TEMPERATURE GRADIENTS AND GLACIATION

Chris Brierley & Alexey Fedorov

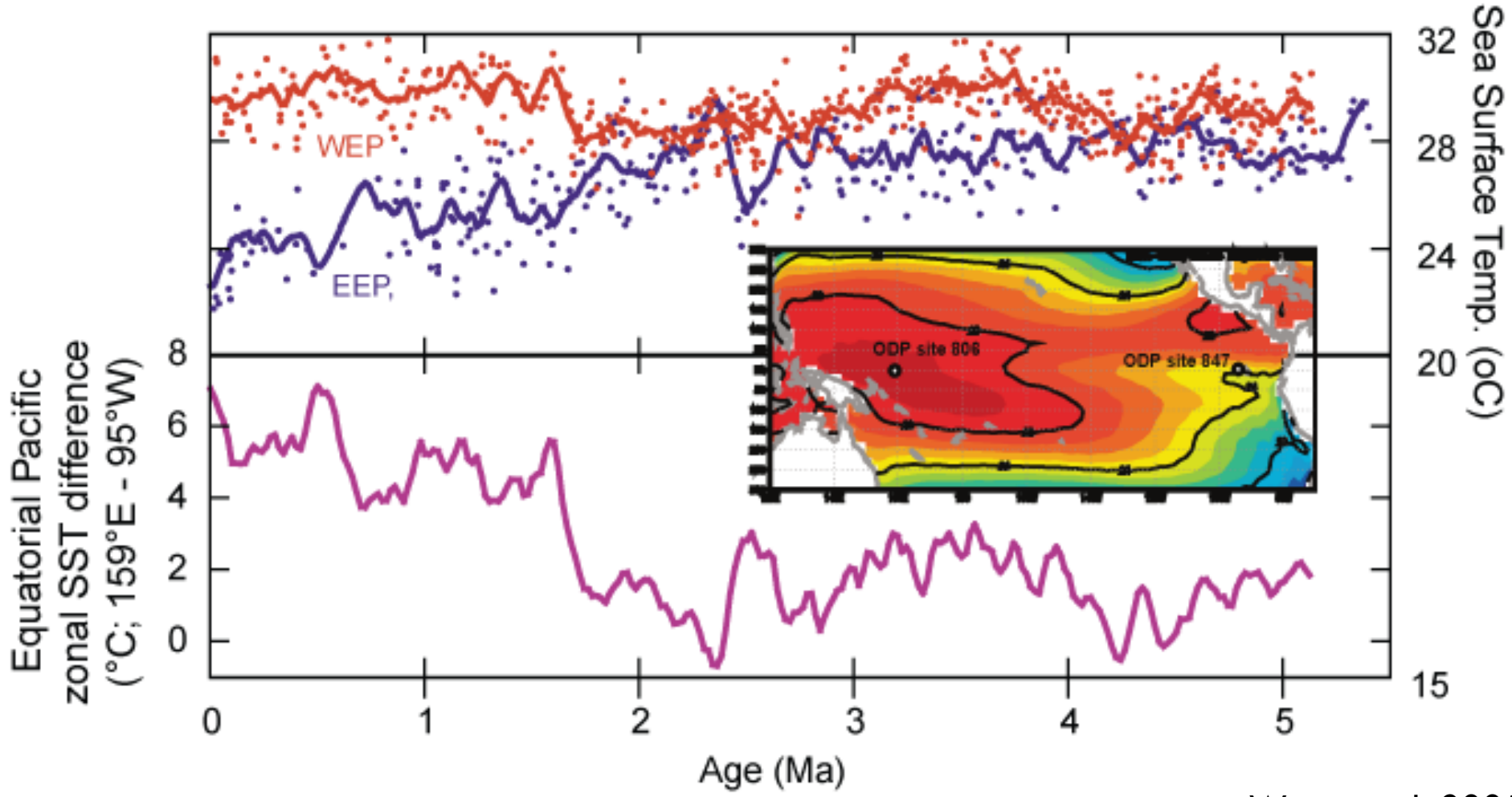
Outline

- Recap on the warm early Pliocene (as we have reconstructed it)
- Methodology to compare meridional SST gradient impacts and zonal SST gradient impacts
- Findings about the onset of Northern Hemisphere Glaciation
- Dominance in reconstructed climate
- Speculations on about Monsoon

Why care about the early Pliocene?

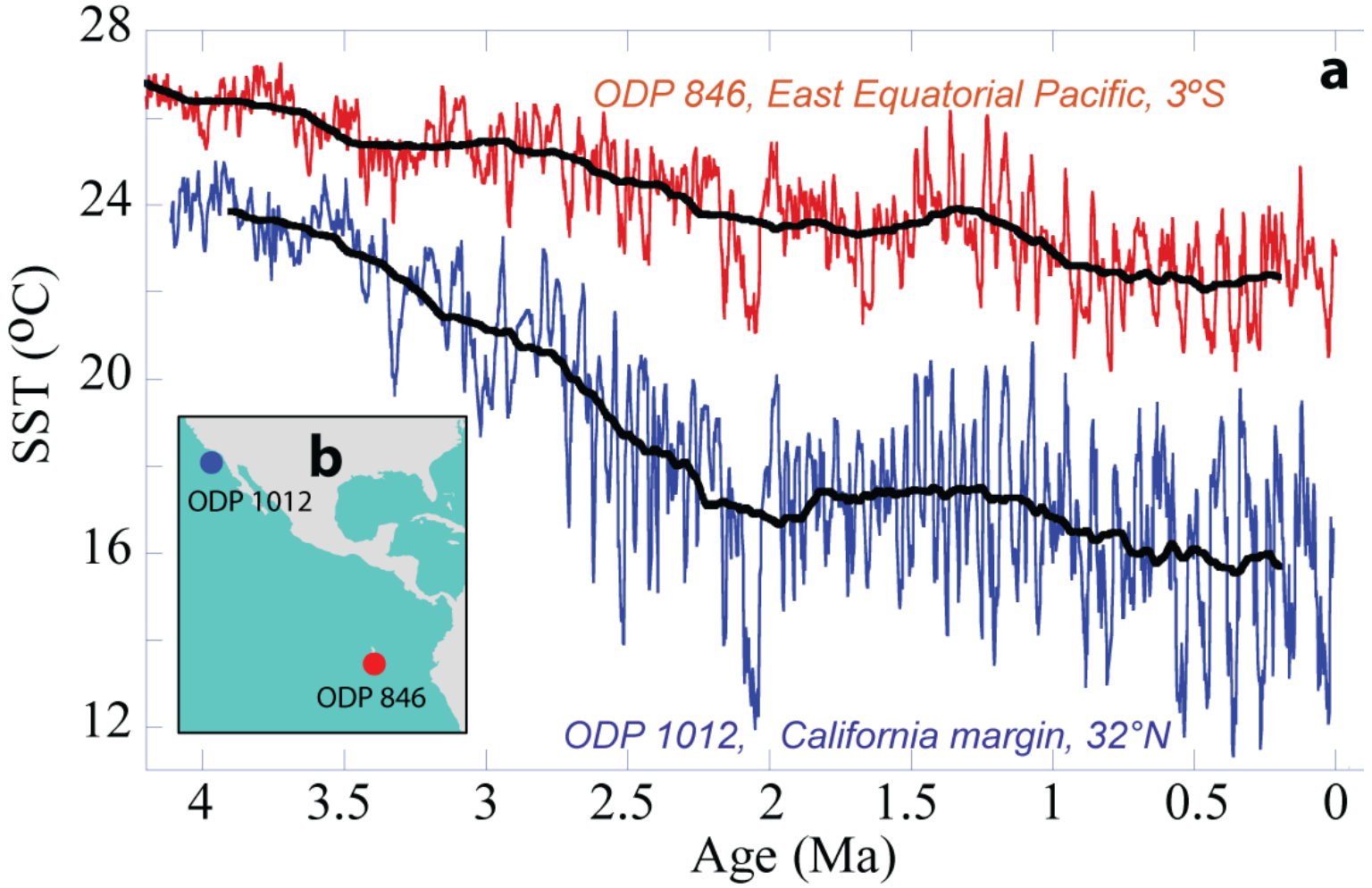
- Natural global warming stabilization experiment
  - Mark's Current best guess: 380 ±25 ppm
- Landmasses approximately same as today
  - New Guinea and Halmahera moving North (c. 5Ma)
  - Isthmus of Panama Closing (c. 5Ma)
- Ice Volume/Sea level
  - Sea Level roughly 25m higher
  - Reduced Greenland ice sheet
  - Reductions in Ice on Antarctica
- Vegetation
  - Forests on coast of Greenland
  - Reduced amount of Tundra
- Sea Surface Temperature data

