Tracking the Strength of the Walker Circulation with Water Isotopes

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General circulation models (GCMs) predict that the mean circulation & hydrological cycle will change in response to anthropogenic warming: as lower-tropospheric water vapor concentration increases, the atmospheric circulation and convective mass fluxes will weaken [*Held and Soden*, 2006]. However, these predictions remain uncertain and difficult to constrain, as convective mass fluxes are poorly observed and incompletely simulated by GCMs. Extending this prediction, simulations spanning the Last Glacial Maximum (LGM) provide crucial information regarding Earth's climate in a colder mean state with low greenhouse gas forcing. While warming simulations show a weakening tropical overturning circulation, by the same mechanism, LGM simulations show a strengthening of tropical circulation in response to cold and dry conditions [*Di Nezio et al.,* 2011].

We demonstrate that stable hydrogen isotope ratios in tropical atmospheric water vapor can trace changes in temperature, atmospheric circulation, and convective mass flux across mean state changes in climate in the past (LGM), present (historical period), and future (2100). We evaluate changes in temperature, the distribution of water vapor, vertical velocity (ω), advection, and water isotopes in vapor (δD_V) in water isotope-enabled GCM experiments (iCESM) for modern vs. LGM atmospheres to identify spatial patterns of circulation change over the tropical Pacific. In high-GHG 'future' simulations, we find that weakened circulation in the tropical Pacific moistens the lower troposphere and weakens convective mass flux, both of which impact the δD of water vapor in the mid-troposphere. Conversely, LGM simulations show large changes resulting from a variety of phenomena including strengthened rising motion in the western Pacific, all which have a distinct isotopic signature. We diagnose cold and warm mean-state changes to the tropical atmospheric overturning circulation, and subsequent impacts of those changes on water vapor & precipitation isotopes to extract an 'isotopic fingerprint' tracking the strength of the Walker Circulation. Our findings constitute a critical demonstration of how water isotope ratios respond to changes in radiative forcing. Moreover, as changes in δD_V can now be observed by satellites, our results develop metrics for the detection of greenhouse gas forcing impacts to the strength of the Walker Circulation. We compare both future and past simulations to available observations from satellite and paleoclimate data.