permafrost
cci

CCI+ PHASE 1 – NEW ECVS
Permafrost

CCN3 Option 6
IMPROVED SOIL DESCRIPTION THROUGH A LANDCOVER MAP DEDICATED FOR THE ARCTIC

D3 Product user guide (PUG)

Version 2.2

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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).

This document is the Product user guide (PUG) of Option 6 within CCN3 of Phase 1 of the Permafrost_cci project. It describes the product of the landcover product targeting proxies for soil properties in tundra regions underlain by permafrost. The product specifications address the main requirements expressed by the users in the User Requirements Document (URDv1.0, RD-3) including those expressed by the Permafrost_cci Climate Research Group (CRG)

The PUG includes the product specifications and formats, including details of meta data.

Landcover information is provided at 10m resolution, polar stereographic projection, covering the Arctic tundra and representing the status 2016-2022. Product level is 4. The datasets are created from the analysis of lower level data, resulting in gridded products. In addition aggregated information (1 km) is provided for further use in the Permafrost_cci project.

1 Introduction

1.1 Purpose of the document

This document describes in detail product specifications of a pan-arctic permafrost region specific landcover product that is consistent. The purpose of this document is to present the structure, syntax and file naming conventions used to describe the landcover product. It provides all the necessary data needed by users to read the products.

1.2 Structure of the document

Section 2 describes the general product properties. The remaining sections detail the thematic content and known issues.

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.

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., G. Hugelius, Strozzi, T.(2021): ESA CCI+ Permafrost CCN3 Option 6: improved soil description through a landcover map dedicated for the Arctic. User Requirements Document, v1.0

[RD-4] Bartsch, A., Widhalm, B., Elimova, A., G. Hugelius, Palmtag, J., Strozzi, T.(2022): ESA CCI+ Permafrost CCN3 Option 6: improved soil description through a landcover map dedicated for the Arctic. Design Engineering, v1.0

[RD-5] Bartsch, A., Efimova, A., Widhalm, B., Muri, X., von Baeckmann, C., Bergstedt, H., Ermokhina, K., Hugelius, G., Heim, B., and Leibmann, M.: Circumarctic landcover diversity considering wetness gradients, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-2295, 2023.

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

A selection of terms relevant for the parameters addressed in Permafrost_cci is provided in [RD-2].

2 General product properties

2.1 Geographical coverage

Permafrost is a phenomenon of the subsurface thermal state across vast areas. Permafrost underlies approx. 24% of the terrestrial Northern Hemisphere (Figure 1). Specifically, tundra regions are very heterogeneous regarding landcover and soil properties what is so far unaccounted for in global landcover datasets. The landcover product does therefore cover all tundra area in the Arctic which is underlain by permafrost. The borders are defined based on the Circumarctic Vegetation Map (CAVM) by Raynolds et al. (2019). Sentinel-2 granules which have partial or full overlap are included in the product. Preference was given to the granule with best coverage in case of multiple granules at a certain location.

