



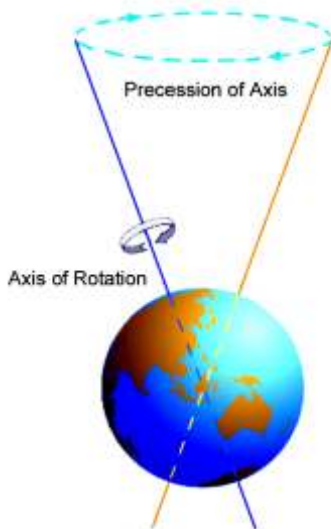
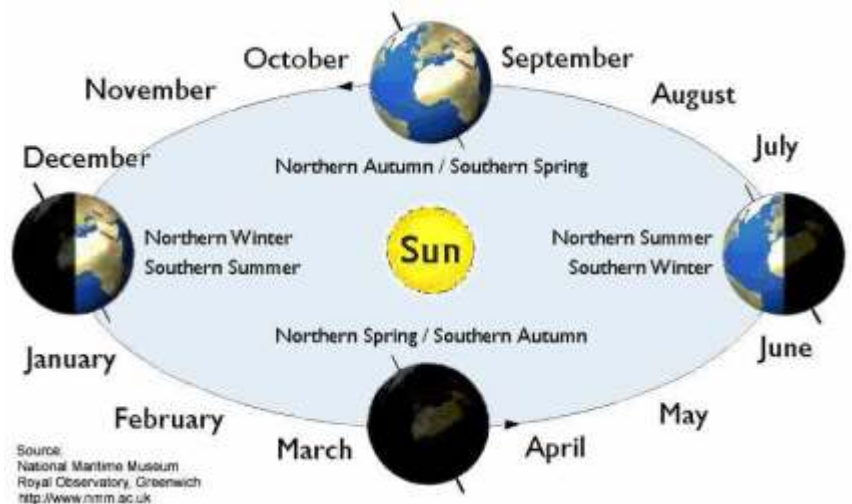
Dr. Milankovitch's Humongous Hypothesis

Milutin Milankovitch (1879-1958)

What causes ice ages? Milutin Milankovitch had big ideas on this question. The mathematician from Serbia was interested in the factors that control the periodic heating and cooling of Earth. Building on the work of others, he set out to show that the onset and retreat of glacial periods could be explained mathematically by changes in the amount of solar energy reaching Earth. These changes result from variations in Earth's orbit over periods exceeding ten thousand years.

The Milankovitch Theory correlates warming and cooling cycles with three orbital elements: eccentricity, axial tilt, and precession.

Eccentricity is a measure of the roundness of an ellipse. Like all planetary bodies, Earth's orbit is elliptical. Its eccentricity varies in a cyclical fashion between zero (perfectly round) and about 0.06 (very slightly oblong) over very long periods of time. Because of the elliptical nature of Earth's orbit, the distance between Earth and the Sun changes over the course of a year; and these differences are magnified when the eccentricity is greater.



Adapted from Hong Kong Space Museum graphic

Axial Tilt refers to the inclination of Earth's axis to the plane of its orbit. The angle of tilt varies between 22.1 and 24.5 degrees, over somewhat shorter cycles than eccentricity. It is because of axial tilt that the Sun angle at any location on Earth changes as the Earth moves along its orbital path. This annual variation in sun angle is what gives us the seasons (see figure above).

Precession is the wobble in Earth's axis (see figure at left). To understand this motion, consider a spinning top or gyroscope. It starts out steady; but as the top slows, its uppermost point begins to trace a circular path. In so doing, the axis of the spinning object describes the shape of a cone in space. The precession of Earth's axis is like that of a spinning top, except that it occurs much more slowly. This precession is caused by the tug of the Sun's and moon's gravity on the Earth. The period of the precession cycle is shorter than those for both eccentricity and axial tilt.

It should also be noted that the gravitational pull of the other planets of the solar system creates a wobble in Earth's elliptical orbit, known as precession of the ellipse. The combined effect of axial precession and precession of the ellipse is to modify where the equinoxes and solstices occur in Earth's orbit, causing a shift in the timing of seasons. Right now, in the northern hemisphere, summer begins in June and winter begins in December. Halfway through the current precession cycle (thousands of years from now) the timing of summer and winter will be reversed. Also because of precession, in less than a thousand years Earth's axis will no longer point to Polaris.

Variations in eccentricity, tilt, and precession do not greatly affect the annual amount of solar energy reaching Earth. However, they appear to change the contrast between the seasons. Milankovitch reasoned that any solar radiation effects would be most pronounced at 65°N latitude, where ice sheets advance in colder periods and retreat in warmer periods and consequently exert an influence on overall global temperatures.

