Investigating Western U.S. Hydroclimate over the Holocene with iCESM and Triple Oxygen Isotopes in Iron Oxides

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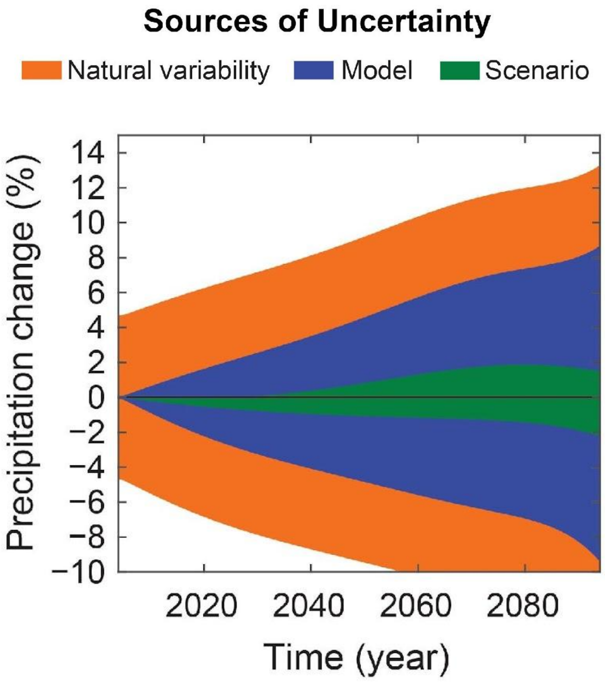
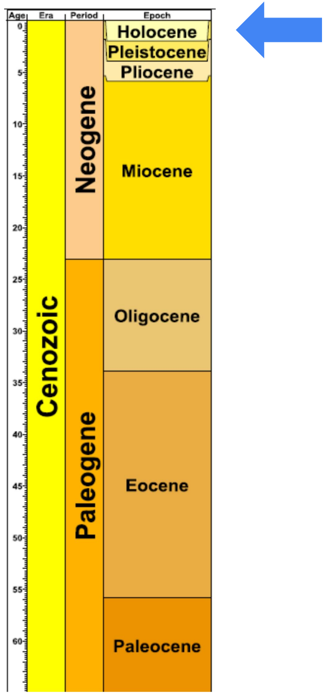
Climate variability in the western U.S.



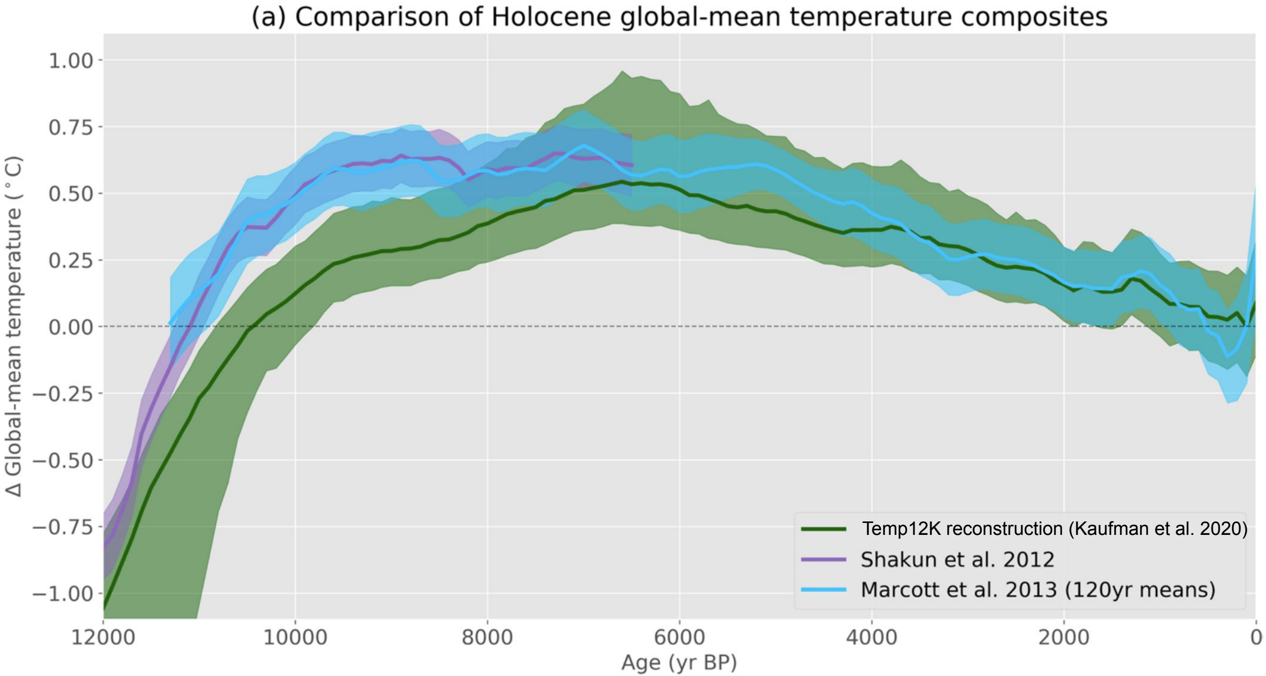
(Fifth National Climate Assessment, 2023)

- Drought-prone region with highly variable rainfall
- How will water supply be impacted in future warming scenarios?
- Use paleoclimate to test models used for future projections

The Holocene (~11,700 years to present)



(http://www.stratigraphy.org)



(Kaufman et al. 2020)

How have the amount, timing, and distribution of precipitation in the western U.S. changed throughout the Holocene?

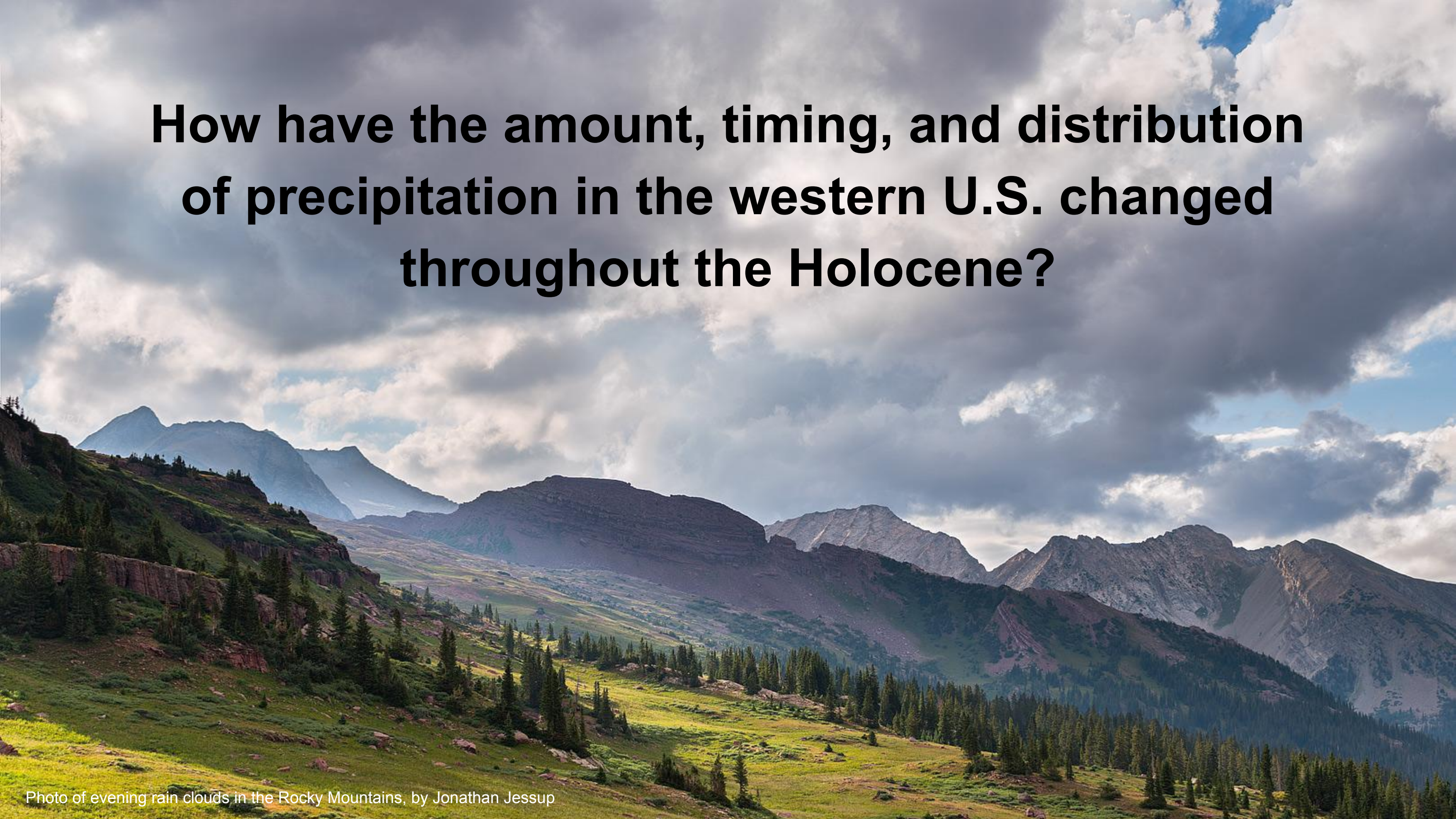
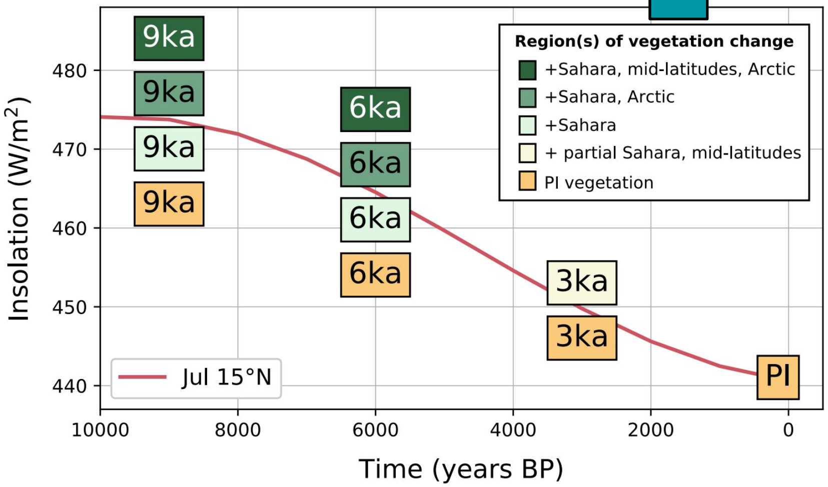


