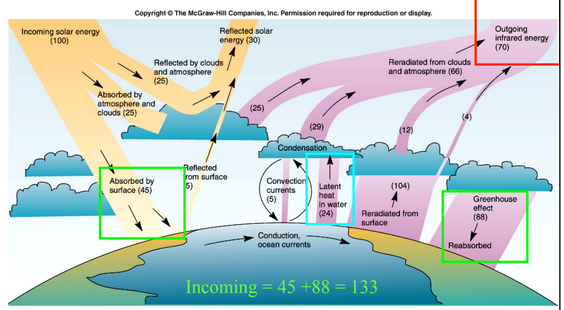
Lecture Ch. 3b

- Simplified climate model
  - Assumptions
  - Calculations
  - Cloud sensitivity
  - Effect of an atmosphere
- Absorption coefficient
- Optical thickness
- Heat transport

Curry and Webster, Ch. 3; Ch. 12 pp. 331-337; also Liou, 1992
For Tuesday, 10/13: Read Ch. 4
For Tuesday, 10/13: Homework Ch. 3, pp.94-95: 1,2,3

Energy Balance



Outgoing = 104 + 24 + 5 = 133

From Cunningham & Cunningham, 2004, Fig. 9.2

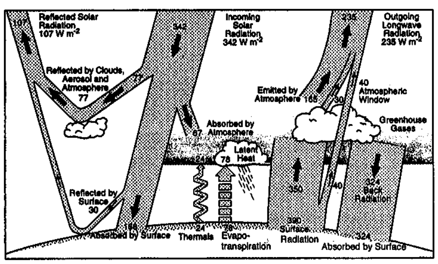
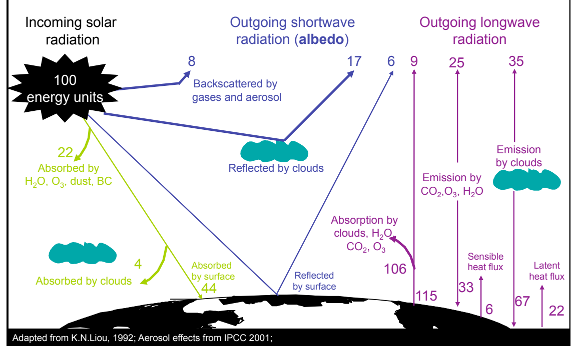


Figure 12.2 Estimated annual mean global energy balance for the Earth. Units are W m^{-2} (Kiehl and Trenberth, 1997).

Atmospheric Radiation Balance



Simplified Climate Model

- Atmosphere described as one layer
  - Albedo α_p~0.31: reflectance by surface, clouds, aerosols, gases
  - Shortwave flux absorbed at surface $F_s = 0.25 * S_0 (1 - \alpha_p)$
- Earth behaves as a black body
  - Temperature T_e: equivalent black-body temperature of earth
  - Longwave flux emitted from surface $F_L = \sigma T_e^4$

Curry and Webster, Ch. 12 pp. 331-337; also Liou, 1992

Absorption and Emission

Note that whereas the disposition of solar radiation is dominated by absorption and scattering, thermal radiation is dominated by emission and absorption.

The rate of transfer of energy by electromagnetic (em) radiation is called *radiant flux* (units are joules per second, J s^{-1}, or watts, W). The radiant flux incident on a unit area is called the *irradiance* (W m^{-2}), denoted by E. The irradiance per unit wavelength interval, centered on wavelength λ, is denoted by E_λ (W m^{-2} μm^{-1}).

- Emissivity – the irradiance from the body divided by the irradiance from a blackbody at the same temperature
- Absorptivity – the amount of irradiance absorbed divided by that absorbed by a blackbody (perfect absorber).

Absorption by Molecules

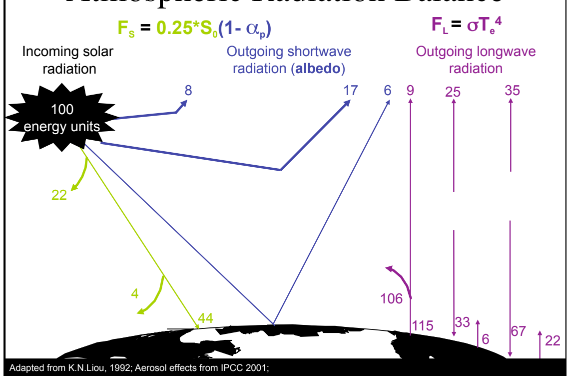
- Occurs only when incident photon has same energy as difference between two energy states
  - States may differ in rotation, vibration or electronic
  - Result may not be chemical, e.g. heating (GHGs)

Consequences of Absorption

- Molecules may lose absorbed photon's energy by several mechanisms
  - Dissociation (breaks apart)
  - Direct reaction (excited molecule reacts with other molecule)
  - Isomerization (internal rearrangement of bonds to make more stable)
  - Collision (losing energy to other molecules w/o chemical changes)
  - Internal energy transfer
  - Luminescence (fluorescence or phosphorescence: emission of a photon)
  - Photoionization (ejection of an electron to form an ion)

Photolysis -- general word describing chemical changes from reactions initiated by light, regardless of the detailed mechanism

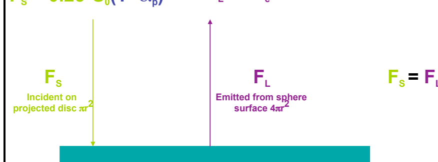
Atmospheric Radiation Balance



Simplified Climate Model

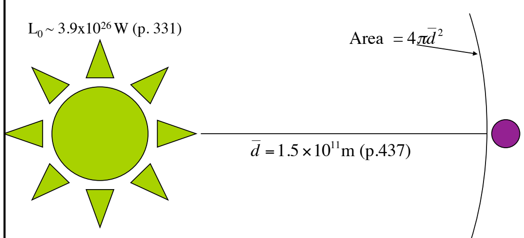
- Incoming shortwave = Outgoing longwave
- Energy absorbed = Energy emitted

