

Outline



- When was the Pliocene?
- What did the Pliocene climate look like?
- Why was the Pliocene climate like that?
 - a) Carbon dioxide increase
 - b) Movement of Indonesia and New Guinea
 - c) Emergence of Isthmus of Panama
 - d) Increase in Tropical Cyclones
 - e) Cloud property changes
- Summary

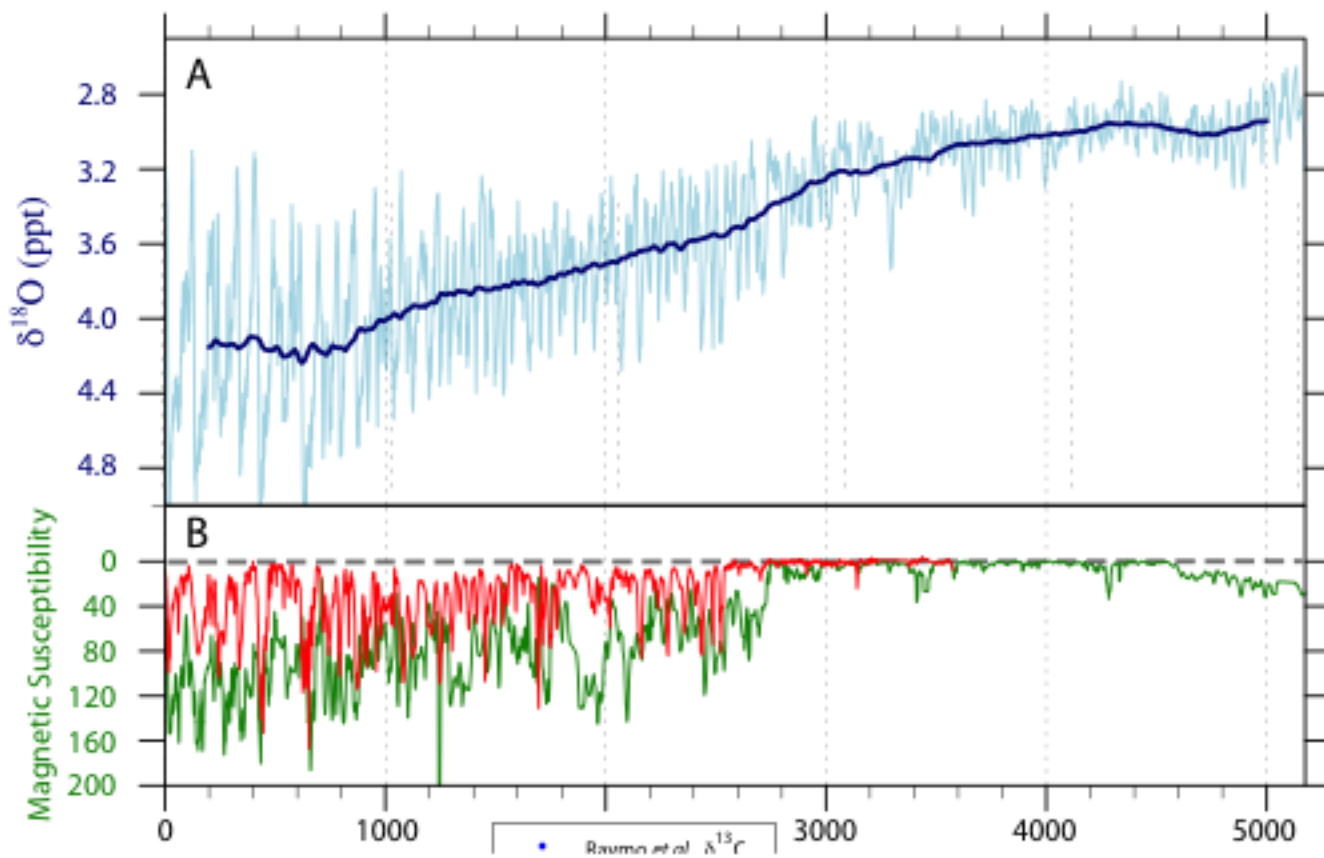
When?

- Time period spanning 5.3~2.6 million years ago
- I'll use 4Ma in this talk
- A relatively-short and recent period in the geological past.
- Deep time in view of most climate scientists inc. IPCC

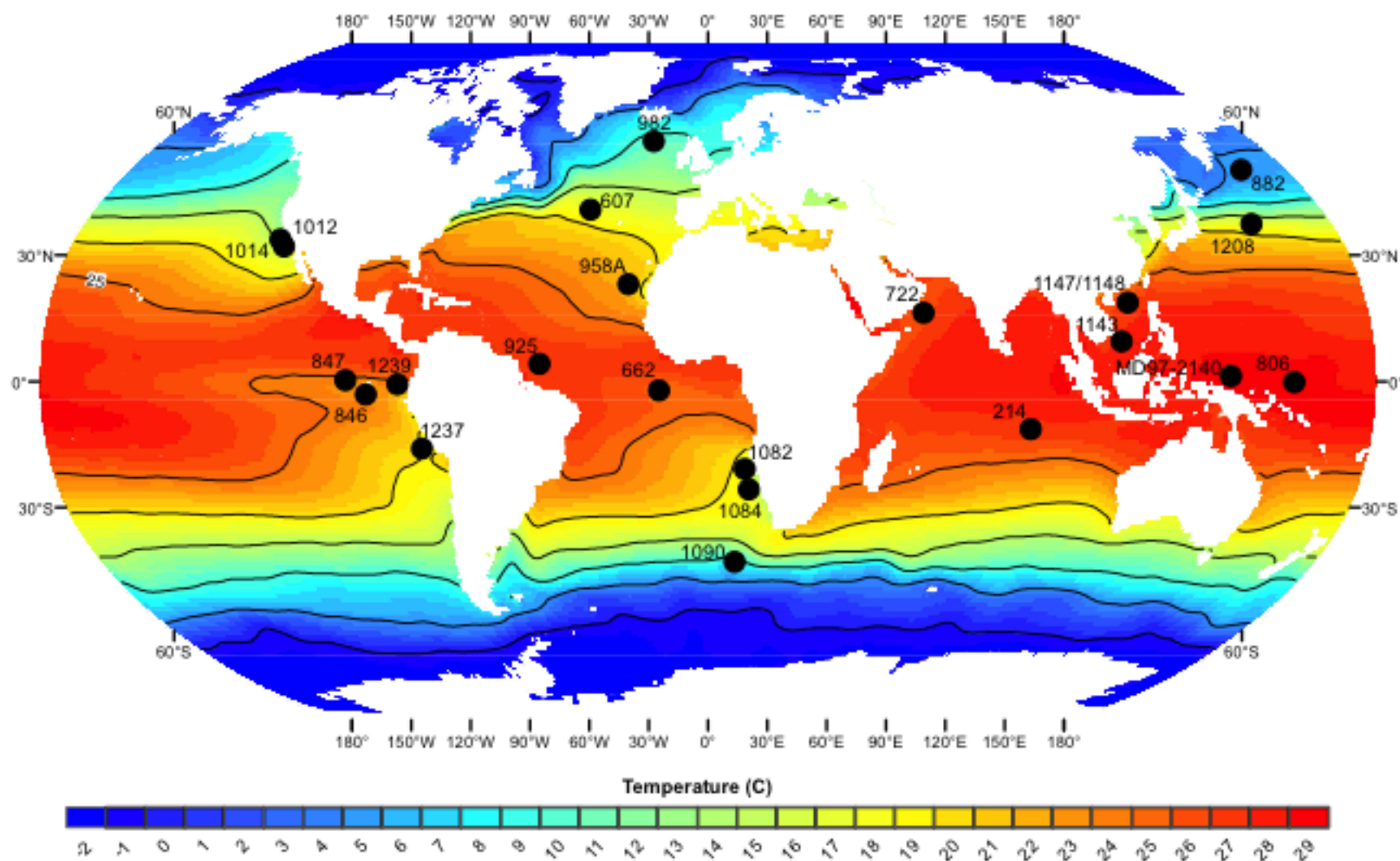
Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP	
Phanerozoic	Cenozoic	Quaternary	Holocene		0.0117	↗	
			Pleistocene	Upper	0.126		
				"Ionian"	0.781		
				Calabrian	1.806	↗	
				Gelasian	2.588	↗	
		Pliocene	Piacenzian	3.600	↗		
			Zanclean	5.332	↗		
		Neogene	Miocene	Messinian	7.246	↗	
				Tortonian	11.608	↗	
				Serravallian	13.82	↗	
	Langhian			15.97			
	Burdigalian			20.43			
	Aquitanian			23.03	↗		
	Oligocene			Chattian	28.4 ±0.1		
				Rupelian	33.9 ±0.1	↗	
	Paleogene			Eocene	Priabonian	37.2 ±0.1	
					Bartonian	40.4 ±0.2	
		Lutetian	48.6 ±0.2				
		Ypresian	55.8 ±0.2		↗		
		Thanetian			↗		

Before the onset of N. H. Glaciation

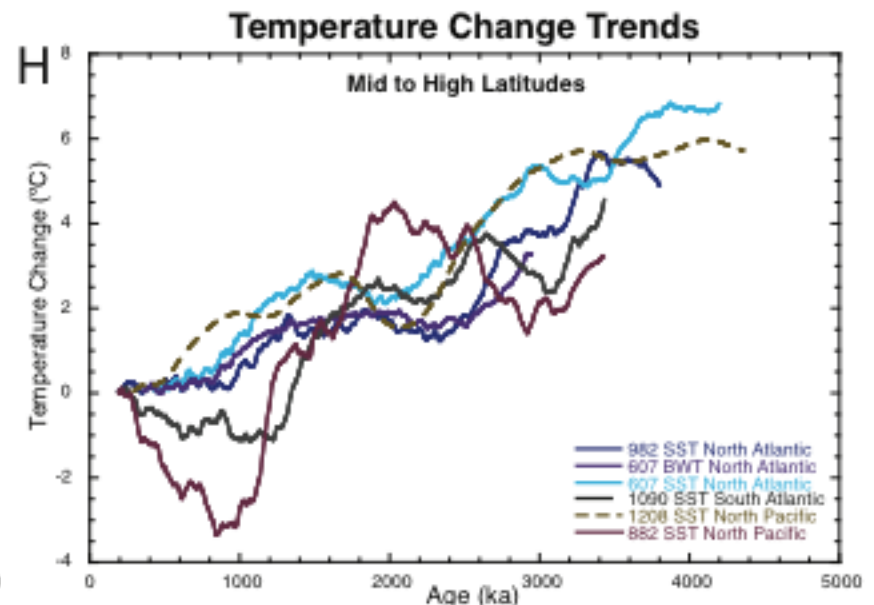
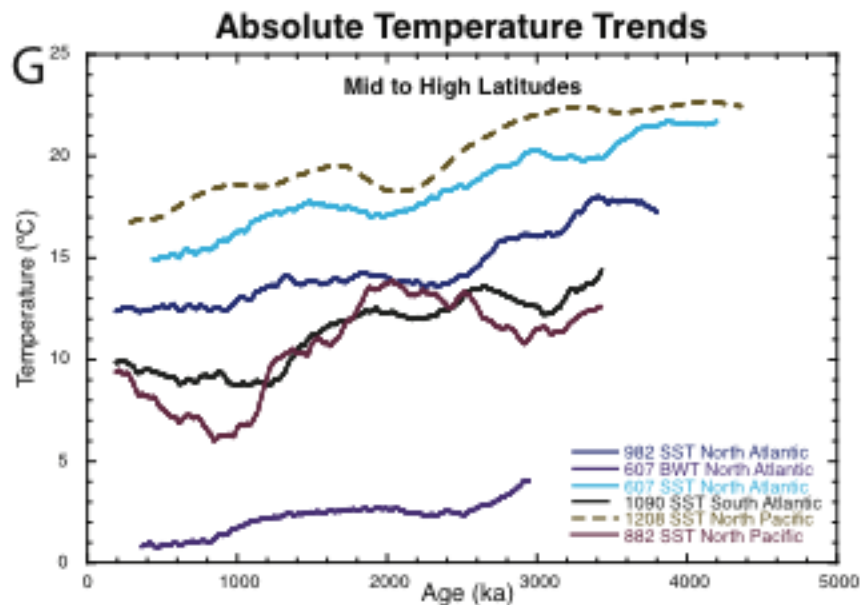
- Glaciation starts at $\sim 3\text{Ma}$
- Part of gradual amplification



