CCI+ PHASE 1 – NEW ECVS
PERMAFROST

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

D4.3 Product User Guide

VERSION 1.0

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TABLE OF CONTENTS

Executive summary

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

In periglacial mountain environments, the permafrost occurrence is patchy, and the preservation of permafrost is controlled by site-specific conditions. Three options initiated within CCN1 and CCN2 address the need for additional regional cases in cooperation with dedicated users in characterizing mountain permafrost as local indicator for climate change and direct impact on the society in mountainous areas. Started in October 2018, CCN1 is led by a Romanian team focusing on case studies in the Carpathians. The specific objective of CCN1 is to develop and deliver maps and products for mountain permafrost, such as (i) rock glacier inventories, (ii) rock glacier kinematic time series of selected rock glaciers and (iii) a permafrost distribution model, primarily derived from satellite measurements. Started in September 2019, CCN2 consists of two options led by Swiss and Norwegian teams focusing on the investigation and definition of a new associated ECV Permafrost product related to rock glacier kinematics. Early 2020, Rock Glacier Kinematics (RGK) has been proposed as a new product to the ECV Permafrost for the next GCOS Implementation Plan (IP). It would consist of a global dataset of surface velocity time series measured/computed on single rock glacier units. A proper rock glacier kinematics monitoring network, adapted to climate research needs, builds up a unique validation dataset of climate models for mountain regions, where direct permafrost (thermal state) measurements are very scarce or even lacking totally. The international Action Group Rock glacier inventories and kinematics, under the IPA (International Permafrost Association), gathering about one hundred members, supports this integration and CCN2 is working closely with this Action Group [RD-10 to RD-13]. Following the recommendations of this IPA Action Group, the overall goal of CCN2 is achieved through the development of two products: (i) regional kinematics-based rock glacier inventories and (ii) rock glacier kinematic time series of selected rock glaciers. User Requirements, Product Specifications and Data Access Requirements are described in D1.1-1.3 of CCN1-2 [RD-20 to RD-22]. Product Validation and Algorithm Selection, Algorithm Theoretical Basis, End-to-End ECV Uncertainty Budget, Algorithm Development Plan and Product Validation Plan are described in D2.1-2.5 of CCN1-2 [RD-23 to RD-27]. System Requirement, System Specification and the System Verification are described in D3.1-3.3 of CCN1-2 [RD-28].

This Product User Guide provides the description of the Climate Research Data Package (CRDP) of CCN1 & CCN2 of the ESA CCI project for mountain permafrost regions, including formats, attributes and metadata. The products required within CCN1 & CCN2 include (i) regional rock glaciers inventories (RGI), (ii) rock glacier kinematic time series (RGK) on selected rock glaciers, and (iii) a mountain permafrost distribution model (MPDM) in the Romanian Carpathians.

Kinematics-based rock glacier inventories, were generated by different CCI groups and external providers according to the standards defined by the IPA Action Group Rock glacier inventories and kinematics [RF-29 and RF-30] in different climatic regions:

- European Alpine sites: Western Alps (Switzerland), Ultental (Italy), Vanoise Massif (France);
- European subarctic/arctic sites: Troms, Finnmark (Northern Norway), Nordenskiöld Land (Svalbard);
- Extra-European sites: Disko Island (Greenland), Tien Shan (Kazakhstan-Kyrgyzstan), Brookes Range (Alaska), Central Andes (Argentina), Southern Alps (New Zeeland).

Rock glacier kinematic time series (RGK) on selected rock glaciers were produced based on Sentinel-1 SAR interferometry, TerraSAR-X offset-tracking and feature tracking on repeat optical airphotos, in the Swiss Alps, Norway, Svalbard and Disko Island (Greenland). In addition, trends in rock glaciers velocity from ALOS-2 PALSAR-2 and Sentinel-1 SAR interferometry were computed in the Romanian Carpathians.

The permafrost distribution model in the Southern Carpathians covers an area of approximately 14.000 km^2 and was produced in raster format (.tiff files) at a spatial resolution of 30 m in the UTM WGS84 (EPSG: 4326) coordinate reference system.

1 Introduction

1.1 Purpose of the document

The products required within CCN1 and CCN2 of the ESA CCI project for mountain permafrost regions include (i) regional Kinematics-based rock glaciers inventories (RGI), (ii) rock glacier kinematic time series (RGK) on selected rock glaciers, and (iii) a mountain permafrost distribution model (MPDM) in the Carpathians. The Product User Guide (PUG) provides to users the description of the Climate Research Data Package (CRDP). This includes formats, attributes and meta data.

1.2 Structure of the document

Section 2 provides the Product User Guide for the rock glaciers inventories generated by external providers in different climatic regions.

Section 3 provides the Product User Guide for the rock glacier kinematic time series (RGK) on selected rock glaciers, including the trends in rock glaciers velocity in the Romanian Carpathians.

Section 4 provides the Product User Guide for a permafrost distribution model at regional scale in the Romanian Carpathians.

1.3 Applicable documents

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

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

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

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

[AD-5] GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO) protocols 3-4

[AD-6] ESA Climate Change Initiative. CCI Project Guidelines. EOP-DTEX-EOPS-SW-10-0002

[AD-7] National Research Council. 2014. Opportunities to Use Remote Sensing in Understanding Permafrost and Related Ecological Characteristics: Report of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/18711.

