Climate

and the

Oceanic Circulation


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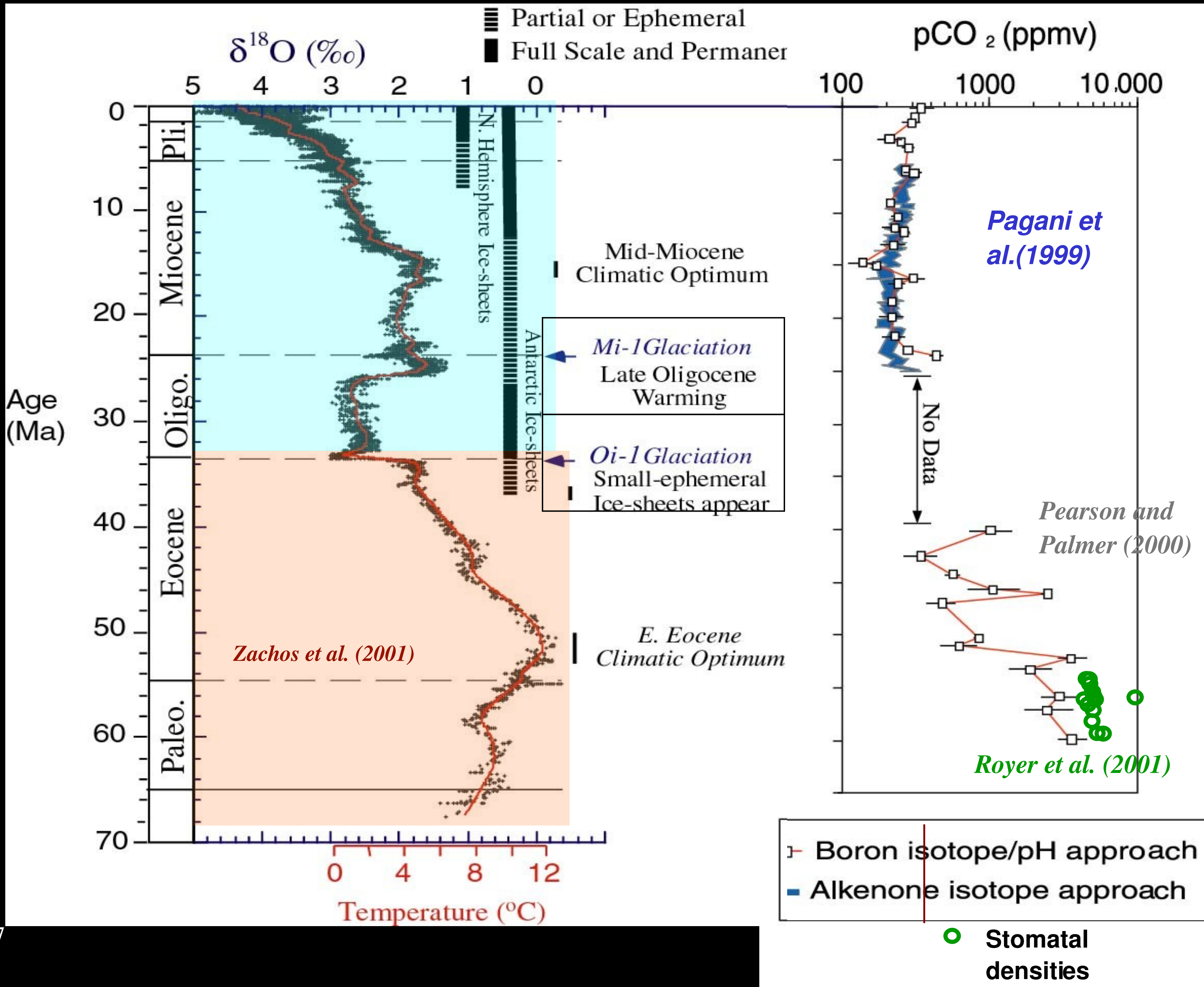
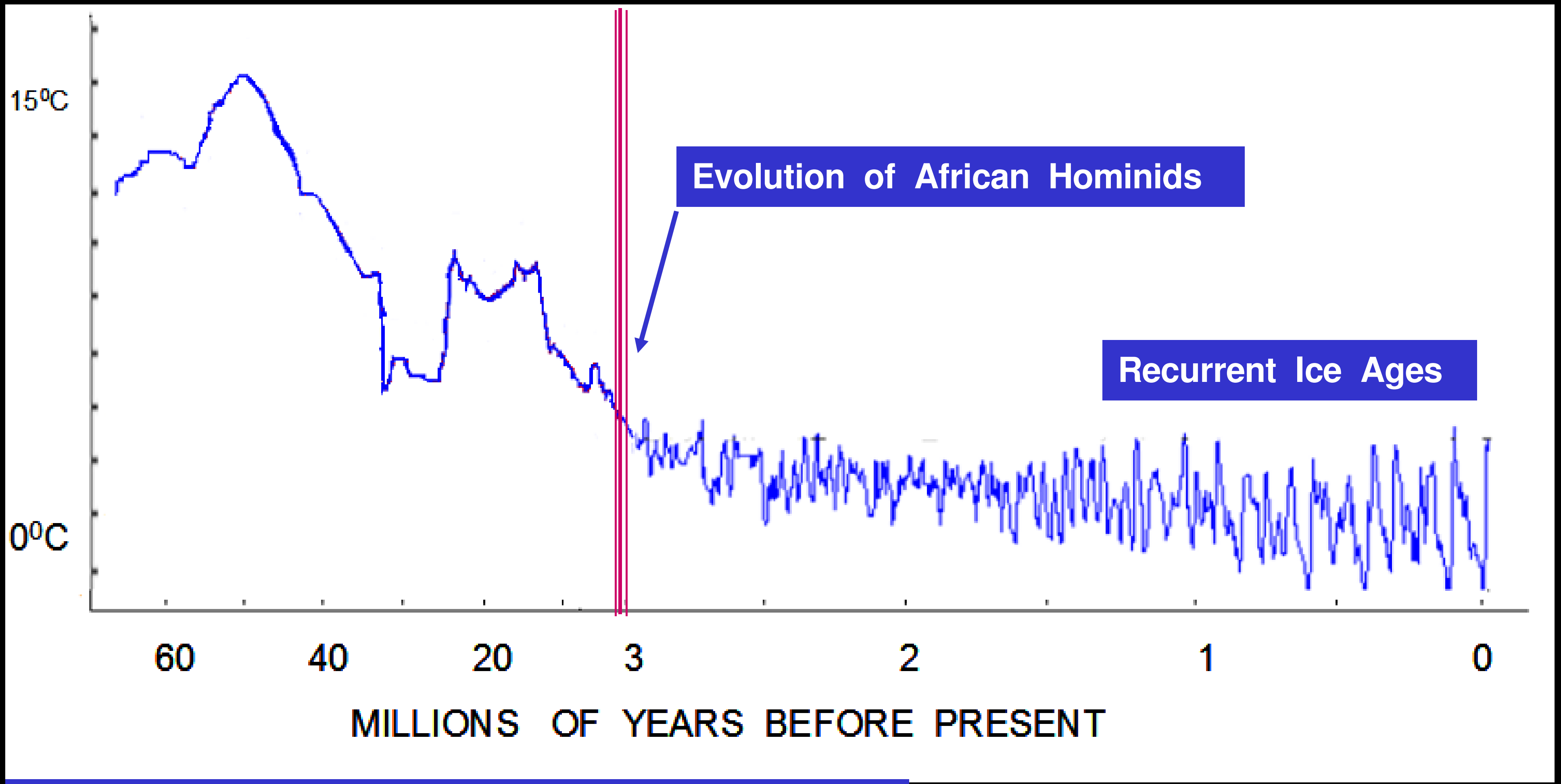
Cenozoic climate history and paleo-pCO_2



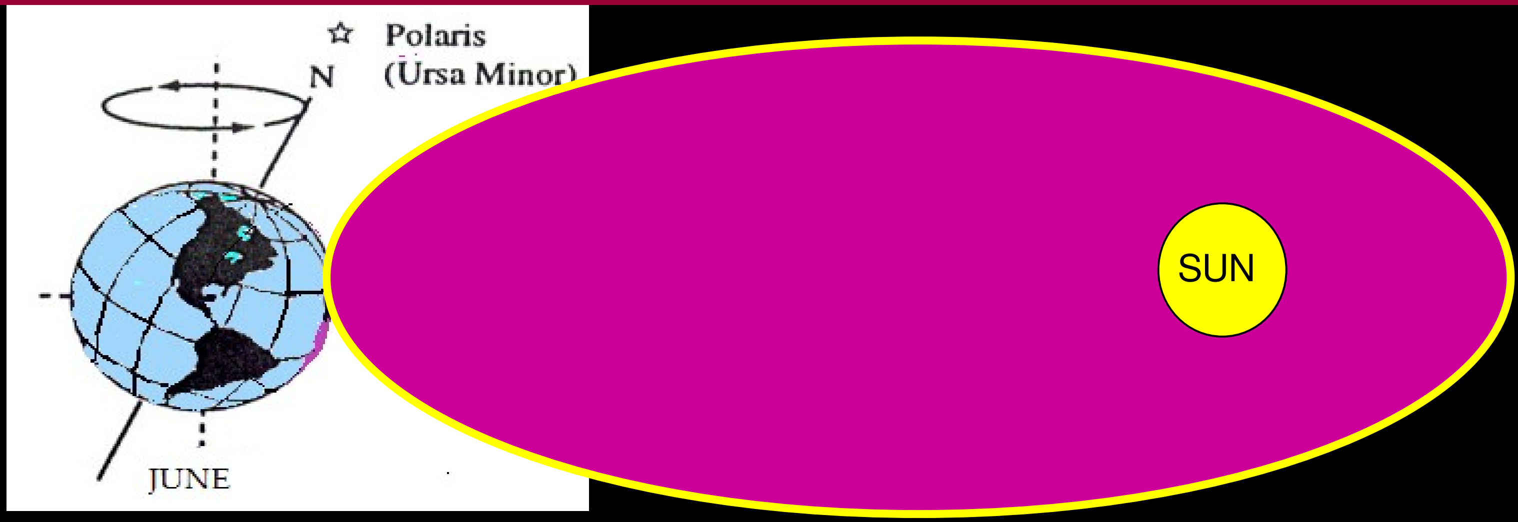
GLOBAL COOLING OVER THE PAST 60 MILLION YEARS.

