CCI+ PHASE 2
PERMAFROST

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

D2.5 Product Validation Plan (PVP)

VERSION 1.0

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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, 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 are largely influenced by climatic factors. There is 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. This 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 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 techniques and spaceborne/airborne optical photogrammetry.

This Product Validation Plan (PVP) defines the rules for unbiased validation and the criteria applied for the two mountain permafrost products (RoGI and RGV). It describes the planned validation activities and lists the available datasets at the different study sites. It presents the timeline related to the validation documents and endorsement.

1 Introduction

1.1 Purpose of the document

The mountain permafrost component of Permafrost_cci Phase 2 focuses on the generation of two products: Rock Glacier Inventory (RoGI) and Rock Glacier Velocity (RGV). The Product Validation Plan (PVP) describes the planning for the validation of the products, as introduced in the PSD [RD-1].

1.2 Structure of the document

Section 1 provides information about the purpose and background of this document. Section 2 defines the rules for unbiased validation and the validation criteria. Section 3 describes the planned validation activities and recalls the justification of the selected algorithms. Section 4 provides an overview of validation documents and endorsement. A list of acronyms is provided in Section 5. 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., Jones, N., Bartsch, A. 2023. ESA CCI+ Permafrost Phase 2 – CCN4 Mountain Permafrost: Rock Glacier inventories (RoGI) and Rock glacier Velocity (RGV) Products. D1.2 Product Specification Document (PSD), v1.0. European Space Agency.

[**RD-2**] Rouyet, 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. D1.1 User Requirement Document (URD), 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 Action Group Rock glacier inventories and kinematics, 13 pp.

[RD-5] 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-6] 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-7] RGIK. 2023. InSAR-based kinematic attribute in rock glacier inventories. Practical InSAR guidelines (version 4.0). IPA Action Group Rock glacier inventories and kinematics, 33 pp.

[RD-8] 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-9] 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-10] RGIK 2023. Instructions of the RoGI exercise in the Goms Valley (Switzerland). IPA Action Group Rock glacier inventories and kinematics, 10 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.

1 Rules for unbiased validation and validation criteria

The Permafrost_cci project team shall ensure independency for the validation implying that the assessment of the rock glacier inventories (RoGI) and the rock glacier velocity time series (RGV) and the documentation of the product uncertainties are established with suitable statistical approaches and using independent datasets. The validation criteria vary for the two mountain permafrost products (RoGI and RGV).

2.1 Rock glacier inventory (RoGI)

The geomorphological elements of the inventories, i.e. the identification of the rock glaciers, the definition of the units/systems, the delineations of the landforms, the spatial connection of the rock glacier to the upslope unit and the activity will follow the recommended methodology and guidelines, developed by the IPA Action Group [RD-4] [RD-5] (see also PVASR and ATBD).

The kinematic components of the inventories, i.e. the identified and characterized moving areas as well as the kinematic attribute and related characteristics (validity time frame, data used, spatial representativeness and reliability) will follow the recommended methodology and guidelines developed by the IPA Action Group [RD-6] [RD-7] (see also PVASR and ATBD).

During the production of the RoGI, several operators will perform the work to provide a consensus-based solution and reduce the impact of single operator's subjectivity. A cross-validation procedure will be applied to evaluate the quality of the final products and report the degree of (dis)agreement between operators (see Section 3.1). The standard products will be made available to the community and evaluated by experts in mountain permafrost. The feedback from the members of the IPA Action Group RGIK (a network of 195 people in January 2023), as well as potential external contributors, will be used at the validation stage. We plan to complement the communication of the products by a survey about the general utility of the datasets and ask for volunteers to contribute to the evaluation.

2.2 Rock glacier velocity (RGV)

The retrieval of RGV products will follow the recommended methodology and guidelines developed by the IPA Action Group RGIK [RD-8] [RD-9] (see also PVASR and ATBD). The products will be evaluated and validated against in-situ GNSS data acquired at the selected pilot sites (see Section 3.2). As defined in the GCOS ECV requirements [AD-3], the required measurement uncertainty depends on the applied methodology (uncertainty of position or displacement measurement) and the spatio-temporal aggregation procedure used to measure and compute the annual velocity value for a defined rock glacier unit. The uncertainty has to be converted into m/yr for each annual velocity value. The ratio between this uncertainty and the considered annual velocity value has to be lower than 20% (threshold value). The comparison between RGV and complementary datasets has to show a difference below the accepted uncertainty threshold to be considered as valid.

As for RoGI, the standard products will be made available to the community and evaluated by experts in mountain permafrost. The feedback from the members of the IPA Action Group RGIK (a network of 195 people in January 2023) will be used at the validation stage. We plan to complement the communication of the products by a survey about the general utility of the datasets and ask for volunteers to contribute to the evaluation.

