Tropical Cyclones and the Climate of the Early Pliocene

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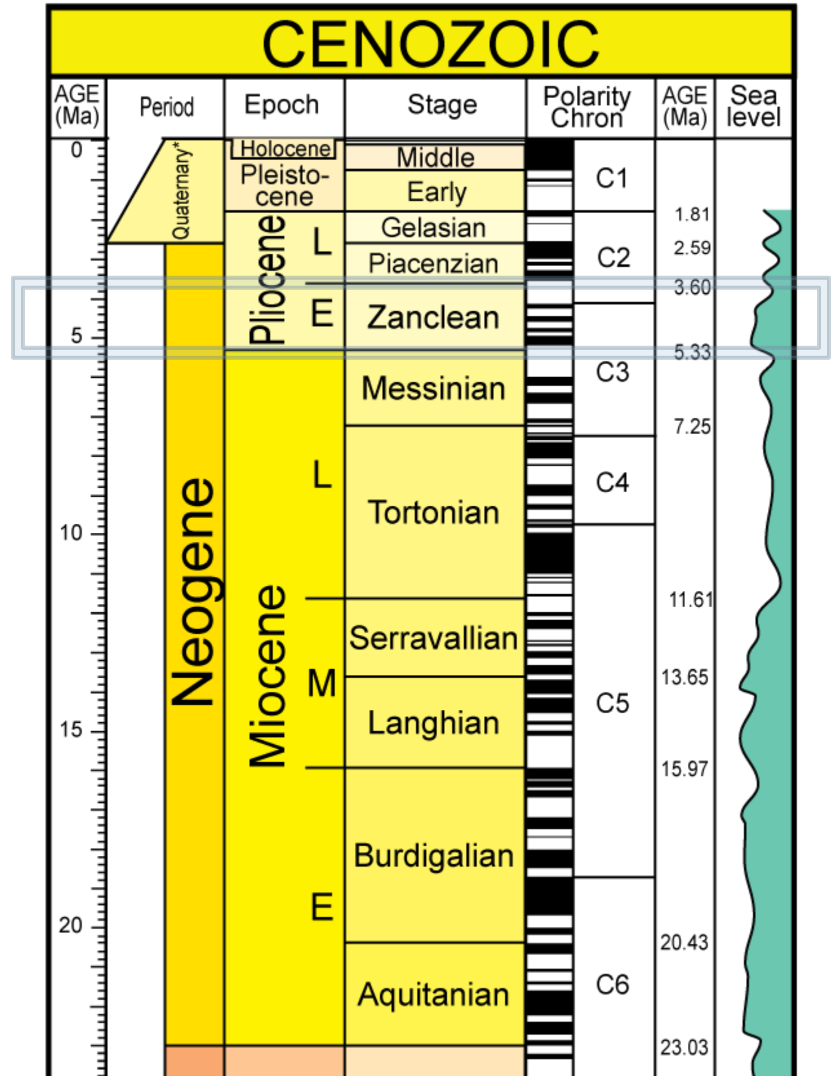
Outline

- Introduction to the early Pliocene climate
  - When & why should we care?
  - Tropical SST differences & comparisons to the future
- Tropical Cyclones
  - Future predictions uncertain
  - Modeling Pliocene tropical cyclones
- A tropical cyclone feedback?
  - The subtropical ocean circulation
  - Warming of the cold tongue
- Does this feedback explain the Pliocene warmpool?

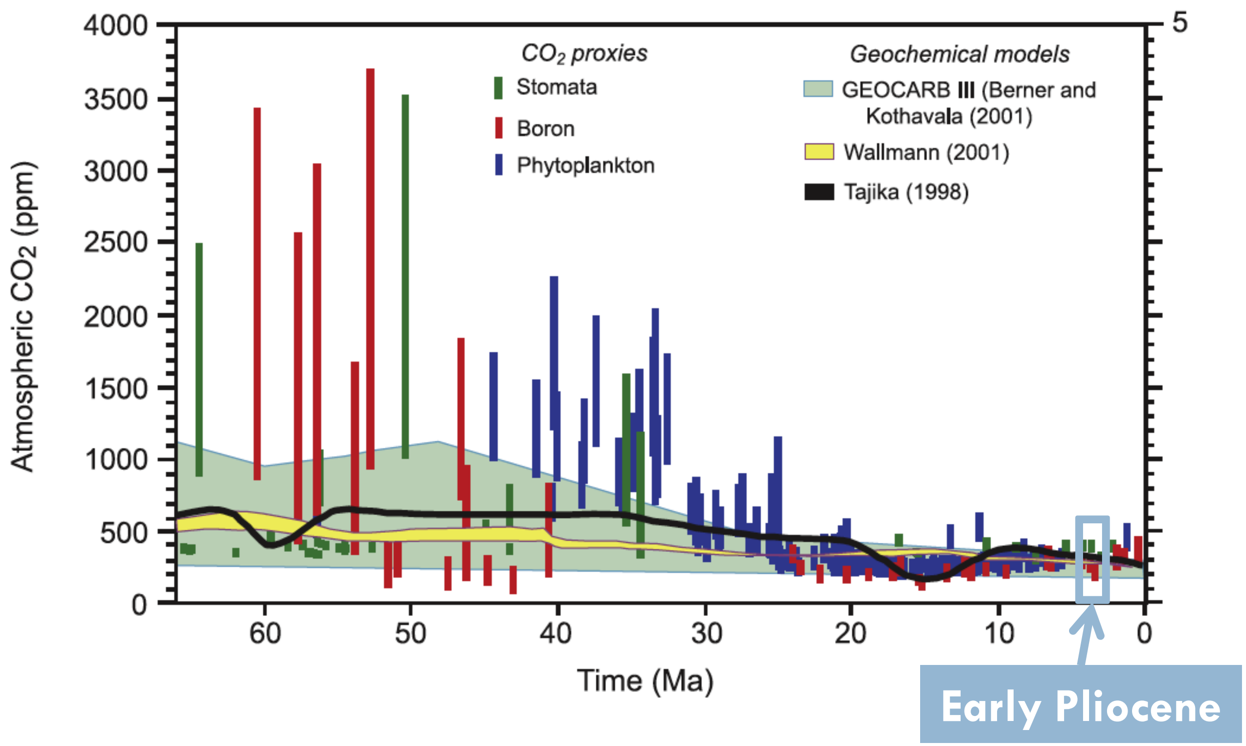
When is the early Pliocene

- 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
  - Pliocene CO_2 was 300 – 400 ppm
  - Present-Day is roughly 390 ppm

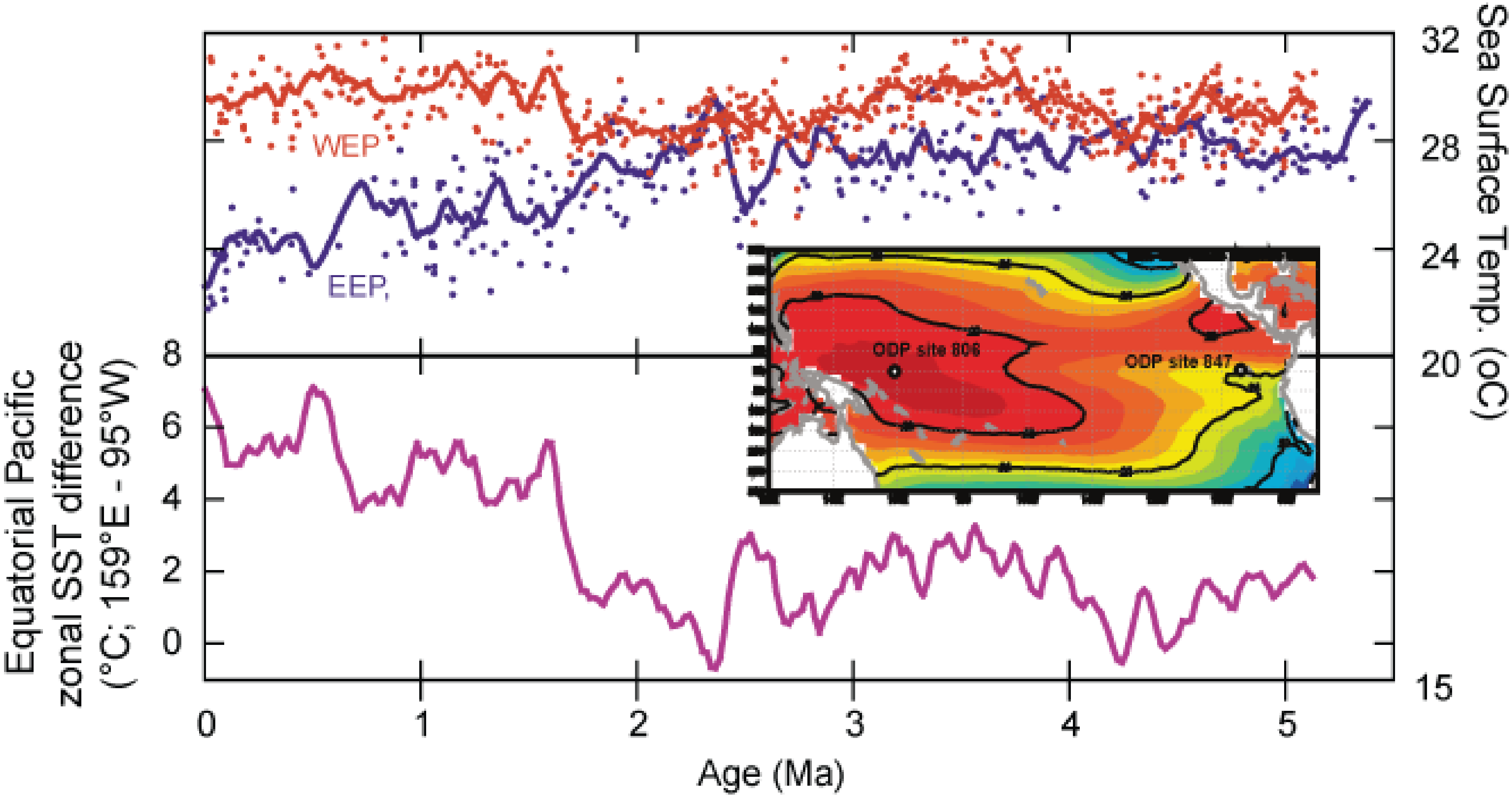


What else do we know about the early Pliocene?

