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, 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 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.

The document outlines the specifications of the Processing System (PS) for the mountain permafrost component of Permafrost_cci Phase 2. It describes purpose and intended use as well as the main requirements, functions and components. Further, it discusses the main operational scenarios and the necessary infrastructure and highlights the functional design from different perspectives (users, system operators and developers). Finally, it summarises the specifications concerning system life cycle design, implementation and maintenance costs and performance.

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 System Specification Document (D3.1) describes:

- the specification of the requirements of a processing system capable of generating the requested data products for mountain permafrost;
- the specification of an operational production system from a system engineering point of view;
- the verification that the system is properly working when executed in other hardware and/or software environments.

1.2 Structure of the document

Section 1 provides information about the purpose and background of this document.

Section 2 specifies the requirements of a processing system capable of generating the CCI mountain permafrost products (RoGI and RGV). The processing is first presented by giving the system overview. Then, different scenarios are discussed, and the workflow of the processing system is recalled. The detailed requirements for data processing functions of each step of the processing chain, including data volumes, the platform specifications and the compliance to all processing needs, are finally listed.
Section 3 incorporates the system requirements and specifies the characteristics of an operational production system from a system engineering point of view. The system design is based on experience with prototype processors developed prior to this project.

Section 4 discusses the verification methodology background of the processing system, presents the module tests and reports the testing procedures.

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.

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[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. D1.1 User Requirement Document (URD), 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. D1.2 Product Specification Document (PSD), v1.0. European Space Agency.

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[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. 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-10] 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, 12 pp.

[RD-11] 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-12] RGIK. 2023. Instructions of the RoGI exercises in the Goms and the Matter Valley (Switzerland). IPA Action Group Rock glacier inventories and kinematics, 10 pp.

[RD-13] 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-14] 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.

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[RD-18] 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. MOUNTAIN PERMAFROST PROCESSING SYSTEM OVERVIEW

2.1 Context

The Permafrost_cci Phase 1 baseline project focused on the ground temperature product and relevant derivatives (active layer thickness and permafrost zones). In Permafrost_cci Phase 2, we extended the scope of the baseline project to mountain permafrost products (Rock Glacier Inventories and Rock Glacier Velocity).

The Processing System (PS) defined in the context of Permafrost_cci is a science-driven system that produces the required data products to satisfy the GCOS and evolved data requirements. It is under configuration control and maintenance (bug tracking, reprocessing, traceability) and is technically capable of being sustainable in the long term beyond funding from the CCI programme.

For Mountain Permafrost, Permafrost_cci, the PS has to consider the following issues for each of the products:

- data archive;
- data production;
- data services.

Data archiving contains the need to retrieve and store the input data, auxiliary products (e.g. DEMs), intermediate products from the applied algorithms, and output data (final products). The data production deals with the generation of the final products, including meta-data and log files. The data services issue is related to data accessibility of the final products for the scientific community. For the Permafrost_cci system it must be considered that all products mandated repositories exist so that the PS only has to consider the datasets that are required for data production. Indeed, selected common services are offered within the CCI projects for sharing among ECVs. Among them are a backup archive for the data, cloud services that can be used by other ECVs, and a CCI product viewer.

The mountain permafrost module of Permafrost_cci includes two products:

- Rock Glacier Inventories (RoGI)
- Rock Glacier Velocity (RGV)

2.3 User Requirements

Specific user requirements are documented in the URD RD-1. All specific user requirements for the Mountain Permafrost: Rock Glacier inventories (RoGI) and Rock glacier Velocity (RGV) Products are listed in Table 1 to complement Table 2 for the baseline project [RD-11].

Table 1: Summary of user requirements for the Rock Glacier Inventories (RoGI) and the Rock Glacier Velocity (RGV) products. In the column 'Type', Background (BG) means that the requirement relates to the initial selection of the study areas, data and/or methods. Production (P) means that the related requirements must be considered during the production phase. Evaluation (E) means that the requirements are related to the quality assessment of the products. The colours related to expected results of the Phase 2 of Permafrost_cci, as previously described in Section 4 (in black: Threshold Requirement; in blue: Breakthrough Requirement; in green: Goal Requirement).

