IMPLICATIONS OF THE VAST PLIOCENE WARMPOOL

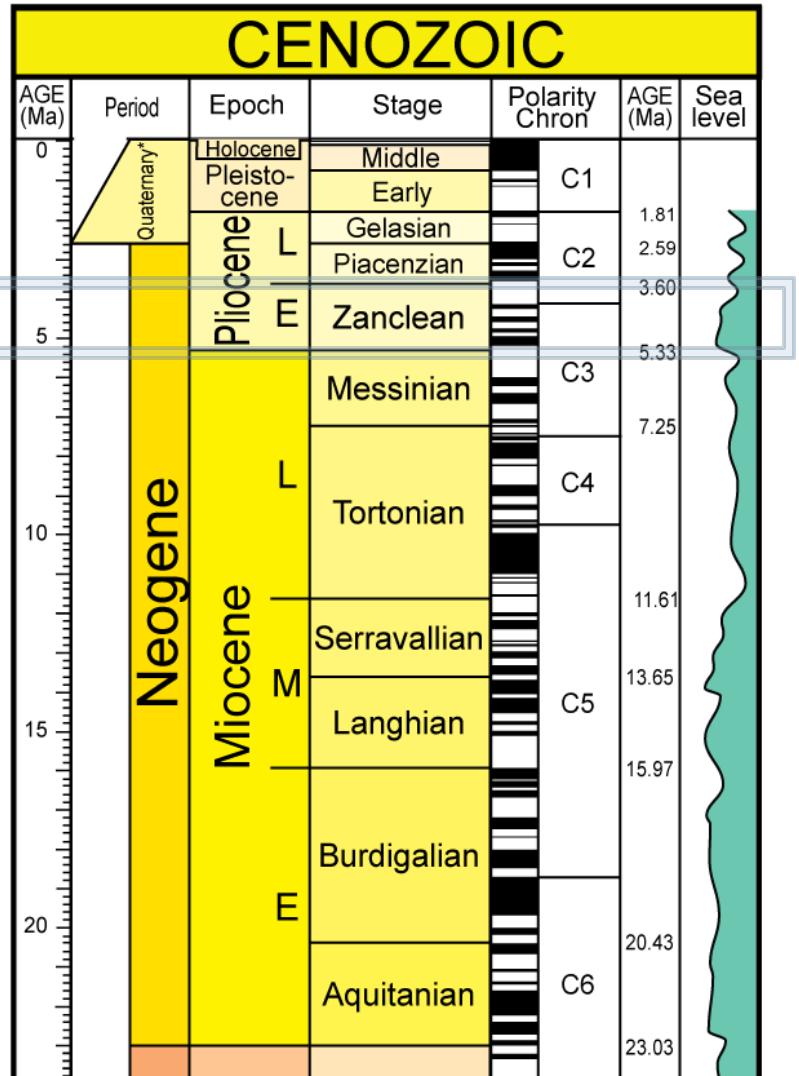
Chris Brierley and Alexey Fedorov

Outline

- Introduction to the Early Pliocene
  - When & why should we care?
- A vast warmpool in the Pacific
  - Paleo-observations & comparison to the future
- Impacts on the global climate
  - Sluggish tropics
- Mechanisms for sustaining a vast warmpool
  - Equatorial mixing
  - A feedback from tropical cyclones

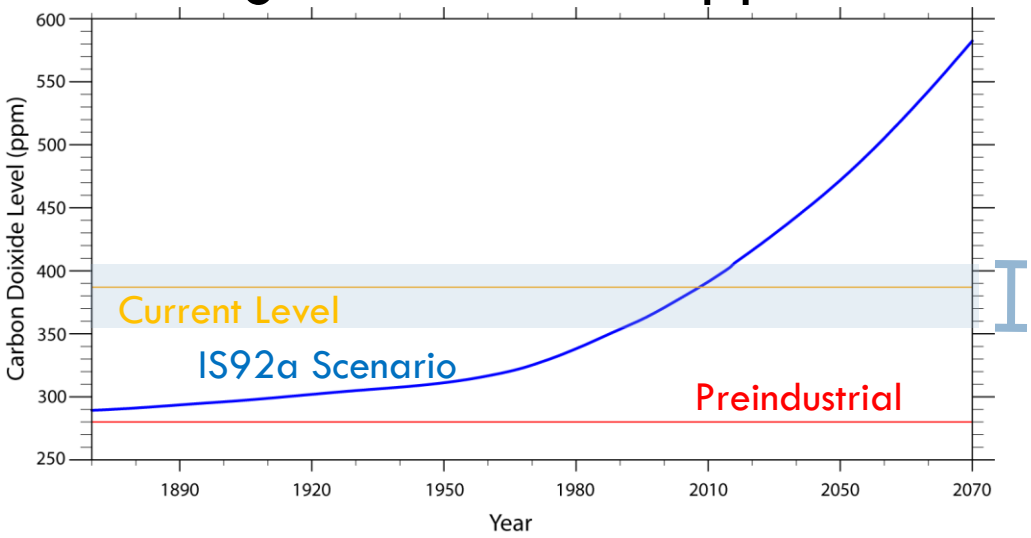
When is the early Pliocene

- Time period spanning 5.3~3.6 million years ago.
- A relatively-short and recent period in the geological past.
- Deep time in view of most climate scientists



Why care about the early Pliocene?

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

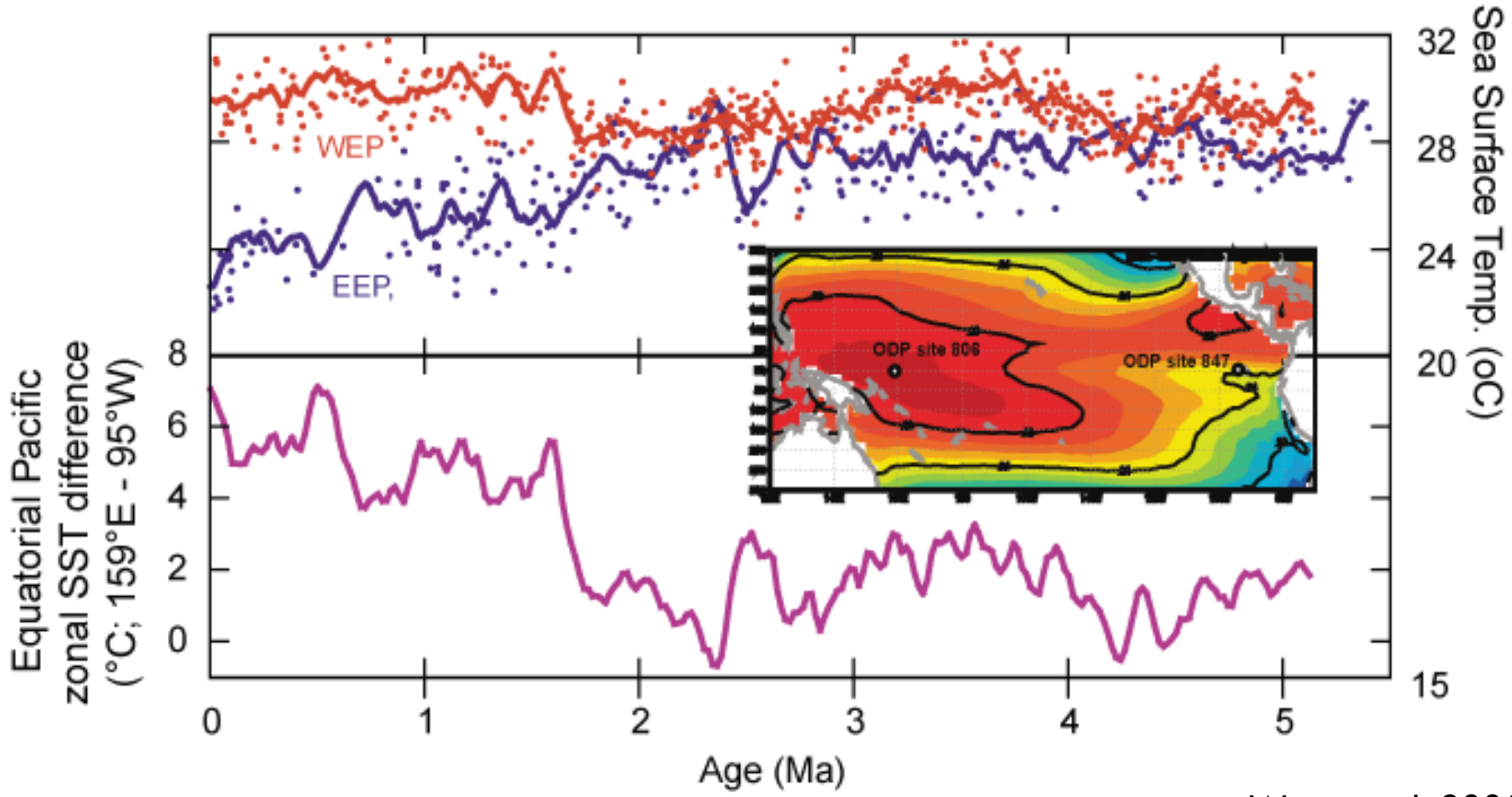


What else do we know about the early Pliocene?

