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The isotopic composition of precipitation from a winter storm - a case study with the limited-area model COSMOiso

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Stable water isotopes are valuable tracers of the atmospheric water cycle, and potentially provide useful information also on weather-related processes. In order to further explore this potential, the water isotopes $H_2^{18}O$ and HDO are incorporated into the limited-area weather forecast and climate model COSMO. The new COSMOiso model includes an advanced microphysical scheme, a convection parameterisation and non-hydrostatic dynamics that facilitate simulations from sub-kilometre to synoptic spatial scales.

In a first case study, the model is applied for simulating a winter storm event in January 1986 over the eastern United States associated with intense frontal precipitation. The modelled isotope ratios in precipitation and water vapour are compared to spatially distributed δ^{18}O observations from a study by Gedzelman and Lawrence (1990). COSMOiso very accurately reproduces the statistical distribution of δ^{18}O in precipitation, and also the synoptic-scale spatial pattern and temporal evolution agree well with the measurements. Deviations at single stations can partly be attributed to errors in the representation of mesoscale atmospheric structures in the model. Grounded on this overall meteorological evaluation, the model is then used for investigating the physical processes causing the synoptic-scale variability of δ^{18}O during the selected event.

Perpendicular to the front that triggers most of the rainfall, COSMOiso simulates a gradient in the isotopic composition of the precipitation, with high δ^{18}O values in the warm air to the east and lower values in the cold sector behind the front. This spatial gradient is connected to a temporal evolution with high δ^{18}O values in the beginning and a decrease later on at locations where the front passes by. Two major processes are identified that contribute to creating the spatial pattern. First, the advection of cold, depleted water vapour to the west of the front and warm, more enriched vapour further to the east, in concert with the progressive removal of heavy isotopes by precipitation in the frontal band, cause a large scale west-to-east gradient of δ^{18}O of vapour and precipitation. Second, this large scale pattern is modulated by microphysical effects, namely the isotope fractionation and equilibration during the interaction of rain drops and water vapour beneath the cloud base.

This investigation illustrates the usefulness of high resolution, event-based model simulations for understanding the complex processes that cause synoptic-scale variability of the isotopic composition of atmospheric waters. In future research, this will be particularly beneficial in combination with laser spectrometric isotope observations with high temporal resolution.