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A coupled heat and moisture tracking framework to assess water cycle changes in a warming climate

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The expected intensification of the global water cycle in a warming climate comes along with an increase in the frequency and intensity of extreme events, such as droughts and floods. From a drought perspective, local limitations of terrestrial evaporation can cause a reduction of water vapor in the atmosphere and thus further induce local and remote precipitation deficits. Despite the existing myriad of tools and models to assess the origin of precipitation, trends and uncertainties in such source–sink relationships remain largely unexplored. The main reason is the scarcity of observations to explore these relationships and validate moisture-tracking models, which are commonly subject to assumptions that limit their reliability and applicability. Lagrangian models, for example, typically establish source–sink relationships based on moisture changes along air parcel trajectories, yet tend to be heavily affected by numerical noise. Moreover, they do not assess the plausibility of a given moisture change by considering the increasing saturation point of air with increasing temperatures, which hampers reliable assessments of trends under global warming.

Here, we present a holistic framework for the process-based evaluation of atmospheric trajectories to infer source–sink relationships of moisture. Building upon previous process-based evaluations of trajectories, we extend the analysis to a coupled heat and moisture diagnosis that includes physics-based limits for the detection of evaporation and precipitation from humidity changes along each trajectory. The framework comprises three steps: (i) the coupled moisture and heat diagnosis of fluxes from Lagrangian trajectories using multi-objective criteria, (ii) the attribution of sources following a mass- and energy-conserving algorithm, and (iii) the bias correction of diagnosed fluxes and the corresponding source–sink relationship. Applying this framework to simulations from the Lagrangian particle dispersion model FLEXPART, driven with ERA-Interim reanalysis data, allows us to quantify errors and uncertainties associated with the resulting source–sink relationships. A comparison to alternative methodologies illustrates the benefit of our coupled heat and moisture tracking approach. Moreover, the multivariate character of this framework paves the way for a cohesive assessment of the spatial dependencies that cause water cycle changes in a warming climate.