be used to infer about any ground ice content [RD-6]. The categories are still based on geomorphological indicators, which have to be adapted regionally (or contextually). If areal or point kinematical data is available, it must be considered to assign the category of activity, which are defined as follow:

- Active: rock glaciers that move downslope in most of their surface
- Transitional: rock glaciers with low movements only detectable by measurement and/or restricted to limited area(s). Depending on the topographic and/or climatic context, they can evolve either towards the relict features (degradation) or toward active features.
- Relict: rock glaciers with no detectable movement and no morphological evidence of recent movement and/or ice content.

- Undefined: inadequate data for discriminating between the activity classes.

81% of the users agree to classify activity according to the categorisation proposed by the IPA Action Group rock glacier inventories and kinematics.

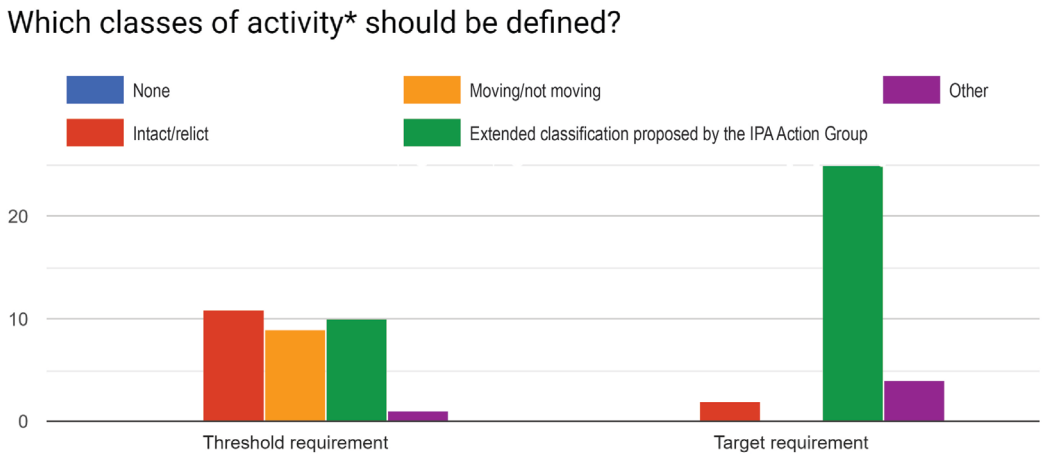

Figure 7: Required classes of activities for the rock glacier inventory according to user survey

b) Rock glacier destabilization [URq_07]

It would be optional, respectively useful (but not required), to discriminate destabilized rock glaciers in the inventories for 38%, respectively 31%, of the users (threshold requirement). It is required for 38% of the users (target requirement).

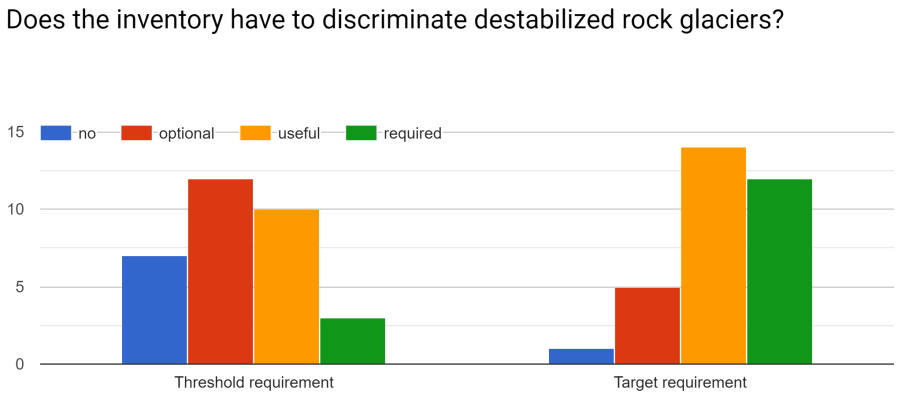

Figure 8: Required information on destabilization state for the rock glacier inventory according to user survey

c) Kinematics [URq_08]

According to users, kinematics can be an associated parameter of regional rock glacier inventories. It should at least be qualitative in order to indicate if rock glaciers are moving or not (44%, threshold

requirement). It would be optimal to know the absolute value of velocity (56%, target requirement) or to use classes of velocity (31%, target requirement).

