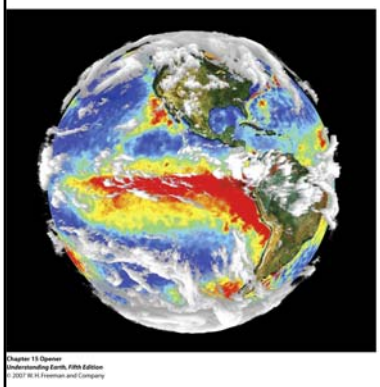

Chapter 15 Opener
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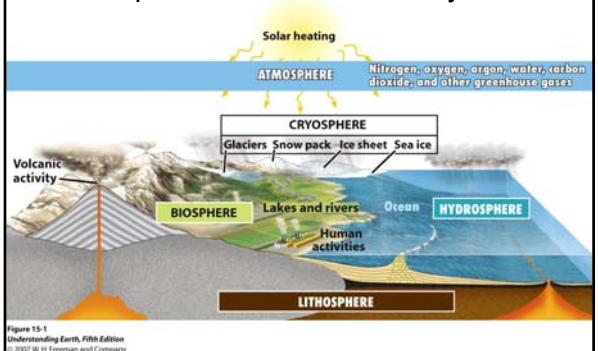
G-100 Lecture

The Climate System & Global Warming

Main Topics

- Components of the climate system
- The greenhouse effect
- Climate variability & proxy records
- The carbon cycle
  - *The inconvenient truth*

Components of the climate system



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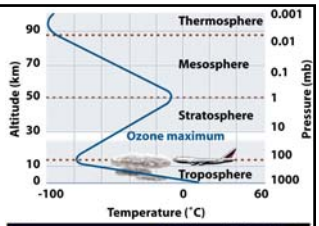
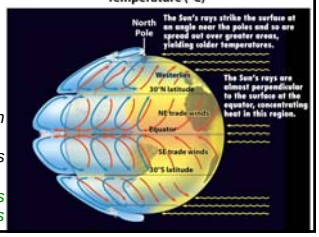
The Atmosphere

- nitrogen (78%)
- oxygen (21%)
- other gases (~1%)
  - ***water vapor (~2%)***
  - argon (0.93%)
  - ***carbon dioxide, CO_2 (0.037% ; 370 ppm)***
  - ozone
  - methane





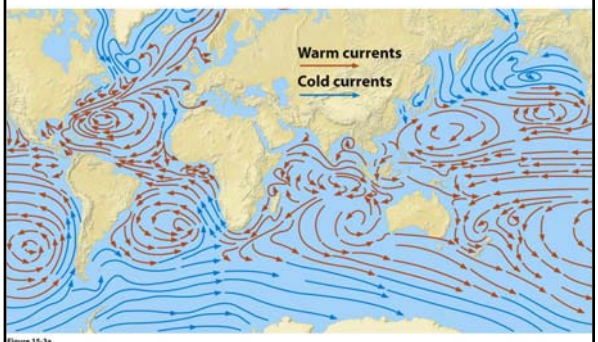
Rotation of Earth

Coriolis forces

Convection in troposphere transports heat from equator to poles

Hydrosphere: Surface ocean currents

heat transport from equator toward poles



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Hydrosphere: Thermohaline ocean currents

ocean conveyor of heat

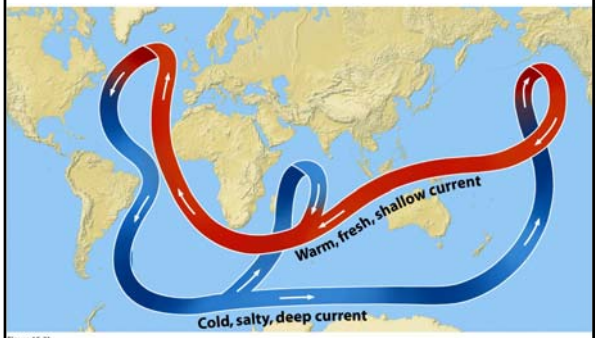

Figure 15-3b
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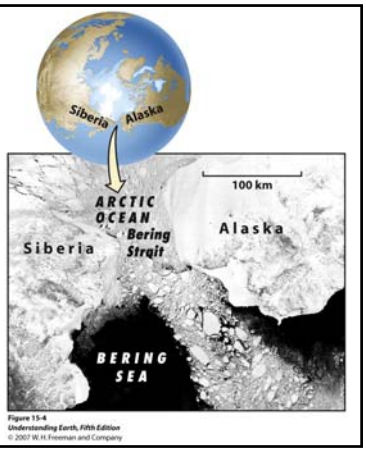
Cryosphere

