Huyber's Analysis of Glacial Cycles Part II

Richard McGehee

Seminar on the Mathematics of Climate Change
School of Mathematics
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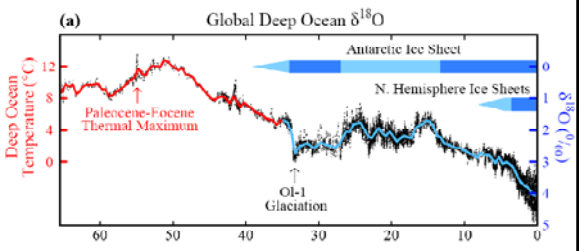
Huyber's Analysis

Peter Huybers, "Glacial variability over the last two million years: an extended depth-derived agemodel, continuous obliquity pacing, and the Pleistocene progression," *Quaternary Science Reviews* **26**, 37-55 (2007).

Pleistocene Progression
Age Model
Correlation with Obliquity
Simple Model

Huyber's Analysis

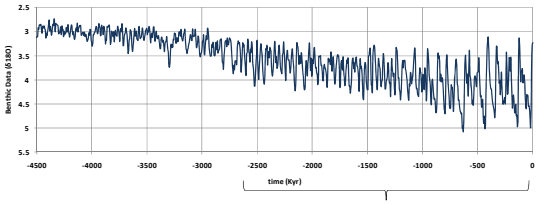
Cenozoic Climate



Hansen, et al, Target atmospheric CO2: Where should humanity aim? *Open Atmos. Sci. J.* 2 (2008)

Huyber's Analysis

^{18}O in Foraminifera Fossils During the Past 4.5 Myr

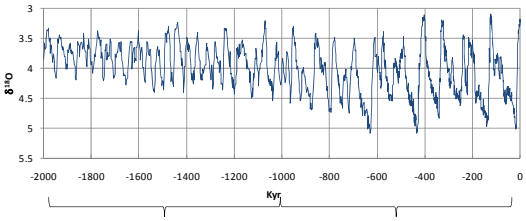


Pleistocene Epoch

Lisiecki, L. E., and M. E. Raymo (2005), A Pliocene-Pleistocene stack of 57 globally distributed benthic d18O records, *Paleoceanography*,20, PA1003, doi:10.1029/2004PA001071.

Huyber's Analysis

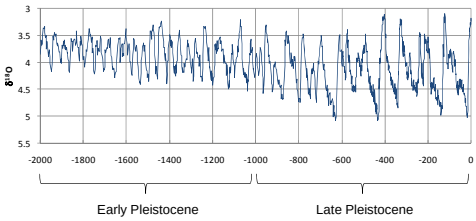
^{18}O in Foraminifera Fossils During the Pleistocene



Early Pleistocene Late Pleistocene

Lisiecki, L. E., and M. E. Raymo (2005), A Pliocene-Pleistocene stack of 57 globally distributed benthic d18O records, *Paleoceanography*,20, PA1003, doi:10.1029/2004PA001071.

Huyber's Analysis



Early Pleistocene Late Pleistocene

The Early Pleistocene climate is dominated by 40 Kyr cycles, while the Late Pleistocene is dominated by 100 Kyr cycles.
What's up?

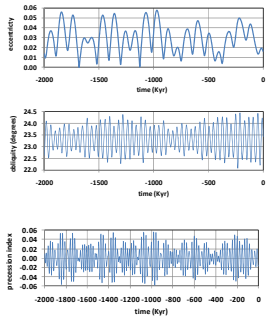
Huyber's Analysis

Earth's orbital cycles

Eccentricity
100 Kyr & 400 Kyr

Obliquity
41 Kyr

Precession
23 Kyr



Huyber's Analysis

Tests of Orbital Hypotheses

Summary

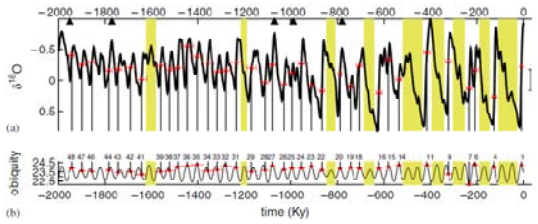
1. We **can reject** the hypothesis that the deglaciations are **unrelated to obliquity**.
2. We **cannot reject** the hypothesis that the deglaciations are **triggered by obliquity.**
3. We **cannot reject** the hypothesis that the deglaciations are **unrelated to either precession or eccentricity**.
4. We **can reject** the hypothesis that the deglaciations are **triggered by eccentricity.**
5. Precession is fuzzy and is different in early and late Pleistocene.

Conclusion

Deglaciation are triggered by obliquity, not by either precession or eccentricity.

