

Title of proposed IPA Action Group:

Defining requirements for the spatial representation of permafrost

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Background and Motivation

Ground affected by permafrost covers approximately 15 % of the Northern Hemisphere and is also present in high mountain regions, such as the Hindukush-Himalaya region. As the global climate warms rapidly, the distribution of permafrost is changing continuously, with regional to global consequences such as reduced ground stability and increased carbon emissions. These impacts underscore the importance of robust and sustained permafrost monitoring. While established global monitoring of permafrost as an Essential Climate Variable (ECV) through the Global Terrestrial Network for Permafrost (GTN-P) focuses on high-quality in situ observations, its scope is limited to a small number of accessible field sites across a large and heterogeneous domain. Due to the widespread and often remote distribution of permafrost, the limited availability of in situ observations results in high uncertainties for panarctic and global-scale permafrost assessments relevant for global models. Progress in permafrost simulations driven by combinations of in situ and Earth Observation (EO) data offers a promising way to address spatial and temporal gaps in permafrost extent monitoring.

The Global Climate Observing System (GCOS), a programme of the World Meteorological Organization (WMO) responsible for coordinating global climate observations, highlights the need for operational techniques to monitor permafrost extent in its Implementation Plan

(Activity B3.5; WMO, 2022). Knowledge of changes in permafrost extent is considered critical for adapting infrastructure and minimizing losses associated with permafrost thaw (WMO, 2022, p. 32, Action B3.5). GCOS therefore advocates the use of satellite derived observations to complement in situ measurements and enable operational monitoring and modelling of the state of permafrost. In addition, permafrost extent has been identified as a target variable for a potential future Copernicus mission (Duchossois et al., 2018).

“Permafrost extent” is directly linked to the concept of permafrost zones, which form the basis for widely used permafrost mapping products, most notably the International Permafrost Association (IPA) map, as also reflected in the new permafrost dictionary (Canadian Permafrost Association, 2025). To support global- to regional-scale permafrost research, including climate modelling, the IPA map is commonly converted into gridded representations suitable for spatial analysis and model integration. Satellite-based retrievals likewise result in gridded products, for example through modelling approaches exploiting land surface temperature or freeze–thaw state information (see Figure 1). The need for well-defined specifications, including accuracy requirements, for such gridded products has been addressed by several initiatives. These include a National Research Council (NRC) action examining opportunities to use remote sensing in understanding permafrost and related ecological characteristics, which resulted in a community review (UAF workshop report; NRC, 2014), as well as an activity of the WMO Polar Space Task Group that produced a community white paper (Bartsch et al., 2014). Further input was provided through a series of user surveys conducted within ESA-funded projects; these surveys were combined with findings from earlier reviews and summarized in Bartsch et al. (2019), before being submitted to GCOS in 2020. More recent work has continued to refine requirement specifications (Bartsch et al., 2023; Loriani et al., 2025).

Despite these efforts, specific requirements for permafrost extent are not yet implemented within the GCOS ECV framework, and the term “permafrost extent” itself is not formally defined in the ECV context. The updated permafrost dictionary defines permafrost extent as either (1) the area of the permafrost region or (2) the proportion of a specified area underlain by permafrost (Canadian Permafrost Association, 2025). While both interpretations are meaningful, their coexistence highlights the need for a clear definition within the ECV framework. This ambiguity is partly rooted in an inherent scale dependency, long recognized by the permafrost community - for example, in discussions regarding the effective spatial resolution of the IPA map. It gets increasingly problematic given the growing availability of satellite-, modelling-, and machine-learning-based products. Establishing a scale-independent definition—analogue to existing Permafrost ECV quantities such as permafrost temperature and active layer thickness—would therefore be beneficial and should ideally emerge from the permafrost research community with IPA endorsement. Opportunities for harmonization with other ECVs should also be explored. In particular, the Snow ECV provides a relevant example, where snow extent is commonly used alongside more precisely defined terms such as snow-covered area within the ECV framework. A similar approach could help improve clarity, consistency, and interoperability for permafrost-related ECV quantities.

