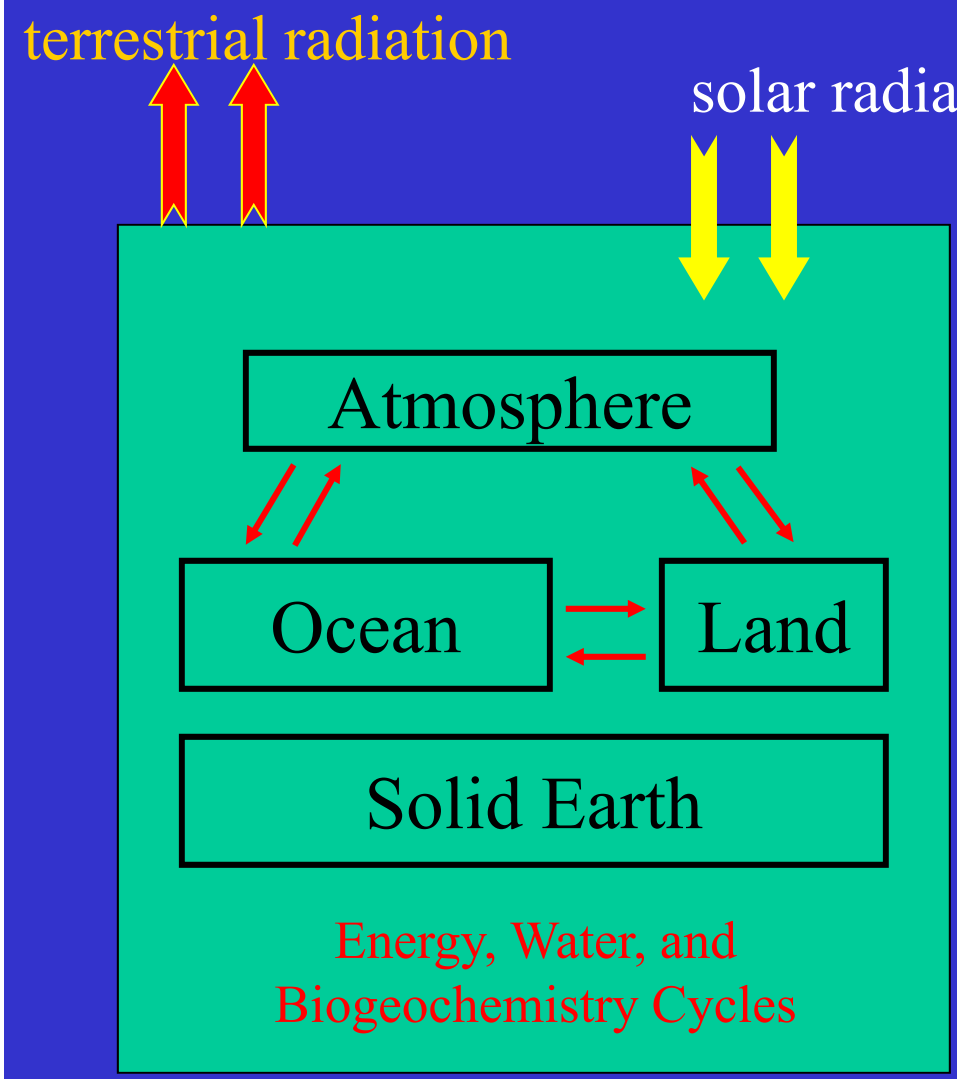
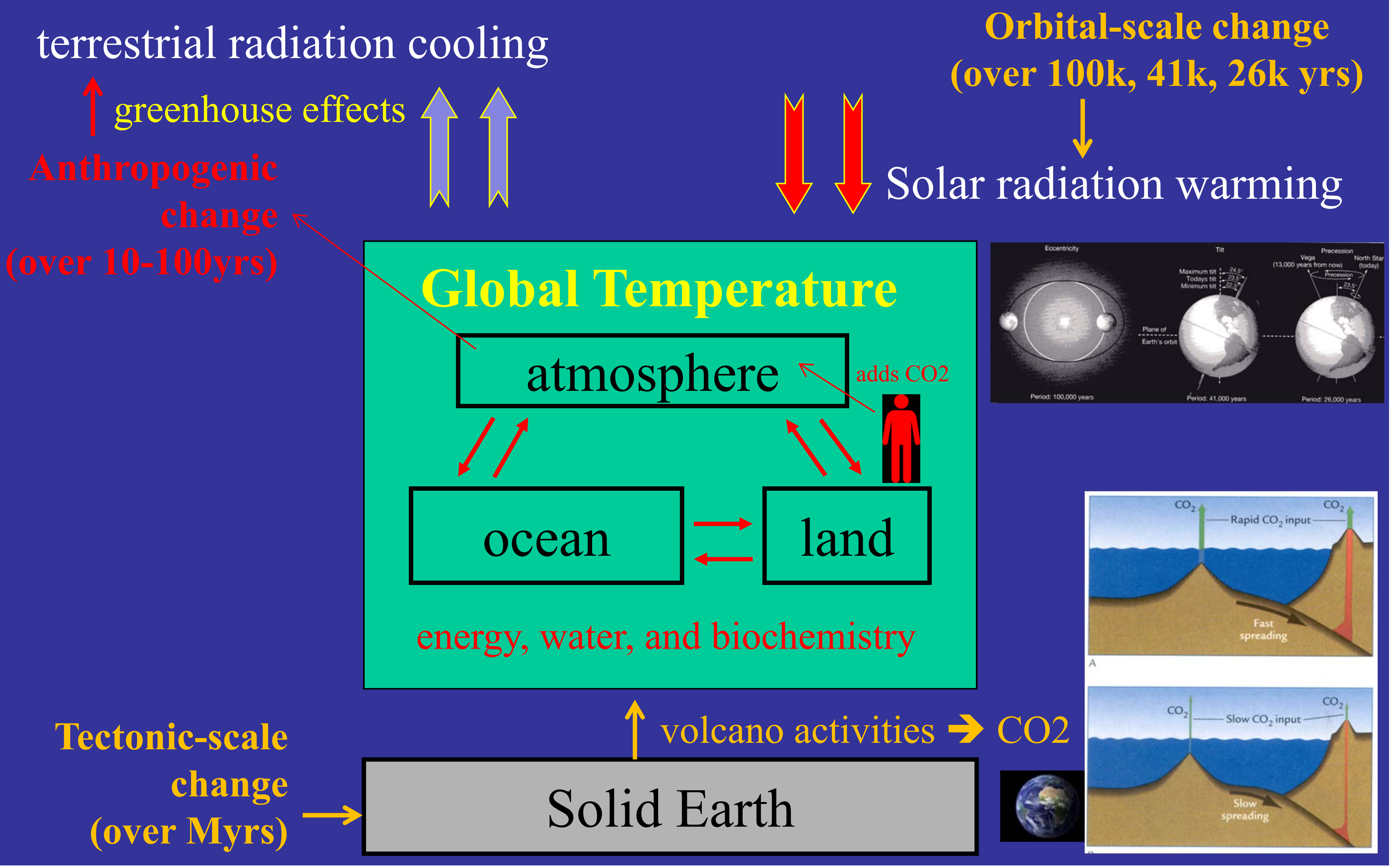
Lecture 2: Earth's Climate System



- Sub-components
- Global cycles
- What comes in
- What goes out

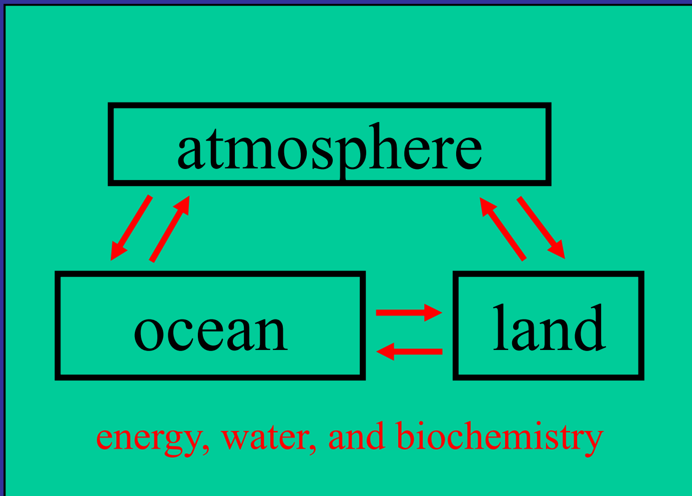
Components of the Climate System



Pop Quiz

- How thick is Earth's atmosphere?