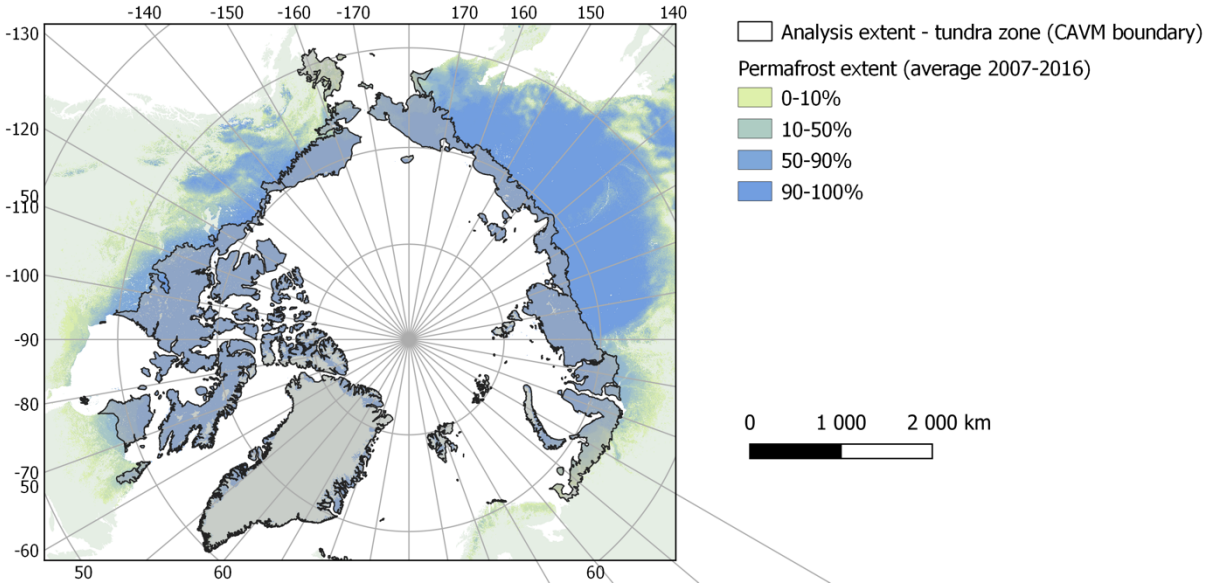

Figure 1: Analyses extent for the landcover product. Permafrost extent: CRDPv1 - Obu et al., 2020, Tundra extent: Circumarctic vegetation map (CAVM) – Raynolds et al. (2019)

2.2 Temporal compositing

The product is static and is a mosaic of acquisitions from 2016 to 2022, depending on availability of cloud free Sentinel-2 data during the vegetation peak season.

2.3 Spatial resolution

The Spatial resolution of the landcover product is linked to the available resolution of the input sensors. This includes Sentinel-1 and Sentinel-2, both with 10m nominal resolution (Sentinel-2 bands partially transferred to 10m, see [RD-4]).

2.4 Product projection system

The Coordinate Reference System (CRS) used for the landcover unit dataset is Polar Stereographic projection (Arctic) based on the World Geodetic System 84 (WGS84) reference ellipsoid. The

coordinates are specified in meters. It covers the tundra region north of the treeline. Higher level products are provided in geographic coordinates at 0.01° resolution.

2.5 File formats

The product is delivered in GeoTIFF format (compressed).

2.6 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>.tif

<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>
CLS – landcover unit

<Product String> : <source>_<algorithm>
SENTINEL1-2_ KMLH
<Source>

- SENTINEL1_2 - Fusion of Sentinel-1 and Sentinel-2 data.

<algorithm>

- KMLH – Two step approach of K-means and Maximum Likelihood (prototype method, Bartsch et al. 2019)

<Additional Segregator>
This should be AREA<TILE_NUMBER>_<Sentinel-2 granule ID>_<Layer type>
<TILE_NUMBER>being the tile number the Permafrost_cci subset index: 1- global, 2-North America, 3-Eurasia, 4-Northern Hemisphere, 17- Arctic tundra CAVM (north of treeline); 18 – Arctic tundra extended;

<Sentinel-2 granule ID>

- Sentinel-2 granule ID: e.g. 42WVC, following the scheme of the Copernicus service, or
- Subregion ID: ALASK – Alaska, CANA1 – Canada mainland, CANA2 – Canada islands UTM10- UTM16, CANA3 - Canada islands UTM17- UTM18, CANA4 - Canada islands

UTM19 – UTM20, GREEN – Greenland, SVALB – Svalbard, RUSS1 – Russia UTM38 – UTM50, RUSS2 – Russia UTM51 – UTM02

<Layer type>

- LCU: layer type 1, corresponding to value of the landcover unit class.

<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 fv01.0 (released in May 2023).

