permafrost cci

CCI+ PHASE 2 – NEW ECVS
PERMAFROST

CCN4 OPTION 7
ICEINSAR: INFERRED ACTIVE LAYER WATER/ICE CONTENT AND FREEZE-THAW PROGRESSION FROM ASSIMILATING INSAR IN PERMAFROST MODEL

D4.2 PRODUCT USER GUIDE (PUG)

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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. The two main products associated to the ECV Permafrost are Ground Temperature (GT) and Active Layer Thickness (ALT). GT and ALT are documented by the Permafrost_cci project based on thermal remote sensing and physical modelling.

The Permafrost_cci models take advantage of additional datasets, such as snow cover and land cover, to estimate the heat transfer between the surface and the underground. However, several challenges remain due to spatially variable subsurface conditions, especially in relation to unknown amounts of water/ice in the active layer that modify the effective heat capacity and the thermal conductivity of the ground. In complex terrain with large spatial heterogeneities, coarse and partly inadequate land cover categorisation, the current results show discrepancies with in-situ measurements, which highlight the need to assimilate new data sources as model input. Although the ground stratigraphy is not directly observable from space, it impacts the dynamics of the ground surface. The seasonal thawing and refreezing induce cyclic subsidence and heave of the ground surface due to ice formation and melt in the active layer, and can therefore be used as indirect indicator of the ground conditions.

Synthetic Aperture Radar Interferometry (InSAR) based on Sentinel-1 images can be used to measure the amplitude and seasonal progression of these displacements. The movement amplitude is related to the amount of water/ice that is affected by a phase change, whilst the timing of the displacement patterns reflects the vertical progression of the thawing/freezing front. Considering the fine to medium spatial resolution of Sentinel-1 images, InSAR time series therefore have the potential to enhance the characterisation of subsurface hydrogeologic and thermal parameters and adapt the existing Permafrost_cci models to improve their performance at the local to regional scale. The *IceInSAR* pilot project (Option 7) will develop a prototype for permafrost model adjustment by assimilating Sentinel-1 InSAR surface displacement maps and time series into the model to constrain stratigraphy parameters. *IceInSAR* will provide pilot products, expected to be used for adjustment of the ECV processing chain of the baseline project in a next phase.

This Product User Guide (PUG) describes of the Climate Research Data Package (CRDP) from the *IceInSAR* Option 7 [RD-1]. It explains the background and status of the Option 7 outcomes, and documents the properties of the delivered data package.

1 INTRODUCTION

1.1 Purpose of the document

This Product User Guide (PUG) describes of the Climate Research Data Package (CRDP) from the *IceInSAR* Option 7 [RD-1]. It explains the background and status of the Option 7 outcomes, and documents the properties of the delivered data package. It has to be read together with the CRDP [RD-1] and the PVIR [RD-2].

1.2 Structure of the document

Section 2 describes the properties of the delivered Option 7 dataset. Section 3 includes a bibliography and a list of acronyms. A glossary of the commonly accepted permafrost terminology can be found in RD-15.

1.3 Applicable Documents

[AD-1] ESA. 2022. Climate Change Initiative Extension (CCI+) Phase 2 – New Essential Climate Variables – Statement of Work. ESA-EOP-SC-AMT-2021-27.

[AD-2] GCOS. 2022. The 2022 GCOS Implementation Plan. GCOS – 244 / GOOS – 272. Global Observing Climate System (GCOS). World Meteorological Organization (WMO).

[AD-3] GCOS. 2022. The 2022 GCOS ECVs Requirements. GCOS – 245. Global Climate Observing System (GCOS). World Meteorological Organization (WMO).

1.4 Reference Documents

[RD-1] Wendt, L., Rouyet, L., Westermann, S., Bartsch, A., Strozzi, T. 2024. ESA CCI+ Permafrost Phase 2. CCN4 Option 7. IceInSAR: Inferred Active Layer Water/Ice Content and Freeze-Thaw Progression From Assimilating InSAR in Permafrost Model. D.3.2 Climate Research Data Package (CRDP). Version 1.0. European Space Agency.

[RD-2] Wendt, L., Rouyet, L., Westermann, S., Bartsch, A., Strozzi, T. 2024. ESA CCI+ Permafrost Phase 2. CCN4 Option 7. IceInSAR: Inferred Active Layer Water/Ice Content and Freeze-Thaw Progression From Assimilating InSAR in Permafrost Model. D.4.1 Product Validation and Intercomparison Report (PVIR). Version 1.0. European Space Agency.

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[RD-4] Rouyet, L., Wendt, L., Westermann, S., Bartsch, A., Strozzi, T. 2023. ESA CCI+ Permafrost Phase 2. CCN4 Option 7. IceInSAR: Inferred Active Layer Water/Ice Content and Freeze-Thaw Progression From Assimilating InSAR in Permafrost Model. D.1.2 Product Specification Document (PSD). Version 1.0. European Space Agency.