The MILANKOVITCH CYCLES AMPLIFY ENORMOUSLY over the **PAST 1 Ma**



NOTE: Time Scale changes at 3 Million Years

MILANKOVITCH CYCLES



Our Planet's Music has Many Beats:

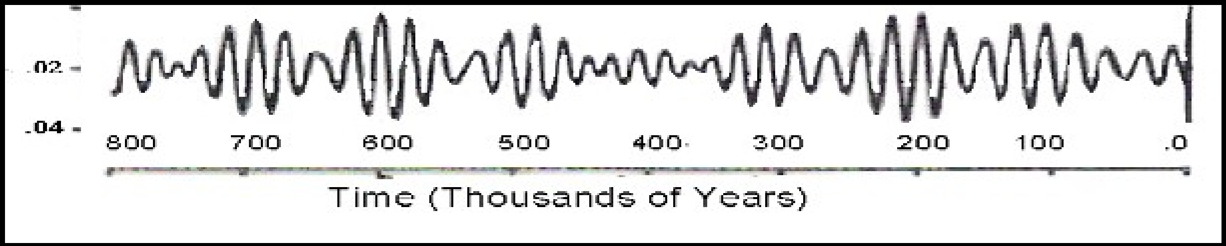
(a) 1 DAY: Day- Night – Day — Spins around its axis

(b) 1 Year: Winter – Summer – Winter — Orbits the Sun

(c) 23,000 Years: Stronger Summer, Stronger Winter — Precession

(d) 40,000 Years: Tilted axis rocks back and forth — OBLIQUITY

(e) 100,000 Years: Eccentricity of the orbit varies



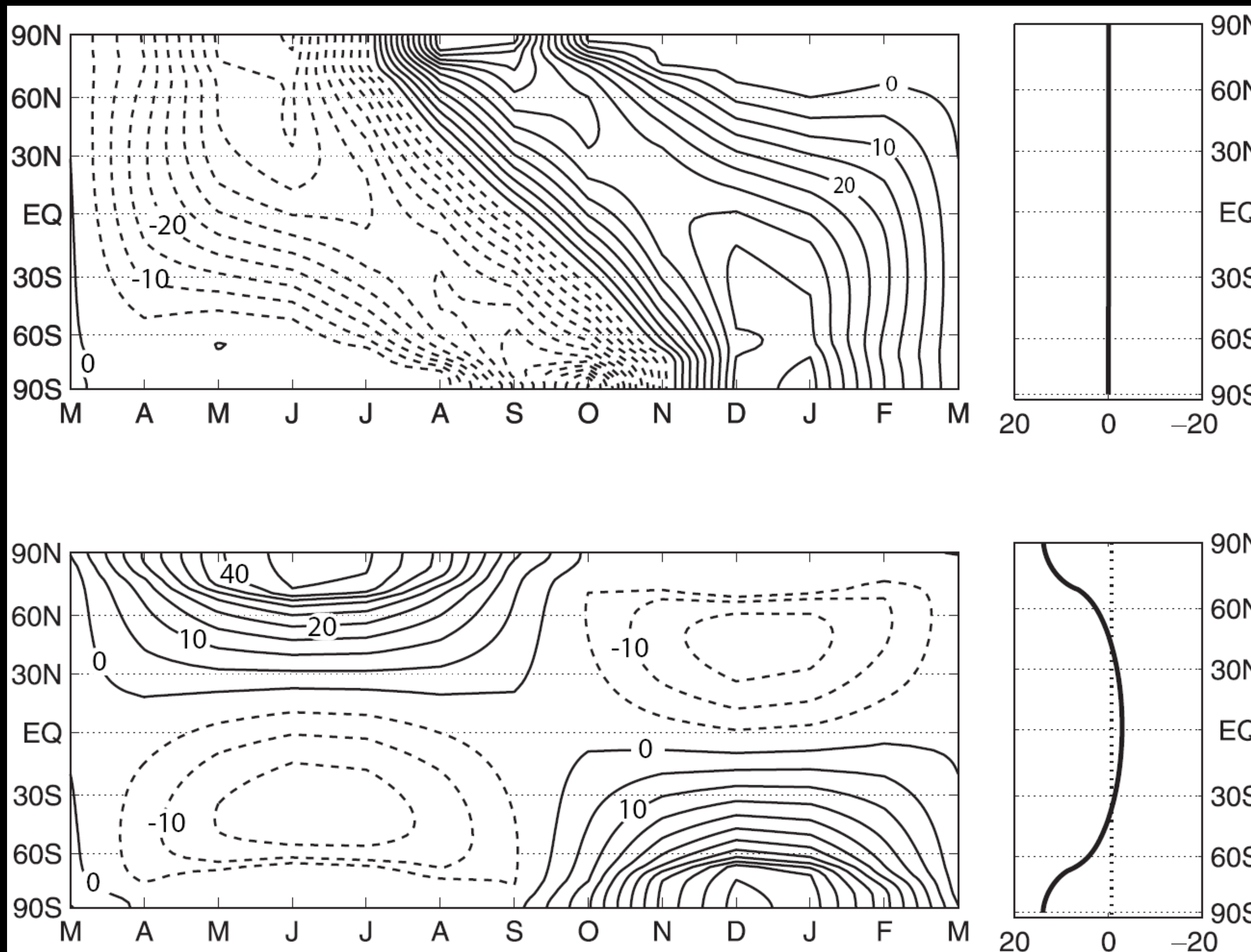
Seasonal and Annual Orbital Insolation Forcing (W/m^2)

Precession Forcing

Seasonal only

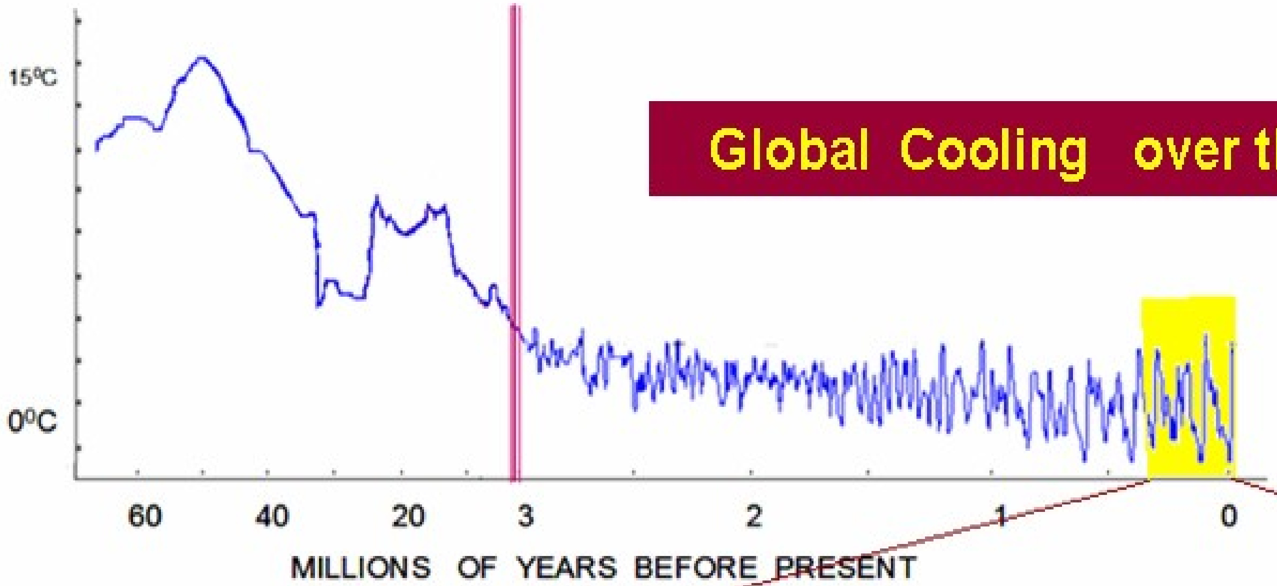
Obliquity Forcing

Seasonal and annual

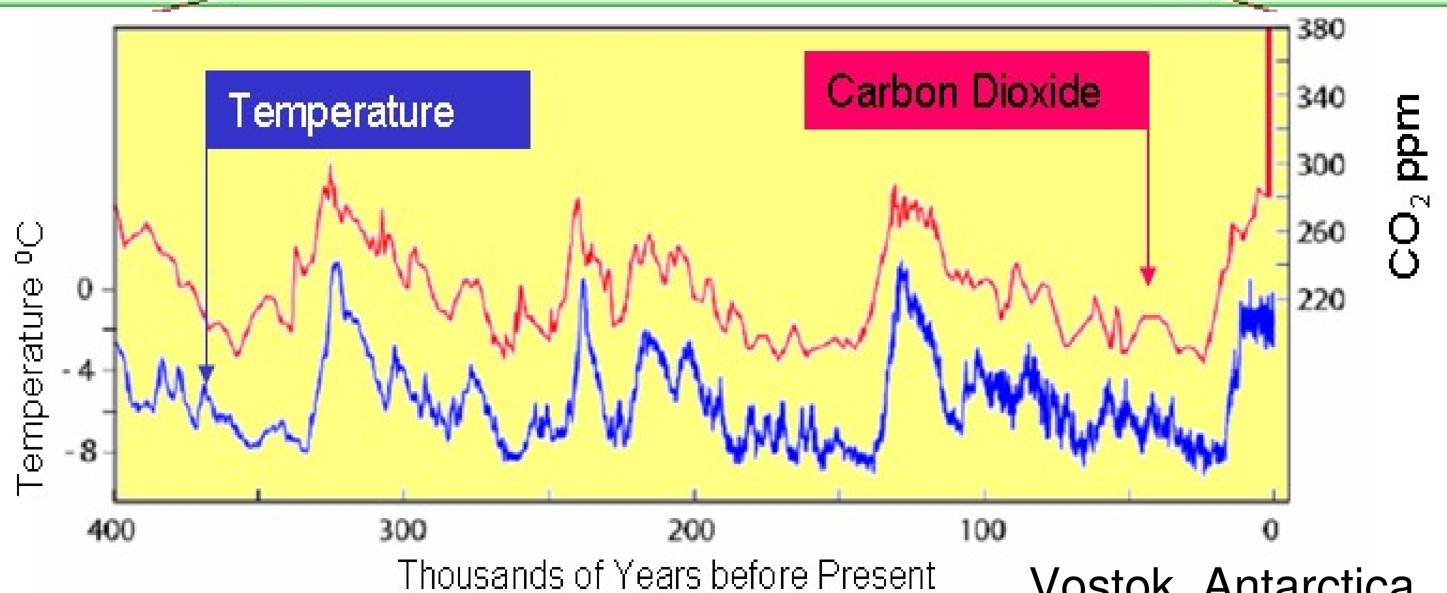


Changes in the incident sunlight . Top: when perihelion shifts from its current date (in January) to six months later. Bottom: when obliquity changes from 22 to 24 degrees. Left-side: The time integral over one year.