[AD-8] IPA Action Group ‘Specification of a Permafrost Reference Product in Succession of the IPA Map’ (2016): Final report.

https://ipa.arcticportal.org/images/stories/AG_reports/IPA_AG_SucessorMap_Final_2016.pdf

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1.4 Reference Documents

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[RD-2] A. Bartsch, S. Westermann, T. Strozzi, A. Wiesmann, C. Kroisleitner: ESA CCI+ Permafrost Product Specifications Document (PSD), v2.0 30 November 2019

[RD-3] A. Bartsch, S. Westermann, B. Heim, M. Wieczorek, C. Pellet, C. Barboux, C. Kroisleitner, T. Strozzi: ESA CCI+ Permafrost Data Access Requirements Document (DARD), v1.0 15 January 2019

[RD-4] A. Bartsch, S. Westermann, T. Strozzi: ESA CCI+ Permafrost Product Validation and Algorithm Selection Report (PVASR), v2.0 30 November 2019

[RD-5] S. Westermann, A. Bartsch, T. Strozzi: ESA CCI+ Permafrost Algorithm Theoretical Basis Document (ATBD), v2.0 30 November 2019

[RD-6] S. Westermann, A. Bartsch, B. A. Heim, T. Strozzi: ESA CCI+ Permafrost End-to-End ECV Uncertainty Budget (E3UB), v2.0 30 November 2019

[RD-7] S. Westermann, A. Bartsch, B. A. Heim, T. Strozzi: ESA CCI+ Permafrost Algorithm Development Plan (ADP), v2.0 30 November 2019

[RD-8] B. Heim, M. Wieczorek, C. Pellet, R. Delaloye, C. Barboux, S. Westermann, A. Bartsch, T. Strozzi: ESA CCI+ Permafrost Product Validation Plan (PVP), v2.0 30 November 2019

[RD-9] A. Wiesmann, A. Bartsch, S. Westermann, T. Strozzi: ESA CCI+ Permafrost System Requirement Document (SRD), v2.0 29 February 2020

[RD-10] A. Wiesmann, A. Bartsch, S. Westermann, T. Strozzi: ESA CCI+ Permafrost System Specification Document (SSD), v2.0 29 February 2020

[RD-11] A. Wiesmann, A. Bartsch, S. Westermann, T. Strozzi: ESA CCI+ Permafrost System Verification Report (SVR), v2.0 31 May 2020

[RD-12] B. Heim, M. Wieczorek, C. Pellet, R. Delaloye, A. Bartsch, D. Jakober, G. Pointner, T. Strozzi, GAMMA: ESA CCI+ Permafrost Product Validation and Intercomparison Rerport (PVIR), v2.0 30 September 2020

[RD-13] J. Obu, S. Westermann, T. Strozzi, A. Bartsch.: ESA CCI+ Permafrost Climate Research Data Package Version 1 (CRDPv1), v2.0 31 May 2020

[RD-14] A. Bartsch, J. Obu, S. Westermann, T. Strozzi: ESA CCI+ Permafrost Product User Guide (PUG), v2.0 27 May 2020

[RD-15] I. Nitze, G. Grosse, B. Heim, M. Wieczorek, H. Matthes, A. Bartsch, T. Strozzi: ESA CCI+ Permafrost Climate Assessment Report (CAR), v2.1 16 October 2020

[RD-16] T. Strozzi, A. Onaca, V. Poncos, F. Ardelean, A. Bartsch: ESA CCI+ Permafrost CCN1 D1. User Requirement, Product Specifications and Data Access Requirements Document, v1.0 15 February 2019

[RD-17] A. Onaca, F. Ardelean, F. Sirbu,V. Poncos, T. Strozzi, A. Bartsch: ESA CCI+ Permafrost CCN1 D2. Algorithm Development Document, v1.0 31 May 2019

[RD-18] A. Wiesmann, T. Strozzi, A. Onaca, F. Sîrbu, A. Bartsch: ESA CCI+ Permafrost CCN1 D3. System Development Document, v1.0 30 September 2019

[RD-19] F. Sîrbu, A. Onaca, V. Poncos, T. Strozzi, A. Bartsch: ESA CCI+ Permafrost CCN1 D3. Product Generation and Validation Document, v1.0 30 April 2020

[RD-20] C. Barboux, A. Bertone, R. Delaloye, A. Onaca, F. Ardelean, V. Poncos, A. Kääb, L. Rouyet, H. H. Christiansen, T. Strozzi, A. Bartsch: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D1.1 User Requirement Document (URD), v1.0 30 November 2019

[RD-21] C. Barboux, A. Bertone, R. Delaloye, A. Onaca, F. Ardelean, V. Poncos, A. Kääb, L. Rouyet, H. H. Christiansen, T. Strozzi, A. Bartsch: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D1.2 Product Specification Document (PSD), v1.0 30 November 2019

[RD-22] C. Barboux, A. Bertone, R. Delaloye, A. Onaca, F. Ardelean, V. Poncos, A. Kääb, L. Rouyet, H. H. Christiansen, T. Strozzi, A. Bartsch: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D1.3 Data Access Requirement Document (DARD), v1.0 30 November 2019

[RD-23] L. Rouyet, T. R. Lauknes, C. Barboux, A. Bertone, R. Delaloye, A. Kääb, H. H. Christiansen, A. Onaca, F. Sirbu, V. Poncos, T. Strozzi, A, Bartsch: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D2.1 Product Validation and Algorithm Selection Report (PVASR), v1.0 April 30, 2020

[RD-24] L. Rouyet, T. R. Lauknes, C. Barboux, A. Bertone, R. Delaloye, A. Kääb, H. H. Christiansen, A. Onaca, F. Sirbu, V. Poncos, T. Strozzi, A, Bartsch: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D2.2 Algorithm Theoretical Basis Document (ATBD), v1.0 April 30, 2020

[RD-25] L. Rouyet, T. R. Lauknes, C. Barboux, A. Bertone, R. Delaloye, A. Kääb, H. H. Christiansen, A. Onaca, F. Sirbu, V. Poncos, T. Strozzi, A, Bartsch: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D2.3 End-to-End ECV Uncertainty Budget (E3UB), v1.0 April 30, 2020

[RD-26] L. Rouyet, T. R. Lauknes, C. Barboux, A. Bertone, R. Delaloye, A. Kääb, H. H. Christiansen, A. Onaca, F. Sirbu, V. Poncos, T. Strozzi, A, Bartsch: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D2.4 Algorithm Development Plan (ADP), v1.0 April 30, 2020

