Climate Change in the Pleistocene
(1.8 m.y.a. to 10,000 years ago)

- On a multi-million year time scale, Earth is now in a glacial interval. (Only during past 2.5 million years of last 300 m.y. have there been ice sheets in Greenland, Iceland.)
- Also, over past 1.8 m.y. there have been glacial cycles (growth and decay of continental ice sheets).
- We are now in a warm cycle (Holocene Epoch).
- Cycles are due to changes in solar insolation and CO_2 – but smaller changes than those due to solar evolution on 100 million-year time scale.

Evidence for Glacial Cycles

(b)

(d)

Moraines (deposited by glaciers)

Till (mix of sediments)

Loess (wind-blown fine sediment)

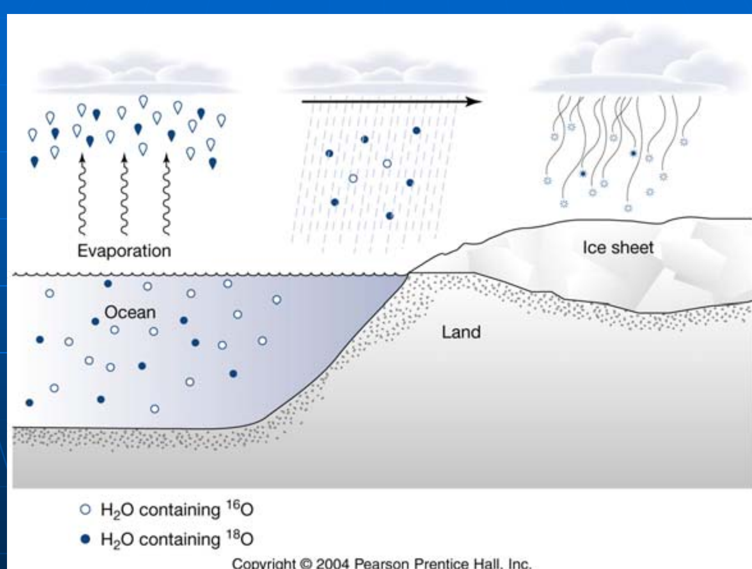
Temperature record

Obtained from oxygen isotope ratios. The ratio of ^{18}O : ^{16}O in the calcium carbonate shells of marine plankton depend on the temperature of the water in which they lived.

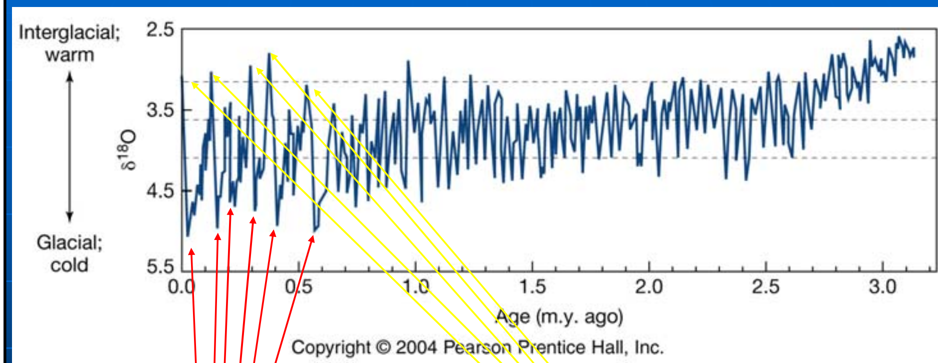
Two reasons:

1. The colder the water the higher the proportion of ^{18}O incorporated into the minerals.
2. 'meteorological distillation' – the ^{18}O rains out first and leaves ice sheets enriched in ^{16}O.

