CCI+ PHASE 2
PERMAFROST

CCN4
MOUNTAIN PERMAFROST: ROCK GLACIER INVENTORIES (ROGI) AND ROCK GLACIER VELOCITY (RGV) PRODUCTS

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Executive summary

The European Space Agency (ESA) 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. The objective of the ESA CCI Permafrost project (Permafrost_cci) is to develop and deliver the required Global Climate Observation System (GCOS) Essential Climate Variables (ECV) products, using primarily satellite imagery. The two main products associated to the ECV Permafrost, Ground temperature (GT) and Active Layer Thickness (ALT), were the primary documented variables during Permafrost_cci Phase 1 (2018–2021). Following the ESA Statement of Work for Permafrost_cci Phase 2 (2022–2025) [AD-1], GT and ALT will be complemented by a new ECV Permafrost product: Rock Glacier Velocity (RGV). This document focuses on the mountain permafrost component of the Permafrost_cci project and the dedicated rock glacier products.

In periglacial mountain environments, the permafrost occurrence is patchy and the preservation of permafrost is controlled by site-specific conditions, which require the development of dedicated products as a complement to GT and ALT measurements and permafrost models. 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 influenced by climatic factors. There are increasing evidence that the interannual variations of the rock glacier creep rates are influenced by changing permafrost temperature, making RGV a key parameter of cryosphere monitoring in mountain regions.

Two product types are therefore proposed by Permafrost_cci Phase 2: Rock Glacier Inventories (RoGIs) and Rock Glacier Velocity (RGV) time series. It agrees with the objectives of the International Permafrost Association (IPA) Action Group on *Rock Glacier Inventories and Kinematics* (RGIK) [RD-5] and concurs with the recent GCOS and GTN-P decisions to add RGV time series as a new product of the ECV Permafrost to monitor changing mountain permafrost conditions [AD-2 to AD-4]. RoGI is an equally valuable product to document past and present permafrost extent. It is a recommended first step to comprehensively characterise and select the landforms that can be used for RGV monitoring. RoGI and RGV products also form a unique validation dataset for climate models in mountain regions, where direct permafrost measurements are very scarce or even totally lacking. Using satellite remote sensing, generating systemic RoGI at the regional scale and documenting RGV interannual changes over many landforms become feasible. Within Permafrost_cci, we mostly use Synthetic Aperture Radar Interferometry (InSAR) technology based on Sentinel-1 images that provide a global coverage, a large range of detection capability (mm–cm/yr to m/yr) and fine spatio-temporal resolutions (tens of m pixel size and 6–12 days of repeat-pass). InSAR is complemented at some locations by SAR offset tracking technique and spaceborne/airborne optical photogrammetry.

This Product Specification Document (PSD) describes the product specifications for RoGI and RGV products, according to the User Requirement Document (URD) [RD-1]. The PSD describes the regions and subareas selected for the RoGI products, as well as the landforms selected as pilot sites for developing the RGV procedure in the first iteration of Permafrost_cci Phase 2. Product resolutions, accuracies, documented attributes, required metadata, file formats and naming conventions are also specified.

1 Introduction

1.1 Purpose of the document

The Product Specification Document (PSD) details the characteristics and properties of the products that are going to be produced in Permafrost_cci Phase 2. This document focuses on the Rock Glacier Inventory (RoGI) and Rock Glacier Velocity (RGV) products of the first iteration of the Permafrost_cci Phase 2 and will be updated during the second iteration. The product specifications are defined in order to obtain mountain permafrost products that are consistent, robust and error-characterised. The structure, syntax and file naming conventions used to describe the final RoGI and RGV are also specified.

1.2 Structure of the document

Section 2 introduces the expected outcomes of the Permafrost_cci project, describes the regions and subareas selected for RoGI consolidation in the first iteration of the project, as well as the pilot sites selected for developing the RGV procedure during the same time frame. Section 3 details the product specifications and format. A bibliography complementing the applicable and reference documents (Sections 1.3 and 1.4) is provided in Section 4.1. A list of acronyms is provided in Section 4.2. A glossary of the commonly accepted permafrost terminology can be found in [RD-16].

1.3 Applicable documents

[AD-1] ESA. 2022. Climate Change Initiative Extension (CCI+) Phase 2 – New Essential Climate Variables – Statement of Work. ESA-EOP-SC-AMT-2021-27.

[AD-2] GCOS. 2022. The 2022 GCOS Implementation Plan. GCOS – 244 / GOOS – 272. Global Observing Climate System (GCOS). World Meteorological Organization (WMO).

[AD-3] GCOS. 2022. The 2022 GCOS ECVs Requirements. GCOS – 245. Global Climate Observing System (GCOS). World Meteorological Organization (WMO).

[AD-4] GTN-P. 2021. Strategy and Implementation Plan 2021–2024 for the Global Terrestrial Network for Permafrost (GTN-P). Authors: Streletskiy, D., Noetzli, J., Smith, S.L., Vieira, G., Schoeneich, P., Hrbacek, F., Irrgang, A.M.

1.4 Reference Documents

[**RD-1**] Rouyet, L., Pellet, C., Delaloye, R., Onaca, A., Sirbu, F., Poncos, V., Brardinoni, F., Kääb, A., Strozzi, T., Bartsch, A. 2023. ESA CCI+ Permafrost Phase 2 – CCN4 Mountain Permafrost: Rock Glacier Inventories (RoGI) and Rock Glacier Velocity Products (RGV). D1.1 User Requirement Document (URD), v1.0. European Space Agency.

[RD-2] Barboux, C., Bertone, A., Delaloye, R., Onaca, A., Ardelean, F., Poncos, V., Kääb, A., Rouyet, L., Christiansen, H. H., Strozzi, T., Bartsch, A. 2019. ESA CCI+ Permafrost Phase 1 – CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D1.2 Product Specification Document (PSD), v1.0. European Space Agency.

[RD-3] Bartsch, A., Matthes, H., Westermann, S., Heim, B., Pellet, C., Onaca, A., Kroisleitner, C., Strozzi, T. 2020. ESA CCI+ Permafrost Phase 1. D1.1 User Requirement Document (URD), v2.0. European Space Agency.

[RD-4] Bartsch, A., Westermann, S., Strozzi, T., Wiesmann, A., Kroisleitner, C. 2020. ESA CCI+ Permafrost Phase 1. D1.2 Product Specification Document (PSD), v3.0. European Space Agency.

[RD-5] Delaloye, R., Barboux, C., Bodin, X., Brenning, A., Hartl, L., Hu, Y., Ikeda, A., Kaufmann, V., Kellerer-Pirklbauer, A., Lambiel, C., Liu, L., Marcer, M., Rick, B., Scotti, R., Takadema, H., Trombotto Liaudat, D., Vivero, S., Winterberger, M. 2018. Rock glacier inventories and kinematics: a new IPA Action Group. Proceedings of the 5th European Conference on Permafrost (EUCOP), Chamonix, 23 June – 1st July 2018.

[RD-6] RGIK. 2022. Towards standard guidelines for inventorying rock glaciers: baseline concepts (version 4.2.2). IPA Action Group Rock glacier inventories and kinematics, 13 pp.

[RD-7] RGIK. 2022. Towards standard guidelines for inventorying rock glaciers: practical concepts (version 2.0). IPA Action Group Rock glacier inventories and kinematics, 10 pp.