Global Cooling over the past 60 Million Years



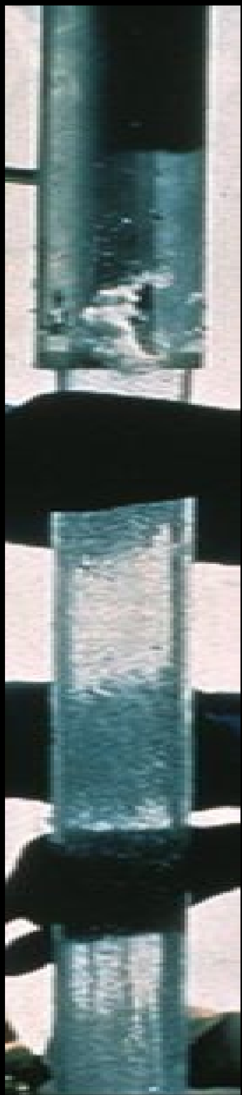
The Cycle of Ice Ages



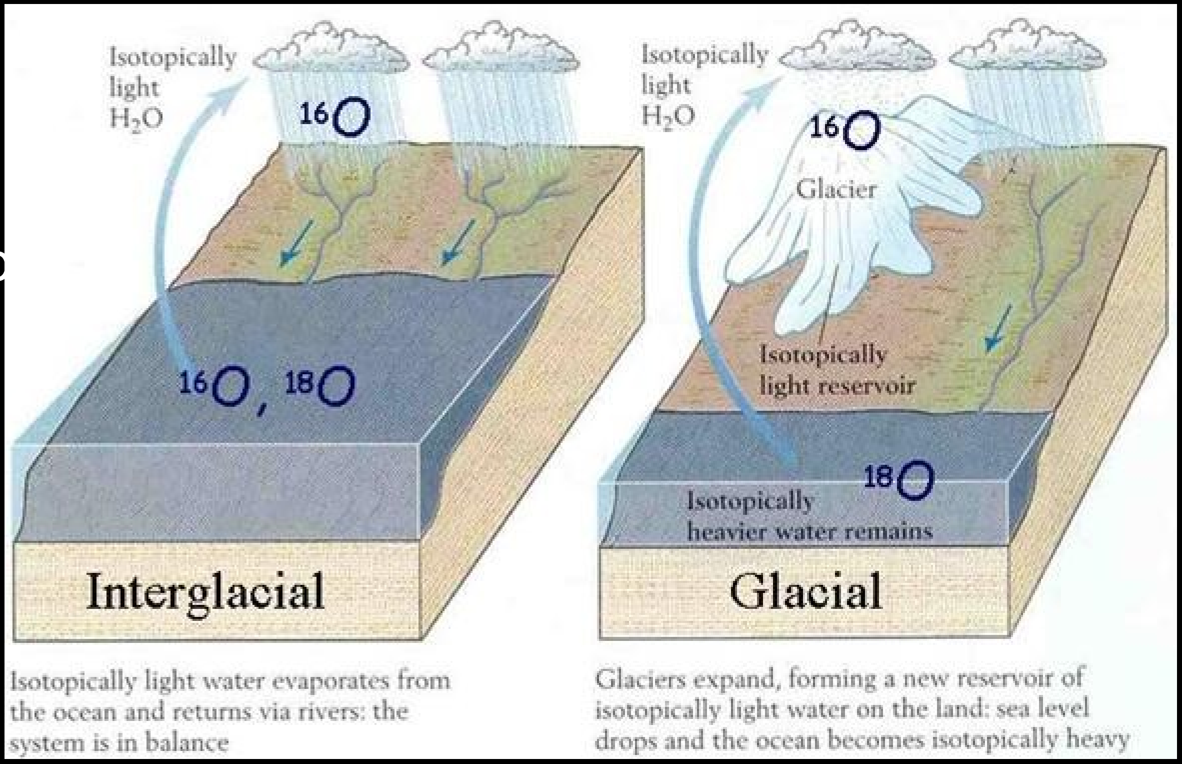
Vostok, Antarctica

How to obtain past data?

- Ice cores - When ocean water evaporates, water with the lighter oxygen isotope (^{16}O) evaporates more easily because it is lighter than a water molecule with the heavier oxygen isotope (^{18}O). When that vapor condenses to form rain, the heavier isotopes that did make it into the clouds condense to a greater extent than the lighter isotopes, again due to mass. The relative concentrations of the heavier isotopes ^{16}O, ^{18}O in an ice core indicate the temperature of condensation at the time, allowing for ice cores to be used in global temperature reconstruction.



Bubbles in the ice also allow to measure past atmospheric concentratio of CO2 and methane.

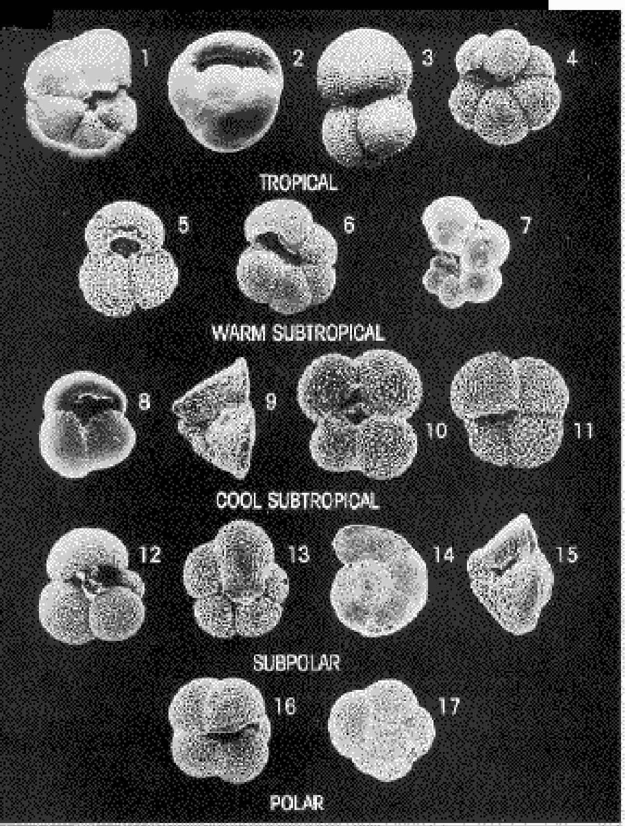


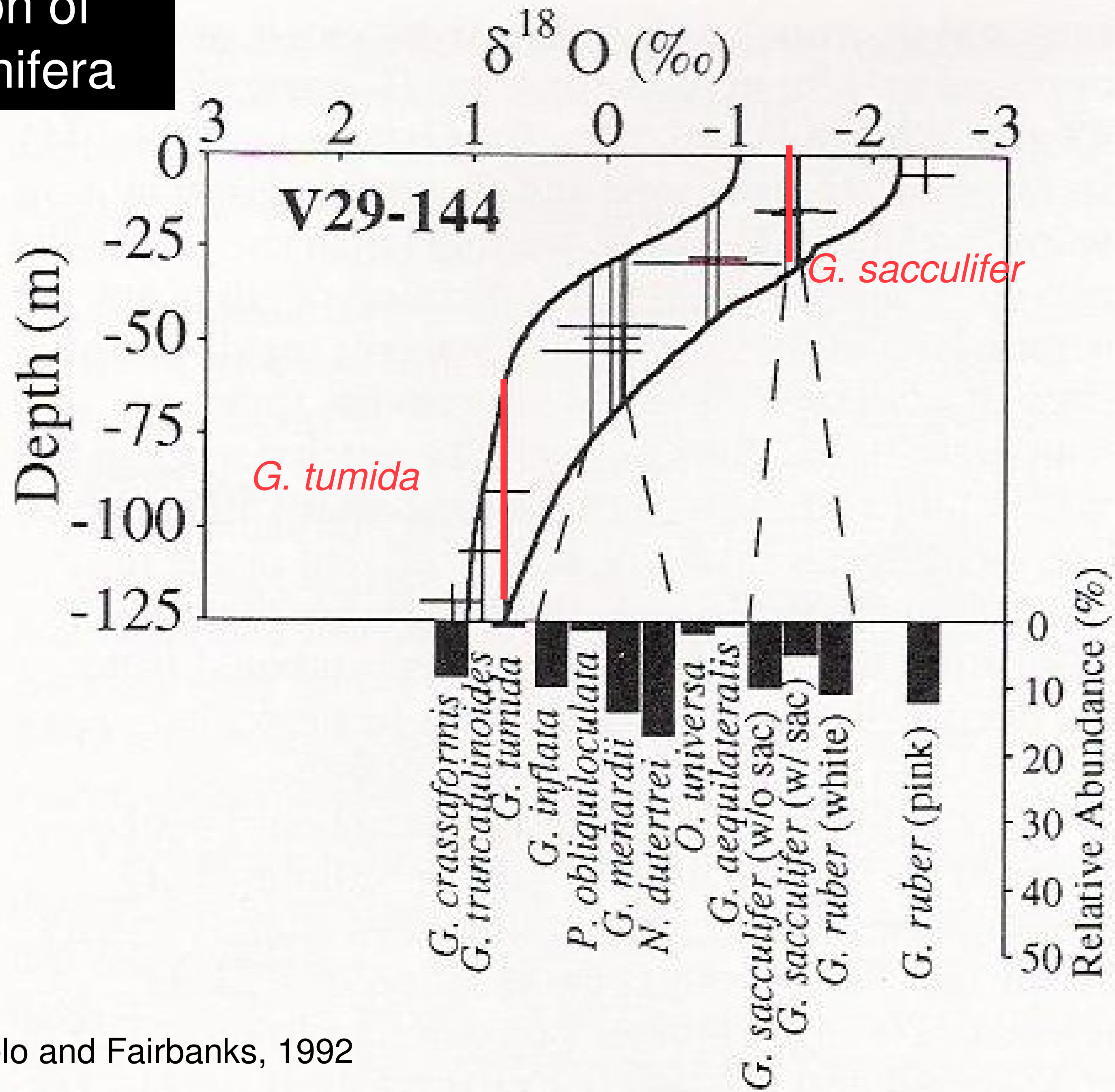
Drill holes in the ocean floor

Deep Sea Drilling Project (1968-1983)
Ocean Drilling Program (1985-2003)
Integrated Ocean Drilling Program (2003- present)

Zooplankton live at different depths in the ocean

Depth Stratification of Planktonic Foraminifera





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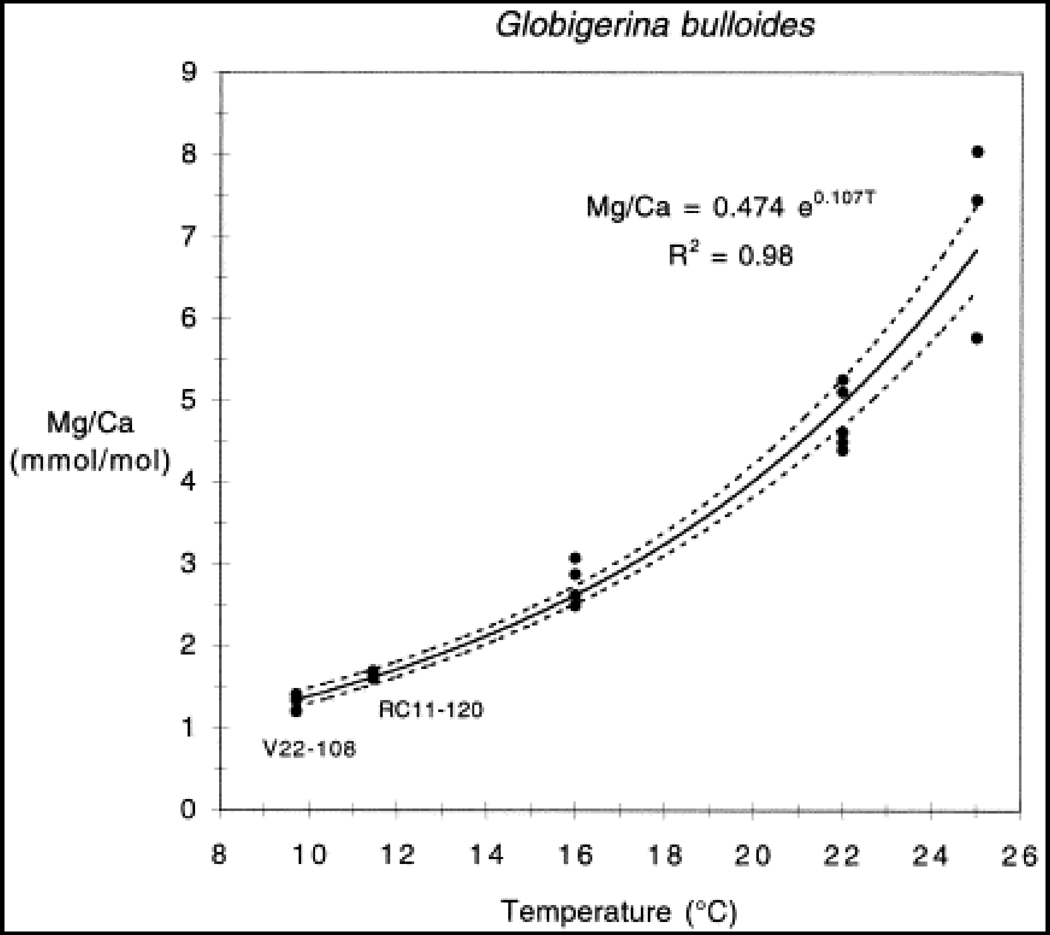
Ravelo and Fairbanks, 1992