- 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

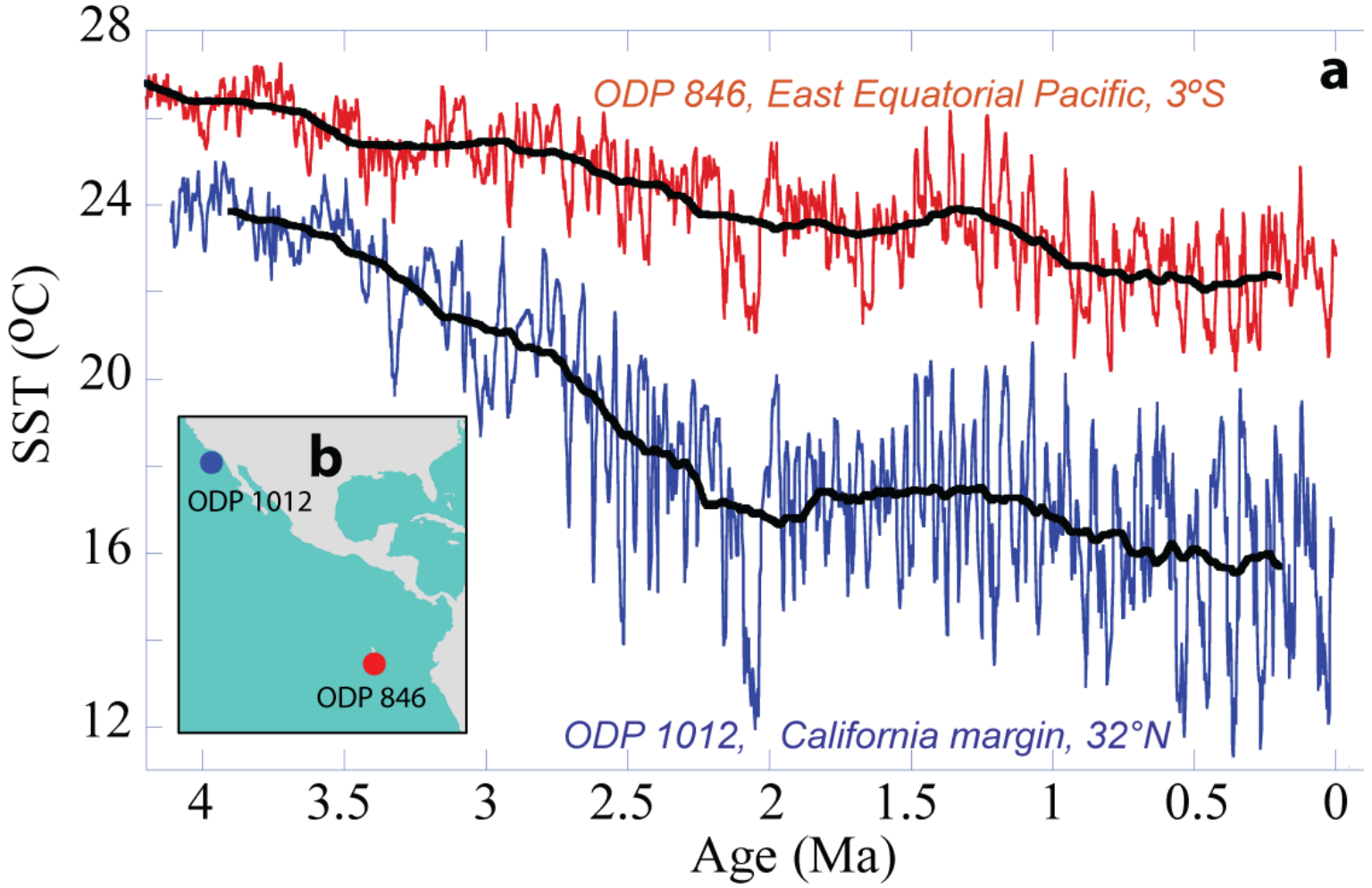
Early Pliocene SSTs

Wara's Permanent El Niño

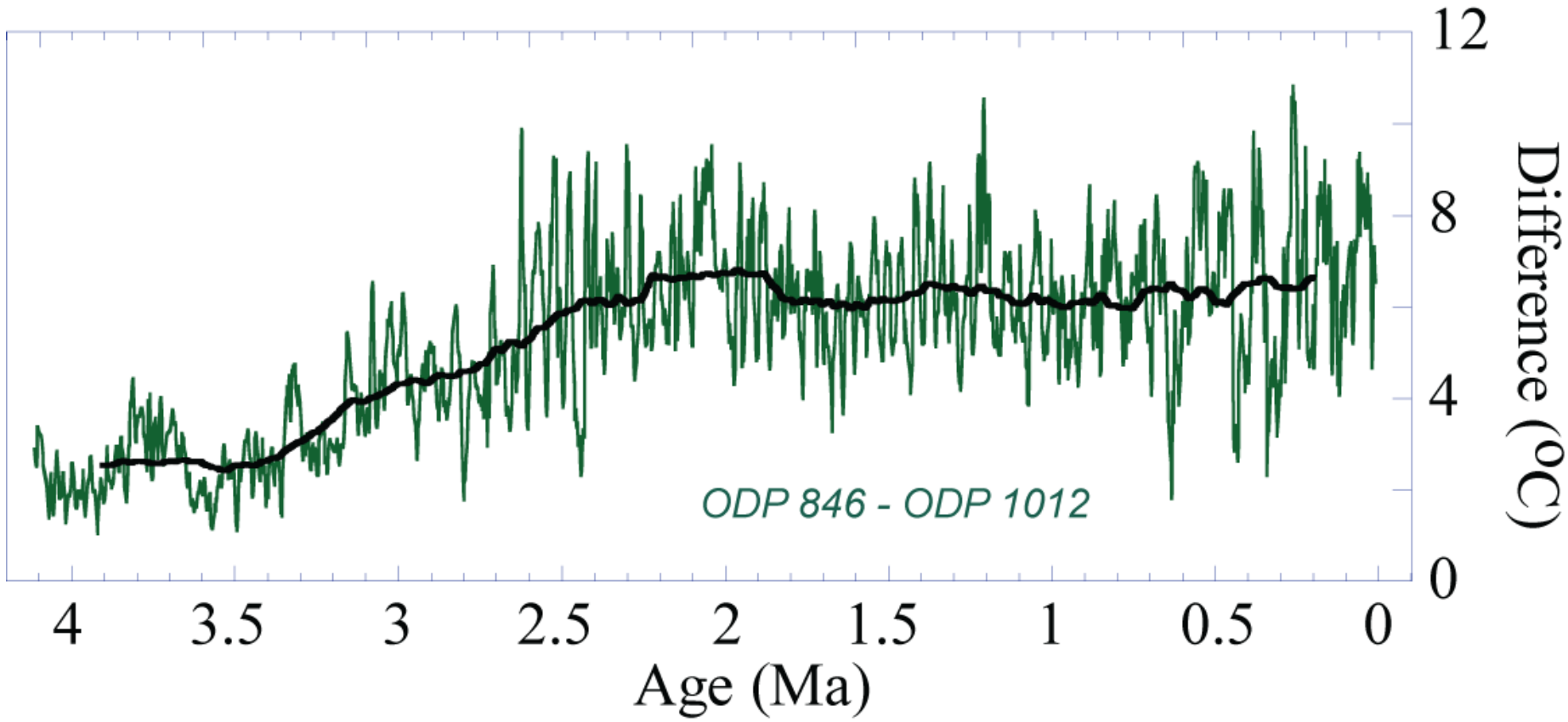


Wara et al. 2005

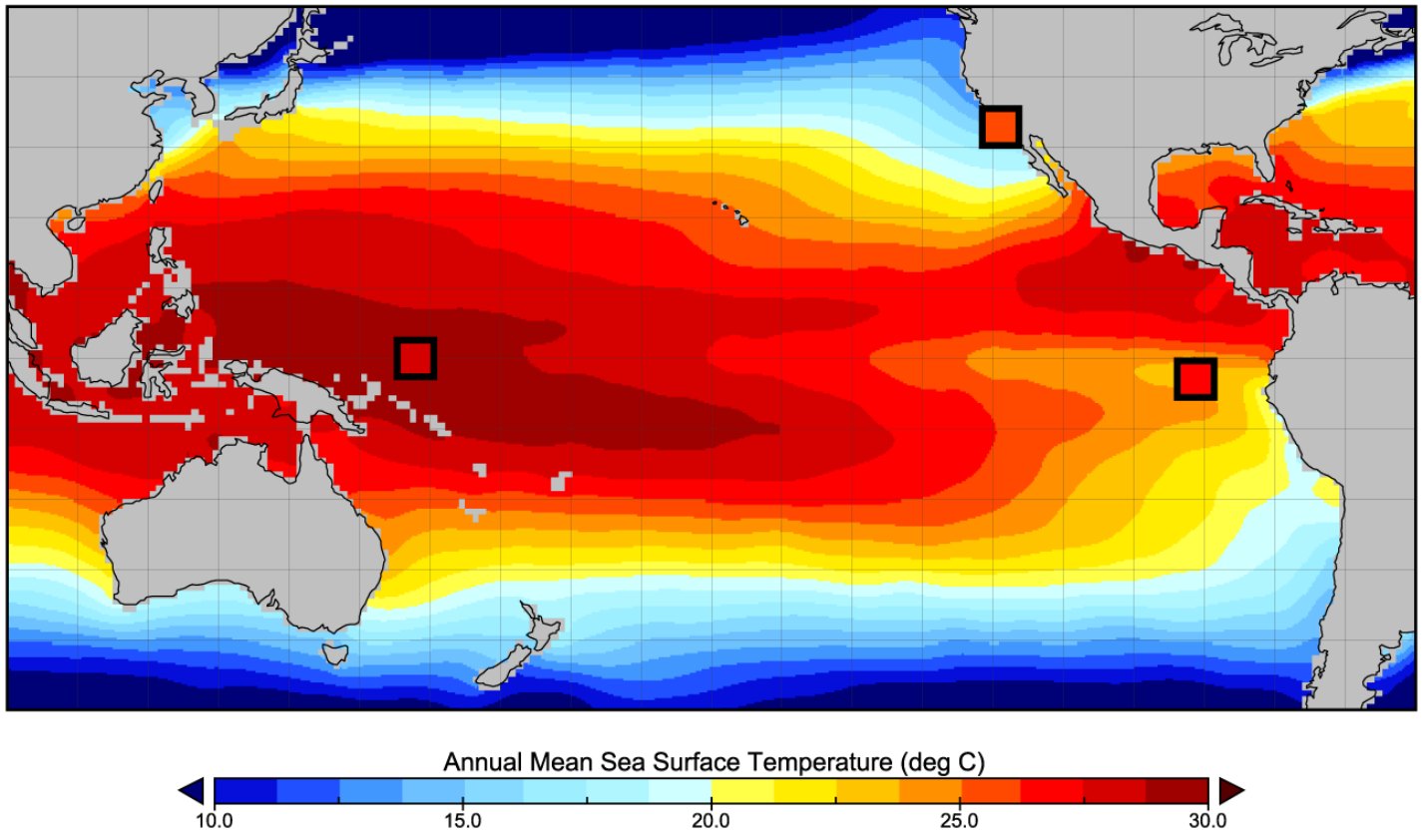
California Margin



Reduced Difference between Equator and Californian Margin

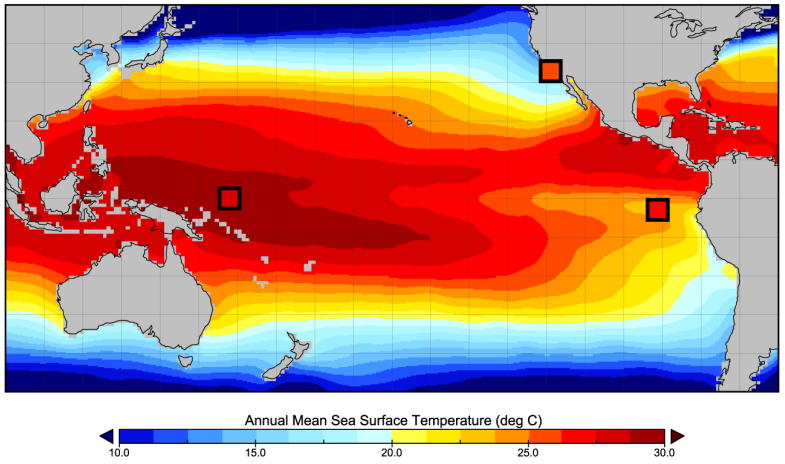


A vast warmpool?

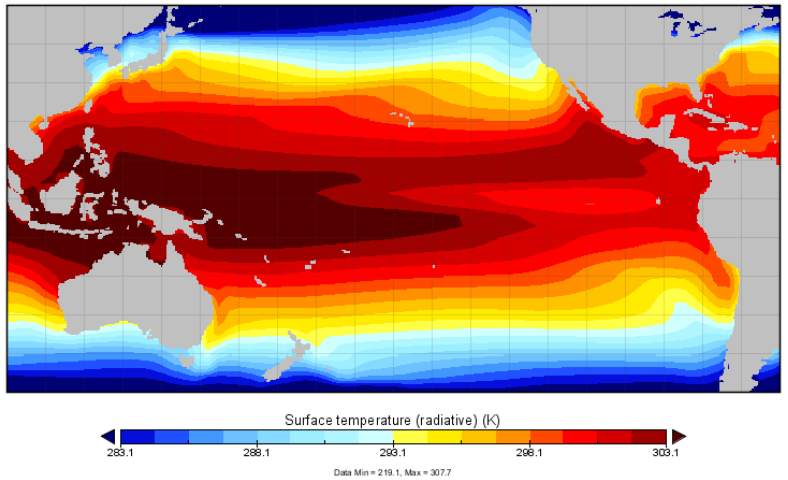


Could this just be Global Warming?

Present Day with Pliocene Obs.



