EGU21-4277, updated on 30 Jun 2022
https://doi.org/10.5194/egusphere-egu21-4277
EGU General Assembly 2021

Disentangling the impact of air-sea interaction and boundary layer cloud formation on stable water isotope signals in the warm sector of a Southern Ocean cyclone

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Stable water isotopes in marine boundary layer water vapour are strongly influenced by the strength of air-sea moisture fluxes and are thus tracers of air-sea interaction. Air-sea moisture fluxes in the extratropics are modulated by large-scale air advection, for instance the advection of warm and moist air masses in the warm sector of extratropical cyclones. A distinct isotopic composition of water vapour in the latter environment has been observed in near-surface water vapour over the Southern Ocean during the 2016/17 Antarctic Circumnavigation coordinated by the Swiss Polar Institute. Most prominently, the second-order isotope variable d-excess shows negative values in the cyclones' warm sector. Here, we present three single-process air parcel models, which simulate the evolution of d-excess and specific humidity in an air parcel induced by dew deposition, decreasing ocean evaporation or upstream cloud formation, respectively. The air-parcel models are combined with simulations with the isotope-enabled numerical weather prediction model $COSMO_{iso}$ (i) to validate the air parcel models, (ii) to study the extent of non-linear interactions between the different processes, and (iii) to quantify the relevance of the three processes for stable water isotopes in the warm sector of the investigated extratropical cyclone. This analysis reveals that dew deposition and decreasing ocean evaporation lead to the strongest d-excess decrease in near-surface water vapour in the warm sector. Furthermore, $COSMO_{iso}$ air parcel trajectories show that the persistent low d-excess observed in the warm sector of extratropical cyclones is not a result of material conservation of low d-excess. Instead the latter feature is sustained by the continuous production of low d-excess values in new air parcels entering the warm sector. We show that with the mechanistic approach of using single-process air parcel models we are able to simulate the evolution of d-excess during the air parcel's transport. This improves our understanding of the effect of air-sea interaction and boundary layer cloud formation on the stable water isotope variability of marine boundary layer water vapour.