Assignment 6. Due February 23, 2018

1. From a molecular perspective, highlight the main points of how greenhouse gases enable the atmosphere to be warm. Your answer should not just be “greenhouse gases trap heat”, but rather a step by step summary of how infrared radiation interacts with greenhouse gas molecules to increase the atmospheric temperature.

2. $\alpha_L$ is the half width of the spectrum at half-maximum and is proportional to temperature and pressure

$$\alpha_L = \alpha_0 \left( \frac{p}{p_0} \right) \left( \frac{T_0}{T} \right)^{1/2}$$

Consider a CO$_2$ absorption line at 15 $\mu$m wavelength. The half-width at half maximum $\alpha_L$ is 0.005 cm$^{-1}$ at STP (273 K and 1000 mb)

(a) What is $\alpha_L$ at 1000 mb and 298 K?
(b) What is $\alpha_L$ at 500 mb and 230 K?
(c) Sketch the Lorentz function for these two cases, and show the center line and $\alpha$ for each.
(d) Is there some general principle that can be assumed about the range of frequencies associated with an absorption line as a function of height in the atmosphere?

3. Precipitable water represents the column amount of water vapor in the atmosphere that is available to precipitate. The amount is often measured using just a radiometer at the ground looking upwards. Based on the strong line approximation for atmospheric transmission, show that the amount of precipitable water (units g m$^{-2}$, like $u$) may be determined from

$$PW = c [1 - F_\nu / F_{0,\nu}]^2$$

where, $c$ is a constant related to the absorption band and known atmospheric parameters, and $F_\nu$ and $F_{0,\nu}$ represents the observed solar flux in the 0.94 $\mu$m H$_2$O absorption band, at the ground and at the top of the atmosphere, respectively. This is the principle for how an upward looking sunphotometer can be used to measure the amount of precipitable water in the atmosphere. You don’t need to derive an expression for $c$ although you can.
Figure 12.7 Upper panel: The upper smooth curve is the emission from the surface (assumed black) in the model of J. Kiehl and K. Trenberth (their Fig. 1; see reference in Endnote 15). The lower curve is the flux at the top of the atmosphere, computed from their narrow-band model (their Fig. 2; see reference in Endnote 15). Lower panel: greenhouse effect $G_\lambda = F_\lambda^+ (\tau = 0) - F_\lambda^+ (\tau \to \infty)$ for the Kiehl–Trenberth model.

Figure 1: Greenhouse gas forcing

4. On the basis of the Figure above, and the details provided in the caption, make an estimate of (Hint, remember that fluxes are an integral under a curve)
(a) the total greenhouse effect You may assume that the current Top of the Atmosphere outgoing longwave flux is 239 W m$^{-2}$, integrated over all wavelengths. Also, the current globally-averaged emission temperature of the surface is 289 K. I get about 170 W m$^{-2}$.

(b) The direct contribution of CO$_2$ to the global greenhouse effect (you should get about 25 W m$^{-2}$). Don’t forget to subtract out water vapor

(c) The extent to which this contribution is magnified by water vapor. I get about a factor or 6.

5. Now, assuming from Fig. ?? that the direct contribution of CO$_2$ to the global greenhouse effect is about 25 W m$^{-2}$, let’s estimate the impact of global warming

(a) Currently, the major source of CO$_2$ to the atmosphere is fossil-fuel combustion, which powers the world economy. Its current concentration is about 400 ppm, compared to pre-industrial concentrations of 275 ppm. Based on the strong line approximation, how much would you estimate that the existing increase in CO$_2$ is contributing to an increased greenhouse effect expressed in Watts per meter squared (I get 5 W m$^{-2}$)?

(b) The increase in surface temperatures due to this increased flux is a bit difficult to estimate, but assuming a ’mid-range’ climate sensitivity (i.e. surface temperature response to a CO$_2$ doubling) of 3 K, what would you expect the temperature rise to date to be (I get 1.5 C)?

(c) If CO$_2$ levels rise from 400 ppm to 1000 ppm by the end of this century, as appears possible, what will be the surface temperature rise compared to the present? (I get 4.2 C)

6. Read Section 4.5.4 in Wallace and Hobbs.