Meteorological Distillation



Temperature Record

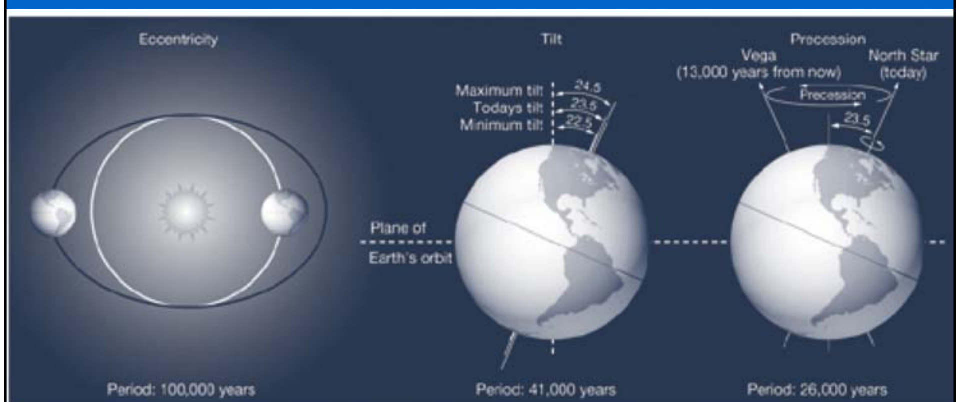


Interglacials

Glacials

Period approx. 100,000 years over last 700,000 years.
Before that, period approx. 40,000 years.

Milankovitch Cycles



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Eccentricity (100,000 year period)
Tilt (obliquity) (41,000 year period)
Precession (26,000 year period)

Milankovitch Cycles

Theory:

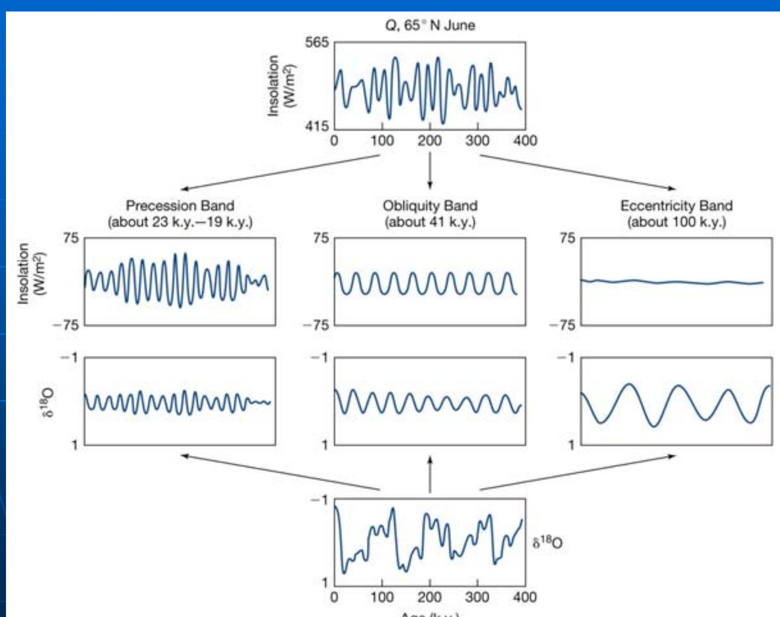
NH glaciation depends on summertime insolation at high northern latitudes.

(Low insolation allows wintertime snow to survive year round.)

Strongly criticized by scientific community in 1920s and 30s. (No good geological record.) Not accepted until after his death.

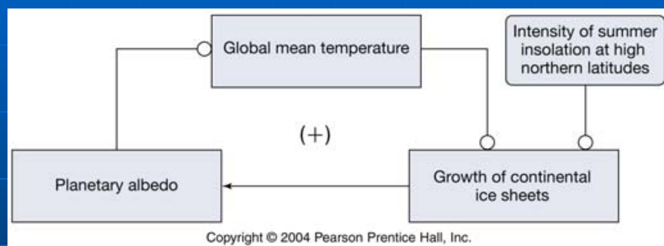
Milankovitch "I do not consider it my duty to give an elementary education to the ignorant, and I have also never tried to force others to apply my theory, with which no-one could find fault."

Test of Theory



Climate Feedbacks

Climate response matches in precession and obliquity bands but amplifies eccentricity forcing. Why?



Growth and destruction of NH ice sheet has a characteristic response time of about 100,000 years so glacial response is sensitive to eccentricity cycle.

But why are SH climate changes in step with those in NH?

