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Application of polarimetric radar to infer ice fabric anisotropy

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Understanding ice flow of ice sheets is not only important to predict their future evolution, but is also required for finding future ice-core sites with an intact stratigraphy and a constrained age-depth relationship of the corresponding climate record. Anisotropic ice flow, induced through the formation of aligned Crystal Orientation Fabric (COF), is in this context important as it may cause ice overturning and folding at larger depths. Here, we use a synthetic radar forward model to explore the feasibility of detecting the crystal orientation fabric orientation and strength using coherent, polarimetric ice-penetrating radar data (ApRES). We compare our results, with ApRES data collected in Antarctica. Some of the sites are located near deep drill ice-core sites (e.g., Dome C), and we validate our approach with ice-core data.

In multilayer models, we distinguish between birefringence (caused by ray propagation through anisotropic COF with unknown strength and orientation) and anisotropic scattering (caused by an unknown depth variability of anisotropic COF). We show analytically that the scattering ratio is determined by the angular dependence of co-polarization extinction nodes. Building on previous work, we infer COF orientation using the depolarization component, and COF strength from the gradient of polarimetric coherence, respectively.

We apply this approach to polarimetric ApRES datasets. We show COF orientation can often reliably be inferred as long as it does not change significantly with depth. Rotation of principal axis with depth, on the other hand, causes a complicated radar response that is not straightforwardly interpreted. At dome positions, where the ice anisotropy develops more gently compared to flank-flow settings, the degree of anisotropy can be estimated with the phase gradient method. This becomes increasingly more difficult for flank-flow settings where phase unwrapping is required. We delineate a number of anisotropic scattering zones which likely correspond to COF patterns changing abruptly. In some cases, boundaries between anisotropic scattering zones coincide with climate transitions within the ice.

We provide our model code in the form of a user-friendly GUI, enabling to quickly explore a wide range of possible COF patterns and their corresponding imprint in the radar data. This is useful both for scientific and educational purposes. Our analysis underlines the potential of coherent, polarimetric radars to infer the COF orientation of ice sheets also away from ice core sites. This will provide important data for the inclusion of ice anisotropy in ice-flow models in the future.