CCI+ PHASE 1 – NEW ECVS
PERMAFROST

D5.1 CLIMATE ASSESSMENT REPORT (CAR)

VERSION 2.1

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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 modelling 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).
There is currently no consistent global Earth Observation-based mapping of the parameters permafrost temperature and active layer thickness as required by GCOS based on Earth Observation records. Permafrost_cci will for the first time provide such information for different epochs and meet the requirements for the production of a climate data record.
The Climate Assessment Report (CAR) summarizes current activities within Permafrost_cci with regard to user requirements defined by the climate modelling user community. User feedback by the IPA and four specific science use cases are presented in this document. V2 includes updates of the use cases and dissemination activities.

In case (1) HIRHAM-CLM is evaluated using the Permafrost_cci products. HIRHAM-CLM results fit the permafrost extent from Permafrost_cci well, with slight overestimation of permafrost extent in southern Alaska and slight underestimation of permafrost extent in the south of western Siberia. A challenge for the model is the PFT setup based on remotely sensed datasets as they do not represent the spatial distribution of tundra PFTs.

The Science use case (2) focuses on the cross-analysis of the existing ESA GlobPermafrost Hot Spot Regions of Permafrost Change (HRPC) product with output from the Permafrost_cci transient permafrost model. The analyses reveal distinct clusters of lake area loss intensity and mean annual ground-temperature MAGT distributions.

Use case (3) comprises applications in collaboration with the HORIZON2020 project Nunataryuk. Permafrost_cci CRDPv0 already provided added value for the discussion of coastal erosion rate observations. High coastal erosion rates in recent years have been confirmed in a Nunataryuk study for several sites across the Arctic. CRDPv0 ground temperatures at 2 m depth have been also increasing at all these sites between 2003-2017.

In order to document known issues in more detail, problems identified in the product validation task have been further analyzed by the Permafrost_cci climate research group. The assessment with borehole data revealed that CRDPv1 contains a model error related to the area extent of the Siberian Yedoma region. Improved parameterization of the Yedoma stratigraphies is suggested.

1 INTRODUCTION

1.1 Purpose of the document

This document provides the assessment of the ECV products of the Permafrost_cci project with respect to climate science applications. The ultimate objective of Permafrost_cci is to develop and deliver permafrost maps as ECV products, primarily derived from satellite-based measurements.

1.2 Structure of the document

The first part of this document provides information on related documents and general permafrost related information. The second part includes information on the products under development.

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, Strozzi, T., Wiesmann, A., Kroisleitner, C., 2019: ESA CCI+ Permafrost Product Specifications Document, v1.0

[RD-3] Bartsch, A., Obu, J., Westermann, S., Strozzi, T., 2019: ESA CCI+ Product User Guide (PUG), v1.1

[RD-4] Bartsch, A., Matthes, H., Westermann, S., Heim, B., Pellet, C., Onaca, A., Kroisleitner, C., Strozzi, T., 2019, User Requirements Document (URD), v1.1

[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+ PVIR, v2.0

1.5 Bibliography

A complete bibliographic list that supports arguments or statements made within the current document is provided in Section 6.1.

1.6 Acronyms

A list of acronyms is provided in section 6.2.

1.7 Glossary

The list below provides a selection of terms relevant for the parameters addressed in Permafrost_cci [RD-1]. A comprehensive glossary is available as part of the Product Specifications Document [RD-2].

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 con-tent, 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

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.

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.

Permafrost	English usage	Russian Usage
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.

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 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. [RD-1]

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 pipe-lines, 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.

2 PRODUCTS GENERATED BY PERMAFROST_CCI

Permafrost_cci is establishing Earth Observation (EO) based products for the permafrost ECV spanning the period from 1997 to 2018. Since ground temperature and seasonal thaw depth cannot be directly observed with space-borne sensors, a variety of satellite and reanalysis data are combined in a ground thermal model to infer these subsurface parameters. 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-3 (CryoGrid-2 in Obu et al., 2019), which yields thaw depth and ground temperature at various depths, while ground temperature then forms the basis for deriving permafrost fraction for a specified location and time.

The beta version (CRDPv0) which has been evaluated in the first version of the CAR covered the year 2003-2017. The version 1 of the Climate Research Data Package [RD-3] consists of time series covering the years from 1997 and 2018 for

1. mean annual ground temperature,
2. active layer thickness (maximum annual active layer depth), and
3. permafrost fraction derived from ground temperature.

3 ASSESSMENT OF PRODUCTS AND OTHER FEEDBACK

3.1 Introduction and Rationale

Warming of the Cryosphere is already exceeding the global average temperature increase and models project further strong warming for these regions (IPCC, 2019; IPCC, 2013). Permafrost is an important component of the Cryosphere and defined as ground that remains frozen for at least two consecutive years (Van Everdingen, 1998). Ongoing permafrost warming (Romanovsky et al., 2010; Biskaborn et al., 2019) and near-surface thawing in permafrost regions, associated with rising air temperatures, are considered to reinforce warming of the atmosphere through the partial conversion of the large permafrost soil organic carbon pool into greenhouse gases, a process termed "permafrost carbon feedback" (Schuur et al., 2015). A further challenge for monitoring the impacts of permafrost thaw dynamics is represented by rapid thaw processes that may mobilize a significant amount of carbon over short time spans of years to decades (Turetsky et al., 2019). Worldwide monitoring of permafrost is therefore essential to understand and assess the feedbacks between climate change and permafrost thaw and their impact on the Earth's climate system.

The recently published thorough analysis of global permafrost temperatures by the Global Terrestrial Network for Permafrost (GTN-P) and the International Permafrost Association (IPA) demonstrated that permafrost is warming at a global scale (Biskaborn et al., 2019). This study showed that during the reference decade (2007 to 2016) ground temperature near the depth of zero annual amplitude in the continuous permafrost zone increased by 0.39 ± 0.15 °C. Over the same period, discontinuous permafrost warmed by 0.20 ± 0.10 °C. Permafrost in mountains warmed by 0.19 ± 0.05 °C and in Antarctica by 0.37 ± 0.10 °C. Globally, permafrost temperature increased by 0.29 ± 0.12 °C.

However, despite the great efforts by the GTN-P/IPA in managing qualified long-term permafrost observations at a global scale, the observation points are very scarce and clustered. For example, Biskaborn et al. (2015) pointed out that GTN-P permafrost boreholes and active layer measurement sites are clustered along transportation corridors in areas with developed infrastructure. They further demonstrated that the distribution of GTN-P sites is concentrated within zones where projected temperature rise is smaller while a much lower number of sites are located within Arctic areas where climate models project very large temperature increases.

There is currently no globally consistent and spatially continuous mapping of the ECV parameters permafrost temperature and active layer thickness. IPA has therefore recently established a permafrost mapping group (action group 'Overseeing the production of the next generation of IPA global permafrost mapping product and service'), which seeks to assess different permafrost mapping initiatives for the compilation of a new global database for permafrost properties. Permafrost_cci contributes to this IPA activity by providing satellite-driven permafrost datasets. The Permafrost_cci products are further expected to aid understanding of permafrost dynamics by satellite-observed land surface changes across large regions, in particular disturbances along latitudinal gradients as well as degradation associated with permafrost coastal processes.

The following sections provide a first assessment of the CRDPv0 by the climate research group with respect to the so far identified applications.