G-H Effect could provide the link

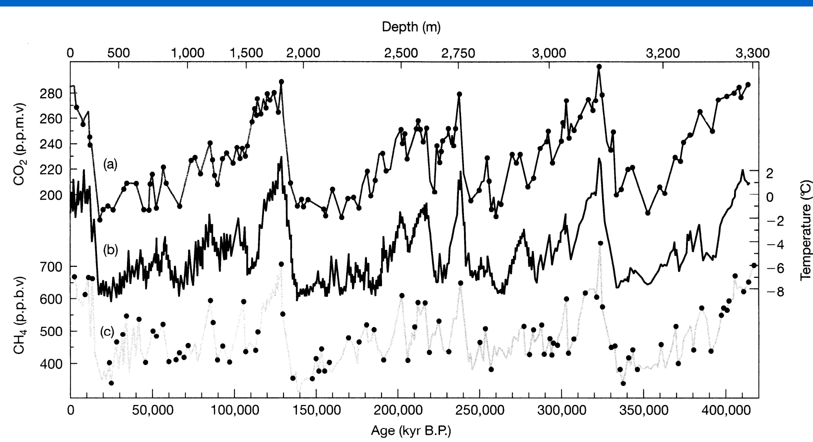


FIGURE 1-9

Measurements of (a) atmospheric CO_2, (b) temperature changes, and (c) atmospheric CH_4 determined from the Vostok ice cores. The temperature changes, DT, were determined from measured values of the deuterium content of the ice. The unit of age on the horizontal axis, kyr B.P., stands for "thousands of years before the present" (where k, for the prefix "kilo-," indicates "thousands"). (After *Climate Change,* 1994, Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.)

Note – very rapid rise in CO_2 levels, 190 ppm to 240 ppm in 4,000 yrs. Drop in CO_2 levels much more gradual (1 ppm per 1,000 years).

G-H gases

There is a strong correlation between temperature and CO_2 and CH_4 concentrations. CO_2 and CH_4 concentrations were significantly lower during glacial periods, and higher during interglacials. But why? (Note – the temperature change precedes the gas concentration change.)

Changes in atmospheric CO_2

On a time scale of millions of years the carbonate-silicate geochemical cycle determines the steady-state atm. CO_2, but on shorter time scales (thousands to hundreds of thousands of years), atm CO_2 can fluctuate from other processes.

There have been several theories proposed for why atm. CO_2 was reduced during glacial periods (and rose during interglacials).

(Note – a reduction in CO_2 causes global cooling – b/c of G-H effect – so causes the SH to cool in sync. with the NH.)

Role of Ocean – Biological Pump

Phytoplankton use nutrients at surface ocean to grow.

Photosynthesis reduces CO_2 in surface waters.

Atmosphere equilibrates with surface ocean waters – determines atm. CO_2 concentration.

Max. efficiency – if all nutrients were depleted, atm. CO_2 would go down to 165 ppm.

Zero efficiency – no depletion – atm. CO_2 would rise to 720 ppm.

(Pre-industrial = 280 ppm)

Why would a glacial ocean support greater biological productivity? (i.e. more photosynthesis.) – Note, last ice age, CO_2 was about 190 ppm.