[RD-27] L. Rouyet , T. Rune Lauknes, C. Barboux, A. Bertone, R. Delaloye, A. Kääb, H. H. Christiansen, A. Onaca, F. Sirbu, V. Poncos, T. Strozzi, A, Bartsch: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. D2.5 Product Validation Plan (PVP), v1.0 April 30, 2020

[RD-28] A. Wiesmann, T. Strozzi: ESA CCI+ Permafrost. CCN1 & CCN2 Rock Glacier Kinematics as New Associated Parameter of ECV Permafrost. System Development Document (SDD), v1.0 30 November 2020

[RD-29] IPA Action Group Rock glacier inventories and kinematics, 2020. Towards standard guidelines for inventorying rock glaciers. Baseline concepts. Last version available on https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_Baseline_Concepts_Inventorying_Rock_Glaciers.pdf

[RD-30] IPA Action Group Rock glacier inventories and kinematics, 2020. Kinematics as an optional attribute of standardized rock glacier inventories. Last version available on: https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_KinematicAttribute.pdf

[RD-31] IPA Action Group Rock glacier inventories and kinematics, 2020. Rock glaciers kinematics as an associated parameter of ECV Permafrost. Last version available on: https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_RockGlacierKinematics.pdf

[RD-32] IPA Action Group Rock glacier inventories and kinematics, 2020. Response to GCOS ECV review – ECV Permafrost. ECV Product: Rock Glacier Kinematics. Available on: https://gcos.wmo.int/en/ecv-review-2020.

1.5 Bibliography

A complete bibliographic list that support arguments or statements made within the current document is provided in Section 5.1.

1.6 Acronyms

A list of acronyms is provided in Section 5.2.

1.7 Glossary

A comprehensive glossary of terms relevant for the parameters addressed in Permafrost_cci is available as part of the User Requirement Documents of the baseline project [RD-1] and of CCN 1-2 [RD-16].

2 Regional rock glaciers inventories

2.1 Terminology

The Rock Glacier Inventory (RGI) identifies, enumerates and describes rock glaciers over a defined area for a defined time interval. Rock glaciers are spatially identified and characterized, as described in the Product Specification Document (PSD) [RD-21]. The kinematic attributes are assigned following the standards described in the Algorithm Theoretical Basis Document (ATBD) [RD-24].
The RGIs are derived for the European Alps, European Subarctic/Arctic and Extra-European sites.
Rock glaciers are discriminated using the technical definition proposed by the IPA Action Group based on aerial imagery/high resolution satellite imagery [RD-31] and/or with existing geomorphological rock glacier inventories.
Slope movements related to rock glaciers are detected based on InSAR data. These movements are spatially identified and characterized through 'moving areas', as defined in the Algorithm Theoretical Basis Document (ATBD) [RD-24]. Slope movements not related to rock glaciers can also be mapped, but this should be indicated in the metadata file and in the remarks attribute.

2.2 Temporal coverage

Moving areas are spatially identified and characterized using InSAR images acquired during the snow-free periods. Slow movements are identified using annual interferograms computed between two or more consecutive summers. Fast movements are identified using summer interferograms, using time intervals from 6 days. At least 15 interferograms are used.
Rock glaciers kinematics refer to annual velocity. Therefore, specific translation rules are followed to derive the rock glacier kinematic attributes from the original velocity classes of the moving areas. These rules are defined in the standards described in the Algorithm Theoretical Basis Document (ATBD) [RD-24]. They take into account (i) the InSAR underestimation of actual 3D displacement due to displacement being detected along the LOS component and (ii) the different temporal coverages between moving areas (e.g. summer) and annual rock glacier kinematic attribute. This is because rock glaciers are often faster in the summer, and by observing the displacement only during the summer, their annual velocity may be overestimated.

2.3 Spatial coverage

Coverage depends on the sensor's geometry. Depending on the region, two or more geometries from ascending and descending orbits are used. However, some rock glaciers are not covered at all due to foreshortening, layover or shadow conditions. Kinematics remains in that case "undefined".

2.4 Spatial resolution

The applied threshold for the minimum size of a rock glacier within a RGI is around 0.01 km^2. Each rock glacier is identified by a point located within the landform perimeter.
Moving areas related to the inventoried rock glaciers are outlined with polygons based on Sentinel-1 InSAR (20-60 m final resolution). Additional InSAR satellite data and/or optical aerial/satellite photogrammetry (1-10 m resolution) are used when available.

2.5 Product projection system

The Coordinate Reference System (CRS) used for the RGI products is UTM, based on the World Geodetic System 84 (WGS84) reference ellipsoid. The coordinates are specified in meters.

2.6 File format

Rock glacier inventory (RGI) format is a point shapefile, containing the location of each rock glacier unit. The moving areas (MA) format is a polygon shapefile, containing the delineation of the detected slope movements. The geomorphological outlines (GO) format is a polygonshapefile, containing the delineation of each rock glacier. The associated attribute tables contain information defined by the standards described in the Algorithm Theoretical Basis Document (ATBD) [RD-24].

2.7 Product file naming convention

The files are named as follows:

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

<CCI Project>
PERMAFROST for Permafrost_cci

<Processing Level>
Indicator - IND

<Data type>
RGI, for the rock glacier inventory.

