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Seismic Full Waveform Inversion (FWI) to characterise the structure of firn

Emma Pearce[1], Adam Booth[1], Paul Sava[2], and Ian Jones[3]
[1]University of Leeds, School of Earth and Environment, Leeds, UK
[2]Colorado School of Mines, Golden, Colorado, US
[3]ION Geophysical

The transformation of snow into ice is a fundamental process in glaciology. The yearly accumulation of fresh snowfall increases the overburden pressure, changing the snow's properties such that it transitions into firn and pure glacier ice thereafter. Additionally, periods of melt and variations in subsurface and surface conditions can lead to the presence of ice layers and firn aquifers within the firn column. Therefore, firn characteristics provide a tool for evaluating past and present climate conditions relating to the amount of snow accumulation, melt, temperature conditions and the subsequent preservation of the snow.

Due to the importance of relationships between firn and other glaciological processes (e.g., settling, sublimation, recrystallization and other deformation processes) it has not been possible to develop a theoretically-based model which accurately predicts firn properties with depth. Therefore, methods of measuring firn are either intrusive or rely on (potentially unreliable) empirical conversions. Full Waveform Inversion (FWI) may offer a new standard for glaciological seismic modelling, mitigating issues within current seismic modelling techniques and paving the way for the recovery of elastic properties, including density. Constraining firn properties also leads to improved corrections for deeper seismic responses, e.g. glacier bed reflectivity.

Using seismic datasets obtained from Norway's Hardangerjøkulen Ice Cap (60.47°N, 7.49°W) along with varying synthetic firn column scenarios (introducing the presence of ice lenses and firn aquifers), we show how FWI can mitigate the dependence on intrusive techniques and empirical relationships. Furthermore, we compare the robustness of the FWI approaches versus traditional glaciological approaches to velocity model building (Herglotz-Wiechert inversion).