Can inter-ocean gateways explain long-term cooling since the early Pliocene?

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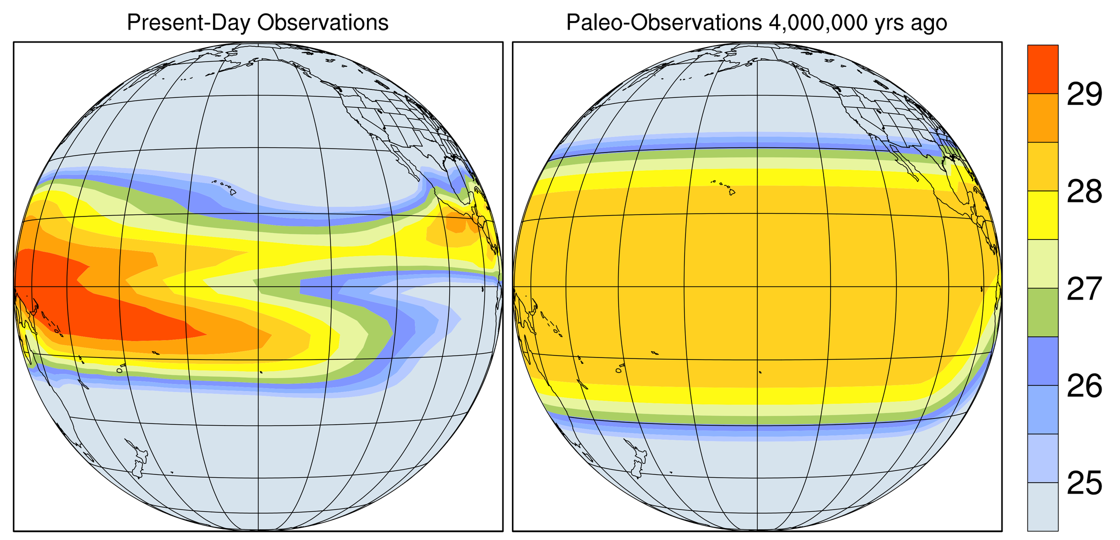
1. Introduction

The climate of the early Pliocene (~4 million years ago) is considered an analogue of future climate change. This comparison is only valid if the boundary conditions of the early Pliocene are similar to those of the future. In other words, was the continental configuration substantively different than at present?



Annual mean sea surface temperatures in the Tropical Pacific (in °C): (left) at present and (right) in the early Pliocene (after Brierley et al., 2009)

Paleo-observations for the early Pliocene show it was a warm world, with CO_2 levels a little higher than preindustrial. There was a dramatically different structure of tropical sea surface temperatures (SST) as shown by the reconstruction from Brierley *et al.* (2009). Climate is most sensitive to tectonics through changes in ocean gateways (whose timings can be uncertain). We test the climate's sensitivity to three possible gateway changes to see if they can explain the critical features of the early Pliocene SST pattern:

- Minimal increase in the warmpool temperature
- Weak gradients along the Equator (esp. the tropical Pacific)
- Smaller meridional temperature gradients