One technique to determine temperature based on sediments

Mg/Ca of foraminifera shells: a function of calcification temperature

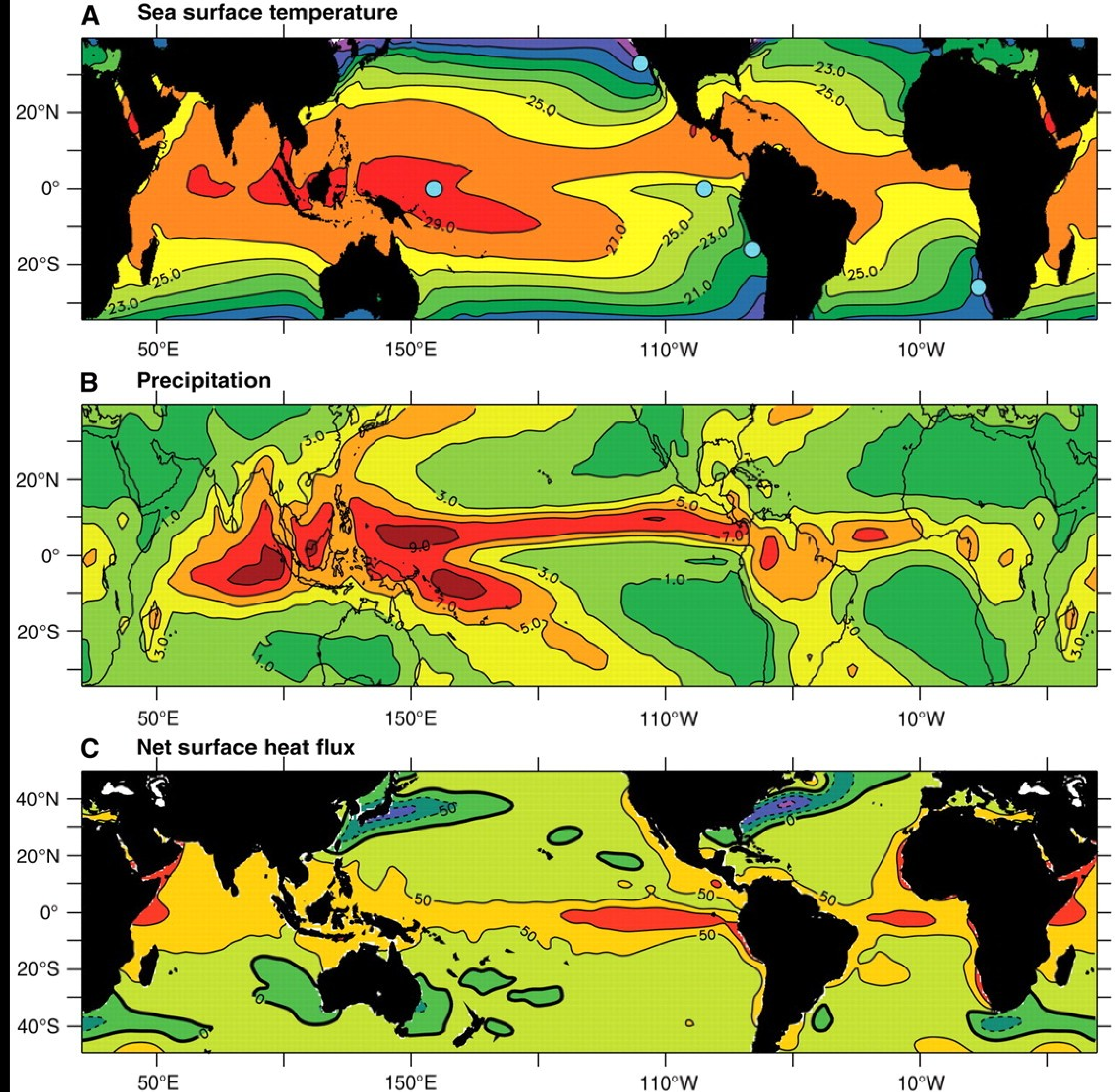


$CaCO_3$

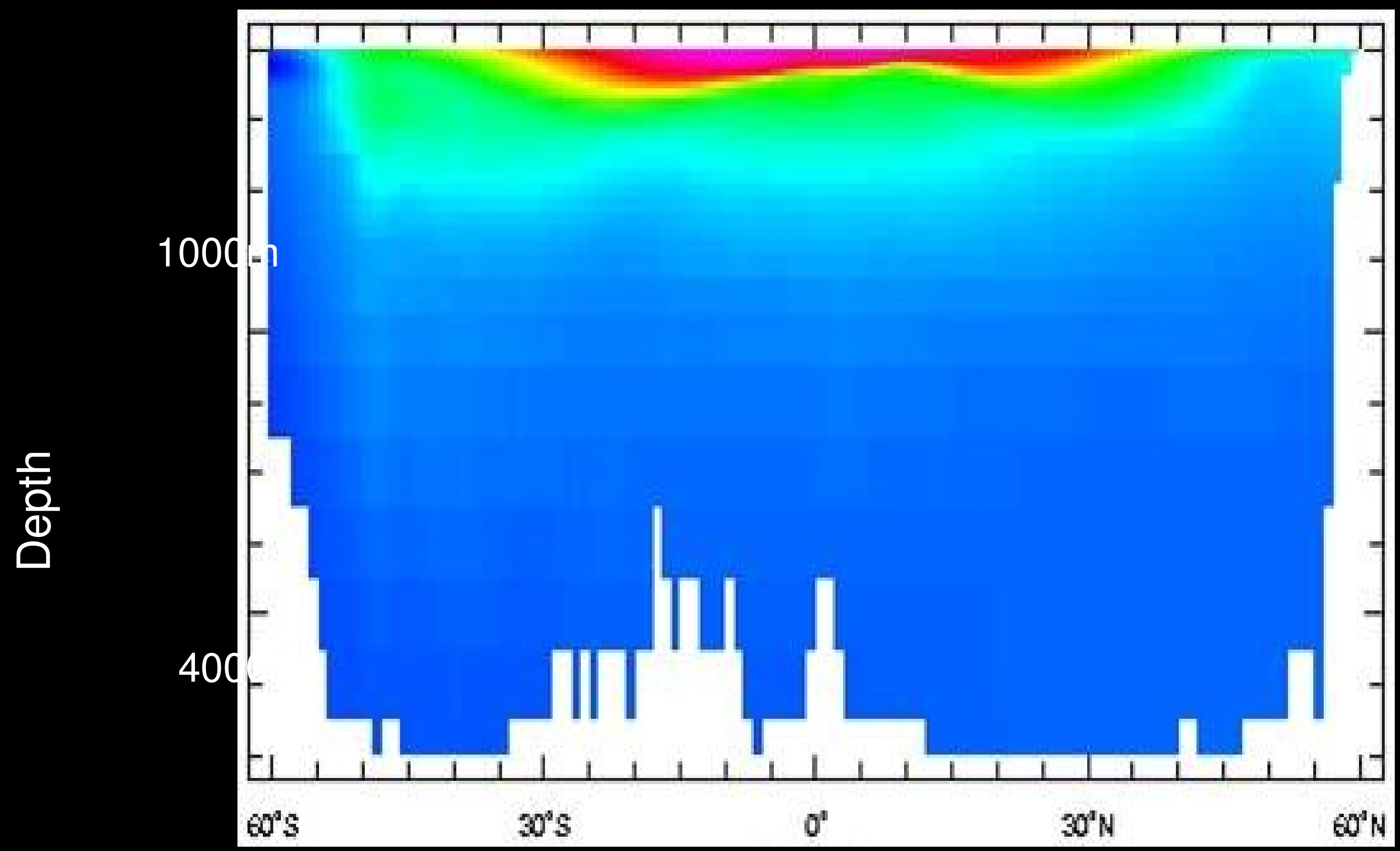
Mg^{2+} substitutes for Ca^{2+}

Mashiotta et al., 1999

The current state of affairs

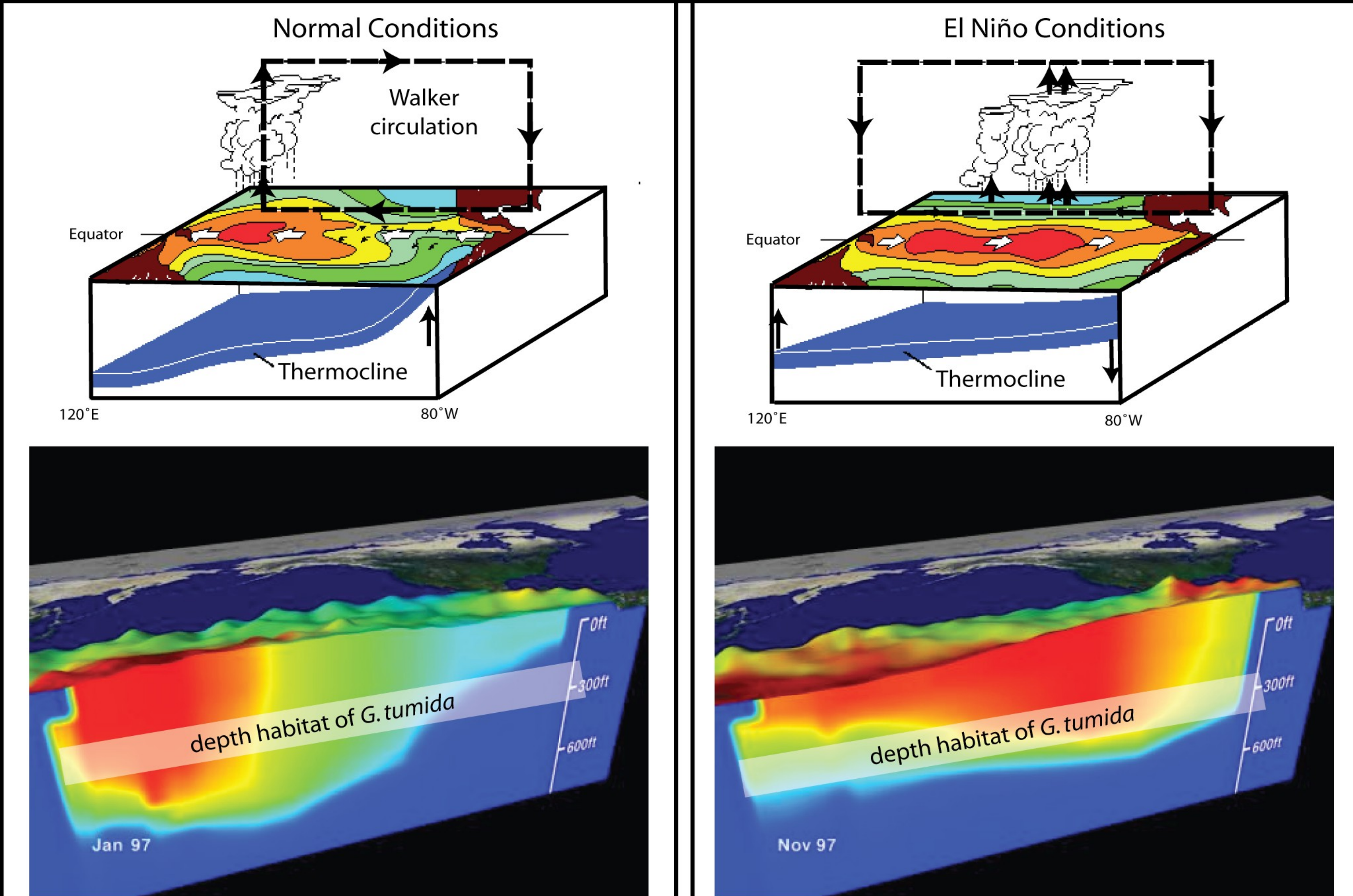

A Sea surface temperature
23.0
25.0
29.0
27.0
21.0
20°N
0°
20°S
50°E
150°E
110°W
10°W
B Precipitation
3.0
1.0
5.0
7.0
9.0
C Net surface heat flux
50
0
40°N
40°S

The region of oceanic warm waters is restricted to the upper ~500m, below which the ocean is very cold and slightly stratified.