(a) 1 km (b) 4 km (c) 10 km (d) 150 km



of the Subcomponents

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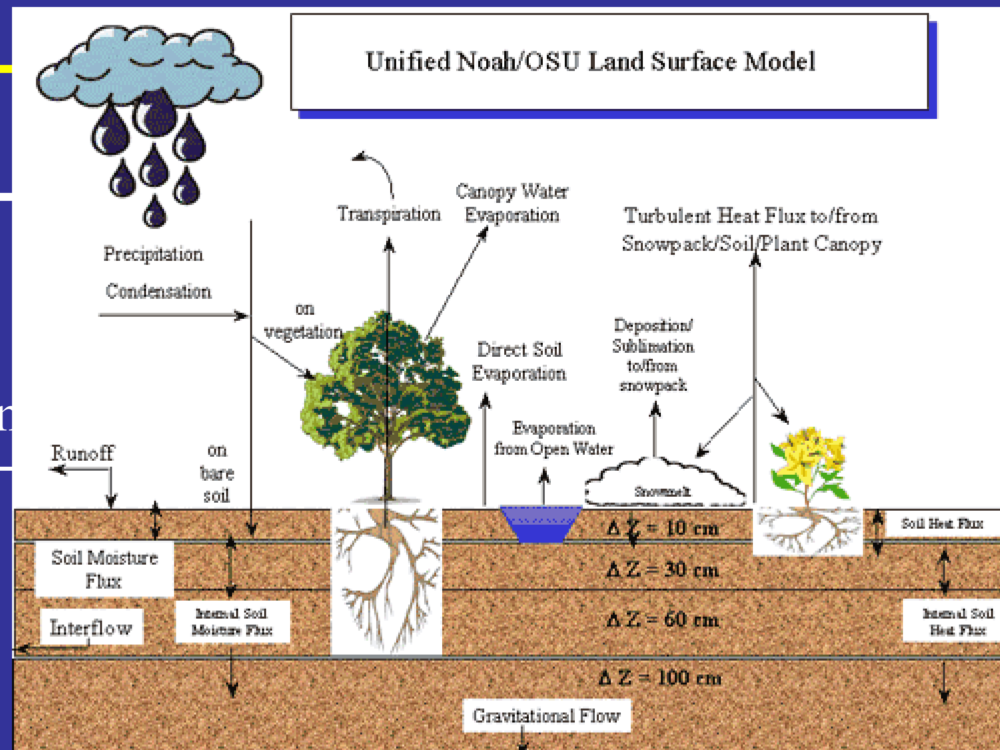
Atmosphere	5.14×10^{18} kg (~ 100-150 km	
Oceans	1.39×10^{21} kg (~ 4 km)	
Solid Earth (Land Surface)	5.98×10^{24} kg (~ 100s meters)	Vegetation, snowcover, and soil conditions affect the local and global climate. More changeable than oceans.



Subcomponent: the Atmosphere

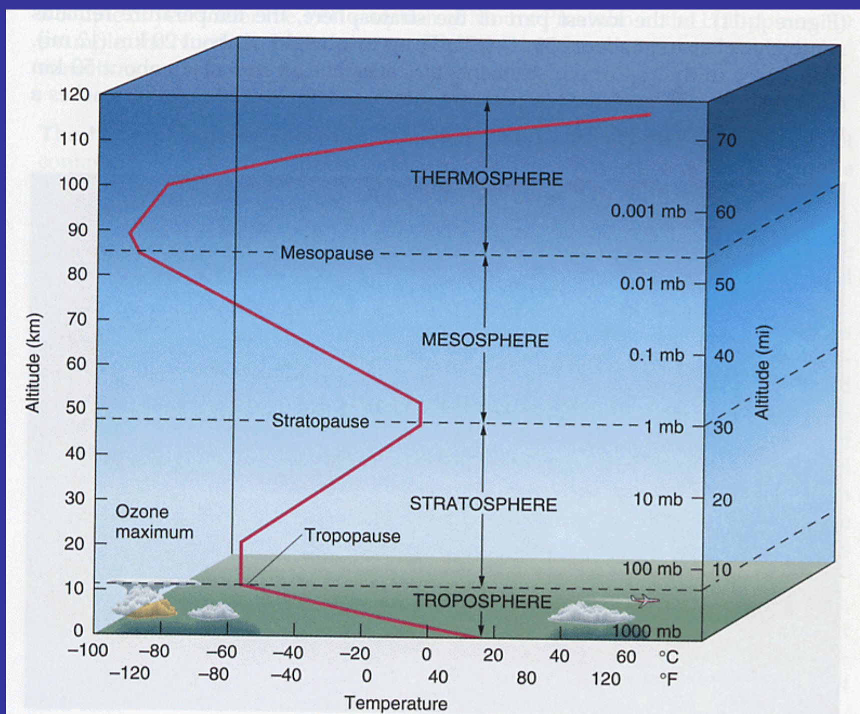
Composition →

Table 3.1. Composition of the atmosphere. Constituents are listed with an indication of whether they are radiatively active, with a mixing ratio representative of the troposphere (trop.) or stratosphere (strat.), how they are distributed vertically, and controlling processes.

Constituent	Tropospheric mixing ratio	Vertical distribution (mixing ratio)	Controlling processes
N_2	0.7808	Homogeneous	Vertical mixing
O_2	0.2095	Homogeneous	Vertical mixing
* H_2O	$\leq$0.030	Decreases sharply in trop. Increases in strat. Highly variable	Evaporation, condensation, transport Production by CH_4 oxidation
Ar	0.0093	Homogeneous	Vertical mixing
* CO_2	345 ppmv	Homogeneous	Vertical mixing Production by surface and anthropogenic processes
* O_3	10 ppmv$	Increases sharply in strat. Highly variable	Photochemical production in stratosphere Destruction in troposphere Transport
* CH_4	1.6 ppmv	Homogeneous in trop. Decreases in middle atmos.	Production by surface processes Oxidation produces H_2O
* N_2O	350 ppbv	Homogeneous in trop. Decreases in middle atmos.	Production by surface and anthropogenic processes Dissociation in middle atmos. Produces NO Transport
* CO	70 ppbv	Decreases in trop. Increases in strat.	Production anthropogenically and by oxidation of CH_4 Transport
NO	0.1 ppbv$	Increases vertically	Production by dissociation of N_2O Catalytic destruction of O_3
* CFC-11 * CFC-12	0.1 ppbv	Homogeneous in trop. Decreases in strat.	Industrial production Mixing in troposphere Photodissociation in stratosphere
ClO	0.1 ppbv$	Increases vertically	Production by photodissociation of CFCs Catalytic destruction of O_3

