Greatly expanded warm pool, permanent El Niño, and weaker Hadley circulation in the early Pliocene

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The big question:

How does the tropical Pacific respond to the elevated concentrations of greenhouse gases in the atmosphere (e.g. the SST gradient along the equator)?
Outline:

- **Paleo-observations of the tropical climate state in the early Pliocene: permanent El Niño and meridional expansion of the tropical warm pool**
- **Mechanisms for sustaining a permanent El Niño: results from ocean modeling**
- **What controls the temperature of the equatorial cold tongue?**
- **Climate impacts: modeling with atmospheric GCMs**
- **A potential role for hurricanes in the early Pliocene climate?**
- **Implications for coupled modeling**
- **Implications for the onset of glacial cycles**
“permanent El Niño”
El Niño of 1997 – a partial analogue of permanent El Niño ~3-5Ma

After McPhaden 1998
### New Data Available in past few years

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<thead>
<tr>
<th>Reference</th>
<th>Method used</th>
<th>Site</th>
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Pacific ocean SSTs

4Ma

SST, °C

Latitude

Indo-Pacific
Atlantic
Pacific ocean SSTs

4Ma

SST, °C

Latitude

Indo-Pacific
Atlantic
Pacific (4Ma):

Zonal temperature gradient (between the East and West Pacific):

\[ \Delta T \sim 6^\circ C \]

Pliocene (~4Ma): \[ \Delta T < 1^\circ C \] - permanent El Niño!

Meridional temperature gradient (between 0° and 30°N/S):

\[ \Delta T \sim 10^\circ C \]

Pliocene: \[ \Delta T \sim 2^\circ C \] - meridional expansion of the warm pool!

All of these with CO₂ at 350-400ppm!
Mechanisms for sustaining a Permanent El Niño: Results from ocean modeling
Trajectories of water parcels (after Harper 2000). After subduction induced by Ekman pumping some water parcels join the subtropical gyre; other parcels travel towards the equator (wind-driven overturning, or the shallow Subtropical Cell - STC).
Temperature along the equator and SSTs (°C) when anomalously warm / cold temperatures ($T^*$) are imposed in the extra-tropical Pacific.

Calculations with idealized ocean GCM:

- $T^*$=10°C: Colder Extra-tropics
- $T^*$=15°C: Standard case
- $T^*$=20°C: Warmer extra-tropics

"Permanent El Niño"
From the point of view of the ocean:

A permanent El Niño implies a reduced poleward heat transport by the ocean.
The dependence of zonal SST gradient on the meridional SST gradient.

\[ \Delta T_{\text{zonal}} \]

- low vertical mixing
- medium vertical mixing
- high vertical mixing

\[ 6^\circ C \]

\[ 10^\circ C \]

\[ \Delta T_{\text{meridional}} \]
Climate impacts: modeling with atmospheric GCMs
**Tropical warm pool (observations)**

**Hypothetical warm pool in the early Pliocene (~4Ma)**
Atmospheric circulation along the equator - the collapse of the Walker circulation

Calculations with an atmospheric GCM:
Overturning streamfunction for the present-day simulation (left) and the early Pliocene (right) showing weaker Hadley circulation in the Pliocene
Precipitation: present-day (top) and the Pliocene (bottom)
Changes in E-P (Pliocene – present)
Changes in water vapor, g/kg (Pliocene – present)
Changes in low and high clouds (Pliocene – present)

- More high clouds
- Fewer low clouds
Implied northward heat transport by the ocean and the atmosphere (from atmospheric GCM)

**Pliocene:**

The difference (Pliocene - Present):
From the point of view of the ocean:

*A permanent El Niño implies a reduced poleward heat transport by the ocean.*
The poleward heat transport paradox for the Pliocene tropical state:

(1) the atmosphere requires the ocean to increase its poleward heat transport (in an atmospheric GCM)

(2) the ocean needs to reduce its heat transport (in an ocean GCM)

(1) contradicts (2)

Thus, an additional mechanism is needed for transporting heat either by the ocean or the atmosphere or simply an increased heat uptake by the ocean. This mechanism is presumably absent in the current generation of coupled models.
Sustaining the Pliocene (and other equable) climate: Is there a role for hurricanes?
Tracks of all tropical cyclones, 1985-2005

Annual average of vertical diffusivity attributable to cyclone mixing (Sriver and Huber 2007)
Statistical downscaling model

North Atlantic

Number of events per millennium

Maximum surface wind speed (kts)

Pliocene Hurricanes - preliminary results with Kerry Emanuel and Chris Brierley
Meridional contraction of the warm pool between 4 and 2 Ma and its impacts on North America: implications for the onset of Northern Hemisphere Glaciation.
Summary:

If the proxy temperature data are correct:

- The early Pliocene (4Ma) is characterized by significantly reduced zonal (along the equator) and meridional (from the equator to the subtropics) SST gradients (for CO₂ concentrations ~ 350-400ppm)

- This implies a significant poleward expansion (50-100%) of the tropical warm pool concurrent with permanent El Niño-like conditions

- This has large climatic implications for the Hadley circulation, ITCZ, precipitation, clouds, water vapor, albedo, summer and winter temperatures and snow cover over North America

- To fully reproduce this climate state an additional mechanism for poleward heat transport/ heat uptake by the ocean is probably needed. This mechanism appear to be absent in the current generation of coupled GCMs