CCI+ PHASE 2
PERMAFROST

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

D1.2 Product Specification Document (PSD)

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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 are 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 for cryosphere monitoring in mountains.

Two product types are therefore proposed by Permafrost_cci Phase 2: Rock Glacier Inventory (RoGI) and Rock Glacier Velocity (RGV). It agrees with the objectives of the International Permafrost Association (IPA) Standing Committee on Rock Glacier Inventories and Kinematics (RGIK) (www.rgik.org) and concurs with the recent GCOS and GTN-P decisions to add RGV 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 rock glacier units to be used for RGV monitoring. RoGI and RGV products also form a unique validation dataset for modelling 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, which provides 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 specifications of the RoGI and RGV products, in agreement with the content of the User Requirement Document (URD) [RD-1]. The PSD version 2.0 presents the new regions selected for RoGI production, as well as the rock glaciers selected for applying the RGV procedure in the second 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 mountain permafrost products of Permafrost_cci Phase 2: Rock Glacier Inventory (RoGI) and Rock Glacier Velocity (RGV). We focus here on the products that will be generated during the second iteration. The specifications are defined 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 new regions selected for RoGI generation in the second iteration of the project, as well as the sites selected for RGV production 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-17].

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., Schmid, L., Echelard, T., Delaloye, R., Sirbu, F., Onaca, A., Poncos, V., Brardinoni, F., Kääb, A., Strozzi, T., Bartsch, A. 2024. ESA CCI+ Permafrost Phase 2 – CCN4 Mountain Permafrost: Rock Glacier Inventory (RoGI) and Rock Glacier Velocity Products (RGV). D1.1 User Requirement Document (URD), v2.0. European Space Agency.

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

[RD-3] 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-4] RGIK. 2022. Towards standard guidelines for inventorying rock glaciers: baseline concepts (version 4.2.2). IPA Rock Glacier Inventories and Kinematics, 13 pp.

[RD-5] RGIK. 2022. Towards standard guidelines for inventorying rock glaciers: practical concepts (version 2.0). IPA Rock Glacier Inventories and Kinematics, 10 pp.

[RD-6] RGIK. 2022. Optional kinematic attribute in standardized rock glacier inventories (version 3.0.1). IPA Rock Glacier Inventories and Kinematics, 8 pp.

[RD-7] RGIK. 2023. Guidelines for inventorying rock glaciers: baseline and practical concepts (version 1.0). IPA Action Group Rock Glacier Inventories and Kinematics, 25 pp. https://doi.org/10.51363/unifr.srr.2023.002.

[RD-8] RGIK. 2023. InSAR-based kinematic attribute in rock glacier inventories (version 4.0). IPA Action Group Rock Glacier Inventories and Kinematics, 33 pp.

[RD-9] RGIK 2023. Rock Glacier Velocity as an associated parameter of ECV Permafrost: baseline concepts (version 3.2). IPA Action Group Rock glacier inventories and kinematics, 13 pp.

[RD-10] RGIK 2023. Rock Glacier Velocity as an associated parameter of ECV Permafrost: practical concepts (version 1.2). IPA Action Group Rock glacier inventories and kinematics, 17 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] Rouyet, L., Echelard, T., Schmid, L., Pellet, C., Delaloye, R., Onaca, A., Sirbu, F., Poncos, V., Brardinoni, F., Kääb, A, Strozzi, T., Jones, N., Bartsch, A. 2023. ESA CCI+ Permafrost Phase 2 – CCN4 Mountain Permafrost: Rock Glacier inventories (RoGI) and Rock glacier Velocity (RGV) Products. D3.2 Climate Research Data Package (CRDP), v1.0. European Space Agency.

[RD-15] 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-16] 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-17] 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 Study areas 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 RoGI in different regions worldwide. The RoGI identified a total of more than 5000 InSAR-based moving areas (MAs) and more than 3600 rock glaciers (RGs). In addition, preliminary 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 in the Swiss, Norwegian, Argentinian, Tien Shan and Disko Island regions. The results are presented 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 conclusions:

- **For the RoGI products**, the project contributed to establishing a common inventorying procedure following a kinematic approach [RD-6] [RD-8]. In a very short period, a large group of operators from nine institutions have worked in parallel to generate comparable RoGI 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 RGIK work, updated basic concepts and new practical guidelines approved these past years [RD-6] [RD-7] [RD-9] [RD-10] were not implemented in the Permafrost_cci Phase 1 products. The applied procedure was therefore partly outdated compared to the international recommendations. **We concluded that we need to take a step back to consolidate the initial RoGI 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. 6–12 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), we fulfilled two objectives:

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

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

- For RoGI: encourage the partners to revise the 12 initial regional RoGI products based on the conclusions from the first iteration, compile inventories in six new regions (*Table 1*, lower part) and explore possibilities to use the generated RoGI products as training data for automated inventorying solution (machine learning).
- For RGV: evaluate the procedure developed during the first iteration with a multi-operator and multi-technique intercomparison exercise, potentially adjust the procedure and generalize the InSAR-based RGV 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)	CCN5 Option 8
Finnmark (Norway)	NORCE Norwegian Research Centre (Norway)	CCN5 Option 8
Nordenskiöld Land (Svalbard)	NORCE Norwegian Research Centre (Norway)	CCN5 Option 8
Southern Venosta (Italy)	University of Bologna (Italy)	CCN4 Option 9
Carpathians (Romania)	West University of Timisoara and Terrasigna (Romania)	CCN4 Option 9
Vanoise Massif (France)	University Grenoble Alpes and Université Savoie Mont-Blanc (France)	External partner
Brooks Range (Alaska)	University of Alaska Fairbanks (U.S.A)	External partner
Central Andes (Argentina)	Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales IANIGLA (Argentina)	External partner
Tien Shan (Kazakhstan)	Graz University of Technology (Austria)	External partner
Southern Alps (New Zealand)	University of Lausanne (Switzerland)	External partner
RoGI new regions (Permafrost_cci 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)	West University of Timisoara and Terrasigna (Romania)	CCN4 Option 9
Manaslu (Nepal)	The Chinese University of Hong Kong (China)	External partner
Sajama (Bolivia–Chile)	Université Grenoble Alpes and Université Savoie Mont-Blanc (France)	External partner
Tsengel Khairkhan (Mongolia)	Mongolian Academy of Sciences (Mongolia)	External partner