[RD-8] RGIK. 2022. Optional kinematic attribute in standardized rock glacier inventories (version 3.0.1). IPA Action Group Rock glacier inventories and kinematics, 8 pp.

[RD-9] RGIK. 2020. Rock glacier inventory using InSAR (kinematic approach) (version 3.0.2). IPA Action Group Rock glacier inventories and kinematics, 40 pp.

[RD-10] RGIK 2022. Rock Glacier Velocity as an associated parameter of ECV Permafrost: baseline concepts (version 3.1). IPA Action Group Rock glacier inventories and kinematics, 12 pp.

[RD-11] Bertone, A., Barboux, C., Delaloye, R., Rouyet, L., Lauknes, T. R., Kääb, A., Christiansen, H. H., Onaca, A., Sirbu, F., Poncos, V., Strozzi, T., Caduff, R., Bartsch, A. 2020. ESA CCI+ Permafrost Phase 1 – CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D4.2 Climate Research Data Package Product Specification Document (CRDP), v1.0. European Space Agency.

[RD-12] Sirbu, F., Onaca, A., Poncos, V., Strozzi, T., Bartsch, A. 2022. ESA CCI+ Permafrost Phase 1 – CCN1 & CCN2. Rock Glacier Kinematics in the Carpathians (CCN1 Budget Extension). Climate Research Data Package Product Specification Document (CRDP), v1.0. European Space Agency.

[RD-13] Bertone, A., Barboux, C., Bodin, X., Bolch, T., Brardinoni, F., Caduff, R., Christiansen, H. H., Darrow, M. M., Delaloye, R., Etzelmüller, B., Humlum, O, Lambiel, C., Lilleøren, K. S., Mair, V., Pellegrinon, G., Rouyet, L., Ruiz, L., Strozzi, T. 2022. Incorporating InSAR kinematics into rock glacier inventories: insights from 11 regions worldwide. The Cryosphere. 16, 2769–2792. https://doi.org/10.5194/tc-16-2769-2022.

[RD-14] Pellet, C., X., Bodin, D., Cusicanqui, R., Delaloye, A., Kääb, V., Kaufmann, J., Noetzli, E., Thibert and A. Kellerer-Pirklbauer. 2022. Rock Glacier Velocity. In Bull. Amer. Soc. Vol. 103(8), State of the Climate in 2021, pp. 43-45. https://doi.org/10.1175/2022BAMSStateoftheClimate.1.

[RD-15] Adler, C., P. Wester, I. Bhatt, C. Huggel, G.E. Insarov, M.D. Morecroft, V. Muccione, and A. Prakash. 2022. Cross-Chapter Paper 5: Mountains. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2273–2318. https://doi.org/10.1017/9781009325844.022.

[RD-16] van Everdingen, R. Ed. 1998, revised in 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.

2 Regions, subareas and pilot sites

2.1 Conclusions from Phase 1

The Permafrost_cci Phase 1 applied the IPA Action Group RGIK guidelines to develop pilot RoGI and RGV results, primarily based on satellite remote sensing products. This led to the generation of 12 RoGIs in different regions worldwide. The RoGIs identified a total of more than 5000 InSAR-based moving areas (MAs) and more than 3600 rock glaciers (RGs). In addition, preliminary rock glacier velocity time series based on radar and optical remote sensing methods (InSAR, SAR offset-tracking and aerial/satellite photogrammetry) were generated on selected rock glaciers located in the Swiss, Norwegian, Argentinian, Tien Shan and Disko Island regions. The results are presented into detailed in the Permafrost_cci Phase I CRDP and an associated peer-reviewed publication [RD-11] [RD-12] [RD-13].

The results of the Permafrost_cci Phase I work led to the following contrasting conclusions:

- **For the RoGI products**, the project contributed to establishing a common inventorying procedure following a kinematic approach [RD-9]. In a very short period, a large group of operators from nine institutions have worked in parallel to generate comparable RoGIs in many regions worldwide. The method and the products are the first international attempt to coordinate the work on RoGI generation using InSAR measurements. The effort can be seen as a complement to the international recommendations of the IPA Action Group RGIK guidelines. However, heterogeneities and discrepancies are identified when comparing the results from the different regions, due to different availability and quality of data (interferograms and auxiliary data) as well as varying initial knowledge in the region (past inventories, field measurements, use of redundant information from different techniques). In addition, due to the simultaneous development the IPA Action Group RGIK work, updated basic concepts and new practical guidelines approved these past years [RD-6] [RD-7] were not implemented in the Permafrost_cci Phase 1 products. The procedure applied in Permafrost_cci is therefore partly outdated compared to the international recommendations. **We concluded that we need to take a step back to consolidate the initial RoGIs before going further with new ones. A cross-check exercise involving multiple operators in small subareas will allow for the identification of the causes of the discrepancies and the improvement of product quality.**
- **For the RGV products**, different groups from Swiss and Norwegian institutions have generated comparable surface velocity time series on several rock glaciers. The proposed methodology turned out easily feasible and promises a large step forward in global monitoring of rock glacier velocity. The examples covered the full range of low to high absolute velocities, small to large velocity variations with rather stable velocities or increasing interannual trends. However, we only generated preliminary time series for one or a couple of selected points for each landform. We also used the initial temporal resolution of the applied technique (e.g. 6 days in all snow-free periods using InSAR), highlighting both the seasonal and interannual variations of the velocity. The next step is to provide standardized annualized RGV products, following the new GCOS and user requirements [AD-3] [RD-1]. For InSAR data, it requires to define a procedure to aggregate the results, both spatially (in a representative area of the rock glaciers) and temporally (in a consistent observation time window, during the snow-free season). **We concluded that this procedure must first be developed on well-studied rock glaciers, with available in-situ**

measurements, to compare the relevance and reliability of the final RGV products using InSAR.

These conclusions served as basis for defining the workplan of Permafrost_cci Phase 2. **In the first iteration of Permafrost_cci Phase 2** (15.11.22 – 15.05.24), it is intended to:

- For RoGI: perform a cross-check exercise with multiple operators to evaluate the RoGIs in selected subareas from the initial regions of Permafrost_cci Phase 1 (*Table 1*, upper part), refine the inventorying procedure and consolidate the initial RoGIs.
- For RGV: further define the procedure to convert initial InSAR time series into RGV and generate pilot ECV products for selected RGs.

In the second iteration of Permafrost_cci Phase 2 (15.05.24 – 15.11.25), it is intended to:

- For RoGI: revise the 12 initial regions based on the conclusions from the first iteration, compile inventories in six new regions (*Table 2*, lower part) and explore possibilities of using RoGI as training data for automated inventorying solution (machine learning).
- For RGV: evaluate the chosen procedure with a multi-institution round-robin, potentially adjust the procedure and generalize the production (generation for more landforms in more regions).