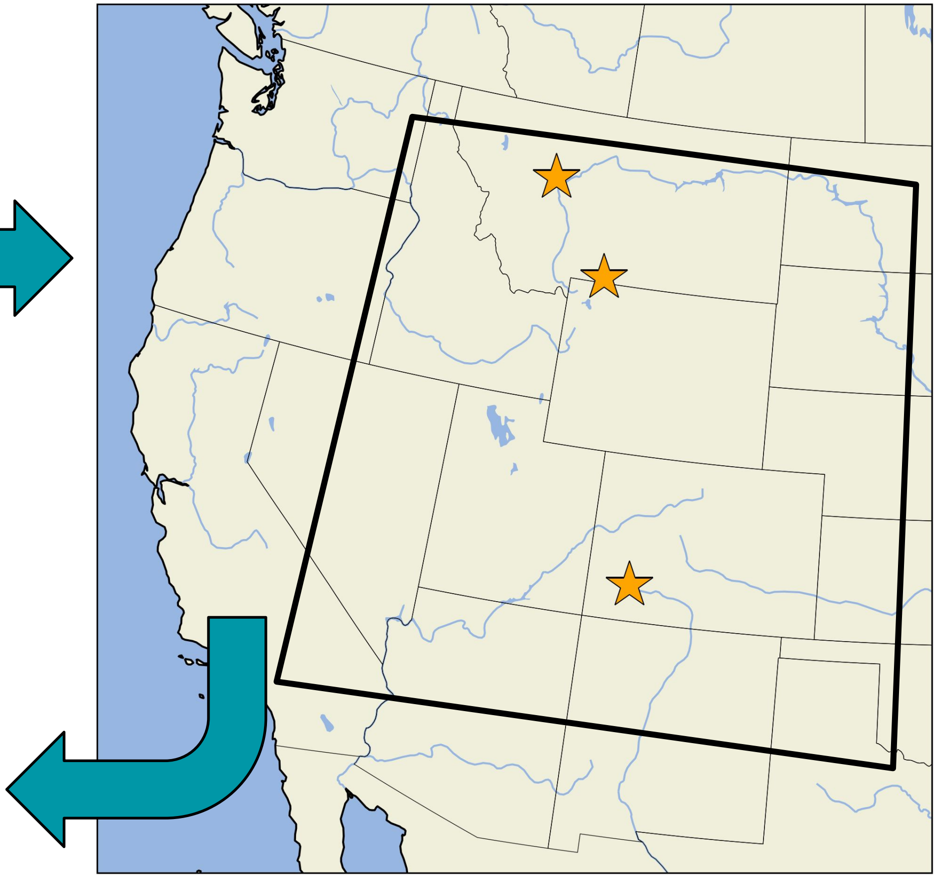
Photo of evening rain clouds in the Rocky Mountains, by Jonathan Jessup

iCESM1.2

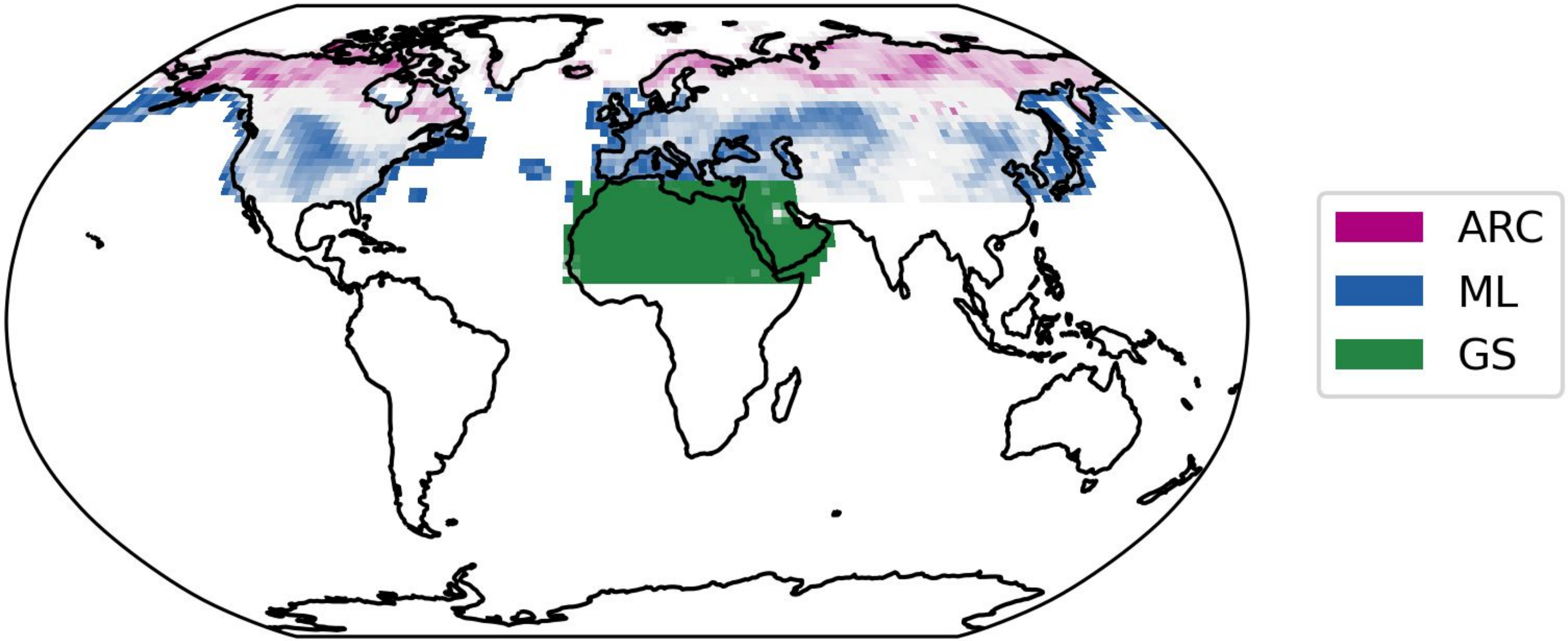
- Isotope enabled (Brady et al. 2019)
- Time slice simulations at **0** (pre-industrial), **3, 6, 9 ka**



