Patterns of Early Pliocene Warmth

Testing Potential Mechanisms

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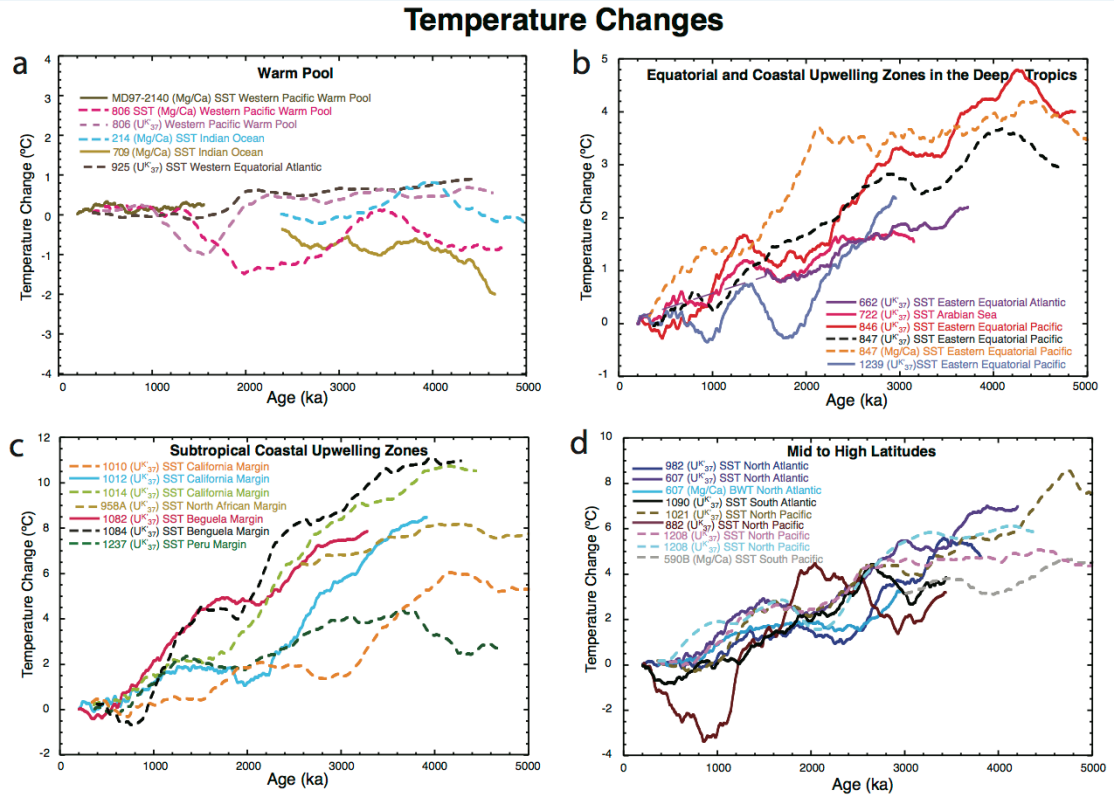
Recap: 3 (tropical) conditions

1. Little increase in peak temperature
2. Reduction in zonal temperature gradient
3. Reduction in meridional temperature gradient



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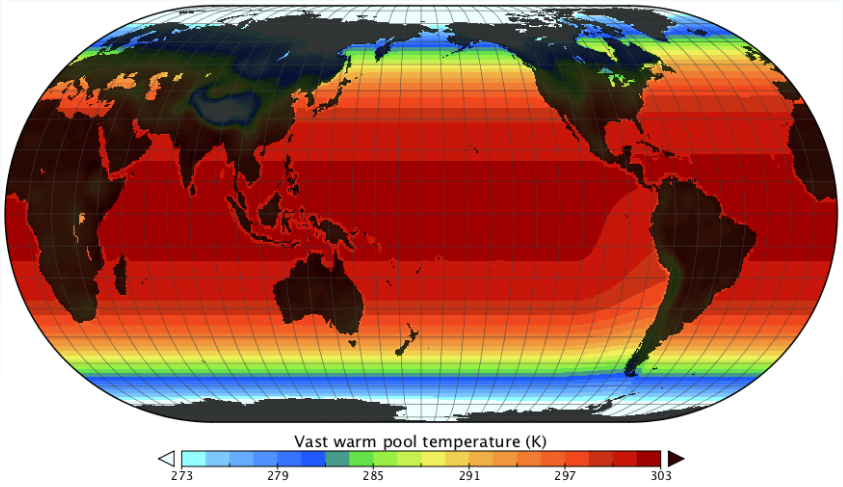
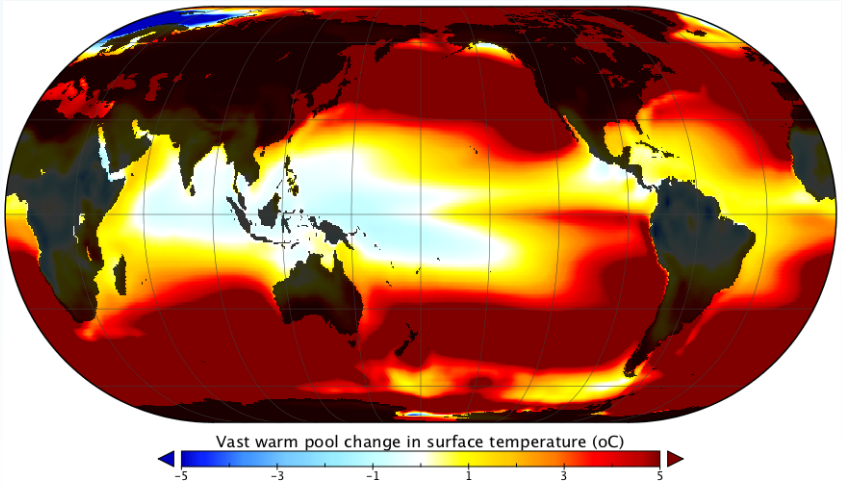
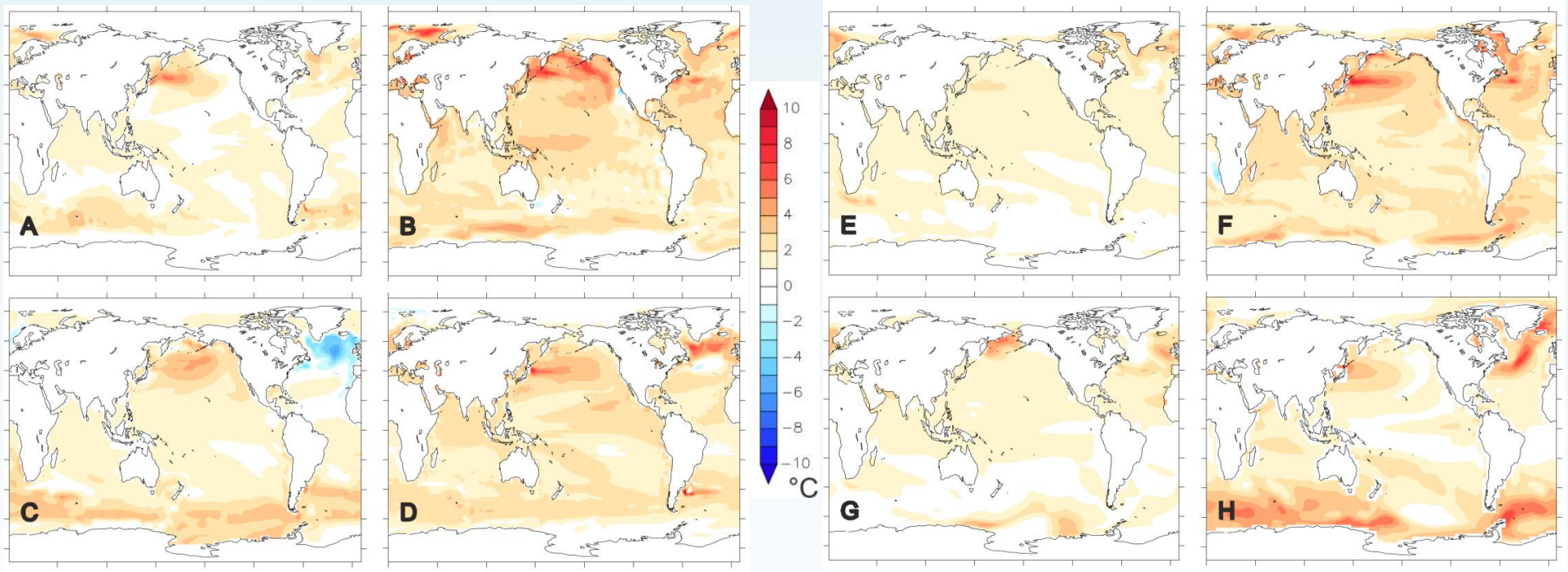
My view: **vast warm pool in the Pacific**