* Radiatively active $ Stratospheric value

Vertical Structure



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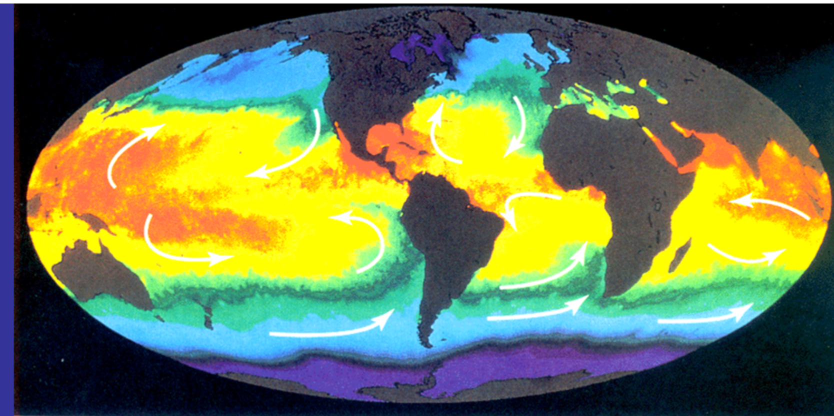
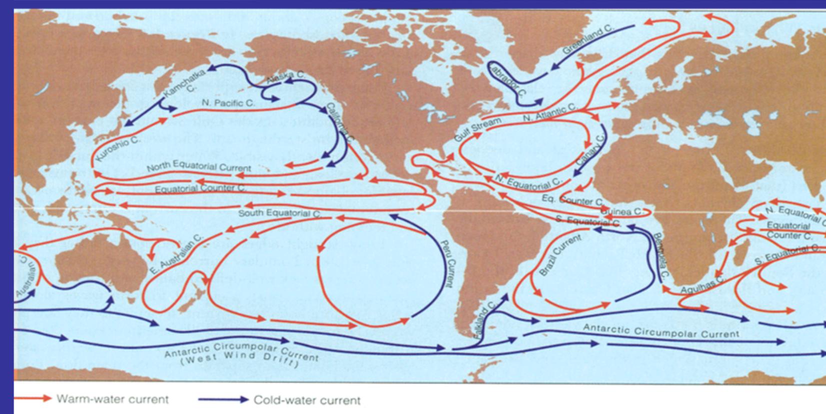
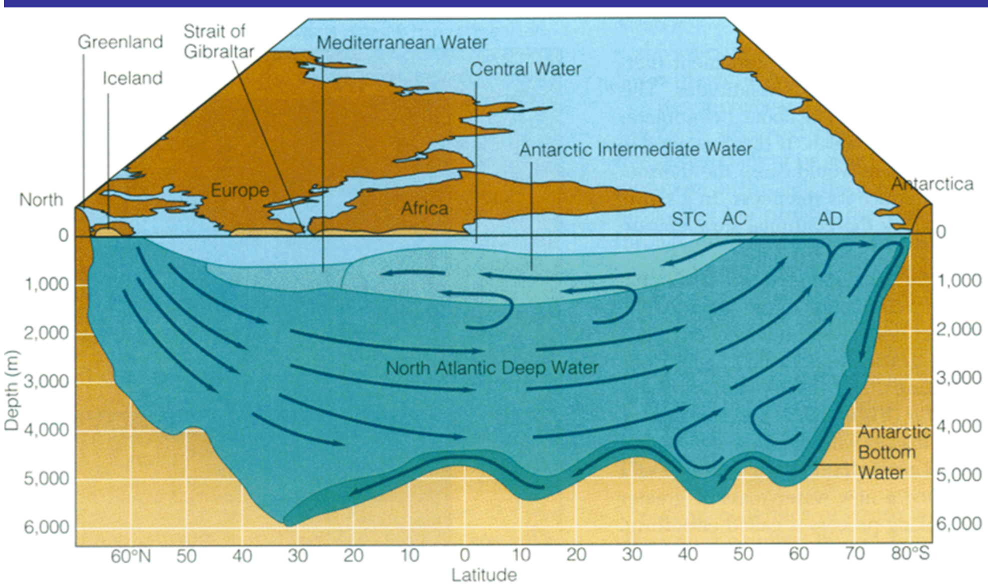
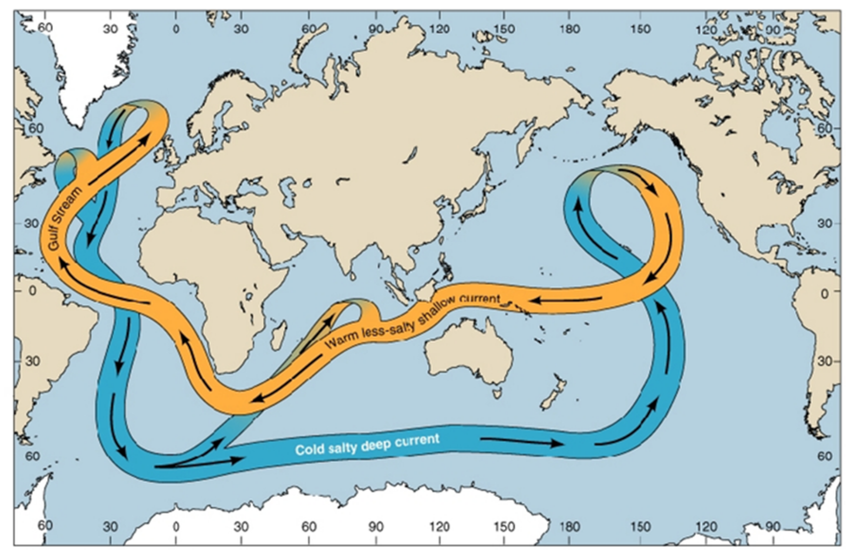
Subcomponent: Global Oceans









Pop Quiz

- What is the average depth of oceans?

(a) 1 km (b) 4 km (c) 100 km (d) 1000 km

Subcomponent: Land Surface

Topography

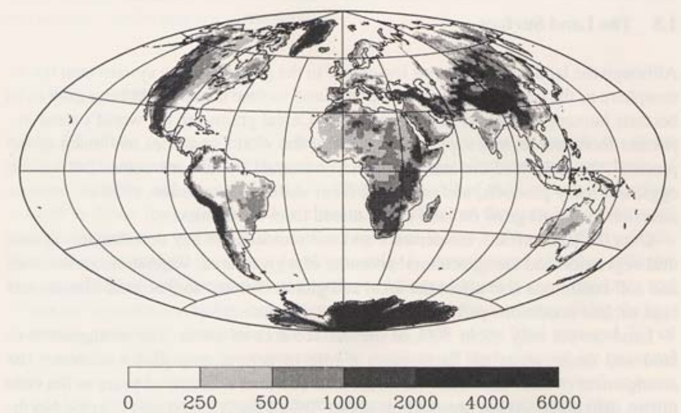


Fig. 1.13 Gray-scale contour plot of the topography of Earth relative to sea level. Resolution of the basic data is one degree of latitude and longitude. Scale is in meters.

Vegetation Type

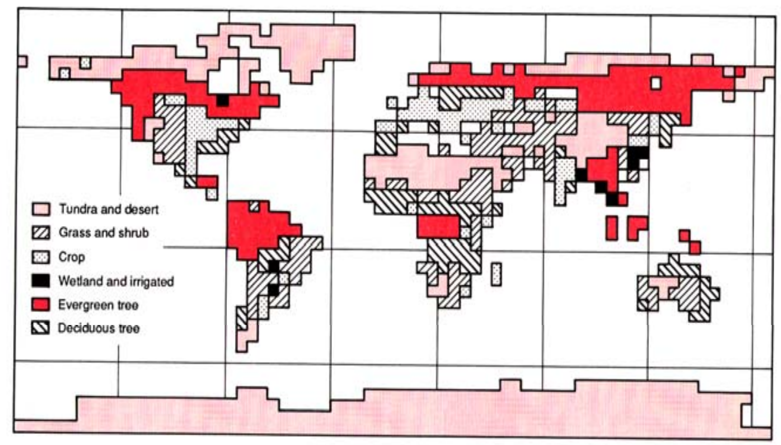
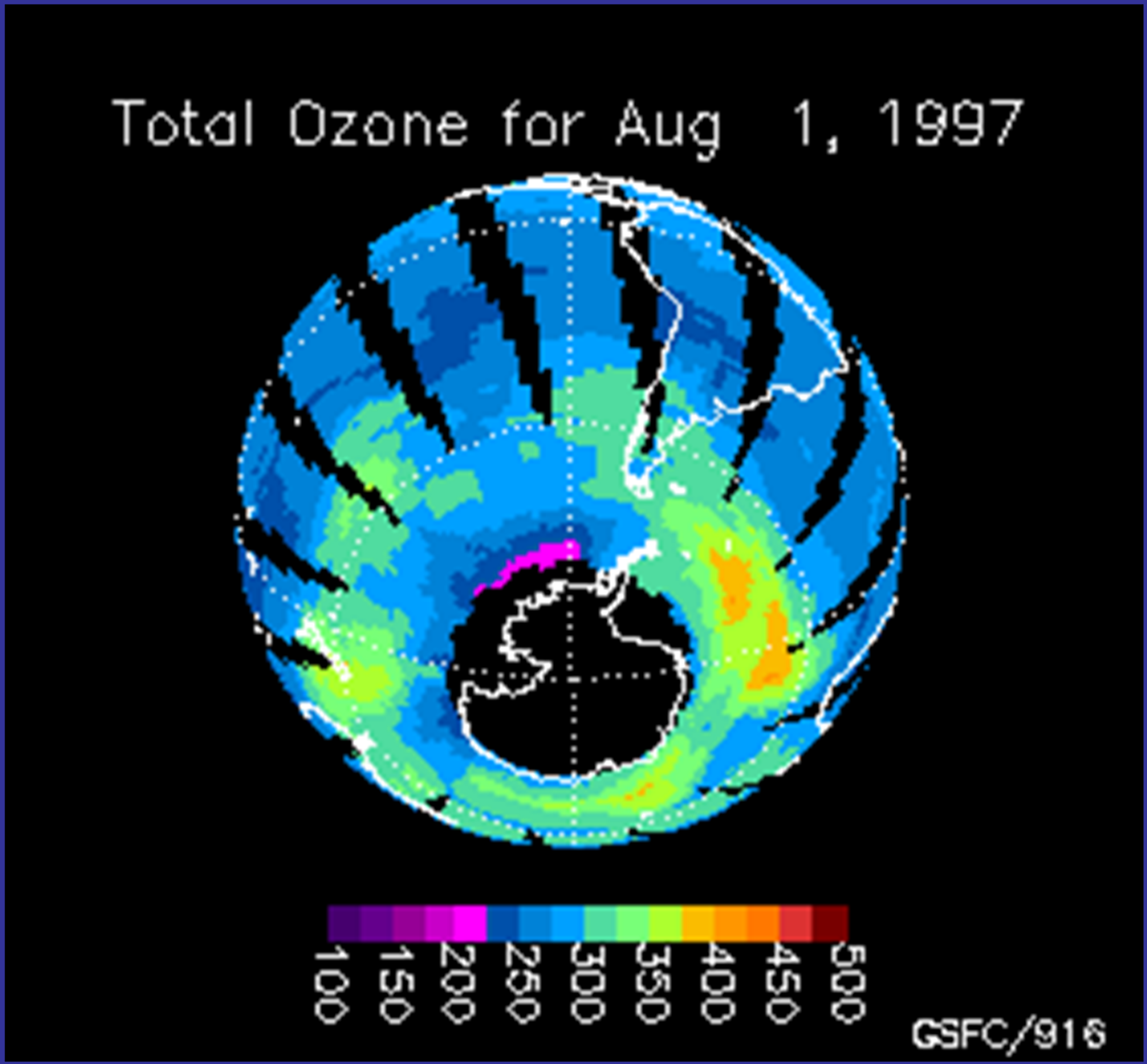