Wara's Permanent El Niño

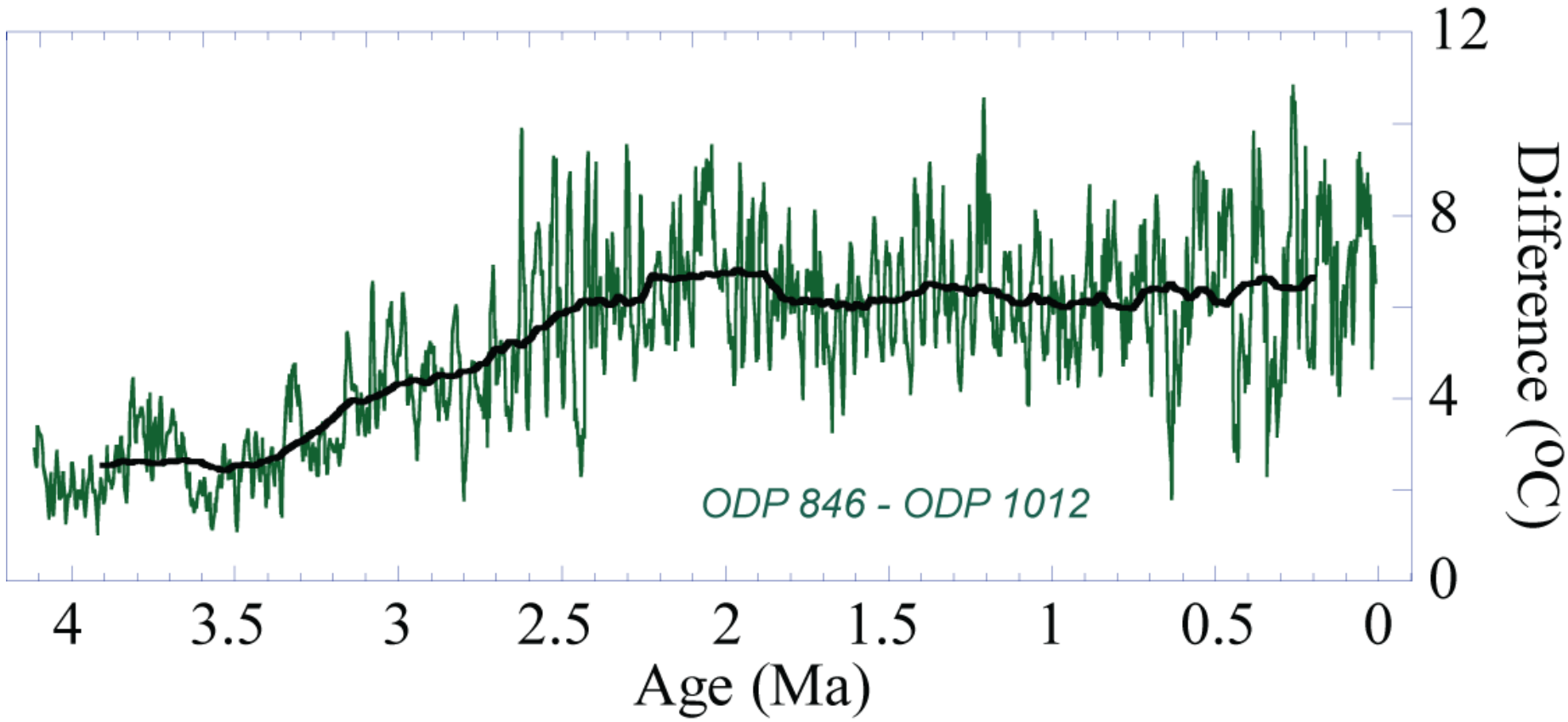


Wara et al. 2005

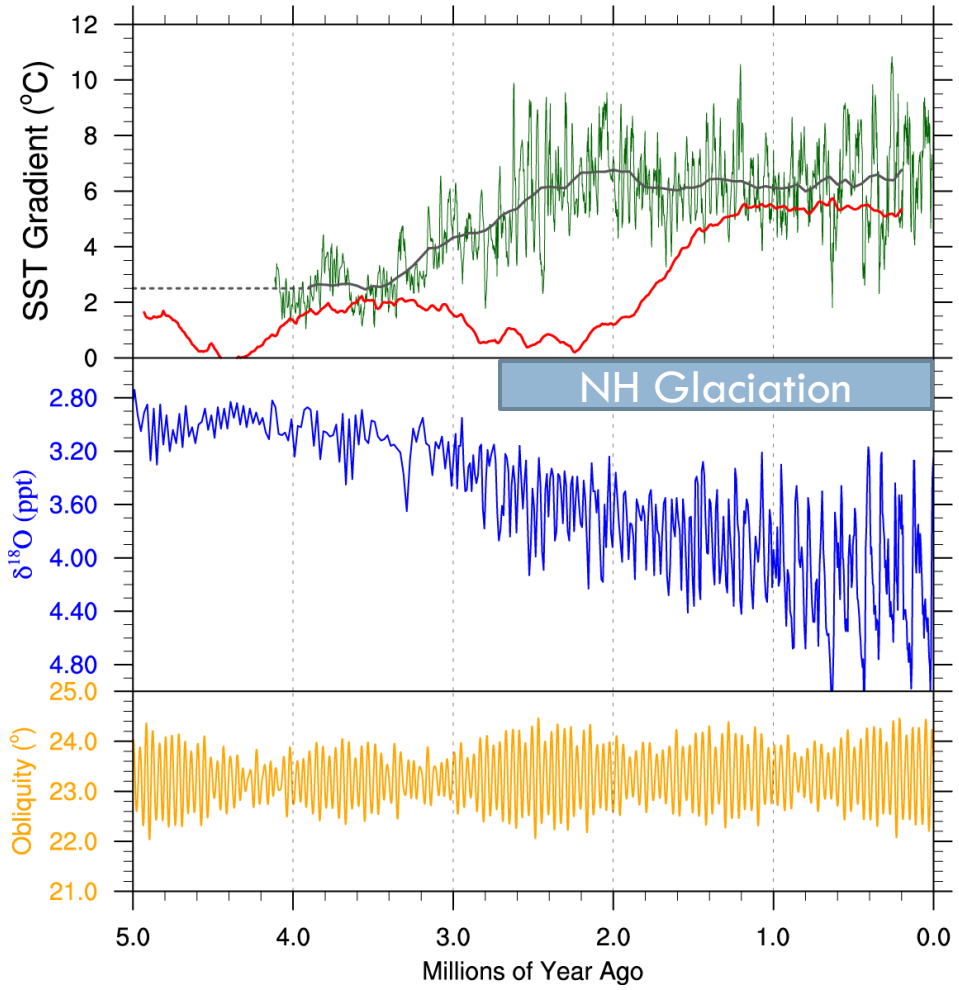
California Margin



Reduced Difference between Equator and Californian Margin



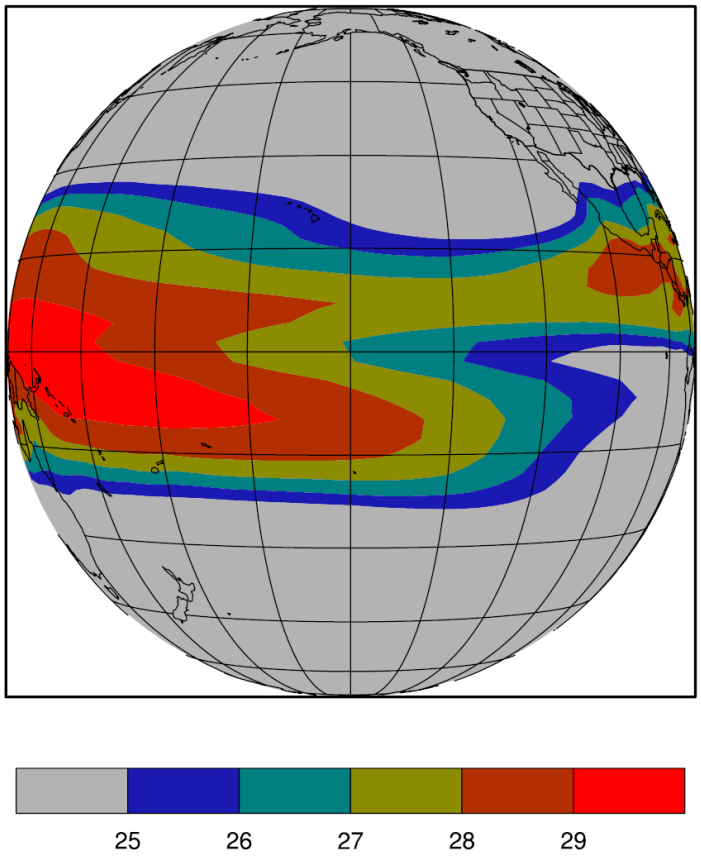
How do these SST gradients compare?