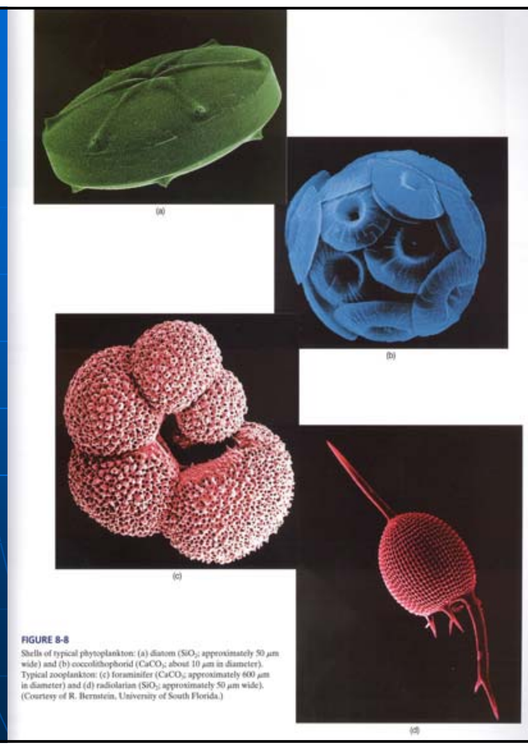


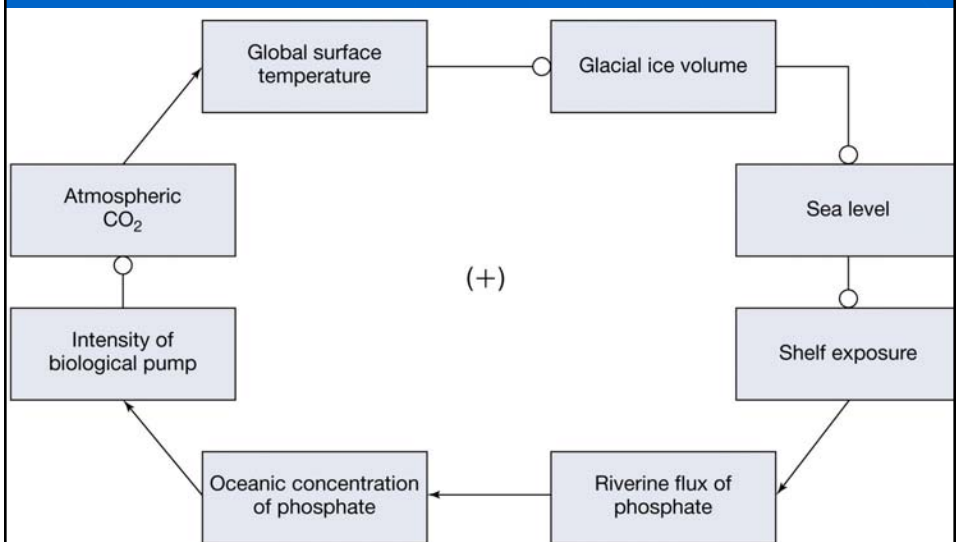
FIGURE 8-8
Shells of typical phytoplankton: (a) diatom (SiO_2; approximately 50 μm wide) and (b) coccolithophorid ($CaCO_3$; about 10 μm in diameter). Typical zooplankton: (c) foraminifer ($CaCO_3$; approximately 600 μm in diameter) and (d) radiolarian (SiO_2; approximately 50 μm wide). (Courtesy of R. Bernstein, University of South Florida.)

From: Kump, Kasting and Crane, 'The Earth System',

Role of Ocean – Biological Pump

1. shelf nutrient hypothesis – more glaciers = lower sea level = continental shelves exposed = more nutrients washed into ocean = increased marine productivity

Role of Ocean – Biological Pump

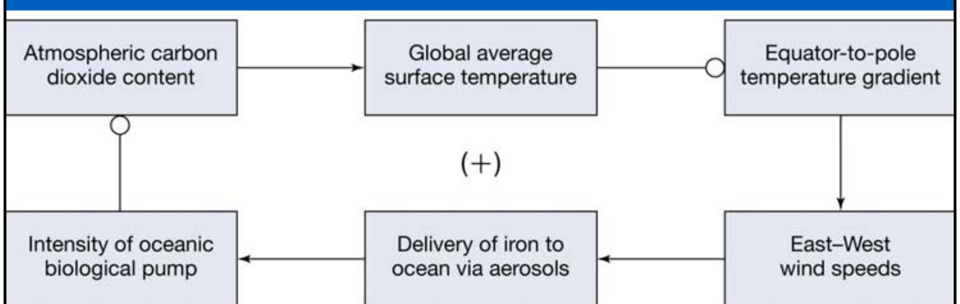


Role of Ocean – Biological Pump

2. iron fertilization hypothesis – iron plays an important role in limiting primary productivity in the ocean. If there is not enough iron, productivity is low. High iron = high productivity.

Iron comes from wind-blown dust (coated with iron) – provided by Saharan and Gobi deserts to Atlantic and Pacific Oceans. During glacial times – more arid + stronger winds = increase of iron flux to ocean

Role of Ocean – Biological Pump



Other theories

Coral reef hypothesis
Cloud albedo feedback
Distribution of salinity in surface ocean changed (via winds/rain) – slows vertical circulation.

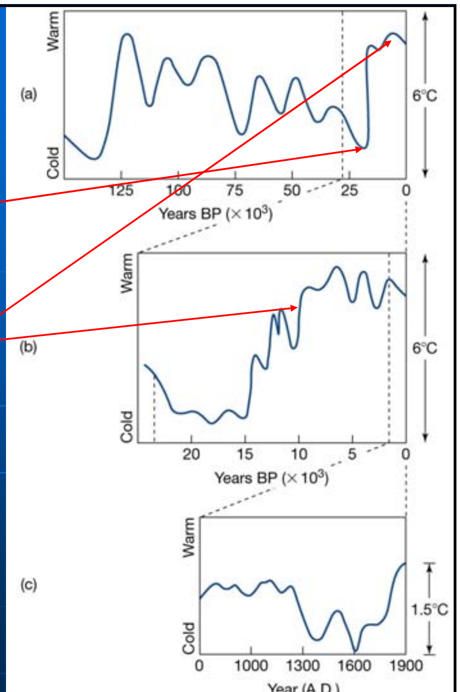
The Holocene (past 10,000 years)

Last major glaciation reached its maximum extent about 21,000 years ago.

