Global Energy Balance

I. One of the major points of this course is how the various components of the earth system move energy and matter on the earth's surface Fig. 1.8
   A. over long time scales the planet must be in energy steady-state (input = output)
   B. in the present system energy balance at the earth's surface is driven by solar radiation
      1. other inputs are minor

II. Some basic physics
   A. electromagnetic radiation is generally propagated as a wave Fig. 3-2
      1. defined by the speed (c), wavelength (λ) and frequency (ν)
         a. $c = \lambda\nu$
         b. $\nu = c/\lambda$
         c. frequency and wavelength inversely related Fig. 3-3
   B. EM spectrum
   C. at times EM radiation behaves more like a particle – photon
      1. $E = h\nu = hc/\lambda$
      2. high frequency photons (short wavelength) are higher energy
      3. high-energy photons can break molecular bonds – initiate chemical reactions
      4. low-energy photons interact with molecules
         a. affect their rotation or vibration Fig. 3-4
   D. Flux
      1. how energy (or any other material) passes through a unit surface area per unit time
         a. here can think of energy as a particle (photon)
         b. $mg/m^2/hr$
   E. energy expressed as Joules (J)
      1. Watt (W) is a unit of power – the rate at which work is done
         a. 1 W = 1 J per second
         b. W/m^2 then become the units of energy flux
      2. Energy flux is important in terms of global climate
      3. polar regions will be cooler than the tropics because the suns rays strike earth at a higher angle – smaller energy flux
   F. Blackbody radiation
      1. a body that emits radiation over all possible frequencies
      2. characteristic distribution of frequencies
   G. the physics of blackbody radiation
      1. radiation intensity versus wavelength defined by the Plank function Fig. 3-7
      2. Wein's law - $\lambda_{max} \approx 2898/T$ (T in °K, wavelength in μm)
      3. Stefan-Boltzman Law
         a. $F = \sigma T^4$
      4. energy flux and blackbody radiation temp. related
         a. energy flux determines the spectrum of the emitted EM radiation Fig. 3-8
         b. shifts the curve along the wavelength axis
   H. Energy output of the Sun predicts a max wavelength in the Vis region
      1. large component of high energy UV

2. also assume the Earth behaves as a blackbody radiator
3. the Earth system responds to both the amount of solar radiation and its EM spectrum
   a. see differences in emission curves for Sun and Earth– why?
      (i) shift to lower wavelength

III. Earth's energy balance
  A. if temps are constant the planet has to be in radiative balance Fig. 3-19
    1. energy input = output
    2. some amount of incoming solar radiation is lost before reaching the surface
    3. some returned to space as IR
  B. incoming solar radiation Next Fig. 3-19
    1. some simply reflected by clouds (An1)
    2. some incoming solar radiation absorbed in the atmosphere (An2) mod Fig. 3-8
       a. ozone at low wavelength, CO_2 and water at high wavelengths
    3. decreases the absolute amount of energy that gets to Earth's surface Last Fig. 3-19
    4. of 100 units only 50 get through the atmosphere
  C. truncated solar spectrum (shortwave radiation) absorbed by earth Fig. 3.2 (w/anim)
    1. clips the solar spectrum by chopping off the high and low ends
    2. re-radiated as long wave IR radiation (heat)
    3. assume Earth is a blackbody radiator
    4. shift in λ_{max} again controlled by Wein's law
  D. some of this IR radiation is adsorbed by greenhouse gases in the atmos. Next Fig. 3-19
    1. plays a major role in warming the atmos. and Earth's sfc.
    2. traps heat and warms the planet
    3. leads to a re-distribution of radiation before it is re-radiated out to space
    4. w/o these greenhouse gases the planet would be much colder - around -20°C
  E. feedback loops between the lithosphere, hydrosphere, atmosphere and biosphere appear to have led to relatively constant favorable temps over most of geol. history
    1. plays a role in controlling the earth's radiative balance
    2. strongly tied to the greenhouse effect

IV. How does Greenhouse effect work
  A. planetary energy balance in the absence of a greenhouse Box 3-1
    1. assume a simple model
    2. planet with no atmosphere and an albedo equal to the present Earth
    3. energy emitted by Earth = energy absorbed by Earth
    4. from the distance of the Sun the Earth looks like a circle (its projected area)
    5. energy absorbed is input minus reflected light
       a. A= albedo, S = solar flux Fig. 2-6
    6. albedo = average shade/color of the planet
       a. low albedo = dark color = absorbs heat (warms up)
       b. high albedo = light color = high reflectance (cools sfc.)
    7. albedo ranges from 1 (white) to 0 (black)
       a. change in albedo therefore affects reflectance/absorbance and planet temp.
    8. assuming black body radiation, Stefan-Boltzman law predicts the temperature of this atmosphereless planet

Next Box 3-1

9. $\sigma T^4_e = (S/4)*(1-A)$
10. given the geometry of a spherical planet, energy adsorbed is $(S/4)*(1-A)$
    a. $A= 0.3$, $S = 1370\ W/m^2$ predicts $T_e = 255°K$ ($-18°C$)

Box 3-2 (w/anim)

B. Now add a greenhouse atmosphere
   1. atmosphere transparent to incoming radiation but behaves like a black-body radiator for outgoing IR radiation
   2. atmos absorbs upwelled heat, re-radiates it in both directions
   3. determine the energy balance for the Earth's surface and top of the atmosphere
      a. surface: $\sigma T^4_s = (S/4)*(1-A) + \sigma T^4_e$ (An1)
      b. atmosphere: $\sigma T^4_s = 2\sigma T^4_e$ (An2)
         (i) atmosphere radiates heat in both directions
   4. substitution of the 2nd equation into the 1st yields the T_e equation for the planet w/o atmos.
      a. $\sigma T^4_e = (S/4)*(1-A)$ (An3)
      b. T_e is the effective radiative temp of the planet
      c. what the temp of the planet "looks" like at the top of the atmosphere
      d. T_e is simply a function of S and A and does not depend on any greenhouse gasses
   5. 2nd equation then yields $T_s = 2^{1/4}T_e$ or $\sigma T^4_s = 2*(S/4)*(1-A)$
      a. T_s then equals 303 (48°K)
   6. oversimplification in part because atmosphere is not perfectly adsobing of Earth's IR
   7. illustrates the basic principles of greenhouse effect
      a. atmosphere absorbs IR radiation from Earth and re-radiates it both upwards and downwards
      b. traps some outgoing heat and warms Earth
   8. top of the atmos radiates heat at a much lower temp.
      a. behaves as if the planet did not have an atmosphere

C. for a multi-layered atmosphere you can also show that T decreases with increasing altitude
   1. talk about the optical thickness of the atmosphere
   2. optical thickness increases as the concentration of greenhouse gasses increase
   3. optically thick atmosphere like that on Venus will lead to very high surface temperature

D. evidence of a "natural" greenhouse effect Fig. 2.4
   1. see that some parts of the atmosphere are transparent to IR – window region
      a. actual spectrum here matches predicted blackbody emission sprectra in this region based on the planet's temp.
   2. dips in curve are indicative of IR adsorption by greenhouse gasses
      a. re-emission occurs throughout the atmosphere
      b. various parts of this curve match up to the black body radiation curves at lower temperatures in the atmosphere where adsorption/re-radiation occur