THE CURIOUS CASE OF THE PLIOCENE CLIMATE

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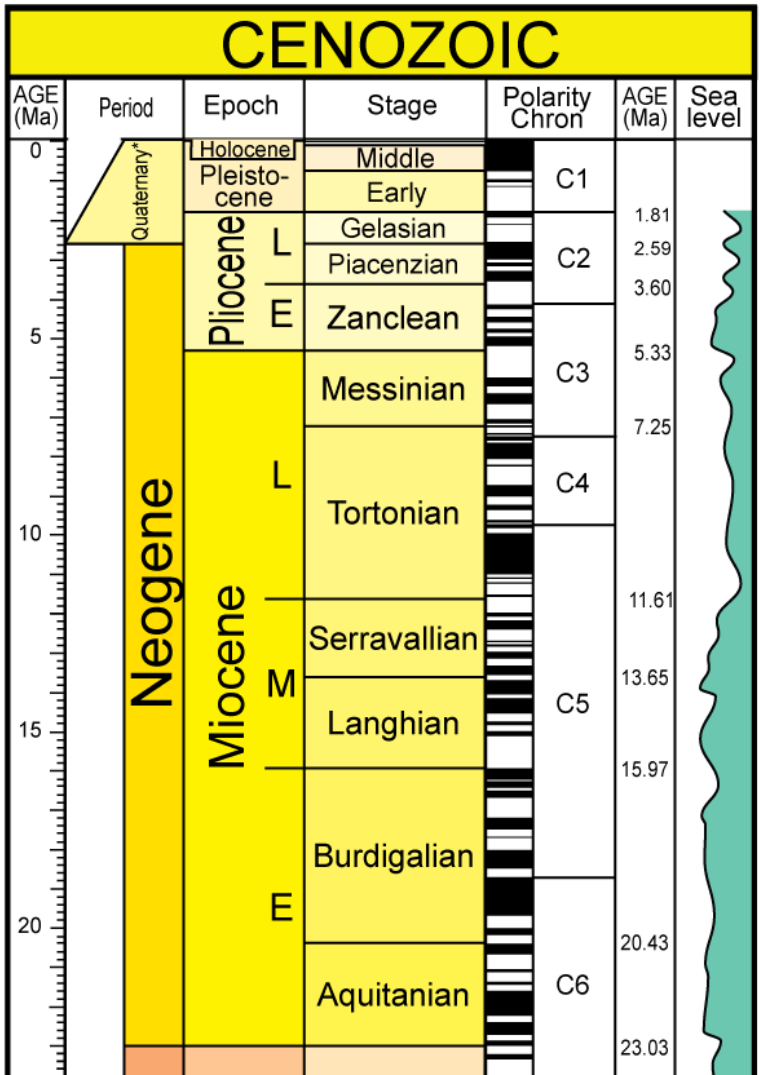
Outline

- Introduce the warm early Pliocene
- Recent Discoveries in the Tropics
- Reconstructing the early Pliocene SSTs
- Climate Impacts of that reconstruction
- Sustaining the warm climate
- Implications for the Pliocene Paradox
- Conclusions and future work

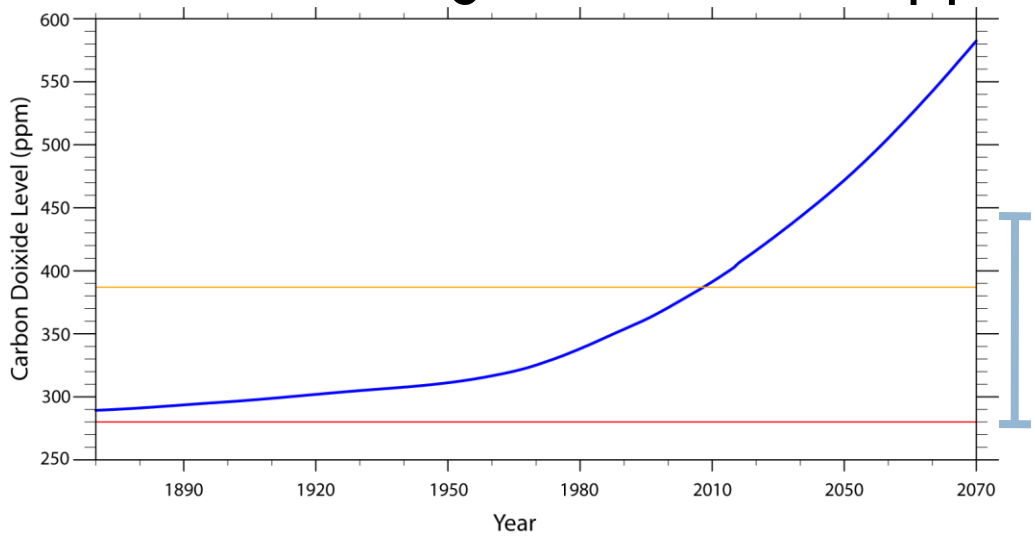
What is the early Pliocene

- A relatively-short and recent period of Earth's history in the scheme of the department.
- Deep Time for AOCD.
- Time period spanning 5.3~3.6 million years ago.

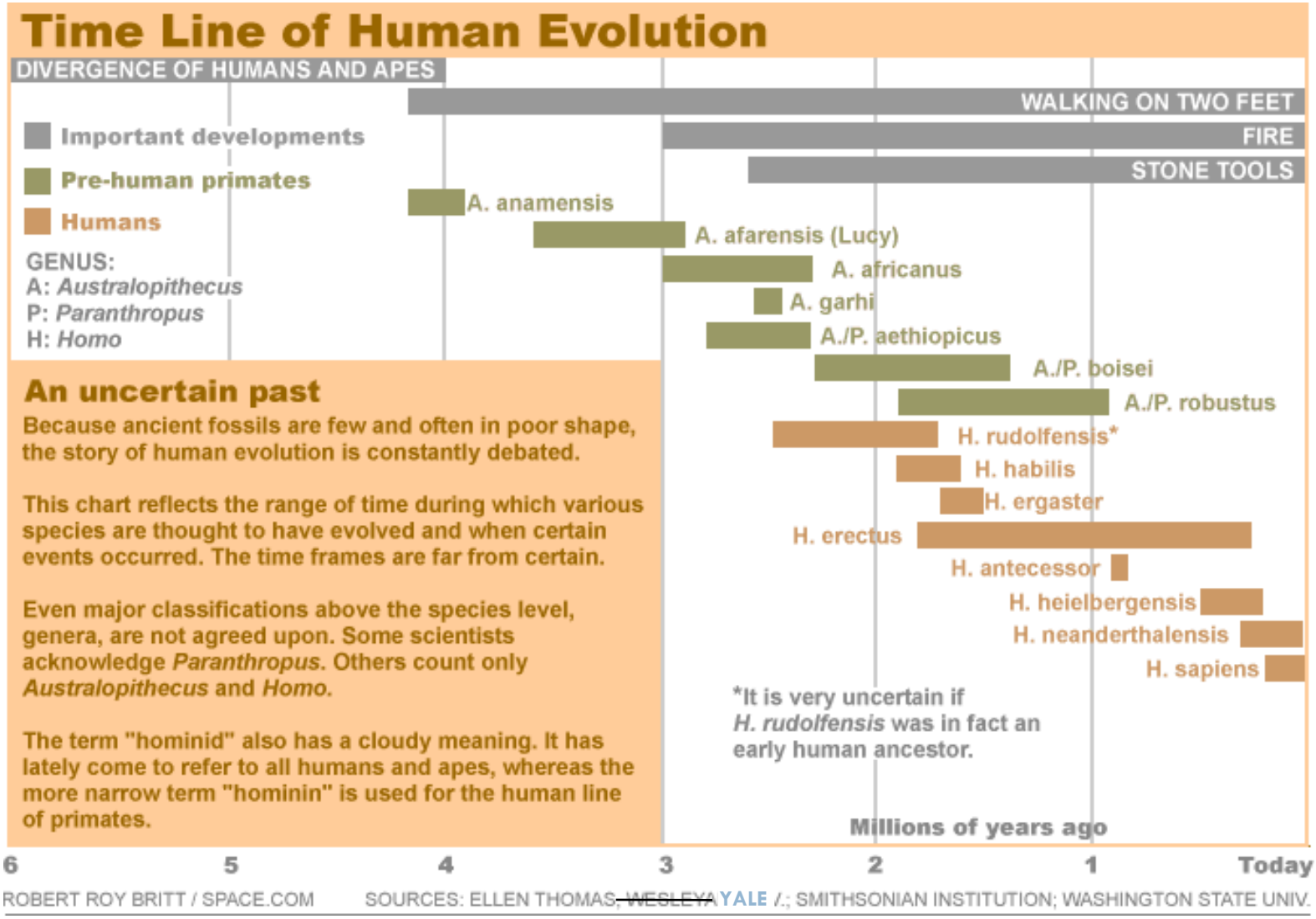


Why care about the early Pliocene?

- Natural global warming stabilization experiment
  - Previous Estimates of CO_2
    - Roughly 420ppm (Raymo et al. 1996 - below)
    - 280-370ppm (van der Burgh et al. 1993)
    - 280-300ppm (Pagani et al. 1999)
  - Mark's Current best guess: 380 ±25 ppm



Hominid evolution



What else do we know about the early Pliocene?

- Landmasses approximately same as today
  - New Guinea and Halmahera moving North (c. 5Ma)
  - Isthmus of Panama Closing (c. 5Ma)
- Ice Volume/Sea level
  - Sea Level roughly 25m higher
  - Reduced Greenland ice sheet
  - Reductions in Ice on Antarctica
- Vegetation
  - Forests on coast of Greenland
  - Reduced amount of Tundra
- Sea Surface Temperature data

How do we know about Ocean Temperatures

genus: *Globigerina* cruise: NIOP C1, Arabian Sea
species: *bulloides* date: 21.08.1992
remarks: umbilical side sample: 313-4-5
size fraction: 250-400 µm depth: 8 - 0m

