



permafrost
cci

**CCI+ PHASE 1 – NEW ECVS
PERMAFROST**

D5.1 CLIMATE ASSESSMENT REPORT (CAR)

VERSION 1.0

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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 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 the added value of Permafrost_cci products as well as related activities of the Climate Research Group. It reviews the user requirements defined by the climate research group including the modelling user community. User feedback by the IPA and four specific Science Use cases are presented in this document. Further on, publications and outreach activities relevant to dissemination of Permafrost_cci activities are listed.

The datasets support regional and latitudinal assessment of permafrost characteristics including a thorough analysis of permafrost thaw dynamics over large regional to continental transects in combination with other datasets. The documentation of the datasets including known issues allows for detailed understanding of the single products. The validation with data from the GTN-P repository has been deemed profound. CRDPv0 already provides valuable information for workshops and communication specifically in the framework of interdisciplinary projects. The expected improvements (length of record, monthly information) will be essential for future use. The need for an improved representation of ground stratigraphy is stressed by several groups. It is further pointed out that the newly assembled Permafrost_cci in situ validation data set is specifically of utility for climate modelling applications.

1 INTRODUCTION

1.1 Purpose of the document

This document summarizes current activities within Permafrost_cci with regard to user requirements defined by the climate research group including the modelling user community. The ultimate objective of Permafrost_cci is to develop and deliver permafrost maps as ECV products, primarily derived from satellite-based measurements. The purpose of the Climate Assessment Report is to document the added value of the ECV data set generated in terms of improvement over existing ECV data products.

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. Section three covers the user feed back and section four reviews the algorithm selection and initial user requirements. The last section provides an overview of publications and outreach.

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

[RD-3] Bartsch, A., Obu, J., Westermann, S., Strozz, 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., Strozz, T., 2019, User Requirements Document (URD), v1.1

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 content, snowcover, and degree and orientation of slope. As a rule, the active layer is thin in the High Arctic (it can be less than 15 cm) and becomes thicker farther south (1 m or more).

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

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

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

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

continuous permafrost

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

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

REFERENCE: Brown, 1970.

discontinuous permafrost

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

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

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

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

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

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 2003 to 2017. 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 2 (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 version 0 of the Climate Research Data Package [RD-3] consists of time series covering the years from 2003 and 2017 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 feedback

The CRDPv0 has been assessed by the Climate Research Group as well as an IPA representative. At least four user case studies are planned or 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. Their status and feedback are detailed below.

3.2.1 Isabelle Gärtner-Roer¹

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

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 projections, 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 ground temperatures 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.

At 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. 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 trends 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. However, 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.

3.2.2 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. Matthes et al. (2017) showed that using CLM4 in HIRHAM significantly reduces the simulated bias in active layer thickness and winter soil temperatures, which significantly feed back to the atmospheric circulation in the model. Recently, an update with respect to CLM5 has been started.

Science Case Study 1 plans a cross-evaluation and assessment of the HIRHAM-CLM atmosphere-land model versus Permafrost_cci GTD, and Permafrost_cci PFR. Model evaluation will also take advantage of the newly assembled Permafrost_cci *in situ* validation data set, especially data of mean annual ground temperature and active layer thickness. HIRHAM-CLM is sensitive to soil parameters like sand, clay and silt as well as organic matter content prescribed in the model. An improved input of soil characteristics will be tested for its impact on soil and atmosphere representation in HIRHAM-CLM.

3.2.3 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 contain 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. The cross-analyzed datasets will contain spatially explicit information on permafrost region disturbances and modelled ground temperatures and information about spatial and temporal correlations between these two parameter sets. Datasets will be provided as vector files for individual features and in raster format for large-scale geospatial datasets. Development of this science use case in Permafrost_cci will allow better understanding of the role of local sub-grid disturbances for broad-scale permafrost vulnerability and change patterns.

The large coverage of datasets developed in ESA funded GlobPermafrost and CCI+ projects allows for a thorough analysis of permafrost thaw dynamics over large regional to continental transects (Alaska, Eastern Canada, Western Siberia, Eastern Siberia). Due to the early stage of research, no conclusions can be drawn yet and further investigation is in process. A poster on the approach was presented at ESA LPS (Grosse et al., 2019).

