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Polarimetric coherence: a data analysis method to determine ice fabric from phase-sensitive radar sounding

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The orientation distribution of ice crystals – the ice fabric – is an important component of ice rheology. The anisotropy of present-day ice fabric provides a record of past deformation, and, in turn, influences the viscosity of ice during future deformation. Our understanding of ice fabric within the polar ice sheets is primarily informed by measurements from ice cores which tend to be located at ice divides. Therefore, remote sensing is necessary to place observational constraints upon spatial variation in ice fabric and to assess its expression and influence across different flow regimes.

Polarimetric radar sounding provides a means to measure ice fabric anisotropy due to the associated dielectric anisotropy (birefringence) of polar ice. Past radar sounding analysis methods have focused upon polarimetric power to infer fabric properties. However, this approach is complicated by the combined effect of birefringent propagation and anisotropic scattering upon polarimetric power and can suffer from angular ambiguity. Here we describe a new phase-based 'polarimetric-coherence' method to determine ice fabric from a 'simple' ground-based radar sounding survey (single-polarized data as a function of azimuth). The coherence method provides a direct way to measure the polarimetric phase shift associated with birefringent propagation and from this we can determine horizontal fabric properties: specifically, the prevailing crystallographic axis and the asymmetry/strength of the fabric.

We describe the application of the coherence method to two different radar systems in two different ice flow regimes. First, we consider data acquired using MCRDs (Multi Channel Coherent Radar Depth Sounder) from the NEEM ice core region in northwest Greenland. Second, we consider data acquired using ApRES (Autonomous phase-sensitive Radio-Echo Sounder) from the Whillans Ice Stream, West Antarctica. In both case studies, we demonstrate that the radar fabric measurements provide new insights about past ice deformation and the stability/instability of ice flow patterns. Additionally, we formulate the analysis method in terms of a second order orientation tensor which enables us to directly compare and cross-validate with ice core fabric data at NEEM.