- 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

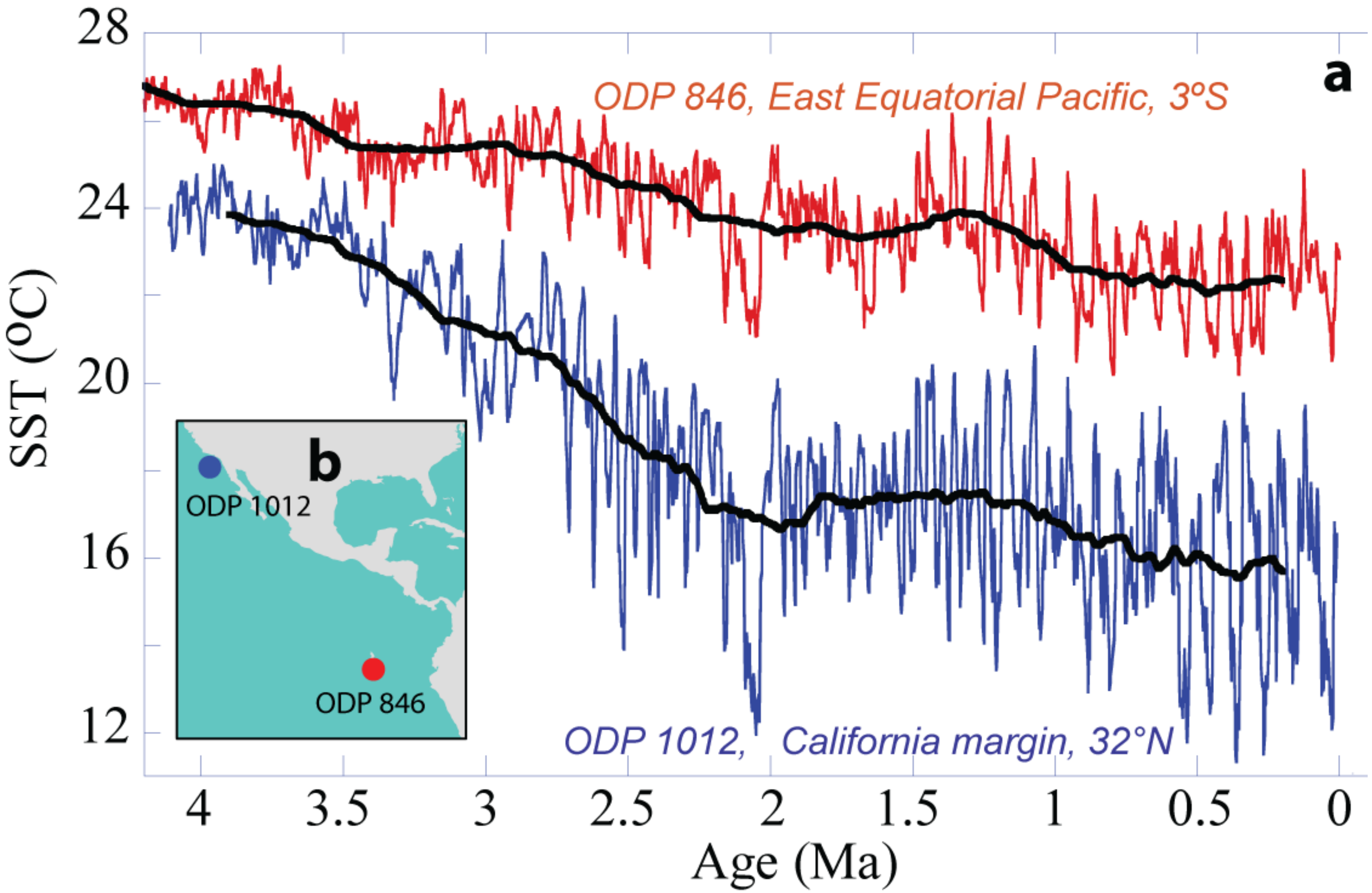
Early Pliocene SSTs

Wara's Permanent El Niño



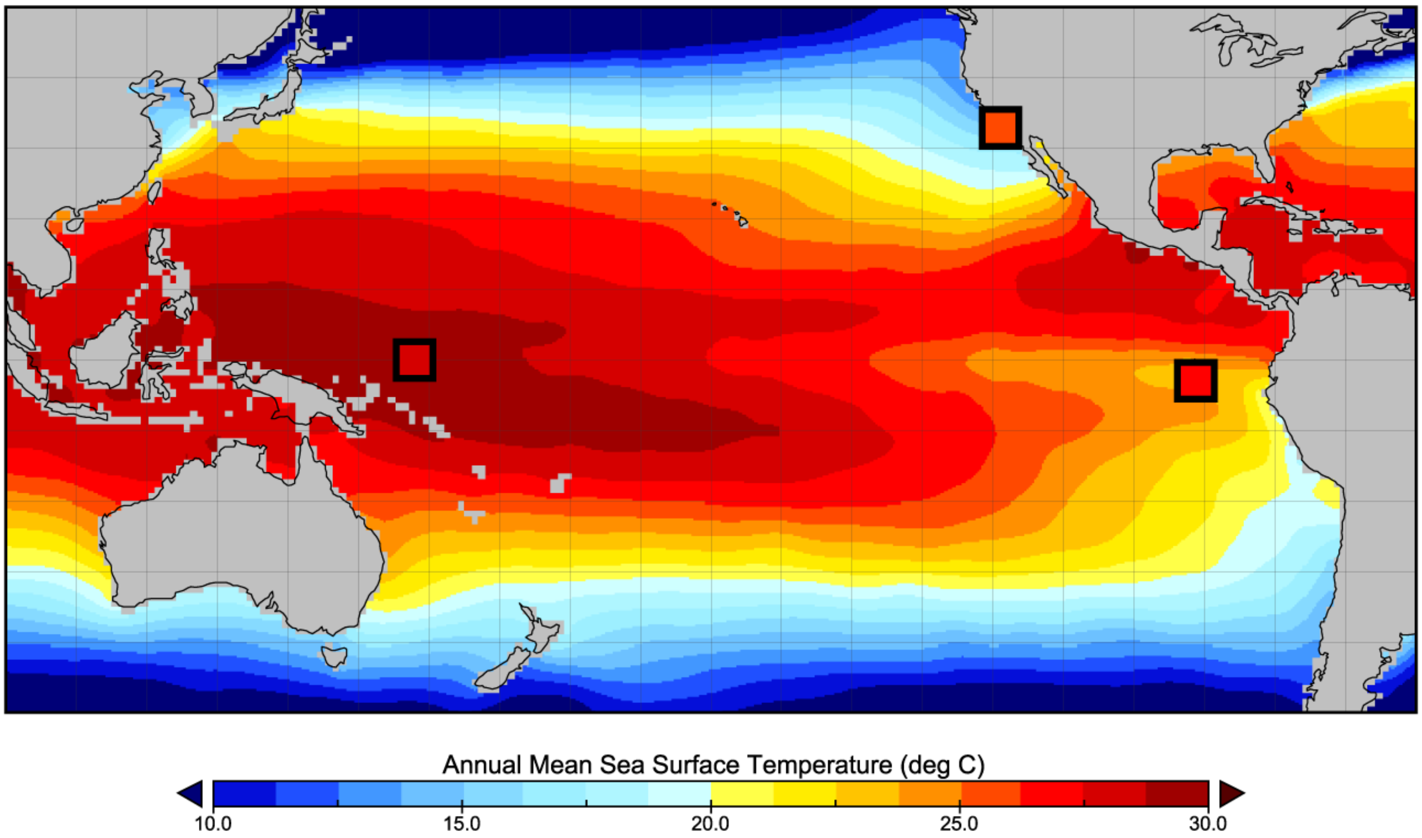
Wara et al., Science. 2005

California Margin



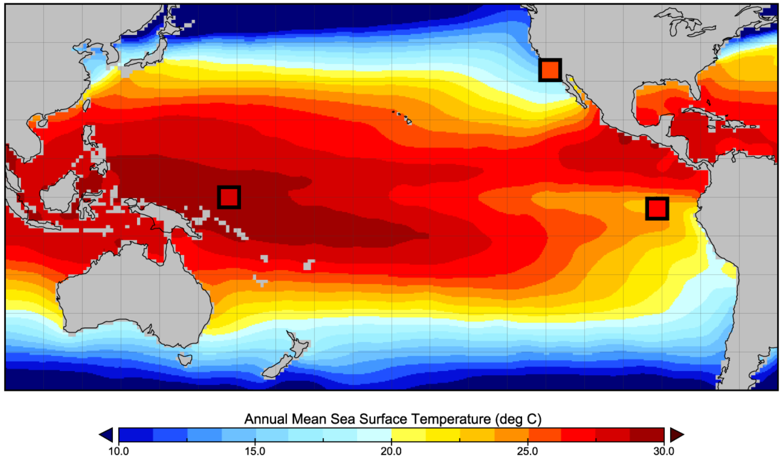
Brierley et al., Science. 2009

A vast warmpool?

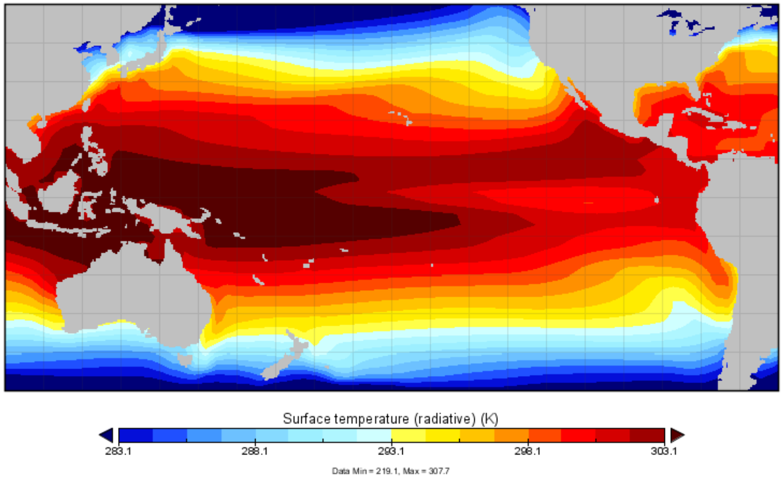


Could this just be Global Warming?

Present Day with Pliocene Obs.



Simulation with Quadrupled CO_2



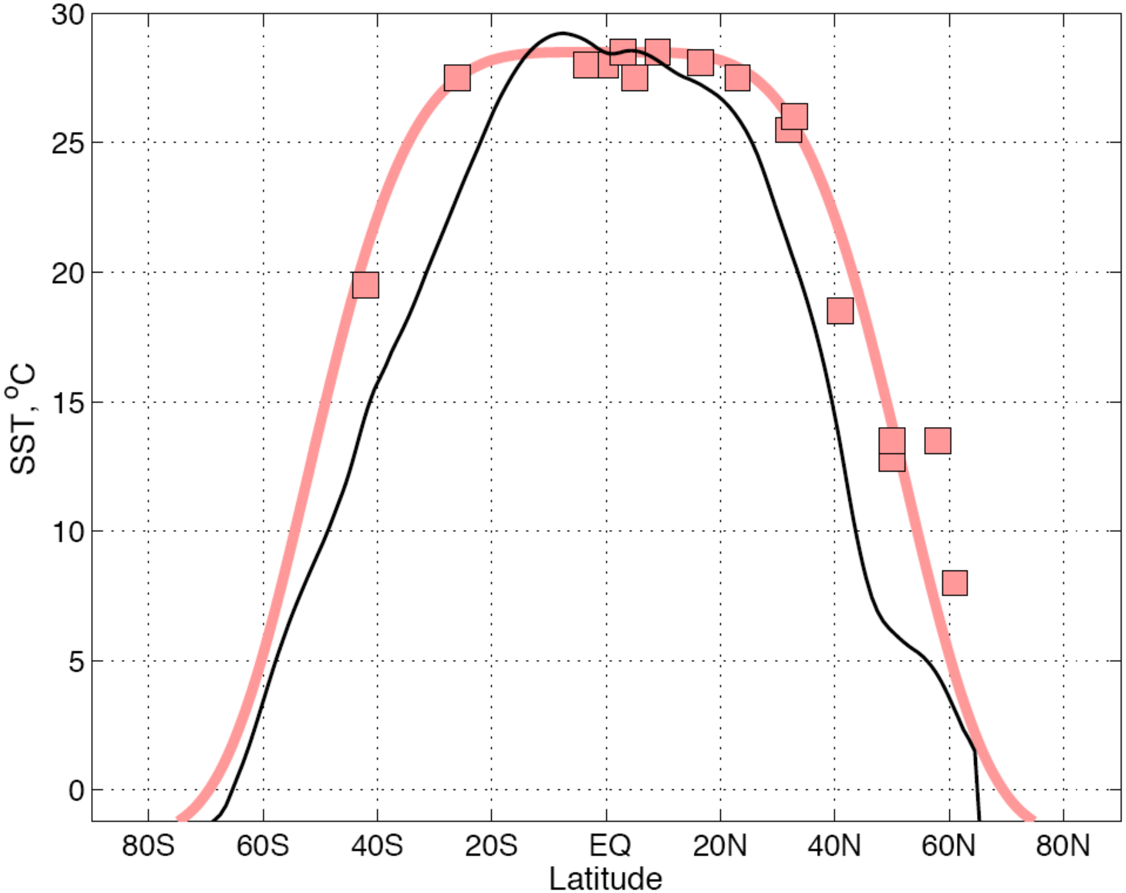
Climate impacts of Vast Warmpool

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.