<product string>: <source>_<algorithm>
Source data (main input), e.g. SENTINEL1, PALSAR, PALSAR2, TSX or AIRPHOTOS
Algorithm, e.g. interferometry (INT), offset-tracking (OFF) and feature tracking (FEA), multiple (MUL)

<Additional Segregator>: <area_layer>
This should be AREA<TILE_NUMBER> being the tile number the subset index: 5-Romania 6-Switzerland, Western Swiss Alps; 7-Norway, Troms; 8- Norway, Finnmark; 9-Svalbard, Nordenskiöld; 10-France, Vanoise; 11-Italy, Sud Val Venosta, Sudtirol; 12-Greenland, Disko Island; 13-Tien Shan; 14-Alaska, Brookes Range; 15-Argentina, Central Andes, 16-New Zealand, Central part of the Southern Alps
<Layer>
In case that the individual layers of the vector/raster product are provided as different NetCDF files, the code of each layer will be detailed as follows:
• RG: layer 1, corresponding to the rock glacier inventories
• MA: layer 2, corresponding to the associated moving areas
• GO: layer 3, corresponding to the optional geomorphological outline of rock glaciers

< Reference date of the production >

The identifying date for this data set:

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. For monthly products DD=01. Annual averages are represented with year only.

fv<File Version>

File version number in the form n{1,}[.n{1,}] (That is 1 or more digits followed by optional . and another 1 or more digits). The most recent version is fv1.0 (released in October 2020).

Example:

ESACCI-PERMAFROST-IND-RGI-SENTINEL1_INT-AREA6_RG-2020-fv01.0.shp

2.8 Feature attributes

For each rock glacier in the study sites the following attributes are recorded:
- ID (a unique alpha-numerical identifier of the rock glacier unit)
- geographic location, (X and Y coordinates of the unit)
- morphological type (undefined, simple or complex unit)
- spatial connection to the upslope unit (talus, debris mantle, landslide, glacier, glacier forefield, poly, undefined)
- activity (active, transitional, relict, undefined)
- destabilization signs visible (yes, no, undefined).
- kinematic class (Undefined, < cm/yr, cm/yr, cm/yr to dm/yr, dm/yr, dm/yr to m/yr, m/yr, > m/yr, Other)
- Multi-year validity time frame of the assigned kinematic class
- Data type, observation time window, temporal frame and dimensionality of the data used (e.g. related to the moving area) to assign the kinematic class
- Spatial representativeness: percentage of surface that is documented by supporting kinematic data (Undefined, < 50%, 50-75%, > 75%)
- Reliability of the kinematic class (Undefined, Low, Medium, High)
- Remarks (e.g. to provide the kinematic information when the kinematic class “Other” is used)

Each rock glacier is linked to moving area(s) whose following attributes are recorded:
- ID (a unique alpha-numerical identifier of the moving area)
- InSAR velocity class (Undefined, < 1 cm/yr, 1-3 cm/yr, 3-10 cm/yr, 10-30 cm/yr, 30-100 cm/yr, > 100 cm/yr, Other).
- Observation time window, temporal frame and sensor type used to perform the characterization
- Reliability of the InSAR velocity class (Undefined, Low, Medium, High)
- Related rock glacier unit
- Remarks

Moving areas not related to rock glaciers can also be mapped, but this should be indicated in the Metadata file and in the Remarks attribute.

2.9 Meta data

Standard formatting for the meta data information (e.g. JASON file) will be prepared at a later stage. Examples from prototypes developed in ESA DUE GlobPermafrost will be followed.

For each inventory a separate documentation file is provided building on the PUG. The documentations include information about the satellite scenes used (date, path, row, sensor, processing), the additional kinematic data used (used techniques, date acquisitions, points/areas measured, accuracy, precision), the date / source / spatial resolution of the available DTM and orthoimages, the available slope movement inventory and/or geomorphological rock glacier inventory as well as the names of the operators and the date / region of the analysis. Of course, references to be cited, acknowledgments and any other important metainformation are mentioned.

2.10 Known limitations

The spatial identification and characterization of the moving areas is technology-dependent. Therefore, it is subject to the limitations from the specific technique used. For the InSAR technique the limitations are described in the Algorithm Theoretical Basis Document (ATBD) [RD-24].

The spatial identification and characterization of a RGI aims to be technology independent and rules for standardization have been defined to take this into account. The assignment of kinematic classes depends on the available kinematic information (e.g. from the moving areas).

The production of deliverables for the investigated climatic regions highlighted the importance of quality and availability of the input datasets used. The main problems found are described below.

The slow movements are investigated mainly using annual interferograms. However, using a long time interval, the quality of the interferograms gets sometimes lower, not least due to loss of phase coherence, and the number of suitable interferograms is generally lower than the number of suitable interferograms with shorter time intervals. Slow movements are therefore more complicated to analyse, and reliability is consequently lower. As result, a larger number of slow movement features (moving areas and rock glaciers) detected with annual interferograms were classified as undefined.

In general, especially for the faster moving rock glaciers, the motion signature is sometimes very clearly visible in the short-term interferograms. However, depending on the region, local effects such as remaining snow, or local displacement gradients hinder the clear quantification of the velocity. Therefore, sometimes, only a single set of interferograms could be used to define the velocity class, which might not be representative if extrapolated over to a full year in cases where the rock glacier undergoes strong seasonal variability in velocity.

The investigated rock glaciers are sometimes connected to other landforms, e.g. rock glaciers connected to a debris-covered glacier in the upper part. The boundary between rock glaciers and debris-covered glaciers is sometimes unclear, and rock glaciers may therefore be mapped together with a debris-covered glacier. In these particular cases, the kinematic attribute was assigned but comments about this limitation added in the remarks field of the attribute table.

Another problem was related to the availability of optical data. The rock glaciers were identified and investigated with help of optical satellite imagery. When high-resolution optical data are not available on the investigated area, the study of the geomorphological characteristics of each rock glacier becomes complicated. Therefore, fields related to geomorphological characteristics (such as the morphology of the unit, the type of spatial connection to the upslope unit, the degree of destabilization and the spatial representativeness) were not provided when high-resolution optical data were not available.

In some cases, rock glaciers are too small compared to the resolution of interferograms possible, thus preventing classification. In some cases, rock glaciers are in areas of foreshortening, layover or shadow for both ascending and descending geometries, or creep in North-South direction that limits the LOS sensitivity of actual displacements.

Despite the limitations described, this work has demonstrated the large potential and feasibility of producing inventories of moving areas and kinematic inventories of rock glaciers on a global scale. Therefore, work will continue towards product standardization, updating and improving the guidelines.