Compilation of PaleoSST data (alkenone and Mg/Ca only)

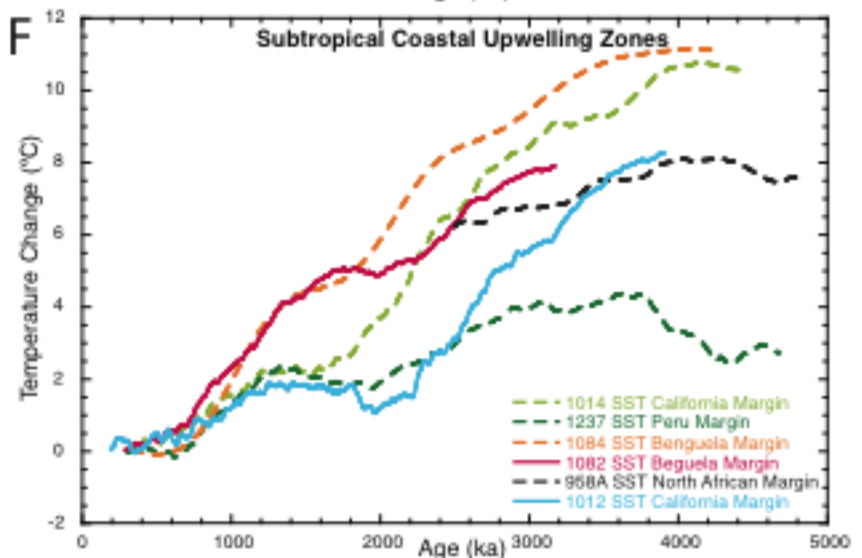
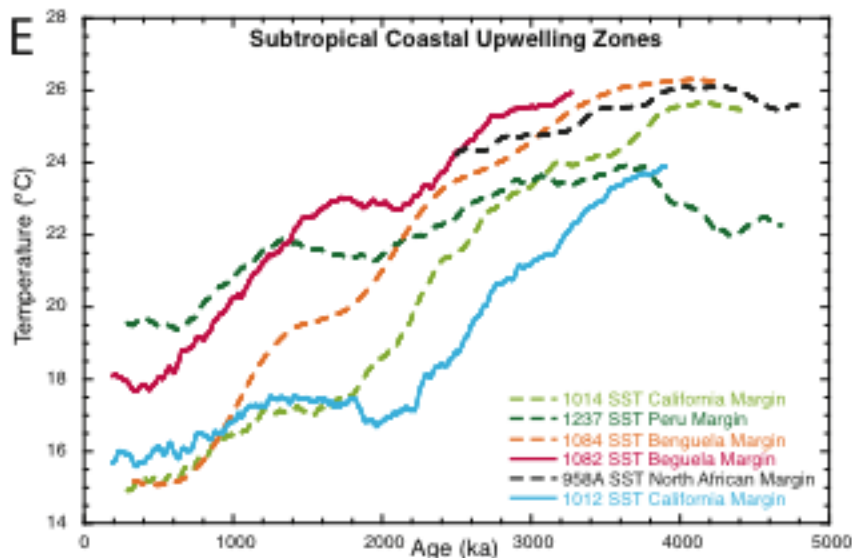


High Latitudes



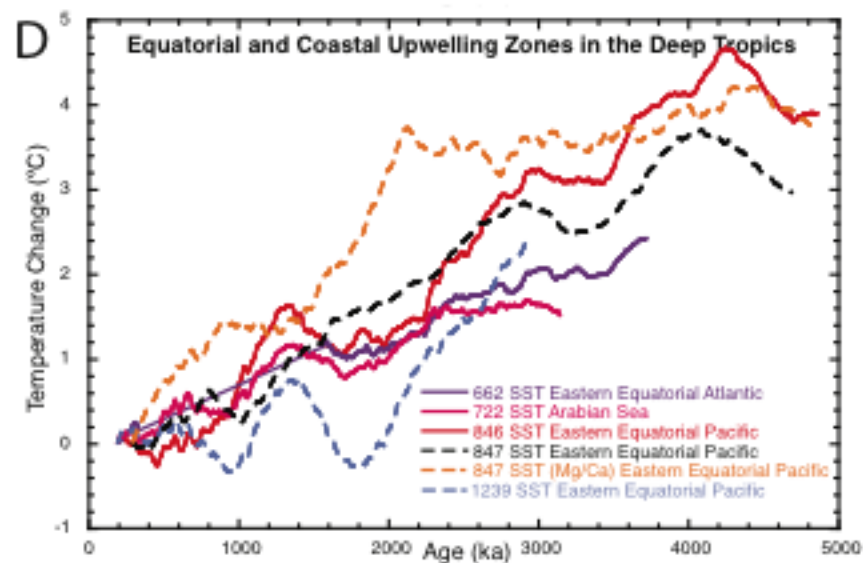
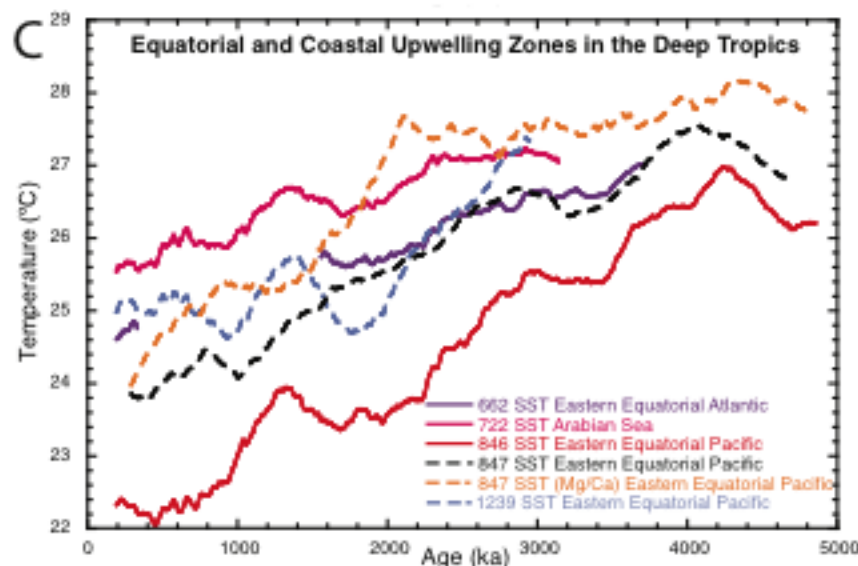
- High latitude warm across the board, by $\sim 5^{\circ}\text{C}$
- Very little data from the South Atlantic

Subtropical Coastal Upwelling



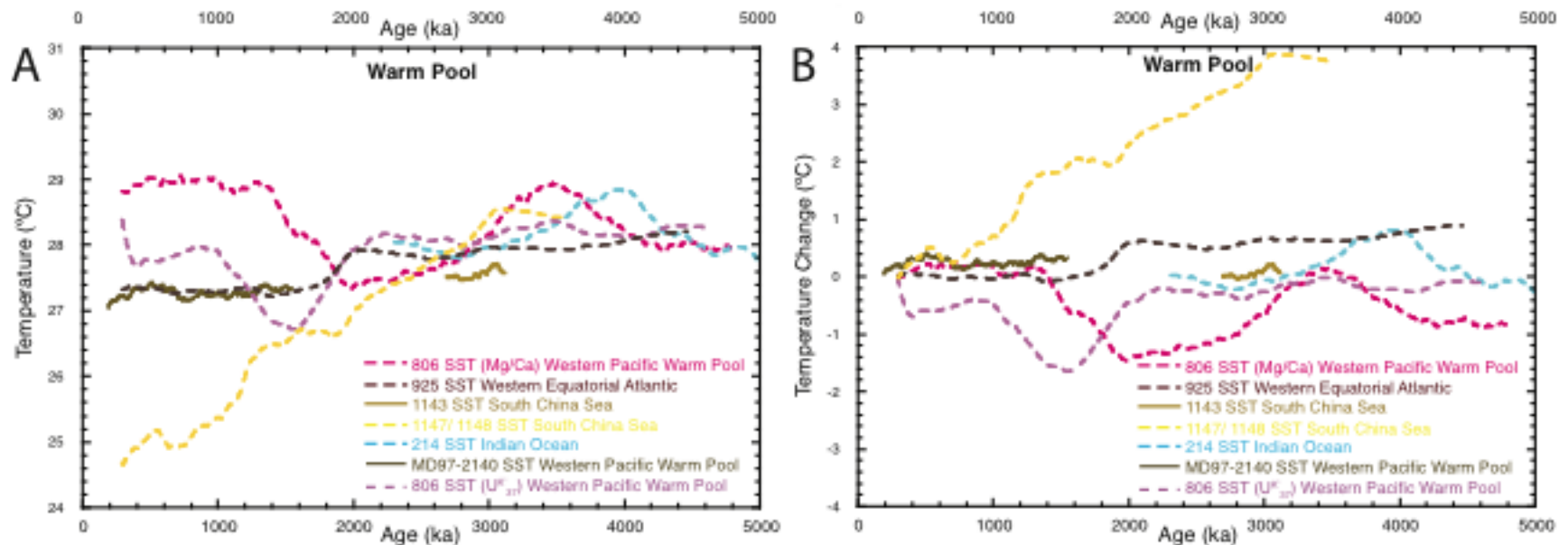
- Lots of warming, but depends on location
- All approaching 24°C