3.2 Year-1 and 2 feedback by Isabelle Gärtner-Roer[1]

[1]University of Zurich/Vice president of the International Permafrost Association

As detailed above, permafrost is warming significantly and a large number of geomorphological and ecological processes are strongly influenced by this warming. While the general trend seems to be clear, long-term observations on permafrost are limited and regionally clustered (e.g. European Alps, Alaska), as described for the GTN-P repository (Biskaborn et al. 2015). Therefore, there is urgent need for a consistent global information on the status of permafrost (permafrost extent and ground temperatures), as well as its changes and future prospections, as there is a wide range of applications and users. The increasing amount and detail of available earth observation data on the global scale, allow for the derivation of such products. Therefore, the ESA project Permafrost_cci comes just in the right moment. In the first project phase, simulations are delivered for the ECV's "ground temperature" and "active layer thickness", as well as for the permafrost extent, as derived from satellite measurements. These products so far cover the Northern Hemisphere and the period 2003-2017, they provide information with a grid spacing of 0.927 km and an annual resolution. The mean annual temperatures of the ground are provided for several depths, down to -10 m. All attributes and known issues are described separately for each parameter, which allows for detailed understanding of the single products.

On a first glance, the delivered maps provide a very nice overview of the permafrost characteristics in the different mountain ranges and the vast regions of lowland permafrost on the Northern Hemisphere. The corresponding datasets allow for a first regional and latitudinal assessment of permafrost characteristics.

A very profound validation was performed by comparing the different simulation products with in-situ data from the GTN-P repository and from PERMOS, as well as with products from the GlobPermafrost project, indicating large deviations. Since the in-situ data are clustered in certain regions with active permafrost monitoring programs/projects, some regions are underrepresented and validations are less detailed. An average temperature difference (all depths, all sites) is given with -1.7° C. Also the simulated active layer thicknesses show clear deviations (average of 76%) and the simulated permafrost extent is generally underestimated. Also with the second match-up analyses (as released in May 2020), the Mean Annual Ground Temperatures (MAGT) are generally overestimated (too warm) and the permafrost extent underestimated. Detailed local/regional assessments, comparing the simulated temperatures with measured temperatures on permafrost (e.g. from PERMOS), indicate that absolute values are very different, but temperature ranges are mostly reflected. Simulated temperatures in shallower depth are more robust, than those in greater depth. Certain effects, such as winters with late and/or thin snow covers which have a cooling effect, are not well represented in the simulation. This is related to difficulties in including snow effects in the global model. In any case the snow cover is the most nervous interface in the permafrost system, as it can have warming or cooling effects, depending on timing and amount of snow.

The simulation of ground temperatures derived from earth observation data is the most important product, as it builds the base for the other products, such as active layer thickness and permafrost extent. Therefore, the focus should be on improving the temperature product, e.g. by a better representation of the snow cover and the better integration of information on ground stratigraphy. If possible, the simulations of ground temperatures should also cover greater depths than -10 m, as the thickness of the permafrost body, as well as changes at the permafrost base, would be additional important information for process studies. Further, the expansion to a real global product (including the Southern Hemisphere) would be a next step. Of course, also for New Zealand and the Andes the permafrost observations are limited. But, for global climate assessments, there is the need to see the global picture, as well as latitudinal and regional patterns. In parallel, the IPA will continue to support the GTN-P repository and foster the systematic and standardized compilation of in-situ data on permafrost temperatures and active layer thicknesses, especially in underrepresented regions.

3.3 Year-2 feedback of the climate research group

Four user case studies are currently in process to cover a broad range of applications demonstrating the value and impact of Permafrost_cci products for different aspects of climate research.

3.4.1 Science Case Study 1

The Team Climate Model HIRHAM is a state-of-the-art atmospheric regional climate model (Christensen et al., 2007), which is used by the AWI Atmospheric section for the circum-Arctic domain. The original land-surface-soil scheme of the model has been replaced by the advanced land model CLM4 (Community Land Model version 4) (Matthes et al., 2017) to improve descriptions of vegetation and soil processes, and especially to improve representation permafrost-related processes.

Model results from this coupled system HIRHAM-CLM are sensitive to a number of boundary conditions. Representation of the cryosphere requires adequate soil stratigraphy information and a good description of the vegetation. Vegetation distribution also impacts feedbacks between land surface and atmosphere. Vegetation distribution in the model is described using plant functional types (PFTs), which can be interpreted as classes of plants with similar phenology. This study aims at quantifying the uncertainties in present day Arctic atmosphere and cryosphere representation associated with these boundary conditions.

In a first step, HIRHAM-CLM was run in a standard configuration for an 18-yr period from 2000 to 2017 with lateral boundary forcing from ERA-Interim over a pan-Arctic domain covering the area north of 60°N. In this setup, PFTs are derived from MODIS data, the stratigraphy information is based on the FAO soil map of the world. Both datasets are relatively coarse in resolution (MODIS ~0.05°, FAO

~0.08°). The resulting map of permafrost extent in panel a of Figure 1 shows that HIRHAM-CLM fits the permafrost extent from Permafrost_cci well, with slight overestimation of permafrost extent in southern Alaska and slight underestimation of permafrost extent in the south of western Siberia. Modelled ALT is shown in panel b of Figure 1, it follows soil parameter distribution (especially organic matter and sand fraction), while Permafrost_cci ALT (Figure 1c) mainly follows a north-south and orography distribution according to air temperature.

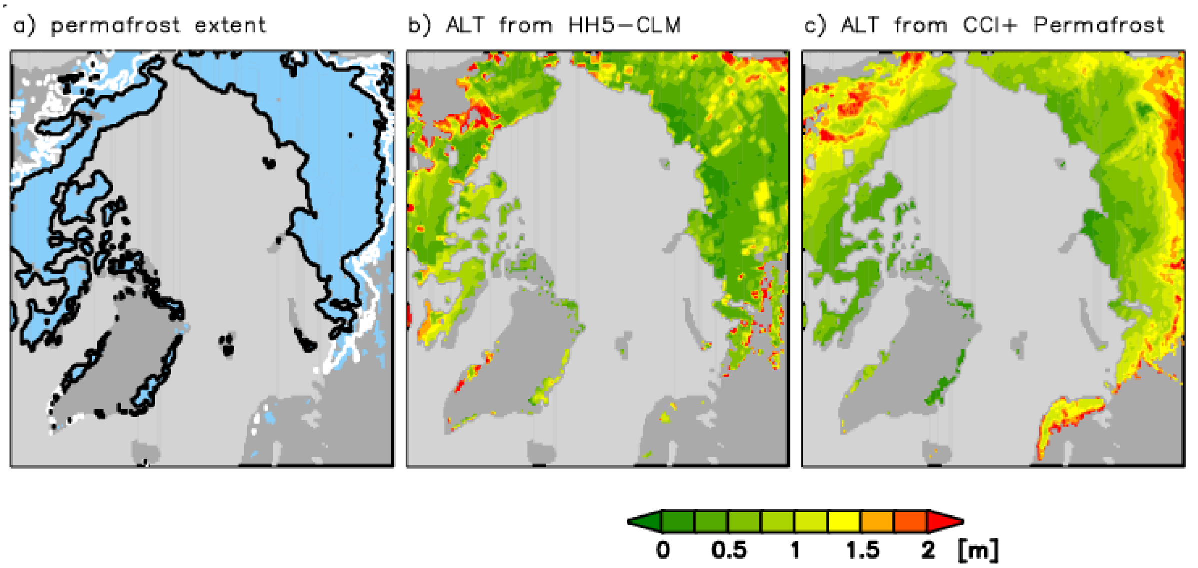


Figure 1: HIRHAM-CLM comparison *a) permafrost extent from HIRHAM-CLM (shading) and Permafrost_cci (contours). Black contours refer to the border of continuous permafrost, white contours refer to the borders of discontinuous permafrost. b) active layer thickness from HIRHAM-CLM. c) active layer thickness from Permafrost_cci.*