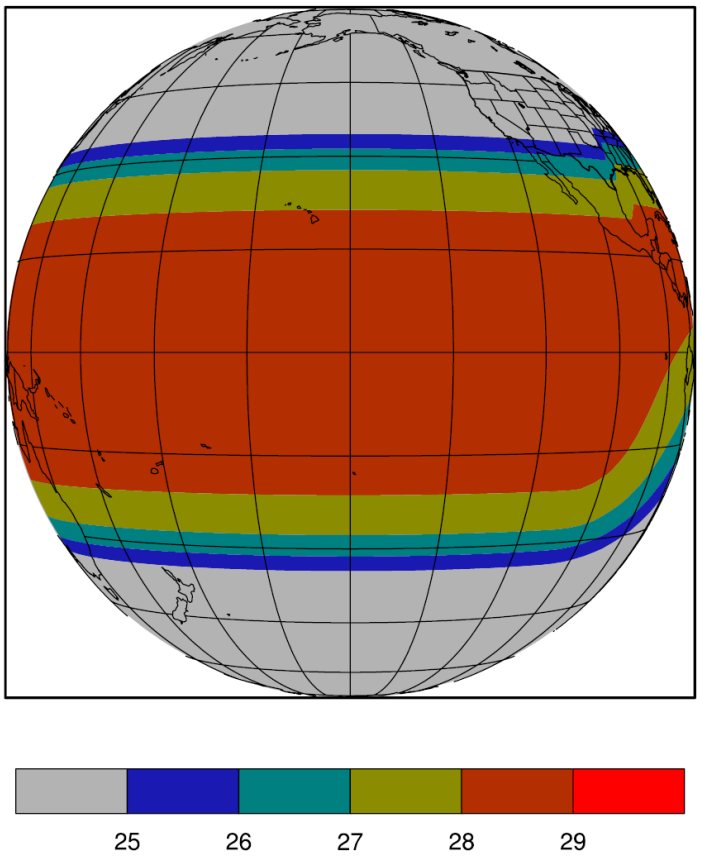
Reconstructing early Pliocene SSTs

Expansion of Warmpool

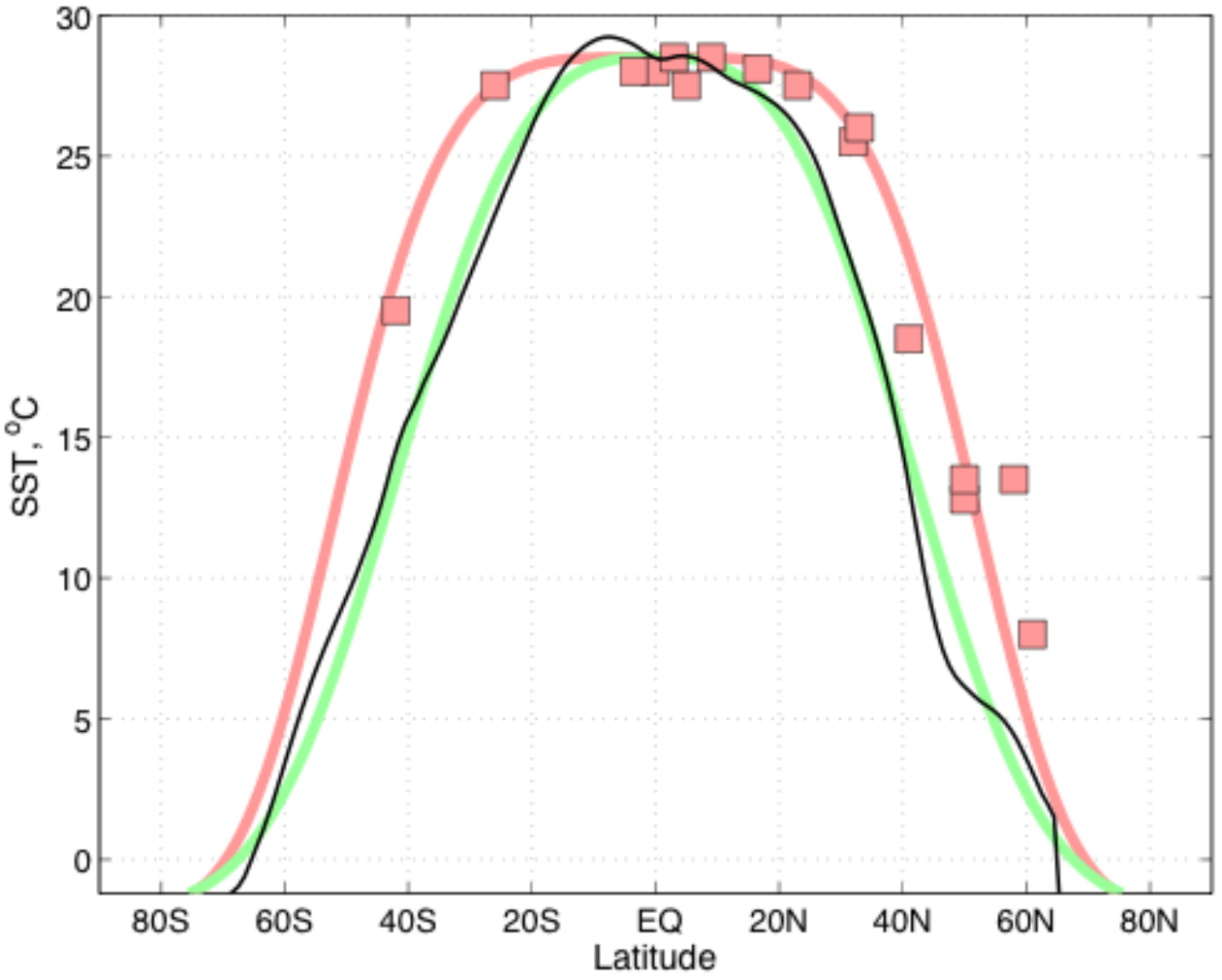
(a) Present-Day SSTs



(b) Early Pliocene SSTs



SST profiles for this work



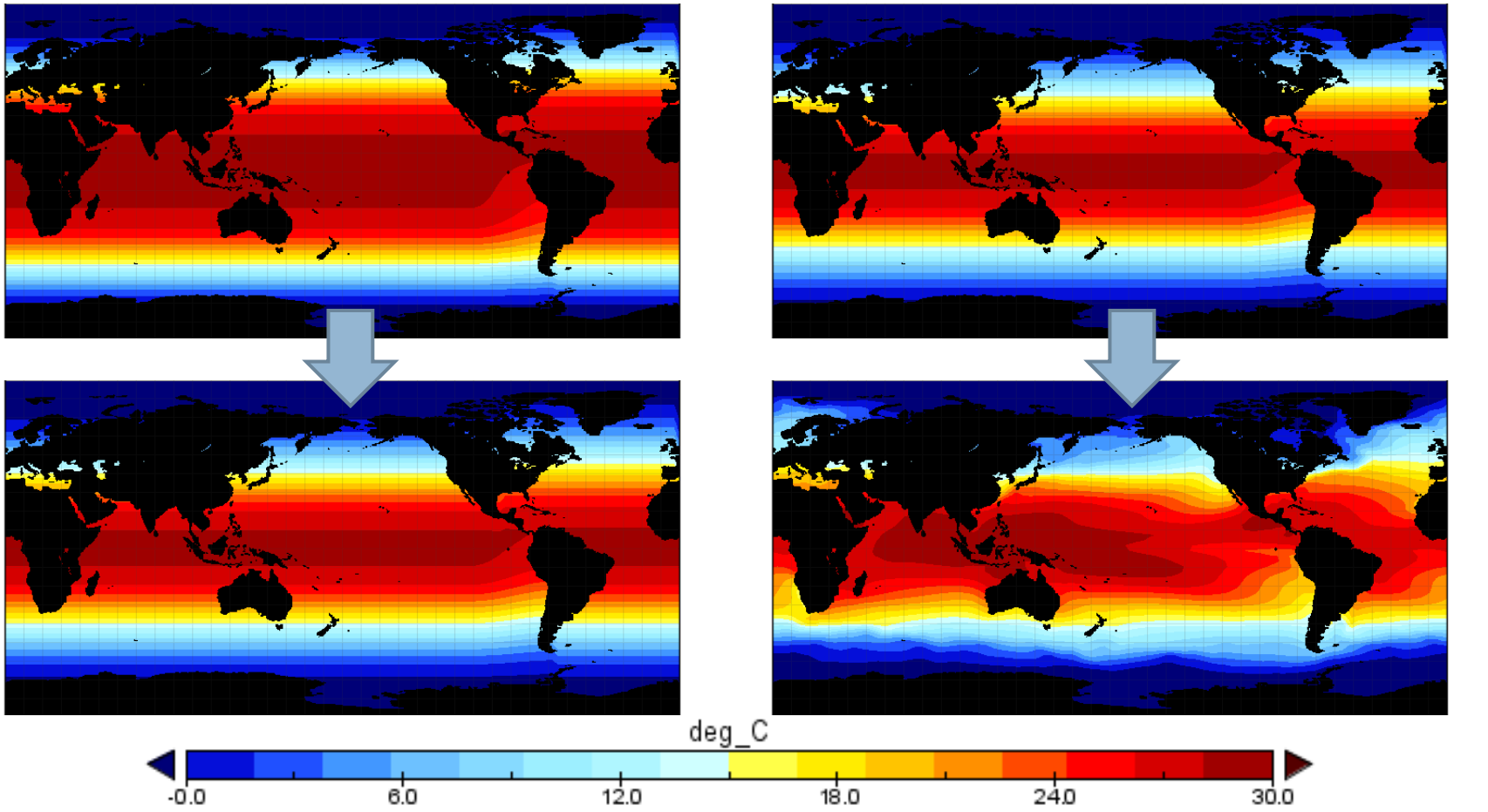
Community Atmospheric Model, v3

- 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
- Modern Boundary conditions (Land, CO_2, Solar etc)

Meridional or Zonal SST dominate?

Meridional SST Impact (3.5-2 Ma)

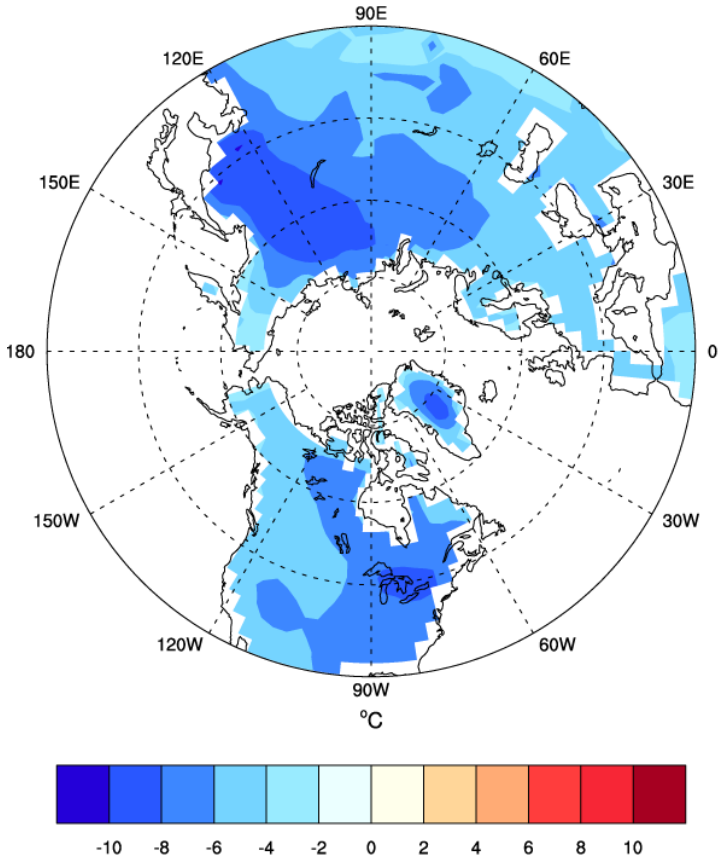
Zonal SST Impact (2.2-1.2 Ma)



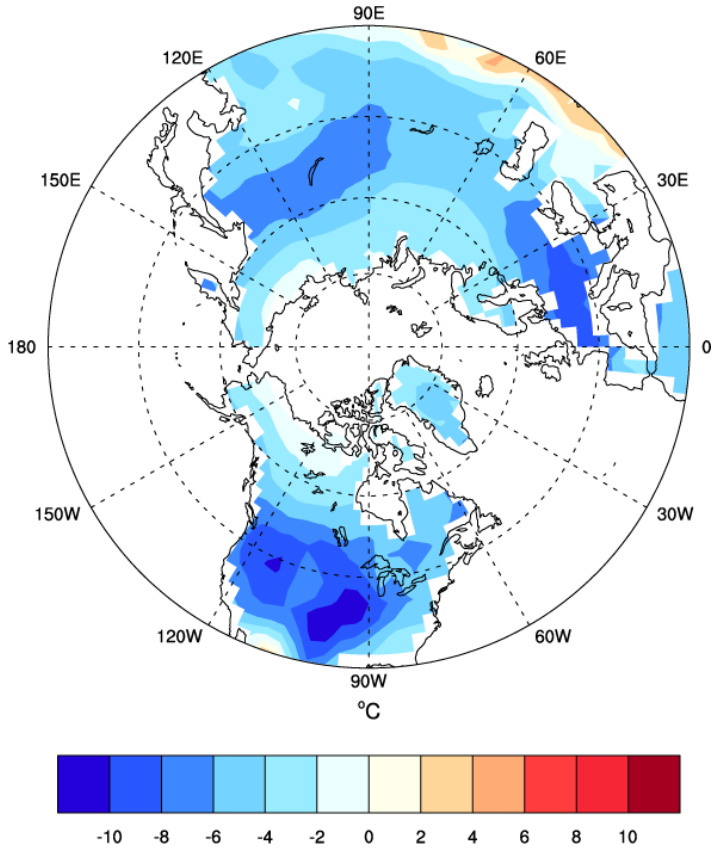
Impacts of Meridional SST Grad.

