Lecture 19: Orbital Variations in Ice Sheets (Milankovitch Cycles)

Chapter 9 (p. 163-174, p. 210-228)

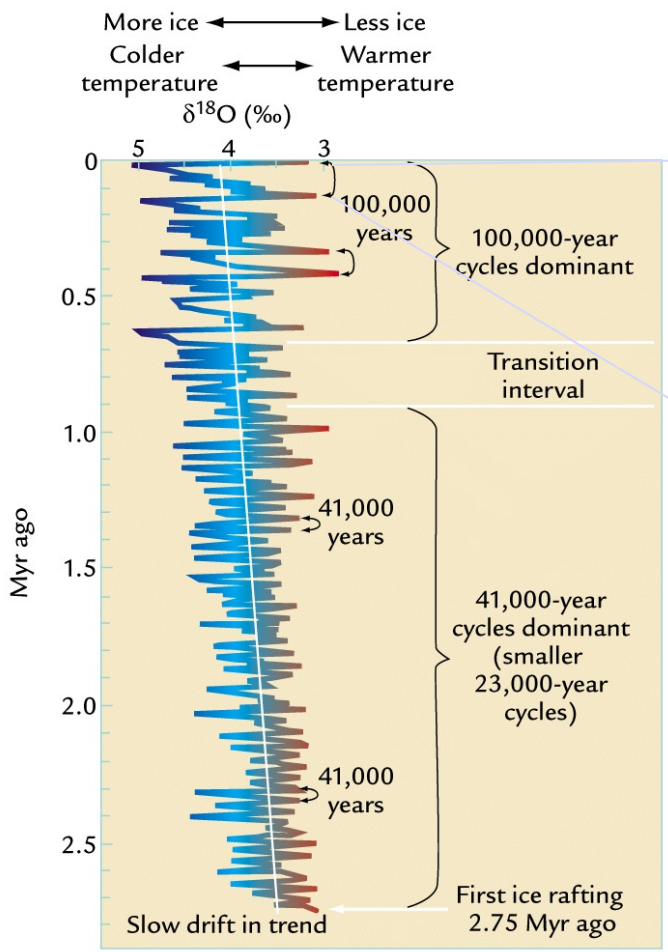
Question:

- What is the temporal pattern of the glacial-interglacial climate change?
- What causes glacial-interglacial climate variability?
- How has glacial-interglacial climate variability changed in through history of the earth?
- What are the outstanding questions in understanding glacial-interglacial climate change?