- Ice Component
  - ice sheets
  - glaciers
  - sea ice
  - frozen lakes and rivers
- Controls *albedo* *(fraction of energy reflected)*



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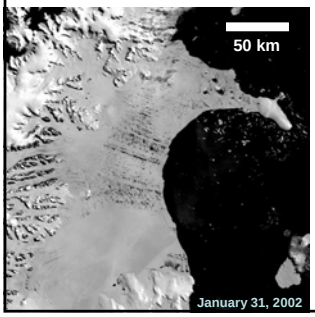
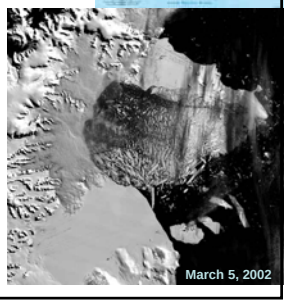
- Antarctica
  - Larsen B ice shelf
  - 220 m thick ice floating on water

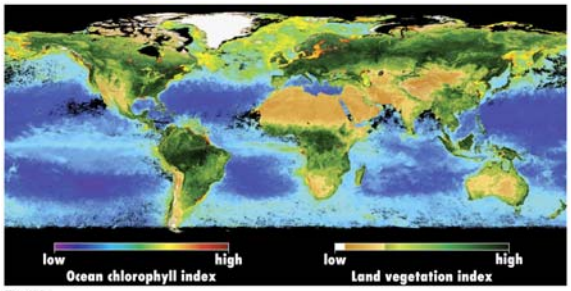
National Snow and Ice Data Center http://nsidc.org/iceshelves/larsenb2002/





Biosphere

- All organisms living near Earth's surface
- Plants & animals
- Microbes: marine & terrestrial



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Components of the climate system

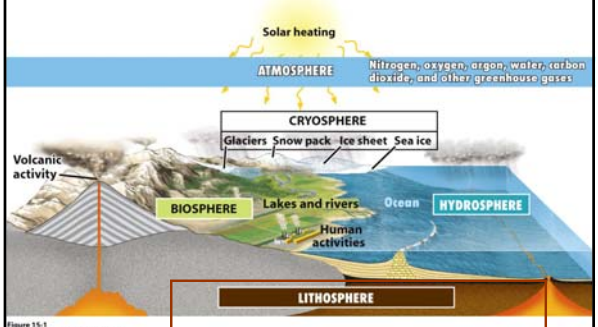

Figure 15-1
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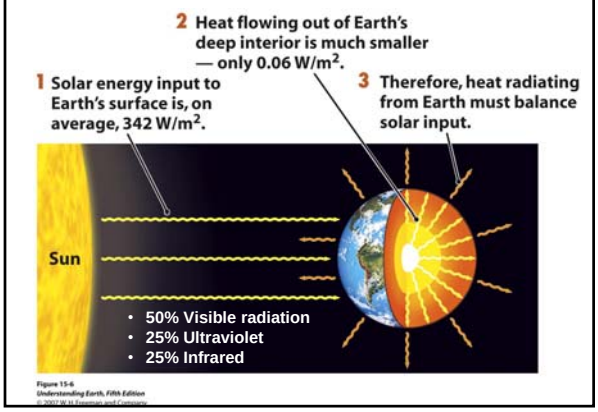
- Land surface: absorbs & returns solar energy
- Topography: affects wind and rain patterns
- Volcanism: atmospheric aerosol & dust levels

