Contributing Processes to the Mid-Pleistocene Transition

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Outline

1. Explanation of the Mid-Pleistocene Transition (MPT).
2. Introduction to the model Saltzman and Maasch developed in 1990 (SM90).

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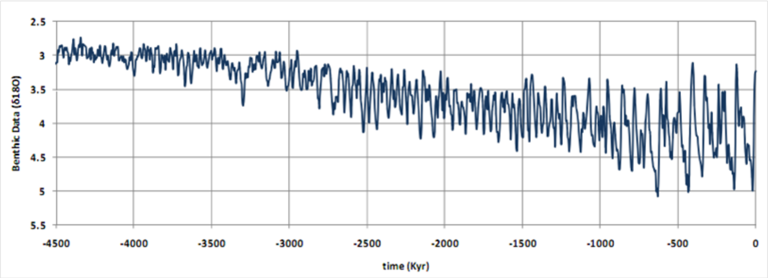
5. Thus, it is a cosmic trick of fate that Milankovitch and Earth has 100kya period. They are only correlated- not causal.
6. Finally, I will outline the only 4 physical changes (1 terrestrial and 3 oceanic) which SM90 suggests may have caused the bifurcation parameter to shift.

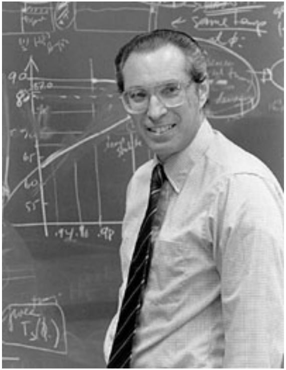
Mid-Pleistocene Transition



Until 1.2 mya, the dominant period was 41kyr and associated to obliquity. After 1.2 mya, the dominant period is (approximately) 100kya cycles.

Barry Saltzman

As a student of Ed Lorenz, Barry Saltzman knew a fair bit about building dynamic minimal complexity climate models. For many years Saltzman developed a 3 variable system to well reproduce the glacial cycles. (Saltzman 1987, 1988, 1990, 1991, 1994).



Saltzman Model of 1990 (SM90)

$M =$ Milankovitch forcing at 65^oN at summer solstice.
$X =$ ice volume
$Y =$ atmospheric CO_2.
$Z =$ North Atlantic Deepwater Formation.
$\dot{} =$ time derivative.
All variables are deviations from the mean.

$$
\begin{aligned}
\dot{X} &= -X - Y - uM(t) \\
\dot{Y} &= -pZ + rY + sZ^2 - Z^2 Y \\
\dot{Z} &= -q(X + Z)
\end{aligned}
\tag{1}
$$

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Maasch and Saltzman show there exists a parameter shift which induces a change from a stable equilibrium solution to 100kyr cycles0. The parameter shift is

$$p = 0.8 \to 1,\ q = 1.2,\ r = 0.7 \to 0.8,\ s = 0.8,\ \text{and}\ u = 0.7$$

where p and r vary linearly in time.

Saltzman Model of 1990 (SM90)

$$\begin{aligned}\dot{X} &= -X - Y - uM(t)\\ \dot{Y} &= -p(a)Z + r(a)Y + sZ^2 - Z^2Y\\ \dot{Z} &= -q(X+Z)\end{aligned}$$

For this research I will refine p and r in terms of a new parameter a. We will consider SM90a for the remainder of the talk.

$$p(a) = 0.8 + 0.2a \quad \text{and} \quad r(a) = 0.7 + 0.1a$$

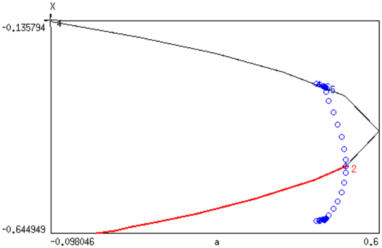
At equilibrium solutions of SM90a we have

