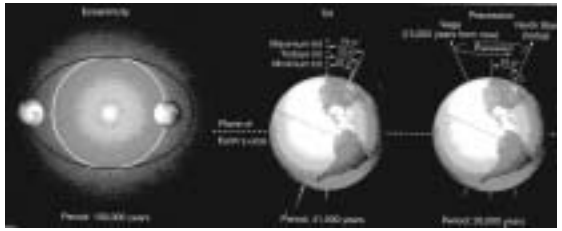
Lecture 10: Seasons and Ice Age

(from *Earth's Climate: Past and Future*)

- Earth's Orbit and Its Variations
- How Seasons Are produced
- Milankovitch Theory on Glacial-Interglacial Cycle

Earth's Orbit and Its Variations



(from *The Earth System*)

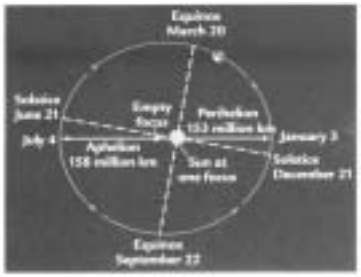
- First, Earth spins around on its axis once every day ➔ The ***Tilt.***
- Second, Earth revolves around the Sun once a year ➔ The shape of the ***Orbit***.
- Both the tilt and the shape of the orbit have changed over time and produce three types of orbital variations:
  (1) obliquity variations
  (2) eccentricity variations
  (3) precession of the spin axis.

Tilt Produces Seasons

(from *Earth's Climate: Past and Future*)

- At present-day, the axis is tilted at an angle of 23.5°, referred to as Earth's "obliquity", or "tilt".
- The Sun moves back and forth through the year between 23.5°N and 23.5°S.
- Earth's 23.5° tilt also defines the 66.5° latitude of the Artic and Antarctic circles. No sunlight reaches latitudes higher than this in winter day.
- The tilt produces ***seasons***!!

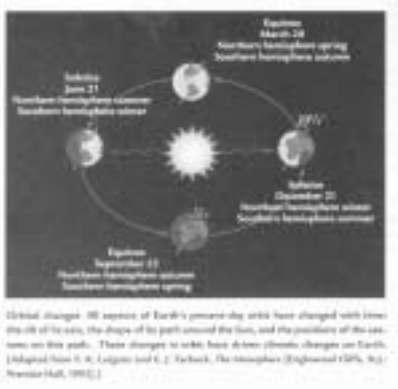
Perihelion and Aphelion



(from *Earth's Climate: Past and Future*)

- The position in which the Earth is closest to the Sun is called "perihelion".
- Perihelion means "near the Sun" in Greek.
- The position in which the Earth is farthest to the Sun is called "aphelion".
- Aphelion means "away from the Sun" in Greek.

Seasons and the Elliptical Orbit



- Seasons

  Solstices: mark the longest and shortest days of the years (June 21 and December 21 in the northern hemisphere, the reverse in the southern)

  Equinoxes: the length of night and day become equal in each hemisphere.

- At the present-day orbit, the winter and summer solstices differ from the aphelion and perihelion by about 13 days.

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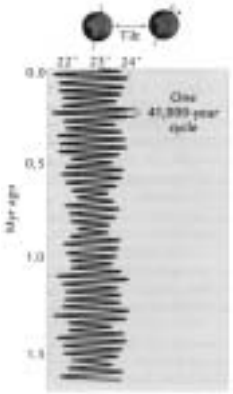
Tilt Change (Obliquity Variation)



- Over time, the tilt angle varies in a narrow range.
- These variations are caused by the gravitational tug of large planets, such as Jupiter.
- The present-day value of the tile is decreasing.
- Cyclic changes in the tilt angle occur at a period of 40,000 years.

(from *Earth's Climate: Past and Future*)

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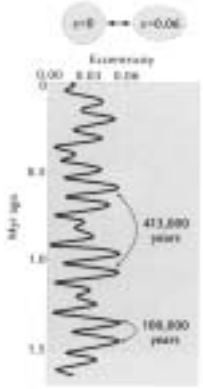
Eccentricity Variations



- Today's eccentricity is 0.0167, lies well toward the lower end of the variation range of Earth's eccentricity (closer to circular).
- The long-term variations in orbital eccentricity are concentrated at two periods: 100,000 years and 413,000 years.

(from *Earth's Climate: Past and Future*)

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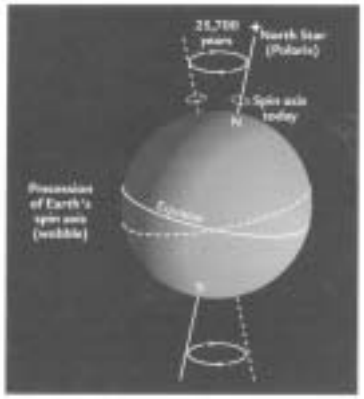
Precession of Axis



- There are two kinds of precession: (1) the precession of the spin axis and (2) the precession of the ellipse.
- Earth's wobbling motion is called the axial precession. It is caused by the gravitational pull of the Sun and Moon.

(from *Earth's Climate: Past and Future*)

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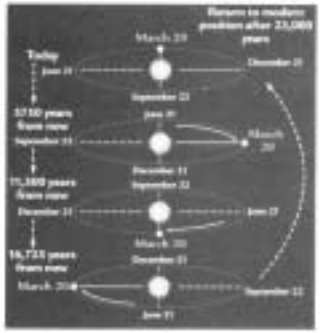
Time Scales of Precession



- The combined effects of these two precessions cause the solstices and equinoxes to move around Earth's orbit, completing one full 360° orbit around the Sun every 23,000 years.