[RD-5] Rouyet, L., Wendt, L., Westermann, S., Bartsch, A., Strozzi, T. 2023. ESA CCI+ Permafrost Phase 2. CCN4 Option 7. IceInSAR: Inferred Active Layer Water/Ice Content and Freeze-Thaw

Progression From Assimilating InSAR in Permafrost Model. D.2.2 Algorithm Theoretical Basis Document (ATBD). Version 1.0. European Space Agency.

[RD-6] Rouyet, L., Wendt, L., Westermann, S., Bartsch, A., Strozzi, T. 2023. ESA CCI+ Permafrost Phase 2. CCN4 Option 7. IceInSAR: Inferred Active Layer Water/Ice Content and Freeze-Thaw Progression From Assimilating InSAR in Permafrost Model. D.2.3 End-to-End ECV Uncertainty Budget (E3UB). Version 1.0. European Space Agency.

[RD-7] Rouyet, L., Wendt, L., Westermann, S., Bartsch, A., Strozzi, T. 2023. ESA CCI+ Permafrost Phase 2. CCN4 Option 7. IceInSAR: Inferred Active Layer Water/Ice Content and Freeze-Thaw Progression From Assimilating InSAR in Permafrost Model. D.2.4 Algorithm Development Plan (ADP). Version 1.0. European Space Agency.

[RD-8] Rouyet, L., Wendt, L., Westermann, S., Bartsch, A., Strozzi, T. 2023. ESA CCI+ Permafrost Phase 2. CCN4 Option 7. IceInSAR: Inferred Active Layer Water/Ice Content and Freeze-Thaw Progression From Assimilating InSAR in Permafrost Model. D.2.5 Product Validation Plan (PVP). Version 1.0. European Space Agency.

[RD-9] Bartsch, A., Matthes, H., Westermann, S., Heim, B., Pellet, C., Onaca, A., Strozzi, T., Kroisleitner, C., Strozzi, T. 2023. ESA CCI+ Permafrost Phase 2. D.1.1 User Requirement Document (URD). Version 3.0. European Space Agency.

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[RD-11] Westermann, S., Bartsch, A., Strozzi, T. 2023. ESA CCI+ Permafrost. D.2.2 Algorithm Theoretical Basis Document (ATBD). Version 4.0. European Space Agency.

[RD-12] Westermann, S., Bartsch, A., Strozzi, T. 2023. ESA CCI+ Permafrost. D.3.2 Climate Research Data Package (CRDP). Version 4.0. European Space Agency.

[RD-13] Bartsch, A., Obu, J., Westermann, S., Strozzi, T. 2024. ESA CCI+ Permafrost. D.4.3 Product User Guide (PUG). Version 4.1. European Space Agency.

[RD-14] Heim, B., Wieczorek, M., Pellet, C., Delaloye, R., Bartsch, A., Strozzi, T. 2024. ESA CCI+ Permafrost. D.4.1 Product Validation and Intercomparison Report (PVIR). Version 4.0. European Space Agency.

[RD-15] 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).

1.5 Bibliography

A complete bibliographic list that supports arguments or statements made within the current document is provided in Section 3.1.

1.6 Acronyms

A list of acronyms is provided in Section 3.2.

2 OPTION 7 PROOF-OF-CONCEPT DATASET

2.1 Background and current dataset

The *IceInSAR* Option 7 is a proof-of-concept study. The primary objective is to evidence the value of Interferometric Synthetic Aperture Radar (InSAR) surface displacement to indirectly document the ground stratigraphy, and elaborate strategies for data assimilation into permafrost models.

To fulfil this objective, a significant focus has been placed on comparing InSAR displacement with in-situ data acquired in Adventdalen, Svalbard (see PVIR [RD-1]) (Wendt, 2024a). An extensive field dataset was acquired on the subsurface stratigraphies and permafrost ECV variables in spring-autumn 2023. Due to the timing of the field campaign, most InSAR analyses have been performed for the 2023 snow-free season. The CRDP is stored on Zenodo (Wendt, 2024b). The data properties are described in the following. Other Option 7 findings are discussed in the CRDP [RD-1] and PVIR [RD-2], but the associated data are not ready to be published at this pilot stage and are therefore not described in the current PUG.

2.2 Documented variables

The current dataset includes 1) generic information about 12 measurement sites, 2) surface displacement from Sentinel-1 InSAR, and 3) laboratory measurements of the core sections.

Generic information on the 12 measurement sites:

- The site name and coordinates.
- The drilling date and depth.
- The thaw depth probing date, the subsidence correction value applied to the thaw depth, the inferred active layer thickness.
- The main sediment deposit type and the main grain size in the active layer.