$$Z = Y = -X.$$

The equilibrium solutions of SM90a are

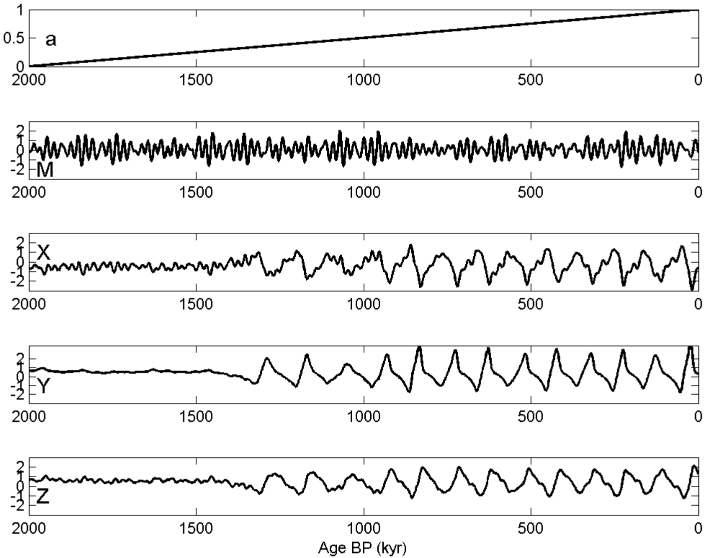
$$X = \frac{1}{2}(-s \pm \sqrt{s^2 - 4(0.1 + 0.1a)}). \tag{2}$$

SM90a

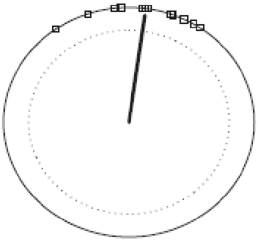


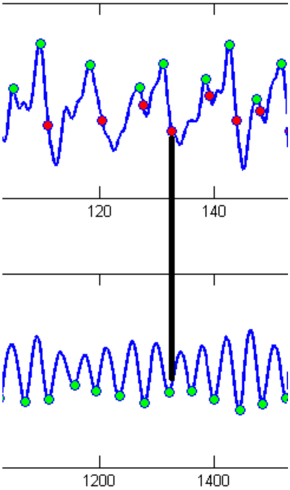
The lower branch of equilibrium solutions, lacking any external forcing, is stable from $a = 0$ until $a = 0.53$. At $a = 0.53$, the system undergoes a sub-critical Hopf's bifurcation and the equilibrium solution becomes unstable. There exists some basin of attraction surrounding the stable manifold. Assuming the external forcing is not too great or too gradual, the solution should stay close to the stable solution until it passes the bifurcation value. Or, the system may exhibit hysteresis along the unstable manifold until a reaches the fold point at $a = 0.6$ at which point the qualitative aspects of the system should change dramatically.

SM90a



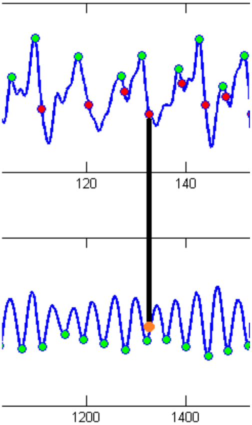
Phase-angle Computations

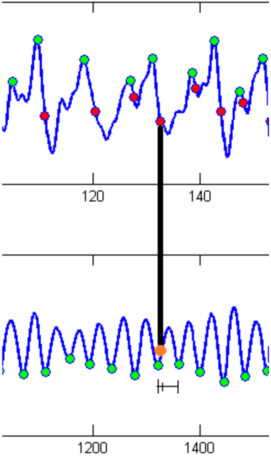


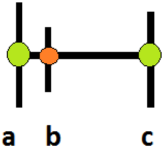


Mini-Goal: How to compute ΔPhase and plot them.

