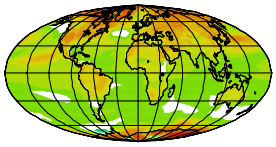
Cause of Pliocene warmth & Intensification of Northern Hemisphere Glaciation



UNIVERSITY OF LEEDS

Talk Outline

UNIVERSITY OF LEEDS

- **The Pliocene – a stranger world than you might think**
- **Climate evolution – the last 5 million years**
- **The mid-Pliocene warm period**
- **Modelling mid-Pliocene climates**
- ***CASE Study 1*: relative contribution to mid-Pliocene warmth**
- ***CASE study 2*: forcing factors important for Northern Hemisphere Glaciation**

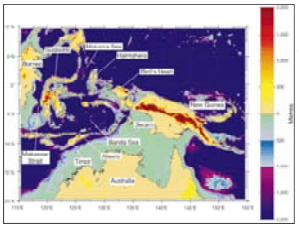
A strange world…….

With big differences……..

Himalayas & Tibetan Plateau

Western Cordillera of North & South America

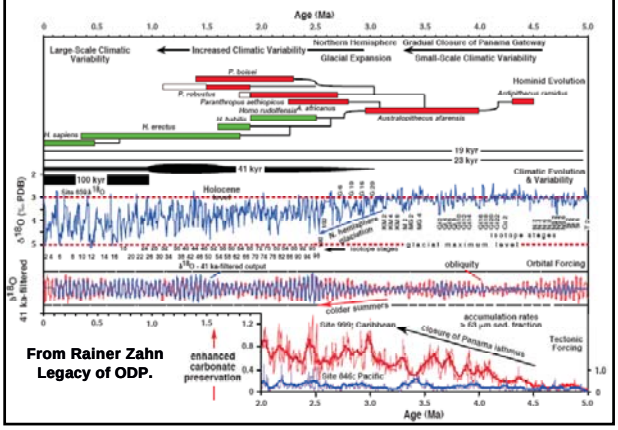
East African Rift



Map of the Indonesian-through flow region. The main islands, crustal fragments, and other topographic features are labelled. Currently most Indonesian through flow passes north of Sulawesi, then west of Sulawesi through the Makassar Strait, and Finally across the Banda arc (from Cane & Molnar, 2001, *Nature)*.

Swan's Cay Island 16 Km from the the Isthmus of Panama

Climate Evolution Over the Last 5 Million Years

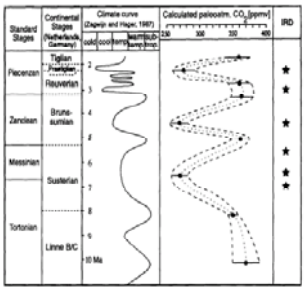


From Rainer Zahn Legacy of ODP.

Cause of Pliocene Warmth

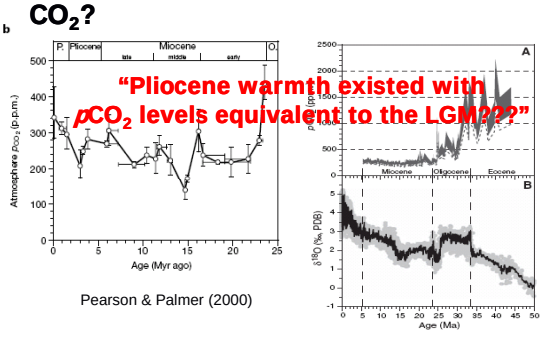
- Stomatal density of fossil leaves.
- Analysis of $\delta^{13}C$ of marine organic carbon.
- Carbon isotopic composition of surface and deep waters.

Best estimate 360-400 ppmv



Problems.....

A Decoupling Between Climate & CO_2?

