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Drivers of stable water isotope variability in the cold and warm sector of extratropical cyclones from two case studies in the Southern Ocean

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Dynamical processes in the atmosphere strongly influence the large temporal and spatial variability of the atmospheric branch of the water cycle. For instance, the advection of air masses by synoptic-scale weather systems induces air-sea moisture fluxes such as evaporation, precipitation and dew deposition. It is important to better investigate and quantify this linkage between dynamical phenomena and details of the atmospheric water cycle. In addition, one of the big challenges in monitoring the atmospheric water cycle is the measurement of turbulent moisture fluxes over the ocean. Stable water isotopes (SWIs) serve as a tool to trace atmospheric processes which shape the atmospheric water cycle and, thus, provide important insights into moist processes associated with weather systems, in particular air-sea fluxes.

In this study, we investigate the impact of air-sea moisture fluxes on the variability of SWI signals in the marine boundary layer. Measurements of the second-order isotope variable deuterium excess in the marine boundary layer of the Southern Ocean show positive/negative anomalies in the cold/warm sector, respectively, of extra-tropical cyclone due to opposing moisture fluxes and non-equilibrium fractionation processes in the two sectors. The drivers of these contrasting SWI signals are analysed using the isotope-enabled Consortium for Small-Scale Modelling model for two case studies. The simulated isotope signals during the case studies show excellent agreement with ship-based isotope measurements from the Southern Ocean performed during the Antarctic Circumnavigation expedition in January and February 2017.

The main driver of SWI variability in the cold sector is enhanced ocean evaporation which substantially modifies the advected SWI signal from the Antarctic continent during a cold air outbreak. In the warm sector, dew deposition on the ocean surface and cloud formation are mainly driving the observed negative deuterium excess anomaly, which can be conserved and advected over several 100 km in the warm sector of an extratropical cyclone.

The results of this study illustrate the strong dependence of the isotopic composition of water vapour in the marine boundary layer on the predominant atmospheric large-scale flow situation.

In particular in the storm track regions, the variability of SWIs in marine boundary layer water vapour is largely shaped by the sign and strength of air-sea fluxes induced by the meridional transport of air masses.