$F_S = 0.25*S_0(1-\alpha_p)$ $F_L = \sigma T_e^4$



Solar Constant

- Luminosity of the sun
- Irradiance at earth $S_0 = L_0/(4\pi d^2) = 1.4\times10^3$ W/m^2



Simplified Climate Model: First 2 Assumptions

- Atmosphere described as one layer
  - Albedo $\alpha_p \sim 0.31$: reflectance by surface, clouds, aerosols, gases
  - Shortwave flux absorbed at surface $F_S = 0.25*S_0(1-\alpha_p)$
- Earth behaves as a black body
  - Temperature T_e: equivalent black-body temperature of earth
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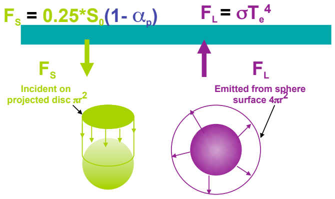
Simplified Climate Model

- Incoming shortwave = Outgoing longwave
- Energy absorbed = Energy emitted

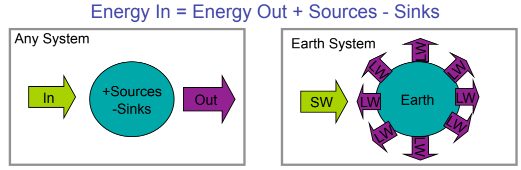
$F_S = 0.25 * S_0 (1 - \alpha_p)$ $\quad F_L = \sigma T_e^4$



At "TOA": $F_S = F_L$

Energy Balance

Energy In = Energy Out + Sources - Sinks



- As a 1st approximation, there are no continuous sources or sinks of energy on Earth (only temporary storage, e.g. ocean)
  - Energy In (Shortwave) = Energy Out (Longwave)

Thermal Equilibrium is the name of this assumption

Simplified Climate Model

- At thermal equilibrium (what happens if not?)

$$F_S = F_L$$
$$0.25 * S_0 (1 - \alpha_p) = \sigma T_e^4$$
$$T_e = [0.25 * S_0 (1 - \alpha_p)/\sigma]^{0.25}$$
$$T_e \sim 255K$$

- Observed surface temperature T = 288K
- What's missing?

Sensitivity to Albedo

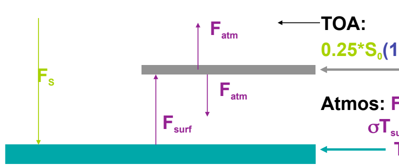
- What if albedo changes?

$$T_e = [0.25 * S_0 (1 - \alpha_p)/\sigma]^{0.25}$$
$$\alpha_p = 0.31,\ T_e \sim 255K$$
$$\alpha_p = 0.30,\ T_e \sim ?$$

- 1% decrease in albedo warms temperature 1K
- 1% increase in albedo cools temperature 1K

Add an Atmosphere!

- Atmosphere is transparent to non-reflected portion of the solar beam
- Atmosphere in radiative equilibrium with surface
- Atmosphere absorbs all the IR emission



TOA: $F_S = F_{atm}$

$0.25 * S_0 (1 - \alpha_p) = \sigma T_{atm}^4$

$T_{atm} = 255K$

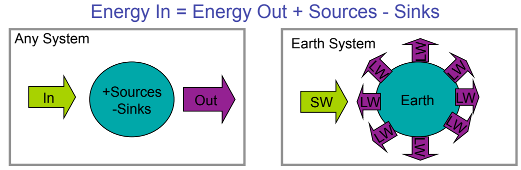
Atmos: $F_{surf} = 2F_{atm}$

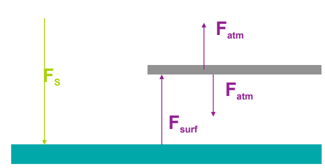
$\sigma T_{surf}^4 = 2\sigma T_{atm}^4$

$T_{surf} = 303K$

Energy Balance

Energy In = Energy Out + Sources - Sinks





TOA: $F_S = F_{atm}$

$0.25 * S_0 (1 - \alpha_p) = \sigma T_{atm}^4$

$T_{atm} = 255K$

Atmos: $F_{surf} = 2F_{atm}$

$\sigma T_{surf}^4 = 2\sigma T_{atm}^4$

$T_{surf} = 303K$

What's (still) wrong?

- With no atmosphere, T_{surf} **= 255K**
- With "atmosphere", T_{surf} **= 303K**
- From observations, T_{surf} **= 288K**

- Real atmosphere:
  - Not perfectly transparent to incoming solar (20 unit absorbed by atm.)
  - Not perfectly opaque to infrared (12 unit "window")
  - Not in pure radiative equilibrium with surface (23 units latent heat)

- Three assumptions were wrong -- but we got very close by adding the greenhouse effect of the atmosphere.

2009 ROAST Topics

Constrained self-assembly rule: Each group needs at least 3 and not more than 4 people.

•Group A: What reductions in CO_2 emissions would be required? C&W 3, 12.
•Group B: What reductions in non-CO_2 GHG emissions would be required? C&W 3, 12.
•Group C: What reductions in particle emissions would be required? C&W 3, 5, 12.
•Group D: What additional emissions to the atmosphere would be required? C&W 3, 5, 12.

N.B. Your 1st step is to refine these topics as a group, and you are encouraged to ask me questions in this process.