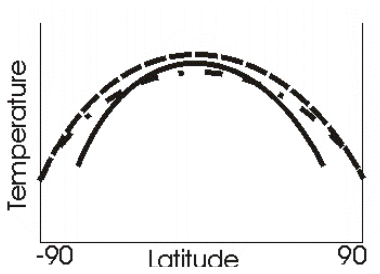


"Pliocene warmth existed with pCO_2 levels equivalent to the LGM???"

Pearson & Palmer (2000)

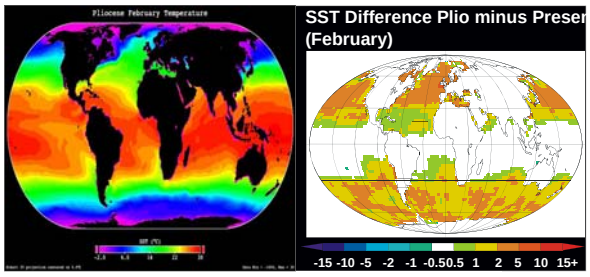
Pagani et al. (2005)

Temperature Gradients: Clue to Causality?



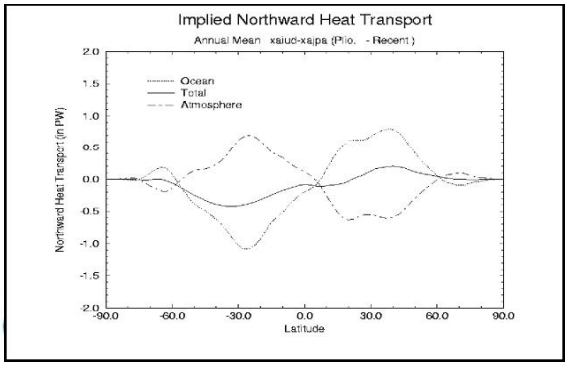
Modern
Enhanced OHT
Higher CO_2

PRISM Estimates of Sea Surface Temperature



http://geology.er.usgs.gov/eespteam/prism/prism3main.html

Ocean Heat Transport, yet more problems



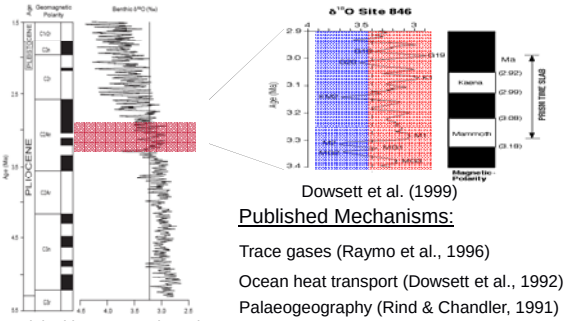
Case Study 1: Cause of Pliocene warmth

UNIVERSITY OF LEEDS

1) The Pliocene & causes of Pliocene warmth
2) Previous modelling studies & limitations
3) An ensemble modelling approach (*tracking changes from the pre-industrial to Pliocene*)
4) Model description
5) Relative contribution to Pliocene warmth
6) Summary

1. Cause(s) of mid Pliocene Warmth

UNIVERSITY OF LEEDS



Lisiecki & Raymo (2005)

Dowsett et al. (1999)

Published Mechanisms:

Trace gases (Raymo et al., 1996)

Ocean heat transport (Dowsett et al., 1992)

Palaeogeography (Rind & Chandler, 1991)

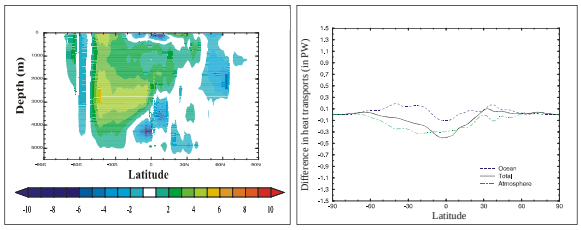
ENSO dynamics (Philander & Federov, 2003)

2. Previous Modelling & Limitations

(Haywood & Valdes, 2004)