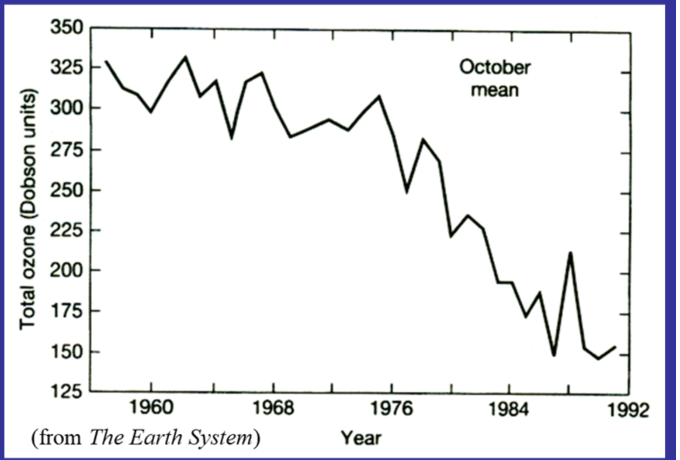
Fig. 5.14 Distribution of general ecotypes on a 5° × 5° grid (Olson et al., 1983).

- ❑ Not important for thermal energy because of its low heat capacity and negligible horizontal transport.
- ❑ Important for moisture exchange with the atmosphere because of greater surface roughness.

The 1997 Ozone Hole



Mean Total Ozone Over Antarctic in October



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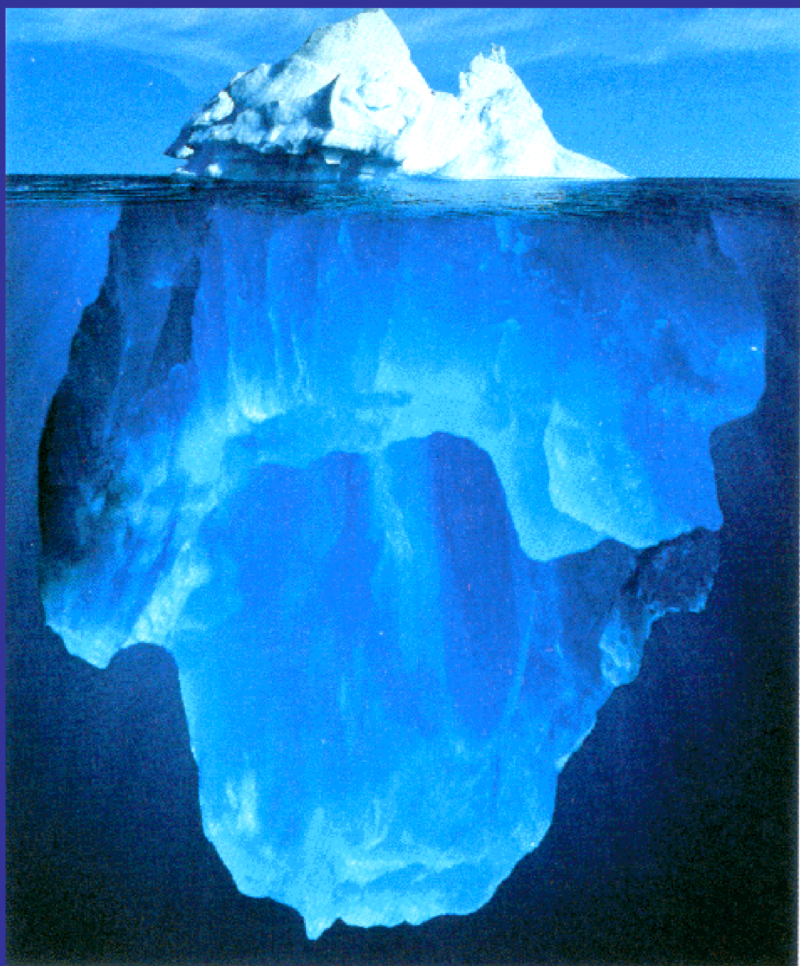
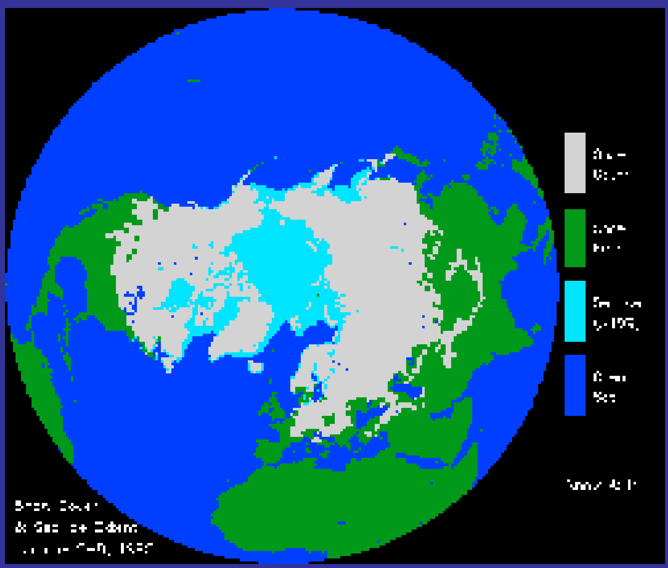
Subcomponent: Cryosphere

Sea Ice



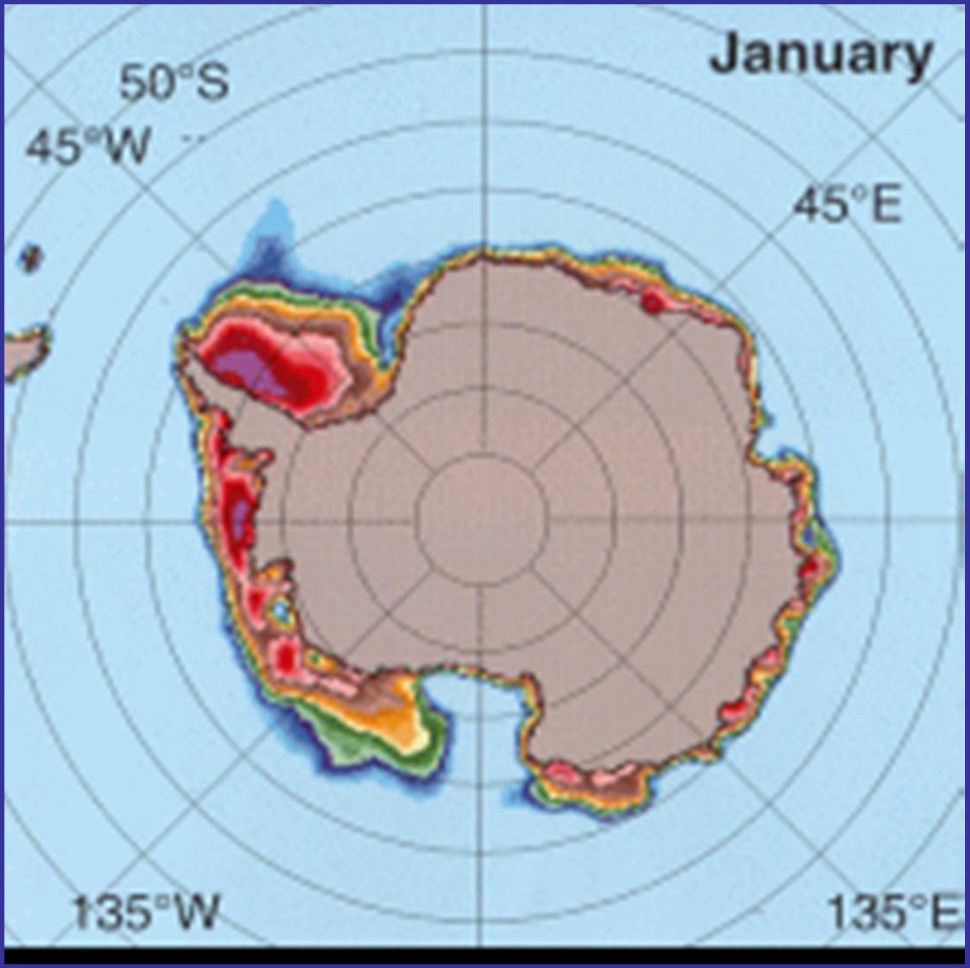
(from *The Blue Planet*)

