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Geospatial modelling of soil organic carbon density in 3D across the northern circumpolar permafrost region

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The northern circumpolar permafrost region contains up to half of the global soil carbon pool and twice as much carbon as currently is in the atmosphere. At the same time, the Arctic is rapidly warming due to climate change, causing the permafrost to thaw. There is a risk that substantial amounts of soil organic carbon (SOC) may be released into the atmosphere as greenhouse gases during this process. This makes permafrost carbon a potentially strong climate feedback that could further amplify global warming.

Currently, only a few studies attempted to quantify this permafrost carbon on a global scale. Despite the advances in estimating how much SOC is stored in the northern circumpolar permafrost region, there are still large uncertainties. Modelling permafrost carbon is particularly challenging due to the scarce availability of reference datasets on SOC content and great subsurface variability in the Arctic environment caused by cryoturbation. The high lateral (i.e. horizontal) and vertical (i.e. along the soil profile) variability results in several obstacles when mapping SOC in permafrost regions.

While previous studies on modelling permafrost carbon focused on quantifying its spatial heterogeneity, they lacked in capturing the complex (vertical) distribution of SOC as a function of depth. Furthermore, they often rely on discrete models to estimate the spatial variation. In this work, we focus on providing more accurate high-resolution, continuous global maps of permafrost SOC density using a 3D digital soil mapping approach. Digital soil mapping has shown to be a valuable tool in mapping SOC, as it can better capture the continuous variation of soil properties. Here, we used a random forest machine learning model to predict SOC based on a number of spatial variables representing soil forming factors (such as topographic attributes, climate, carbon age and land cover). The reference dataset that we used to train the model consists of soil profile observations from the permafrost region of the Northern Hemisphere, excluding alpine permafrost. We harmonised this dataset from existing databases and recent studies that provide information on carbon content from soil core measurements. Information on the bulk density was needed to calculate the SOC density and estimated for missing observations using pedotransfer

functions. Results indicate that 3D modelling of permafrost carbon produces substantially different results than conventional 2D approaches. Furthermore, accounting for the vertical variation in SOC improves the prediction accuracy.