# Greatly Expanded Warmpool and the Onset of Glacial Cycles


Chris Brierley and Alexey Fedorov - Dept. Geology & Geophysics, Yale University

Christopher.Brierley@Yale.edu - http://earth.geology.yale.edu/~cmb243



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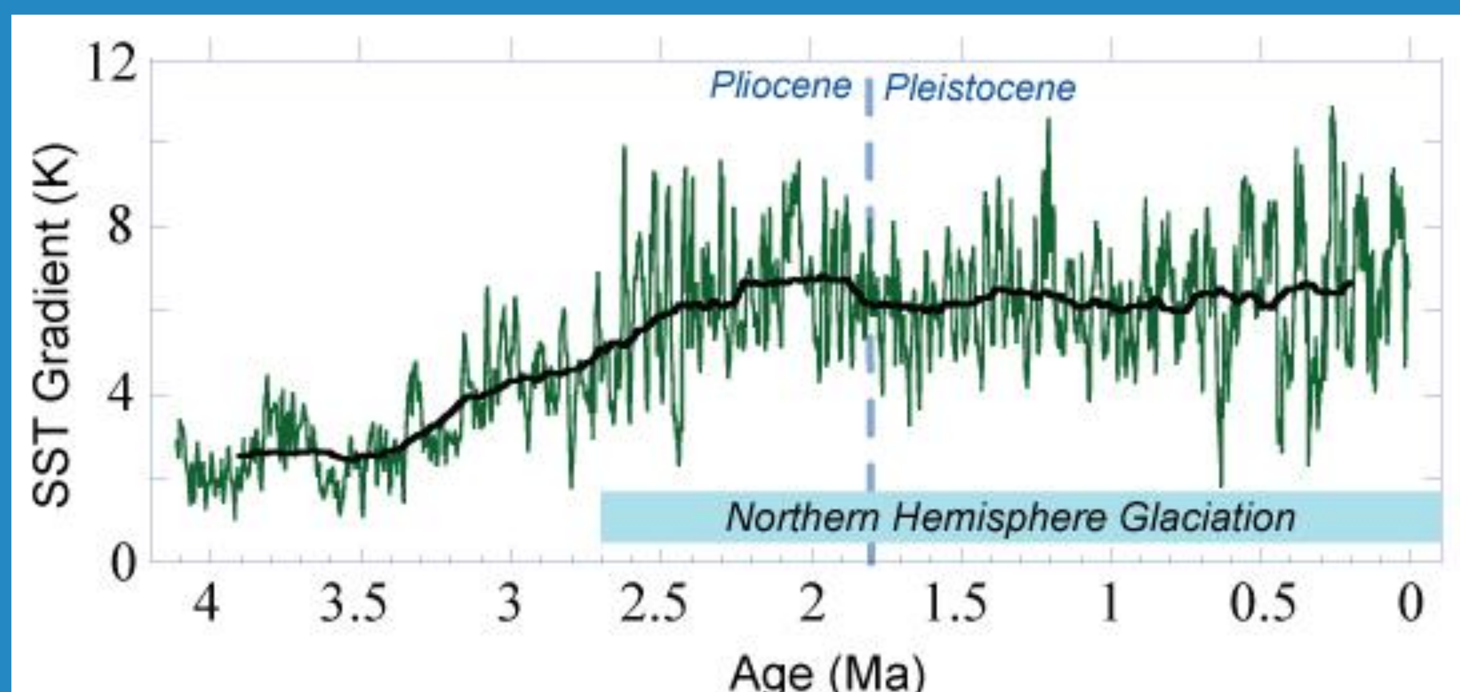
## Motivation

The Pliocene saw a remarkable shift in climate; from a stable, warm climate to one with periodic large ice sheets in the Northern Hemisphere. The most reliable information about the evolution of the Pliocene climate comes from ocean sediment cores. Sea-surface temperatures (SSTs) can then be calculated (through alkenone unsaturation ratios and Mg/Ca ratios) to create local time-series. These local time-series show a gradual change from a rather uniform tropical Pacific to one incorporating significant spatial variations similar to the present-day Pacific - see 1.