2.2 RoGI new regions (Phase 2 second iteration)

We here describe the three RoGI areas of the main Permafrost_cci partners (Sections 2.2.1–2.2.3) and briefly introduced the three new regions investigated by external partners (Sections 2.2.4–2.2.6). Two additional regions are briefly introduced (Sections 2.2.7–2.2.8).

Two additional regions must be mentioned: The Himachal Pradesh region in NW India, and the Bhutanese Himalayas. These regions are not directly part of Permafrost_cci and therefore not described in the following. However, RoGI work are related to parallel projects/collaborations at the University of Bologna (PI: Francesco Brardinoni) and the University of Fribourg (PI: Cécile Pellet). In additional, the production of interferograms for the inventory of rock glaciers in the Himachal Pradesh region in NW India is supported by Permafrost_cci. As these study areas are in good synergy with Permafrost_cci iteration 2, the results may be analysed together with the six other RoGI if the timeline matches the Permafrost_cci deliveries.

2.2.1 Goms – Binntal (Switzerland)

PI: Reynald Delaloye (University of Fribourg)

The Goms – Binntal study area has already been inventoried in Permafrost_cci iteration 1 and served as pilot area for the development of the consensus-based RoGI procedure and the generation of online training tool for inventorying rock glaciers. The results and GIS data package is available in the menu dedicated to educational "Tools" of the RGIK website (https://www.rgik.org). The current RoGI covers 17 km^2, within two small areas located on both sides of the Rhone valley, in the Goms district (Upper Valais). On the right side of the valley, facing South-East, the first area covers elevations from 1440 m a.s.l, up to the Heji Zwächte peak (3086 m a.s.l). On the left side of the valley, facing West, the second area covers elevations from 1850 m a.s.l, up to the Mittaghorn peak (3014 m a.s.l). Further work on large-scale RoGI generation covering the entire Swiss Alps is ongoing, through the work package 1 of the RoDynAlpS project "Rock glacier dynamics at multiple spatio-temporal scales in Switzerland" (2023–2027), funded by the Swiss National Foundation (SNF).

2.2.2 Northern Vensota (Italy)

PI: Francesco Brardinoni (University of Bologna)

The Northern Venosta study area (720 km^2) occupies the northwestern portion of South Tyrol (Autonompus Province of Bozen/Bolzano) in the Central-Eastern Italian Alps. This comprises the eastern and northern sides of respectively the upper and lower Vinschgau/Venosta Valley, as well as five tributary valleys, i.e., Langtaufers/Vallelunga, Planeiltal/Val di Planol, Matschtal/Val di Mazia, Schnalstal/Val Senales, and Zeilbachtal. Elevation ranges from about 520 m a.s.l. at the Venosta Valley outlet up to the 3738 m a.s.l. of Weisskugel. Bedrock geology is dominated by metamorphic lithologies (chiefly paragneiss, micaschists, and orthogneiss, and lesser marble), with limestones and dolostones in lower Vallelunga (Keim et al., 2013). The climate is dry, with mean annual precipitation ranging from 506 mm (1921–2020) at Schlanders/Silandro (698 m a.s.l.) on the Venosta Valley floor to 779 mm (1972–2020) at Zufritt/Gioveretto Dam (1851 m a.s.l.) in upland valleys. According to Permanet modeling (https://www.permanet.eu) and field-based evidence, discontinuous mountain permafrost roughly occurs above threshold elevations varying between 2300 and 2700 m a.s.l., depending on topographic aspect and microclimatic, site-specific conditions (Boeckli et al., 2012).

According to the existing regional geomorphological inventory (Scotti et al., 2024), the study area hosts 709 rock glaciers that cover a combined area of 28.5 km^2.

2.2.3 Rila and Pirin Mts (Bulgaria)

PI: Flavius Sirbu (West University of Timisoara)

The Rila and Pirin Mountains are located in the western and southwestern parts of Bulgaria. They are among the highest mountain ranges in the Balkan Peninsula (Musala Peak at 2925 m a.s.l.). The predominant bedrock consists mainly of granites with metamorphic rock intrusions (e.g., schists, marbles and gneiss). The landscape was shaped by the Pleistocene and Holocene glaciers, resulting in a typical Alpine relief, distinguished by glacial valleys, cirques, alpine lakes and very steep ridges. The climate is a transition between continental and Mediterranean, with precipitations averaging at about 1000 mm/year and a mean annual air temperature (MAAT) of -3.2ºC at Musala Peak. In the Pirin Mountains, Snezhnika and Banski Suhodol glacierets are the southernmost perennial surface ice bodies in Europe (Onaca et al., 2022). The most recent and complete rock glacier inventory consists of 122 features (Magori et al., 2020). The rock glaciers are located in valleys with all expositions and have an average altitude of about 2391 m a.s.l., in a zone where permafrost occurs only in favourable topographic conditions. The current inventory uses polygons to delineate rock glacier bodies and contains information about their geology, morphometry and morphology. However, it does not contain any information about the dynamic state of rock glaciers.