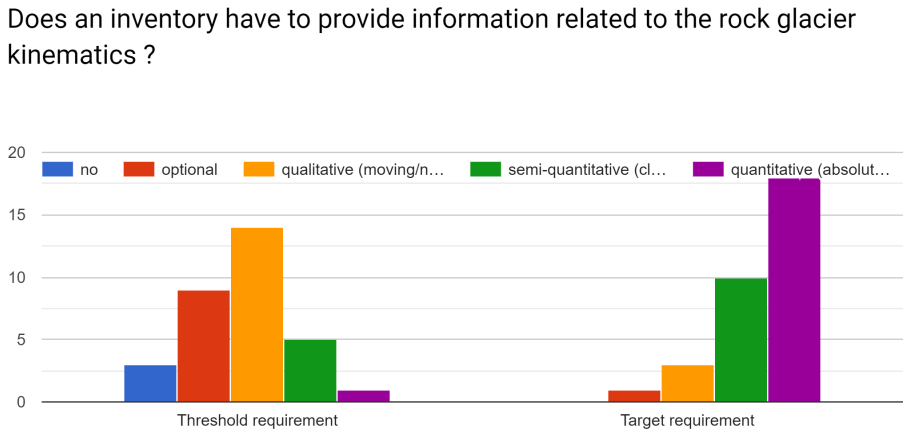

Figure 9: Need for kinematics as part of a rock glacier inventory according to user survey

To the question "which velocity information has to be given?", users noticed that values could refer to the maximum velocity computed on the fastest area or to the mean velocity computed on the largest moving area. Knowing the range of velocity (min, max, mean, std) would be interesting.

d) Moving area(s) identification and classification [URq_09]

Moving area(s) are defined as spatially outlined area(s) with an almost homogeneous deformation rate. It is useful (53%, target requirement) or required (34%, target requirement) to identify moving area(s) to a specific rock glacier. 75% of users find useful or optional to identify them as a threshold requirement.

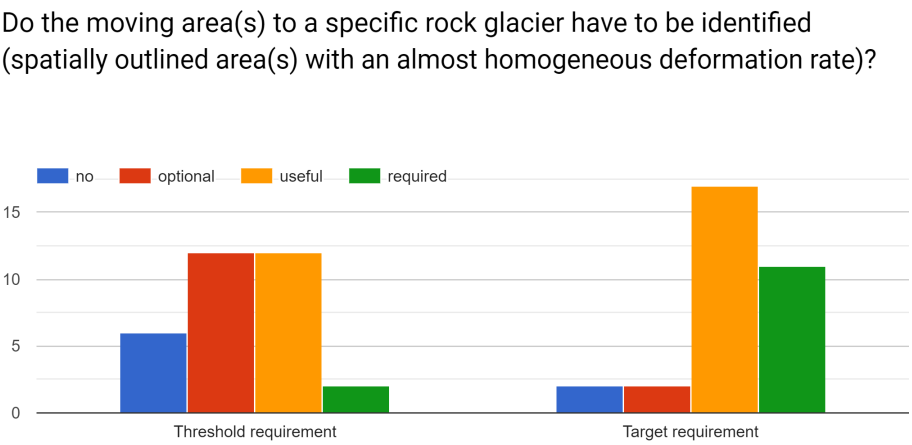

Figure 10: Need for identification of areas with homogenous deformation rate as part of a rock glacier inventory according to user survey

If identified, the moving area should be classified according to their velocity rate (87%, target requirement).

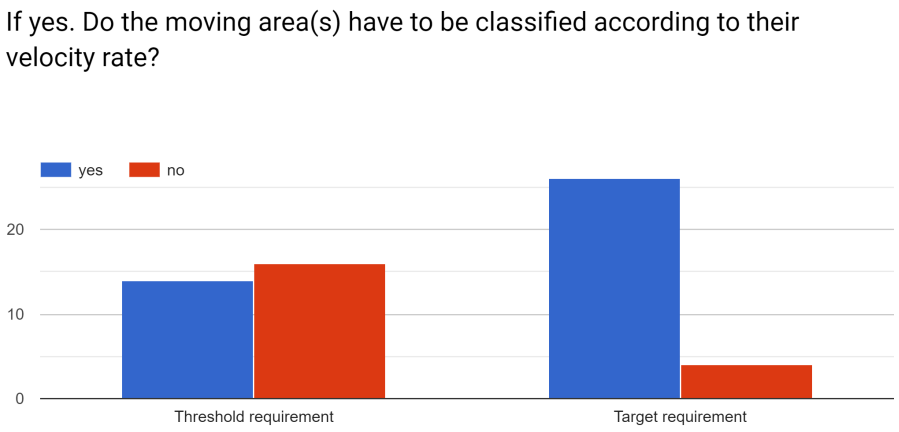

Figure 11: Need for classification of kinematics as part of a rock glacier inventory according to user survey

Two users proposed qualitative classes of velocity applied to these moving area(s) (e.g. low/high activity). Six users agreed to classify these moving area(s) in quantitative classes of velocity in the order of cm/yr, dm/yr, m/yr and higher. The remaining did not give their opinion.

3.1.1.5 Error/Uncertainty **[URq_10]**

According to users up to 30% of rock glaciers in an inventory could be undefined, which means that they can be identified (localized) without defined attributes.