Colder North America

Winter Surf. Temperature

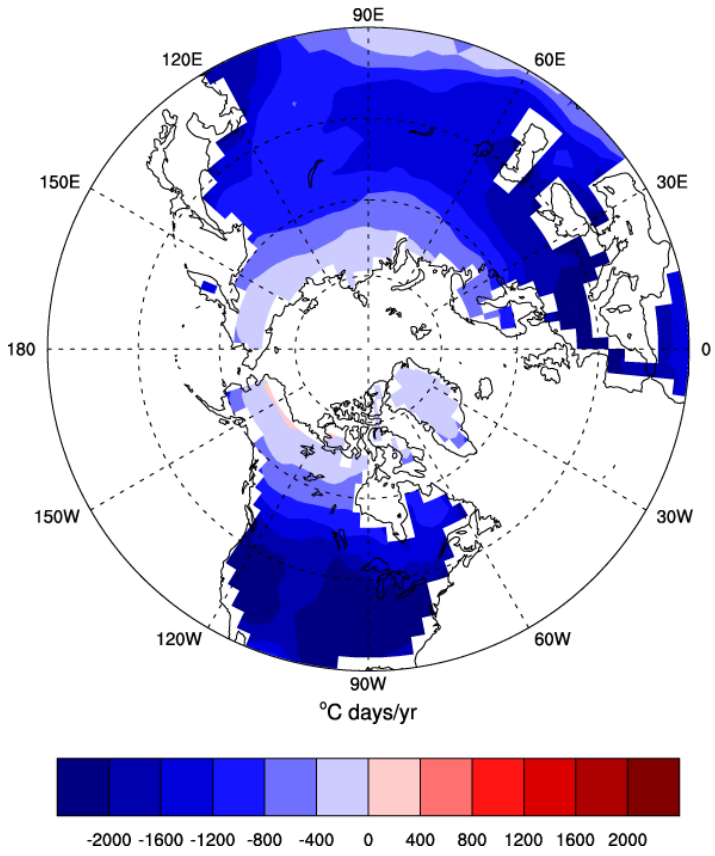


Summer Surf. Temperature

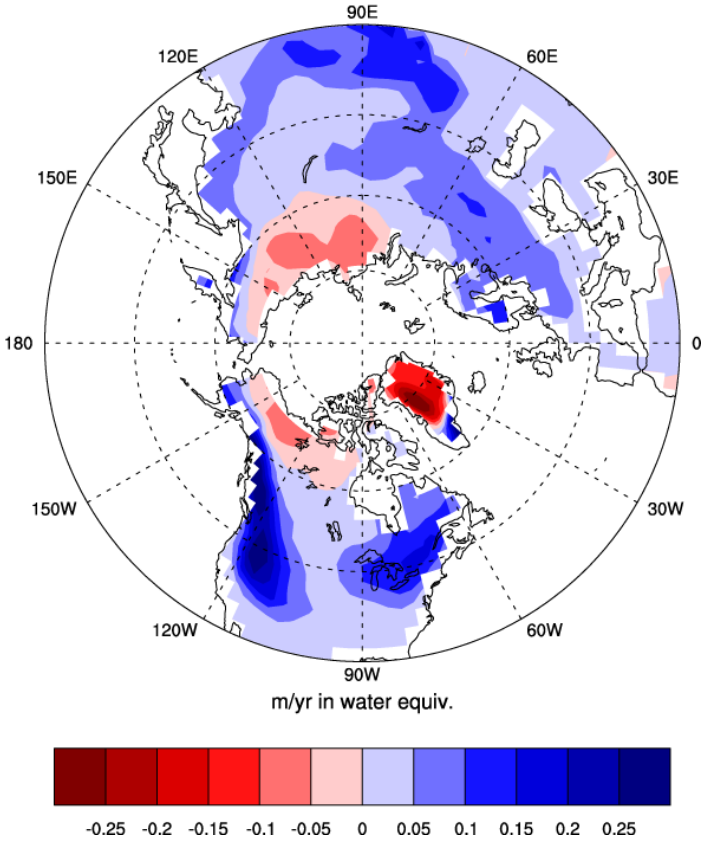


Colder North America - 2

Positive Degree Days



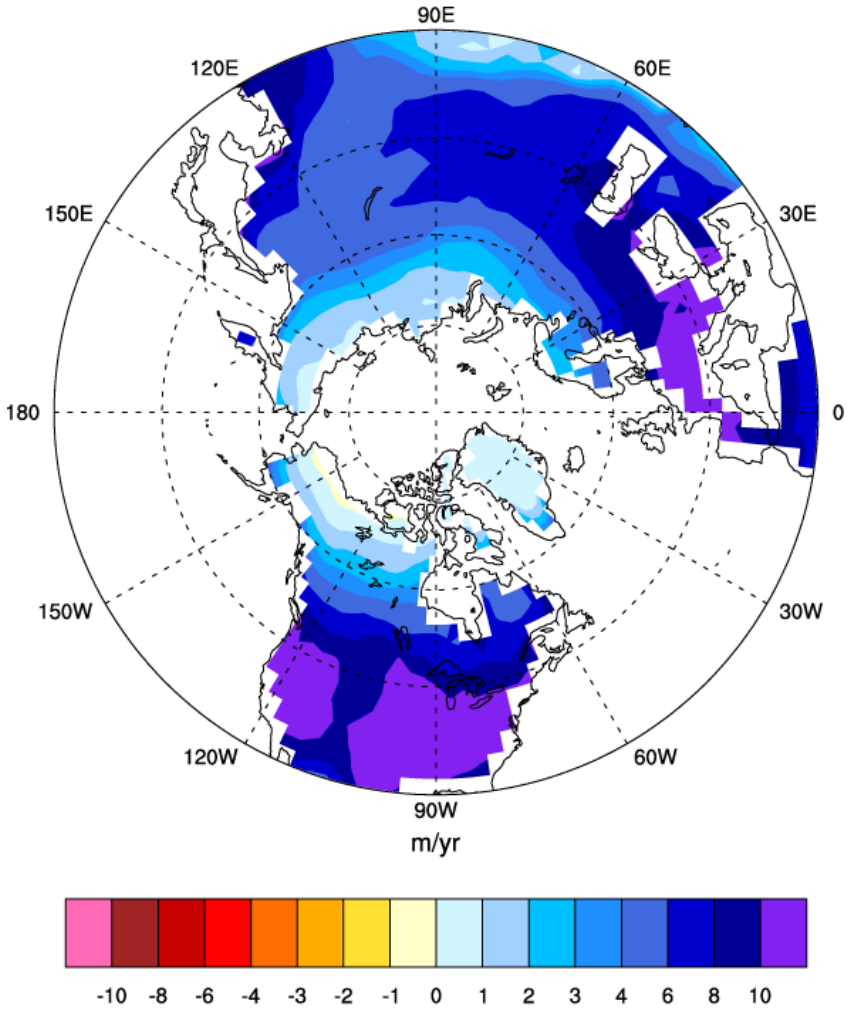
Snow Accumulation



Change in Mass Balance

- Combine above two diagnostics:
- $dm/dt = Acc - \beta * pdd$

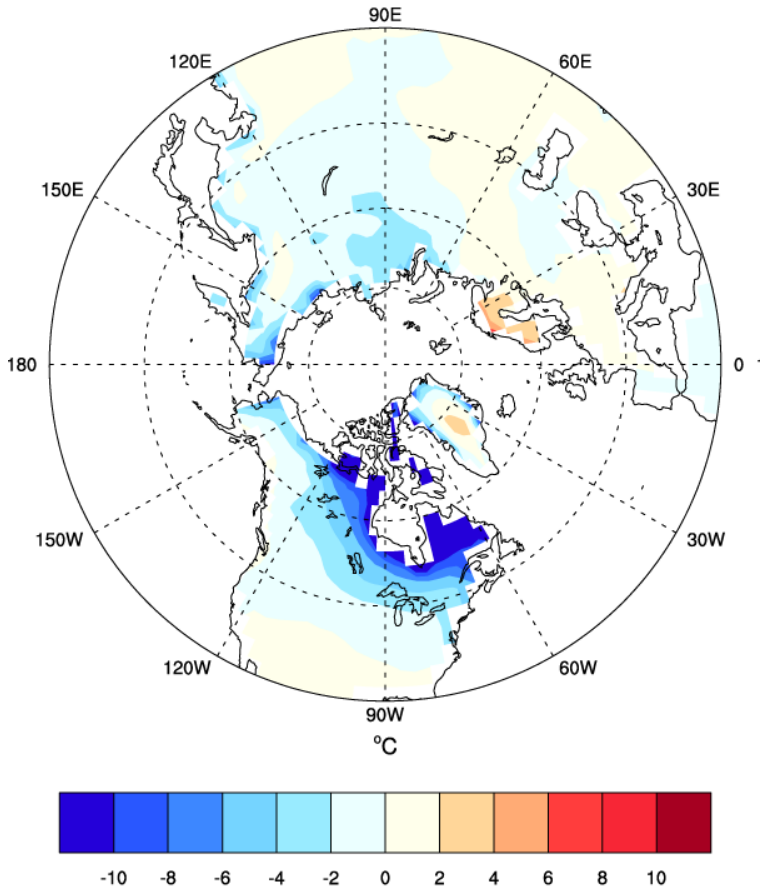
- Observed changes in meridional SST grad from 3.5 - 2 Ma cause strong reduction in snow melt in N. H.



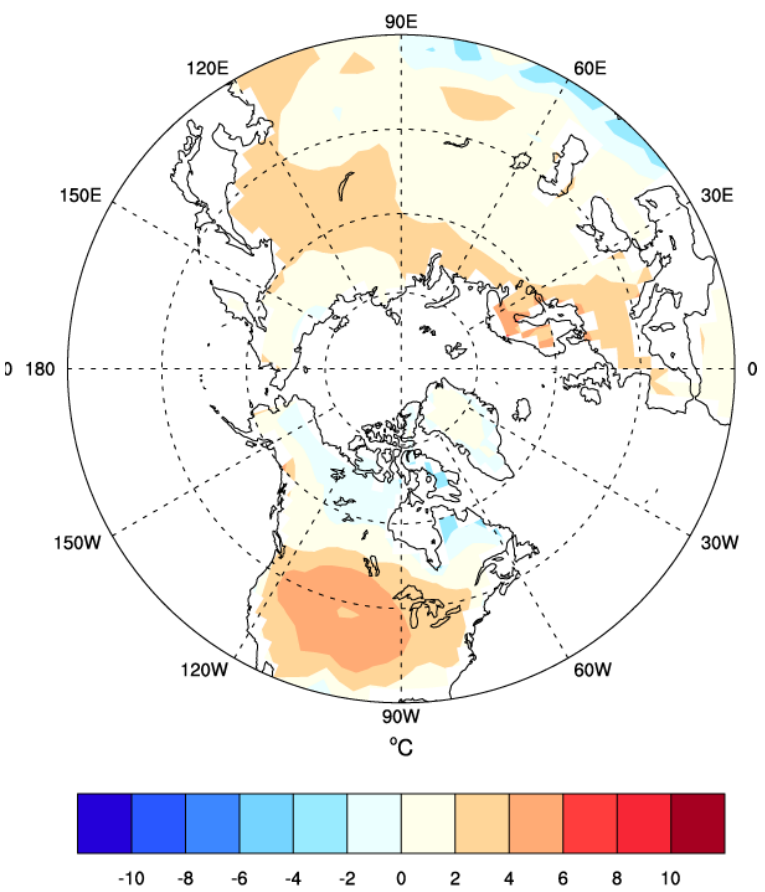
Impacts of Zonal SST Grad.

Changes in North America

Winter Surf. Temperature

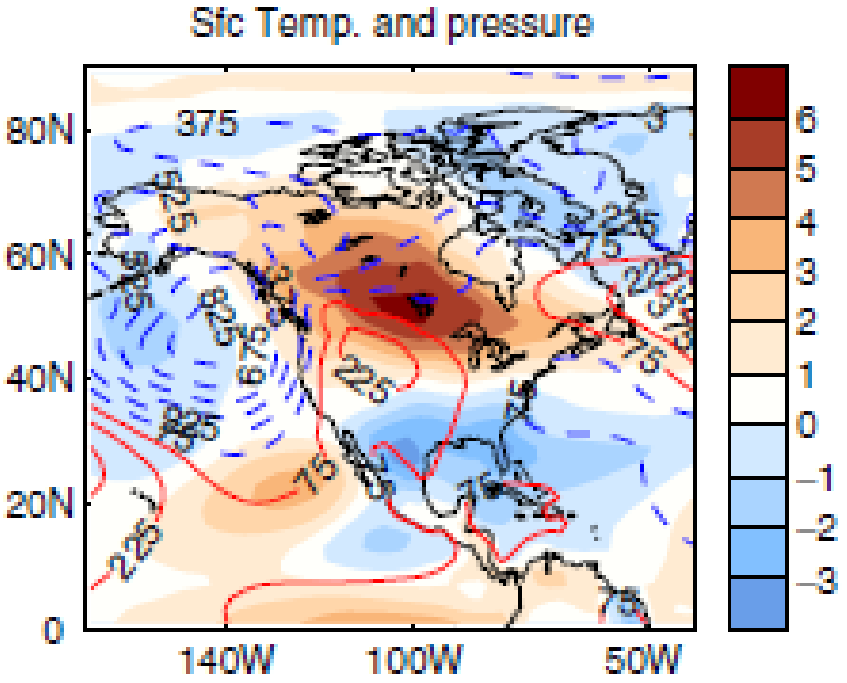


Summer Surf. Temperature



Previous Findings – Pt 1

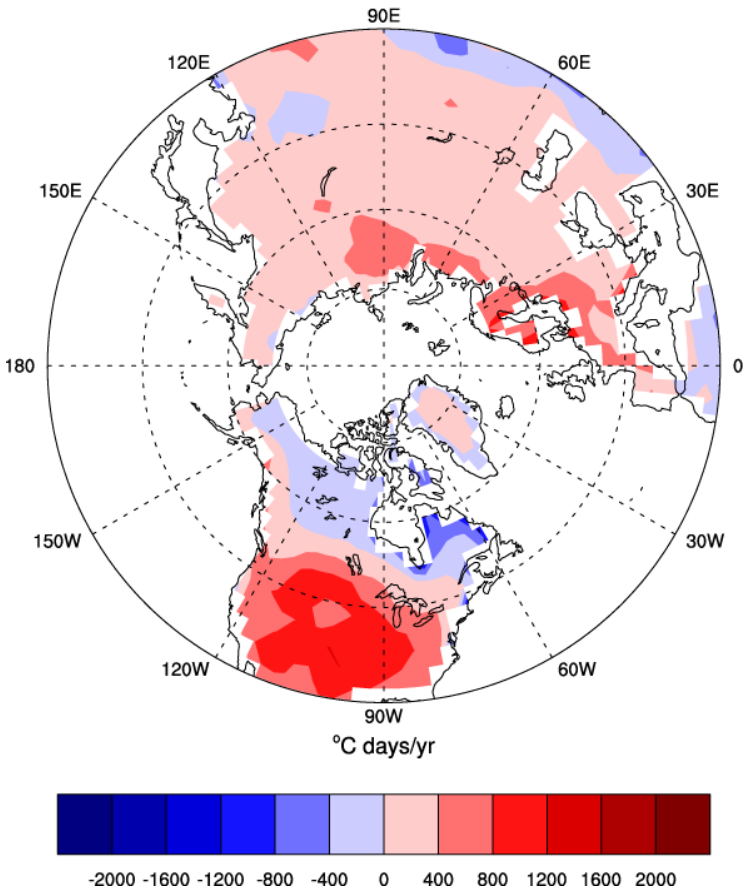
- Barriero et al (06) performed an AGCM experiment to look at permanent El Niño.
- They showed the annual mean temp.
- Concluded that permanent El Niño could prevent glaciation



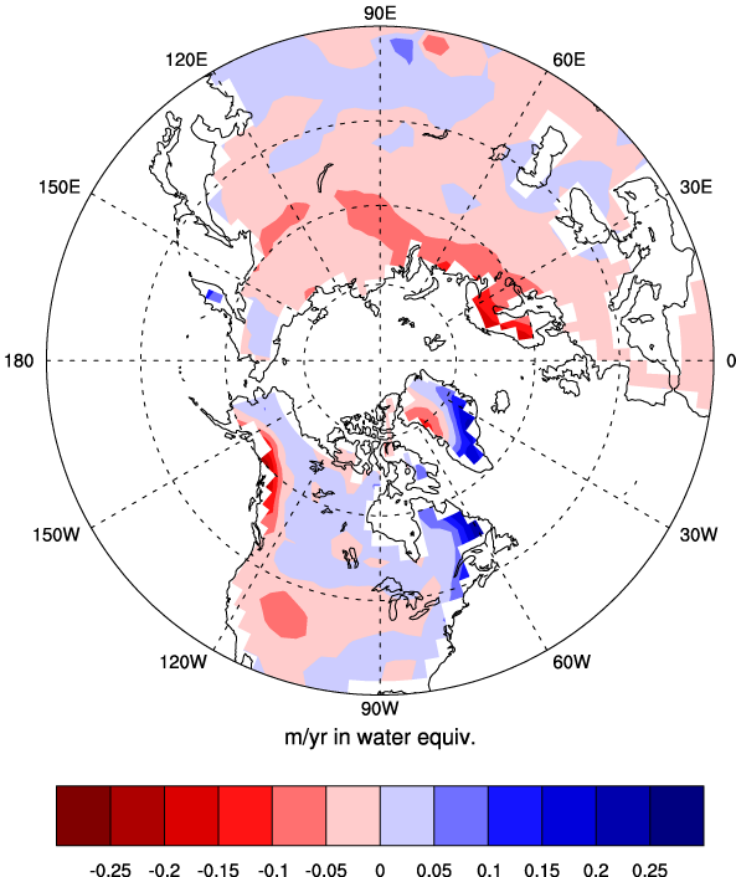
This is the anomaly caused by a permanent El Niño, so positive is reversed from my previous figure.