UNIVERSITY OF LEEDS

First coupled ocean-atmosphere GCM simulation for the mid Pliocene

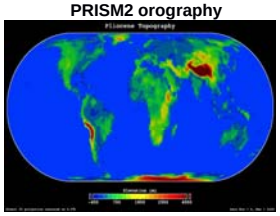


Relative importance of forcing mechanisms on mid Pliocene warmth:
Higher CO_2 levels = 1.9 Wm^{-2}
Changes in surface albedo = 2.3 Wm^{-2} (55% ice sheets, 45% sea-ice)
Cloud radiative forcing = 1.8 Wm^{-2}

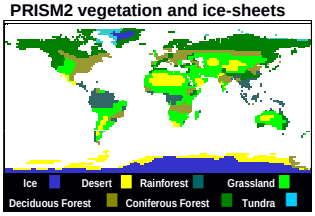
2. Diagnosing Effect of Boundary Condition Changes

UNIVERSITY OF LEEDS

PRISM2 orography



PRISM2 vegetation and ice-sheets



Trace gases: CO_2 @ 400 ppmv

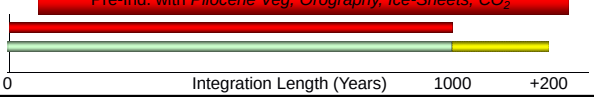
Monthly sea surface temperatures and sea-ice coverage/depth predicted by the GCM

3. An Ensemble Modelling Approach

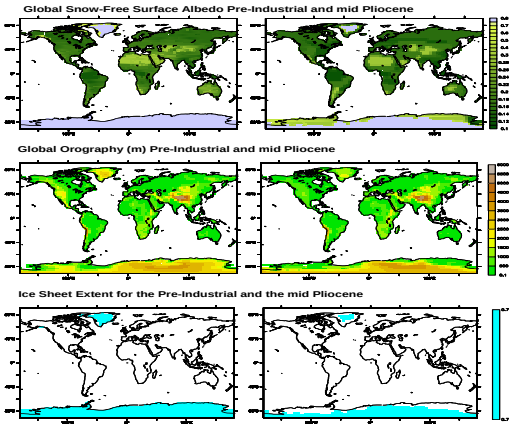
(*tracking changes from the pre-industrial to Pliocene*)

UNIVERSITY OF LEEDS

1. Pre-Industrial Control (**PreInd**^{Control})
   Pre-Ind. Vegetation, Ice-Sheets, Orography & CO_2
2. Pre-Industrial with Pliocene Vegetation (**PreInd**^{PlioVeg})
   Pre-Ind. Ice-Sheets, Orography, CO_2 with *Pliocene Vegetation*
3. Pre-Industrial with Pliocene Vegetation & Orography (**PreInd**^{PlioVegOrog})
   Pre-Ind. Ice-Sheets, CO_2 with *Pliocene Vegetation & Orography*
4. Pre-Industrial with Pliocene Vegetation, Orography & Ice-Sheets (**PreInd**^{PlioVegOrogIce})
   Pre-Ind. CO_2 with *Pliocene Veg, Orography, Ice-Sheets*
5. Pliocene Control with Pliocene Veg., Orography, Ice-Sheets & CO_2 (**Plio**^{Control})
   Pre-Ind. with *Pliocene Veg, Orography, Ice-Sheets, CO_2*