3.1.2 Kinematical time series for selected rock glaciers

3.1.2.1 Summary of user requirements

Table 2. Requirements for kinematical time series for selected rock glaciers in mountain permafrost areas

	Threshold requirement	**Target requirement**
	Coverage and sampling	
Geographical coverage [URq_11]	European Alps	Global coverage
Geographical sampling [URq_12]	Sufficient rock glaciers representative in a defined regional context	At least 30% of representative rock glaciers in a defined regional context
Update [URq_13]	5 years	1 year
	Resolution	
Time resolution [URq_14]	Yearly or seasonally with an annual time step	Yearly or seasonally with an annual time step
Temporal extent [URq_15]	Past 5-10 years	As far as possible back in time
Velocity value [URq_16]	Semi-quantitative value	Exact value
Horizontal resolution [URq_17]	tbd	tbd
	Error/Uncertainty	
Precision & accuracy [URq_18]	< 5 cm/yr	< 1 cm/yr

3.1.2.2 Coverage and sampling

a) Geographical coverage [URq_11]

Users are mainly interested in regional application (86%, threshold requirement). European Alps are in that case the primarily investigated areas. It would be optimal to have a global coverage as a target requirement (67%, target requirement).

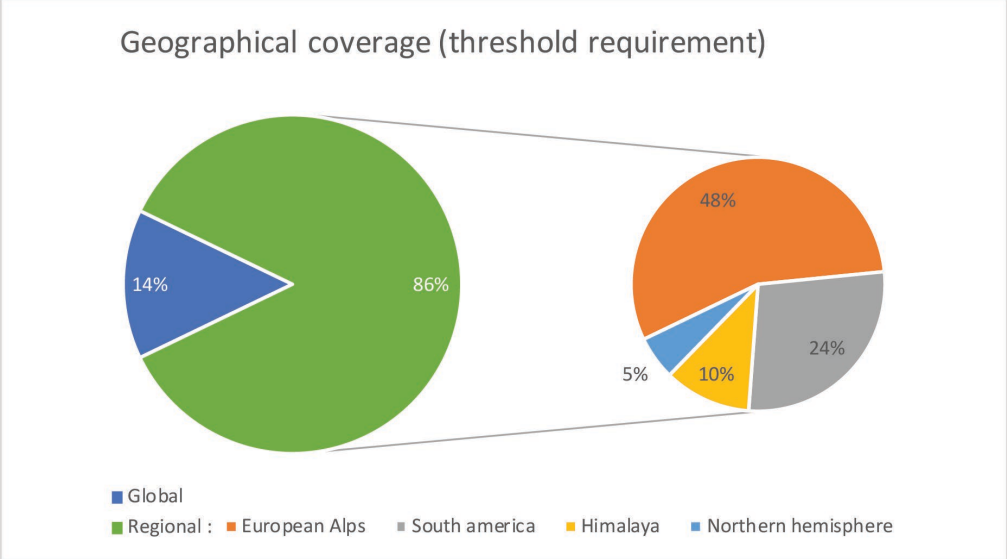

Figure 12: Required geographical coverage for kinematic details of a rock glacier inventory according to user survey

b) Geographical sampling [URq_12]

At least 30% of rock glaciers should be selected in a regional rock glacier inventory for deriving kinematical time series. The selection should take into account data availability and selected rock glaciers should be representative of the region. According to users, they could be selected randomly in order to represent different topographical and geomorphological settings.

c) Update [URq_13]

An update of the time series every 5 years will be acceptable for 92% of the users (threshold requirement), and it would be nice to have an update every year for 53% of the users (target requirement).

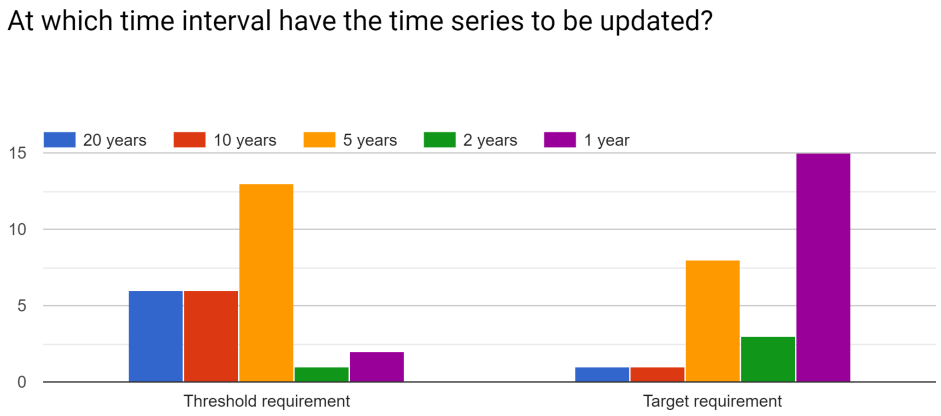

Figure 13: Required update frequency for kinematic details of a rock glacier inventory according to user survey

3.1.2.3 Resolution

a) Time resolution [URq_14]

Users of kinematical time series request mainly yearly data (64%, threshold requirement) referring to the mean annual velocity of the rock glacier. Taking into account that displacements are monitored by remote sensing methods (in general restricted to snow-free period), the summer velocity (maximum or mean over the period) would be acceptable according to 6 users in comments (the remaining did not give their opinion). The velocity value has to be computed with a time step of 1 year.