Glacial and Interglacial Cycle

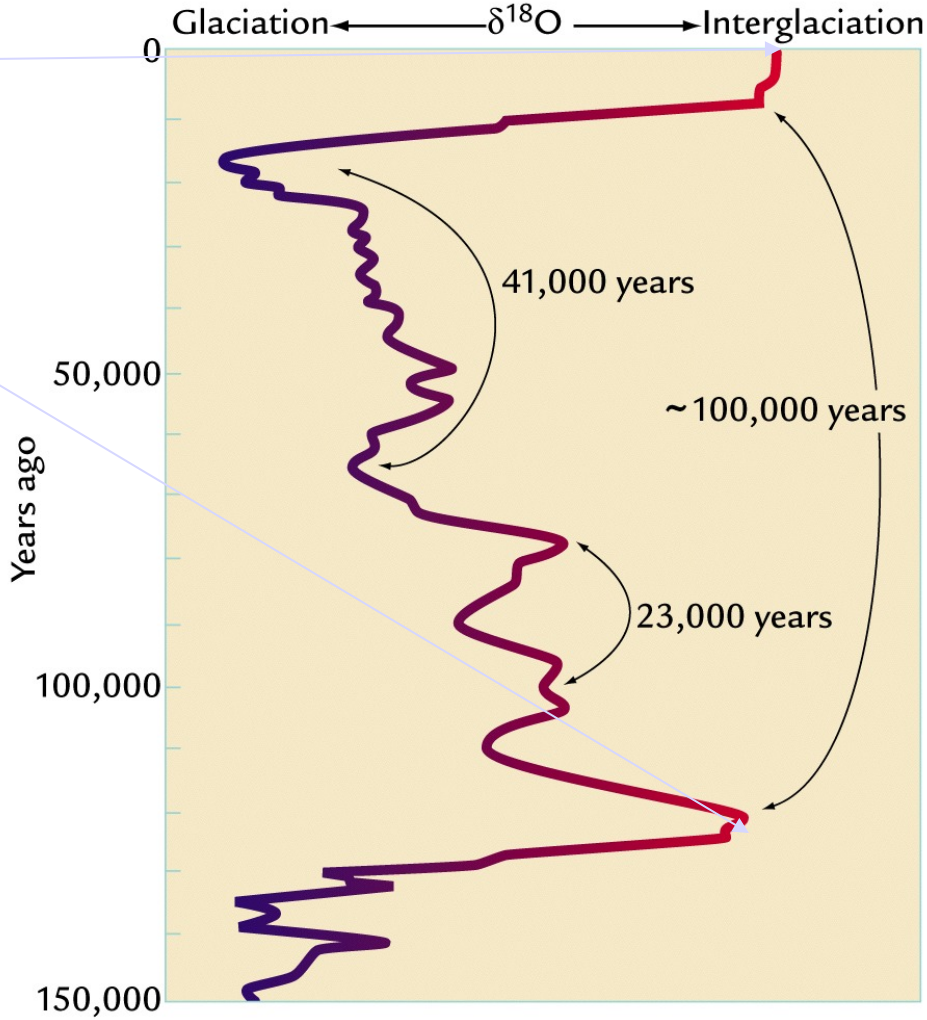
Smaller variability prior to 0.65MY ago

Larger variability, 100K cycle in recent 0.65MY



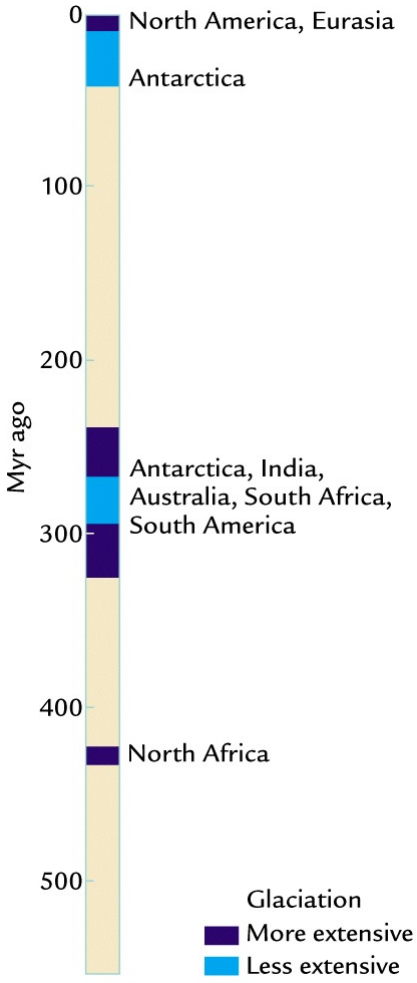
Sawtoothed features:

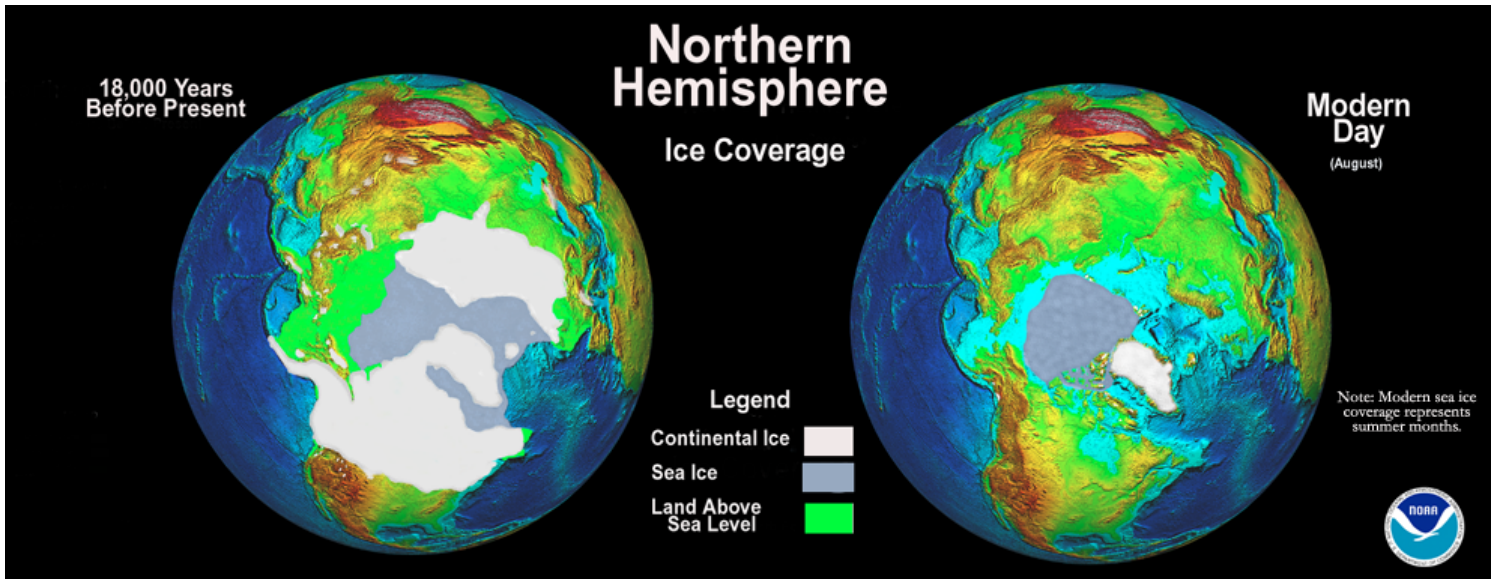
Slow glaciation & rapid deglaciation



Slow shift toward a colder, more glacial world

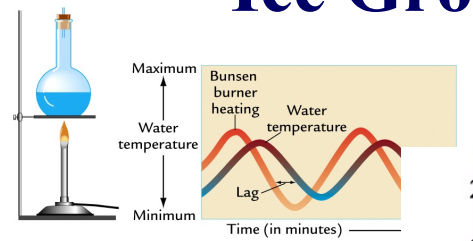
18000 yrs ago, ice sheets surrounded much of the Arctic Ocean. Today, ice sheets exist only on Greenland.