Earth's energy balance



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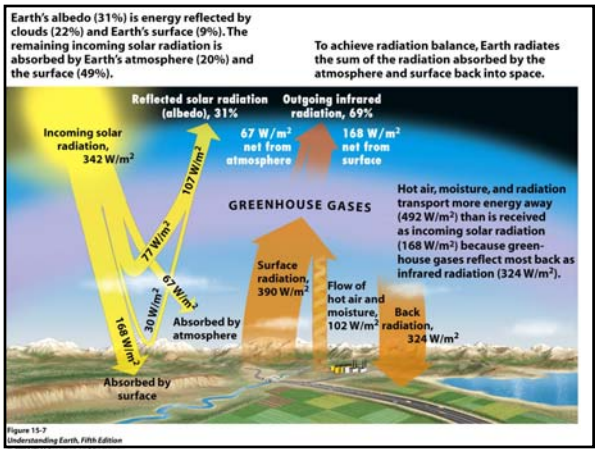

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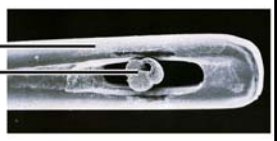
Positive & Negative Feedbacks

- Water vapor
  - As T rises, water vapor rises
  - *Greenhouse effect enhanced*
- Albedo
  - As T rises, ice in cryosphere reduced, albedo reduced, more energy absorbed by surface
  - Surface T must rise, *greenhouse effect enhanced*
- Radiation
  - T rises, amount of infrared energy radiated back to space increases, surface T lowers, *greenhouse effect stabilized*
- Plant Growth
  - More CO_2 in atmosphere → more plants
  - But plants convert CO_2 to organic C
  - Overall, *greenhouse effect reduced*
- *Interplay is complex, poorly understood*

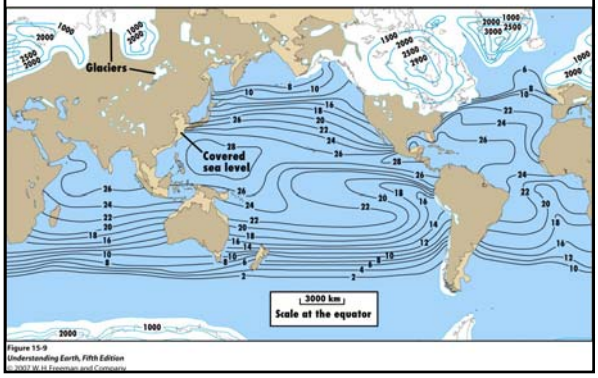
Climate Variability: Proxy Records

- *Knowing how climate has changed in past is key to predicting future climate change*
- Pleistocene Ice Ages
  - Wisconsin glaciation peak ice volume 18,000 years ago
  - Latest in series of ice ages
  - Best proxy records of past ice ages:
    - Ocean sediment cores
    - Polar ice cores
      - Antarctica



Ice extent: peak of Wisconsin glaciation

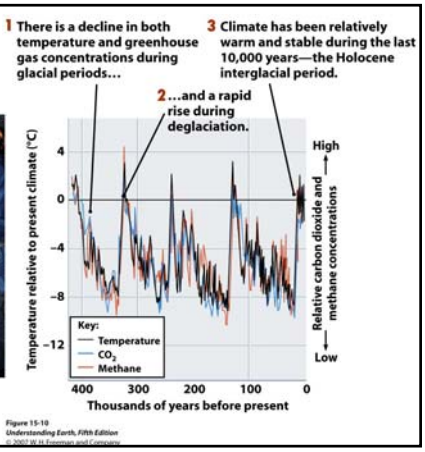
- Larger ice sheets; less extensive oceans



Climate Variability: Proxy Records

- **Ocean sediment cores—Oxygen isotope records**
  - ^{16}O lighter, evaporates preferentially relative to ^{18}O
  - Thus, when Earth is cool and ice sheets large, seawater and sediment precipitated from it have a high $^{18}O/^{16}O$ ratio
    - Changes in the $^{18}O/^{16}O$ ratio record changes in global temperature
- **Polar ice cores—Oxygen isotope & gas records**
  - Stratigraphic records are of annual climate changes
  - When ice sheets grow large, taking more ^{16}O than ^{18}O from the oceans, ice has a low $^{18}O/^{16}O$ ratio
  - Bubbles of air trapped in ice give concentration of CO_2, CH_4