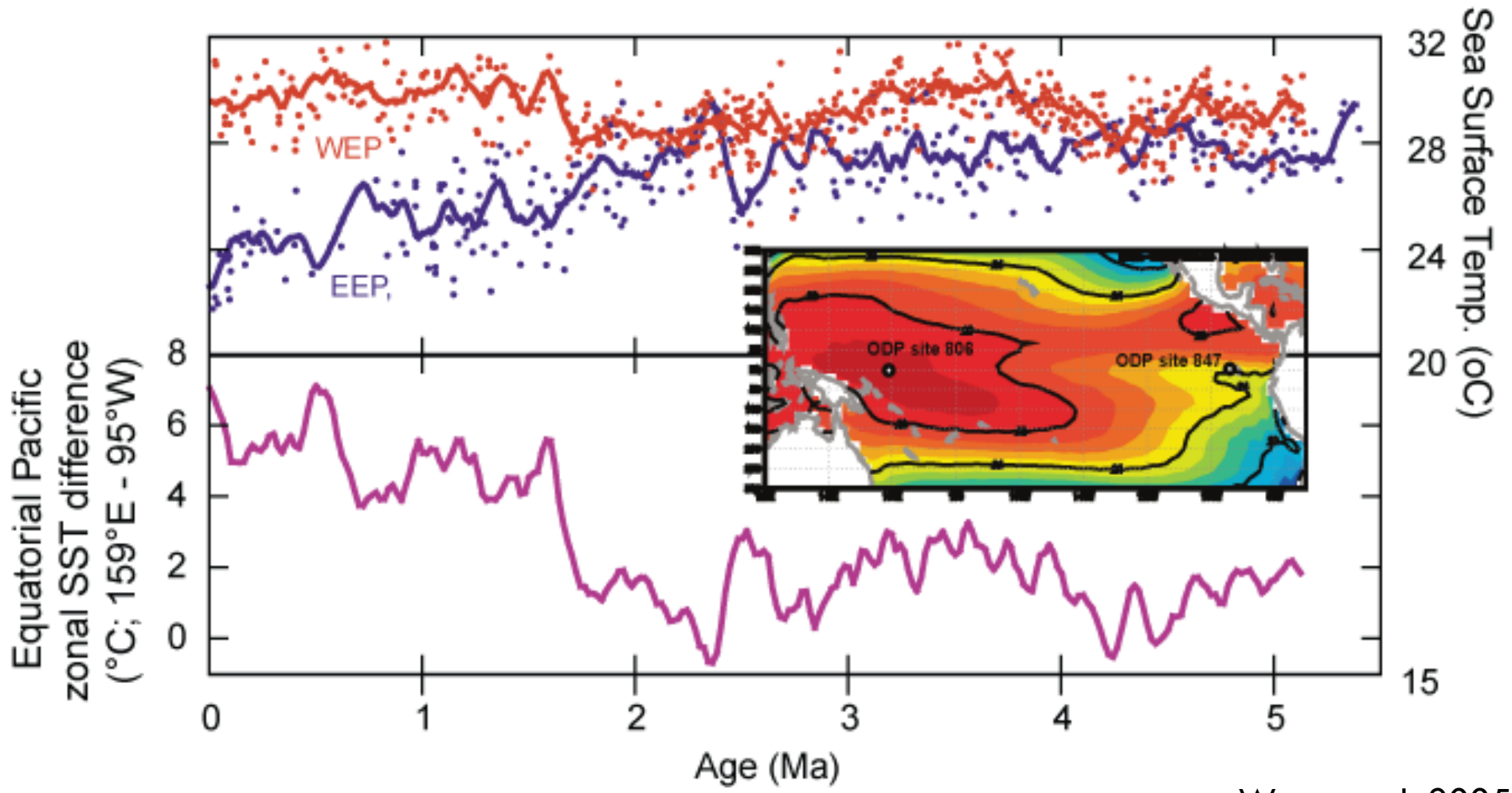
genus: *Globigerinoides* cruise: NIOP C1, Arabian Sea
species: *ruber* date: 21.08.1992
remarks: umbilical side sample: 313-4-5
size fraction: 250-400 µm depth: 8 - 0m

genus: *Globigerinoides* cruise: NIOP C1, Arabian Sea
species: *sacculifer* date: 07.02.1993
remarks: umbilical side sample: mst-8 B20, sed. trap
size fraction: 250-400 µm depth: 1265 m

- Foraminifers
- Modern Analogue Technique/Foram Transfer Functions.
- The ratio of Magnesium to Calcium is also dependent on temperature:

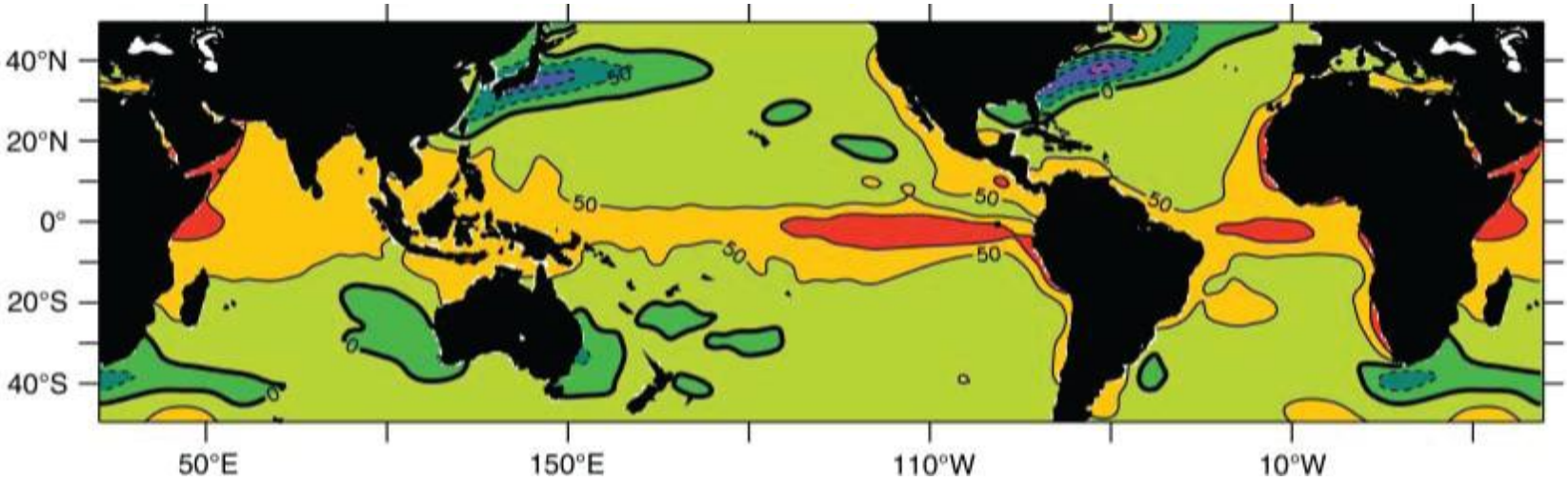
$$SST = 11.1 \times \ln\left(2.7^{Mg/Ca}\right) + Offset$$

Wara's Permanent El Niño



Wara et al. 2005

Alexey's Paradox

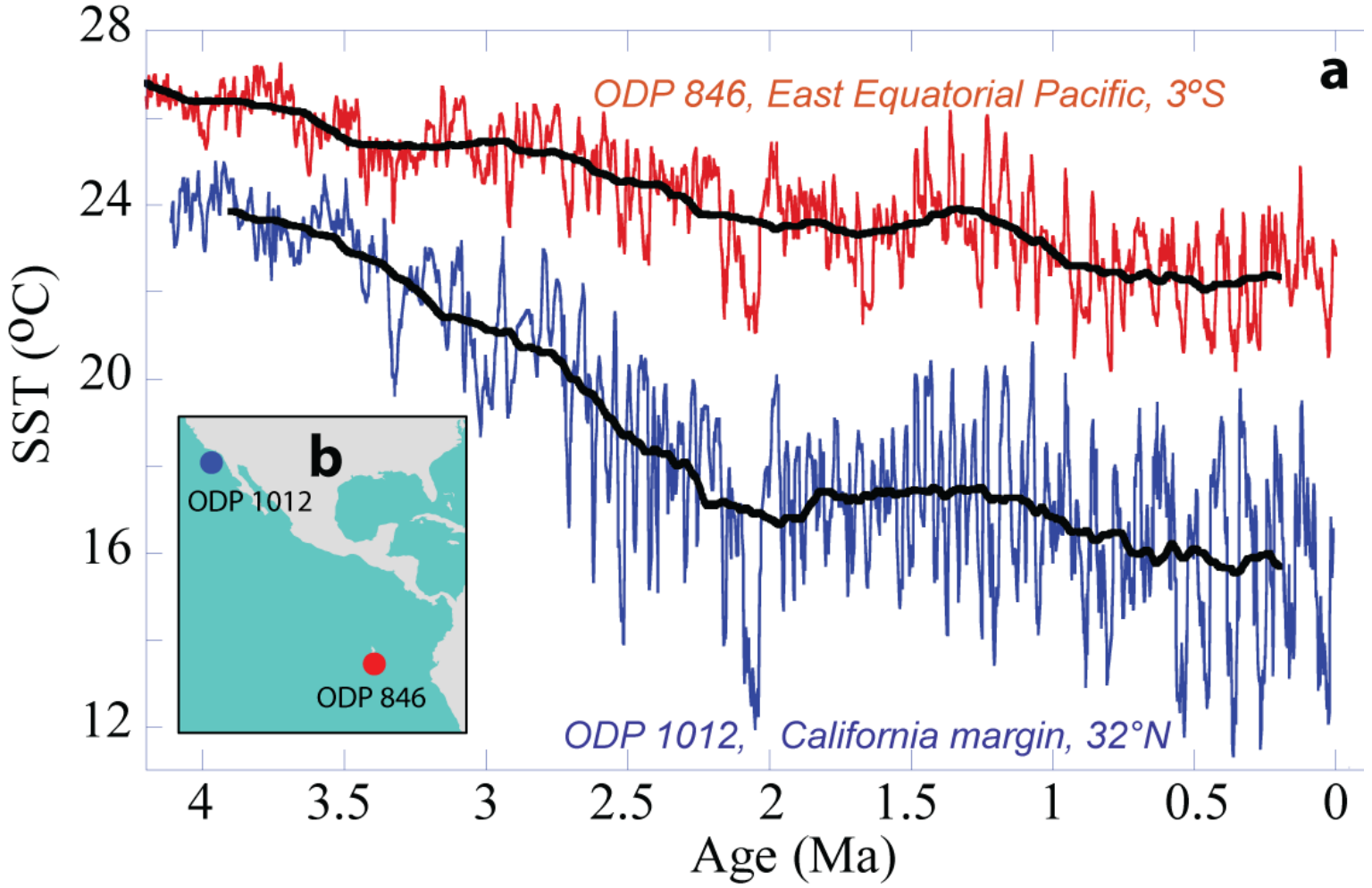


- Present-day heat uptake is dominated by the equatorial cold tongue.
- If we remove this, how can the ocean absorb heat to transfer it polewards?
- If poleward heat transport reduces, how can the high latitudes be warmer?