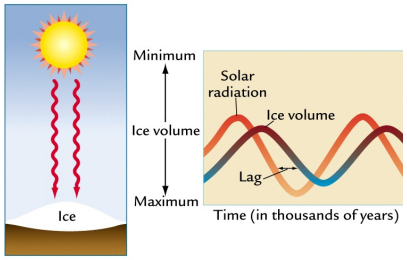




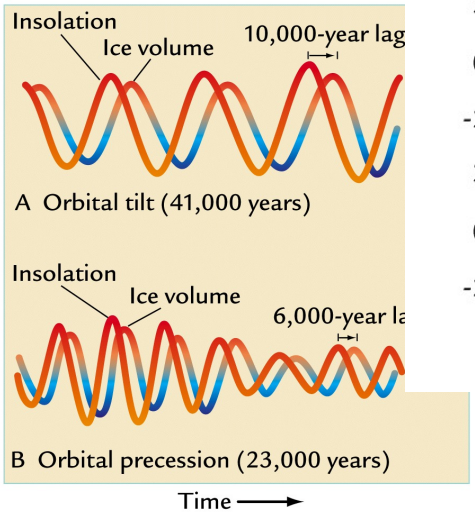
Tectonic-scale cooling caused ice sheets to appear, but why did they grow and melt over (the shorter) orbital-scales?

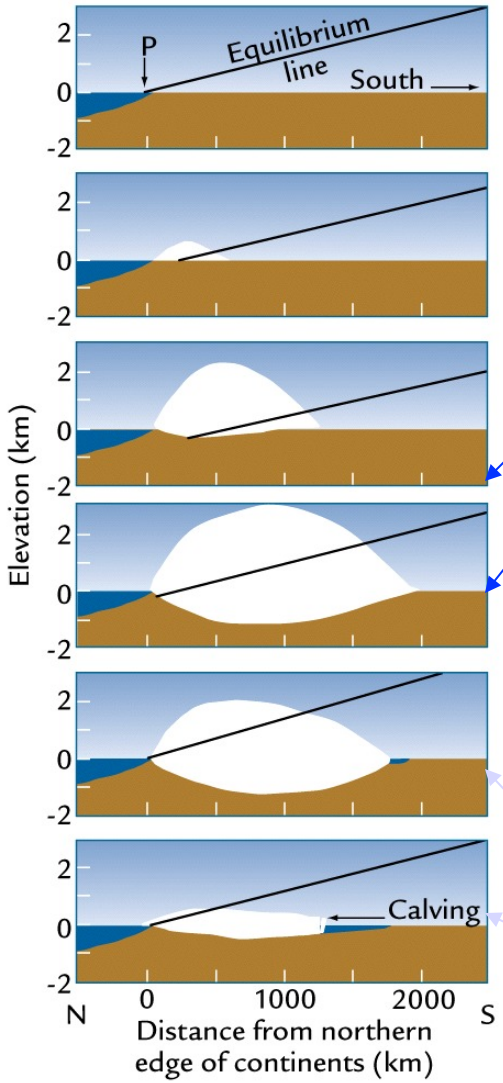
Ice Growth and Decay: Force and Response





Ice sheets lags behind summer insolation forcing





A No ice sheet (interglacial)

B Insolation drops, equilibrium line shifts south, ice sheet starts to grow

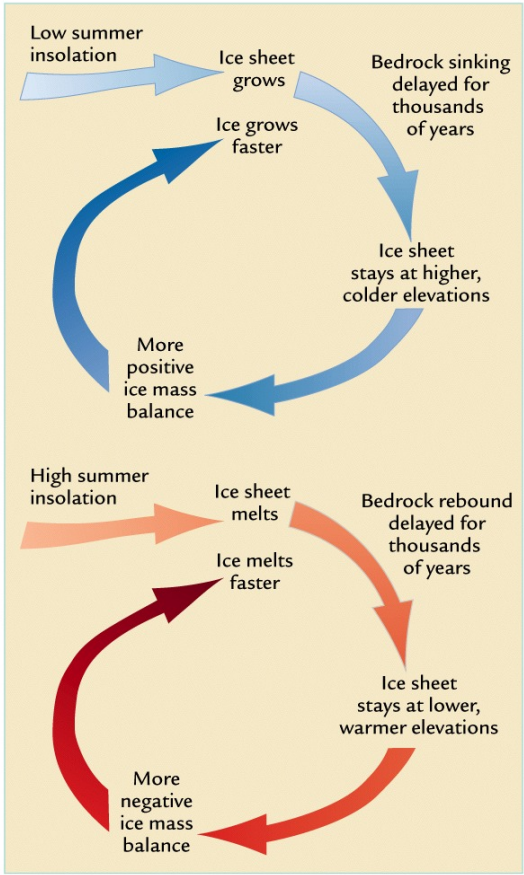
C Insolation at a minimum, ice sheet grows rapidly, ice depresses bedrock

