EOSC 112: Lecture Summary: Monday, September 17

Text Coverage: pp. 42 – 46 – Atmospheric composition and structure plus p. 49 - 50, Earth's Global Energy budget.

Review: Last time we saw that the 1) the atmosphere absorbs longwave photons because the photons excite a particular vibration/rotation in the molecules of CO_2, H_2O, O_3 (ozone), CH_4 (methane), etc.. 2) The absorption is selective, creating wavelength ranges ("windows") where most of the longwave radiation escapes to space. 3) We are currently filling in some of these windows by releasing fossil CO_2, increasing methane production, and creating new greenhouse gasses like CFCs (chloroflurocarbons) 4) A simple one-layer model with an partially absorbing atmosphere does a good job of reproducing the observed current globally-averaged surface temperature (288-289 K) with reasonable values of S (1370 $\mathrm{W\,m^{-2}}$), Albedo A (0.3), and *absorp* (0.8). In the this week's lab we show, however that the one-layer model can't reproduce the predicted future surface temperature increase obtained by more sophisticated models, because it lacks any coupling between the surface temperature and the albedo and absorption (*feedback*)

Atmospheric Structure

The vertical variation of temperature and humidity are just as important as the surface temperature in determining the character of the planet's climate.

- Figure 3-9, p. 44 shows the vertical structure of pressure vs. altitude in the atmosphere:
- Pressure decreases with height because pressure is caused by the net weight of air above a point. (About 10 metric tonnes of air at sea-level). Note that 90% of the atmosphere's mass is contained in the bottom 20 km of the atmosphere.
- Atmosphere has 4 main layers, but we're concerned with only two: *troposphere (mixed layer)*, stratosphere (stratified layer).
- Stratosphere is stratified because of ozone absorption (heating). See Figure 3-11. Hard ultraviolet is continually breaking oxygen molecules, producing more single O atoms for ozone formation ($O_2 + O = O_3$). This molecule splitting produces vibration (heat), plus O_3 itself then absorbs more UV photons and heats the air.
- The troposphere is mixed by convection from the heated surface (a good thing, since we're very messy, with millions of tonnes of pollution being mixed up through the atmosphere each day.).
- Temperature decreases with height as the kinetic energy of the molecules is converted to gravitational potential energy.
- Much of the energy for mixing comes from water vapor condensing to form clouds. A single $\mathrm{m^3}$ of water: 1) weighs one metric tonne 2) is less compressible than steel 3) requires 2.5 Million Joules of energy to convert to steam. This is equivalent to 3.5 pounds of TNT. One hurricane can release a megaton of energy per minute.

- The energy available at the surface determines the height of the *tropopause* (boundary between troposphere and stratosphere). Can be 20 km at equator, but only a few km at poles.

- At surface, energy is fed to air by *conduction*, warm air then rises (*convection*). Conduction is the exchange of energy via molecular vibration, while convection is exchange via mass transport. Upward transport includes both air and water vapor.

- The temperature decrease with height in the troposphere is called the *lapse rate*. A representative value in mid-latitudes (where we live) is about 7 K/km.

- Figure 3-18: The temperature difference between 10 km and the surface mean that very high clouds act like "heat lamps" on the surface. Suppose the surface is at 290 K and emits $\sigma 290^4 \approx 400 \ \mathrm{W\,m^{-2}}$. At 1 km, a cloud would have a temperature of 273 K and emit $\sigma T^4 \approx 315 \ \mathrm{W\,m^{-2}}$, but at 10 km the temperature is 220 K and the emission is only 133 $\mathrm{W\,m^{-2}}$ (is the cloud is black). That means that in an atmosphere with high cloud over the surface, the high cloud is receiving about 400 $\mathrm{W\,m^{-2}}$ from below, and sending only 133 $\mathrm{W\,m^{-2}}$ out to space. The difference (400 -133 = 267 $\mathrm{W\,m^{-2}}$) is kept in the atmosphere as heat. (In reality the heating is significantly less than this, because the atmosphere itself is absorbing and emitting at intermediate temperatures.

Earth's Global Energy Budget: Figure 3-19 summarizes the energy flow between radiation, thermal convection and evaporation. Note the notation – the earth receives 100 "units" (really 240 $\mathrm{W\,m^{-2}}$) in the shortwave, and then spreads it around and recycles it in the longwave and as thermals (*sensible heat*) and evaporation. Some important points:

- Note that the atmosphere and ocean absorb 70 units (45 + 25) but shed (via thermals, evaporation and radiation) twice that (5 + 24 + 104 = 133). This is because 88 units are sent back down to the surface via the greenhouse effect.

- If the planet was dry, then the temperature would be much higher, because we couldn't shed 24 units as evaporation and would have to shed them as thermals.

- There is currently a very intense debate about the correct value of the atmospheric absorption, which may be as much as 20% higher than the 25 units shown in Figure 3.19. It is important to figure out what the right value is, because it is the energy difference between the surface and the atmosphere that drives the planetary winds.