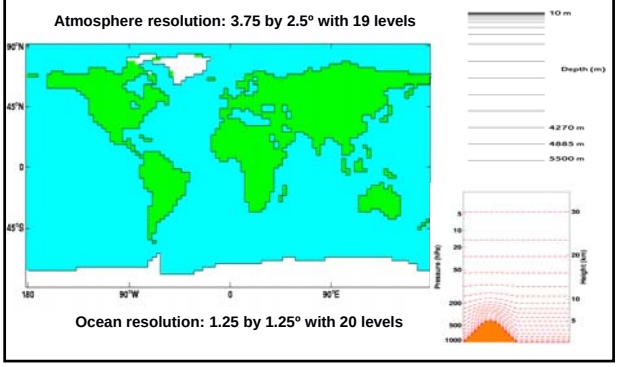
0 Integration Length (Years) 1000 +200



4. The Hadley Centre Coupled Climate Model (HadCM3)

UNIVERSITY OF LEEDS

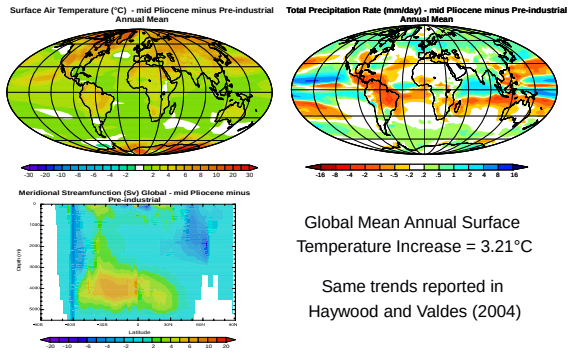
Atmosphere resolution: 3.75 by 2.5° with 19 levels



Ocean resolution: 1.25 by 1.25° with 20 levels

5. Relative Contribution to mid Pliocene Warmth – Control Simulation ($Plio^{Control}$)

UNIVERSITY OF LEEDS



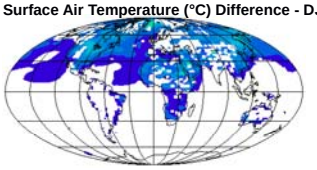
Global Mean Annual Surface Temperature Increase = 3.21°C

Same trends reported in Haywood and Valdes (2004)

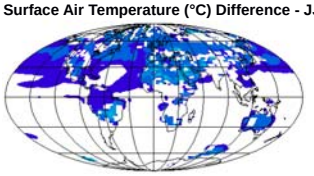
5. Relative Contribution to mid Pliocene Warmth – Effect of Vegetation ($PreInd^{PlioVeg}$)

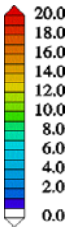
UNIVERSITY OF LEEDS

Surface Air Temperature (°C) Difference - DJF



Surface Air Temperature (°C) Difference - JJA

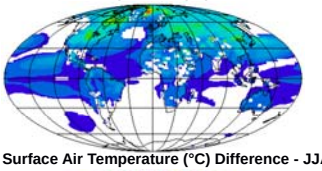




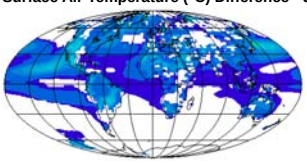
5. Relative Contribution to mid Pliocene Warmth – Effect of Orography ($PreInd^{VegOrog}$)

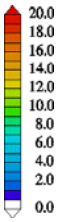
UNIVERSITY OF LEEDS

Surface Air Temperature (°C) Difference - DJF



Surface Air Temperature (°C) Difference - JJA

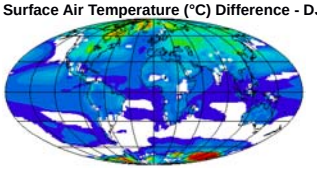




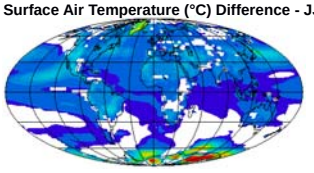
5. Relative Contribution to mid Pliocene Warmth – Effect of Ice ($PreInd^{VegOrogIce}$)

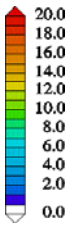
UNIVERSITY OF LEEDS

Surface Air Temperature (°C) Difference - DJF



Surface Air Temperature (°C) Difference - JJA

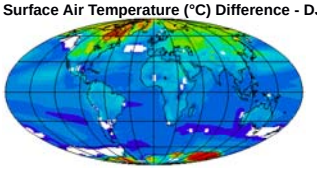




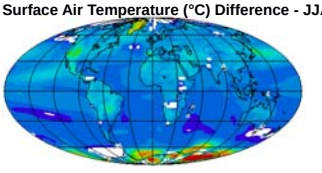
5. Relative Contribution to mid Pliocene Warmth Effect of CO_2 ($PreInd^{VegOrogIceCO2}$ a.k.a $Plio^{Control}$)

