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Multi-frequency, polarimetric radar sounding of the interior of glaciers and ice sheets

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Ice-penetrating radar has been used to peer into the interior and bed of glaciers and ice sheets. Radar studies can potentially reveal much more than simply the geometry of the bed rock and internal layers (isochrones). Echo intensity from within ice varies in terms of radio-wave frequency and polarization. This talk reviews recent radar measurements, and relevant theoretical and ice-core based studies, with an emphasis on evaluation of the echo intensity rather than phase and two-way travel time of the echo.

Radio-wave propagation within Antarctic and Greenland ice sheets as well as cold glaciers is affected by firn/ice density, impurity (acid), temperature, and orientation of ice crystals. Variations in density and crystal orientation cause permittivity non-uniformities, while acidity variations cause conductivity non-uniformities. Dielectric attenuation during the two-way travel is frequency independent in the HF and VHF ranges so that frequency dependence of the permittivity- and conductivity-based reflectivities can be used to distinguish reflection causes. Dual-frequency radar measurements in Antarctica found that the primary reflection cause is altered from acidity to crystal orientation as ice flows downstream. Ice deformation develops a preferred fabric of the crystal orientation. Therefore, anisotropy in the fabric is related to strain that have been applied to the ice. Theoretical investigation using ice cores from the ice sheets shows that birefringence is significant in the VHF and UHF ranges even at dome summit regions. Radar measurements with various polarization planes identified whether birefringence or anisotropic reflection causes apparent anisotropy in the echo.

Multi-frequency, polarimetric radar measurements can also provide crucial information about polythermal and temperate glaciers, which includes liquid water within the ice body. Multi-frequency radar data were interpreted using Mie theory so that water content is derived near the cold-temperate surface in a polythermal glacier. Alternations of the radar polarization plane caused significant variations of the echo intensity in a temperate ice cap. A simple scattering model showed that a horizontal water-filled conduit gives a range of the variation consistent with the observed one.

All of these findings in the interior ice ultimately help interpret apparent bed reflectivity. In addition to theoretical and ice-core related work, it is crucial to map these frequency and polarization dependent features over the wide area using airborne radar.