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Molecular diffusion of stable water isotopes in polar firn as a proxy for past temperatures

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Polar precipitation archived in ice caps contains information on past temperature conditions. Such information can be retrieved by measuring the water isotopic signals of δ^{18}O and δD in ice cores. These signals have been attenuated during densification due to molecular diffusion in the firn column, where the magnitude of the diffusion is isotopologoue specific and temperature dependent. By utilizing the differential diffusion signal, dual isotope measurements of δ^{18}O and δD enable multiple temperature reconstruction techniques. This study assesses how well six different methods can be used to reconstruct past surface temperatures from the diffusion-based temperature proxies. Two of the methods are based on the single diffusion lengths of δ^{18}O and δD, three of the methods employ the differential diffusion signal, while the last uses the ratio between the single diffusion lengths. All techniques are tested on synthetic data in order to evaluate their accuracy and precision. In addition, a benchmark test is applied to thirteen high resolution data sets from Greenland and Antarctica, which represent a broad range of mean annual surface temperatures and accumulation rates. The presented methods are found to accurately reconstruct the temperatures of the synthetic data, and the estimated temperatures are shown to be unbiased. Both the benchmark test and the synthetic data test demonstrate that the most precise reconstructions are obtained when using the single isotope diffusion lengths, with precisions around $0.5\,^{\circ}$C. In the benchmark test, the single isotope diffusion lengths are also found to reconstruct consistent temperatures with a root-mean-square-deviation of $0.7\,^{\circ}$C. The techniques employing the differential diffusion signals are more uncertain, where the most precise method has a precision of $1.5\,^{\circ}$C. The diffusion length ratio method is the least precise with a precision of $11.8\,^{\circ}$C. The absolute temperature estimates from this method are also shown to be highly sensitive to the choice of fractionation factor parameterization. From the combined analyses of the synthetic data and ice core data, this study demonstrates that methods based on the single isotope diffusion lengths result in the most accurate and precise estimates of past temperatures.