Land Ice



- ❑ The cryosphere is referred to all the ice near the surface of Earth: including sea ice and land ice.
- ❑ For climate, both the surface and the mass of ice are importance.
- ❑At present, year-round ice covers 11% of the land area and 7% of the world ocean.

Seasonal Cycle of Antarctic Ice



(figures from Gloersen, P. et al. 1992; animated by D. B. Reush)

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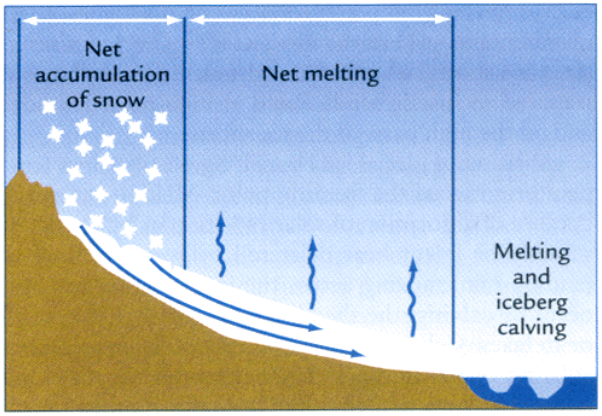
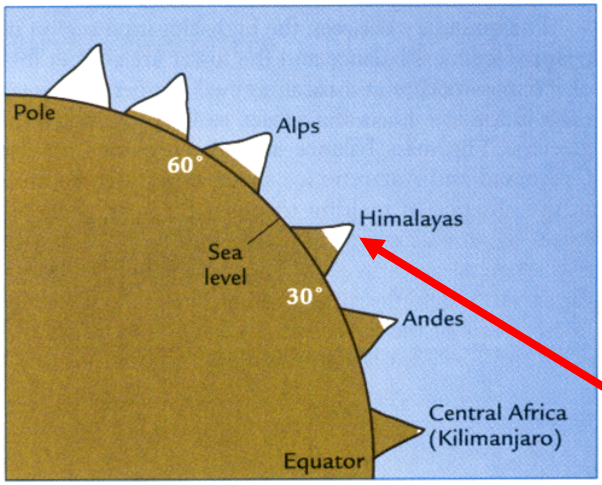
Land Ice





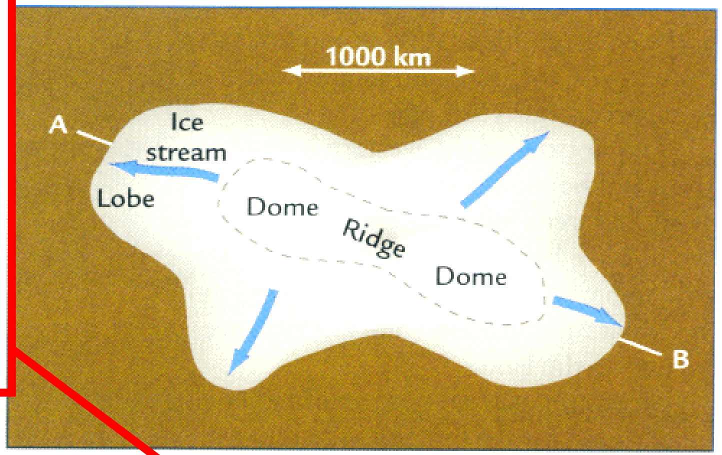
(from *Earth's Climate: Past and Future*)

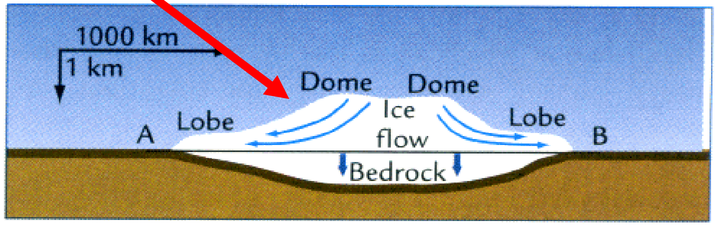
❑ **Continental Ice Sheets:**

100-1000 km in horizontal extend.

1-4 km in thickness.

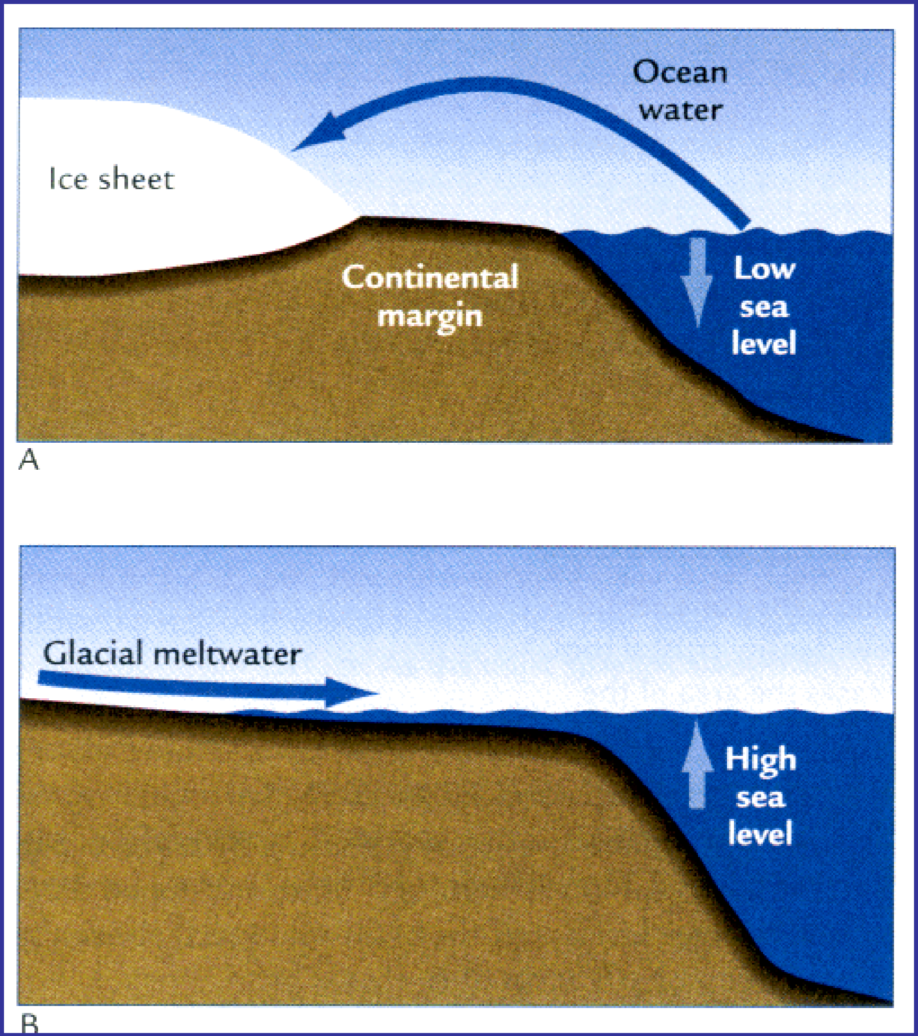
Two larges sheets: Antarctic Ice Sheet and Greenland Ice Sheet.





❑ **Mountain Glaciers:** a few kilometers in length and 10-100 meters in width and thickness.

Land Ice and Sea Level



(from Earth's Climate: Past and Future)

- The Antarctic Ice Sheet holds the equivalent in seawater of 66 meters of global sea level.
- The Greenland Ice Sheet holds the equivalent of 6 meters of global seawater.