(Thompson et al. 2022)

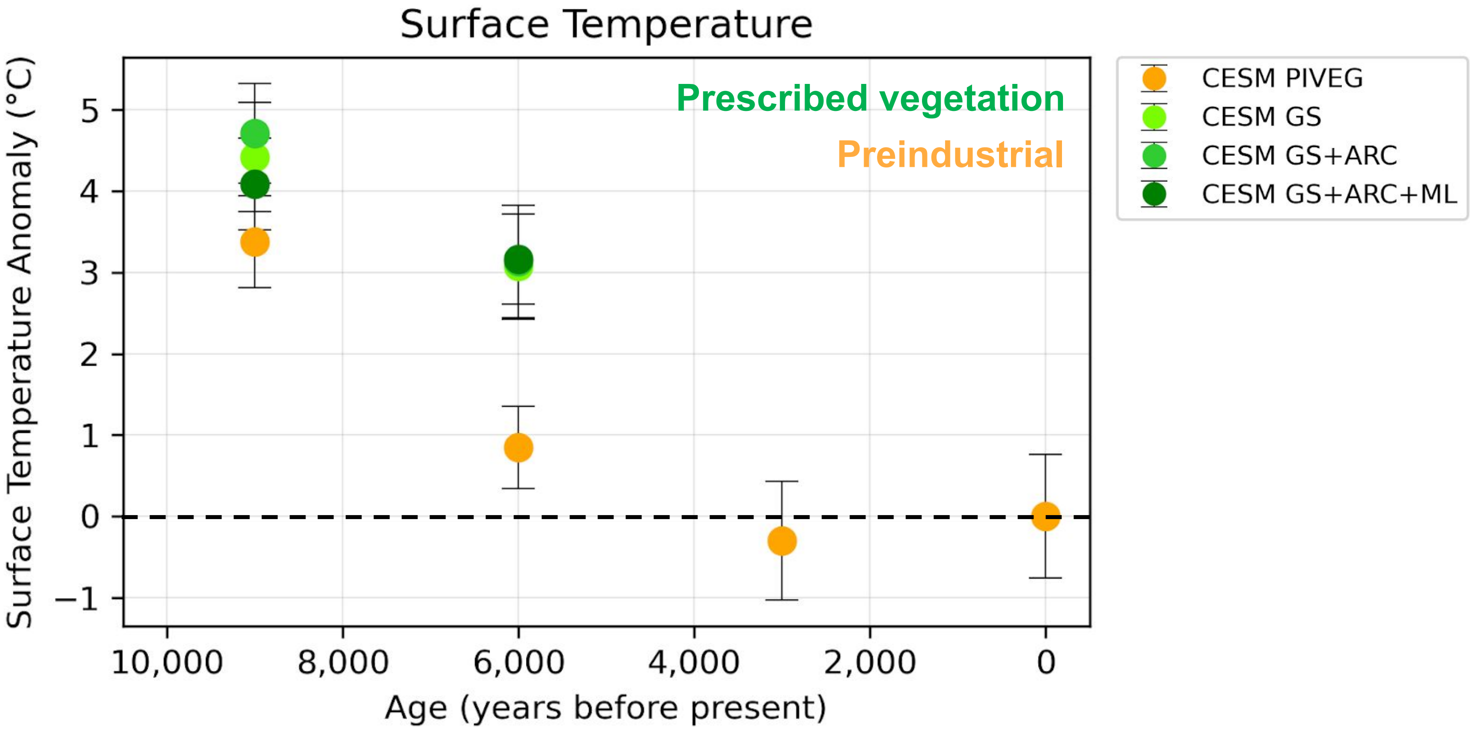


Modified vegetation cover (%) in iCESM



Vegetation makes summer warmer and drier, especially at 6 ka

Regional Mean JJA Anomalies



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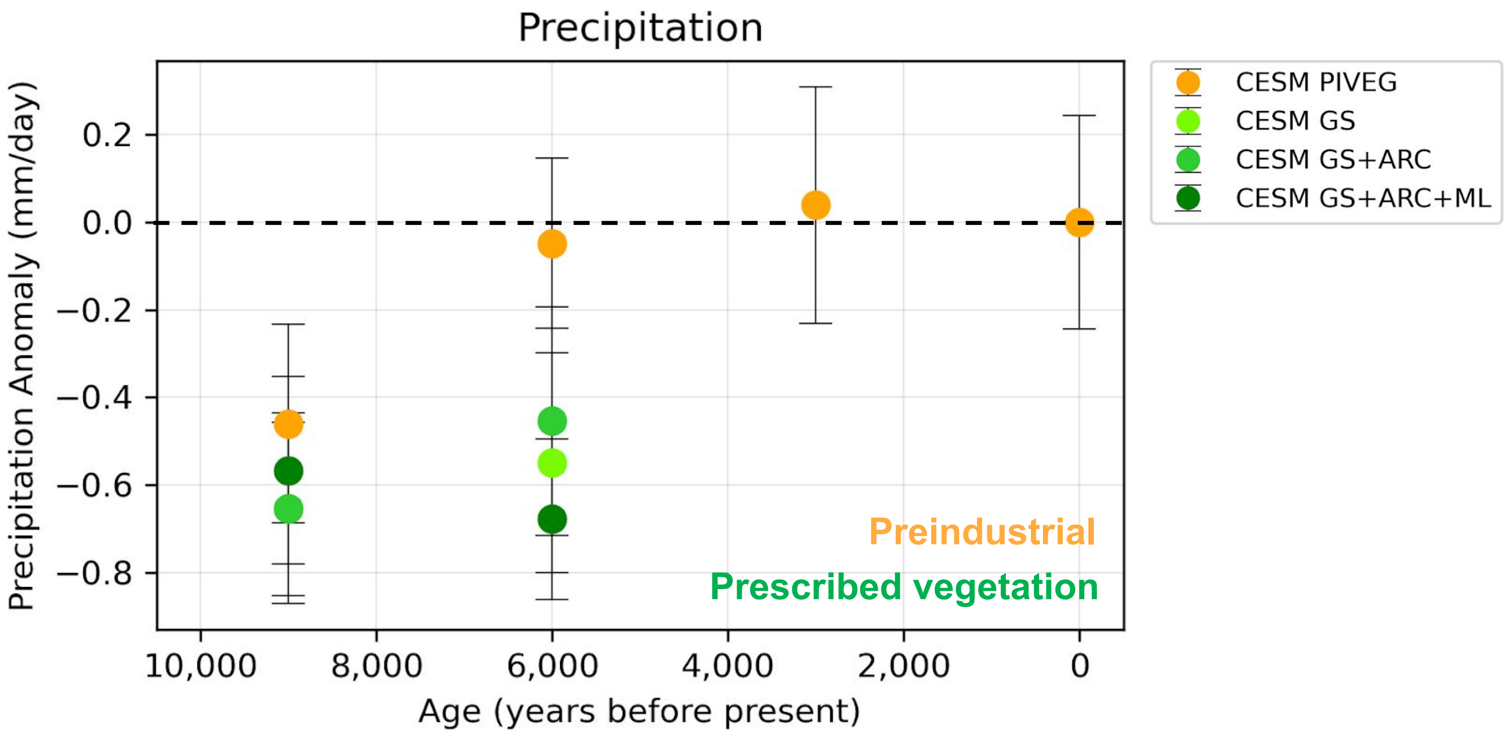