Huyber's Analysis

Obliquity Skipping



Why do some obliquity maxima not trigger deglaciations?

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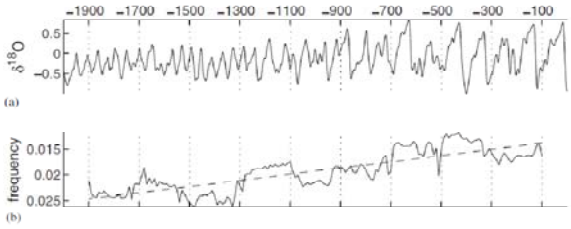
Frequency Progression



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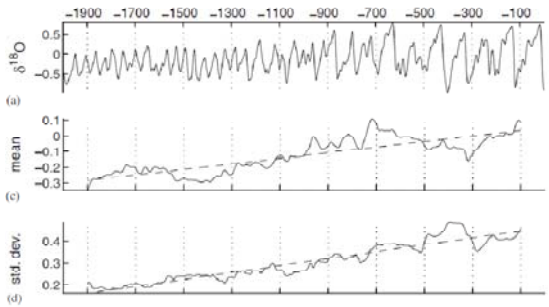
Mean and Variance Progression



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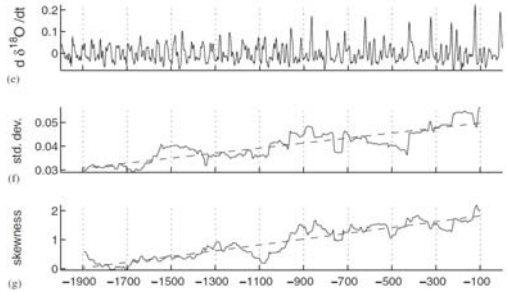
Variance and Skewness of Derivative



Huyber's Analysis

Triggering Model

$$V_t = \begin{cases} V_{t-1} + \eta & \text{if } V_t < T_t \\ 0 & \text{if } V_t \geq T_t \end{cases}$$

$$T_t = at + b - c\theta'_t$$

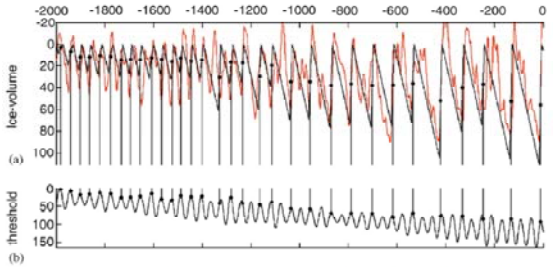
V_t : ice volume at time t
T_t : threshold variable
η : rate of increase of ice volume
θ'_t : normalized obliquity

Units and constants

t : Kyr
V : chosen so that η = 1.
θ': mean zero and variance one
a = 0.05
b = 126
c = 20

Huyber's Analysis

Triggering Model

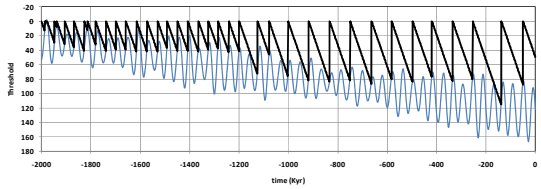


black: model
red: data

Huyber's Analysis

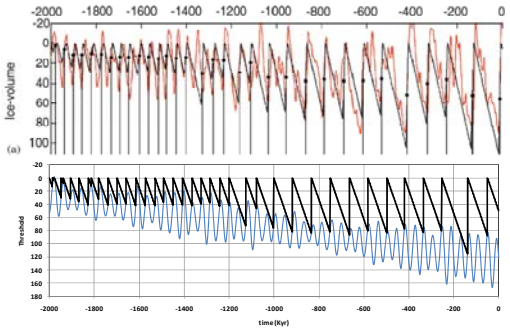
Triggering Model

Attempt to reproduce Huyber's simulation



Huyber's Analysis

Triggering Model



Huyber's Analysis

Obliquity Computations

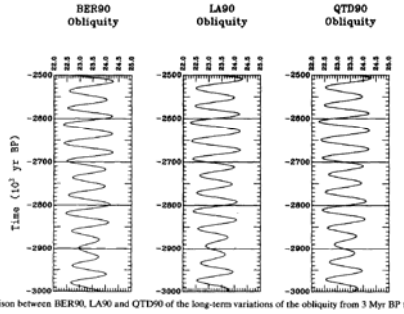


Fig. 8. Comparison between BER90, LA90 and QTD90 of the long-term variations of the obliquity from 3 Myr BP to 2.5 Myr BP.

A. Berger and M.F. Loutre, Astronomical solutions for paleoclimate studies over the last 3 million years, *Earth and Planetary Science Letters* **111** (1992) 369-382.

