CHANGING TEMPERATURE GRADIENTS LINKED TO HOLOCENE MOISTURE TRENDS IN THE NORTHERN HEMISPHERE

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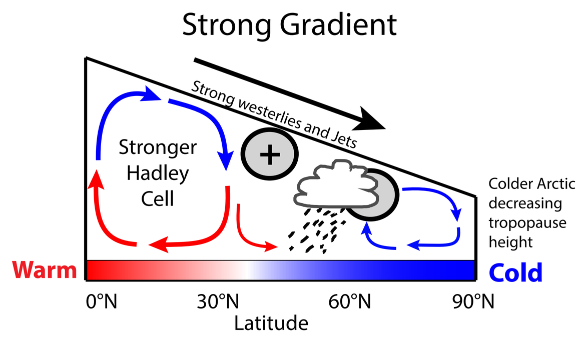
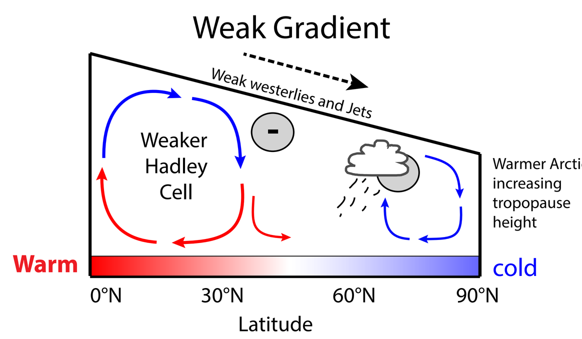
Abstract

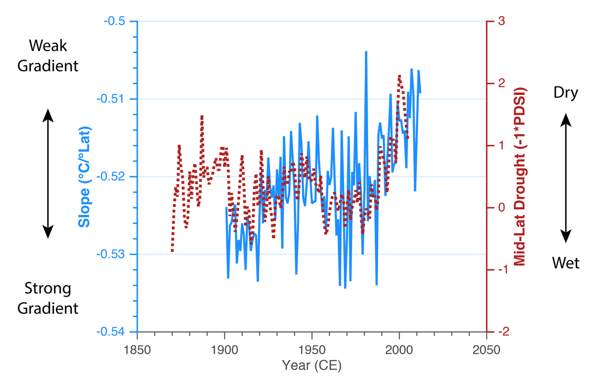
The temperature gradient between the warmer low latitudes and colder high latitudes drives global circulation patterns and associated moisture transport. Here we characterize the Holocene evolution of the Northern Hemisphere latitudinal temperature gradient (LTG) and compare it with mid-latitude moisture balance in a new compilation of paleoclimate records spanning from 10°S to 90°N. The primary trends show that weaker early to middle Holocene LTGs (warming of the Arctic with respect to the equator) coincided with substantial increases in mid-latitude (30°N-50°N) aridity. Our findings imply that a weaker temperature gradient led to weaker mid-latitude westerly flow, weaker cyclones, and decreased mid-latitude moisture transport. These results are significant for current warming, as northern high latitudes are warming at rates nearly double the global average, decreasing the equator-to-pole LTG to values comparable with the early to middle Holocene.

