Using Bayesian Methods to Detect Abrupt Transitions in Transient Holocene Climate Model Simulations

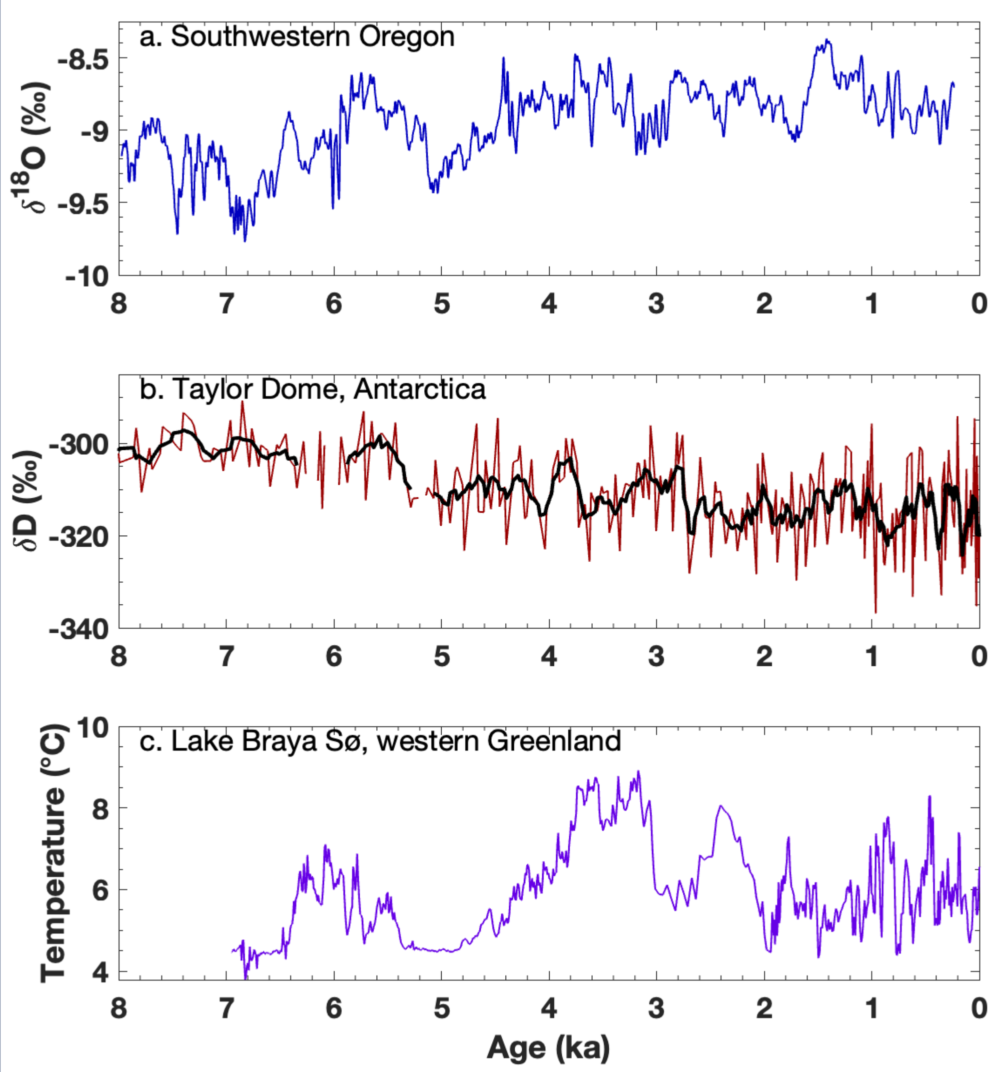
Allison Lawman[1,2], Carrie Morrill[2], Bette Otto-Bliesner[3], Esther Brady[3], Robert Tomas[3]

[1]CIRES, CU Boulder, [2]NOAA National Centers for Environmental Information, [3]National Center for Atmospheric Research

Motivation & Overview:

Our understanding of abrupt climate changes during the Holocene is limited. Although some paleoclimate proxy records indicate intervals of abrupt change during the Holocene, the spatial extent and temporal evolution of these changes remain uncertain. Furthermore, model-data discrepancies exist, with many climate models unable to simulate the abrupt transitions observed in proxy records (Fig. 1). To reconcile these disagreements and develop a more comprehensive picture of abrupt climate change, here we investigate key factors for simulating abrupt climate change under Holocene background conditions.

