Chapter 14 Pleistocene Glaciations
What does an ice age look like?

February

Reconstruction of land and sea ice 21,000 years ago

July

Details still contested, especially the sea ice edge

CLIMAP reconstruction
Fig 14-4 $\delta^{18}$O from ocean sediments = Proxy for (1) ocean temperature and (2) ice volume on land

100,000 yr “glacials”

The Pleistocene
(1) \( \delta^{18}O \) from ocean sediments as proxy for ocean temperature

“fractionation” occurs when the rate of a process depends on the isotope

- The colder the water the more plankton favor \( ^{18}O_2 \) over \( ^{16}O_2 \) as they grow CaCO\(_3\) shells.
- Thus the ratio of \( ^{18}O_2 \) to \( ^{16}O_2 \) in sediments might reflect near surface water temperature.

\[
\delta^{18}O = \frac{^{18}O_2 / ^{16}O_2 \text{ (in sample)}}{^{18}O_2 / ^{16}O_2 \text{ (in standard, ie modern sea water)}} \times 1000
\]
(2) $\delta^{18}$O from ocean sediments as proxy for ice volume

- Fractionation of isotopes during evaporation and precipitation favors light isotopes being transported to ice sheets.
- Sediments become rich in heavy isotopes when ice sheets are large because ice sheets preferentially store light isotopes.
Fig 1-9 $\delta^{18}$O from ice cores tell us about temperature

Condensation and rainfall preferentially remove heavy isotopes from clouds - even more so when air is cold (nevermind the details)
Milankovitch cycles,
Milankovitch curves,
Milankovitch insolation,
Milankovitch theory,
Milankovitch hypothesis…?

Milutin Milankovitch
Earth’s orbit varies over time due to influence of the Sun, Jupiter, and the Moon.

- **Eccentricity** (ellipticity)
  ~100 kyr, 400 kyr

- **Obliquity** (tilt)
  ~41 kyr

- **Precession** (wobbly top)
  ~19, 23 kyr

kyr = 1,000 years
Milutin Milankovitch (1879 - 1958)

“Summer insolation minima in the Northern Hemisphere lead to ice sheet advances”
How an ice sheet works (roughly):

- **Net accumulation** creates surface slope
- Surface slope causes ice to **flow towards edges**
- Accumulation (and mass flow) is balanced by **ablation and/or calving**
Ice sheets are very sensitive to summertime temperatures!

- Ice sheet has parabolic shape.
- Line represents melt zone
- Small warming increases melt zone a lot because of shape!
Influence of shape

Furthermore temperature has a powerful influence on melting
Accumulation

Greenland - average accumulation \(\sim 30\) cm/year.

Antarctica - average accumulation \(\sim 10\) cm/year.

- moisture content of air decreases with height (temp)
  
- ice sheets experience a strong negative feedback on their vertical growth
Compilation of $\delta^{18}O$ from about 20 deep sea cores

Imbrie et al., 1984
Ice volume and June insolation at 65N (upside down)

Wiggles do not match well - ice volume has too much 100k yr cycle

Best match when ice volume is shifted by 6 kyr (6,000 years), as above, but no good reason for it!
In defense of Milankovitch

Gerard Roe,
*Earth and Space Sciences*,
*UW*
Shouldn’t we be thinking about how insolation changes ice growth or melt NOT ice volume?

Old/Wrong idea? - Instant relationship between ice volume and insolation

New/Right idea? - Turn up the sun and ice melts
Ice ablation/accumulation and June insolation at 65N (upside down)

Wiggles match quite well

No phony shift in time!
major difference is large negative rates of change during major deglaciations
Summary - 1

• Waxing and waning of global ice volume strongly controlled by high latitude, northern hemisphere insolation

  (i.e., Milankovitch’s original idea, sort of)

• Reason for deglaciation still unknown

• Changes the question from does orbital forcing affect global ice volume (it does), to what causes the big deglaciations?
• Another question - Why are the southern hemisphere climate variations nearly the same as in the northern hemisphere, yet the insolation curves are quite different?

Read text on glacial climate feedbacks (p279-287) on your own.