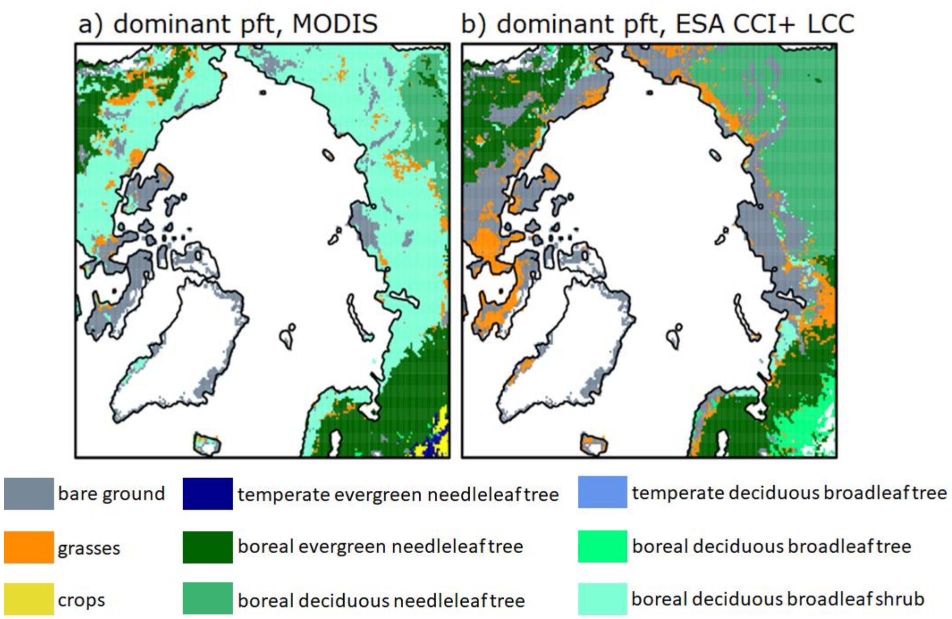


Figure 2: HIRHAM-CLM setup for PFTs a) dominant plant functional types in the original model setup. b) plant functional types derived from CCI Landcover Classes.

In order to apply the stratigraphy product created in Permafrost_cci, plant functional types for HIRHAM-CLM were then created from Landcover_cci in the next step of the study. CCI LC provides a tool that converts their Land Cover Classes into generic plant functional types and aggregates the 300m resolution to the required target grid. The tool was used with limited success. Since the HIRHAM-CLM is a regional model running on a rotated grid, it was not possible to produce a final PFT map with the CCI LC tool. The association of the generic PFTs from the tool to CLM's actual PFTs required the generation of a lookup table with CLM specific PFTs. CLM follows a tile approach in representing vegetation, which means that each grid cell can contain different PFTs. Figure 2 shows in panel (a) the dominant PFTs from the original model setup and in panel (b) the dominant PFTs derived from CCI LC. The most prominent difference between the two PFT distributions is the loss of almost all grid cells with dominant shrub PFTs, those are replaced with bare ground in the northern areas of the domain and boreal deciduous needleleaf trees in southern parts of the eastern Arctic.

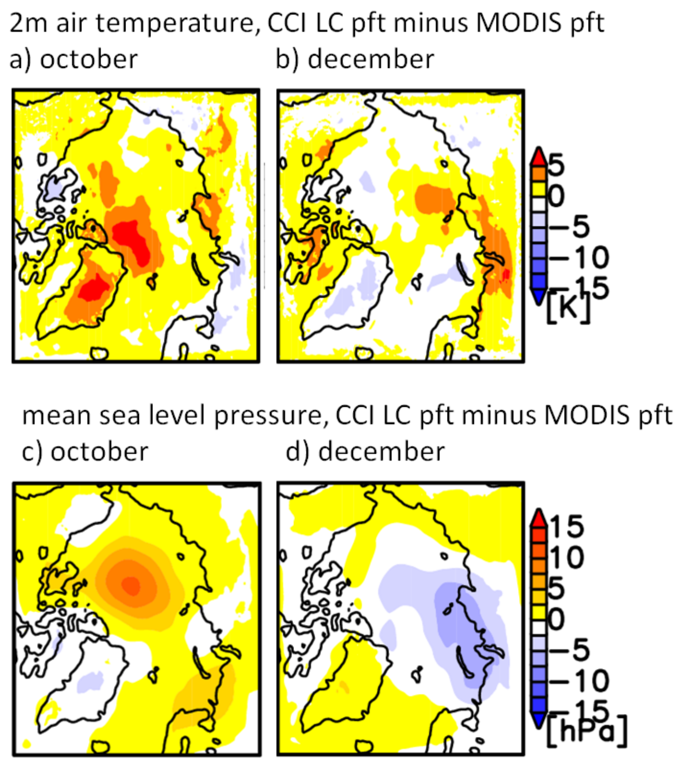


Figure 3: Difference in 2m air temperature between model runs with CCI LC PFTs and MODIS PFTs for a) October and b) December. Difference in mean sea level pressure between model runs with CCI LC PFTs and MODIS PFTs for c) October and d) December.

These shifts in vegetation result in prominent differences of surface parameters for the atmosphere component of HIRHAM-CLM, e.g. in roughness length and albedo, which leads to large scale differences in modelling atmosphere state variables like temperature and mean sea level pressure. First test runs with the CCI LC PFT distributions for one year illustrate those differences (Figure 3). In October (panel a), in some areas differences in albedo over land translate into differences in 2m air temperature in the range of at most +/- 5K. Shifts from shrub dominated to bare ground or grass dominated grid cells lead to higher albedos and subsequently lower temperatures south of Tamyr and

Yamal peninsulas. Similarly, in the Lena Basin, there is a shift from shrubs to trees, which decreases albedo and subsequently leads to higher temperatures. In other areas, like over the Arctic Ocean, differences in temperature are circulation driven. Mean sea level pressure differences for October (Figure 3c) are up to 15hPa, with a prominent positive difference over the Arctic ocean In December, when there is next to no sunlight, impacts on temperature (Figure 3b) are dominated by changes in circulation (Figure 3d). The negative difference in mean sea level pressure of up to 7hPa indicates an increase in cyclonic activity, which is associated with an inflow of warm and moist air into the Arctic in winter and matches the positive differences in 2m air temperature of up to 5K in the same region.

In the next steps of this study, we will extend the model run with CCI LC PFTs to the full ERA5 period from 1979-2019. We will then produce a further model run with the new stratigraphy data set developed within Permafrost_cci. Comparison of those model runs on climatological time scales will allow us insights into the impact of those boundary conditions on cryosphere and atmosphere representation. Evaluation of the model results with in situ data and CCI Permafrost products will additionally allow us to quantify the impact of the boundary conditions with regard to model performance.

3.4.2 Science Case Study 2

The Science use case 2 in Permafrost_cci focuses on the cross-analysis of the existing ESA GlobPermafrost Hot Spot Regions of Permafrost Change (HRPC) product with output from the Permafrost_cci transient permafrost model. The HRPC contains information on Landsat-based trends of landscape disturbances, which may trigger changes in the ground thermal regime or become enhanced by regional to local changes in ground thermal regime.

We hypothesize that climatic fluctuations directly impact permafrost properties and ground thermal regime as measured by active layer thickness (ALT) or permafrost/ground temperature. This in turn will likely impact the initiation and enhancement of permafrost region disturbances (PRD).

Based on this hypothesis we spatially compared the HRPC data products (Nitze et al., 2018 a,b) with the dynamic annual (1997-2018) ALT and PFR (permafrost probability) as well as static permafrost temperature Permafrost_cci data products for all four core transects of the HRPC data analysis in western Siberia (T1), eastern Siberia (T2), Alaska (T3), and eastern Canada (T4).