When the used method enables to compute the measurement on a smaller period, the weekly mean value computed every week would be valuable (28%, target requirement).

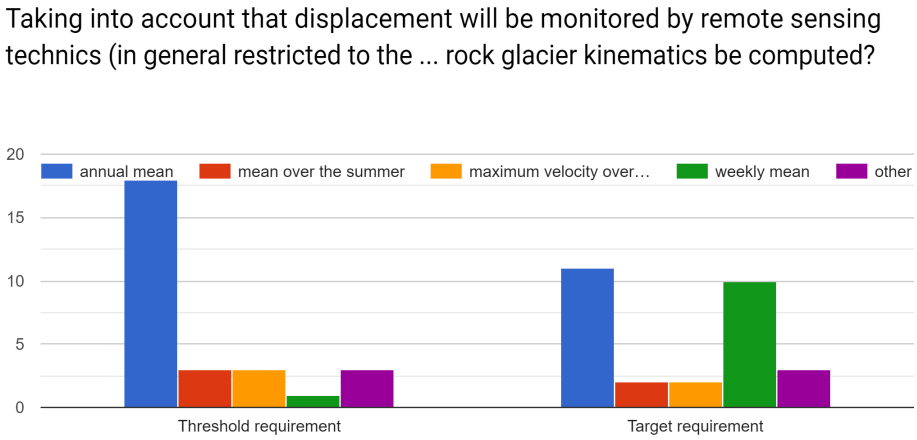

Figure 14: Required temporal aggregation for kinematic details of a rock glacier inventory according to user survey

b) Temporal extent [URq_15]

The users asked to investigate time series in the past and to compute velocity value at least for the last 5-10 years (57%, threshold requirement) or as far as possible (86%, target requirement).

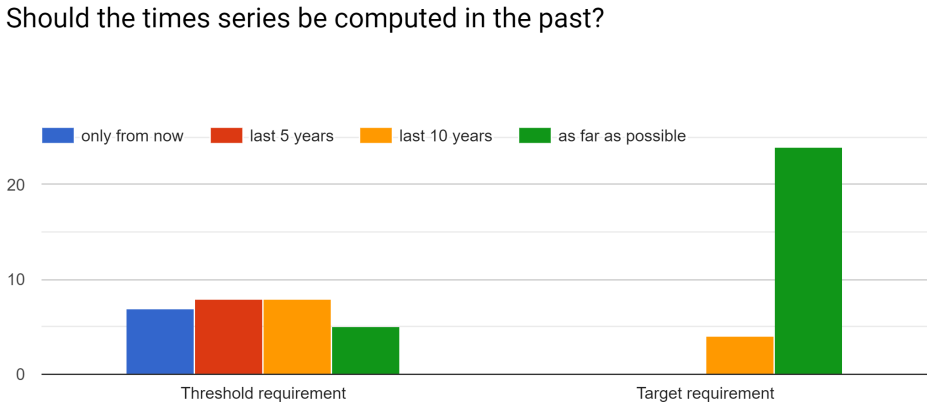

Figure 15: Required extent back in time for kinematic details of a rock glacier inventory according to user survey

c) Velocity value [URq_16]

48% of the users request at least velocity classes (threshold requirement) whereas 65% of the users request an exact value of velocity (target requirement). As noticed by a user, the rest (velocity class and relative trend) can be easily calculated from the exact value.

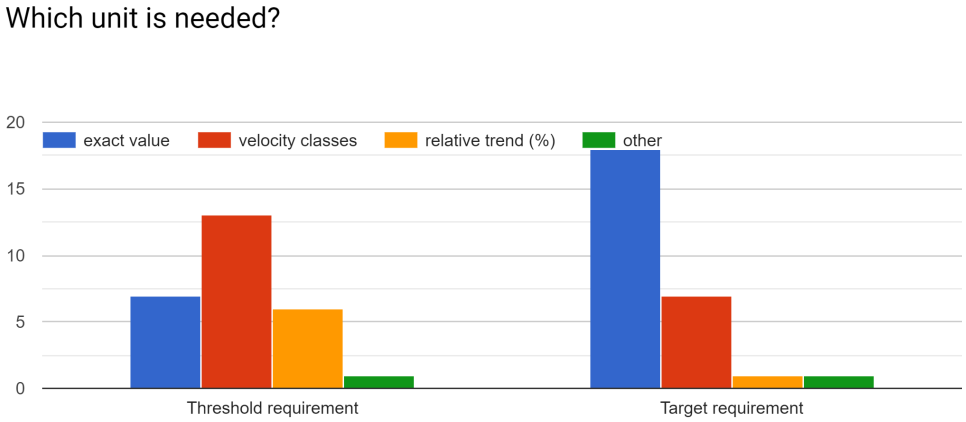

Figure 16 Required unit for kinematic details of a rock glacier inventory according to user survey

d) Horizontal resolution [URq_17]

As a threshold requirement, 56% of the users request a mean value computed over the whole moving landform. The proportion is lower for target requirement and we see discrepancy regarding the

requested position. Users suggest in comments to know range values over the moving landform (mean, max, min) or velocity field.

