An Assessment of Simulated Oxygen Isotope Changes During Spontaneous Dansgaard-Oeschger Type Oscillations in General Circulation Models

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Abstract

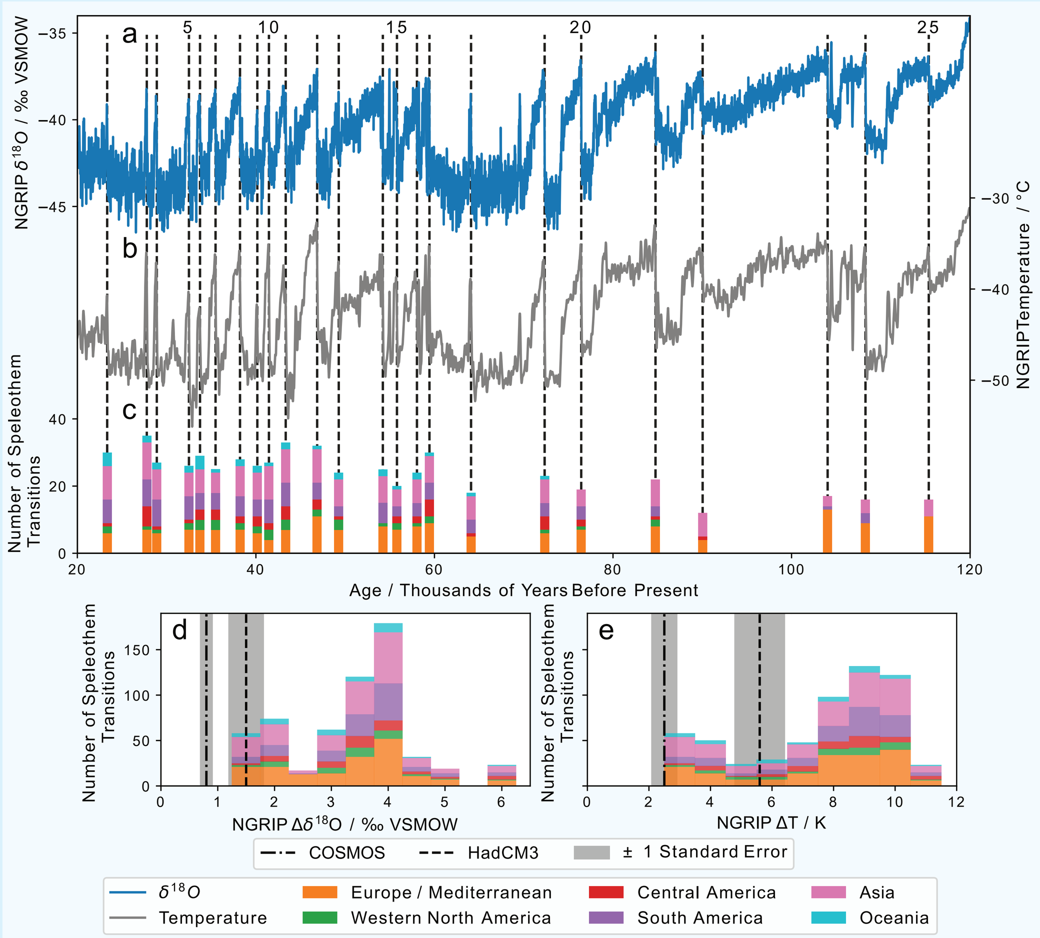
Several general circulation models have now demonstrated the ability to simulate spontaneous millennial-scale oscillations that resemble Dansgaard-Oeschger (DO) events. It is often unclear how representative of DO events these simulations are, particularly outside of the polar regions. To test this, we directly compare simulated $\delta^{18}O$ changes from two isotope-enabled models to a compilation of 111 speleothem records from 67 caves across the low- and mid-latitudes. We find that both models successfully reproduce the observed pattern of changes in Europe and the Mediterranean, Asia, and Central America. However, they perform less well for Western North America, South America, and Oceania, and the simulated changes are also generally too small in their magnitude. Where the models do reproduce the observed changes, we find evidence that the isotopic variability is influenced by both local and remote drivers. Care should therefore be taken when attributing observed changes to any single driver.