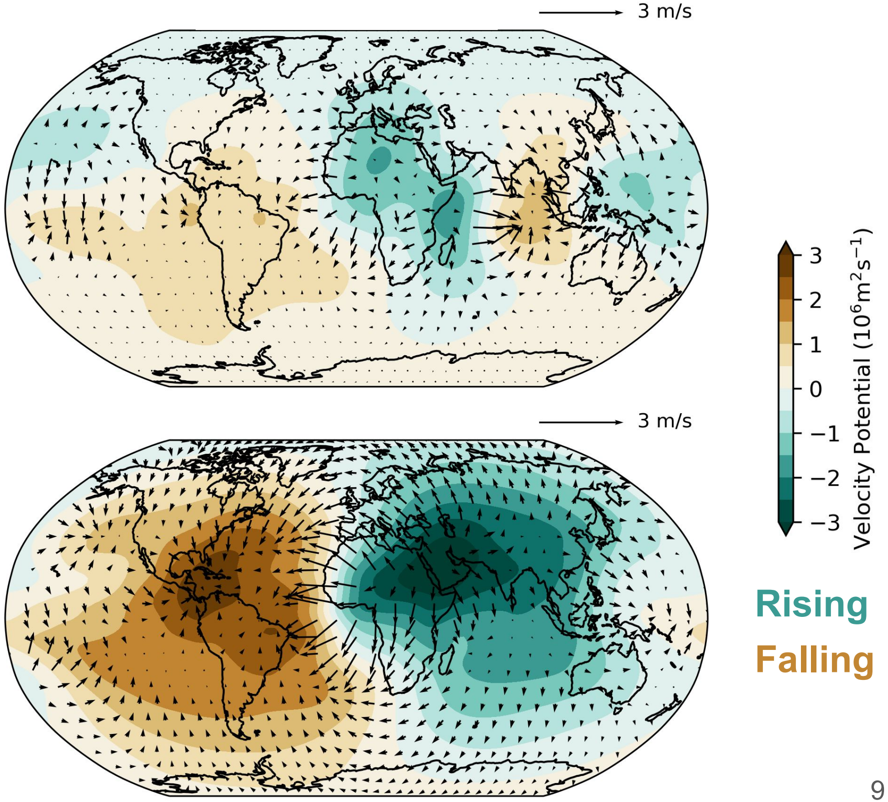
Green Sahara drives convection over Africa and subsidence over Americas

Annual Upper-Level Velocity Potential and Divergence

9 ka | **6 ka**

Effect of boundary conditions

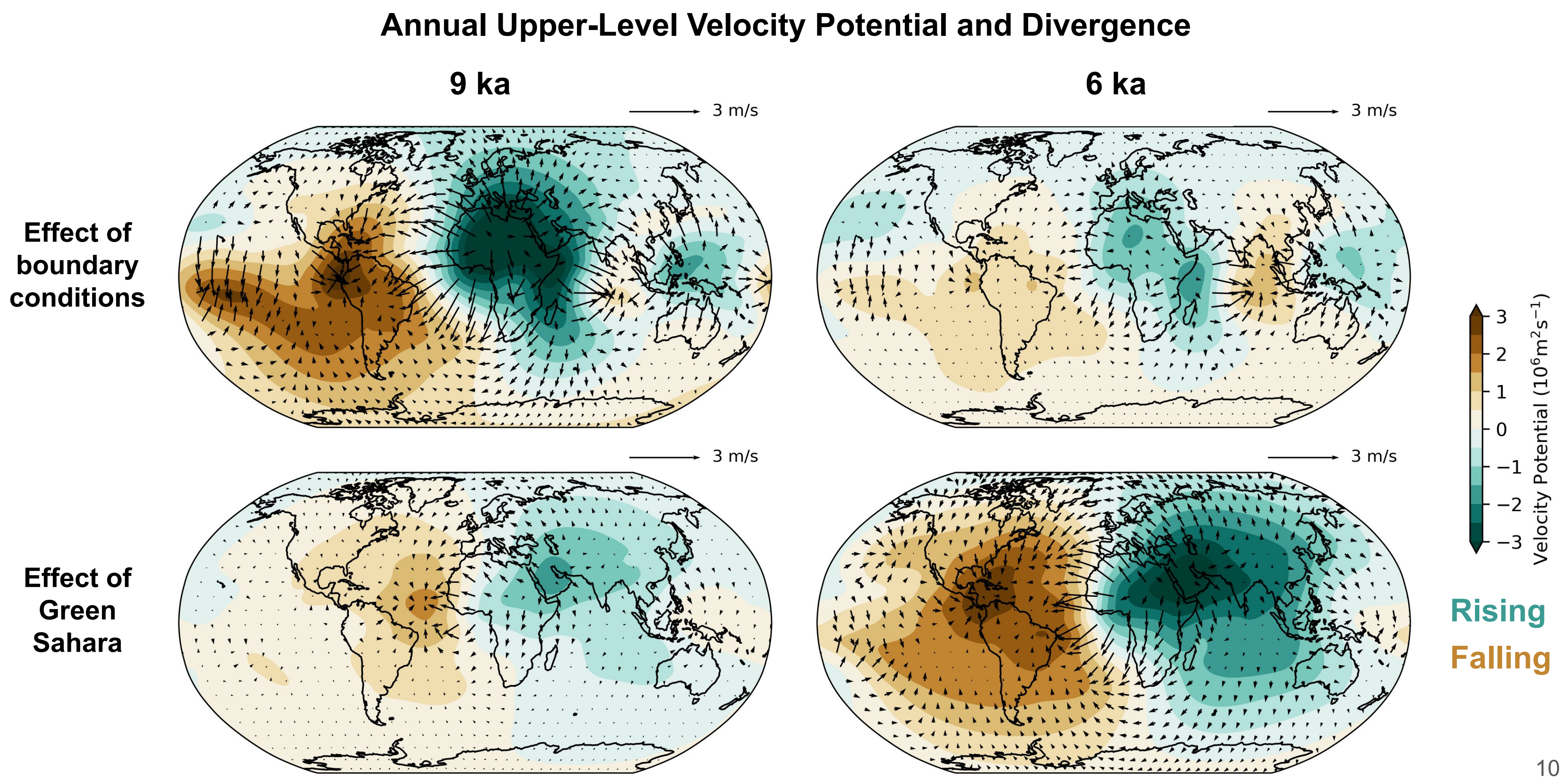
Effect of Green Sahara



Rising

Falling

Boundary conditions have larger impact than GS at 9 ka

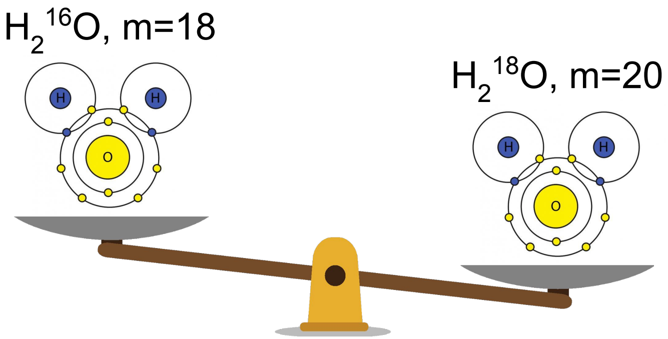


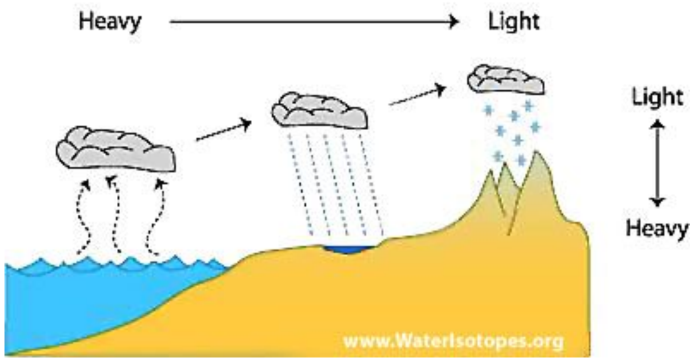
ars

Water isotopes

- Differ in atomic mass
- Tell us about past temperature and precipitation (e.g., moisture source and trajectory)
- Enrich understanding of past water cycle. Exciting!