Example proxy records with abrupt climate transitions during the Holocene



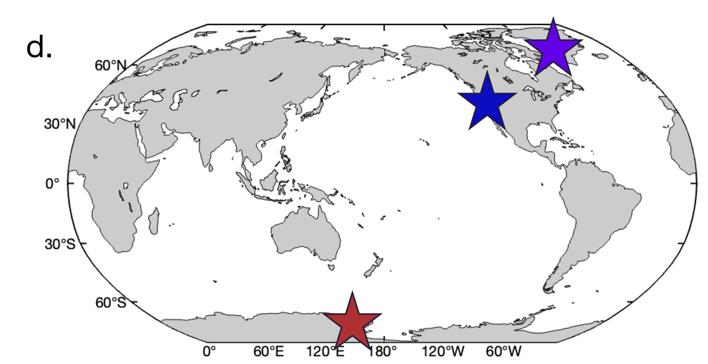
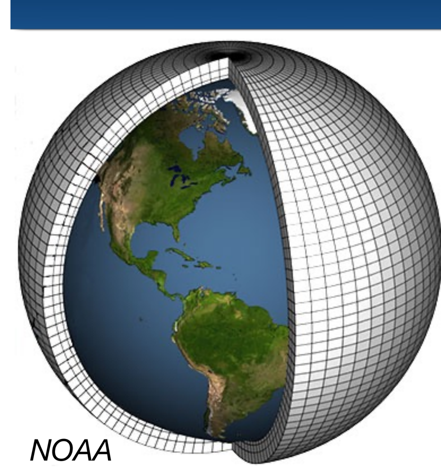


Fig. 1. Selected proxy records with abrupt climate transitions during the Holocene. (**a**) Cave speleothem oxygen isotope ($\delta^{18}O$) record (blue) from Oregon Caves National Monument (Ersek et al., 2012). (**b**) Hydrogen isotope (δD) record (red) from Taylor Dome, Antarctica. Smoothed δD record (black). (**c**) Temperature reconstruction (purple) from western Greenland (von Gunten et al., 2012). The temperature time series in (**c**) is based on measurements of alkenone unsaturation (U^{K}_{37}) in sediment from Lake Braya Sø. All proxy records are subset to 8-0 ka before present (ka, thousand years). (**d**) Map indicating proxy record locations (stars). Star colors correspond to the line colors in (**a-c**).

Global Climate Model Projections:



Community Climate System Model Version 3 (CCSM3)

- Transient Holocene simulations (subset to 5.9-3.6 ka)
- Community Atmospheric Model 3 (CAM3), 26 vertical levels
- T31, ~3.75° latitude/longitude horizontal resolution
- Dynamic vegetation