A large number of external partners took part in the product generation. Therefore, many elements will probably be improved / updated in the future. Standard formatting for the metadata file (e.g. JASON file) will be prepared at a later stage. Useful information is provided with the documentation files.

3 Rock glacier kinematic time series

3.1 Kinematic time series from optical data

3.1.1 Terminology

Horizontal displacements can be measured from repeat orthorectified airphotos or high-resolution optical satellite data using cross-correlation techniques (Kääb and Vollmer, 2000). The results consist of the two-dimensional horizontal displacement components. Possibility to perform such measurements based on airphotos depends much on the availability, quality and accessibility of suitable imagery and varies a lot from country to country. While airphotos with good quality are accessible for instance in Switzerland and over parts of Norway, access is very complicated for instance in Central Asia. Modern high-resolution optical satellite data are commercial and access thus limited by finances available. Cold-war era spy satellite data from the US Corona program can be useful but availability is variable.

3.1.2 Temporal coverage

High resolution airphotos and satellite data can be available from around the 1960s on, though highly variable from country to country. Displacements are typically measured over time intervals of several years, i.e. are a pluriannual average.

3.1.3 Spatial coverage

As the temporal coverage, also the spatial coverage of suitable high-resolution optical data is highly variable and needs to be investigated from case to case.

3.1.4 Spatial resolution

Suitable image resolutions of available data ranges from a few metres (e.g. Corona spy images) to a few decimetres (e.g. 30 cm for best satellite data, or 20 cm for modern airphotos).

3.1.5 Product projection system

The Coordinate Reference System (CRS) used for the optical rock glacier velocities is UTM, based on the World Geodetic System 84 (WGS84) reference ellipsoid. The coordinates are specified in meters.

3.1.6 File format

Optical rock glacier velocities are provided in ASCII files with tab or space delimited columns for point coordinates, horizontal displacement components between two dates, and measurement quality indicators.

3.1.7 Product file naming convention

The files are named as follows:

ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>[-<Additional Segregator>]-<date 1>-<date 2>-<Indicative Date>-fv<File version>.<extension>

<CCI Project>
PERMAFROST for Permafrost_cci

<Processing Level>
Level 2 – L2: Retrieved environmental variables at the same resolution and location as the level 1 source. Level 0 – L0: 2D horizontal displacements between two dates.

<Data_type>
RGK, for the kinematic time series.

<product string>: <source>_<algorithm>
Source data (main input), e.g. AIRPHOTOS, …
Algorithm, e.g. interferometry (INT), offset-tracking (OFF) and feature tracking (FEA), multiple (MUL)

<Additional Segregator>
This should be AREA_<TILE_NUMBER> being the tile number the subset index: 5-Romania 6-Switzerland, Western Swiss Alps; 7-Norway, Troms; 8- Norway, Finnmark; 9-Svalbard, Nordenskiöld; 10-France, Vanoise; 11-Italy, Sud Val Venosta, Sudtirol; 12-Greenland, Disko Island; 13-Tien Shan; 14-Alaska, Brookes Range; 15-Argentina, Central Andes, 16-New Zealand, Central part of the Southern Alps

<Reference to RGI ID>
When available, reference to the unit's identifier from the rock glacier inventory, e.g. RG-06-0001-01.

<Date 1>-<Date 2>
Date of first and second image for which displacements are computed.

< Reference date of the production >
The identifying date for this data set:
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. For monthly products DD=01. Annual averages are represented with year only.

fv<File Version>
File version number in the form n{1,}[.n{1,}] (That is 1 or more digits followed by optional . and another 1 or more digits).

Example:

ESACCI-PERMAFROST-L2-RGK-AIRPHOTOS_FEA-AREA6-06-0001-01_17082011-18082016_2020-fv01.0.csv

3.1.8 Point attributes

For each measurement point of a file the attributes X, Y, dX displacement, dY displacement, length of displacement, azimuth of displacement, correlation coefficient are given.

3.1.9 Meta data

Standard formatting for the meta data information (e.g. JASON file) will be prepared at a later stage. Examples from prototypes developed in ESA DUE GlobPermafrost will be followed.

Further documentation files are provided based on the PUG. They contain the image sources and characteristics, operator, data of production, measurement parameters, and references.

3.1.10 Known limitations

A number of factors can make optical image matching difficult or reduce its accuracy:

- Images can have low radiometric quality (low contrast, shadows), which reduces correlation quality;
- Lack of visual contrast to match;
- Natural changes such as different snow covers or local terrain disturbances can produce mismatches;
- Different illumination conditions and shadows can lead to mismatches;
- Geometric distortions from image acquisition, storage or scanning appear falsely as displacements;
- Errors in the DEM used for image orthorectification translate to lateral distortions and appear falsely as displacements.
- Standard formatting for the metadata file (e.g. JASON file) will be prepared at a later stage. Useful information is provided with the documentation files.

3.2 Kinematic time series from SAR data

3.2.1 Terminology

Kinematic time series (RGK) from SAR data are processed using Synthetic Aperture Radar Interferometry based on Sentinel-1 images, according to specifications described in the ATBD [RD-24] and following the methodology published by Strozzi et al. (2020). The SAR geometry is chosen according to the slope orientation of the considered rock glacier (ascending for east-facing slopes, descending for west-facing slopes). All subsequent Sentinel-1 interferograms generated. Those with low coherence (e.g. due to snow in winter seasons) are discarded. It should however be noted that the data availability can vary from site to site (e.g. descending geometry in Svalbard was not available before 2018). The velocity series are generated by unwrapping the LOS phase of atmospheric corrected interferograms. A local calibration point in an area expected to be stable is used for each rock glacier. All values are projected along the local slope using an available DTM.

