permafrost
cci

CCI+ PHASE 1 – NEW ECVS
PERMAFROST

D3.1 SYSTEM REQUIREMENT DOCUMENT (SRD)

VERSION 2.0

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PREPARED BY

b·geos GAMMA REMOTE SENSING UiO : University of Oslo

AWI UNI FR UNIVERSITÉ DE FRIBOURG UNIVERSITÄT FREIBURG Stockholm University

West University of Timisoara TERRASIGNA

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Author team

Andreas Wiesmann, GAMMA

Annett Bartsch, B.GEOS

Sebastian Westermann, UIO

Tazio Strozzi, GAMMA

ESA Technical Officer:

Frank Martin Seifert

EUROPEAN SPACE AGENCY CONTRACT REPORT

The work described in this report was done under ESA contract. Responsibility for the contents resides in the authors or organizations that prepared it.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Within the European Space Agency (ESA), the Climate Change Initiative (CCI) is a global monitoring program which aims to provide long-term satellite-based products to serve the climate modeling and climate user community. Permafrost has been selected as one of the Essential Climate Variables (ECVs) which are elaborated during Phase 1 of CCI+ (2018-2021).

This novel ECV permafrost product should benefit a wide range of applications and users, thus a thorough user requirement analysis was performed at the beginning of the project which is summarized in this report.

This document outlines the system requirements for the Permafrost_cci processing capable of producing the Permafrost_cci ECVs. This document provides details on the Permafrost_cci processing system, system scenarios, workflows and a detailed list of requirements. The requirements are grouped by type and identified by a unique 3 level identifier.

1 INTRODUCTION

The European Space Agency (ESA) Climate Change Initiative aims to generate high quality Essential Climate Variables (ECVs) derived from long-term satellite data records to meet the needs of climate research and monitoring activities, including the detection of variability and trends, climate modelling, and aspects of hydrology and meteorology.

1.1 Purpose of the document

The aim of this document is to collect all requirements on the Permafrost_cci Processing System (PS). Main sources are the reference documents listed in Table 1, especially the SoW with its Annex and the first project deliverables (in particular the URD and PSD), and the CCI project guidelines.
The processing algorithms and output products are being defined to some degree in parallel to this document. This affects some key areas such as the system performance and sizing. Therefore, the document is updated continuously but it is also kept generic to be independent from the details of the algorithms to be implemented. When appropriate and necessary, TBC (To Be Confirmed) and TBD (To Be Defined) has been used.

The requirements 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.

The scope of the SRD is defined in the SoW [AD-1]: “Create a System Requirements Document (SRD) specifying the requirements of a Processing System capable of generating ECV data products as specified in the applicable technical annex (A-I). The SRD shall include verifiable requirements on the following: Data processing function of each step of its processing chain, including data volumes; Platform specification; Compliance to all processing needs defined by the Task 3 inputs.”

1.2 Structure of the document

In Section 2 the Permafrost_cci processing is presented by giving the system overview. In Section 3 different scenarios are discussed. Section 4 describes the workflow of the processing system for the Permafrost_cci products, ground temperature and its derivatives. The detailed requirements are finally listed in Section 5.

1.2 Document status

This document is based on issue 1.0 of the Data Access Requirements Document (DARD), Issue 1.0 of the Product Specification Document (PSD), and Issue 1.1 of the User Requirements Document (URD); refinement of this document will be necessary for catchment of future issues of these documents.

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-PF-17-0032. Issue 1.4 r2 EOP-SEP/SOW/0031-1.4 r2

[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, the Global Observing System for Climate: Implementation Needs (2016 GCOS Implementation Plan, 2015.

[AD-5] Bartsch, A.; Grosse, G.; Kääb, A.; Westermann, S.; Strozzi, T.; Wiesmann, A.; Duguay, C.; Seifert, F. M.; Obu, J.; Goler, R.: GlobPermafrost – How space-based earth observation supports understanding of permafrost. Proceedings of the ESA Living Planet Symposium, pp. 6.