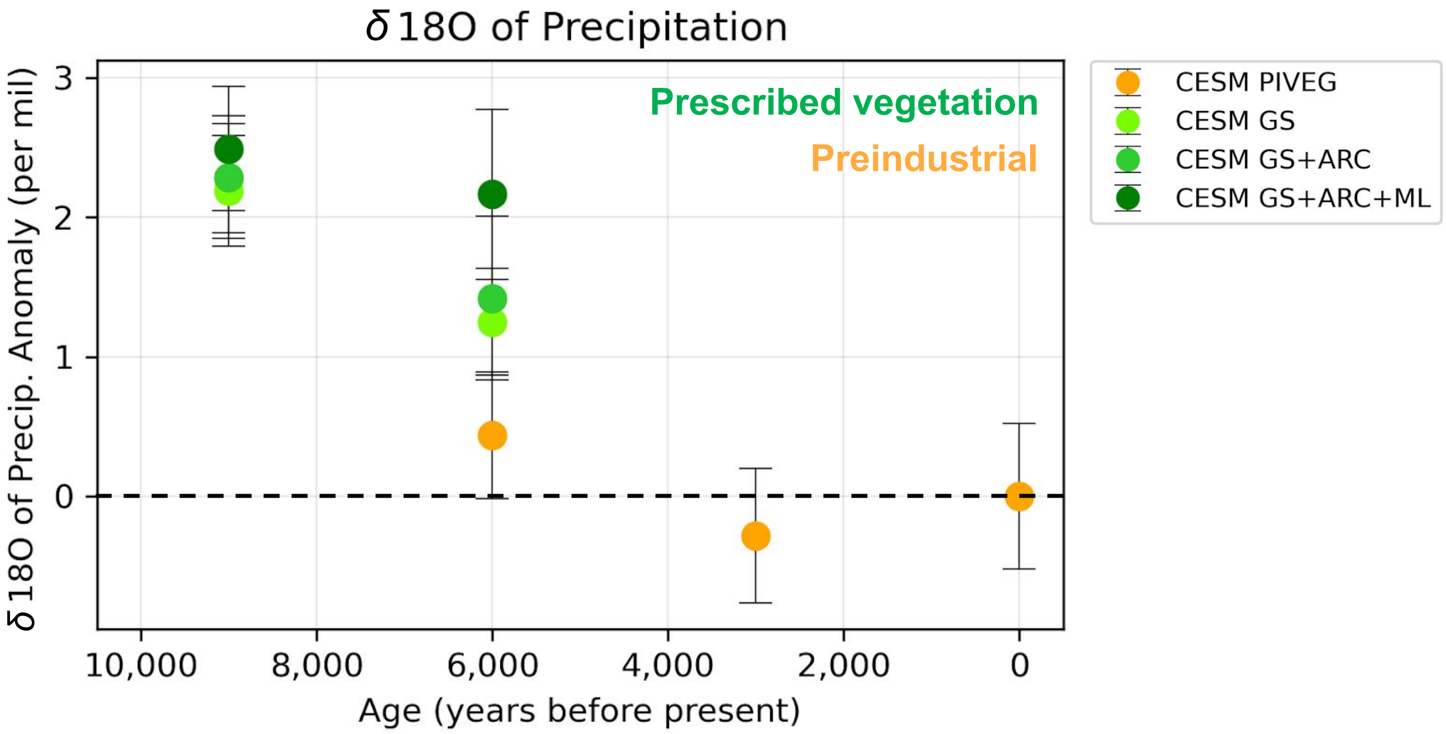
$$\delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right) \times 1000 ‰$$



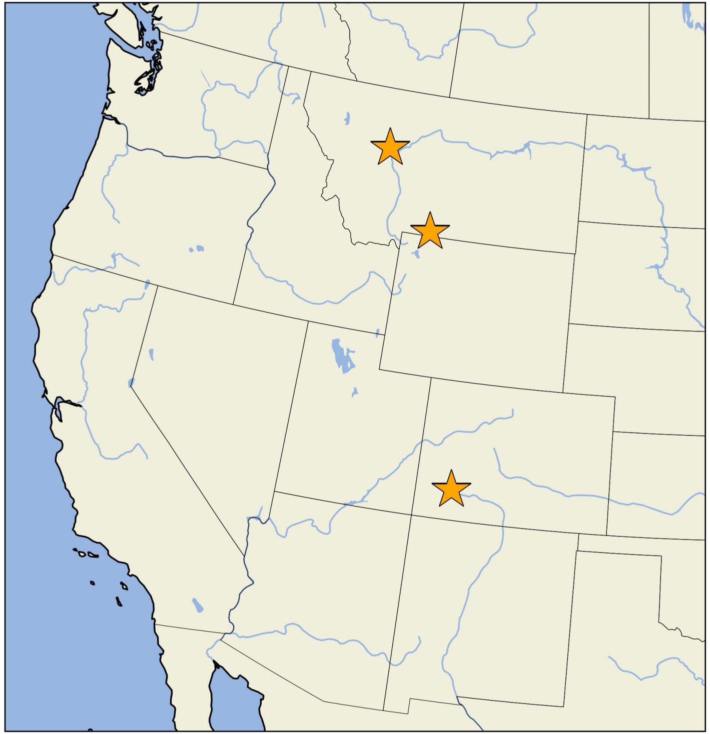


Vegetation increases δ18O of precipitation at 6 ka

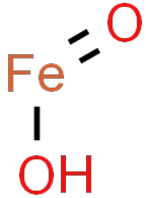
Regional Mean JJA Anomalies



Iron oxide proxy measurements

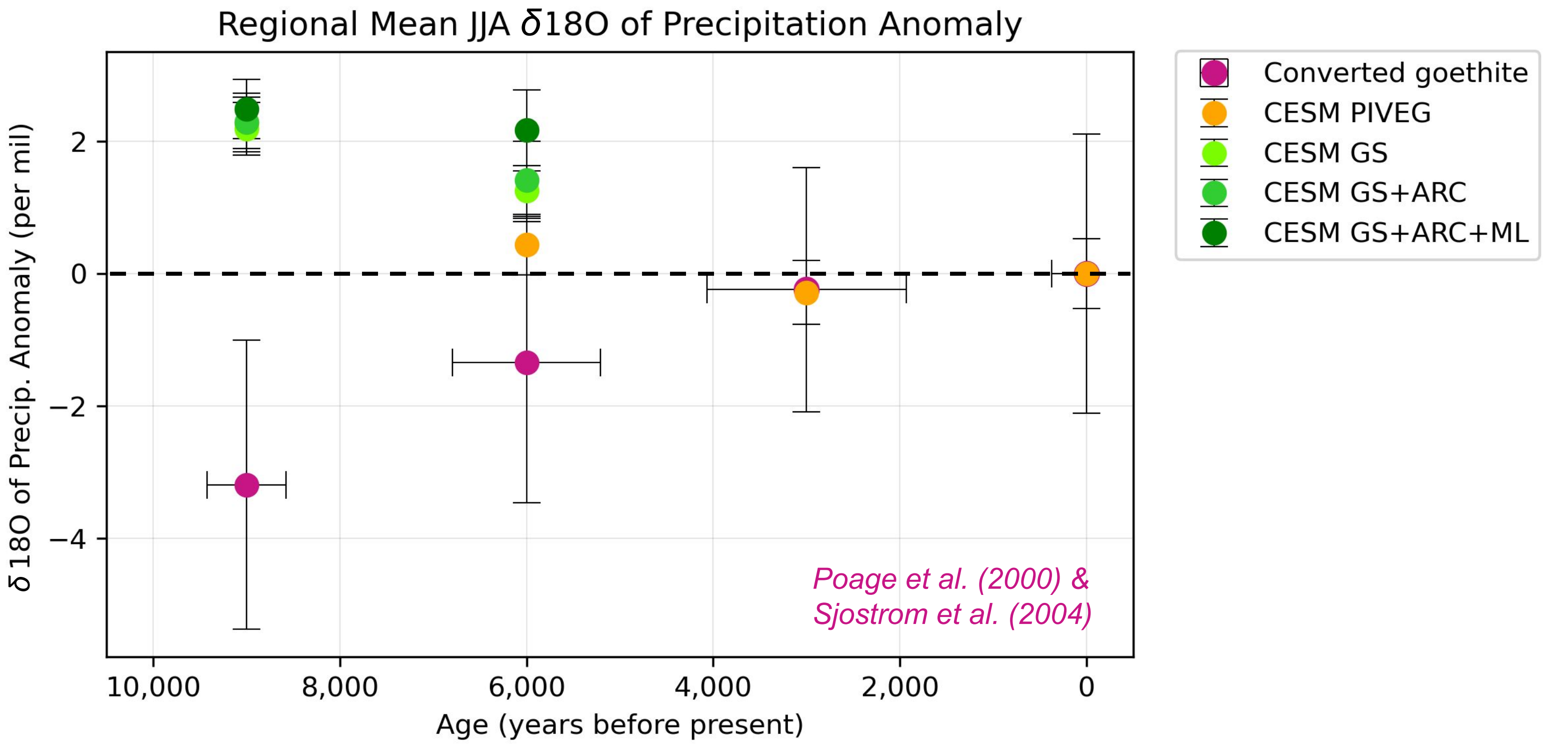


- Iron oxides are abundant on Earth in many geologic settings
- Ferricrete = goethite-rich stream sediments formed in naturally acidic drainages
  - Several samples from different times over the Holocene at each site
- Record isotopic composition of past water