Examples:
ESACCI-PERMAFROST-L4-CLS-SENTINEL1_2_KMLH-AREA17_LCU_ALASK-2016-2022-fv01.0.tif

2.7 Meta data

Meta data are provided as an auxiliary dataset. A shape file is provided which contains the extent of the granules and as attributes acquisition dates and a quality flag:

1) Good
2) Medium – acquisition outside from vegetation peak season or from unusually dry or wet period
3) Low – partially cloud affected and in cases similar issues as under (2)
4) No Sentinel-2
5) No Sentinel-1
6) No DEM data

2.8 Higher level products

An aggregated version of the landscape units is provided for a 1 km grid (as for CCI Landsurface Temperature). It includes:

- Center coordinate of grid point
- Fraction of each landcover unit within each grid cell (one file per unit [1, … , 23])
- Landcover unit with fraction majority

File name for majority layer:

ESACCI-PERMAFROST-L4-CLS-SENTINEL1_2_KMLH-AREA17_LCU_MAJORITY-2016-2022-fv01.1.csv

2.9 Product access

Bartsch, A., Efimova, A., Widhalm, B., Muri, X., von Baeckmann, C., Bergstedt, H., Ermokhina, K., Hugelius, G., Heim, B., & Leibmann, M. (2023). Circumpolar Landcover Units (1.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8399018

3 Thematic content

3.1 Terminology

This product addresses tundra specific landcover units, which reflect specific soil conditions and vegetation communities.

Units are assigned abundance of vegetation types including shrub growth form/height as well as moisture conditions. The following shrub types are considered (following the differentiation of the CAVM, Reynolds et al. 2019 and Walker et al. 2018):

- Prostrate dwarf shrub – approximately 5 cm, also referred to as prostrate shrub
- Erect dwarf shrub – up to 40 cm, also referred to as dwarf shrub
- Low shrub – up to 2m
- Tall shrubs – tundra biome species taller than 2m

Vegetation coverage is derived from AVA (Arctic Vegetation Archive) data for Western Siberia (Zemlianskii et al. 2023).

Figure 2: Dwarf shrubs (erect, up to 40 cm), dwarf birch (Betula Nana). Photo A. Bartsch (Northern Ural foothills, 2018)

Figure 3: Low shrubs, dwarf birch (Betula Nana). Photo A. Bartsch (Northern Ural foothills, 2018)

Figure 4: Low shrubs (stick height is 140 cm) in an incised creek channel, willow (Salix ssp). Photo A. Bartsch (Northern Ural foothills, 2018)

3.2 Abstract of data publication

Landcover units have been derived from Copernicus Sentinel-1 und Sentinel-2 data acquired between 2016 and 2022 for the Arctic tundra biome. 23 units of which 20 represent different vegetation characteristics and soil conditions are provided. The units have been identified with K-means over a representative transect and in a second step retrieved across the entire Arctic north of the treeline. The description of the units is based on several thousand samples from vegetation surveys and soil probes.

The units are supplied at 10m resolution in nine irregular tiles. Auxiliary data for quality information and input acquisition dates are supplied in a separate shape file.

3.3 Pixel attributes

Table 1: Landcover unit properties (vegetation characteristics based on https://avarus.space/) and soil characteristics (source: Palmtag et al. 2022; nd – no data; (..)- low number of samples; AVA – Arctic vegetation archive), source [RD-5]