1.4 Reference Documents

Table 1: Reference Documents.

Ref	**Title**	**Version**
[RD-1]	User Requirements Document (URD)	1.1
[RD-2]	Product Specification Document (PSD)	2.0
[RD-3]	Data Access Requirements Document (DARD)	1.0
[RD-4]	CCN 1 Rock glacier kinematics in the Carpathians (Romania): D1. User Requirement, Product Specifications, and Data Access Requirements Document	1.0

1.5 Acronyms

AD	Applicable document
ALT	Active Layer Thickness
B.GEOS	b.geos GmbH
CliC	Climate and Cryosphere project
CCI	Climate Change Initiative
CMUG	Climate Modelling User Group
CR	Cardinal requirement (as outline in [AD-1])
ECV	Essential Climate Variable
EO	Earth Observation
ESA	European Space Agency
ESA DUE	ESA Data User Element
GAMMA	Gamma Remote Sensing AG
GCOS	Global Climate Observing System
GT	Ground Temperature
GTN-P	Global Terrestrial Network for Permafrost
GUIO	Department of Geosciences University of Oslo
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
NetCDF	Network Common Data Format
PE	Permafrost Extent
PERMOS	Swiss Permafrost Monitoring Network
PF	Permafrost
PS	Processing System
PSTG	Polar Space Task Group
RD	Reference Document
RMSE	Root Mean Square Error
RS	Remote Sensing
WCRP	World Climate Research Program
WMO	World Meteorological Organisation

2 PERMAFROST_CCI PROCESSING SYSTEM OVERVIEW

2.1 Context

The Permafrost_cci project is focused on the product ground temperature and relevant derivatives (active layer thickness and permafrost zones). This implies the production of consistent, stable, and error-characterised products, covering the period with available EO data from 1981 to date. The project consists of different phases. It starts with pre-operational system development and demonstration, later includes large scale ECV data processing, final validation and climate-user assessment. Each phase will involve multiple cycles of ECV algorithm development, processing, validation, user assessment, and feedback, to ensure progressive iterative development towards meeting the GCOS requirements [AD-4].
The processing system (PS) is defined in the context of the CCI Programme and hence is a science-driven system that produces the required data products to satisfy the GCOS and evolved data requirements. It is built on the heritage of the prototype systems, system specifications and requirements generated in precursor projects, is capable of processing long time series, and rapidly reprocessing them, 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.

The Permafrost_cci 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 first issue it must be considered that for all products mandated repositories exist so that the PS only has to consider the datasets that are required for data production.
Selected common services may be 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 common data access layer shared among all ECVs provides harmonised access to CCI data for climate modellers. This shall lower the barrier for climate users to use several of the ECVs. The individual production and data environments per ECV are close to the scientific groups to support an agile, continuous development and nimble reaction to issues with short cycles. The production environments are optimised for re-processing and validation. Strict versioning ensures production of stable product releases. Optionally, sharing of an environment by production and development allows for access to long time series also for the scientific improvement cycle.