Do PlioMIP models get this pattern?



Haywood et al. (2013, Clim. Past), Figure S5: Annual mean sea surface temperature anomalies for all models in the multi-model mean for Experiment 2 (a: CCSM4, b: COSMOS, c: GISS-E2-R, d: HadCM3, e: IPSLCM5A f: MIROC4m, g: MRI-CGCM2.3, h: NorESM-L).

Why?

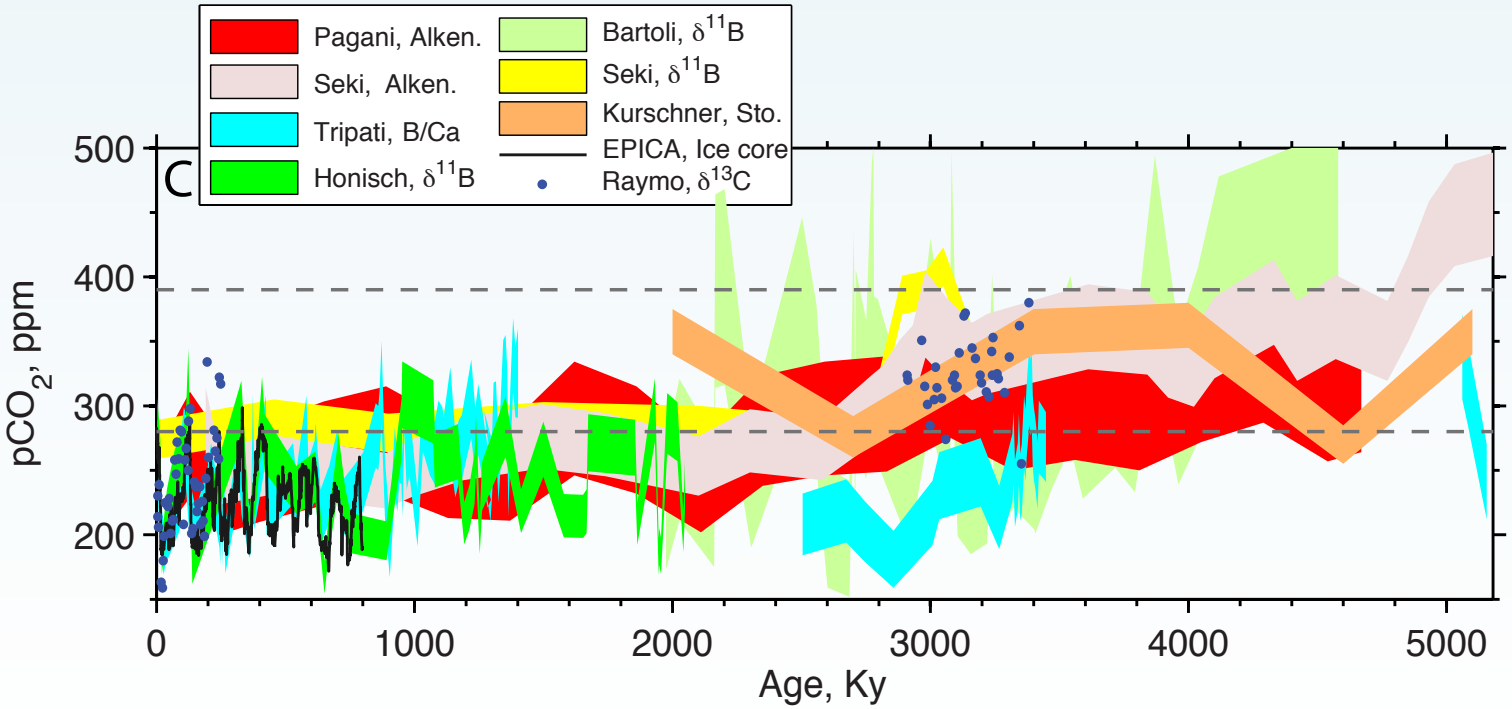
- Probably unrelated to solar forcing (too long/stable for orbital variability, but too short for stellar evolution)
- Many possible explanations hypothesized
- Falling into three broad categories
  - Unknown changes in forcing
    - Carbon dioxide increase
  - Changes in land configuration
    - Isthmus of Panama
    - Indonesian set up
    - Bering Strait
  - Models not capturing feedbacks correctly
    - Changes in ocean mixing
    - Change in cloud properties
- But which, if any, can explain the vast warm pool?

