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Using stable water isotopes to improve our understanding of snow processes across scales

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Cryospheric processes and interactions between the cryosphere and other Earth system components are complex, host important climate feedbacks and are often difficult to measure. Yet their understanding is crucial for predicting the evolution of the cryosphere in a changing climate. Stable water isotopes are natural tracers of phase change processes within the hydrological cycle. The variability of the individual and combined isotope species offer a way to constrain environmental climatic conditions during phase change processes. Thus, they are a prime tool to investigate air-snow interactions, which are at the core of one of the most uncertain but eminently important climate feedbacks. In polar settings these phase change processes are predominantly vapor deposition and snow or ice sublimation. However, the principle of isotopic fractionation during sublimation has been controversially discussed and the usefulness of tracing stable water isotopes in cryospheric processes is thus debated.
Here we demonstrate through field observations and laboratory experiments that air-snow humidity exchange leaves an isotopic fingerprint in the snow isotopic composition. We present in-situ data from the Greenland Ice Sheet and new results from cold-laboratory wind tunnel experiments. The measurements comprise isotopic signatures of snow, vapor and of the humidity flux itself. We show that snow sublimation is a fractionating process and outline how this information can be used to improve cryospheric process understanding. Specifically, we investigate the process of drifting and blowing snow by observing the evolution of both vapor and snow isotopic composition during cold-laboratory wind tunnel experiments. We document the existence of hitherto unobserved airborne snow metamorphism; a process observable on the macro-scale only through the lens of stable water isotopes. Based on the combined observations of in-situ surface humidity fluxes and wind tunnel experiments we discuss a physical explanation for the observed isotopic fractionation during snow sublimation. These insights and the data set

will be the basis for determining the fractionation factors associated with airborne snow metamorphism. Our results have important implications for the interpretation of stable water isotope signals from snow and ice cores and challenge the translation of the second-order parameter d-excess signal in polar regions as moisture source signal.