Equatorial/Tropical Upwelling



- Lots of warming, but depends on location
- Removal of upwelling
- All increase at similar rate

Warm Pool

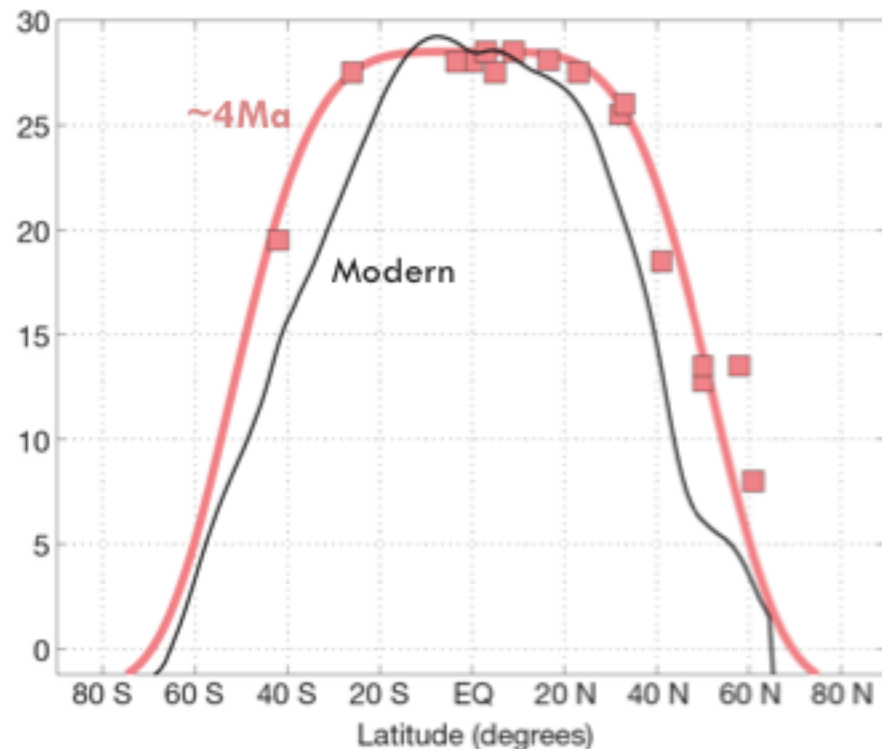


- Constant temperature
- Convergence at $\sim 28^{\circ}\text{C}$
- Expansion of warmpool into South China Sea

Three conditions

1. No increase in peak temperature
2. Reduction in zonal temperature gradient
3. Reduction in meridional temperature gradient

Prior Work



Greatly Expanded Tropical Warm Pool and Weakened Hadley Circulation in the Early Pliocene

Chris M. Brierley,^{1*} Alexey V. Fedorov,^{1,†} Zhonghui Liu,^{2*} Timothy D. Herbert,³
Kira T. Lawrence,⁴ Jonathan P. LaRiviere⁵

The Pliocene warm interval has been difficult to explain. We reconstructed the latitudinal distribution of sea surface temperature around 4 million years ago, during the early Pliocene. Our reconstruction shows that the meridional temperature gradient between the equator and subtropics was greatly reduced, implying a vast poleward expansion of the ocean tropical warm pool. Corroborating evidence indicates that the Pacific temperature contrast between the equator and 32°N has evolved from ~2°C 4 million years ago to ~8°C today. The meridional warm pool expansion evidently had enormous impacts on the Pliocene climate, including a slowdown of the atmospheric Hadley circulation and El Niño-like conditions in the equatorial region. Ultimately, sustaining a climate state with weak tropical sea surface temperature gradients may require additional mechanisms of ocean heat uptake (such as enhanced ocean vertical mixing).



- Brierley *et al.* (2009) - paleobs. & modeling study
- Reduced Meridional SST Gradient (Eq-Subtropics)

What? – A quick summary

- A warm world in geologically recent past
- Significantly warmer poles (without ice)
- Very weak temperature gradients in the Tropics
 - ▣ Vast Warm Pool
- Change in structure of climate:
 - ▣ High sensitivity of climate structure

Why?

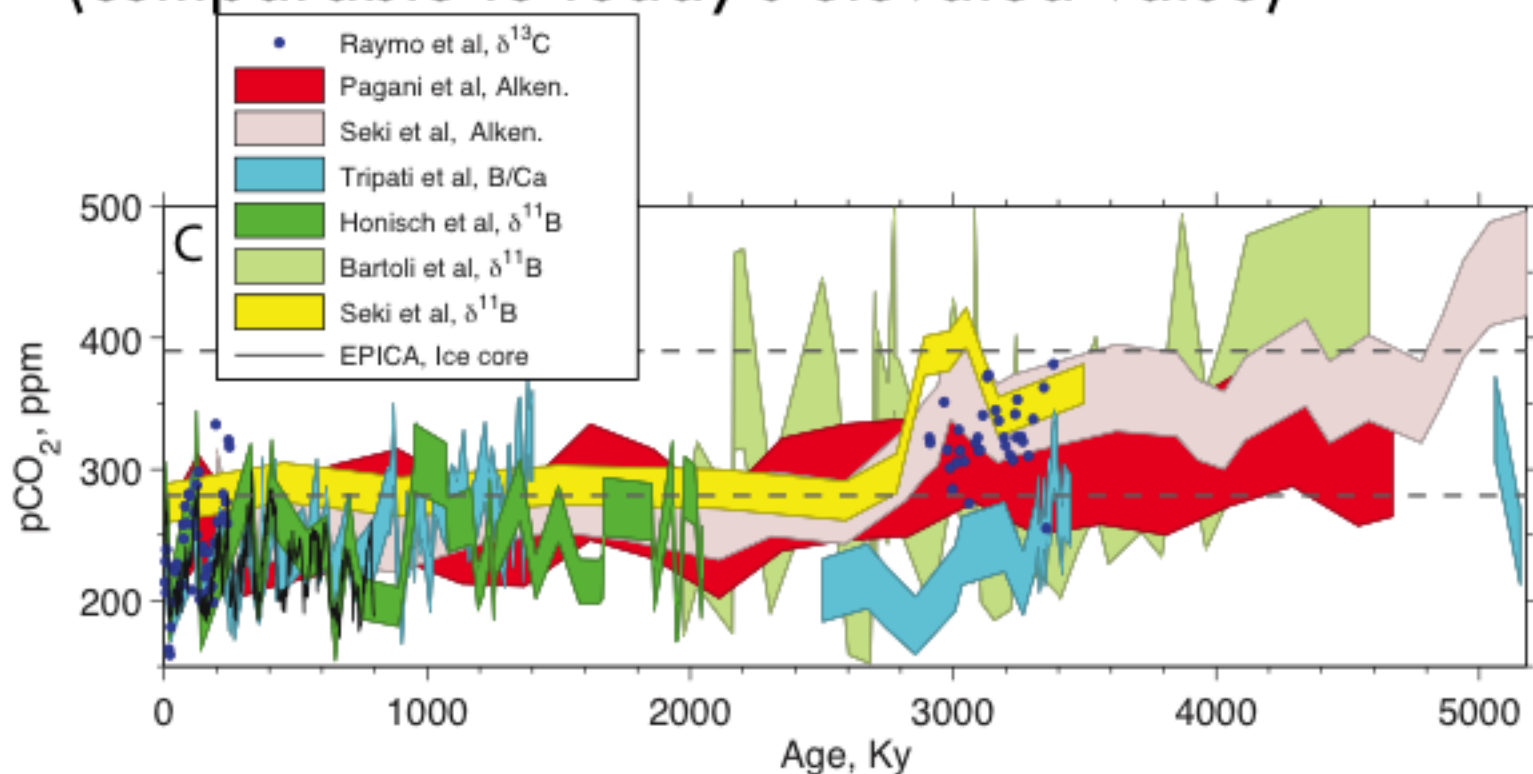
- Probably unrelated to solar forcing (too long/stable for orbital variability, but too short for stellar evolution)
- At least 5 possible explanations hypothesized:
 - a) Carbon dioxide increase
 - b) Movement of Indonesia and New Guinea
 - c) Emergence of Isthmus of Panama
 - d) Increase in Tropical Cyclones
 - e) Cloud property changes
- 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. ($\sim 3.75^\circ$) and $\sim 3^\circ$ in ocean (better at Eq)
- All simulations for 500 years starting from preindustrial control conditions (figures show average of last 50yrs)

A) Carbon Dioxide

- Still large uncertainty as to the actual value
- Small carbon dioxide increase up to at most 400ppm (comparable to today's elevated value)

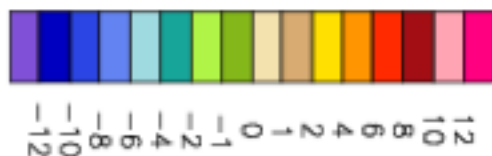
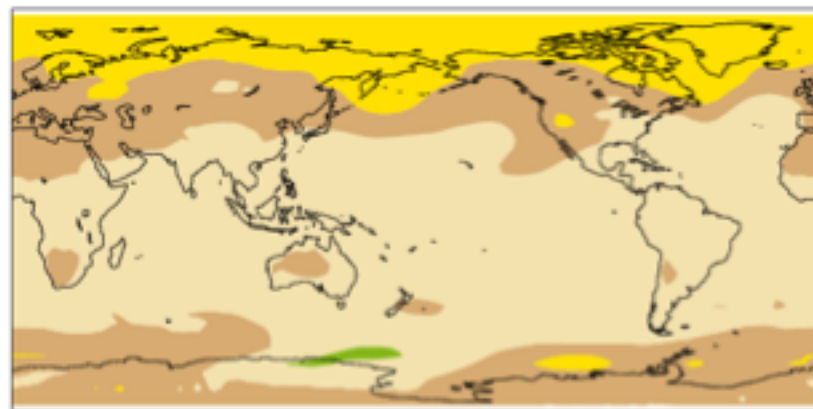


