THE ICE AGE CLIMATE EXPERIMENT

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The Plio-Pleistocene Climate Transition

ODP Site 846

Transitional response 100 kyr
smaller, less variable ice sheets

Onset of Northern Hemisphere Glaciation
IT’S ALL ABOUT FEEDBACKS: Albedo

NASA. Photo #: STS045-152-105
IT’S ALL ABOUT FEEDBACKS: Dust
IT’S ALL ABOUT FEEDBACKS: CO₂ & G.G.
From Levitus Ocean Atlas (1994)
Uk$^{37}$ Temperature = 14.4°C

\[ \text{Uk}^{37} = \frac{[C_{37:2}]}{[C_{37:2} + [C_{37:3}]]} \]
SST CHANGE REALLY SIMILAR!
SST VARIATIONS OUT OF PHASE W/ TROPICAL FORCING!

(Liu and Herbert, 2004)
SST VARIANCE INCREASES EXPONENTIALLY
SST VARIATIONS BECOME COHERENT AT ~2.7 Ma!

In the diagram, the coherence of SST variations is shown for different regions over time. The graph focuses on the 41 kyr band, with coherence values ranging from 0.2 to 0.8. The regions labeled include EEqPac-Arabian Sea, EEqPac-EEqAtl, and Arabian Sea-EEqAtl.
The CO$_2$-Ice Age Connection

• Tropical SST strongly linked to “high latitude” $\delta^{18}$O signal, last 2.7 Ma
• 41 kyr response can’t originate in tropics
• 41 kyr response not likely driven by thermocline processes $\rightarrow$ atmosphere
• “Memory” component stronger than for $\delta^{18}$O, suggests biogeochemical cycle control
• Key “innovation” involved coupling of N. Hemisphere ice sheet growth to CO$_2$, other G.G. for last $\sim$2.7 Ma on orbital to $\sim$400 kyr time scales
• Did CO$_2$, G.G. drive the long-term trend, past 3.5 Ma?
ICE AGE/SST EVOLUTION HIGHLY ASYMMETRICAL
Future work

- Ocean temperature evolution of the last ~5 million years
  - how do temperature changes propagate throughout the climate system?
  - how closely are different regions of the ocean linked?
- What's happening in the southern hemisphere?

Cleaveland and Herbert, in prep
Evolutive Spectra

ETP: Productivity
SST
δ\textsuperscript{18}O

Spectral Density

Time (ka)

Frequency (cycles/kyr)

Period

0.01 0.02 0.03 0.04 0.05
E-W SST comparison: Not the thermocline, through the atmosphere?

![Graph showing SST variations over time](image_url)

- Warm Pool SST (Medina Elizade et al., 2006)
- E. Eq. Pac. Cold Tongue (Liu & Herbert, 2004)
3 Ma Frequency Shift?

~3Ma

5 Ma

41 K

23 K

41 K

23 &
Tropical SST response

- highly similar SST response across multiple tropical locations, despite differences in local dynamics

Cleaveland and Herbert, 2007
PUZZLE #2: where is the memory?
High/Low Latitude Connections
Heat Flux Hypothesis

~3Ma Change from a Locally to Non-Locally Balanced Heat Budget

(From Philander and Fedorov 2003)
(After Da Silva et al, 1994)
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Onset of Northern Hemisphere Glaciation

$\delta^{18}O$ vs. Age (ka)

Mix et al. 1995; Shackleton et al. 1995
• Same Finding: In the 41 K band, High Ice Volume corresponds to low SST, high Productivity and Weak High Latitude Solar Forcing (Low Tilt)
Since ~3 Ma
Obliquity Controls
Tropical Thermocline
Depth (Philander and
Fedorov 2003)

Low Tilt ⇒ La Niña

High Tilt ⇒ El Niño
Phase relationships vary little over the past 5 Myrs.
High/Low Latitude Connections

Sarmiento et al. (2004)

Time Transgressive High Latitude Productivity Crash
Low Latitude Alkenone Records

\[ C_{37} \text{ Total (Productivity)} \]

\[ \text{Uk'}^{37} \text{ Temperature} \]

\[ \text{Benthic } \delta^{18}O \]

From (Mix et al., 1995; Shackleton et al. 1995)

\[ \text{(Lawrence et al., in review)} \]