(from *Earth's Climate: Past and Future*)

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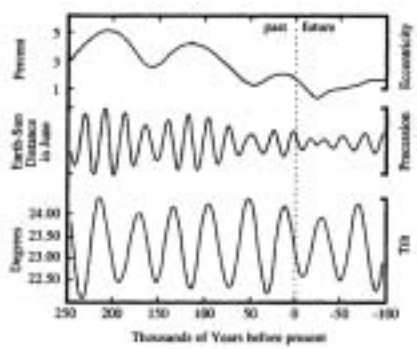
Variations In Orbit Parameters



(~100k years)

(~23K years)

(~40K years)

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Insolation Control of Ice Sheets

- Ice sheets reacted strongly to insolation changes.
- ***Summer*** insolation control the size of ice sheet by fixing the rate of ice melting.

(from Earth's Climate: Past and Future)

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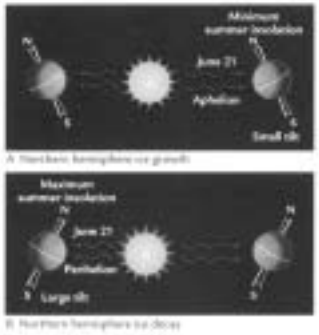
Milankovitch Theory



- Milankovitch suggested that the critical factor for Northern Hemisphere continental glaciation was the amount of summertime insolation at high northern latitudes.
- Low summer insolation occurs during times when Earth's orbital tilt is small.
- Low summer nsolation also results from the fact that the northern hemisphere's summer solstice occurs when Earth is farthest from the Sun and when the orbit is highly eccentric.

(from Earth's Climate: Past and Future)

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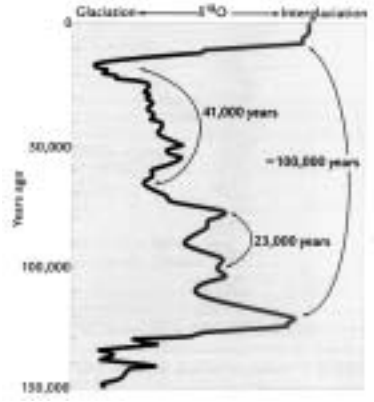
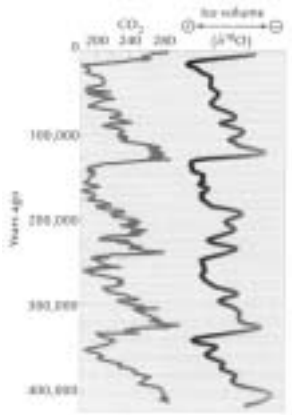
Ice Sheet Changes Over the Last 150,000 Years



- A closer look of the last 150,000 years of the $\delta^{18}O$ record shows 23,000-year and 41,000-year cycles.

(from Earth's Climate: Past and Future)

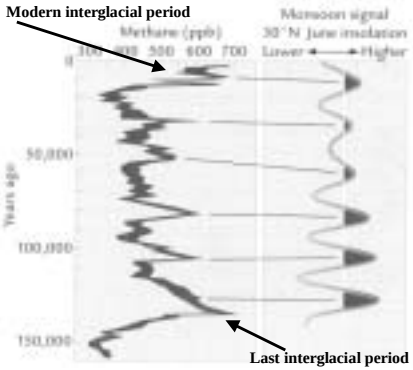
Ice Sheet And CO2



- The longest orbital-scale record of CO2 changes comes from the Vostok ice core drilling site.
- The CO2 record shows a series of regular oscillation between CO2 values as high as 280-300 ppm and as low as 180-190 ppm over the last 400,000 years.
- The dominant period of CO2 variations is about 100,000 years.

(from *Earth's Climate: Past and Future*)

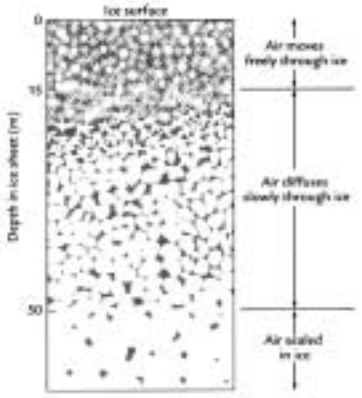
Orbital-Scale Changes in Methane



- The Vostok ice record shows a series of cyclic variations in methane concentration, ranging between 350 to 700 ppb (part per billion).
- Each Ch4 cycle takes about 23,000 years.

(from *Earth's Climate: Past and Future*)

Trapping Gases in the Ice

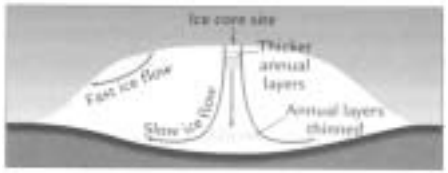


- Air moves freely through snow and ice in the upper 15 m of an ice sheet.
- Flow is increasingly restricted below this level.
- Bubbles of old air are eventually sealed off completely in ice 50 to 100 m below the surface.

(from *Earth's Climate: Past and Future*)

Ice Core Drilling

(from *Earth's Climate: Past and Future*)



- The best place on an ice sheet to take ice cores is at the top.
- Ice cores can be dated by counting annually deposited layer (or ice flow model).
- Annual layering is recorded in several properties of ice cores, the most obvious of which are layers of dust easily visible to the eye.
- Dust is usually deposited at the end of cold, dry windy winters.
- One of the most famous ice core drilling is at a site high on the Antarctic ice sheet, which is called the Vostok ice record.