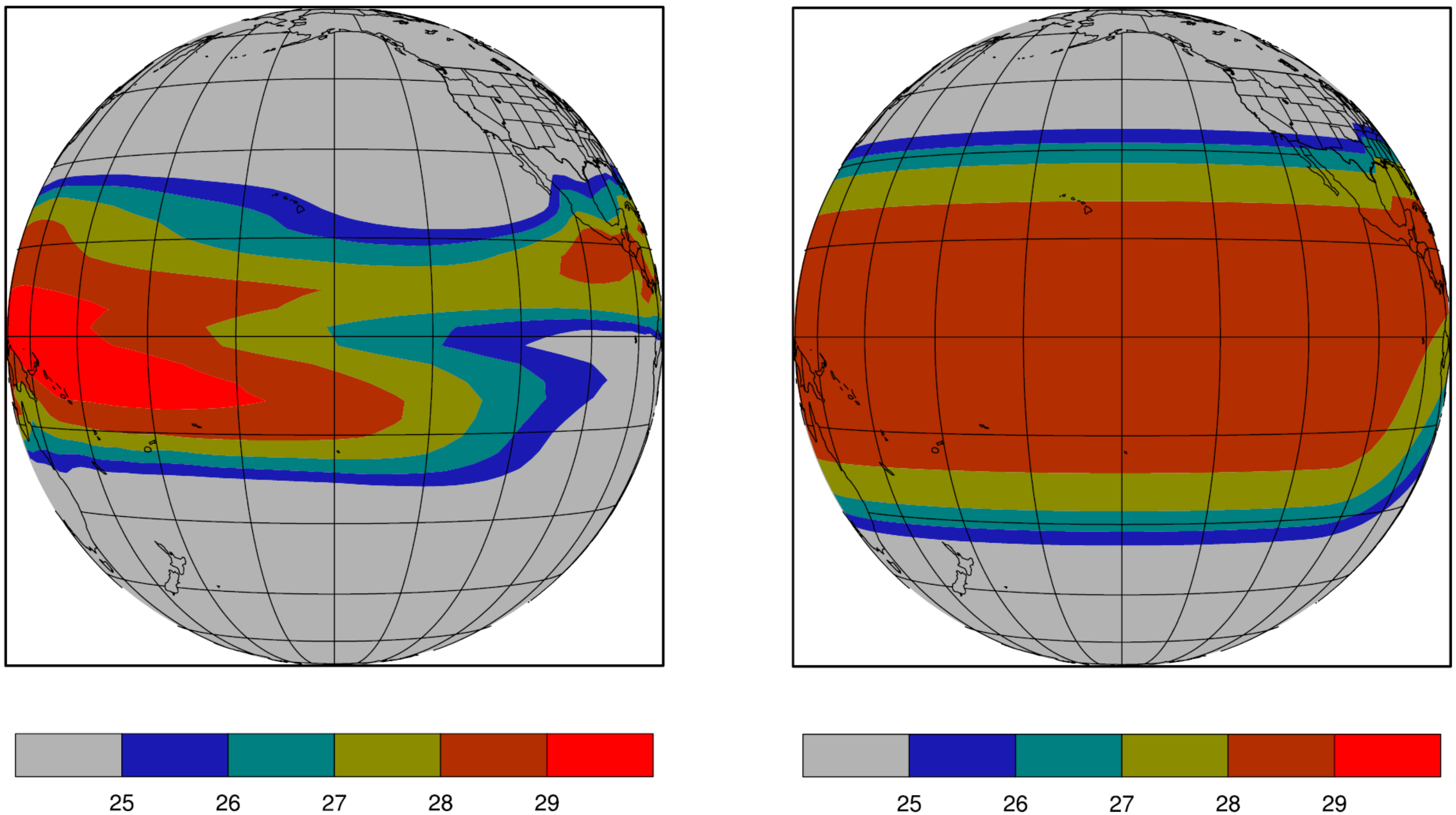
Reconstructed SST profile



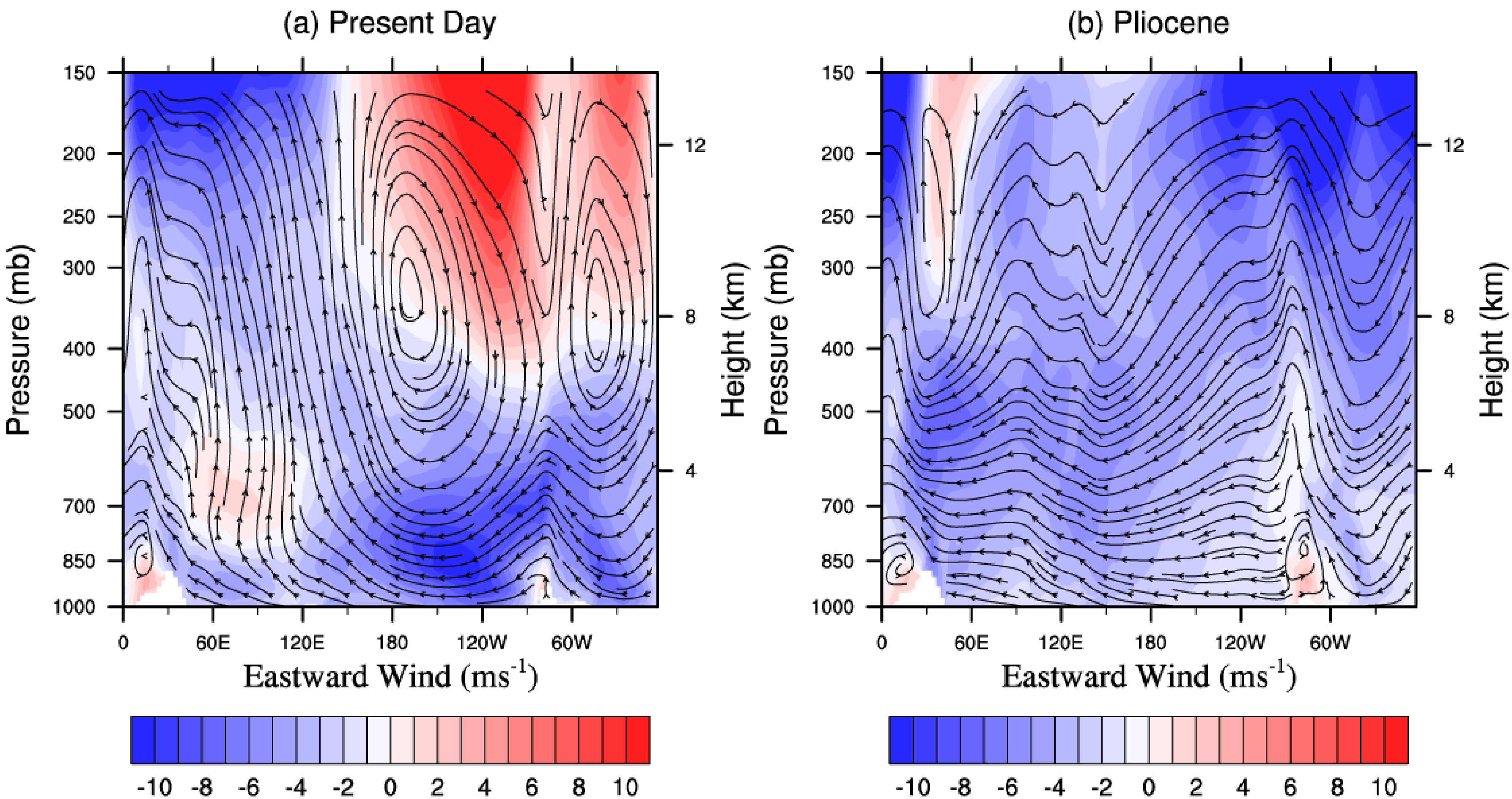
- Extend zonally across Pacific
- Shift meridionally for seasonal cycle.

Expansion of Warmpool

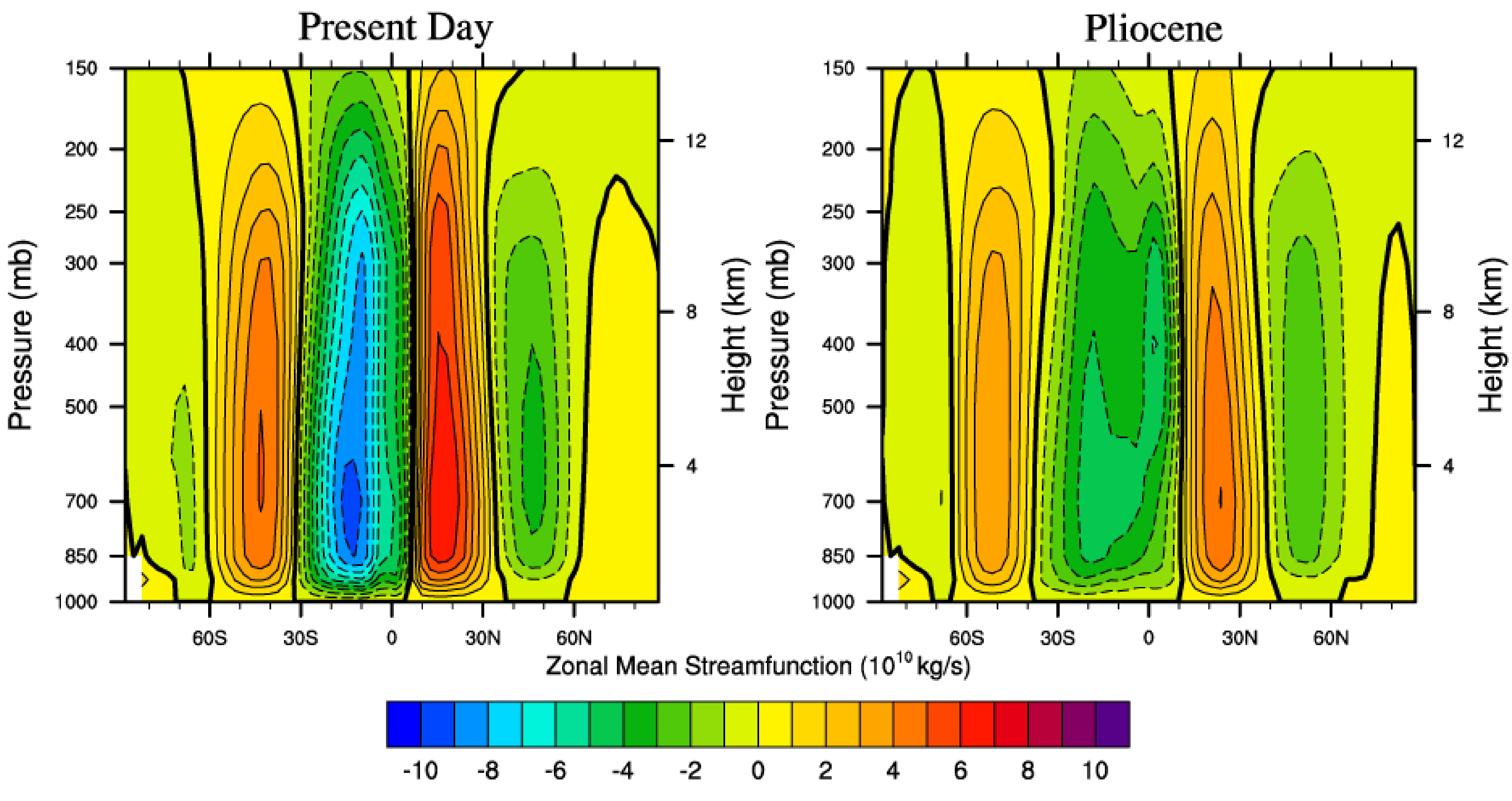
(a) Present-Day SSTs (b) Early Pliocene SSTs



