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Mapping permafrost in the Northern Hemisphere

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Due to the permafrost develops at certain subsurface depths, it cannot be directly observed by remote sensing, and ground-based surveys are costly. As a result, there remains considerable uncertainty in our current understanding of permafrost distribution. This study employs an ensemble simulation approach using multiple machine learning models, integrating the most comprehensive international ground borehole observations with environmental parameters derived from remote sensing, such as freezing and thawing indices. We have developed high-accuracy data products for the Northern Hemisphere at a spatial resolution of 1 km, including mean annual ground temperature, active layer thickness, and subsurface ice content. From the perspectives of formation conditions and vulnerability, we classified permafrost zones into five types: climate-driven, climate-driven with ecosystem regulation, climate-driven with ecosystem protection, ecosystem-driven, and ecosystem-protected. This classification provides a more detailed representation of the vulnerability of permafrost across the Northern Hemisphere.
Specifically, the novel permafrost datasets for the Northern Hemisphere, including the mean annual ground temperature (MAGT) at the depth of zero annual amplitude (DZAA) (approximately 3 m to 25 m) and active layer thickness (ALT) with 1-km resolution for the period of 2000–2016, as well as the probability of permafrost occurrence and the biophysical zonation. These datasets integrate unprecedentedly large amounts of field data (1,002 boreholes for MAGT and 452 sites for ALT) and multisource geospatial data, especially remote sensing data, using statistical learning modelling with an ensemble strategy. Thus, the resulting data are more accurate than those of previous circumpolar maps (bias=0.02 ℃, RMSE=1.32 ℃ for MAGT; bias=2.71 cm, RMSE=86.93 cm for ALT). The datasets suggest that the areal extent of permafrost (MAGT≤0 ℃) in the Northern Hemisphere, excluding glaciers and lakes, is approximately 14.77 (13.60–18.97) million square kilometers and that the areal extent of permafrost regions (permafrost probability>0) is approximately 19.82 million square kilometers. We developed a rule-based decision framework to delineate the biophysical permafrost zones in the Northern Hemisphere at 1-km resolution that incorporates the interactions among biophysical factors on permafrost vulnerability. The permafrost regions was classified into five types: climate-driven (19%), climate-driven/ecosystem-modified (41%), climate-driven/ecosystem protected (3%), ecosystem-driven (29%), and ecosystem-protected (8%). This map indicate that the 81% of the permafrost regions in the Northern Hemisphere are affected by ecosystems, indicating the dominant role that ecological processes have in controlling permafrost stability. The finding highlights the importance of reducing ecosystem disturbances (natural and human activity) to help slow permafrost degradation and lower the related risks from a warming climate. The map is potentially useful for predicting permafrost degradation and ecological transitions, and for assessing the future risks to infrastructure and society from climate warming, as well as for planning the mitigative strategies and measures of engineering infrastructure in cold regions.

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