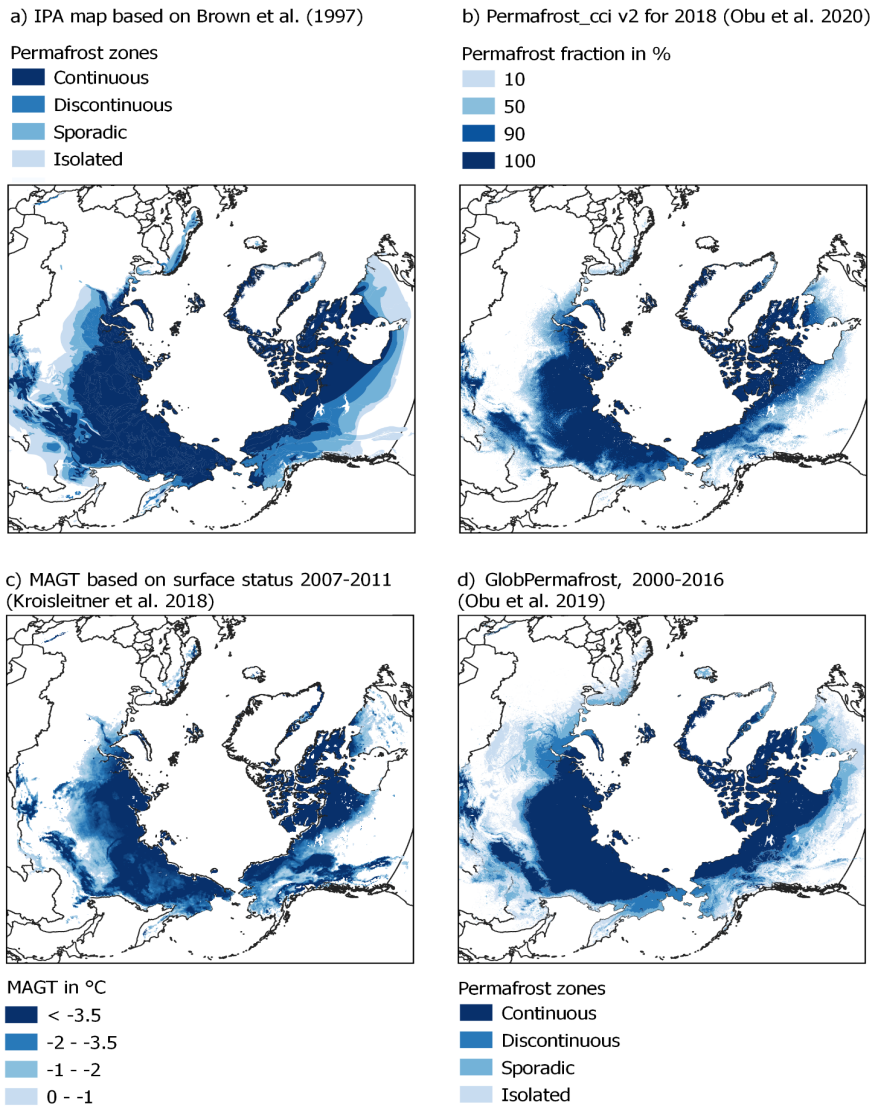


Figure 1: Examples for representations of permafrost extent based on a) the IPA map, b) transient modelling using land surface temperature, c) empirical modelling using surface state and d) equilibrium modelling using land surface temperature (source: Bartsch et al. 2023).

Objectives and Scope

To review and further develop the concept of a gridded representation of permafrost, including a critical assessment and revision of previously proposed specifications and scale-dependency in light of recent advances in observation and modelling approaches.

To define requirements for a spatial representation of permafrost that are independent of the retrieval technique, while ensuring compatibility with established mapping products, modelling frameworks, and remote sensing–based methodologies.