2.2.4 Manaslu (Nepal)

PI: Lin Liu (Chinese University of Hong Kong)

The Manaslu study area is located in the Nepalese Himalayas. The current AOI covers 1970 km^2, including the Manaslu (8163 m a.s.l.), Nemjung (7140 m a.s.l.), Kang Guru (6981 m a.s.l.) high mountain peaks. Meeting with the external partners of the Nepalese RoGI region is planned for September 2024. The size and extent of the inventoried region may be adjusted in the Fall.

2.2.5 Sajama (Bolivia–Chile)

PI: Diego Cusicanqui (Université Grenoble Alpes and Université Savoie Mont-Blanc).

The Sajama study area is located in the Andes. The current AOI covers 14661 km^2 in Bolivia and Chile. It covers a large part of the Sajama National Park which includes the Nevada Sajama, an extinct volcano and the highest peak in Bolivia (6542 m a.s.l.). Meeting with the external partners of the Bolivian–Chilean RoGI region is planned for September 2024. The size and extent of the inventoried region may be adjusted in the Fall.

2.2.6 Tsengel Khairkhan (Mongolia)

PI: Avirmed Dashtseren (Mongolian Academy of Science).

The Tsengel Khairkhan region is located in the Mongol-Altai Mountain range, in Western Mongolia. The current AOI covers 208 km^2. Meeting with the external partners of the Mongolian RoGI region is planned for September 2024. The size and extent of the inventoried region may be adjusted in the Fall. The RoGI work is in synergy with an ongoing Norwegian–Mongolian research collaboration, part of the Permafrost4Life project led by Sebastian Westermann (UiO).

2.3 Plan for RGV generation (Phase 2 second iteration)

2.3.1 RGV intercomparison exercise

A working group consisting of 20–30 persons has been set up to work on RGV production. The group involves Permafrost_cci partners and other established institutions active in the RGIK community. The objective is to simultaneously generate RGV on similar landforms, intercompare results using various methods and identify concrete issues occurring during the production. Three rock glaciers in the Alps have been selected for this purpose (*Table 2*; *Figure 1*) and three sets of techniques will be applied (in-situ measurements, optical remote sensing, radar remote sensing). The work will be performed in Summer–Fall 2024 and a workshop will be organized at the end of November to compare the results, identify differences and problems in the recommended workflow and/or lack of clarity in the guidelines. The long-term objective is to refine the RGV procedure and product requirements, and foster the establishment of long-term monitoring strategies.

Table 2. *Selected sites for the RGV intercomparison exercise*

Rock glacier name/country	Lat/Long coordinates	In-situ data	Optical data	Radar data	Velocity range	Slope orientation
Gran Sommetta (IT)	45.921428 N 7.669550 E	Annual since 2012	Annual UAV from 2013	Sentinel-1 coregistrated SLC images 2014-2024	0.2–2 m/yr	NNW
Grosses Gufer (CH)	46.425292 N 8.083018 E	Annual since 2007	Aerial images from the 50ties		0.2–5 m/yr	NW
Laurichard (FR)	45.018091 N 6.399865 E	Annual since 2000			about 1 m/yr	N

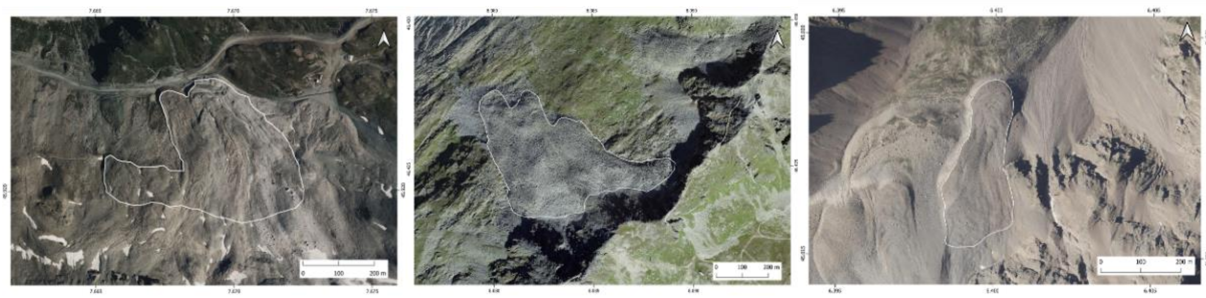

Figure 1. *Views of the three selected rock glaciers for the RGV intercomparison exercise. Left: Gran Sommetta, Italy. Middle: Grosses Gufer, Switzerland. Right: Laurichard, France.*

To produce RGV, the participants can choose between different datasets and applicable techniques:

- **In-situ measurements:** The participants of the "in-situ group" will use annual GNSS data to derive RGV. Two levels of data are provided: E-N-H positions for all measured points, and calculated velocity for all measured points.
- **Optical remote sensing:** The participants of the "optical group" will use aerial optical images acquired by manned or unmanned aircrafts to derive RGV. Two levels of data are provided: orthorectified images or DEM, and displacement fields (raster or vector format).

- **Radar remote sensing:** The participants of the "radar group" will use Sentinel-1 Synthetic Aperture Radar (SAR) images to derive RGV. Synthetic Aperture Radar Interferometry (InSAR) or SAR offset tracking can be used for this purpose. One level of data is provided by Gamma Remote Sensing AS: coregistered Single Look Complex (SLC) Sentinel-1 images.

The procedure to perform the work will be described in the ATBD version 2.0.

2.3.2 Swiss sites (UNIFR/GAMMA)

In Permafrost_cci first iteration, the InSAR-RGV procedure was tested on four pilot sites: Diestelhorn, Réchy (Becs-de-Bosson), Steintälli and Bru [RD-14] (Schmid, 2024). In the second iteration, results will be updated at the initial pilot sites, and we will extend the production to other Swiss rock glaciers. The priority sites are: Gänder, Breithorn, Grabengufer, Perroc, Petit-Vélan, Chessi, Monte Prosa, Tellers Davains and Wassan. Their locations are shown on *Figure 2* and their properties listed in *Table 3*. As for iteration 1, the results will compare with GNSS-RGV products from periodic and permanent GNSS monitoring (PERMOS, 2023; UNIFR, 2024).

