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Inferences on geothermal flux in glaciated regions via active seismic methods

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Ice dynamics are strongly modulated by the thermal regime of the polar ice sheets, as englacial temperature plays a vital role in determining the ability of ice to flow, either by internal deformation, basal sliding, or some combination of the two mechanisms. This thermal regime reflects a complex interplay between the downward advection of surface temperature through accumulation, horizontal thermal advection via ice flow, and the upward conduction of heat due to geothermal flux and any frictional heating from basal sliding and/or internal deformation. Of these parameters, geothermal flux and its variability beneath the ice sheets is the least understood, yet it is an integral component in ice dynamics for controlling whether the subglacial bed is frozen or thawed; a high flux produces basal meltwater which lubricates and smooths the bed, allows for basal sliding, and helps promote fast ice flow, whereas a low flux keeps the bed frozen and rougher, thereby prohibiting basal sliding. Here we present a novel active seismic approach to estimate geothermal flux in glaciated regions and determine how it shapes the thermal regime of the subglacial bed.

Englacial seismic attenuation, a measure of the amplitude decay of a seismic wave travelling in ice, is quite sensitive to variations in englacial temperature, especially as the pressure-melting temperature is approached. These observations have been repeated numerous times in laboratory experiments, though field measurements have been limited and difficult to obtain. Utilizing the spectral ratio method, where the offset-dependent decay of the frequency spectrum of a seismic reflection yields seismic attenuation, we are able to calculate seismic attenuation through the ice column. The results given here are from three wide-angle common midpoint (CMP) seismic reflection datasets across Antarctica and Greenland where englacial and basal seismic reflections are observed, whose calculated seismic attenuations exhibit a positive correlation with observed englacial temperatures. These seismic attenuation profiles are colocated with *in situ* borehole temperature profiles to develop a relationship between seismic attenuation and englacial temperature. Coupled with seismic amplitude variation with offset (AVO) constraints on the thermal state of the subglacial bed, we obtain a basal boundary condition of frozen or thawed for our temperature relationship in deriving a thermal gradient to the bed. Using surface GPS measurements, we back out any frictional heating at the bed due to basal sliding, leaving geothermal flux as the only source for upward conduction of heat, allowing us to make an estimate of heat flux at the subglacial bed.

This technique for estimating geothermal flux in glaciated regions will provide a first order approach for constraining heat flow beneath the polar ice sheets, where direct measurements are sparse and extremely difficult to obtain. While we are unable to provide precise measurements of geothermal flux, we can obtain numerous course measurements in a region over the length of a field season. These measurements will provide ice sheet modelers with better details on where the bed will maintain a thawed or frozen state, as well as provide geodynamicists with better constraints on the recent geologic thermal state of polar regions.