permafrost
cci

CCI+ PHASE 1 – NEW ECVS
PERMAFROST

D4.3 PRODUCT USER GUIDE (PUG)

VERSION 2.0

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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).

The PUG provides the description of the Climate Research Data Package (CRDP). This includes formats, attributes and meta data. The CRDP v0 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.

CRDPv1 covers the years from 1997 to 2018, with the data available for each year of the period. It covers Arctic and High-Mountain permafrost environments of the northern hemisphere. The projection is Arctic Polar Stereographic, with 0.927 km grid spacing. It is provided in NetCDF format including meta data following the NetCDF Climate and Forecast (CF) Metadata Convention 67.

Known limitations include regional biases and implications of the size of the model ensemble, shortcomings of input stratigraphy and the modelled snow cover.

1 INTRODUCTION

1.1 Purpose of the document

This document provides the user requirements of climate science and climate services for ECV products of the Permafrost_cci project. The ultimate objective of Permafrost_cci is to develop and deliver permafrost maps as ECV products primarily derived from satellite measurements.

Permafrost is an Essential Climate Variable (ECV) within the Global Climate Observing System (GCOS), which is characterized by subsurface temperatures and the depth of the seasonal thaw layer. Complementing ground-based monitoring networks, the Permafrost CCI project is establishing Earth Observation (EO) based products for the permafrost ECV spanning the last two decades. Since ground temperature and thaw depth cannot be directly observed from space-borne sensors, a variety of satellite and reanalysis data are combined in a ground thermal model. The algorithm uses remotely sensed data sets of Land Surface Temperature (MODIS LST/ ESA LST CCI) and landcover (ESA Landcover CCI) to drive the transient permafrost model CryoGrid CCI, which yields thaw depth and ground temperature at various depths, while ground temperature forms the basis for permafrost fraction.

The PUG provides the description of the Climate Research Data Package (CRDP). This includes formats, attributes and meta data.

The CRDP v1 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.

1.2 Structure of the document

The first part of this document details general properties of all products. Attributes and known issues, with reference to the Product Validation and Intercomparison Report (PVIR) are described in a separate chapter. Bibliography and abbreviations are provided at the end of the document.

2 General product properties

2.1 Temporal compositing

Grid products of CDRP v1 are released in annual files, covering the start to the end of the Julian year. This corresponds to average annual ground temperatures, as well as the maximum depth of seasonal thaw, which corresponds to the active layer thickness

2.2 Spatial resolution

The spatial resolution of the grid product is 926.63 m. Grid attributes are computed in each cell of that size within the time period indicated above. The spatial resolution is limited by the spatial resolution of remotely sensed Landsurface Temperature.

2.3 Product projection system

The Coordinate Reference System (CRS) used for CRDPv1 is Polar Stereographic projection (Arctic) based on the World Geodetic System 84 (WGS84) reference ellipsoid. The coordinates are specified in meters. It covers the northern hemisphere, extending down to 35 °N latitude in the North America and down to 25 °N in Asia.

2.4 File formats

The product is delivered in NetCDF format, with each time slice and parameter as an individual file.

2.5 Geographical subsets

CDRP v1 covers the northern hemisphere.

2.6 Product file naming conventions

The files for each product type are named as follows:

ESACCI-<CCI Project>-<Processing Level>-<Source>-<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.

<Source>
MODIS - MODIS Landsurface temperature is used as the main input for the L4 production for 2003-2018 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.

<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>
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 fv02.0 for 2003 – 2017, and fv01.0 for 1997-2002 and 2018 (released in May 2020).

Examples:
ESACCI-PERMAFROST-L4-MODIS-GTD-CRYOGRID-AREA4_PP-2011-fv02.0.nc
ESACCI-PERMAFROST-L4-ERA5-GTD-MODISLST_BIASCORRECTED-AREA4_PP-1997-fv01.0.nc

2.7 Meta data

Meta data are included in all files following the NetCDF Climate and Forecast (CF) Metadata Convention 71.

3 Ground temperature

3.1 Terminology

Mean annual temperature of the ground of CRDP v1 is provided for particular depths [RD-1].
The mean annual temperature of the ground usually increases with depth below the surface. In some northern areas, however, it is not un-common 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.
REFERENCES: von Everdingen, 1998

3.2 Abstract of data publication

This dataset contains permafrost ground temperature data produced as part of the European Space Agency's (ESA) Climate Change Initiative (CCI) Permafrost project. It forms part of the first version of their Climate Research Data Package (CRDP v1). It is derived from a thermal model driven and constrained by satellite data. Grid products of CDRP v1 are released in annual files, covering the start to the end of the Julian year. This corresponds to average annual ground temperatures and is provided for specific depths (surface, 1m, 2m, 5m , 10m).