Global Warming and Sea-Level Change

Global Warming
(2.5°C by 2100)

Thermal Expansion
(11 inches)

Glacier and Ice Caps
(6.3 inches)

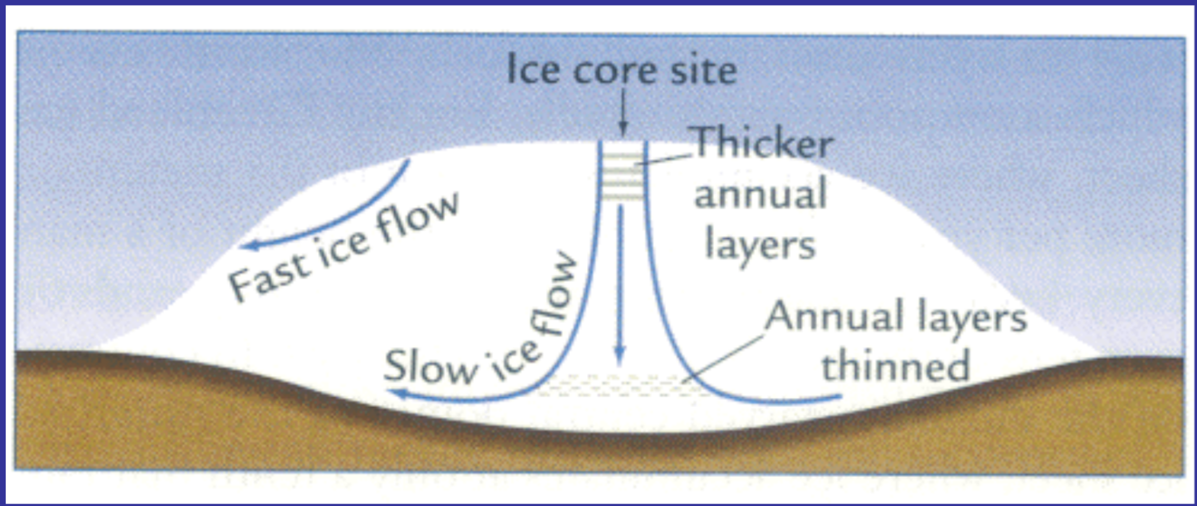
Greenland Ice Sheet
(2.4 inches)

Antarctic Ice Sheet
(-0.4 inches)

Sea Level Rise
(19.3 inches by 2100)

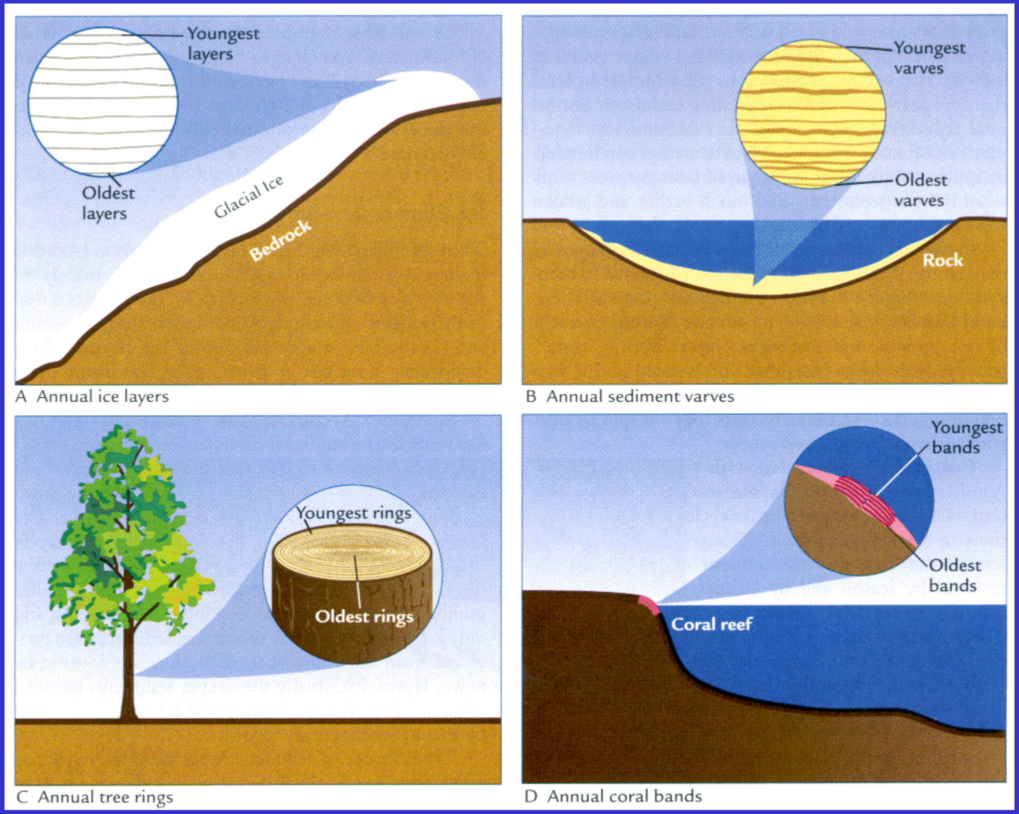
Glacial Ice

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



- Ice cores retrieve climate records extending back thousands of years in small mountain glaciers to as much as hundreds of thousands of years in continental sized ice sheets.
- The Antarctic ice sheet has layers that extend back over 400,000 years.
- The Greenland ice sheet has layers that extended back 100,000 years.

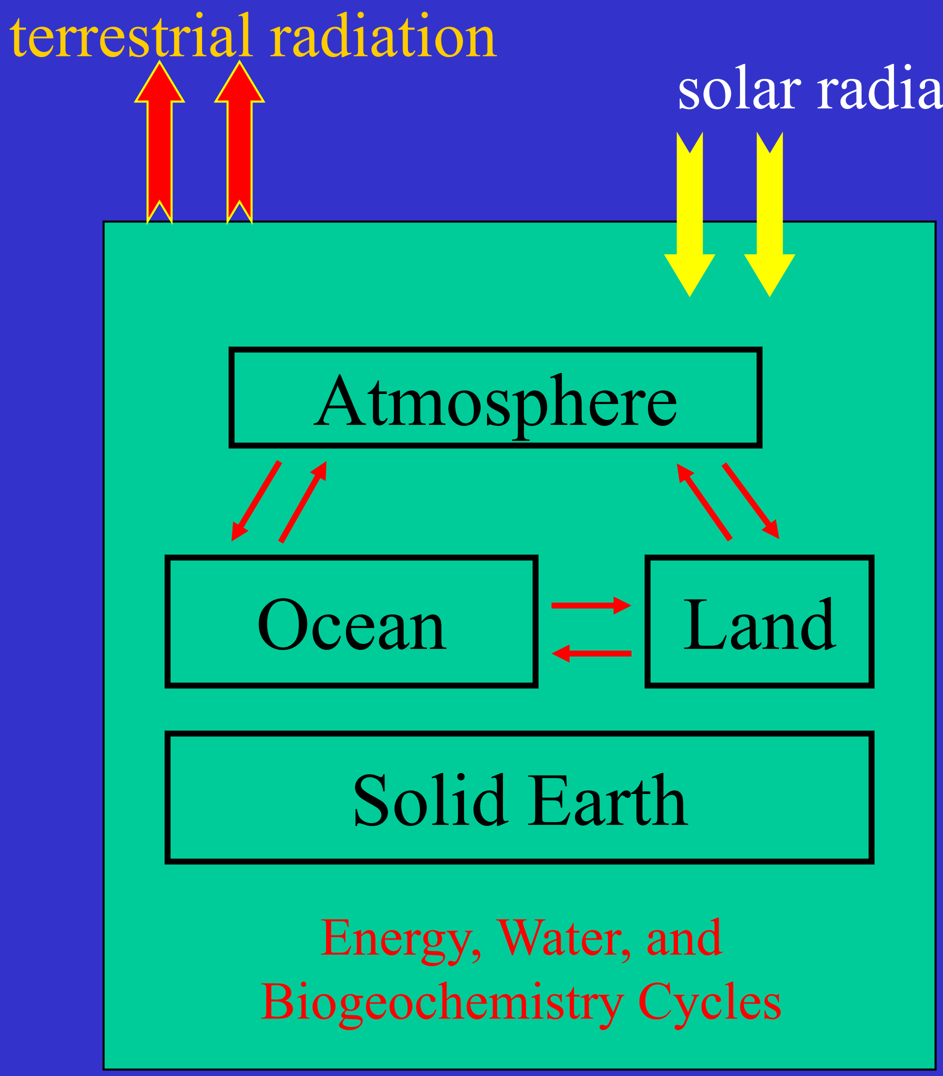
Climate Archives



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

- Much of climate history is recorded in four climate archives:
  (1) Sediments
  (2) Ice
  (3) Corals
  (4) Trees
- How are those records dated?
- Hoe much of Earth's history each archive spans?
- What is the resolution of climate history yielded by each?

