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Oxygen isotope fractionation during the freezing of seawater

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The dependence of oxygen isotope fractionation on ice growth rate during the freezing of seawater was investigated, focusing on columnar ice, based on laboratory experiments and field observations in McMurdo Sound, Antarctica, and the Sea of Okhotsk. The laboratory experiments were performed in a tank filled with seawater, with sea ice grown under calm conditions at various room temperatures, ranging from -5 to -20 oC, which correspond to the growth rates from 2.2×10-7 to 9.3×10-7 m/s. In McMurdo Sound, the ice growth rate was monitored using thermistor probes for first-year land-fast ice that grew to a thickness of about 2 m, ranging from 0.8×10-7 to 1.7×10-7 m/s. In the Sea of Okhotsk, the growth rate was modeled by coupling the thermodynamic properties of the ice sheet with in-situ meteorological data. Combining these data sets allowed, for the first time, examination of fractionation at a wide range of growth rates from 0.8×10-7 to 9.3×10-7 m/s. In the analysis attempts were made to validate a stagnant boundary-layer (SBL) fractionation model using two independent data sets. Particular interest was in optimizing the parameters used in Eicken's (1998) model that included the effect of brine entrapment during freezing, based on the SBL model. The results show that the slope of the curve showed an abrupt change at the growth rate around 2.0×10-7 m/s and that the optimum values of equilibrium pure ice fractionation factor and boundary layer thickness were significantly different between these two ranges of growth rates. Besides, for practical use the empirical formula which correlates growth rates with effective fractionation coefficient for the whole range of growth rates was also obtained. By applying it to a real sea ice sample collected in the Sea of Okhotsk, it was shown that the vertical profile of oxygen stable isotope fractionation in sea ice is useful to reveal the growth rate history of the sea ice.