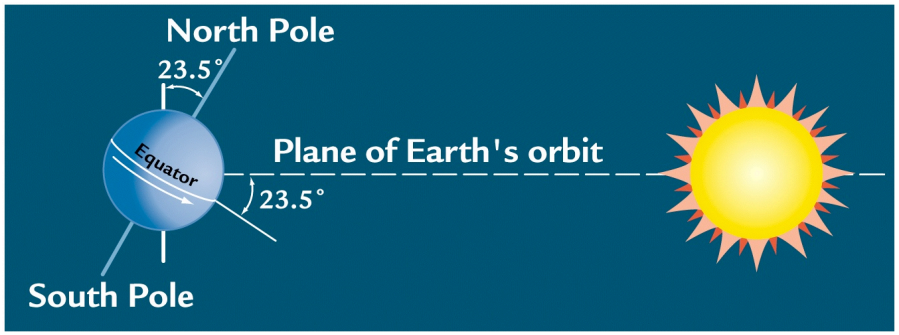
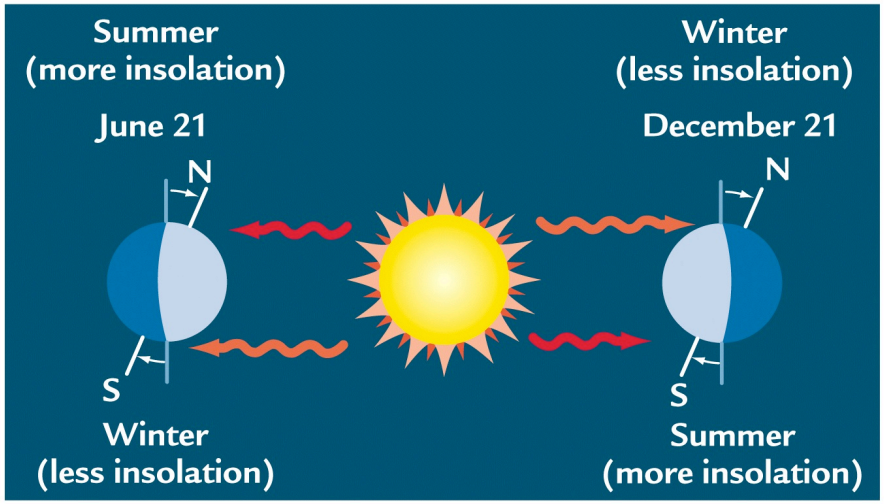
Orbital Variations and Insolation:

Obliquity or Tilt

- Tilt angle presently 23.5°
- Variations in tilt angle modulate seasonality, especially in high latitudes
  - North-south insolation gradient
  - Winter & summer insolation anticorrelated
  - Impacts annual mean insolation at a given latitude
- Variations in tilt angle have no impact on global average insolation