Temperature along a section in the mid-Pacific (152W)

El Niño



January 1997 Normal

November 1997 El Niño

EXAMPLES OF PAST CLIMATE VARIATIONS

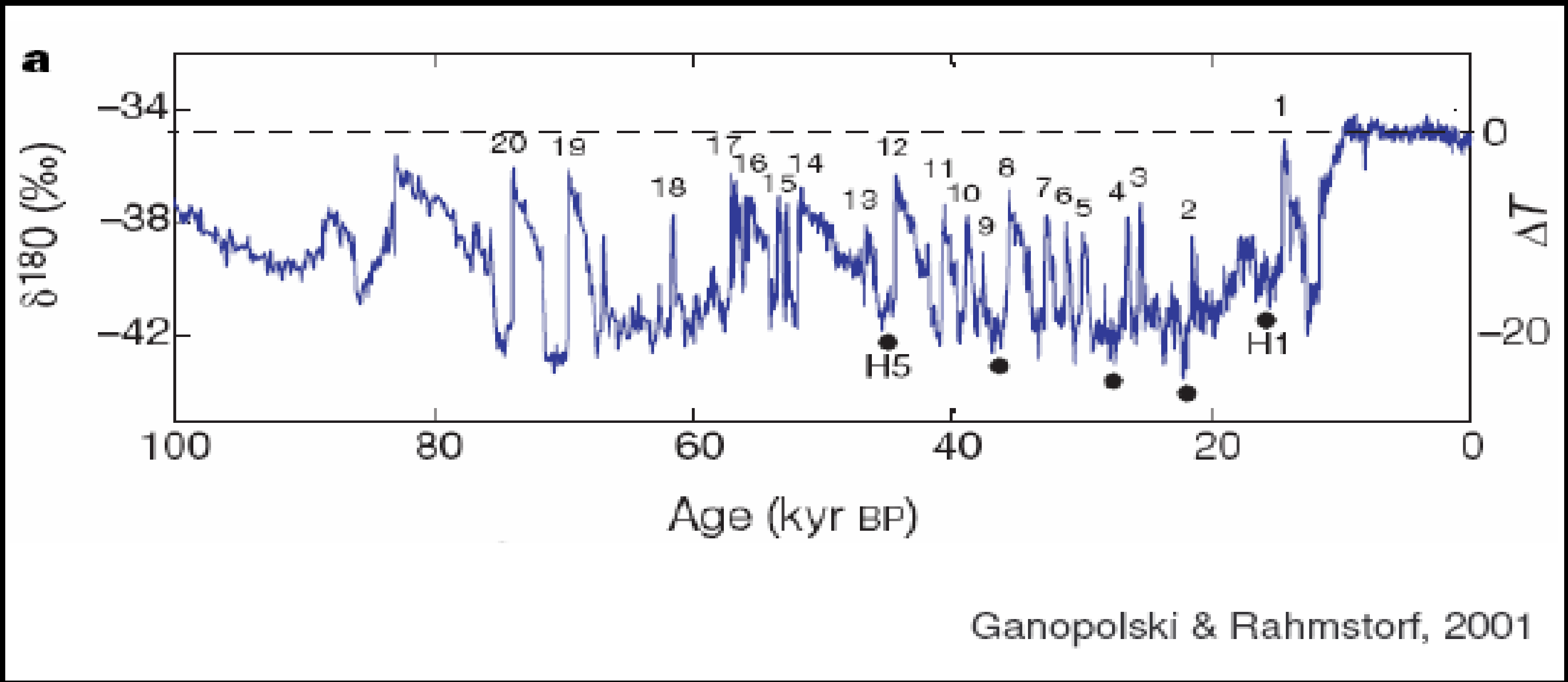
1. Abrupt climate changes

2. Milankovitch forcing

3. Middle Pliocene ~ 3.000.000 years ago

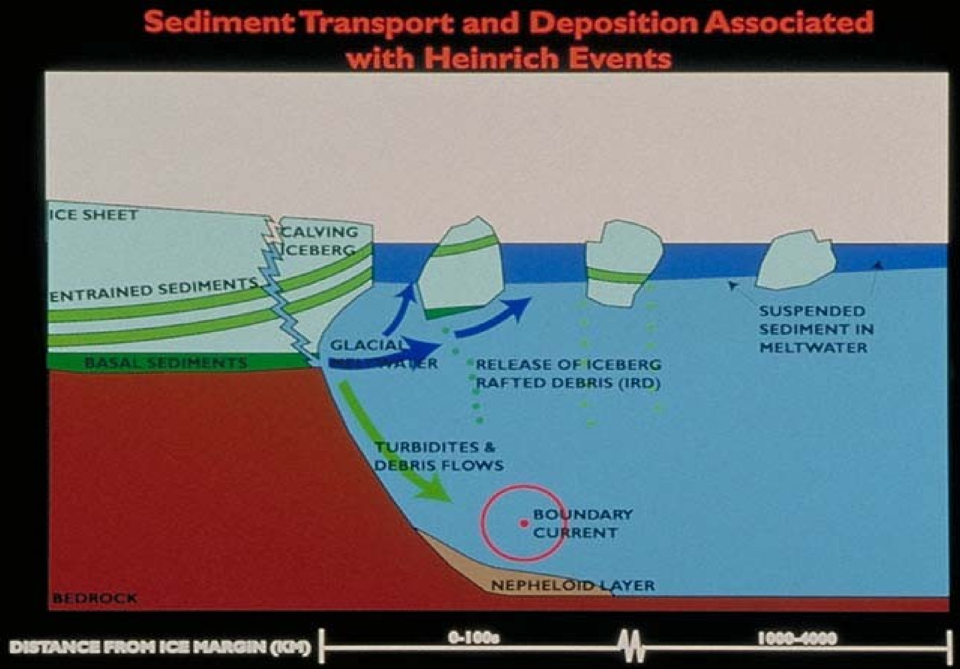
Abrupt Climate Changes

Dansgaard-Oeschger events: Rapid reorganizations of climate in North Atlantic during glacial period

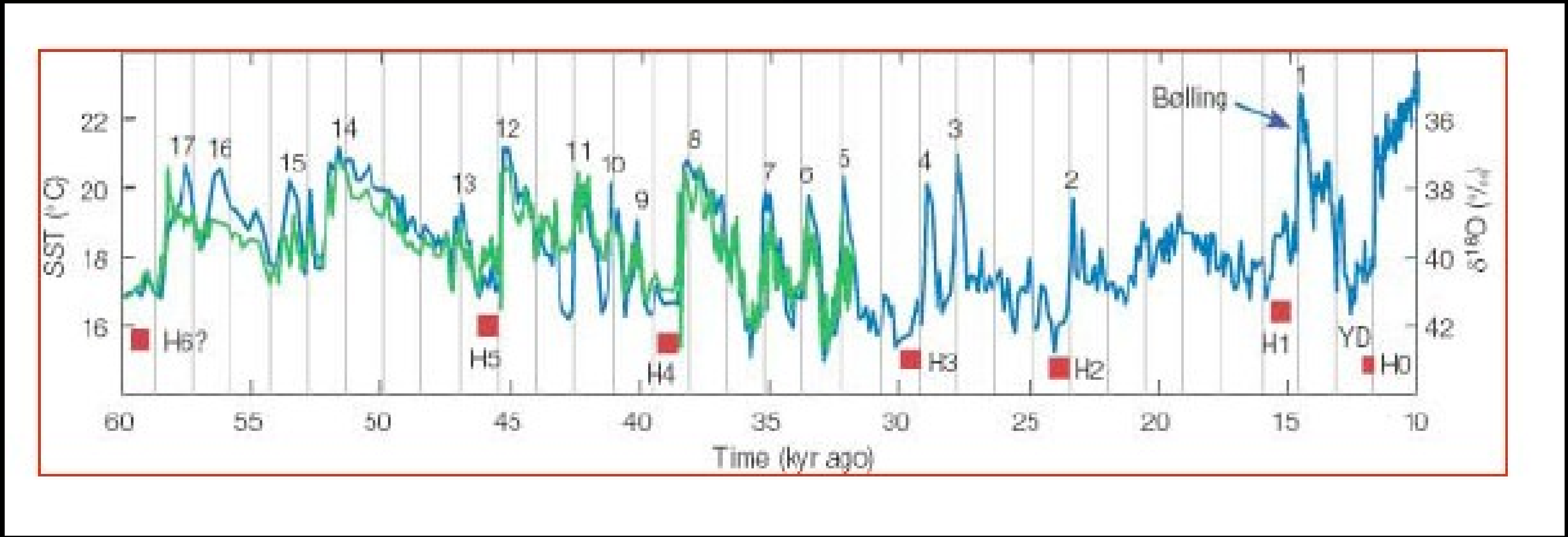


- 5-10C warming in decades, followed by a plateau and slow cooling.
- Have a tendency to happen every ~1500 years, and 3000, 4500 yrs.
- Have global extent, although largest signal is in North Atlantic,

