Ice cloud formation pathways and their isotopic signals in high-resolution COSMO$_{iso}$ simulations of the African monsoon

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Abstract
Tropical ice clouds have an important effect on the Earth's climate system through their influence on the global radiation budget. These ice clouds are often poorly represented in climate models, which highlights the need for a better understanding of their formation, structure and variability. This study investigates the formation pathways of ice clouds and their isotopic signals of the African monsoon during June and July 2016. We use the isotope-enabled COSMO$_{iso}$ model to simulate the hydrological cycle and its isotopic composition of the African monsoon at different model resolutions and with different representations of deep convection. More specifically, we perform three sensitivity experiments with a (1) 14 km horizontal grid spacing and parameterized convection, (2) 14 km grid spacing and explicit convection, and (3) 7 km grid spacing and explicit convection. To evaluate the credibility of the model simulations, the isotopic composition of monthly precipitation is compared to station-based GNIP observations across Equatorial Africa. Next, we adopt a Lagrangian analysis to examine the history and processes of air parcels that contribute to the formation of ice clouds. Hereby, we (i) distinguish different ice cloud formation pathways, that is, formation through the liquid phase versus directly from the vapor phase, (ii) assess the isotopic signals in these ice cloud formation pathways, and (iii) examine the influence of different ascent rates that range from relatively slow ascent (>600 hPa in two days) to rapid convection (>600 hPa in two hours). Furthermore, this analysis can elucidate the origin and pathways of moisture that contributes to ice cloud formation. The two-month simulations may also serve to investigate whether the isotopic composition of ice clouds reflects information about the stage and intensity of the monsoon system.