CO₂ in a climate model

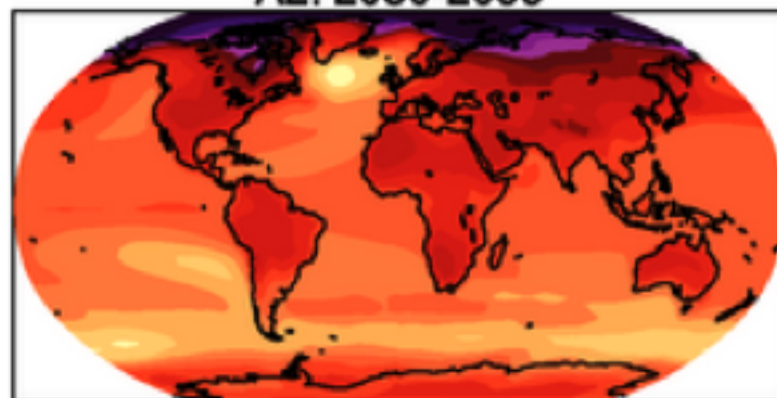
+100ppm SAT CESM

IPCC, Ensemble Mean Pattern

Adding 100ppm CO₂ - CESM CTL
mean = 0.98 rmse = 1.15 K

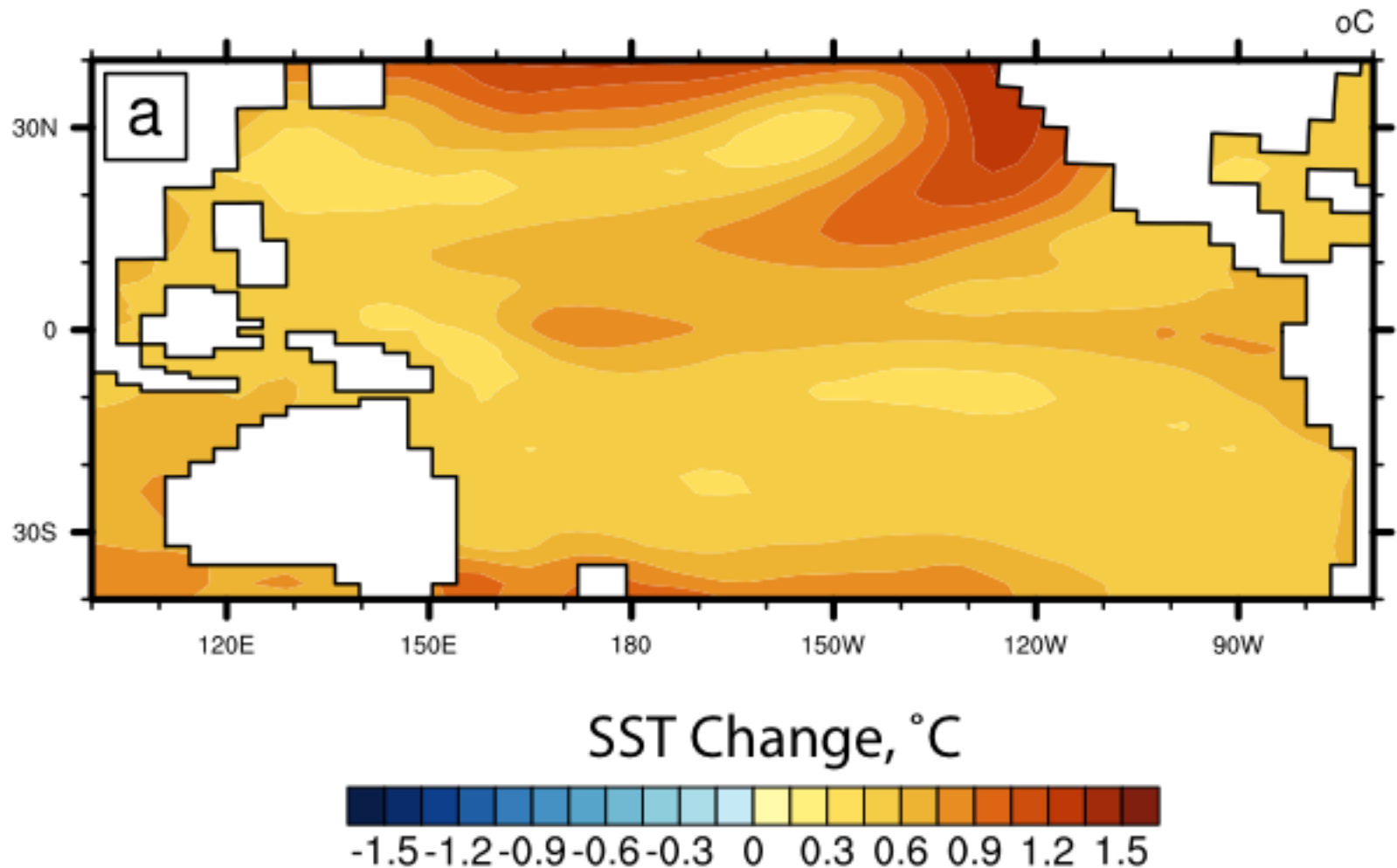


A2: 2080-2099



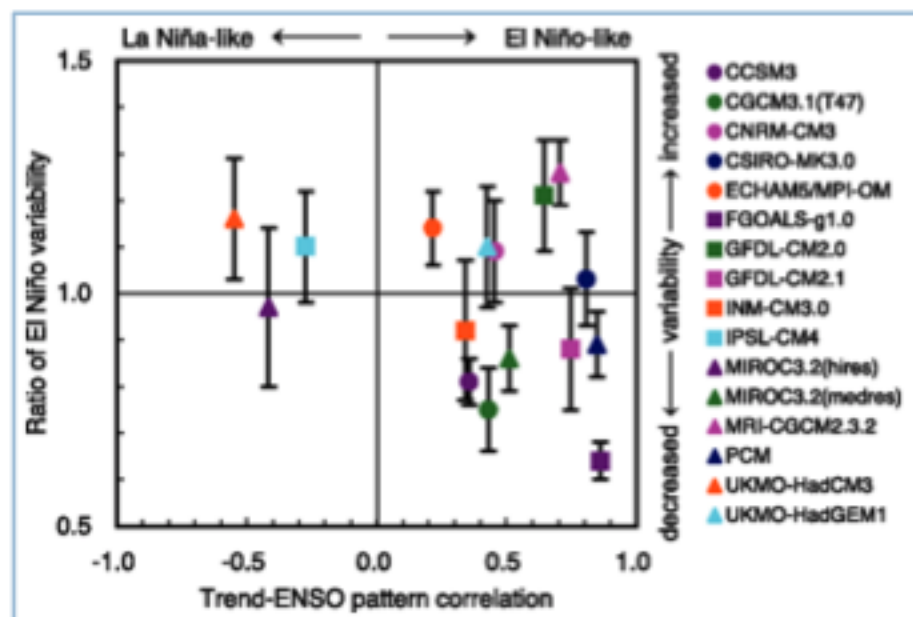
Impact on Trop. Pac.

Carbon Dioxide - Preindustrial



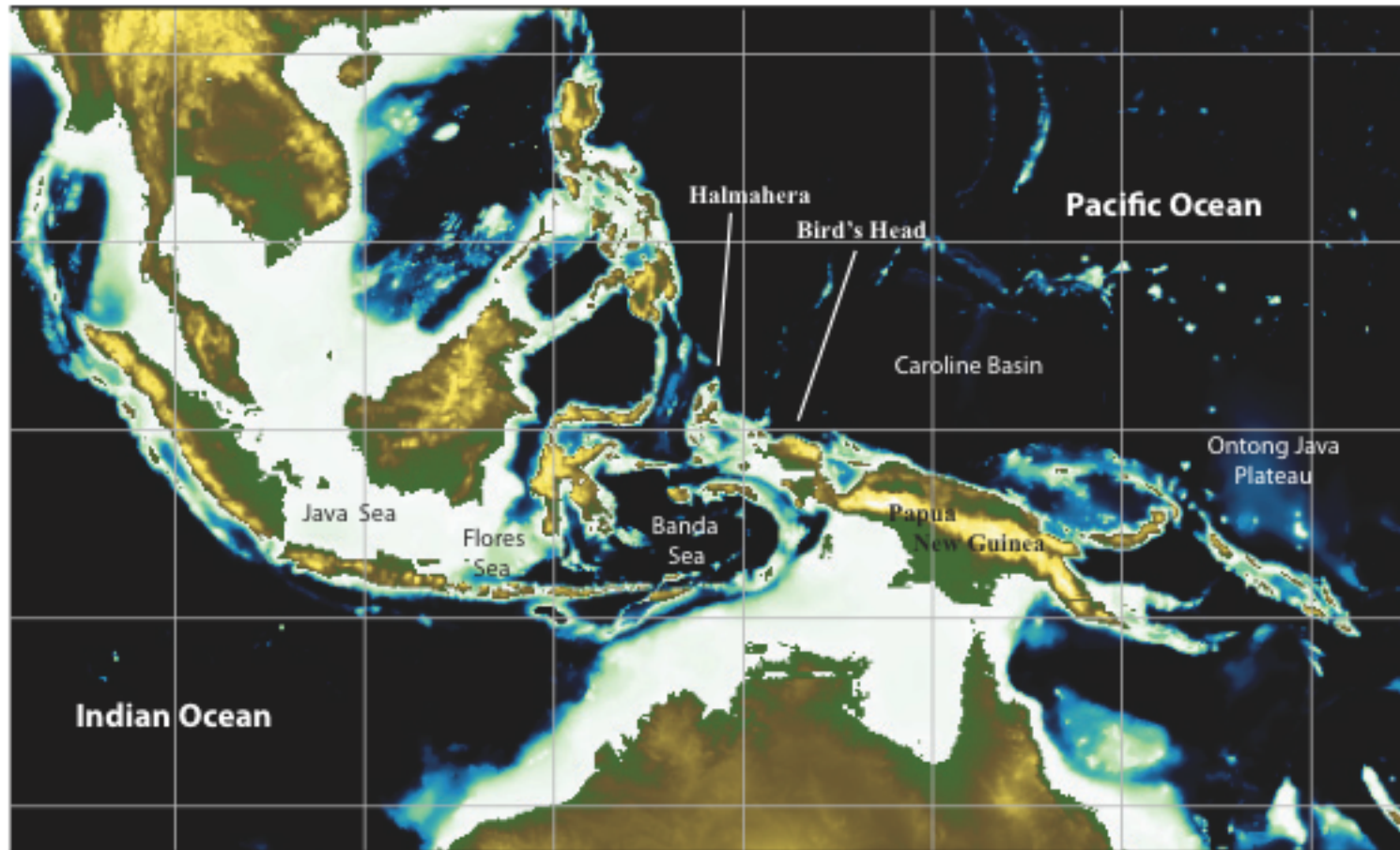
Model Dependent?