Changes in North America - 2

Positive Degree Days

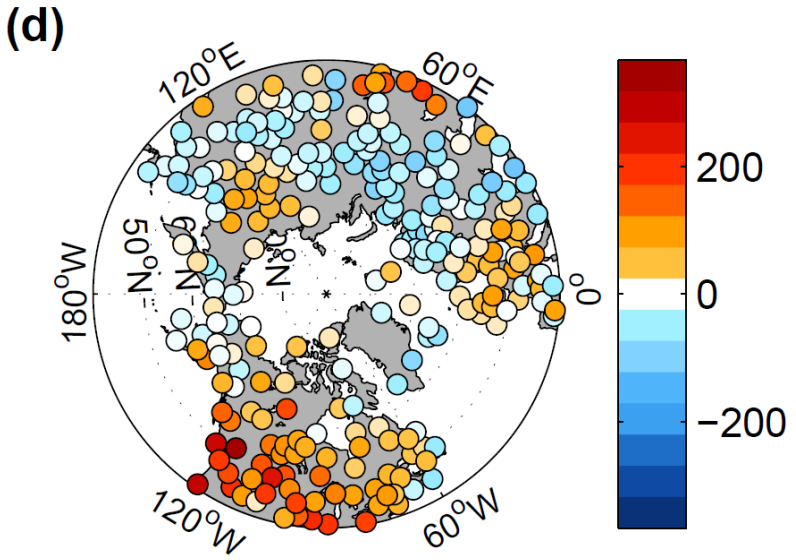


Snow Accumulation



Previous Findings – pt 2

- Huybers & Molnar '07
- Determined present-day El Niño impacts on North America.
- Opposite Response.
- Appear to only include winter temperature changes, not summer ones.

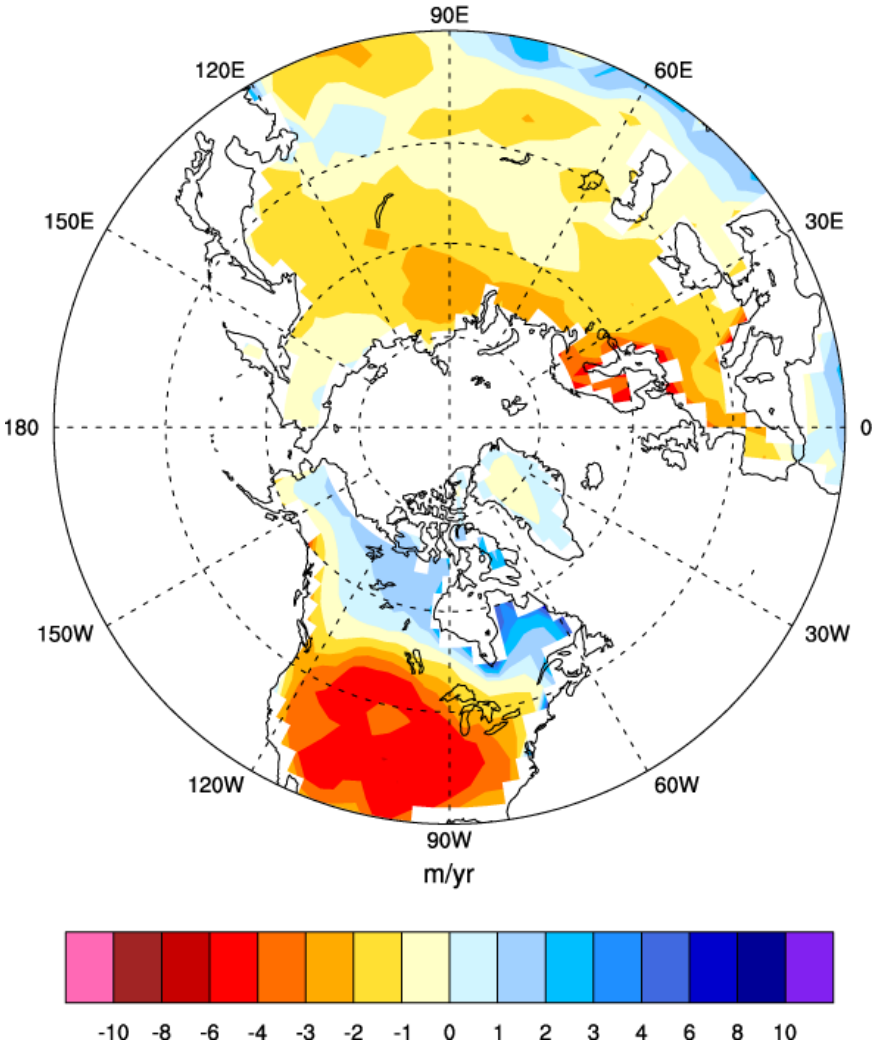


This is the anomaly caused by an El Niño, so positive is reversed from my previous figure.

Change in Mass Balance

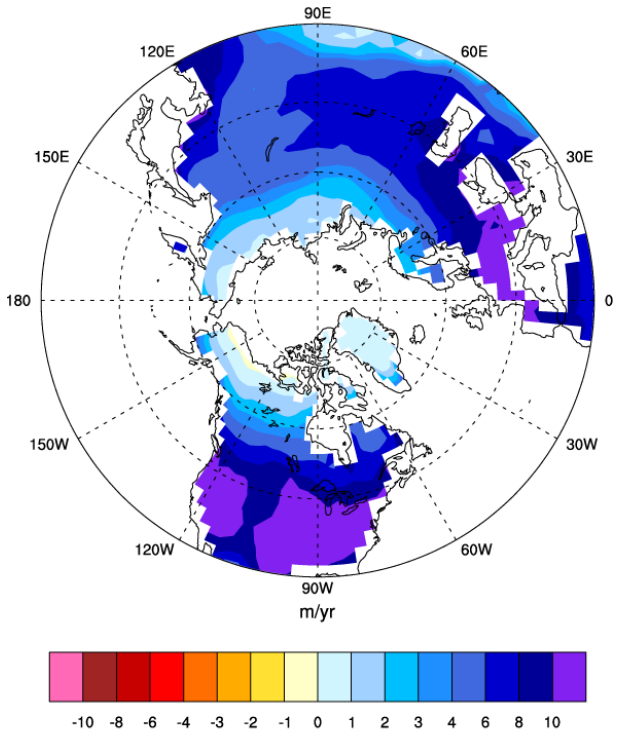
- Combine above two diagnostics:
- $dm/dt = Acc - \beta * pdd$

- Observed changes in zonal SST grad from 2.2 – 1.2 Ma cause variable response in snow melt in N. H.

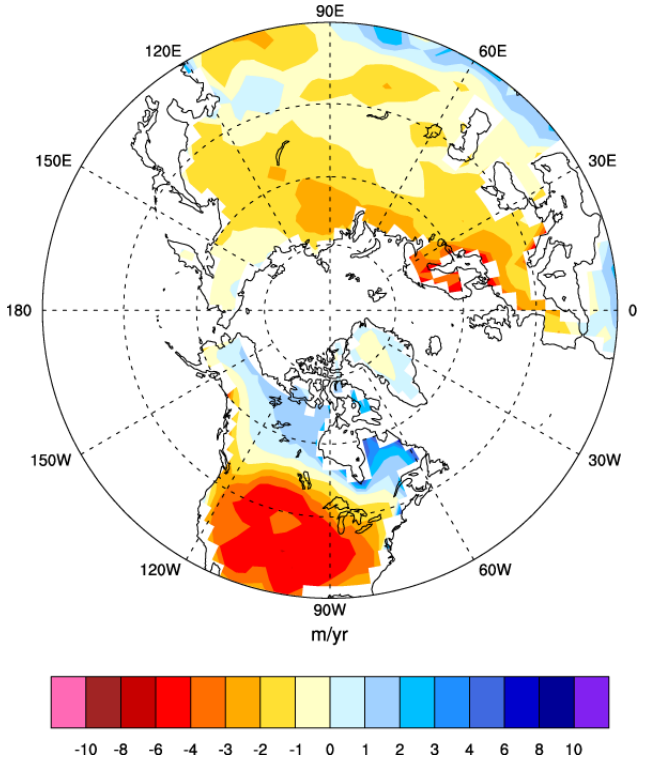


Meridional SST changes dominate!

Meridional SST Impact (3.5-2 Ma)



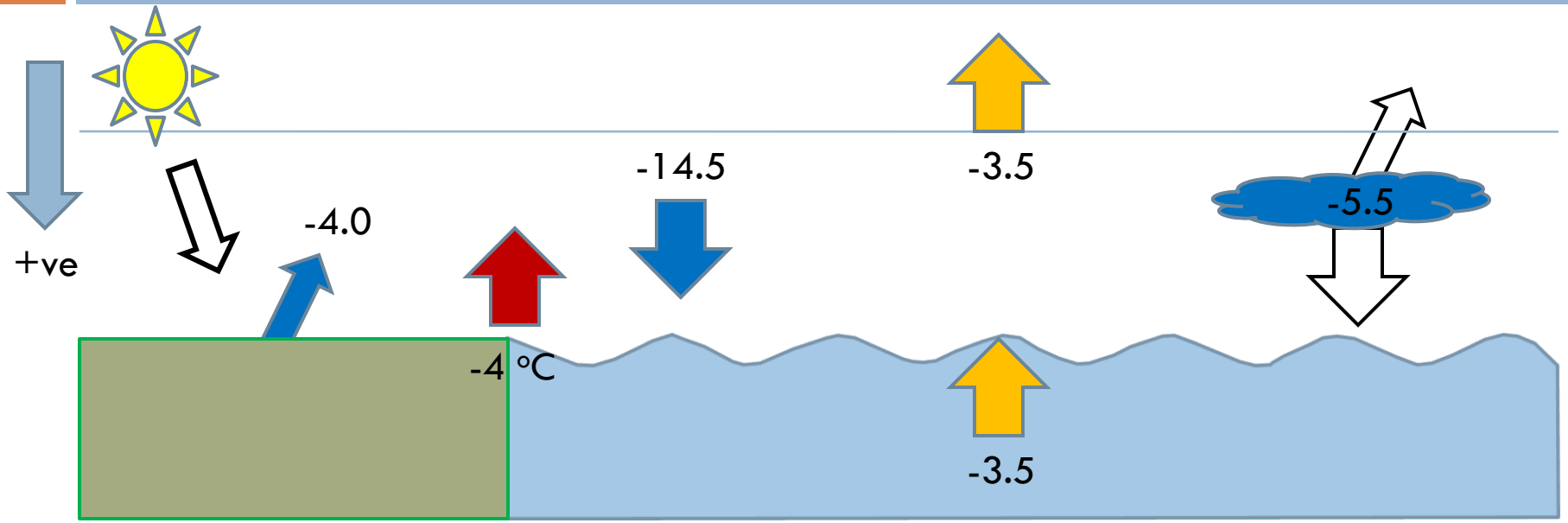
Zonal SST Impact (2.2-1.2 Ma)



Does the Meridional SST gradient always dominate?

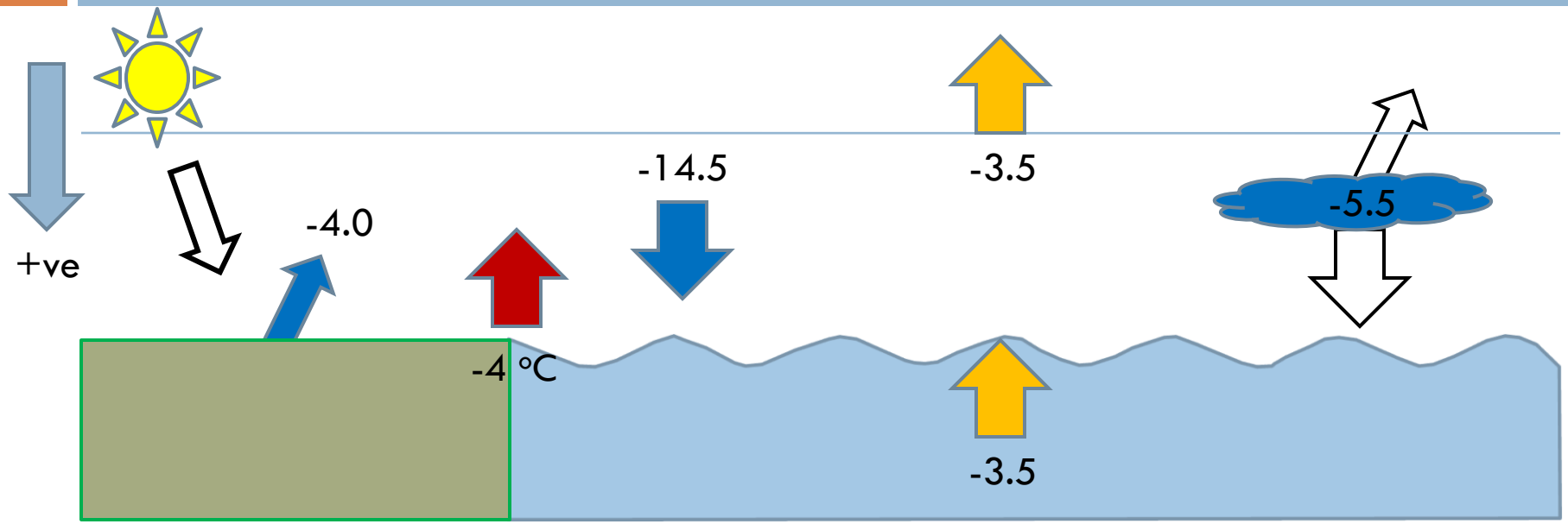
- When we described our early Pliocene reconstruction, we looked at different properties that could help to sustain a warmer climate.
- Are these similarly dominated by the changes in meridional SST gradient?

