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Lateral Variability in Firn Properties Revealed by Active Source Seismic Surface Waves

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Determination of snow and firn properties such as density, stratigraphy, depth to glacial ice and elastic properties, have important implications in glaciology including the study of past snow accumulation rates, paleoclimate interpretation, glacier flow dynamics and crevasse formation. We present a new method for polar firn and shallow ice imaging that exploits the dispersive properties of seismic surface waves. We show that Rayleigh waves present in conventional active source seismic reflection data can yield shear wave velocity profiles several tens of meters deep and image firn and shallow ice structure in polar environments. The gradational increase of seismic phase velocity and density from surface snow to the firn-ice transition causes dispersion of seismic surface waves. We tested the multichannel analysis of surface waves (MASW) method on a seismic reflection line on Jakobshavn Glacier, Greenland, and obtained a continuous 10 km long by 85 m deep shear wave velocity profile of the near surface. Shear wave velocity estimates derived from surface wave dispersion curves are in good agreement with conventional seismic refraction data. The shallow velocity structure of the 10 km long profile correlates well with ice internal layers imaged by a coincident ground-penetrating radar line. Lateral shear wave velocity variability of up to 10% suggests shallow ice density and shear strength variability at the few hundred-meters to kilometer scale along the 10 km profile. This observation lends support to shallow ice core variability that has been observed at the local scale on the Greenland ice sheet. We conclude that seismic surface wave analysis can be used for continuous firn and shallow ice profiling along active source seismic profiles.