Simulation with Quadrupled CO_2



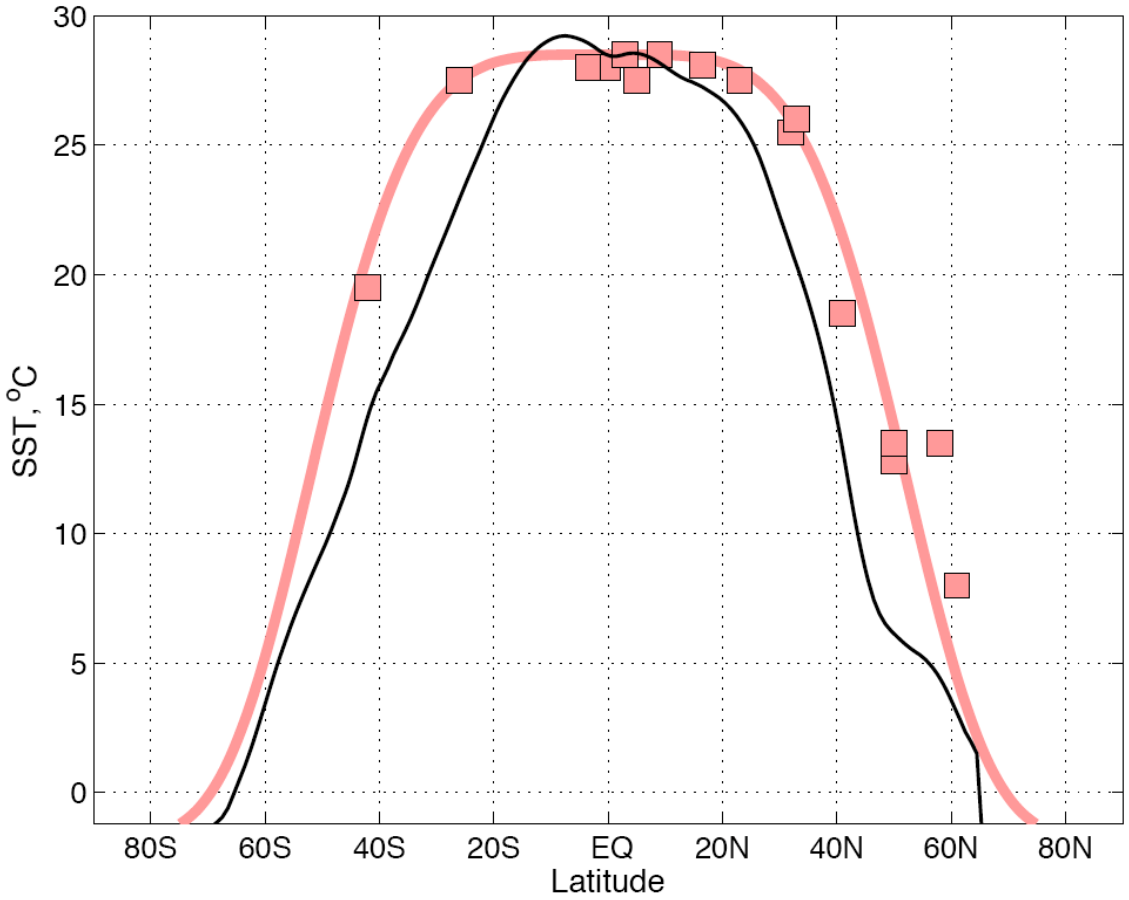
Climate impacts of Vast Warmpool

Use atmosphere model to simulate response to SST pattern

AGCM requires more than 3 SSTs

- Compile PaleoSST observations to get SST profile
  - Use only Mg/Ca and Alkenone SSTs
  - Unfortunately few in Pacific so 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
  - So add further 2°C, as most SST records show this much warming.

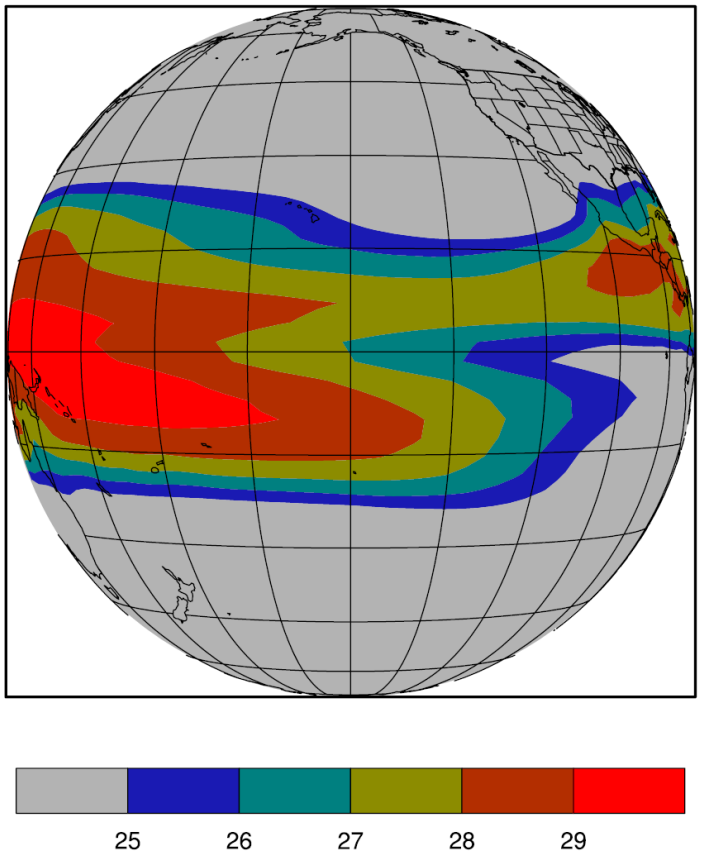
Reconstructed SST profile



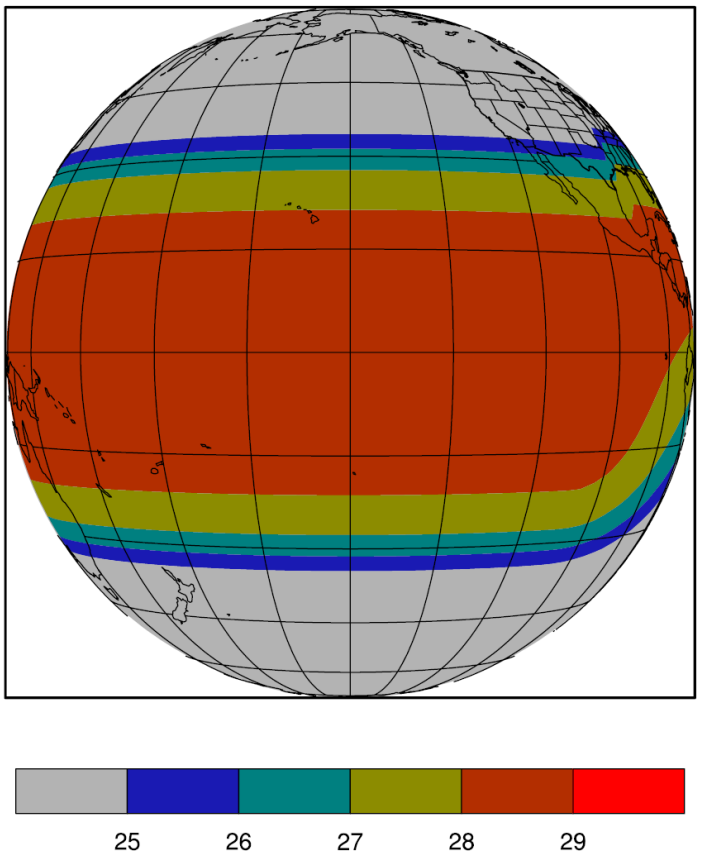
- Extend zonally across Pacific
- Shift meridionally for seasonal cycle.