Vostok ice core



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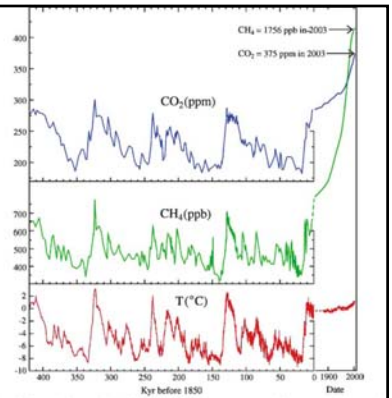
Temperature and CO_2 in polar ice

- last 400,000 years
- last century



from: Hansen (2005) Climate Change

Figure 1. Record of atmospheric CO_2, CH_4, and temperature extracted from Antarctic ice core b
Petit et al. (1999) and from *in situ* and other data for the past century. The temperature change fo
the past century, for comparability to the ice core record for earlier times, is twice the global mea
temperature change of Hansen et al. (2001). The temperature zero-point is the mean for 1880–1899

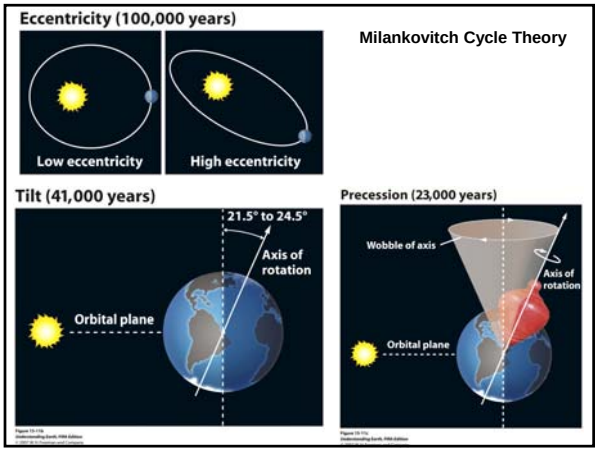
Climate Variability: Processes

Milutin Milanković b. 1879 / d. 1958 (Serbian Mathematician)

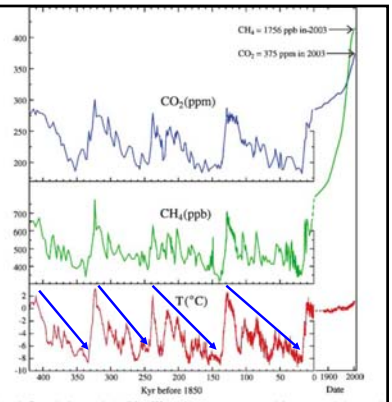
(1930) *Mathematische Klimalehre und astronomische Theorie der Klimaschwankungen*

(Mathematical science of climate and astronomical theory of the variations of the climate)

- **Milankovitch Cycle Theory**
  - Earth's climate determined by its position and orientation relative to the sun
    - Eccentricity of Earth's orbit (100,000 year cycles)
    - Tilt of rotation axis (41,000 year cycles)
    - Precession of rotation axis (23,000 year cycles)



- 100,000 year cooling cycles
  - major Pleistocene glaciations largely eccentricity-driven
- Shorter variations
  - tilt & precession
  - positive feedbacks
- Abrupt changes
  - Melting 14,500 years ago
  - Rapid onset of Younger Dryas ice age 13,000 to 11,500 years ago
  - Rapid change in atmospheric circulation



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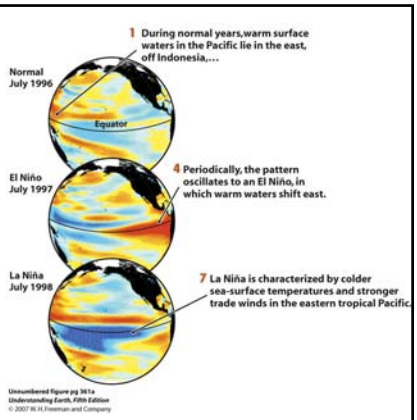
temperature change of Hansen et al. (2001). The temperature zero-point is the mean for 1880–1899

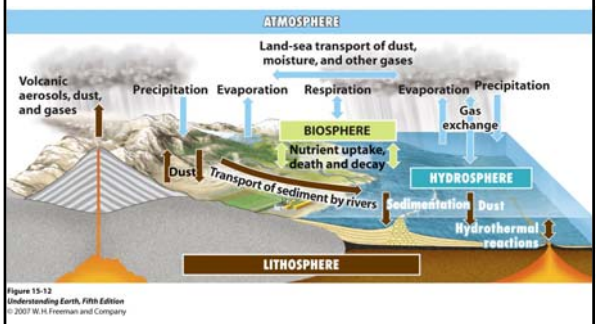
- Regional patterns superimposed on global climate changes
- El Niño-Southern Oscillation *ENSO*
- Atmospheric circulation interactions with sea & land surface



