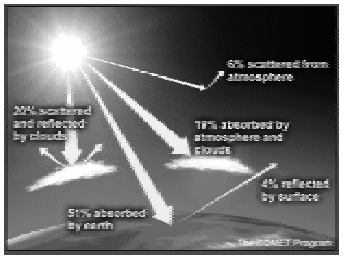
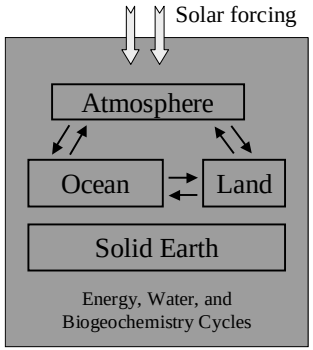
Lecture 2: Light And Air



- Earth, Mars, and Venus Compared
- Solar Radiation
- Greenhouse Effect
- Thermal Structure of the Atmosphere

Earth's Climate System



- 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.

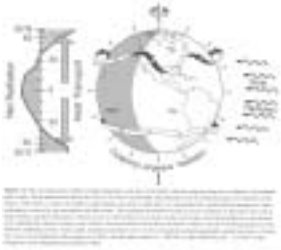
If sunlight strength does not change, how can Earth's climate change?

➔ *Change in the composition of the atmosphere*

➔ *Change in the magnitude of the greenhouse effect*

➔ *Global climate change*

Global Energy Cycle



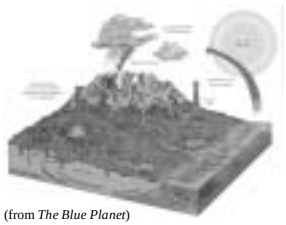
(from *Climate Change 1995*)

- **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 Water Cycle



(from *The Blue Planet*)

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

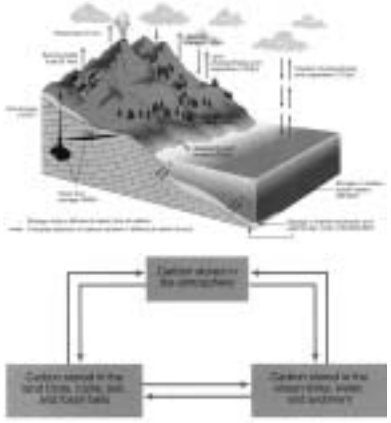
Water Reservoirs:

- 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:

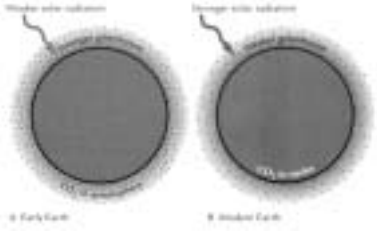
- Evaporation (from ocean+land to atmosphere)
- Precipitation (from atmosphere to ocean+land)
- Transpiration (land to atmosphere via vegetation)
- Surface Runoff (land to ocean)

Global Biogeochemistry Cycle



With the same strength of sunlight, changes in the greenhouse effect can result in global temperature change.

Earth's Thermostat – Chemical Weathering



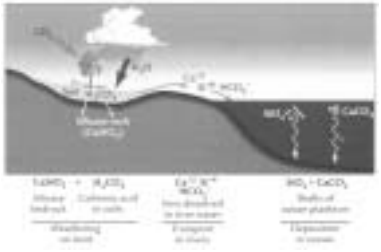
(from *Earth's Climate: Past and Future*)

- Chemical weathering acts as Earth's thermostat and regulate its long-term climate.
- This thermostat mechanism lies in two facts:

  (1) the average global rate of chemical weathering depends on the state of Earth's climate,

  (2) weathering also has the capacity to alter that state by regulating the rate which CO_2 is removed from the atmosphere.

Chemical Weathering



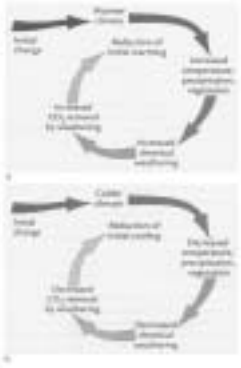
(from *Earth's Climate: Past and Future*)

- The precipitation process in the atmosphere dissolve and remove CO_2 from the atmosphere.
- Rocks exposed at Earth's surface undergo chemical attack from this rain of dilute acid.
- This whole process is known as ***chemical weathering***.
- The rate of chemical weathering tend to increase as temperature increases.
- Weathering requires water as a medium both for the dissolution of minerals and for the transport of the dissolved materials to the ocean

  ➔ The rate of chemical weathering increases as precipitation increases.

