TEMPERATURE GRADIENTS AND GLACIATION
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

![Graph showing SST (°C) vs. Age (Ma) for two locations: ODP 846, East Equatorial Pacific, 3°S and ODP 1012, California margin, 32°N.](image-url)
Reduced Difference between Equator and Californian Margin

ODP 846 - ODP 1012
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
Combine above two diagnostics:

\[ \frac{dm}{dt} = \text{Acc} - \beta \ast \text{pdd} \]

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
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
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:
  \[ \frac{dm}{dt} = \text{Acc} - \beta \cdot \text{pdd} \]

- 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)
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

<table>
<thead>
<tr>
<th>Heat Transfer Process</th>
<th>Change in Pliocene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Temperature</td>
<td>-4.0 °C</td>
</tr>
<tr>
<td>Water Vapor/Lapse Rate Feedback</td>
<td>-14.5 Wm(^{-2})</td>
</tr>
<tr>
<td>Cloud Feedbacks</td>
<td>-5.5 Wm(^{-2})</td>
</tr>
<tr>
<td>Surface Albedo Changes</td>
<td>-4.0 Wm(^{-2})</td>
</tr>
<tr>
<td>Imbalance</td>
<td>-3.5 Wm(^{-2})</td>
</tr>
</tbody>
</table>
## Components from SST gradients

### Heat Transfer Process

<table>
<thead>
<tr>
<th>Heat Transfer Process</th>
<th>Meridional SST Grad</th>
<th>Zonal SST Grad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Temperature</td>
<td>-3.2 °C</td>
<td>-0.8 °C</td>
</tr>
<tr>
<td>Water Vapor/Lapse Rate</td>
<td>-11.0 Wm(^{-2})</td>
<td>-3.7 Wm(^{-2})</td>
</tr>
<tr>
<td>Cloud Feedbacks</td>
<td>-2.5 Wm(^{-2})</td>
<td>-3.6 Wm(^{-2})</td>
</tr>
<tr>
<td>Surface Albedo Changes</td>
<td>-1.9 Wm(^{-2})</td>
<td>-1.6 Wm(^{-2})</td>
</tr>
<tr>
<td>Imbalance</td>
<td>1.5 Wm(^{-2})</td>
<td>-5.2 Wm(^{-2})</td>
</tr>
</tbody>
</table>

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![Diagram showing components from SST gradients](image_url)
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

Time Line of Human Evolution

DIVERGENCE OF HUMANS AND APES

Important developments
Pre-human primates
Humans

GENUS:
A: Australopithecus
P: Paranthropus
H: Homo

A. anamensis
A. afarensis (Lucy)
A. africanus
A. garhi
A./P. aethiopicus
A./P. boisei
A./P. robustus
H. rudolfensis*
H. habilis
H. ergaster
H. erectus
H. antecessor
H. heidelbergensis
H. neanderthalensis
H. sapiens

An uncertain past
Because ancient fossils are few and often in poor shape, the story of human evolution is constantly debated.

This chart reflects the range of time during which various species are thought to have evolved and when certain events occurred. The time frames are far from certain.

Even major classifications above the species level, genera, are not agreed upon. Some scientists acknowledge Paranthropus. Others count only Australopithecus and Homo.

The term "hominid" also has a cloudy meaning. It has lately come to refer to all humans and apes, whereas the more narrow term "hominin" is used for the human line of primates.

*It is very uncertain if H. rudolfensis was in fact an early human ancestor.
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)

Boreal Winter (DJF)
Existence of the Monsoon

- Traditionally the monsoon is thought to have started at \(~9\text{Ma}\).
- 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 \(~8\text{Ma}\) (from Kroon et al., 1991). Reproduced with permission of the Ocean Drilling Program.
So the traditional view is of a slowly developing upwelling system over ~9 Myr.

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 warm pool had a spatial pattern.
- The meridional contraction of the warm pool 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.