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Changing length scales of moisture transport — their isotopic imprint and implications for remote moisture dependence

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Isotope ratios in water vapor record evaporation (E) and precipitation (P) along moisture transport paths. At low latitudes, the path-integrated E-P signal is dominated by local E and P, providing an indicator of tropical water balance. In contrast, at high latitudes, E and P patterns upstream overwhelm local signals, reflecting the dependence on remote moisture sources. This dependence defines the length scales of moisture transport.

In the zonal mean, moisture transport length scales can be represented visually in two dimensions by moist isentropic surfaces, along which poleward moisture transport occurs. These surfaces explain why Rayleigh distillation reasonably approximates meridional variations in high-latitude isotope ratios while also providing a physical basis for why polar isotope-temperature relationships are distinct in space and time.

Isotopically enabled GCM simulations and short-duration Antarctic ground-based observations both lend support for the isentropic view of moisture transport. They also suggest that this framework provides a simple means to predict changes in length scale in a warmer climate, assuming zonal-mean humidity changes follow Clausius-Clapeyron scaling. However, isotopic observations with the vertical resolution and temporal coverage necessary to easily evaluate recent and expected future variations in moist isentropic transport are lacking.

Here, we consider two possible alternative methods for testing predictions about long-term moisture length-scale changes with isotopic observations. Using the two-decade-long AIRS satellite

record, we consider the extent to which mid-free tropospheric hydrogen isotope ratios, normalized by humidity, can provide a measure of length scale in a total-column sense. Second, we ask to what extent moist isentropic transport is set by episodic events, such as warm conveyor belts, that can be observed by infrequent but high-vertical-resolution airborne isotopic measurements. We discuss the implications of enhanced transport efficiency, expected in a warmer future, for increasing length scales and strengthening hydrological dependencies between remote locations.