Global Mean Analysis



Heat Transfer Process	Change in Pliocene
Surface Temperature	-4.0 °C
Water Vapor/Lapse Rate Feedback	-14.5 Wm^{-2}
Cloud Feedbacks	-5.5 Wm^{-2}
Surface Albedo Changes	-4.0 Wm^{-2}
Imbalance	-3.5 Wm^{-2}

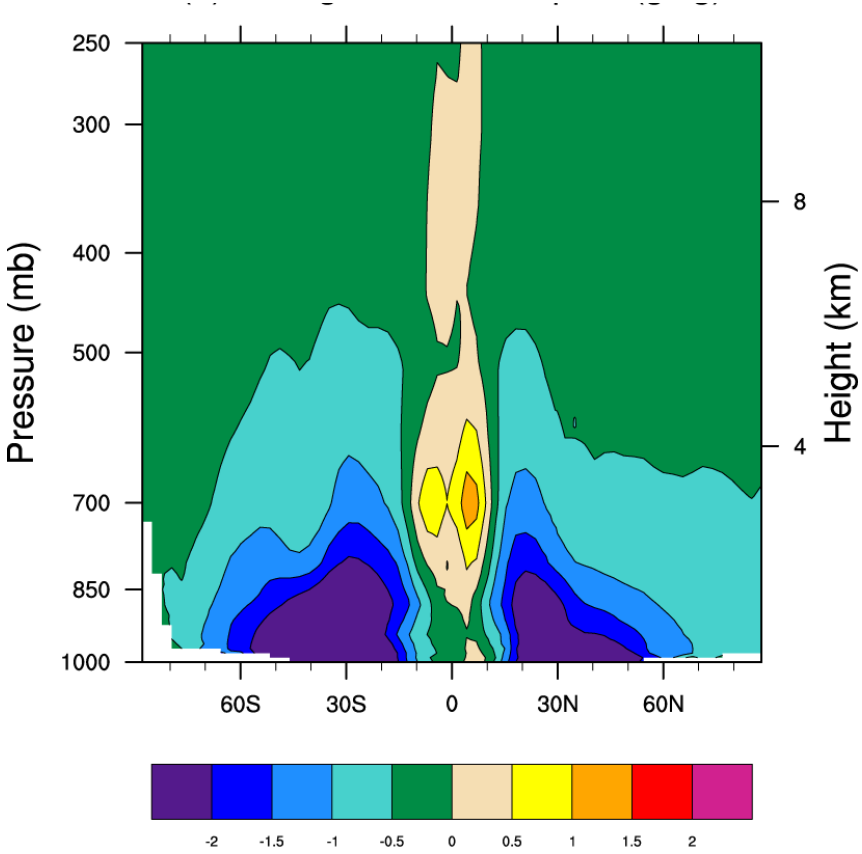
Components from SST gradients



Heat Transfer Process	Meridional SST Grad	Zonal SST Grad
Surface Temperature	-3.2 °C	-0.8 °C
Water Vapor/Lapse Rate	-11.0 Wm^{-2}	-3.7 Wm^{-2}
Cloud Feedbacks	-2.5 Wm^{-2}	-3.6 Wm^{-2}
Surface Albedo Changes	-1.9 Wm^{-2}	-1.6 Wm^{-2}
Imbalance	*1.5* Wm^{-2}	*-5.2* Wm^{-2}

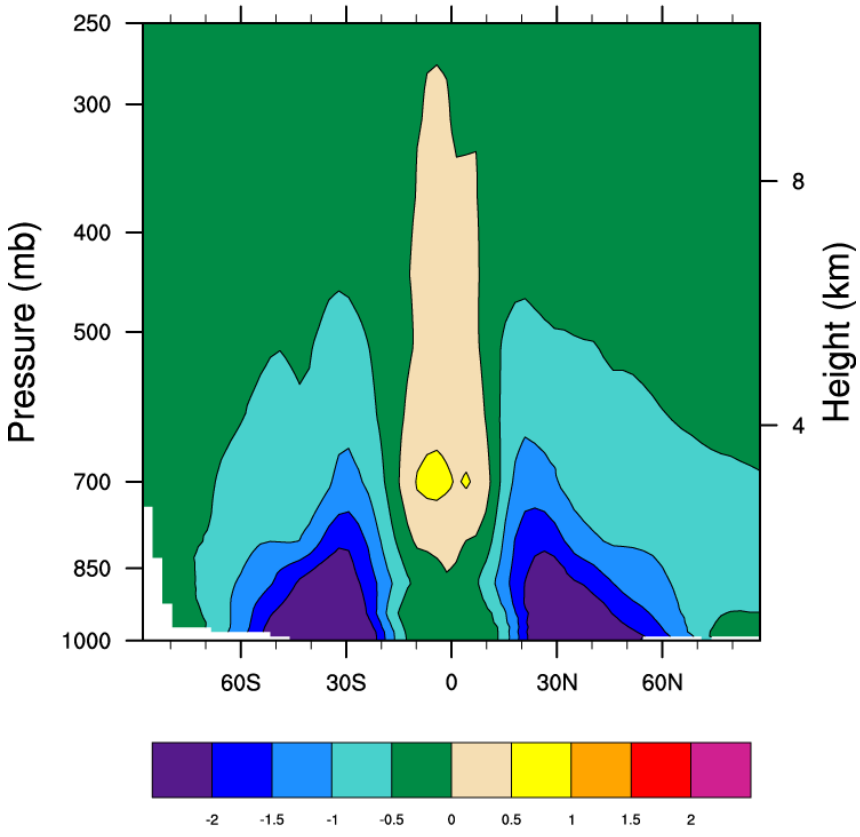
Water Vapor Content

- Difference between present-day conditions and early Pliocene reconstruction.
- Much less water vapor, related to Clausius Clapeyron.
- Increased water vapor with increased deep convection in ITCZ

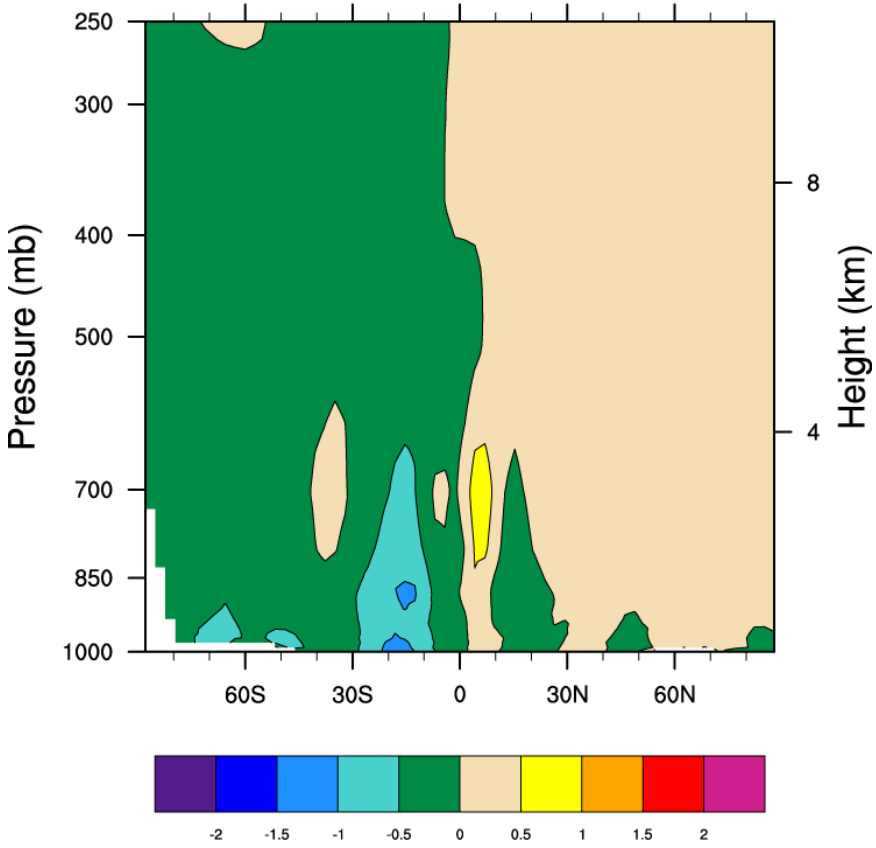


Water Vapor Content

Meridional SST Impact (3.5-2 Ma)

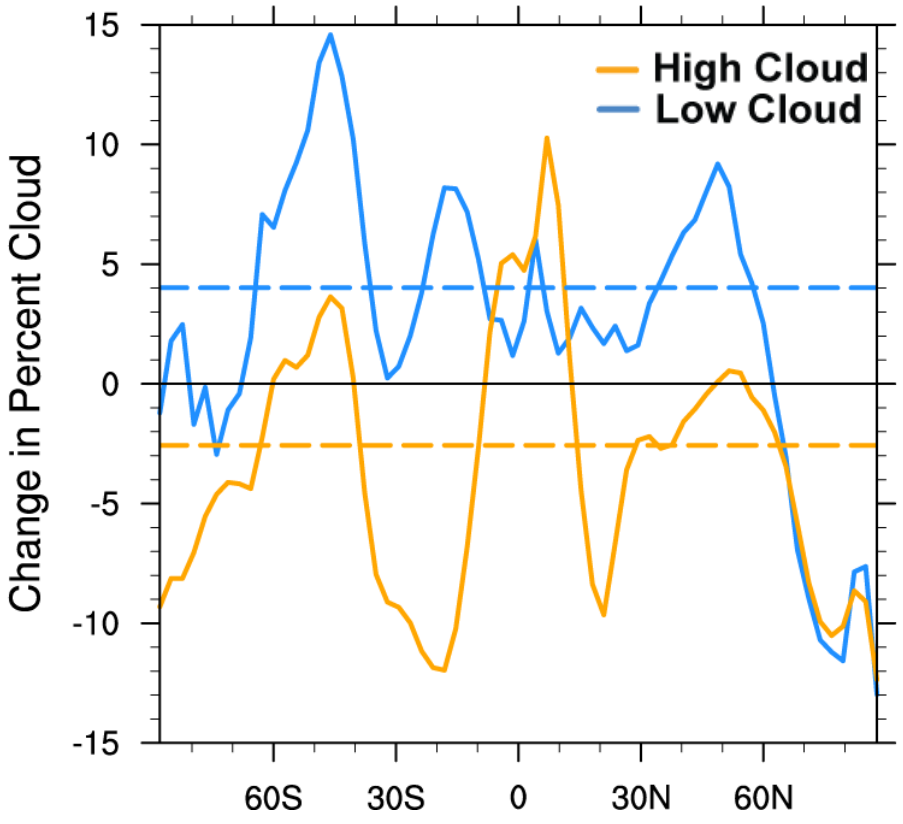


Zonal SST Impact (2.2-1.2 Ma)



