The role of sublimation as a driver of climate signals in the water isotope content of surface snow: laboratory and field experimental results

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Abstract. Ice core water isotope records from Greenland and Antarctica are a valuable proxy for paleoclimate reconstruction, yet the processes influencing the isotope snow signal are currently under debate. Apart from precipitation input, post-depositional processes at and below the surface are hypothesized to contribute to the isotope signal that is archived as an ice core climate proxy. Recent field studies have demonstrated that surface snow isotopes vary between precipitation events and co-vary with vapor isotopes, which implies a dependency of vapor isotopic composition on the snow isotope content and postulates vapor-snow exchange as a driving mechanism. Here we investigate how vapor-snow exchange and sublimation processes influence the isotopic composition of the snowpack. Controlled laboratory experiments under dry air flow show an increase of snow isotopic composition of up to 8 ‰ $\delta^{18}O$ in the uppermost layer, with an attenuated signal down to 3 cm snow depth over the course of 4-6 days. This enrichment is accompanied by a decrease in the second-order parameter d-excess, which strongly suggests kinetic fractionation processes. Using a simple mass-balance and diffusion box model in conjunction with our observed laboratory vapor isotope signals, we are able to reproduce the observed changes in the snow. This indicates that sublimation alone can lead to a strong enrichment of stable water isotopes in surface snow and subsequent enrichment in the layers below. To compare laboratory experiments with realistic polar conditions, we completed four 2-3 day field experiments at the East Greenland Ice Core Project site (Northeast Greenland) in summer 2019. High-resolution sampling of both natural and isolated snow was conducted under clear-sky conditions, and demonstrated that the snow isotopic composition changes on short timescales. The observed isotope change was substantially less than was observed under continuous and high sublimation rate conditions in the laboratory. A change of snow isotope content associated with sublimation is currently not implemented in isotope-enabled climate models and is not taken into account when interpreting ice core isotopic records. However, our results demonstrate that post-depositional processes such as sublimation influence the preservation of water isotopes in surface snow, suggesting that the ice core water isotope signal may effectively integrate across multiple parameters, resulting in a continuous climate record that should be interpreted as such.