Characterizing microstructural arrangement and effective properties of dry snow: thermal conductivity

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A microstructural quantity, the contact tensor, is introduced to characterize the directional arrangement of bonding in the snowpack. The contact tensor is particularly useful in quantifying weak layers that develop a preferred directional arrangement, as evidenced by chains of grains in depth hoar and other faceted layers. Like other snow microstructural variables—grain size and shape, bond size, etc...—the directional arrangement of bonds impacts thermo-mechanical properties like strength, stiffness, and conductivity. The most important contribution of the contact tensor is to explain the directional dependence of snow’s properties. Snow’s strength, stiffness, and conductivity are not necessarily equal in all directions because the grains might not be uniformly packed.

The contact tensor is applied here to effective thermal conductivity. Dry, dense snow was subject to large (100 and 50 K/m) temperature gradients in a lab. The resulting morphology was typical of temperature gradient metamorphism, like depth hoar or other faceted layers. Underpinning the importance of microstructure to material properties, the derived effective heat conductivity increased in the direction of the applied gradient without appreciable changes in density. Tomography from these tests yielded measureable microstructural data used to analytically predict the thermal conductivity. Through the contact tensor, the analytical model accounts for ~40\% of the observed increase in effective heat conductivity. The model also calculates a decrease in conductivity in directions perpendicular to the temperature gradient. This prediction is consistent with field observations of depth hoar layers. Snow metamorphism models parameterized by density alone cannot account for such behavior.