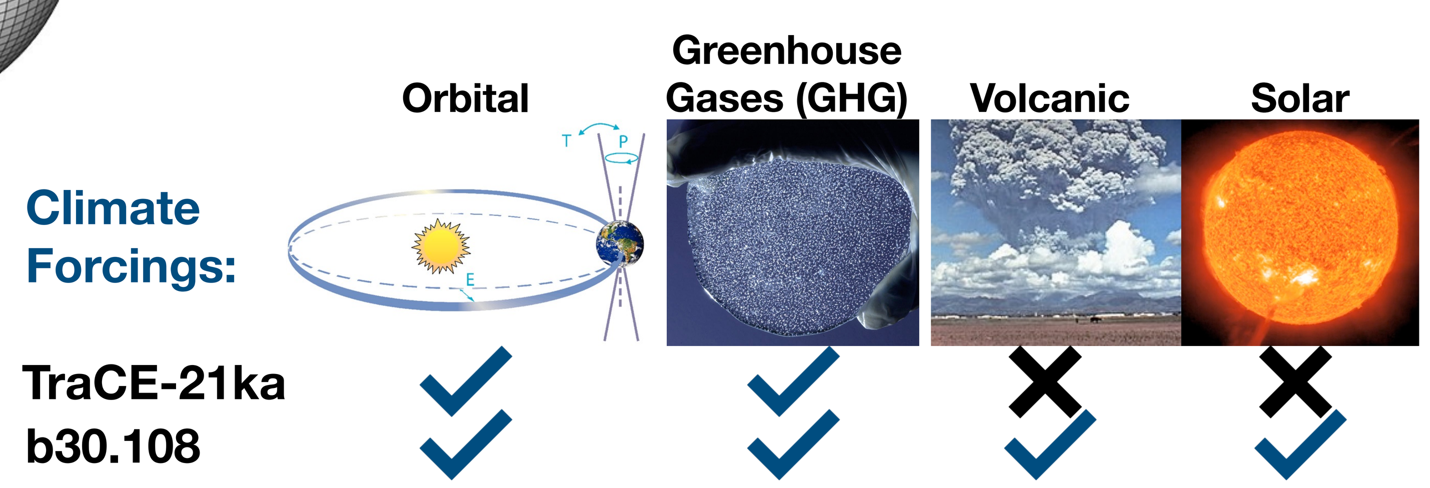


Fig. 2. Summary of climate forcings in the TraCE-21ka and b30.108 transient climate model simulations (5.9-3.6 ka). Orbital forcing during the Holocene is primarily due to precession. Greenhouse gas concentrations (e.g., CO_2, CH_4) inferred from ice cores. Volcanic forcing in b30.108 is statistical (Ammann & Naveau, 2010), based on the distribution and magnitude of volcanic eruptions from the past millennium. Volcanic aerosols are applied zonally. Solar variations inferred from ^{10}Be measurements in ice cores. Solar forcing varies annually and is applied as an adjustment at all wavelengths. *Image credits: Orbital (IPCC AR5; Rahmstorf and Schellnhuber, 2006), air bubbles in ice (British Antarctic Survey), solar (NOAA).*

Bayesian Methods to Detect Abrupt Climate Transitions:

Regional Case Study (b30.108): Equatorial Africa

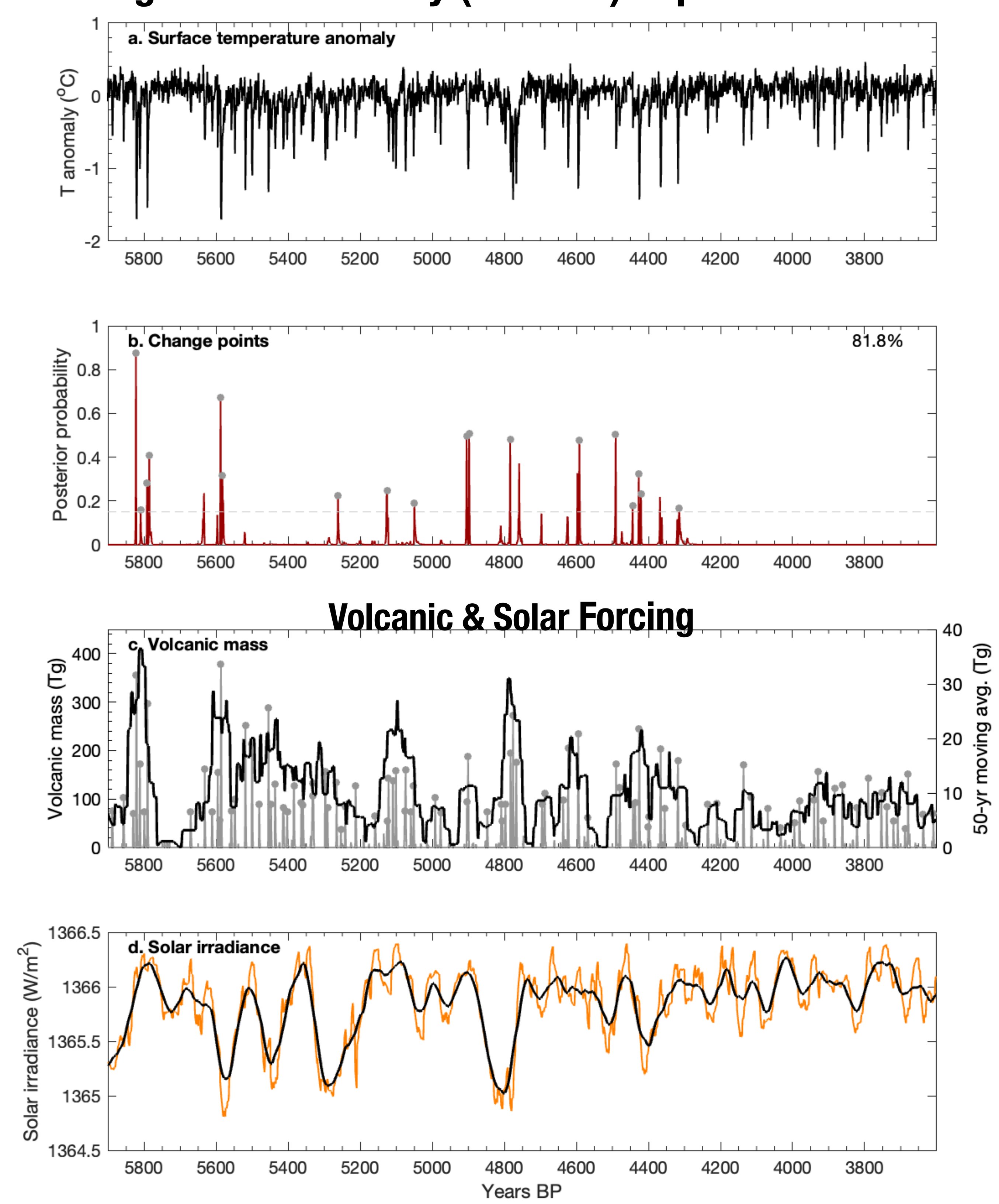


Fig. 3. Bayesian methods to detect abrupt climate transitions. (**a**) Simulated annual temperature anomalies for equatorial Africa (9°S-13°N, 0-33°E, Fig. 5b white box) from the b30.108 transient Holocene simulation. Anomalies calculated relative to the mean of the full-length time series. (**b**) Posterior probability for the number of changepoints and their locations calculated using a Bayesian approach for detecting change points in climate records (Ruggieri, 2013, 2018). (**c**) Volcanic forcing in the b30.108 simulation. The global, area-weighted total mass of volcanic aerosols in Tg (left axis, gray). The 50-year running mean of volcanic mass (right axis, black). Volcanic mass peaks > 30 Tg indicated by gray circles. (**d**) Annual solar irradiance in the b30.108 simulation (orange) and the 50-year running mean (black). Change points larger than a 15% probability (horizontal dashed line) that occur within -1 to +5 years of a peak in volcanic mass (> 30 Tg, gray circles in **c**) are indicated by gray circles in (**b**) with the percentage of change points displayed in the upper right corner.