Last glacial retreat until today to present = Holocene

Temperature data obtained through palynology (pollen) and dendrochronology (tree rings)

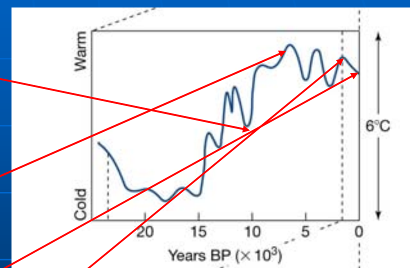
Temperature changes predicted for global warming in the 21st century are larger than anything in past 10,000 years, and comparable to the warming that took place after the last glacial maximum.

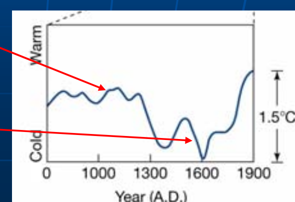


The Holocene
(past 10,000 years)

Temperature changes in Holocene:

- Younger Dryas (changes in ocean thermohaline circulation, North Atlantic Drift)
- Holocene Climatic Optimum (summer temps slightly higher than now)
- (European) Medieval Warm Period
- Little Ice Age



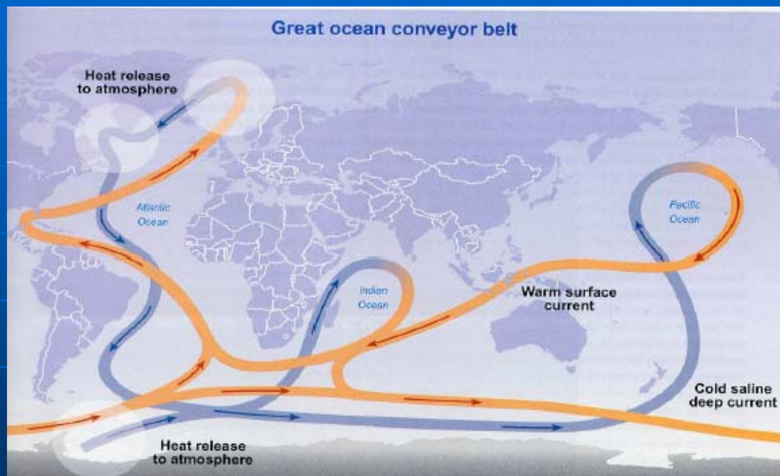


The Holocene
Causes of temperature change

- **volcanoes** (global cooling of 0.2 – 0.3 ºC for 1 – 3 years after an eruption) (L.I.A.)
- **Milankovitch** orbital forcing (H.C.O. and M.W.P.)
- changes in **ocean thermohaline circulation** in North Atlantic (Y.D.)
- **sunspots** (dark areas on Sun, but surrounded by bright areas called pages) – 11-year cycle – only about 0.1% change in brightness (net warming). But sunspot cycle shows good agreement with temperature cycle – may be an indirect effect (X-rays/cosmic rays influence cloud albedo?) (L.I.A.)
- **CO_2 and aerosols** (Recent climate change - past 200 years)
- **ENSO events** (atm. and oceanic circulation patterns in tropical Pacific that impact tropical precipitation and mid-latitude climate) (Recent climate change - past 200 years)

