High-Resolution Marine Ice Core and Marine Sediment Records

Archives of Orbital Oscillations (Milankovitch Cyclicity) in Climate

Summary
High-resolution marine ice core and marine sediment records contain climate proxy data (e.g., sediment lithology, stable isotopes preserved in foraminifera tests). These records archive the impact of orbital oscillations (Milankovitch Cyclicity) which influence the amount of incoming solar radiation on Earth’s climate.

Learning Objectives
Students will be able to:

• Explain how a range of core data (including oxygen isotope data) are used to examine and make inferences about past climate trends and events.
• Find trends and cyclicity in graphs of climate proxy data.
• Discuss evidence of past climate change and trends to recent concerns over global climate change.

National Science Education Standards
Standard A: Science as Inquiry
Standard D: Earth and Space Sciences

Ocean Literacy Essential Principles
7. The ocean is largely unexplored.

Target Age: Grades 9-12, undergraduate
Time: One class period

Background
Milankovitch cycles are driven by Earth’s natural orbital oscillations, which influence the amount of incoming solar radiation (insolation) received. Periodic oscillations in insolation affect temperature and precipitation patterns, particularly in the high latitudes. Changes in insolation at the high latitudes are the principle driver of glacial cycles over the past several million years. These oscillations are manifest in many different types of climate proxy data including lithology, sediment grain size, sediment color, magnetic susceptibility, gamma ray, stable isotopes, etc. Milankovitch cycles are pervasive through the geologic record.

There are three major periodicities of Milankovitch cycles: eccentricity of Earth’s orbit around the Sun, obliquity in Earth’s axial tilt relative to the plane of the ecliptic, and precession of the seasons (see attached Figure 1). **Eccentricity** is a term used to describe the degree of deviation from a perfect circle; the greater the eccentricity, the greater the elliptical deviation from a circle. A perfect circle has an eccentricity of 0 and a flattened circle (= straight line) has an eccentricity of 1. Earth’s orbit around the Sun has an eccentricity that ranges from 0.005 to 0.058 with a mean of 0.028. The eccentricity today is 0.017. There is a range of periodicities (95 kyr to 136 kyr) with an average of about 100 kyr (100,000 years). There is also a long eccentricity cycle with a periodicity of 413 kyr.

**Obliquity** describes the Earth’s axial tilt, which ranges between 24.5° and 22.1°. Today the axial tilt is 23.5°. The periodicity of obliquity is about 41 kyr. Cooler summers in the high latitudes created by less tilt are more favorable for triggering an ice age compared with the warmer high-latitude summers expected when the tilt is greater. **Precession** of...
the equinoxes has a cyclicity of 19 to 26 kyr. Because the spinning, Earth wobbles like a top, this affects the time of year the Earth is closest to the Sun (owing to our slightly elliptical orbit around the Sun). Today, we are closest to the Sun (perihelion) on about January 3 (Northern Hemisphere winter), and furthest from the Sun (aphelion) on about July 4 (Northern Hemisphere summer). About 11,000 years ago, the Northern Hemisphere was at its closest distance from the Sun during the summer months.

The attached pages include examples of Milankovitch cyclicity in ODP core data, including oxygen isotope data from ODP Sites 1089 (southern South Atlantic) and 983 (northern Atlantic), core photos, color reflectance, and bulk density from Core 198-1208A-8H (Shatsky Rise), benthic foraminifer oxygen isotope data from ODP Leg 108, Site 659 (eastern tropical Atlantic) and Leg 154, Site 929A (Ceara Rise, western tropical Atlantic), and gamma ray attenuation, magnetic susceptibility, and color reflectance data from ODP Site 1218 (central tropical Pacific).

**What To Do: Milankovitch Cyclicity Exercise**

The attached Figure 2 shows benthic foraminifera $\delta^{18}O$ data for the past 5.5 million years.