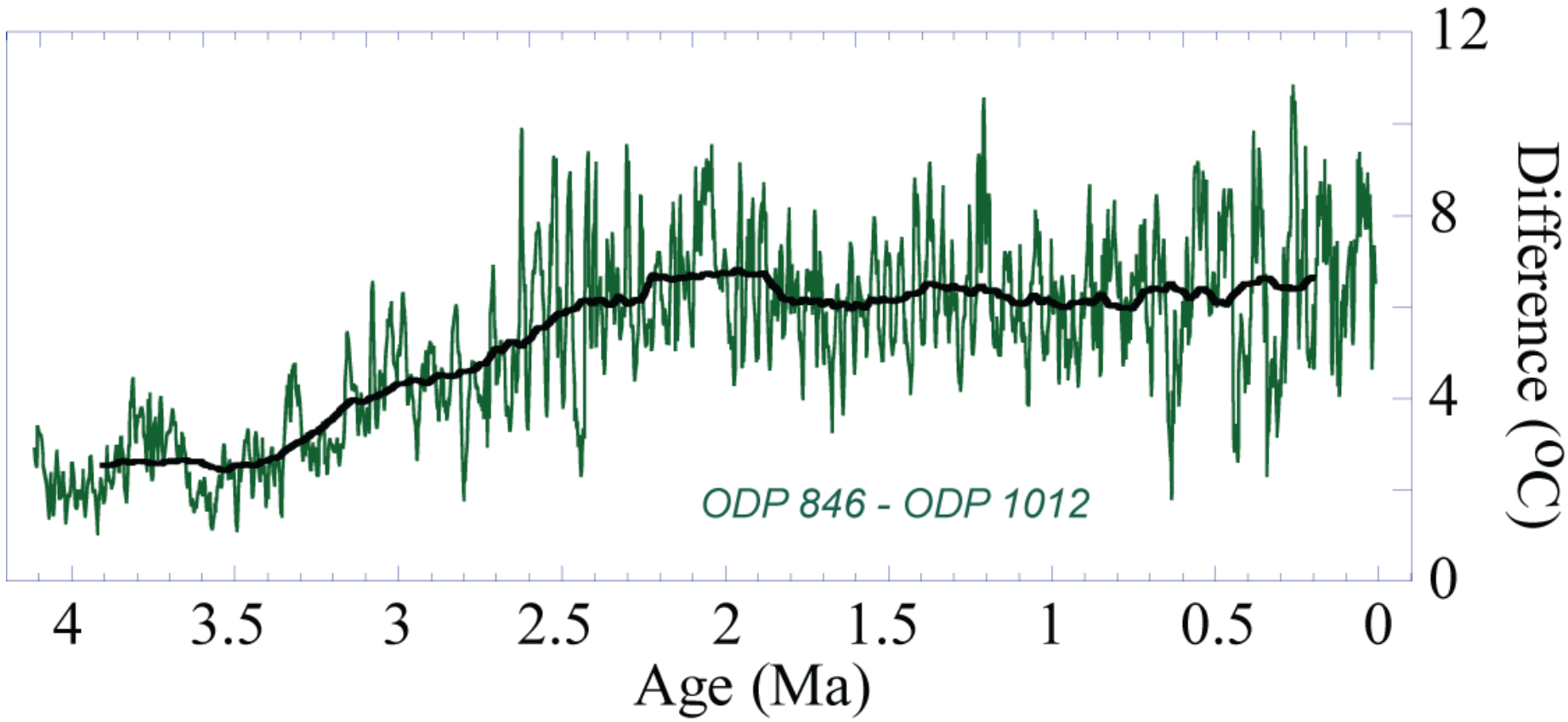
Alkenones

- Another geochemical proxy derived from ~~forams~~ ALGAE
- The relative proportion of unsaturated alkenone in the foram's shell varies with temperature.
- Can be done at Yale in Mark Pagani's lab.

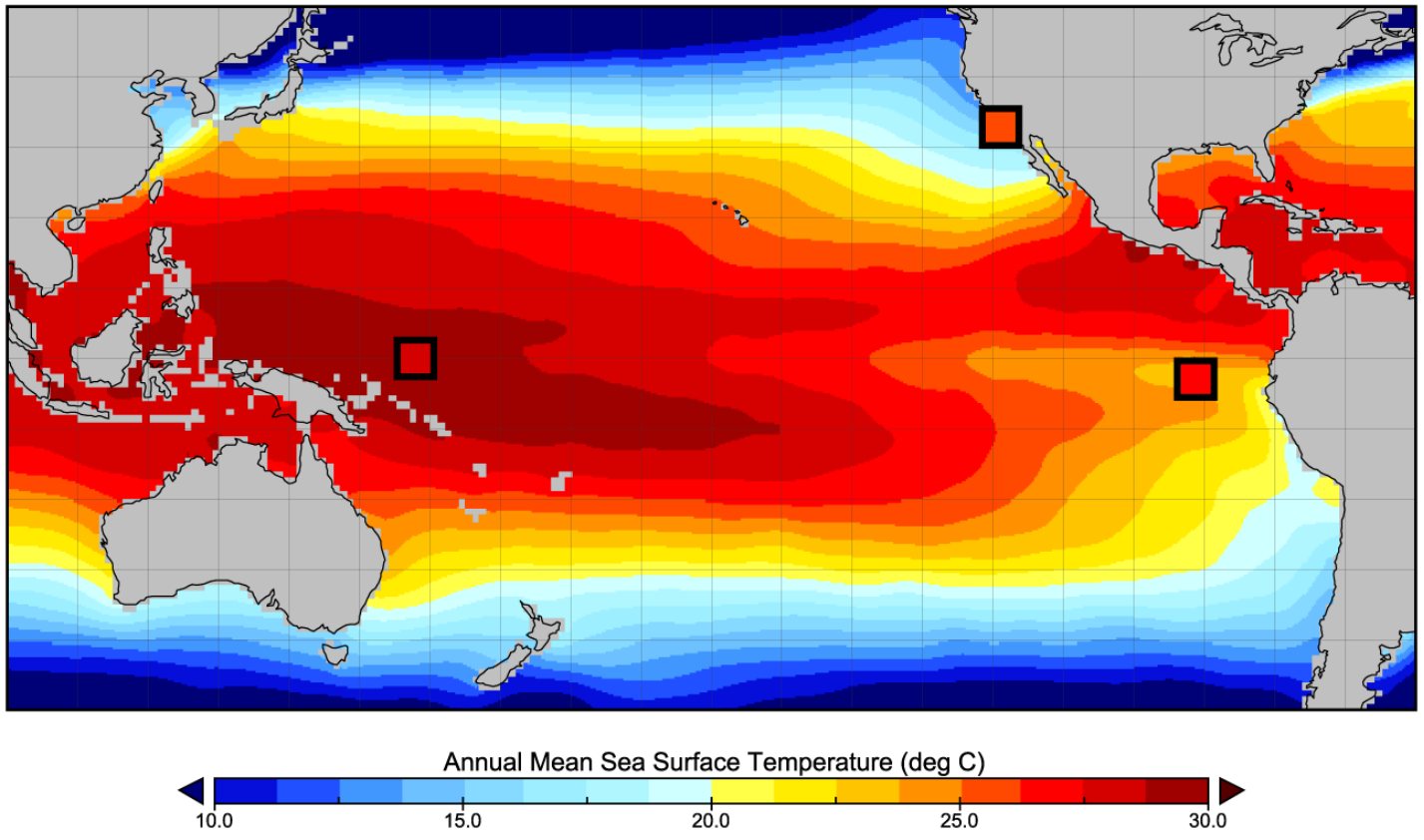
California Margin



Reduced Difference between Equator and Californian Margin

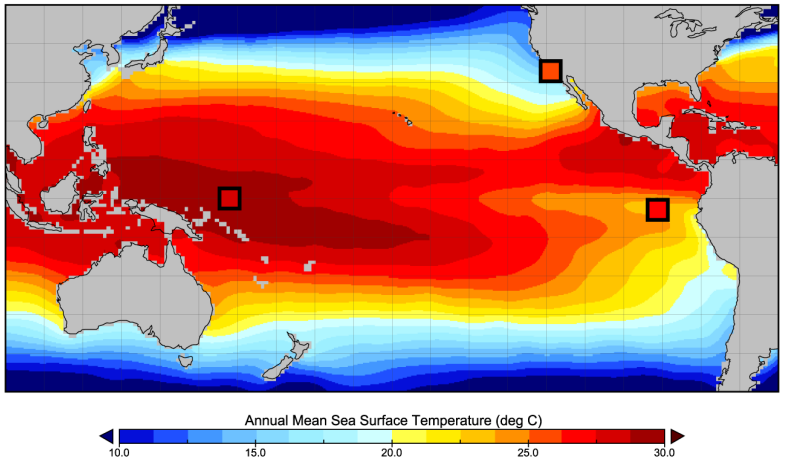


A vast warmpool?

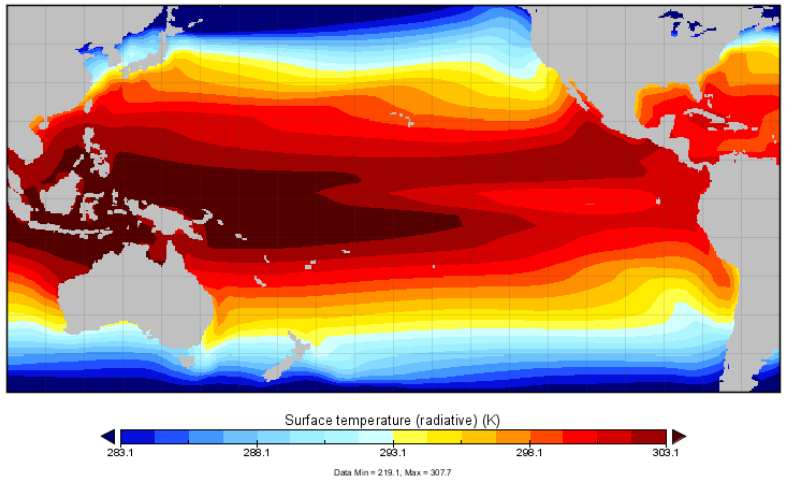


Could this just be Global Warming?

Present Day with Pliocene Obs.



