Huyber's Analysis of Glacial Cycles

Richard McGehee

Seminar on the Mathematics of Climate Change
School of Mathematics
November 17, 2010

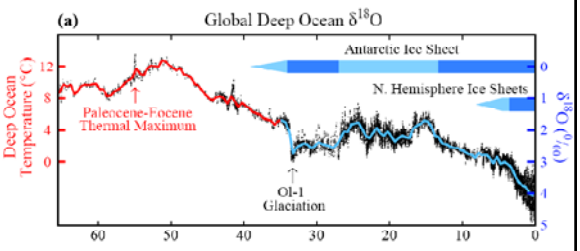
Huyber's Analysis

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

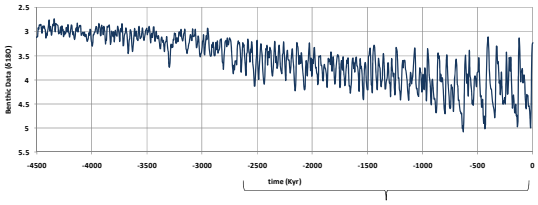
Cenozoic Climate



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

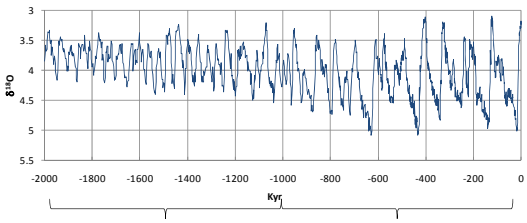


Pleistocene Epoch

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

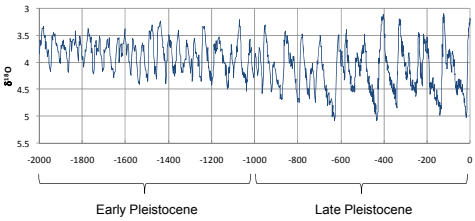
^{18}O in Foraminifera Fossils During the Pleistocene



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?

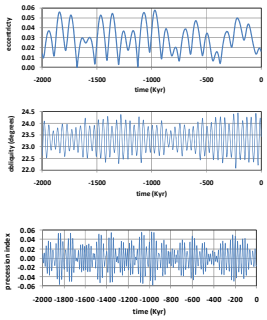
Huyber's Analysis

Earth's orbital cycles

Eccentricity
100 Kyr & 400 Kyr

Obliquity
41 Kyr

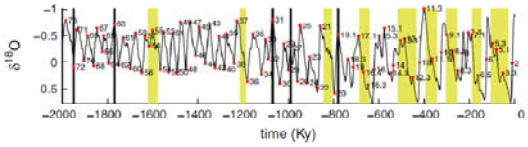
Precession
23 Kyr



Huyber's Analysis

Data Analysis

^{18}O data are usually "orbitally tuned," *i.e.*, the age model is partially determined by Milankovitch cycles.
Huybers reworked the data using only geomagnetic markers, ^{18}O events, and depth.

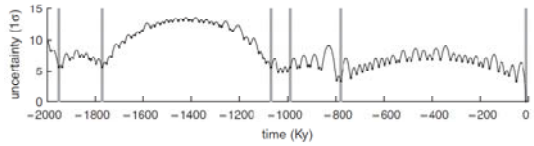


Vertical black lines: Geomagnetic events
Red dots: 18O events
Yellow bars: Obliquity cycle skipped

Huyber's Analysis

Data Analysis

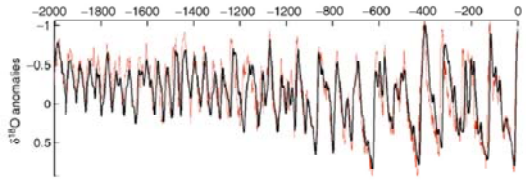
The ages for geomagnetic events are uncertain. Consequently, the 18O events are uncertain, and the entire age model is uncertain.



Huyber's Analysis

Data Analysis

Huyber's age model agrees well with other age models, but contains no bias introduced by "orbital tuning".



Black: Huyber stack
Red: Lisiecki and Raymo stack

Huyber's Analysis

Deglaciations

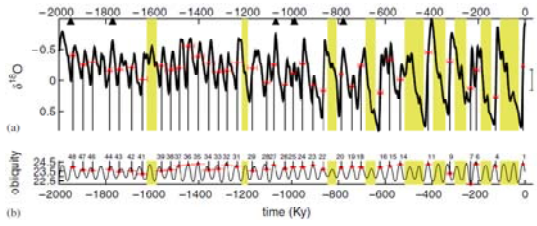
Hypothesis: Deglaciations are triggered by obliquity changes

Identification of Deglaciations

1. Smooth the stack using a 5 Kyr running average.
2. Find local minima and the following local maxima.
3. The $\delta^{18}O$ level must change by at least one standard deviation of the entire record to be called a deglaciation.
4. The time midpoint between the local minimum and the local maximum is defined as the time of the deglaciation.

Huyber's Analysis

Deglaciations



Red dots: deglaciations.

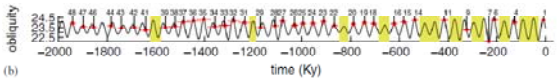
Huyber's Analysis

Rayleigh's R

Rayleigh's R is the statistic used to test the hypothesis that the deglaciations are triggered by obliquity.