Laboratory measurements of the core sections:

- Core type indicating if the core section was retrieved intact or disturbed.
- Volumetric Ice Content (VIC), Excess Ice Content (EIC) and Pore Ice Content (PIC) for each core section at each site.
- Main grain type for each core section at each site.

The surface displacement time series and resulting maximal seasonal displacement from Small Baseline Subset (SBAS) InSAR based on Sentinel-1 images in a descending orbit (see ATBD [RD-5]):

- Cumulative displacement for each coring site during the thawing season 2023 (26/05/2023 – 23/09/2023) and the extracted maximal subsidence value.
- Cumulative displacement for each coring site during the thawing season 2021 (05/06/2021 – 15/10/2021) and the extracted maximal subsidence value.

The line-of-sight displacement have been converted to vertical displacements, assuming no horizontal displacement. Negative values indicate thaw subsidence. Positive values indicate frost heave.

Details on the procedure to retrieve all variables are explained in Wendt (2024a).

2.3 Spatial coverage and resolution

The study area is Adventdalen, Svalbard. The dataset includes measurements at 12 locations across the valley. Coring data are point-scale. InSAR results are extracted around the same locations. The InSAR pixel resolution is approx. 30m. When possible, the thaw depth was probed at the core location, as well as 10 and 20 meters in each cardinal direction from the coring site. The reported thaw depth value consists in the average of the 9 measurements. At three sites, the active layer was only measurable at the coring location, due to abundant gravel in the active layer of the surrounding. At one site, only 5 measurements instead of 9 could be made due to abundant rocks.

2.4 Temporal coverage and resolution

All field data have been acquired in 2023, between April 16th and May 1st for the cores, and between September 10th and 13th for the thaw depth. SBAS InSAR displacement time series are from 2023 (26/05/2023 – 23/09/2023), and 2021 (05/06/2021 – 15/10/2021). The Sentinel-1 repeat-pass was 12d in 2023 (Sentinel-1A), and 6d in 2021 (Sentinel-1A+B), which determines the respective temporal resolution of the displacement time series.

2.5 Projection system

The coordinates of the coring sites are in WGS 1984 UTM 33N.

2.6 Data format

The data package is provided as excel file (xlsx format).

2.7 Data version and dissemination

The dataset is available in the Zenodo repository:

> Wendt, L. (2024b). Ground ice contents and InSAR displacements from Adventdalen, Svalbard. [Data set]. Zenodo. https://doi.org/10.5281/zenodo.11187360.

A scientific article will detail the findings associated with this dataset (Wendt, et al., submitted).

3 REFERENCES

3.1 Bibliography

Wendt, L. (2024a). Assessing ground ice changes in Svalbard from SAR interferometry and modelling. M.Sc. thesis. Department of Geoscience, Faculty of Mathematics and Natural Sciences, University of Oslo. http://hdl.handle.net/10852/112526.

Wendt, L. (2024b). Ground ice contents and InSAR displacements from Adventdalen, Svalbard. [Data set]. Zenodo. https://doi.org/10.5281/zenodo.11187360.

Wendt, L. Rouyet, L., Christiansen, H. H., Lauknes, T. R., Westermann, S. (submitted). InSAR sensitivity to active layer ground ice contents in Adventdalen, Svalbard.

3.2 Acronyms

AD	Applicable Document
ADP	Algorithm Development Plan
ALT	Active Layer Thickness
ATBD	Algorithm Theoretical Basis Document
B.GEOS	B.Geos GmbH
CAR	Climate Assessment Report
CCI	Climate Change Initiative
CRDP	Climate Research Data Package
ECV	Essential Climate Variable
EO	Earth Observation
ESA	European Space Agency
E3UB	End-To-End ECV Uncertainty Budget
GAMMA	Gamma Remote Sensing AG
GCOS	Global Climate Observing System
GMS	Ground Motion Service
GT	Ground Temperature
GTN-P	Global Terrestrial Network for Permafrost
UIO	University of Oslo
INSAR	Synthetic Aperture Radar Interferometry
IPA	International Permafrost Association
NORCE	Norwegian Research Centre AS
PE	Permafrost Extent
PF	Permafrost Fraction
PSD	Product Specification Document
PUG	Product User Guide
PVASR	Product Validation and Algorithm Selection Report
PVIR	Product Validation and Intercomparison Report
PVP	Product Validation Plan
RD	Reference Document
RMSE	Root Mean Square Error

SAR	Synthetic Aperture Radar
SD	Surface Displacement
SSD	System Specification Document
URD	Users Requirement Document
URq	User Requirement
WMO	World Meteorological Organisation