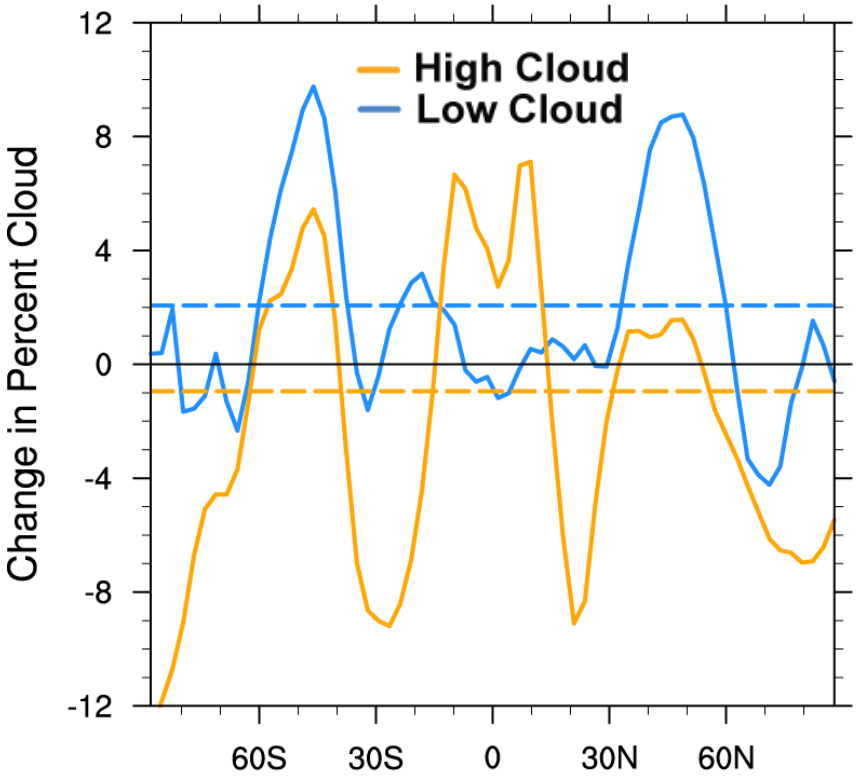
Cloud Cover

- Difference between present-day conditions and early Pliocene reconstruction.
- Increase in low level cloud
- Increased in high cloud/convection in ITCZ, but strong reduction in high cloud in subtropics

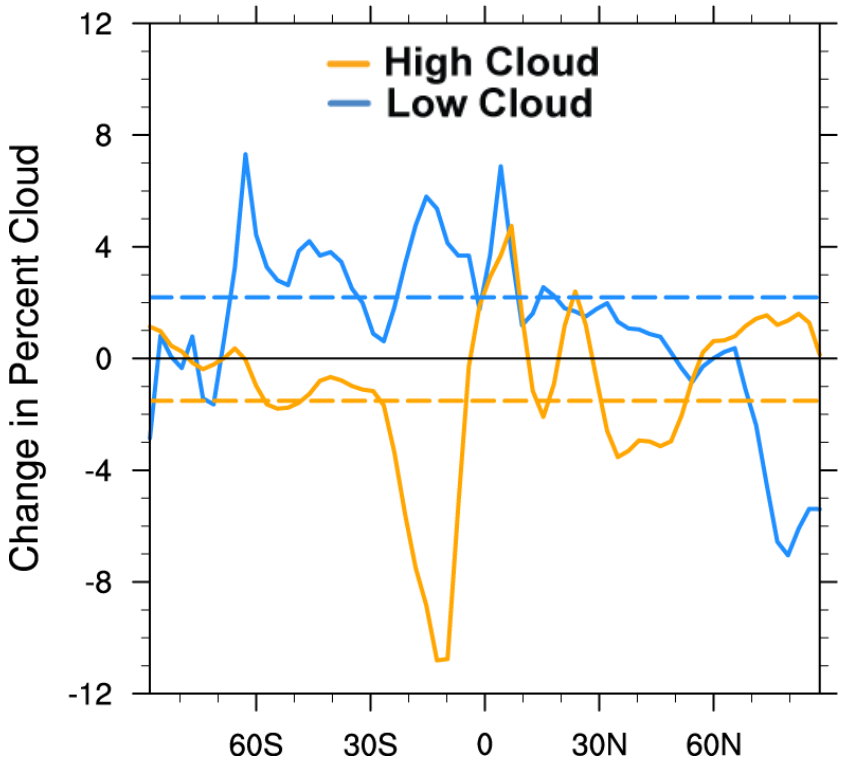


Cloud Cover

Meridional SST Impact (3.5-2 Ma)

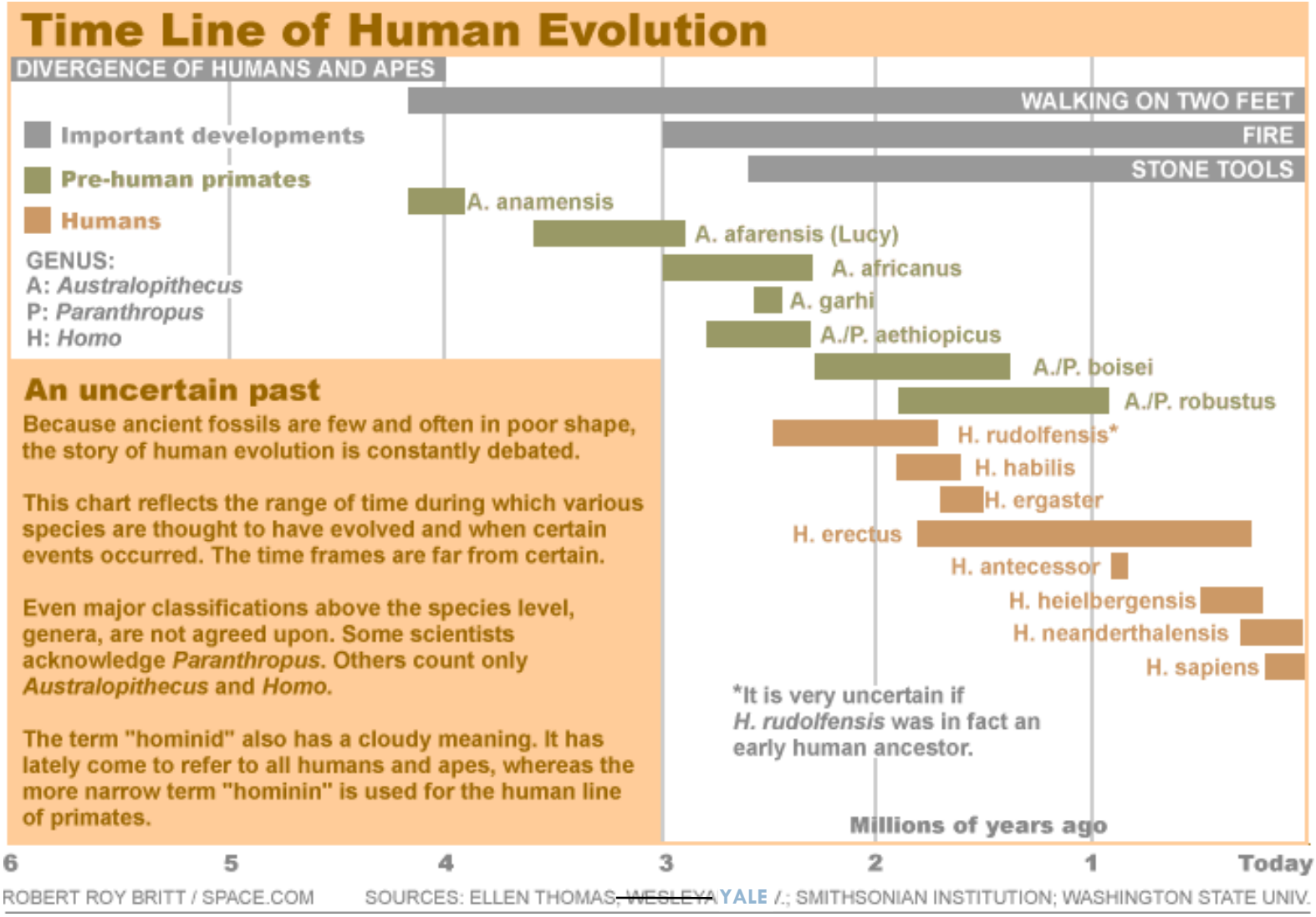


Zonal SST Impact (2.2-1.2 Ma)



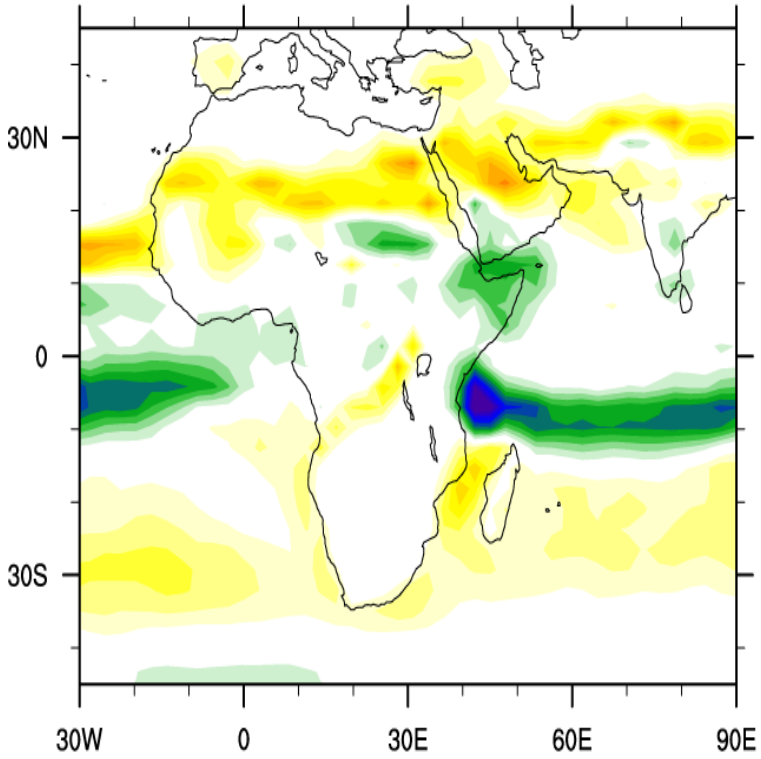
Impacts on African Rainfall

Hominid evolution

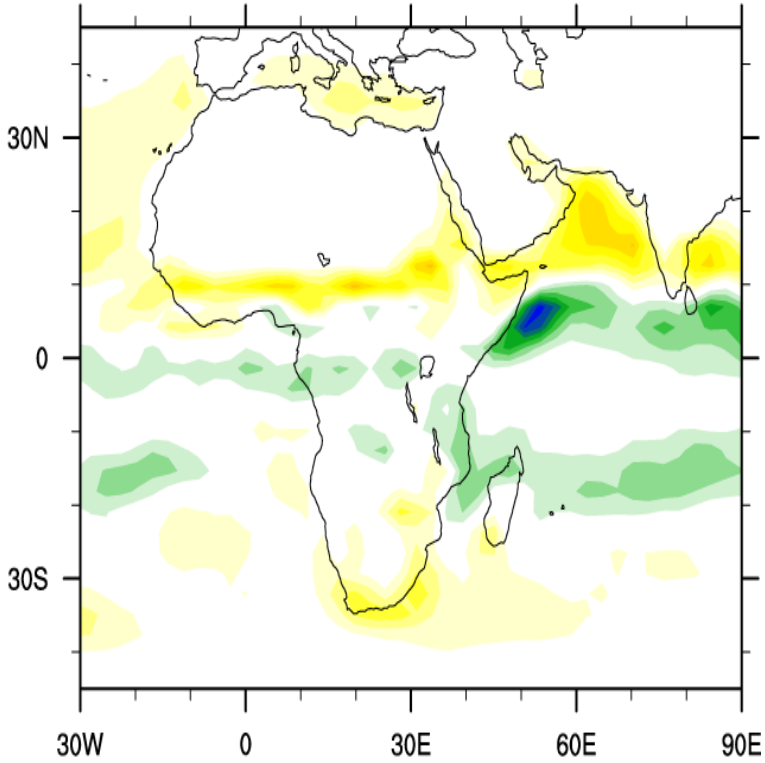


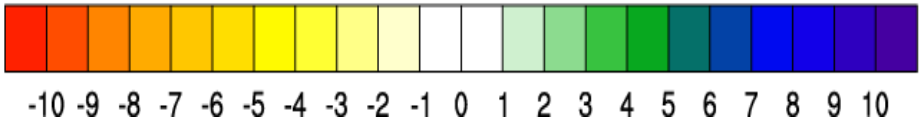
Meridional SST gradient impact on African rainfall (mm/day)

Boreal Summer (JJA)