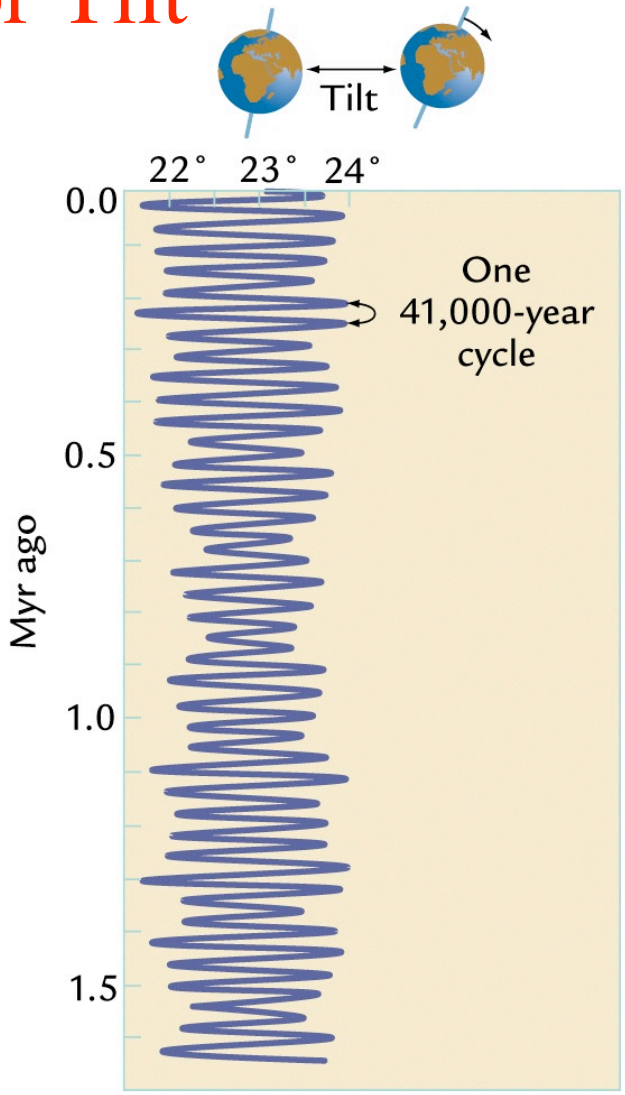




Orbital Variations and Insolation:

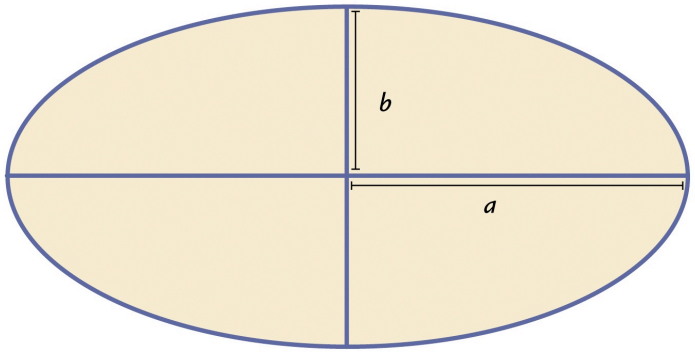
Obliquity or Tilt

- Tilt of axis of rotation varies from 22.5 ° and 24.5 °.
  - Dominant period of 41 kyr
- Variations in tilt angle modulate seasonality, especially in high latitudes
  - North-south insolation gradient
  - Winter & summer insolation anticorrelated (good for Milankovitch's theory)
  - Impacts annual mean insolation at a given latitude
- Variations in tilt angle have no impact on global average insolation



Orbital Variations and Insolation:

Eccentricity

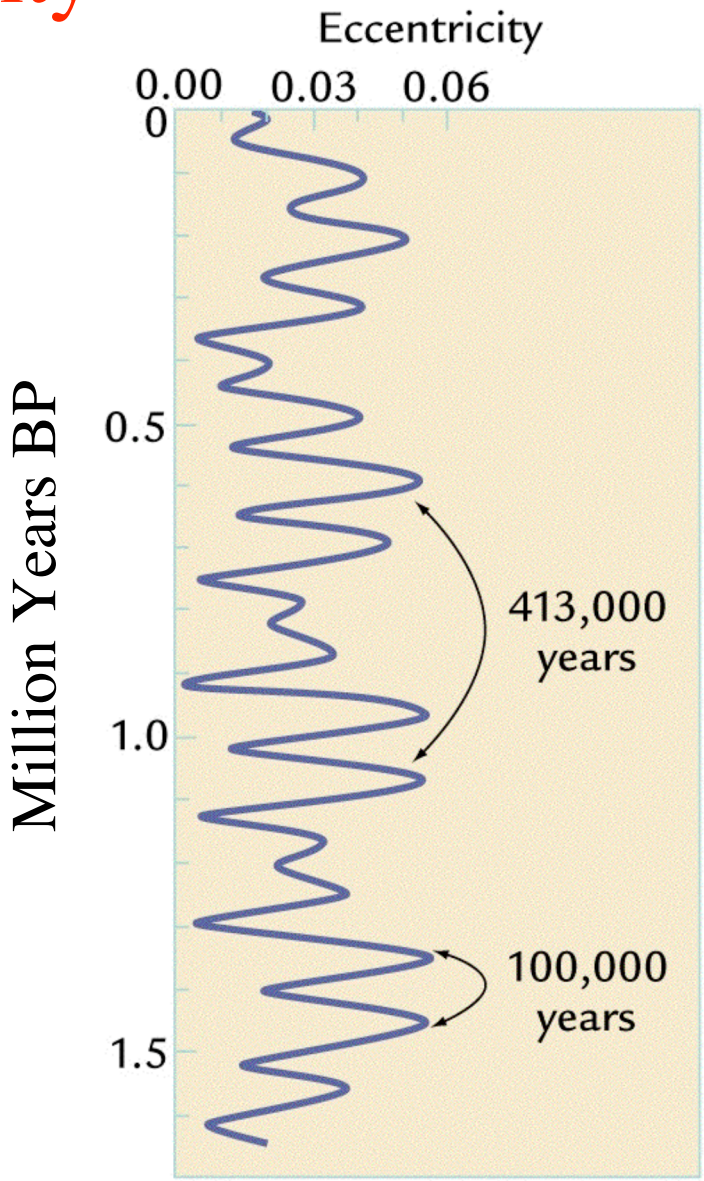


Eccentricity $\varepsilon = \frac{(a^2 - b^2)^{1/2}}{a}$

- Eccentricity

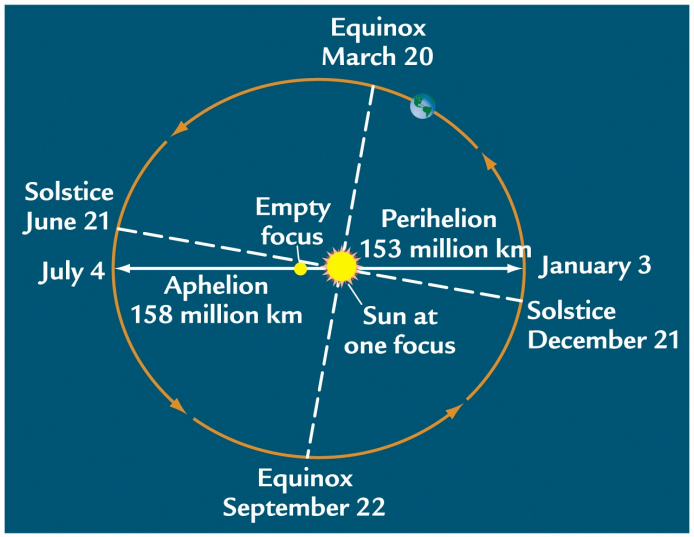
  $e = (a^2 + b^2)^{1/2} / a$

- e varies from 0.005 to 0.067 with four periods ranging from 95-131 kyr (100kyr) and at 413 kyr
- Slight change in global, annual average insolation (0.18%, or 5 Wm^{-2})



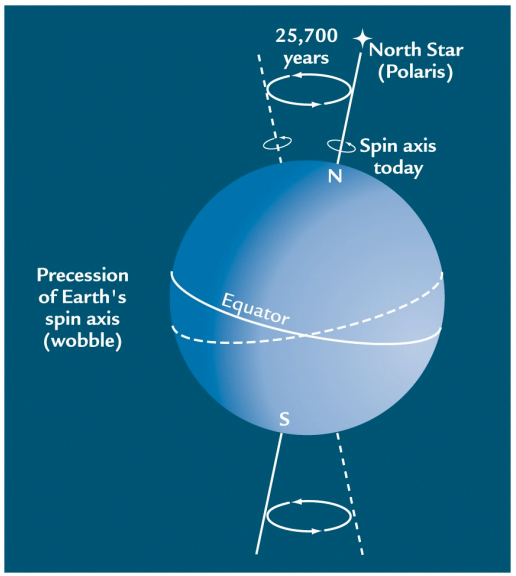
Orbital Variations and Insolation:

Precession

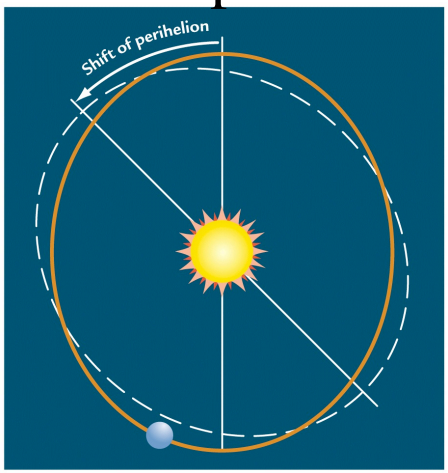


- Precession of Equinoxes is due to:
  - Wobble of Earth's axis of rotation around a line perpendicular to the Earth-Sun plane (25.7kyr)
  - Precession of the ellipse in absolute space
- Modulates seasonality at all latitudes, especially in the tropics (e = 0)
- No effect on the annual mean insulation (anywhere)

