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Simultaneous estimation of snow depth and freezing-ground uplift by GPS Interferometric Reflectometry over a permafrost area

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Ground surface movements and snow cover during freeze/thaw cycles of permafrost are important variables for studying climate change. GPS-IR has emerged as an effective technique to estimate the relative elevation changes of ground surface such as the thaw subsidence of frozen ground and snow depth variations. In permafrost areas, the freezing process of the ground is always accompanied by the snow accumulations, making it hard for GPS-IR to separate these two distinct signals from the estimated elevation changes. In this study, using the Signal to Noise Ratio (SNR) collected by a permafrost GPS site SG27 (Northern Alaska) in 2018, we proposed a physical model-based method to simultaneously estimate the daily snow depths and freezing-ground uplifts with GPS-IR. First, we applied GPS-IR to the SNR data to obtain the daily elevation changes of the ground surface from September 1 in 2018 to August 31 in 2019. The elevation change measurements indicate the onset of snow season on October 18 in 2018 and the end of snow-cover on June 15 in 2019. Second, we used the thermal index Accumulated Degree Days of Freezing (ADDF) calculated from the temperature records to determine the onset of the permafrost freezing season as of September 17 in 2018. Third, we fitted the Stefan function to the estimated elevation changes (i.e. freezing-ground uplifts) from September 17 to October 18 in 2018. The Stefan model agrees with the freezing uplifts with an R^2 of 0.65. Forth, we extended the fitted model to the time when the ground was completely frozen (November 1) to estimate daily freezing-ground uplifts up to 1.75 cm under the snowpack. Last, we extracted the snow depths from the estimated elevation changes by subtracting the corresponding freezing-ground uplifts. Our study is the first attempt to simultaneously estimate the daily freezing-ground uplifts and snow depths over the permafrost area with GPS-IR, providing the measurements to understand the coupling effects of the permafrost and snow cover.