Model Framework

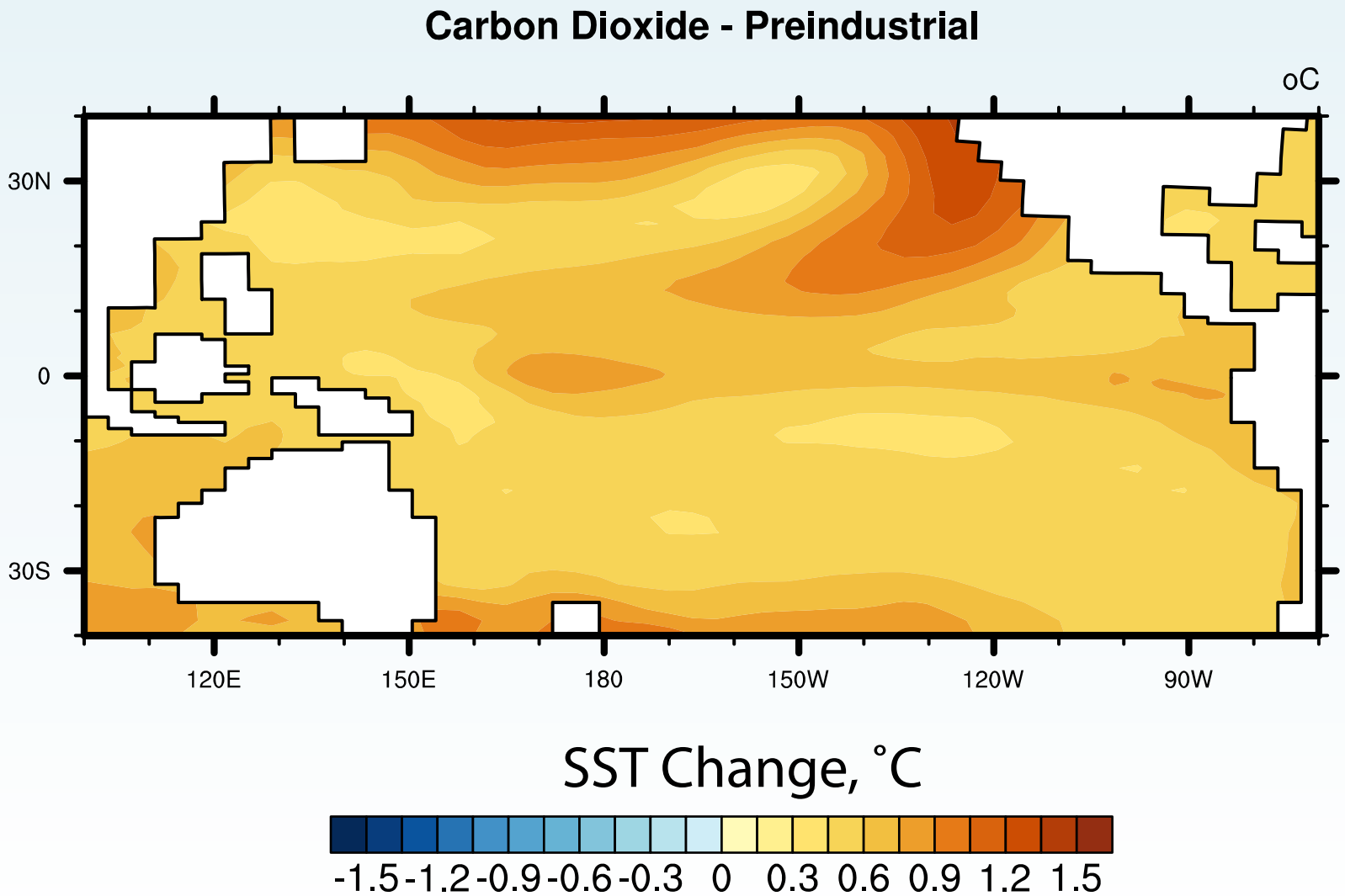
- Test sensitivity of tropical climate to each hypothesis individually
- Using NCAR's Community Earth System Model (CESM)
  - Newly released model to be included in next IPCC
  - Atmosphere (CAM4), ocean (POP2), sea ice (CICE) and land surface (CLM4) models coupled together
  - Low resolution version aimed at Paleoclimate work
  - T31 in atmos. (~3.75°) and ~3° in ocean (better at Eq)
- All simulations for 500 years starting from preindustrial control conditions (figures show average of last 50yrs)

Carbon Dioxide

- Still large uncertainty as to the actual value
- Small carbon dioxide increase (up to something comparable to today's elevated value)



Forcing: Impact on Trop. Pac.



