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Comparison of elastic moduli from seismic diving-wave and ice-core microstructure analysis in Antarctic polar firn

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The densification of firn depends on the elastic properties of firn, processes which are still not fully explained by the usual models. Geophysical methods provide spatially distributed data, while the analysis of firn cores is restricted to finite locations, but with a different vertical resolution. In this study, we compared elastic moduli in polar firn derived from refraction seismic velocity analysis and vertical density profiles from the firn-core measurements to elastic properties derived from microstructure modelling based on firn-core data. The seismic data were obtained with a small electrodynamic vibrator source (ElViS) near Kohnen Station, East Antarctica. The analysis of diving waves resulted in velocity–depth profiles for P-, SH- and SV-wave velocities.

Elastic moduli of firn were derived by combining P- and S-wave velocities and densities obtained from firn-core measurements. P-wave velocities derived from diving-wave analysis range from 2060 $m\,s^{-1}$ at 10 m depth to 3400 $m\,s^{-1}$ at 70 m depth, S-wave velocities from 1250 $m\,s^{-1}$ to 1700 $m\,s^{-1}$, respectively. The structural finite-element method (FEM) was used to calculate the components of the elastic tensor from firn microstructure derived from X-ray tomography of firn-core samples at depths of 10, 42, 71 and 99 m. Shear and bulk moduli range from 0.39 GPa to 2.42 GPa and 0.68 GPa to 2.42 GPa, respectively. The elastic moduli from seismic observations and the structural FEM agree within 8.5% for the values derived at a depth of 71 m, and are within the uncertainty range. Our study demonstrates that elastic moduli of firn can be consistently obtained from two independent methods, which are based on dynamic (seismic) and static (tomography and FEM) observations, respectively. The agreement of the results for both methods indicates that elastic properties in firn can be acquired as spatially distributed data with the seismic approach, supported by local density information. Thus, information about elastic properties can be derived over larger lateral distances than would be possible with the static method. This enables the analysis of the firn and conclusions of the densification models might be drawn from observations of spatial and temporal changes in elastic properties.