Table 1. *Permafrost_cci Phase 2 regions and responsible institutions*

RoGI consolidation (Permafrost_cci Phase 2 first iteration)		
RoGI region	**Responsible institution**	**CCI affiliation**
Western Alps (Switzerland)	University of Fribourg (Switzerland)	CCN4 Baseline
Disko Island (Greenland)	Gamma Remote Sensing (Switzerland)	CCN4 Baseline
Troms (Norway)	NORCE Norwegian Research Centre (Norway)	Option 8 Proposal
Finnmark (Norway)	NORCE Norwegian Research Centre (Norway)	Option 8 Proposal
Nordenskiöld Land (Svalbard)	NORCE Norwegian Research Centre (Norway)	Option 8 Proposal
Southern Venosta (Italy)	University of Bologna (Italy)	CCN4 Option 9
Carpathians (Romania)	WUT and Terrasigna (Romania)	CCN4 Option 9
Vanoise Massif (France)	University of Savoie / University Grenoble Alps (France)	External partner
Brooks Range (Alaska)	University of Alaska Fairbanks (USA)	External partner
Central Andes (Argentina)	IANIGLA (Argentina)	External partner
Tien Shan (Kazakhstan/Kirghizistan)	University of St. Andrews (UK) / TU Graz (Austria)	External partner
Southern Alps (New Zealand)	University of Lausanne (Switzerland)	External partner
Proposed RoGI in new regions (Permafrost_cci Phase 2 Phase 2 second iteration)		
RoGI region	**Responsible institution**	**CCI affiliation**
Goms – Binntal (Switzerland)	University of Fribourg (Switzerland)	CCN4 Baseline
Northern Vensota (Italy)	University of Bologna (Italy)	CCN4 Option 9
Rila and Pirin Mts (Bulgaria)	WUT and Terrasigna (Romania)	CCN4 Option 9
To be defined	The Chinese University of Hong Kong (China)	External partner
To be defined	Queen's University (Canada)	External partner
Tsengel Khairkhan	Mongolian Academy of Sciences (Mongolia)	External partner

2.2 RoGI regions and subareas (Phase 2 first iteration)

During the first iteration, the Permafrost_cci Phase 1 regions are used to consolidate the RoGI generation procedure. The regional inventories are briefly described in the following subsections. Complementary information can be found in reference documents [RD-2] [RD-11] [RD-12] [RD-13]. Each responsible partner has selected one or two subarea(s) to perform a cross-check exercise during Permafrost_cci Phase 2. The size and location of these subareas are specified at the end of each subsection. The size variability can be explained by the variable density and complexity of landforms between the subareas. The precise delineation of the subareas may still be subject to some adjustments during the design of the exercise.

2.2.1 Western Swiss Alps (Switzerland)

The Permafrost_cci Phase 1 *Western Swiss Alps* region (46° N, 7.5° E) covers an area of around 1500 km^2, in a region called Bas-Valais. This mountain region is characterised by reliefs higher than 4000 meters, with five main valleys that mostly oriented North-South. Based on InSAR, 677 moving areas related to rock glaciers were detected. A total of 619 rock glacier units were identified and characterized with kinematic information extracted from the moving areas: 337 are simple units and 103 are composite landforms composed of 282 units.

For the cross-check exercise of Permafrost_cci Phase 2, a subarea of ~24 km^2 has been selected in the eastern part of the initial region (see "RoGI-subarea_WesternSwissAlps1.kml" in attachment). A larger version of the same area (~72 km^2) is also considered as a complement ("RoGI-subarea_WesternSwissAlps2.kml" in attachment).

2.2.2 Disko Island (Greenland)

The Permafrost_cci Phase 1 *Disko Island* region (70° N, 53° W) is a roughly 8500 km^2 large island offshore in Western Greenland. It begins at the same geographical latitude as Ilulissat, the neighbouring city on the mainland of Greenland. Towards the North, the Vaigat Strait (Sullorsuaq) separates Disko from the mainland. The topography of Disko spans from sea-level up to 1920 m a.s.l. The climatic conditions favour the formation of a small ice cap and several valley glaciers. Based on InSAR, 588 moving areas related to rock glaciers were detected. A total of 570 rock glacier units were identified and characterized with kinematic information extracted from the moving areas.

For the cross-check exercise of Permafrost_cci Phase 2, two subareas have been selected. The first covers ~688 km^2 in the northeastern part of the initial region see "RoGI-subarea_Disko1.kml" in attachment). The second covers ~106 km^2 in the southern part of the initial region (see "RoGI-subarea_Disko2.kml" in attachment).

2.2.3 Troms (Norway)

The Permafrost_cci Phase 1 *Troms* region (69.5° N 20°E) is located in Kåfjord, Lyngen, Storfjord and Tromsø municipalities in the County of Troms and Finnmark in Northern Norway and covers ca. 7614 km^2. The alpine topography is characterized by a high altitudinal gradient with deep narrow fjords and high mountain peaks up to ca 1800 m a.s.l. in the central part of the area (Lyngen Alps). This subarctic region is at the transition between discontinuous/sporadic permafrost zones and seasonal frost. Based on InSAR, 750 moving areas related to rock glaciers were detected. A total of 414 rock glacier units were identified and characterized with kinematic information extracted from the moving areas: 290 are simple units and 50 are composite landforms composed of 124 units. Results from this work are now published in Rouyet et al. (2021).

For the cross-check exercise of Permafrost_cci Phase 2, a subarea of ~377 km^2 has been selected in the central-eastern part of the initial region (see "RoGI-subarea_Troms.kml" in attachment).

2.2.4 Finnmark (Norway)

The Permafrost_cci Phase 1 *Finnmark* region (70° N, 28° E) is located in Gamvik, Berlevåg and Tana municipalities in the County of Troms and Finnmark in Northern Norway and covers ca 2920 km^2. The topography consists of a series of mountains reaching 724 m a.s.l., distributed around the large Tana fjord. This subarctic region is at the transition between discontinuous/sporadic permafrost zones and seasonal frost. Based on InSAR, 71 moving areas related to rock glaciers were detected. A total of 57 rock glacier units were identified and characterized with kinematic information extracted from the moving areas: 11 are simple units and 8 are composite landforms composed of 46 units. Results from this work is now published in Lilleøren et al. (2022).

For the cross-check exercise of Permafrost_cci Phase 2, a subarea of ~137 km^2 has been selected in the western part of the initial region (see "RoGI-subarea_Finnmark.kml" in attachment).

2.2.5 Nordenskiöld Land (Svalbard)

The Permafrost_cci Phase 1 *Nordenskiöld Land* region (78° N, 15.5° E) covers ca 3726 km^2 of Spitsbergen (Svalbard archipelago). Nordenskiöld is delimited by Isfjorden in the North-West and Van Mijenfjorden in the South-East. Mountain peaks reach up to ca 900 m a.s.l. in the western part, ca. 1000 m a.s.l. in the North and ca. 1200 m a.s.l. in the South-East. This arctic region is characterized by continuous permafrost and significant glacial influence. Based on InSAR, 472 moving areas related to rock glaciers were detected. A total of 260 rock glacier units were identified and characterized with kinematic information extracted from the moving areas: 209 are simple units and 23 are composite landforms composed of 51 units.

For the cross-check exercise of Permafrost_cci Phase 2, a subarea of ~228 km^2 has been selected in the western part of the initial region (see "RoGI-subarea_Nordenskiöld.kml" in attachment).