D Insolation rises, equilibrium line moves north, ice sheet at maximum size, bedrock depression increases

E Insolation at a maximum, equilibrium line far to north, ice melts rapidly, bedrock starts to rise

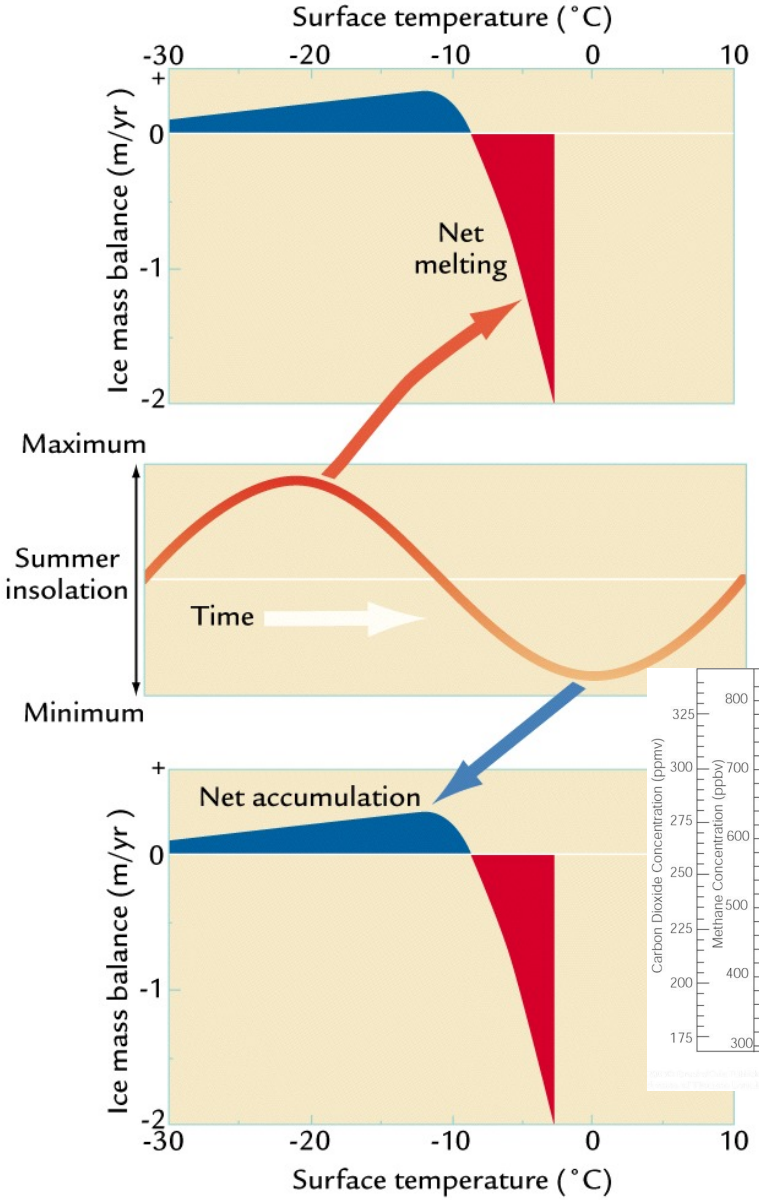
F Insolation starts to drop, last ice remnants melt, bedrock rises rapidly

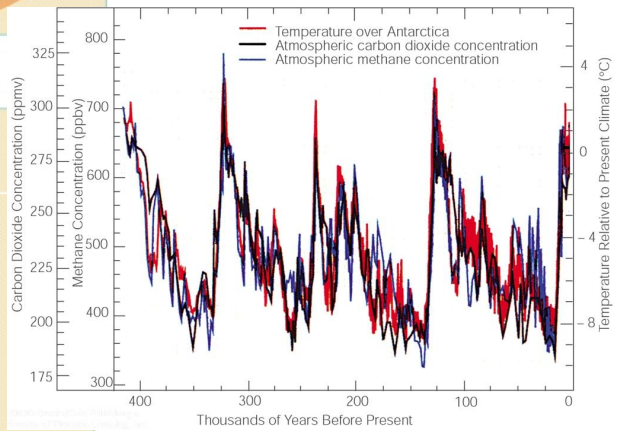
Delayed bedrock sinking → + feedback to ice growth