Walker Circulation Collapses



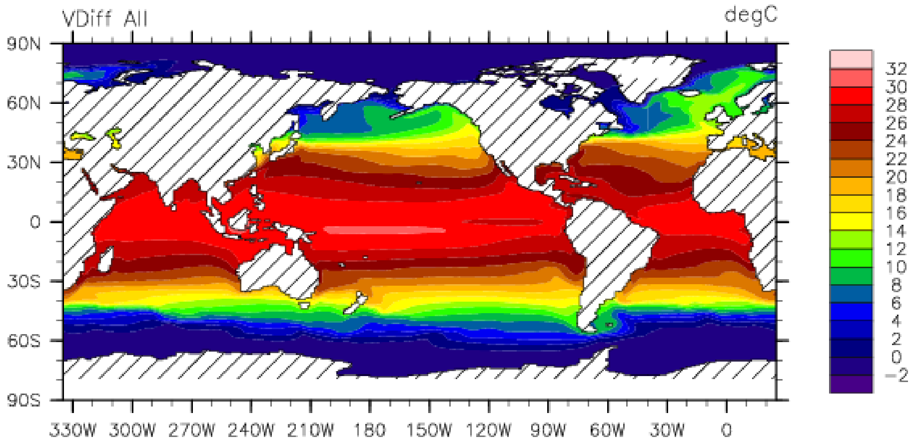
Hadley Circulation Weakens

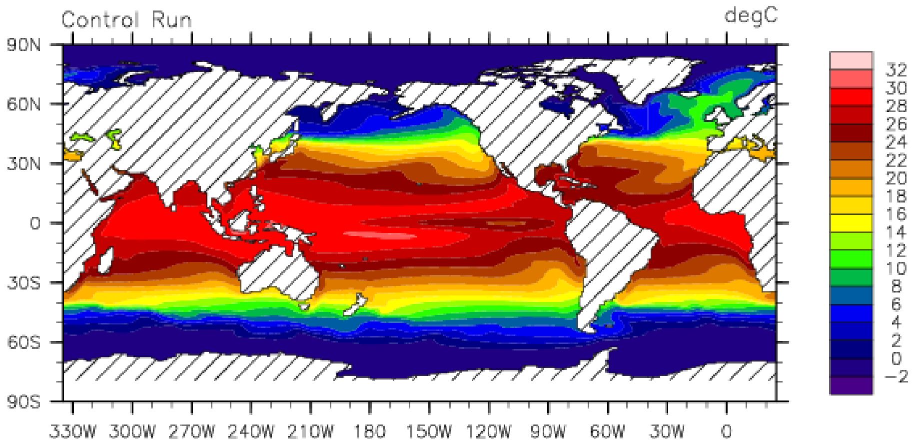


Brierley et al., Science. 2009

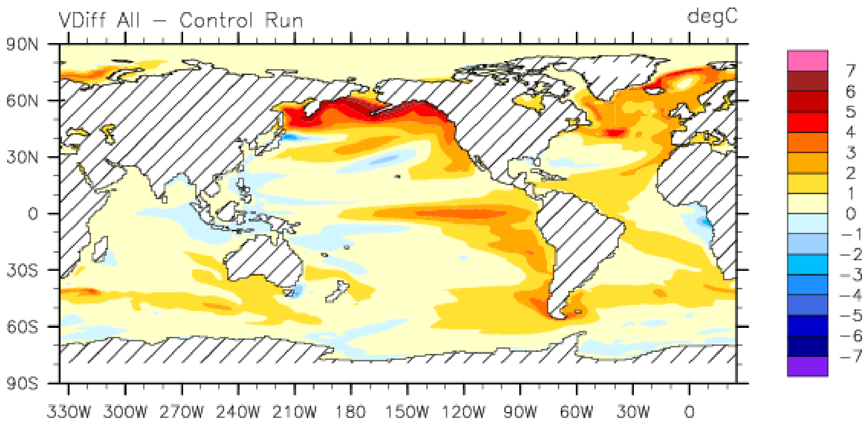
Coupled Modeling of Pliocene

Sea Surface Temperature (10x, ctl)



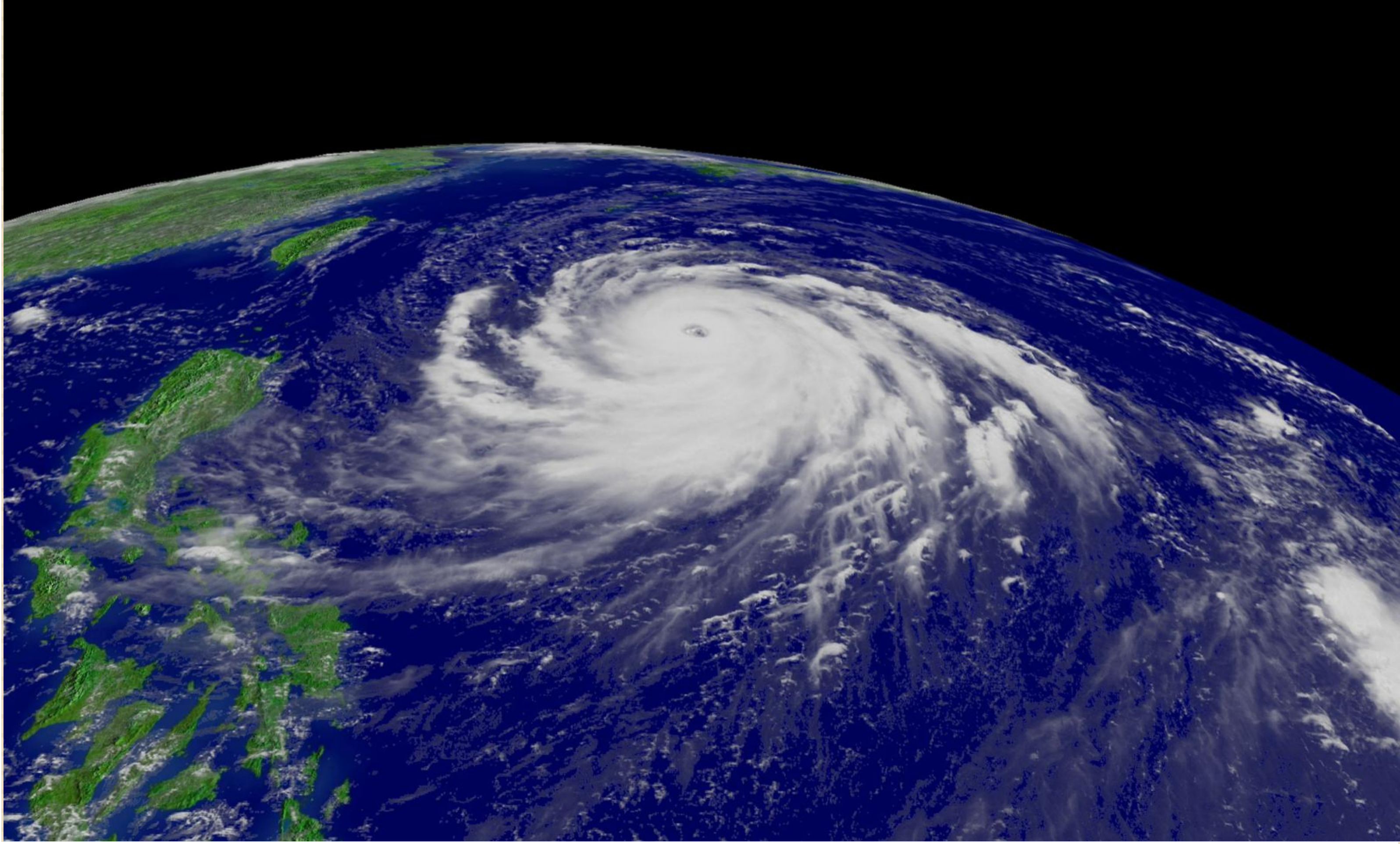


Difference



Early Pliocene Summary

- Early Pliocene boundary conditions similar to anthropocene.
- Observations of tropical climate differ from projections, with a vast warmpool across the Pacific
- Sluggish atmospheric circulation.
- Models do not simulate vast warmpool, yet the climate state appears to have existed for ~1Ma
- Additional mixing may help sustain a Pliocene state

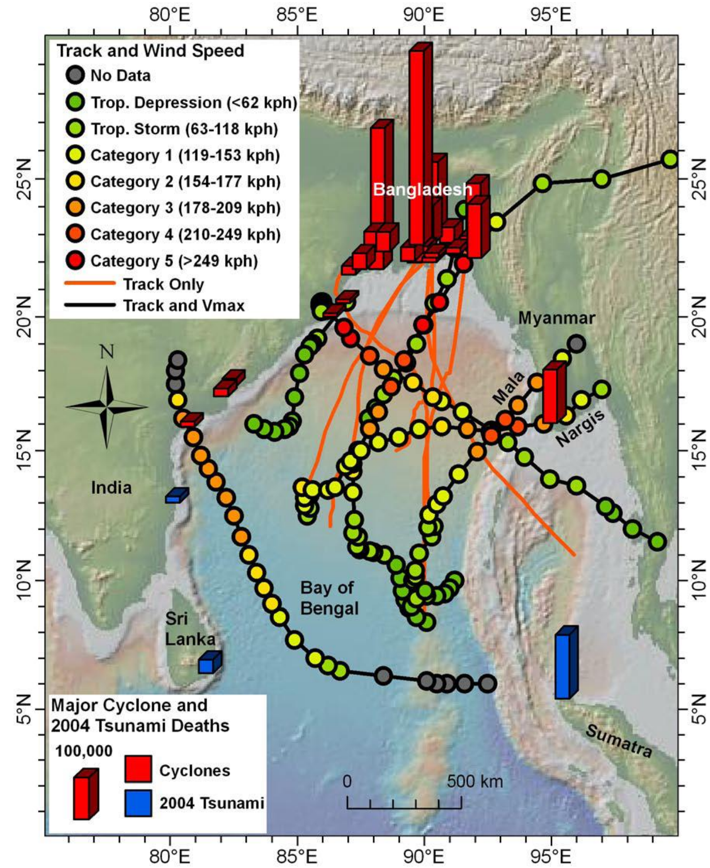


Tropical Cyclones

What would the tropical cyclone distribution have looked like in the Early Pliocene?

