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Migration of air bubbles in ice under a temperature gradient, with application to “Snowball Earth"

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To help characterize the albedo of “sea-glaciers" on Snowball Earth, a study of the migration rates of air bubbles in fresh-water ice under a temperature gradient was carried out in the laboratory. The migration rates of air bubbles in both natural glacier ice and laboratory-grown ice were measured for temperatures between -36 °C and -4 °C and for bubble diameters of 23 - 2000 μm. The glacier ice was sampled from a depth near close-off (74 meters) in the JEMS2 ice core from Summit, Greenland. Migration rates were measured by positioning thick sections of ice on a temperature-gradient stage mounted on a microscope inside a freezer laboratory. The maximum and minimum migration rates were 5.45 $\mu m\ hr^{-1}\ (Kcm^{-1})^{-1}$ at -4 °C and 0.03 $\mu m\ hr^{-1}\ (Kcm^{-1})^{-1}$ at -36 °C. Besides a strong dependence on temperature, migration rates were found to be proportional to bubble size. We think that this is due to the internal air pressure within the bubbles, which may correlate with time since close-off and therefore with bubble size. Migration rates show no significant dependence on bubble shape. Estimates of migration rates computed as a function of bubble depth within sea-glaciers indicate that the rates would be low relative to the predicted sublimation rates, such that the ice surface would not lose its air bubbles to net downward migration. It is therefore unlikely that air-bubble migration could outrun the advancing sublimation front, transforming glacial ice to a nearly bubble-free ice type, analogous to low-albedo marine ice.