3.2.2 Temporal coverage

Sentinel-1 data are available since 2014, but regular acquisitions are mainly available only since 2016. The temporal interval between measurement is 6 days (12 days before 2016 and if an acquisition is missing). The measurement period varies from site to site depending on snow conditions.

3.2.3 Spatial coverage

RGK examples currently consists in a couple of sites per study area (06-Swiss Alps, 07-Troms, Norway, 08-Finnmark, Norway, 09-Nordenskiöld Land, Svalbard, 12-Disko Island, Greenland). The number of documented rock glaciers is meant to increase in the future.

3.2.4 Spatial resolution

Velocity measurements document a selected pixel at each site. A 4x1 multi-looing factor is applied to the interferograms leading to a spatial resolution of ca 20 m.

3.2.5 Product projection system

Latitude/longitude coordinates of the points are documented.

3.2.6 File format

RGK files are in csv format.

3.2.7 Product file naming convention

The files are named as follows:

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

<CCI Project>
PERMAFROST for Permafrost_cci

<Processing Level>
level 2, 3 (L2, L3) or Indicator (IND); L2- Retrieved environmental variables at the same resolution and location as the level 1 source, L3 - Level 2 variables mapped on a defined grid with reduced requirements for ancillary data. Three, IND - Indicators derived from satellite data.

<Data_type>
RGK, for the kinematic time series.

<product string>: <source>_<algorithm>
Source data (main input), e.g. SENTINEL1, PALSAR, PALSAR2, TSX or AIRPHOTOS
Algorithm, e.g. interferometry (INT), offset-tracking (OFF) and feature tracking (FEA), multiple (MUL)

<Additional Segregator>:<AREA_INSARLEVEL>
This should be AREA<TILE_NUMBER> being the tile number the subset index: 5-Romania 6-Switzerland, Western Swiss Alps; 7-Norway, Troms; 8- Norway, Finnmark; 9-Svalbard, Nordenskiöld; 10-France, Vanoise; 11-Italy, Sud Val Venosta, Sudtirol; 12-Greenland, Disko Island; 13-Tien Shan; 14-Alaska, Brookes Range; 15-Argentina, Central Andes, 16-New Zealand, Central part of the Southern Alps
INSAR processing level IL0 for LOS time series

- IL1 for time series in absolute velocity
- IL2 for time series in relative velocity
- IL3 regional indexes

So far, only IL0 and IL1 available.

<Reference to RGI ID>
When available, reference to the unit's identifier from the rock glacier inventory, e.g. RG-06-0001-01.
< Reference date of the production >
The identifying date for this data set:
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. For monthly products DD=01. Annual averages are represented with year only.

fv<File Version>
File version number in the form n{1,}[.n{1,}] (That is 1 or more digits followed by optional . and another 1 or more digits). The most recent version is fv1.0 (released in November 2020).

Example:
ESACCI-PERMAFROST-L3- RGK- SENTINEL1_INT-AREA6_IL1-06-0001-01_2020-fv01.0.csv

3.2.8 Pixel attributes

The following attributes are documented for both the selected point (on rock glacier) and at the InSAR reference location (expected to be stable):

- Latitude/longitude coordinates
- Elevation from available DEM
- Slope projected mean velocity
- LOS incidence angle and track angle
- LOS unit vector (East, North, Up)
- Slope/Aspect from available DTM
- Velocity series in m/yr projected along slopes, for acquisition dates YYYYMMDD
- LOS velocity series in m/yr, for acquisition dates YYYYMMDD (can be used in post-processing to correct for phase unwrapping errors)
- Coherence for acquisition dates YYYYMMDD (can be used in post-processing to include or exclude point on time series)

- Scale factor from LOS to projection along the slope (can be used in post-processing to correct for phase unwrapping errors)

3.2.9 Meta data

Standard formatting for the meta data information (e.g. JASON file) will be prepared at a later stage. Examples from prototypes developed in ESA DUE GlobPermafrost will be followed.

Separate documentation files are provided based on the PUG. They include information about the satellite scenes used (date, path, row, sensor, processing), the date / source / spatial resolution of the available DTM, as well as the names of the operators and the date / region of the analysis. References to be cited, acknowledgments and any other important metainformation are mentioned.

3.2.10 Known limitations

The current processing chain still require to be refined. Among the current identified challenges, here are the most important for improving the quality of the products:

- Selection of InSAR reference pixels (based on local knowledge, to account for ground stability at the chosen location) and relevant pixels for rock glacier monitoring based on interdisciplinary considerations (geomorphological expertise to focus on representative sections of the landforms and SAR expertise to account for potential InSAR limitations).
- Phase ambiguity and unwrapping errors: bias must be expected, especially for fast moving landforms. Due to small multi-looking factors (4x1), the quality of the phase estimate can be low at specific locations. Processing tests with 8x2 multi-looking factors may be performed in the future. With the assumption that errors may still remain, techniques to filter out outliers due to poor quality interferograms should also be tested.
- Atmospheric corrections: time series based on short temporal baseline (6 days) of image pairs do not benefit from a redundant network of interferograms usually used to correct atmospheric effects.
- Coherence estimation: coherence is used to consider a new point on the kinematic time series. Estimation window size, multi-looking and location might be optimized. In addition, if a filter based on coherence estimate is not sufficiently robust, other approaches, e.g. using amplitude dispersion, can be investigated.
- Standard formatting for the metadata file (e.g. JASON file) will be prepared at a later stage. Useful information is provided with the documentation files.

3.3 Trends in rock glaciers velocity in Southern Carpathians (Romania)

3.3.1 Terminology

Rock glacier dynamics may be related to the state of the underlying or surrounding permafrost layers. Melting conditions for the permafrost layer could translate into an increased dynamic of the rock glaciers. Thus, both the spatial extent of the measured glacier activity and velocity values may be quantitative indicators of the state of the permafrost layer.

The velocity of the rock glaciers is provided as mm/year in slant-range direction. Also, the direction of the measurement is provided, to project the slant-range direction to the most realistic direction provided by a Digital Elevation Model or other specialist's information, at a later time.

