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The contribution of grain boundary melting to the water budget of polycrystalline ice

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Even well below the melting temperature many environmentally important impurities remain dissolved in liquid solutions above their eutectics. Such impurities are found in atmospheric particles and are eventually layered into glaciers and ice sheets as snow is compressed into ice. Thus, even at cold temperatures reservoirs of chemically reactive aqueous solutions exist in the cryosphere. The faster diffusion in such unfrozen liquids results in an effective bulk diffusion proportional to the phase fraction of liquid, $D_{eff} = \phi_l D_l$, which affects the redistribution of chemical, isotopic, and insoluble impurity constituents within polycrystalline ice. Grain boundaries in ice are nanoscopic compared with the veins and nodes known to contain bulk liquid water well below melting. However, grain boundaries dominate the ice surface area and therefore may contribute substantially to the available liquid at sub-freezing temperatures. Using measured equilibrium thicknesses of impurity rich ice grain boundaries we calculate their contribution to the liquid budget of polycrystalline ice for environmentally relevant grain sizes. Our results demonstrate that near the colligative melting temperature the volume fraction of liquid at grain boundaries can be significant and may dominate the equilibrium phase fraction. This finding may have far reaching effects relating to ice core timelines, glacial mechanics, and chemical reservoirs in frozen clouds.