Delayed bedrock rebounding → + feedback to ice decay

Link to earth's orbital change: Milankovitch Theory





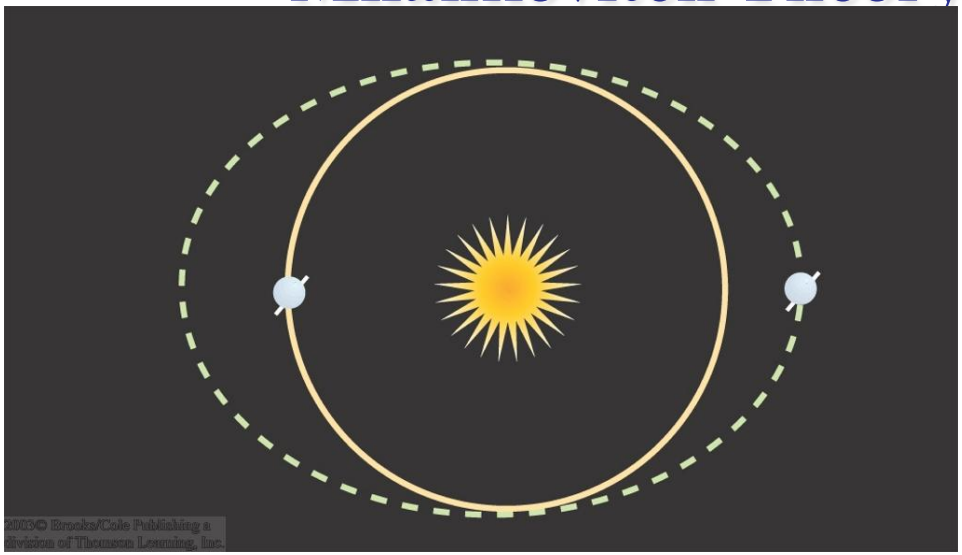
Milutin Milankovitch first proposed the following idea in the 1930s.

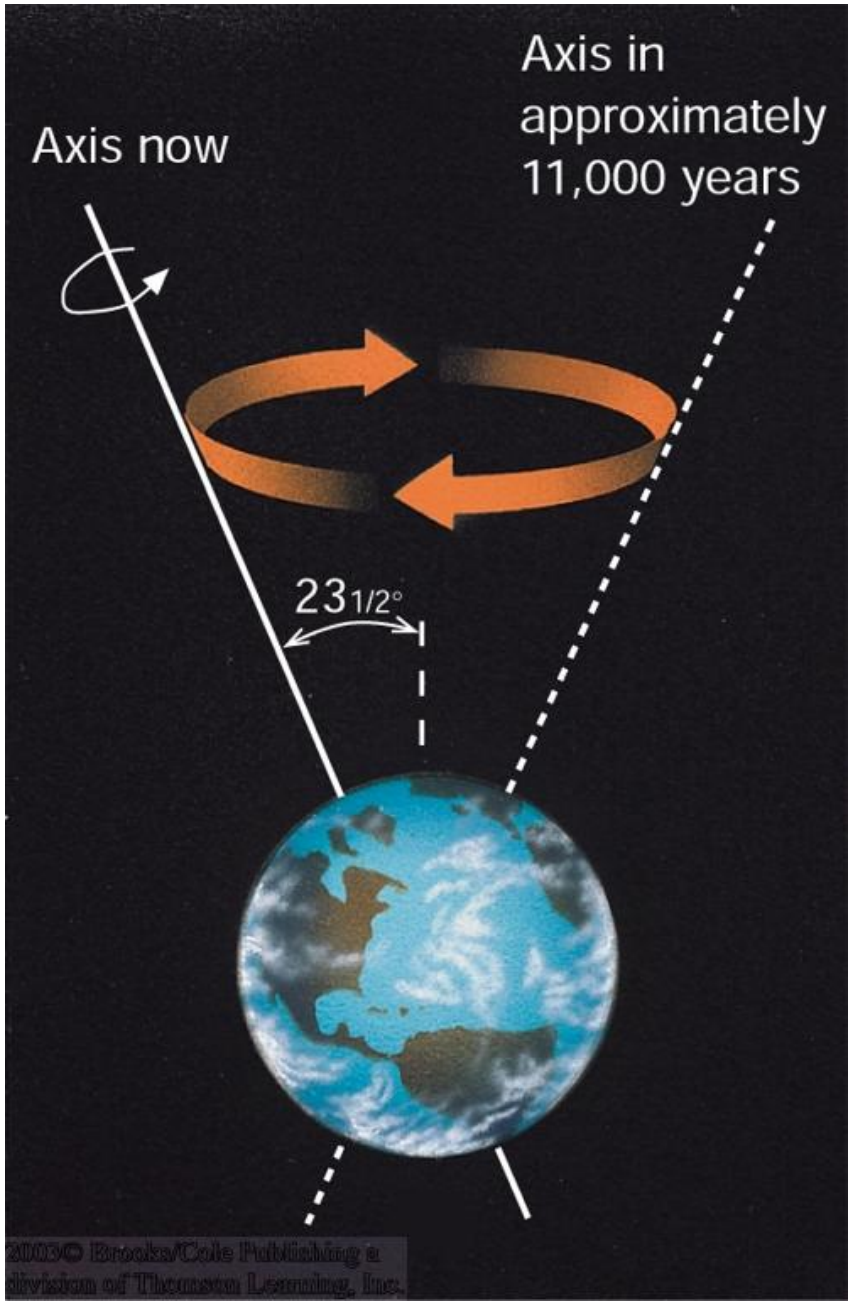
High summer insolation heats land → glacier ablates