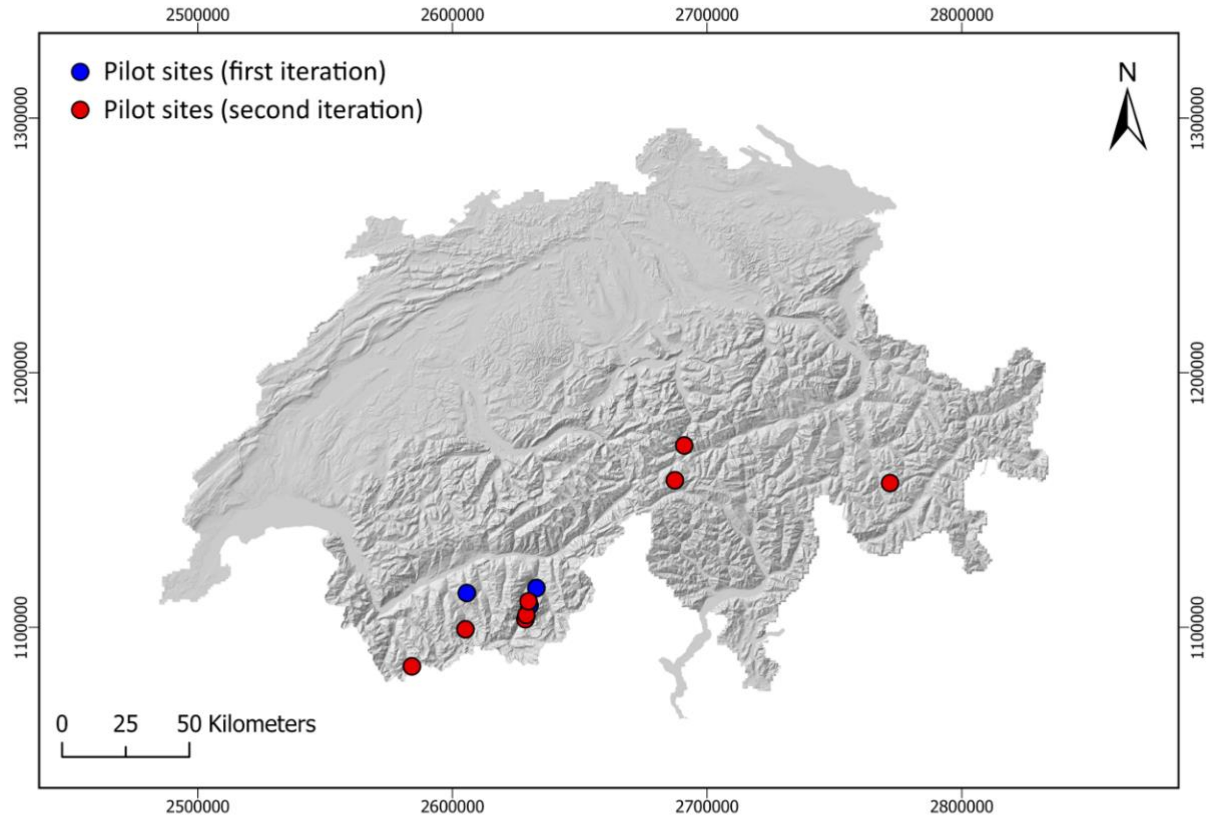

Figure 2. *Map showing the location of the new RGV sites in Switzerland (red dots).*

2.3.3 Italian sites (UniBo/GAMMA)

As part of the Option 9, The InSAR-RGV procedure applied for the Swiss sites will be conducted at 11 rock glaciers located in western South Tyrol, within the so-called broader study areas of Southern and Northern Venosta (*Figure 3*). These include: Similaun and Lazaun in Val Senales, Hintergrath, Razoi, Zay, Serristori-1 and Serristori-2 in Val di Solda, Rossbank, Lago lungo, Sternai-1 and Sternai-2 in Val d'Ultimo. Basic attributes for the study rock glaciers are reported in *Table 3*.

Figure 3. *Map showing the location of the RGV sites (red dots) in western South Tyrol, Italy.*

2.3.4 Norwegian sites (NORCE/UiO)

As part of the Option 8, NORCE and UiO will process RGV on Norwegian rock glaciers within the regions studied during Permafrost_cci Phase 1 [RD-11] [RD-13]. The objective is to apply a combination of radar and optical remote sensing technique: InSAR, SAR offset tracking (OT), feature tracking (FT) based on photos from manned and unmanned aircrafts, building on previous research and available datasets in the selected areas (Eriksen et al., 2018; Rouyet, et al., 2021; Lilleøren et al., 2022). For some sites, this combination will allow cross-validation. In other cases where velocity is too low or too high for one or another specific technique, we will take advantage of the complementarity of the techniques to document all velocity ranges. The Adjet ridge is ideal for this purpose as it includes many rock glaciers units with a wide range of velocity, over short distances. This area has also been studied into details during the multi-operator exercise of the first iteration (*Figure 4*). In addition, three additional landforms in the two other Norwegian regions (Svalbard and Finnmark) are selected (*Table 3*).

