



**permafrost**  
cci

**CCI+ PHASE 2 – NEW ECVS  
PERMAFROST**

**D1.2 PRODUCT SPECIFICATIONS DOCUMENT (PSD)**

**VERSION 5.0**

**15 AUGUST 2024**

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**GAMMA REMOTE SENSING**



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## 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) and continued during Phase 2 of CCI+ (2022-2025).

This document is the Permafrost\_cci Product Specification Document (PSD) corresponding to the iteration 1 dataset of Phase 2 of the Permafrost\_cci project. It describes the product specifications of the Permafrost products. The product specifications address the main requirements expressed by the users in the User Requirements Document (URDv4.0, RD-3) including those expressed by the Permafrost\_cci climate research group (CRG). Since the range of potential user communities of a Permafrost product is very wide it is not possible to cover all those requirements. For this reason, the PSD establishes priorities between those requirements, putting in the first place those more sensible to climate researchers, while considering current technical constraints.

The PSD includes a glossary of permafrost relevant terms, the product specifications and formats, including details of meta data.

Ground temperature and active layer thickness are considered the primary variables that require climate-standard continuity as defined by GCOS. Permafrost fraction and zone are secondary parameters, but of high interest to users. Annual averages of ground temperature and annual maxima of thaw depth (active layer thickness) are provided at 1km spatial resolution during phase 1 as well as phase 2 of Permafrost\_cci. Product level is 4. The data sets are created from the analysis of lower level data, resulting in gridded, gap-free products.

# 1 INTRODUCTION

## 1.1 Purpose of the document

This document describes in detail product specifications in order to obtain a permafrost product that is consistent, stable and error-characterised. The purpose of this document is to present the structure, syntax and file naming conventions used to describe the different permafrost products. It provides all the necessary data needed by permafrost algorithm developers and users to write and read the permafrost products respectively.

## 1.2 Structure of the document

This document contains a glossary of permafrost specific terms in section 1.7. Section 2 describes the area covered for the service as well as regions of interest for evaluation. The remaining sections detail the product specifications and format.

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

[AD-5] CMUG (2022): CCI+ Deliverable D2.3: Suitability of CCI ECVs for Climate Science and Services. v3.0

[AD-6] GCOS-244, The 2022 GCOS Implementation Plan. 2022.

[AD-7] GCOS-245, The 2022 GCOS ECV requirements. 2022.

## 1.4 Reference Documents

[RD-1] van Everdingen, Robert, ed. 1998 revised 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/>; accessed 23.09.2009)

[RD-2] Bartsch, A., Westermann, S., Heim, B., Wieczorek, M., Pellet, C., Barboux, C., Kroisleitner, C., Strozzi, T. (2019): ESA CCI+ Permafrost Data Access Requirements Document, v1.0

[RD-3] Bartsch, A., Matthes, H., Westermann, S., Heim, B., Pellet, C., Onacu, A., Kroisleitner, C., Strozzi, T. (2024): ESA CCI+ Permafrost User Requirements Document, v4.0

[RD-4] Westermann, S. Bartsch, A., Strozzi, T. (2019): ESA CCI+D2.1 Product Validation Algorithm Selection Report (PVASR). V1.0

[RD-5] Heim, B., Wieczorek, M., Pellet, C., Barboux, C., Delaloye, R., Bartsch, A., Strozzi, T. (2019): ESA CCI+ PVIR, v1.0

[RD-6] Heim, B., Wieczorek, M., Pellet, C., Delaloye, R., Bartsch, A., Strozzi, T. (2020): ESA CCI+ D.4.1 Product validation and intercomparison report (PVIR), v2.0

[RD-7] Heim, B., Lisovski, S., Wieczorek, M., Pellet, C., Delaloye, R., Bartsch, A., Jakober, D., Pointer, G., Strozzi, T. (2021): ESA CCI+ D.4.1 Product validation and intercomparison report (PVIR), v3.0

[RD-8] Bartsch, A., Westermann, S., Heim, B., Wieczorek, M., Pellet, C., Barboux, C., Delaloye, R., Kroisleitner, C., Strozzi, T. (2020): ESA CCI+ Permafrost Data Access Requirements Document, v2.0

[RD-9] Heim, B., Wieczorek, M., Pellet, C., Delaloye, R., Bartsch, A., Strozzi, T. (2024): ESA CCI+ Permafrost Product Validation and Intercomparison Report (PVIR), v4.0

## 1.5 Bibliography

A complete bibliographic list that supports 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

The list below provides a selection of terms relevant for the parameters addressed in Permafrost\_cci [RD-1].