Global Cycles



- The ultimate driving force to Earth's climate system is the heating from the Sun.
- The solar energy drives three major cycles (energy, water, and biogeochemisty) in the climate system.

Global Energy Cycle

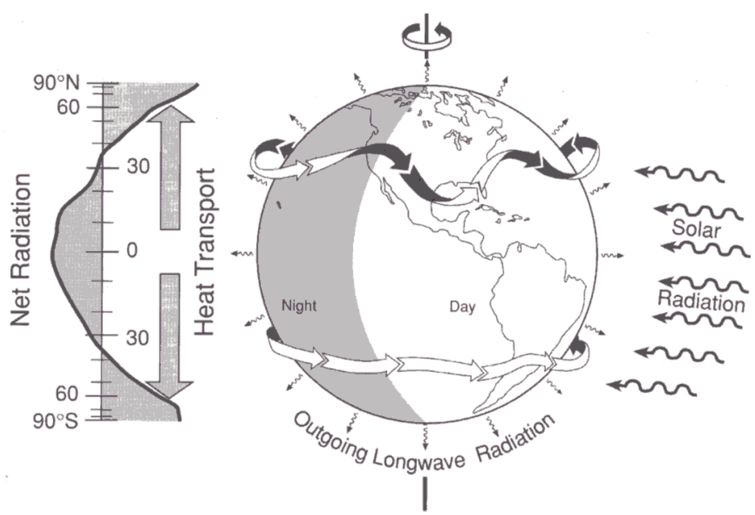


Figure 1.2: The incoming solar radiation (right) illuminates only part of the Earth while the outgoing long-wave radiation is distributed more evenly. On an annual mean basis, the result is an excess of absorbed solar radiation over the outgoing long-wave radiation in the tropics, while there is a deficit at middle to high latitudes (far left), so that there is a requirement for a poleward heat transport in each hemisphere (arrows) by the atmosphere and the oceans. This radiation distribution results in warm conditions in the tropics but cold at high latitudes, and the temperature contrast results in a broad band of westerlies in the extra-tropics of each hemisphere in which there is an embedded jet stream (shown by the "ribbon" arrows) at about 10 km above the Earth's surface. The flow of the jetstream over the different underlying surface (ocean, land, mountains) produces waves in the atmosphere and adds geographic spatial structure to climate. The excess of net radiation at the equator is 68 Wm^{-2} and the deficit peaks at −100 Wm^{-2} at the South Pole and −125 Wm^{-2} at the North Pole; from Trenberth and Solomon (1994).

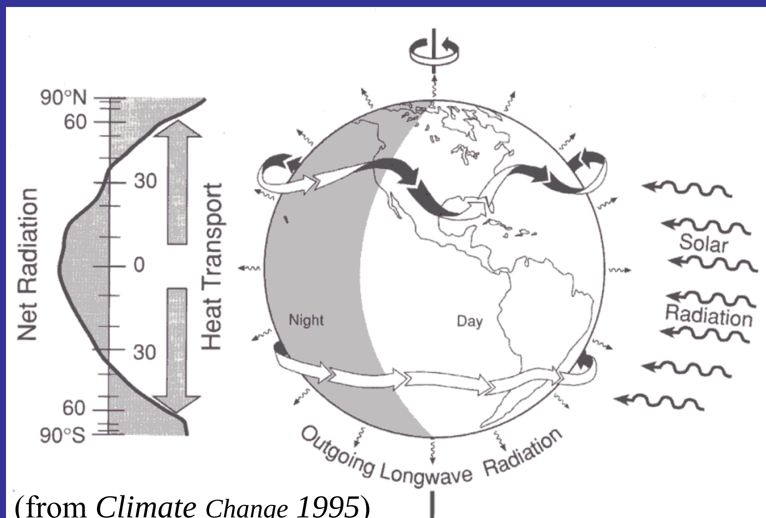
(from *Climate Change 1995*)

- **Sunlight drives air motions in the atmosphere**

➔ Winds blow over oceans to drive currents

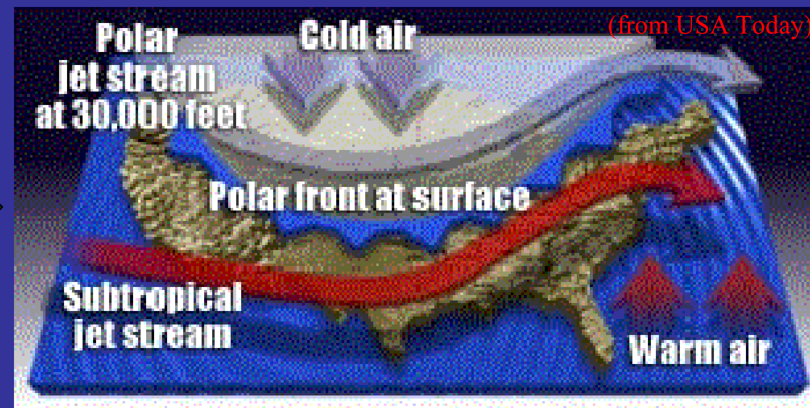
➔ Air and ocean motions together keep the tropics from too warm and the poles from too cold.

Global Energy Cycle

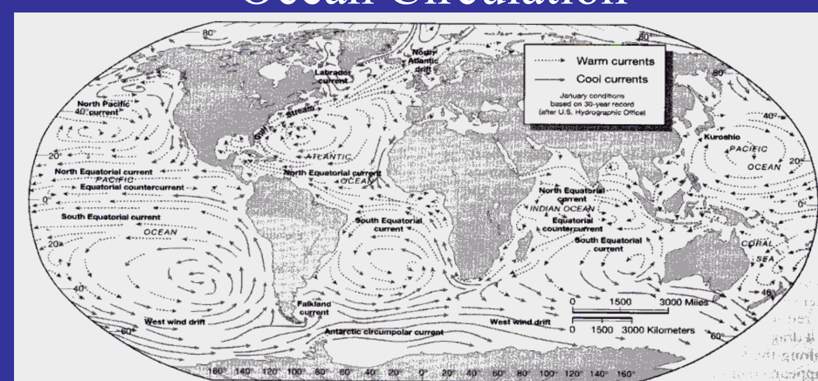


(from *Climate Change* 1995)