Simulation with Quadrupled CO_2

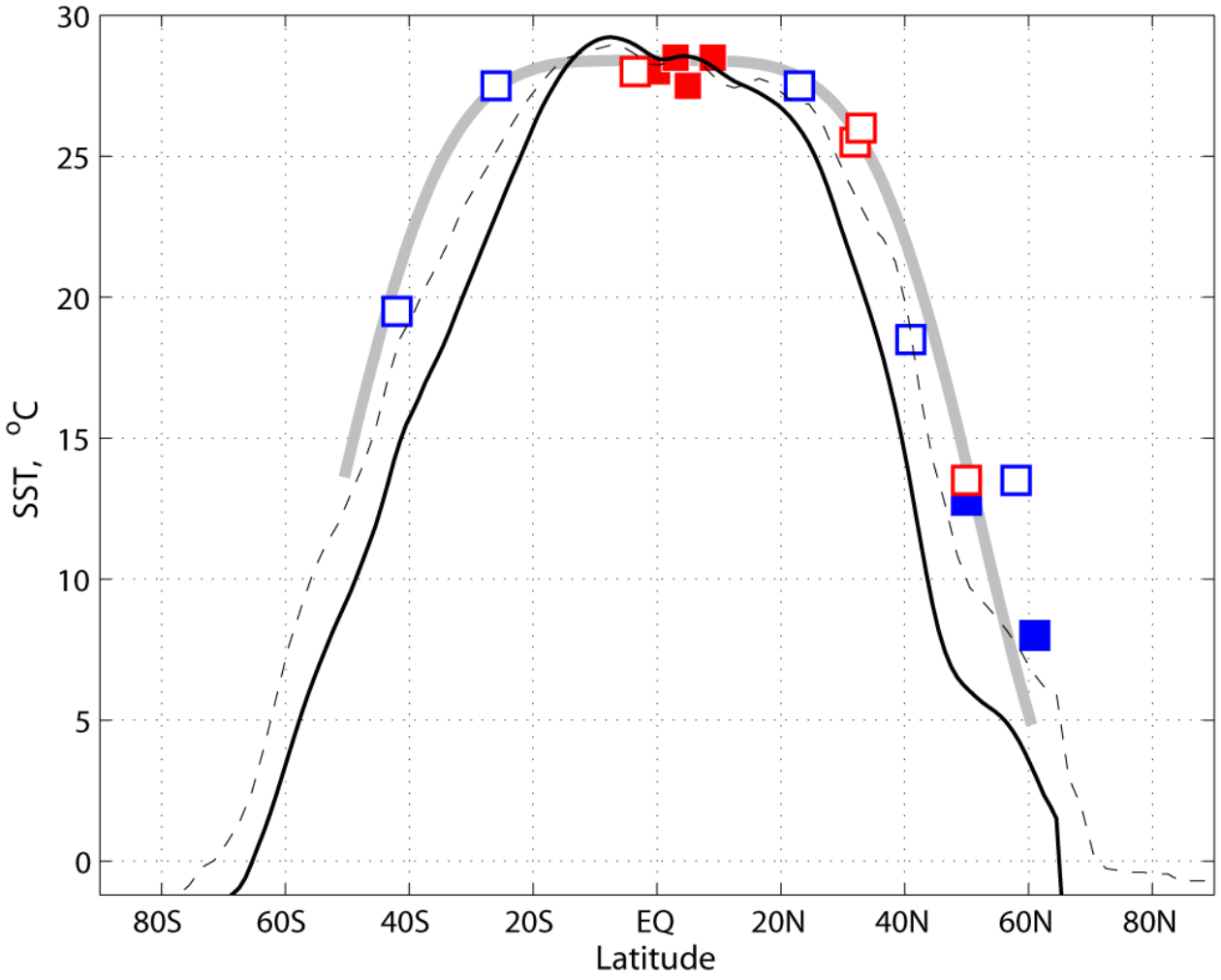


Reconstructing early Pliocene SSTs

A Reconstruction

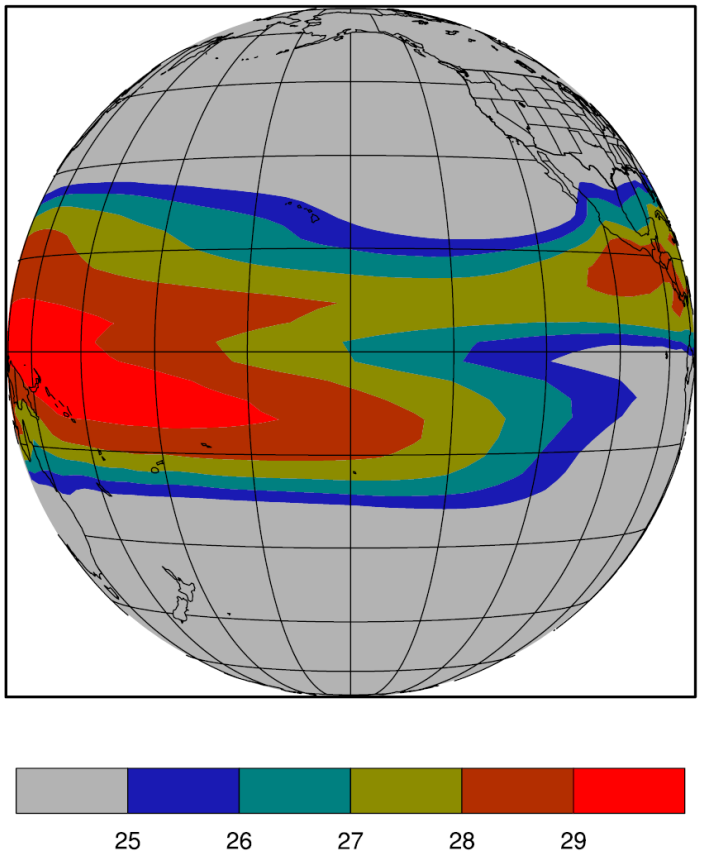
- 17 'Reliable' PaleoSST observations
  - i.e. not Foram Transfer Functions/Modern Analogue Technique
- Unfortunately not all in Pacific
  - Correct by removing 4°C from North Atlantic records. Assumes THC exists. Data at 50°N fits this adjustment.
- Some records don't extend all the way back to 4.2 Ma, but only to 3Ma
  - add further 2°C, as most SST records show this much warming.

Reconstructed SST profile

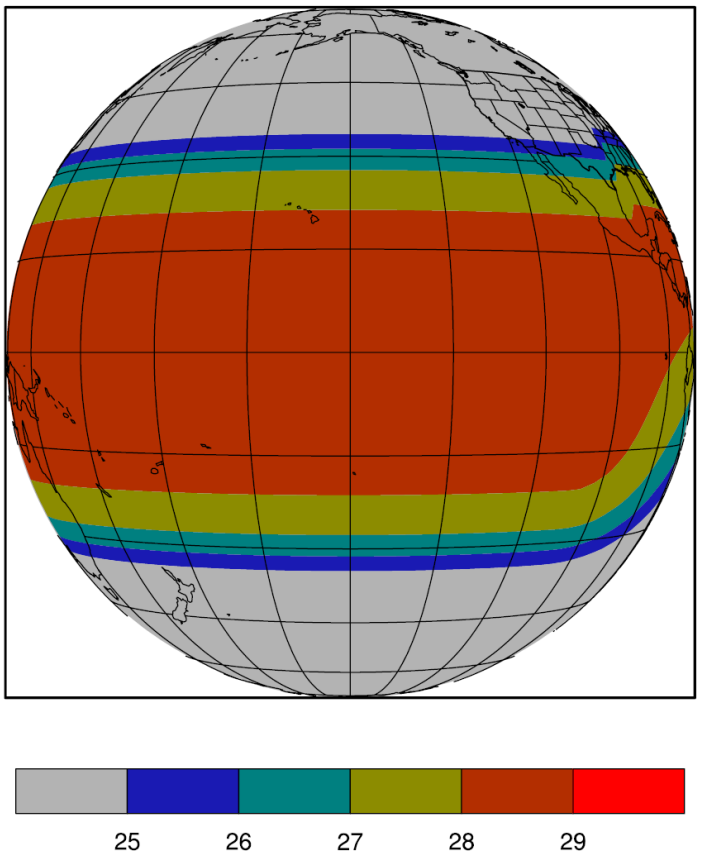


Expansion of Warmpool

(a) Present-Day SSTs



(b) Early Pliocene SSTs



Assessing the impacts

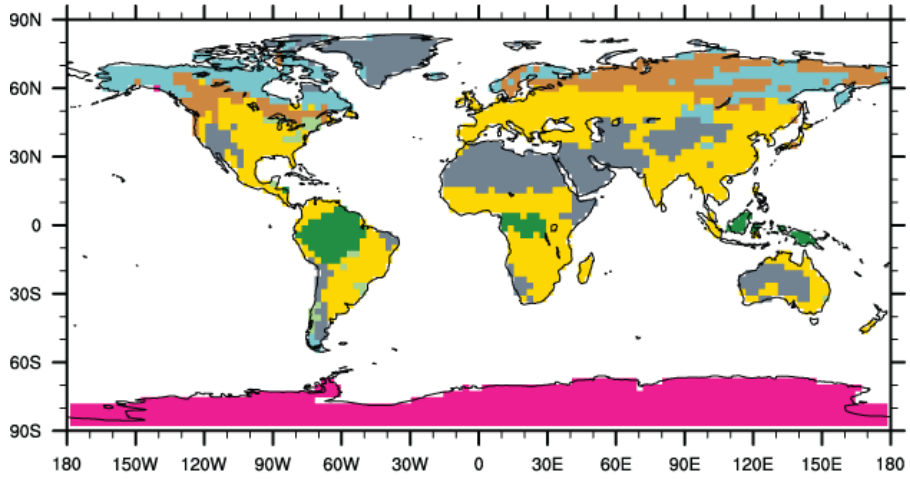
- Atmospheric general circulation model
- Prescribe boundary conditions:
  - Topography
  - Land Surface (vegetation type)
  - Sea-ice cover
  - Atmospheric Composition
  - Sea-Surface Temperatures

Community Atmospheric Model, v3

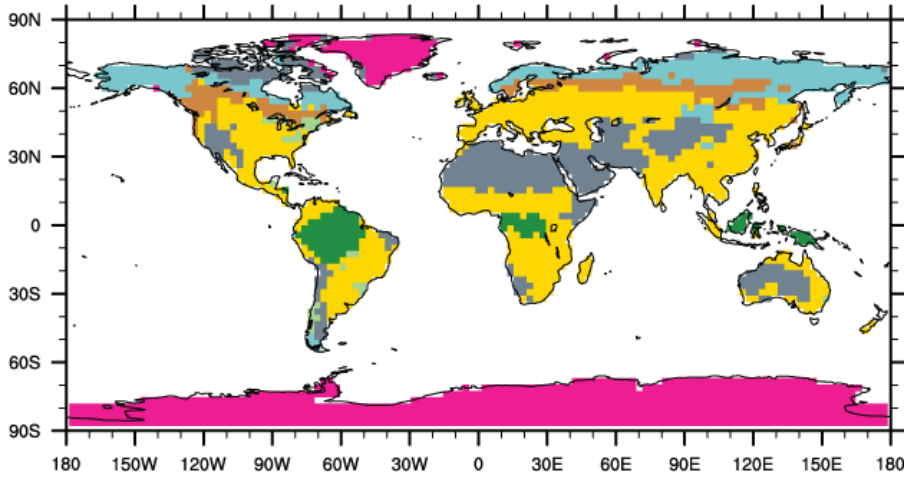
- Developed at National Center for Atmospheric Research in Colorado
- Part of coupled model used in most recent IPCC
- Has a resolution of T42 ~ 2.8 x 2.8 degrees latitude-longitude