2 Planned validation activities

3.1 Rock glacier inventory (RoGI)

All steps of the RoGI procedure, including the characterization of the morpho-kinematic attributes, will be performed by a group of multiple operators from different institutions. The cross-validated final output is the results of a consensus between the team operators.

The degree of subjectivity of the procedure will be evaluated by documenting the discrepancies between operators for all the attributes of the RoGI output layers. The uncertainty will be reported as the degree of disagreement, expressed as the percent of results discarding with the consensus-based final decision.

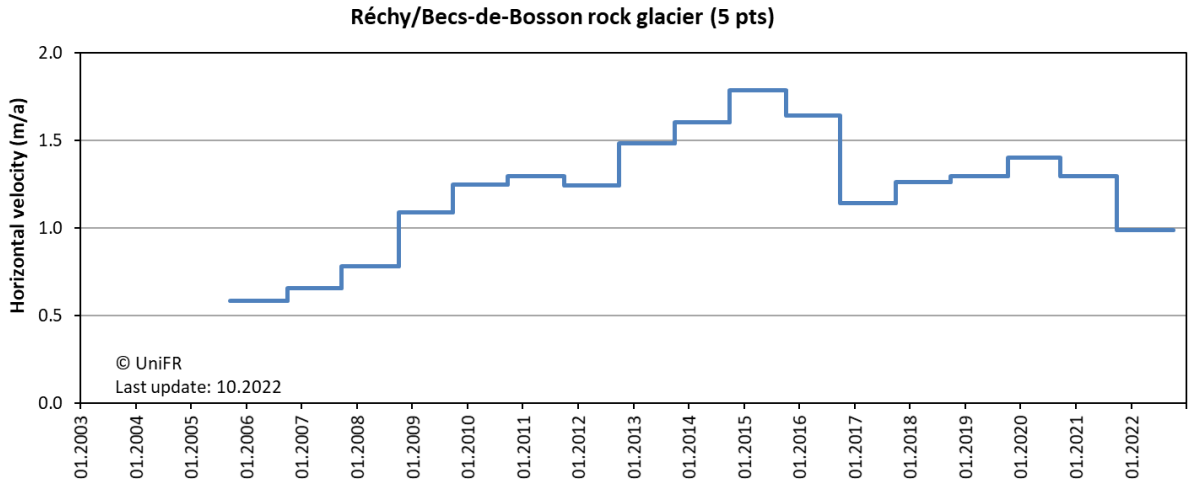
3.2 Rock glacier velocity (RGV)

The InSAR RGV will be generated following the procedure described in the ATBD. The selected pilot sites and available validation data are summarized in *Table 1*. The results will be compared with the GNSS RGV at the same sites. As we aim for documenting the interannual velocity trends, the comparison will focus on the relative velocity changes (%) instead of the absolute values.

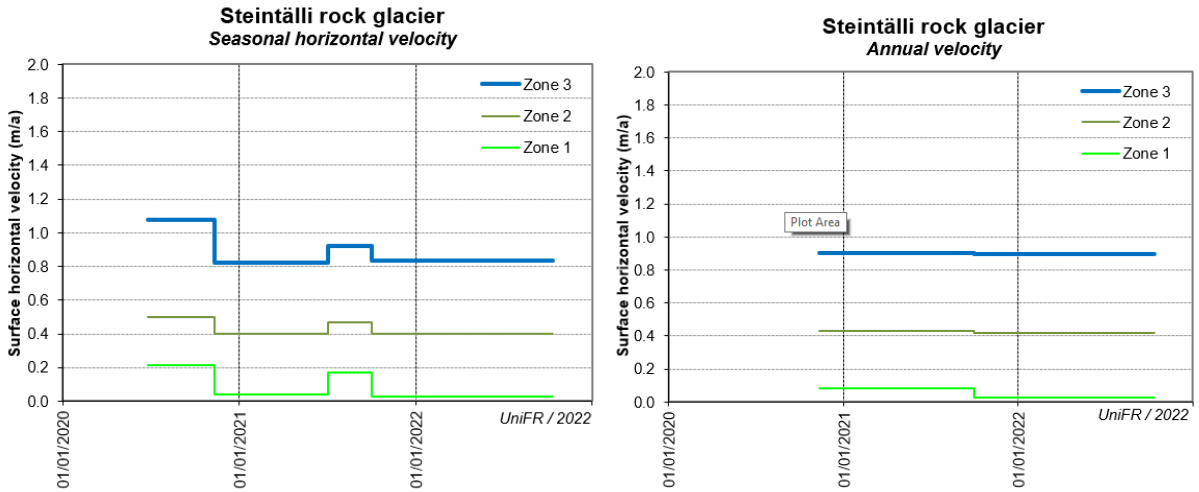
In total 14 landforms have been selected as first or second priority pilot sites (see PSD). All these sites are part of a long-term monitoring strategy led by the University of Fribourg (Unifr). Data acquisition is foreseen in the coming seasons, which will ensure follow-up validation potential when updating the products in the future.