Case A: It covers the Northern Hemisphere (north of 30°) for the period 2003-2017 based on MODIS Land Surface temperature merged with downscaled ERA5 reanalysis near-surface air temperature data.
Case B: It covers the Northern Hemisphere (north of 30°) for the period 1997-2002 based on downscaled ERA5 reanalysis near-surface air temperature data which are bias-corrected with the Case A product for the overlap period 2003-2018 using a pixel-specific statistics for each day of the year.

3.3 Pixel attributes

Layer	Attribute	Units	Data type	notes
GST	Ground surface temperature (depth 0)	Kelvin	Integer	Scaled by 100
T1m	Ground temperature at 1m depth	Kelvin	Integer	Scaled by 100
T2m	Ground temperature at 2m depth	Kelvin	Integer	Scaled by 100
T5m	Ground temperature at 5m depth	Kelvin	Integer	Scaled by 100
T10m	Ground temperature at 10m depth	Kelvin	Integer	Scaled by 100

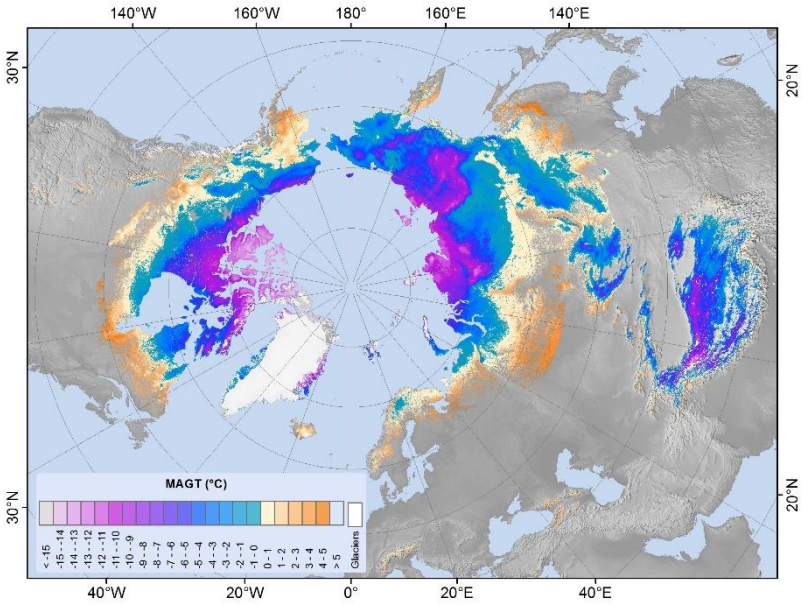

Figure 1: Example of Mean Annual Ground Temperature at 1 m depth in 2005

3.4 Previous version

CRDP_v0 (file version 1 2003-2017)

Obu, J.; Westermann, S.; Barboux, C.; Bartsch, A.; Delaloye, R.; Grosse, G.; Heim, B.; Hugelius, G.; Irrgang, A.; Kääb, A.M.; Kroisleitner, C.; Matthes, H.; Nitze, I.; Pellet, C.; Seifert, F.M.; Strozzi, T.; Wegmüller, U.; Wieczorek, M.; Wiesmann, A. (2019): ESA Permafrost Climate Change Initiative (Permafrost_cci): Permafrost Ground Temperature for the Northern Hemisphere, v1.0. Centre for Environmental Data Analysis, 19 December 2019. doi:10.5285/9a333481e9a34c7a8f78902f77ad3fe7. http://dx.doi.org/10.5285/9a333481e9a34c7a8f78902f77ad3fe7

4 ACTIVE LAYER THICKNESS

4.1 Terminology

Active Layer Thickness is 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°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°C) layer of ground.
REFERENCES: Muller, 1943; Williams, 1965; van Everdingen, 1985.

4.2 Abstract of data publication

This dataset contains permafrost active layer thickness data produced as part of the European Space Agency's (ESA) Climate Change Initiative (CCI) Permafrost project. It forms part of the first version of their Climate Research Data Package (CRDP v1). It is derived from a thermal model driven and constrained by satellite data. Grid products of CDRP v1 are released in annual files, covering the start to the end of the Julian year. The maximum depth of seasonal thaw is provided, which corresponds to the active layer thickness.