Tropical Cyclone Basics

- Some of most deadly natural disasters
- Roughly 90 storms occur every year.
- Strong winds on scales smaller than GCMs
- Feed on energy extracted from the ocean



Fatalities from the 7 major cyclone events (> 10,000 deaths) from 1584 up to Cyclone Nargis compiled from the Emergency Events Database (EM-DAT) and other sources with storm track and wind speed compared against 2004 Indian Ocean tsunami deaths. Additional cyclone track: 2006 Cyclone Mala with 22 deaths in Myanmar. *Fritz et al. Nature Geosci. (2009)*

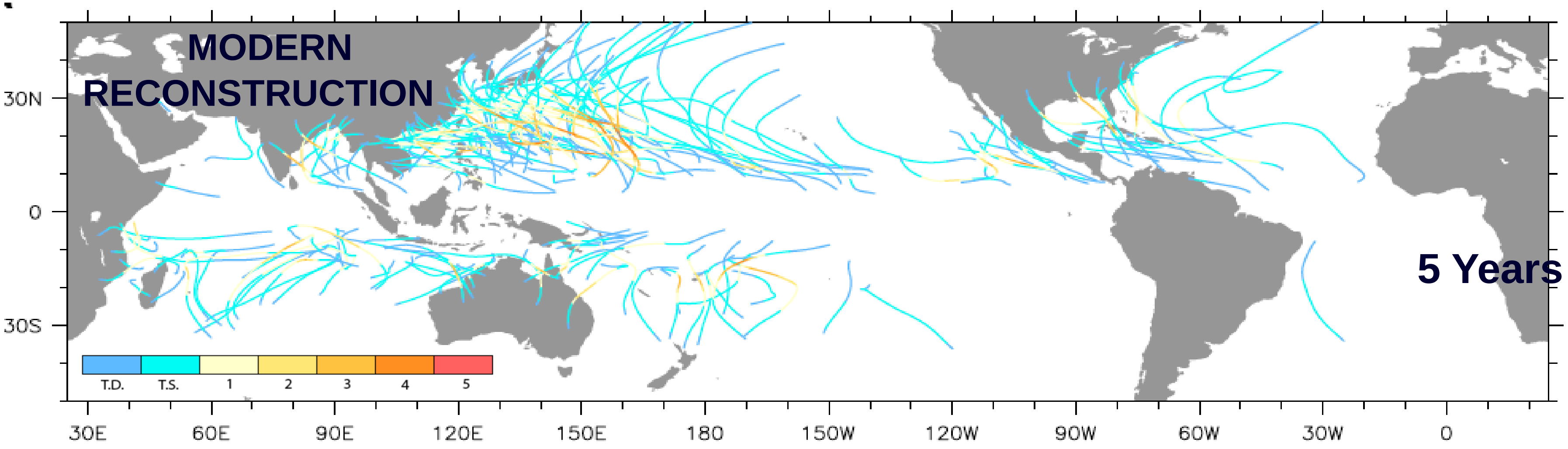
Future behavior of tropical cyclones

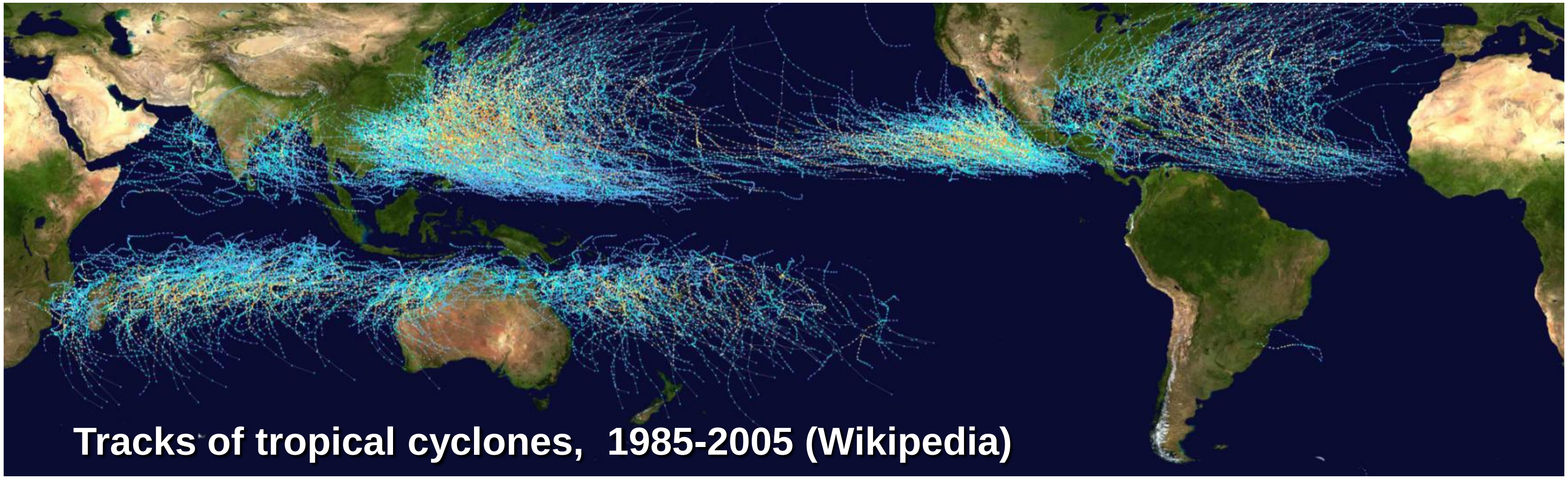
- Known to be controlled by SSTs and vertical wind shear among other things
- Future behavior still uncertain as residual between SST and wind shear increases (at least over N. Atl.)
- IPCC AR4 says
  - >66% chance increase in peak wind and rain intensity
  - ~50% chance decrease in frequency, with regional variations
- *Pliocene was both warmer with weaker wind shear*

Statistical Downscaling Model

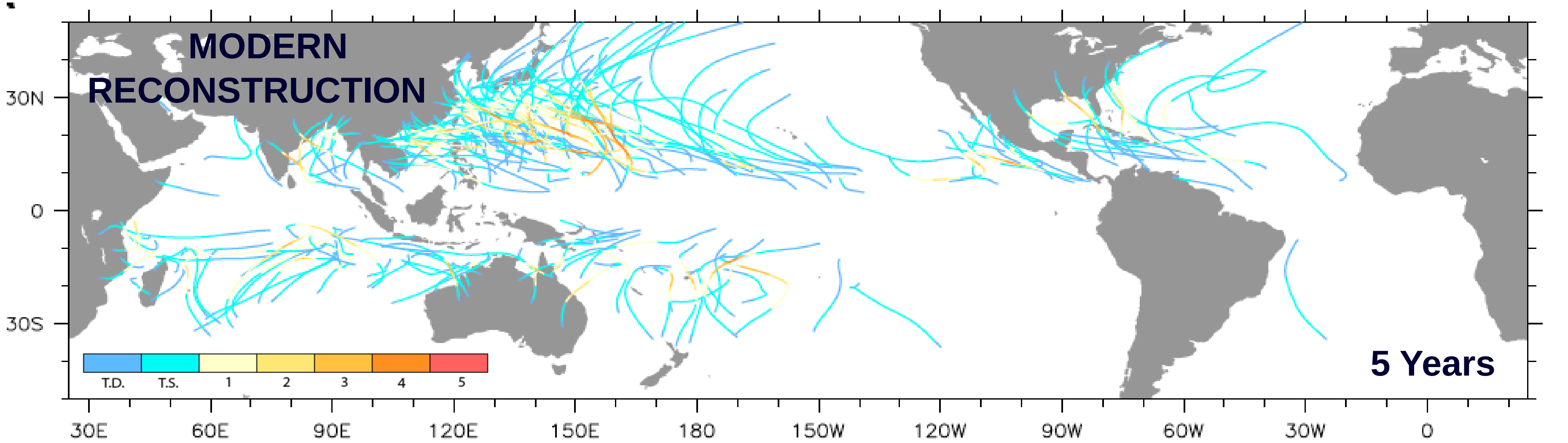
- Create realization of large scale atmospheric flow
- Embed weak vortex and use hurricane track prediction model to work out where it would go
- Use 2D CHIPS model to determine intensity along track
- Repeat until have at least 10,000 synthetic tropical cyclones.
  - Most tracks don't even reach tropical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