The GNSS RGV are shown in the following sections. Except for Steintälli and Bru (recent sites/data), additional information about the sites and the available in-situ data can be found on the Unifr website (see hyperlinks in the headers of the following sections).

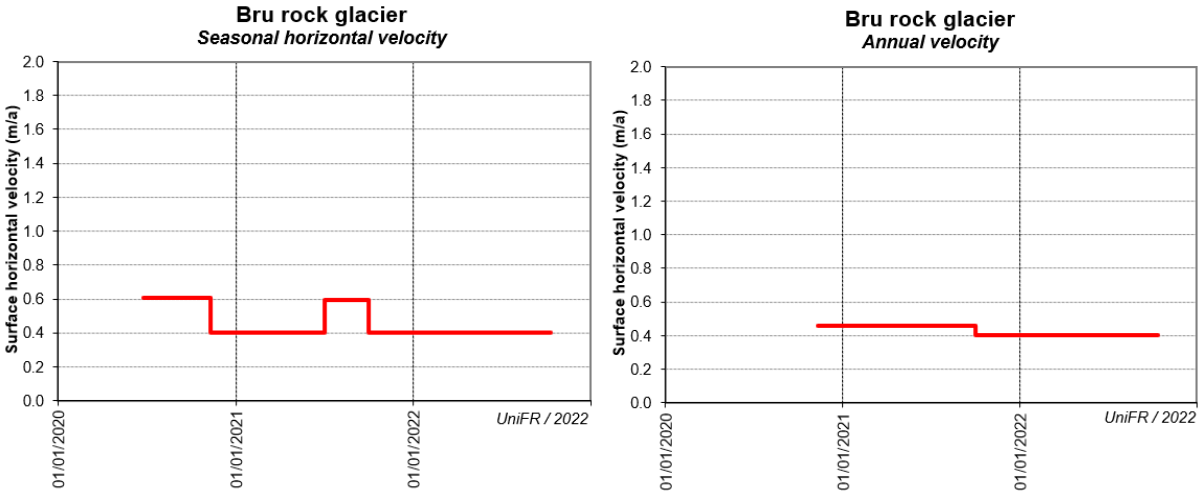
3.2.1 Réchy/Becs-de-Bosson GNSS RGV (hyperlink)



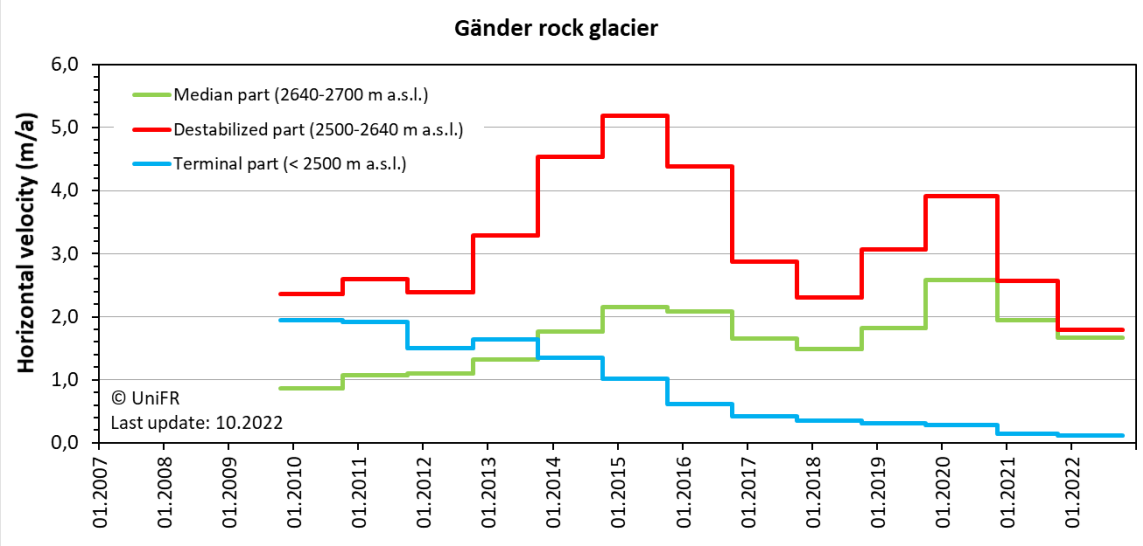
3.2.2 *Steintälli GNSS RGV (recent site)*