3.2.4 Science Case Study 3

The overall strategy of the HORIZON2020 Nunataryuk project (2017-2022) is to transdisciplinarily 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 will be a 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 will be used as the common thread for early consultations with community representatives and other stakeholders at the local and global level. Time series as developed by Permafrost_cci will be therefore of high value to the project. They are expected to be utilized as part of scenario building workshops, stakeholder communication as well as to interpret natural science results of the project. The spatial resolution and extent comply with the requirements of Nunataryuk. CRDPv0 already provides valuable information for workshops and communication. The expected improvements (length of record, monthly information) will be essential for future use in the project.

3.2.5 Science Case Study 4

This science case study is exploring different scientific evaluations of the Permafrost_cci ECV products. We assemble a data collection on ground temperature in time, space and depth with metadata on stratigraphy, ground ice, texture and data of the buffer layer on vegetation, infrastructure, and surface habitus to apply a ‘3-layer Permafrost Earth System approach’ (Vincent et al., 2017): The two geo/cryosphere layers are the active layer and permafrost. The 3rd layer, the buffer layer, consists of the biosphere (vegetation from polar desert to tundra to boreal) and hydrology (e.g., snow) also including infrastructure.

The first assembled in situ data collection on annual mean ground temperature (MAGT) and active layer thickness (ALT) spans permafrost regions from Scandinavia, Mongolia, China to higher latitude permafrost and all altitude ranges from lowland to mountain permafrost. Using this new validation data set with depth- and time-specific pair-wise analyses for MAGT colder than 0.5 °C already showed the Permafrost_cci performs well, with only a small model bias, small RMSE and a relative

percentage error < 5%. However, the performance of the Permafrost_cci product worsens with ‘warm non-permafrost temperatures’ with a high temperature underestimation by the model, and a high relative percentage error > 50%. As a consequence of this cold model bias, simulated permafrost extent is overestimated in the circum-Arctic.

The validation and evaluation efforts also innovatively applied EO microwave-derived ground temperature, the Freeze-Thaw to Temperature (FT2T) product for comparison with the Permafrost_cci permafrost temperature product. Simulated Permafrost_cci ground temperatures are also colder than MAGT retrievals from the FT2T model. The direct comparison reveals regional differences that are largest for northern central Siberia and the Canadian High Arctic.

In contrary, GTN-P PERMOS investigations showed in the Swiss Alps a too warm model bias and a too low extent of permafrost simulated by Permafrost_cci. Furthermore, the vast majority of inventoried ESA GlobPermafrost slope movement products are located outside of the simulated Permafrost_cci permafrost extent area.

Integrating metadata on stratigraphy, ground ice, vegetation and more in the validation will in turn lead to process understanding of linkages of vegetation, hydrology, lithology, topography, climate and permafrost properties.

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 first project year (Y1=year 1; red: not started, yellow: ongoing, green: completed).

ID	Parameter	Requirements	Source	Type	Y1
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	Yellow

		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 AND OUTREACH

5.1 Publications related to the work of Permafrost_cci

Turetsky MR, Abbott BW, Jones MC, Walter Anthony K, Olefeldt D, Schuur EAG, Koven C, McGuire AD, Grosse G, Kuhry P, Hugelius G, Lawrence DM, Gibson C, Sannel ABK (2019): Permafrost collapse is accelerating carbon release. *Nature*, 569, 32-34. doi: 10.1038/d41586-019-01313-4.

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>.

Acknowledgement of ESA GlobPermafrost and CCI+ Permafrost initiatives as a great international framework and inspiration for research on remote sensing of permafrost landscapes:

Rouyet, L.; Lauknes, T.R.; Christiansen, H.H.; Strand, S.M.; Larsen, Y. Seasonal dynamics of a permafrost landscape, Adventdalen, Svalbard, investigated by InSAR. *Remote Sens. Environ.* 2019, 231, 111236.

5.3 News stories

- Success Story “Arctic Lakes from Space” on UN space4water portal, <http://space4water.org/s4w/web/news/arctic-lakes-space>, published on 29 Oct 2018.

- International Permafrost Association (IPA) News on “GlobPermafrost products available through the Permafrost Information System (PerSys) portal”, <https://ipa.arcticportal.org/news/929-globpermafrost-products-available-through-the-permafrost-information-system-persys-portal>, published on 25 Mar 2019.