ID	Derived description	Group	Soil wetness (AVA)	Organic layer thickness	SOC density	Mineral content
1	Water	Water	-	-	-	-
2	shallow water/abundant macrophytes	Wetland	nd	high	nd	nd
3	wetland, permanent	Wetland	aquatic	low to medium	medium	medium
4	wet to aquatic tundra, abundant moss	Wetland	wet to aquatic	low to medium	(medium)	(low)
5	moist tundra, abundant moss, prostrate shrubs	Tundra	moist to wet	low to medium	(medium)	(medium)
6	dry to moist tundra, partially barren, prostrate shrubs	Tundra	dry to moist	medium	medium	high
7	dry tundra, abundant lichen, prostrate shrubs	Tundra	dry	low to medium	(medium)	(high)
8	dry to aquatic tundra, dwarf shrubs (& sparse tree cover along treeline)	Shrub tundra	dry to aquatic	medium	medium	medium
9	dry to moist tundra, prostrate to low shrubs	Shrub tundra with tussocks	dry to moist	low to medium	medium	medium
10	moist tundra, abundant moss, prostrate to low shrubs	Shrub tundra with tussocks	moist	low	high	medium
11	moist tundra, abundant moss, dwarf and low shrubs	Shrub tundra with tussocks	moist	low	high	medium
12	moist tundra, dense dwarf and low shrubs (& sparse tree cover along treeline)	Shrub tundra	moist	medium	(medium)	(low)
13	moist to wet tundra, dense dwarf and low shrubs (& sparse tree cover along treeline)	Shrub tundra	moist to wet	(low)	nd	nd
14	moist tundra, abundant moss, low shrubs	Shrub tundra	moist	medium	medium	medium

15	moist to wet tundra, partially barren	Shrub tundra	moist to wet	high	(low)	(high)
16	moist tundra, abundant forbs, dwarf to tall shrubs	Shrub tundra	moist	medium	(medium)	(high)
17	recently burned or flooded, partially barren	Shrub tundra/ disturbed	nd	low to medium	nd	nd
18	forest (deciduous) with dwarf to tall shrubs	Forest	nd	nd	nd	nd
19	forest (mixed) with dwarf to tall shrubs	Forest	nd	nd	nd	nd
20	forest (needle leave) with dwarf and low shrubs	Forest	nd	nd	nd	nd
21	Partially barren	Barren	dry	(low)	(low)	(very high)
22	Snow/ice	Snow/ice	-	-	-	-
23	Other (incl. shadow)	Shadow/Other	-	-	-	-