To develop strategies for uncertainty characterization, including the identification of suitable dataset types and methodological approaches for quantifying and communicating uncertainties in permafrost extent products.

Work Packages & Deliverables

The goal of this action group is to establish a community-consensus baseline that supports the GCOS process for revising the Permafrost ECV. This baseline shall include target and threshold requirements in accordance with GCOS guidelines.

The primary deliverable of the action group will be a community paper that reviews and synthesizes the current state of gridded representations of permafrost and discusses scale-dependency issues for permafrost extent mapping. This review will cover existing concepts, techniques for deriving gridded permafrost products from in situ observations, modelling, and Earth Observation data, as well as the quantities required to meet GCOS objectives. This includes the consideration of the GCOS target (WMO 2022) of supporting infrastructure adaptation and loss minimization in regions affected by permafrost degradation.

The work will be organized into the following three work packages:

WP 1: Scrutinising ‘permafrost extent’ within the ECV framework, including clarification of terminology, scale dependency, and specification of target and threshold requirements.

WP 2: Establishment of a benchmarking scheme for EO derived Permafrost ECV quantities, supporting uncertainty characterization and further product developments.

WP 3: Community synthesis and dissemination, culminating in the preparation and publication of the community paper as the main deliverable, including engagement with relevant stakeholders and coordination with GCOS.

Action Group Members

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Proposed Timeline

- **April 2026:** Online kick-off meeting to initiate the action group and align on objectives, scope, and roles.
- **May 2026:** Hybrid coordination meeting held in conjunction with **EGU 2026**, focusing on discussion of the current state of permafrost specifications (Part I).
- **June 2026:** Open, in-person community meeting at **ACOP 2026** to present current specifications to a broader audience and to launch a structured community survey.
- **October 2026:** Closure of the community survey and consolidation of responses.
- **November 2026:** In-person drafting workshop at **AWI Potsdam** to develop the review and requirement formulations (budgeted activity).
- **December 2026:** Finalization of the draft review paper, including refined phrasing of requirements and preparation for submission.
- **March 2027:** Conclusion of the project and submission of the results to the IPA and publication of the community review paper in a scientific journal.

Budget

We request 3,000 € to support the activities of the proposed 1-year IPA Action Group. The funds will be used primarily to cover costs associated with a three-day, in-person drafting workshop planned for November 2026 in Potsdam.

This workshop will be essential for consolidating community input, drafting the review paper, and formulating the proposed ECV requirements in a collaborative setting. The requested budget will mainly support travel and local expenses for key contributors to ensure effective participation and timely delivery of the Action Group's outputs.

Secretarial support

We would appreciate the IPA secretariat providing the standard information for IPA Action Groups on the IPA website. We would like to request assistance in disseminating our action group activities and products through the IPA listserv and social media channels.

IPA Frozen Ground

The Action Group acknowledges its responsibility to provide a 500-word progress report for inclusion in the IPA's annual *Frozen Ground* Newsletter and commits to preparing and submitting the report by the required deadline.

References

World Meteorological Organization (2022). The 2022 GCOS Implementation plan (GCOS-244).

World Meteorological Organization (2022, updated 2025). The 2022 GCOS ECV Requirements (GCOS-245).

National Research Council (2014) Opportunities to use remote sensing in understanding permafrost and related ecological characteristics: report of a workshop. National Academies Press, Washington, DC. <https://doi.org/10.17226/18711>

Bartsch, A., Strozzi, T., and Nitze, I.: Permafrost Monitoring from Space, *Surveys in Geophysics*, 2023. <https://link.springer.com/article/10.1007/s10712-023-09770-3>

