Astronomy 171
SOLAR SYSTEM ASTRONOMY

Winter Quarter 2000

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- **Part 24 of Course outline:**

Ice Ages

What are they? Why should we care about them? Their link to motions of the Earth

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Some good web sites:

- Geology 151 at U. Mich - a great deal of detailed information
  http://www-personal.umich.edu/~hoaglund/courses.html
- A few drawings that are variations of those presented here from Brown Univ:
  http://www.brown.edu/Courses/GE_0001/glacIceAges.htm
- A good list of lists on ice ages and life during the last ice age:
  http://bvmuseum.myriad.net/websites.html

There are quite a few sites having to do with ice ages, with evolution, with creation, etc. from the self-styled Institute for Creation Research. Whatever "research" they carry out is the antithesis of what is normally considered scientific research. This Institute, which basically tries to advance the agenda of religious fundamentalism, draws conclusions based at least in part on distorted facts, non-facts, fictions, and highly selective treatment of what is known.

What Are Ice Ages?

- In the last 2 million yrs polar ice sheets have periodically extended to low latitudes
  - A general cooling of global temperatures
  - A major lowering of sea levels everywhere
  - The growth of mountain glaciers
- They come about every 100,000 years

- Evidence for earlier epochs of glaciation

Global Ice Cover Today

Ice Cover 18,000 yrs Ago

The Major Land Ice Sheets

- Ice on Earth: ~27,000,000 cubic kms.
- Greenland (~10%)
  - 1,730,000 square kilometers of ice
  - average thickness 1.6 kms
- Antarctica (~90%)
  - 12,500,000 square kilometers of ice
  - average thickness 1.9 kms.

Why Should We Care:
Ice and Sea-Level Changes:

- The last ice age ended about 10,000 yrs ago
- At the height of the last ice age there was about 82,000,000 cubic kms of ice
- Sea-levels would have been lower by 425 ft.
- If today?s 27,000,000 km^3 of ice were to melt, sea-levels would rise by 210 ft.
- London, New York, Tokyo would disappear as would quite a few countries

Global Warming Floods Florida!

- If all global ice sheets melted, sea-level would rise 210 feet
- If only West Antarctic sheet melted, sea-levels would rise about 17 feet.
- If that happens, the only parts of Florida left are those in green

What are the Immediate Causes of Ice Ages?

- A small drop in summertime temperature is critical - reduces melting of ice and snow
  - A global cooling by only 5°C or 8°F
- Transition from cold to warm appears rapid
  - Could mean oscillation between two stable states of the Earth?s climate.

What do You Want to Predict?

- People have always looked for correlations between events in the sky on on the Earth.
- An example: attempts have been made to correlate all kinds of things with sunspot numbers.

Fundamental Causes of Ice Ages

- Variation in Sun's energy output
- Volcanic activity
- Positions of continents relative to each other and the poles (start 20,000,000 yrs ago)
- Astronomical cycles - proposed by Milankovich in 1920s and 1930s

Global Temperature and Deep Sea Cores

- There are two stable isotopes of oxygen. They are a natural global thermometer
- H_2O^{18} is heavier than H_2O^{16} so it falls more readily as rain over oceans - like distillation.
- The more ice on land the higher is the ratio of O^{18} to O^{16} in the oceans (shells, etc).
- Measure O^{18} / O^{16} ratio vs. depth below floor
- Look for cyclic behavior in the result.