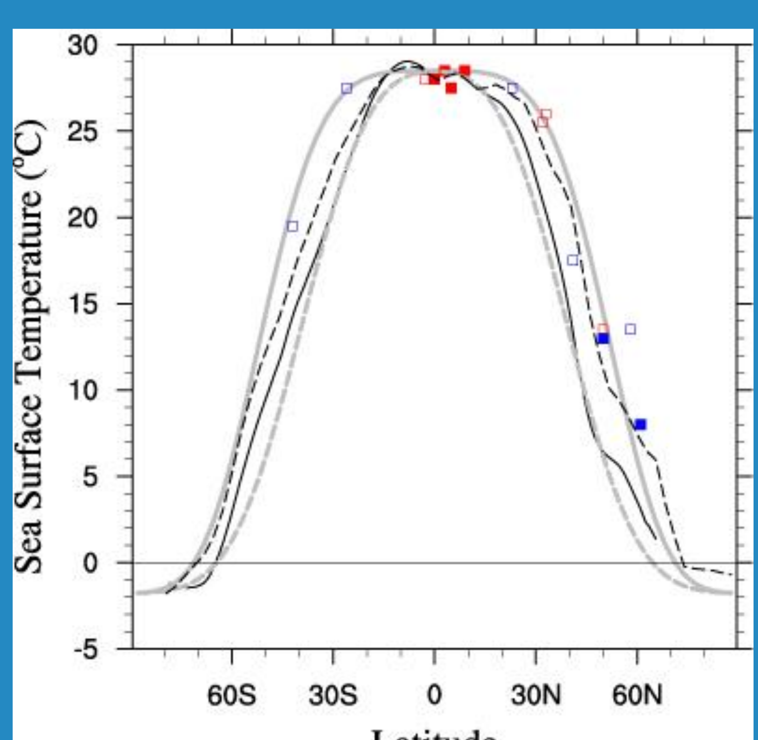



**1: Paleo-Observations of SST gradients.**
*The green line is the difference between ODP 896 (in the Eastern Equatorial Pacific) and ODP1012 (in the Californian Coastal Margin). It is a measure of the Tropical meridional SST gradient on the Eastern side of the basin, and reaches present-day values by the end of the Pliocene - from Brierley et al. (2008).*

## Method

We use an atmospheric general circulation model to investigate the global impact of the changes in SST gradient - in our case the community atmosphere model (CAM3). We use T42 resolution and 355 ppm of $CO_2$. We combined the data shown in 1 to other data (slightly adjusted to represent the central Pacific) to create a latitudinal SST profile for the Early Pliocene (2). We apply a hypothetical fit to the SST profile (solid, gray line in 2) at every longitude, creating a zonally uniform ocean surface. The North Atlantic has slightly warmer high latitudes than the Pacific, because of northward transport of heat by the ocean.