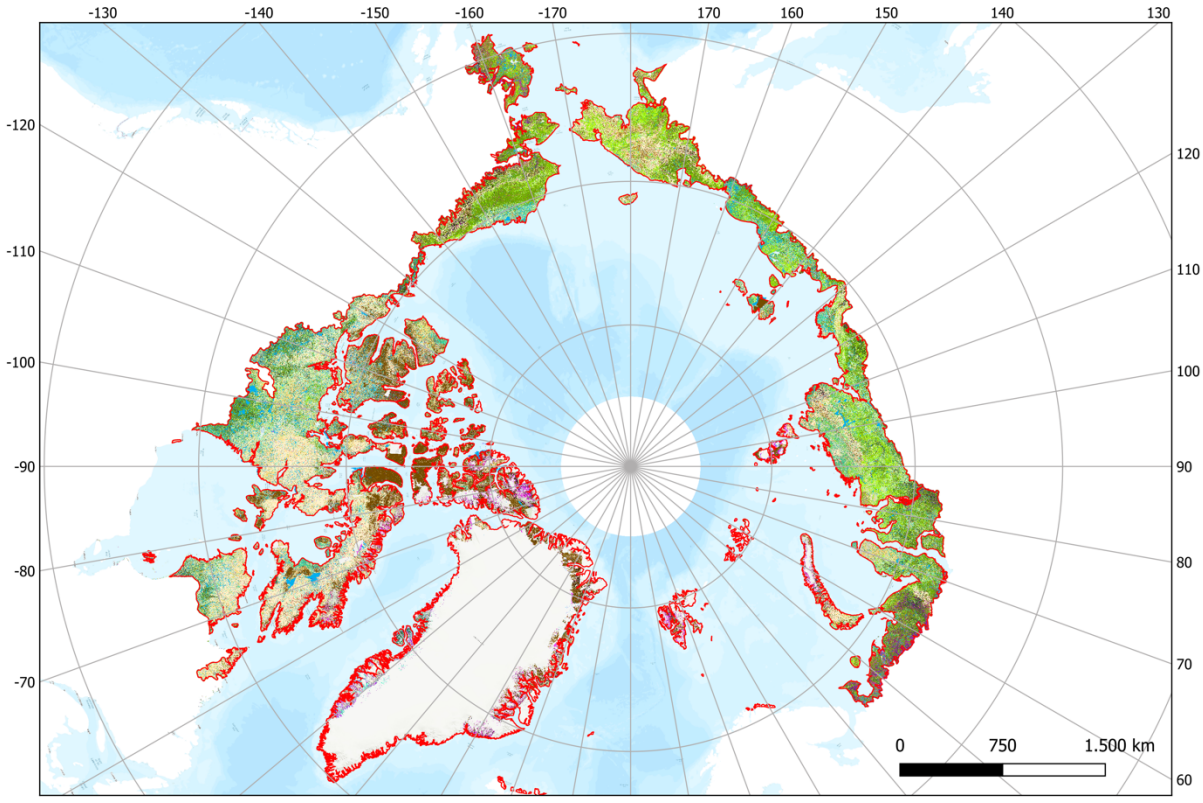

Figure 5: CALU within CAVM extent (red outline; source: Raynolds et al. 2019). For legend see Table 1.