Theoretical Framework and Latitudinal Temperature Gradients

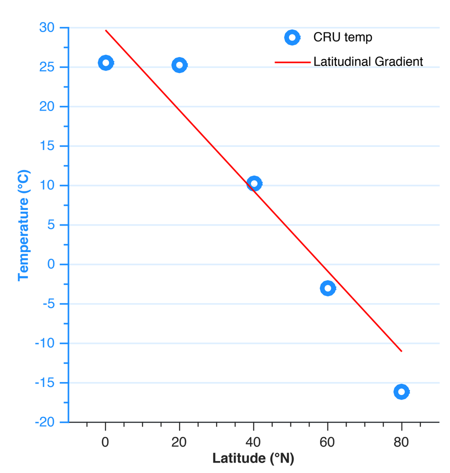


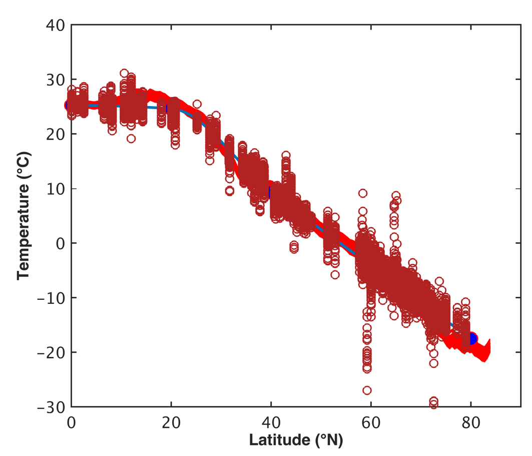


Conceptual diagram. Top: Colder high latitudes lead to a strong temperature gradient between the equator and the pole, strengthening the subtropical jet, and enhancing mid-latitude moisture transport. Bottom: Warming of the high latitudes reduces the LTG and causes weaker Hadley Circulation, weaker westerly jets, and decreased mid-latitude moisture transport.