Wobble



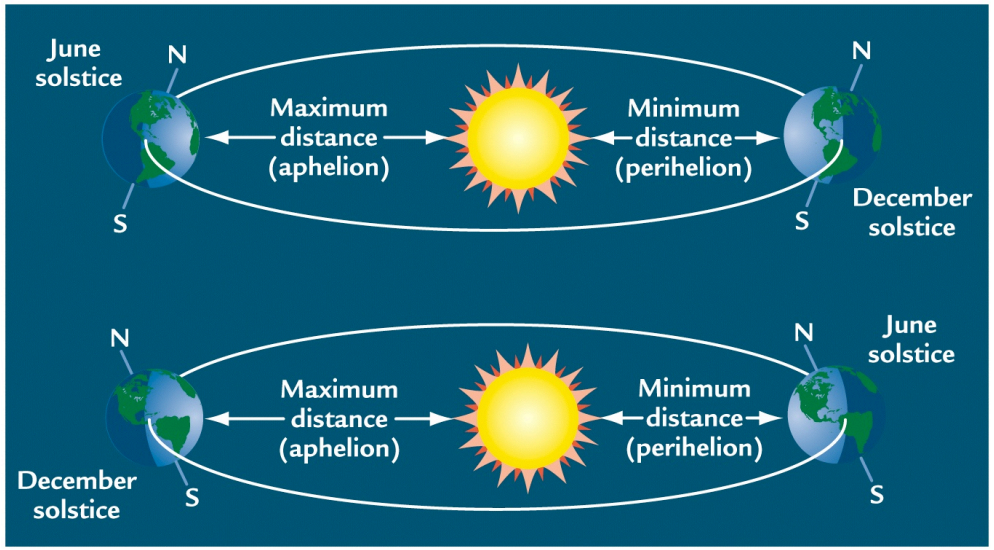
Precession of Ellipse



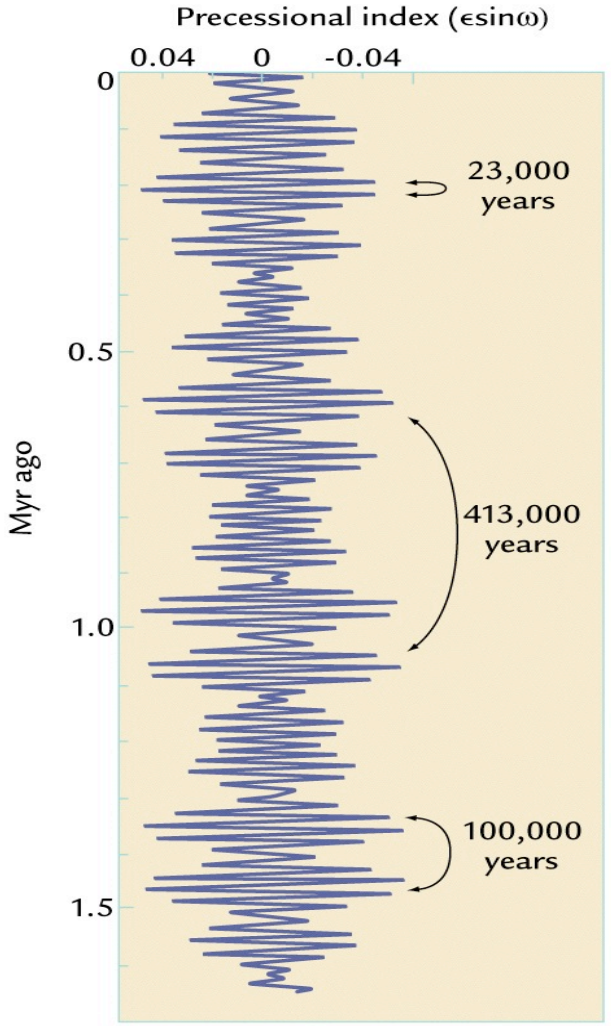
Orbital Variations and Insolation:

Precession

- The Wobble of Earth's axis and the precession of the ellipse combine to create variations in the *seasonality* of insolation (timing and amplitude)
  - Dominant power at 23kyr and 19.7ky, averaging about 21.7 years.