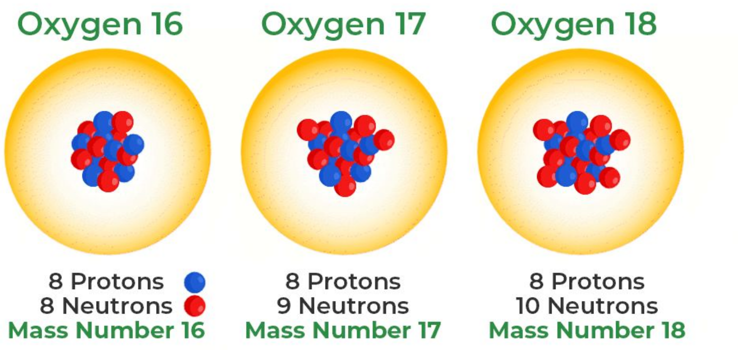


Proxy measurements disagree with the simulated isotope trend

Proxy-Model Comparison

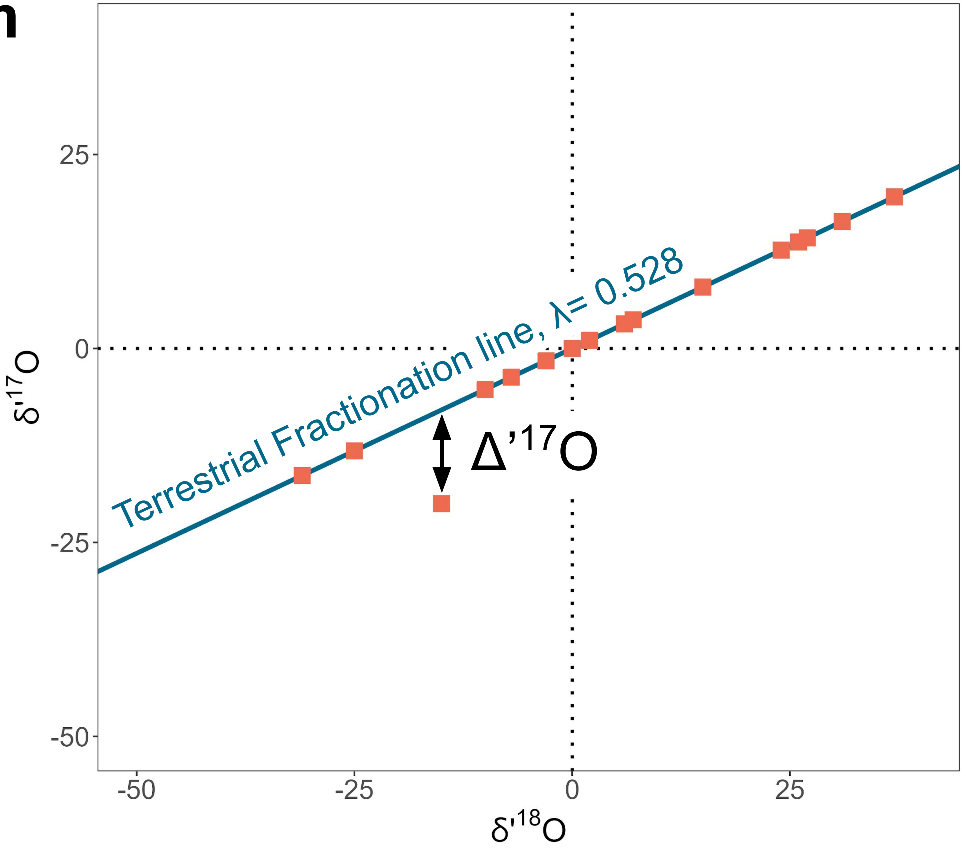


Δ'17O tracks nonequilibrium processes



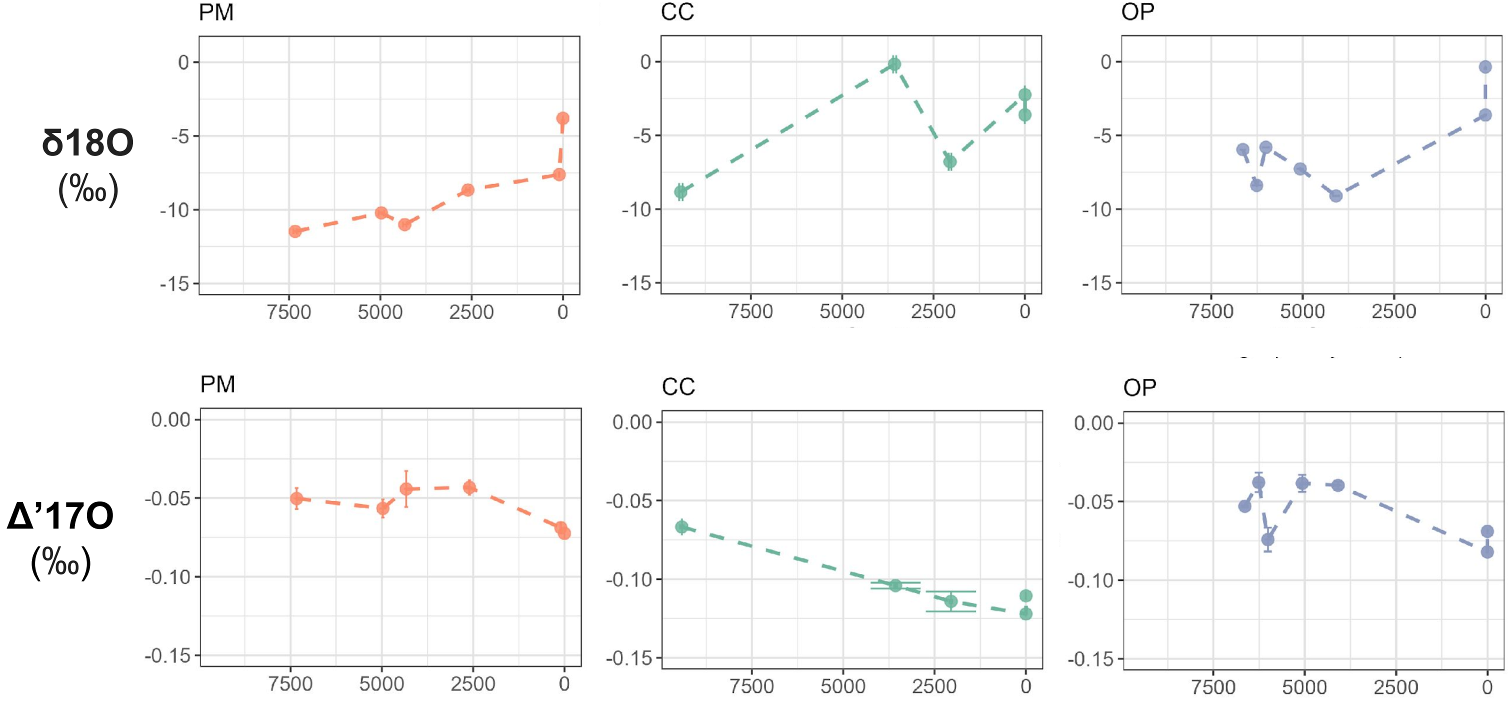
$$\Delta'^{17}O = \delta'^{17}O - 0.528 * \delta'^{18}O$$