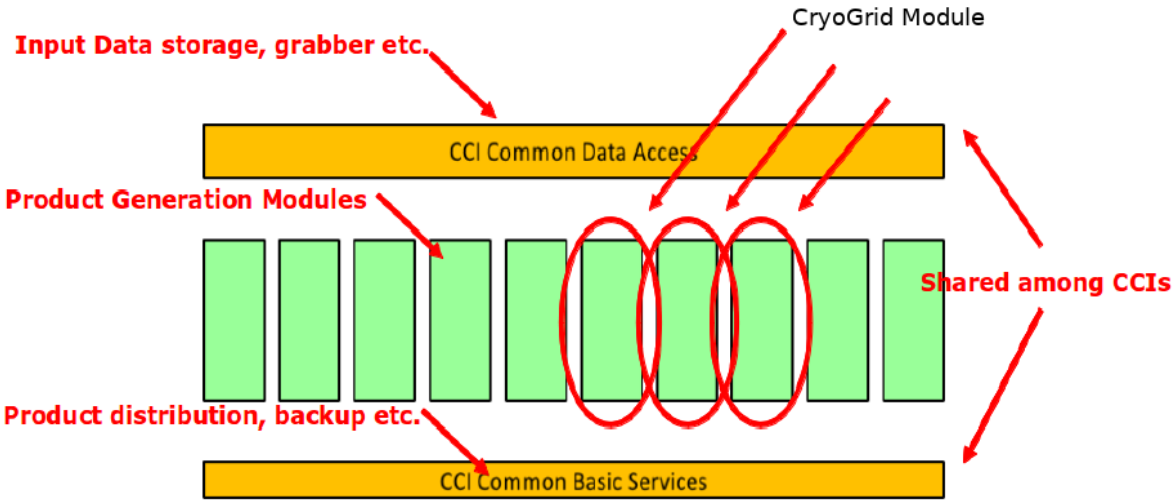

Figure 1: Common data access and de-centralized production environments.

2.2 User Requirements

The User Requirements are documented in the User Requirements Document [RD-1]. It outlines the requirements for Permafrost_cci ECVs (ground temperature - GRD; active layer thickness – ALT and permafrost extent - PFT) obtained through engagement with users from across climate applications, including the detection of variability and trends as well as climate modelling. The primary parameters to be evaluated are requirements for the GCOS parameters permafrost temperature and depth of active layer (GCOS Action 33 [URq_08]), based on an approach which allows for subsequent retrieval of permafrost extent as identified through the WMO RRR (Rolling Requirements Review process) process.

The ECV Permafrost is currently not listed as ‘space-observable’ in GCOS-200 [AD-4]. Accuracy requirements are so far formulated for ground temperature only and with respect to in situ measurements:

- Horizontal Resolution: Sufficient sites to characterise each bio-climate zone
- Temporal Resolution: Daily to weekly
- Accuracy: 0.1 K

A range of surveys are, however, available which target the ECV Permafrost with respect to use of satellite data. User requirements have been gathered within the framework of the ESA DUE Permafrost project, at the DUE-IPA-GTNP-CliC workshop in Frascati in February 2014 and in addition as a community white paper on request by the WMO Polar Space Task Group [AD-2]. A subset of these requirements has been demonstrated within GlobPermafrost and assessed by user organizations. A further user requirements survey has been conducted and published as part of the ESA Living Planet Symposium proceedings [AD-5].

The **open user survey** carried out within the framework of GlobPermafrost in 2016 clearly showed that the

- actual ground temperature (87%) in addition to
- active layer thickness (83%) is of higher interest than
- permafrost fraction (48%).

An additional survey has been setup within permafrost_cci to capture the needs of so far identified dedicated case studies as well as extended climate modelling requirements [URq_10,11,12,13]. Application cases include also mountain permafrost (PERMOS, Switzerland and Carpathian, Romania [RD-4]) and Arctic coastal erosion (HORIZON2020 Nunataryuk) monitoring.

Interviews with climate modellers and permafrost specialists have been carried out in addition to the online survey of ESA DUE GlobPermafrost in 2016. It has been pointed out that a new ground stratigraphy product for the permafrost domain needs to be compiled in close consultation with climate modelers [URq_11]. It is consensus in the community that currently existing classifications are heavily flawed for permafrost so that such a product has been sought after by the community by a long time and is still not available to date.

All specific user requirements are listed in Table 2. It provides a summary of the identified user requirements that is organised by EO data product. For each user requirement, the source and the type of work it will address are identified. We aim to meet as many of these requirements as possible in the course of the annual cycle, taking into account data availability and workload constraints.

Table 2: Summary of user requirements from [RD-1]. Background (BG) means that this is a continuous activity, production (P), and dissemination (D) means that the related requirement has to be considered during production, and dissemination, respectively. Parameters are Permafrost Extent (PE), Ground Temperature (GT) and Active Layer Thickness (ALT).