Huyber's Analysis

Random Growth Triggering Model

$$V_t = \begin{cases} V_{t-1} + \eta_t & \text{if } V_t < T_t \\ 0 & \text{if } V_t \geq T_t \end{cases}$$

$$T_t = at + b - c\theta'_t$$

V_t : ice volume at time t
T_t : threshold variable
η : rate of increase of ice volume
θ'_t : normalized obliquity

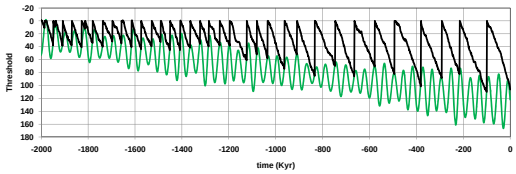
Now η_t is a random variable, normally distributed, mean = 0, variance = 1.
η_1 , η_2 ... are independent.

Units and constants

t : Kyr
V : chosen so that η = 1.
θ': mean zero and variance one
a = 0.05
b = 126
c = 20

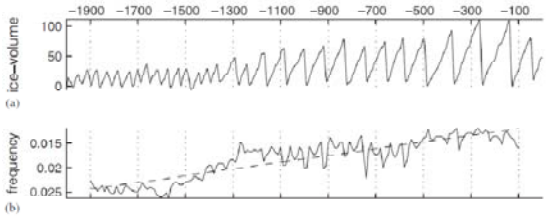
Huyber's Analysis

Stochastic Triggering Model



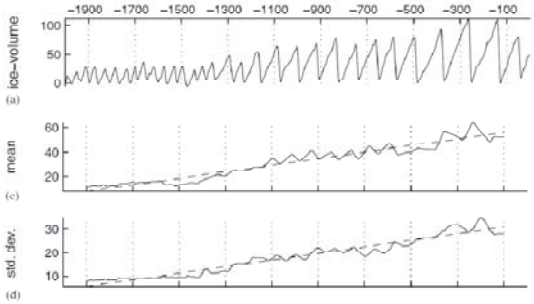
Huyber's Analysis

Stochastic Triggering Model



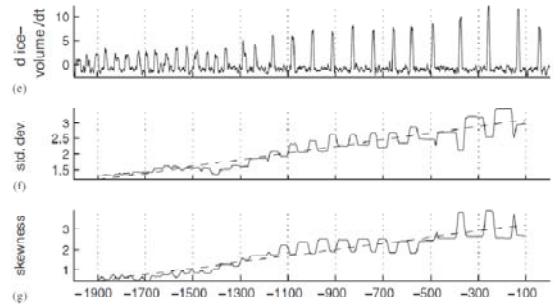
Huyber's Analysis

Stochastic Triggering Model



Huyber's Analysis

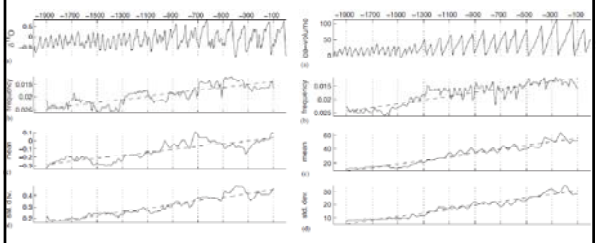
Stochastic Triggering Model



Huyber's Analysis

Stochastic Triggering Model

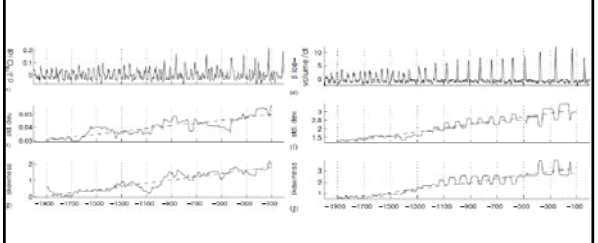
data model



Huyber's Analysis

Stochastic Triggering Model

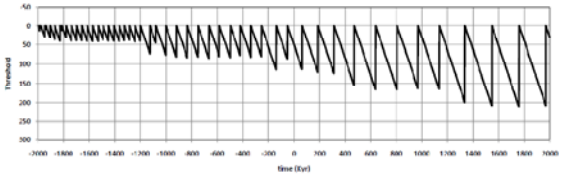
data model



Huyber's Analysis

Triggering Model

Predicting the future



Huyber's Analysis

Summary

The late Pleistocene glacial cycles are characterized by rapid deglaciations followed by slower glacial advance.

Deglaciations are triggered by obliquity, not by either precession or eccentricity.

The longer periods in the late Pleistocene are caused by deglaciations skipping obliquity cycles.

There is a large stochastic component.