$$\delta' = 1000 \ln\left(\frac{\delta}{1000} + 1\right)$$

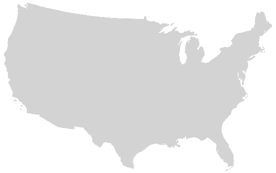


Decreasing D’17O over time supports the increased monsoon input interpretation

Water isotope trends at sample sites

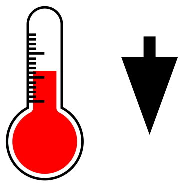


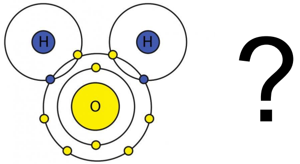
High
Δ’17O



Low
Δ’17O

Conclusions





- Discrepancy between model and proxy δ18O
- Remote vegetation changes have important impacts on the western U.S. (and haven't really been investigated!)
  - At 6 ka, warming and drying of the western U.S. is driven by increased convection and divergence over the (green) Sahara
- Future Work
  - Vapor transport model for Δ'17O
  - Why does simulated δ18O disagree with proxy record?

Acknowledgements

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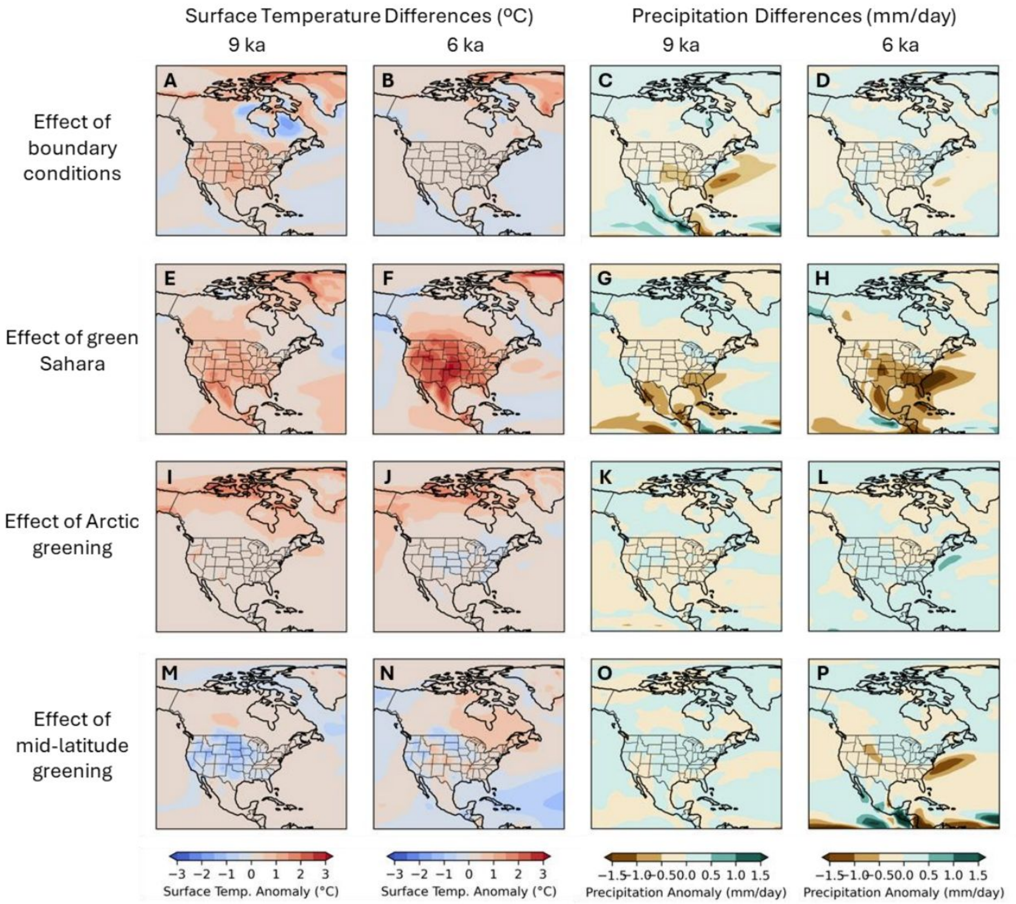


Figure 4. Mean JJA surface temperature and precipitation differences among simulations at 9 and 6 ka over North America, including the isolated effects of boundary conditions, Green Sahara, Arctic greening, and mid-latitude greening.