- International Permafrost Association (IPA) News on “Advances in hemispheric permafrost mapping”, <https://ipa.arcticportal.org/news/931-advances-in-hemispheric-permafrost-mapping>, published on 10 May 2019.

- ESA news story on permafrost within the “Space for our climate” section of the “Observing the earth” web page including tweets by the climate office, @ESA_EO and @ccipermafrost, http://www.esa.int/Our_Activities/Observing_the_Earth/Space_for_our_climate/Satellites_yield_insight_into_not_so_permanent_permafrost, published on 17 May 2019.

5.4 Outreach activities

GlobPermafrost & Permafrost_cci information event at the AGU Fall Meeting (10-14 December 2018, Washington D.C., USA)

- Along the 2018 AGU Fall Meeting, the project was presented within the framework of the GlobPermafrost information event supported by ARCUS (Arctic Research Community of the US) and at the meeting of the Permafrost Carbon Network.

Agorà presentation at the ESA Living Planet Symposium, 13.-17.5. 2019, Milan, Italy

- Permafrost_cci and its link to HORIZON2020 activities was covered in the discussion on ‘EC and ESA collaboration: Polar Science Challenges and future activities’

CCI booth presentations at the ESA Living Planet Symposium, 13.-17.5. 2019, Milan, Italy

- Permafrost_cci has been presented two times during breaks as well as for the ESA Climate detectives initiatives

5.5 Presentations at scientific conferences

Oral presentation at the AGU Fall Meeting, 10 - 14 December 2018, Washington D.C., USA

- Sebastian Westermann, Tazio Strozzi, Andreas Wiesmann, Kristoffer Aalstad, Joel Fiddes, Andreas Kaab, Jaroslav Obu, Frank Martin Seifert, Guido Grosse, Birgit Heim, Heidrun Matthes, Ingmar Nitze, Annette Rinke, Gustaf Hugelius, Juri Palmtag, Chloé Barboux, Reynald Delaloye, Christine Kroisleitner and Annett Bartsch, Circumpolar mapping of permafrost temperature and thaw depth in the ESA Permafrost CCI project

Oral presentation at the EGU General Assembly, 7-12 April 2019, Vienna, Austria

- Annett Bartsch, Tazio Strozzi, Marina Leibman, Barbara Widhalm, Artem Khomutov, Damir Mullanurov, and Anatoly Gubarkov, Added value of InSAR derived displacements through combination with in situ observations over continuous permafrost, central Yamal

Poster presentation at the EGU General Assembly, 7-12 April 2019, Vienna, Austria

- Sebastian Westermann, Tazio Strozzi, Andreas Wiesmann, Kristoffer Aalstad, Joel Fiddes, Andreas Kääh, Jaroslav Obu, Frank Martin Seifert, Guido Grosse, Birgit Heim, Heidrun Matthes, Ingmar Nitze, Annette Rinke, Gustaf Hugelius, Juri Palmtag, Chloé Barboux, Reynald Delaloye, Christine Kroisleitner, and Annett Bartsch, Circumpolar mapping of permafrost temperature and thaw depth in the ESA Permafrost CCI project

Oral presentation at the ISSI workshop on “Natural and man-made hazards monitoring by the Earth Observation missions: current status and scientific gaps”, 15-18 April 2019, Bern

- Annett Bartsch, What space can tell us on permafrost thawing and greenhouse gas release in polar regions?

Oral presentations at the ESA Living Planet Symposium, 13-17 May 2019, Milan, Italy

- Annett Bartsch, Guido Grosse, Andreas Kääh, Sebastian Westermann, Tazio Strozzi, Andreas Wiesmann, Claude Duguay, Frank Martin Seifert, Jaroslav Obu, Ingmar Nitze, Birgit Heim, Antonie Haas, Barbara Widhalm, Sina Muster, Gustaf Hugelius, Reynald Delaloye, Cecile Pellet and Heidrun

Matthes, Examining Environmental Gradients in permafrost regions – achievements of the ESA DUE GlobPermafrost project and opportunities for ESA CCI+ Permafrost