**active layer**

The layer of ground that is subject to annual thawing and freezing in areas underlain by permafrost. In the zone of continuous permafrost the active layer generally reaches the permafrost table; in the zone of discontinuous permafrost it often does not. The active layer includes the uppermost part of the permafrost wherever either the salinity or clay content of the permafrost allows it to thaw and refreeze annually, even though the material remains cryotic ( $T < 0^{\circ}\text{C}$ ).

The active layer is sometimes referred to as the "active zone"; the term "zone," however, should be reserved for the zones of discontinuous and continuous permafrost.

In Russian and Chinese literature, the term active layer covers two distinct types: (1) the seasonally thawed layer overlying permafrost, and (2) the seasonally frozen layer overlying unfrozen ground inside or outside permafrost areas.

REFERENCES: Muller, 1943; Williams, 1965; Brown, 1971; van Everdingen, 1985.

### **active-layer thickness**

The thickness of the layer of the ground that is subject to annual thawing and freezing in areas underlain by permafrost.

The thickness of the active layer depends on such factors as the ambient air temperature, vegetation, drainage, soil or rock type and total water content, snowcover, and degree and orientation of slope. As a rule, the active layer is thin in the High Arctic (it can be less than 15 cm) and becomes thicker farther south (1 m or more).

The thickness of the active layer can vary from year to year, primarily due to variations in the mean annual air temperature, distribution of soil moisture, and snowcover.

The thickness of the active layer includes the uppermost part of the permafrost wherever either the salinity or clay content of the permafrost allows it to thaw and refreeze annually, even though the material remains cryotic ( $T < 0^{\circ}\text{C}$ ).

Use of the term "depth to permafrost" as a synonym for the thickness of the active layer is misleading, especially in areas where the active layer is separated from the permafrost by a residual thaw layer, that is, by a thawed or noncryotic ( $T > 0^{\circ}\text{C}$ ) layer of ground.

REFERENCES: Muller, 1943; Williams, 1965; van Everdingen, 1985.

### **continuous permafrost**

Permafrost occurring everywhere beneath the exposed land surface throughout a geographic region with the exception of widely scattered sites, such as newly deposited unconsolidated sediments, where the climate has just begun to impose its influence on the thermal regime of the ground, causing the development of continuous permafrost.

For practical purposes, the existence of small taliks within continuous permafrost has to be recognized. The term, therefore, generally refers to areas where more than 90 percent of the ground surface is underlain by permafrost.

REFERENCE: Brown, 1970.

### **continuous permafrost zone**

The major subdivision of a permafrost region in which permafrost occurs everywhere beneath the exposed land surface with the exception of widely scattered sites.

Taliks associated with rivers and lakes may occur in the continuous permafrost zone.

REFERENCE: Brown, 1970.

**depth of zero annual amplitude**

The distance from the ground surface downward to the level beneath which there is practically no annual fluctuation in ground temperature .

A change of no more than 0.1°C throughout the year is arbitrarily considered as "practically no annual fluctuation". The temperature at the depth (or level) of zero annual amplitude ranges from about -0.1°C at the southern limit of the permafrost region to about -15°C in the extreme polar reaches of the zone of continuous permafrost. The depth of zero annual amplitude varies widely but generally lies between 10 and 20 m below the ground surface, depending on climatic and terrain conditions such as amplitude of annual surface temperature variation, vegetation, snowcover and characteristics of the soils and rocks including thermal diffusivity (see thermal properties of frozen ground).

SYNONYMS: (not recommended) zone of minimum annual amplitude, zone of zero annual amplitude.

REFERENCE: Muller, 1943.

**discontinuous permafrost**

Permafrost occurring in some areas beneath the exposed land surface throughout a geographic region where other areas are free of permafrost.