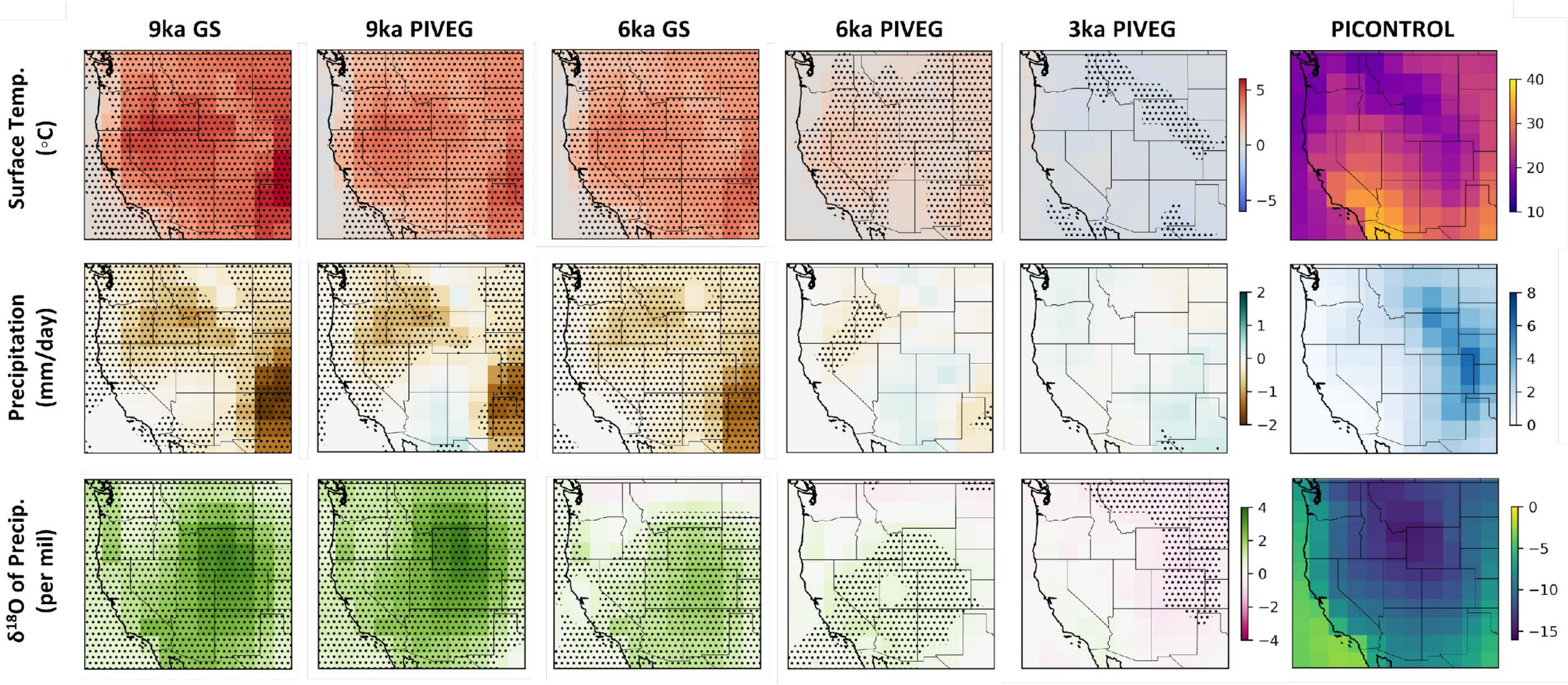
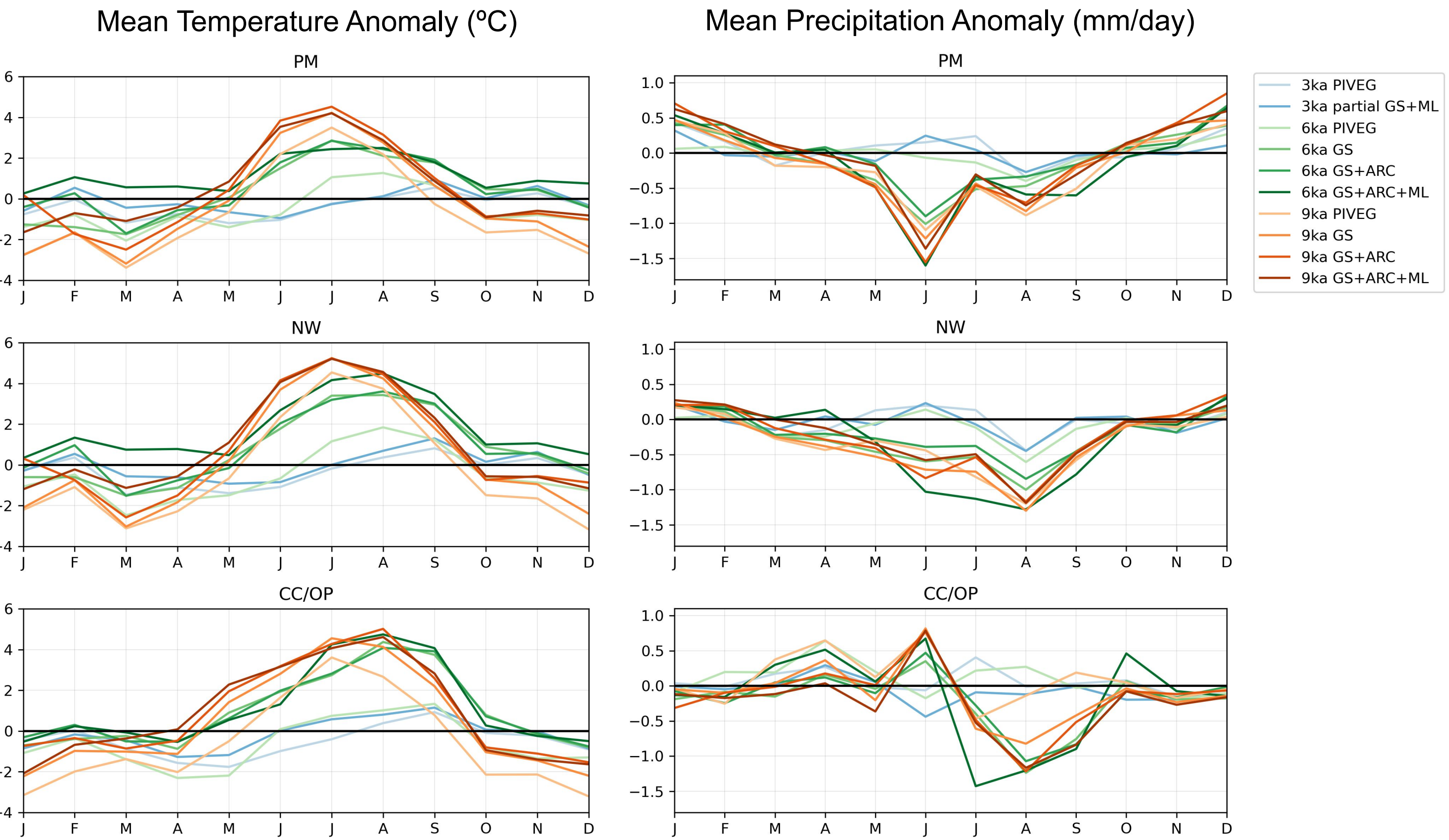
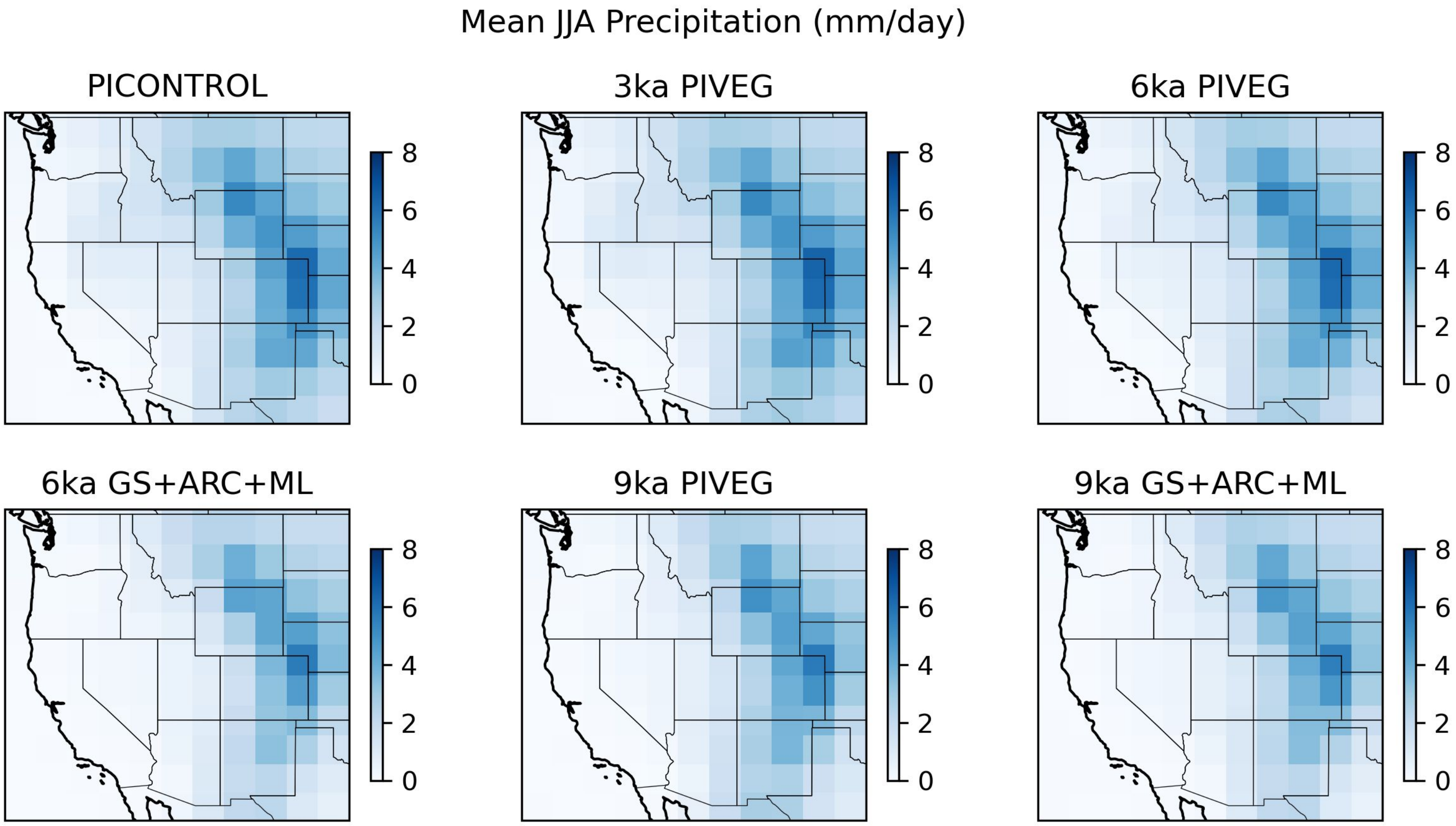


Figure S2. Mean JJA temperature, precipitation, and $\delta^{18}O$ of precipitation anomalies relative to PICONTROL (right column) in select simulations over time. Stippling covers areas that are significantly different (p values < 0.05) from the PICONTROL simulations.

Largest differences between simulations occur during summer months




Mean JJA Precipitation (mm/day)
PICONTROL
3ka PIVEG
6ka PIVEG
6ka GS+ARC+ML
9ka PIVEG
9ka GS+ARC+ML
0
2
4
6
8