Lake drainage - ground temperature relationship

A first cross-analysis between current Permafrost_cci products and GlobPermafrost HRPC disturbance trends focused on the analysis of the spatial relationship between lake drainage and mean annual ground temperature. Lake changes were quantified using trends of multispectral indices of Landsat-time series data from 1999 through 2014 (Nitze et al., 2017, 2018). This includes net lake changes of each individual lake (<1ha) within the transects, as well as the gross increase and decrease (individual fractions of lake area gain and loss). Lakes in permafrost often exhibit a dynamic behaviour, where lakes often expand over time and ultimately drain once they reach a drainage gradient or permafrost destabilizes. Lake drainage can occur in different magnitudes, where lakes can drain completely or only partially.

Figure 4 shows the relation between net lake area loss of shrinking lakes (negative net lake change) from the HRPC lake change datasets (Nitze et al., 2018) for all 4 analyzed continental scale permafrost transects. It reveals distinct clusters of lake area loss intensity and mean annual ground-temperature

MAGT distributions. All sites show a bimodal distribution of lake area loss, but with different magnitude. The first cluster is typically located at 0-20 % lake area loss (net change), which is caused by subtle lake fluctuations, data uncertainty, partial lake drainage or a combination of these factors. Lakes with a lake area increase were kept from the analysis. This cluster is the most dominant in T4 (Eastern Canada), which is characterized by mostly stable lake areas across the transect region and thus the permafrost temperature gradient. The second cluster is typically close to 100%, which translates to complete lake drainage. This second cluster is more common in Transects T1-T3, which are more dominated by frozen ice-rich sediments rather than glacially-carved bedrock like T4. The relation of these drainage clusters to MAGT is diverse among the different transects. While T2 is characterized by cold MAGT of predominantly <-4 °C, complete lake drainage events clustered at around -6 °C. In T1 and T3, which have very strong lake dynamics (Nitze et al., 2018a), the complete drainage cluster is close to 0 °C, which may indicate the influence of landscape-scale permafrost degradation and widespread surface permafrost loss in the affected regions. However, regional conditions and differences should be considered and more detailed local to regional-scale analysis will reveal further links between ground temperature, other environmental factors, and the dynamics of permafrost region disturbances such as lake drainages.

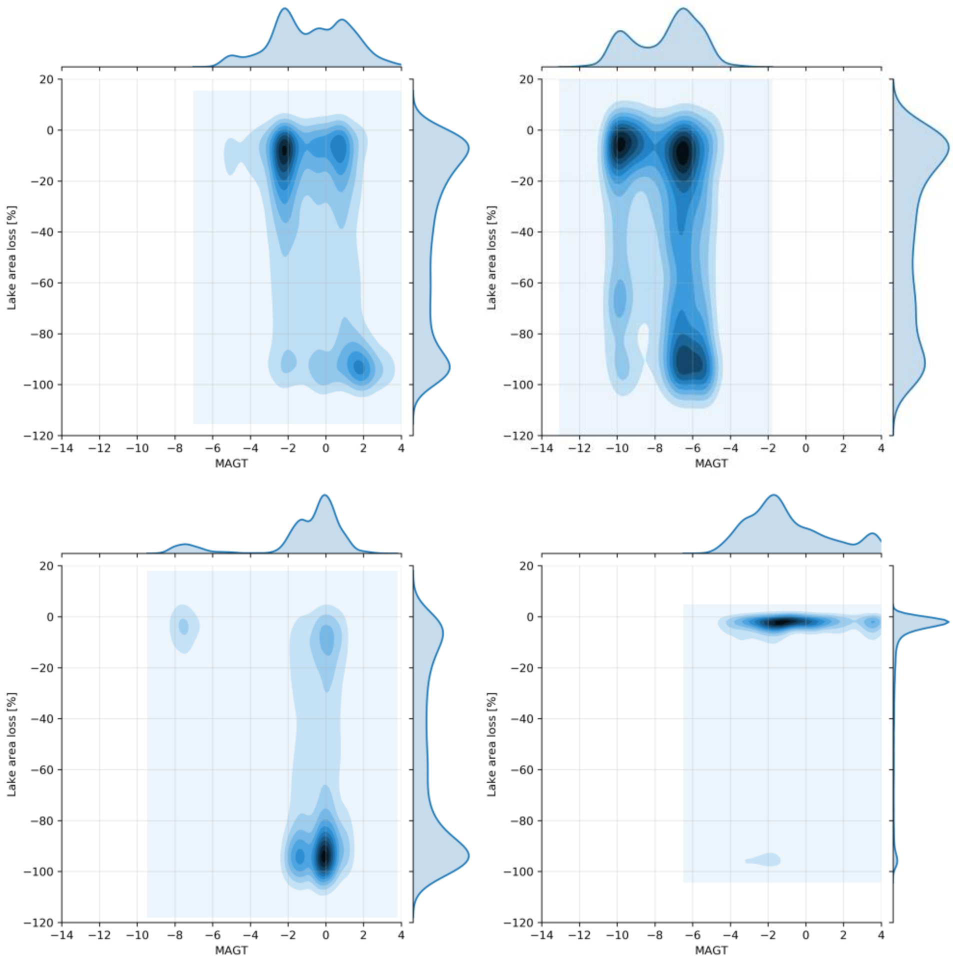


Figure 4: 2D density plots of lake area loss % (per lake) vs. MAGT. Darker colors represent a higher density and thus more lake drainage events. Upper left: T1 Western Siberia; upper right: T2 Eastern Siberia; lower left: T3 Alaska; lower right: T4 Eastern Canada.

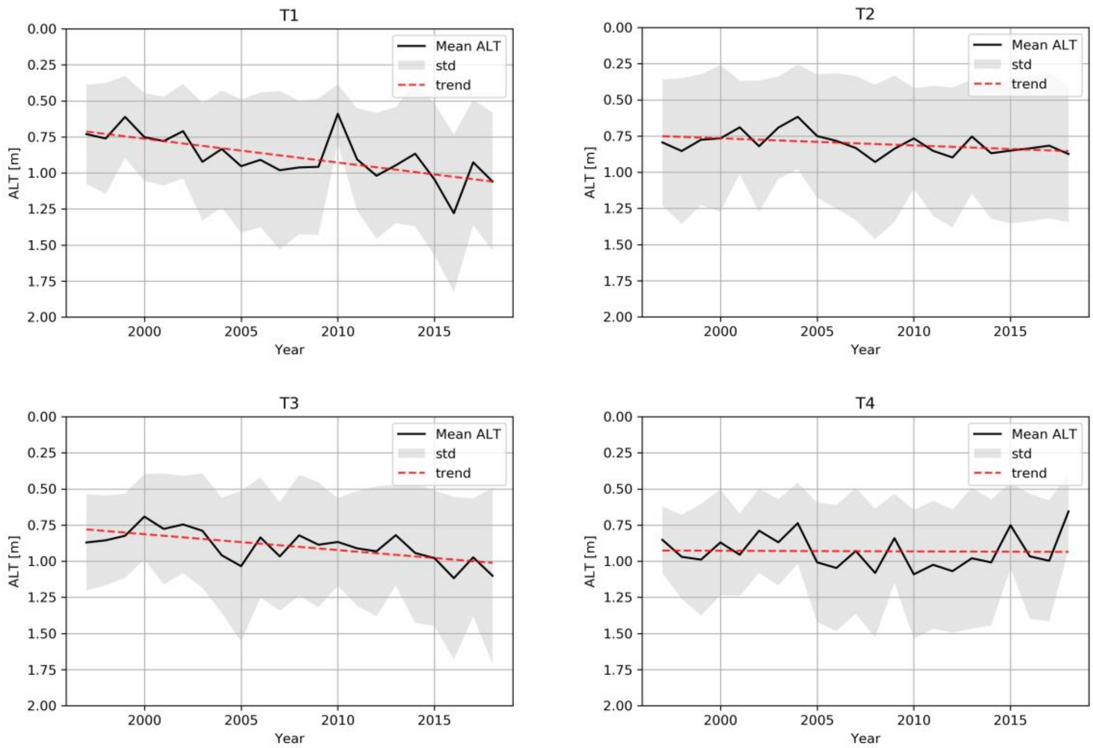


Fig 5. Comparison of Active Layer Thickness dynamics (in meter) in different HRPC Transects (T1: Western Siberia, T2: Eastern Siberia, T3: Alaska, T4: Eastern Canada) derived from annual ALT datasets (1997-2018).