ID	PARAMETER	USER REQUIREMENTS	TYPE
URq_01	RoGI	Relevant geographical coverage at the local-regional scale (valley side, drainage basin, mountain range).	BG
URq_02	RoGI	Inventory based on several recent datasets over the 5-10 past years.	BG
URq_03	RoGI	Identification by a primary marker (point) and rock glacier outline as a polygon following the extended and/or restricted geomorphological footprints). Each RGU must imperatively be associated with one single RGS.	P
URq_04	RoGI	Differentiation of rock glacier units (RGU) and mono-unit or multi-unit systems (RGS), based on distinct timing of formation, different connections to the upslope unit or distinct activities/kinematics.	P
URq_05	RoGI	Mandatory documentation of the temporal properties (acquisition data, time frame/window) of the data sources used for RoGI generation, required for comparison and potential future update.	P
URq_06	RoGI	Updated activity categorization: active, transitional, or relict.	P
URq_07	RoGI	Optional attribute, only documented when geomorphological or kinematic evidence is available.	P
URq_08	RoGI	Semi-quantitative 'half an order-of-magnitude' categories: cm-dm/yr, dm/yr, dm-m/yr, m/yr, etc.	BG/P
URq_09	RoGI	Semi-quantitative velocity classes, depending on the applied technique. For InSAR: 1-3 cm/yr, 3-10 cm/yr, 10-30 cm/yr, 30-100 cm/yr, etc.	BG/P
URq_10	RoGI	The data properties (data source, dimensionality, time	E

		window/frame) must be documented for all attributes. The reliability and spatial representativeness of moving areas and kinematic attributes must be qualitatively assessed (low, medium, high).	
URq_11	RGV	Multiple sites in a defined region, allowing for preliminary analysis of similar/dissimilar trends.	BG
URq_12	RGV	Active or transitional rock glaciers with movement related to permafrost creep. Sites where long-term monitoring is feasible. Rock glacier units fully characterised following RoGI requirements.	BG
URq_13	RGV	1 year, i.e. measured or computed once a year.	BG/P
URq_14	RGV	Observation time window < 1 year (e.g. summer period only). At least 1 month and consistent over time (max. ≈15 days of difference).	BG/P
URq_15	RGV	Temporal extent: past 5-10 years	BG/P
URq_16	RGV	Annual mean velocity value. Unit: m/yr	P
URq_17	RGV	The velocity is aggregated from flow field or several discrete points covering a large part of the rock glacier unit. The aggregation procedure and the considered area should be consistent over time.	BG/P
URq_18	RGV	Maximal relative error of the velocity data: 20%. If the error exceeds 20%, the site must be discarded, or alternative techniques should be considered in accordance with the absolute velocity measured/computed of the selected rock glacier.	E
URq_19	RGV	Problems occurred with the latest velocity data that imply major changes of the technique. The RGV consistency is not ensured. A new time series should start with adjusted technique and settings. A merging of the two time series is allowed only if they overlap for at least one (ideally several) year(s).	E

2.4 Processing System Scenarios

The product specifications for RoCI and RGV are described in detail in the PSD [RD-2]. Table 2 below gives a summary of the specifications.

Table 2: Permafrost_cci Phase 2 mountain permafrost product specifications (NA: Not Applicable).

	Rock Glacier Inventories (RoGI)	Rock Glacier Velocity (RGV)
Description	A RoGI consists of 3 files: the Rock glacier locations (primary markers) including morpho-kinematic attributes, the rock glacier outlines and the InSAR-based moving areas	A RGV product 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
Spatial Coverage	European Alps, European Subarctic/Arctic and Extra-European	Selected rock glaciers in the European Alps (iteration 1), European