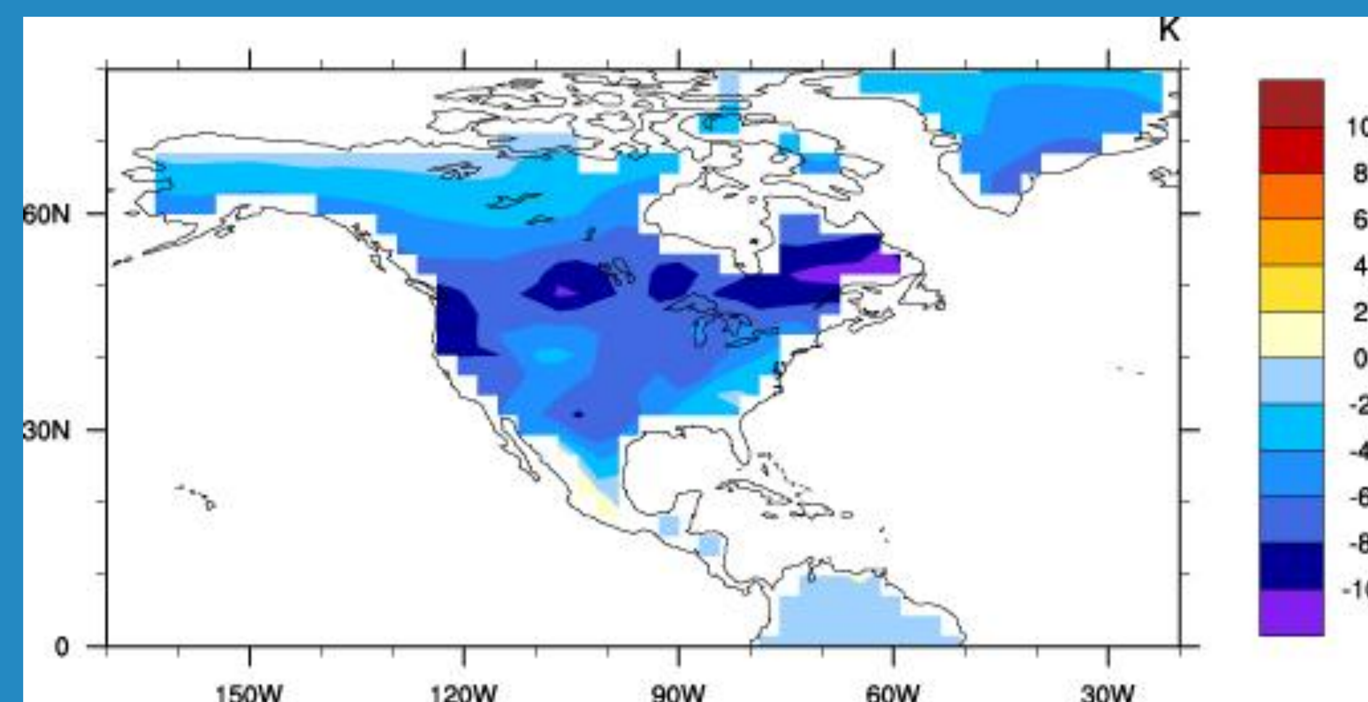
A control profile was created by applying a hypothetical fit to the present-day observations at every longitude (dashed, gray line in 2). This allows us to isolate the impacts of the increase of meridional SST gradient over the Pliocene shown in 1.




**2: Meridional Variations in Sea Surface Temperature.** *The markers indicate paleo-observations. The solid, black line is the present-day observations at 180º. The dashed, black line is the Pliocene SST reconstruction from the PRISM dataset at 180º. The solid, gray line shows the SST profile used for the Early Pliocene. The dashed, gray line is our hypothetical fit to the present-day observations.*