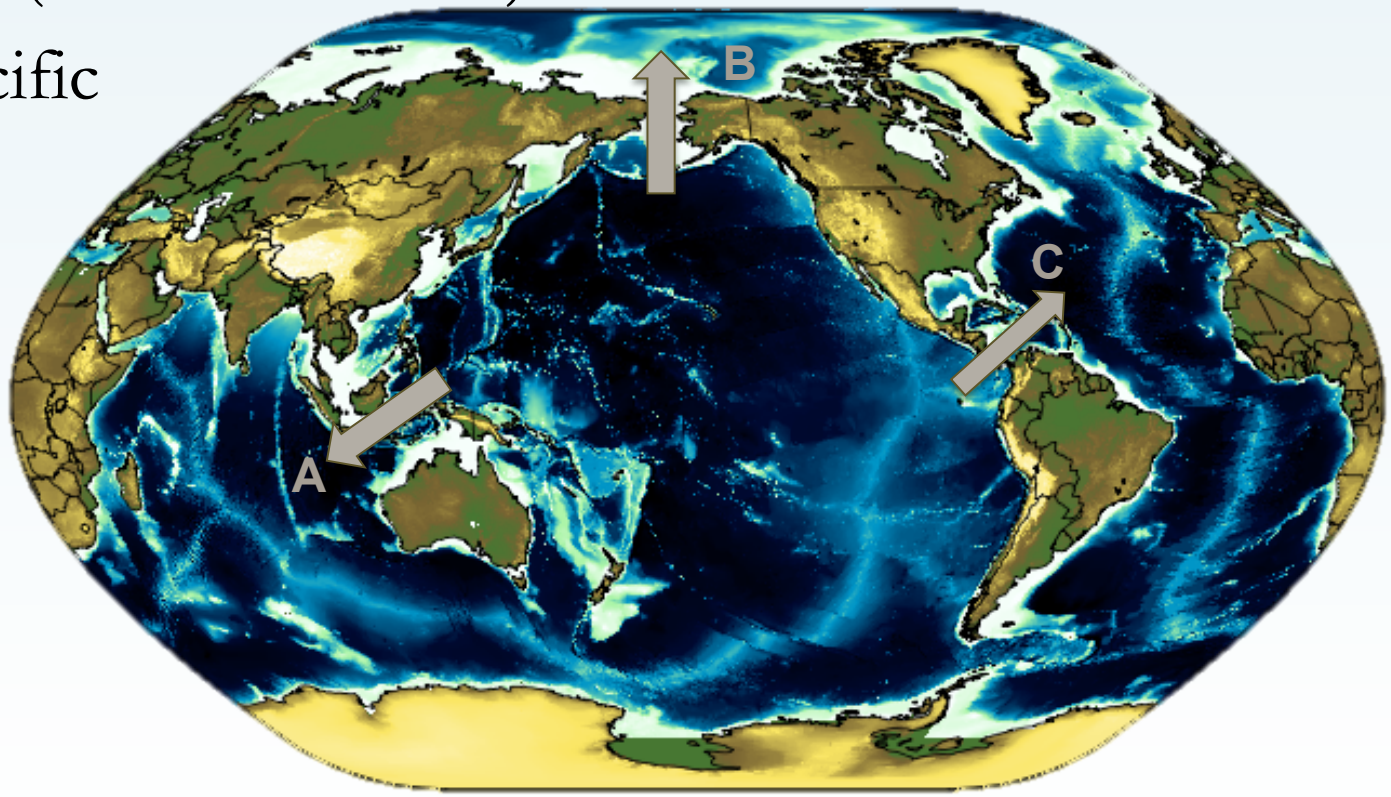
Ocean Gateways

- Climate is sensitive to changes in connections between oceans

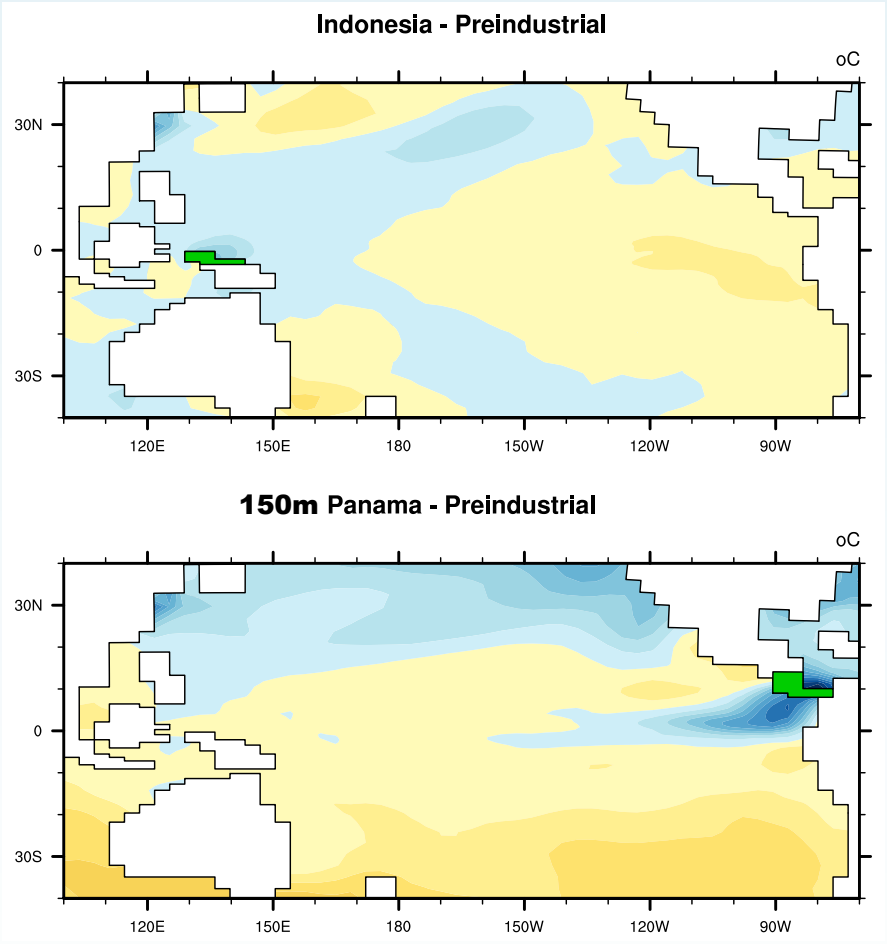
A. Indonesia Throughflow (Pacific to Indian)

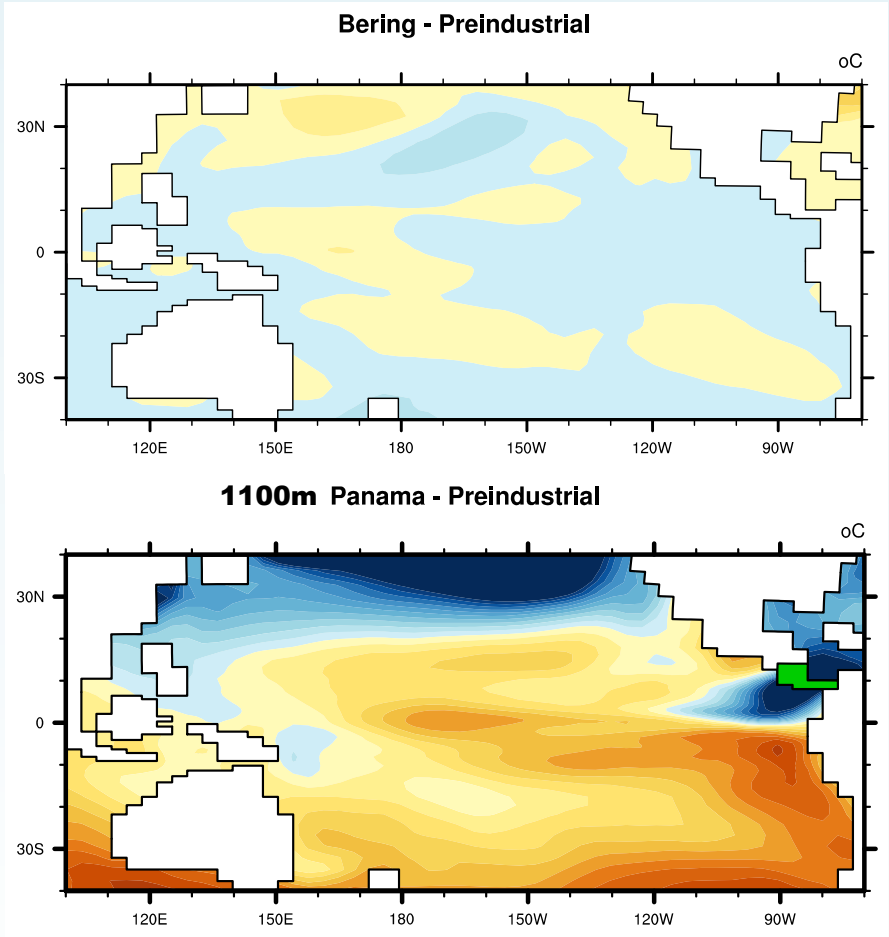
B. Bering Strait (Pacific to Arctic)

C. Panama (Pacific to Atlantic)



Land Configuration: Impact on Trop. Pac.