Active layer thickness dynamics

The active layer trends show clear differences between the different transect regions (Figure 5). Transects T1 and T3 show the largest increase in mean ALT, which correlates with the observed lake drainage dynamics. Larger regions within both transects were particularly affected by lake drainage within the past two decades (Nitze et al., 2017, 2018, 2020). Transect T2 was much less affected by ALT deepening, while Transect T4 has a flat trend, although with strong annual fluctuation.

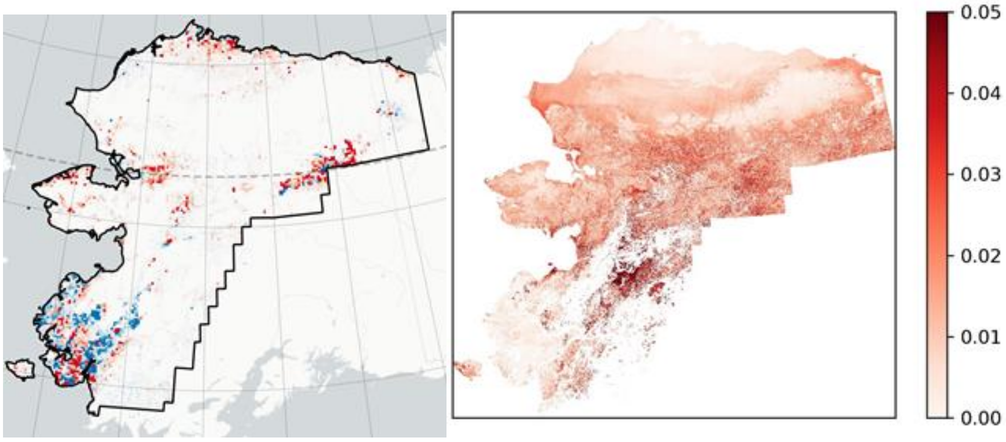


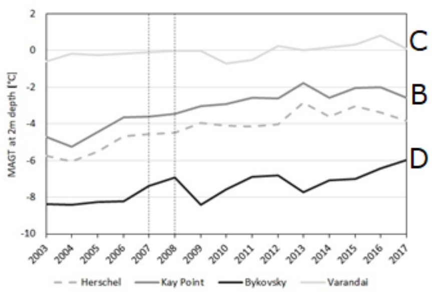
Figure 6: Spatial comparison of (left) Lake area change (1999-2014) from HRPC Datasets and (right) increase in Active Layer Thickness (ALT) trends in °C from annual CCI ALT dataset in T3 Alaska.

Over the coming months we will investigate the relationship between further permafrost region disturbances (PRD), such as wildfires and thaw slumps, and CCI data products. Additionally, we will analyze the clusters and in-depth relationships with a multi-scale approach, which will help to better understand the relationship between permafrost properties (ALT, ground temperature) and observed disturbances.

3.4.3 Science Case Study 3

The overall strategy of the HORIZON2020 Nunataryuk project (2017-2022) is to bring together high-ranking European and international specialists of the Arctic coast, including natural scientists and the key European socio-economic science groups, to address these pressing challenges. The project is user-driven, directly addressing the concerns of local and global stakeholders with regards to permafrost thaw in coastal areas of the Arctic. Permafrost thaw is the core focus of Nunataryuk and is also used as the common thread for consultations with community representatives and other stakeholders at the local and global level. Time series as developed by Permafrost_cci are therefore of high value to the project. They are utilized as part of scenario building workshops, stakeholder communication as well as to interpret natural science results of the project. The latter overlaps with case study 3. CRDPv0 (2002-2017 records) already provided valuable information (Bartsch et al. 2020). In order to assess SAR applicability for coastal erosion quantification, data acquired at three different wavelengths (X-, C-, L-band; TerraSAR-X, Sentinel-1, ALOS PALSAR 1/2) have been investigated. Four regions which feature high erosion rates have been selected. All three wavelengths have been investigated for Kay Point (Canadian Beaufort Sea Coast). C- and L-band have been studied at all sites, including also Herschel Island (Canadian Beaufort Sea Coast), Varandai (Barents Sea Coast, Russia), and Bykovsky Peninsula (Laptev Sea coast, Russia). Erosion rates have been derived for a one-year period (2017-2018) and in case of L-band also over 11 years (2007-2018). The Landsat trend product (see case study 2) has been in addition assessed for long-term trend retrieval. Derived retreat rates agree among the datasources /SAR and Landsat trends) and with rates available from other data sources. The derived rates suggest an increase of erosion at all four sites in recent years (Figure 7), but uncertainties are also high. However, CRDPv0 ground temperatures at 2 m depth have been also increasing at all these sites between 2003-2017.

	Rate from GlobPermafrost trend product 1999-2014	Rate from L-band SAR 2007-2018	Previously published rates
Varandai (c)	n.a.	-5.41 ± 2.64	-1.8 (1951-2013) [1]
Herschel (B)	-4.19 ± 2.8	-7.02 ± 2.65	-6.8 (2012-2013) [2]
Kay Point (B)	-3.94 ± 1.4	-5.90 ± 0.41	-1.7 (1990-2011) [3]
Bykosvky (D)	-5.83 ± 2.8	-4.81 ± 1.37	-1 - -2 (1951-2006) [4]



(1) Sinistyn et al. 2019, (2) Obu et al. 2016, (3) Irrgang et al. 2017, (4) Lantuit et al. 2011

Figure 7: Erosion rate retrieval summary from Bartsch et al. (2020). Most sites show increased recent rates (left) as well as increasing ground temperatures (right, source CRDPv0).

3.4.4 Science Case Study 4

- The independent validation of the Permafrost_cci results (presented in the PVIR, [RD-6]) is carried out with strong support of the user community; with in situ measurements characterised by community-wide management best practices with open data access and a collaborative user environment within an international framework: WMO and GCOS delegated the global monitoring of the ECV Permafrost to the Global Terrestrial Network for Permafrost (GTN-P) managed by the International Permafrost Association (IPA). Identified discrepancies are further analyzed as part of the Climate Assessment. Specifically impacts of stratigraphy parameterization have been investigated for CRDPv1.