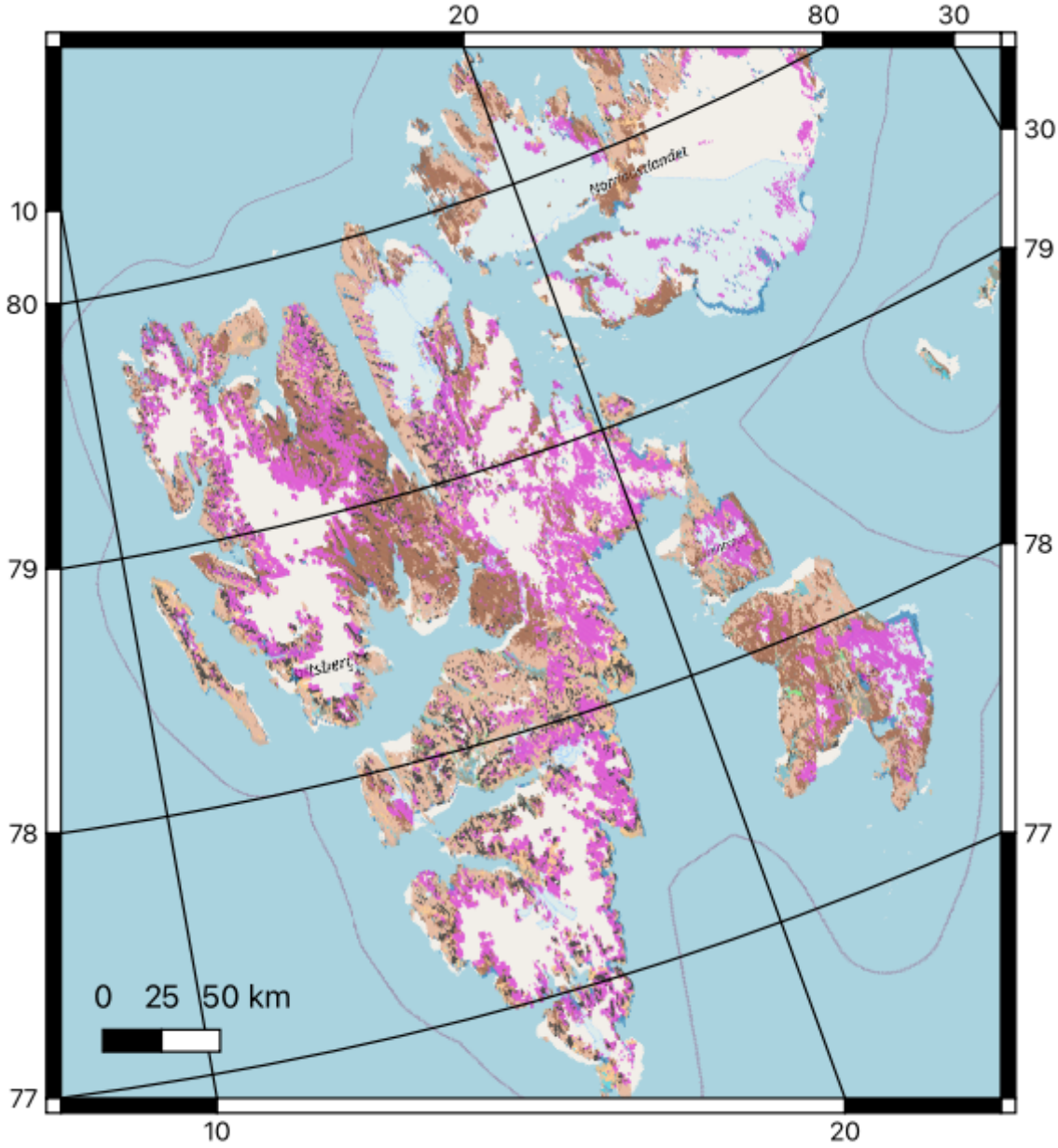

Figure 6: Example for L4 for Svalbard – aggregated 1km gridded product. Landcover unit with majority (for legend see Table 1). Units 6 and 21 (partially barren types) are dominant in snow/ice free areas.

3.4 Compatibility with CCI Landcover

The translation scheme in Table 2 is suggested for combination with CCI Landcover. Tree line uncertainties need to be addressed. The assignment to forest should be run in a first step. A threshold of 15 % of a CALU forest unit may be used to assign an area to forest. In some regions also values down to 1% could be applicable. An issue are also dense low shrubs in the proximity of the treeline (unit #12). They are classified as forest in CCI Landcover and should be therefore translated to Mosaic with trees and shrubs (or alternatively to forest) depending on abundance.

Table 2: Suggested translation scheme of CALU classes to Landcover_cci using abundance statistics at target pixel extent

CALU ID	**CCI Landcover ID**	**CCI Landcover name**	**Translation using fraction within 300 m x 300 m areas**
1	210	Water	majority
2	180	Shrub or herbacious cover, flooded	majority
3	180	Shrub or herbacious cover, flooded	majority
4	180	Shrub or herbacious cover, flooded	majority
5	130	Grassland	majority
6	130	Grassland	majority
7	140	Lichen and mosses	majority
8	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	majority
9	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	majority
10	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	majority
11	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	majority
12	100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	majority, then 100 (or 60) if > 50%, 110 if < 50%
13	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	majority
14	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	majority
15	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	majority
16	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	majority, then 100 if > 50%, 110 if < 50%
17	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	Majority
18	60	Tree cover, broadleaved, deciduous, closed to open	60 if > 15% (or 1%)
19	80	Tree cover, mixed leave type	90 if > 15% (or 1%)
20	70/80	Tree cover, needle leaved	80 if > 15% (or 1%)
21	150	sparse vegetation	majority
22	220	permanent snow and ice	majority
23	0	no data	majority

Figure 7: Example for CALU Class 12 'dry to moist tundra, dense dwarf and low shrubs' (foreground). Dense extensive areas of especially Betula nana are common in the proximity of the treeline and classified as forest in CCI Landcover. (Photograph A. Bartsch, 2018, Northern Ural foothills).

4 Known limitations

Cloudiness is a common issue across the Arctic and the vegetation peak season is comparably short. This is leading to low data quality in cases where no cloud free acquisition was made by Sentinel-2 since launch until Summer 2022. These granules are flagged in an auxiliary dataset (shape file of granule extent with quality flag in attributes; flag values 2 and 3). Data was missing in several cases for either Sentinel-1, Sentinel-2 or issues occurred with the use of the Copernicus elevation model for shadow masking (see Figure 8).