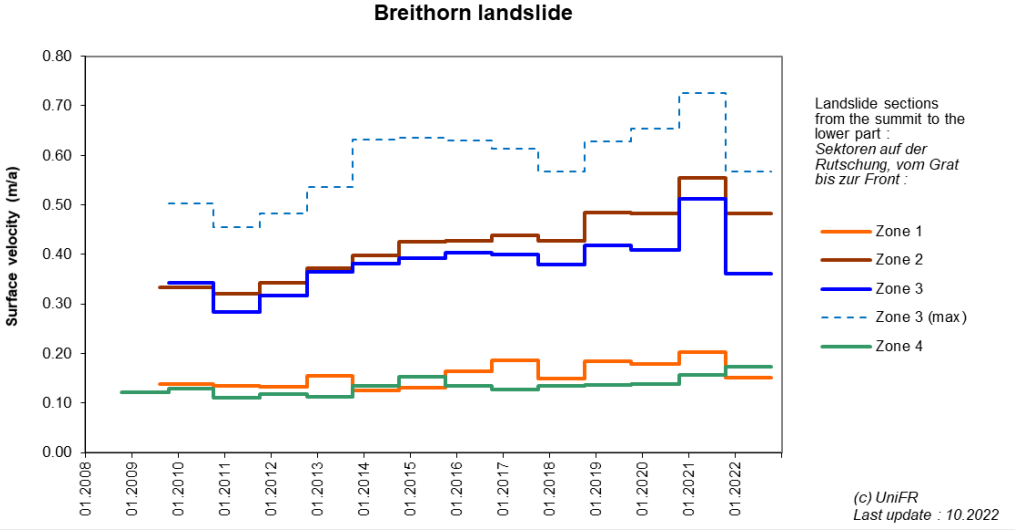
3.2.3 *Bru GNSS RGV (recent site)*



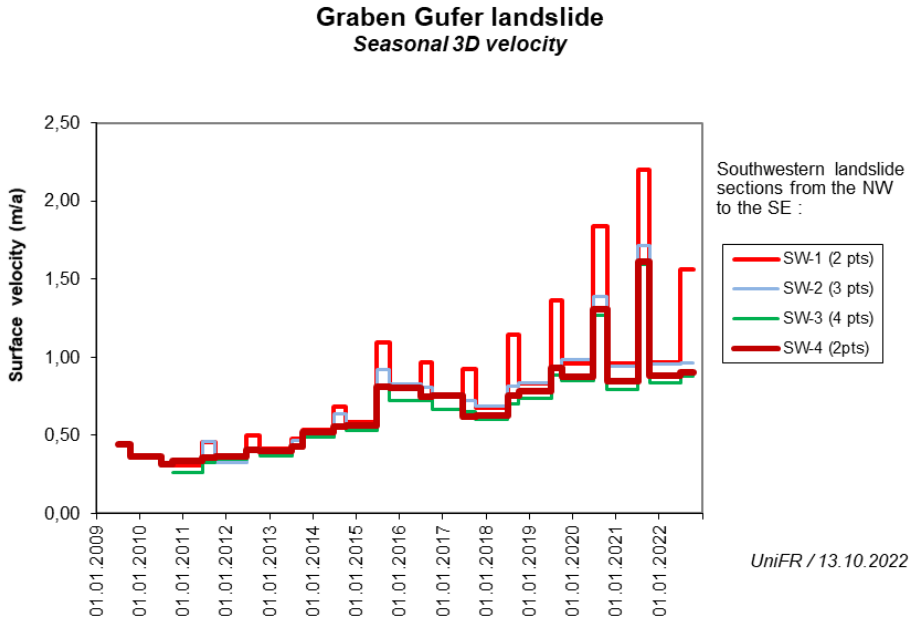
3.2.4 *Gänder GNSS RGV (hyperlink)*



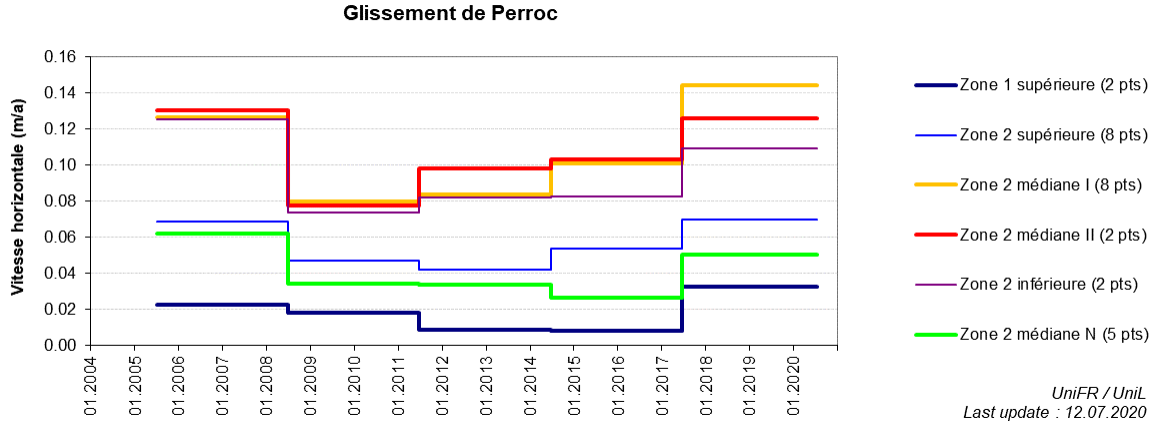
