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Subglacial sediment distribution from constrained surface-wave inversion using the MuLTI algorithm: Examples from Midtdalsbreen, Norway

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Fast ice flow can be associated with the deformation of subglacial sediment. Seismic shear velocities, Vs, increase with the rigidity of a material, hence can be used to distinguish soft sediment from hard bedrock substrates. Although seismic reflection methods are widely applied to characterise base-ice properties, seismic responses can only be reliably inferred in the few metres either side of the reflective interface (e.g., the glacier bed). Depth sampling can be extended into the subglacial environment by interpreting the Rayleigh wave, or 'groundroll', component of the seismic dataset, and the inversion of Rayleigh wave dispersion curves is a means of evaluating the variation of Vs with depth.

However, Rayleigh wave inversions can be highly ambiguous and lack depth sensitivity. We address these problems through the use of a new algorithm, 'MuLTI' (Multimodal Layered Transdimensional Inversion). As a Bayesian inversion, MuLTI yields a probability distribution of the variation of Vs with depth to facilitate comprehensive uncertainty assessment, and improves depth sensitivity by including external depth constraints. In synthetic trials, the addition of depth constraints reduces the error between the true and best-fit models by a factor of 10, and halves the vertically-averaged spread of the error distribution. Depth constraints can be drawn from any external source, including borehole and radar datasets, provided that constrained horizon also represents a seismic contrast.

We demonstrate the application of MuLTI for a Rayleigh wave dataset acquired using active-source (MASW) techniques to characterise sediment distribution beneath the frontal margin of Midtdalsbreen, an outlet of Norway's Hardangerjøkulen ice cap. Ice thickness (0-20 m) is constrained using collocated GPR data. Outputs from MuLTI suggest that partly-frozen sediment (Vs 500-1000 m/s), overlying bedrock (Vs 2000-2500 m/s), is present in patches with a maximum thickness of $\sim$4 m, although this approaches the resolvable limit of our Rayleigh wave frequencies (14-100 Hz). Uncertainties immediately beneath the glacier bed for the constrained inversion are low, $< \pm 280$ m/s.

In terms of broader applications, the higher uncertainties from unconstrained inversions may not impede the distinction between sediment and bedrock substrates, but the reduced range from MuLTI would be critical if Vs observations were to be used to quantify detailed variations in sediment properties. Being supplied only with a Rayleigh wave dispersion curve, MuLTI is compatible with data acquired either from active- or passive- (e.g., teleseismic) sources.