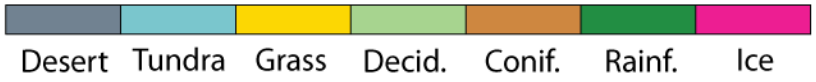
Landcover Differences

Pliocene



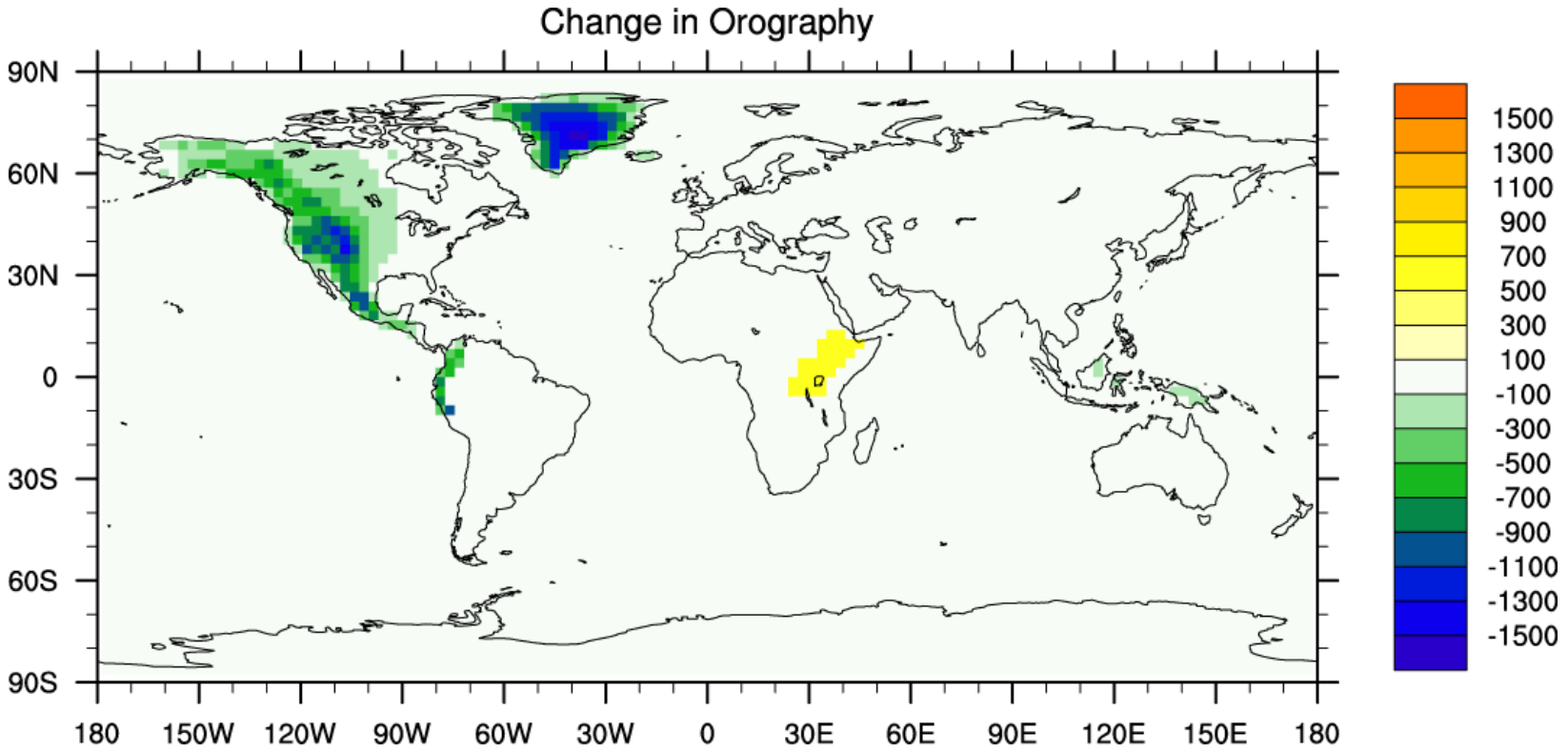
Present-Day





- Removal of Greenland Ice Sheet
- Adjustment of Tundra

Topography Differences



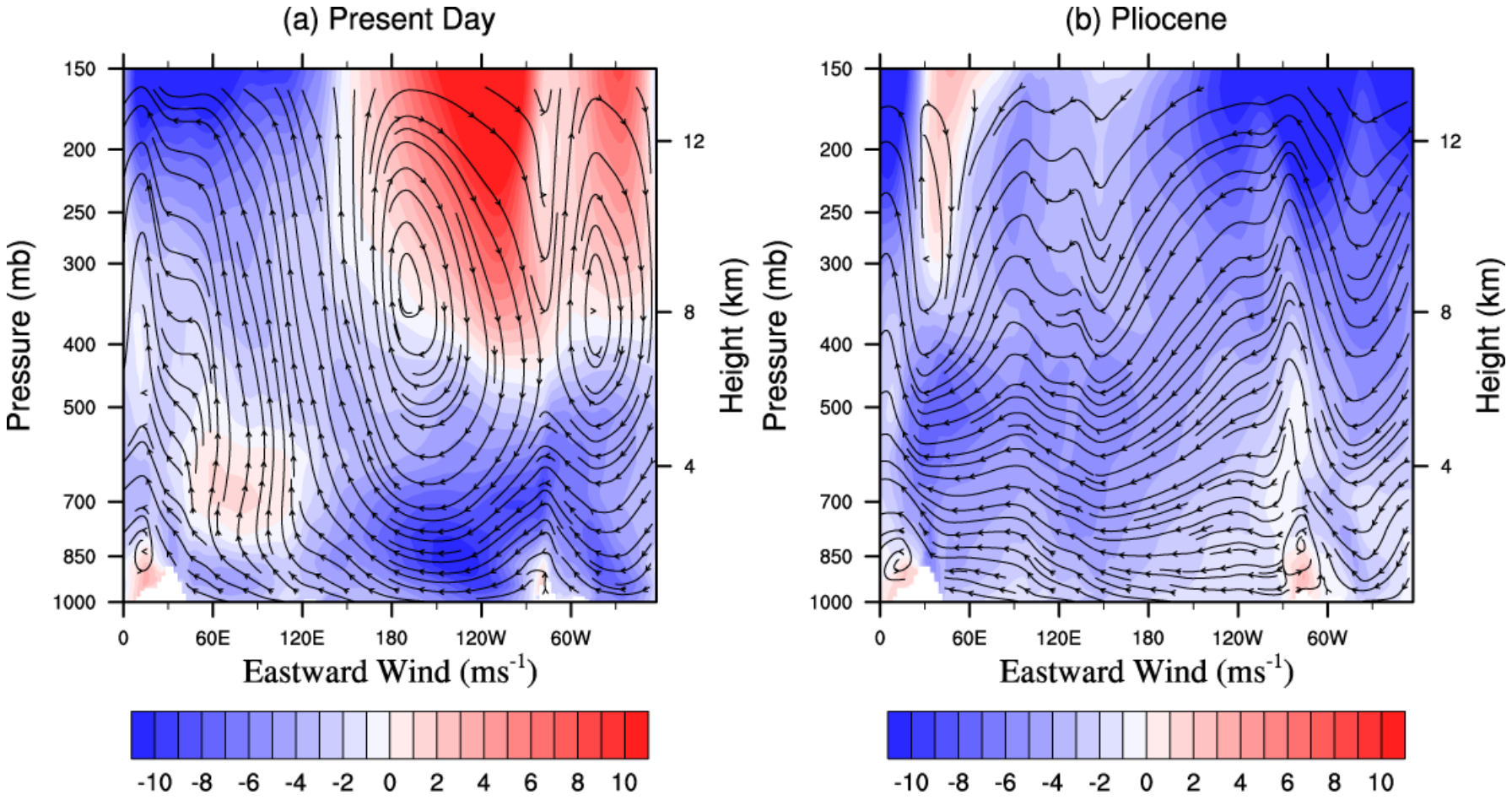
- Lowering of Greenland
- Lowering of American Cordilla
- Raising of East African Highlands

Sea-Surface conditions

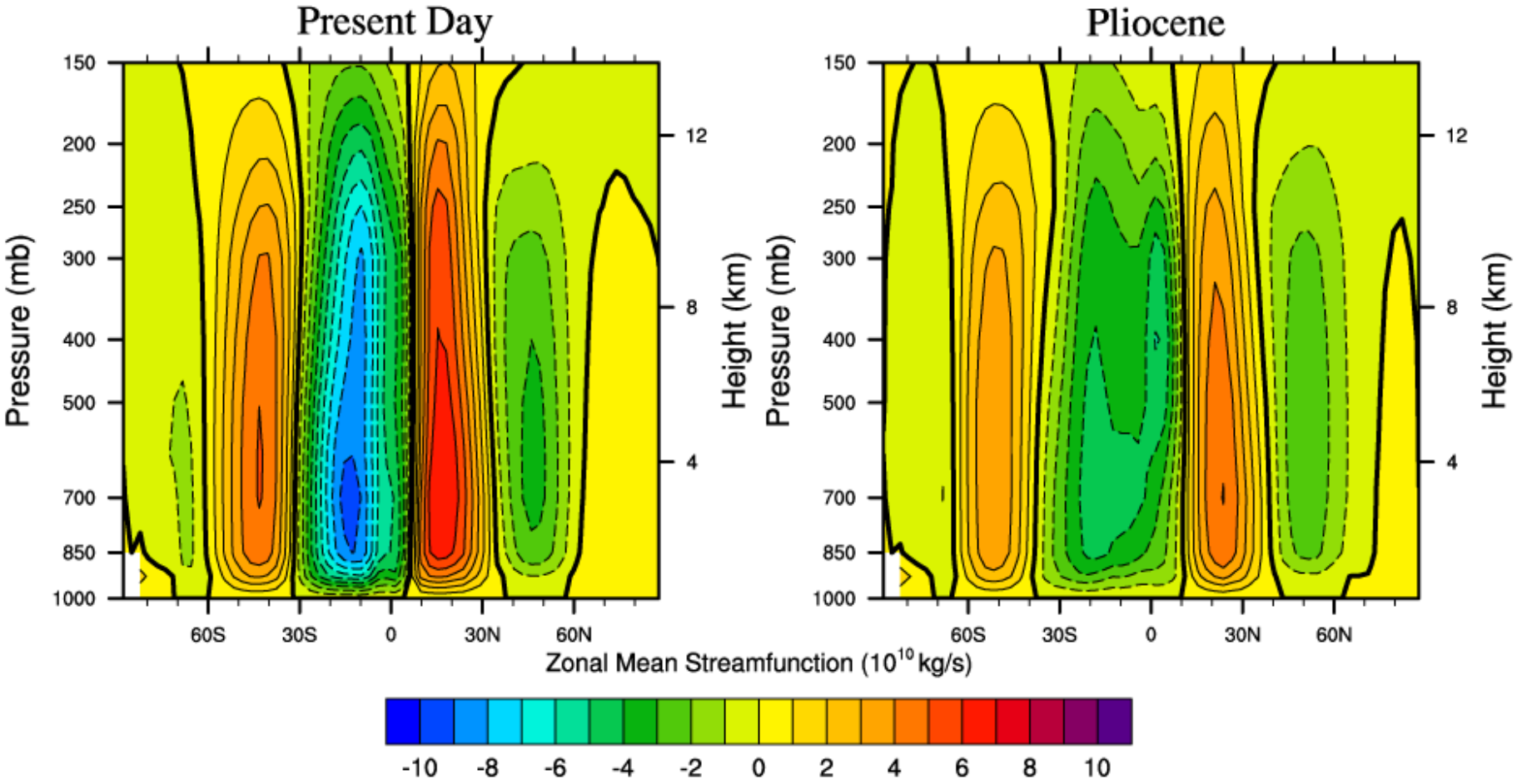
- SSTs taken from our profile
- Seasonal cycle included by shifting profile N/S
- Fractional sea ice cover set from SST
  - No sea ice if SST > 0.8oC
  - Increases linearly for SST < 0.8oC, until complete coverage at -1.8oC