The Carbon Cycle

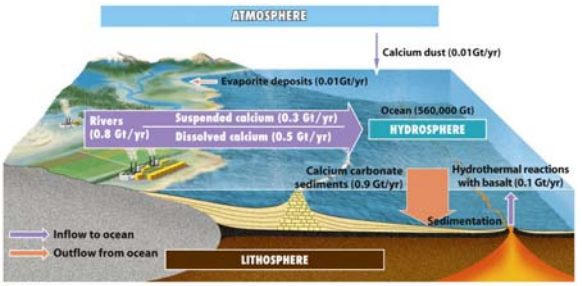
- Geochemical Cycles
  - Geochemical reservoirs
  - Residence time = capacity/influx = average time in reservoir
  - Chemical reactions
    - $Ca^{2+} + 2HCO_3^- = H_2CO_3 + CaCO_3$
    - $H_2CO_3 = H_2O + CO_2$
    - *thus, cycles of C and Ca are coupled*
  - Transport across interfaces

Transport processes between components of the climate system



The Calcium Cycle

- River inputs to ocean balanced by sedimentation
  - residence time = reservoir size/flux in = 600,000 years



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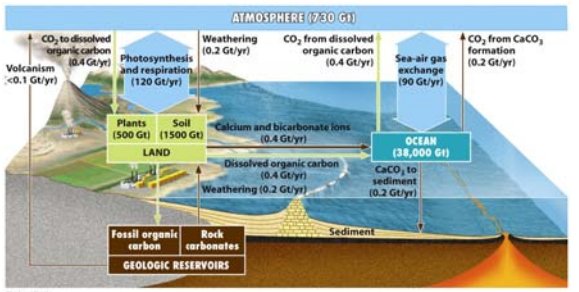
The Carbon Cycle

- Four reservoirs
- Four subcycles
  - air-sea gas exchange; photosynthesis; dissolved organic carbon; carbonate weathering
  - T, wind ; respiration/decay; to oceans--to air ; bicarbonate->ppt shells



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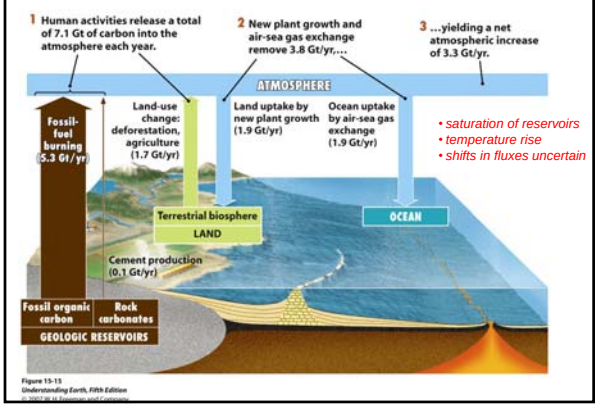
Anthropogenic perturbations of carbon cycle



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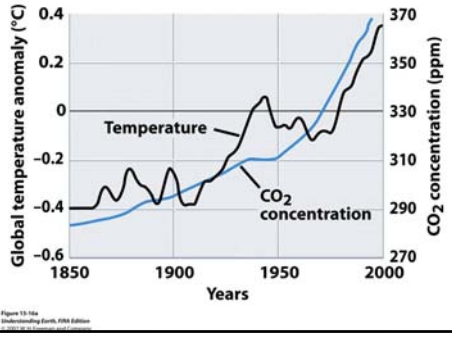
Anthropogenic perturbations of carbon cycle

- *Industrial revolution: fossil fuel burning*
- *deforestation*
- *enhanced greenhouse effect*



Anthropogenic perturbations of carbon cycle

from: Hansen (2005) Climate Change

- *20th century rise in CO_2 & T is anomalous compared to last millenium*
- *CO_2 is higher than it has ever been in last 20 million years*