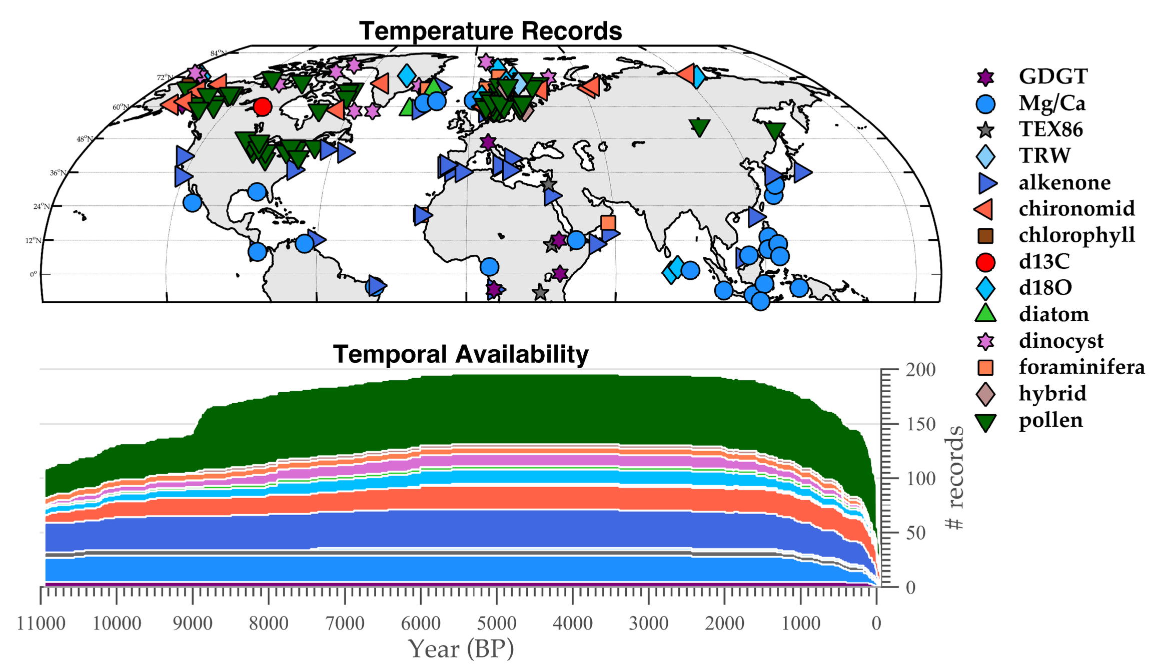


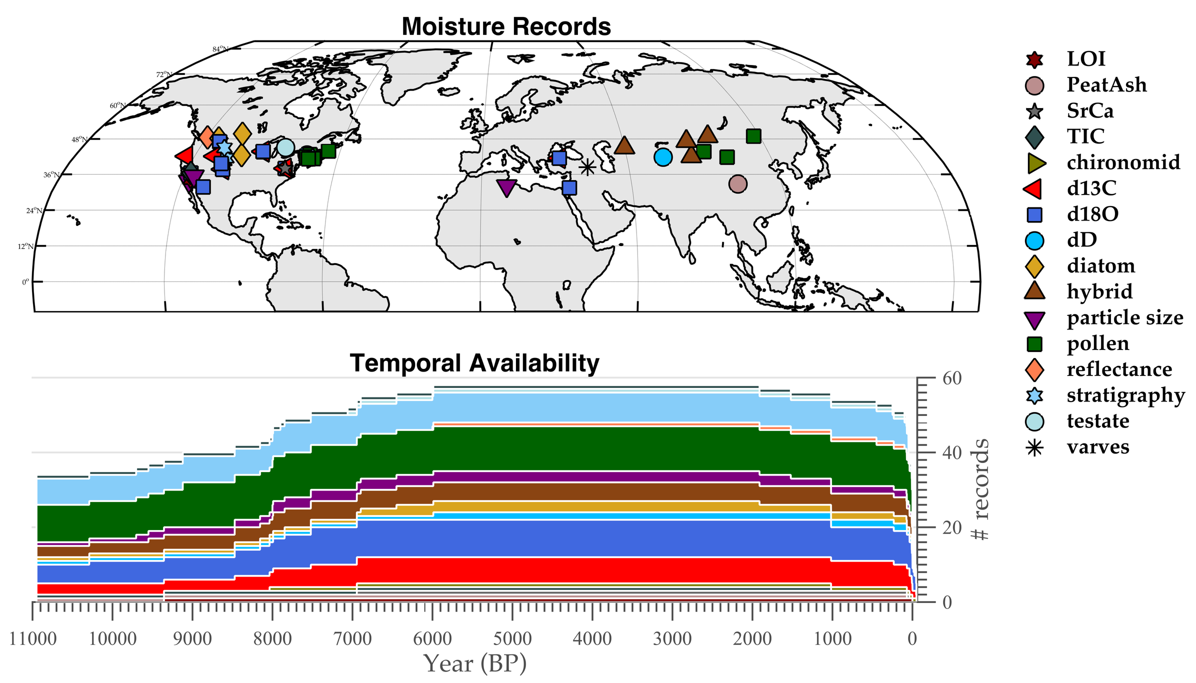
Historic changes in the latitudinal temperature gradient using TS3.2 CRU reanalysis data[1] (blue) are compared with mid-latitude drought[2] (dashed red). The trend toward weaker gradients (less negative slopes) characterizes recent Arctic Amplification. Mid-latitude (30°N-50°N) almer drought severity index[2] closely tracks the LTG (r = -0.52, p<0.0001), although much of the current drought trends are driven by local warming enhancing evaporation.