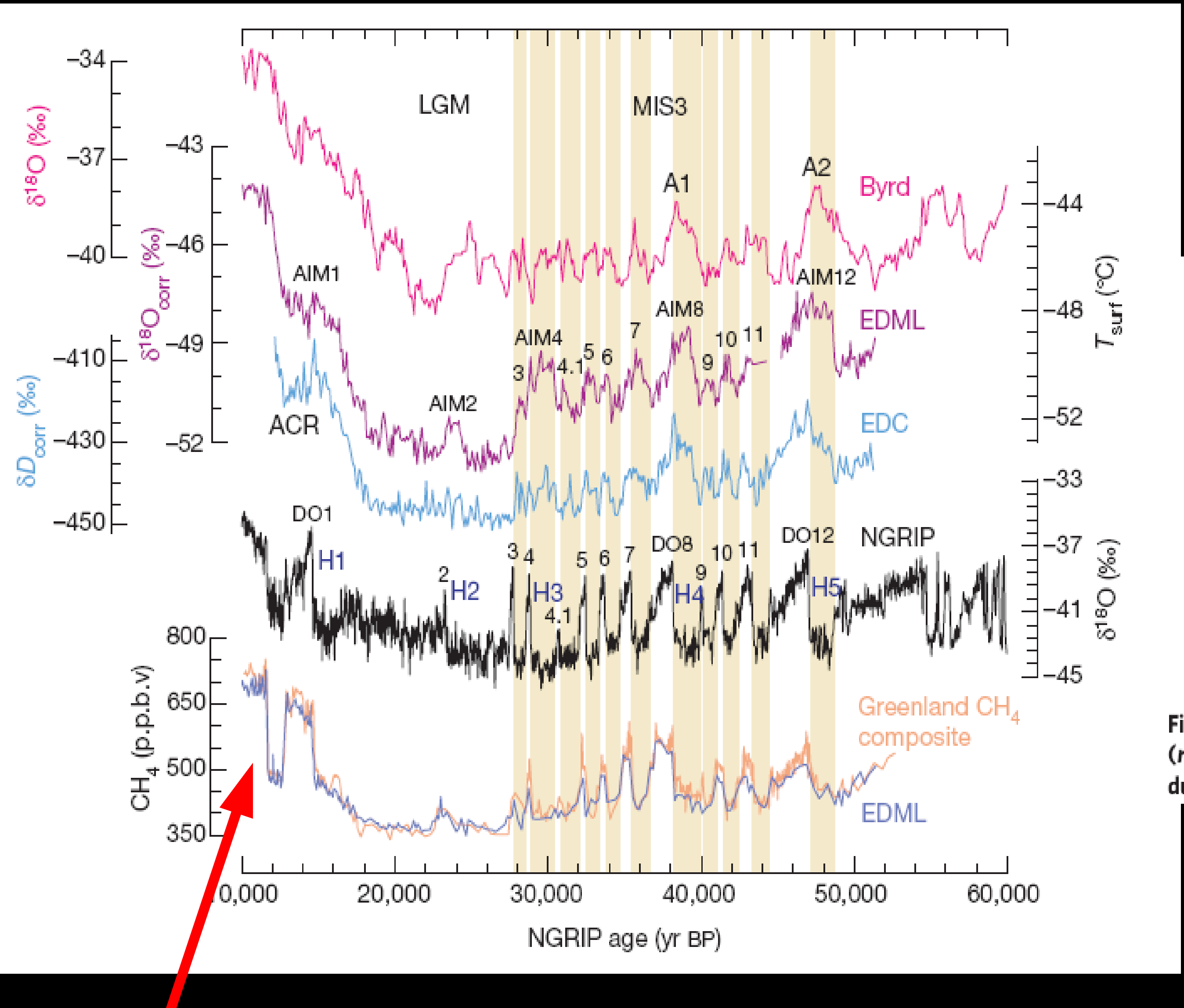
Heinrich events: massive episodic iceberg discharges in North Atlantic



- Characterized by layers of coarse sediments in North Atlantic.
- Are associated with cool conditions in the north Atlantic, and weakened NADW formation.



Coupling of glacial variability between Greenland and Antarctica (EPICA 2006)



The longer the period of cold conditions in Greenland, the larger the Antarctic warming.

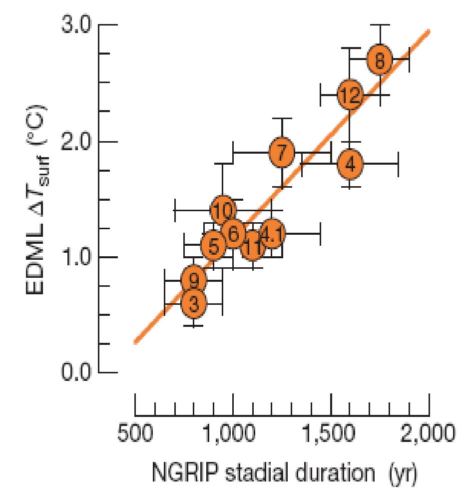
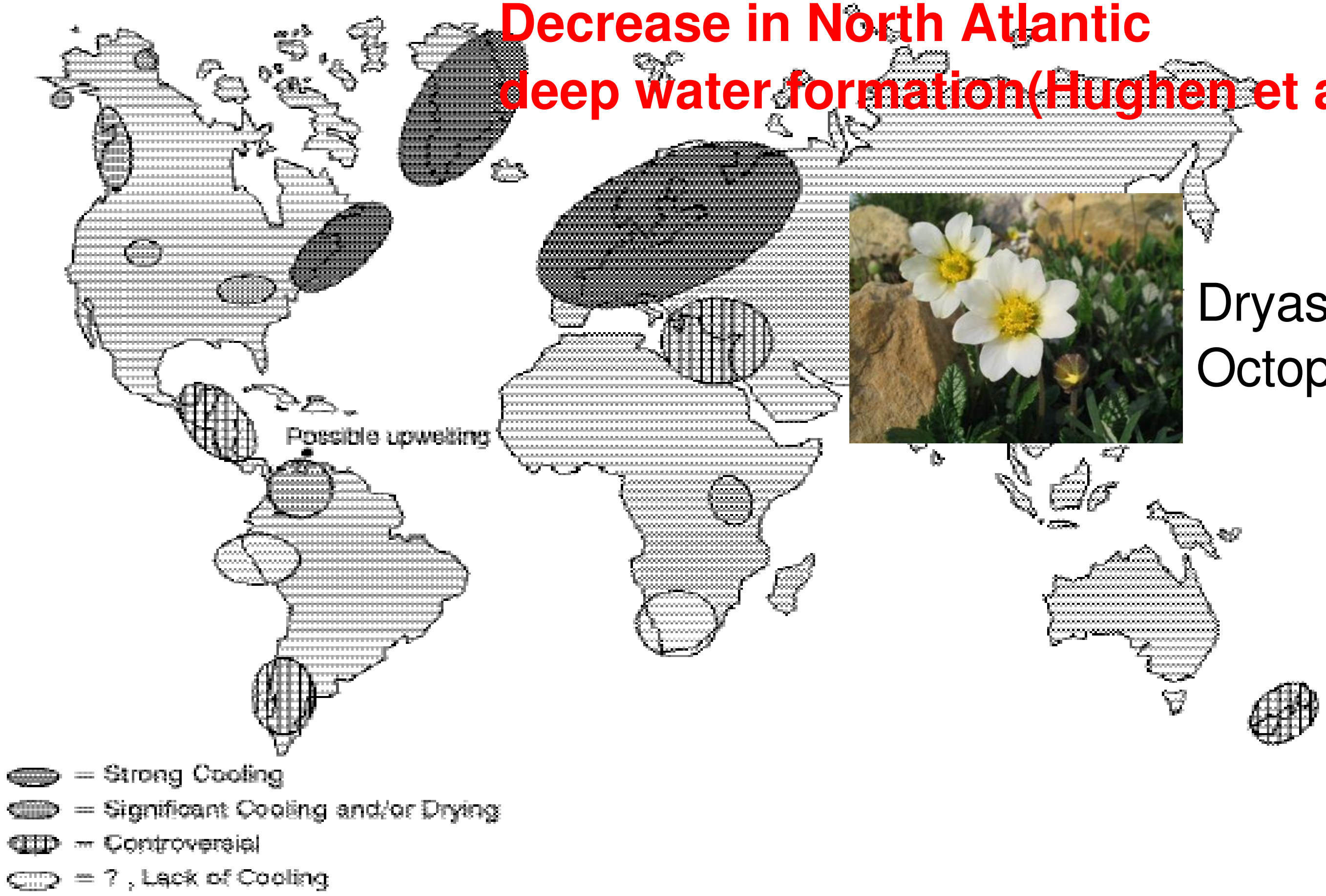


Figure 3 | Amplitudes of Antarctic warmings show a linear relationship (r^2 = 0.85) with the duration of the accompanying stadial in Greenland during MIS3. The amplitude was determined from the Antarctic $\delta^{18}O$

The Younger Dryas

Decrease in North Atlantic deep water formation(Hughen et al 1998)



Dryas Octopelata

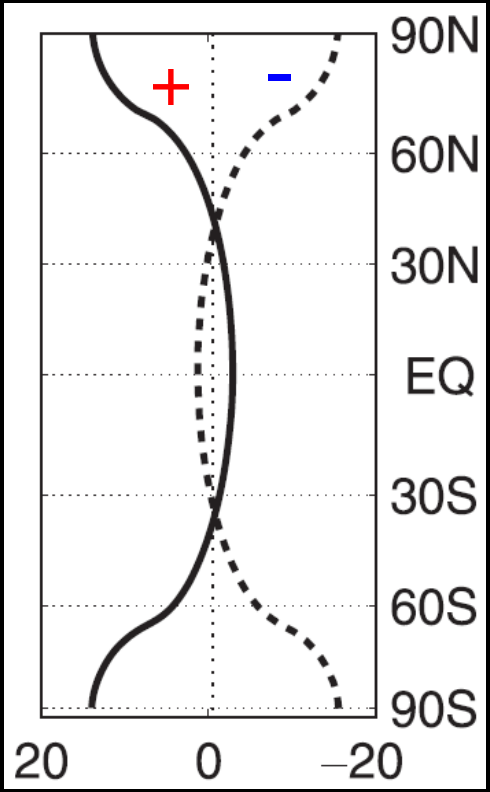
FIGURE 2.4 Global extent of terrestrial (pollen) and ice core (isotopic) evidence where the Younger Dryas cooling (11,500 – 13,000 BP) has been found. While northern hemispheric evidence is consistently strong for cooling, southern hemispheric sites contain controversial evidence and in some cases lack of evidence for a cooling during the YD interval. Possible upwelling in the Cariaco Basin during this time is also indicated, attributed to trade wind increase. Strong cooling ranges from 13-4° C; controversial means some sites show cooling and some do not (after Peteet, 1995).