ID	Parameter	Requirements	Source	Type
URq_01	PE/GT/ALT	higher spatial resolution than a map scale of 1:10,000,000	IPA Mapping group report	BG
URq_02	PE/GT/ALT	data need to be related to a time stamp	IPA Mapping group report	P
URq_03	PE/GT/ALT	form of delivery for maps and data need to be flexible	IPA Mapping group report	D
URq_04	PE/GT/ALT	high data quality	IPA Mapping group report	BG
URq_05	PE/GT/ALT	benchmark dataset needs to be developed	IPA Mapping group report, GlobPermafrost/IPA mapping group workshop	P
URq_06	PE/GT/ALT	evaluation through community	GlobPermafrost/IPA mapping group workshop	P

URq_07	PE/GT/ALT	terminology for modelling output 'potential'	GlobPermafrost/IPA mapping group workshop	D
URq_08	GT/ALT	depth of active layer, permafrost temperature in K and seasonal soil freeze/thaw needs to be addressed	GCOS	BG
URq_09	PE	Threshold: uncertainty 10-25%, hor. res. 10-100 km, temp. res. 3-5 days, timeliness 5-6 days; breakthrough uncertainty 7-8.5%, hor. res. 0.85 - 1 km, temp. res. 14-36 hours, timeliness 14-36 h	OSCAR	BG
URq_10	PE/GT/ALT	Distribution as NetCDF	CMUG	D
URq_11	PE/GT/ALT	Development of a new ground stratigraphy product for the permafrost domain	GlobPermafrost survey	P/D
URq_12	GT	Threshold: pan-arctic, yearly, last decade, 10km, RMSE<2.5°C, Target, global, monthly, 1979- present, 1km, subgrid variability, RMSE < 0.5°C	Permafrost_cci survey	BG
URq_13	ALT	Threshold: pan-arctic, yearly, last decade, 10km, RMSE<25cm, Target, global, monthly, 1979- present, 1km, subgrid variability, RMSE<10cm	Permafrost_cci survey	BG

3. PERMAFROST_CCI PROCESSING SYSTEM SCENARIOS

3.1 Sensor Constellation and Temporal Coverage

The sensor constellation and temporal coverage is described in detail in the corresponding DARD document [RD-3]. The summary is given in Table 3 below.

Table 3: Sensor constellation and temporal coverage of data necessary for the production of PERMAFROST products

Product	CP-1	CP-2	CP-3
PERMA FROST	MODIS (1999-2018) Landcover_cci: • MERIS • SPOT-Vegetation	MODIS (1999-2018) Landcover_cci: • MERIS • SPOT-Vegetation If available in time: LST_cci & Snow_cci: AVHRR/1 (1981-2015) AVHRR/2 (1998-2016) AVHRR/3 (2006-2019) ATSR-2 (1995-2003) AATSR (2002-2013) MODIS (1999-2019) SLSTR (2016-2019) Merged AVHRR (1981-2019) Merged ATSR-2, AATSR & SLSTR (1995-2019) Merged Terra and Aqua MODIS (1999-2019) Merged all missions (1981-2019) SMMR (1978-1987) SSM/I, SSMIS (1987-2019) Merged all missions (1978-2019)	LST_cci & Snow_cci: AVHRR/1 (1981-2015) AVHRR/2 (1998-2016) AVHRR/3 (2006-2020) ATSR-2 (1995-2003) AATSR (2002-2013) MODIS (1999-2020) SLSTR (2016-2020) Merged AVHRR (1981-2020) Merged ATSR-2, AATSR & SLSTR (1995-2020) Merged Terra and Aqua MODIS (1999-2020) Merged all missions (1981-2020) SMMR (1978-1987) SSM/I, SSMIS (1987-2020) Merged all missions (1978-2020) Landcover_cci: • MERIS SPOT-Vegetation

3.2 Products and Variables

The Permafrost_cci product ground temperature is provided as derivatives permafrost temperature and depth of active layer. The products are described in detail in the PSD [R-2]. Table 4 below gives a summary of the specifications.

Table 4: Permafrost_cci baseline ECV product specifications for version 1 (phase 2).