Discontinuous permafrost occurs between the continuous permafrost zone and the southern latitudinal limit of permafrost in lowlands. Depending on the scale of mapping, several subzones can often be distinguished, based on the percentage (or fraction) of the land surface underlain by permafrost, as shown in the following table.

<u>Permafrost</u>	<u>English usage</u>	<u>Russian Usage</u>
Extensive	65-90%	Massive Island
Intermediate	35-65%	Island
Sporadic	10-35%	Sporadic
Isolated Patches	0-10%	-

SYNONYMS: (not recommended) insular permafrost; island permafrost; scattered permafrost.

REFERENCES: Brown, 1970; Kudryavtsev, 1978; Heginbottom, 1984; Heginbottom and Radburn, 1992; Brown et al., 1997.

**discontinuous permafrost zone**

The major subdivision of a permafrost region in which permafrost occurs in some areas beneath the exposed land surface, whereas other areas are free of permafrost.

The zone of discontinuous permafrost lies between the continuous permafrost zone and the southern latitudinal limit of permafrost in lowlands. Near its northern boundary, discontinuous permafrost is extensive, where-as near its southern boundary it occurs as isolated patches of permafrost, and sporadic permafrost. There is no sharp distinction, or boundary, between the continuous and discontinuous permafrost zones.

REFERENCE: Brown, 1970.



### **disequilibrium permafrost**

Permafrost that is not in thermal equilibrium with the existing mean annual surface or sea-bottom temperature and the geothermal heat flux.

REFERENCE: Mackay, 1972a.

### **equilibrium permafrost**

Permafrost that is in thermal equilibrium with the existing mean annual surface or sea-bottom temperature and with the geothermal heat flux.

SYNONYM: contemporary permafrost.

REFERENCE: Mackay, 1972a.

### **extensive discontinuous permafrost**

1. (North-American usage) Permafrost underlying 65 to 90 percent of the area of exposed land surface.

2. (Russian usage) Permafrost underlying 70 to 80 percent of the area of exposed land surface.

It is suggested that this term be used as a replacement for "widespread" discontinuous permafrost, because the word "widespread" can mean either "extensively distributed" or "widely spaced".

SYNONYM: widespread discontinuous permafrost.

REFERENCE: Heginbottom and Radburn, 1992.

### **ground ice**

A general term referring to all types of ice contained in freezing and frozen ground .

Ground ice occurs in pores, cavities, voids or other openings in soil or rock and includes massive ice. It generally excludes buried ice, except in Russian usage. Ground ice may be epigenetic or syngenetic, contemporaneous or relict, aggrading or degrading, perennial or seasonal. It may occur as lenses, wedges, veins, sheets, seams, irregular masses, or as individual crystals or coatings on mineral or organic particles. Perennial ground ice can only occur within permafrost bodies.

REFERENCES: Mackay, 1972b; Pollard and French, 1980.

### **ice content**

The amount of ice contained in frozen or partially frozen soil or rock.

Ice content is normally expressed in one of two ways:

1. on a dry-weight basis (gravimetric), as the ratio of the mass of the ice in a sample to the mass of the dry sample, expressed as a percentage, or

2. on a volume basis (volumetric), as the ratio of the volume of ice in a sample to the volume of the whole sample, expressed as a fraction.

The volumetric ice content cannot exceed unity whereas the gravimetric ice content can greatly exceed 100 percent.

REFERENCES: Penner, 1970; Anderson and Morgenstern, 1973; Johnston, 1981.

### **isolated patches of permafrost**

Permafrost underlying less than 10 percent of the exposed land sur-face.

Individual areas of permafrost are of limited areal extent, widely separated, and are completely surrounded by unfrozen ground.

SYNONYMS: (not recommended) insular permafrost; island perma-frost; scattered permafrost.

REFERENCES: Heginbottom and Radburn, 1992.

### **mean annual ground-surface temperature (MAGST)**

Mean annual temperature of the surface of the ground.

Permafrost exists if the mean annual ground-surface temperature is perennially below 0°C. Although the mean annual surface temperature may be below 0°C, the surface temperature will fluctuate during the year, causing a layer of ground immediately beneath the surface to thaw in the summer and freeze in the winter (the active layer). Small changes in the annual range of surface temperature and in the mean annual surface temperature from year to year, or over a period of a few years, may cause a layer of ground between the bottom of the active layer and the permafrost table to remain at a temperature above 0°C, creating a talik or residual thaw layer. [RD-1]

### **mean annual ground temperature (MAGT)**

Mean annual temperature of the ground at a particular depth.