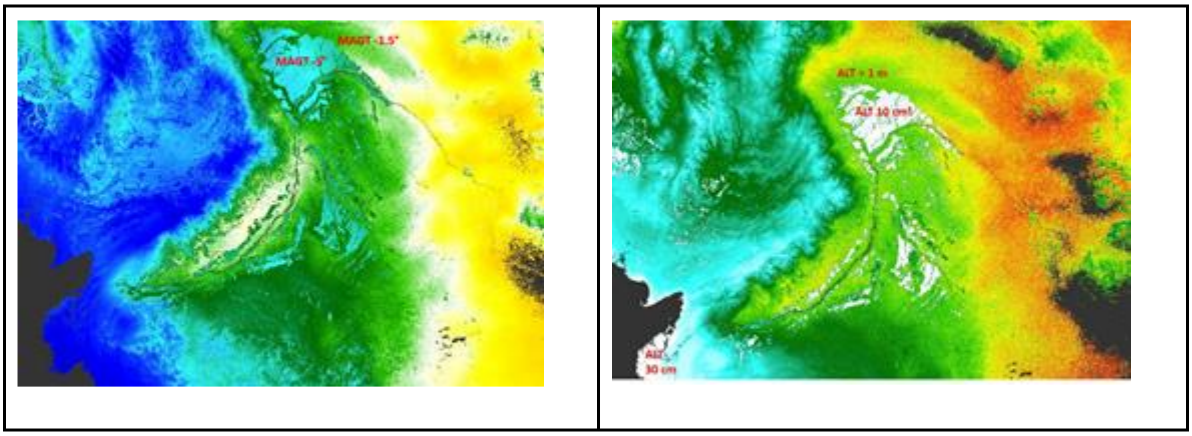


Figure 8: CRDPv1 (left) Permafrost_cci GTD 1 m depth (year 2017) and (right) Permafrost_cci ALT (year 2017), zoom on Central Yakutia (RU).

The assessment with borehole data revealed that CRDPv1 contains a model error related to the area extent of the Siberian Yedoma (Grosse et al., 2013) due to parameterization of the Yedoma stratigraphies in boreal regions (personal communication, S. Westermann, UiO). This is visible in a 4 °C colder MAGT (–5 °C MAGT instead of –1 to –1.5 °C MAGT in the surrounding boreal Yakutian region) in all years (1997 to 2018) and a magnitude lower ALT (0.10 m instead of 1 m to 1.5 m in the surrounding boreal Yakutian region) (Figure 8). The Yedoma formed as a fine-grained permafrost sequence during the late Pleistocene (e.g., Schirrmeister et al. 2011; Strauss et al., 2017) is also termed Ice Complex due to its high ground ice content. During intense Holocene warming phases a heterogeneous landscape developed with thaw basins (alases) on the Yedoma uplands and ALT developing much deeper than today in late summer, like this reducing the upper ground ice content in the first upper meters. For example, Windirsch et al. 2020 describe a long Permafrost core drilled in boreal Yedoma in central Yakutia. As a consequence of the cold bias in the warm temperature range, the binary match-up of "permafrost" versus "no permafrost" for Permafrost_cci PFR permafrost probability versus in situ MAGT ranges (match-up locations shown in Figure 9) shows that PFR permafrost probability in the grid cell is overestimated compared to in situ-derived "no permafrost" and MAGT ≤0.5 °C. Permafrost_cci PFR permafrost probability in the grid cell >0% occurs together with a wide range of "warm" in situ MAGT >0 °C. A large fraction of Permafrost_cci PFR permafrost probability grid cells > 60% occurs together with an in situ MAGT range from 0 to 5 °C occurring at regional scales that are already independent from pixel-scale heterogeneity.

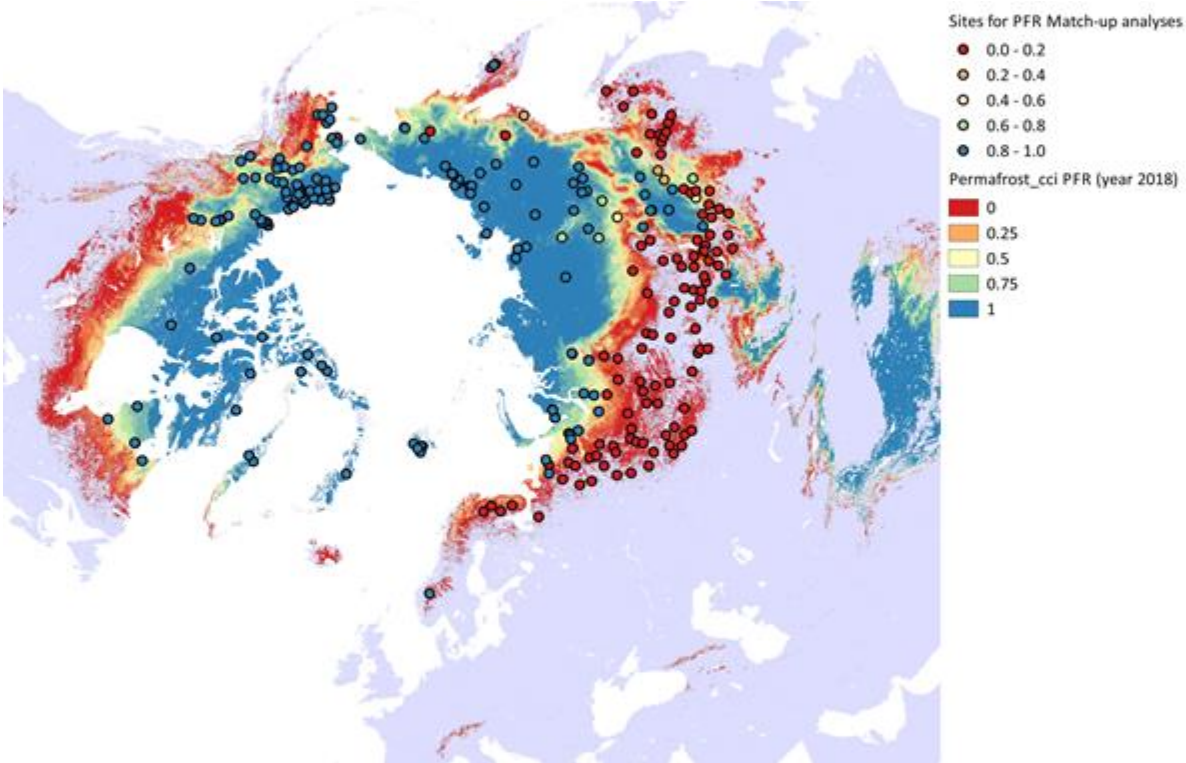


Figure 9: Sites for Permafrost_cci CRDPv1 PFR Match-up analyses. Colours of sites depict the fraction of years per site classified as Permafrost = yes (MAGT and ALT sites included). [RD-6]

4 PROGRESS IN REGARD TO USER REQUIREMENTS

4.1 Algorithm selection

The process of the algorithm selection as detailed in the User Requirements Document (URD) [RD-4] has been driven by the requirements of the climate research community. The user community deemed the selected algorithm as appropriate for their applications.

4.2 Product specification

In Table 1, we specify user requirements from the URD [RD-4] and added for each year a column to mark the respective status of achievement. We aimed to complete as many requirements as possible, which are marked in green.

Table 1: Summary of user requirements. 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). The last column indicates the achievement status for the second project year (Y2=year 2; red: not started, yellow: ongoing, green: completed).

