Total Cenozoic Range: 5.4‰
Antarctica 1.2‰
Northern Hemisphere 1.1‰
Deep sea temperature 3.1‰

Orbital Forcing of Climate
Orbital Control of Climate Change

• Total insolation received by earth determined by strength of sun and earth-sun distance. These change only very gradually over many millions of years.

• Spatial and temporal distribution of insolation depends on the details of the earth’s orbit which change through time (10’s - 100’s kyr).

• This can cause changes in atmospheric and ocean physics.

• These changes in atmospheric and ocean physics result in changes in greenhouse gases and albedo which change global climate.
Tilt (Obliquity)

Low tilt: weak seasons, extreme difference in equator-pole insolation
High tilt: extreme seasons, equator and poles more similar
Maximum Tilt

- High Northern Latitudes: Arctic winter and summer extends further south (increasing seasonality). Higher annual average insolation.
- Tropics: Lower annual average insolation. Increase in seasonal North-South gradients of insolation across equator.
- High Southern Latitudes: Arctic winter and summer extends further south (increasing seasonality). Higher annual average insolation.
Eccentricity

- Solstice (June 21) and Equinox (September 22)
- Perihelion (January 3) and Aphelion (July 4)
- Sun at one focus
- 153 million km
- 158 million km

Eccentricity graph showing:
- ε=0
- ε=0.06
- Myr ago
- 413,000 years
- 100,000 years
Maximum eccentricity

- Increase in insolation received at perihelion
- Decrease in insolation received at aphelion
• [http://www.youtube.com/watch?v=J9Chu4-VIT0&feature=related](http://www.youtube.com/watch?v=J9Chu4-VIT0&feature=related)
Precession

When NH summer occurs at perihelion

- When NH summer occurs at perihelion (every 23 kyr):
  - Warmer summer and cooler winter in Northern Hemisphere
  - Warmer winter and cooler summer in Southern Hemisphere
- When NH winter occurs at perihelion (every 23 kyr):
  - Opposite of above
- When either NH spring or SH spring occurs at perihelion (every 11.5 kyr):
  - Warmer equator
How do we define the months?

June: when NH is most tilted towards the sun
December: when SH is most tilted towards the sun
Amplitude modulation

Wave 1 (red) and Wave 2 (blue)

Beat Pattern (in green)

http://www-math.mit.edu/daimp/Beats.html
http://www.philtulga.com/subtraction.html
Spectrum of summer insolation at 65°N
(dark peaks only)
Lake Level data

For longer view of monsoon, look at cave deposits
Brazil (10°S)  Wang et al., 2004