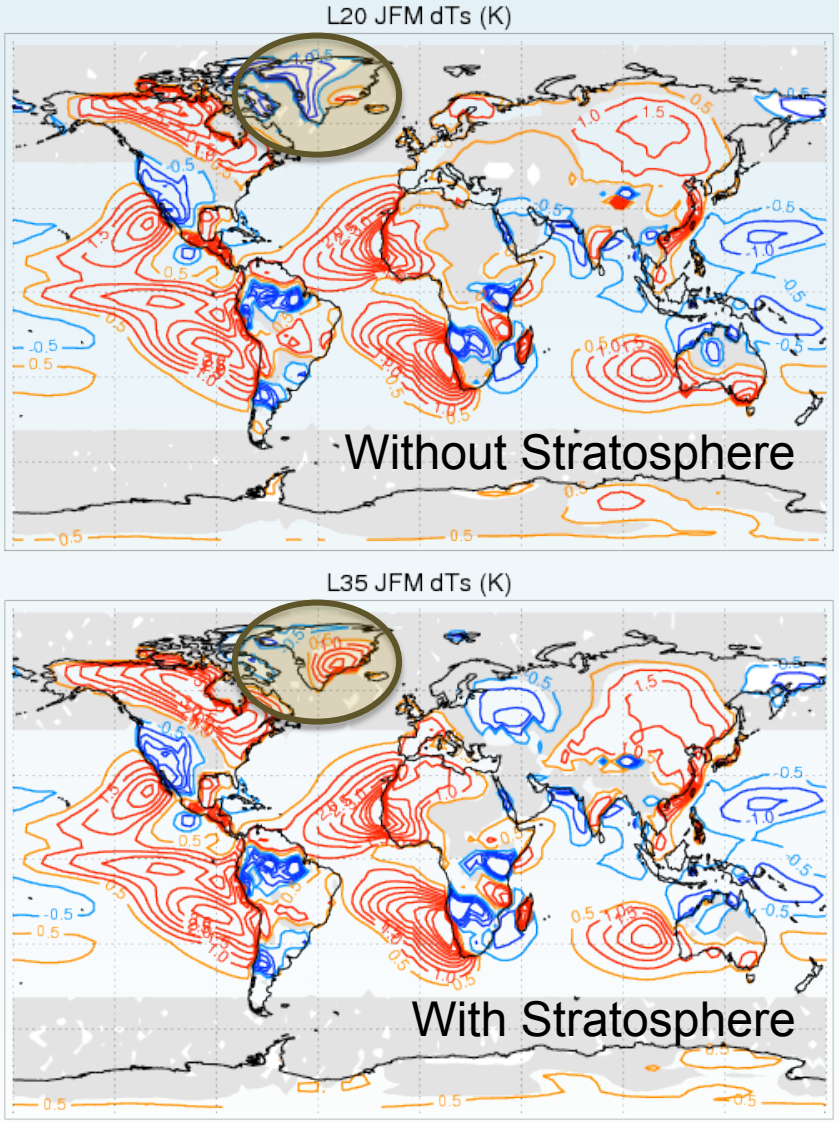
SST Change, °C

-1.5 -1.2 -0.9 -0.6 -0.3 0 0.3 0.6 0.9 1.2 1.5

Model Feedbacks: Stratosphere

Stratosphere

- Normal climate models only resolve troposphere
- Stratosphere (with its ozone) improve predictions
- Modifies NH response to tropical changes
- Needs vast warm pool to exist, before it does much
- Joshi & Brierley (2013)

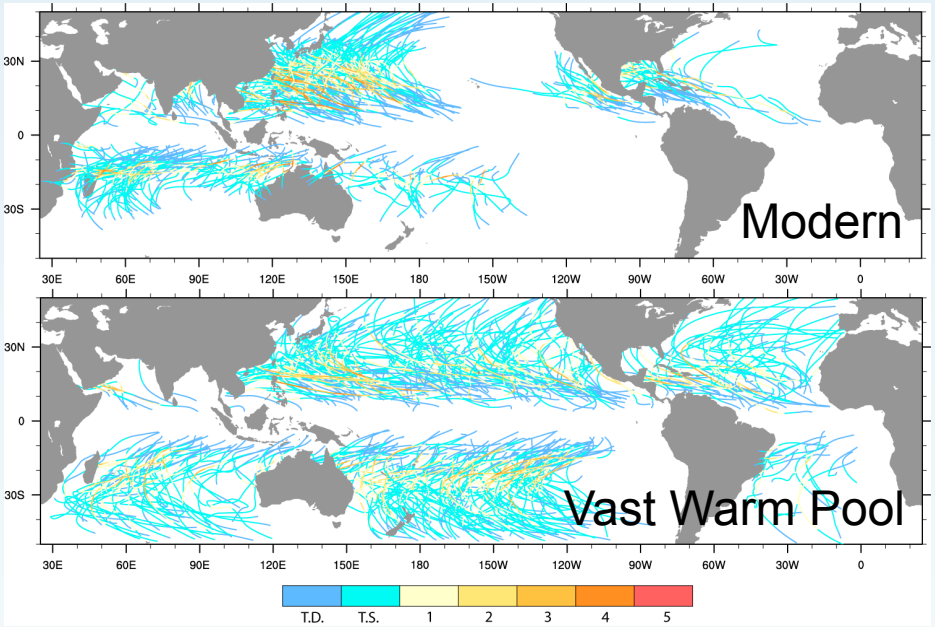


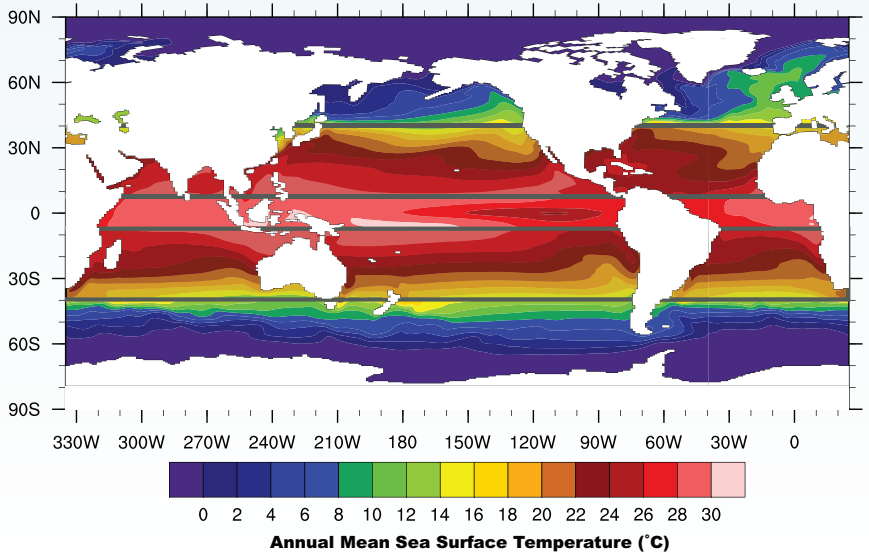
Surface temp impacts of imposing Pliocene vast warm pool in Tropics