Loriani, S., Bartsch, A., Calamita, E. J. F. Donges, S. Hebden, M. Hirota, A. Landolfi, T. Nagler, B. Sakschewski, A. Staal, J. Verbesselt, R. Winkelmann, R. Wood & N. Wunderling: Monitoring the Multiple Stages of Climate Tipping Systems from Space: Do the GCOS Essential Climate Variables Meet the Needs? *Surv Geophys* (2025). <https://doi.org/10.1007/s10712-024-09866-4>

Bartsch, A., Gay, B., Schüttemeyer, D., Malina, E., Miner, K. Grosse, G. , Fix, A., Tamminen, J., Bösch, H., Parker, R. J., Rautiainen, K., Hashemi, J., Miller, C. E: "Advancing the Arctic Methane Permafrost Challenge (AMPAC) With Future Satellite Missions," in *IEEE Journal of Selected Topics*

in Applied Earth Observations and Remote Sensing, vol. 18, pp. 6279-6298, 2025, doi:
10.1109/JSTARS.2025.3538897

Bartsch, Annett; Allard, Michel; Biskaborn, Boris Kolumban; Burba, George; Christiansen, Hanne H; Duguay, Claude R; Grosse, Guido; Günther, Frank; Heim, Birgit; Högström, Elin; Kääh, Andreas; Keuper, Frida; Lanckman, Jean-Pierre; Lantuit, Hugues; Lauknes, Tom Rune; Leibman, Marina O; Liu, Lin; Morgenstern, Anne; Necsoiu, Marius; Overduin, Pier Paul; Pope, Allen; Sachs, Torsten; Séjourné, Antoine; Streletskiy, Dmitry A; Strozzi, Tazio; Ullmann, Tobias; Ullrich, Matthias S; Vieira, Goncalo; Widhalm, Barbara (2014): 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., 20 pp,
<https://doi.pangaea.de/10013/epic.45648.d001>

Bartsch, A.; Grosse, G.; Kääh, A.; Westermann, S.; Strozzi, T.; Wiesmann, A.; Duguay, C.; Seifert, F. M.; Obu, J.; Goler, R. (2016): GlobPermafrost – How space-based earth observation supports understanding of permafrost. Proceedings of the ESA Living Planet Symposium, pp. 6.
https://www.researchgate.net/publication/308873969_GLOBPERMAFROST_-HOW_SPACE-BASED_EARTH_OBSERVATION_SUPPORTS_UNDERSTANDING_OF_PERMAFROST

Bartsch, A., Matthes, H., Westermann, S., Heim, B., Pellet, C., Onacu, A., Kroisleitner, C., Strozzi, T. (2019): ESA CCI+ Permafrost User Requirements
Document https://climate.esa.int/documents/2926/CCI_PERMA_URD_v4.0.pdf

Duchossois G., P. Strobl, V. Toumazou, S. Antunes, A. Bartsch, T. Diehl, F. Dinessen, P. Eriksson, G. Garric, M-N. Houssais, M. Jindrova, J. Muñoz-Sabater, T. Nagler, O. Nordbeck, User Requirements for a Copernicus Polar Mission - Phase 1 Report, EUR , Publications Office of the European Union, 29144 ENLuxembourg, 2018, ISBN 978-92-79-80961-3, doi:10.2760/22832, JRC111067 <https://publications.jrc.ec.europa.eu/repository/handle/JRC111067>

Gisnås, K., Westermann, S., Schuler, T. V., Litherland, T., Isaksen, K., Boike, J., and Etzelmüller, B.: A statistical approach to represent small-scale variability of permafrost temperatures due to snow cover (2014): *The Cryosphere*, 8, 2063-2074, <https://doi.org/10.5194/tc-8-2063-2014>.

National Research Council (2014). Opportunities to Use Remote Sensing in Understanding Permafrost and Related Ecological Characteristics: Report of a Workshop. Washington, DC: The National Academies Press. <https://doi.org/10.17226/18711>.

Canadian Permafrost Association. (2025). *Permafrost Dictionary*. Retrieved December 16, 2025, from <https://canadianpermafrostassociation.ca/permafrost-dictionary.htm>