ESS11
Prof. Jin-Yi Yu

Negative Feedback From Chemical Weathering

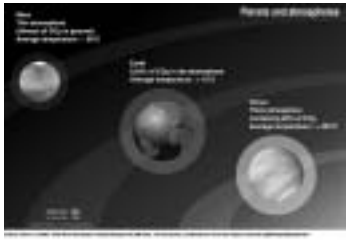


(from *Earth's Climate: Past and Future*)

- The chemical weathering works as a negative feedback that moderates long-term climate change.
- This negative feedback mechanism links CO_2 level in the atmosphere to the temperature and precipitation of the atmosphere.
- A warm and moist climate produces stronger chemical weathering to remove CO_2 out of the atmosphere ➔ smaller greenhouse effect and colder climate.

ESS11
Prof. Jin-Yi Yu

Earth, Mars, and Venus



Planet	Distance to the Sun	Radius	Planetary Albedo	Mean Surface Temperature
Venus	0.72 AU	12,104 km	0.80	730°K
Earth	1.00 AU	6,370 km	0.30	288°K
Mars	1.52 AU	6,794 km	0.22	218°K

ESS11
Prof. Jin-Yi Yu

Three Factors To Determine Planet Temperature

- Distance from the Sun
- Albedo
- Greenhouse effect

ESS11
Prof. Jin-Yi Yu

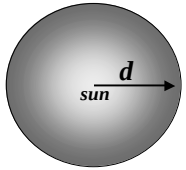
Distance From the Sun

- Solar Luminosity (***L***)
  the constant flux of energy put out by the sun

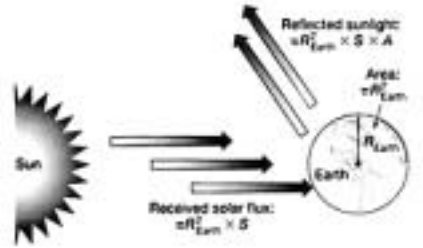
  $L = 3.9 \times 10^{26}$ W

- Solar Flux Density (S_d)
  the amount of solar energy per unit area on a sphere centered at the Sun with a distance ***d***

  $S_d = L / (4 \pi d^2)$ W/m^2



Albedo = [Reflected] / [Incoming] Sunlight



Albedo is the percentage of the sunlight that is reflected back to the space by the planet.

Albedo Depends On Color

TABLE 2-1 Average Albedo Range of Earth's Surfaces

Surface	Albedo range (percent)
Fresh snow or ice	40–90%
Old, melting snow	40–70
Clouds	40–90
Desert sand	30–50
Soil	5–30
Tundra	15–35
Grasslands	10–25
Forest	5–20
Water	5–10

Adapted from W. D. Sellers, Physical Climatology (Chicago: University of Chicago Press, 1965), and from R. G. Barry and R. J. Chorley, Atmosphere, Weather, and Climate, 4th ed. (New York: Methuen, 1982).

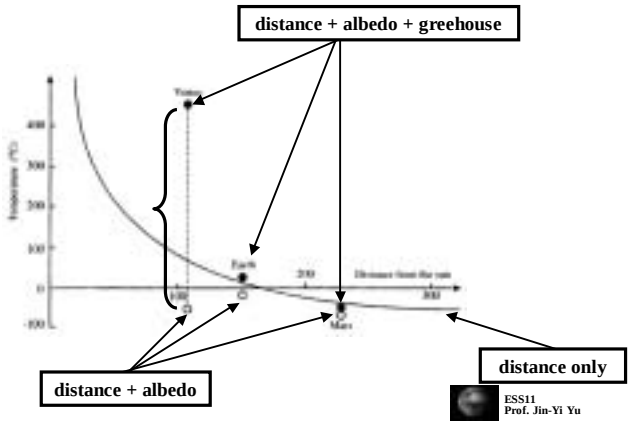
(from *Earth's Climate: Past and Future*)

The brighter a color, the more it reflects sunlight.

Albedo of Earth, Mars, and Venus

Planet	Distance to the Sun	Radius	Planetary Albedo	Mean Surface Temperature
Venus	0.72 AU	12,104 km	0.80	730°K
Earth	1.00 AU	6,370 km	0.30	288°K
Mars	1.52 AU	6,794 km	0.22	218°K

Global Temperature



Greenhouse Effects

- On Venus ➔ 510°K (very large!!)
- On Earth ➔ 33°K
- On Mars ➔ 6°K (very small)

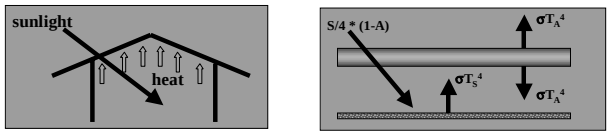
Greenhouse Gases

Important Atmospheric Greenhouse Gases

Name and Chemical Symbol	*Concentration (ppm by volume)*
Water vapor, H_2O	0.1 (South Pole)–40,000 (tropics)
Carbon dioxide, CO_2	360
Methane, CH_4	1.7
Nitrous oxide, N_2O	0.3
Ozone, O_3	0.01 (at the surface)
Freon-11, CCl_3F	0.00026
Freon-12, CCl_2F_2	0.00047

Why Is It Called "Greenhouse Effect"?