	Permafrost temperature	**Depth of active layer**
Parameter	temperature	depth
Description	temporally averaged ground temperature	seasonal maximum thaw depth
Spatial Coverage	global	global
EO Data	LST, Snow and Landcover	LST, Snow and Landcover
Spatial Resolution	1km	1km
Spatial Aggregation	none	none
Spatial Filling	Clouds: ERA5	Clouds: ERA5
Weather Station Data	Not Applicable	Not Applicable
Period	1997-2018	1997-2018
Frequency	daily	annually
Temporal Aggregation	monthly	annually
Update Frequency	annually	annually
Map Projection	Polar Stereographic	Polar Stereographic
Coding	8 bit	8b bit
Format	NetCDF	NetCDF
Accuracy Target	RMSE < 2.5°C	RMSE < 25 cm
Uncertainty Metric	RMSE	RMSE
Metadata	Stratigraphy	Stratigraphy
Data Access	CCI data portal	CCI data portal

3.3 Reprocessing Capability

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 due to 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.

3.4 Improvement Cycle

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 and shown in Figure 2.

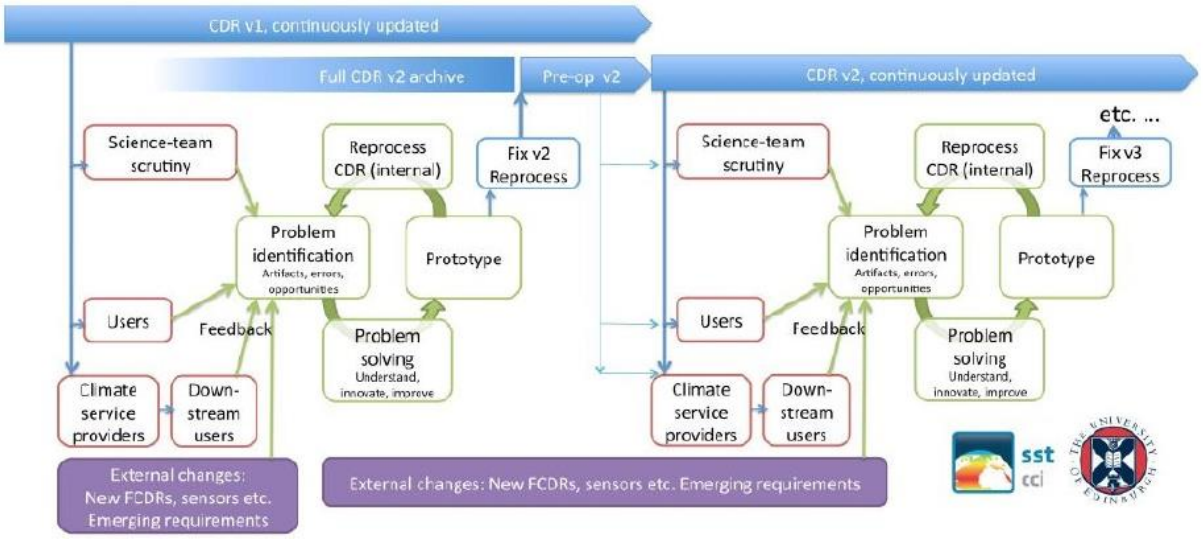

Figure 2: Model improvement and product versioning (by C. Merchant for SST_cci).

3.5 Interaction with Users

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 enabled through the dedicated CCI product portals.

4. PERMAFROST_CCI PROCESSING SYSTEM PRODUCTION WORKFLOW

The basic processing system production workflow is given in **Error! Reference source not found.**. It has the main parts preprocessing, retrieval, product generation and verification/validation. The input data are EO data, station data (point data), and auxiliary data such as DEM and masks. The output of

the production are the Permafrost_cci products as described in the PSD [R-2]. In the following the Permafrost_cci module will be presented in further detail.