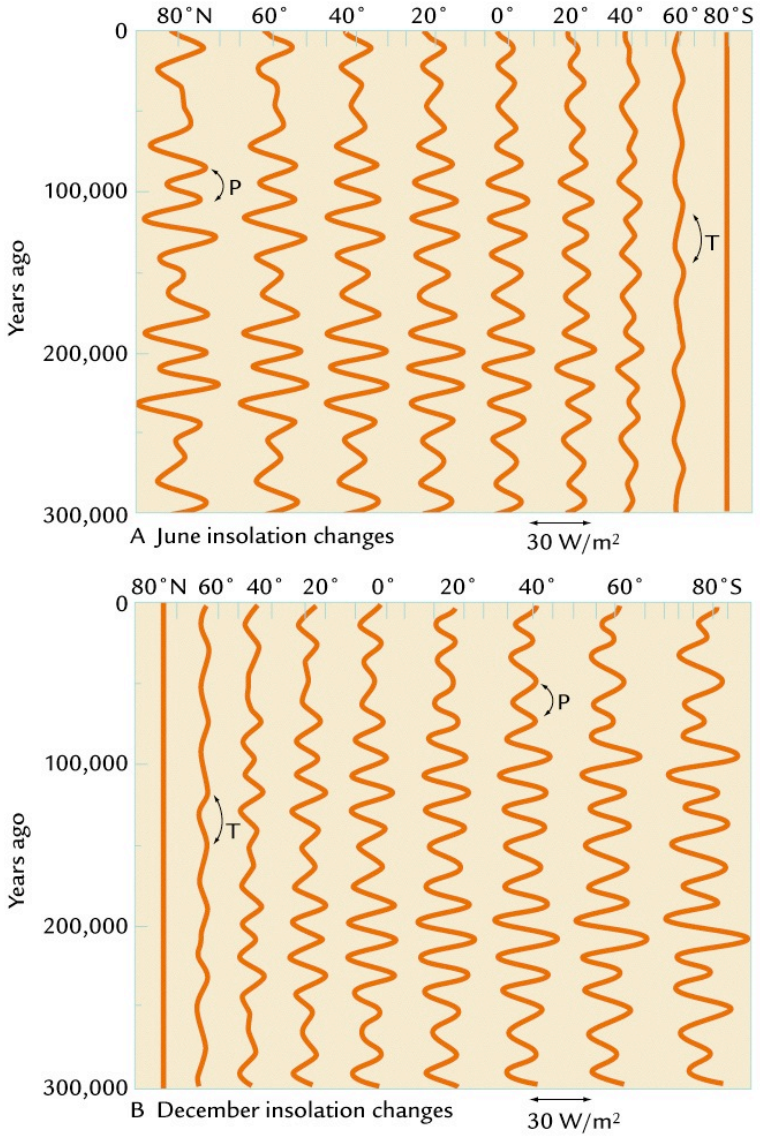
- Effect of precession is strongly modulated by eccentricity.



Orbital Variations and ToA Insolation:

Tropics vs. High latitudes

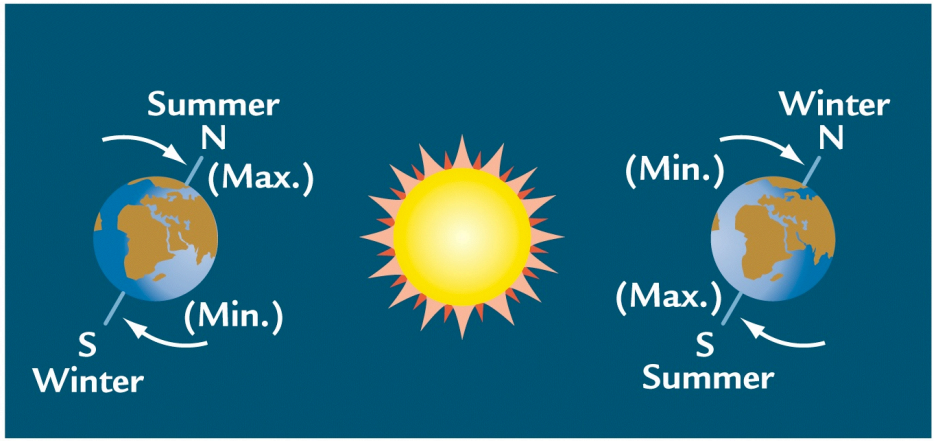
- In the tropics, seasonal insolation changes are predominately due to changes in precession (23kyr).
- In the high latitudes, seasonal changes in insolation are due to both tilt (41kyr) and precessional (23kyr) changes.