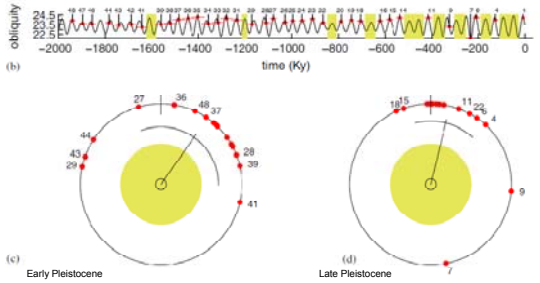
$$R = \left| \frac{1}{N} \sum_{n=1}^{N} e^{i\phi_n} \right|$$

φ_n = phase of the obliquity sampled at the n^{th} deglaciation event.



Huyber's Analysis

Rayleigh's R



Huyber's Analysis

Tests of Hypotheses

H_0: Obliquity phase of the deglaciation event is uniformly distributed on the interval [0,2π].

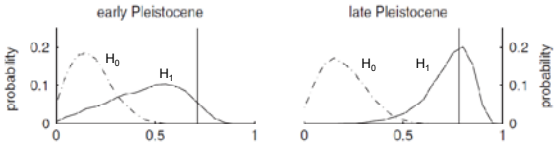
H_1: Obliquity phase of the deglaciation event is distributed about the obliquity maximum, with a distribution determined by the age model uncertainty

Using Rayleigh's R as the statistic, can we reject H_0 and/or H1 with 99% confidence?

Same questions, with "obliquity" replaced by "precession" and by "eccentricity."

Huyber's Analysis

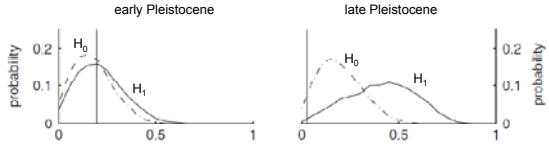
Tests of Obliquity Hypotheses



Conclusion: For both the early and late Pleistocene, we **can reject** the hypothesis that the obliquity phase for deglaciation events is uniformly distributed. We **cannot reject** the hypothesis that the obliquity phase is distributed close to the obliquity maximum.

Huyber's Analysis

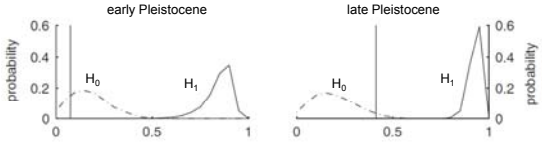
Tests of Precession Hypotheses



Conclusions: For the early Pleistocene, we **cannot** reject **either** the hypothesis that the precession phase for deglaciation events is uniformly distributed **or** the hypothesis that the precession phase is distributed close to the precession maximum.
For the late Pleistocene, we **cannot** reject the uniform hypothesis, but we **can** reject the precession maximum hypothesis.

Huyber's Analysis

Tests of Eccentricity Hypotheses



Conclusion: For both the early and late Pleistocene, we **cannot reject** the hypothesis that the eccentricity phase for deglaciation events is uniformly distributed. We **can reject** the hypothesis that the eccentricity phase is distributed close to the eccentricity maximum.

Huyber's Analysis

Tests of Orbital Hypotheses

Summary

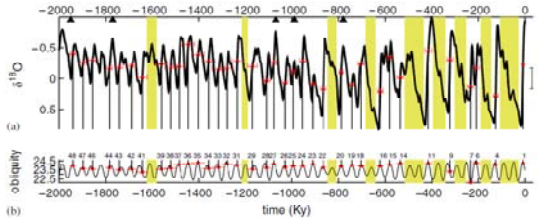
1. We **can reject** the hypothesis that the deglaciations are **unrelated to obliquity**.
2. We **cannot reject** the hypothesis that the deglaciations are **triggered by obliquity.**
3. We **cannot reject** the hypothesis that the deglaciations are **unrelated to either precession or eccentricity**.
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?

Huyber's Analysis

Triggering Model

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

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

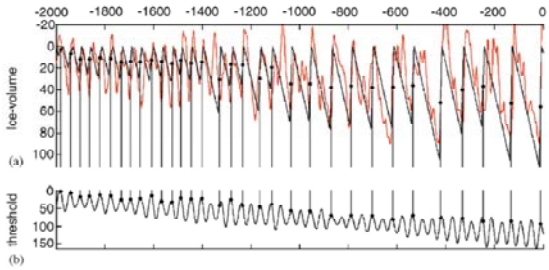
V_t : ice volume at time t
T_t : threshold variable
η : rate of increase of ice volume
θ'_t : normalized obliquity

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

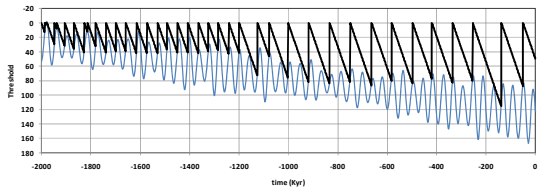


black: model
red: data

Huyber's Analysis

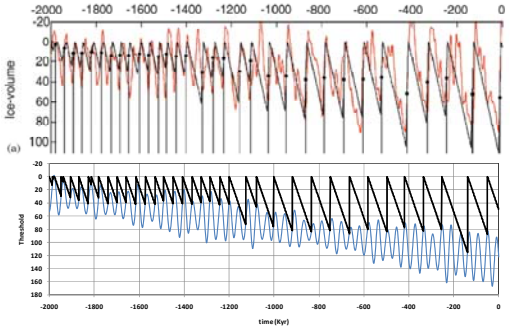
Triggering Model

Attempt to reproduce Huyber's simulation



Huyber's Analysis

Triggering Model



Huyber's Analysis

Triggering Model

Predicting the future