Low summer insolation keeps land cool → glacier persists or grows

Changes in climatic cycles of glacial-interglacial periods were initiated by variations in the Earth's orbital parameters (Earth-Sun geometry factors)

Milankovitch Theory of Climate Change

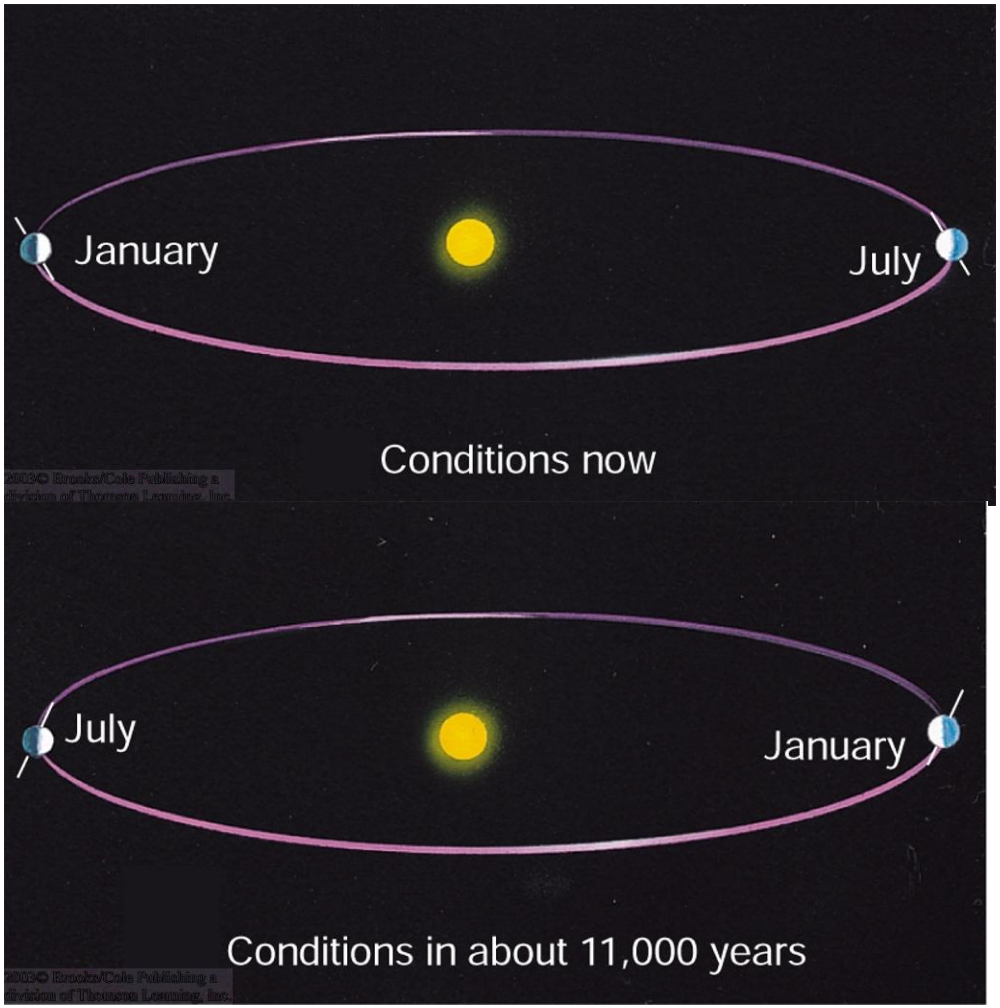




Climate change may be driven by changes in earth's

- **Orbit eccentricity: from ellipse to circle at 100,000 year cycles;**
- **Wobble (precession), from the north pole pointing toward or away from the sun in June at 23,000 year cycles, and**
- **Tilt (obliquity): from 22.2° to 24.5° at 41,000 year cycles.**