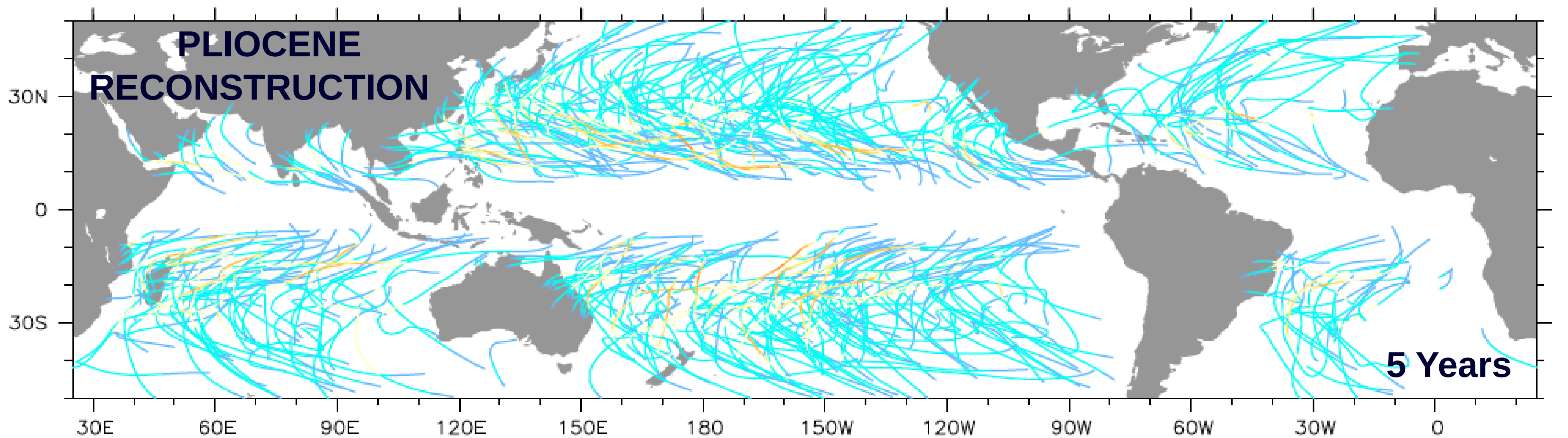
Synthetic Tracks for Present-day





Synthetic Tracks for Pliocene



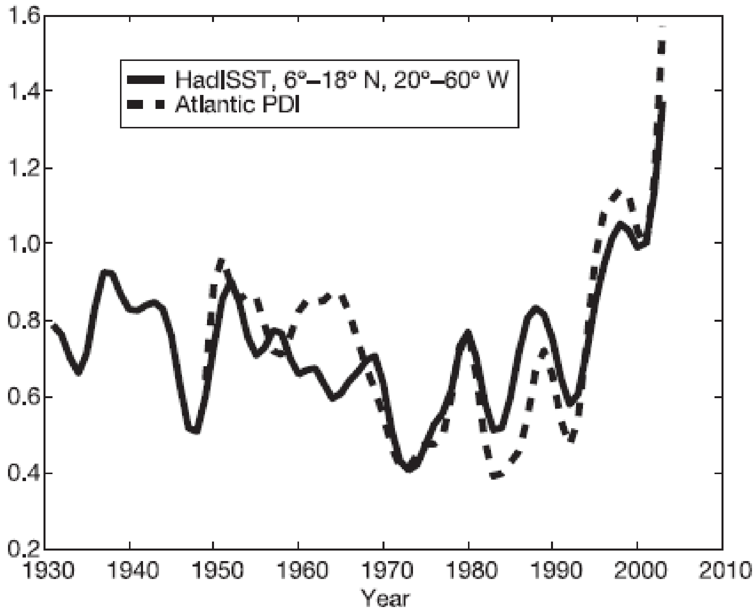


Power Dissipation Index

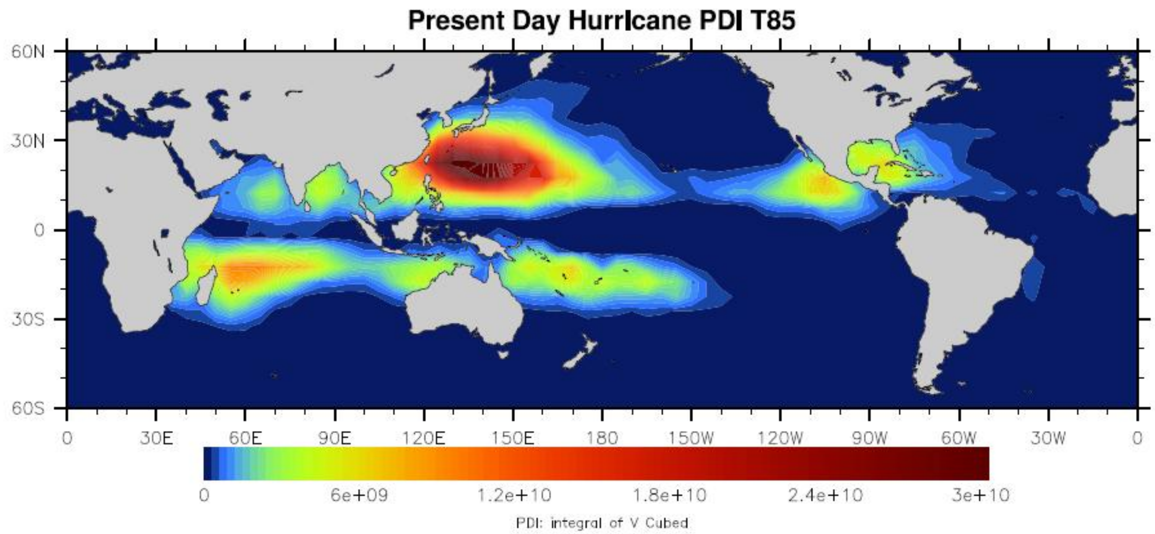
- Defined by Emanuel (2005) as

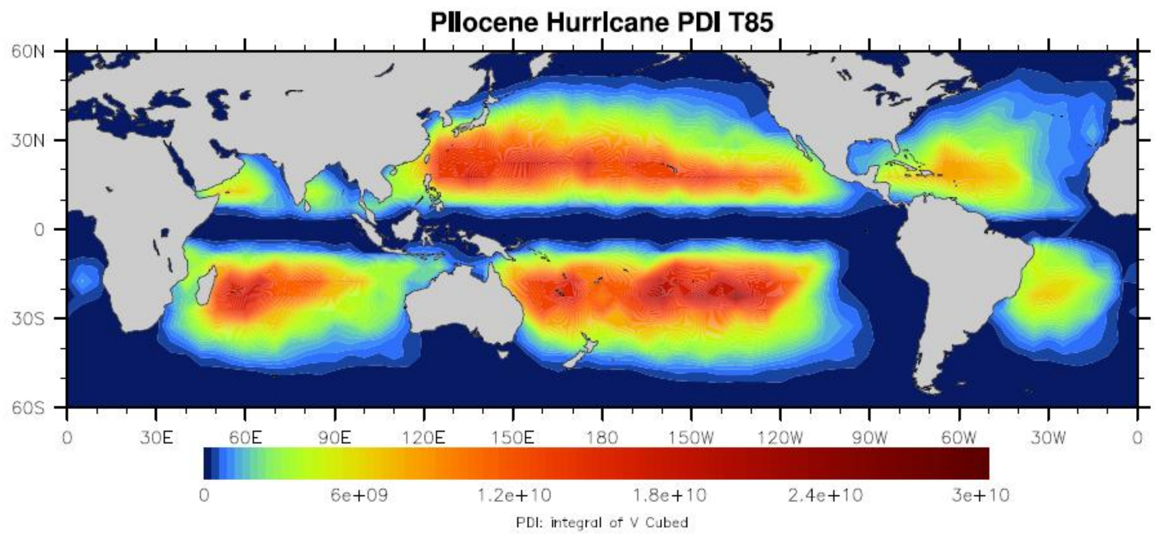
$$\mathrm{PDI} \equiv \int_0^{\tau} V_{\max}^3 \, dt$$

- 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



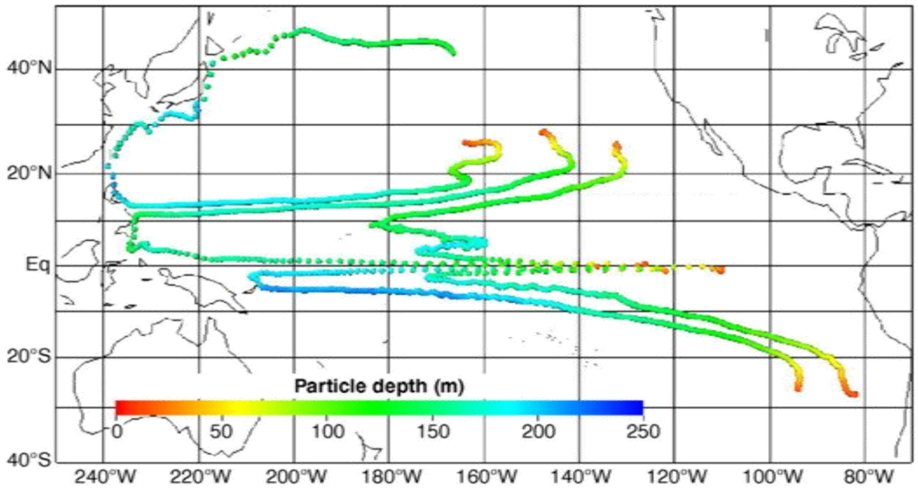


A climate feedback

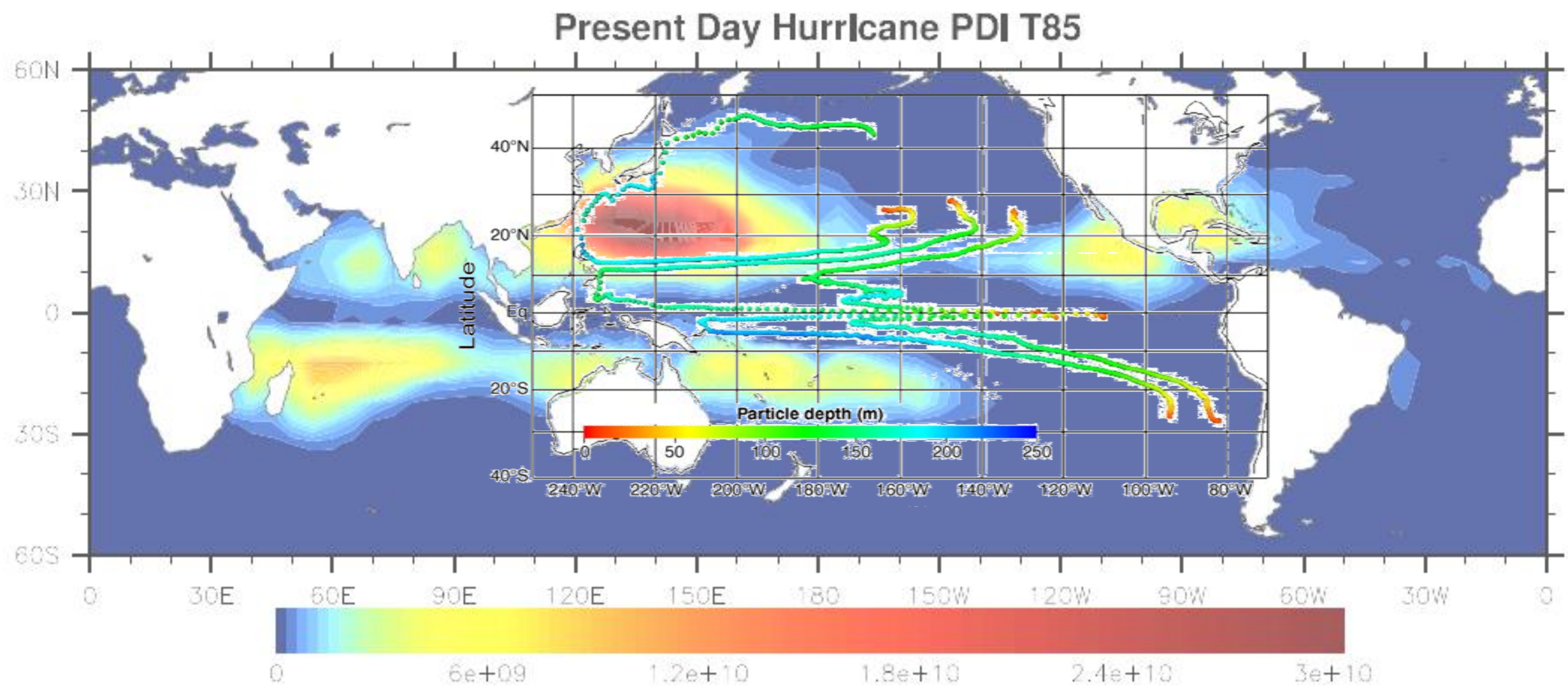
Could the changes in the tropical cyclone in the Pliocene have provided a feedback to keep the climate in an alternative, warm state?