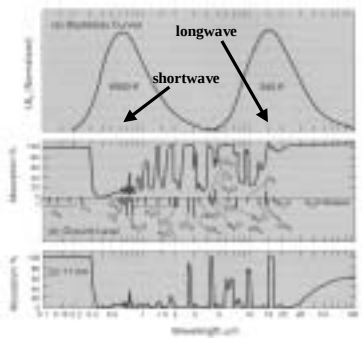
Greenhouse **Atmosphere**



- **allow sunlight to come in**
- **trap heat in the atmosphere (house)**

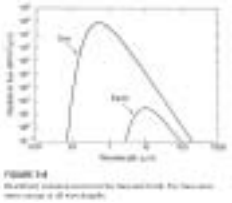
Different Wavelengths of Solar and Earth's Radiation

Normalized Planck Function



(from *Climate System Modeling*)

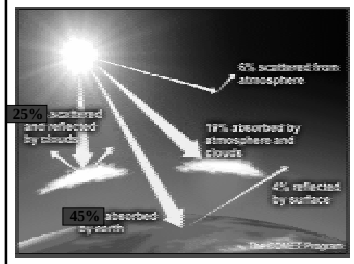
Planck Function



(from *The Earth System*)

ESS11
Prof. Jin-Yi Yu

Where Does the Solar Energy Go?



(from NCAR/COMET website)

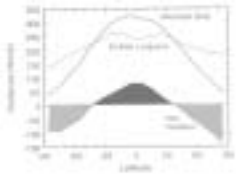
Incoming solar energy (100)

- 70% absorbed
  - 45% by Earth's surface (ocean + land)
  - 25% by the atmosphere and clouds
- 30% reflected and scattered back
  - 20% by clouds
  - 6% by the atmosphere
  - 4% by surface

ESS11
Prof. Jin-Yi Yu

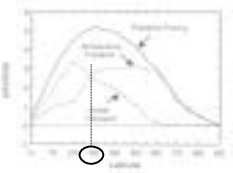
Polarward Energy Transport

Annual-Mean Radiative Energy



Polarward heat flux is needed to transport radiative energy from the tropics to higher latitudes

Polarward Heat Flux



The atmosphere dominates the polarward heat transport at middle and high latitudes. The ocean dominates the transport at lower latitudes.

(1 petaWatts = 10^{15}W)

(figures from *Global Physical Climatology*)

ESS11
Prof. Jin-Yi Yu

How Do Atmosphere and Ocean Transport Heat?

Atmospheric Circulation

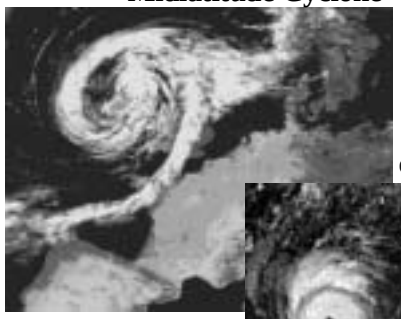
(from USA Today)

Ocean Circulation

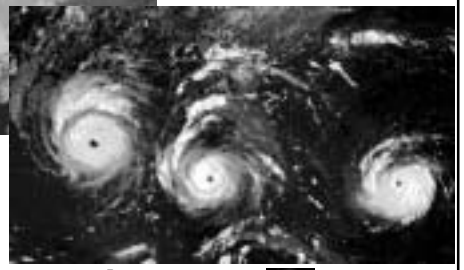
(top from *The Earth System*)
(bottom from USGCRP)

ESS11
Prof. Jin-Yi Yu

Midlatitude Cyclone



(from *Weather & Climate*)



Tropical Hurricane

ESS11
Prof. Jin-Yi Yu

They Are the Same Things…

(from *Weather & Climate*)

- ***Hurricanes:*** extreme tropical storms over Atlantic and eastern Pacific Oceans.
- ***Typhoons:*** extreme tropical storms over western Pacific Ocean.
- ***Cyclones:*** extreme tropical storms over Indian Ocean and Australia.

ESS11
Prof. Jin-Yi Yu