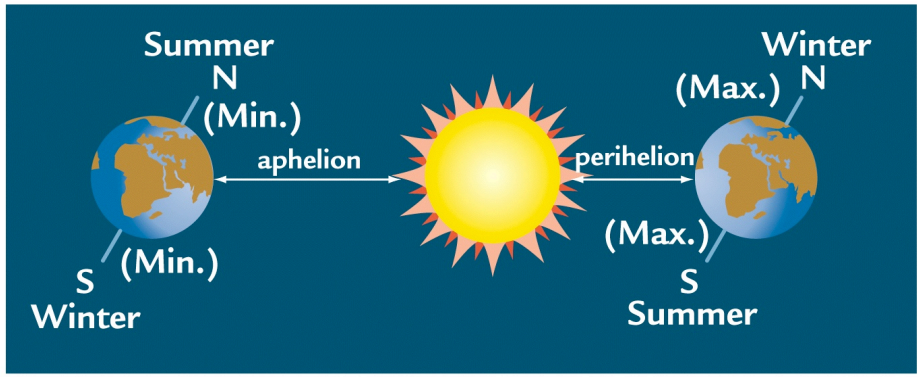
Orbital Variations and Insolation:

Phasing of Hemispheric Insolation

- Tilt changes cause summer insolation changes in Northern Hemsisphere that are in phase. Ditto for winter.
- Precession changes causes changes in summer insolation that are out of phase between hemispheres.