ID	Parameter	Requirements	Source	Type	Y2
URQ_01	PE/GT/ALT	higher spatial resolution than a map scale of 1:10,000,000	IPA Mapping group report	BG	green
URQ_02	PE/GT/ALT	data need to be related to a time stamp	IPA Mapping group report	P	green
URQ_03	PE/GT/ALT	form of delivery for maps and data need to be flexible	IPA Mapping group report	D	green
URQ_04	PE/GT/ALT	high data quality	IPA Mapping group report	BG	yellow
URQ_05	PE/GT/ALT	benchmark dataset needs to be developed	IPA Mapping group report, GlobPermafrost/IPA mapping group workshop	P	yellow
URQ_06	PE/GT/ALT	evaluation through community	GlobPermafrost/IPA mapping group workshop	P	yellow
URQ_07	PE/GT/ALT	terminology for modelling output 'potential'	GlobPermafrost/IPA mapping group workshop	D	green
URQ_08	GT/ALT	depth of active layer, permafrost temperature in K and seasonal soil freeze/thaw needs to be addressed	GCOS	BG	green

URQ_09	PE	Threshold: uncertainty 10-25%, hor. res. 10-100 km, temp. res. 3-5 days, timeliness 5-6 days;	OSCAR	BG	
		breakthrough uncertainty 7-8.5%, hor. res. 0.85 - 1 km, temp. res. 14-36 hours, timeliness 14-36 h			
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,	Permafrost_cci survey	BG	
		Target, global, monthly, 1979-present, 1km, subgrid variability, RMSE < 0.5°C			
URQ_13	ALT	Threshold: pan-arctic, yearly, last decade, 10km, RMSE<25cm,	Permafrost_cci survey	BG	
		Target, global, monthly, 1979-present, 1km, subgrid variability, RMSE<10cm			

5 PUBLICATIONS

5.1 Publications list

Published

Bartsch, A., Ley, S., Nitze, I., Pointner, G., & Vieira, G. (2020). Feasibility study for the application of Synthetic Aperture Radar for coastal erosion rate quantification across the Arctic. *Frontiers in Environmental Science*, 8(143).

Bergstedt, H., Bartsch, A., Neureiter, A., Höfler, A., Widhalm, B., Pepin, N., and Hjort, J. "Deriving a Frozen Area Fraction From Metop ASCAT Backscatter Based on Sentinel-1," in IEEE Transactions on Geoscience and Remote Sensing. https://doi.org/10.1109/TGRS.2020.2967364

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Bergstedt, H., Bartsch, A., Duguay, C., Jones, B. (accepted): Influence of surface water on coarse resolution C-band backscatter: Implications for freeze/thaw retrieval from scatterometer data. Remote Sensing of Environment.

Biskaborn, B. K.; Smith, S. L.; Noetzli, J.; Matthes, H.; Vieira, G.; Streletskiy, D. A.; Schoeneich, P.; Romanovsky, V. E.; Lewkowicz, A. G.; Abramov, A.; Allard, M.; Boike, J.; Cable, W. L.; Christiansen, H. H.; Delaloye, R.; Diekmann, B.; Drozdov, D.; Etzelmüller, B.; Grosse, G.; Guglielmin, M.; Ingeman-Nielsen, T.; Isaksen, K.; Ishikawa, M.; Johansson, M.; Johannsson, H.; Joo, A.; Kaverin, D.; Kholodov, A.; Konstantinov, P.; Kröger, T.; Lambiel, C.; Lanckman, J.-P.; Luo, D.; Malkova, G.; Meiklejohn, I.; Moskalenko, N.; Oliva, M.; Phillips, M.; Ramos, M.; Sannel, A. B. K.; Sergeev, D.; Seybold, C.; Skryabin, P.; Vasiliev, A.; Wu, Q.; Yoshikawa, K.; Zheleznyak, M., Lantuit, H. (2019): Permafrost is warming at a global scale. Nature Communications, 10, 264. https://doi.org/10.1038/s41467-018-08240-4

Biskaborn, B. K., Lanckman, J.-P., Lantuit, H., Elger, K., Streletskiy, D. A., Cable, W. L., and Romanovsky, V. E. (2015): The new database of the Global Terrestrial Network for Permafrost (GTN-P), Earth Syst. Sci. Data, 7, 245–259.

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T. Popp, M.I. Hegglin, R. Hollmann, F. Ardhuin, A. Bartsch, A. Bastos, V. Bennett, J. Boutin, C. Brockmann, M. Buchwitz, E. Chuvieco, P. Ciais, W. Dorigo, D. Ghent, R. Jones, T. Lavergne, C.J. Merchant, B. Meyssignac, F. Paul, S. Quegan, S. Sathyendranath, T. Scanlon, M. Schröder, S.G.H. Simis, U. Willén (2020): Consistency of satellite climate data records for Earth system monitoring. Bulletin of the American Meteorological Society. https://journals.ametsoc.org/bams/article/doi/10.1175/BAMS-D-19-0127.1/348541/Consistency-of-satellite-climate-data-records-for.

Runge, A. and Grosse, G. (2020): Mosaicking Landsat and Sentinel-2 Data to Enhance LandTrendr Time Series Analysis in Northern High Latitude Permafrost Regions. Remote Sensing, 12 (15), 2471. doi: 10.3390/rs12152471

Strozzi T., R.Caduff, N. Jones, C. Barboux, R, Delaloye, X. Bodin, A. Kääb, E. Mätzler, L. Schrott Monitoring Rock Glacier Kinematics with Synthetic Aperture Radar. Remote Sensing 2020, 12(3), 559

Accepted

Nitze, I., Cooley, S., Duguay, C., Jones, B. M., & Grosse, G. (2020). The catastrophic thermokarst lake drainage events of 2018 in northwestern Alaska: Fast-forward into the future. *The Cryosphere Discussions*, 1-33.

Submitted/In review/In revision

Kääb, A., Strozzi, T., Bolch, T., Caduff, R., Trefall, H., Stoffel, M., and Kokarev, A.: Inventory, motion and acceleration of rock glaciers in Ile Alatau and Kungöy Ala-Too, northern Tien Shan, since the 1950s, The Cryosphere Discuss., https://doi.org/10.5194/tc-2020-109, in review, 2020.

5.2 Other documents related to the work of Permafrost_cci

IPA confirmed their support of the project as part of a publication in Strand S.M., Christiansen H.H., 2019: Report from the International Permafrost Association: Increasing regional activities on a global scale. Permafrost and Periglacial Processes. 30:121–125, https://doi.org/10.1002/ppp.2000.

5.3 News stories

- IPA: Frozen Ground 43, the News Bulletin of the IPA, 2020 https://ipa.arcticportal.org/publications/frozen-ground
- Details on Permafrost_cci in Biorama (latest issue, in German only)
- Use of GlobPermafrost map for HORIZON2020 Nunataryuk outreach https://nunataryuk.org/news/139-new-map-shows-extent-of-permafrost-in-northern-hemisphere
  Also the cover image of Permafrost and Periglacial Processes, volume 31, issue 3, July-September 2020, shows new permafrost map produced by UNEP Grid Arendal based on submarine permafrost map by Overduin et al. 2019 and land-based permafrost by Obu et al. 2019.

5.4 Outreach activities

- The project status was presented at the AGU 2019 fall meeting and modeling results at SouthCOP, New Zealand.
- A tweet was published by ESA for the release of the 1st permafrost satellite dataset (along AGU in San Francisco): https://twitter.com/esaclimate/status/1204322375694798851?s=20.
- G. Hugelius (University Stockholm) presented permafrost related issues at the COP25 and represented Permafrost_cci in this context. Relevant material on CRDPv0 was also provided to Knowledge Exchange.
- Permafrost_cci is collaboration partner of the IASC T-MOSAIC Remote Sensing Action Group: https://www.t-mosaic.com/remote.html.
- The joint meeting with T-MOSAIC within the framework of ASSW took place, due to the COVID-19 outbreak crisis, as an open zoom meeting on the 31st of March 2020.
- ESA published a multimedia animation showing mean ground temperature change for 2003-2017: https://www.esa.int/ESA_Multimedia/Videos/2020/02/Permafrost_extent_2003-2017/(lang)/fr
- The project was presented at the online AOS conference on the 1st of April 2020, which also took place as an open zoom meeting.
- The Climate office has been supported for a media exchange on the Norilsk oil spill. Records have been specifically extracted for this site. Feedback was provided to knowledge exchange on the 'climate stories'.
- CRDPv0 data were included in the WebGIS of the GlobPermafrost Permafrost Information System.
- A news story has been published by ESA on the 25th of February: http://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate/Picturing_permafrost_in_the_Arctic.
- The Climate from Space application has been reviewed regarding the Permafrost component and feedback provided. For the WGClimate ECV Inventory, verification of Permafrost datasets (for publication in v3.0) has been provided to ECMWF.