Case A: It covers the Northern Hemisphere (north of 30°) for the period 2003-2017 based on MODIS Land Surface temperature merged with downscaled ERA5 reanalysis near-surface air temperature data.
Case B: It covers the Northern Hemisphere (north of 30°) for the period 1997-2002 based on downscaled ERA5 reanalysis near-surface air temperature data which are bias-corrected with the Case A product for the overlap period 2003-2018 using a pixel-specific statistics for each day of the year.

4.3 Pixel attributes

Layer	Attribute	Units	Data type	notes
1	Active layer thickness	meter	integer	Scaled by 100

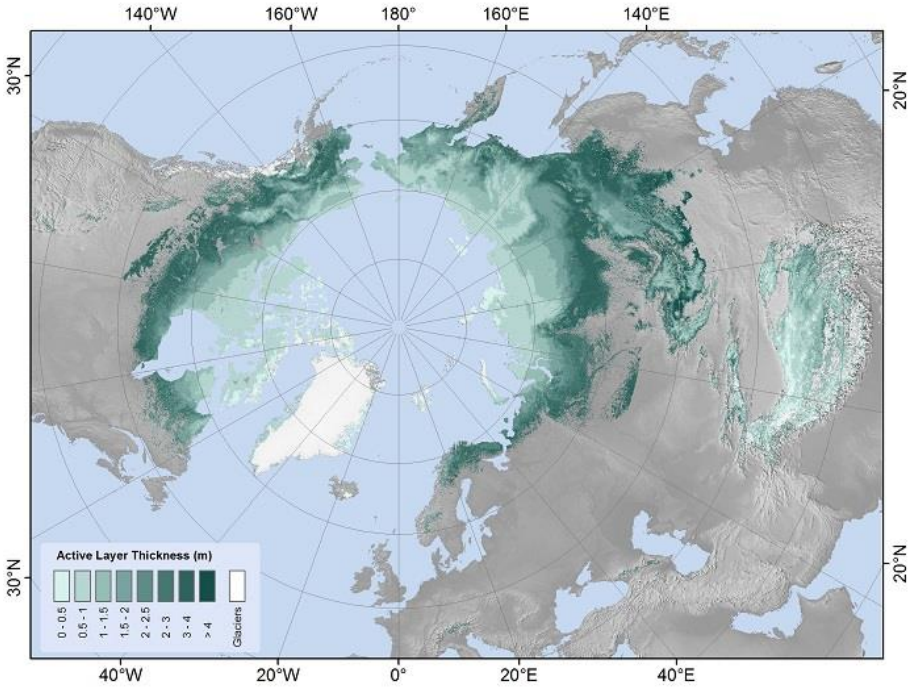

Figure 2: Example of Active Layer Thickness for 2015

4.4 Previous version

CRDP_v0 (file version 1 2003-2017)

Obu, J.; Westermann, S.; Barboux, C.; Bartsch, A.; Delaloye, R.; Grosse, G.; Heim, B.; Hugelius, G.; Irrgang, A.; Kääb, A.M.; Kroisleitner, C.; Matthes, H.; Nitze, I.; Pellet, C.; Seifert, F.M.; Strozzi, T.; Wegmüller, U.; Wieczorek, M.; Wiesmann, A. (2019): ESA Permafrost Climate Change Initiative (Permafrost_cci): Permafrost Active Layer Thickness for the Northern Hemisphere, v1.0. Centre for Environmental Data Analysis, *19 December 2019*. doi:10.5285/1ee56c42cf6c4ef698693e00a63795f4. http://dx.doi.org/10.5285/1ee56c42cf6c4ef698693e00a63795f4

5 PERMAFROST EXTENT

5.1 Terminology

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

Continuous permafrost is 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.

Discontinuous permafrost corresponds to 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.

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

5.2 Abstract of data publication

This dataset contains permafrost extent data produced as part of the European Space Agency's (ESA) Climate Change Initiative (CCI) Permafrost project. It forms part of the first version of their Climate Research Data Package (CRDP v1). It is derived from a thermal model driven and constrained by satellite data. Grid products of CDRP v1 are released in annual files, covering the start to the end of the Julian year. This corresponds to average annual ground temperatures (at 2 m depth) which forms the basis for the retrieval of yearly fraction of permafrost-underlain and permafrost-free area within a pixel. A classification according to the IPA (International Permafrost Association) zonation delivers the well-known permafrost zones, distinguishing isolated (0-10%) sporadic (10-50%), discontinuous (50-90%) and continuous permafrost (90-100%).