3.2.5 *Breithorn GNSS RGV (hyperlink)*



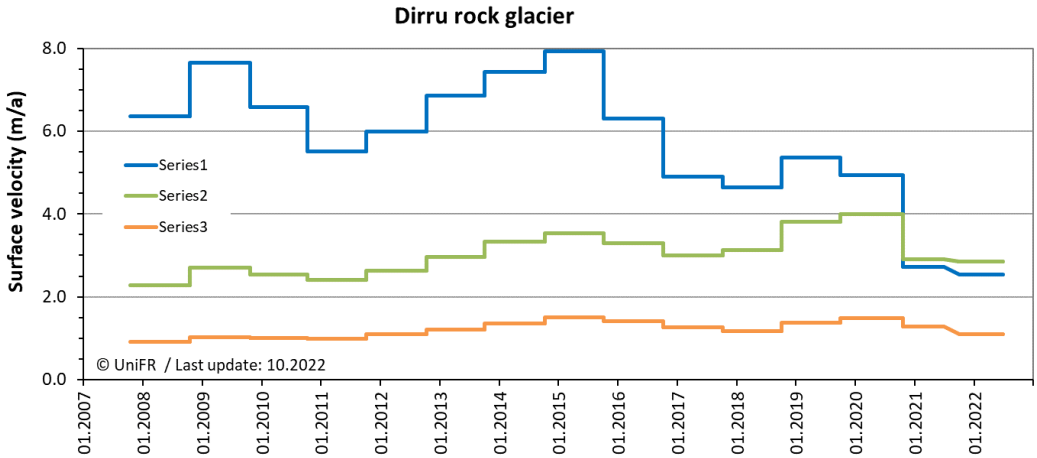
3.2.6 *Grabengufer GNSS RGV (hyperlink)*



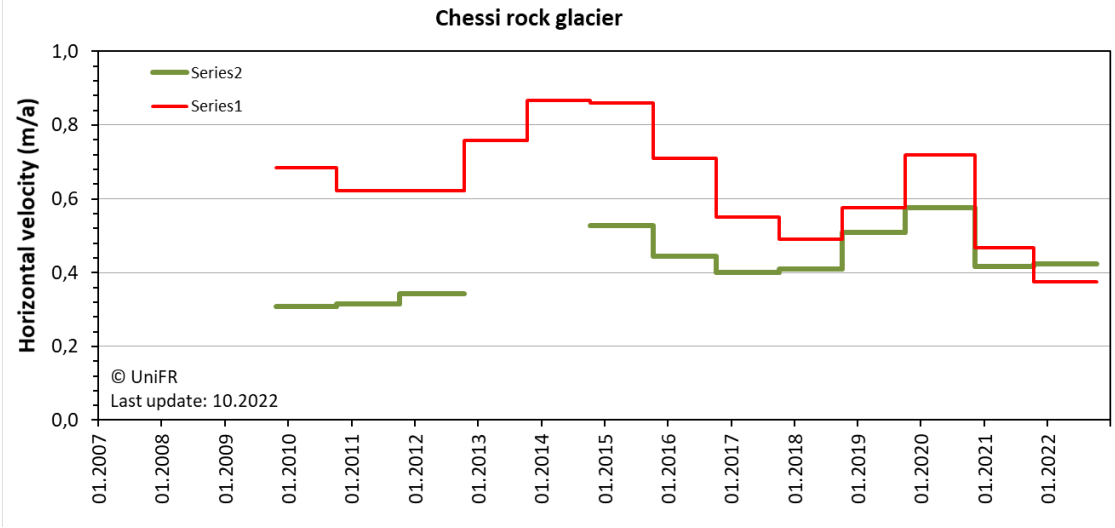
3.2.7 *Perroc GNSS RGV (hyperlink) - Not measured in 2022*