A History of Sunshine and Ice

- Graph below shows volume of Earth?s ice sheets from ocean cores inferred from O^{18} / O^{16} ratio vs. depth below ocean floor. The right side of the graph is about 600,000 yrs ago. Terminations of ice ages are marked.
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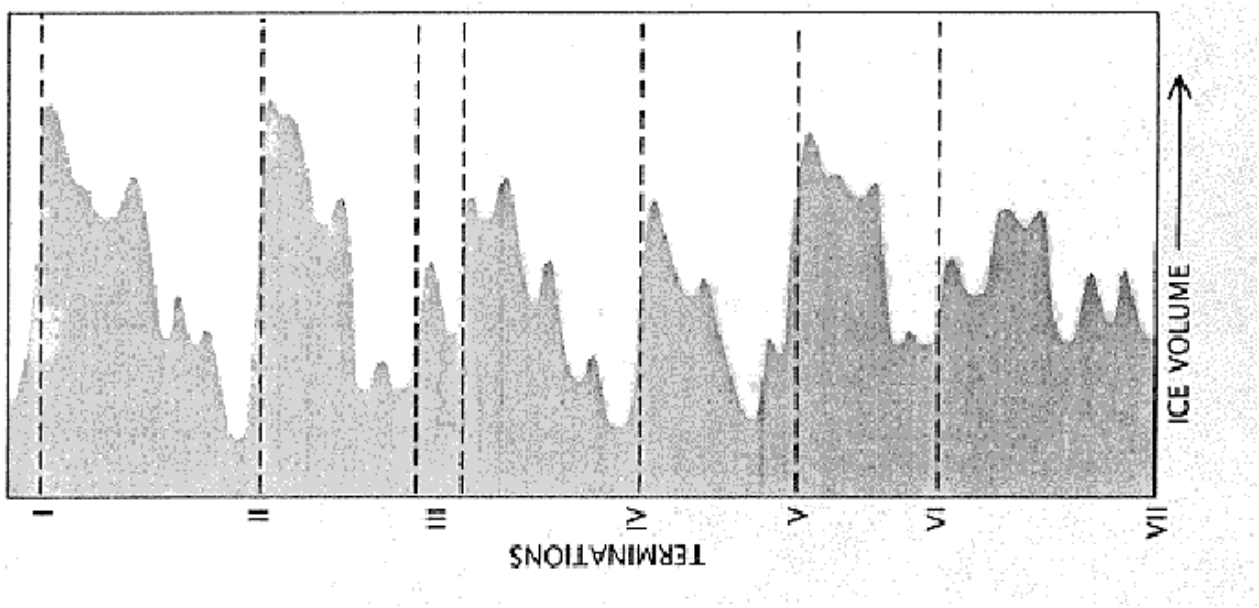
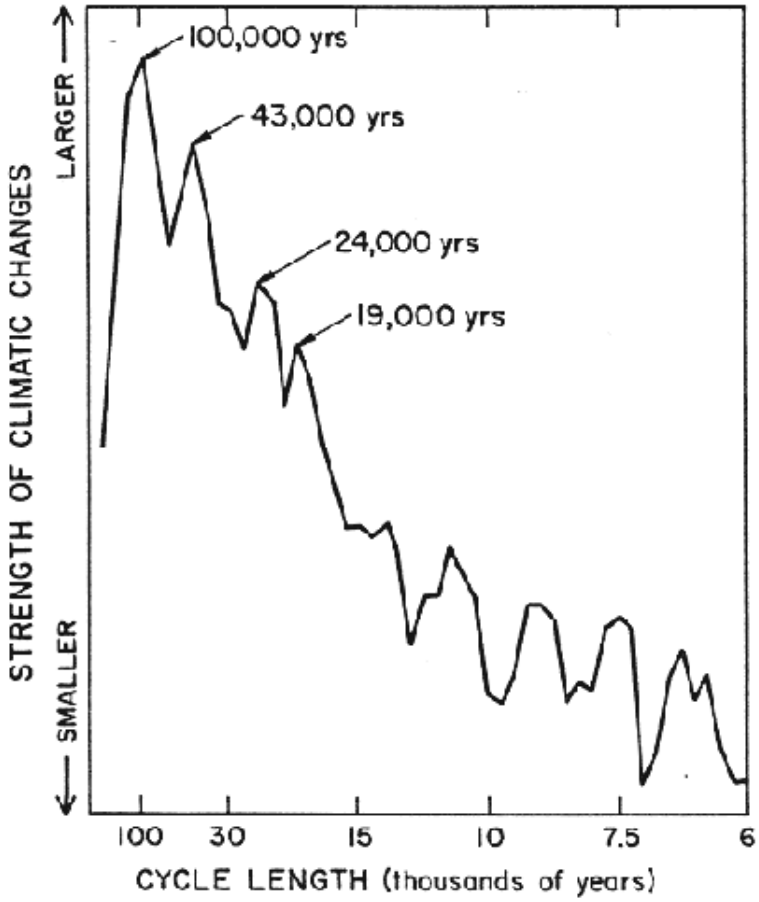


How Do You Analyze the Data

- Question: Is there periodic behavior in the variation of ice with time?
- Technique: Called spectral analysis. Uses what is called a Fast Fourier Transform (FFT) to see what periods might be present in the data.
- And the answer is ?..

Cycles Found in Deep Sea Cores

- There are only 4 strong cycles. Weaker ones are noise.
- The stronger the cycle the more important it is in explaining the variation with time of the O^{18} to O^{16} ratio.