5.5 Presentations at scientific conferences

2nd International REKLIM Conference, 23-26 September 2019, Berlin

Matthes, H., A. Rinke: The relationship between Arctic air and soil temperatures mediated by snow – insights from observations and regional model sensitivity experiments. Oral presentation.

Heim, B., M. Wieczorek, A. Irrgang, B. Biskaborn, H. Matthes, G. Grosse, A. Haas, S. Westermann: ESA CCI+ Permafrost - Validation using international and national permafrost monitoring networks. Poster presentation.

EGU General Assembly, 4-8 May 2020, Vienna, Austria.

- Bartsch and the ESA DUE GlobPermafrost and ESA CCI+ Permafrost Teams, Data collections of ESA DUE GlobPermafrost and ESA CCI+ Permafrost.
- Kroisleitner, A. Bartsch, B. Heim and M. Wiezorek, The potential of satellite derived surface state to empirically estimate pan-arctic ground temperature at specific depths and the essential role of in-situ data.
- F. Sirbu, A. Onaca, F. Ardelean, B. Magori and P. Urdea, Present state of marginal mountain permafrost in South Eastern Europe.
- Wieczorek, M., Heim, B. , Böhmer, T. , Gebhardt, N. , Bartsch, A. and Herzschuh, U. (2020) Challenges in creating and exemplary applications of two cross-repository data compilations on sedimentary pollen and permafrost soil temperature, EGU General Assembly 2020, Online, 4 May 2020 - 8 May 2020. doi:https://doi.org/10.5194/egusphere-egu2020-14019

ASSW – Arctic Observation Summit, April 2019

- Bartsch, A. et al. : Status of Permafrost_cci

Upcoming Events

Polar CORDEX meeting, October 5-7 2020, online

- Matthes et al., ESA CCI+ Permafrost, Data sets and application

AGU Fall Meeting 2020, online.

- Nitze et al., Permafrost region disturbances in space and time: a pan-arctic perspective, AGU Fall Meeting 2020.
- Bartsch et al., Progress in monitoring landcover and human presence in the Arctic based on satellite data, AGU Fall Meeting 2020.
- M. Wieczorek, B.Heim, S. Westermann, J. Obu, U. Herzschuh, F.M. Seifert, T. Strozzi and A. Bartsch, Comparison of in situ ground temperatures and active layer depths with the ESA CCI+ Permafrost Mean Annual Temperature and Active Layer Thickness products, AGU Fall Meeting 2020.

Regional Conference on Permafrost, 11-16 July 2021, Boulder, CO, USA. Submitted proceedings contributions:

- M. Darrow, R. Caduff, R. Daanen, L. Arenson, C. Barboux, R. Delaloye and T. Strozzi, Comparing Slope Movement Rates in the Brooks Range, Alaska, USA, 2021 Regional Conference on Permafrost (RCOP 2021).
- Matthes et al., Uncertainties from land surface boundary conditions: atmosphere and cryosphere present day representation in a Regional Arctic Climate Model, USA, 2021 Regional Conference on Permafrost (RCOP 2021).

ESA EO4Polar virtual event

- Discussion session on Landsurface remote sensing: Chair A. Bartsch

- Grosse, G.: Progress and gaps regarding quantifying and monitoring permafrost thaw dynamics with multi-decadal optical timeseries data. Keynote, Landsurface remote sensing session. ESA EO4Polar, virtual event.
- Bartsch, A. EO challenges for monitoring ice and water in the ground across the Arctic. Keynote, Arctic freshwater session, virtual event.

- Guido Grosse, Annett Bartsch, Julia Boike, Joerg Brauchle, Matthias Fuchs, Ben Jones, Mark Lara, Anna Liljedahl, Ingmar Nitze, Tabea Rettelbach, Alexandra Runge, Ken Tape, Mathias Ulrich: Need for broad access to high and very high-resolution satellite imagery for quantifying and monitoring permafrost thaw dynamics. ESA EO4Polar, virtual event.
- Heim, Birgit; Wieczorek, Mareike; Irrgang, Anna; Matthes, Heidrun; Grosse, Guido; Haas, Antonie; Westermann, Sebastian; Obu, Jaroslav; Pellet, Cécile; Barboux, Chloé; Delaloye, Reynald; Strozzi, Tazio, Bartsch, Annett; Seifert, Frank Martin: ESA CCI+ Permafrost - Validation Using International and National Permafrost Monitoring Networks. ESA EO4Polar, virtual event.
- Runge A., Grosse, G.: Combining Landsat and Sentinel-2 data in high spatial and temporal resolution time series analysis for a comprehensive assessment of retrogressive thaw slumps in high latitude permafrost regions. ESA EO4Polar, virtual event.
- Tazio Strozzi, Annett Bartsch, Sebastian Westermann, Jaroslav Obu, Guido Grosse, Birgit Heim, Andreas Wiesmann, Christine Kroisleitner, Kristoffer Aalstad, Joel Fiddes, Andreas Kääb, Heidrun Matthes, Ingmar Nitze, Annette Rinke, Mareike Wieczorek, Gustaf Hugelius, Juri Palmtag, Chloé Barboux, Cécile Pellet, Aldo Bertone, Reynald Delaloye, Frank Martin Seifert: Space-borne studies of permafrost in the Arctic within ESA's CCI. ESA EO4Polar, virtual event.

5.6 Specific tasks

Conference organization:
G. Grosse is member of the International Scientific Committee of the 16th International Circumpolar Remote Sensing Symposium (ICRSS) (Postponed to May 2021, Fairbanks, Alaska)

Meeting organization
A.Bartsch and B. Heim have been involved in the joint organization of the T-MOSAIC Remote Sensing Action Group and Permafrost_cci at the ASSW 2020 in April (online event)

Contribution to new overarching activities:
Team members are actively involved in contributing with expertise to the started NSF-funded Permafrost Discovery Gateway, a new data portal for remote sensing and model based Big Datasets relevant for permafrost

5.7 Student teaching and courses

Remote Sensing of Permafrost Regions, MSc Module taught by G. Grosse & I. Nitze at University of Potsdam (4 hrs/week; SS 2019, WS 2019/2020, WS 2020/2021)

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6.2 Acronyms

ACOP	Asian Conference on Permafrost
ALT	Active Layer Thickness
Arctic CORDEX	Coordinated Regional Climate Downscaling Experiment
ASSW	Arctic Science Summit Week
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 Version 4
CLM5	Land Community Model Version 5
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
FT2T	Freeze-Thaw to Temperature
GAMMA	Gamma Remote Sensing AG
GCOS	Global Climate Observing System
GCW	Global Cryosphere Watch
GTD	Ground Temperature at certain depth
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
HRPC	Hot Spot Regions of Permafrost Change
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
PFR	Permafrost Fraction
PSTG	Polar Space Task Group
PUG	Product User Guide
PVIR	Product Validation and Intercomparison Report
RASM	Regional Arctic System Model
RCOP	Regional Conference on Permafrost
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
ZAMG	Zentralanstalt für Meteorologie und Geodynamik