For more than thirty years, starting in the early 1900's, Milankovitch worked to clarify the mathematical relationships between orbital geometry and climate change. His theory was largely forgotten for a time but regained favor in the final decades of the Twentieth Century, following studies on deep-sea sediments and ice cores. These modern investigations showed a close association between major climate changes and orbital variations. In other words, predictable changes in Earth's orbit appeared to be the cause of ice ages. Although widely regarded by the scientific community, the Milankovitch Theory is not the final word on climate change, as it does not fully explain the geologic record of global warming and cooling. Many questions on this subject remain to be answered.



On the next page are graphs showing the kinds of information Milankovitch used for investigating possible connections between climate change and orbital variations. The first three graphs show measures of eccentricity, axial tilt, and precession. The bottom graph shows relative ice sheet volumes (determined from oxygen isotope measurements as proxy) and times of maximum glaciation. The four graphs span the period from present day to 750,000 years ago.

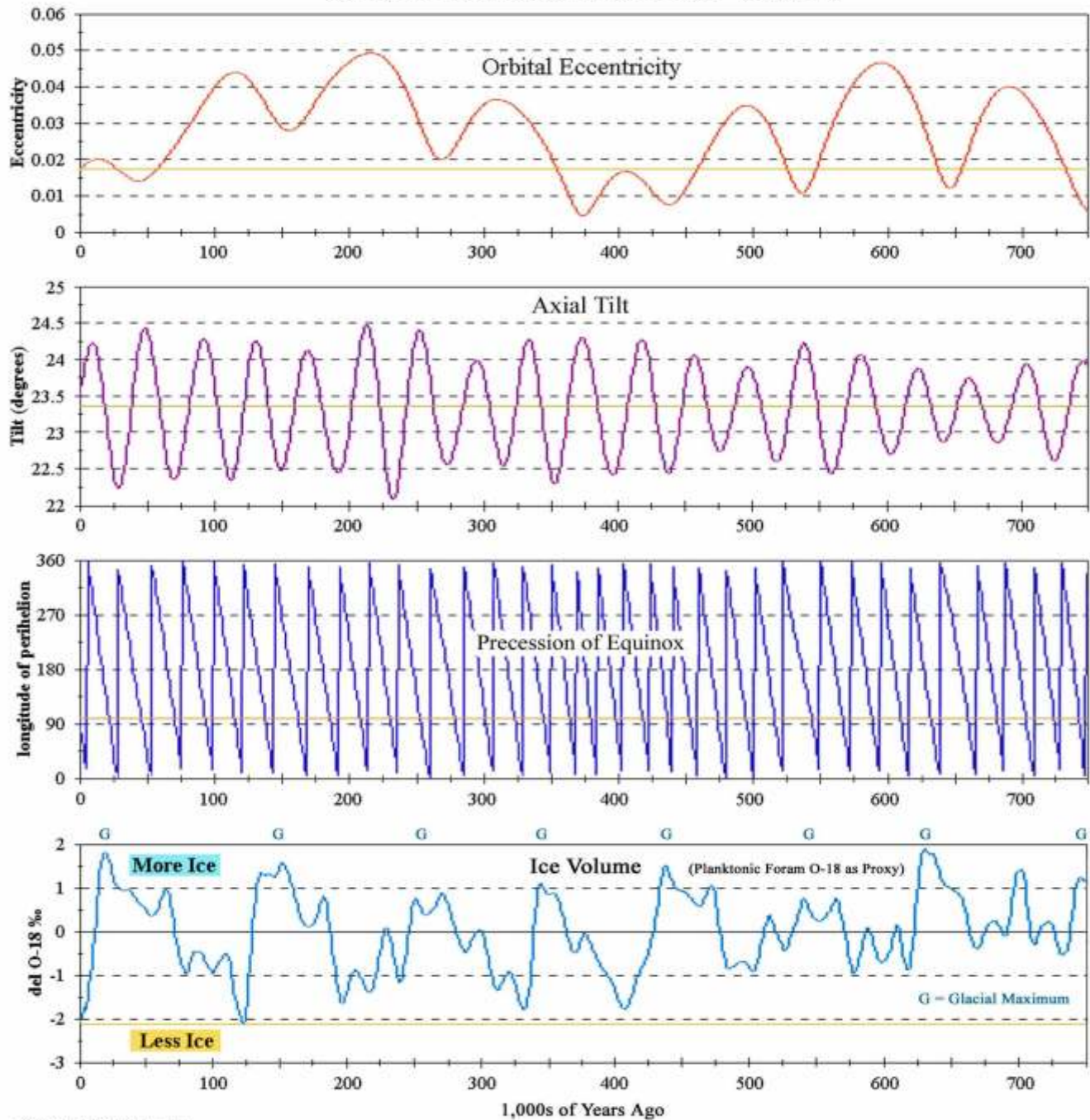
After studying the graphs, answer these questions:

1. What is the approximate period, in years, for each of the following orbital cycles? (Period is the term for the repeating time interval between peaks of a cycle – use a ruler to measure):
Eccentricity _____ Tilt _____ Precession _____
2. What is the approximate period between glacial maxima (give calculated average)? _____
3. Which of the three orbital factors – eccentricity, tilt, or precession – appears to have the strongest association with ice volume? Explain.