Model Feedbacks: Ocean Mixing

Tropical Cyclones

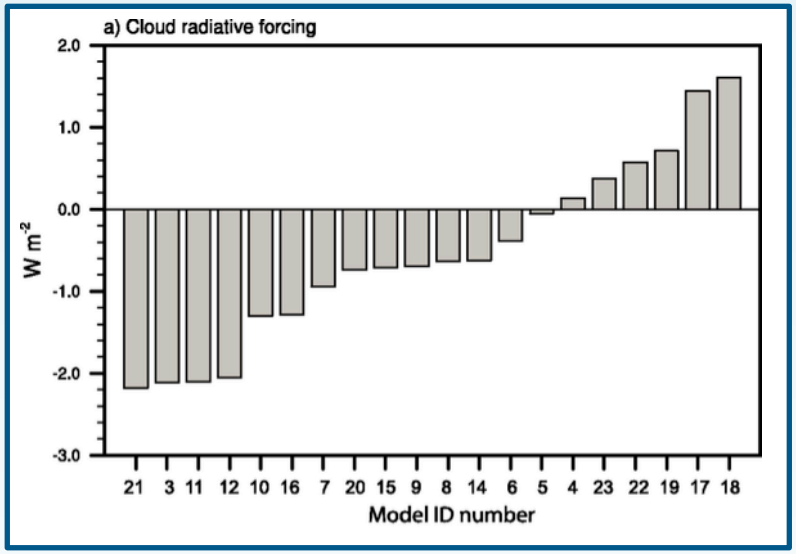
- Too small to be well simulated in paleo resolution models
- A vast warm pool has storms across much of tropical ocean
- Observations indicate cyclones give vertical mixing up to 1 cm^2s^{-1} (Sriver & Huber, 2007)
- As first order, include 2 broad stripes of additional upper ocean mixing (Fedorov et al. 2010)





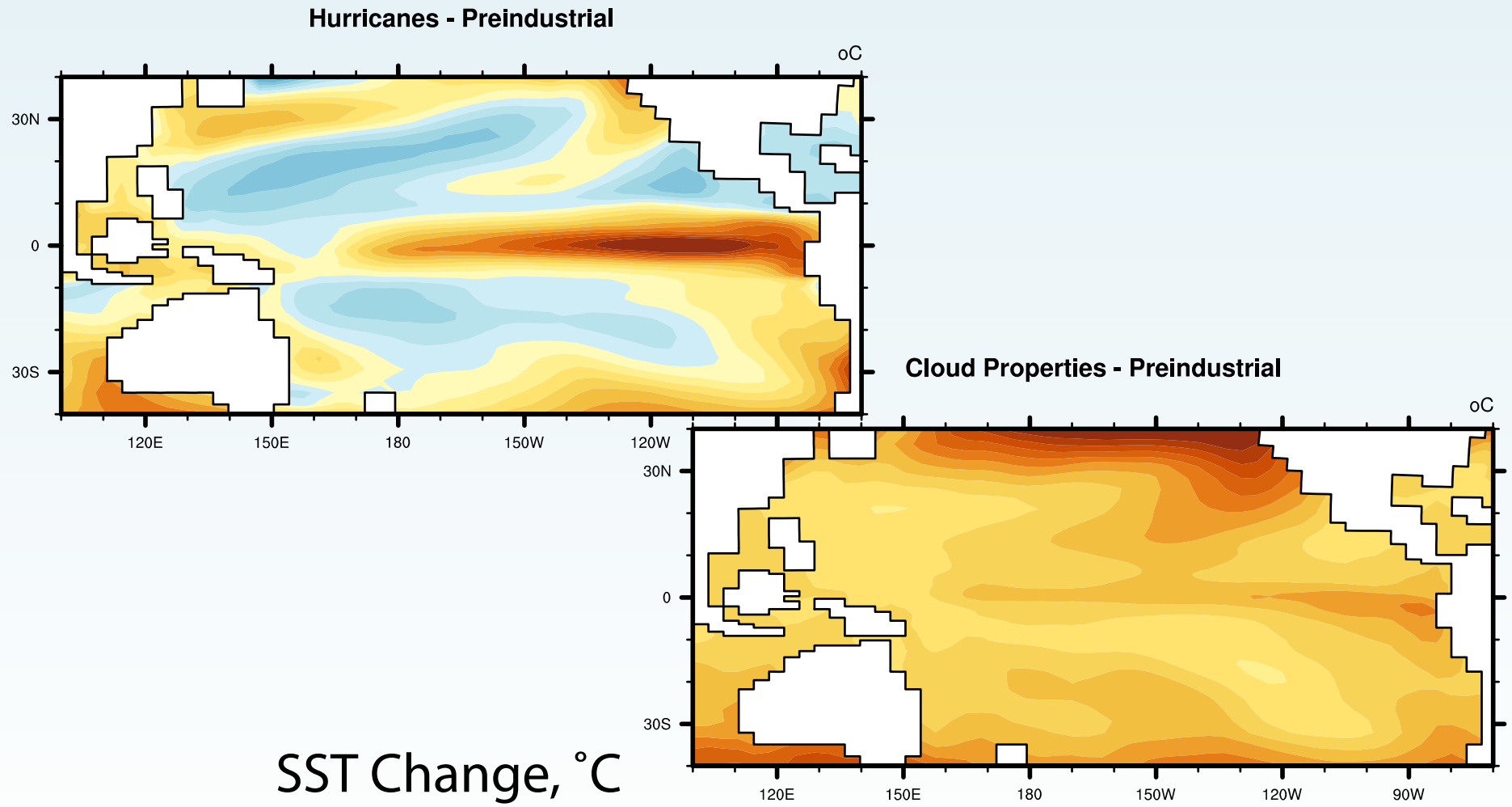
Cloud Properties

- Cloud properties and feedbacks are the largest cause of uncertainty in climate projections
- Barreiro & Philander (2008) use a simple climate model to test sensitivity of climate to reduction in cloud albedo in extratropics
- Mimic this by reducing cloud liquid water to 80% polewards of 35°N/S in shortwave radiation code



