EGU21-11395
https://doi.org/10.5194/egusphere-egu21-11395
EGU General Assembly 2021

Applying Computed Tomography (CT) scanning for segmentation of permafrost constituents in drill cores

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Computed X-ray Tomography is a non-destructive technique that allows three-dimensional imaging of soil samples' internal structures, determined by variations in their density and atomic composition. This study's objective was to develop an image processing workflow for the quantitative analysis of ice cores using high-resolution CT in order to determine the volume fraction and vertical distribution of ice, mineral, gas, and organic matter in permafrost cores. We analyzed a 155 cm permafrost core taken from a Yedoma permafrost upland on Kurungnakh Island in the Lena River Delta (northeast Siberia). The obtained results were evaluated and compared with the results of detailed, but sample-destructive laboratory analysis. The frozen permafrost core was subjected to a computerized X-ray imaging procedure with a resolution of 50 micrometers. As a result, we obtained 31000 images. Noise in the raw images is removed with a non-local means denoising filter. We chose multilevel thresholding method for the image segmentation step. Threshold values were determined based on the histograms of the images. We measured the volumetric ice content (VIC) using Java-based image processing software (ImageJ). In addition, the vertical profiles were analyzed in 1-2cm intervals. We received bulk densities and VIC by freeze-drying and standard laboratory analysis. From the top of the core and until roughly 86 cm, it mainly consists of ice and organic, with an average of 67% and 30% results, respectively. The rest of the volume is divided almost equally between air and mineral parts. Below 86 cm, it consists almost entirely of pure ice. The ice content constitutes around 97% of the composition, and air rises to roughly 3%, while mineral and organic are almost equal to zero. The difference between VIC derived through CT scan and laboratory-derived VIC lies within the range of -37% to 25%. However, the vast majority of values lie within the range of -10% to 10%. This image processing technique to quantify VIC provides a non-destructive analog to traditional laboratory analysis that could help increasing the vertical resolution for quantifying mineral, ice, gas, and organic components in permafrost cores as well as enhance the volumetric estimate.