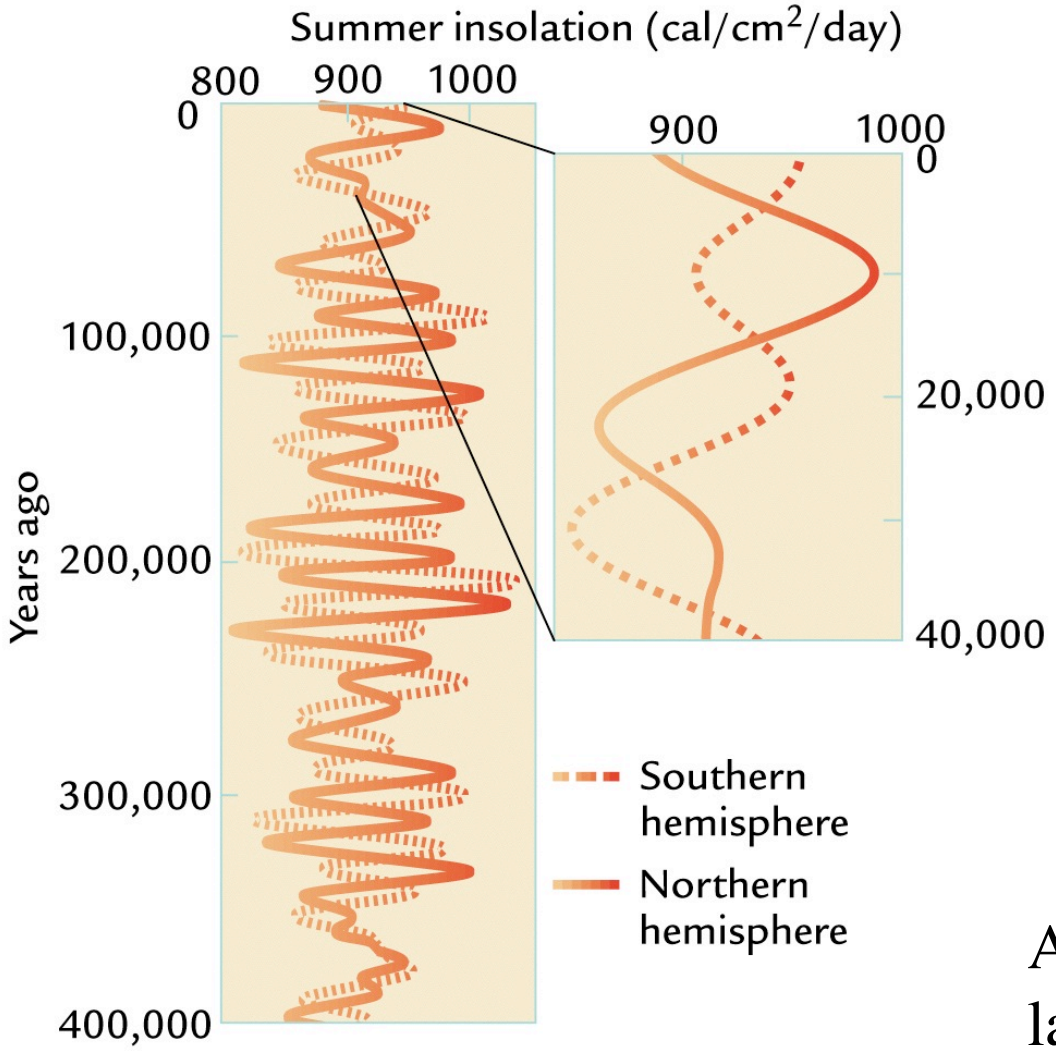
A Tilt



B Precession

Orbital Variations and Insolation:

Phasing of Hemispheric Insolation



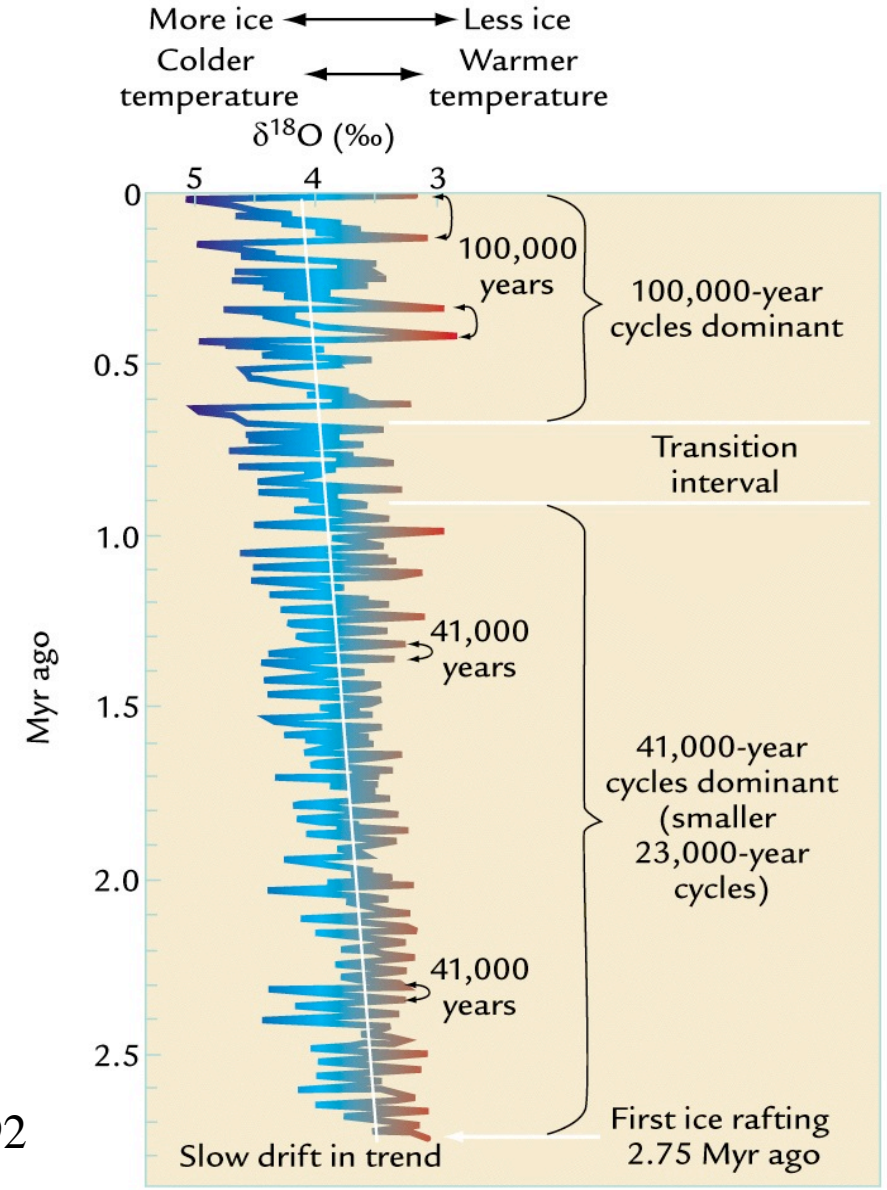
At 65 ° latitude

Summary: impact of orbital changes on insolation

- Amplitude of the seasonal cycle of TOA insolation:
  - For reference, today the seasonal cycle is +/- 150Wm^{-2} in the midlatitudes, and +/-15 Wm^{-2} in the tropics
  - The net effect of orbital changes on seasonal insolation is ~ +/- 30 Wm^{-2} in the midlatitudes, and +/-20 Wm^{-2} in the tropics.
  - Precession (23kyr) dominates in the tropics; Precession and tilt (41kyr) affect the high latitudes.
- Note that overall, insolation changes are larger in the extratropics than in the tropics, but the latter may have a large impact on climate.
- Tilt and precession cause summer insolation changes that are out of phase with winter insolation changes (double whammy on ice volume).
- Hemispheric Synchroneity:
  - Tilt changes cause summer insolation changes in both hemispheres. Ditto for winter.
  - Precession causes changes in summer insolation that are out of phase between hemispheres. Ditto for winter.
- Only eccentricity can change the global, annual average insolation (by about .18%, or 5 Wm^{-2} .

The Ice Age Cycles:
Some specific questions we will ask

- Does global ice volume vary with characteristic periods of precession (~23kyr and 41kry)?
  - Convincing evidence came from the ocean sediment records
  - Continguous record of an oxygen isotope in the water column that is thought to reflect the change in volume of the ocean
  - Chronology is "ok".



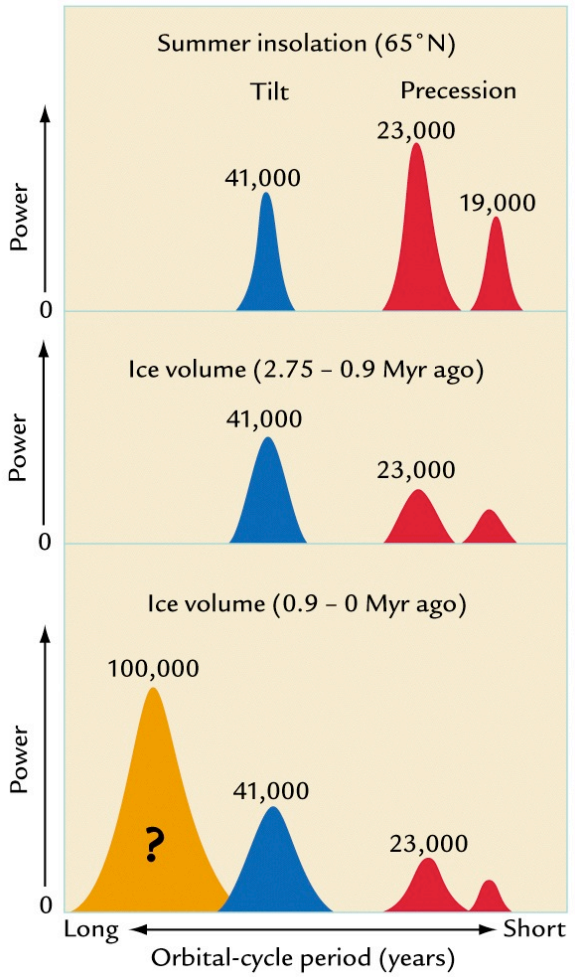
From Raymo 1992

The Ice Age Cycles:
Some specific questions we will ask

- How closely does Insolation at 65N match the changes in global ice volume?

•Not a linear match of insolation vs ice volume, but you wouldn't expect it to be.

•Too much power at 100kr in ice volume



The Ice Age Cycles:
Some specific questions we will ask

- Changes in global ice volume are though to be dominated by changes in the northern hemisphere ice volume. Is ice volume in the Northern Hemisphere anticorrelated with that in the Southern Hemisphere, as Milankovitch requires?
- Why are CO_2 and global ice volume so highly correlated?
- Are changes in CO_2 fundamental to the glacial cycles, or do they simply cause weak positive feedbacks?
- Why do (high latitude) insolation changes cause changes in atmospheric CO_2? Why is it CO_2 so highly correlated with ice volume?