Expansion of Warmpool

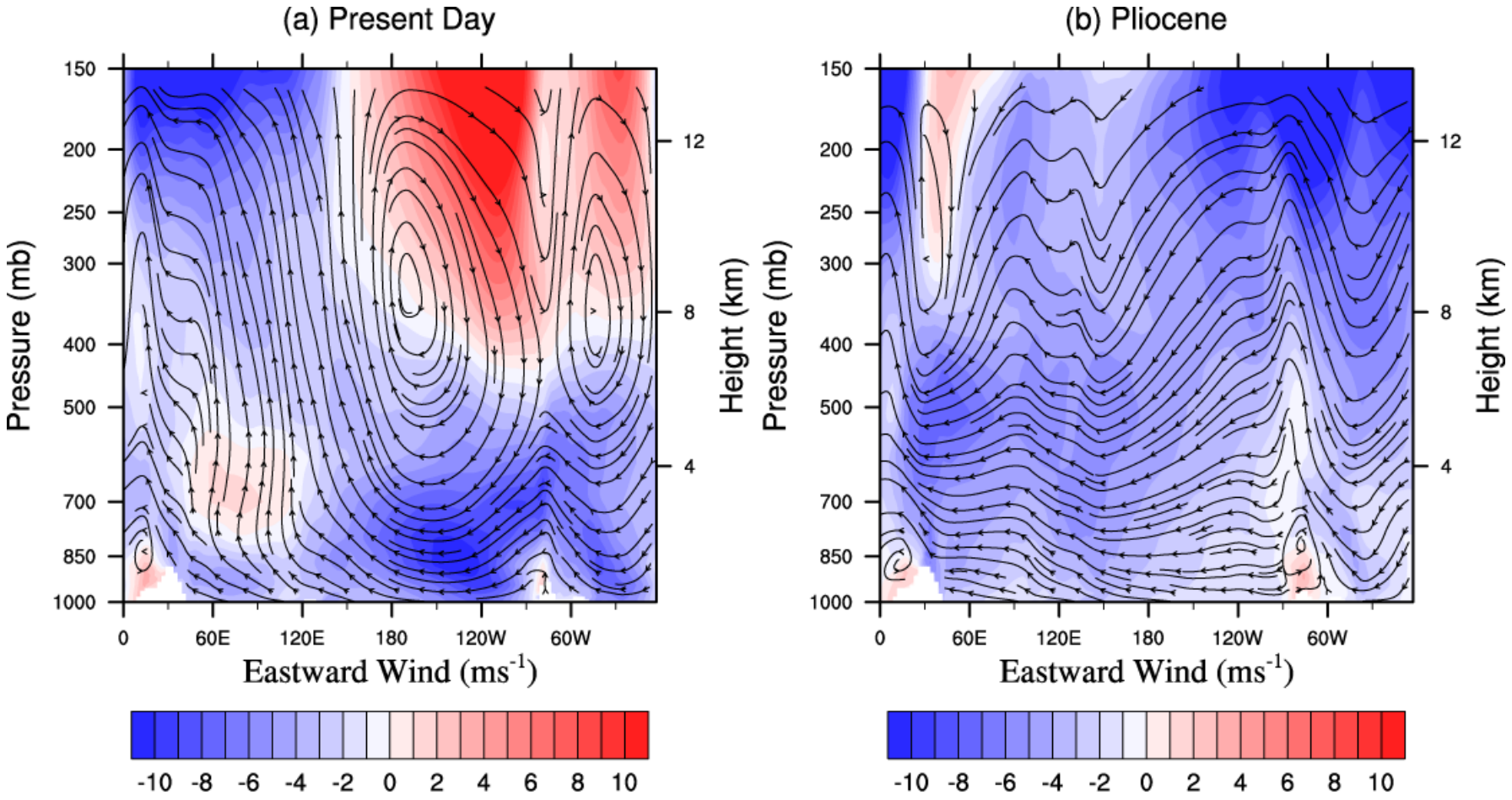
(a) Present-Day SSTs



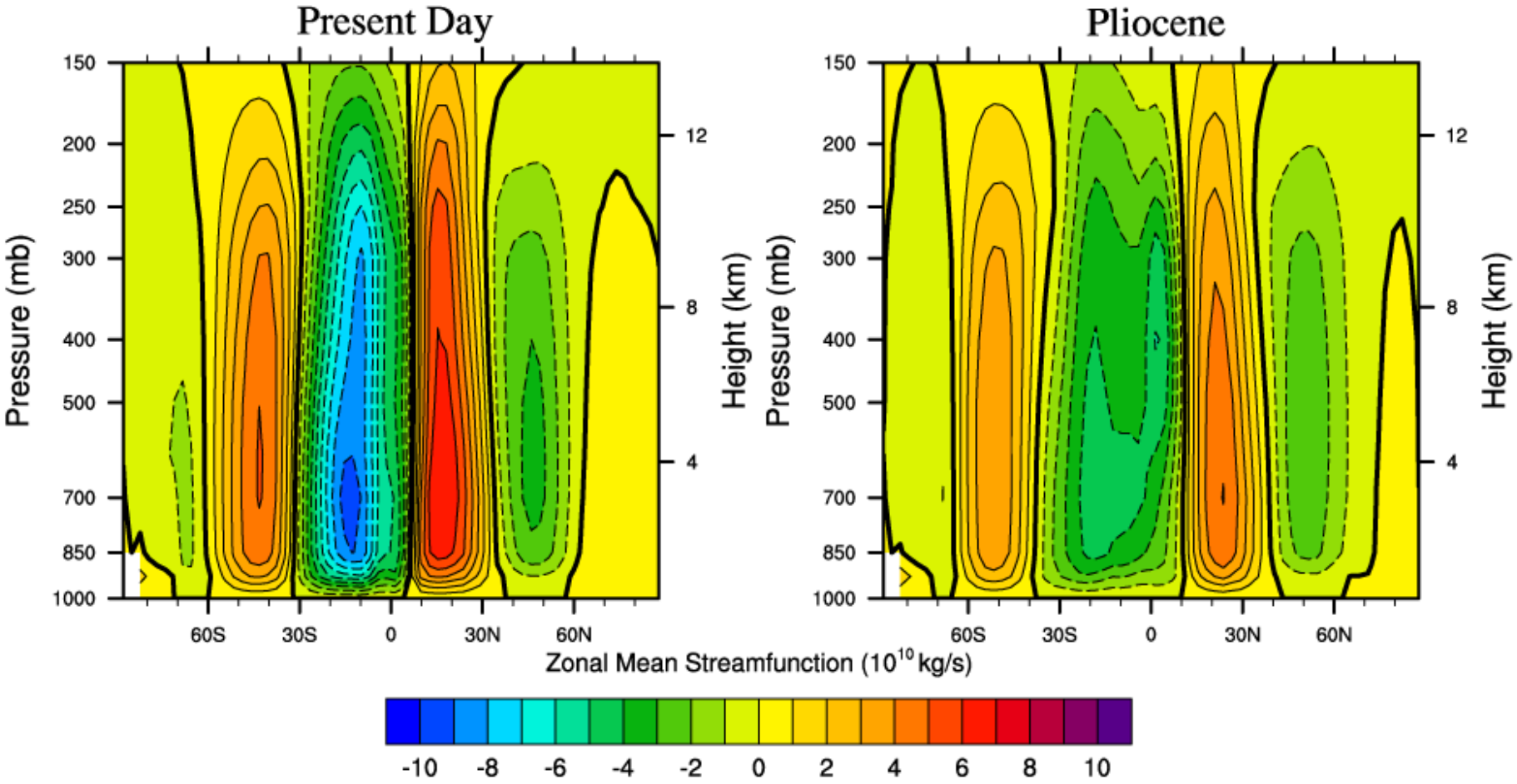
(b) Early Pliocene SSTs



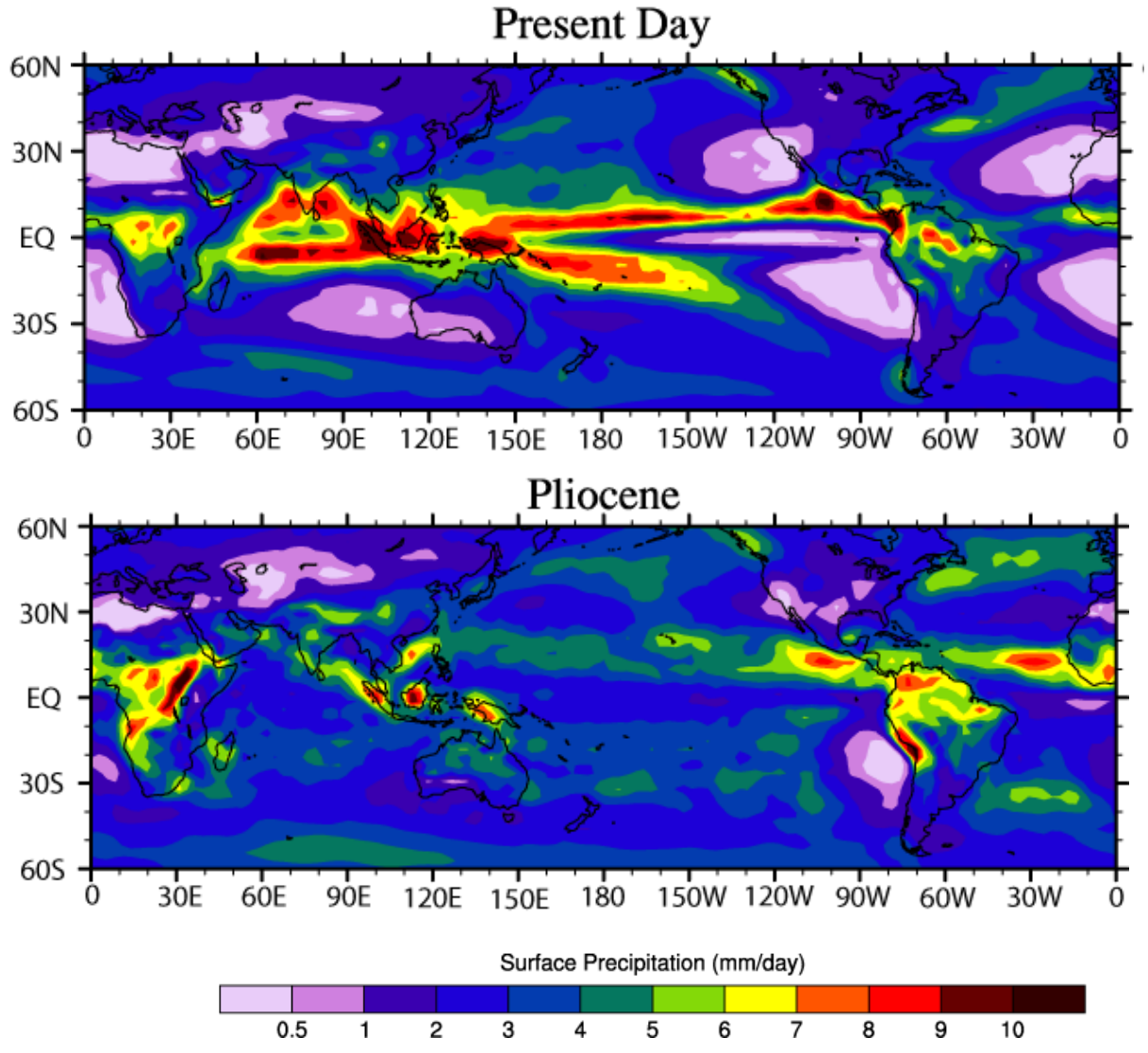
Walker Circulation Collapses



Hadley Circulation Weakens



Precipitation Changes

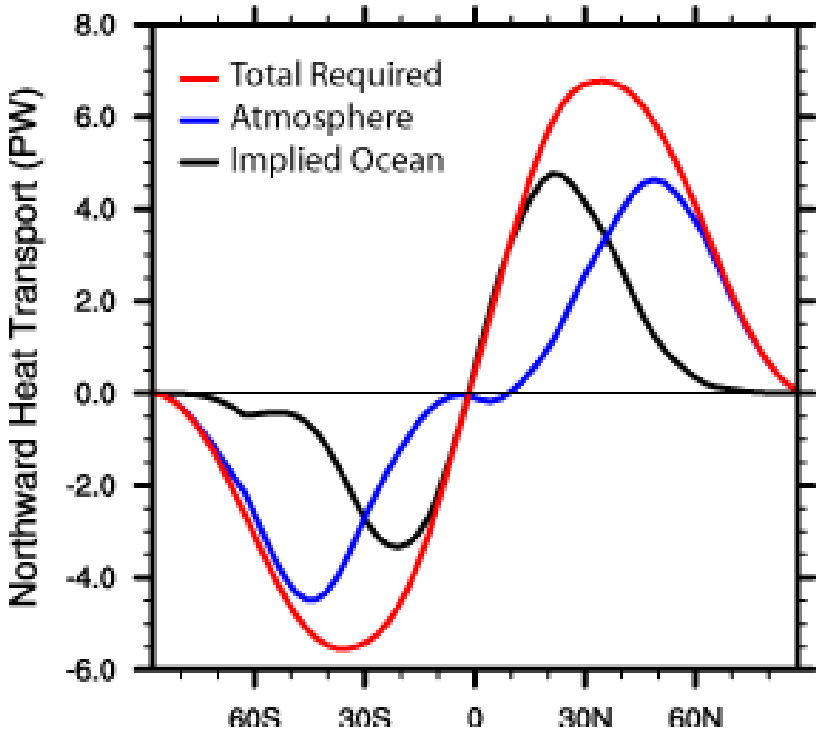


Sustainable Climate?

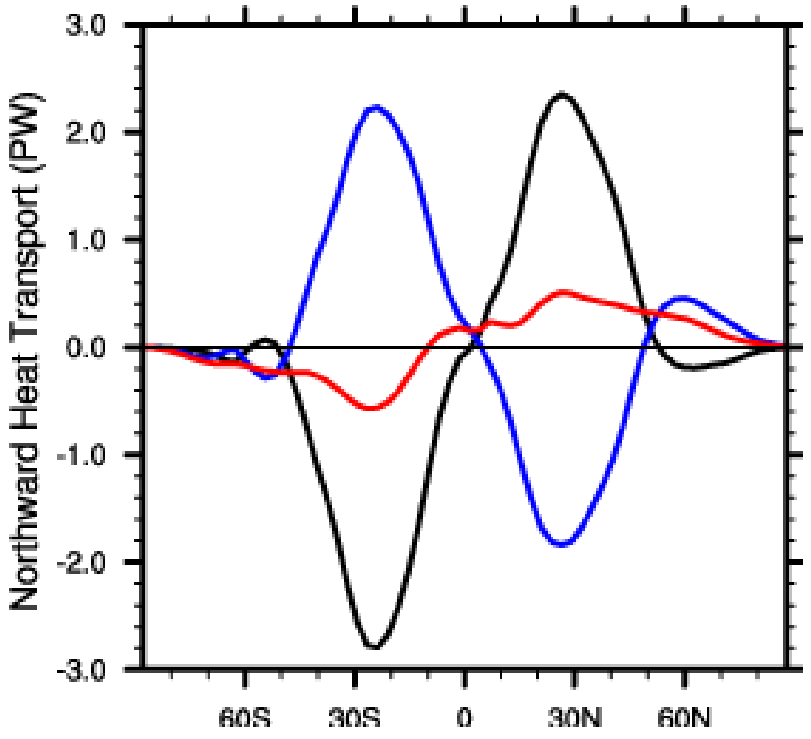
- Models do not simulate vast warmpool
- State appears to have existed for ~1Ma