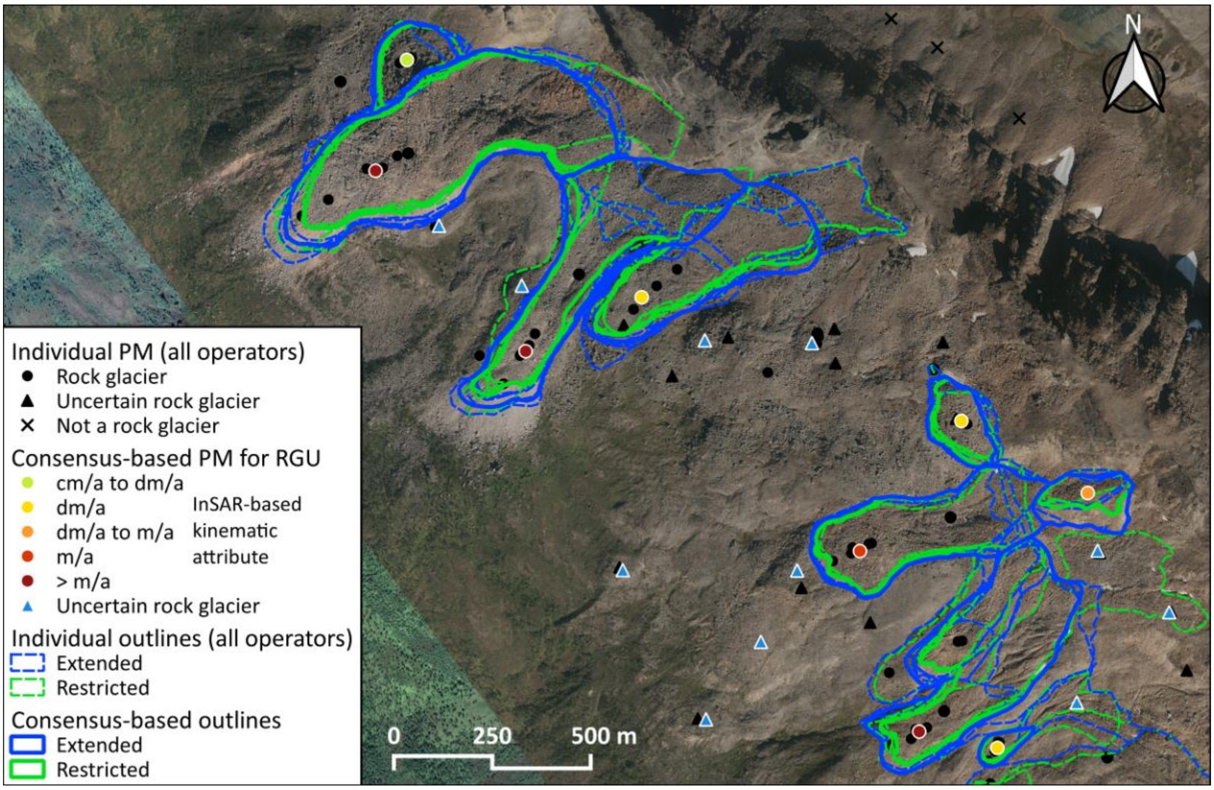

Figure 4. *Location map of the RGV sites in Troms, Northern Norway, along the Adjet ridge, previously studied during the RoGI multi-operator exercise (iteration 1).*

Table 2. *Characteristics of the sites selected for RGV production in Permafrost_cci iteration 2*

Partner institutions	Country	Name	Region	Elevation	Slope Aspect	Surface Velocity	Main applied method(s)	Validation data
UNIFR GAMMA (Baseline)	**Switzerland**	Distelhorn	Zermatt Valley	2370–2650	NW	0.5–3 m/yr (GNSS)	InSAR	
		Réchy (Becs-de-Bosson)	Réchy Valley	2610–2850	W	0.5–2 m/yr (GNSS)	InSAR	GNSS (periodic+permanent)
		Steintälli	Zermatt Valley	2960–3150	WSW	0.2–1 m/yr (GNSS)	InSAR	
		Bru	Zermatt Valley	2840–2960	NW	0.5–1 m/yr (GNSS)	InSAR	GNSS (periodic)
		Gänder	Zermatt Valley VS	2410–2770	NW	0.5–2 m/yr (GNSS)	InSAR	
		Breithorn	Zermatt Valley VS	2620–3150	W	0.1–0.7 m/yr (GNSS)	InSAR	
		Grabengufer	Zermatt Valley VS	2760–2960	NW	1–1.5 m/yr (GNSS)	InSAR	
		Perroc	Arolla Valley VS	2100–2750	W	0.1–0.3 m/yr (GNSS)	InSAR	
		Petit-Vélan	Gd-St. Bernard VS	2510–2820	NE	0.1–1.5 m/yr (GNSS)	InSAR	
		Chessi	Zermatt Valley VS	2500–2900	WNW	0.1–1 m/yr (GNSS)	InSAR	
		Monte Prosa	Gotthard TI	2430–2600	NW	0.2–1 m/yr (GNSS)	InSAR	
		Tellers Davains	Sursés Valley GR	2500–2900	W	1–2.5 m/yr (GNSS)	InSAR	
		Wassen	Uri Valley UR	2330–2520	W	0.5–2 m/yr (GNSS)	InSAR	
NORCE UiO (Option 8)	**Norway**	Adjet RGU fid 32	Skitbotndalen, Troms	600–1295	SW	cm–dm/yr (InSAR-RoGI)	InSAR	Cross-validation optical/radar remote sensing
		Adjet RGU fid 33				> m/yr (InSAR-RoGI)	OT/FT	
		Adjet RGU fid 36				> m/yr (InSAR-RoGI)	OT/FT	
		Adjet RGU fid 37				dm/yr (InSAR-RoGI)	InSAR	
		Adjet RGU fid 39				m/yr (InSAR-RoGI)	InSAR/OT/FT	
		Adjet RGU fid 40				> m/yr (InSAR-RoGI)	OT/FT	
		Adjet RGU fid 41				dm/yr (InSAR-RoGI)	InSAR	
		Adjet RGU fid 93				dm/yr (InSAR-RoGI)	InSAR	
		Adjet RGU fid 103				dm–m/yr (InSAR-RoGI)	InSAR/OT/FT	
		Sverdrup	Longyeardalen, Svalbard	70–180	ESE	dm/yr (InSAR-RoGI)	InSAR/OT/FT	
		Huset			ESE	cm–dm/yr (InSAR-RoGI)	InSAR	
		Ivarsfjord	Gamvik, Finnmark	60–170	W	mm–cm/yr (InSAR-RoGI)	InSAR/UAV FT	
UniBo GAMMA (Option 9)	**Italy**	Lazaun	Val Senales (NV)	2485–2750	NE	m/a (InSAR-RoGI)	InSAR	GNSS & UAV SfM available
		Similaun	Val Senales (NV)	2560–2900	SW	not available yet	InSAR	
		Hintergrath	Val di Solda (SV)	2630–2830	NE	dm–m/a (InSAR-RoGI)	InSAR	