- Ingmar Nitze, Guido Grosse, Benjamin Jones, Vladimir Romanovsky and Julia Boike, Monitoring permafrost region disturbances
- Sebastian Westermann, Tazio Strozzi, Andreas Wiesmann, Kristoffer Aalstad, Andreas Kääh, Jaroslav Obu, Frank Martin Seifert, Guido Grosse, Birgit Heim, Heidrun Matthes, Ingmar Nitze, Annette Rinke, Gustaf Hugelius, Juri Palmtag, Chloé Barboux, Reynald Delaloye, Christine Kroisleitner and Annett Bartsch, ESA Permafrost CCI - mapping changes in permafrost temperature and thaw depth at global scale
- Christine Kroisleitner, Annett Bartsch, Helena Bergstedt, Jaroslav Obu and Sebastian Westermann, Representation of circumarctic mean annual ground temperature by satellite derived surface status and its consistence with MAGT from Cryogrid-1
- Tazio Strozzi, Urs Wegmüller, Rafael Caduff, Reynald Delaloye and Chloé Barboux, Monitoring Rock Glacier Kinematics with Sentinel-1 SAR Interferometry

Poster presentations at the ESA Living Planet Symposium, 13-17 May 2019, Milan, Italy

- Birgit Heim, Mareike Wieczorek, Anna Irrgang, Boris Biskaborn, Heidrun Matthes, Annette Rinke, Guido Grosse, Antonie Haas, Sebastian Westermann, Jaros Obu, Chloe Barboux, Cecile Pellet, Reynald Delaloye, Frank Martin Seifert, Gustaf Hugelius, Yuri Palmtag, Tazio Strozzi, Christine Kroisleitner and Annett Bartsch, ESA CCI+ Permafrost - Validation using international and national permafrost monitoring networks
- Guido Grosse, Ingmar Nitze, Sebastian Westermann, Birgit Heim, Annett Bartsch and Tazio Strozzi, Cross-Analysis of the ESA GlobPermafrost Hot Spot Regions of Permafrost Change Product with Transient Permafrost Model Results as a Science Use Case in ESA Permafrost CCI+
- Tazio Strozzi, Andreas Kääh and Annett Bartsch, Multi-Frequency SAR Exploitation Synergy for Surface Deformation Monitoring in Low-Land Permafrost Areas: L-, C-, and X-band InSAR data on Central Yamal (Russia)

Oral presentation at the International REKLIM CONFERENCE, 23-25 October 2019, Berlin, Germany

- Heidrun Matthes and Annette Rinke, The relationship between Arctic air and soil temperatures mediated by snow – insights from observations and regional model sensitivity experiments.

Poster presentations at the International REKLIM CONFERENCE, 23-25 October 2019, Berlin, Germany

- Birgit Heim, Mareike Wieczorek, Anna Irrgang, Boris Biskaborn, Heidrun Matthes, Annette Rinke, Guido Grosse, Antonie Haas, Sebastian Westermann, Jaros Obu, Chloe Barboux, Cecile Pellet, Reynald Delaloye, Frank Martin Seifert, Gustaf Hugelius, Yuri Palmtag, Tazio Strozzi, Christine Kroisleitner and Annett Bartsch, ESA CCI+ Permafrost validation using international and national permafrost monitoring networks.
- Antonie Haas, Birgit Heim, Annett Bartsch, Andreas Walther, Christian Schäfer-Neth, Frank-Martin Seifert, Permafrost-related research data - their accessibility, visualisation, and publication using GIS and WebGIS technology.

5.6 Specific tasks

Session chairing: *ESA Living Planet Symposium*

G. Grosse, A. Bartsch, S. Westermann, C. Duguay were chairing two oral and one poster session on Remote Sensing of Permafrost Regions at the ESA Living Planet Symposium, Milan, Italy, May 2019

Contribution to new overarching activities:

- Team members are actively involved in contributing with expertise to the new NSF-funded Permafrost Discovery Gateway, a new data portal for remote sensing and model based Big Datasets relevant for permafrost
- A. Bartsch is actively involved in T-MOSAIC, a program of the International Arctic Science Committee, including its recently established remote sensing working group (co-chair)

5.7 Student teaching and courses

Introduction to approaches for monitoring permafrost from space by A. Bartsch at the International Summer School ‘Investigating alpine permafrost dynamics from space to the field’, EURAC, Bozen, July 2019.

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

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6.2 Acronyms

ALT	Active Layer Thickness
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
CRDP	Climate Research Data Package
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
HPRC	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
RD	Reference Document
RMSE	Root Mean Square Error
RS	Remote Sensing
SAR	Synthetic Aperture Radar
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