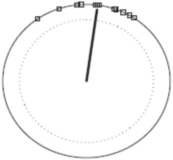
Phase-angle Computations



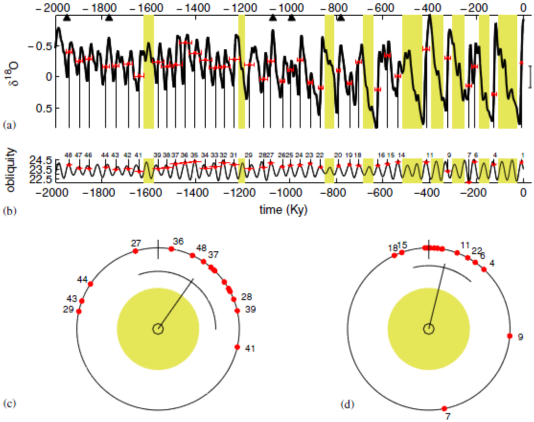




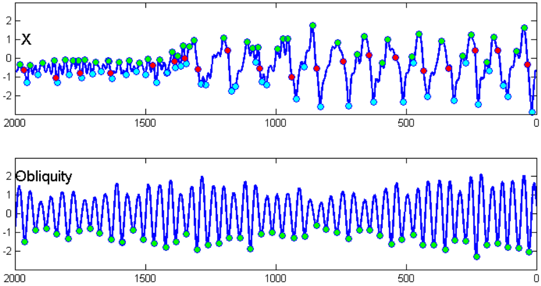
$$\Delta\text{Phase} = \left(\frac{b-a}{c-a}\right) 2\pi$$

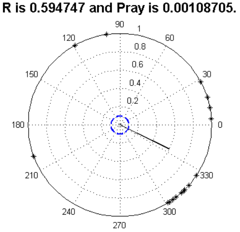


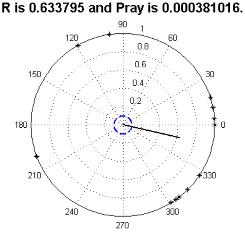
Huybers δ018 analysis



"During the early Pleistocene deglaciations occur nearly every obliquity cycle giving a 40Ka timescale, while late Pleistocene deglaciations more often skip one or two obliquity beats, corresponding to 80 or 120 Ka glacial cycles which, on average, give the 100Ka variability." [Huybers 2007, 2011]





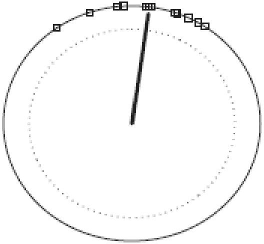


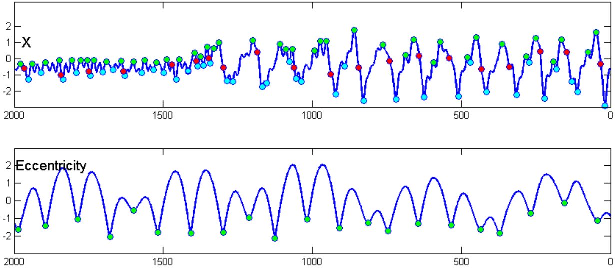
Obliquity ΔPhase for all time

Obliquity ΔPhase since 1.2 MYA.

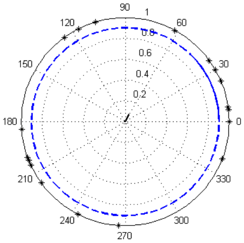
Lisiecki δO18 data analysis

"The relative phase of eccentricity and glacial cycles has been stable since 1.2 Myr ago, supporting the hypothesis that 100,000-yr glacial cycles are paced by eccentricity." [Lisiecki 2010]

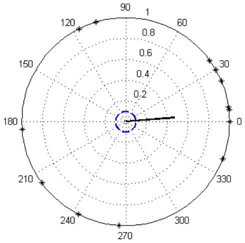




R is 0.0757758 and Pray is 0.904205.



R is 0.471338 and Pray is 0.0162411.



Eccentricity ΔPhase for all time

Eccentricity ΔPhase since 1.2 MYA.

Physical Implications

The dynamical system listed in equation 1 is a nondimensionalization of a more physically intuitive version of the model.

$$\begin{aligned} \dot{I}' &= -a_0 I' - a_1 \mu' + uM \\ \dot{\mu}' &= -b_0 I' + b_1 \mu' - (b_2 - b_3 N')N' - b_4 N'^2 \mu' \\ \dot{N}' &= -c_0 I' - c_2 N' \end{aligned} \tag{3}$$

When we consider the parameter shift from $a = 0$ to $a = 1$, the only parameters which alter in the above equation are b_1 and b_2 which alter from 7×10^{-5} to 8×10^{-5} and 2.52×10^{-20} to 3.16×10^{-20}, respectively.

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2. A lesser dependence on atmospheric CO_2 in the north Atlantic deep water formation carbon sink,
3. Strengthening the solubility pump, or
4. Intensifying the pycnocline which would decrease overturning circulation.