2.2.6 Southern Venosta (Italy)

The Permafrost_cci Phase 1 *Southern Venosta* region (46.5 °N, 11° E) occupies the north-eastern portion of the Ortles-Cevedale massif in South Tyrol, Central-Eastern Italian Alps (46°3' N, 10°5' E). It covers about 970 km^2 and includes the southern side of lower Vinschgau (Val Venosta) as well as five tributary valleys: Ultental (Val d'Ultimo), Martelltal (Val Martello), Laasertal (Val di Lasa), and Suldental (Val di Solda). Elevation ranges from 3905 m a.s.l. on Mount Ortles, down to about 500 m a.s.l. at the Ultental outlet. Based on InSAR, 614 moving areas related to rock glaciers were detected. A total of 330 rock glaciers were identified and characterized with a kinematic attribute information extracted from the moving areas: 212 are simple units and 118 are composite landforms.

For the cross-check exercise of Permafrost_cci Phase 2, a subarea of ~39 km^2 has been selected in the western part of the initial region (see "RoGI-subarea_SouthernVenosta.kml" in attachment).

2.2.7 Carpathians (Romania)

The Permafrost_cci Phase 1 *Carpathians* region is located in the western part of the Southern Carpathians mountain range (45 N, 22.5º E). It covers 413 km^2 and reaches 2509 m a.s.l. at its highest point. An existing geomorphological rock glacier inventory was made in 2017 and includes 306 rock glaciers (Onaca et al., 2017). The inventory was updated in 2022 to align with the other Permafrost_cci RoGIs, following the IPA Action Group RGIK. Because of the marginal periglacial conditions, the velocity is generally low compared to the other RoGIs. Therefore, Persistent Scatterers Interferometry (PSI) maps have been used to identify the moving areas assign a kinematic attribute to the units.

For the cross-check exercise of Permafrost_cci Phase 2, two subareas have been selected. The first covers ~36 km^2 in the central part of the initial region see "RoGI-subarea_Carpathians1.kml" in attachment). The second covers ~34 km^2 in the southern part of the initial region (see "RoGI-subarea_Carpathians2.kml" in attachment).

2.2.8 Vanoise Massif (France)

The Permafrost_cci Phase 1 *Vanoise* region (45.5° N, 7° E) is located between N 45.6° and N 45.2° in the French Alps, covering approximately 2000 km², and reaching 3855 m a.s.l. at its highest point (la Grande Casse). Though it has no strictly delimited boundaries, the massif is here confounded with the territory of the "Parc national de la Vanoise" and mostly includes the highest parts of the Arc and Isère rivers watersheds. The mean elevation of the massif is 2325 m a.s.l. About 60 % of the terrain lies above 2500 m a.s.l., and about 4 % is covered with glaciers. Based on InSAR, 338 moving areas related to rock glaciers were detected. A total of 275 rock glaciers were identified and characterized with a kinematic attribute information extracted from the moving areas. Of those, only 126 RGs were kinematically categorized, for which external information on surface velocity was also available.

For the cross-check exercise of Permafrost_cci Phase 2, two subareas have been selected. The first covers ~64 km^2 in the central-northern part of the initial region see "RoGI-subarea_Vanoise1.kml" in attachment). The second covers ~75 km^2 in the western part of the initial region (see "RoGI-subarea_Vanoise2.kml" in attachment).

2.2.9 Brooks Range (Alaska)

The Permafrost_cci Phase 1 *Brooks Range* region (68° N, 150° W) is a roughly 1000 km wide mountain range spanning E-W through northern Alaska at a latitude of about 67°N. As test-site, a 1230 km^2 large rectangular shaped area was selected in the midst of the mountain range, including a 50 km long section of the Dalton Highway connecting Fairbanks and Deadhorse that partly suffers impact from slope motion. Based on InSAR, 538 moving areas related to rock glaciers were detected. A total of 434 rock glaciers units were identified and characterized with a kinematic attribute information extracted from the moving areas.

For the cross-check exercise of Permafrost_cci Phase 2, a subarea of ~149 km^2 has been selected in the northwestern part of the initial region (see "RoGI-subarea_BrooksRange.kml" in attachment).

2.2.10 Central Andes (Argentina)

The Permafrost_cci Phase 1 *Central Andes* region (33° S, 69.5° W) is located in Argentina, in the most southern part of the Dry Andes, where extensive areas with permafrost conditions are found. Most of the selected area consists of the Cordón del Plata mountain range, Cordillera Frontal, where the maximum height surpasses 6000 m a.s.l., and the minimum altitude is approx. 2000 m. a.s.l. Furthermore, within this region, permafrost occurs from ~3600 m a.s.l. on upwards (Ruiz and Trombotto Liaudat, 2012). Based on the InSAR data, a total of 837 moving areas related to glaciers, debris-covered, and rock glaciers were detected. A total of 580 rock glaciers units were identified and characterized with a kinematic attribute information extracted from the moving areas.

For the cross-check exercise of Permafrost_cci Phase 2, two subareas have been selected. The first covers ~78 km^2 in the northern-central part of the initial region see “RoGI-subarea_CentralAndes1.kml” in attachment). The second covers ~62 km^2 in the northeastern part of the initial region (see “RoGI-subarea_CentralAndes2.kml” in attachment).

2.2.11 Tien Shan (Kazakhstan/Kirghizistan)

The Permafrost_cci Phase 1 *Tien Shan* region (43° N, 77° W) is located in the central part of Ile Alatau (Northern Tien Shan) between Kazakhstan and Kirghizistan. It covers about 350 km^2 and includes the Small Almaty, Big Almaty and Left Talgar valleys. Several mountain peaks are higher than 4000 m a.s.l. with the highest being Pik Talgar 4973 (m a.s.l.). Based on InSAR, 93 moving areas related to rock glaciers were detected. A total of 75 rock glaciers units were identified and characterized with a kinematic attribute information extracted from the moving areas.

For the cross-check exercise of Permafrost_cci Phase 2, a subarea of ~110 km^2 has been selected in the western part of the initial region (see “RoGI-subarea_TienShan.kml” in attachment).

2.2.12 Southern Alps (New Zealand)

The Permafrost_cci Phase 1 *Southern Alps* region (43° S, 170° E) is located in New Zealand, within an elongated mountain range of ~800 km length and ~60 km width crossing nearly the entire Southern Island from north-east to south-west. The highest elevation is reached at Mount Cook (3724 m a.s.l.). The orientation of the Southern Alps perpendicular to the main oceanic perturbations coming from the west provokes a strong precipitation gradient from west to east. Precipitations are intense in the west and around the Main Divide (i.e. the main crest) and decrease strongly towards the east. As a consequence, glaciers are numerous around the highest areas close to the Main Divide, hindering the presence of rock glaciers. Based on the InSAR data, a total of 116 moving areas related rock glaciers were detected. A total of 112 rock glaciers were identified and characterized with a kinematic attribute information extracted from the moving areas.

For the cross-check exercise of Permafrost_cci Phase 2, a subarea of 13 km^2 has been selected in the southwestern part of the initial region (see RoGI-subarea_SouthernAlpsNZ.kml” in attachment).