Case A: It covers the Northern Hemisphere (north of 30°) for the period 2003-2017 based on MODIS Land Surface temperature merged with downscaled ERA5 reanalysis near-surface air temperature data.

Case B: It covers the Northern Hemisphere (north of 30°) for the period 1997-2002 based on downscaled ERA5 reanalysis near-surface air temperature data which are bias-corrected with the Case A product for the overlap period 2003-2018 using a pixel-specific statistics for each day of the year.

5.3 Pixel attributes

Layer	Attribute	Units	Data type	notes
1	Permafrost fraction	percent	integer	yearly fraction of permafrost-underlain and permafrost-free area within a pixel

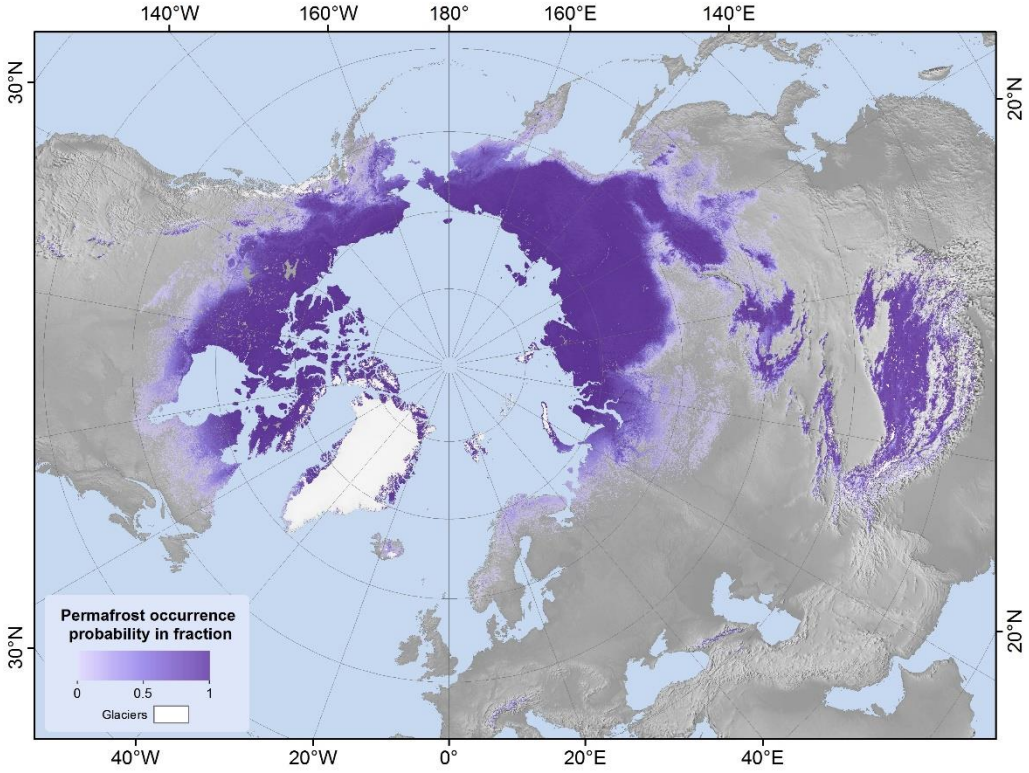

Figure 3: Example of Permafrost extent (fraction) for 2015

5.4 Previous version

CRDP_v0 (file version 1 2003-2017)

Obu, J.; Westermann, S.; Barboux, C.; Bartsch, A.; Delaloye, R.; Grosse, G.; Heim, B.; Hugelius, G.; Irrgang, A.; Kääb, A.M.; Kroisleitner, C.; Matthes, H.; Nitze, I.; Pellet, C.; Seifert, F.M.; Strozzi, T.; Wegmüller, U.; Wieczorek, M.; Wiesmann, A. (2019): ESA Permafrost Climate Change Initiative (Permafrost_cci): Permafrost Ground Temperature for the Northern Hemisphere, v1.0. Centre for

Environmental Data Analysis, *19 December 2019*. doi:10.5285/9a333481e9a34c7a8f78902f77ad3fe7. http://dx.doi.org/10.5285/9a333481e9a34c7a8f78902f77ad3fe7

6 KNOWN LIMITATIONS

The ground temperatures are currently modelled too low in especially Central Asia (Mongolia, China, and Kazakhstan) [RD-2], presumably because of incorrectly modelled snow cover. The currently used stratigraphies do not necessarily represent the real ground conditions. The largest errors are expected where bedrock is represented as moisture rich ground. Stratigraphies are defined based on land cover classification and the results can be unreliable specifically when the land cover does not represent the real conditions. Despite these limitations, modeled annual average ground temperatures agree reasonably well with in-situ measurements in boreholes.