The mean annual temperature of the ground usually increases with depth below the surface. In some northern areas, however, it is not uncommon to find that the mean annual ground temperature decreases in the upper 50 to 100 metres below the ground surface as a result of past changes in surface and climate conditions. Below that depth, it will increase as a result of the geothermal heat flux from the interior of the earth. The mean annual ground temperature at the depth of zero annual amplitude is often used to assess the thermal regime of the ground at various locations [RD-1]

### **n-factor**

The ratio of the surface freezing or thawing index to the air freezing or thawing index.

At any site, (standard) air temperatures are seldom the same as surface (air/substrate boundary) temperatures. Because air temperatures (measured at weather stations) are usually available and surface temperatures are not, the n-factor (an empirically determined coefficient) is used to relate air temperatures to surface temperatures in order to establish the thermal boundary condition at the surface, particularly for engineering purposes.

The difference between air and surface temperatures at any specific time and location is greatly influenced by climatic, surface and subsurface conditions (e.g., latitude, cloud cover, time of day or year, relative humidity, wind speed, type of surface--wet, dry, moss, snow, natural vegetated terrain, mineral soil, pavements-- and thermal properties of the ground). The average surface temperature and n-factor may vary significantly from year to year, even for a given surface and location, as well as for different sites, surfaces and soil systems.

Values of the freezing and thawing n-factors have been determined for a large number of sites and surfaces and are widely used for predicting surface temperatures and the thermal regime of the ground. The data vary widely, however, and indicate that a rigorous value of n for a given site cannot simply be chosen from these data. Direct determination of the n-factor for a specific location is much better and requires concurrent observations of air and surface temperatures throughout at least one and preferably several complete freezing and thawing seasons.

REFERENCES: Carlson and Kersten, 1953; Lunardini, 1978, 1981.

### **permafrost**

Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years .

Permafrost is synonymous with perennially cryotic ground: it is defined on the basis of temperature. It is not necessarily frozen, because the freezing point of the included water may be depressed several degrees below 0°C; moisture in the form of water or ice may or may not be present. In other words, whereas all perennially frozen ground is permafrost, not all permafrost is perennially frozen. Permafrost should not be regarded as permanent, because natural or man-made changes in the climate or terrain may cause the temperature of the ground to rise above 0°C.

Permafrost includes perennial ground ice, but not glacier ice or icings, or bodies of surface water with temperatures perennially below 0°C; it does include man-made perennially frozen ground around or below chilled pipelines, hockey arenas, etc.

Russian usage requires the continuous existence of temperatures below 0°C for at least three years, and also the presence of at least some ice.

SYNONYMS: perennially frozen ground, perennially cryotic ground and (not recommended) biennially frozen ground, climafrost, cryic layer, permanently frozen ground.

REFERENCES: Muller, 1943; van Everdingen, 1976; Kudryavtsev, 1978.

### **permafrost boundary**

1. The geographical boundary between the continuous and discontinuous permafrost zones.
2. The margin of a discrete body of permafrost.

### **permafrost degradation**

A naturally or artificially caused decrease in the thickness and/or areal extent of permafrost.

Permafrost degradation may be caused by climatic warming or by changes in terrain conditions, such as disturbance or removal of an insulating vegetation layer by fire, or by flooding caused by a landslide-blocked stream, or by human activity. It may be expressed as a thickening of the active layer, a lowering of the permafrost table, a raising of the permafrost base, or a reduction in the areal extent or the complete disappearance of permafrost. [RD-1]

### **permafrost region**

A region in which the temperature of some or all of the ground below the seasonally freezing and thawing layer remains continuously at or below 0°C for at least two consecutive years.

The permafrost region is commonly subdivided into permafrost zones. [RD-1]

### **permafrost zone**

A major subdivision of a permafrost region.

A permafrost region is commonly subdivided into permafrost zones based on the proportion of the ground that is perennially cryotic. The basic subdivision in high latitudes is into zones of continuous permafrost and discontinuous permafrost.