	Rock Glacier Inventories (RoGI)	Rock Glacier Velocity (RGV)
	subareas	Subarctic/Arctic and Extra-European sites (iteration 2)
EO Data	Sentinel-1, TerraSAR-X, Cosmo-SkyMED, ALOS-2 PALSAR-2, SAOCOM	Sentinel-1
Spatial Resolution	Minimum recommended size of inventoried rock glaciers: 0.01 km^2 InSAR-based moving areas: 2-40m resolution after multi-looking.	Due to spatial averaging of pixels showing similar velocity patterns, the resolution depends on rock glacier size, data coverage and moving patterns.
Spatial Aggregation	none	The velocity is aggregated from the InSAR flow field over one or more area(s) representing the downslope movement of a rock glacier unit. 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 consistent over time.
Spatial Filling	NA	NA
Weather Station Data	NA	NA
Period	2014-2023	2014-2023
Frequency	NA	Initial velocity data: 6-12 days during snow-free periods Final product: Yearly
Temporal Aggregation	NA	The initial velocity data are annualized. The observation time window is at least one month (between June-October). The chosen period remains consistent throughout the entire time series for each pilot site (max. ±15 days of difference).
Update Frequency	NA	Yearly
Map Projection	UTM WGS84	UTM WGS84
Coding	8 bit	8 bit
Format	gpkg	csv
Accuracy Target	1/10 of a wavelength	0.2 m/a
Uncertainty Metric	Reliability attributes Levels of discrepancies between RoGI operators	Interferometric coherence Relative error of the velocity data
Metadata	Yes	Yes
Data Access	UNIFR Permafrost_cci webpage (until future RGIK RoGI database)	UNIFR Permafrost_cci webpage (until future RGIK RGV database)

It is an important requirement on the processing system that data can be reprocessed. Consequently, the process has to be reproducible and the system sufficiently powerful to allow reprocessing in time. Reprocessing can be required by improved input data quality, improved processing software or improved algorithms. An important feature is the possibility to only run parts of the system. That allows to keep intermediate results and allows to reduce the reprocessing resources and time.

Another common topic identified in the Systems Engineer Working Group is the versioning and improvement cycle. A favourite approach is suggested by the SST_CCI Science Leader C. Merchant, see SRD of the baseline project [RD-11].

There is no foreseen direct interaction between the PS and the users. Communication with the users is done through the project management. Data access for the users is planned via the UNIFR website, while waiting for the upcoming international RoGI and RGV database in development by the Rock Glacier Inventories and Kinematics (RGIK) Community. The necessary links will be made towards the dedicated CCI product portals.

2.5 Processing System Production Workflow

The basic processing system production workflow of the modelling component is given in the corresponding SRD [RD-11]. It described the main parts: preprocessing, retrieval, product generation and verification/validation. The basic processing system production workflow for the mountain permafrost component is detailed in the Algorithm Technical Basis Document [RD-3].

2.5.1 Rock Glacier Inventories (RoGI)

In the first iteration of Permafrost_cci Phase 2, a cross-validation exercise based on a multi-operator inventorying procedure in 12 subareas of the initial regions has been performed to identify potential discrepancies between multiple operators, adjust the guidelines and evaluate the quality of the final products. The inventorying procedure includes two main phases.

During the first phase, the team had to:

• Detect and locate the rock glacier units by primary markers (points).

• Detect, delineate and classify the moving areas using InSAR data (iterative process with the first bullet point of rock glacier identification).

During the second phase, the team had to:

- Document the rock glacier characteristics (attributes).
- Delineate the rock glacier outlines.

Each phase is divided into three steps:

- Step 1: Individual work by each team operator. At the end of this step, all the operators send their results to the PI.

- Step 2: Compilation and summary from the PI. At the end of this step, the PI has chosen a suggested solution to potential discrepancies between operators, to be discussed with the team.
- Step 3: Discussion and consensus-based final decision by the inventory team. At the end of this step, the team agrees to the intermediate (first phase) or the final outputs (second phase).

The products are described in the CRDP cover sheet [RD-4].

2.5.2 Rock Glacier Velocity (RGV)

The processing line for RGV consists of the measurement of the InSAR time series on selected rock glaciers, potentially complemented by time series from SAR offset tracking, feature tracking on repeat optical airphotos.