Pliocene Paradox - Atmosphere

Pliocene Heat Transports



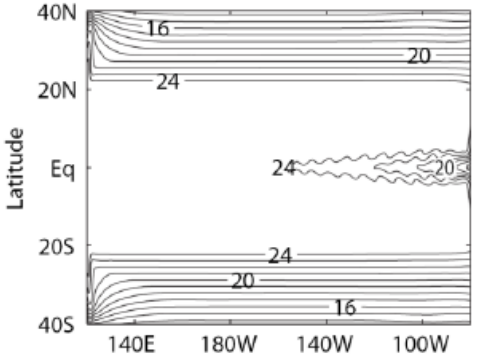
Change from Present-day



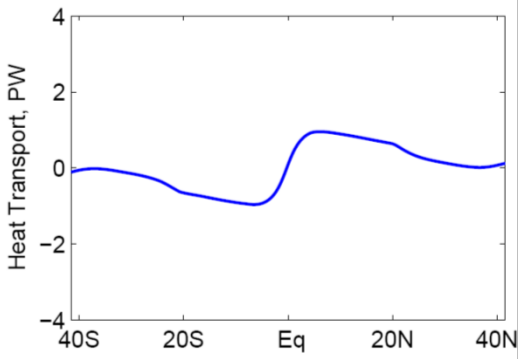
Pliocene Paradox - Ocean

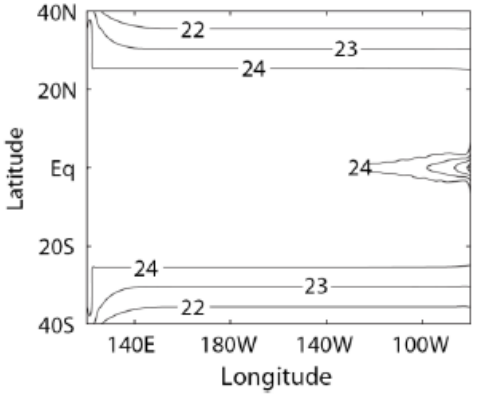
Idealised Tropical SSTs

Ocean Heat Transport

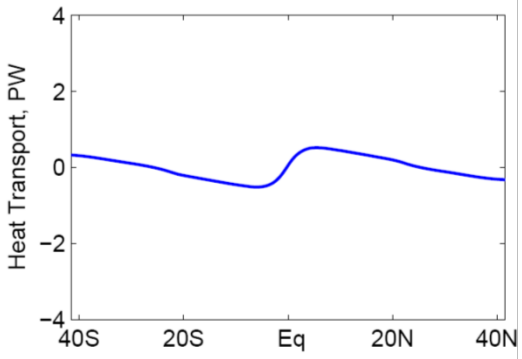


Present Day





Pliocene



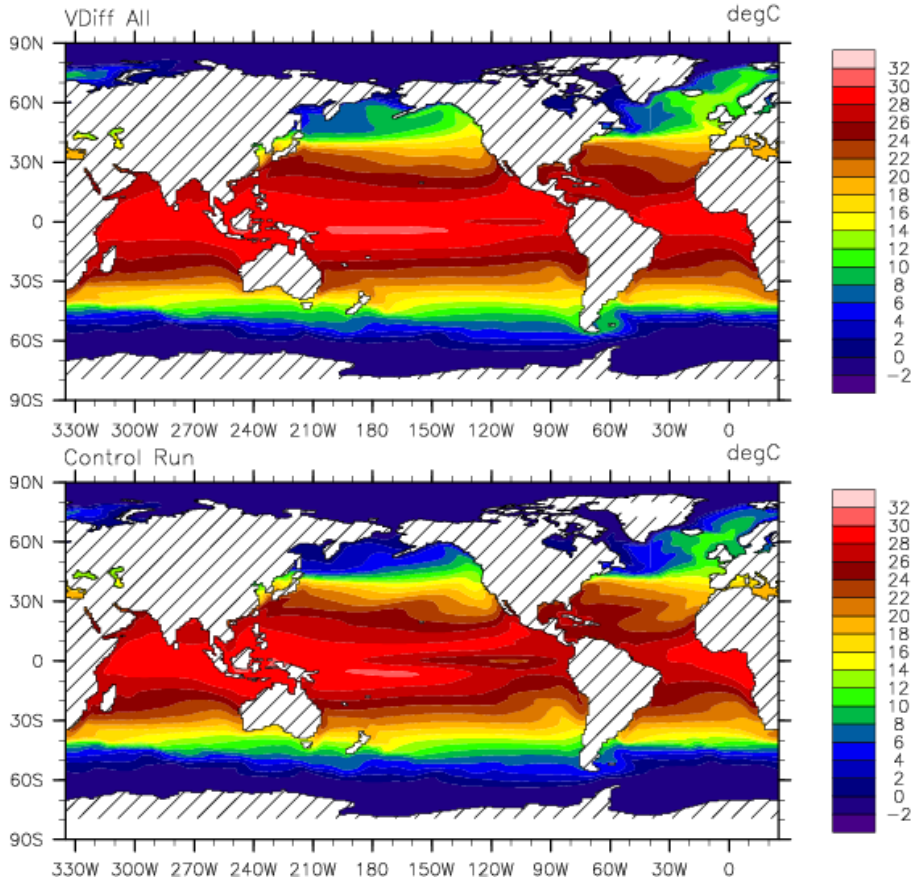
Increased Vertical Mixing

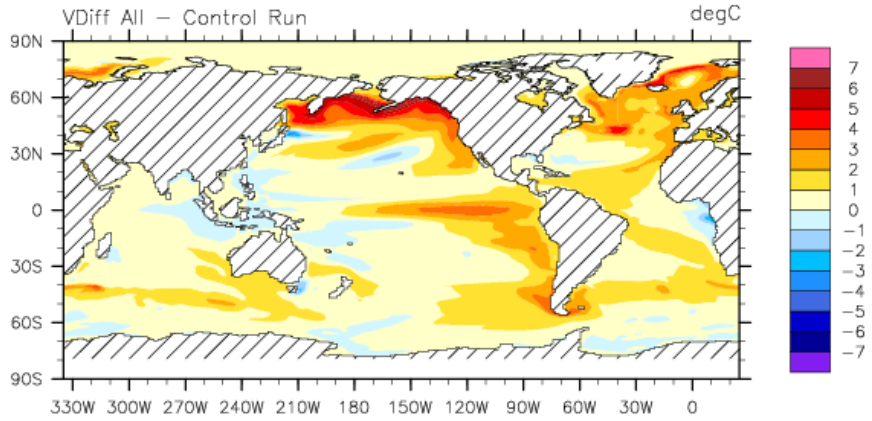
Maybe the Pliocene had a different mixing regime from the present-day?

10x Vertical Diff. throughout Tropics

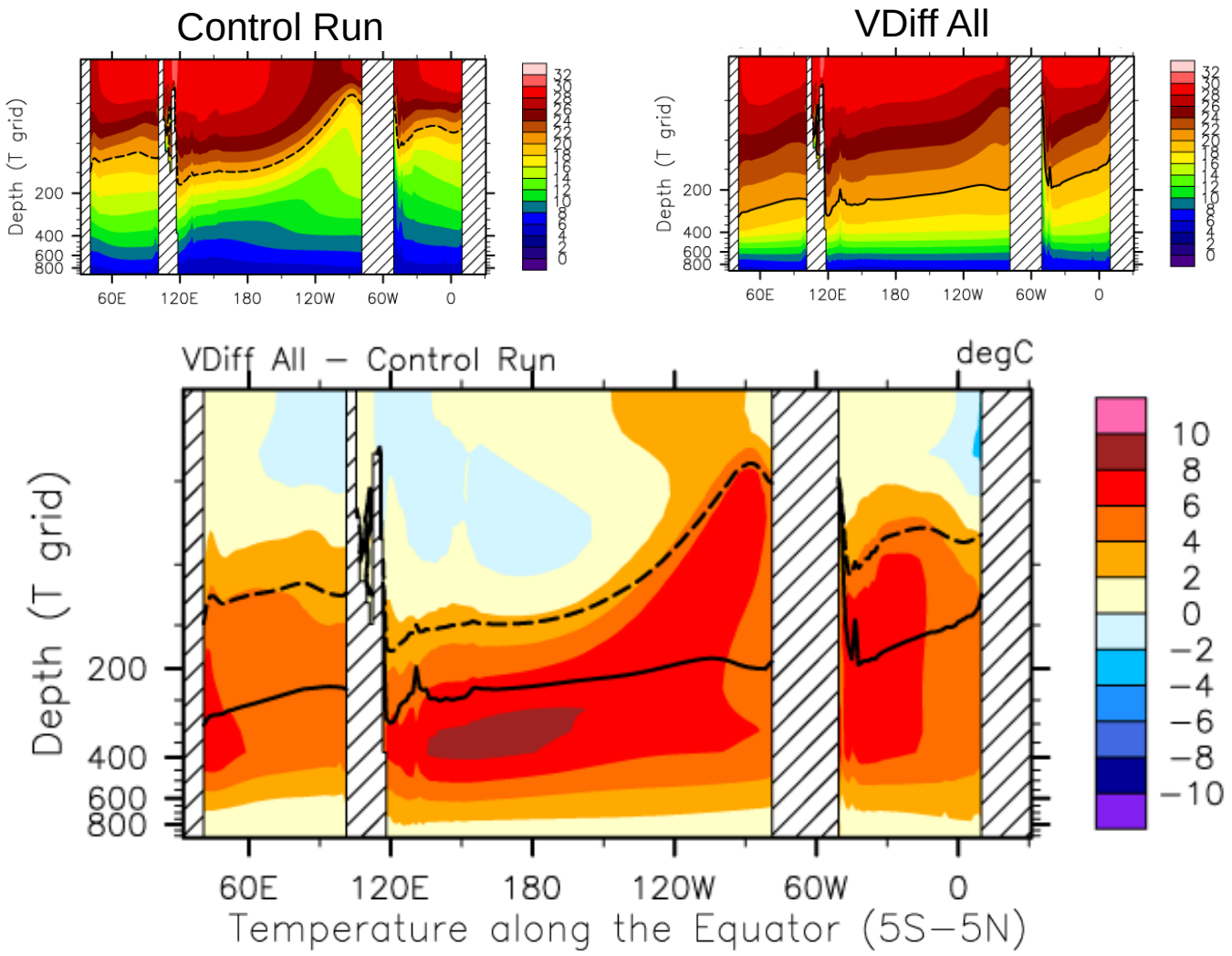
Sea Surface Temperature (10x, ctl)

Difference



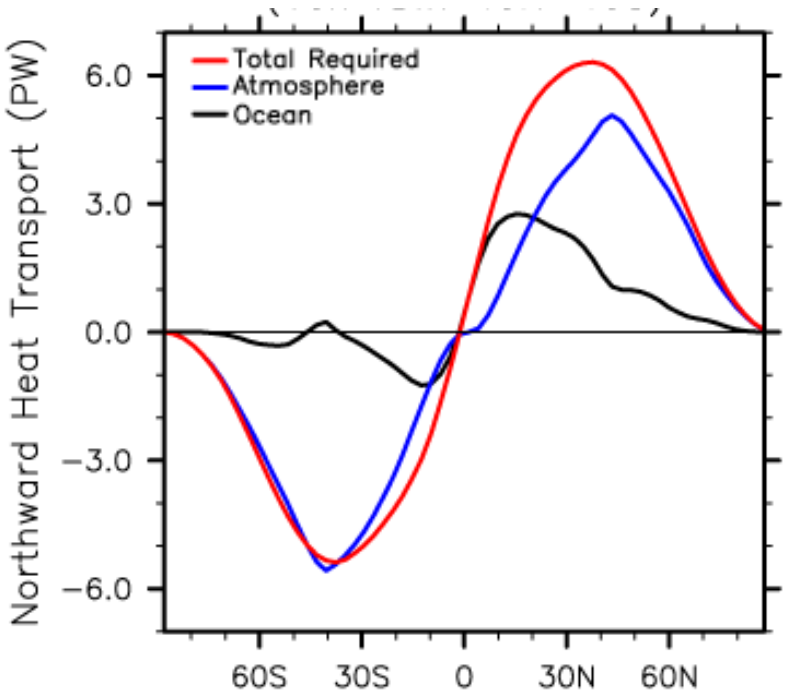


Deeper Equatorial Thermocline

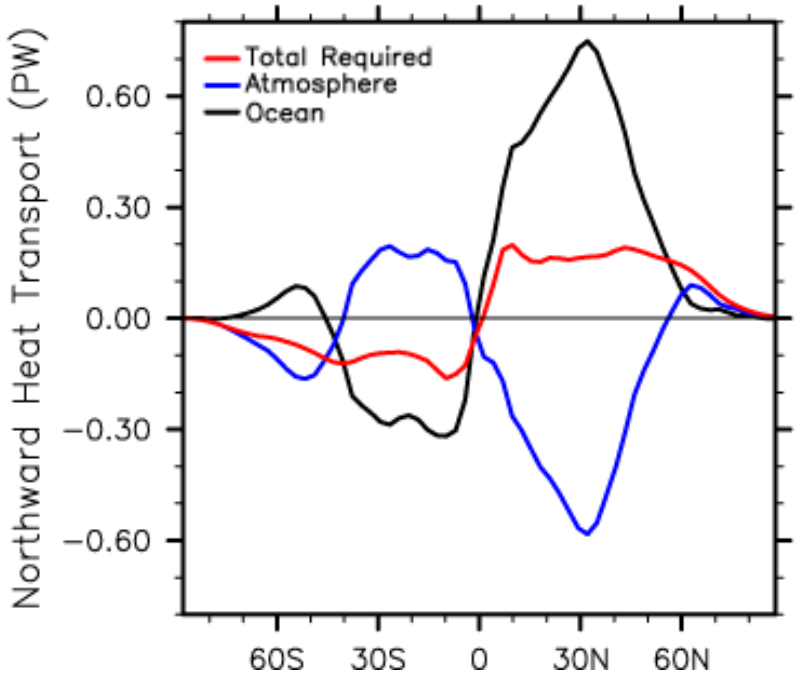


Additional Ocean Heat Transport

Heat transport w/ extra mixing



Impact of extra mixing



Tropical Cyclones

Could Tropical Cyclone changes provide this additional mixing?