Compared to the GlobPermafrost product (Obu et al., 2019), differences exist for both ground temperatures and modelled permafrost extent [RD-2]. These differences are in particular caused by the different thermal model employed in the Permafrost_cci processing chain, but also to the transient nature of the selected approach, in contrast to the steady-state "equilibrium" model employed in GlobPermafrost. Differences in the modelled permafrost zonations (i.e. continuous, discontinuous and sporadic permafrost) can also be caused by the different size of the model ensemble. In GlobPermafrost, the simple and computationally efficient equilibrium model facilitated an ensemble size large enough to provide permafrost percentages with discretization of 0.5%. In the CCI products, only seven ensemble members are employed (in year 2) to compute permafrost fraction, which means that the boundaries between zonations (90% between continuous and discontinuous, 50% between discontinuous and sporadic, 10% between sporadic and isolated/no permafrost) are not explicitly resolved, which can lead to both under- and overestimation of the class extents.

The limitations from ground temperature and permafrost extent layers are also inherited by active layer thickness datasets, which is not featured in the GlobPermafrost permafrost extent product. The active layer thickness is strongly dependent on the employed ground stratigraphy. As ground stratigraphies are known to vary on short distances, the performance of the active layer thickness product strongly varies in space, being less accurate especially where ground stratigraphies are incorrect.

7 REFERENCES AND ACRONYMS

7.1 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] ESA Climate Office 2020: CCI Data Standards v2.2. Reference CCI-PRGM-EOPS-TN-13-0009

7.2 Reference Documents

[RD-1] Bartsch, A., Westermann, Strozzi, T., Wiesmann, A., Kroisleitner, C. (2019): ESA CCI+ Permafrost Product Specifications Document, v1.0

[RD-2] Heim, B., Wieczorek, M., Pellet, C., Barboux, C., Delaloye, R., Bartsch, A., Kroisleitner, C., Strozzi, T. (2019): ESA CCI+ Permafrost Product Validation and Intercomparison Report, v1.0

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Washburn, A.L., 1973: Periglacial processes and environments. Edward Arnold, London, 320p.

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Williams, J.R., 1965: Ground water in permafrost regions: An annotated bibliography. U.S. Geological Survey, Professional Paper 696, 83p.

7.4 Acronyms

ACOP	Asian Conference on Permafrost
ALT	Active Layer Thickness
Arctic CORDEX	Coordinated Regional Climate Downscaling Experiment
AWI	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
B.GEOS	b.geos GmbH
CALM	Circumpolar Active Layer Monitoring
CliC	Climate and Cryosphere project
CLM4	Land Community Model
CCI	Climate Change Initiative
CMIP-6	The Coupled Model Intercomparison Project
CMUG	Climate Modelling User Group
CRESCENDO	Coordinated Research in Earth Systems and Climate: Experiments, Knowledge, Dissemination and Outreach
CRG	Climate Research Group
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
GCW	Global Cryosphere Watch
GT	Ground Temperature
GTN-P	Global Terrestrial Network for Permafrost
GTOS	Global Terrestrial Observing System
GUIO	Department of Geosciences University of Oslo
HIRHAM	High Resolution Limited Area Model
IASC	International Arctic Science Committee
ILAMB	International Land Model Benchmarking
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
LS3MIP	Land Surface, Snow and Soil Moisture
MAGT	Mean Annual Ground Temperature
NetCDF	Network Common Data Format
NSIDC	National Snow and Ice Data Center
PCN	Permafrost Carbon Network
PE	Permafrost Extent
PERMOS	Swiss Permafrost Monitoring Network
PF	Permafrost
PSTG	Polar Space Task Group
RASM	Regional Arctic System Model
RD	Reference Document
RMSE	Root Mean Square Error
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SCAR	Scientific Committee on Antarctic Research
SU	Department of Physical Geography Stockholm University
TSP	Thermal State of Permafrost
UNIFR	Department of Geosciences University of Fribourg
URD	Users Requirement Document
WCRP	World Climate Research Program
WMO	World Meteorological Organisation
WMO OSCAR	Observing Systems Capability Analysis and Review Tool
WUT	West University of Timisoara