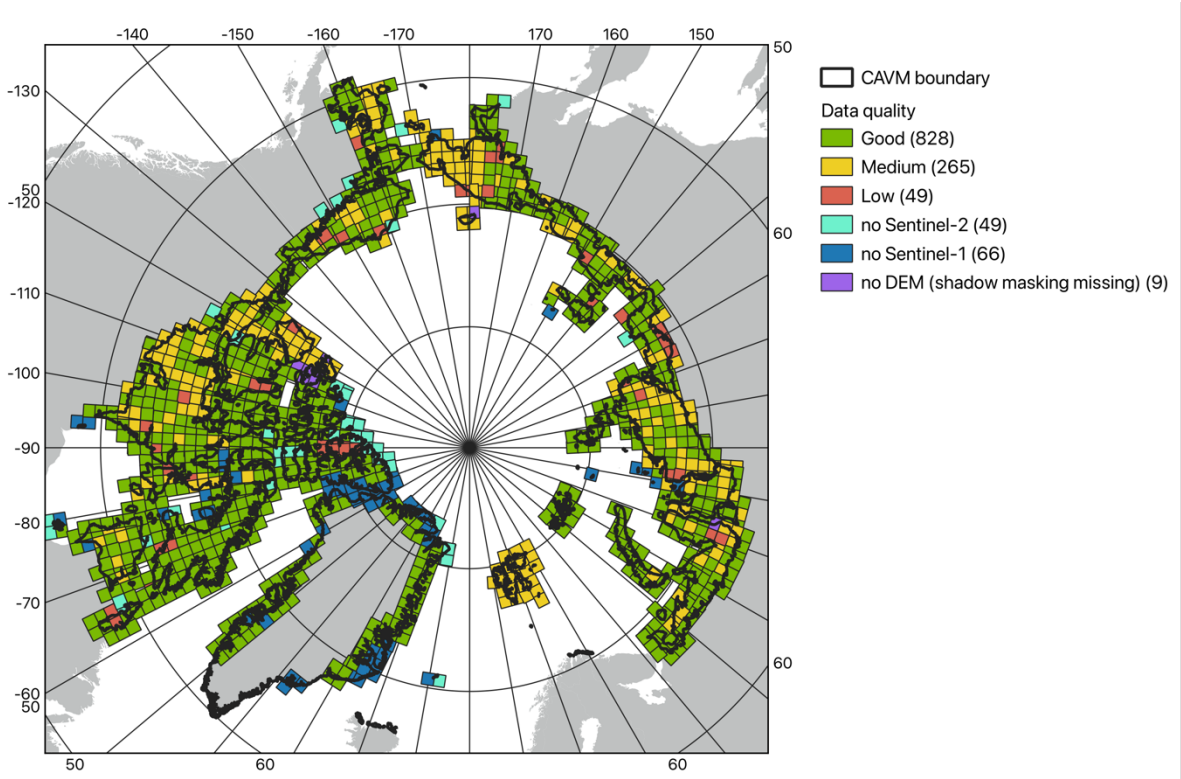

Figure 8: Extent of granules overlapping with the CAVM and data quality. Source: [RD-5]

The lack of data from the peak vegetation season or unusually dry or wet conditions can lead to shifts in class assignments especially among the wetland and shrub tundra classes (example in Figure 9).