REFERENCES: Muller, 1943; Brown, 1967, 1978; Washburn, 1979; Pewe, 1983.

### **sporadic discontinuous permafrost**

1. (North-American usage) Permafrost underlying 10 to 35 percent of the exposed land surface.
2. (Russian usage) Permafrost underlying 5 to 30 percent of the exposed land surface.

Individual areas of permafrost are completely surrounded by unfrozen ground.

SYNONYMS: (not recommended) insular permafrost; island permafrost; scattered permafrost.

REFERENCES: Muller, 1943; Brown, 1967; Heginbottom and Radburn, 1992.

### **talik**

A layer or body of unfrozen ground occurring in a permafrost area due to a local anomaly in thermal, hydrological, hydrogeological, or hydrochemical conditions .

Taliks may have temperatures above 0°C (noncryotic) or below 0°C (cryotic, forming part of the permafrost). Some taliks may be affected by seasonal freezing. Several types of taliks can be distinguished on the basis of their relationship to the permafrost (closed, open, lateral, isolated and transient taliks), and on the basis of the mechanism responsible for their unfrozen condition (hydrochemical, hydrothermal and thermal taliks):

1. closed talik - a noncryotic talik occupying a depression in the permafrost table below a lake or river (also called "lake talik" and "river talik"); its temperature remains above 0°C because of the heat storage effect of the surface water;
2. hydrochemical talik - a cryotic talik in which freezing is prevented by mineralized groundwater flowing through the talik.
3. hydrothermal talik - a noncryotic talik, the temperature of which is maintained above 0°C by the heat supplied by groundwater flowing through the talik;
4. isolated talik - a talik entirely surrounded by perennially frozen ground; usually cryotic (see isolated cryopeg), but may be noncryotic (see transient talik);
5. lateral talik - a talik overlain and underlain by perennially frozen ground; can be noncryotic or cryotic;
6. open talik - a talik that penetrates the permafrost completely, connecting suprapermafrost and subpermafrost water, (e.g., below large rivers and lakes).

It may be noncryotic (see hydrothermal talik) or cryotic (see hydro-chemical talik).

SYNONYMS: (not recommended) through talik, penetrating talik, perforating talik, piercing talik;

7. thermal talik - a noncryotic talik, the temperature of which is above 0°C due to the local thermal regime of the ground;
8. transient talik - a talik that is gradually being eliminated by freezing, e.g., the initially noncryotic closed talik below a small lake which, upon draining of the lake, is turned into a transient isolated talik by permafrost aggradation (see also closed-system pingo).

REFERENCES: Williams, 1965; Washburn, 1973; van Everdingen, 1976.

## 2 KEY REGIONS FOR STUDY

### 2.1 Global Permafrost distribution

Permafrost is a phenomenon of the subsurface thermal state across vast areas. Permafrost underlies approx. 24% of the terrestrial Northern Hemisphere (Figure 1). Southern hemisphere permafrost occurs in the Andean mountains, in the Southern Alps in New Zealand and ice-free areas of the Antarctic continent and neighbouring islands. All regions where permafrost can occur on the Northern Hemisphere will be covered in Permafrost\_cci phase 2.