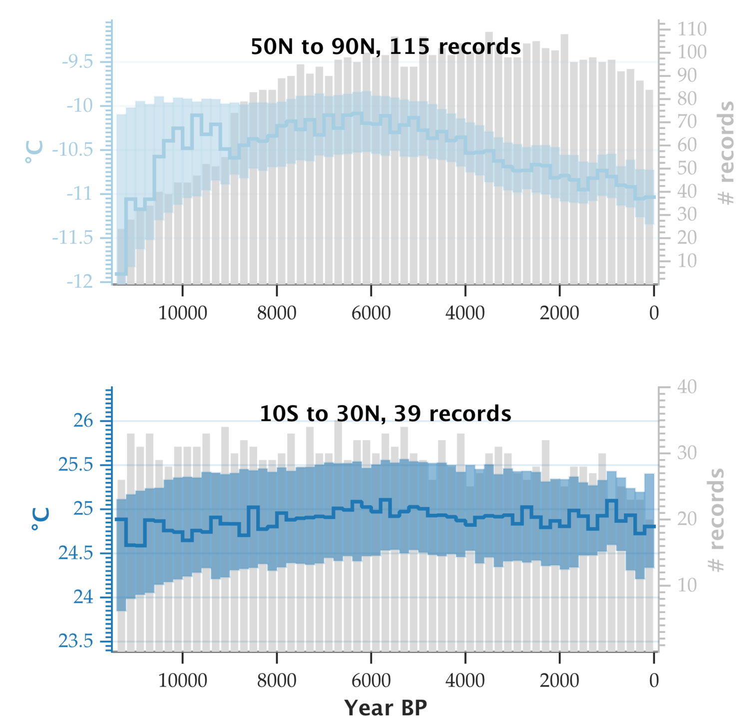


Three methods were tested for calculating the Northern Hemisphere LTGs. The first method used weighted linear regression across temperatures composited for five 20° zonal bands (left). The second method used regression on the distribution of individual Holocene records rather than zonal composites (right). The third method for calculating the LTG relied on the difference between high- and low-latitude temperature composites (next panel).