2.3 Pilot sites for RGV generation (Phase 2 first iteration)

In order to assess the performance of InSAR for generating RGV products, the InSAR-based time series need to be **validated against in situ measurements**. This restricts the selection of study sites to rock glaciers currently being monitored with periodic Global Navigation Satellite Systems (GNSS) measurements and/or permanent GPS devices (Global Positioning System). Given the extensive network of terrestrial geodetic surveys available in Switzerland, the first iteration of Permafrost_cci will focus on Swiss pilot sites. The initial site selection was based on the list of monitored rock glaciers provided by Delaloye et al. (2010) and Cicoira et al. (2022). We considered the frequency and duration of the in-situ measurements as primary criteria to prioritize the sites. Rock glaciers having been previously analysed by GAMMA using InSAR were also added to the initial selection. We also include permafrost-affected landslides to take advantage of the availability of in-situ datasets at these locations. The dynamics of permafrost-affected landslides is also related to the mountain permafrost conditions and are therefore interesting to include in this study, to evaluate if velocity observations made on rock glaciers are also applicable to other landforms in periglacial environments. The procedure to select InSAR time series, define the observation time window and aggregate the results both spatially and temporally can be tested similarly for both landform types.

Besides the availability of in-situ time series, there are other criteria which need to be considered to select and prioritize the pilot sites. They are mostly related to **the actual velocity of the rock glacier and the detection capability of the InSAR technology**. The temporal baseline and SAR wavelength restrict the maximum velocity that can be reliably detected with InSAR technology. For Sentinel-1 data, which has a temporal baseline of 6 (2016–2021) to 12 days (2014–2016 & 2021–present) and a 5.6 cm wavelength, the detection capability is up to 1.7 m/yr (6-days interval) and 0.85 m/yr (12-days interval) (Strozzi et al., 2020). In addition, the spatial resolution of the InSAR products and the directionality of the measurements (along the line-of-sight) also lead to intrinsic limitations in terms of size and orientation of the considered landforms (Barboux et al., 2014).

To sum up, the following criteria have been considered to select and prioritize the pilot sites:

In-situ measurements criteria:

- Available permanent GNSS and frequency of periodic GNSS measurements (biannual, annual or every 2-3 years). The rock glaciers monitored with high frequency GNSS measurements are prioritized for this pilot study.
- Duration of the GNSS measurements (start-end years): The sites with long measurement periods, overlapping with Sentinel-1 acquisition period (since 2014), are prioritized for this pilot study.

InSAR limitations:

- Current velocities: With a 6-days interval and a 5.6 cm wavelength, line-of-sight velocities of up to 1.7 m/yr can be detected using InSAR. Rock glaciers moving significantly faster have therefore been discarded for this pilot study.
- Orientation of the rock glacier: SAR satellites have a polar orbit and viewing azimuth direction perpendicular to their tracks (approximatively towards East and West). East- and West-facing slopes are therefore well suited for documenting RGV with InSAR. North- and South-facing slopes are not well suited to detect the horizontal component of the downslope movement, which may lead to significant underestimation of the absolute velocity. Rock glaciers on E/W-facing slopes are therefore prioritized for this pilot study.

- Size of the rock glacier: Large areas allow for documenting time series on several InSAR pixels in order to compare the velocity patterns in different parts of the rock glaciers, discard unreliable locations and use the redundancy of information when spatially aggregating the results. The spatial resolution of Sentinel-1 is 20 x 5 m (range x azimuth). Small rock glaciers are left aside for this pilot study.

These criteria have been assessed on a qualitative scale of 0 (not suitable) to 3 (very suitable) for every initially listed rock glacier and permafrost-affected landslide (Delaloye et al., 2010; Cicoira et al., 2022). The sites are distributed into three categories: first, second and third priority. *Figure 1* shows the distribution of the pilot sites. All potential pilot sites are summarized in *Table 2*.

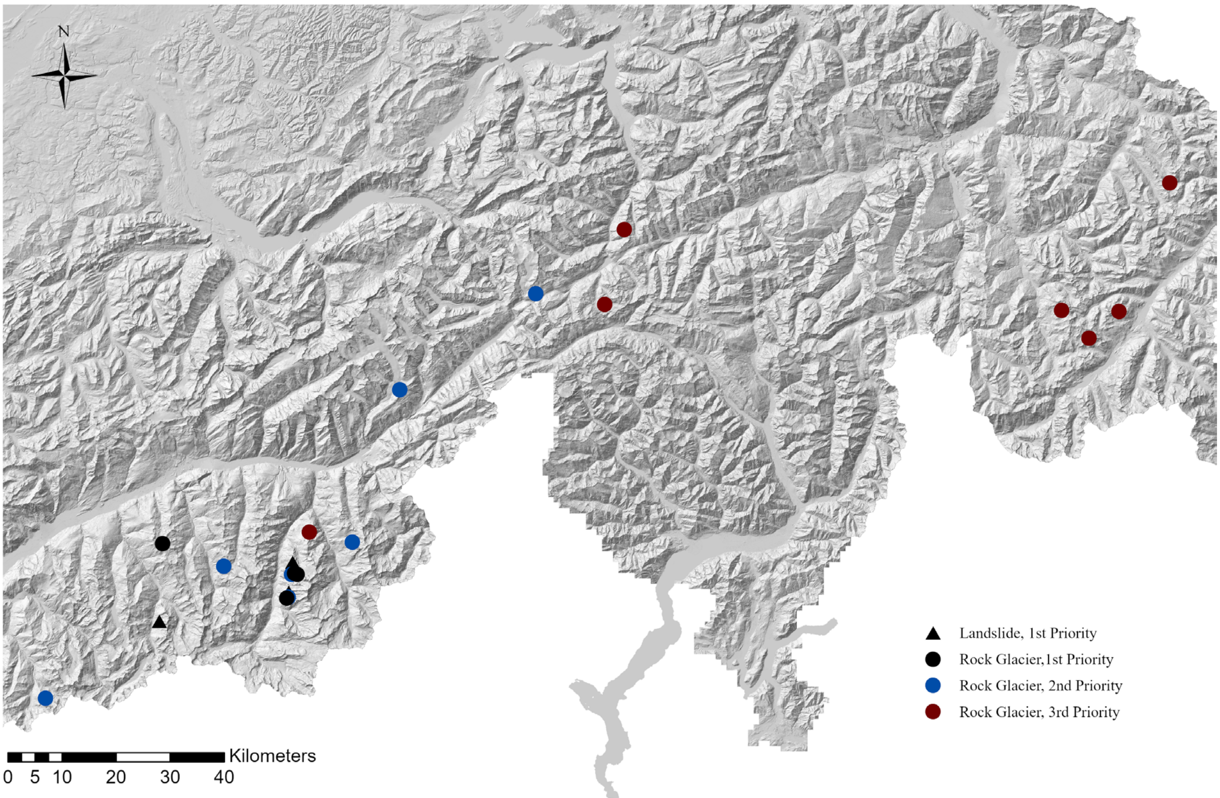

Figure 1. *Location map of the selected pilot sites for developing the RGV production (black: first priority, blue: second priority, red: third priority, circles: rock glaciers, triangles: landslides)*

In the following, the first priority sites are briefly described:

2.3.1 Réchy (Becs de Bosson)

The Réchy (Becs de Bosson) rock glacier is located in the upper Vallon de Réchy, in the Valais alps. This active rock glacier extends between 2610 and 2850 m a.s.l., and is oriented towards West. It consists of two main lobes and is connected to a Little ice Age glacier forefield. Permafrost can be found in the lower part of the rock glacier. Becs de Bosson has been surveyed since 1986, first with optical photogrammetry and since 2001 with GNSS measurements (Delaloye et al., 2010; Lambiel & Delaloye, 2004; Perruchoud & Delaloye, 2007). These are done at least twice a year and complemented by a permanent GPS. The site is also included in the PERMOS network as a "kinematics site" (PERMOS, 2022) and exhibits surface velocities up to 2 m/yr. Strozzi et al. (2020) have also measured the seasonal and interannual changes of velocity at this site using InSAR.