3.3.2 Temporal coverage

The temporal coverage of the rock glacier kinematics measurements will be every 6-12 days during the ice/snow-off periods, with a relevant number of acquisitions per period (at least 15) in order to form multiple combinations of interferograms, remove sub-optimal ones (high baseline, high atmospheric effects) and still be left with enough measurements for accurate velocity estimates.

The temporal coverage of the glacier's kinematics should be yearly (average displacement rate per year) after 2015, assuming that in the ice-on periods the glaciers are more or less stable. Within a year, the glacier displacement could vary with short-term climatic conditions, thus an annual average should be more relevant.

3.3.3 Spatial coverage

Coverage depends on the sensor's geometry. All rock glaciers in Retezat mountains are covered.

3.3.4 Spatial resolution

Spatial resolution of 100 m^2 is possible in slant-range, with Sentinel-1. Taking slant-range to ground-range, a spatial resolution of around 200 m^2 is possible on flat areas.

3.3.5 Product projection system

The Coordinate Reference System (CRS) used for the glaciers kinematics products is UTM, based on the World Geodetic System 84 (WGS84) reference ellipsoid. The coordinates are specified in meters.

3.3.6 File format

All the resulting products are in raster format, .tiff files

3.3.7 Product file naming convention

The naming of the products follows the ECV naming convention.
File names:
ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>[-<Additional Segregator>]-<Indicative Date>[<Indicative Time>]-fv<File version>.<extension>

<CCI Project>
PERMAFROST

<Processing Level>

L3 for Level 3; Level 2 variables mapped on a defined grid with reduced requirements for ancillary data.

< Data type >
RGI, when the parameter is ‘presence of a rock glacier’ as part of the rock glacier inventory; RGK, when the parameter is velocity.

<Product string>: <source>_<algorithm>
Source data (main input), e.g. SENTINEL1, PALSAR, PALSAR2, TSX and AIRPHOTOS
Algorithm, e.g. interferometry (INT), offset-tracking (OFF) and feature tracking (FEA), multiple (MUL)

<Additional Segregator>
This should be AREA<TILE_NUMBER>_<LAYER>

<AREA> being the tile number the subset index: 5-Romania

<LAYER> In case that the individual layers of the vector/raster product are provided as different NetCDF files, the code of each layer will be detailed as follows:

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

<Indicative Date>
The identifying date for this data set:
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. For monthly products DD=01. Annual averages are represented with year only.

fv<File Version>
File version number in the form n{1,}[.n{1,}] (That is 1 or more digits followed by optional . and another 1 or more digits). The most recent version is fv1.0 (released in May 2019).

Examples:

Yearly products (2019 in this example)
ESACCI-PERMAFROST-L3- RGK-SENTINEL1_INT- AREA5-2019-fv1.0.tif

Monthly products (July 2019 in this example)
ESACCI-PERMAFROST-L3- RGK-SENTINEL1_INT- AREA5-20190701-fv1.0.tif

3.3.8 Product attributes

The following attributes will be recorded for each selected rock glacier:

- Reference rock glacier ID
- Rock Glacier Kinematic Time Series (velocity values)

3.3.9 Meta data

Standard formatting for the meta data information (e.g. JASON file) will be prepared at a later stage. Examples from prototypes developed in ESA DUE GlobPermafrost will be followed.

In addition, separate documentation files are provided based on the PUG. They indicate the methodology used for deriving the Rock Glacier Kinematic Time Series (InSAR, optical, etc.) and the related accuracy. Additional information regarding the velocity type (annual mean, snow-free period mean, maximum, seasonal), and the time period of measurement should be specified. The producer and the date of production should be indicated.
In addition, they should contain the acquisition geometry (heading, incidence angle for InSAR-based measurements).

3.3.10 Known limitations

Standard formatting for the metadata file (e.g. JASON file) will be prepared at a later stage. Useful information is provided with the documentation files.

4 Mountain permafrost distribution model in the Carpathians

4.1 Terminology

The mountain permafrost distribution model (MPDM_CCI) is a classification algorithm that uses a random forest approach (RF) to extrapolate permafrost distribution at a regional scale based on data from local training sites. Random forest is a classification and regression algorithm that computes a number of individual classification trees and uses each classification in order to produce high accuracy results based on the majority "vote" of the classification trees. Because of the use of multiple sub-classifications, it is, in general, a robust tool that has a low sensitivity to outliers and errors in input data. The MPDM_CCI is implemented in the open source software R, making it easy to use for any user. Because the MPDM_CCI model can be computationally intensive for large regions when using high-resolution input data, it has a built-in function that allows the division of the study area in smaller patches that can be independently classified and the merged to form the overall output. Using this function, the model can be run on a desktop computer, although the running time increases significantly.

The MPDM_CCI was implemented in the following steps:

a) Preparation of predictors:

- Selection of satellite image(s) that cover the entire area and are cloud free;
- Deriving indexes from the satellite images that are used as predictors along with the four bands (R, G, B, NIR): NDVI, NDSI, NDWI;
- Deriving predictors from a DEM: Aspect, Convergence index, Curvature, Plan curvature, Profile curvature, Easting, Northing, Gradient, Mid slope position, Normalized height, Direct potential solar radiation, Indirect potential solar radiation, Total potential solar radiation, Slope, Standardize height, Texture, Topographic Positioning Index, Valley Depth, Channel network base level, LS factor, Slope height, Total catchment area, Topographic positioning index, Terrain roughness index, Wetness index;
- Test of predictor correlation and remove highly correlated predictors.

b) Preparation of training data:

- Build training data points with presence/absence of permafrost constructed based on previous research (ground surface temperature data from iButton data loggers, geophysical measurements and expert knowledge of the area).

c) Running the model and production of the uncertainty map and predictor importance ranking.

d) Evaluation of the uncertainty map for any positional bias and systematic errors.

e) Evaluation of the predictor importance ranking and eliminate unnecessary predictors.

f) If necessary, make adjustments to the model and/or input data, based on steps e) and f).

g) Run the model and produce all the model outputs: permafrost extension map, uncertainty map, accuracy assessment, predictor importance ranking.

h) Validation of results.