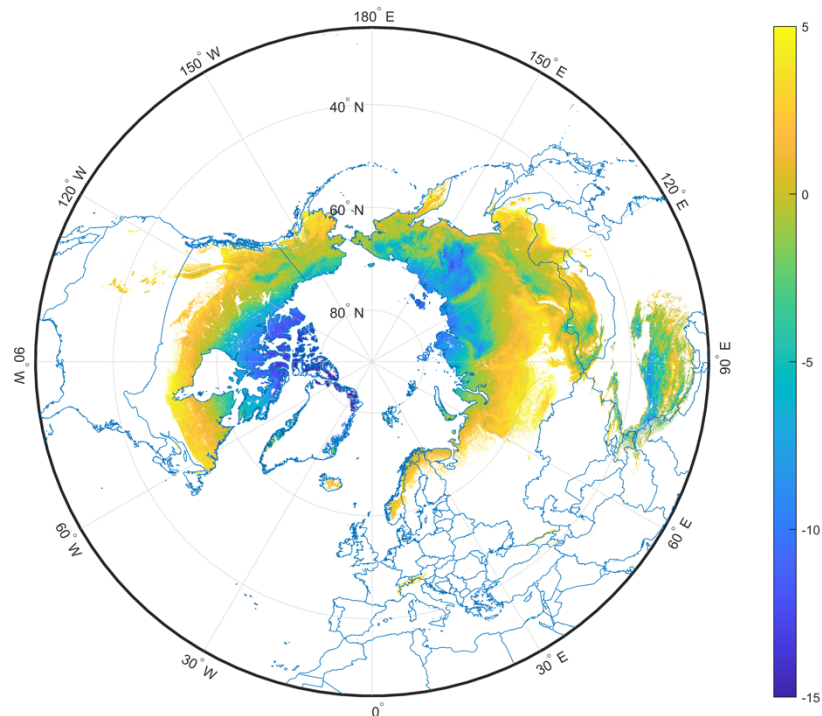


Figure 1: CRDPv4 example of Mean Annual Ground Temperature at 2 m depth in 2019 (in °C, colour axis).

### 2.2 Regions for evaluation

The validation is carried out independently from the algorithm development team and uses the WMO Global Terrestrial Network for Permafrost (GTN-P), also specifically the mountain permafrost monitoring program PERMOS in Switzerland and additional international and national ground monitoring programs, e.g., Roshydromet RHM, and from data repositories: the Canadian data repository for Polar research Nordicana-D (<http://www.cen.ulaval.ca/nordicanad/dpage.aspx?doi=45291SL34F28A9491014AFD>), the German data repository for Earth and Environment, PANGAEA, the US Arctic Data Centre, and the NASA ARCTIC-BOREAL VULNERABILITY EXPERIMENT ABOVE ([https://above.nasa.gov/field\\_data\\_products.html](https://above.nasa.gov/field_data_products.html)) for validation throughout the project. All available maps and data are documented in the Data Access Requirements Document (DARD, [RD-2], [RD-8]). Especially GTN-P borehole sites in Alaska are investigated in comparison to GIPL2 runs (Dmitry Nicolsky, University of Alaska Fairbanks, USA) and the ESA DUE GlobPermafrost map (equilibrium

model) for benchmarking [RD-4, RD-5, RD-9]. Further regional comparisons are made for mountain regions in the European Alps (e.g., PERMOS). Evaluation also considers rock glacier inventories where available [RD-6].

### 3 PRODUCTS SPECIFICATIONS

#### 3.1 Ground temperatures, active layer thickness and permafrost fractions

##### 3.1.1 Product description

This product includes the ECV state variables ground temperature and active layer thickness, derived from a thermal model driven and constrained by EO data. In addition, the product provides a yearly fraction of permafrost-underlain and permafrost-free area within a pixel, as well as the areal fraction underlain by a talik (permafrost-free zone on top of degrading permafrost, which is the result of near-surface permafrost degradation). Classification according to the IPA permafrost map delivers the well-known permafrost zones, distinguishing sporadic, discontinuous and continuous permafrost. The model spin-up largely follows the accelerated spin-up procedure described in Westermann et al., (2022), Sect. 3.1.4. While the main transient model run starts in the year 1980, the deeper parts of the vertical temperature profile are initialized to reflect climate conditions in the period 1950 to 1979, the first thirty-year period for which the ERA5 reanalysis is available. To ensure that the near-surface temperature cycle is independent of the initial conditions, transient simulations from 1980 to 1996 were conducted before processing the “Permafrost\_CCI product years” 1997 to 2021.

##### 3.1.2 Temporal compositing

The temporal resolution is one year, which corresponds to average Mean Annual Ground Temperature (MAGT), as well as the maximum depth of seasonal thaw, which corresponds to the active layer thickness (ALT).

##### 3.1.3 Spatial resolution

The spatial resolution of the Permafrost\_CCI products is linked to the best available resolution of the input sensor. Here, the spatial resolution is limited to 0.01°, which is the spatial resolution of remotely sensed LST. However, we apply ensemble-based modelling of subpixel variability, i.e. different ensemble members represent different ground stratigraphies and snow depths found within 1km pixels. This is required for computation of permafrost and talik fractions.

