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MODELING IN-SITU HYSTERETIC VARIATION OF UNFROZEN WATER CONTENT IN HIGH-LATITUDE FINE-GRAINED PERMAFROST

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Unfrozen water content (UWC) is one of the key variables in modeling of thermal regime of permafrost as it influences calculation of bulk soil thermal parameters (e.g. Romanovsky & Osterkamp 2000). However, in-situ UWC measurements from periglacial environments are sparse and continuous timeseries over several complete freeze-thaw cycles are rarely available for validation of UWC parameterization schemes.

One of the models that describe variation of UWC with sub-freezing temperature T in fine-grained soil is a power function: $\theta(T) = a|T|^{-b}$ where $a, b > 0$ for $T < T^* < 0°C$ (Lovell, 1957). a and b are empirical parameters that require site-specific calibration. T^* is the lowest temperature at which all water in the soil sample is unfrozen; it depends on the soil grain size and freezing point of the pore water as a free substance.

With availability of 3 years of in-situ monitoring data from fine-grained high-latitude permafrost, we describe seasonal UWC dynamics in the active layer. We calibrate the parameters of the UWC model using one year of UWC and ground temperature records. We then use the calibrated model to predict UWC from ground temperatures in the following two years. The UWC was monitored at a site in Ilulissat, West Greenland (69° 14' N, 51° 3' W, 33 m above sea level), situated in continuous permafrost with mean annual air temperature -5.1°C (years 2003 - 2012). Core samples from the site contain up to 55% clay (grain size < 2μm) and 25% fine silt (grain size 2 - 6μm). Active layer thickness is 0.9 meters. The volumetric UWC and ground temperature are measured in 3-hourly intervals, 8 times per day, with two Steven's Hydra Probe II SD-12 sensors employing frequency domain reflectometry technology. The two sensors are placed at depths of 0.3 and 0.55 meters respectively.

The UWC dynamics are distinctly different between periods of soil freezing and thawing respectively. UWC during freezing is up to 50% higher than during thawing at the same ground temperature. Zero-curtain conditions during freezing lasts for ca. 3 weeks, during which UWC decreases steadily. On the contrary, the thawing of same volume of water happens abruptly over the course of ca. 2 days according to the sensor measurements. Microscopic processes of ice formation and melting likely contribute to different rates of freezing and thawing. Different freeze-thaw patterns can be observed even during events of partial thawing during frozen period. Nevertheless, we observe that the freezing and thawing patterns respectively remain the same every year. Between ca. 15th June – 31st August, the ground is unfrozen at the sensor depth and soil drying and possibly water runoff dominate the UWC variation despite low hydraulical conductivity of the soil.

Due to the observed freeze-thaw hysteresis, we split the UWC calibration into two seasons and calibrate two sets of a and b parameters on UWC measurements. Freezing season starts around the time when maximum depth of active layer is reached (1st September) and lasts until 28th February when the lowest ground temperatures are recorded. In the thawing season, only days between 1st March – 15th June (while the UWC variation is dominated by ground temperature as opposed to water circulation) are used for calibration. The model calibrated on freezing and thawing seasons 2012/2013 predicts UWC measurements in the following two years 2013/2014 and 2014/2015 within 5%.

In this work, we demonstrate that the calibrated model is able to predict the future UWC dynamics from measured or modeled ground temperatures with high accuracy. We also show that the freeze-thaw hysteresis is an important factor and its influence on heat transport in the ground should be considered when accounting for the UWC in permafrost models.

References:

Lovell, Jr. C. 1957. Temperature effects on phase composition and strength of partially-frozen soil. Highway Research Board Bulletin, 168.

Romanovsky, V. E. & Osterkamp, T. E. 2000. Effects of Unfrozen Water on Heat and Mass Transport Processes in the Active Layer and Permafrost. Permafrost and Periglacial Processes, 11: 219-239.