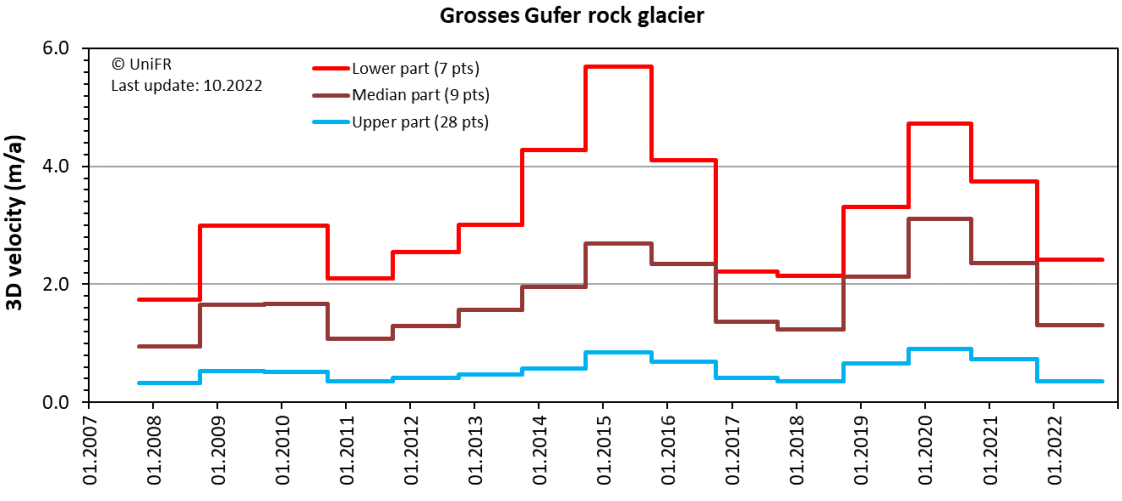
3.2.8 *Dirru GNSS RGV (hyperlink)*



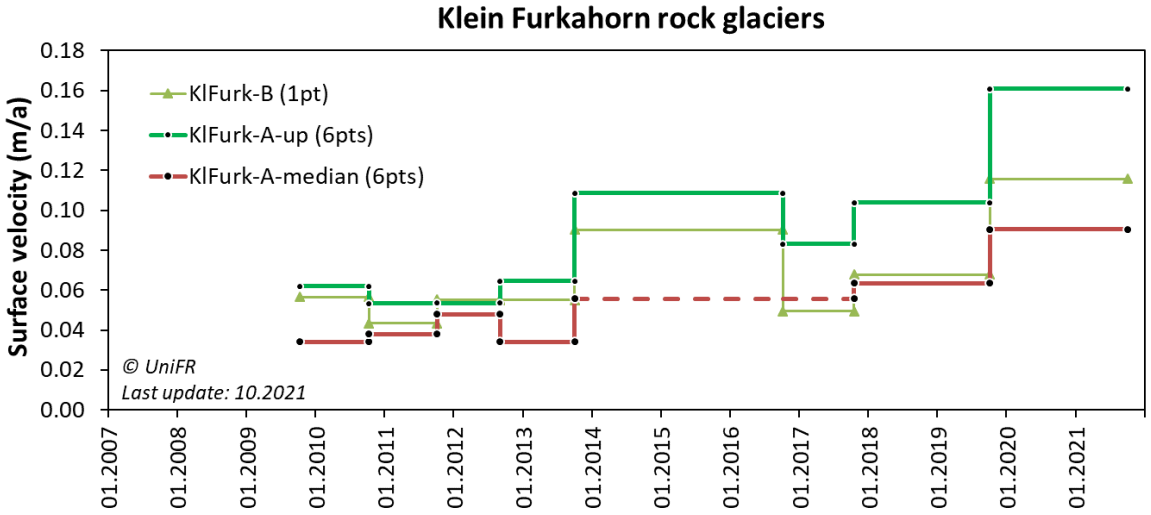
3.2.9 *Chessi GNSS RGV (hyperlink)*



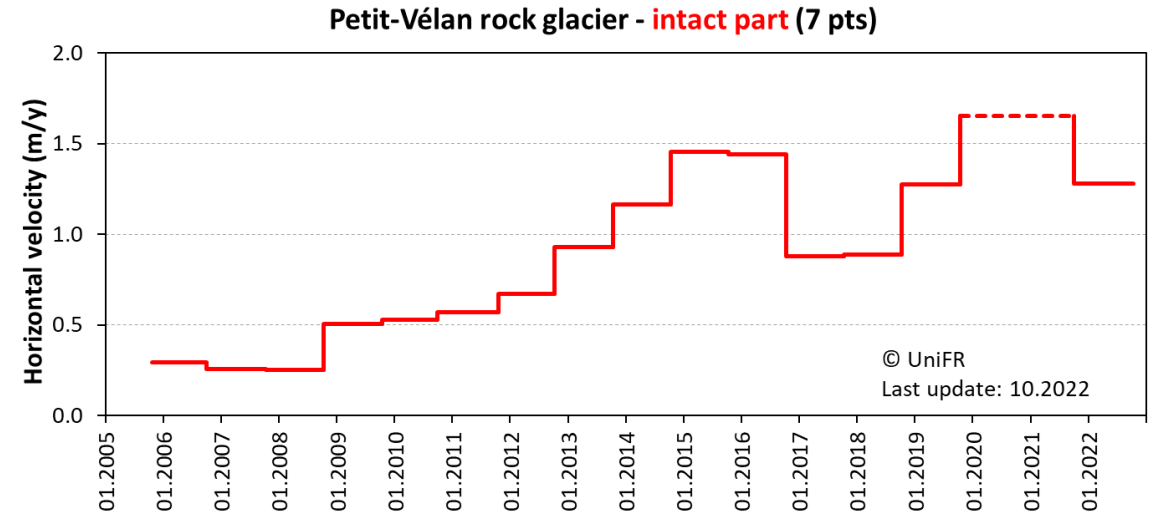
3.2.10 *Grosses Gufer GNSS RGV (hyperlink)*