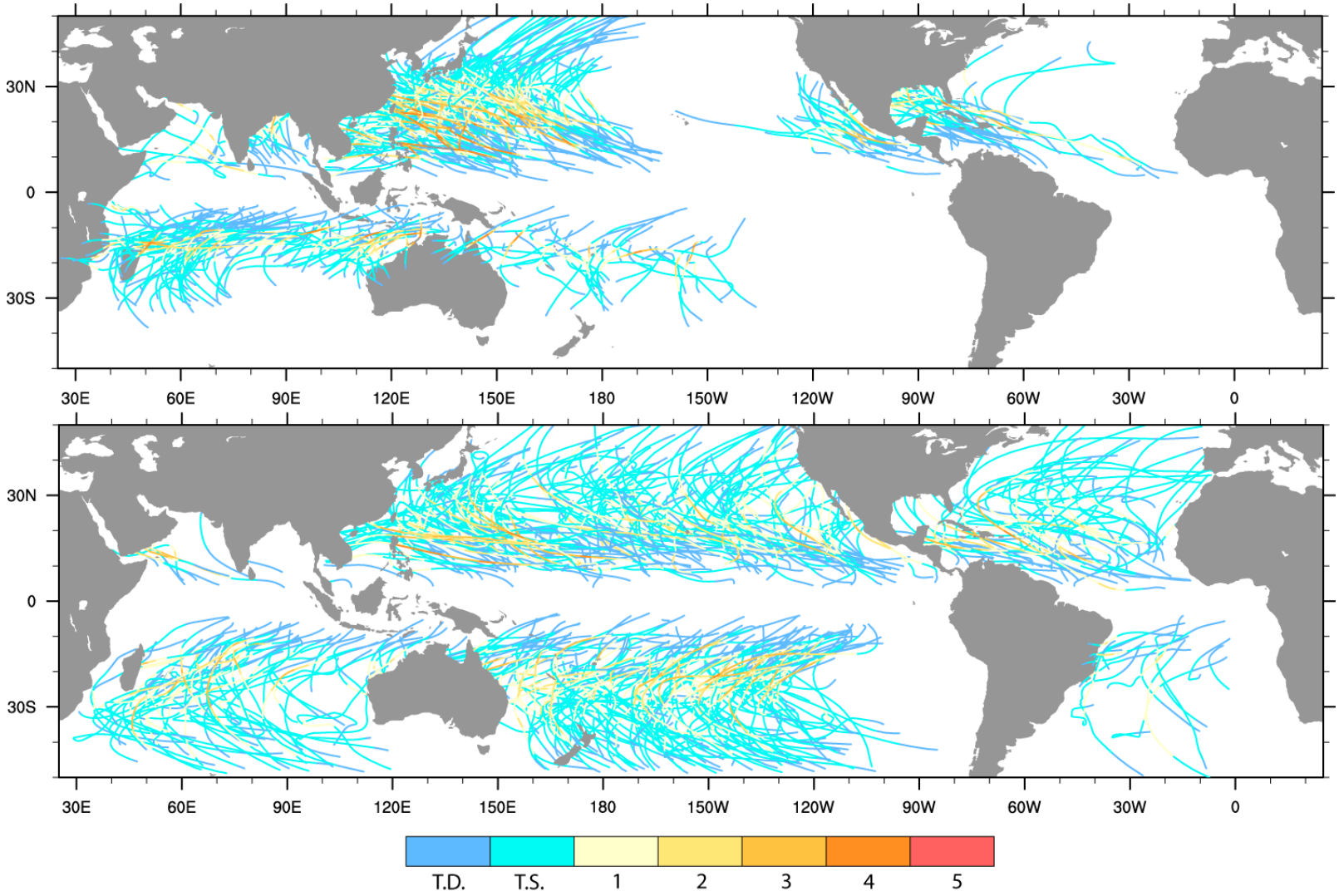
Tropical Cyclones

- Roughly 90 storms occur every year.
- Strong winds on scales smaller than GCMs
- Known to be controlled by SSTs and vertical wind shear among other things
- Future behavior still uncertain as residual between wind shear and SSTs increases
- In Pliocene was both warmer and had weaker wind shear

Statistical Downscaling Model

- Create realization of large scale atmospheric flow
- Embed weak vortex and use hurricane track prediction model to work out where it would go
- Use 2D CHIPS model to determine intensity along track
- Repeat until have at least 10,000 synthetic tropical cyclones.
  - Most tracks don't even reach tropical depression status

Synthetic Tracks



Modern

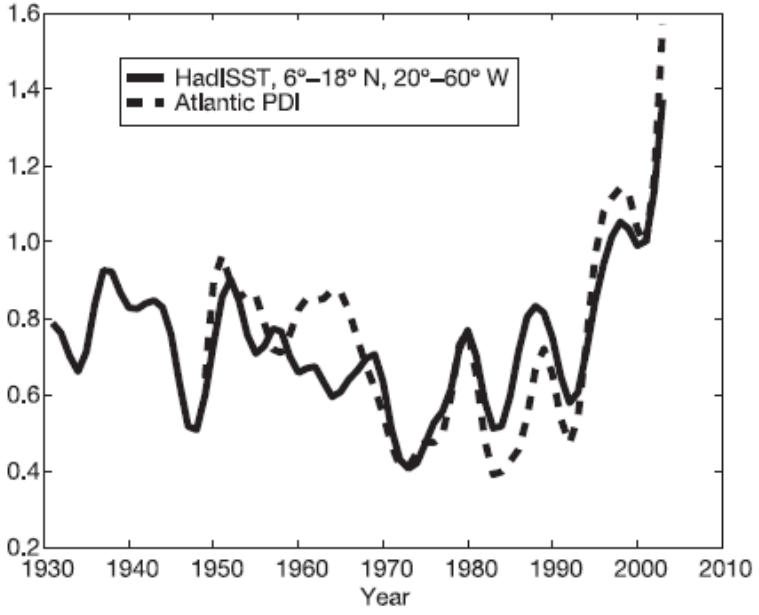
Pliocene

Power Dissipation Index

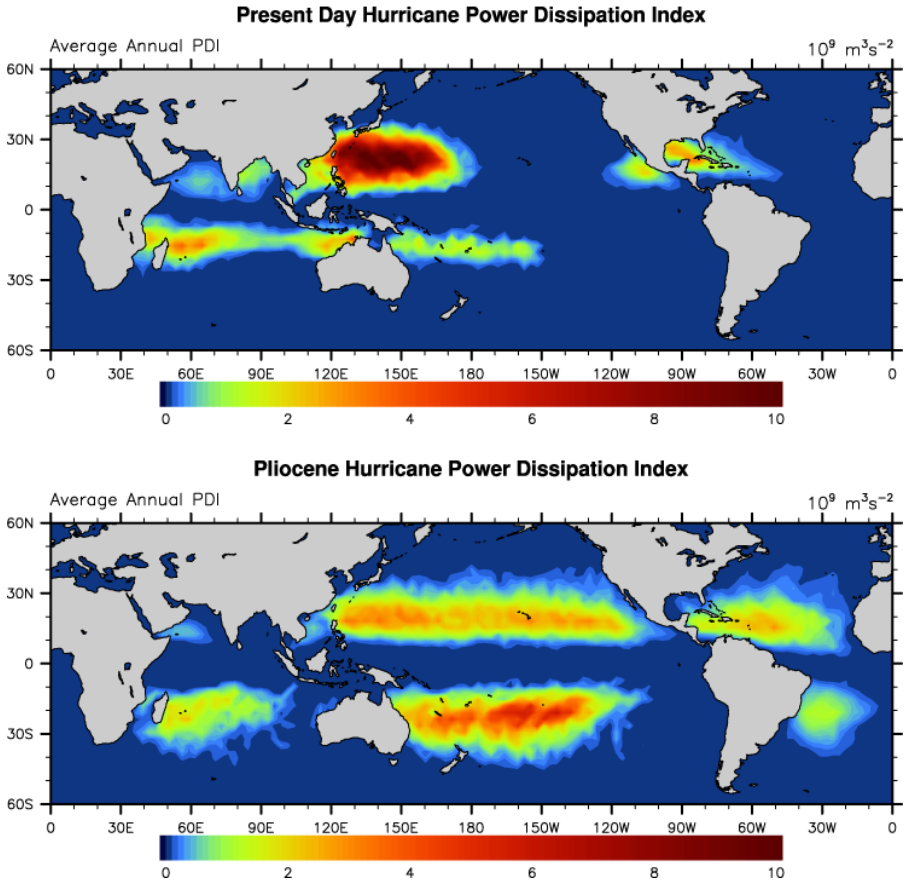
- Defined by Emanuel (2005) as

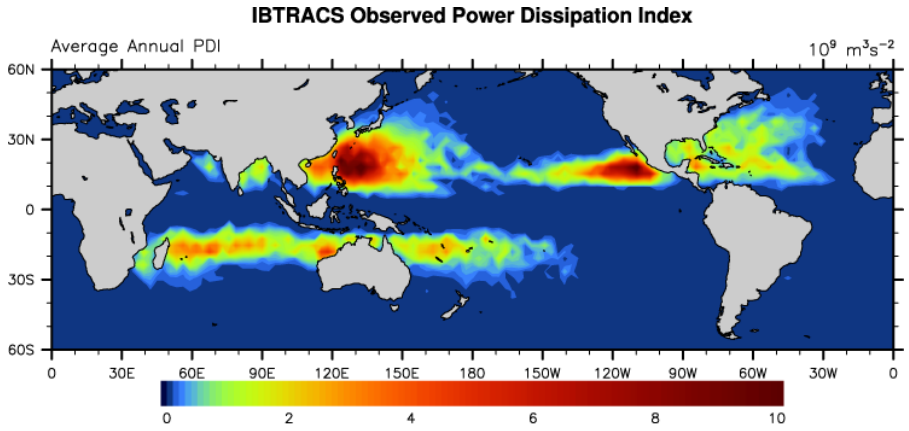
$$\mathrm{PDI} \equiv \int_0^\tau V_{\max}^3 \mathrm{d}t$$

- Increasing in recent years in the N. Atlantic
- Related to turbulent mixing in the ocean
- Useful diagnostic to look at spatial distribution of TCs