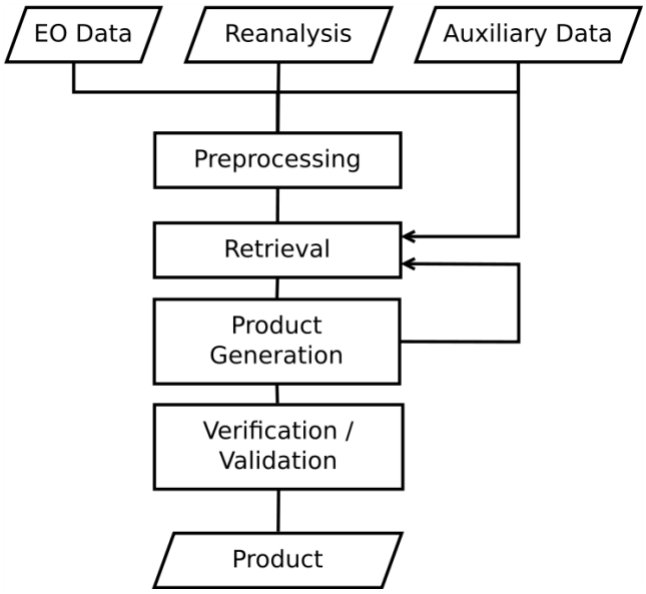

Figure 3: Permafrost_cci module high level diagram.

Figure 3 shows the high-level processing steps for generation the Permafrost_cci products. It consists of 6 steps:

1. Selection of yearly data sets of EO-input and ERA-5 reanalysis in daily increments, as well as ancillary data of parameter sets for the product generation module;
2. Pre-processing of eight-day data sets of all input data sets;
3. Assignment of stratigraphic information and subgrid properties for each pixel, using EO landcover products; retrieval of depth- and time-resolved profiles of ground temperature for each pixel of the CryoGrid CCI permafrost model
4. Generation of annual products of ground temperature, active layer thickness and permafrost extent
5. Verification of products to identify out-of-range pixels
6. Merging of tiles to global annual products

Step 1 is performed once and generates a list of the tiles to be processed in order to form the final output product. Step 2 -5 are performed tile-by-tile independently. After completing the processing of all individual tiles, step 6 merges all permafrost tile-products towards the final annual permafrost products.

Preprocessing

Preprocessing consists of generation of eight-day data sets of all input of the CryoGrid CCI model. This is in particular accomplished by merging satellite-derived land surface temperature and ERA-5 reanalysis air temperature for the purpose of gap-filling cloud-covered periods, followed by calculation of temporal averages.

Retrieval

The retrieval algorithm uses the CryoGrid CCI permafrost model, which solves the partial differential equation of heat conduction for each pixel. The output of the model is time series of depth-profiles of ground temperatures from which all permafrost_cci products can be calculated

Product Generation

In the product generation step, annual average ground temperatures at different depths, active layer thickness and permafrost fraction are derived from the fully resolved depth profiles of ground temperature.
In the final step, the resulting maps are put in the delivery product format as requested and specified in the PSD [R-2].

Verification/Validation

The products undergo defined procedures to ensure product integrity and quality. The main potential problem is lack of convergence of the CryoGrid CCI model which cannot explicitly be checked for during the model run – since this will produce unreasonable values for ground temperature, a simple out-of-range filter is applied.

5. DETAILED PERMAFROST_CCI 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 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.

Given the large amounts of data to be processed, the development is towards an automated high-performance processing chain. This processor shall be implemented on a sufficiently powerful (possibly distributed) computing infrastructure that is capable of processing and reprocessing all the required products within the project schedule.