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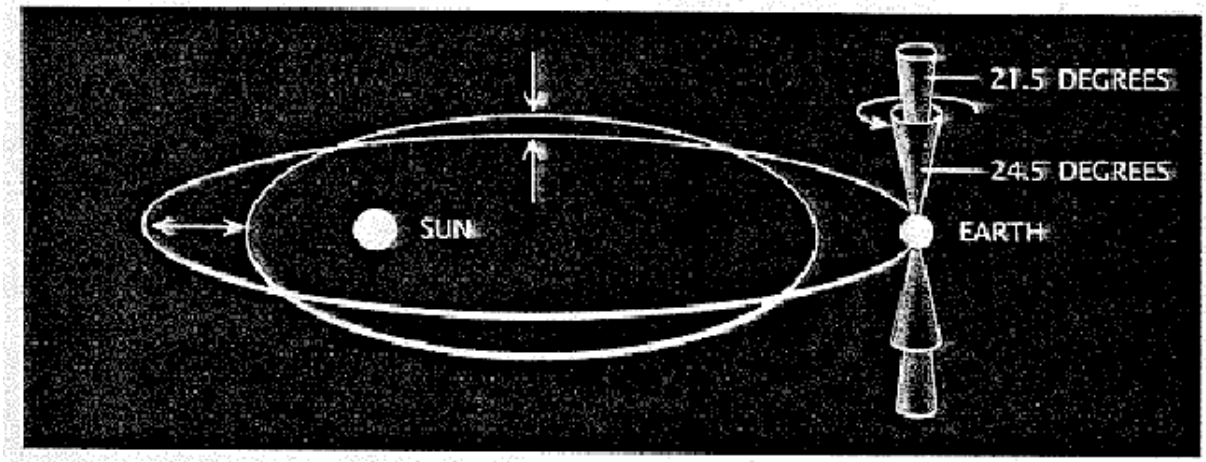
How I "Made" the Model Data

Astronomical Cycles: Pacemakers of Glaciation

- Eccentricity of Earth?s orbit (100,000 yrs)
- Precession of Earth?s axis (26,000 yrs)
- Angle of tilt of the axis (40,000 yrs)

