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Diffraction imaging and velocity analysis of Antarctic GPR data

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The polar ice sheets have a controlling effect on the rise of global sea levels associated with ongoing climate change. Due to the generally low attenuation of high-frequency electromagnetic waves in ice, ground penetrating radar (GPR) signals can penetrate polar ice caps to depths of several kilometers. This makes GPR a key tool for determining the thickness of the ice sheets, investigating their internal structure, and characterizing the underlying bedrock topography. Since most GPR data are acquired in a bi-static, quasi-zero-offset manner, conventional signal processing techniques do not, however, allow for determining of the radar-wave velocity of the investigated ice masses, let alone its spatial variability. This is problematic, as this information is necessary for accurate imaging in general and for obtaining reliable estimates of the ice thickness in particular. Moreover, variations in radar-wave velocity directly reflect variations in ice water content, which is a key parameter for assessing the current state of ice sheets and for predicting their evolution. Here, we address this problem through diffraction imaging, which focuses on estimating the spatially variable radar-wave velocity from the scattered part of the GPR wavefield. To assess the potential of this method, we apply it to a 10-km-long GPR profile with a nominal center frequency of 60 MHz and a depth penetration in excess of 5 kilometers, which was acquired by the Polar Research Institute of China across the Lambert Glacier in East Antarctica. Our results suggest the presence of strong lateral radar-wave velocity variations, which, in turn, suggest correspondingly prominent variations in ice water content. The inferred radar-wave velocity model also allows for an enhanced depth imaging of the reflected part of the GPR wavefield through migration, thus corroborating its overall validity.