4.2 Temporal coverage

The permafrost distribution model produces a map of permafrost probability extent for a unique moment in time and it is not suited for change detection. The training data for the model in the Southern Carpathians has been collected in the summer of 2019, and the validation data has been collected in the spring of 2019. The date of the year in which the different data has been collected depends on the technique used for acquisition. For the training data, a period with snow-free conditions and minimum cloud cover was required, and for the validation data thick snow cover was required.

4.3 Spatial coverage

The Southern Carpathians are located in a marginal periglacial environment, where the permafrost occurrence is patchy and the preservation of permafrost is controlled by site-specific conditions. The results, permafrost distribution map and the uncertainty map associated with it, cover the whole area of the Southern Carpathians (approximately 14.000 km^2).

The training data used for the model is based on site specific data from the Retezat, Parâng and Făgăraș Mountains. The validation of the model has been performed in one of the study sites, the central part of Retezat Mountains.

4.4 Spatial resolution

The spatial resolution of the permafrost distribution map and the uncertainty map associated with it is 30m. The input data that have a higher resolution, the remote sensed images from Sentinel 2, have been resampled to 30m.

4.5 Product projection system

The Coordinate Reference System for of the permafrost distribution map and the uncertainty map associated with it is: UTM WGS84, EPSG: 4326.

4.6 File format

All the resulting products are in raster format, .tiff files.

4.7 Product file naming convention

The naming of the products follows the ECV naming convention.

The files for each parameter and month will be named as follows:

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

<CCI Project>
PERMAFROST for permafrost_cci

<Processing Level>
L4 for Level 4; Data sets are created from the analysis of lower level data, resulting in gridded, gap-free products.

<Data type>
GTD, when the parameter is ground temperature at a certain depth, ALT, if the parameter is active layer thickness, PFR if the parameter is permafrost extent (fraction), PFF if the parameter is permafrost-free fraction, PFT if the parameter is fraction underlain by talik and PZO if the parameter is permafrost zone, PPM is for permafrost probability map

<Product String> : <source>_<algorithm>
Source data (main input), e.g. SENTINEL2 or LANDSAT
Algorithm, e.g. MPDM for MPDM_CCI based in Random Forest approach

<Additional Segregator>
This should be AREA<TILE_NUMBER>_<layer>

<tile_number> being the tile number of the subset index: 1- global, 2-North America, 3-Eurasia, 4-Northern hemisphere, 5-Romania

<layer>In case that the individual layers of the pixel product are provided as different NetCDF files, the code of each layer (where available) will be detailed as follows:

- PP: layer 1, corresponding to the Julian day, or day of the year of detection of the permafrost parameter.
- CL: layer 2, corresponding to the confidence level
- LC: layer 3, corresponding to the ground stratigraphy

<Indicative Date
The identifying date for this data set:
Format is YYYYMMDD, where YYYY is the four-digit 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. For monthly products DD=01. Annual averages are represented with year only. The permafrost distribution map is represented with year only (YYYY – format).

Example: ESACCI-PERMAFROST-L4-PFR-SENTINEL2-MPDM- AREA5_CL-2003-fv01.0.nc

4.8 Pixel attributes

The permafrost probability map has pixel values ranging from 0 (minimum permafrost probability) to 1 (maximum permafrost probability). The map is further classified based on the AUC validation into a binary map with 0 for permafrost absence areas and 1 for permafrost presence

4.9 Meta data

Meta data are included in all files following the NetCDF Climate and Forecast (CF) Metadata Convention 73.

4.10 Known limitations

none

5 REFERENCES

5.1 Bibliography

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Permafrost and Periglacial Processes,11, 315-326

Strozzi, T., Caduff, R., Jones, N., Barboux, C., Delaloye, R., Bodin, X., Kääb, A., Mätzler, E. and Schrott, L, 2020. Monitoring Rock Glacier Kinematics with Satellite Synthetic Aperture Radar. Remote Sensing, 12(3), 559, HTTPS://DOI.ORG/10.3390/RS12030559.

5.2 Acronyms

AD	Applicable Document
ADP	Algorithm Development Plan
ATBD	Algorithm Theoretical Basis Document
AUC	Area Under the Receiver Operating Curve
B.GEOS	b.geos GmbH
CCI	Climate Change Initiative
CCN	Contract Change Notice
CR	Cardinal Requirement (as defined in [AD-1])
CRS	Coordinate Reference System
DARD	Data Access Requirement Document
DEM	Digital Elevation Model
ECV	Essential Climate Variable
ESA	European Space Agency
ESA DUE	ESA Data User Element
E3UB	End-to-End ECV Uncertainty Budget
GAMMA	Gamma Remote Sensing AG
GCOS	Global Climate Observing System
GO	Geomorphological Outline
GTOS	Global Terrestrial Observing System
GUIO	Department of Geosciences University of Oslo
INSAR	Synthetic Aperture Radar Interferometry
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
L4	Level 4
LST	Land Surface Temperature
MA	Moving Area
MPDM	Mountain Permafrost Distribution Model
NORCE	Norwegian Research Centre AS

PE	Permafrost Extent
PSD	Product Specifications Document
PVASR	Product Validation and Algorithm Selection Report
PUG	Product User Guide
PVP	Product Validation Plan
QA4EO	Quality assurance framework for earth observation
RF	Random Forest
RD	Reference Document
RGI	Rock Glacier Inventories
RGK	Rock Glacier Kinematic Time Series
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SWE	Snow Water Equivalent
T	Temperature
UNIFR	Department of Geosciences University of Fribourg
UNIS	University Centre in Svalbard
URD	Users Requirement Document
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WUT	West University of Timisoara