		Razoi	Val di Solda (SV)	2545–2820	W	dm–m/a (InSAR-RoGI)	InSAR	
		Zay	Val di Solda (SV)	2395–2740	W	dm–m/a (InSAR-RoGI)	InSAR	
		Serristori-1	Val di Solda (SV)	2790–2920	WSW	dm/a (InSAR-RoGI)	InSAR	
		Serristori-2	Val di Solda (SV)	2720–2780	NW	dm/a (InSAR-RoGI)	InSAR	
		Rossbank	Val d’Ultimo (SV)	2450–2785	NE	dm/a–m/a (InSAR-RoGI)	InSAR	
		Lago Lungo	Val d’Ultimo (SV)	2385–2550	NW	dm/a–m/a (InSAR-RoGI)	InSAR	
		Sternai-1	Val d’Ultimo (SV)	2700–3005	E	dm/a–m/a (InSAR-RoGI)	InSAR	
		Sternai-2	Val d’Ultimo (SV)	2690–2875	E	dm/a–m/a (InSAR-RoGI)	InSAR	

3 Products specifications and formats

3.1 Rock Glacier Inventory (RoGI)

3.1.1 Product description

RoGI products consist of three vector files:

- The Primary Markers (PM), i.e. the points identifying and locating rock glaciers within the 12 areas. "Certain" and "uncertain" RGU can be differentiated and landforms that could be misinterpreted as rock glaciers but are not attributed to permafrost creep (e.g. glacial features, solifluction lobes, landslides) have in some cases been highlighted with an extra category "not a rock glacier". Attributes documenting the morpho-kinematic characteristics of the identified landforms are assigned to each "certain" RGU.
- The Moving Areas (MA), i.e. the polygons detected, delineated, and characterized (assignment of a velocity class) using Synthetic Aperture Radar Interferometry (InSAR) data. The MA files were used to categorize the kinematic attribute in the PM files.
- The Geomorphological Outlines (GO), i.e. the polygons outlining the restricted and/or extended geomorphological footprints of the rock glacier units categorized as "certain".

3.1.2 Input data

PM/GO products are based on optical imagery. Web Map Services (WMS) such as the Google Earth, Bing and ESRI orthoimages, are the main data sources. Additional data are used when available (high-resolution DEMs-based products and orthophotos available at the PI institutions or from other national/regional mapping services). MA products are based on InSAR data including wrapped interferograms from Sentinel-1 (and potentially ALOS, SAOCOM, Cosmo-SkyMed, and/or TerraSAR-X), potential complementary InSAR products processed with alternative methods (e.g. velocity maps from Stacking or Persistent Scatterer Interferometry algorithms), a layer displaying an index to reproject the LOS displacement along the direction of the steepest slope (normalization factor) or a mask highlighting N–S facing slopes where the movement is likely to be underestimated on InSAR data.

3.1.3 Temporal coverage

Rock glaciers identification (PM points) and outlining (GO polygons) are performed using the most recent optical imagery from Google Earth, Bing and ESRI WMS, potentially complemented by national/regional datasets (additional high-resolution DEMs-based products and orthophotos). The imagery date varies between the areas but is similar within each inventory team.

MA polygons are spatially identified and characterized using InSAR images acquired during the snow-free periods. The velocity class assigned to the MA is expressed in cm/yr. Sentinel-1 is the primary data source with images since 2016. Additional data based on ALOS, SAOCOM, Cosmo-SkyMed and TerraSAR-X SAR sensors are used where/when available.

The kinematic attribute refers to a category of annual velocity, expressed in cm/yr, dm/yr or m/yr. Specific translation rules are followed to derive the rock glacier kinematic attributes from the original velocity classes of the MAs. These rules are defined in the InSAR guidelines [RD-8].

3.1.4 Spatial coverage

In iteration 1, RoGI were generated in 12 areas selected in Romania, Switzerland, Norway, France, Italy, Greenland, Kazakhstan, Alaska U.S.A., Argentina, and New Zealand. Six additional areas are added in iteration 2 (see Section 2.2; Table 1). The InSAR data are clipped to the AOI extent. However, the actual coverage of interpretable InSAR information depends on the signal quality (e.g. low on wet, snow-covered, or vegetated surfaces), as well as the topography in respect to the sensor viewing geometry. Some areas cannot be documented with InSAR due to low coherence (decorrelation of the interferometric signal), layover or shadow. When the coverage is reduced on specific rock glaciers, the kinematic attribute remains "undefined".

3.1.5 Temporal resolution

The temporal resolution of the InSAR data depends on the repeat-pass of the SAR sensor and the time interval used to generate the interferograms. For Sentinel-1, the maximal temporal resolution is 6 days. Fast movements were identified using summer interferograms, using time intervals from 6 days up to several months. Slow movements were identified using annual interferograms computed between two or more consecutive summers.