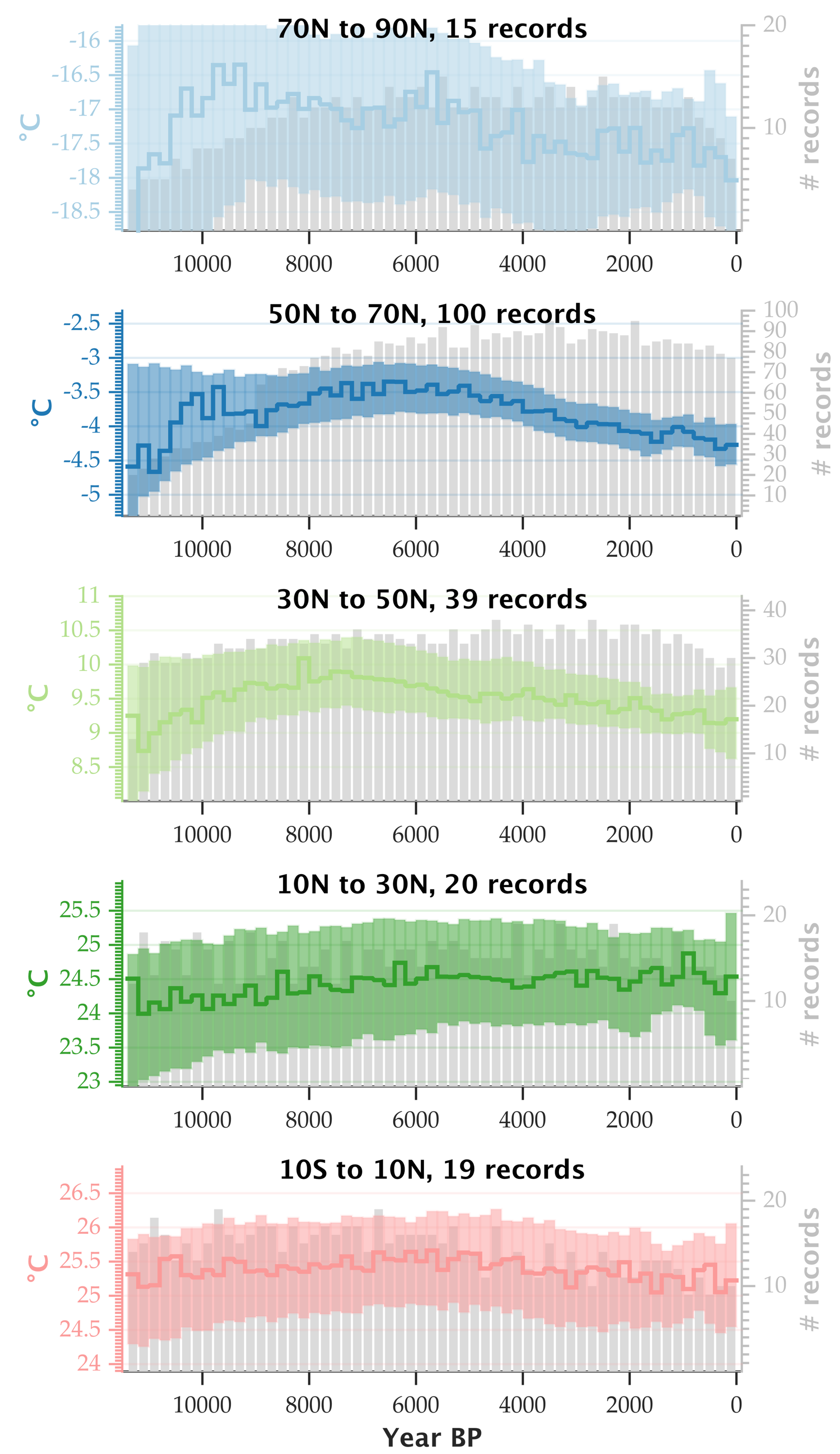




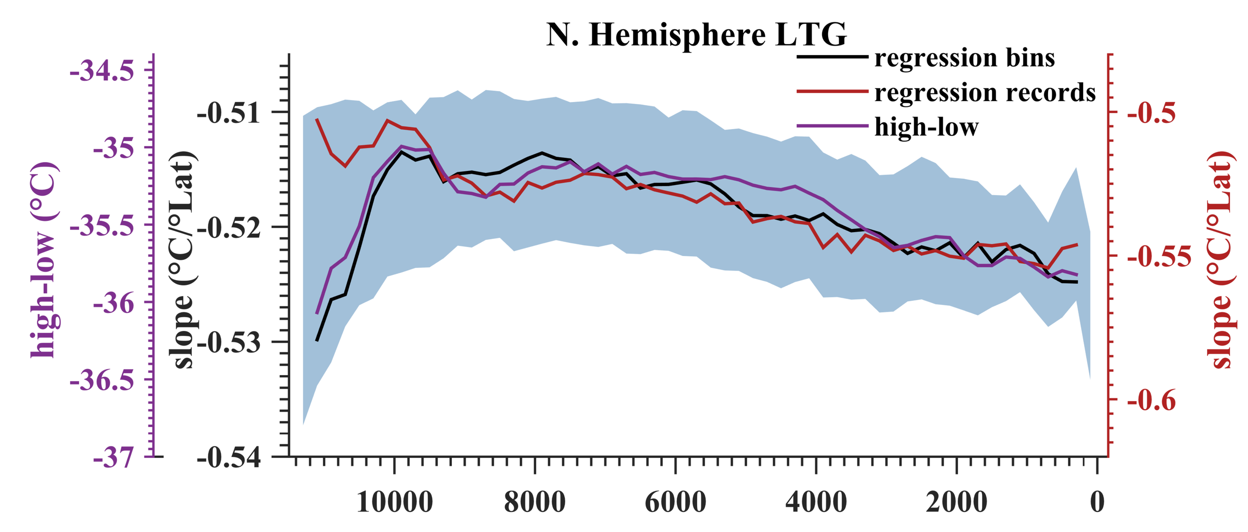
Holocene dataset: Spatial and temporal distribution of temperature proxy records (left) and moisture proxy records (right). Records were selected that span the 2ka-6ka minimum interval, with ~> 400-year resolution, and age control at least every 3000 yrs. Proxy data were obtained from Marcott[3], Sundqvist[4], Chen[5], and Wanner[6] datasets, NOAA paleoclimate[7] and PANGAEA[8] data libraries, in addition to individual data contributions. Only calibrated (°C) temperature proxies north of 10°S were used in this analysis. When both season-specific and mean-annual reconstructions were available, the annual temperature series were used. Moisture proxies (excluding those interpreted as monsoon records) between latitudes 30°N-50°N were used to characterize mid-latitude aridity. We included both calibrated records (e.g., to mm of precipitation) and un-calibrated records (e.g., δ18O) that were interpreted by the original authors as linearly related to moisture such as precipitation, precipitation minus evaporation, lake level, drought severity, etc.