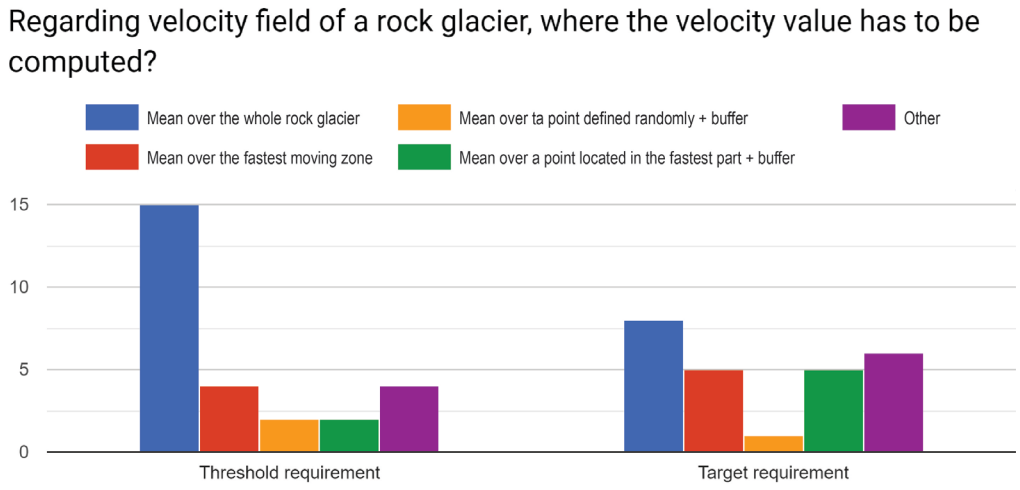

Figure 17: Required spatial aggregation of kinematic details of a rock glacier inventory according to user survey

3.1.2.4 Error/Uncertainty **[URq_18]**

50% of the users request at least a rmse < 5cm/yr (threshold requirement). Having a rmse < 1 cm/yr would be valuable (42%, target requirement).

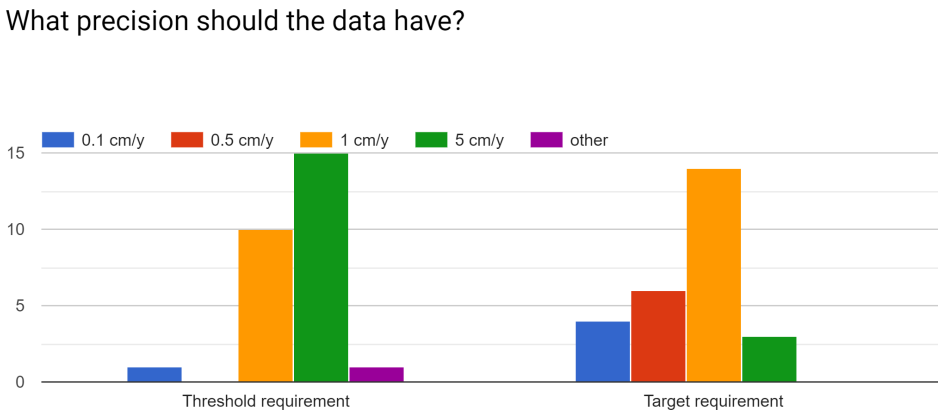

Figure 18: Required precision for kinematic details of a rock glacier inventory according to user survey

3.2 Specific user requirements for temperature and ALT in Romania (CCN1)

Specific user requirements for the case study that include mountain permafrost in Southern Carpathians for ground temperature and active layer thickness have been determined. Six Romanian researchers from West University of Timișoara, University of Bucharest, National Museum of Banat and Chinese Academy of Sciences responded to the GlobPermafrost and CCI Permafrost survey. According to this survey, and as documented in the User Requirements Document for the CCI+ Permafrost baseline proposal [RD-3], the selected answers were related to the scientists working in mountain permafrost areas. The requirements are related to the threshold and target for both ground temperature and active layer thickness (Table 1 and Table 2).