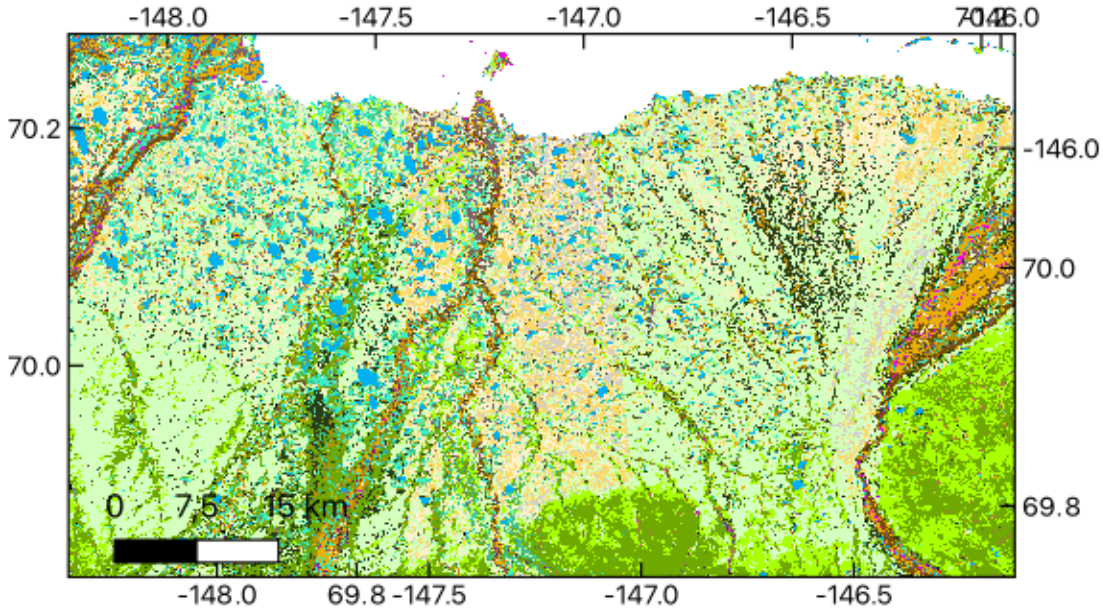

Figure 9:Example for area with low quality due to lack of input data from the vegetation peak season on the Alaskan North Slope. The center area (low quality region) is largely classified as 'dry to moist tundra, partially barren, prostrate shrubs', the surrounding is dominated by 'dry to moist tundra, prostrate to low shrubs'.

Water can be classified as 'no data' in proximity to coasts as a masking for the coastline was applied as part of the Sentinel-1 pre-processing as well as postprocessing based on the Copernicus DEM. In some cases, water is also included in the snow/ice class. Snow/ice miss-assignment occurs specifically for larger river courses.

High latitude mountainous regions such as Svalbard or the Books Range in Alaska can have misclassifications due to shadows. The class 'other' has been assigned where steep slopes can be identified from digital elevation models (Copernicus DEM), but DEM quality is not sufficient in some cases.

CAL units are developed for the tundra biome. Nevertheless, three forest classes have been included for the purpose of separation of non-tundra in transitions zones. No specific assignment to forest species and types should be made although a separation for deciduous, mixed and needle leave is suggested. Patches with trees with limited growth (height and/or crown diameter) along the treeline are not captured as forest since the spatial resolution is not sufficient in this case.

5 References

5.1 Bibliography

Bartsch, Annett; Widhalm, Barbara; Pointner, Georg; Ermokhina, Ksenia; Leibman, Marina; Heim, Birgit (2019): Landcover derived from Sentinel-1 and Sentinel-2 satellite data (2015-2018) for subarctic and arctic environments. Zentralanstalt für Meteorologie und Geodynamik, Wien, PANGAEA, https://doi.org/10.1594/PANGAEA.897916

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Palmtag, J., Obu, J., Kuhry, P., Richter, A., Siewert, M. B., Weiss, N., Westermann, S., and Hugelius, G.: A high spatial resolution soil carbon and nitrogen dataset for the northern permafrost region based on circumpolar land cover upscaling, Earth Syst. Sci. Data, 14, 4095–4110, https://doi.org/10.5194/essd-14-4095-2022, 2022.

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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
CALU	Circumarctic Landcover Units
CAVM	Circumarctic Vegetation Map
CCI	Climate Change Initiative
CRG	Climate Research Group
CRDP	Climate Research Data Package
CRS	Coordinate Reference System
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
GTN-P	Global Terrestrial Network for Permafrost
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
NetCDF	Network Common Data Format
PSD	Product Specifications Document
RD	Reference Document
RMSE	Root Mean Square Error
RS	Remote Sensing
SU	Department of Physical Geography Stockholm University
URD	Users Requirement Document
WGS 84	World Geodetic System 1984