Atmospheric Circulation



Ocean Circulation



atmosphere

ocean ⇄ land

Global energy cycle

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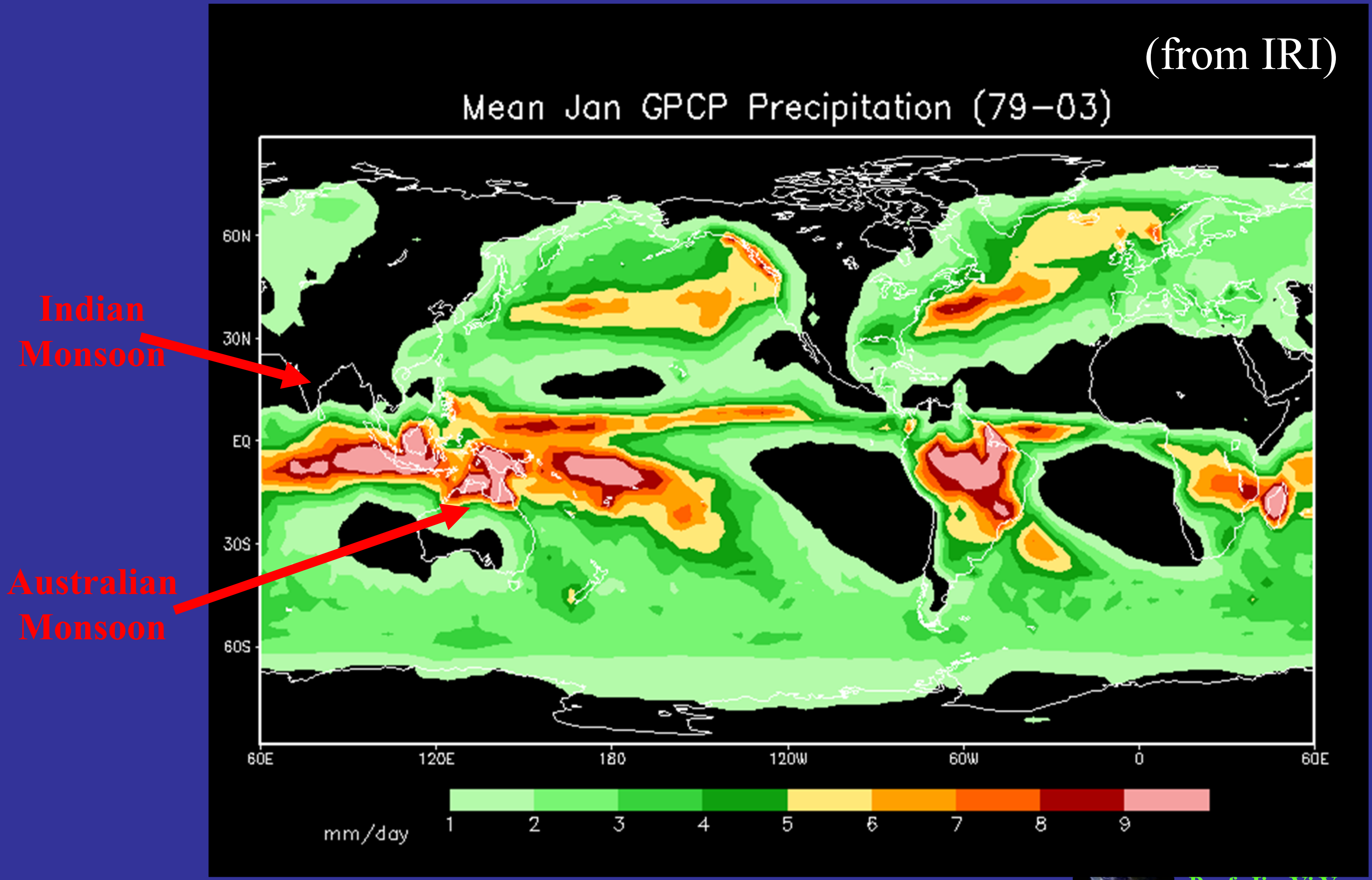
Seasonal Cycle of Rainfall



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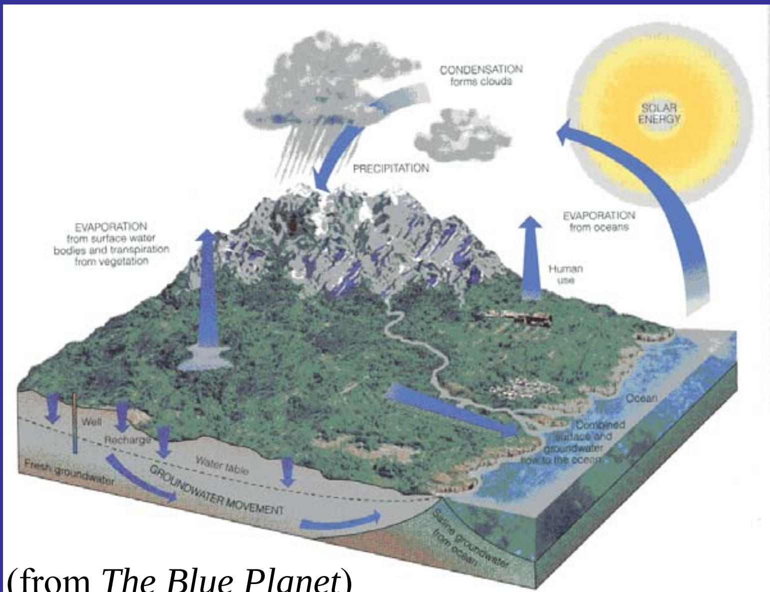
Global Water Cycle



(from *The Blue Planet*)

The water cycle describes the fluxes of water between the various reservoirs of the climate system.

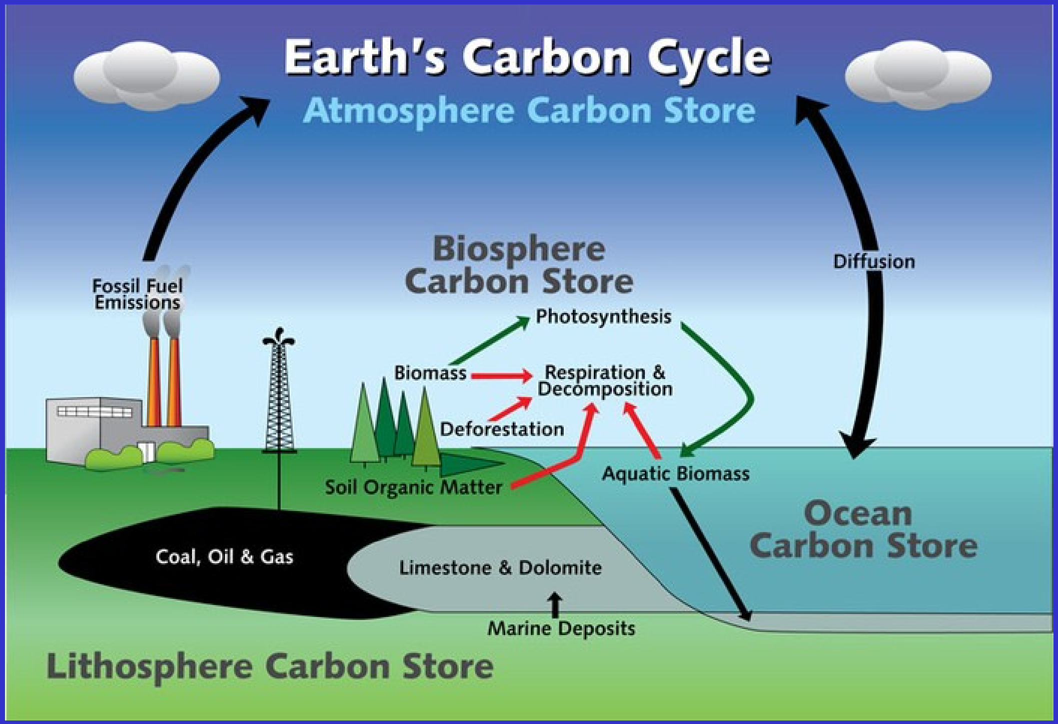
Water Reservoirs:

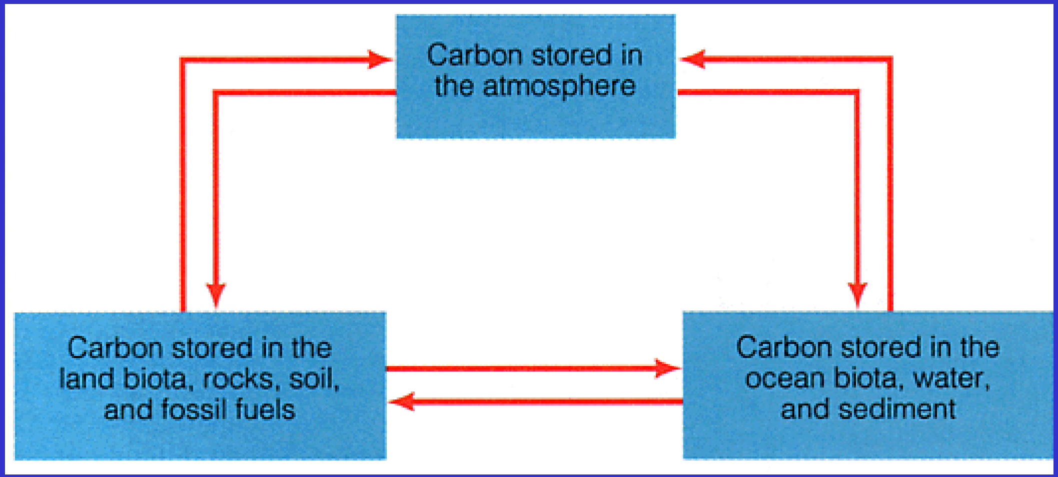
- Ocean (97.5% of global water)
- Polar Ice Sheet (2.01%; 77.2% of fresh water)
- Groundwater (0.58%; 22.1% of fresh water)
- Atmosphere & surface streams, lakes (very small fraction)

Water Fluxes:

- Evaporation (from ocean+land to atmosphere)
- Precipitation (from atmosphere to ocean+land)
- Transpiration (land to atmosphere via vegetation)
- Surface Runoff (land to ocean)

Global Biogeochemistry Cycle





Pop Quiz

- Where can we observe the ozone hole phenomenon?

Over the _____ (a) Arctic (b) Antarctic (c) Equator