3.1.6 Spatial resolution

The recommended minimum size of rock glaciers to be included in a RoGI is about 0.01 km^2 [RD-7]. 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]. Optical aerial/satellite images and DEMs were used to morphological interpretation and rock glacier delineation (outlines). The resolution typically varies between < 0.5 m and a couple of meters depending on the data sources used for generating the orthomosaics in the WMS services, and the potential use of additional high-resolution datasets. Moving areas related to the inventoried rock glaciers are outlined based on Sentinel-1 InSAR (20–60 m final resolution). Additional InSAR products with higher resolution (e.g. 3–10 m final resolution for CosmoSky-Med and TerraSAR-X) were used when available.

3.1.7 Product accuracy

Permafrost_cci Phase 2 RoGI are produced following a morpho-kinematic approach for which both rock glaciers that are moving and those that are not moving were identified. The movement rates of the active rock were documented rates using InSAR, primarily based on the Sentinel-1 SAR satellites. Rock glaciers that are not moving have also been morphologically identified. They were either characterized with a kinematic attribute < cm/yr or remain kinematically undefined, depending on the InSAR signal quality. 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 is 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. Similarly, the kinematic attribute of the rock glacier units is documented with low, medium and high categories depending on the quality and the spatial representativeness of the detected MAs. The reliability of the outlines is estimated with a scale from 0 (low) to 2 (high) for each boundary (front, lateral margins and upslope limit), and summed up to give a reliability estimate for the entire landform. The sources of uncertainties can be further described in 'Comments' fields.

3.1.8 Product attributes

For the Primary Markers (PM), the following attributes are documented:

- ID (unique alpha-numerical identifier of the rock glacier unit).
- X and Y coordinates (WGS84 coordinate system).
- Morphological type (simple, complex).
  Additional related attribute: the "Completeness" field defining if the rock glacier is complete visible or not (complete, unclear connection the upslope, truncated front, uncertain).
- Spatial connection to the upslope unit (talus-, debris mantle-, landslide-, glacier-, glacier forefield-, poly-connected, other, uncertain, unknown).
  Additional related attributes: the "Upslope Current" field defining if the rock glacier is currently connected to the upslope unit or not, and a "Comment" field to further describe morphological characteristics.
- Kinematic attribute (< cm/yr, cm/yr, cm/yr to dm/yr, dm/yr, dm/yr to m/yr, m/yr, > m/yr, undefined).
  Additional related attributes: the "Type of Data" field to define the type of data used to assign the kinematic attribute (Optical, Radar, Lidar, Geodetic, Other), the "Kinematic Period" field to document the applicable period of the kinematic attribute (year(s) with available data), the Reliability of the kinematic attribute (low, medium, high, undefined) and a specific "Comment" field to further document the applied method and the data quality.
- Activity (active, active uncertain, transitional, transitional uncertain, relict, relict uncertain, uncertain) and the "Activity Assessment" field documenting how the activity has been assessed (morphological evidence only or with kinematic data).
- Destabilization signs (yes - ongoing, yes - completed, no, undefined).

For the Moving Areas (MA), the following attributes are documented:

- ID (unique alpha-numerical identifier of the moving area)
- Velocity class (< 1 cm/yr, 1–3 cm/yr, 3–10 cm/yr, 10–30 cm/yr, 30–100 m/yr, > 100 cm/yr).
- 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).
- Additional comments.

For the Geomorphological Outlines (GO), the following attributes are documented:

- ID (unique alpha-numerical identifier of the moving area)
- Outline type (extended, restricted, other).

- Reliability of the front, the left margin, the right margin, and upslope limit (2 – high, 1 – medium, 0 – low) and Reliability Index (automatic summation of the values assigned to the reliability attributes of these four different boundaries).
- Additional comments.

3.1.9 Data documentation and dissemination

A Zenodo data package and ESSD paper based on the outcomes of the Permafrost_cci Phase 2 iteration 1 is currently in preparation and expected to be openly available in Fall 2024. In the future, other locations may be considered for hosting the international RoGI database, in the framework of the RGIK IPA Standing Committee.

3.1.10 Product projection system

The Coordinate Reference System (CRS) used for the RoGI products is the World Geodetic System 1984 (WGS84). The coordinates are in meters.

3.1.11 Metadata

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

3.1.12 File formats

All datasets are provided in a geopackage vector format (.gpkg), a platform-independent database container that is a more flexible alternative to the shapefile (.shp) format. The inventory with the Primary Markers (PM layer) is a point vector file. The InSAR-based Moving Areas (MA layer) and the Geomorphological Outlines (GO layer) are polygon vector files.

3.1.13 Product file naming conventions

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

<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>-<AREA_NUMBER>.

<REGION_NUMBER> follows the same numbering has for Permafrost_cci Phase 1: 5–Carpathians (Romania); 6–Western Alps (Switzerland); 7–Troms (Norway); 8–Finnmark (Norway); 9–Nordenskiöld Land (Svalbard); 10–Vanoise Massif (France); 11–Venosta (Italy); 12–Disko Island (Greenland); 13–Tien Shan (Kazakhstan); 14–Brooks Range (Alaska); 15–Central Andes (Argentina), 16–Southern Alps (New Zealand), 23–Balkan Mountains (Bulgaria), 24–Manaslu (Nepal), 25–Sajama (Bolivia–Chile), 26–Tsengel (Mongolia).
<AREA_NUMBER> is a one or more digit(s) number, depending on the area(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:

- PM: layer 1, corresponding to the rock glacier Primary Markers
- MA: layer 2, corresponding to the associated Moving Areas
- GO: layer 3, corresponding to the 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).

Example:
ESACCI-PERMAFROST-IND_SENTINEL1-INSAR_ROGI-AREA_6-1_RG_2023-fv01.0.gpkg

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).