Table 3. *Requirements for ground temperature in mountain regions* **[URq_19]**

	Threshold requirement	Target requirement
	Coverage and sampling	
Geographical coverage Which region should the product cover? E.g.: global, pan-arctic, global with regional specific products …	Global with regional specific products	Southern Carpathians
Temporal sampling Which temporal resolution should the dataset have? E.g.: decadal, annual, monthly …	Annual	Monthly
Temporal extent Which time period should the dataset cover? E.g.: last decade, 1979-present …	Last decade	1979-present
	Resolution	
Horizontal resolution Which horizontal resolution is needed? E.g.: 10km, 1km …	1 km	100 m
Sub-grid scale variability Is a sub-grid scale representation of temperature variability desirable? Yes/no	Yes	Yes
Vertical resolution/scale Which vertical resolution is required? Should vertical levels be scaled? E.g. Exponential increase of layer thickness, starting with 0.5cm …	Exponential increase of layer thickness, starting with 0.5cm	Exponential increase of layer thickness, starting with 0.5cm
Vertical extent Which vertical extent should be covered? E.g.: 15m, 30m …	30 m	15 m
	Error/uncertainty	
Precision What precision should the data have? E.g.: tenth of a degree, 1 degree …	One degree	Tenth of a degree
Accuracy Which accuracy should the data have	0°c rmse < 0.1k, Lower than -3°c rmse < 0.5k	0°c rmse < 0.1k, Lower than -3°c rmse < 0.5k

in comparison with observation? E.g. Rmse < 1.5k …		

Table 4. *Requirements for active layer thickness in mountain regions* **[URq_20]**

	Threshold requirement	Target requirement
	Coverage and sampling	
Geographical coverage Which region should the product cover? E.g.: global, pan-arctic, global with regional specific products …	Global with regional specific products	Southern Carpathians
Temporal sampling Which temporal resolution should the dataset have? E.g.: decadal, annual, monthly …	Annual	Montly
Temporal extent Which time period should the dataset cover? E.g.: last decade, 1979-present …	Last decade	1979-present
	Resolution	
Horizontal resolution Which horizontal resolution is needed? E.g.: 10km, 1km …	1 km	0.1 km
	Error/uncertainty	
Precision What precision should the data have? E.g.: 1cm, 10cm …	10 cm	10 cm
Accuracy Which accuracy should the data have in comparison with observation? E.g. Rmse < 0.25m …	Rmse < 0.25m	Rmse < 0.25m
Stability What temporal stability is needed with regard to accuracy? E.g.: rmse < 0.25m …	0.25	0.25

3.4 Specific user requirements for rock glaciers in Romania (CCN 1)

The specific objective of CCN 1 is to develop and deliver maps and products, such as rock glacier inventories, trends in velocity of selected rock glaciers and permafrost distribution model for Southern Carpathians, primarily derived from satellite measurements. The Specific user requirements for these case studies are listed in Tables 3 to 5.

Table 5. *Requirements for rock glaciers inventory in Romania.* **[URq_21]**

	Threshold requirement	Target requirement
	Coverage and sampling	
Geographical coverage Which region should the product cover? E.g.: global, pan-arctic, global with	Southern Carpathians	Southern Carpathians

regional specific products …		
Temporal extent Which time period should the dataset cover? E.g.: last decade, 1979-present …	Last decade	Last decade
	Resolution	
Horizontal resolution Which horizontal resolution is needed? E.g.: 10km, 1km …	10 m	0.5 m
	Error/uncertainty	
Accuracy Which accuracy should the data have in comparison with observation? E.g. Rmse < 1.5k …	10 m	0.5 m

Table 6. *Requirements for trends in velocity of rock glaciers in Romania.* **[URq_22]**

	Threshold requirement	Target requirement
	Coverage and sampling	
Geographical coverage Which region should the product cover? E.g.: global, pan-arctic, global with regional specific products …	Southern Carpathians	Southern Carpathians
Temporal resolution Which temporal resolution should the dataset have? E.g.: decadal, annual, monthly …	Annual	Monthly
Temporal extent Which time period should the dataset cover? E.g.: last decade, 1979-present …	Last decade	Last decade
	Resolution	
Horizontal resolution Which horizontal resolution is needed? E.g.: 10km, 1km …	20 m	1 m
Vertical resolution/scale Which vertical resolution is required?	20 m	1 m
Vertical extent Which vertical extent should be covered? E.g.: 15m, 30m …	-	-
	Error/uncertainty	
Accuracy Which accuracy should the data have in comparison with observation?	3 cm	6-7 mm

Table 7. *Requirements for permafrost distribution model in Romania.* **[URq_23]**

	Threshold requirement	Target requirement
	Coverage and sampling	
Geographical coverage Which region should the product	Southern Carpathians	Retezat and Parâng mountains

cover? E.g.: global, pan-arctic, global with regional specific products …		
Temporal extent Which time period should the dataset cover? E.g.: last decade, 1979-present …	Present	Present
	Resolution	
Horizontal resolution Which horizontal resolution is needed? E.g.: 10km, 1km, …	30 m	10 m
	Error/Uncertainty	
Accuracy Which accuracy should the model have in comparison with observation? (%)	75%	90%

4 User requirements feasibility

The following subsections highlight and revise the user requirements that are judged to be not fully feasible or that need refinement within the scope of the CCN1 and CCN2 options.