- The majority of climate models show weakening of the Equatorial SST gradient with increasing CO_2 , but not all.
- This is an area of active research
- However, changes are an order of magnitude less than Pliocene paleo-obs, and come with warming of west Pacific

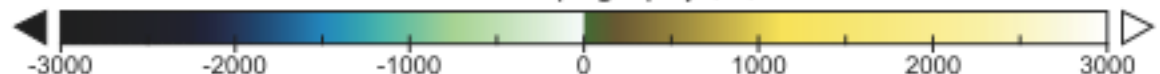


B) Indonesia

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

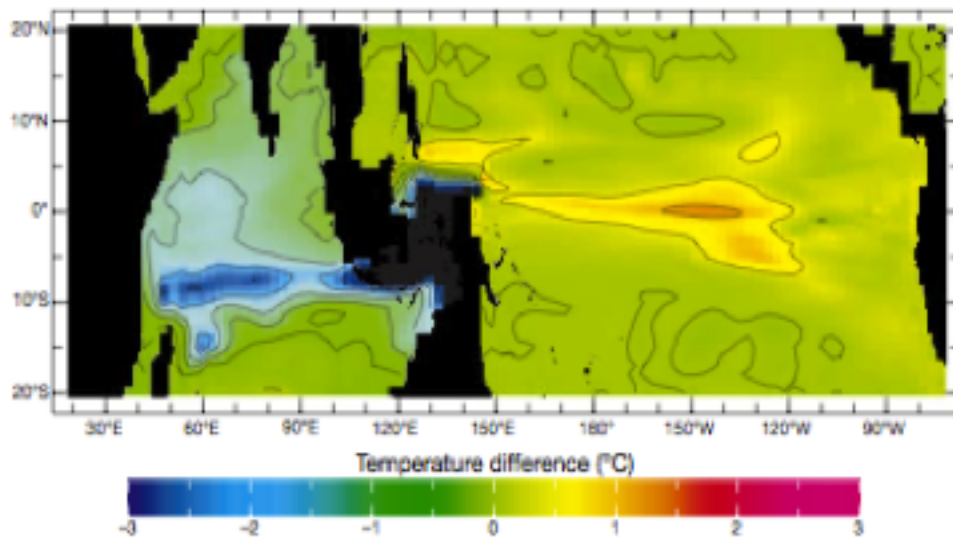


Surface Topography (m)



Prior Studies

Cane & Molnar (2001) Ocean-only

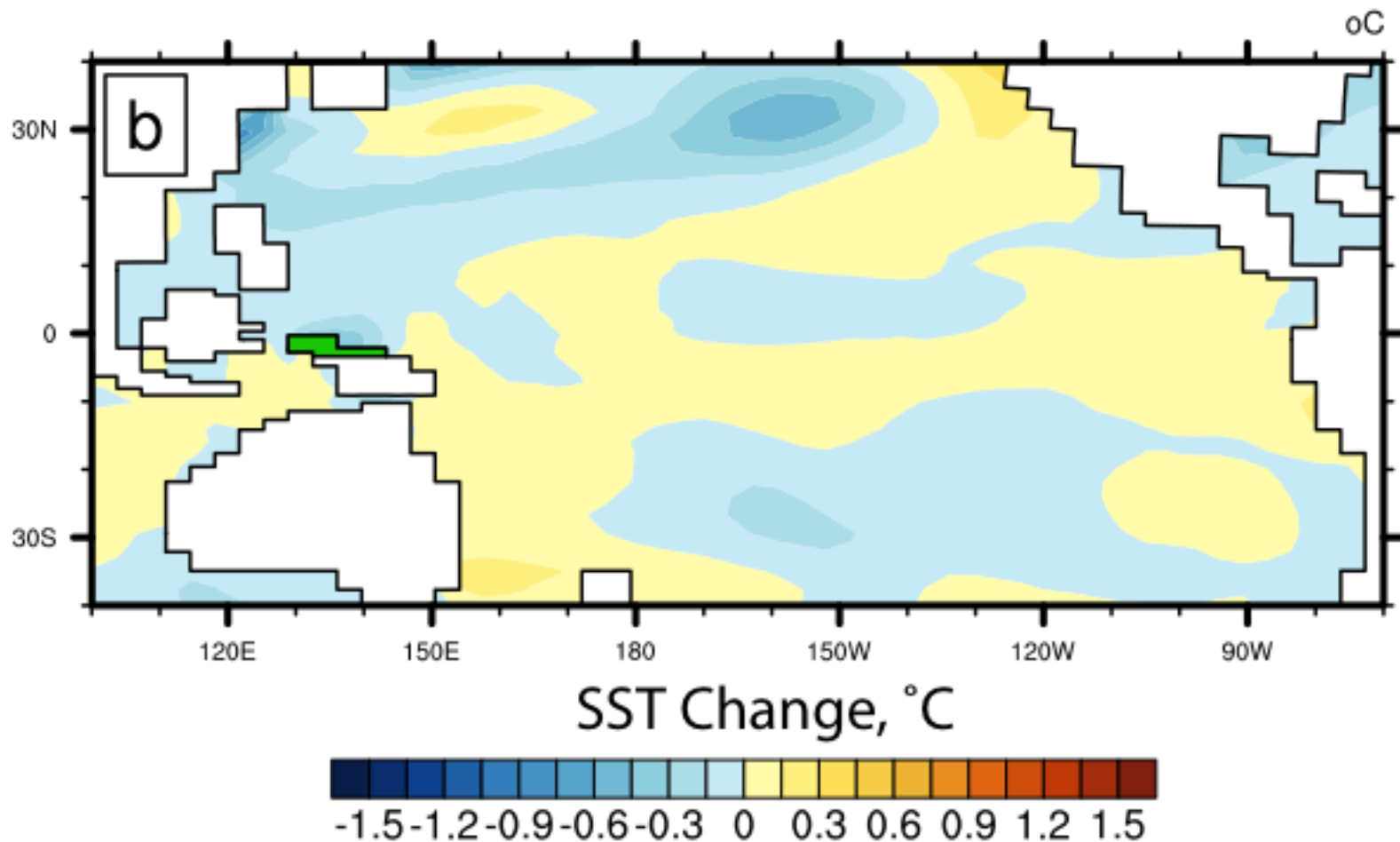


Jochum et al (2009) – Coupled

- Reduction in total Indonesian Throughflow
- Some changes in source water to Southern Hemisphere
- Only found SST changes of $<0.3^{\circ}\text{C}$ in Pacific
- Changes in ENSO statistics

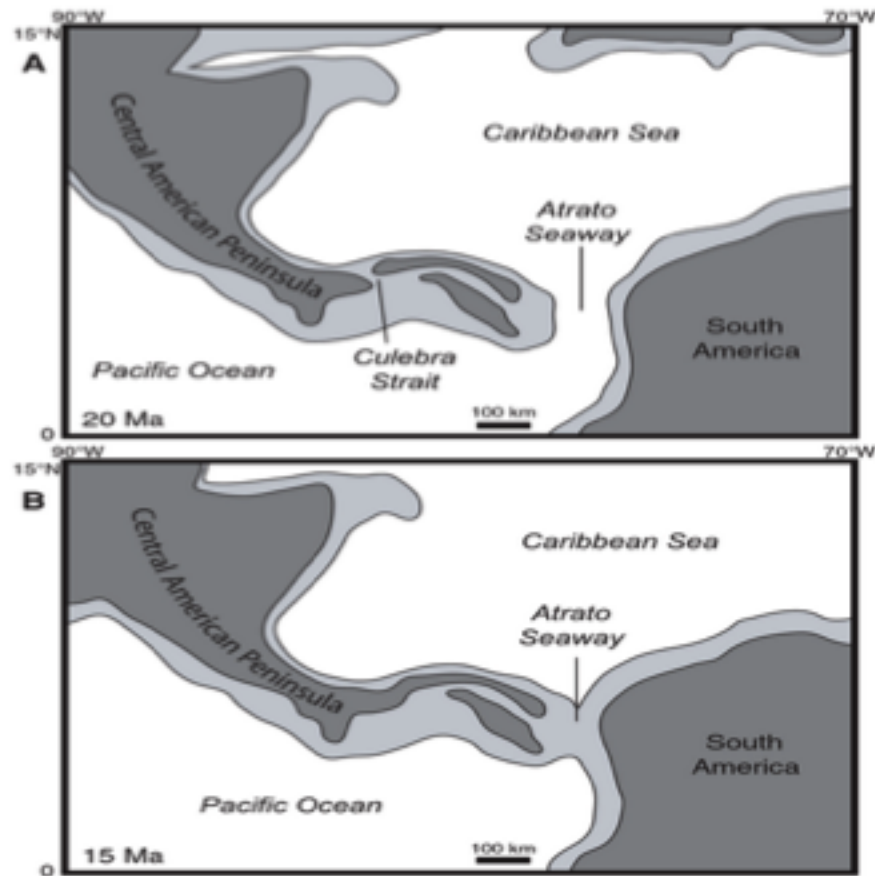
Impact on Trop. Pac.

Indonesia - Preindustrial



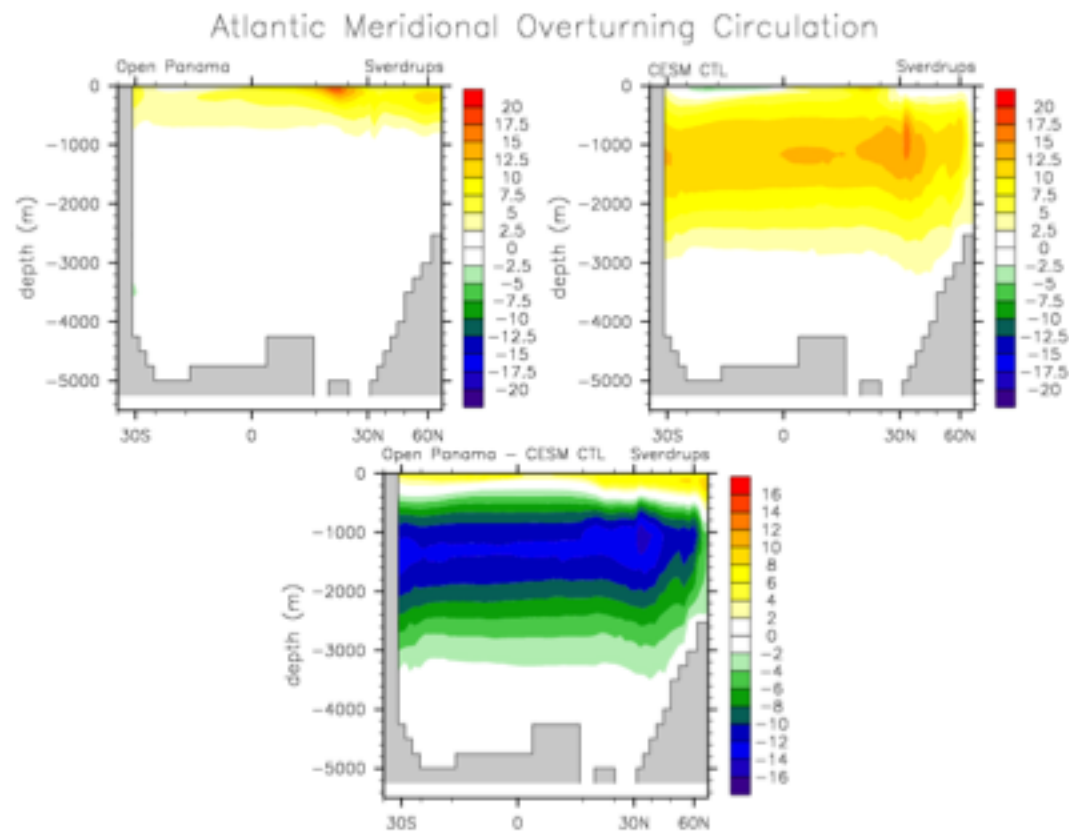
C) Isthmus of Panama

- Central American Seaway slowly constricted during Miocene
- No flow between Atlantic & Pacific sometime in Pliocene
- Proposed as trigger for glacial cycles at 2.7Ma, but now thought to have shut earlier
- Tested in a variety of models
- I've removed Panama to a depth of 1km, so a very strong perturbation