Climate impacts of Vast Warmpool

Walker Circulation Collapses



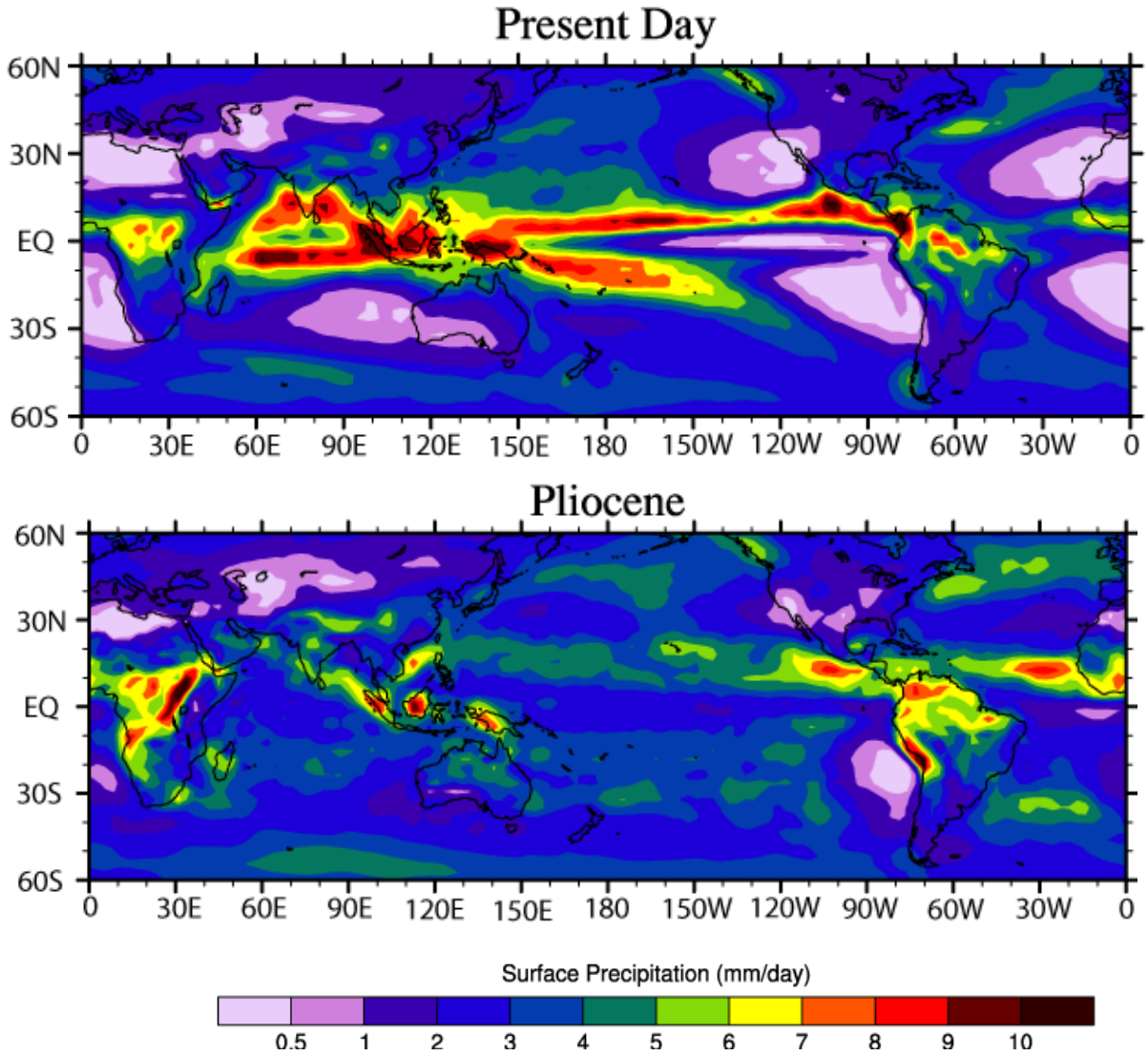
Hadley Circulation Weakens



Robustness of Weakening

Model Run	Maximum Strength of Overturning N. H. (10^{10} kg/s)	S. H. (10^{10} kg/s)
Present Day	7.0	9.6
Pliocene	5.0	4.4
Present-day, but Pliocene SST and sea ice	5.0	4.5
Removing Greenland ice sheet	*+0.3*	*-0.2*
Altering Topography	*+0.2*	*0.0*
Removing Indonesian Landmass	*+0.8*	*-0.1*

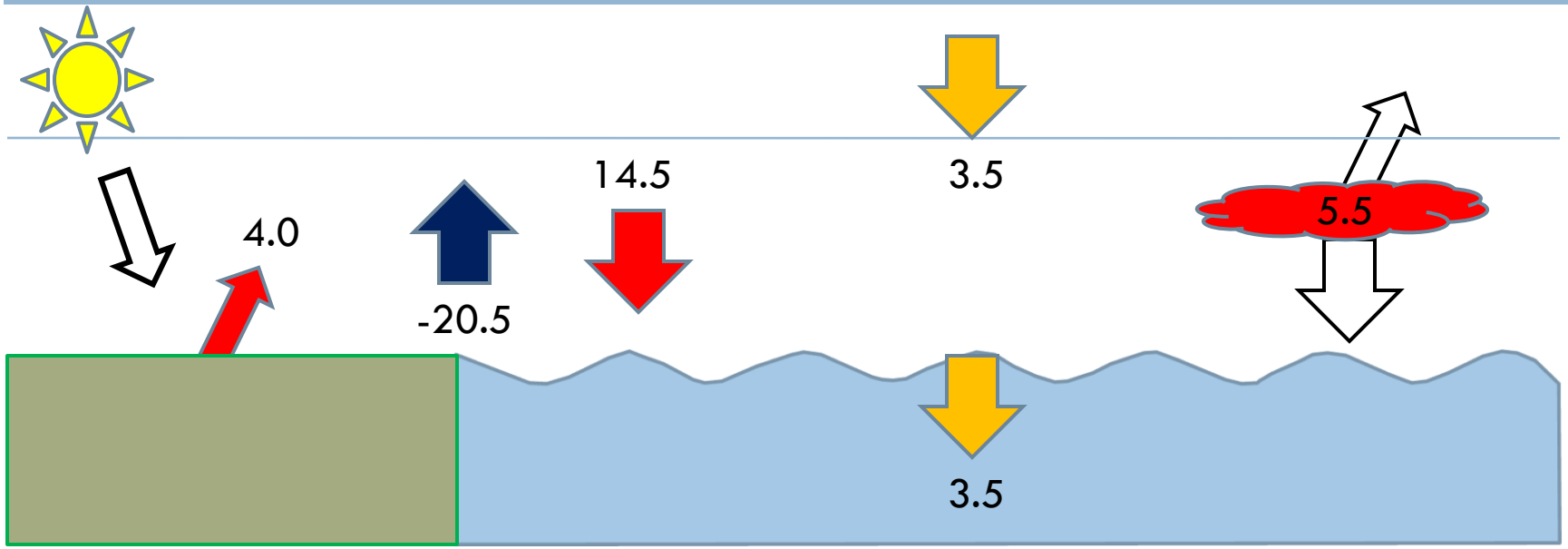
Precipitation Changes



Sustained Warm Climate

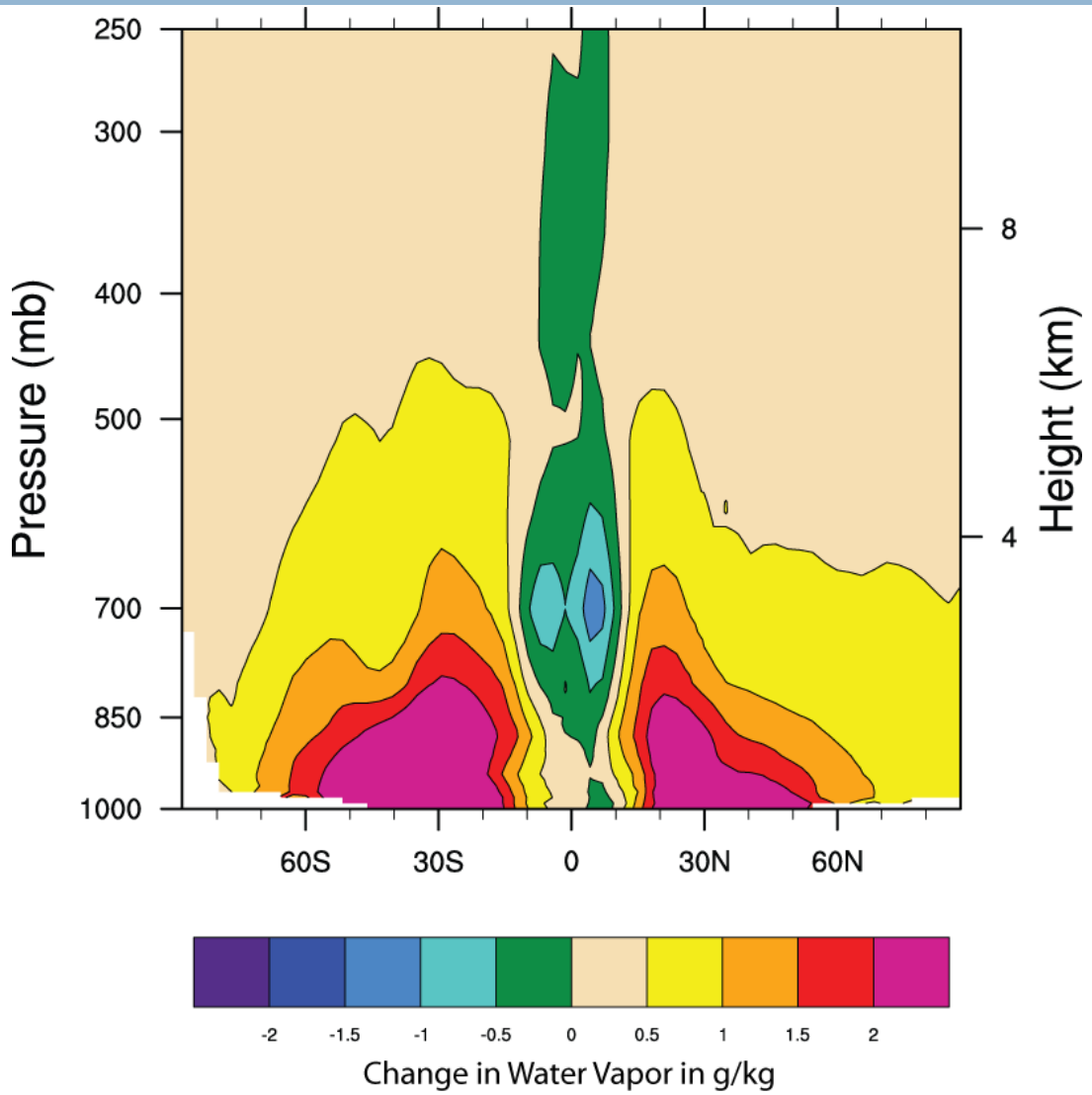
How does the atmosphere respond to the new SST conditions and reach a new equilibrium state?