4. Which other orbital factor has a distinct relationship to ice volume? Explain.

5. In comparing the orbital cycles with the glacial record, can it be concluded that orbital factors trigger ice ages? Are there any problems with matching the data between graphs?

Orbital Variations and Ice Volume



Source: Illinois State Museum
http://www.museum.state.il.us/exhibits/ice_ages/why_glaciations1.html

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Teachers' Notes

Objectives: Students will learn about three important factors influencing global warming and cooling – orbital eccentricity, axial tilt, and precession. They will examine graphs and draw conclusions regarding the strength of the connection between orbital variations and the occurrence of ice ages.

Grade Level: Middle/High

NSES: A3, A4, A5, A6, B5, B6, B10, D6, D7, D9, G2, G3, G4, G5, G6, G7

NHSCF: 1a, 4a, 4b, 4c, 5c, 5g, 6a, 6b, 6c

Key Concepts

Cyclical variations in three orbital elements – eccentricity, axial tilt, and precession – act together to influence Earth's global climate and correlate well with the geologic record of past glacial periods. Of the three named factors, eccentricity has the longest periodicity (about 100,000 years) and shows the strongest association with the timing of ice ages.

Milutin Milankovitch is the mathematician/scientist credited with the comprehensive mathematical model relating orbital mechanics to global temperatures. The theory tying orbital variations to the growth and retreat of ice ages bears his name.

The Milankovitch Theory, however, is an incomplete explanation for all observed changes in climate over the last million years. Earth's climate system is too complex to be boiled down into a few mathematical formulas. Many questions about internal and external forcing of the climate system remain and are the subject of extensive ongoing research.

The three graphs of orbital variations are mathematically derived. The graph on ice volume is not based on direct measurement but is actually a record of oxygen-18 to oxygen-16 ratios in deep-sea sediments. Paleoclimatologists use these ratios as a proxy for past global temperatures and ice volumes. Students' are asked to examine the data for the purpose of finding any associations between orbital factors and the glacial record. This is the same process, in simplified form, that scientists have undertaken to identify possible cause-effect relationships.

The concept of orbital eccentricity is easily understood and is the subject of another student activity, "Totally Elliptical." Axial tilt is also a simple concept, but its relationship to seasons on Earth is often a source of confusion to students. There are many good websites explaining why seasons occur. Classroom demonstrations are also helpful in presenting this concept. Any confusion over the meaning of precession may be eliminated by doing simple demonstrations with tops or gyroscopes.

Earth's orbital mechanics incorporate two types of precession: axial precession and precession of the ellipse. Axial precession refers to the wobble of Earth's rotational axis. This phenomenon occurs on a cycle of about 26,000 years and is the reason that the true north star shifts over the millennia. Precession of the ellipse refers to the wobble of Earth's elliptical orbit. The combined effect is a modulated precession of Earth's axis relative to the Sun with a period of about 22,000 years. It is the latter periodicity that correlates closely with ice volume.

For more information on the life and work of Milutin Milankovitch, visit these websites:

<http://earthobservatory.nasa.gov/Features/Milankovitch/>

<http://www.emporia.edu/earthsci/student/howard2/milan.htm>

For further information on orbital variations and climate change, visit these websites:

<http://www.physicalgeography.net/fundamentals/6h.html>

<http://scienceworld.wolfram.com/physics/PrecessionoftheEquinoxes.html>

<http://www.newscientist.com/topic/climate-change>

<http://www.astro.uiuc.edu/projects/data/Seasons/seasons.html> (Flash animation)

http://www.museum.state.il.us/exhibits/ice_ages/laurentide_deglaciation.html
(mpg video animation)

ANSWER KEY

1. What is the approximate period, in years, for each of the following orbital cycles? (Period is the term for the repeating time interval between peaks of a cycle – use a ruler to measure):
Eccentricity 100,000± Tilt 41,000± Precession 22,000±
2. What is the approximate period between glacial maxima (give calculated average)? 100,000±
3. Which of the three orbital factors – eccentricity, tilt, or precession – appears to have the strongest association with ice volume? Explain.
Sample response: Orbital eccentricity appears to have the strongest association with ice volume. The eccentricity cycles closely match the glacial periods (occurring about once every 100,000 years). The lowest points in eccentricity nearly coincide with peaks in ice volume.
4. Which other orbital factor has a distinct relationship to ice volume? Explain.
Sample response: Precession of the equinox also appears to be related to ice volume. The many smaller peaks in ice volume closely match the precession cycles.
5. In comparing the orbital cycles with the glacial record, can it be concluded that orbital factors trigger ice ages? Are there any problems with matching the data between graphs?
Sample response: The close matches of eccentricity and precession to ice volume make it seem as though these factors could cause ice ages. However, the intervals between glacial maximum values are not all the same, so the match between eccentricity and ice volume is not perfect. Also, the shapes of the peaks and valleys of the ice volume graph are quite varied. It is hard to account for some of these differences using only the information in the graphs.