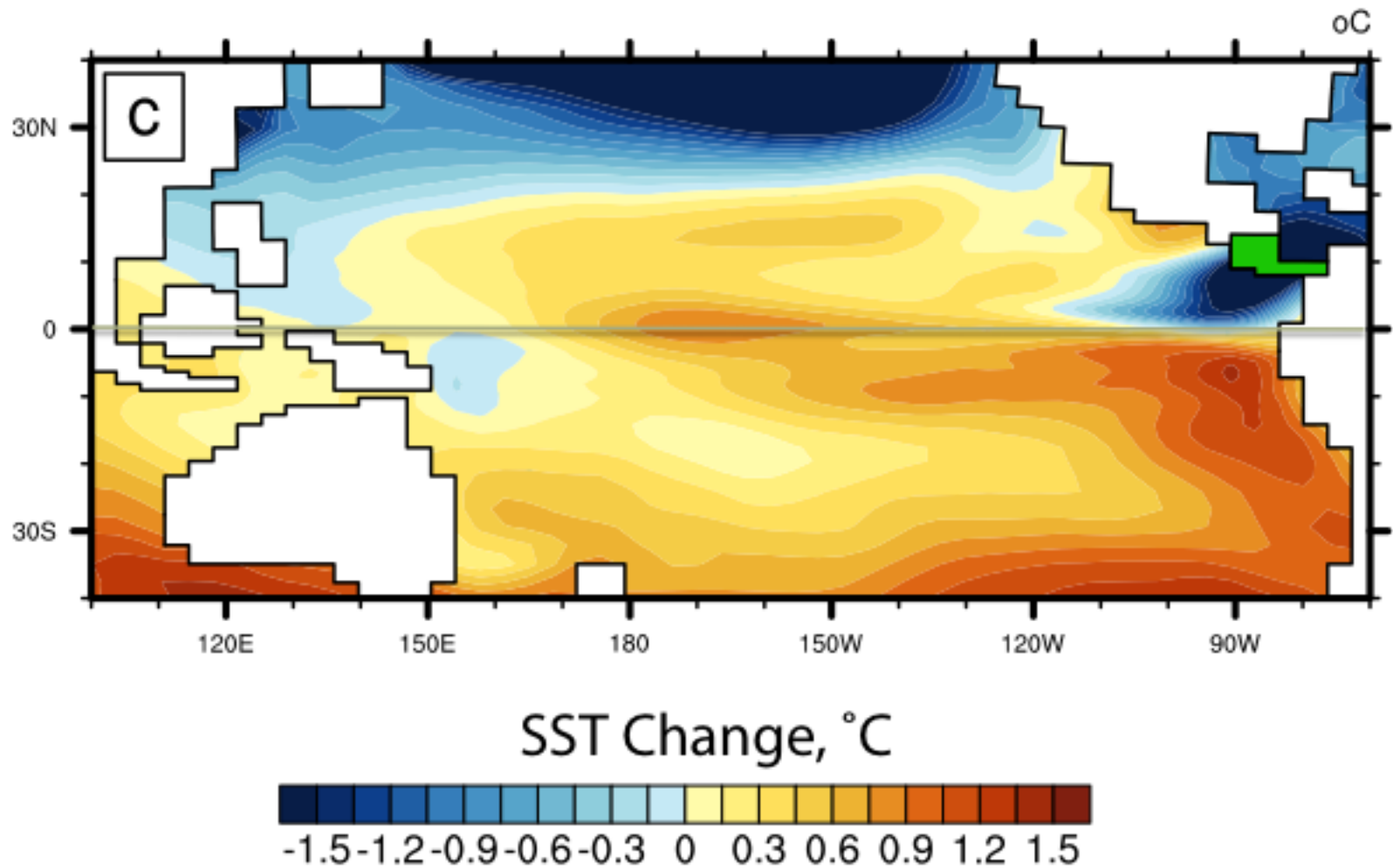
Shutdown of AMOC

- The Atlantic Meridional Overturning Circulation (AMOC) is has sinking in North Atlantic to $\sim 1.5\text{km}$ and then flowing southward
- Depends on salinity difference between N Atl. and N Pac. which is driven by flow of atmospheric water over Panama to Pac.
- Allowing ocean return flow in Northern hemisphere kills the AMOC
- *Figure after 1000 yrs of simulation rather than 500 yrs*



Impact on Trop. Pac.

Panama - Preindustrial

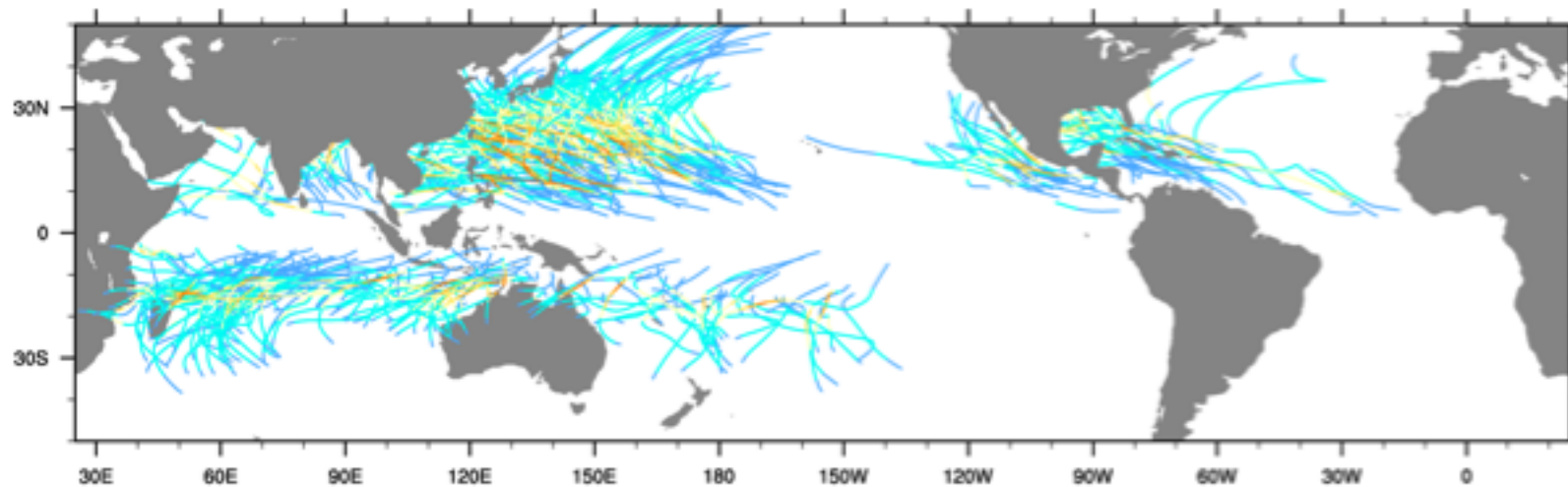


D) Tropical Cyclones

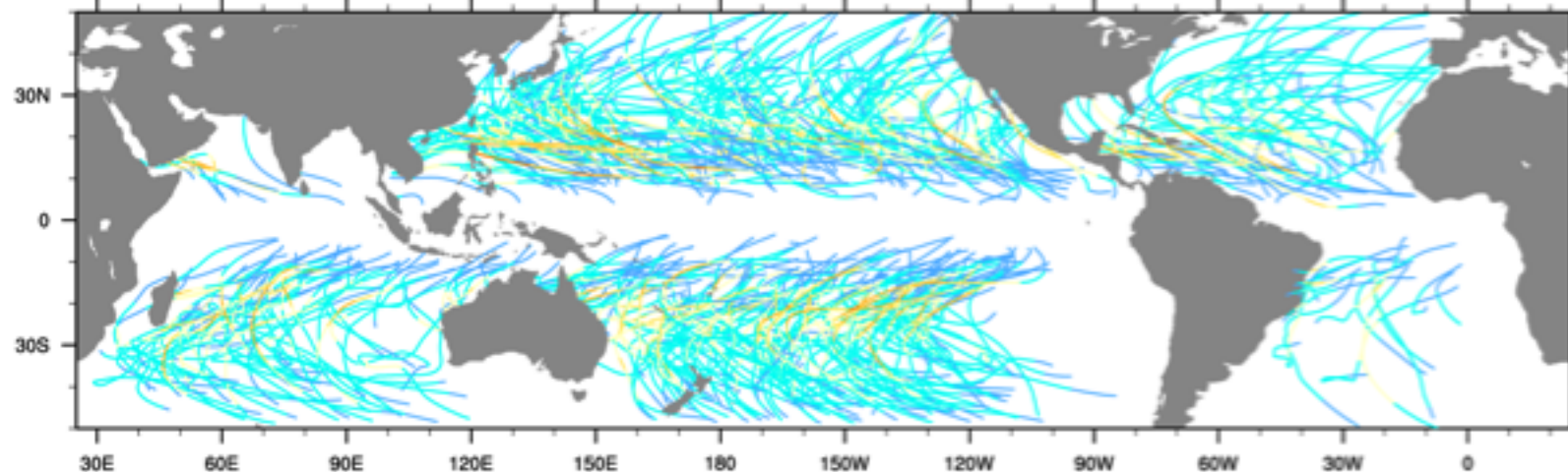


- When we created reconstruction of vast warm pool, we suggested that an increase in ocean vertical mixing would deepen thermocline and lead to reduced SST gradients
- Later suggested this mixing may be from tropical cyclones (a.k.a. hurricanes)

