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Quantifying the influence of natural forcing on oxygen isotope variability in alpine and polar ice core sites

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Stable water isotope ratios are routinely used to infer past climatic conditions in palaeoclimate archives. In particular, oxygen isotope ratios in precipitation co-vary with temperature in high latitudes, and have been established as indicators for past temperature changes in ice-cores. The timescales for which this holds, and the validity of spatial/temporal regression slopes are difficult to constrain based on the observational record.

Here, surface climate and oxygen isotope ratio variability are compared across an ensemble of millennial-long simulations with the isotope-enabled version of the Hadley Centre Coupled Model version 3 (iHadCM3). The ensemble consists, amongst others, of paired experiments. One half were performed as conventional palaeoclimate equilibrium simulations for the Last Glacial Maximum (LGM, orbital and trace gas concentrations of 21kyrs BP), the mid Holocene (conditions 6kyrs BP) and the pre-industrial period (PI, 1850CE) analogously to the simulations in the Palaeoclimate Modeling Intercomparison Project. The second half of the ensemble is additionally perturbed by radiative forcing variations from solar variability and volcanic forcing as for the last millennium. Each simulation is continued for at least 1050 years.

We find that global mean surface temperature and precipitation decrease significantly in all considered climate states (LGM, 6k, PI). Post-volcanic temperature reduction is fairly consistent across the globe, but weak in Antarctica. In the PI state, we find a significant increase in the AMOC strength after eruptions. This does not occur for the LGM state. No significant responses to solar forcing were detectable in the isotopic record. Correlating precipitation-weighted $\delta^{18}O$ ($\delta^{18}O_{pr}$) at these locations with surface temperature across the globe shows strong linear relationships and teleconnections. In Greenland, $\delta^{18}O_{pr}$, at the decadal scale, shows high correlations across the Northern hemisphere for the PI simulations, but this spatial representativeness is smaller in the LGM.

We finally examine the detectability of strong interannual volcanic impacts in the climate and isotope record at ice core drill sites in West and East Antarctica, Greenland, the European Alps and the Tibet Plateau. At all locations, modeled isotope and climate variance is higher in the naturally forced simulations. On annual time scales, we find only weak imprints of sub-supervolcanic

eruptions in annual $\delta^{18}O_{pr}$ at most locations compared to interannual variability, with the exception of the Tibet plateau. We extend this epoch analysis to high-resolution ice core records to assess the consistency between modeled and measured isotope variations for prominent volcanic eruptions over the last millennium.

The inclusion of natural forcing in the simulations alleviates the discrepancy between modeled and observed isotope variability. However, the gap cannot be closed completely. This suggests that improving our understanding of the signal formation process, the dynamical origins of isotope signatures, and model biases at all latitudes is important to constrain the regional to global representativeness of stable water isotopes in ice cores.