Milankovitch Theory of Climate Change



Return to modern position after 23,000 years

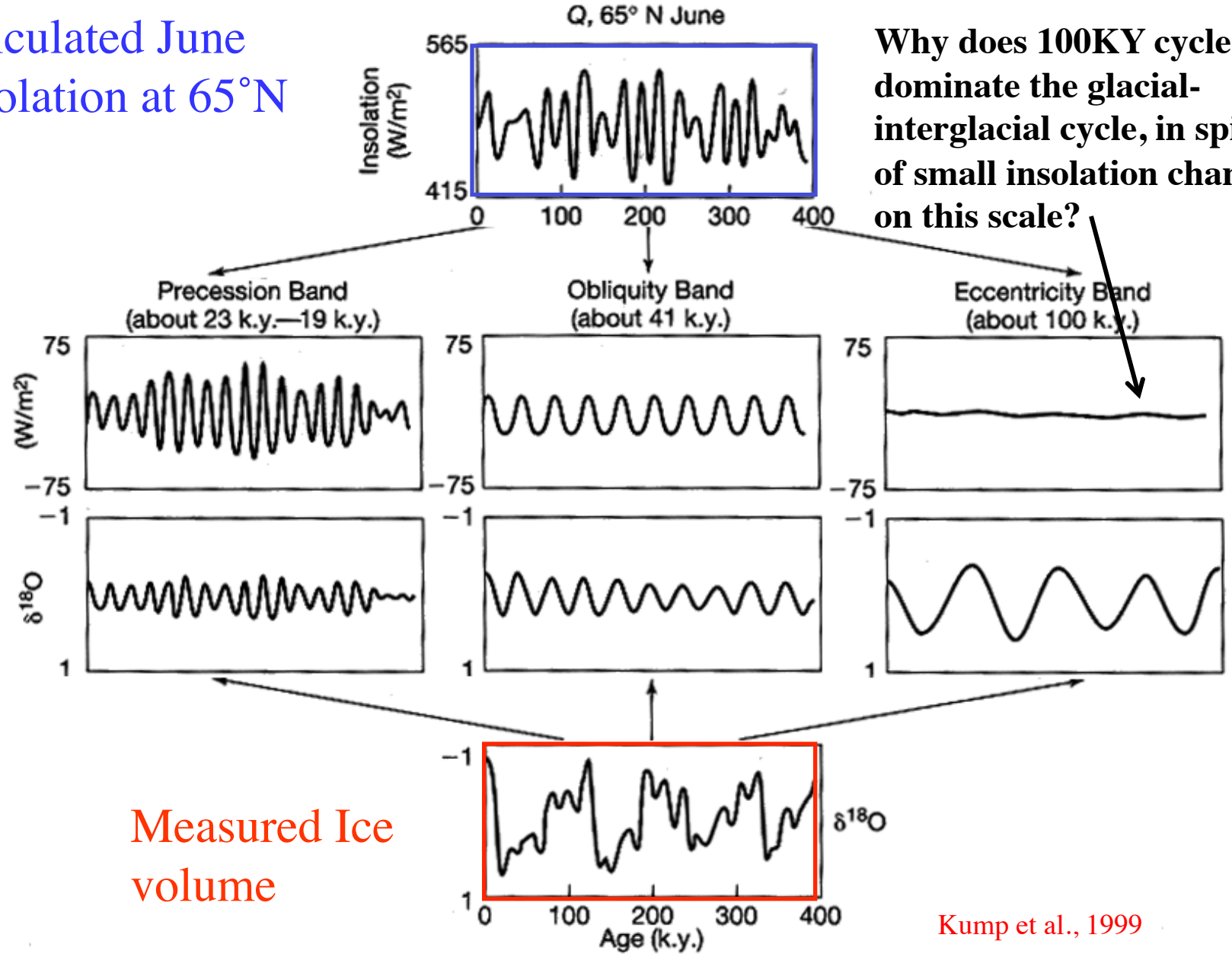
The precession of the earth's axis changes seasonal variations.

Presently the earth is closest to the sun (perihelion) in January (the N.H. winter), most distant from the sun (aphelion) in July.

In about 11,500 years, the earth will be closer to the sun in July (the N.H. summer), most distant from the sun in January.

Testing the Milankovitch Theory

Calculated June insolation at 65°N

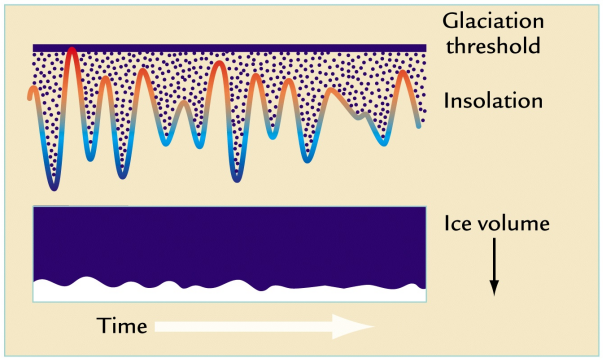


Why does 100KY cycle dominate the glacial-interglacial cycle, in spite of small insolation change on this scale?