NAS, 2002

Obliquity Forcing of Tropical Climate

High obliquity induces anomalous heating of high latitudes (+)
Low obliquity induces anomalous cooling of high latitudes (-)

The half-period of these changes is ~20,500 years



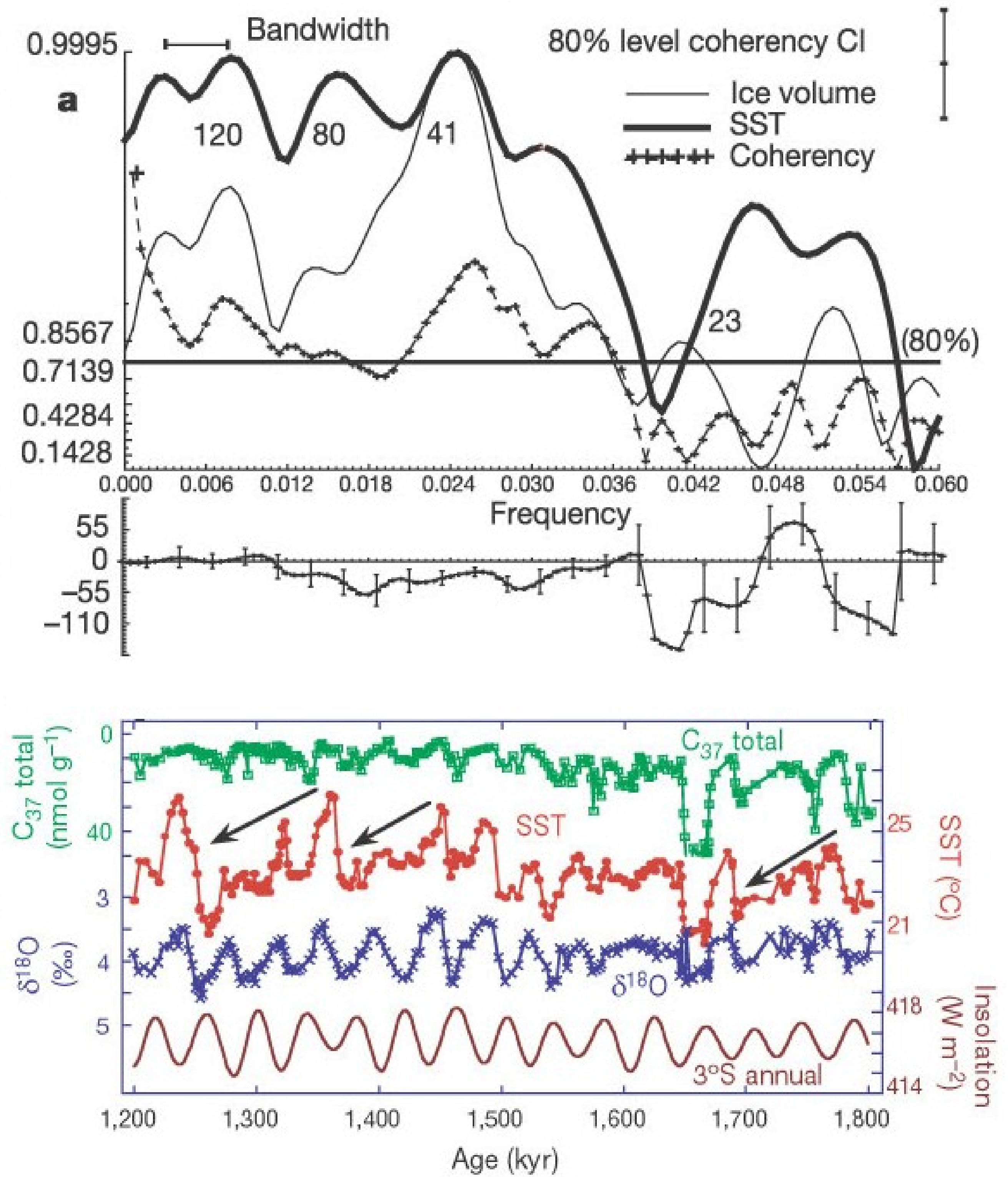
Observations of Obliquity Forcing:

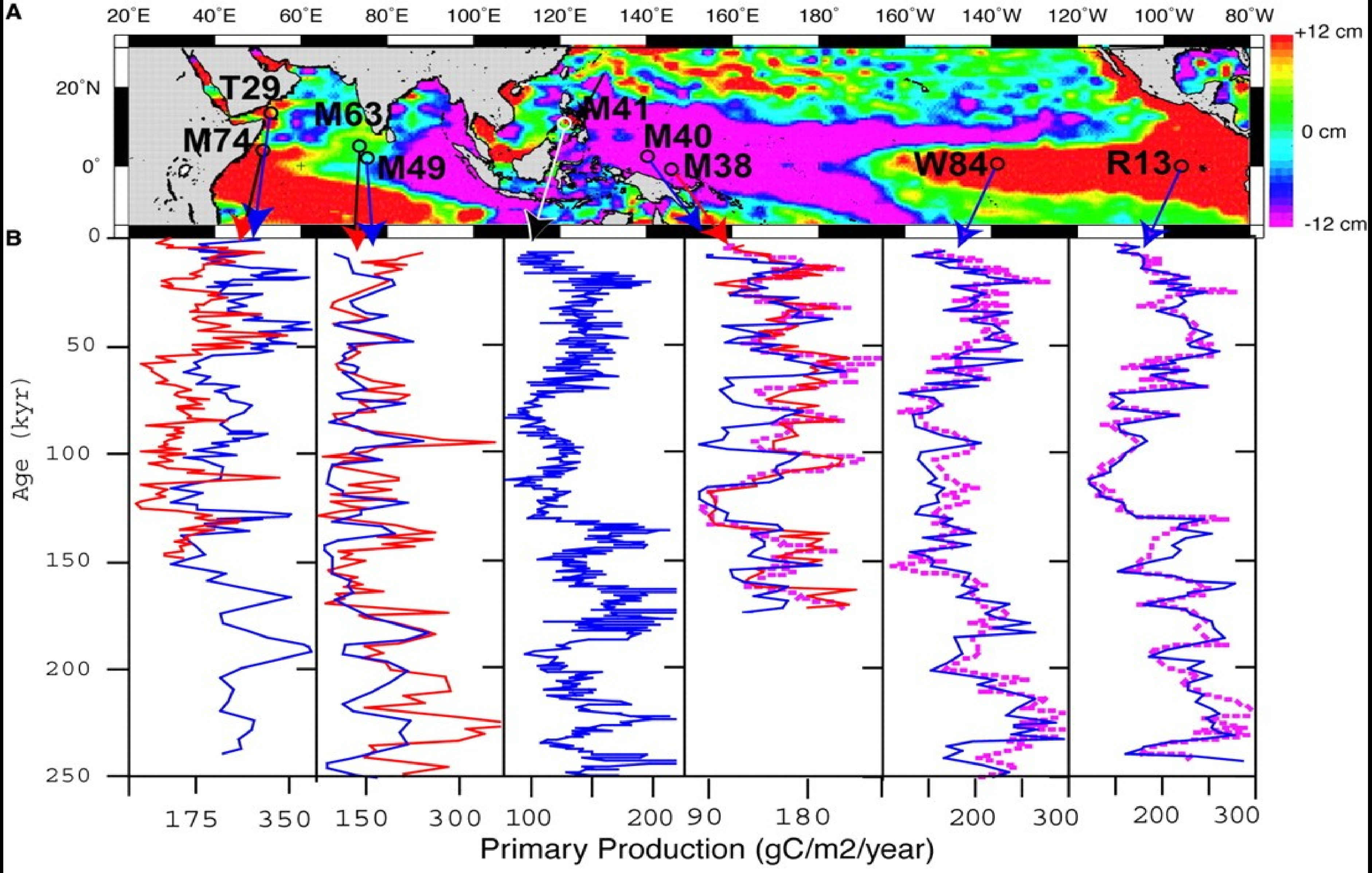
- During the early Pleistocene the Eastern Equatorial Pacific SST, productivity and high latitude ice volume varied mainly with obliquity.

- The eastern equatorial Pacific SST varied out of phase with the local insolation, and lead the ice volume by ~3kyr.

=> the EEP is responding to high latitude orbital forcing.

(Herbert and Liu 2004)



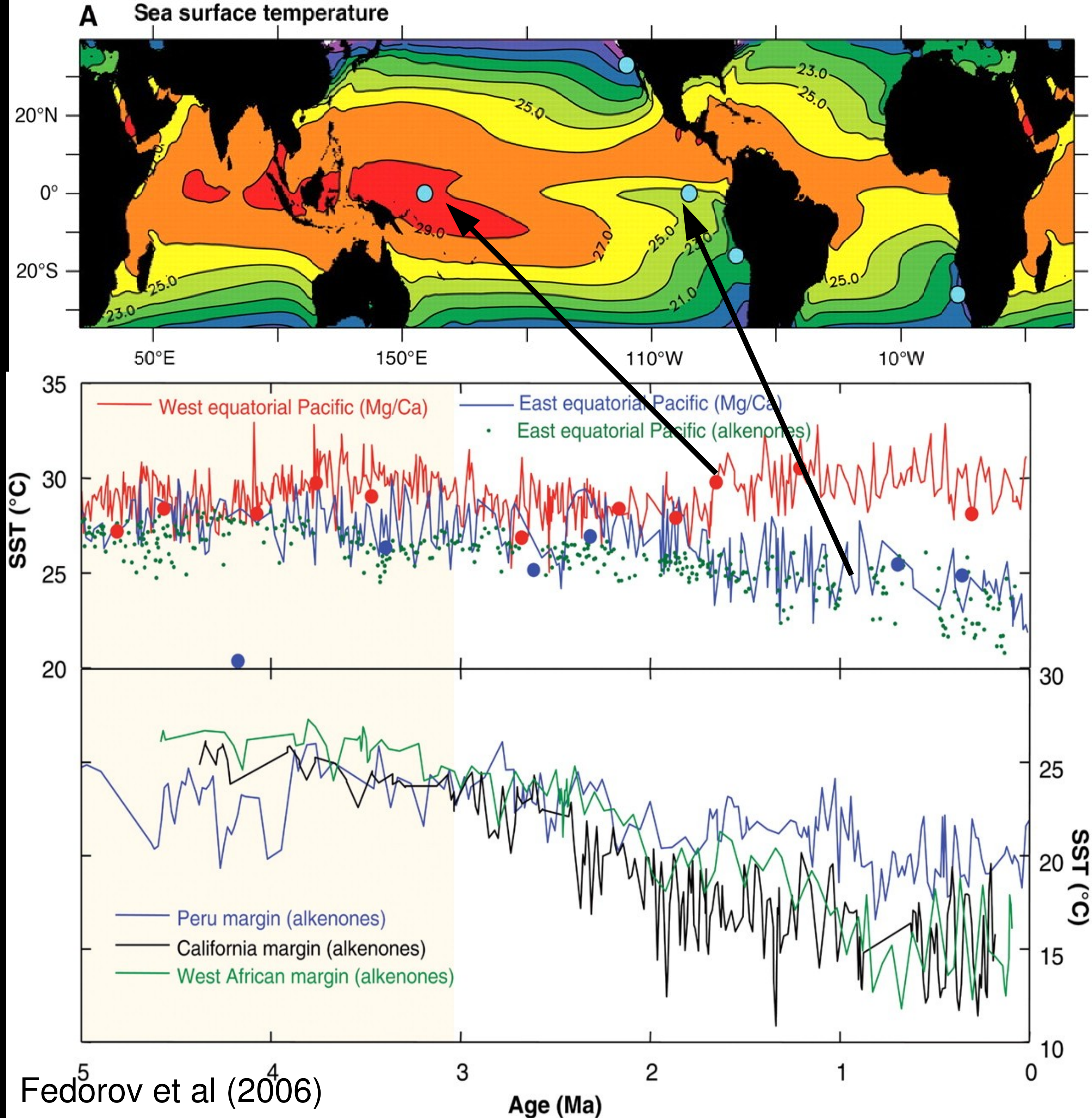


Primary production (the thermocline) across the Pacific was large (shallow) during glacial periods and small (deep) during interglacials, and vary with obliquity (Beaufort et al. 2001).