Key Points

1. We compare isotope-enabled simulations of Dansgaard-Oeschger events from two climate models to a compilation of speleothem oxygen isotope records
2. Both models successfully reproduce the signs of the isotopic changes across most of the Northern Hemisphere but generally underestimate their magnitudes
3. The isotopic changes simulated by HadCM3 are more consistent with the speleothem records than those simulated by COSMOS

Materials and Methods

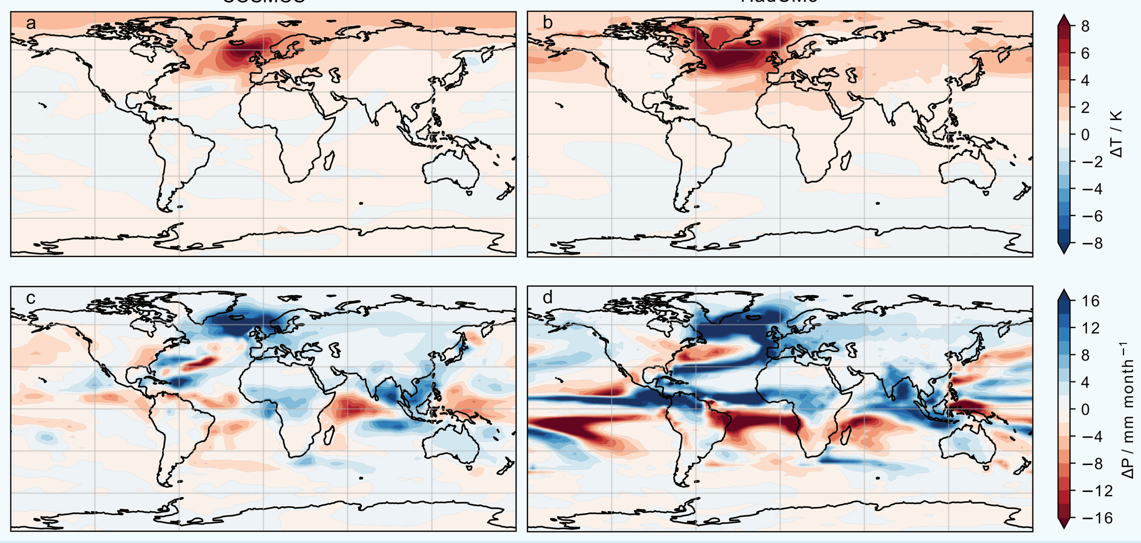
We investigate two spontaneously-oscillating simulations from the isotope-enabled GCMs COSMOS (Zhang et al., 2021) and HadCM3 (Armstrong et al., 2022). We calculate the stadial-interstadial differences in temperature T, precipitation P, and the precipitation-weighted isotope ratio $\delta^{18}O_{pw}$. We compare $\Delta\delta^{18}O_{pw}$ to the speleothem compilation of Fohlmeister et al. (2023).



The NGRIP $\delta^{18}O$ (a, Andersen et al. 2004) and temperature (b, Kindler et al. 2014) records from 20 to 120 ka BP, as well as the number of speleothem $\delta^{18}O_{sp}$ transitions in the Fohlmeister et al. (2023) compilation from each of our six regions that are associated with each DO event (c). Also shown are histograms of the NGRIP $\Delta\delta^{18}O$ (d) and ΔT (e) of each DO event, weighted by the number of associated speleothem transitions in each region, and with the simulated $\Delta\delta^{18}O_{pw}$ and ΔT at the NGRIP site in the two models overlaid.

Temperature and Precipitation

Both models show strong increases in temperature and precipitation amount across the North Atlantic region. There is little temperature change elsewhere, but there are large and heterogeneous precipitation changes.



The stadial-interstadial differences in annual mean temperature T (a,b) and precipitation amount P (c,d) for the COSMOS (a,c) and HadCM3 (b,d) models.

References

Andersen, K. K. et al. High-resolution record of Northern Hemisphere climate extending into the last interglacial period. Nature 431, 147–151 (2004).