2.3.2 Steintälli

Steintälli is a South-West-facing rock glacier in the Matter Valley. It is situated in a small valley between the Gugla and Chli Dirruhorn summits, and ranges from 2960 to 3150 m a.s.l. It consists of two lobes with different lithologies. These two lobes also have different velocities, the upper lobe moves about 1 m/yr and the lower one about 0.2 m/yr. There is a permanent GPS installed on the site (Wiry et al., 2016). Since 2020, Steintälli is also surveyed annually with GNSS by the University of Fribourg.

2.3.3 Bru

The Bru rock glacier is located in the valley between the Bruflüe and the Freiplatten, South of the Steintälli rock glacier. The elevation ranges from 2840 to 2960 m a.s.l. There are a few GNSS measurement points on the rock glacier, which are being periodically measured since 2020, as for the Steintälli rock glacier. The velocity of the rock glacier is around 0.6 m/yr. Bru has so far not been examined in any published study.

2.3.4 Gänder

Gänder is a rock glacier which has been intensively studied in the past years. It is situated in the Wildbach catchment, with an elevation extending from 2410 to 2770 m a.s.l. The West-oriented rock glacier has a terminal part which has been destabilized in the past. Gänder has been examined in multiple studies, also including InSAR measurements (Barboux et al., 2014; Delaloye et al., 2013). In the past, Gänder has moved up to 6 m/yr. Recent velocities have decreased down to 2 m/yr. Gänder is one of the most rapid sites being examined in this study, at the limit of the detection capability of Sentinel-1 InSAR.

2.3.5 Breithorn

Breithorn is a large and deep-seated permafrost-affected landslide located above Herbriggen in the Matter Valley. The site ranges from 2620 to 3150 m a.s.l. Recent geophysical examinations have confirmed the occurrence of permafrost. Velocities have gradually increased in the past years, now reaching up to 0.7 m/yr. In the past, Strozzi et al. (2009) have also examined this site using InSAR. GNSS measurements have been conducted biannually since 2009.

2.3.6 Grabengufer

Grabengufer is a large deep-seated landslide situated in the Matter valley. It is connected to a destabilized rock glacier (Delaloye et al., 2013). The elevation extends from 2760 to 2960 m a.s.l. GNSS measurements performed biannually since 2009 have shown a strong acceleration in the past years. Current velocities are up to 1.5 m/yr.

2.3.7 Perroc

Perroc is a permafrost-affected landslide. It is West-oriented and situated in the Arolla Valley in the Val d'Hérens. The elevation ranges from 2100 to 2750 m a.s.l. Periodic GNSS measurements are regularly being conducted since 2005, currently every three years (measurement frequency). Perroc is the slowest site being examined in this study, with velocities between 0.1 and 0.3 m/yr. There is also one permanent GPS installed on the landslide.

Table 2. *Characteristics of the pilot sites for defining the RGV production based on InSAR*

Priority	Site	Canton	Region	Elevation	Slope Aspect	Surface Velocity	Duration of periodic GNSS	Frequency of periodic GNSS	Permanent GNSS	Responsible institution(s) *	PERMOS site **
First priority	Réchy (Becs-de-Bosson)	VS	Réchy Valley	2610 – 2850	W	0.5 – 2 m/yr (2022)	2004 – now	biannual	yes	UniFR (periodic + permanent)	yes
	Steintälli	VS	Zermatt Valley	2960 – 3150	WSW	0.2 – 1 m/yr (2022)	2020 – now	annual	yes	UniFR (periodic)	
	Bru	VS	Zermatt Valley	2840 – 2960	NW	0.5 – 1 m/yr (2022)	2020 – now	annual		UniFR (periodic)	
	Gänder	VS	Zermatt Valley	2410 – 2770	NW	0.5 – 2 m/yr (2022)	2009 – now	annual		UniFR (periodic)	
	Breithorn (Landslide)	VS	Zermatt Valley	2620 - 3150	W	0.1 – 0.7 m/yr (2022)	2009 – now	biannual	yes	UniFR (periodic)	
	Grabengufer (Landslide)	VS	Zermatt Valley	2760 – 2960	NW	1 – 1.5 m/yr (2022)	2009 – now	biannual	yes	UniFR (periodic)	
	Perroc (Landslide)	VS	Arolla Valley	2100 – 2750	W	0.1 – 0.3 m/yr (2020)	2005 – now	every 3 years	yes	UniFR (periodic + permanent)	
Second priority	Dirru	VS	Zermatt Valley	2520 – 2950	WNW	1 - 3 m/yr (2022)	2007 – now	biannual	yes	UniFR (periodic)	
	Chessi	VS	Zermatt Valley	2500 – 2900	WNW	0.1 – 1 m/yr (2022)	2009 – now	annual		UniFR (periodic)	
	Grosses Gufer	VS	Aletsch	2360 – 2600	NW	0.4 – 2.5 m/yr (2022)	2007 – now	annual	yes	UniFR (periodic + permanent)	yes
	Klein Furkahorn	UR	Furka	2630 – 2740	ENE	0.05 – 0.2 m/yr (2021)	2009 – now	every 2 years		UniFR (periodic)	
	Petit-Vélan	VS	Gd-St. Bernard	2510 – 2820	NE	0.1 – 1.5 m/yr (2022)	2005 – now	annual		UniFR (periodic)	
	Gruben	VS	Saas Valley	2760 – 2920	SW	0.1 – 1 m/yr (2022)	2012 – now	biannual	yes	UniFR (periodic + permanent)	yes
	Bonnard	VS	Anniviers Valley	2840 – 3000	WSW	0.5 – 2 m/yr (2019)	2006 – 2019	annual	yes	UniFR (periodic)	
Third priority	Monte Prosa	TI	Gotthard	2430 – 2600	NW	0.2 - 1 m/yr	2009 – now	biannual		UniFR (periodic)	
	Trais Fluors	GR	Upper Engadine	2730 – 2830	NE	~1 m/yr	2001 – now	annual		SLF (periodic)	
	Distelhorn	VS	Zermatt Valley	2370 – 2650	NW	0.5 – 3 m/yr				GAMMA (InSAR)	
	Flüela	GR	Flüela Valley	2380 – 2670	NE	0.1 – 0.6 m/yr					
	Tellers Davains	GR	Sursés Valley	2500 – 2900	W	1 – 2.5 m/yr				GAMMA (InSAR)	
	Wassen	UR	Uri Valley	2330 – 2520	W	0.5 – 2 m/yr				GAMMA (InSAR)	
	Gianda Grischa	GR	Upper Engadine	2500 – 2900	W	0.5 – 1 m/yr					

* Responsible institution(s) refer to the institution(s) owning available velocity data that have been collected/processed until now. ** PERMOS is the Swiss Permafrost monitoring network that – among other variables (permafrost temperature, active layer thickness, permafrost resistivity) – systematically document rock glacier velocity at several locations.