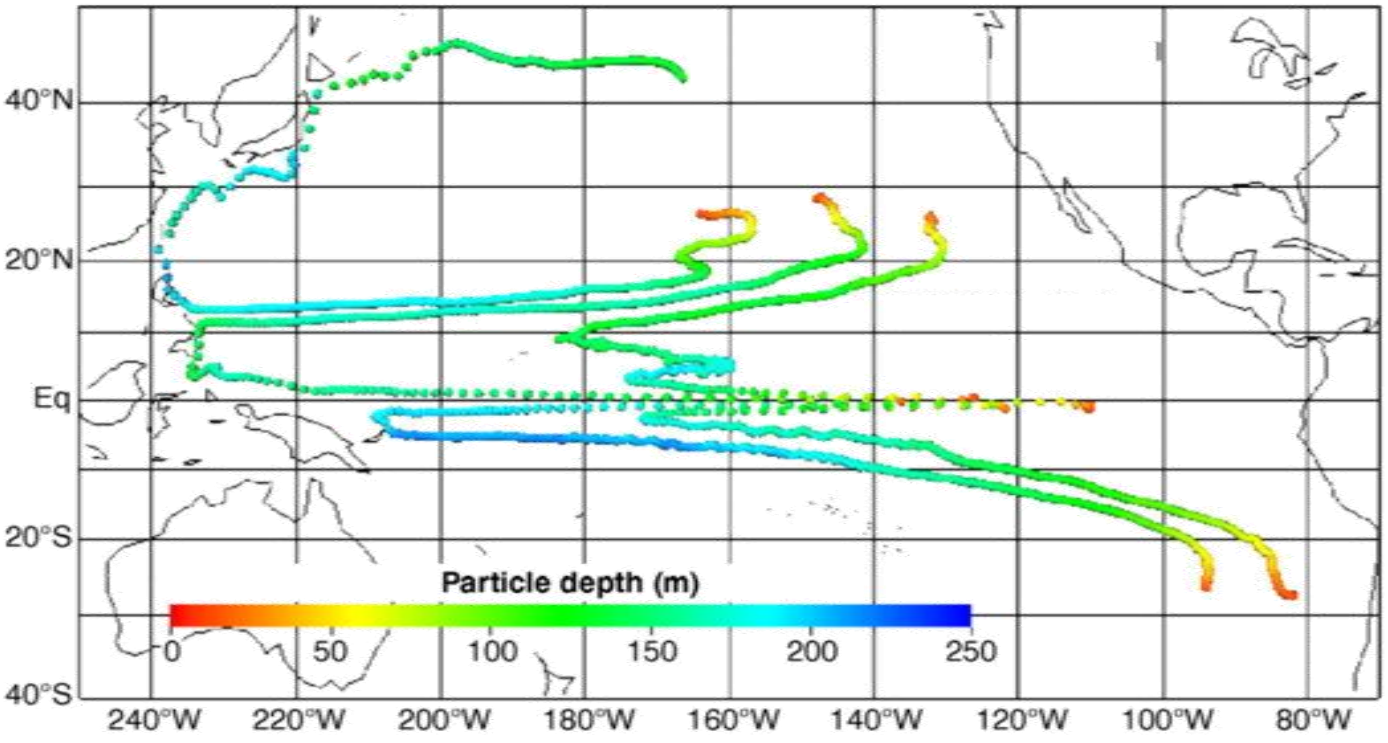
PDI Patterns



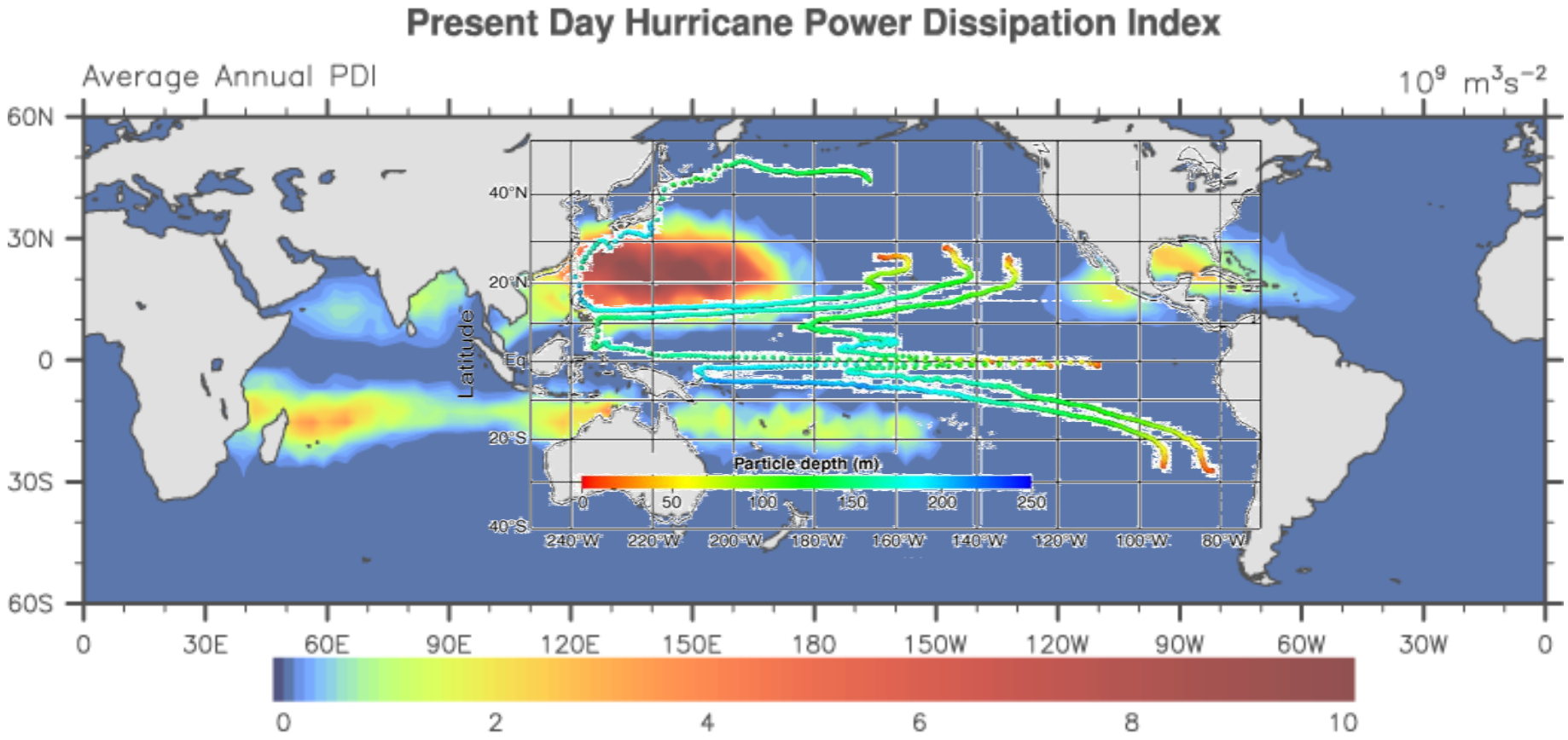


Trajectories within Subtropical Cell

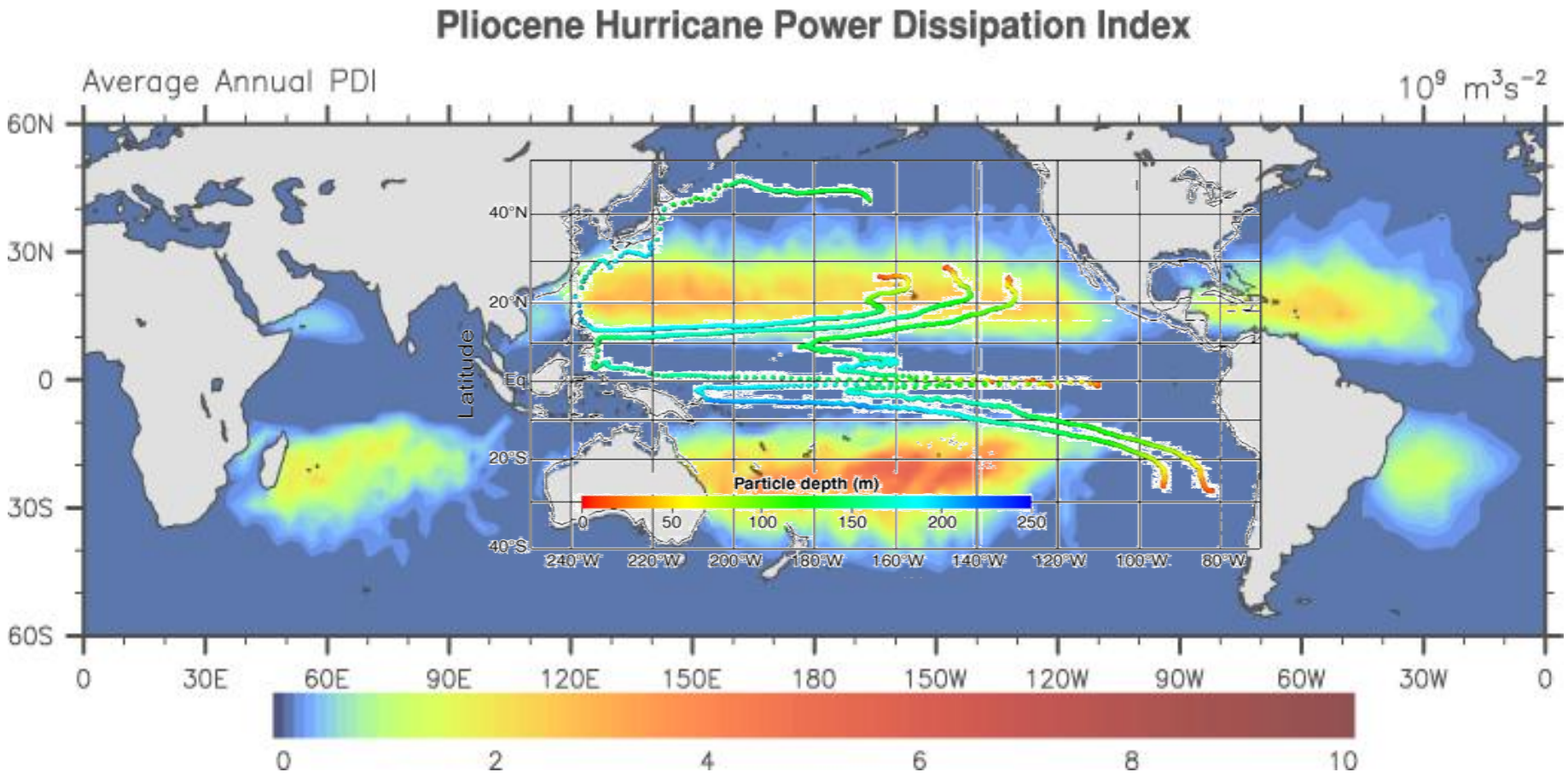
- Water is subducted in subtropical East Pacific
- Travels west towards warm pool
- Catches EUC and upwells in cold tongue
- From Gu & Philander '97



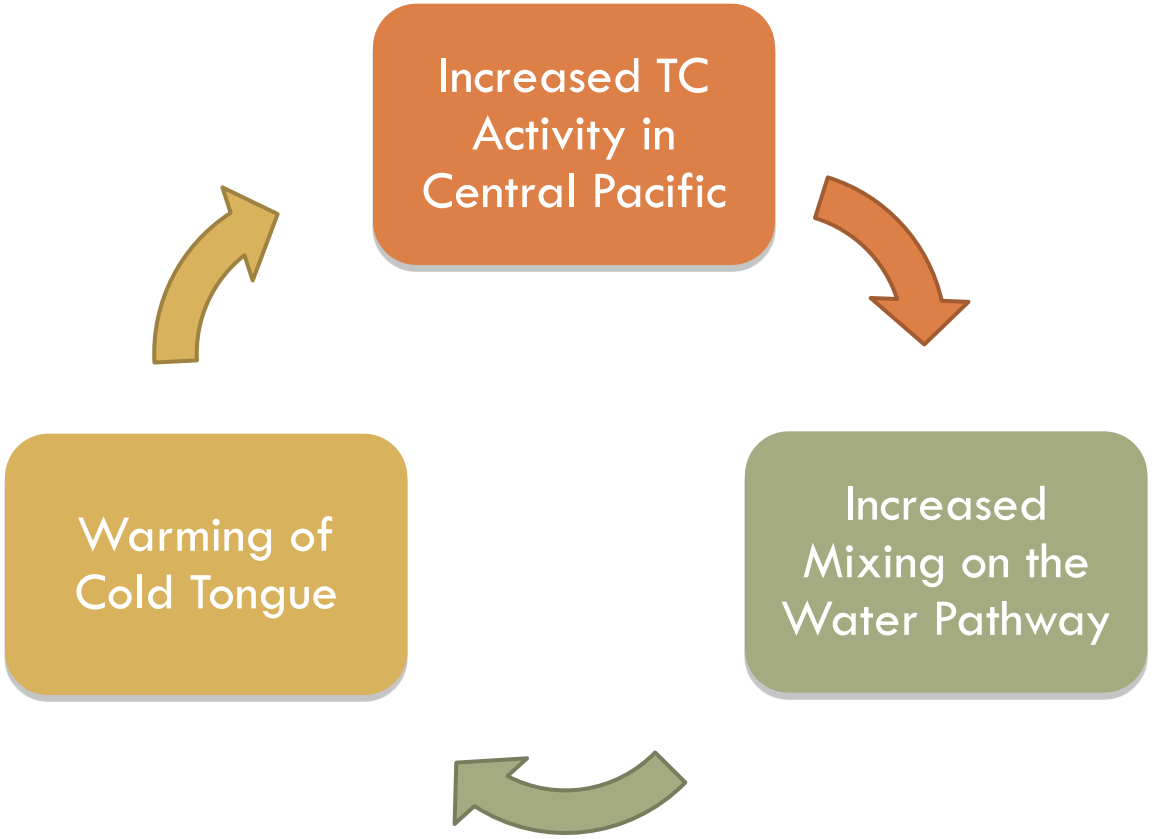
Present-Day Subduction Pathways



Pliocene Subduction Pathways



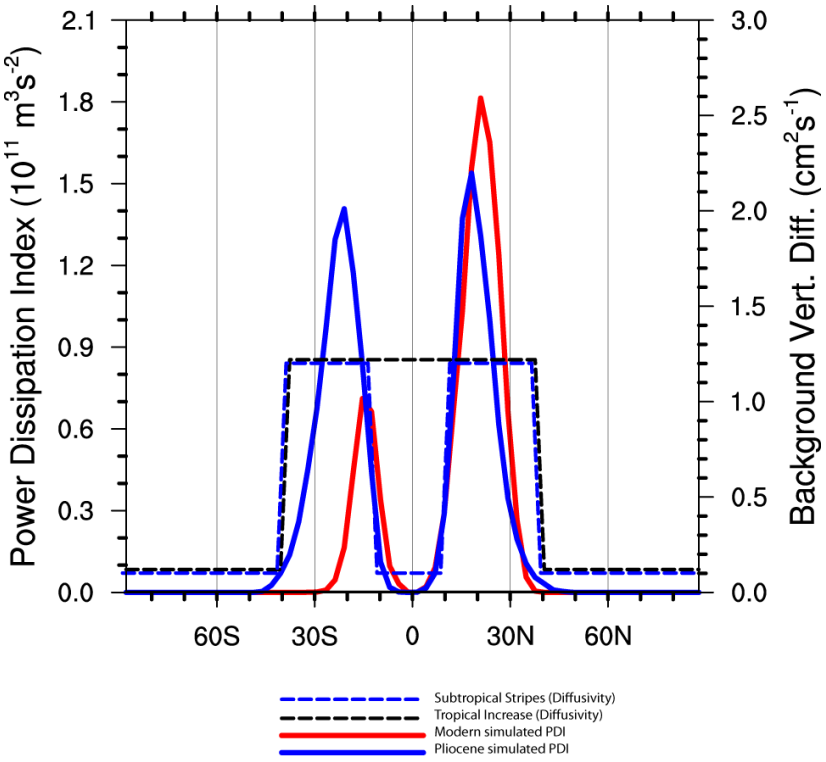
Tropical Cyclone Feedback



- This feedback should exist in theory
- Need a magnitude to determine if important in practice

