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Local moistening and dehydration mechanisms derived using Lagrangian mass balance from Tropospheric Emission Spectrometer measurements of HDO and H2O

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A Lagrangrian mass transport model, dually constrained by H2O and HDO/H2O measurements from TES, is utilized in the intertropical regions to quantify turbulent moistening from a local tropospheric water vapor source, the humidity and isotopic composition of that local water vapor source, and the effective isotopic fractionation that occurs during dehydration events. The processes which form the dominant water vapor source for each region (i.e., convective detrainment, cloud or precipitation evaporation, or direct mixing) are exposed by comparing joint probability distributions of the derived water vapor source H2O and HDO/H2O values to those values expected from direct mixing between free tropospheric and marine boundary layer air, and to those values expected as boundary layer moisture rises and forms clouds which a) evaporate, b) precipitate, or c) recycle sub-cloud residual vapor following post-condensational exchange. Vapor formed from post-condensational exchange and strong convective recycling is found to contribute ~35-40% to total summertime turbulent moistening in the subtropical regions, while cloud evaporation primarily forms the vapor source for local turbulent moistening in the dry subtropics. In the dry subtropics, local turbulent moistening is found to be twice as sensitive to mixing rates as in other intertropical regions, is found to impact the large-scale humidity field substantially (~3%/day), and is an aspect of tropospheric hydrology that is largely ignored in advection-condensation models. Over tropical monsoonal areas, the most intense mixing zones are found to have relatively dry and depleted local source waters as a result of post-condensational exchange and recycling effects, which results in higher effective isotopic fractionation rates along moisture pathways than those predicted by Rayleigh theory. This mechanism provides an explanation for isotopic anomalies found in tropical ice cores, and is supported by past modeling work. Outside of these regions, the effective isotopic fractionation in the intertropics is found to fall below equilibrium fractionation rates calculated from Rayleigh theory, which indicates reversible moist adiabatic processes (i.e., cloud evaporation) imprint signals on the tropospheric distribution of isotopologues. The regional differences between effective and equilibrium isotopic fractionation rates found from the mass budget model are used here to provide a proxy for precipitation efficiency in the 850-500 hPa layer, and are found to be in reasonable agreement with results calculated from the model's condensation rates and TRMM precipitation rate profiles. The rehydrating effect of cloud evaporation is found here as an important aspect of climate, yet is neglected in advection-condensation models since this effect is likely to occur during last saturation. Several important mechanisms of the climate system emerge in this study: turbulence provides substantial local moistening to regions most sensitive for global water vapor feedback; local moistening is sensitive to the regional balance of condensation and precipitation rates, which is a balance imprinted on isotopologues in water vapor; and, isotopic depletion during convective recycling provides a mechanism for the anomalous isotopic signals observed in tropical ice cores. These results also provide a measure of the usefulness of assimilating satellite observations of isotopologues into more comprehensive isotope-enabled GCMs.