3 Products specifications and formats

3.1 Rock glacier inventories (RoGI)

3.1.1 Product description

RoGI products comprise primary markers (points) identifying rock glaciers. Optionally, RoGIs also include the outlines (polygons) following the restricted/extended geomorphological footprints of the landforms. Attributes documenting the morpho-kinematic characteristics of the identified landforms are assigned to each rock glacier unit. The Permafrost_cci project includes an additional layer of information: the InSAR-based moving areas used to categorize the kinematic attribute. RoGI products from the Phase 2 will be standardized for all selected subareas (see Section 2.2). We present here an updated version of the Product Specifications, based on the new User Requirements from Phase 2 [RD-1] and the PSD from Phase 1 [RD-2].

3.1.2 Spatial resolution

The recommended minimum size of rock glaciers included into a RoGI is 0.01 km^2 [RD-6]. The positioning of the primary marker on the rock glacier unit/system should avoid, as far as possible, any temporal variation and updating. The point must be located somewhere in the lower half of the rock glacier unit/system [RD-7].

Moving areas related to the inventoried rock glaciers are outlined based on Sentinel-1 InSAR (20–60 m final resolution). Complementary higher resolution TerraSAR-X InSAR (3–10 m final resolution) and/or optical aerial/satellite photogrammetry (1–10 m final resolution, depending on the image resolution) will also be used when available over the subareas.

3.1.3 Product accuracy

Permafrost_cci RoGIs will comprehensively include all active rock glaciers whose movement can be detected based on Sentinel-1 InSAR (and complementary remote sensing data). The cross-check exercise in the defined subareas follows a morpho-kinematic approach for which rock glaciers that are not moving (i.e. not documented by InSAR information) may still be identified (primary marks) but will remain kinematically undefined. Minimum detectable displacement rates from Sentinel-1 InSAR are in the order of 1/10 of a wavelength (i.e. around 5–6 mm). For time intervals of 48–6 days this translates to minimum detectable rates of around 4–34 cm/yr, respectively. Slower displacements can be detected using annual or bi-annual temporal baseline. Maximum detectable displacement is limited by phase coherence loss due to high deformation and are in the order of 1/2 wavelength (i.e around 2.8 cm) during the time interval used to build the interferograms, i.e. 20–170 cm/yr for time intervals of 48–6 days. For a specific time interval, a movement higher than the maximal value of deformation rate will be decorrelated on the interferogram. In this case, a moving area can be drawn but the velocity class must remain undefined [RD-9].

The product accuracy will be documented according to the Goal Requirement of URq_10 [RD-1]. For the moving areas, the reliability of the detection is qualitatively estimated (low, medium, high) based on the difficulty to interpret the signal and/or delineate the moving area. For the kinematic attribute of the rock glacier units, the accuracy is documented by two attributes: the spatial representativeness (percentage of surface documented by kinematic data: low < 50%, medium 50–75%, high > 75%) and the reliability of the kinematic attribute (low, medium, high).

3.1.4 Product attributes

For each rock glacier in Permafrost_cci RoGIs, the following attributes will be recorded:

- ID (unique alpha-numerical identifier of the rock glacier unit)
- X and Y coordinates (WGS 84 coordinate system)
- Morphological type (simple, complex, undefined)
- Spatial connection to the upslope unit (talus-, debris mantle-, landslide-, glacier-, glacier forefield-, poly-connected, undefined)
- Activity (active, transitional, relict, undefined)
- Destabilization signs (yes, no, undefined)
- Kinematic attribute (< cm/yr, cm/yr, cm/yr to dm/yr, dm/yr, dm/yr to m/yr, m/yr, > m/yr, other, undefined)
- Multi-year validity time frame of the kinematic attribute (year(s))
- Data used to assign the kinematic attribute (text containing information regarding the dimensionality, the data type, the time observation window)
- Spatial representativeness of the kinematic attribute, as percentage of the surface documented by supporting kinematic data (low: < 50%, medium: 50-75%, high: > 75%, undefined)
- Reliability of the kinematic attribute (low, medium, high, undefined)
- Remarks/comments

For each moving area associated to the rock glaciers, the following attributes will be recorded:

- ID (unique alpha-numerical identifier of the moving area)
- InSAR velocity class (< 1 cm/yr, 1–3 cm/yr, 3–10 cm/yr, 10–30 cm/yr, 30–100 m/yr, >100 cm/yr, other, undefined).
- Time observation window (text documenting the time window when the detection and characterization of the moving area has been performed).
- Reliability of the detected moving area (low, medium, high, undefined)
- Reference ID of the related rock glacier unit
- Remarks

3.1.5 Data documentation and dissemination

Data and documentation will be available on the UNIFR Permafrost_cci webpage (https://www.unifr.ch/geo/geomorphology/en/research/cci-permafrost.html). In the future, other locations may be considered for hosting the international RoGI database, in the framework of the IPA Action Group RGIK.

3.1.6 Product projection system

The Coordinate Reference System (CRS) used for the global permafrost products will be UTM based on the World Geodetic System 84 (WGS84) reference ellipsoid. The coordinates are in meters.

3.1.7 Metadata

Metadata should document all data used for producing the RoGI (type, date, processing) as well as the chosen approach (kinematical, geomorphological, both). The producer and the date of production should be indicated.

3.1.8 File formats

All datasets will be provided in shapefile (.shp) format. The inventory with primary markers (RGI layer) is a point shapefile. The InSAR-based moving areas (MA layer) is a polygon shapefile. Optional geomorphological outlines (GO layer) is a polygon shapefile.

3.1.9 Product file naming conventions

ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>-<Additional Segregator>-<Layer Type>-<Indicative Date>-fv<File version>.nc

<CCI Project>
PERMAFROST for Permafrost_cci

<Processing Level>
Indicator (IND)

<Data Type>
This should be structured as: <SENSOR>-<METHOD>
<SENSOR> is the primary remote sensing data source used to document the kinematics, in this case: SENTINEL-1. <METHOD> is the primary method used to process the data, in this case: INSAR.

<Product String>
ROGI, when the product is Rock Glacier Inventory.

<Additional Segregator>
This should be structured as: SUBAREA_<REGION_NUMBER>-<SUBAREA_NUMBER>.
<REGION_NUMBER> follows the same numbering has for Permafrost_cci Phase 1: 6–Western Alps (Switzerland); 7–Troms (Norway); 8–Finnmark (Norway); 9–Nordenskiöld Land (Svalbard); 10–Vanoise Massif (France); 11–Southern Venosta (Italy); 12–Disko Island (Greenland); 13–Tien Shan (Kazakhstan); 14–Brooks Range (Alaska); 15–Central Andes (Argentina), 16–Southern Alps (New Zealand); 17–Carpathians (Romania). <SUBAREA_NUMBER> is a one or more digit(s) number, depending on the subarea(s) in the region.