Determining impact of closed windows

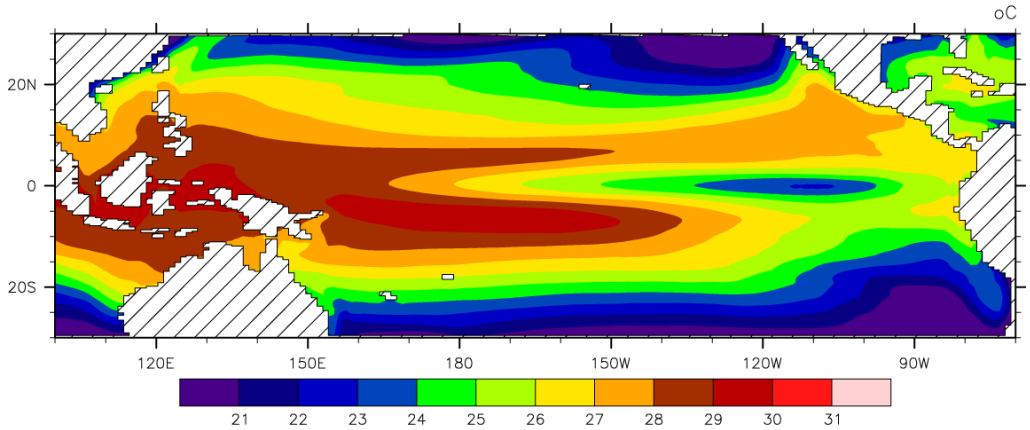
- Similar set up to previous experiment, but with mixing only enhanced between 10° to 40°
- This is unrealistically large, but guarantees that the windows in the subtropical pathways are closed.

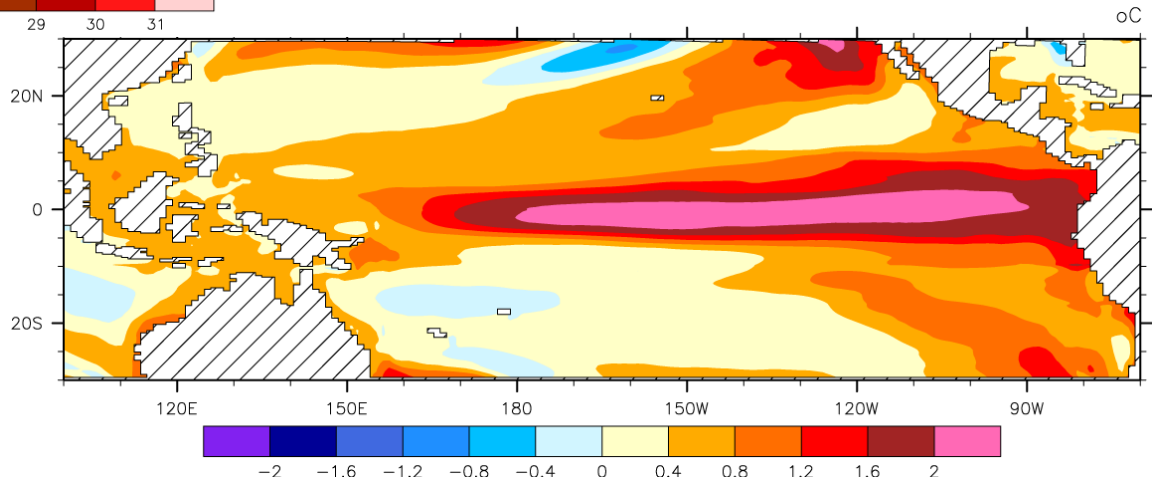


Including “tropical cyclone” mixing

Control

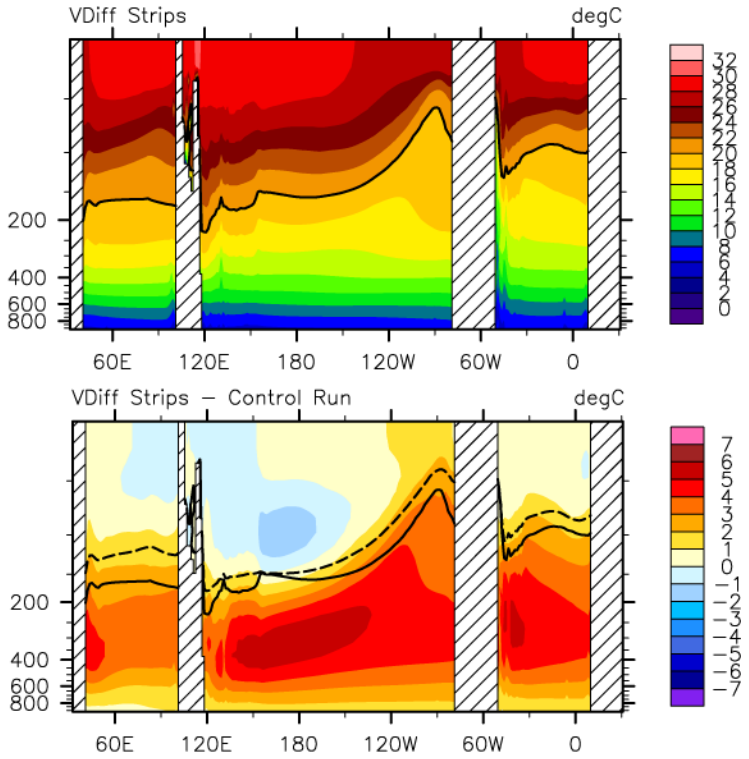
Impact of Stripes



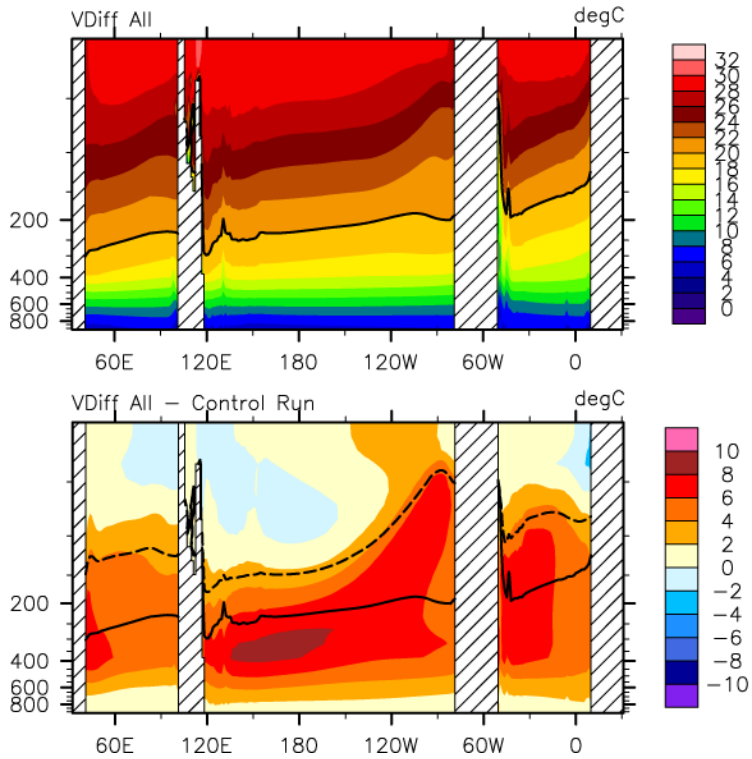


Impact on the thermocline

Tropical Cyclones Mixing

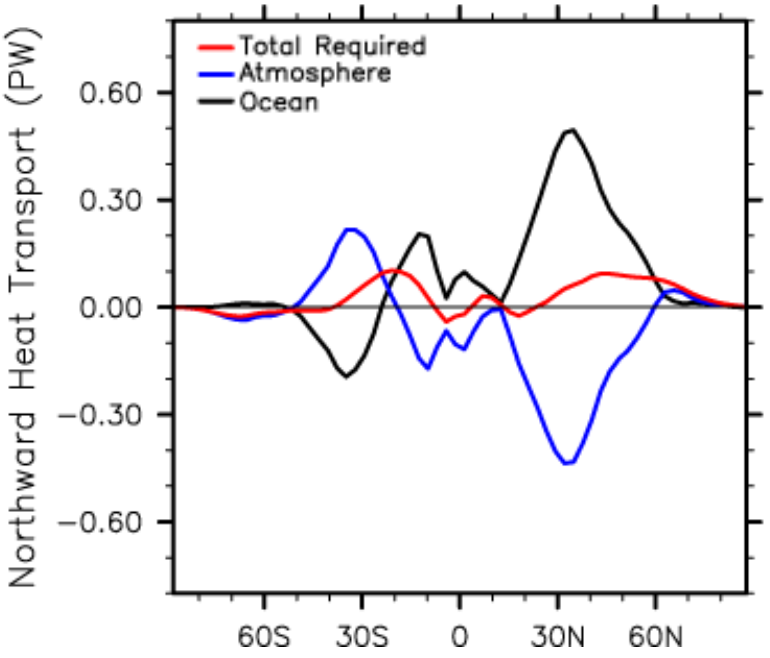


Mixing Everywhere

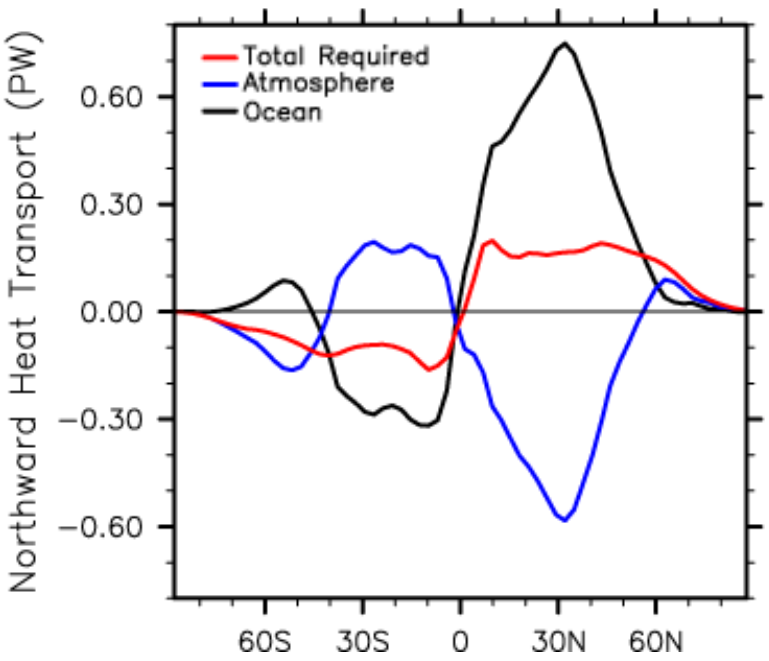


Changes in Heat Transports

"Tropical Cyclone" mixing



Extra mixing throughout Tropics (from earlier)



Conclusions

- The Tropical Pacific had a different SST distribution in the early Pliocene than at Present.
  - One vast warmpool stretching from Indonesia towards California
- This vast warmpool created a sluggish atmospheric circulation.
- Sustaining the warmpool needs an additional physical process included in climate models
- Tropical cyclone feedbacks could be that process
- This feedback could be important in future projections