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Three-dimensional measurements of the deformation of snow induced by a cone penetration test

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Cone penetration tests (CPT), such as rammsonde measurements, are common to get an objective vertical profile of snow hardness. Penetrometers with a very high resolution like the snow micro-penetrometer (SMP) capture, in addition to the mean hardness, information about the snow microstructure from the measured force fluctuations. During the indentation, the snow next to the cone tip is compacted, which affects the measured hardness and is not accounted for in the existing models. It is thus necessary to better understand the deformation field and processes occurring next to the tip in order to link the snow microstructure and the measured signal of the SMP. To this end, we introduce combined measurements of 3D micro-tomography imaging of the snow and penetration tests conducted with the SMP. Since sintering is very active in snow, CPT in snow are highly rate dependent. Consequently, CPT and tomographic imaging cannot be conducted incrementally. Several samples spanning different seasonal snow types were imaged twice at a resolution of 15 microns: once before and once after a CPT performed with the SMP. To fully recover and quantify the displacements between the pre-CPT and post-CPT images, which is a difficult task due to the presence of very large discontinuous displacements, a new and specific algorithm was developed. It combines image correlation and matching between grains based on morphological criteria. The analysis of the computed displacement field and the associated re-organization of bonds give new insight to interpret the SMP signal in terms of microstructural parameters.