To produce RGV, the following steps are required, following the RGV pratical guidelines from the IPA action Group RGIK [RD-11]:

- **Design of the monitoring setup**, which controls initial data acquisition.
- **Initial data acquisition**, which yields initial data.
- **Initial data preparation**, which pre-processes and evaluates initial data, yielding quality-controlled initial data.
- **Velocity data processing**, which calculates and provides cleaned velocity data that can be used for RGV processing.
- **RGV processing**, which temporally and spatially sorts and aggregates the velocity data to produce RGV.
- **RGV consistency evaluation**, which evaluates the consistency of the RGV during the entire chain of RGV production and provides recommendations for long-term monitoring.

Specific procedure based on InSAR data is described in the ATBD [RD-3]. The products are described in the CRDP cover sheet [RD-4].

2.6 Detailed Processing System Requirements

The systems need to be designed to be sustainable. Hence, there is a need to plan for evolution from the prototype approach towards compliance with applicable software standards e.g. appropriate components of ECSS-E-ST-40C. This implies that the requirements for configuration control and maintenance (bug tracking, reprocessing, traceability), operability and transferability are priorities. They shall at the start of the project identify the correspondence between the documentation set within this project and those required by the applicable Software Standard.

Since the system is science-driven it must be capable of being regularly updated as scientific understanding improves and new algorithms are developed. The incorporation of new algorithms needs to consider trade-offs in cost, complexity and scientific impact on the quality and consistency of outputs, and the introduction of new algorithms must not jeopardise the output generation. The design should also be modular and flexible while at the same time capable of rapid reprocessing, thus the overall design needs to be developed with end-to-end throughput of the ECV production as a design priority.

The requirements of the Permafrost_cci baseline PS were collected in [RD-11]. They have a unique 3 level identifier of the format "PF-TYPE-ID". The "PF" stands for Permafrost_cci. The "TYPE" is defined similarly as in other CCI projects:

FUN: functional
PER: performance
SIZ: sizing
INT: interface
OPE: operational
RAM: availability, maintainability, security

The "ID" is a 4-digit number. Here, we include additional detailed processing system requirements related to the parameters to be computed for the rock glacier products of Permafrost_cci Phase 2.

High Level System Requirements

Id	Content
PF-FUN-0120	Produce, validate and deliver Rock Glacier Velocity products
FP-FUN-0110	Produce, validate and deliver Rock Glacier Inventory products

3.1 Processing System Overview

The Permafrost_cci Phase 2 PS for mountain permafrost is aligned with the PS of the modelling part [RD-12]. It generates products and supports the process of algorithm improvement, reprocessing and validation. It provides products and services to the permafrost community supporting their climate change impact assessment over a wide range of scales. The PS will be used by the Permafrost_cci consortium but can also be applied by others as the overall workflow is very generic. The key difference to data production in other science projects is their often-missing dissemination, i.e. the work ends with a publication and generated data products are not shared. The Permafrost_cci PS is specified to provide products in a transparent and documented way, with accompanying meta-data, documentation, uncertainty and validation reports (project outreach).

The Permafrost_cci PS can be understood as a value-adding layer between the data provider and the users. There are interfaces to the different user communities, which receive products and can provide feedback. Another interface is with the EO data providers. Depending on the module, EO data are obtained from the providers and ingested into the PS. Feedback is given to the providers about issues found with the data, processing improvements and requirements for the continuity of the service. Another interface is towards third-party sources to receive ancillary and validation datasets.

The SSD of the baseline project [RD-12] gives an overview of the processing system (PS) with its main modules, functions and components. It also summarises its designated use and the system requirements. In the following, we remind the major characteristics of the Permafrost_cci PS and specify the peculiarities of the mountain permafrost modules.

