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Time-lapse GPR to quantify internal glacier deformation

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The estimation of surface flow velocities using satellite imagery, photogrammetry, or GPS data is now a standard practice in glaciology. In contrast, assessing internal ice deformation remains a significant challenge, often relying upon sparse measurements and theoretical models constrained by limited data. This study explores the potential of repeat, common-offset, ground-penetrating radar (GPR) reflection surveys as a tool to address this challenge. While GPR reflection data are traditionally utilized to determine glacier bed geometry, they also reveal key information about internal glacier structures, including the distribution of air pockets, debris, and water channels. Over time, these structures deform in response to glacier dynamics, suggesting that time-lapse GPR measurements could offer insights into internal flow velocities. In this regard, we propose a localized cross-correlation (LCC) approach, inspired by feature-tracking methods, as a starting point for a non-linear inversion of the deformation field. We test our methodology on synthetic GPR profile data, where electromagnetic wave propagation is modeled in a simplified flowing glacier containing randomly distributed scatterers, as well as on repeat GPR profiles acquired on the Findelen Glacier, Switzerland. In both cases, the GPR measurements are considered along the direction of glacier flow, and the corresponding data are diffraction enhanced and migrated prior to analysis. Our findings demonstrate that the proposed approach successfully retrieves the two-dimensional along-flow velocity field, highlighting its potential for field applications and future extension to three-dimensions.