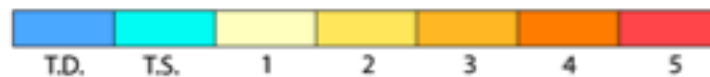
Synthetic Tracks



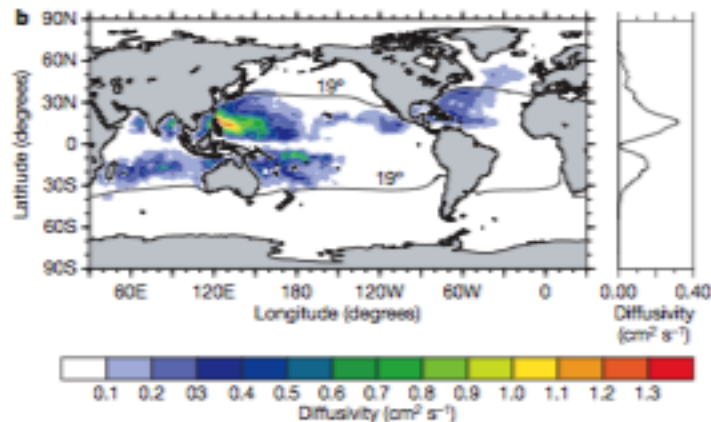
Modern



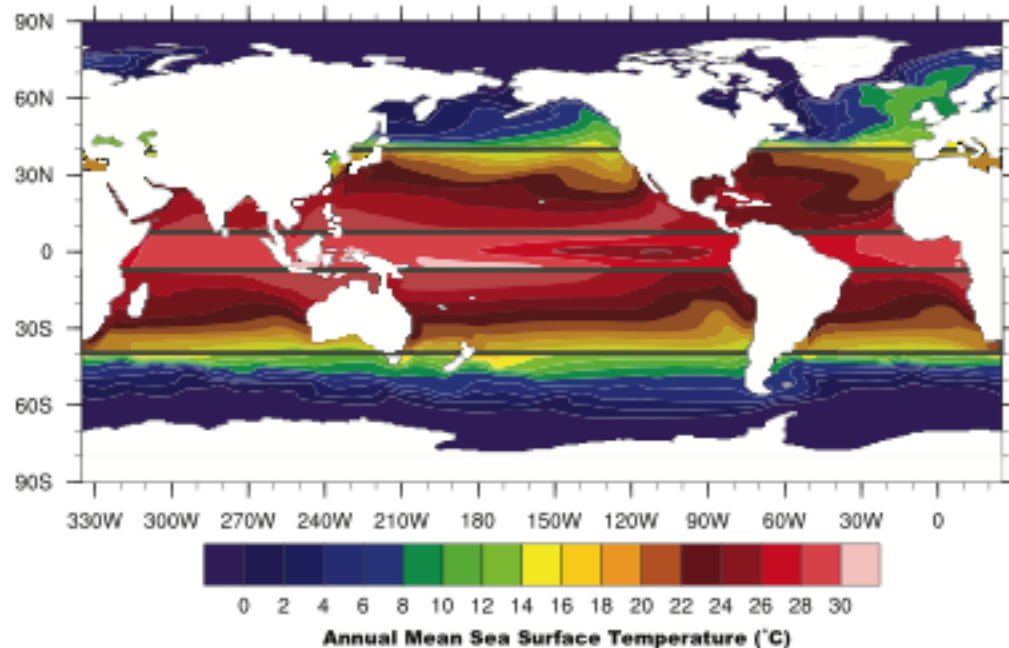
Pliocene



Model hurricanes

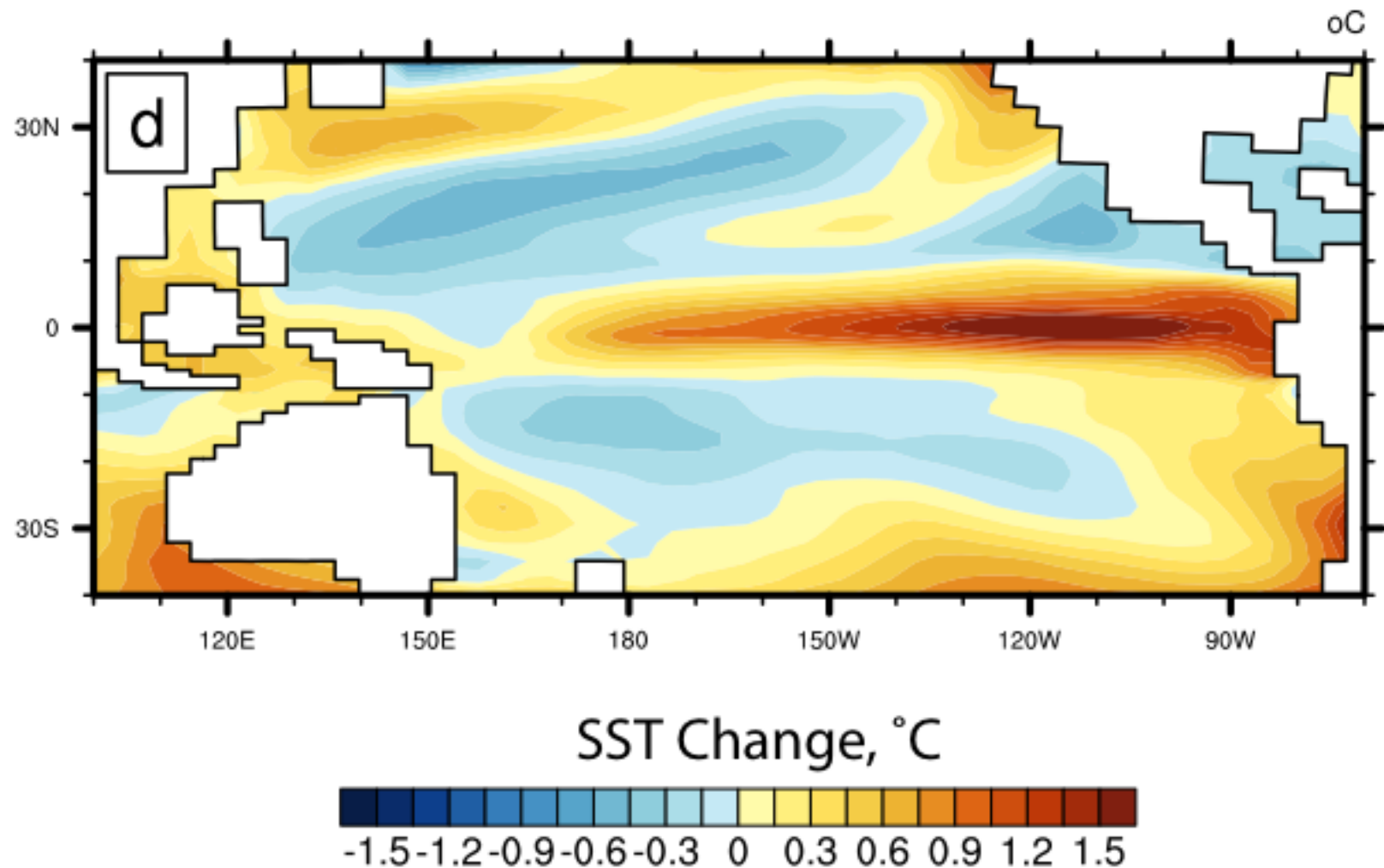


- Observations indicate hurricanes give vertical mixing up to $1 \text{cm}^2 \text{s}^{-1}$ (Srifer & Huber, 2007)
- As first order, include 2 broad stripes of mixing in upper ocean (Fedorov et al. 2010)



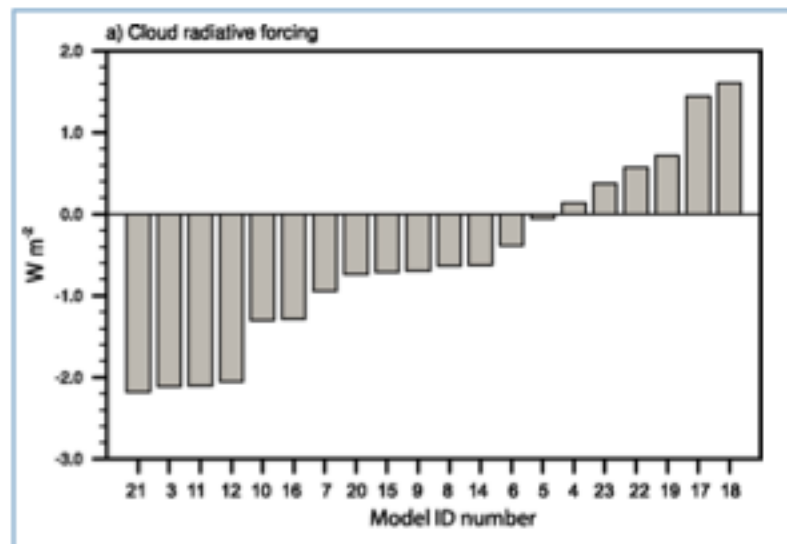
Impact on Trop. Pac.

Hurricanes - Preindustrial



e) Cloud Properties

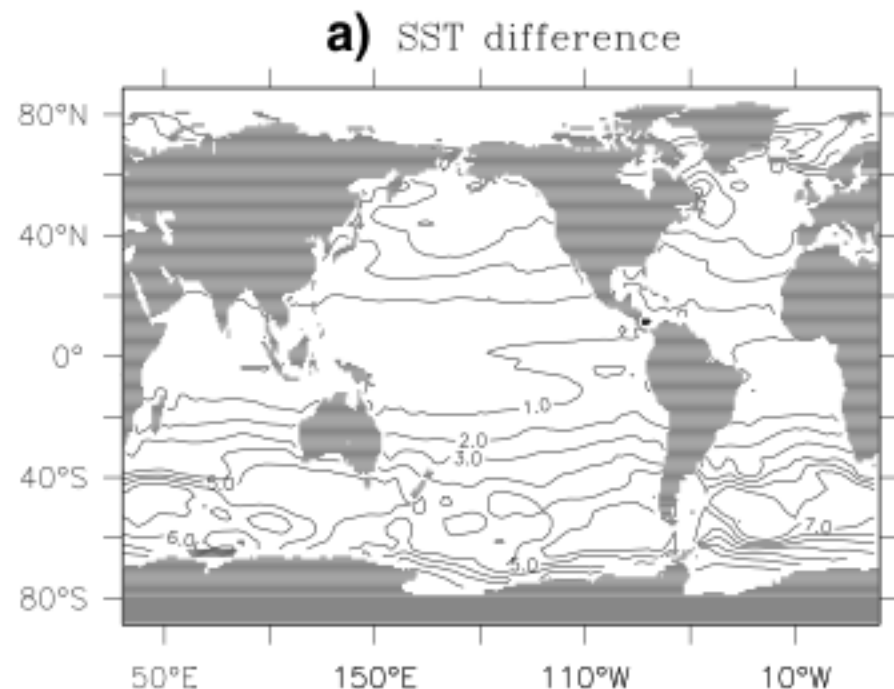
- Cloud properties and feedbacks are the largest cause of uncertainty in climate projections
- Their properties are influenced by the amount of aerosols in the air (called aerosol indirect effects)
- The aerosols are not well constrained in the past and could change with land surface and ocean conditions