3.2 Processing System Workflow and Operational Scenarios

As for the Permafrost_cci model PS, the mountain permafrost development teams consist of scientists and operators that manage the production and continuous development. Actors in the operational scenarios are users with different roles depending on how they use the system:

- Permafrost_cci users (end-user)
  - → are interested in best existing permafrost products
  - → are skilled in permafrost applications
  - → provide feedback and proposals
  - → request data format compatible with their communities
- Development team
  - → mandated to run Permafrost_cci in dialogue with users
  - → develops the PS further
  - → issues product versions
- Validation experts
  - → are part of the international community
  - → support development team
  - → have local expertise
  - → give feedback on the products
- Auditor/Project Manager

→ project supervision

The basic processing system production workflow of the Permafrost_cci PS can be found in [RD-12].

3.3 Functional Design

In this section. we discuss and present the major functional blocks of the Permafrost_cci PS and the peculiarities of the mountain permafrost modules.

3.3.1 Services

Most of the necessary services are provided through the CCI environment such as the data exchange storage, the document management system and user interaction. For the mountain permafrost PS development, software repositories and issue trackers are hosted at GAMMA, UNIFR and NORCE.

Processor software repository

An important element of the modern software development process is source control (or version control). Cooperating developers commit their changes incrementally to a common source repository, which allows them to collaborate on code without resorting to crude file-sharing techniques (shared drives, email). Source control tools track all prior versions of all files, allowing developers to "time travel" backward and forward in their software to determine when and where bugs are introduced. These tools also identify conflicting simultaneous modifications made by two (poorly-communicating) team members, forcing them to work out the correct solution (rather than blindly overwriting one or the other original submission). The software repository contains the actual processing code and all prior versions. The write access to the processor repository is restricted to the development team. As all software changes are updated directly in the repository, the software changes are published almost immediately and are made available for review.

3.3.2 Processors

The processors cover the necessary tools to produce the different Permafrost_cci products. The Permafrost_cci is organized in modules covering the production of the different products. In general, a distributed processing approach is followed. Consequently, the modules are portable (can be executed on different systems).

Table 3: Permafrost_cci mountain permafrost modules

COMPONENT	PURPOSE	IMPLEMENTATION
RoGI module	Identify, characterize and outline rock glaciers Identify, characterize and outline moving areas based on InSAR data	New processor implemented around QGIS
RGV module	Compute time series of annualized surface velocity on rock glaciers	New processors implemented around the Gamma and NORCE software

3.3.3 Concept for continuous improvement

Continuous improvement is an important aspect in the CCI projects. In order to ensure a transparent process, Software Modularity, Software Version Concept, Version Control, and Version Numbering are important issues. This section defines the structures and functions that extend the production environment for continuous improvement. Focus is on flexibility, rapid testing and prototyping. The concepts described are processors, versioning, and a test environment. The concept of processors and versioning contribute to the modularity of the system.

The software of the PS and the processing algorithms codes are under version control. The software repository contains the actual processing code and all prior versions. All software changes are documented in the repository. Version numbering of the processor is reflected in the repository by revisions and tags. Revisions are usually linked to commits and indicate the sequential order of documented changes. Tags are set to indicate software releases of frozen software states. Subversion is a good candidate for version control. Together with Redmine, it is a complete Free and Open-Source Software (FOSS) version control and issue tracking system.

Data processors help to organize the data processing in modules. Due to the differing input and output datasets/formats, the modules are normally not shared among products (even if the functionality is the same). A processor is a software component that can be parametrised and that generates a (higher level) output product of a certain type from one or several input products of certain types. A PS module consists of the sequential call of processors. Each processor has its own version information. Parameters and environment variables are provided in dedicated parameter files within the code. Feedback is received by a return code, messages on stdout/stderr and in log files.

3.3.4 System Documentation

The documentation contains the PS documentation consisting of manuals, specifications and reports, as well as the product documentation consisting of product specifications, manual and validation reports. At this stage no advanced functionality such as collaborative editing etc. seems to be necessary so that the basic functionality of any FOSS Control Management System (CMS) might be sufficient for this task.

The PS documentation includes requirement documents, design and interface control documents, test documents, manuals, and maintenance information. Permafrost_cci deliverables to name here are ATBD and the PUG. The SRD and SSD define requirements and design of the system.