5.1 High Level System Requirements

PF-FUN-0010	Develop and validate algorithms to approach the GCOS ECV and meet the wider requirements of the Climate Community (i.e. long term, consistent, stable, uncertainty-characterized) global satellite data products from multi-sensor data archives. [CR-1]
PF-FUN-0020	Produce, validate and deliver consistent time series of multi-sensor global satellite ECV data products for climate science. [CR-2]
PF-FUN-0030	The *Permafrost_cci* system shall be able to generate different products: 1. GTD, when the parameter is ground temperature at a certain depth 2. ALT, if the parameter is active layer thickness 3. PFR if the parameter is permafrost extent (fraction) 4. PFF if the parameter is permafrost-free fraction 5. PFT if the parameter is fraction underlain by talik 6. PZO if the parameter is permafrost zone
PF-FUN-0040	Generate and fully document a production system capable of processing and reprocessing the data, with the aim of supporting transfer to operational activities outside CCI (such as C3S). [CR-4]

PF-OPE-0050	All project documentation shall be made publicly available via the CCI Open Data Portal: http://cci.esa.int.
PF-OPE-0060	The PS shall capitalise on existing European assets through their reuse, particularly Open Source scientific tools and prototype ECV processing systems from prior projects. (heritage)
PF-INT-0070	The global Permafrost community shall play an active role in its creation according to given guidelines and advice from a strategic operations team. They shall also give feedback from the implementation to the strategic team.
PF-SIZ-0080	The system shall implement a data production line that is sufficiently flexible to continuously update and extend the database (e.g. with data from new sensors or better acquisitions).
PF-INT-0090	The available data shall be frequently reported and properly disseminated to the interested user communities.
PF-OPE-0100	Minimum maintenance and cost

5.2 Functional Requirements

PF-FUN-1020	The Products shall be uniquely identified.
PF-FUN-1030	The PS shall store data in a structured way using type, revision, date.
PF-FUN-1040	If input data is retrieved directly from a third party ground segment, the PS has to ensure that links are maintained and functionality is regularly checked.
PF_FUN-1050	The PS shall be able to reprocess also parts of the products.
PF-FUN-1060	The PS shall be able to do partial processing.
PF-FUN-1070	The PS shall be flexible in form of delivery for maps and data.
PF-FUN-1080	The PS shall include proper Product Description

5.3 Performance Requirements

PF-SIZ-2010	The PS shall be able to do long time series processing in due time.
PF-SIZ-2020	The PS shall be able to do reprocessing in due time.

PF-SIZ-2030	The PS shall be able to run on the available hardware infrastructure
PF-SIZ-2040	The PS shall have sufficient space for output data
PF-SIZ-2050	The PS shall have sufficient space for auxiliary data
PF-SIZ-2060	The PS shall have sufficient space for input data

5.4 Interface Requirements

PF-INT-3010	The PS shall have the capability and interfaces to extend for future adaptations.
PF-INT-3020	The PS shall have or use a long-term storage for its products
PF-INT-3030	The PS shall have a self-standing documentation

5.5 Operational Requirements

PF-OPE-4010	Development of the PS shall be under version control.
PF-OPE-4020	The system should be decoupled from the research
PF-OPE-4030	Development of the system shall be based on the user requirements, the selected algorithms and the validation protocols used to generate the baseline products for the worldwide glacier inventory.
PF-OPE-4040	The PS development shall be overseen by a science team that drives the development process.
PF-OPE-4050	Each PS installation includes a set of test tools, data and benchmark data to test PS integrity (end-to-end, interfaces)
PF-OPE-4060	If a module is based on a prototype, the prototype state has to be frozen until it is implemented.
PF-OPE-6611	The verification is regarded as successful, when all tests agree within TBD limits. Hashes are to be preferred where applicable.

5.6 Reliability and Maintenance Requirements

PF-FUN-5010	The operational processor shall not overwrite existing data. Versioning shall be used instead.

PF-RAM-5020	The system developed shall be detailed as a separate self-standing document providing an overview of the system and its components, functionality of the system and its subsystems, inputs, outputs, resource key interfaces, and resource requirements.
PF-FUN-5030	Verification of the correct implementation of the prototype system against the algorithms developed in Task 2 is a fundamental part of the process.
PF-RAM-5040	The verification shall be documented in a Verification Report. It shall contain the chosen approach and the justification, the selected verification data set and the verification results.
PF-RAM-5050	The PS shall provide means against data loss of its input / output products.
PF-FUN-5060	All data stored in the system shall be available for the long-term (at least 15 years).