Global Mean Analysis



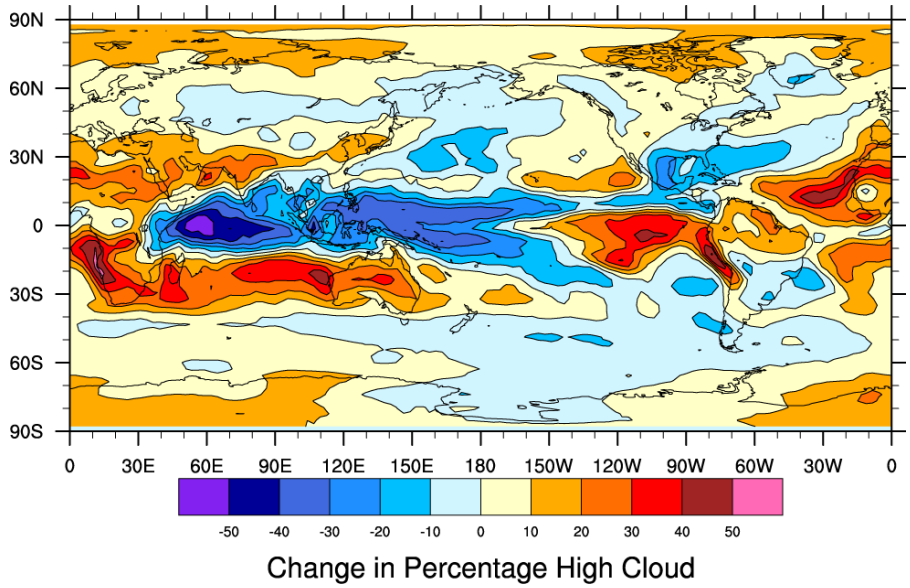
Heat Transfer Process	Change in Pliocene (Wm^{-2})
Blackbody Radiation from Surface	-20.5
Water Vapor/Lapse Rate Feedback	14.5
Cloud Feedbacks	5.5
Surface Albedo Changes	4.0
Imbalance	3.5

Increased Water Vapor

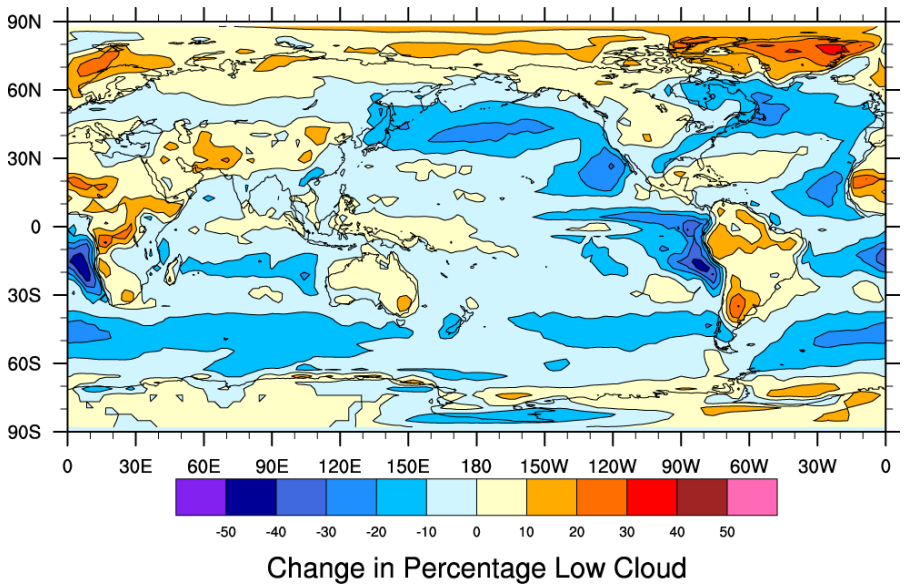


Cloud Changes

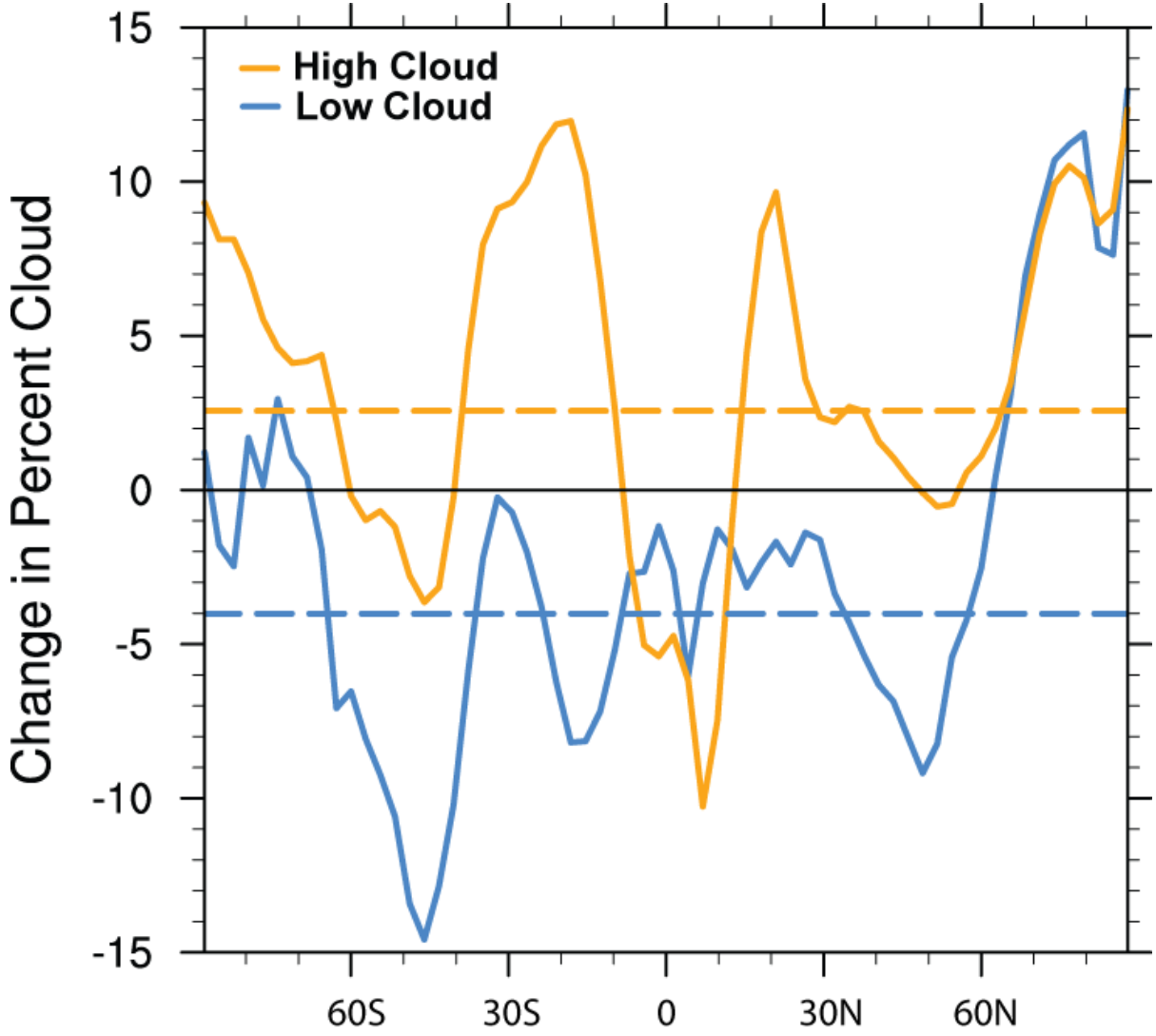
High Cloud (net Warming)



Low Cloud (net Cooling)



Cloud Changes – Zonal Mean



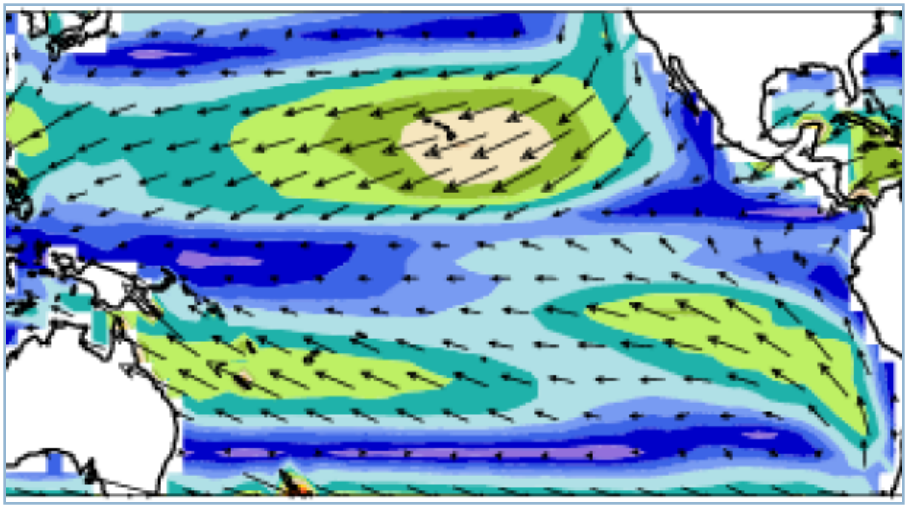
Mechanisms for a Permanent El Niño

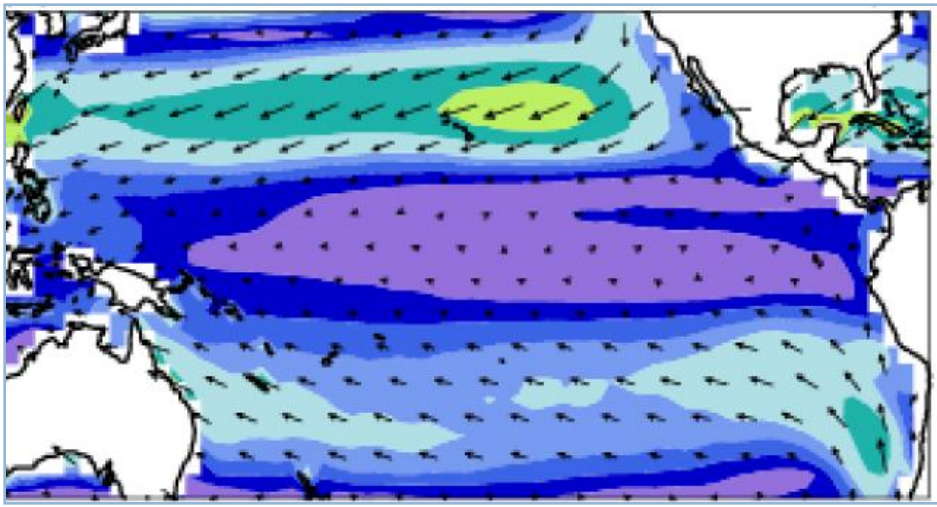
How can you create a Permanent El Niño with a negligible SST gradient in the equatorial Pacific?

Is there upwelling in the EEP?