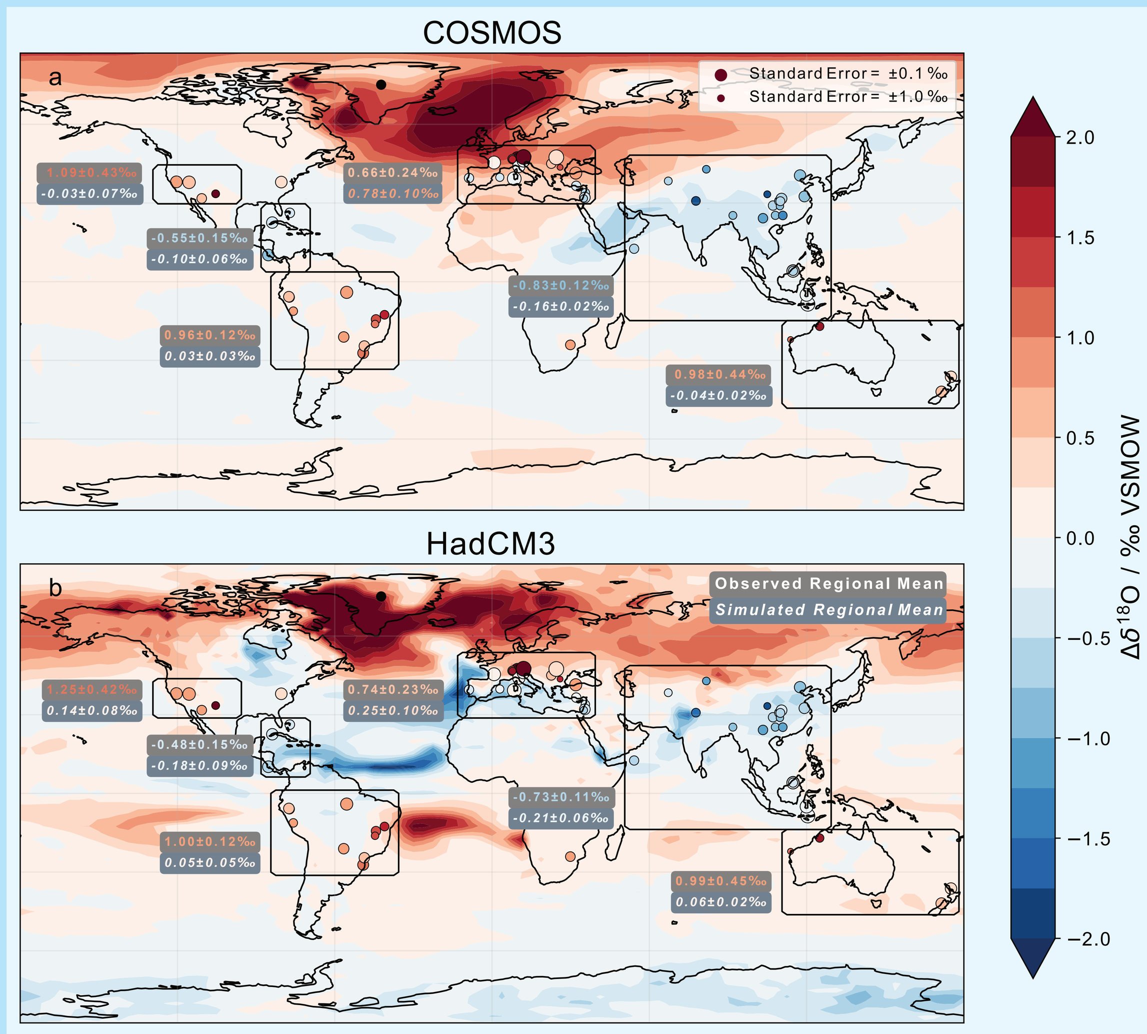
Armstrong, E., Izumi, K. & Valdes, P. Identifying the mechanisms of DO-scale oscillations in a GCM: a salt oscillator triggered by the Laurentide ice sheet. Clim Dyn (2022).

Fohlmeister, J. et al. Global reorganization of atmospheric circulation during Dansgaard–Oeschger cycles. PNAS 120, e2302283120 (2023).

Kindler, P. et al. Temperature reconstruction from 10 to 120 kyr b2k from the NGRIP ice core. Climate of the Past 10, 887–902 (2014).

Zhang, X. et al. Direct astronomical influence on abrupt climate variability. Nat. Geosci. 14, 819–826 (2021).