Climate Change in the Pleistocene and Holocene

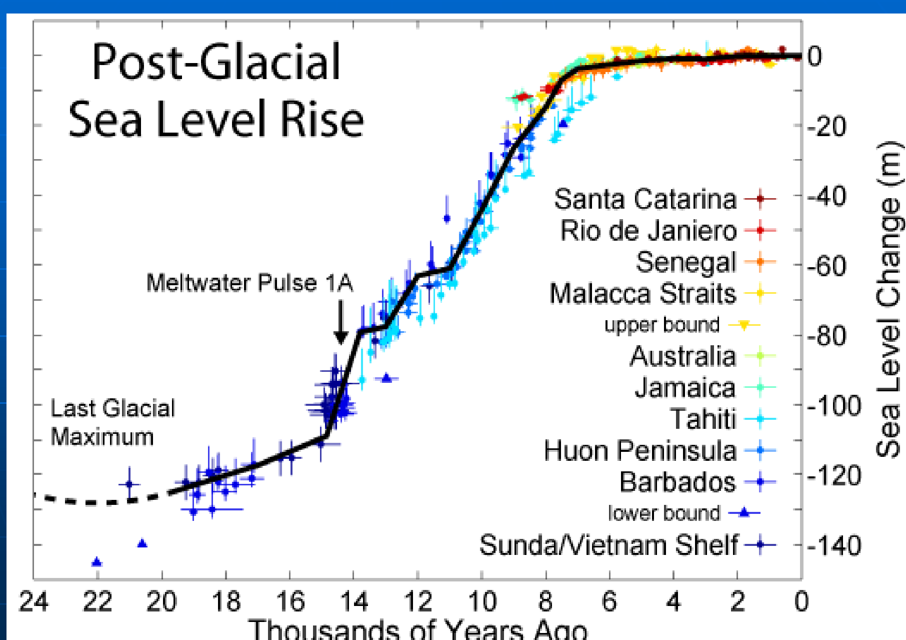
Melting Sea Ice and the Thermohaline Circulation



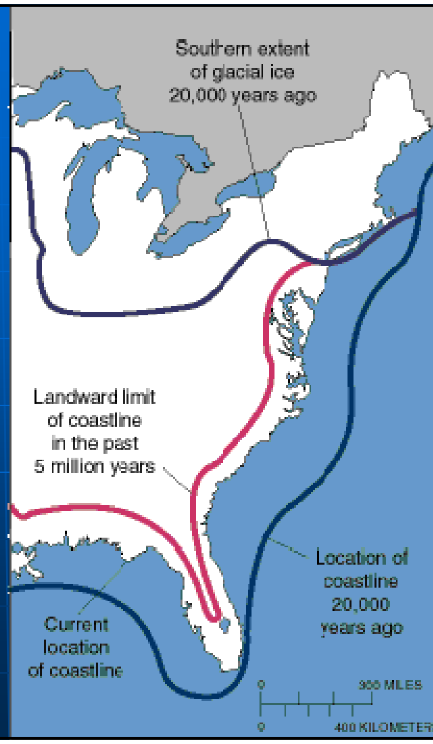
The melting of ice shelves returns fresh water to the ocean. Changes in the rate of this process could affect ocean circulation by changing the surface salinity.

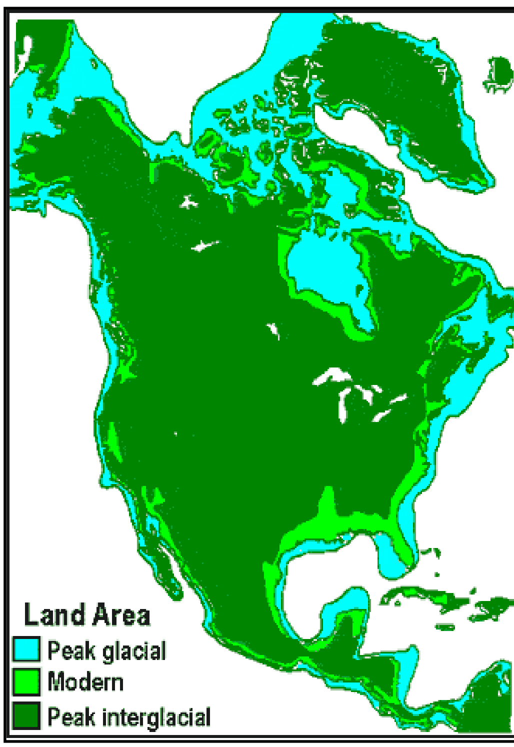
Schneider, Stephen, *Overview of "Dangerous" Climate Change*, Scientific Symposium on Stabilization of Greenhouse Gases, U.K. Met. Office, Feb. 2005.

Climate Change in the Pleistocene and Holocene



Climate Change in the Pleistocene and Holocene





Climate Change in the Pleistocene and Holocene

<u>Glaciers and Glacial Geology</u>
Jennifer L. Aschoff
Montana State University
July 1999
http://www.earthscape.org/t1/low01/low01bk/low01bk.html