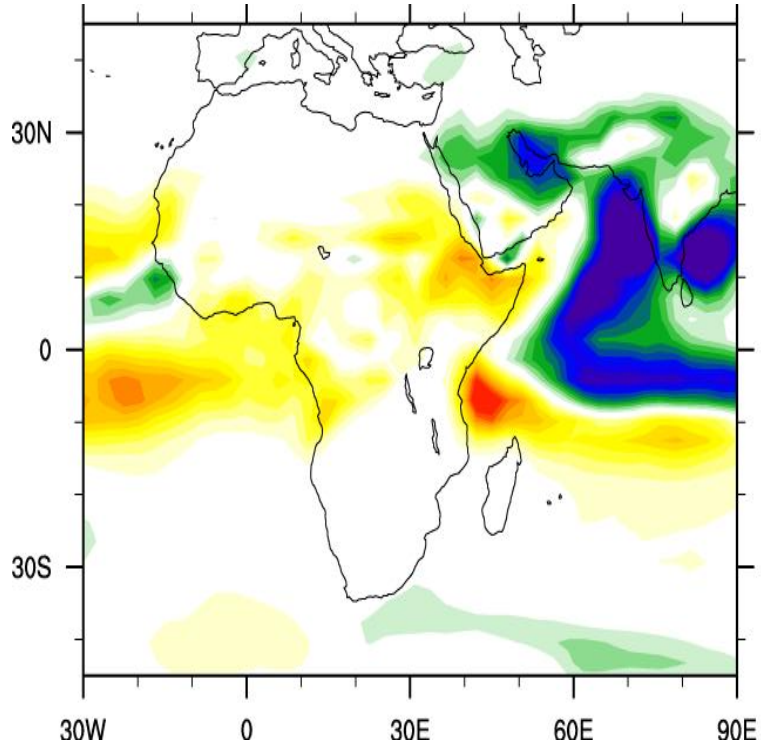
Boreal Winter (DJF)





Zonal SST gradient impact on African rainfall (mm/day)

Boreal Summer (JJA)



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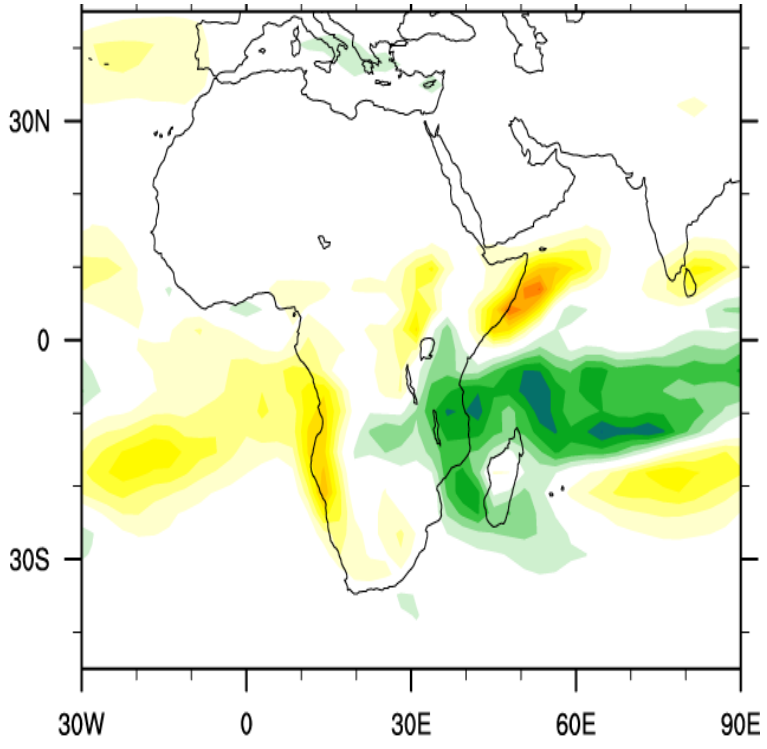
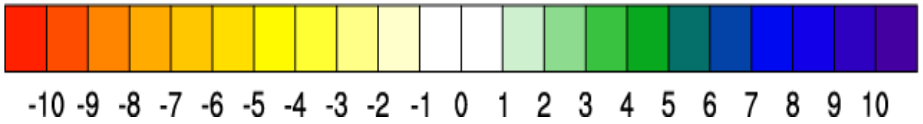




Existence of the Monsoon

- Traditionally the monsoon is thought to have started at ~9Ma.
- Caused by uplift of the Tibetan Plateau providing heat source

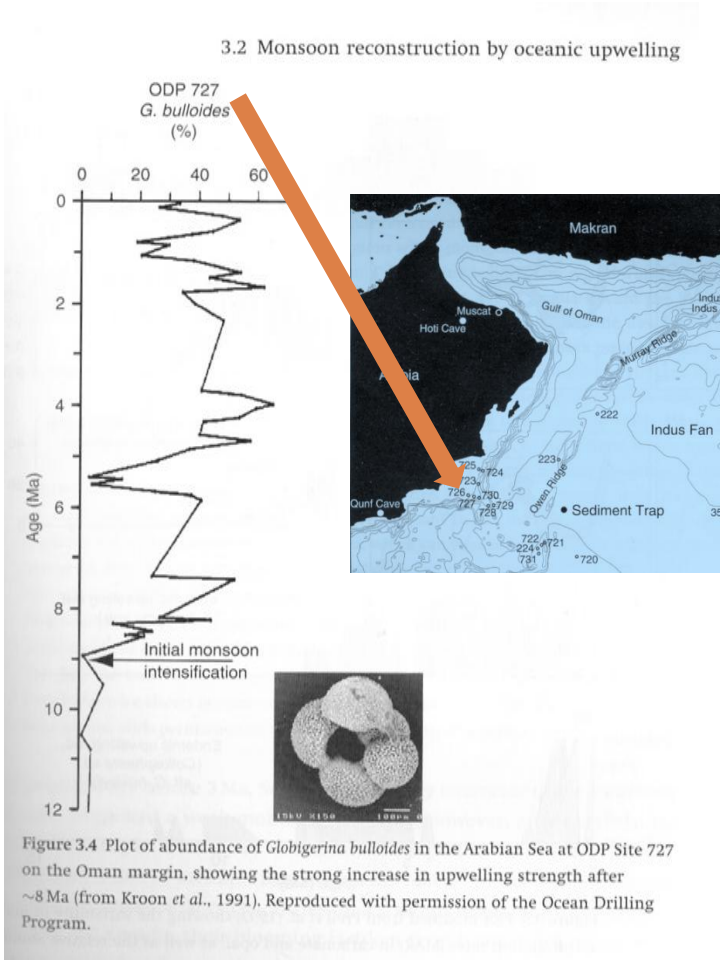
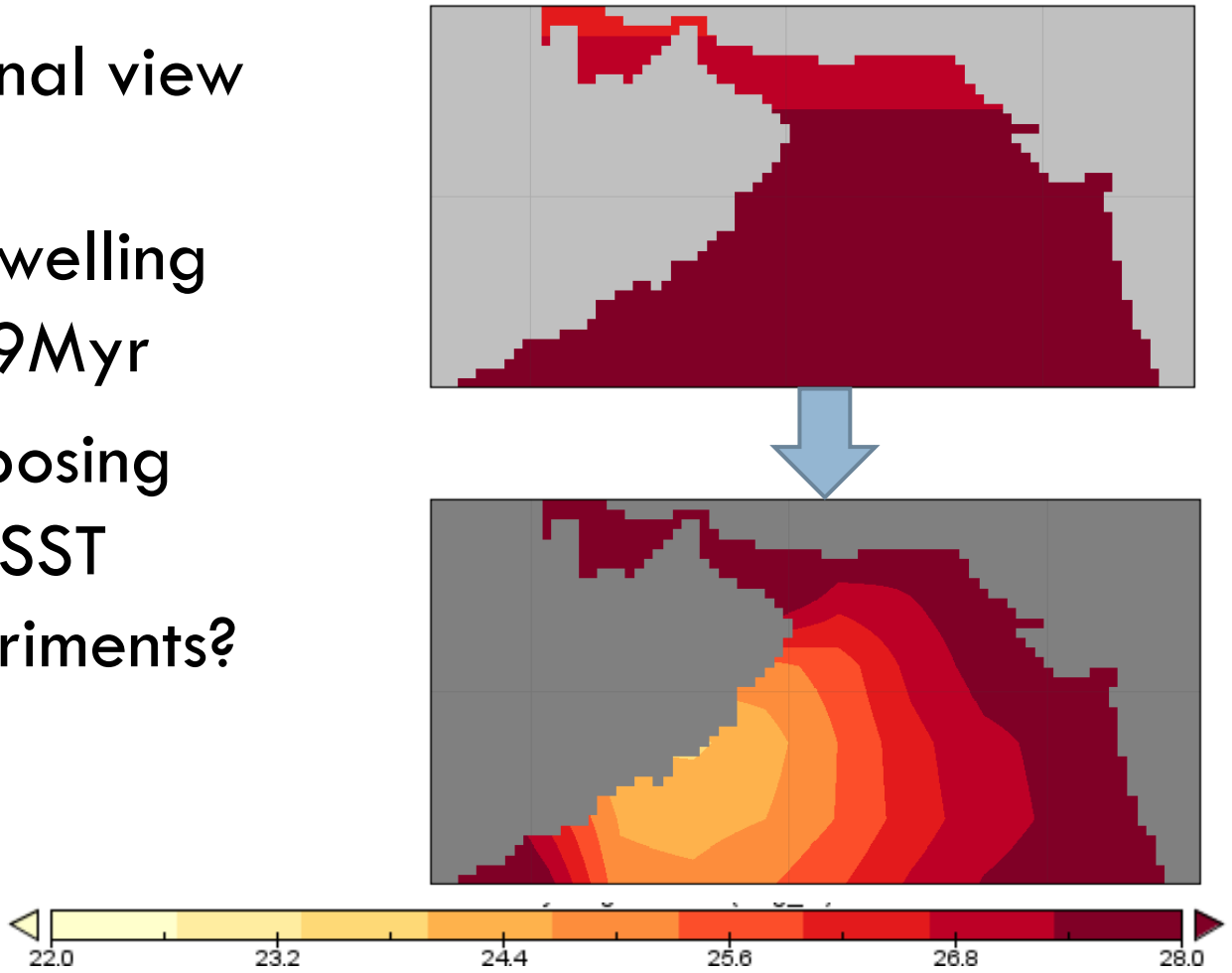


Figure 3.4 Plot of abundance of *Globigerina bulloides* in the Arabian Sea at ODP Site 727 on the Oman margin, showing the strong increase in upwelling strength after ~8 Ma (from Kroon *et al.*, 1991). Reproduced with permission of the Ocean Drilling Program.

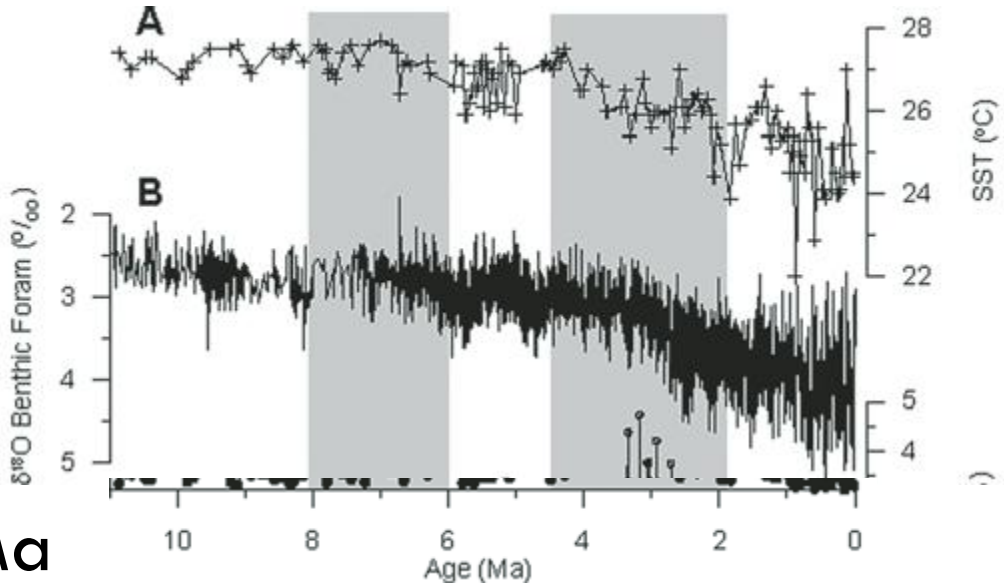
Zonal SST Gradient Expt

- So the traditional view is of a slowly developing upwelling system over ~9Myr
- What am I imposing with my zonal SST gradient experiments?



So is that result relevant?

- Recent SST data from ODP site 772 (near the previous one)
- Implies that the upwelling zone only developed since 4.2Ma



- If there is an alternate mechanism that controls SST then monsoon may not be controlled by tectonics.

Conclusions

- The early Pliocene had a vast pool of warm water in the Pacific.
- The decay of this warmpool had a spatial pattern.
- The meridional contraction of the warmpool is in the right sense to have contributed to the onset of Northern Hemisphere glaciation.
- In general meridional SST changes appear to dominate over zonal ones in high latitudes. This is not true in the Tropics where zonal SSTs dominate rainfall patterns.