Conclusions

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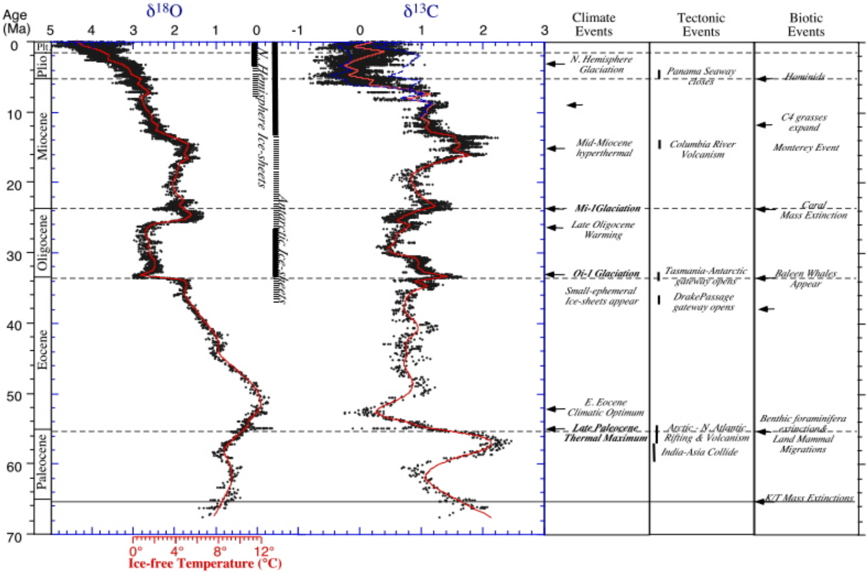
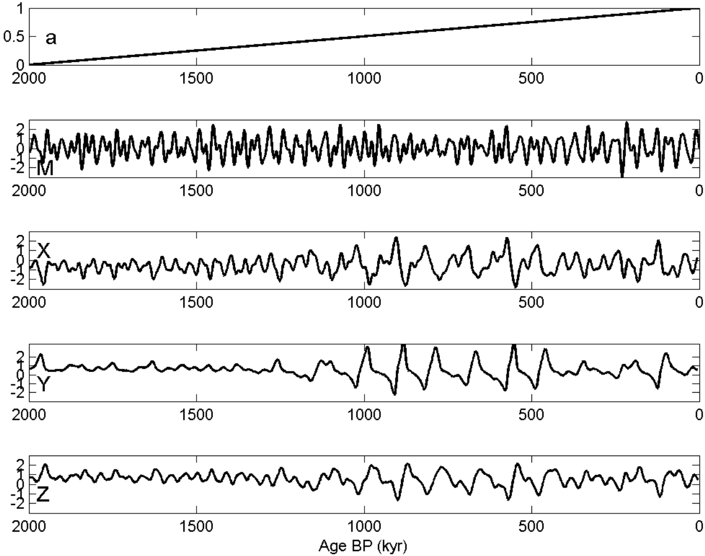
- Additionally, this model supports the work of Huybers and not Lisiecki (yet?).
- Further scientific exploration into the physical processes is necessary to learn more about the Mid-Pliestocene Transition.
- SM90a provides a direction of inquiry by suggestion 4 likely physical candidates.

Bonus



Age (Ma)
δ18O
δ13C
Climate Events
Tectonic Events
Biotic Events
Plt
Plio
Miocene
Oligocene
Eocene
Paleocene
N. Hemisphere Ice-sheets
Antarctic Ice-sheets
N. Hemisphere Glaciation
Mid-Miocene hyperthermal
Mi-1Glaciation
Late Oligocene Warming
Oi-1 Glaciation
Small-ephemeral Ice-sheets appear
E. Eocene Climatic Optimum
Late Paleocene Thermal Maximum
Panama Seaway closes
Columbia River Volcanism
Tasmania-Antarctic gateway opens
DrakePassage gateway opens
Arctic - N Atlantic Rifting & Volcanism
India-Asia Collide
Hominids
C4 grasses expand
Monterey Event
Coral Mass Extinction
Baleen Whales Appear
Benthic foraminifera extinctions& Land Mammal Migrations
K/T Mass Extinctions
0° 4° 8° 12°
Ice-free Temperature (°C)

Bonus: Massive Obliquity



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