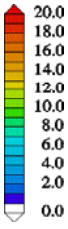
LEEDS

Surface Air Temperature (°C) Difference - DJF



Surface Air Temperature (°C) Difference - JJA





6. Summary – Relative Contribution to mid Pliocene Warmth

UNIVERSITY OF LEEDS

Total Warming = 3.21°C


= 0.62˚C


= 0.52˚C


= 0.81˚C

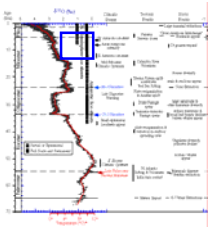
= 1.26˚C

Case Study 2: Intensification of Northern Hemisphere Glaciation

UNIVERSITY OF LEEDS

- **Motivation**
- **Experimental Design**
- **Results**
- **Conclusions**
- **Future Work / Implications**

The Causes of Northern Hemisphere Glaciation?



5 main hypotheses

(1) Closure of Panama Seaway

(2) Tectonic Uplift

(3) Termination of 'Permanent El Nino'

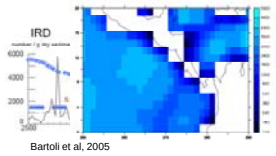
(4) Decrease in CO_2

(5) Oribital variations

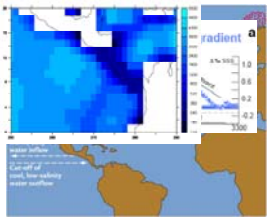
Lunt et al., EGU 2008

The Causes of Northern Hemisphere Glaciation?

5 main hypotheses



Bartoli et al, 2005


Ruddiman, p163

(1) Closure of Panama Seaway

(2) Tectonic Uplift

(3) Termination of 'Permanent El Nino'

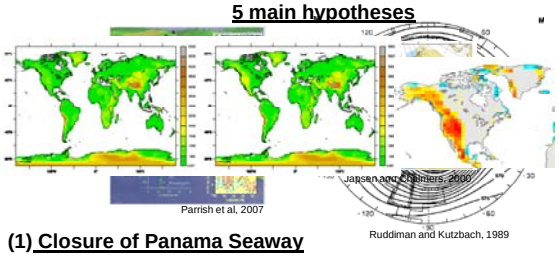
(4) Decrease in CO_2

(5) Oribital variations

Lunt et al., EGU 2008

The Causes of Northern Hemisphere Glaciation?

5 main hypotheses


Parrish et al, 2007

Jansen and Sjaunjers, 2000

Ruddiman and Kutzbach, 1989

(1) Closure of Panama Seaway

(2) Tectonic Uplift

(3) Termination of 'Permanent El Nino'

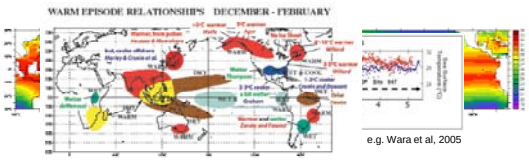
(4) Decrease in CO_2

(5) Oribital variations

Lunt et al., EGU 2008

The Causes of Northern Hemisphere Glaciation?

5 main hypotheses



Molnar and Cane, 2002

e.g. Wara et al, 2005

(1) Closure of Panama Seaway

(2) Uplift of Rockies

(3) Termination of 'Permanent El Nino'

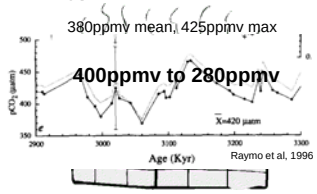
(4) Decrease in CO_2

(5) Oribital variations

Lunt et al., EGU 2008

The Causes of Northern Hemisphere Glaciation?