2. Method

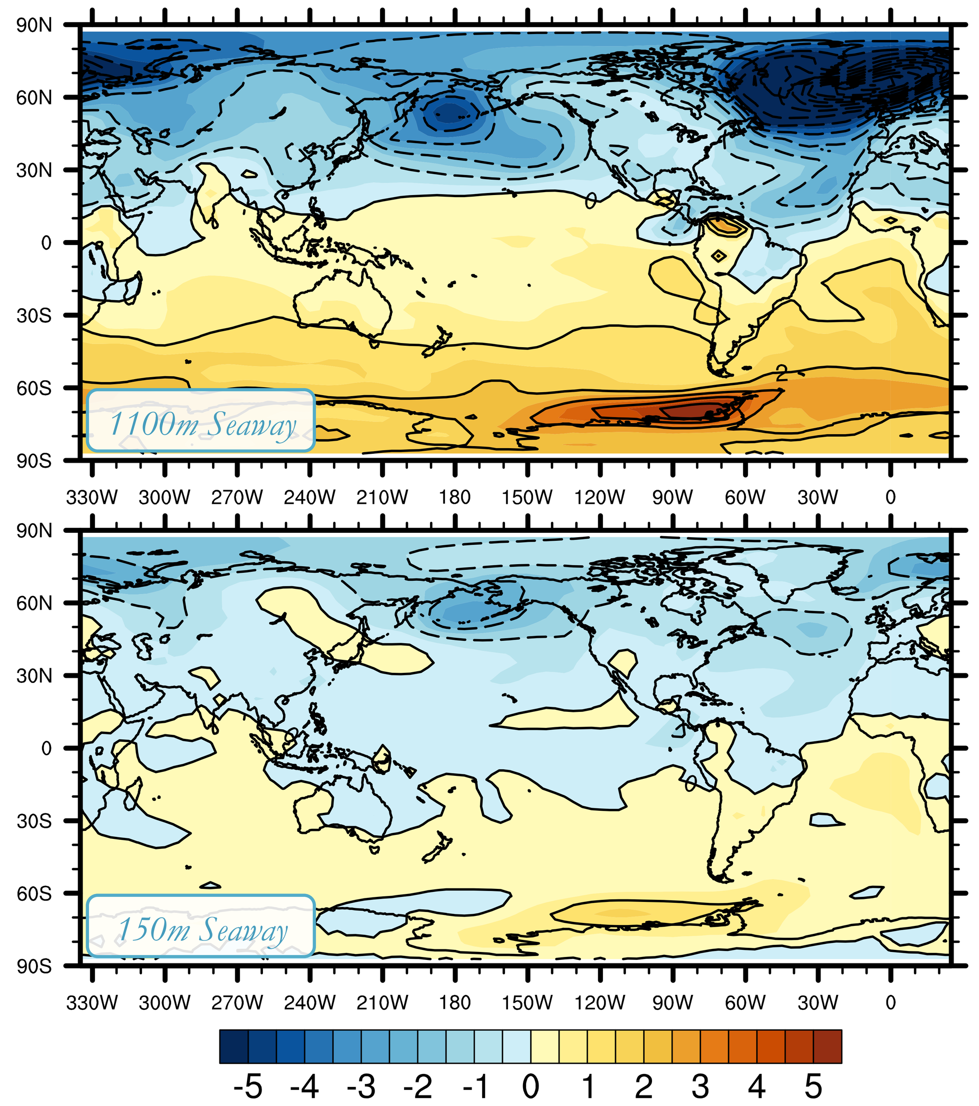
We use a common model framework to compare the impacts of all the gateway changes – the Community Earth System Model at its low-resolution. This coupled model has atmosphere and land components with a spectral grid at T31. The ocean and sea-ice components have a rotated pole grid with a nominal resolution of 3°, which increases towards the Equator. The model does have a cold bias, related to insufficient poleward heat transport.

Each experiment starts from, and is compared to, the same preindustrial simulation. The vegetation, greenhouse gases and orbital configuration remain at their 1850 conditions throughout. Each experiment involves altering 5 ocean grid points and all model runs are 500 years long. We show the difference in surface air temperature averaged over the final 25 years.

3. Panama

The closure of the Central American Seaway weakens the Atlantic Meridional Overturning Cell (AMOC) and cools the North Atlantic - suggesting a connection to the onset of glaciation at ~2.7 Ma. Yet, evidence implies an earlier closure (Molnar, 2007).

Steph *et al.* (2010) suggest that closure of the seaway led to global shoaling of the thermocline in the tropical Pacific, itself a possible explanation for the Pliocene SST pattern (e.g. Brierley *et al.*, 2009).

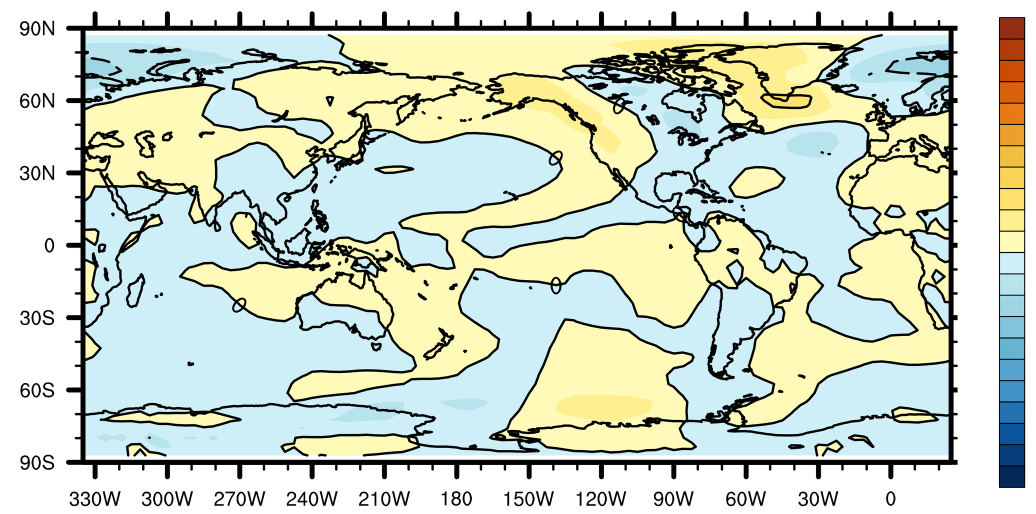


Open – Closed Central American Seaway impact on surface temperature for two different depths of channel (in °C)