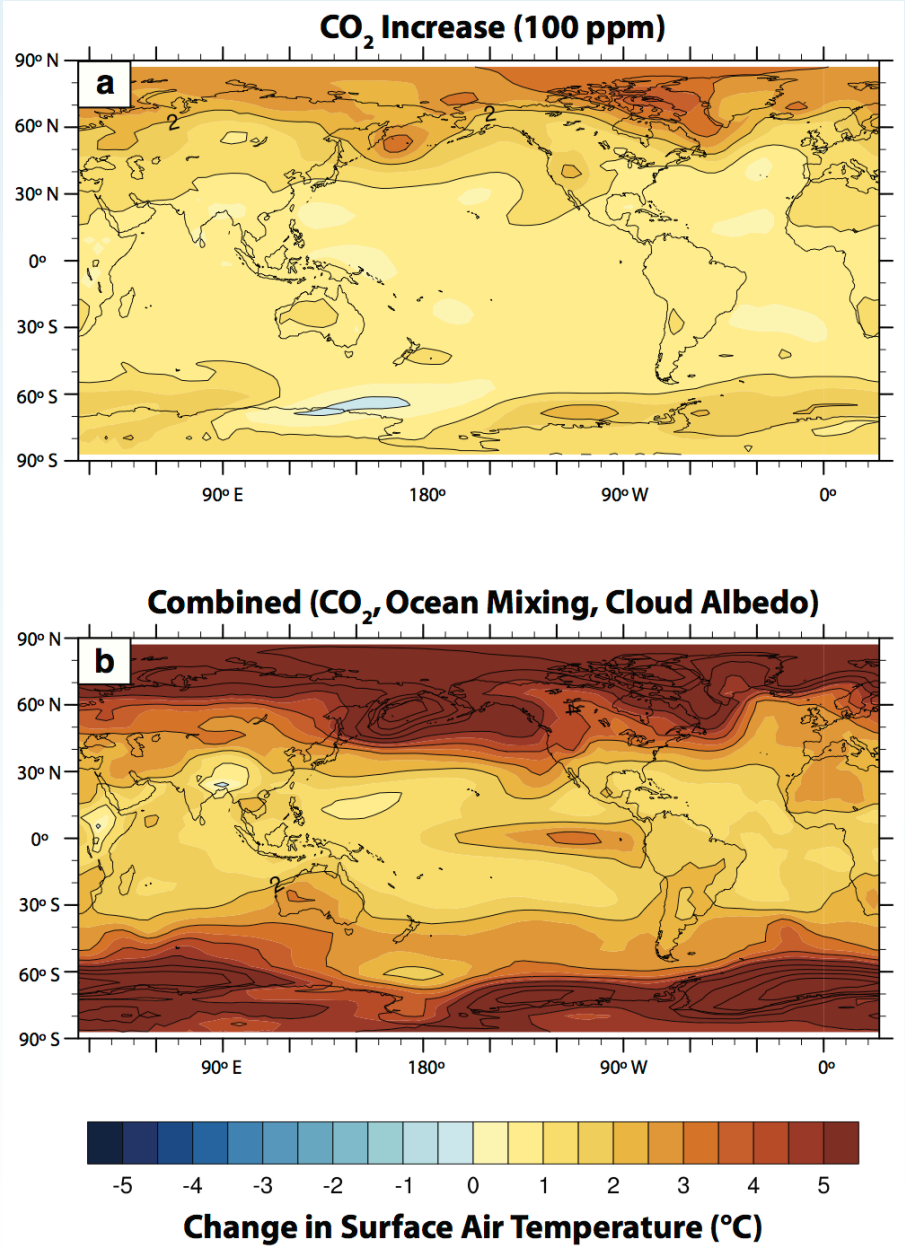
IPCC AR4 fig 10.11a). Global mean cloud radiative forcing from coupled models under A1B scenario – not even the sign is certain

Model Feedbacks: Impact on Trop. Pac.



Combination

- Looking for:
  - Reduction in equatorial SST gradient of ~4°C
  - No warming in West Pacific
  - Reduction in meridional gradient in both hemispheres
- None of my single patterns do this
- Perhaps they do when combined together
- Combine CO_2 changes to ocean & cloud feedbacks, but neglect tectonics & stratosphere



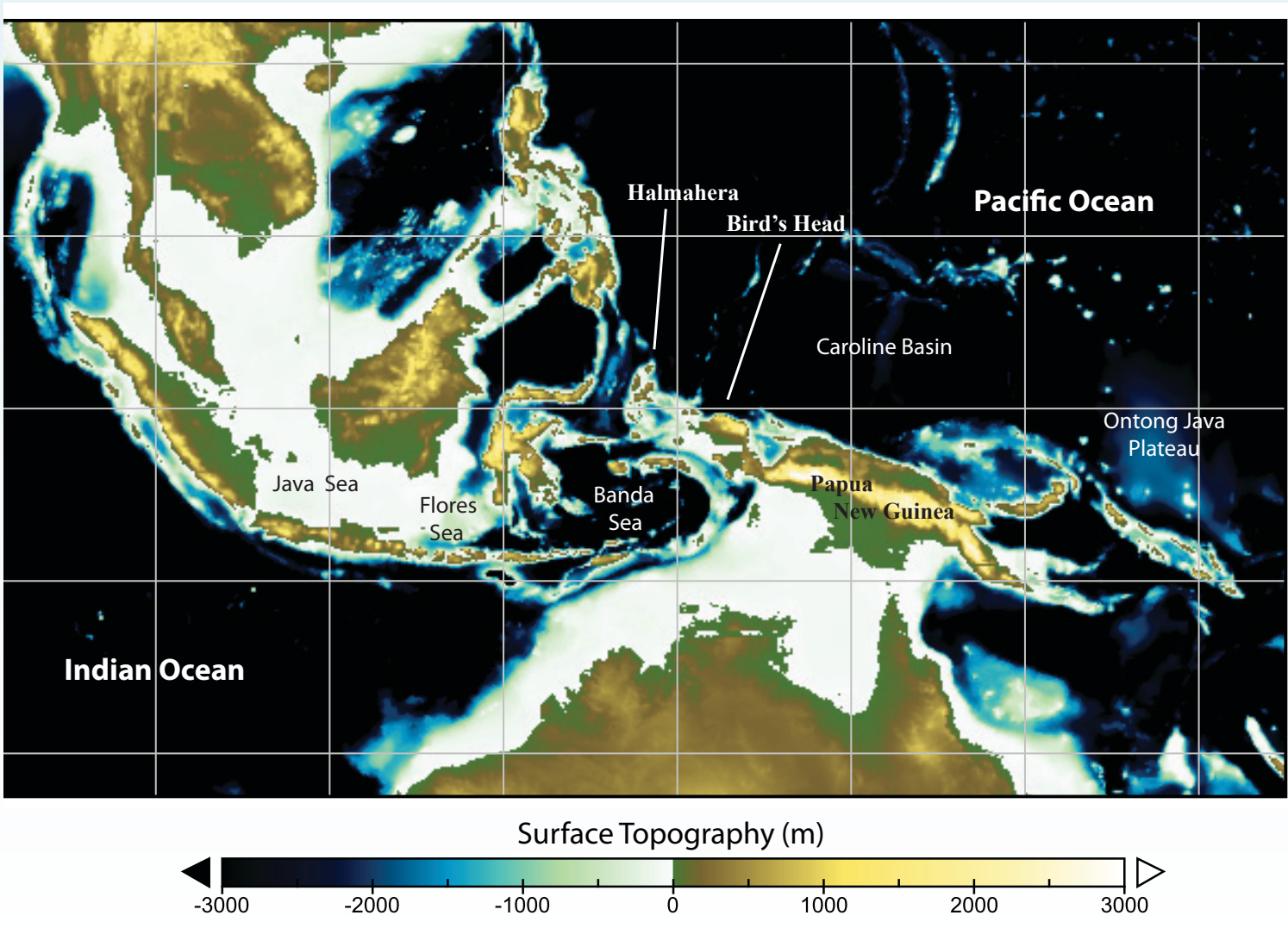
Conclusions

- Current models with known forcing do not recreate a vast warm pool
- Plausible tectonic changes do not reduce the discrepancy
- Simulating the early Pliocene may require incorporating additional climate feedbacks into the models