3.2.2 Input data

Sentinel-1 Single-Look Complex (SLC) SAR images in Interferometric Wide (IW) swath mode is the primary data source. For SAR offset tracking, higher resolution SAR images (TerraSAR-X and CosmoSky-Med) may be used. RGV processed with optical feature tracking is based on airphotos from manned aircrafts or Unmanned Aerial vehicle (UAV).

3.2.3 Temporal coverage

Using Sentinel-1 12-days temporal baselines, 2015–2024 (10 years) years can be processed. Using 6-days temporal baselines, the temporal coverage is reduced to 2017–2021 (6 years). All time series are within the URq_15 Breakthrough Requirement (5–10 years) [RD-1]. When processing historical archives of aerial photos, the URq_15 Goal Requirement may be reached [RD-1].

3.2.4 Spatial coverage

Based on radar or optical remote sensing, velocity time series are produced for several pixels and aggregation strategies are developed to picture the interannual trends of the rock glaciers. The RGV represents the flow field over one or more area(s) representing the downslope movement of a rock glacier unit (Goal Requirement of URq_17 [RD-1]). 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) is documented and remains consistent over time.

3.2.5 Temporal resolution

Using InSAR, the initial velocity data is based on Sentinel-1 InSAR time series with a 6–12 days frequency collected during snow-free periods for the years 2015–2024 (observation time window < 1 year but covering at least one month). The velocity data is then annualized, following the URq_13 Breakthrough Requirement [RD-1]. The observation time window will be at least one month (between June–October), following the URq_14 Breakthrough Requirement [RD-1]. The chosen period is documented and remains consistent throughout the entire time series for each pilot site (max. ±15 days of difference), as required by URq_14 [RD-1]. Using SAR offset tracking, longer intervals may be considered but URq_13 and URq_14 will still be fulfilled. When processing historical archives of aerial photos, the measurement frequency may be > 1 year (2–5 year), corresponding to the URq_13 Threshold Requirement [RD-1].

3.2.6 Spatial resolution

Sentinel-1 data used for RGV production has an initial ground resolution of 25 m. Additional SAR images have higher resolution (< 10 m). For optical feature tracking, the image resolutions will range from a few metres (e.g. Corona spy images) to a few decimetres (e.g. 10–40 cm for airphotos). Using UAV images, the resolution can go down to cm resolution. The final RGV product corresponds to a spatial aggregation of several pixels, as described in Section 3.2.3. The size of the total contributing area varies from site to site.

3.2.7 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. Accuracy using offset/feature tracking will vary between mm–dm depending on the image resolution. For each site, the applied method(s) will be selected based on the minimal–maximal velocity of the landform and the detection capability of the technique. The accuracy is expected to have a relative error lower or equal to 20%, correspond to the threshold requirement of URq_18 [RD-1].

3.2.8 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 one single discrete point, and related specifications)
- Start date (date of first observation)
- Velocity data (computed RGV data in m/yr)

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/yr)
- 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)

3.2.9 Data documentation and dissemination

At the end of Permafrost_cci Phase 2, data and documentation will be made available on the UNIFR Permafrost_cci webpage (https://www.unifr.ch/geo/geomorphology/en/research/cci-permafrost.html) and/or in an openly data repository such as Zenodo. In the future, other locations may be considered for hosting the international RGV database, in the framework of the RGIK IPA Standing Committee.

3.2.10 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.

3.2.11 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.

3.2.12 File formats

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

3.2.13 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>
This should be structured as: SUBAREA_<REGION_NUMBER>-<AREA_NUMBER>.
<REGION_NUMBER> follows the same numbering has for Permafrost_cci Phase 1: 5–Carpathians (Romania); 6–Western Alps (Switzerland); 7–Troms (Norway); 8–Finnmark (Norway); 9–Nordenskiöld Land (Svalbard); 10–Vanoise Massif (France); 11–Venosta (Italy); 12–Disko Island (Greenland); 13–Tien Shan (Kazakhstan); 14–Brooks Range (Alaska); 15–Central Andes (Argentina), 16–Southern Alps (New Zealand), 23–Balkan Mountains (Bulgaria), 24–Manaslu (Nepal), 25–Sajama (Bolivia–Chile), 26–Tsengel (Mongolia).
<AREA_NUMBER> is a one or more digit(s) number, depending on the area(s)/site(s) within the region. Current sites: 0–Diestelhorn; 1–Rechy-Becs-de-Bosson; 2–Steintalli; 3–Bru; 4–Gander; 5–

Breithorn; 6–Grabengufer; 7–Perroc, 8–Petit-Velan, 9–Chessi, 10–Monte-Prosa, 11–TellersDavains, 12–Wassen, 13–Adjet3-2, 14–Adjet-33, 15–Adjet-36, 16–Adje-t37, 17–Adjet-39, 18–Adjet-40, 19–Adjet-41, 20–Adjet-93, 21–Adjet-103, 22–Sverdrup, 23–Huset, 24–Ivarsfjord, 25–Gran-Sommetta, 26–Grosses-Gufer, 27–Laurichard, 28–Lazaun, 29–Similaun, 30–Hintergrath, 31–Razoi, 32–Zay, 33–Serristori1, 34–Serristori2, 35–Rossbank, 36–LagoLungo, 37–Sternai1, 38–Sternai2.

<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-AREA_6-1-2023-fv01.0.csv

4 References

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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
FT	Feature Tracking
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
MAGST	Mean Annual Ground Surface Temperature
NORCE	Norwegian Research Centre AS
OT	Offset Tracking
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
UAV	Unmanned Aerial Vehicle
UiO	University of Oslo
UniBo	University of Bologna
UNIFR	University of Fribourg
URD	Users Requirement Document
URq	User Requirement
UTM	Universal Transverse Mercator
SfM	Surface from Motion
TR	Threshold Requirement
WUT	West University of Timisoara