We open the Seaway to either 150m or 1100m depth, both of which lead to a weaker AMOC and cooler North Atlantic. The open seaway runs have deeper thermoclines, but only in the Northern hemisphere. This may be model specific (Zhang *et al.*, 2012), but does not show the weaker gradients in the tropical Pacific implied by the paleo-observations.

4. Indonesia

Cane & Molnar (2001) were the first to suggest that Pliocene changes in the Indonesian throughflow had far reaching climate impacts. The gradual northwards movement of New Guinea leads to a change in the source water from the South Pacific to the North Pacific.

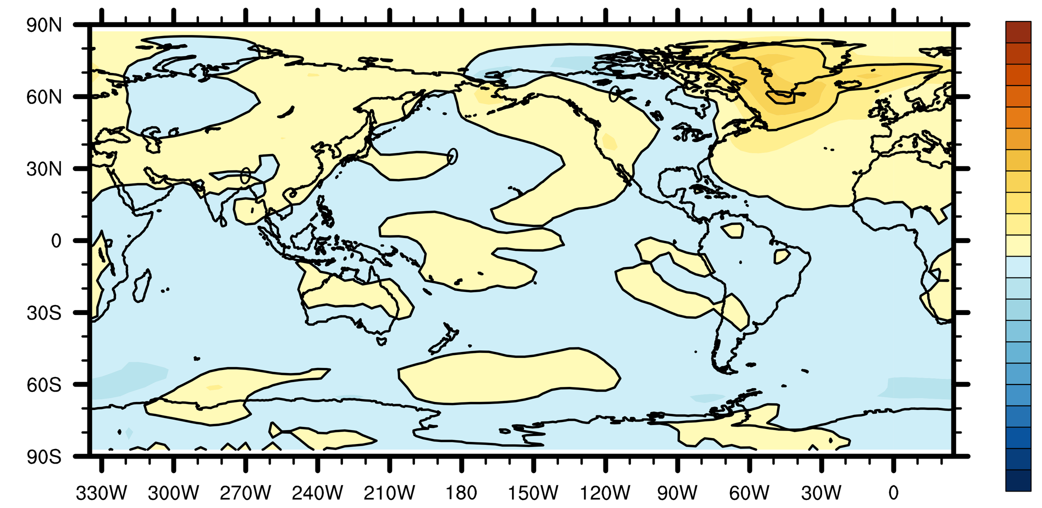


South – North Pacific Inflow impact on surface temperature (in °C)

We show only weak impacts on the global climate arising from this shift in source water. The temperature changes are rarely statistically significant and the high latitude changes shown could arise from internal variability. This lack of impact on the mean climate agrees with Jochum *et al.* (2009). Tectonic movement within the Indonesian archipelago would probably not invalidate using the Pliocene as a future analogue. However, changes in tidal mixing there may be important (Brierley & Fedorov, 2011).

5. Bering Strait

The Bering Strait, connecting the Arctic and North Pacific, is currently open, but closes during times of low sea level, such as glacial periods. Marincovich & Gladenkov (1999) show that the Bering Strait was permanently closed prior to 4.8Ma. Since Shaffer & Bendtsen (1994), several studies have shown it plays a role in setting the strength of the AMOC.



Closed – Open Bering Strait impact on surface temperature (in °C)

Here we see a marginally stronger AMOC leading to a warming of the North Atlantic by up to 2°C. The cooling of the North Pacific seen by earlier authors (e.g. Hu *et al.*, 2010) is not present. However, the model has some significant cold biases in that region already. There are no statistically significant SST changes in the Tropics.

6. Conclusions

We have used sensitivity experiments to ask what impact gateway changes have on the global climate. In particular, we wondered if they could explain the difference between present day SSTs and our tropical SST reconstruction of the early Pliocene.

Changes in Indonesia do not have a large global impact. Changes in the Central American Seaway and Bering Strait significantly alter the AMOC. Yet, neither seems to lead towards the SST pattern of the early Pliocene. So what does explain the difference then: errors in our understanding of the early Pliocene or missing feedbacks in the current crop of climate models?

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