Land Configuration: Ocean Gateways

A) Indonesia

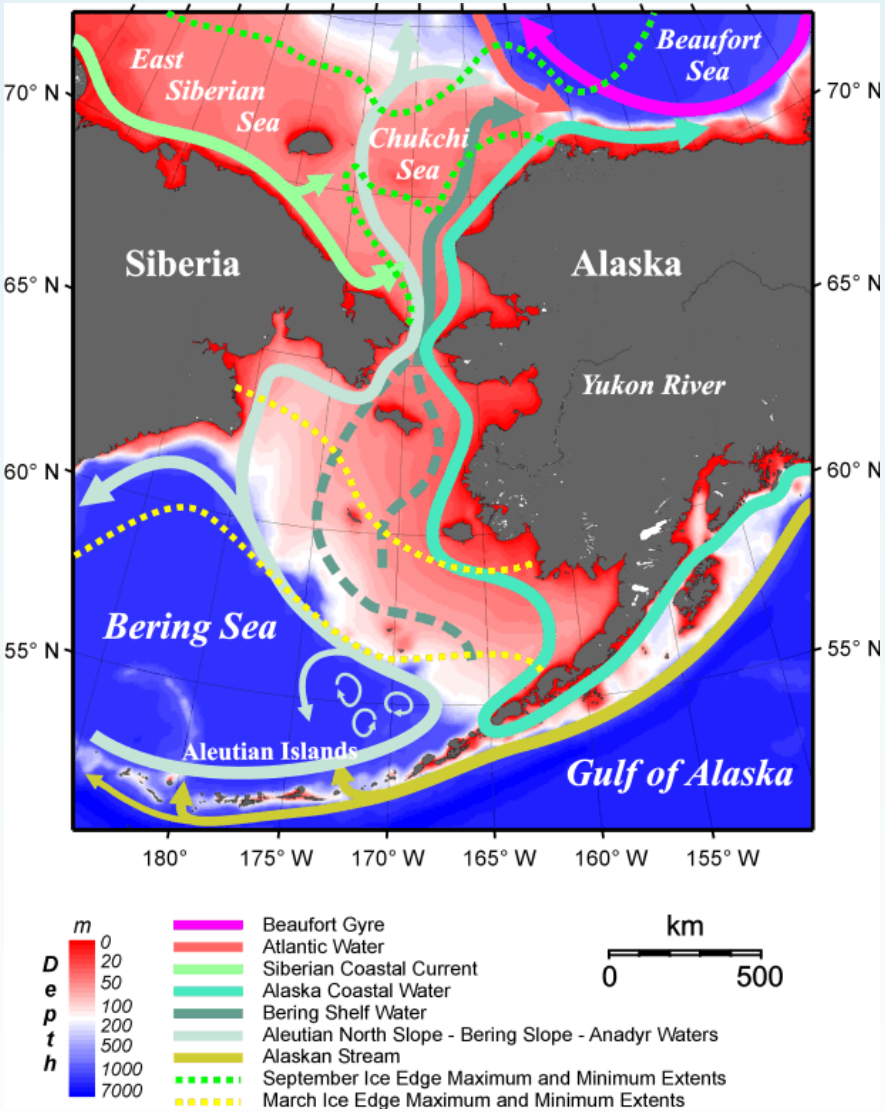
- Proposed by Cane & Molnar (2001) as cause of East African Aridification ca. 4Ma



Land Configuration: Ocean Gateways

B) Bering Strait

- Was closed in Miocene and opened since
- Still only shallow
- Susceptible to changes in global sea level
- Closed during glacial stages, with impact on poleward heat transport (Hu et al., 2010)

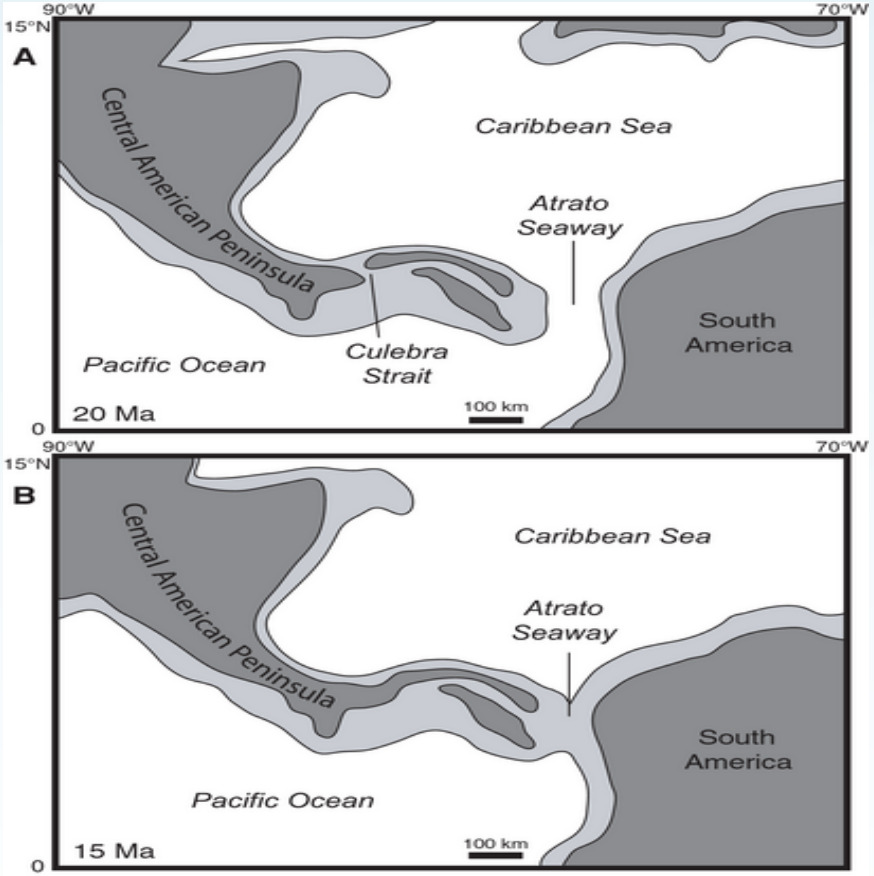


http://www.ims.uaf.edu/NS/

Land Configuration: Ocean Gateways

C) Isthmus of Panama

- Central American Seaway slowly constricted during Miocene
- No flow between Atlantic & Pacific sometime in Pliocene
- Proposed as trigger for glacial cycles at 2.7 Ma, but now thought to have shut earlier
- Tested in a variety of models
- I've removed Panama to a depth of 150 km (a deeper opening increases impacts)



Kirby et al. (2008), PLoS One