Regional Case Study (b30.108): Maritime Continent

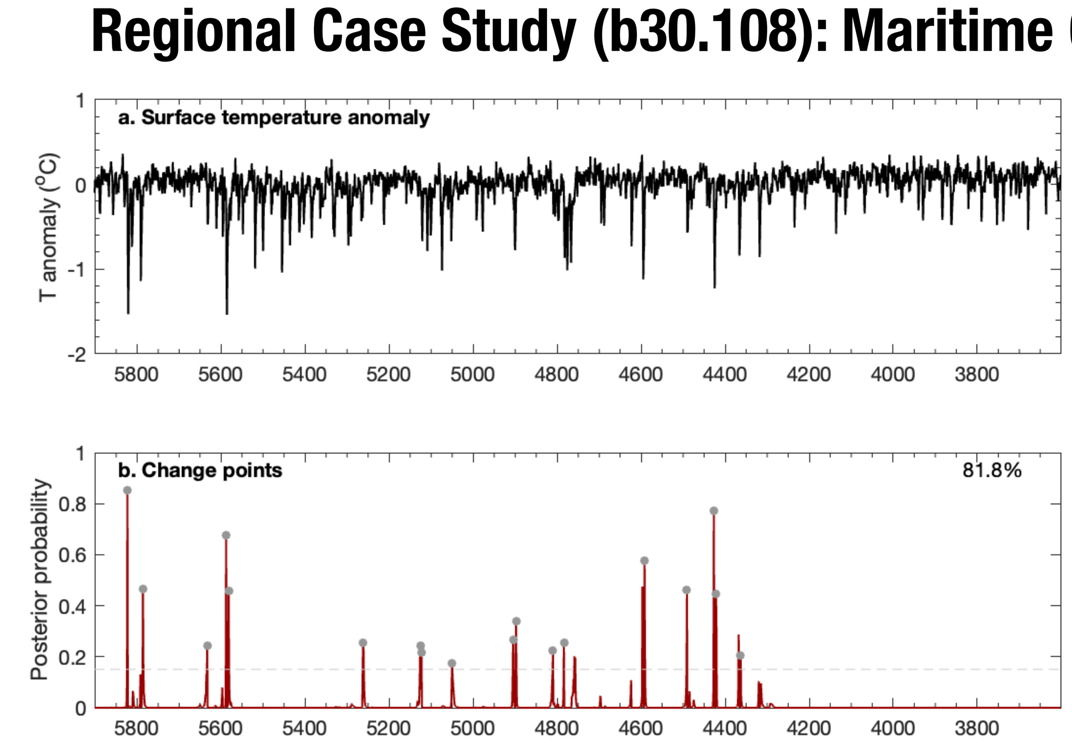
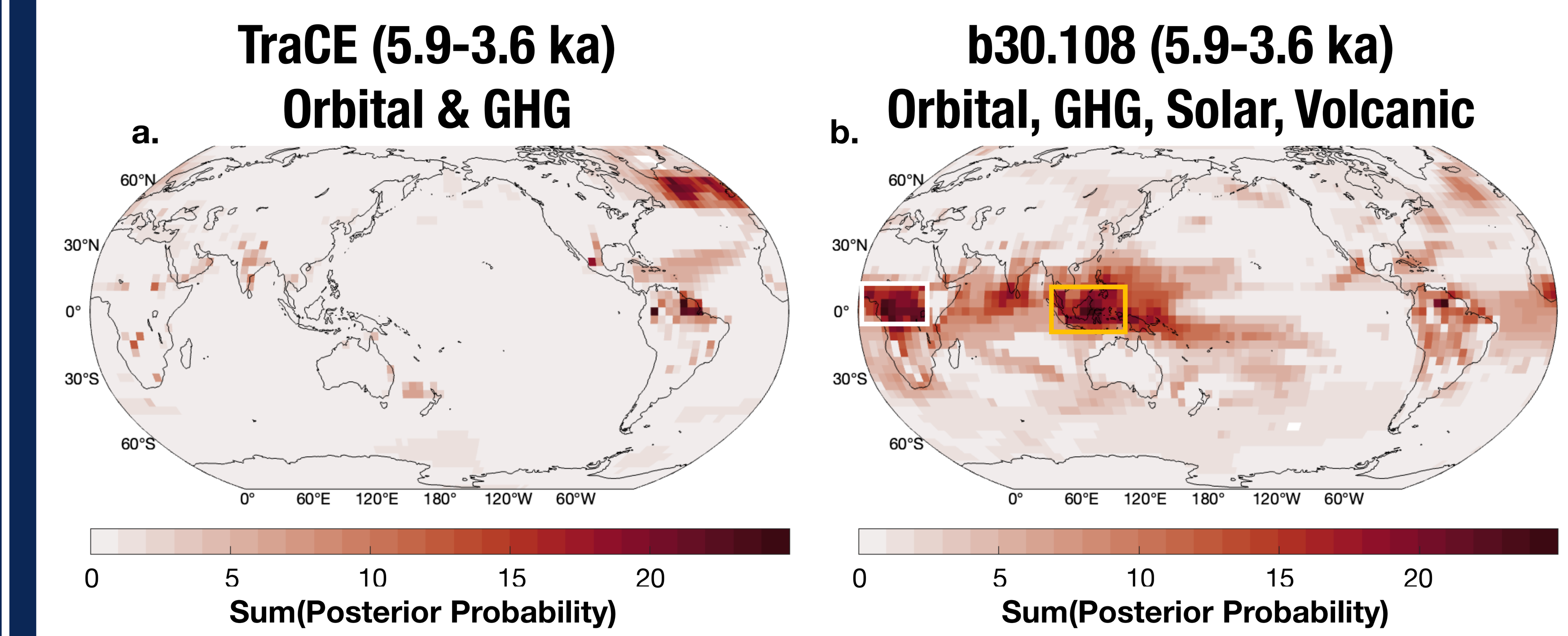


Fig. 4. Same as Fig. 3a, 3b except for the Maritime Continent (9°S-13°N,100-142°E, Fig. 5b yellow box).