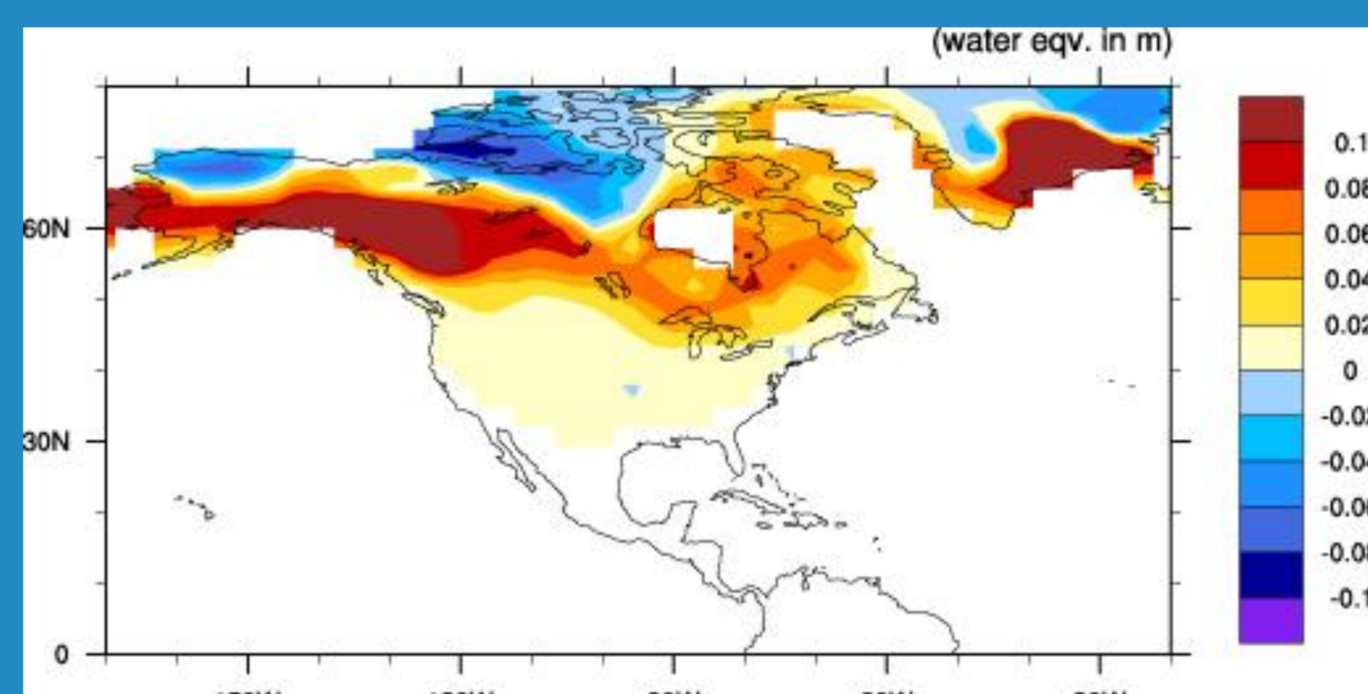
## Extra-tropical Impacts

The changes in simulated climate between the two model runs show the impacts of the increase in meridional SST gradient that occurred throughout the Pliocene. The Hadley circulation strengthens as the gradient increases, and the inter-tropical convergence zones (ITCZs) grows stronger and more compact. Both simulations are missing a Walker circulation and have dual ITCZs, because of the symmetrical nature of the prescribed SSTs.




**3: Impact of the Pliocene Increase in Meridional SST Gradient on Summer Temperatures.** Change in climatological JJA surface temperature between model runs based on the solid and dashed lines in **2**.

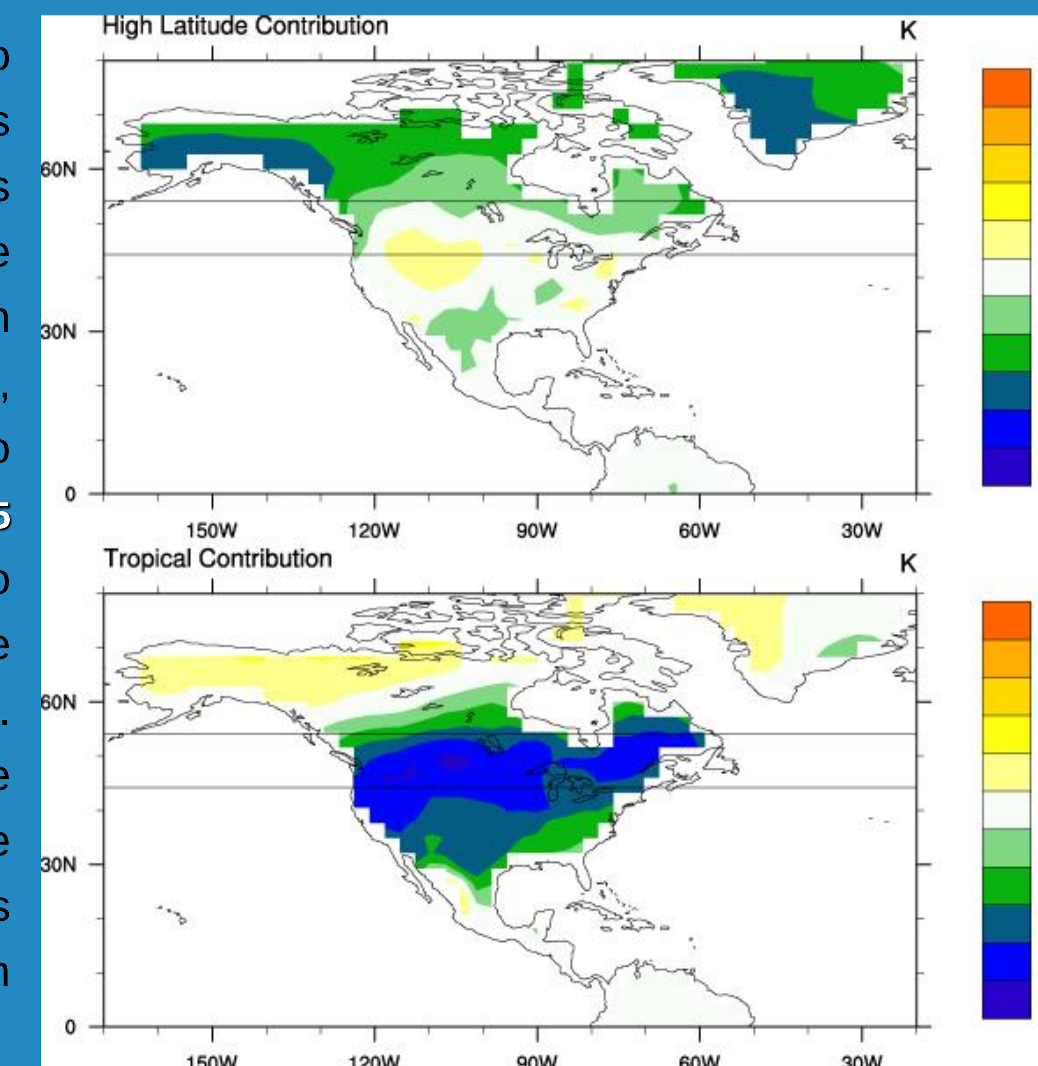
The most intriguing change in climate that occurred in the Pliocene is the onset of Northern Hemisphere glaciations (1). Could the gradual increase in meridional SST gradient have played a role in this? The atmospheric model used in this study does not incorporate an ice model, and the orbital configuration used is taken from the present interglacial, so we will not suddenly form an ice-sheet. We can investigate necessary conditions that would be conducive to ice growth however. 3 and 4 investigate two of these necessary conditions. The cooling of summer temperatures in 3 is needed to allow ice to persist throughout the year, and subsequently build-up into an ice-sheet. The increase in snow cover in 4 will allow more rapid ice build-up and help prevent complete melting in the summer. These show that the Pliocene increase in meridional SST gradient could have contributed to the onset of Glacial cycles.