1. Compile a list of observations about trends in this climate proxy record.
2. How might this record be related to Milankovitch climate cyclicity?
3. The core photo, reflectance, and bulk density data from Core 198-1208A-8H show clear evidence of cyclicity. The base of polarity Chron C1r.1n (1.07 Ma) occurs at 55.85 mbsf, and the top of Chron C2n (1.77 Ma) occurs at 85.01 mbsf. What is the likely periodicity of the cycles in Core 8H?
Figure 1. Three dominant periodicities of Milankovitch cyclicity.
(From: www.homepage.montana.edu/~geol445/hyperglac/time1/milankov.htm)
Figure 2. Benthic foraminifera δ18O data show the fluctuating sequences of glacials and interglacials for the past 5.5 million years. (From: http://en.wikipedia.org/wiki/Image:Five_Myr_Climate_Change.png)

Earth’s axial tilt (obliquity) ranges from 22.1° to 24.5°. (From: http://en.wikipedia.org/wiki/Image:Earth_obliquity_range.png)

High-resolution records of orbital oscillations (Milankovitch cyclicity) in climate.

Figure 2. Benthic foraminifera δ18O data show the fluctuating sequences of glacials and interglacials for the past 5.5 million years. (From: http://en.wikipedia.org/wiki/Image:Milankovitch_Variations.png)
Oxygen isotope data from ODP sites 1089 and 983. The δ¹⁸O reference is from SPECMAP, a stacked composite oxygen isotope curve. The numbers refer to Marine Isotope Stages (MIS); interglacial periods are odd numbers, glacials are even. Site 1089 (ODP Leg 177) is in the southern South Atlantic and Site 983 (ODP Leg 162) is in the northern North Atlantic (from Hodell, Gersonde, and Blum, 2002. Leg 177 Synthesis, Proceedings of the Ocean Drilling Program, Scientific Results, Volume 177). (From: www-odp.tamu.edu/publications/177_SR/synth/synth.htm)
Composite digital core photograph, color reflectance, and bulk density for Core 198-1208A-8H. This core is Pleistocene in age.

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Fig. 3. (A through D) High-resolution 4-My-long $\delta^{18}$O time series representing four intervals of the Cenozoic. The data are from Site 659, eastern equatorial Atlantic (58); Site 588, southwest Pacific (59); Site 929, western equatorial Atlantic (60); Site 522, south Atlantic (61); and Site 689, Southern Ocean (68). Sampling intervals range from 3 to 10 ky. Note that the $\delta^{18}$O axes on all plots are set to the same scale (3.0%), though at different ranges to accommodate the change in mean ocean temperature/ice volume with time. The Plio-Pleistocene ages for Site 659 are constrained by oxygen isotope records directly or indirectly calibrated to Northern Hemisphere summer insolation at 65°N, based on the astronomical solutions of Berger and Loutre (123). The Site 929 age model is also calibrated to an orbital curve derived from the formulations of Laskar (2) with corrections for tidal dissipation (29). The upper curves in (A) and (C) represent Gaussian band-pass filters designed to isolate variance associated with the 400- and 100-ky eccentricity cycles. The 400-ky filter has a central frequency = 0.0025 and a bandwidth = 0.0002; the 100-ky central frequency = 0.01 and bandwidth = 0.002. Filters were not constructed for the two records, at sites 588 and 522, which have not been orbitally tuned.

Benthic foraminifer oxygen isotope data from ODP Leg 108, Site 659 and ODP Leg 154, Site 929A.

Fig. 4. Spectral density as a function of frequency for (A) the Plio-Pleistocene (0 to 4 Ma) and (B) Oligocene-Miocene (20.5 to 24.5), as based on the benthic $\delta^{18}$O time series of Sites 659 and 929. The analyses were performed using the Blackman-Tuckey method (Arand Software). Both records were detrended and resampled at 1-ky steps. Both records have been tuned to the orbital spectrum Atlantic [Web note 1 (36)] (58, 60).

Spectral analysis of benthic foraminifer oxygen isotope data from Figure 3 above.