5 main hypotheses



(1) Closure of Panama Seaway

(2) Uplift of Rockies

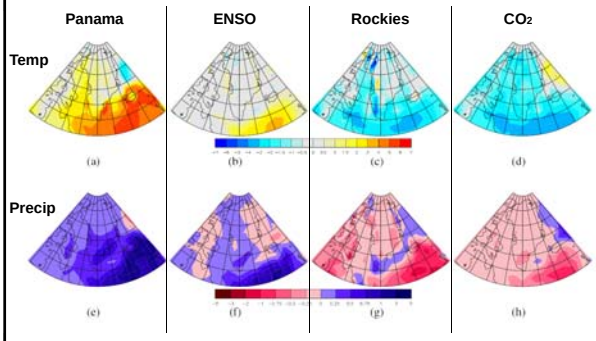
(3) Termination of 'Permanent El Nino'

(4) Decrease in CO_2

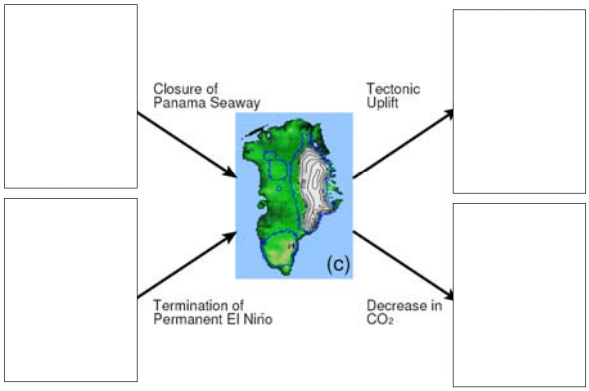
(5) Oribital variations

Lunt et al., EGU 2008

GCM results…

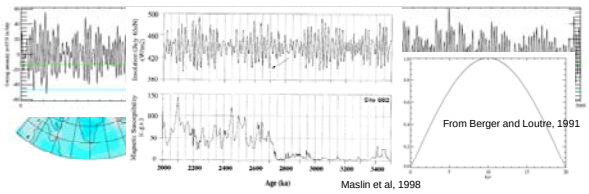


Ice sheet model results…



The Causes of Northern Hemisphere Glaciation?

5 main hypotheses



(1) Closure of Panama Seaway

(2) Uplift of Rockies

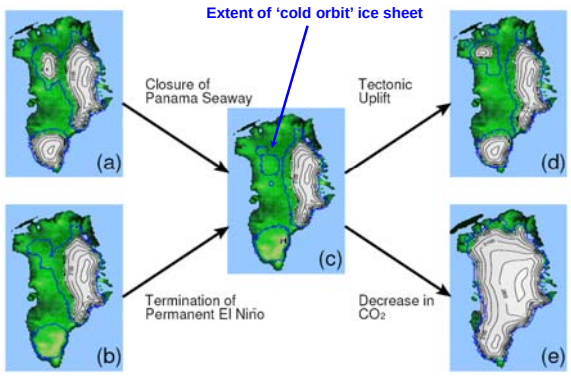
(3) Termination of 'Permanent El Nino'

(4) Decrease in CO_2

(5) Oribital variations

Lunt et al., EGU 2008

Ice sheet model results…(2)



Lunt et al., EGU 2008

Conclusions

➢ **Enhancement of Greenland glaciation in the late Pliocene driven by decrease in atmospheric CO_2**

➢ Greenland ice sheet waxed and waned on orbital timescales prior to 3 Ma.

➢ ENSO and tectonic forcing factors, with or without orbital trigger, did not play an important role in Greenland glaciation.

Future Work / Implications

➢ Improvement of CO_2 records of the pre-ice core era.

➢ Improvement of IRD records in North Atlantic (including provenance).

➢ Need for transient model simulations (using fully coupled Earth System Models).

➢ Strong dependence on CO_2 has obvious implications for future ice sheet stability.