4.1 Regional rock glacier inventories

For regional rock glacier inventories, we identify the following user requirements that are not fully feasible:

URq_08: Kinematics attribute: Users noticed that "values of the optional associated attribute kinematics could refer to the maximum velocity computed on the fastest area or to the mean velocity computed on the largest moving area. Knowing the range of velocity (min, max, mean, std) would be interesting".

However, the velocity value associated to an inventoried rock glacier has to be spatially representative to it and should allow to give an overview of the situation at global scale when looking at the whole regional rock glacier inventories. Moreover, this value can be derived using in situ approaches (e.g. repeated GNSS field campaigns, permanent GNSS stations) and/or remote sensed based approaches (e.g. InSAR, photogrammetry, UAV). These different information sources should also be evaluated and interpreted in a global point of view in order to define a standard for this associate kinematics attribute that can be derived at global scale. This is one of the main tasks of the next coming workshop of the IPA Action Group (February 2020). The defined standards will be used for the delivered rock glacier inventories in CCN2.

URq_09: **Moving areas:** According to users, the optional moving area(s) related to a rock glacier should be classified according to their displacement rate, and quantitative classes are suggested.

The standard should be representative for classes of velocity in the order of cm/yr, dm/yr, m/yr and higher and need a common agreement. This is a task of the next workshop of the IPA Action Group (February 2020). The defined standards will be used for the delivered rock glacier inventories in CCN2.

URq_10: Error/uncertainty: Users suggest that up to 30% of rock glaciers in an inventory could be undefined, which means that they are identified (localized) without defined attributes.

It is important to note that delivered rock glacier inventories in CCN2 will be done using a kinematical approach based on InSAR data (see PSD). The InSAR limitations have also to be taken into account especially considering that some areas can not be imaged due to layover and shadow effects. Thus, the use of InSAR may lead to some gaps in the resulting rock glacier inventories due to undetected movement (not imaged or not moving). If no rock glacier inventory exists primarily in the selected area or if no systematic analysis of the remained not imaged and not moving areas is not performed on optical data, the delivered rock glacier inventory won't be exhaustive as some rock glaciers won't not even be localized. For each delivered rock glacier inventories the approach used to derive the product will be indicated.

4.2 Kinematical times series of selected rock glacier

URq_12: Geographical sampling: At least 30% of rock glaciers should be selected in a regional rock glacier inventory for deriving kinematical time series.

As noticed by many users, the feasibility is dependent on the data availability, data resolution as well as data processing techniques. The selection should take into account data availability and selected rock glaciers should be representative of the region. According to users, they could be selected randomly in order to represent different topographical and geomorphological settings. The definition of standards for the selection of rock glacier representative of a region will be one of the main tasks of the next workshop of the IPA Action Group (February 2020).

URq_14: Time resolution: Users of kinematical time series request mainly yearly data referring to the mean annual velocity of the rock glacier. The velocity value has to be computed with a time step of 1 year.

However, remote sensing-based methods are mainly used during snow-free seasons, which may result in an inability to determine mean annual value of velocity (only seasonal mean value). The definition of standards for the temporal resolution of kinematical time series will be one of the main tasks of the next workshop of the IPA Action Group (February 2020). The defined standards will be used for the delivered rock glacier time series in CCN1 and CCN2.

URq_15: Temporal extent: The users asked to investigate time series in the past and to compute velocity value at least for the last 5-10 years.

Time series will be investigated in the past as much as possible (see DARD). However, an investigation as far as ahead cannot be insured.

URq_17: Horizontal resolution of the velocity value: We see discrepancy regarding the requested position of the velocity value. The definition of standards for the horizontal resolution of the velocity value will be one of the main tasks of the next workshop of the IPA Action Group (February 2020). The defined standards will be used for the delivered rock glacier time series in CCN1 and CCN2.

5 Summary

All specific user requirements are listed in Table 8. It provides a summary of the identified user requirements that is organised by EO data product. For each user requirement, the source and the type of work it will address are identified. We aim to meet as many of these requirements as possible in the course of the annual cycle, taking into account data availability and workload constraints.

Table 8: *Summary of user requirements. Background (BG) means that this is a continuous activity, production (P) means that the related requirement has to be considered during production. Parameters are Rock Glacier Inventories (RGI), Kinematical Time Series for selected rock glaciers (KTS), Ground Temperature (GT) and Active Layer Thickness (ALT).*