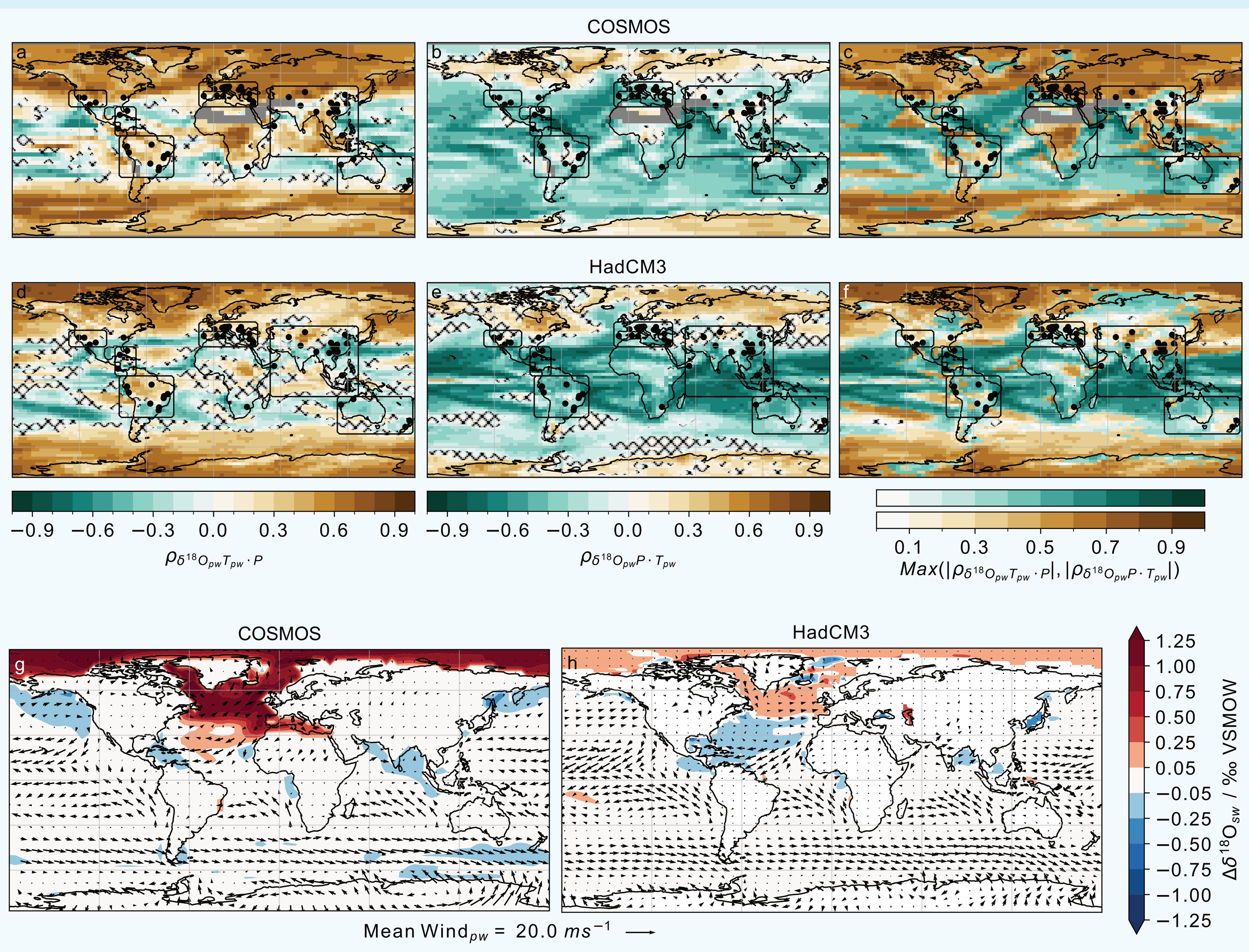
Proxy - Model Comparison



The stadial-interstadial $\Delta\delta^{18}O_{pw}$ of precipitation in the COSMOS (a) and HadCM3 (b) simulations (contours) along with the median stadial-interstadial drip-water equivalent $\Delta\delta^{18}O_{dw\text{-}eq}$ at each cave site in the Fohlmeister et al. (2023) speleothem compilation (coloured circles). The location of the NGRIP Greenland ice core is also shown with a black dot.

Local and Remote Drivers

We investigate the impact on simulated $\delta^{18}O_{pw}$ of changes in local temperature and precipitation, as well as the remote impact of changing surface sea water $\delta^{18}O_{sw}$ in moisture source regions. We find evidence that both the local and remote drivers influence the simulated isotopic changes.



Partial correlations at interannual timescales in COSMOS (a-c) and HadCM3 (d-f). The partial correlation between $\delta^{18}O_{pw}$ and T_{pw} at constant P ($\rho_{\delta^{18}O_{pw}T_{pw}\cdot P}$) is shown in a & d, and that between $\delta^{18}O_{pw}$ and P at constant T_{pw} ($\rho_{\delta^{18}O_{pw}P\cdot T_{pw}}$) is shown in b & e. Panels c & f show whichever of these partial correlations is stronger, with green shading where P is the dominant influence on $\delta^{18}O_{pw}$ and brown where T_{pw} has the stronger influence. Grid cells with partial correlations that are not significant at the 5% level are hatched. The precipitation-weighted mean surface wind field (arrows) and the stadial-interstadial $\Delta\delta^{18}O_{sw}$ (filled contours) are also shown for both COSMOS (g) and HadCM3 (h), from which one can infer the component of $\Delta\delta^{18}O_{pw}$ that is due to changes in the $\delta^{18}O_{sw}$ of moisture source regions.