Present Day

Pliocene

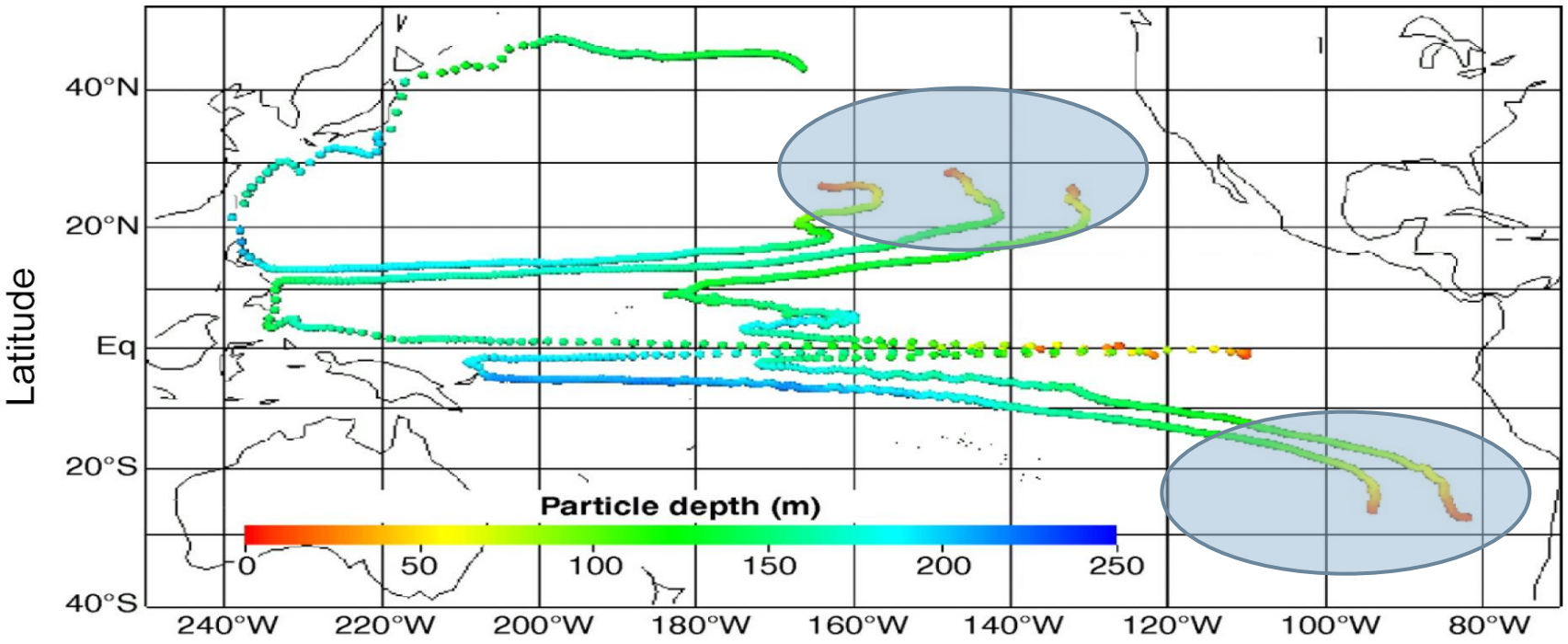




Surface Windstress from Atmosphere, N/m^2

Yes, but a reduced amount

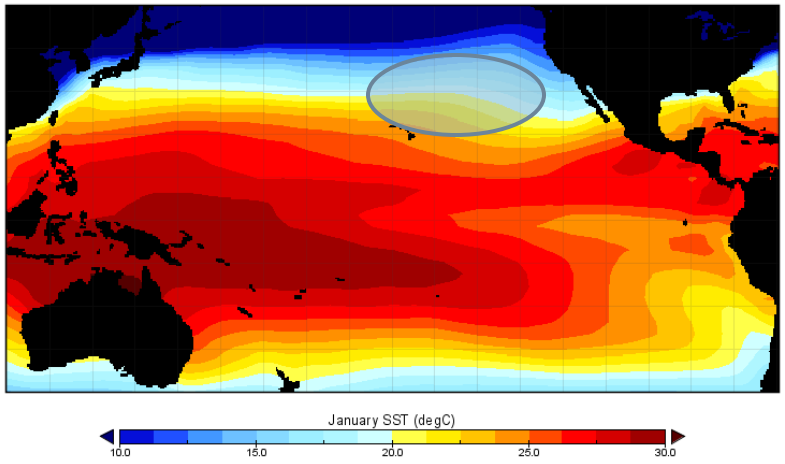
Water Source Regions



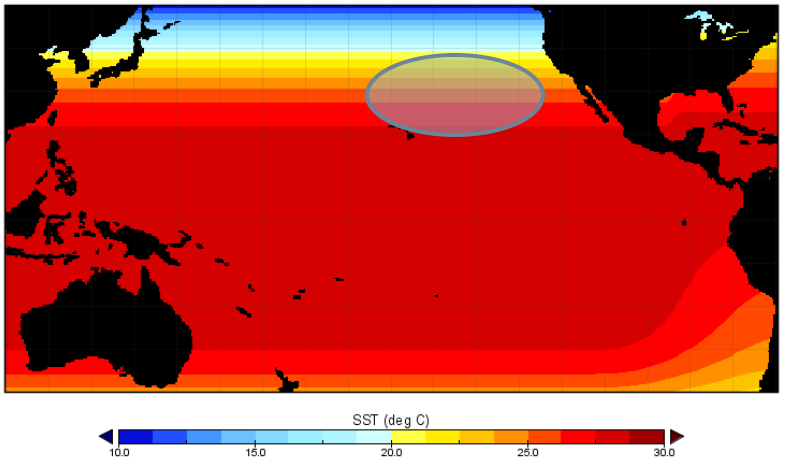
Water upwelling in cold tongue comes from subtropical subduction zones

Temperature in Source Regions

Present-Day



Our Pliocene



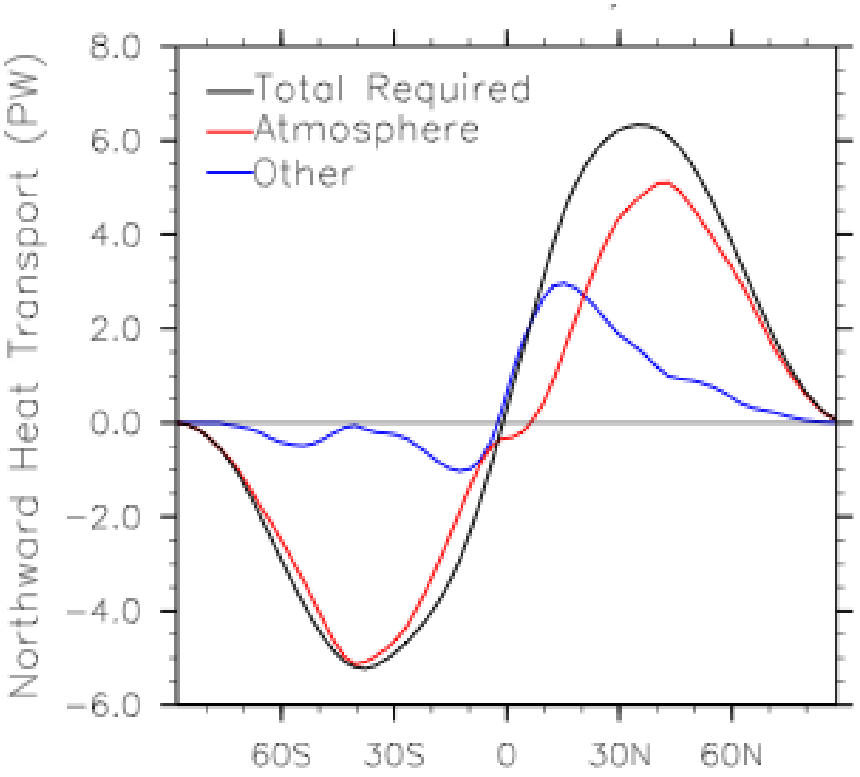
Significantly warmer subduction zones

Heat Transport

Does this vast warmpool, with its small meridional gradient, solve the Pliocene paradox?

Poleward Heat Transport

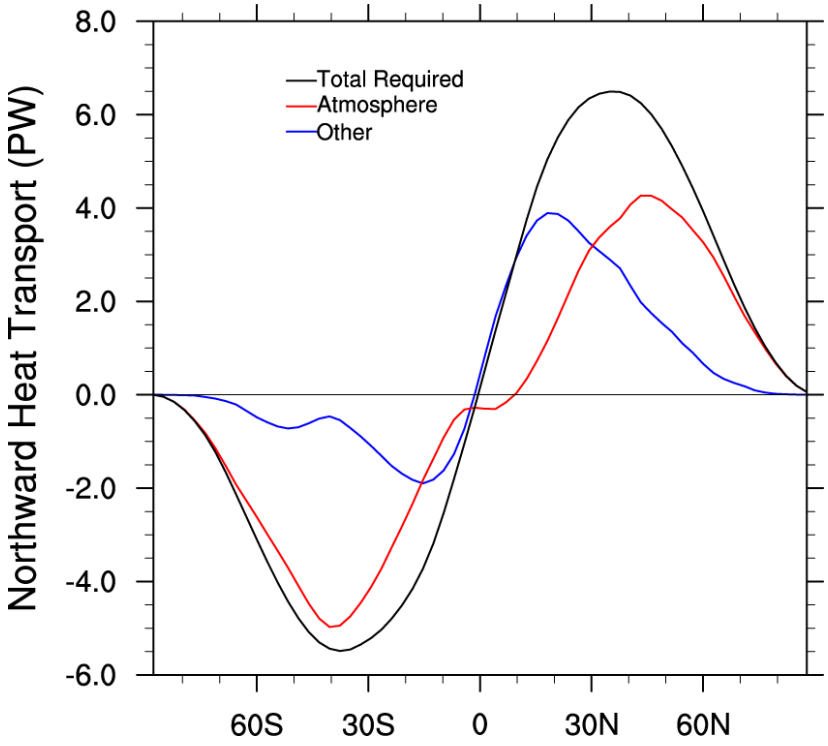
- Possible to diagnose heat transport by analysis of local heat balance at the top and bottom of the atmosphere.
- Atmosphere dominates poleward of 20° today.



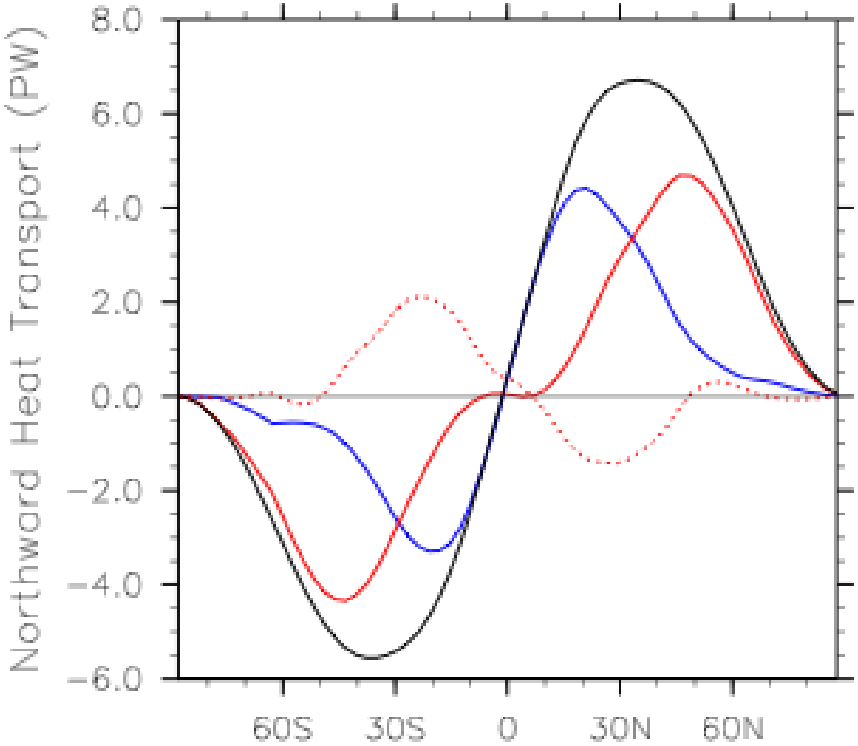
- Ocean important near equator in Modern Climate

Pliocene Heat Transport

PRISM (no meridional expansion of warmpool)



Our Pliocene with its vast warmpool



Summary

What have we found and where do we take it from here?

Conclusions

- The Pliocene is the nearest the Earth has to an analog of our anthropogenic future.
- We have discovered that the Pacific was a vast pool of warm water in the Pliocene.
- This lead to a sluggish tropical circulation.
- The poleward expansion of the warmpool explains permanent El Nino.
- We are still left with a heat transport paradox.

Future Work

- What can solve our heat transport paradox?
  - Thermal regulation of the maximum SST
  - Increased vertical mixing
    - Possibly through increased hurricanes
- What caused the gradual increase in meridional SST gradient?
  - Does it tie with Northern Hemisphere Glaciation?