The effect of melt on seismic anisotropy of ice polycrystalline aggregates

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Observations of P-wave (Vp) and S-wave (Vs) velocities in Antarctic and Greenland ice sheets show a strong decrease of 25% of Vs in their deep parts, while Vp remains approximately constant. The drastic Vs decrease corresponds to the basal “echo free zone”, where large-scale disturbances and strong preferred ice crystal orientation are found. According to Wittlinger and Farra (2014), the low Vs may be due to the presence of unfrozen liquids resulting from pre-melting at grain joints and/or melting of chemical solutions buried in ice. In this contribution we investigate the evolution of seismic velocity anisotropy during deformation of temperate ice by means of microdynamic numerical simulations. Temperate ice is modelled as a two-phase non-linear viscous aggregate constituted by a solid phase (ice polycrystal) and a liquid phase (melt). The viscoplastic full-field numerical approach (VPFFT-ELLE) (Lebensohn and Rollet, 2020) is used to calculate the mechanical response of the two-phase aggregate, which deforms purely by dislocation glide. Viscoplastic deformation is coupled with dynamic recrystallisation processes, such as grain boundary migration, intracrystalline recovery and polygonisation (Llorens et al., 2017), all driven by the reduction of surface and strain energies. The changes in P- and S-wave velocities are calculated with the AEH-EBSD software (Vel et al., 2016) from single crystal stiffness and microstructural measurements of crystal preferred orientations (CPO) during deformation. Regardless the amount of melt and intensity of recrystallisation, all simulations evolve from a fabric defined by randomly oriented c-axes to a c-axis preferred orientation (CPO) distribution approximately perpendicular to the shear plane. For purely solid aggregates, the results show that the highest Vp and lowest Vs velocities are rapidly aligned with the CPO (at a shear strain of 1), and then evolve to a strong single maximum with progressive deformation. This alignment has been previously predicted in models, experiments and measured in ice core samples. When melt is present, the maximum and
minimum seismic velocities are not aligned with the CPO and both Vp and Vs are considerably lower than in cases without melt. However, if the bulk modulus of ice is assumed for the melt phase, the presence of melt produces a remarkable decrease in S-wave velocity while Vp is maintained constant. These results suggest that the decrease in S-wave velocity observed at the base of ice sheets could be explained by the presence of overpressured melt, which would be unconnected at triple grain junctions in the ice polycrystal.

References: