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Measuring the elastic modulus of snow

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The elastic modulus is a fundamental mechanical property of snow and key for the interpretation of seismic measurements, assessment of slope stability or development of constitutive models. However, literature values scatter by orders of magnitude due to visco-plastic peculiarities of ice and microstructural variability. Hitherto still no cross-validated measurement exists.
To this end we employ P-wave propagation experiments under controlled laboratory conditions on decimeter-sized snow specimen prepared from artificial snow and subjected to isothermal sintering, to cover a considerable range of densities (170 – 370 kgm^−3). The P-wave modulus was estimated from wave propagation speeds in transverse isotropic media and compared to microstructure-based finite element calculations (FEM) facilitated by X-ray tomography imaging of sub-sample microstructures. Heterogeneities and size differences between acoustic and FEM sample volumes were characterized by SnowMicroPen measurements, yielding an elastic modulus as a by-product. The moduli derived from the acoustic and FEM method are in very good agreement (R2 = 0.99) over the entire range of densities covering values from 10 – 340 Mpa. A remaining bias (24 %) between both methods can be explained by layer heterogeneities which systematically reduce the estimates from the acoustic method.
The consistency of these first-principle methods supports the validity of long-standing, published FEM moduli for various snow types and opens non-destructive routes to time-resolved elasticity measurements during fast sintering.

Significance statement

The work contains the first cross-validated measurements of the elastic modulus of snow. Due to influences of visco-plasticity, commonly effective moduli are measured which is reflected by a considerable scatter of published values. Our results show that it is possible to measure the true elastic modulus of snow.

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