3.4 Development, Life Cycle, Cost and Performance

This section discusses the system development in the future, potential development strategies, efforts and costs. The development is driven by several factors such as the availability of new technology, faster algorithms, new scientific findings and improved product algorithms, new available EO data, and user needs.

3.4.1 Re-use and Development

Development is needed to bring the existing prototypes of the PS modules to a higher operational level satisfying the requirements listed in the previous sections and to add the missing components such as those for user services, data handling, life cycle management, archiving etc.

Requirements addressed by this section are:

→ PF-OPE-4030 Development based on user requirements
→ PF-OPE-4020 Development decoupled from research
→ PF-OPE-4060 Freeze prototype
→ PF-FUN-5030 Verification of implementation

In the Table 4 we summarise the tools that were used, adapted, configured and integrated during development of the PS within the CCI and beyond.

Table 4: Permafrost_cci mountain permafrost development tools.

NAME	USAGE	REMARKS
Redmine	Issue tracking	FOSS
Python3	Scripting, netcdf4 reader, pyresample, rasterio, InSAR post-processing	FOSS
QGIS	GIS	FOSS
Gamma software (ISP, DIFF&GEO)	InSAR processing	Commercial
NORCE software	InSAR processing	Proprietary

3.4.2 System Life Cycle Drivers and Considerations

The PS needs to be incrementally adapted to integrate new functional extensions, improved algorithms and input datasets. New EO data make adaptations necessary and most likely also have an impact on the hardware infrastructure. The life cycle plan cannot be static as it is not foreseeable. Currently, the following driving factors are identified:

- Availability of the existing processor module prototypes
- Functional extension of the system
- New workflows
- Improved algorithms
- New Sensors
- Hardware improvements
- Dependencies on 3rd parties (other ECVs, data providers, new users)

To answer the first two points, the system is initially based on the prototype. Incrementally, additional components and functions are added and interfaces to data providers and users are extended. The third and fourth points on workflow and algorithm development require the addition of tools for validation and user feedback. The new sensors and the increased data volume and resolution are a qualitative change, too. The existing methods need to be adapted to make use of new sensors. For the longer perspective renewal of hardware and optional change of software layers must be taken into account. The PS design is prepared for this by the modularity of its functional components. The last item is not so relevant for Permafrost_cci at the moment as the dependence on other CCI projects is minor.

3.4.3 Sizing and Performance Analysis

In the SRD, no specific requirements are present concerning the processing time performance. At the moment it is mainly labour hours that drive the processing rather than CPU core hours. Full reprocessing of historical data requires a variable amount of work, depending on the product. The data storage budget for inputs and outputs for historical data and for the yearly increase of acquired data is in the low TB range initially.

The budgets for data storage are estimated in Table 5. The budget for data storage mainly depends on the amount of input data to be managed. This comprises historical data and data acquired continuously.

Table 5: Permafrost_cci mountain permafrost annual data storage budget.

DATA	PRODUCT	TIME SPAN	HISTORICAL DATA	SIZE / Y
Sentinel-1, ALOS-2 PALSAR-2, TerraSAR-X, Cosmo-SkyMED, SAOCOM, DEM, optical imagery	RoGI	2014-present	NA	< 10 TB
Sentinel-1, DEM	RGV	2014-present	NA	< 10 TB

3.4.4 Cost Estimation

The costs for the PS are composed of costs for storage, processing, network, development and integration, operations, dissemination and labour. The different modules have different needs.

The RGV module is developed around the GAMMA and NORCE software. The costs for the development and testing of the system are covered by the current project. The computing environment is provided by GAMMA and NORCE. The storage of RGV products is provided by GAMMA, UNIFR and NORCE and will be made available for download by the end-users.
RoGI are mapped manually by external providers based on optical imagery and InSAR maps produced by the CCI team and made available in the shared QGIS projects. The processing and mapping costs are covered by the current project. The storage of intermediate (InSAR maps) and final (RoGI) products is provided by GAMMA, UNIFR (InSAR data and RoGI). RoGI will be made available for download by the end-users.

5 REFERENCES

5.1 Bibliography

N.A.

5.2 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