##### 3.1.4 Pixel attributes

ECV variable	unit	property	Product string
ground temperature at certain depth (maximum 10 m)	K, scaled by 100	annual average	GTD
active layer thickness	m, scaled by 100	annual maximum	ALT
permafrost fraction	0-1	annual minimum	PFR

### 3.2 Product accuracy

With respect to the threshold user requirements documented in [RD-3] the following accuracy is targeted in phase 2:

- Ground temperature: 2.5 degree C compared to GTN-P boreholes
- Active layer thickness: RMSE <0.25m for ALT < 1.0 m and RMSE <0.5 m for ALT >1.0 m

Product accuracy of the phase 1 dataset is documented in [RD-7]. The accuracy of V4.0, CRDP V3 (phase 2, iteration 1) is documented in [RD-9] and demonstrates for Mean Annual Ground Temperature (MAGT) time series from 1997 to 2021 across all depths a mean bias of -0.73 °C for the whole range of validation data including none-permafrost sites. Considering only permafrost measurement borehole sites with an MAGT <1 °C, we get a median bias of 0.35°C. Geographically, the extreme residuals showed no obvious spatial clusters..

Active layer thickness of the V3.0, CRDP V2 (phase 2, iteration 1) is characterized by an absolute bias of 30 cm, a median bias of --13 cm (95 % CI: -90 to 48 cm) with a robust temporal stability around 60 %. A large bias > 1 m occurs only in a few match-up pairs in Alaska, Canada and Russia and Permafrost\_cci bias < -1.5 m mainly occurs in Svalbard and Scandinavia for rocky and pebble terrain.

### 3.3 Data dissemination for all products

All CCI map time series are distributed via the CCI portal and in addition visualised in maps@awi contributing to the Permafrost Information System hosted by AWI.

The validation datasets for ground temperature will be published as standardised depth-time series in form of a permafrost community data publication on PANGAEA in the course of 2024, the validation dataset for active layer depths will be published accordingly at a later step.

### 3.4 Data documentation

The data documentation is available on the ESA CCI webpage (<https://climate.esa.int/en/projects/permafrost/>).



## 4 PRODUCT FORMATS

### 4.1 Product projection system

The projection has been changed to the specifications of the LST\_cci datasets, as they will be used as input in phase 2. The projection is in geographic coordinates at 0.01° resolution. Information on product projection, ellipsoid and pixel size are included in the NetCDF.

### 4.2 Subsets

CRDPv3 pertains Arctic and High-Mountain permafrost environments, extending from 85°N down to 35 °N latitude in the North America and down to 25 °N in Asia.

### 4.3 File formats

All datasets are provided in NetCDF format.

### 4.4 Product file naming conventions

The files for each product type are named as follows:

ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>[-<Additional Segregator>]-<Start Date>-<End Date>-fv<File version>.nc

<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.

<Product String> : <source>\_<algorithm>

MODIS\_CRYOGRID or ERA5\_MODISLST\_BIASCORRECTED

<Source>

- MODIS - MODIS Landsurface temperature is used as the main input for the L4 production for 2003-2021 data. Sensors of auxiliary data are listed in the meta data.
- ERA5 - Downscaled and bias corrected ERA reanalyses data based on statistics of the overlap period between ERA reanalysis and MODIS LST are used for data before 2003. Sensors of auxiliary data are listed in the meta data.

<algorithm>

- CRYOGRID – data from CRYOGRID algorithm
- MODISLST\_BIASCORRECTED - Downscaled and bias corrected ERA reanalyses data based on statistics of the overlap period between ERA reanalysis and MODIS LST are used for data before 2003. Sensors of auxiliary data are listed in the meta data

<Additional Segregator>

This should be AREA<TILE\_NUMBER>\_<Layer type>

<TILE\_NUMBER>being the tile number the subset index: 1- global, 2-North America, 3-Eurasia, 4-Northern Hemisphere

<Layer type>

- PP: layer type 1, corresponding to value of the permafrost parameter.

<Start Date> and <End Date>

The identifying date for this data set:

Format is YYYYMMDD, where YYYY is the four digit year, MM is the two digit month from 01 to 12 and DD is the two digit day of the month from 01 to 31.

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 fv04.0 (released in November 2023).