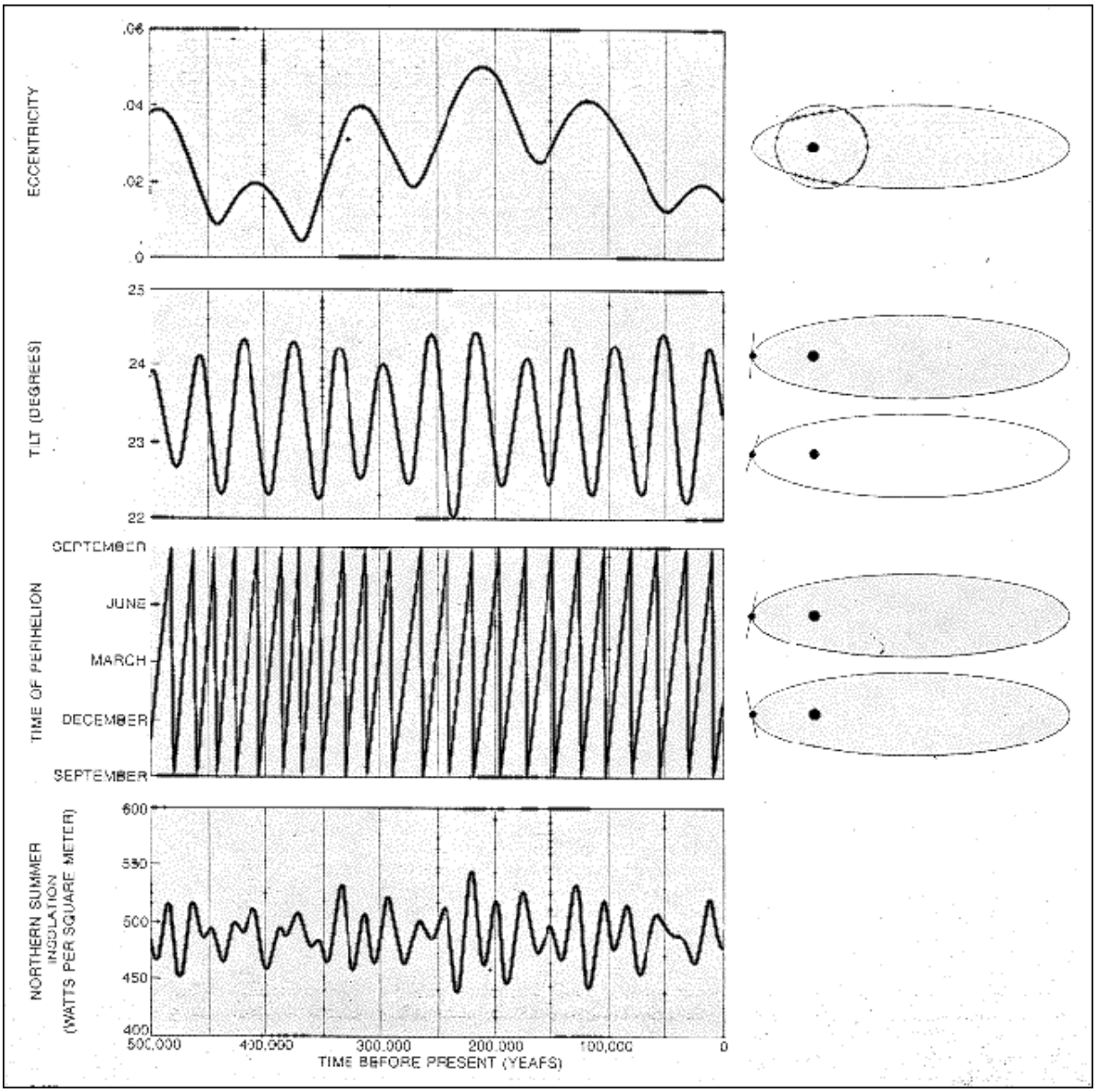
- 

Variations in Earth?s Orbit

- Three Parameters
- **Eccentricity**
- **Axis tilt angle**
- **Time of perihelion**
- **Summer sun at 60-70^{o} north latitude in July**

The Three Key Parameters

- Orbital eccentricity of Earth changes from near 0 to .05 with period of ~100,000 year
- Angle of tilt of axis changes from 22 to24 degrees with period of 40,000 years
- Time of perihelion: complex - what direction does axis point at perihelion? Has two superimposed periods: 19,000 and 23,000 years

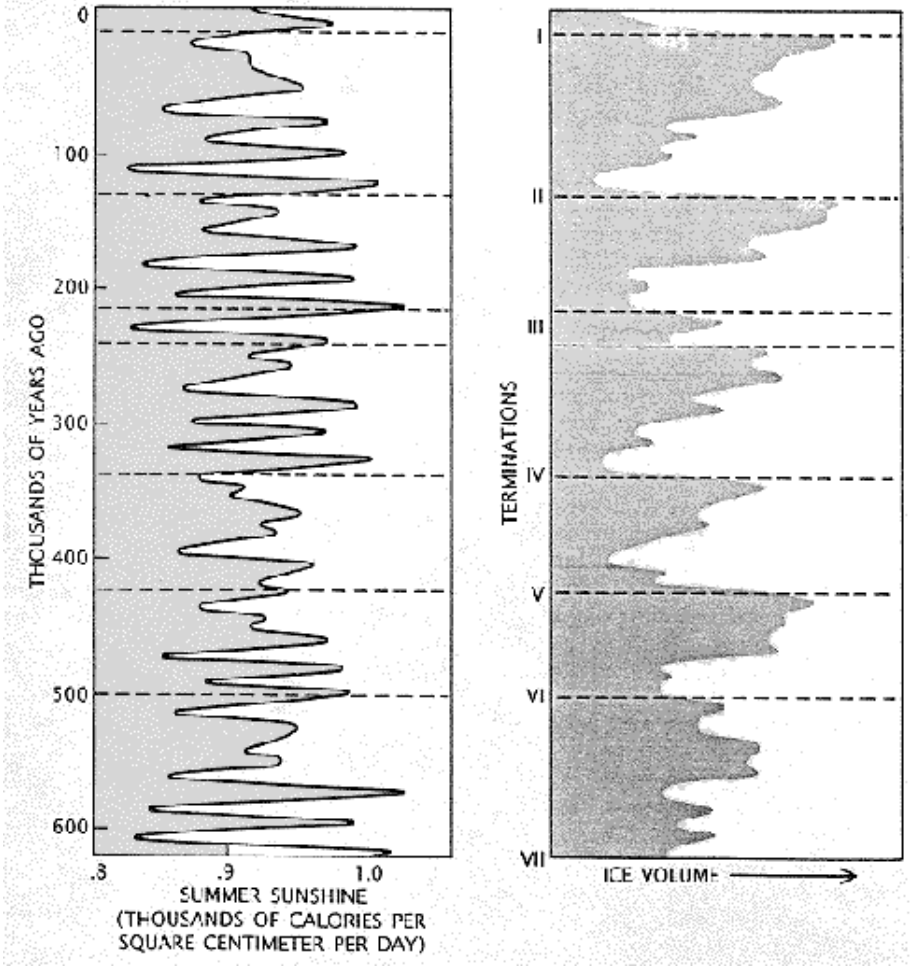


Cycles Found in Deep Sea Cores

- The stronger the cycle the more important it is in explaining the the variation with time of the O^{18} to O^{16} ratio.
- There are only 4 strong cycles. Weaker ones are noise.

A History of Sunshine and Ice

- Left graph shows predicted effects of changes in astronomical cycles on summer sunshine at high northern latitudes.

- ***Range is 20%***
- Right graph shows volume of Earth?s ice sheets from ocean cores.
- 

Conclusions: Causes of Ice Ages

- Milankovitch theory most likely direct cause of ice ages - based on orbital motions of earth.
- Locations of continents and oceans most likely play important role as well - they may have to be "just so" for Milankovitch effects to kick in.
- Volcanic dust, impacts, etc. secondary.

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