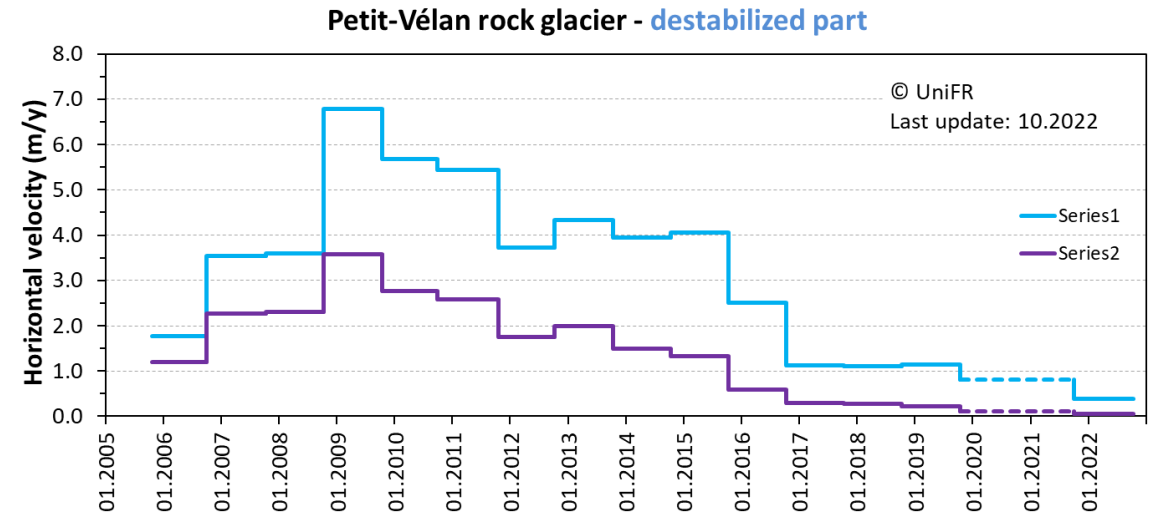


3.2.11 Klein Furkahorn GNSS RGV (hyperlink)

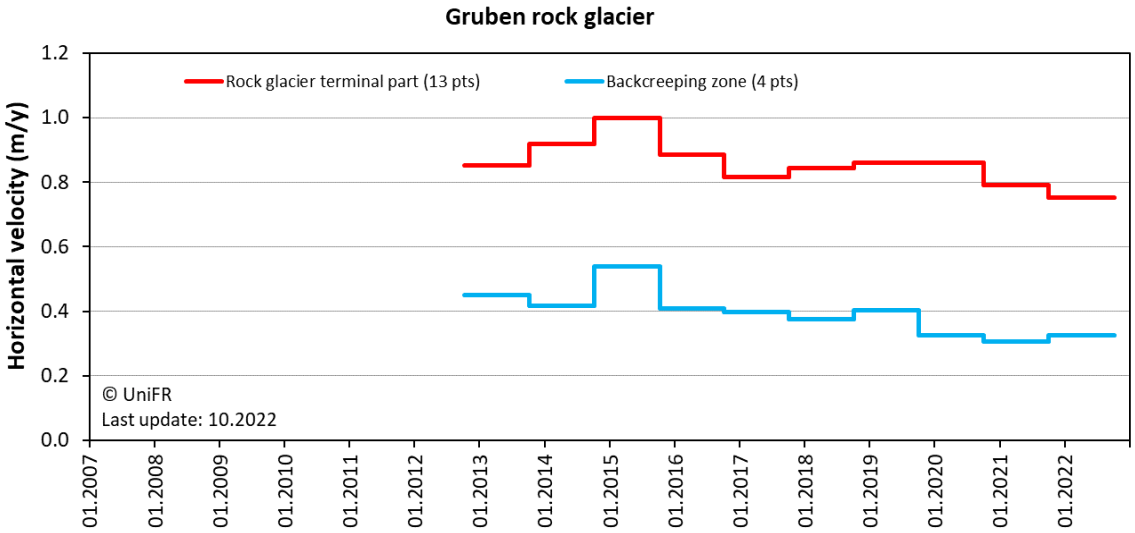


3.2.12 Petit-Vélan GNSS RGV (hyperlink)





3.2.13 Gruben GNSS RGV (hyperlink)



3.2.14 Bonnard GNSS RGV

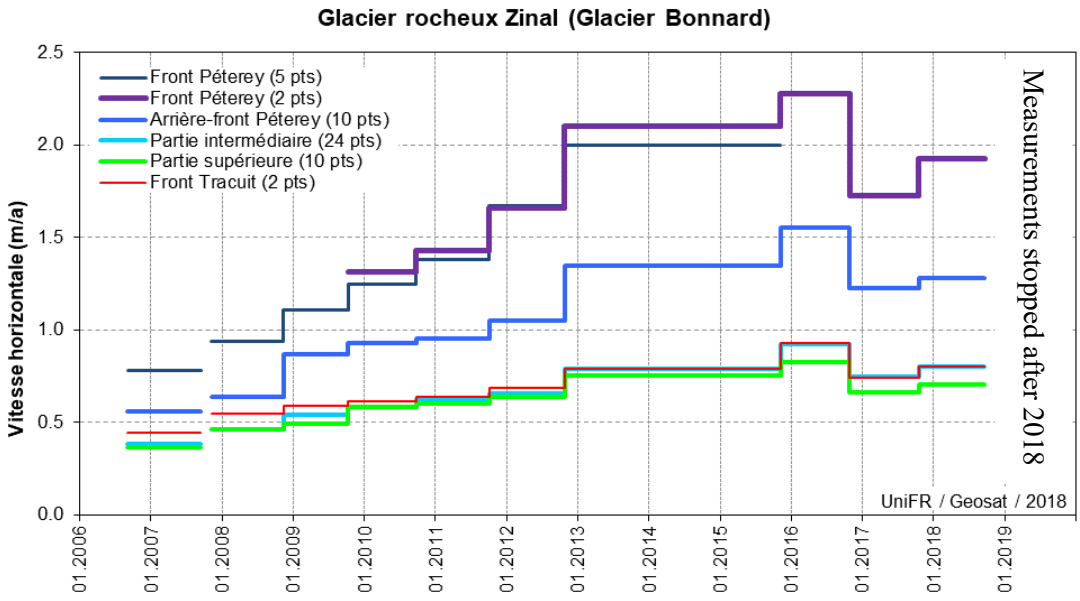


Table 1. *Characteristics of the pilot sites selected for defining the RGV production procedure based on InSAR*

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 documents rock glacier velocity at several locations.

4. Validation documents and endorsements

Table 2 provides an overview of the deliverables including information about product validation, intercomparison and assessment for RoGI and RGV products. These will be complemented with the updated versions of the reference documents generated by the RGIK community, i.e. the baseline concepts for RoGI and RGV generation [RD-4] [RD-6] [RD-8] and the related practical guidelines [RD-5] [RD-7] [RD-9] [RD-10].

Table 2. *Documents related to validation of the Permafrost_cci mountain permafrost products*

Deliv. No.	Name	Date	Comment
D1.1 D1.2	User Requirement Document Product Specification Document	15 February 2023 (KO+3)	Describes data format and publication
D2.1	Product Validation and Algorithm Selection Report	May 2023 (KO+6)	Documents the selection of the methods and criteria to provide standard products
D4.1	Product Validation and Intercomparison Report and Product User Guide	February 2024 (KO+15)	Provides a summary on quality and uncertainty of Permafrost_cci products and describes the delivered Permafrost_cci products