Trajectories within Subtropical Cell

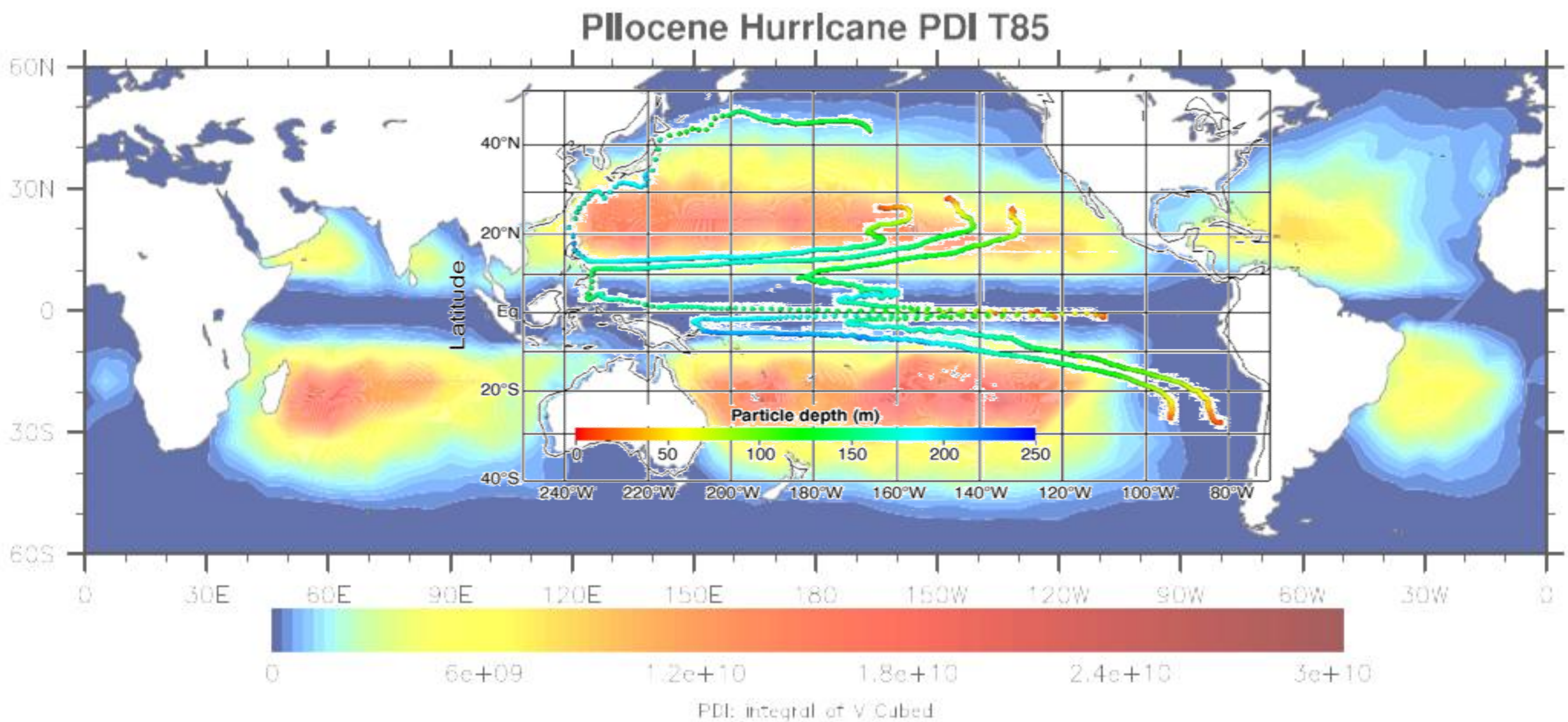
- Water is subducted in subtropical East Pacific
- Travels west towards warm pool
- Catches EUC and upwells in cold tongue
- From Gu & Philander '97



Present-Day Subduction Pathways

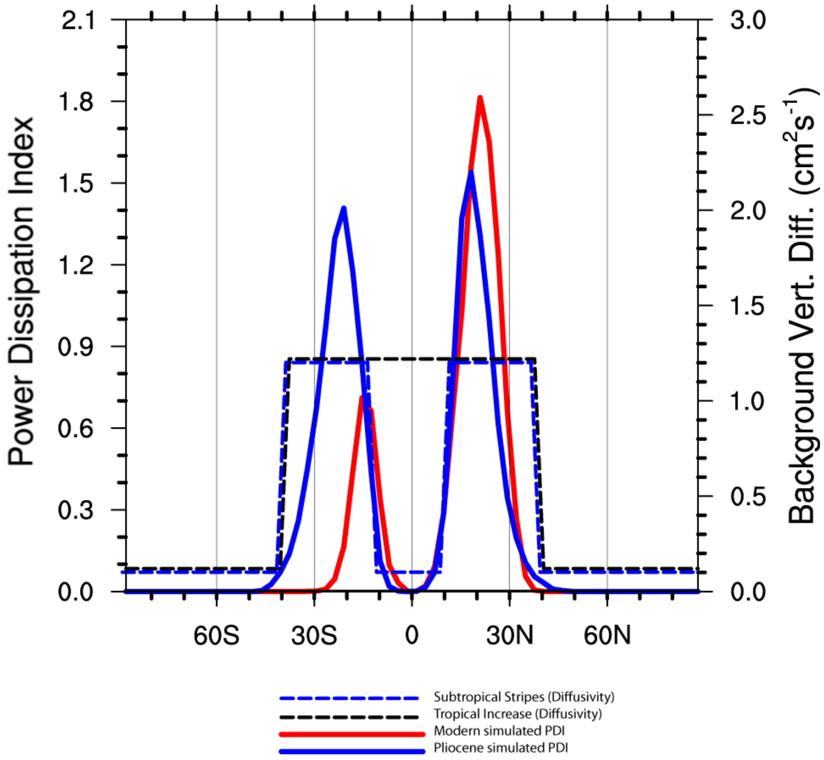


Pliocene Subduction Pathways



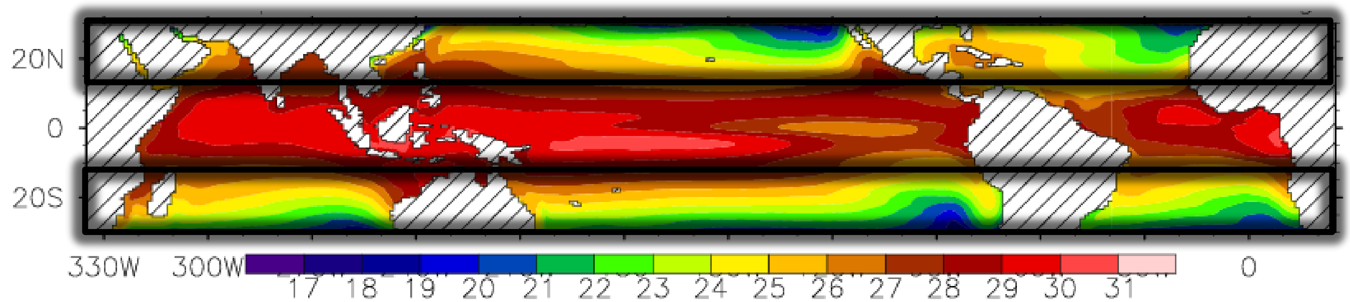
Determining impact of closed windows

- Background vertical mixing enhanced by x10 in top 200m between 8° to 40°
- Possibly excessive, but guarantees that the windows in the subtropical pathways are closed.