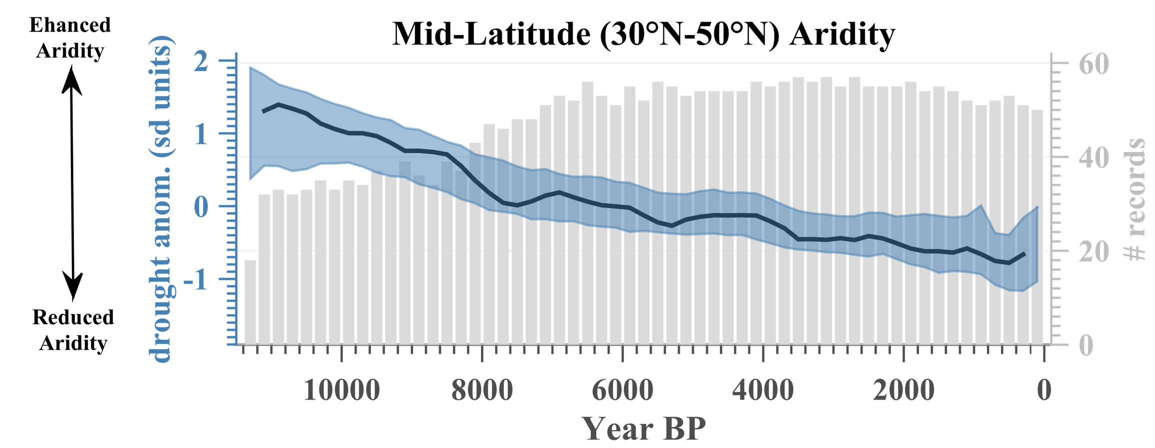


High (50-90N) and low (10S-30N) latitude hemisphere temperature composites. The low latitude composite was subtracted from the high latitude composite to characterize the equator-to-pole temperature difference as a third method for assessing the LTG. During the early- to mid-Holocene the high latitudes warmed with respect to the equator where temperatures remained relatively stable over the past 11.5 ka.



Temperature Composites: Holocene latitudinal temperature composites with the number of contributing records in gray. Errors were calculated using a bootstrap sampling approach. The Holocene composites show little long-term change in the equatorial regions, and greater low-frequency variability with increasing latitude.





Holocene latitudinal temperature gradients and mid-latitude aridity: Top: Northern Hemisphere latitudinal temperature gradient as characterized using three different methods including regression across latitudinally distributed composites (black), regression on all records (red), and high latitudes minus low latitudes (purple). Average mid-latitude (30°N-50°N) aridity (bottom). The discrepancies during the earliest parts of the records likely reflect the decreasing data density and quality for the earliest Holocene. The gradual trend toward a stronger LTG was mirrored by decreasing aridity across the mid-latitudes, leading us to speculate that the reduced LTG during the early to middle Holocene caused weaker baroclinicity, weaker mid-latitude westerly flow, weaker cyclones, and decreased mid-latitude moisture transport.

Takehome: We find strong associations between changes in the LTG and mid-latitude aridity over the Holocene, yet the implications of these findings for current and future climates remain uncertain. Future impacts of Arctic amplification on circulation are a topic of debate and might altogether be overwhelmed by the competing influences of climate change on hemispheric circulation such as tropical warming (e.g., ref. 9). Nonetheless, historic LTGs, as represented by TS3.2 CRU reanalysis data[1], have been decreasing rapidly over the past 20 years. Although the impacts of these recent changes on circulation have not been fully characterized, the proxy evidence presented here shows that a reduced Northern Hemisphere LTG coincided substantial aridity across the mid-latitudes that persisted for millennia during the early-to-mid-Holocene.

Acknowledgements: We thank the Science Foundation Arizona Bisgrove Post-Doctoral Fellowship for supporting this research. We thank Dr. Bryan Shuman and Dr. John Barron for data contributions. We also thank the PAGES2k project for access to preliminary data and Dr. Julien Emile-Geay for matlab code which was modified for this analysis.

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