The Pliocene Paradox

The Pliocene Paradox

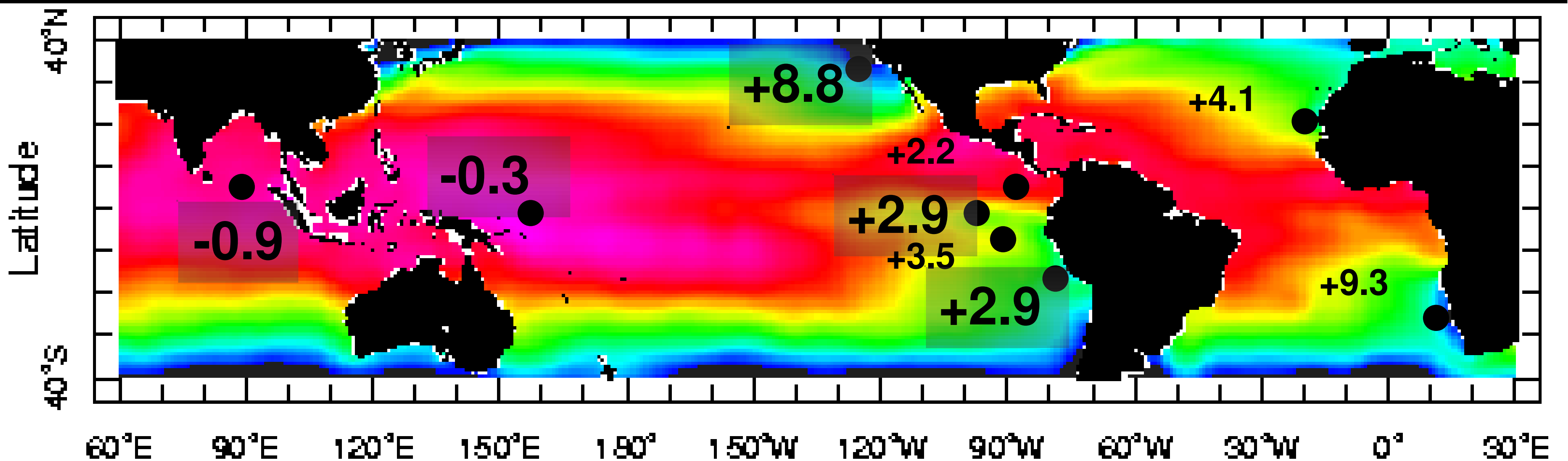
3 million years ago CO2~ 300-400 ppm, but the equatorial cold tongues were largely reduced and sea level was ~25m higher.



Fedorov et al (2006)

SST difference (warm Pliocene – modern)

Warm Pliocene (3 – 4.6 Ma) average SST – modern mean annual SST



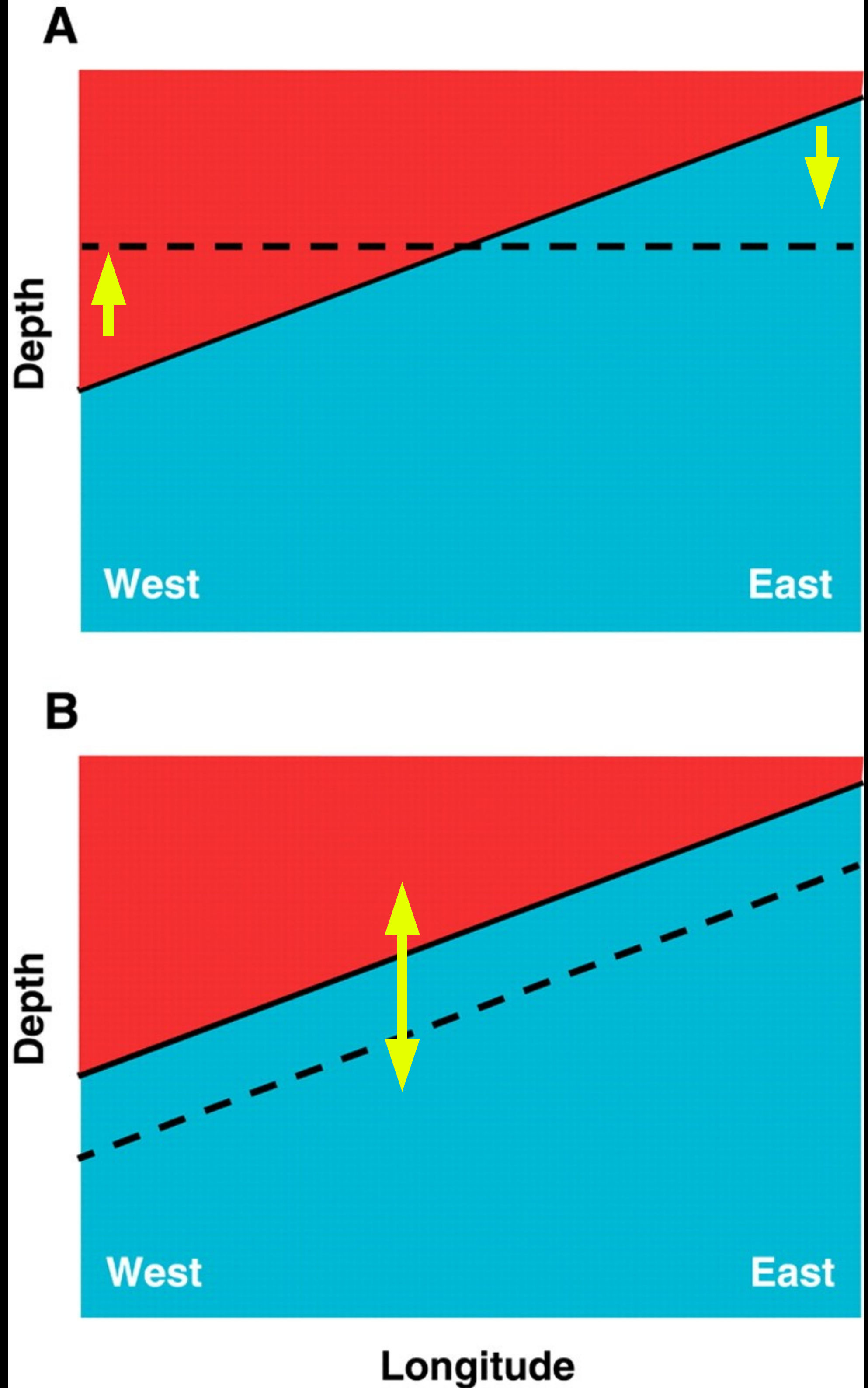
Pacific and Atlantic upwelling regions were all significantly warmer during the early Pliocene compared to today

How can the tropical oceans maintain a longitudinally symmetric state?

Possible variations of the equatorial thermocline

On interannual time scales:
El Niño-like changes (adiabatic redistribution of surface waters)

On long time scales (Pliocene, obliquity):
El Abuelo-like changes (diabatic processes change the mean depth)



Questions:

- ***How can the tropical oceans maintain a longitudinally symmetric state?*** ***Why did it end ~3Ma ago? Did the termination of this state contribute to the onset of the Ice Ages?***

- ***Obliquity signal (41K) dominates SST in the eastern equatorial Pacific . SST variations are in phase with high-latitude insolation (more sunlight locally corresponds to colder temperatures). Are the tropics connected to high latitudes through ocean circulation?***

- ***How can climate in Greenland change so fast and maintain the new state?***

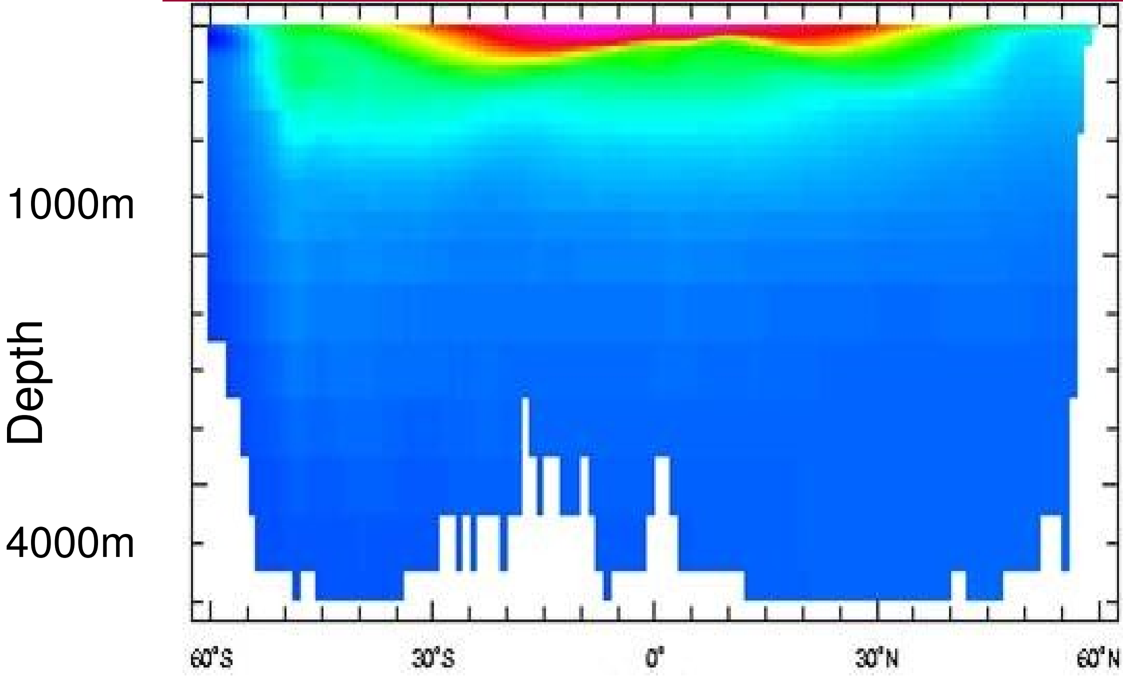
Could the current increase in CO_2 concentration bring us back to an oceanic state with no tropical cold tongues? Can it induce rapid climate changes?

Understanding these past climate changes will help us understand future ones.

Due to the long time scales of ocean circulation the only way to test the models used to predict the response of the climate to an increase in greenhouse gases is through the simulation of past climates.

What do we know about ocean circulation, and the processes that maintain the vertical stratification and the thermocline?

WHY IS THE OCEAN SO COLD?



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