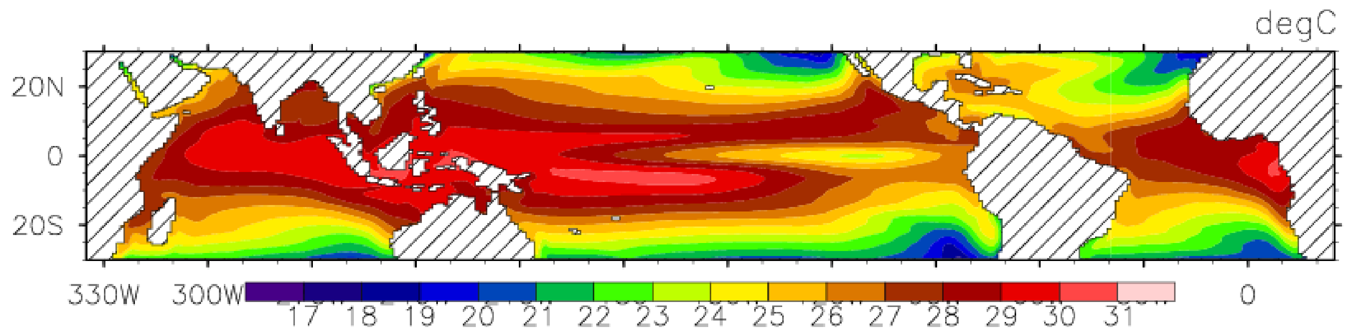


Including "tropical cyclone" mixing

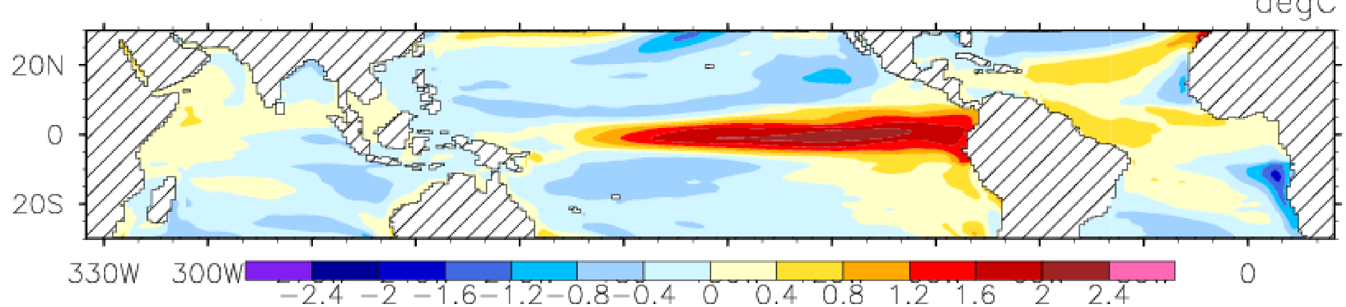
Increased mixing in strips



Control



Difference

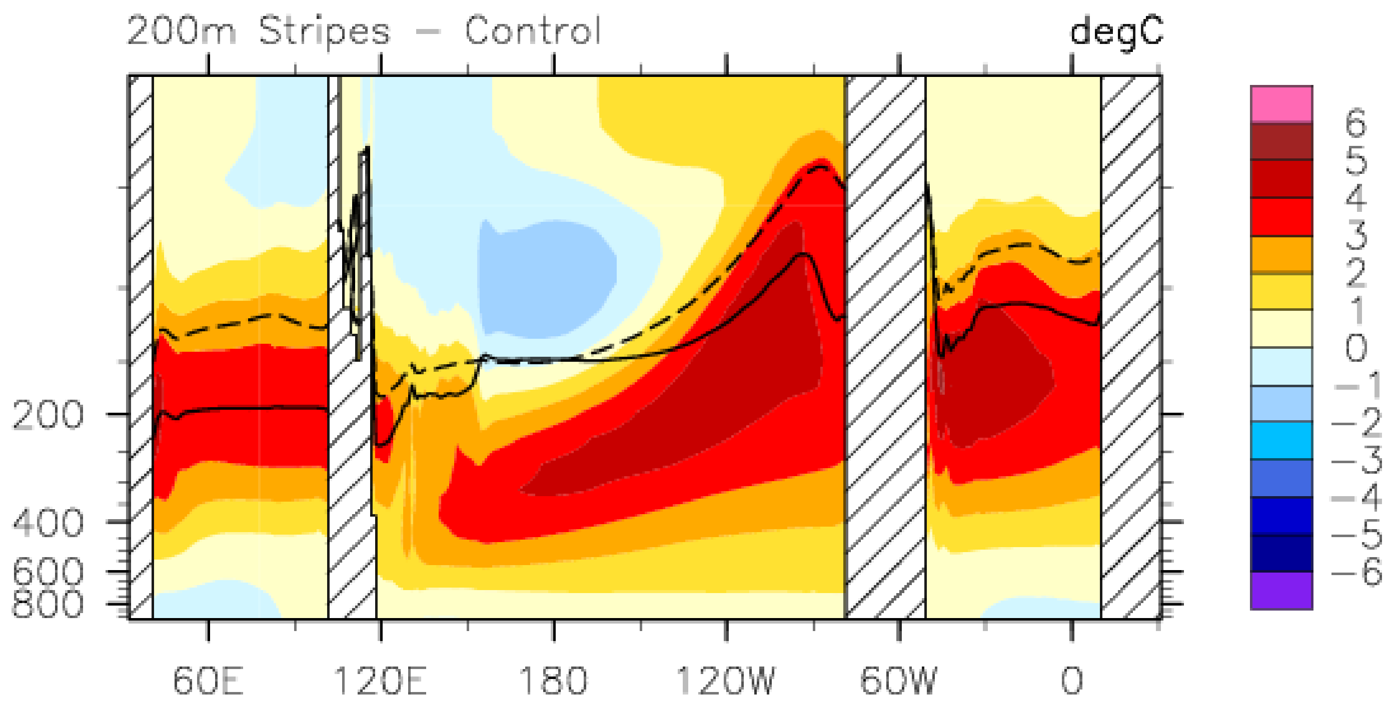


Impact on the thermocline

Warming of subsurface eq. ocean.

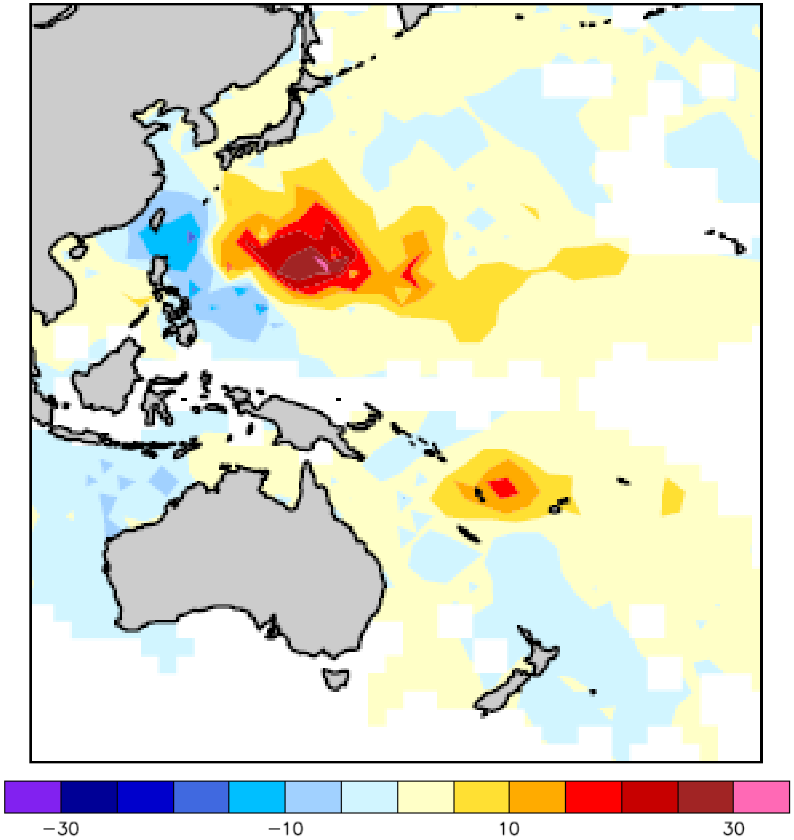
Deepening of thermocline.

Suppresion of interannual variability.



Solid line: 20°C isotherm in mixing run
Dashed line: 20°C isotherm in control run

Impact of El Niño on Cyclones



Average change in PDI (in 10^8 m^3s^{-1}) between an El Niño year and a neutral year, calculated from IBTrACS

- El Niño causes reduction in number of hurricanes (N. Atl. Storms)
- Increase in intensity of typhoons (W. Pac.), but reduced amount of landfalls

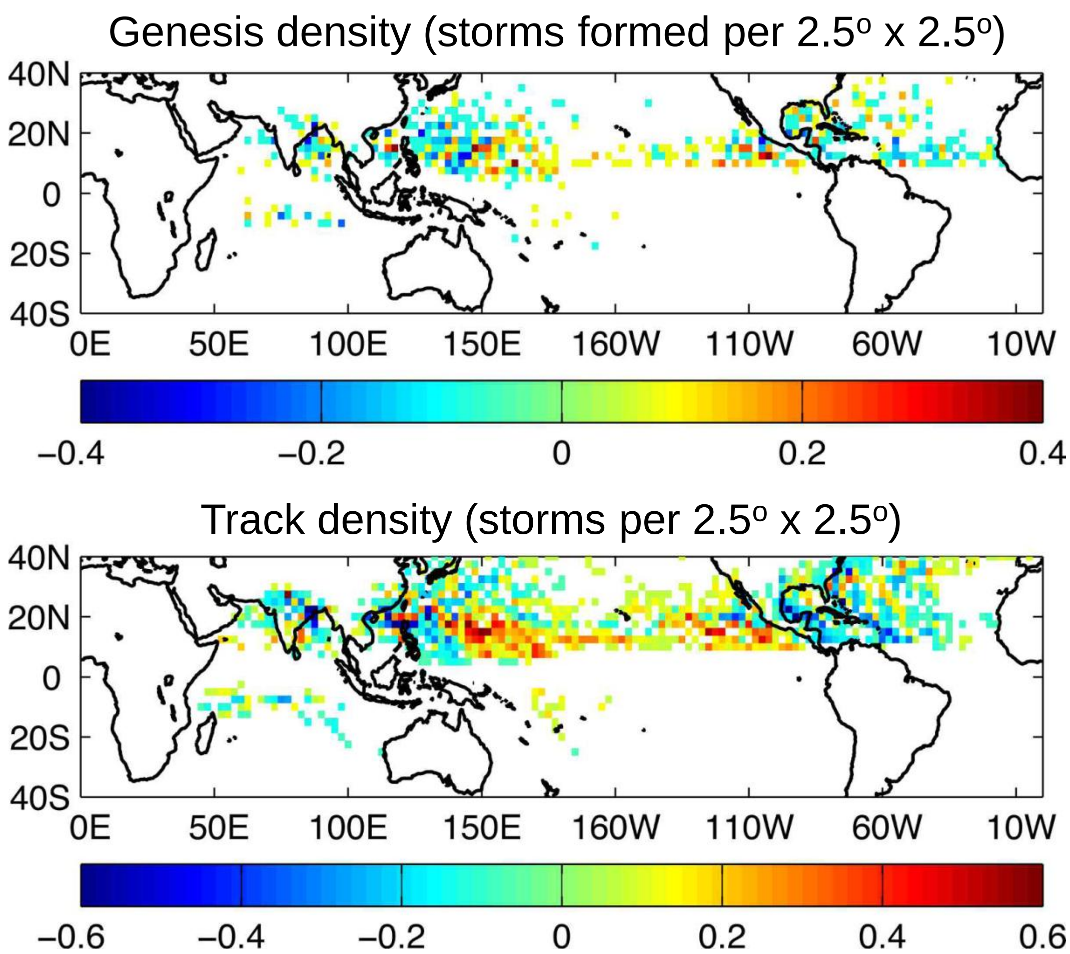
E. Eq. Pac. Warming on Cyclones

Warming of the cold tongue leads to:

- Formation of more storms in central and eastern Pacific
- More storms passing over subtropical overturning cell

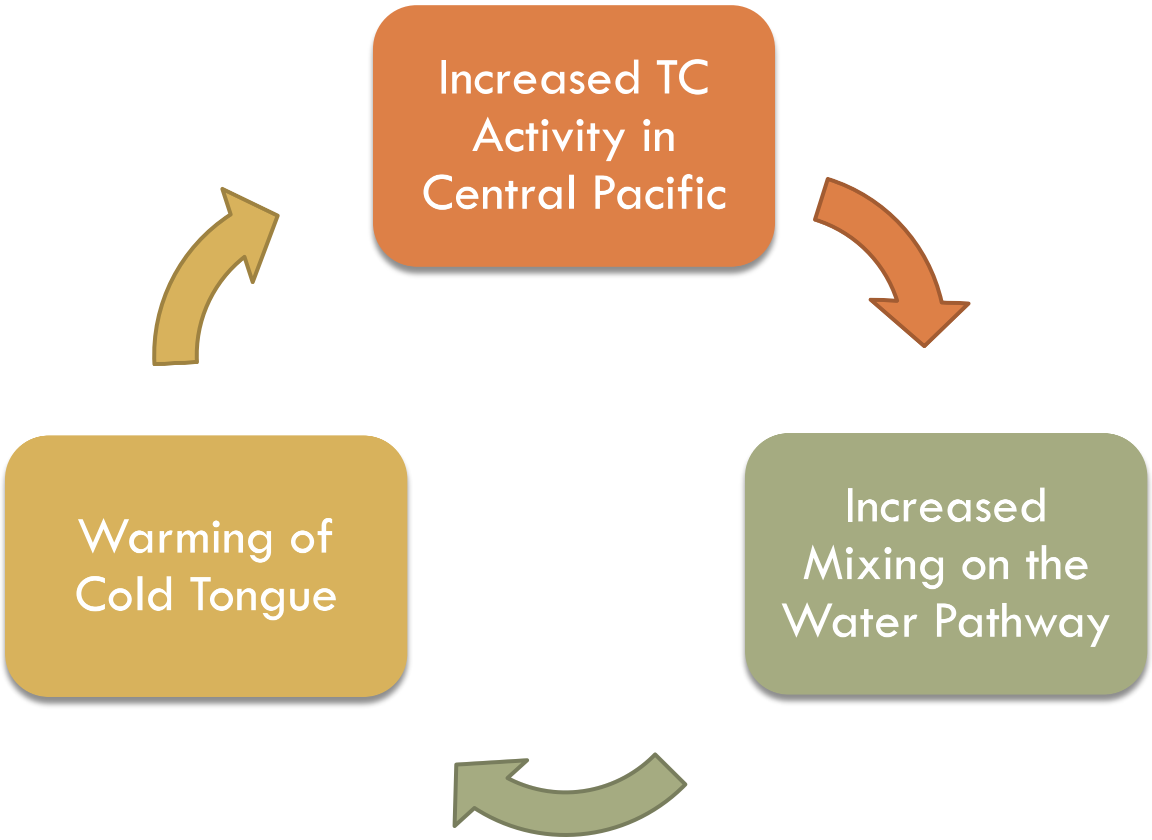
El Nino (~1yr) is much shorter than STC (~20yrs) so not expect impact on EEP

Permanent change may feedback on EEP



Camargo et al., J. Clim. (2007)

Tropical Cyclone Feedback



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

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