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

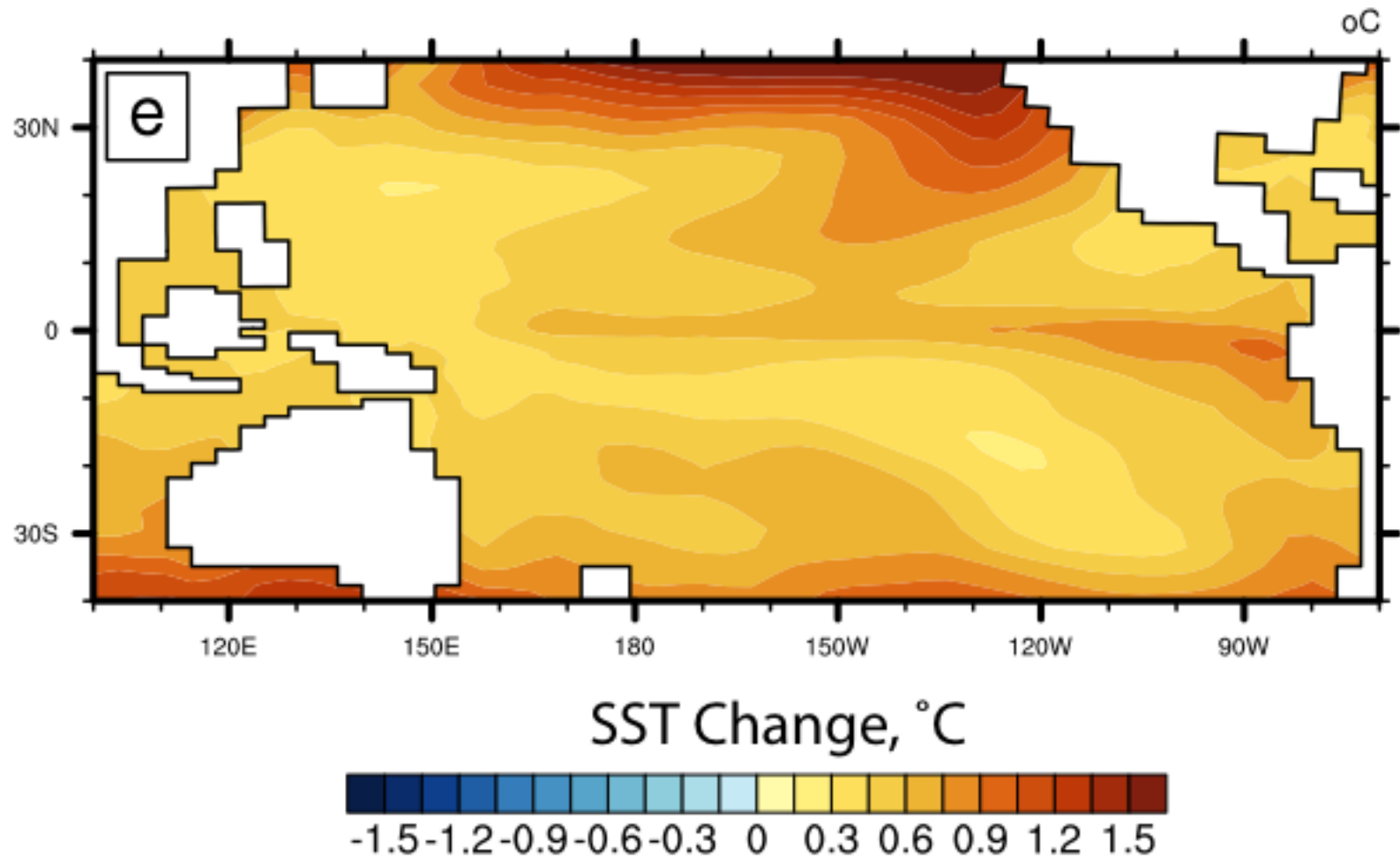
Cloud Albedo

- Barreiro & Philander (2008) use a simple climate model to test sensitivity of climate to reduction in cloud albedo in extratropics
- Find a weakening of equatorial SST gradient
- Their method is not applicable in a more complex model like CESM
- Reduce the cloud liquid water to 80% polewards of 35°N/S in the shortwave radiation code

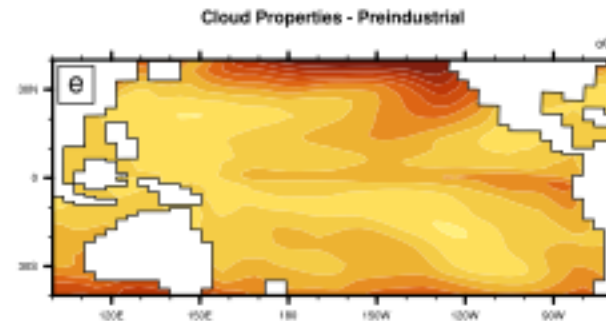
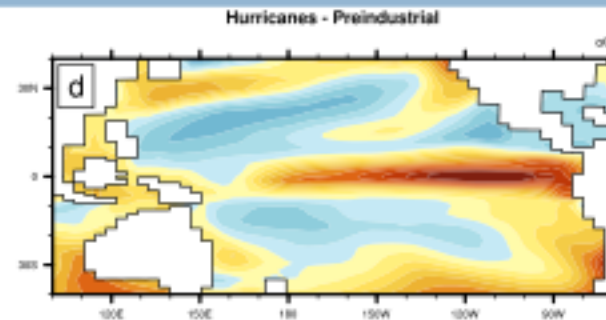
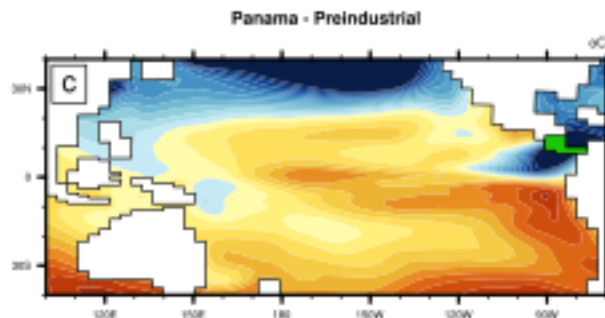
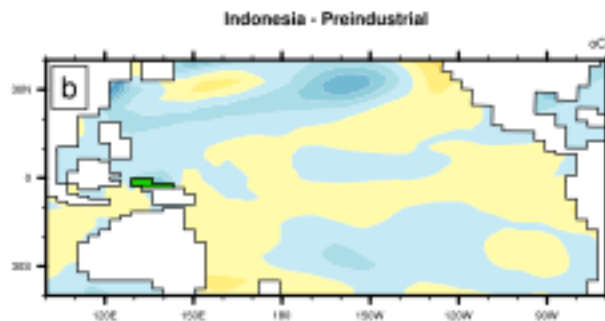
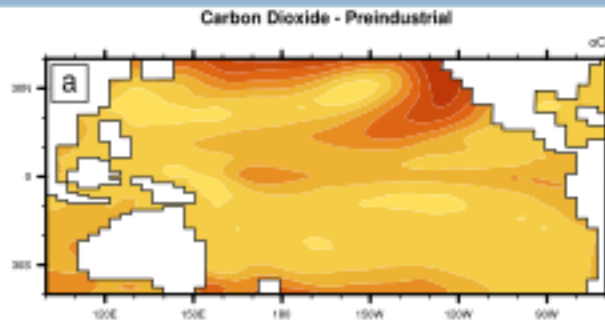


Impact on Trop. Pac.

Cloud Properties - Preindustrial



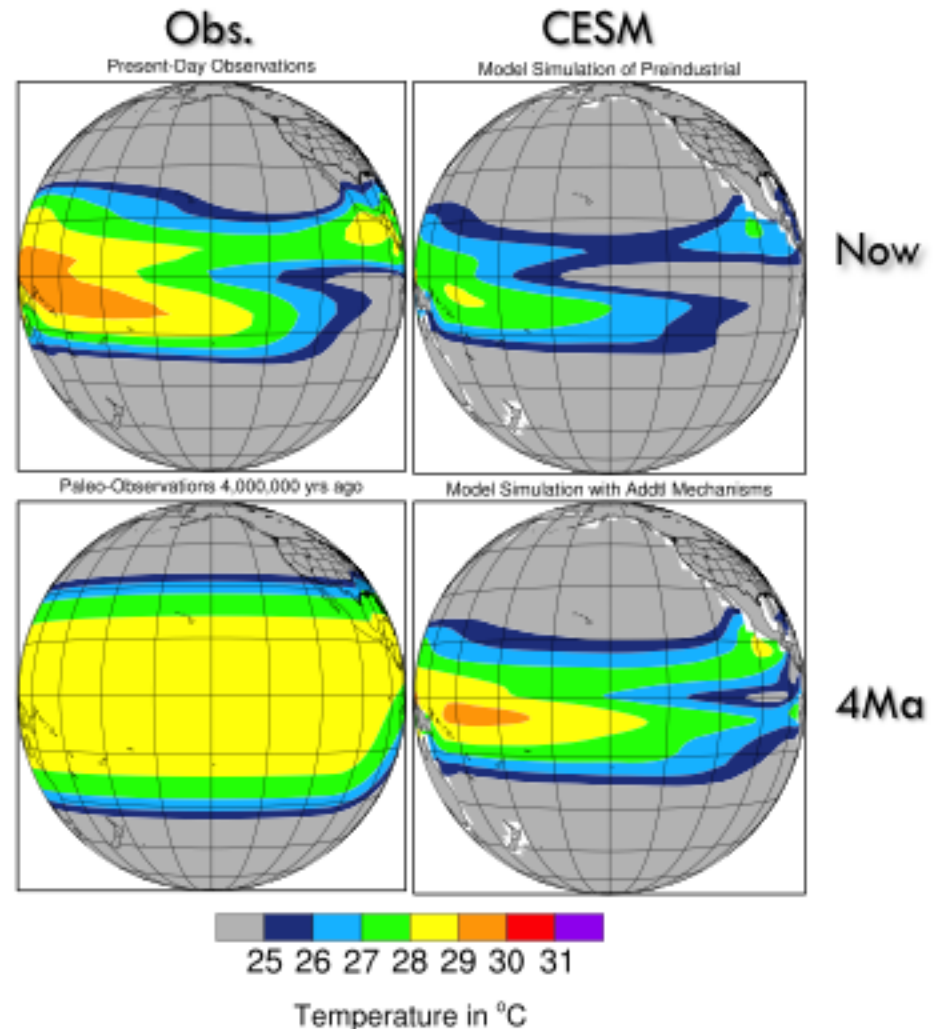
Comparison



- Looking for:
 - Reduction in equatorial SST gradient of $\sim 4^{\circ}\text{C}$
 - No warming in West Pacific
 - Reduction in meridional gradient in both hemispheres
- No single pattern does this

Combination

- If none of the hypotheses explain the pattern individually, perhaps they all combine together
- Ran for 200 yrs from end of Panama simulation, but skipped Indonesian changes
- There is some improvement in the model simulations (right), but it certainly does not reach the flatness of the reconstruction (left)



Summary

- There is no silver bullet to explain the vast warm pool of the Early Pliocene among the hypotheses already out there
- A combination of all the hypotheses approaches the reconstruction, but most of the impacts are pushing the envelope
- We may need another explanation – be it a new climate mechanism, new forcing or reinterpretation of the paleo-observations: any suggestions?

BEYOND CONVENTIONAL CLIMATE SENSITIVITY: UNDERSTANDING EARLY PLIOCENE WARMTH

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