Kump et al., 1999

Testing the Milankovitch Theory

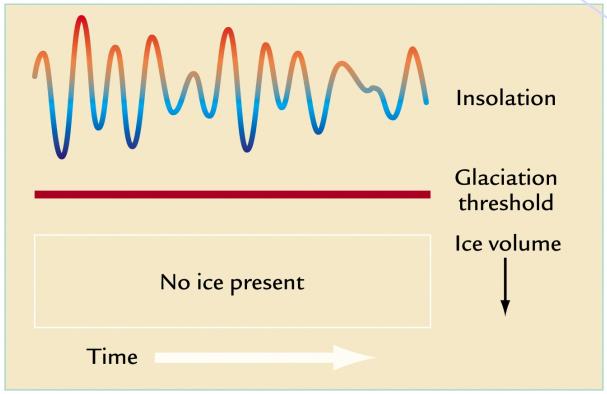
Ice sheet evolution



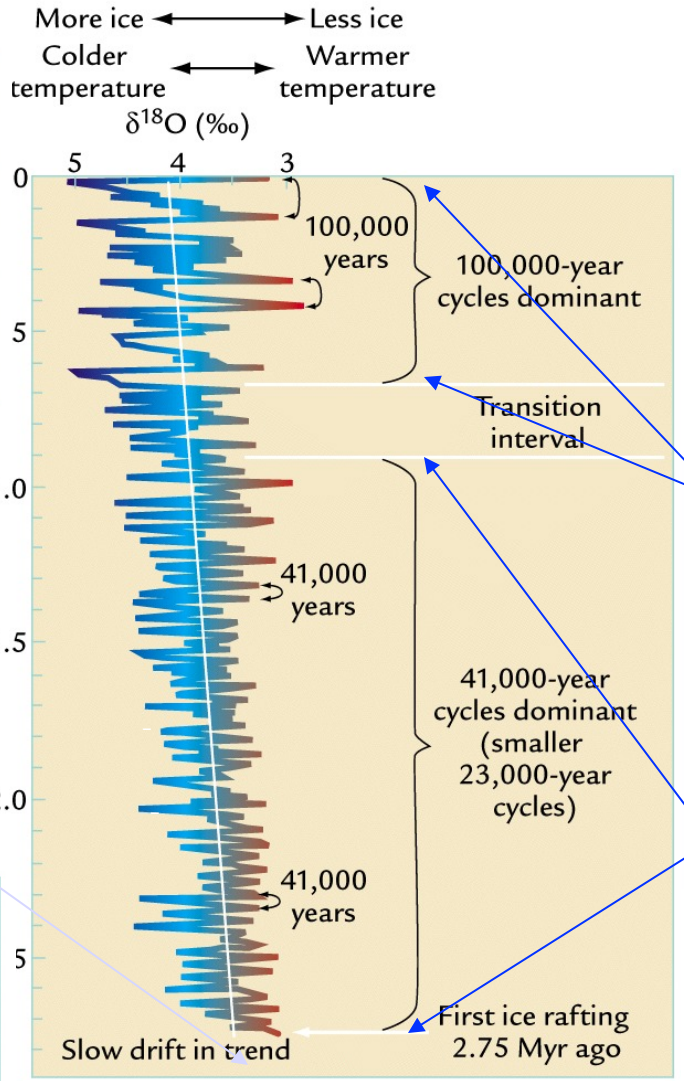
(D) Permanent glaciation phase

Large-ice sheet can lead to permanent glaciation Phase

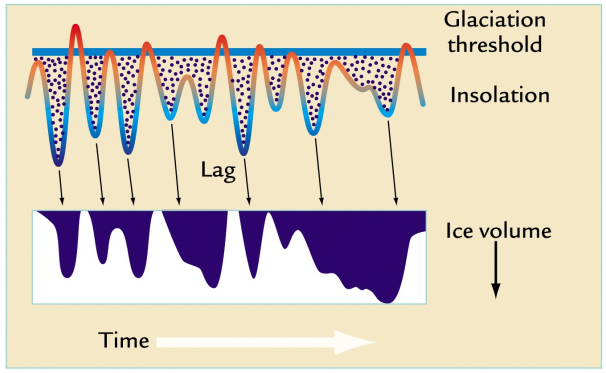
Preglaciation Phase



(A) Preglaciation phase



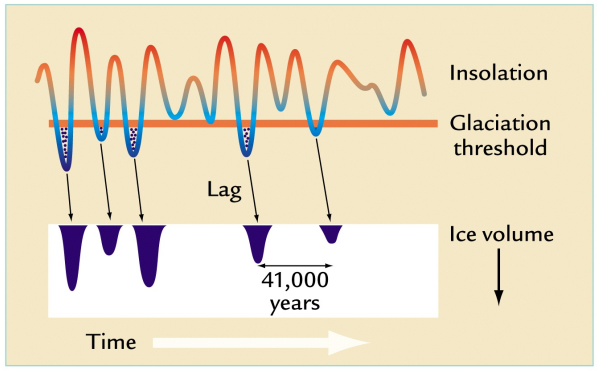
Ocean sediments have 2 key indicators of past glaciations.



(C) Large glaciation phase

Large Glaciation Phase

Small Glaciation Phase



(B) Small glaciation phase

Discussion:

- **What is the temporal pattern of the glacial-interglacial climate change and why?**

- **What causes glacial-interglacial climate variability?**
  - **In recent 650KY, why is the glacial-interglacial variability strongest on 100KY cycle, corresponding to the weakest insolation change, and weakest at 23KY-19KY, corresponding to the strongest insolation change?**

- **How has glacial-interglacial climate variability changed in through history of the earth? Can you think of causes for changes in glacial-interglacial climate variability?**

- **What do we don't know about glacial-interglacial climate change?**