**4: Impact of the Pliocene Increase in Meridional SST Gradient on Winter Snow Cover.** Change in climatological DJF snow-cover (which is prescribed to never exceed 1m) between model runs based on the solid and dashed lines in **2**.

## Attribution

Moving between the two profiles shown in 2 involves changes in both the Tropics and High Latitudes. We performed a third simulation with a combined SST profile, which merges the two profiles in the extratropics. 5 shows the contributions to the cooling in 3 from the High Latitudes and Tropics. Both contributions are needed to reproduce the overall cooling. It appears that the tropical contribution dominates the total pattern.




**5: Dividing the changes shown in 3 into Tropical and High Latitudes components.** The two thin black lines show the latitudes over which the transition between the two profiles in **2** occurs. The surface temperature changes over the ocean are strongly constrained by the prescribed SSTs, but not those changes over land. Some elements of the patterns may be attributable to natural variations between the model simulations.

## Conclusions

- **The Early Pliocene is characterized by a vast meridional expansion of the tropical warm pool.**
- **Gradual increases in meridional SST gradient and contraction of the warm pool occurred between 4 and 2 Ma.**
- **The increase in meridional SST gradient appears to be a necessary condition for the inception of ice sheets in the Northern Hemisphere.**
- **Changes in zonal gradients are also important (Barreiro et al, 2006), although to a lesser extent.**
- **Tropical temperature changes, especially the contraction of the warm pool are a critical component of this effect.**

## Future Work

- **The impacts on glacial inception need to be investigated further by using an ice sheet model forced by the climate change described here.**
- **Further investigations are needed to uncover causes for the increase in the meridional SST gradient.**
- **Simulating Pliocene-like changes in the warm pool extent and their effect of North America within a coupled model is the ultimate goal**

References


Barreiro et al., 2006. Simulations of warm tropical conditions with application to middle Pliocene atmospheres, *Clim. Dyn.*, **26**,349-65

Brierley et al., 2008. Greatly Expanded Tropical Warm Pool and Weakened Hadley Circulation in the Early Pliocene, *Submitted.*