Examples:

ESACCI-PERMAFROST-L4-GTD-MODIS\_CRYOGRID-AREA4\_PP-2011-fv04.0.nc

ESACCI-PERMAFROST-L4-GTD-ERA5\_MODISLST\_BIASCORRECTED-AREA4\_PP-1997-fv04.0.nc

#### 4.5 File meta data - NetCDF

The following attributes are included in the NetCDF file:

Global Attribute	Content
<b>title</b>	ESA CCI permafrost <parameter name>
<b>institution</b>	University of Oslo
<b>source</b>	<text>
<b>history</b>	YYYY-MM-DD HH:MM:SS
<b>references</b>	<a href="http://cci.esa.int/Permafrost">http://cci.esa.int/Permafrost</a> [and publications]
<b>tracking_id</b>	<xxxxxxxx-yyyy-zzzz-nnnn-mmmmmmmmmmm> a UUID (Universal Unique Identifier) value
<b>Conventions</b>	CF-1.10
<b>product_version</b>	<number>
<b>summary</b>	ESA CCI Permafrost product level 4
<b>keywords</b>	<text>

Global Attribute	Content
<b>id</b>	<filename>
<b>naming authority</b>	no.uio
<b>keywords_vocabulary</b>	NASA Global Change Master Directory (GCMD) Science Keywords, Version 15.8
<b>cdm_data_type</b>	Grid
<b>comment</b>	These data were produced at ESACCI as part of the ESA Permafrost CCI+ project Contract No 4000123681/18/I-NB
<b>date_created</b>	<file creation date>
<b>creator_name</b>	University of Oslo
<b>creator_url</b>	<a href="https://www.uio.no/english/">https://www.uio.no/english/</a>
<b>project</b>	Climate Change Initiative - European Space Agency
<b>geospatial_lat_min</b>	25
<b>geospatial_lat_max</b>	85
<b>geospatial_lon_min</b>	-180
<b>geospatial_lon_max</b>	180
<b>geospatial_vertical_min</b>	0.0
<b>geospatial_vertical_max</b>	0.0
<b>time_coverage_start</b>	YYYYMMDDTHHMMSSZ
<b>time_coverage_end</b>	YYYYMMDDTHHMMSSZ
<b>time_coverage_duration</b>	P<number of years>Y
<b>time_coverage_resolution</b>	P<number><unit>
<b>standard_name_vocabulary</b>	CF Standard Name Table v79
<b>license</b>	ESA CCI Data Policy: free and open access
<b>platform</b>	<name>
<b>spatial_resolution</b>	<number><
<b>geospatial_lat_units</b>	none
<b>geospatial_lon_units</b>	none
<b>geospatial_lon_resolution</b>	<number><
<b>geospatial_lat_resolution</b>	<number><
<b>key_variables</b>	<name>
<b>Format_version</b>	CCI Data Standards v2.3

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## 5.2 Acronyms

AD	Applicable Document
ALT	Active Layer Thickness
AWI	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
B.GEOS	b.geos GmbH
CCI	Climate Change Initiative
CRDP	Climate Research Data Package
CRG	Climate Research Group
CRS	Coordinate Reference System
DARD	Data Access Requirements Document
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
GCMD	Global Change Master Directory
GIPL	Geophysical Institute Permafrost Laboratory
GTD	Ground Temperature at certain depth
GTN-P	Global Terrestrial Network for Permafrost
GUIO	Department of Geosciences University of Oslo
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
LST	Land Surface Temperature
MAGT	Mean Annual Ground Temperature
MAGST	Mean Annual Ground Surface Temperature
NetCDF	Network Common Data Format
NSIDC	National Snow and Ice Data Center
PFR	Permafrost extent (Fraction)
PFF	Permafrost-Free Fraction
PFT	Permafrost underlain by Talik
PSD	Product Specifications Document
PSTG	Polar Space Task Group

PZO	Permafrost Zone
RD	Reference Document
RMSE	Root Mean Square Error
RS	Remote Sensing
SLF	Institut für Schnee- und Lawinenforschung, Davos
SU	Department of Physical Geography Stockholm University
TSP	Thermal State of Permafrost
UAF	University of Alaska, Fairbanks
UNIFR	Department of Geosciences University of Fribourg
URD	Users Requirement Document
WGS 84	World Geodetic System 1984
WUT	West University of Timisoara