D5.1	Climate Assessment Report	May 2024 (KO+18)	Describes climate science study cases using the Permafrost_cci products and user's feedback

5. Acronyms

AD	Applicable Document
AI	Artificial Intelligence
ALT	Active Layer Thickness
ADP	Algorithm Development Plan
ATBD	Algorithm Theoretical Basis Document
BR	Breakthrough Requirement
CAR	Climate Assessment Report
CCI	Climate Change Initiative
CCN	Contract Change Notice
CRDP	Climate Research Data Package
DEM	Digital Elevation Model
E3UB	End-to-End ECV Uncertainty Budget
ECV	Essential Climate Variable
EO	Earth Observation
ESA	European Space Agency
GAMMA	Gamma Remote Sensing AG
GCOS	Global Climate Observing System
GNSS	Global Navigation Satellite System
GR	Goal Requirement
GT	Ground Temperature
GTN-P	Global Climate Observing System
GTOS	Global Terrestrial Observing System
IANIGLA	Instituto Argentino de Nivología, Glaciología y Ciencias Ambientale
InSAR	Interferometric Synthetic Aperture Radar
IPA	International Permafrost Association
KA	Kinematic Attribute
LOS	Line-of-sight
MA	Moving Area
MAGT	Mean Annual Ground Temperature
MAGT	Mean Annual Ground Surface Temperature
NORCE	Norwegian Research Centre AS
PERMOS	Swiss Permafrost Monitoring Network
PI	Principal Investigator
PM	Primary Marker
PSD	Product Specification Document
PUG	Product User Guide
PVASR	Product Validation and Algorithm Selection Report
PVIR	Product Validation and Intercomparison Report
PVP	Product Validation Plan
RD	Reference Document
RG	Rock Glacier
RGIK	Rock Glacier Inventories and Kinematics
RGU	Rock Glacier Unit
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
WMO	World Meteorological Organization