<Layer Type>
The individual layers of the vector product are provided as different files. The code of each layer is as followed:

- RG: layer 1, corresponding to the rock glacier primary markers
- MA: layer 2, corresponding to the associated moving areas
- GO: layer 3, corresponding to the optional geomorphological outlines of the rock glaciers

<Indicative Date>
Format is YYYYMMDD, where YYYY is the four digits year, MM is the two digits month from 01 to 12 and DD is the two digits day of the month from 01 to 31. Annual or multi-annual products are represented with YYYY only.

fv<File Version>
File version number in the form n{1,}[.n{1,}] (two digits followed by a point and one or more digits).

<u>Example:</u>
ESACCI-PERMAFROST-IND-SENTINEL1-INSAR-ROGI-SUBAREA6-1-RG-2023-fv01.0.shp

3.2 Rock glacier velocity (RGV)

3.2.1 Product description

RGV is a time series of annualized velocity produced with the objective to document the long-term changes of rock glacier creep rate in a climate-oriented perspective. Based on satellite remote sensing techniques, such as InSAR, one RGV is the result of a spatial aggregation of flow field measurements selected within a consistent area representative of the downslope movement of the rock glacier unit. Temporally, the initial InSAR measurements are aggregated during a consistent observation time window each year. The products from the Phase 2 will be standardized for all selected pilot sites (see Section 2.3). We present here an updated version of the Product Specifications, based on the new User Requirements from Phase 2 [RD-1] and the PSD from Phase 1 [RD-2].

3.2.2 Temporal resolution

The initial velocity data will be based on Sentinel-1 InSAR time series with a 6-12 days frequency collected during snow-free periods for the years 2015-2022. The initial velocity data will be annualized, following the Goal Requirement of URq_13 [RD-1]. The observation time window will be at least one month (between June-October), following the Breakthrough Requirement of URq_14 [RD-1]. The chosen period will be documented and will remain consistent throughout the entire time series for each pilot site (max. ±15 days of difference), as required by URq_14 [RD-1].

3.2.3 Spatial resolution

Velocity time series will be produced for several pixels across the pilot sites to document the variability of the velocity patterns, evaluate these differences and potentially divide the landforms in subareas affected by different kinematics. According to URq_17 [RD-1], the velocity will then be aggregated from the InSAR flow field over one or more area(s) representing the downslope movement of a rock glacier unit (Goal Requirement). For each pilot site, the aggregation procedure (e.g. size and location of the considered area(s), number of pixels used to average the time series) will be consistent over time.

3.2.4 Product accuracy

Based on a single interferogram procedure, the expected accuracy of Sentinel-1 InSAR is 6 to 7 mm for each measurement (Strozzi et al., 2020). The accuracy can go down to a mm accuracy using multi-temporal InSAR but these techniques are mostly applicable for slow-moving landforms. The accuracy is expected to have a relative error lower or equal to 10%, correspond to the breakthrough requirement of URq_18 [RD-1].

3.2.5 Product attributes

For each RGV time series the following attributes will be recorded:

- ID (unique alpha-numerical identifier of the RGV time series)
- Reference ID of the related rock glacier unit (when a RoGI is available)
- Technique used (description of the platform, sensor type and processing approach)
- Area considered for RGV processing (area-based, several discrete points, three discrete points or single discrete point, and related specifications)
- Start date (date of first observation)
- Velocity data (computed RGV data in m/y)

For each velocity data (each annual increment of the time series), the following attributes will be recorded:

- ID (unique alpha-numerical identifier of the RGV data)
- Reference ID of the related RGV time series
- Start date (start date of the observation time window)
- End date (end date of the observation time window)
- Base data (data/platform/sensor used for the data acquisition)
- Velocity data (computed RGV data in m/y)
- Relative error of the velocity data (ideal: < 5%, medium: 5-20%, minimal: 20%)
- Consistency of the RGV time series (ideal: no problem with newly added velocity data, medium: problems with newly added velocity data but no major change of procedure, high: problems with newly added velocity data and major change of procedure)
- Comments (documentation of any changes or specific aspect of the data production worth archiving and relevant for the data analysis and usage)

3.2.6 Data documentation and dissemination

Data and documentation will be available on the UNIFR Permafrost_cci webpage (https://www.unifr.ch/geo/geomorphology/en/research/cci-permafrost.html). In the future, other locations may be considered for hosting the international RoGI database, in the framework of the IPA Action Group RGIK.

3.2.7 Product projection system

The Coordinate Reference System (CRS) used for the mountain permafrost products will be UTM based on the World Geodetic System 84 (WGS84) reference ellipsoid. The coordinates are in meters.

3.2.8 Metadata

Metadata should indicate the methodology used for deriving the RGV time series (InSAR, GNSS, optical photogrammetry, etc.) as well as additional information regarding observation time window, temporal and horizontal resolution, and the spatio-temporal aggregation procedure applied to provide the RGV. The producer and the date of production should be indicated.

3.2.9 File formats

All datasets will be provided in comma-separated values (csv) format.

3.2.9 Product file naming conventions

ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>-<Additional Segregator>-<Indicative Date>-<Indicative Time>-fv<File version>.csv

<CCI Project>
PERMAFROST for permafrost_cci

<Processing Level>
Indicator (IND)

<Data Type>
This should be structured as: <SENSOR>-<METHOD>

<SENSOR> is the primary remote sensing data source used to document the kinematics, in this case: SENTINEL-1. <METHOD> is the primary method used to process the data, in this case: INSAR.

<Product String>
RGV, when the product is Rock Glacier Velocity.

<Additional Segregator>
SITE<NUMBER>, documenting the pilot sites, according to the following numbers: 1-Rechy; 2-Steintälli; 3-Bru, 4-Gänder, 5-Breithorn, 6-Grabengufer, 7-Perroc.

<Indicative Date>
Format is YYYYMMDD, where YYYY is the four digits year, MM is the two digits month from 01 to 12 and DD is the two digits day of the month from 01 to 31. Annual products are represented with YYYY only.

fv<File Version>
File version number in the form n{1,}[.n{1,}] (two digits followed by a point and one or more digits).

Example:
ESACCI-PERMAFROST-IND-SENTINEL1-INSAR-RGV-SITE1-2023-fv01.0.csv

4 References

4.1 Bibliography

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4.2 Acronyms

AD	Applicable Document
ALT	Active Layer Thickness
BR	Breakthrough Requirement
CCI	Climate Change Initiative
CCN	Contract Change Notice
DEM	Digital Elevation Model
ECV	Essential Climate Variable
EO	Earth Observation
ESA	European Space Agency
GAMMA	Gamma Remote Sensing AG
GCOS	Global Climate Observing System
GR	Goal Requirement
GT	Ground Temperature
GTOS	Global Terrestrial Observing System
IANIGLA	Instituto Argentino de Nivología, Glaciología y Ciencias Ambientale
InSAR	Interferometric Synthetic Aperture Radar
IPA	International Permafrost Association
MAGT	Mean Annual Ground Temperature
MAGT	Mean Annual Ground Surface Temperature
NORCE	Norwegian Research Centre AS
PSD	Product Specification Document
RD	Reference Document
RG	Rock Glacier
RGIK	Rock Glacier Inventories and Kinematics
RGV	Rock Glacier Velocity
RoGI	Rock Glacier Inventory
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
UiO	University of Oslo
UNIFR	University of Fribourg
URD	Users Requirement Document
URq	User Requirement
UTM	Universal Transverse Mercator
TR	Threshold Requirement
WUT	West University of Timisoara