ID	PARAMETER	REQUIREMENTS	TYPE
URQ_01	RGI	Regional and global coverage	BG
URQ_02	RGI	Current year overview	BG
URQ_03	RGI	Identification of rock glaciers by a point	P
URQ_04	RGI	Multi-unit differenciation	BG
URQ_05	RGI	Update every 10 years	-
URQ_06	RGI	Rock glacier activity according to IPA Action Group classification [RD-6]	P
URQ_07	RGI	Rock glacier destabilization (optional)	P
URQ_08	RGI	Kinematics attribute to be defined	BG/P
URQ_09	RGI	Moving areas identification and classification	P
URQ_10	RGI	Precision & accuracy (up to 30% of rock glaciers in an inventory could be undefined)	P
URQ_11	KTS	At east regional coverage	BG
URQ_12	KTS	Sufficient rock glaciers representative in a defined regional context (“representatives” has to be defined)	BG/P
URQ_13	KTS	Update every 5 years	-
URQ_14	KTS	Yearly or seasonally data with an annual time step	P
URQ_15	KTS	At least past 5 years have to be investigated	P
URQ_16	KTS	Exact value of velocity	P
URQ_17	KTS	Horizontal resolution of the velocity value has to be defined	BG
URQ_18	KTS	Precision and accuracy < 1 cm/y	BG
URQ_19	GT	Threshold: global with regional specific product, yearly, last decade, 1km, subgrid variability, RMSE<0.1k; Target: Southern Carpathians, monthly, 1979- present, 100m, subgrid variability, RMSE<0.1k.	BG
URQ_20	ALT	Threshold: global with regional specific product, yearly, last decade, 1km, RMSE<0.25m; Target: Southern Carpathians, monthly, 1979- present, 100m, RMSE<0.25 cm.	BG
URQ_21	RGI	Threshold & Target: Southern Carpathians, Last decade	BG
URQ_22	KTS	Threshold: Southern Carpathians, yearly, last decade,	BG

		RMSE<3cm; Target: Southern Carpathians, monthly, Last decade, RMSE<0.6 cm.	

CCN1 and CCN2 options address the need for additional regional cases in cooperation with dedicated users in characterising mountain permafrost as local indicator for climate change and direct impact on the society in mountainous area.
Requirements analysis related to the ECV permafrost variables ground temperature and active layer thickness from the baseline project were first reassessed for the specific conditions of mountain permafrost, also considering new knowledge, products or publications (CCN1). The definition of a new ECV Permafrost variable related to rock glacier kinematics is proposed (CCN2). Thus, requirements analysis was assessed for the two related remote sensed products "regional rock glacier inventory" and "kinematical time series of selected rock glacier" that could serve to validate and assess the impact of the baseline permafrost models in mountains regions.

The following concluding remarks can be drawn for global mountain permafrost products:

- CCN2 is working closely with IPA Action Group Rock glacier inventories and kinematics gathering around one hundred international scientists involved in the definition of standards to inventory and monitor rock glaciers.
- Results from the user survey show that people are mainly interested in regional applications. However, a global knowledge would be a valuable information.
- Regarding rock glacier inventories:
    - Each rock glacier should be identified by a point. Additional outlines of its extended or restricted geomorphological footprint would be valuable information.
    - The majority of users indicate that kinematics information is useful in an inventory and should at least highlight the current situation according to classes of velocity or even better absolute velocity value (mean, min, max, std).
    - Users underline the fact that time information has to be included in the data. Investigation in the past would be also interesting but is optional.
- Regarding time series:
    - At least 30% of rock glaciers should be selected in a regional rock glacier inventory for deriving kinematical time series.
    - We see discrepancy regarding the way to spatially compute the velocity value.
    - The majority of users request mean annual velocity times series with an update every 5 years.
- Users are aware that results will be dependent on the used remote sensing technique and require to consider flexible and feasible solutions for the developments of products at global scale.

The additional following concluding remarks can be drawn for regional applications:

- Specific user requirements for the case study that include mountain permafrost for ground temperature and active layer thickness highlight the need for products with a higher spatial resolution compared with the global products;

- High resolution data are also required by users for specific products, such as rock glaciers inventory, kinematical time series of selected rock glaciers and permafrost distribution model.

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6.2 Acronyms

AUC	Area Under the Receiver Operating Curve
BTS	Bottom Temperature of Snow Cover
CCI	Climate Change Initiative
CCN	Contract Change Notice
CRS	Coordinate Reference System
DARD	Data Access Requirement Document
DEM	Digital Elevation Model
ECV	Essential Climate Variable
EO	Earth Observation
ERT	Electrical Resistivity Tomography
ESA	European Space Agency
ESA DUE	ESA Data User Element

GAMMA	Gamma Remote Sensing AG
GCOS	Global Climate Observing System
GFI	Ground Freezing Index
GPR	Ground Penetrating Radar
GST	Ground Surface Temperature
GTOS	Global Terrestrial Observing System
IPA	International Permafrost Association
MAGT	Mean Annual Ground Temperature
MAGT	Mean Annual Ground Surface Temperature
MRI	Mountains Research Initiative
MTD	Miniature Temperature Data Loggers
NMA	National Meteorological Administration
NSIDC	National Snow and Ice Data Center
PSD	Product Specifications Document
RF	Random Forest
RD	Reference Document
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
S4C	Science for the Carpathians
T	Temperature
URD	Users Requirement Document
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WUT	West University of Timisoara