Spatial Patterns of Abrupt Transitions:



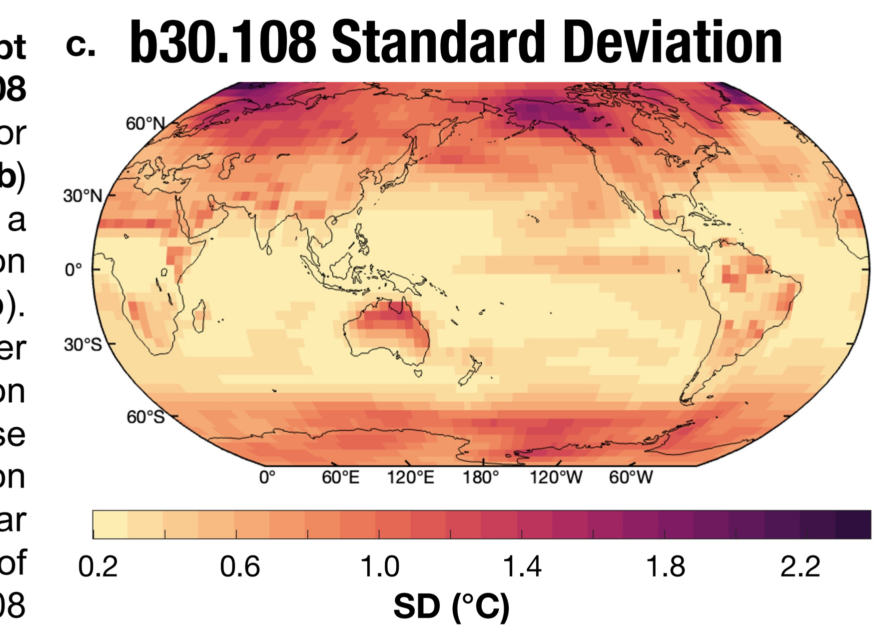


Fig. 5. Simulated spatial pattern of abrupt temperature transitions in TraCE and b30.108 from 5.9-3.6 ka. (a, b) The sum of the posterior probability distribution in (**a**) TraCE and (**b**) b30.108. Posterior probability calculated using a Bayesian approach for detecting change points on annual temperature anomalies (e.g., Fig. 3b). Warmer red colors indicate locations with a larger number of change points. The TraCE simulation only includes changes in orbital and greenhouse gas (GHG) forcing. The b30.108 simulation includes orbital, GHG, volcanic (Fig. 3c) and solar (Fig. 3d) forcing. (**c**) The standard deviation of annual temperature anomalies in the b30.108 simulation.

Conclusions & Future Work:

Conclusions:

- Bayesian change point detection methods identify abrupt climate transitions in transient climate model simulations for the Holocene.
- Abrupt transitions are more frequent in simulations with solar and volcanic forcing compared to simulations with only orbital and GHG changes.
- Volcanic forcing alone is likely insufficient to capture multi-decadal to centennial abrupt transitions observed in paleoclimate proxy records.

Future Work:

- Investigate the timing of change points relative to minima and maxima in solar irradiance.
- Apply the Bayesian change point algorithm to high-resolution proxy records for the Holocene.

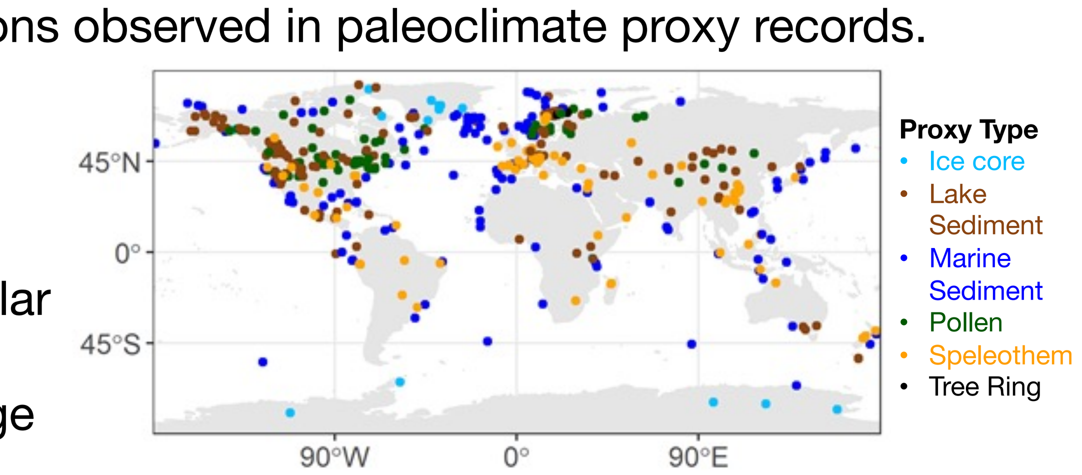


Fig. 6. Holocene Proxy Records. Records with a minimum 150-year resolution that cover at least 3,000 years of the Holocene.

References:

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Contact:
allison.lawman@colorado.edu