Introduction to Huybers’ 2009 Model

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Outline of the talk

• Introduction
  • Glacial cycles
  • Milankovitch Cycles
  • Mid-Pleistocene Transition problem

• Huybers’ analysis of deglaciations
  • Hypothesis testing
  • Motivation for the structure of Huybers’ model

• Huybers’ model

• Model performance
What are glacial cycles?
Milankovitch cycles drive glacial cycles

- Milankovitch Cycles
  - Eccentricity
  - Obliquity
  - Precession

  Fluctuation in Incoming Solar radiation

  Glacial Cycles
Eccentricity

Precession

http://earthobservatory.nasa.gov/Library/Giants/Milankovitch/milankovitch_2.html
Analysis of Milankovitch cycles’ periodicity

Laskar’s computations

Eccentricity

Obliquity

Precession

Spectra

400 Kyr  100 Kyr

41 Kyr

23 Kyr  19 Kyr
Power spectrum of glacial cycles data

Dominant peak at ~ 0.25 = 40 kyr period

Deglaciation period

Last 5 Mil ~ 1 Mil

Dominant peak at ~ 0.1 = 100 kyr period

Last 1 Mil

Deglaciation event

Ice volume
“Did the main forcing for glacial cycles change from obliquity to eccentricity?”

(40kyr phase) (100kyr phase)

Mid-Pleistocene Transition Problem
Huybers’ Analysis of Deglaciations: Issue of circular reasoning

- Data sets (stacks of data from individual sediment cores) are usually “orbitally tuned”
- Using tuned data sets to conclude that Milankovitch theory is valid is circular reasoning.
- Huybers re-derived the age model without using orbital tuning, then conducts a statistical hypothesis test.
- He concludes that the deglaciations are triggered by only obliquity.

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

1. State the research question, and the appropriate null & alternative hypothesis
   - H0 = deglaciations are independent of orbital phasing
   - H1 = deglaciations always occur during the same phase of orbital forcing

2. Choose appropriate assumptions about the data.
   (independence, distribution…)
   - Time series data, correlated temporally… etc.

3. Choose appropriate test statistic depending on assumptions from 2, and compute it for given data
   - Rayleigh’s $R = \frac{1}{N} | \sum_{n=1}^{N} \cos \phi_n + i \sin \phi_n |$

4. Calculate the P-value, which is the probability of obtaining the test statistic as extreme as the calculated value from 3
   - To be shown on the next slide
Hypothesis Testing: Results

Dashed line for pdf of H0, Solid is pdf of H1

<table>
<thead>
<tr>
<th></th>
<th>Early Pleistocene (2–1 Ma)</th>
<th>Late Pleistocene (1–0 Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( R )</td>
<td>( \text{cv 1%} )</td>
</tr>
<tr>
<td>Obliquity</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Precession</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Hypothesis Testing: Conclusions

1. H0 is only rejected for obliquity for both early and late Pleistocene
2. Power (probability of correctly rejecting H0 when H1 true) is high enough.
   • Late Pleistocene’s power is noteworthy – early Pleistocene is known to have 40kyr
3. Eccentricity does not pace deglaciations (H0 not rejected and high power)
4. Precession is inconclusive
Motivation for the model structure

Obliquity forcing

LINEAR

Obliquity Cycle Skipping
Huybers’ Model

\[ V_t = V_{t-1} + k_t \]  \hspace{2cm} \text{Discrete Ice Volume Growth}

\[ T_t = at + b + c\theta_* \]  \hspace{2cm} \text{Threshold (}\theta_*\text{ = scaled obliquity)}

If \( V_t \geq T_t \), then reset over 10kyr to \( V_t = 0 \) \hspace{2cm} \text{Growth Terminating criterion}

Figure:
Model simulation for last 2 Mil years with \( a=0.05, b=126, c=20 \)
How did obliquity give rise to the shift to 100kyr period?

“...An explanation for the 100 Ka glacial cycles only requires a change in the likelihood of skipping an obliquity cycle, rather than new sources of long-period variability.”

- Peter Huybers, 2007
Model performance

Red: original d18O data
Black: Model output
Dots: deglaciations
Curve: Threshold function from model
Evolutionary frequency spectrum (400Ka sliding window)
Model performance

Model output

Original d18O data
OBLIQUITY

NOT ECCENTRICITY