EOSC 112: Lecture Summary: Friday, September 14

Text Coverage: pp. 46 – 48 – Physical Causes of the Greenhouse Effect

Review: Recall from last time we added an atmosphere that is "black" (completely absorbing) for terrestrial (longwave) photons (with wavelength $\lambda > 3\ \mu$m) and "transparent" (completely transmitting) for solar (shortwave) photons (with wavelength $\lambda < 3\ \mu$m). With this atmosphere the Earth's surface becomes much hotter than the 255 K T_e we found on Monday. This is because there are now two sources of downward radiative flux to the ground: the sun (with shortwave $S_{avg} = 240\ \mathrm{W\,m^{-2}}$), and the black atmosphere, which is also emitting 240 $\mathrm{W\,m^{-2}}$ but in the longwave (thermal). The picture looks like:

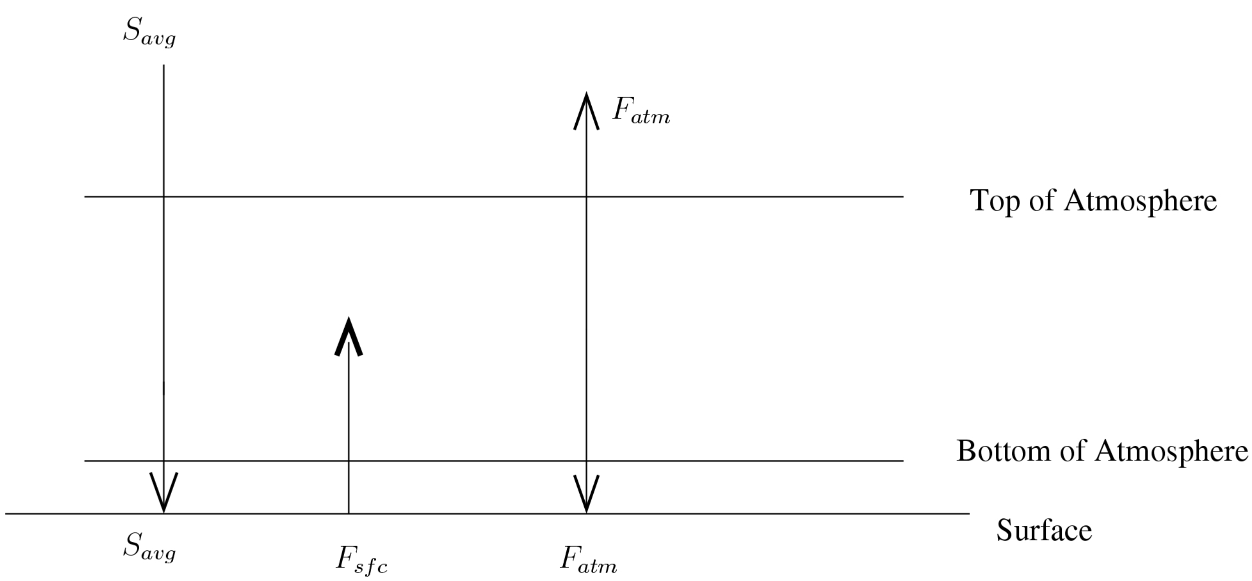

Figure 1: Short (S_{avg}) and longwave (F_{atm}) fluxes for a completely absorbing atmosphere. (Units: $\mathrm{W\,m^{-2}}$). Note that none of F_{atm} makes it through the top of the atmosphere.

Last time we found the following relations for the fluxes from the atmosphere (F_{atm}) and the surface (F_{sfc}) (p. 43)::

$$F_{atm} = S_{avg} \tag{1}$$
$$F_{sfc} = 2S_{avg} \tag{2}$$

and using the Stefan-Boltzman equation (p. 40) we can get T_{sfc} for a black surface:

$$T_{sfc} = \left(\frac{2S_{avg}}{\sigma}\right)^{1/4} \tag{3}$$

- For $S_{avg} = 240\ \mathrm{W\,m^{-2}}$, $T_{sfc} = 303\ K$, so now weve gone from too cold to too hot, compared to the current global average temperature of 288 K (15 °C).

- The extra heat being beamed down to the surface is stored in the atmosphere as the vibrational energy of the molecules, which then send a flux of thermal photons (F_{atm}) back to the surface.

Question:

- How is it possible for the atmosphere to be (almost) transparent in the shortwave and nearly opaque in the longwave?

  Figure 3-12 shows that certain molecules, H_2O, CO_2 and many others, have an appetite for photons of very particular wavelengths. For example, as Figure 3-13 shows, CO_2 absorbs very strongly at wavelengths of 15 μm, 3 μm and 4.5 μm. In between each of these absorption "bands" are "windows" where photons can escape to space. Each of the absorption bands is associated with a different type of twisting or bending motion that creates a temporary electric charge distortion (a "dipole moment") that interacts with the photon. Oxygen (O_2) and nitrogen (N_2), with their simpler structure, don't interact with photons in the same way (see p. 48, Figure 3-15), and so are transparent to longwave radiation. (But O_2 does absorb very short-wavelength ultraviolet photons, breaking apart into single oxygen atoms).

- Click here to see a different view of the absorption bands, overlayed with the Planck functions for solar and terrestrial radiation. This figure shows why the 15 μm CO_2 absorption band is so important: it is placed near the maximum for terrestrial emission, and so "filling in" the 10 μm "window" by increasing CO_2 concentration produces a large reduction in the emitted radiation. As CO_2 concentrations go up, the atmosphere becomes more and more absorbing in the longwave, and less and less of the surface flux escapes to space.

- Click here to see examples of the absorption behavior of many natural and man-made molecules. The top axis shows the wavelength (in μm) that they absorb at. Note that many of them absorb at wavelengths close to the 10 μm emission maximum. This is why it is more accurate to speak of "greenhouse gasses" in the plural, rather than just CO_2. Note also that water vapor (H_2O), is an important absorber at all essentially all thermal wavelengths above 6 μm. This because it absorbs by spinning like a top, in addition to vibrating in specific ways.

- Click here to see an estimate of how big an effect each of these gasses has on changing the surface temperature of the Earth. (Note that H_2O, which is the most important greenhouse gas after CO_2, is missing from the figure, because its concentration depends on surface temperature). Note that the total impact of the all greenhouse gasses on the surface temperature is about twice that of CO_2 alone. (0.75 K for CO_2, 1.5 K for all gasses). Also note the large uncertainties for some of the gasses.

A more realistic model with partial absorption

- If the atmosphere isn't completely black in the longwave, then some of the surface flux, F_{sfc}, will escape to space, as shown in this figure:

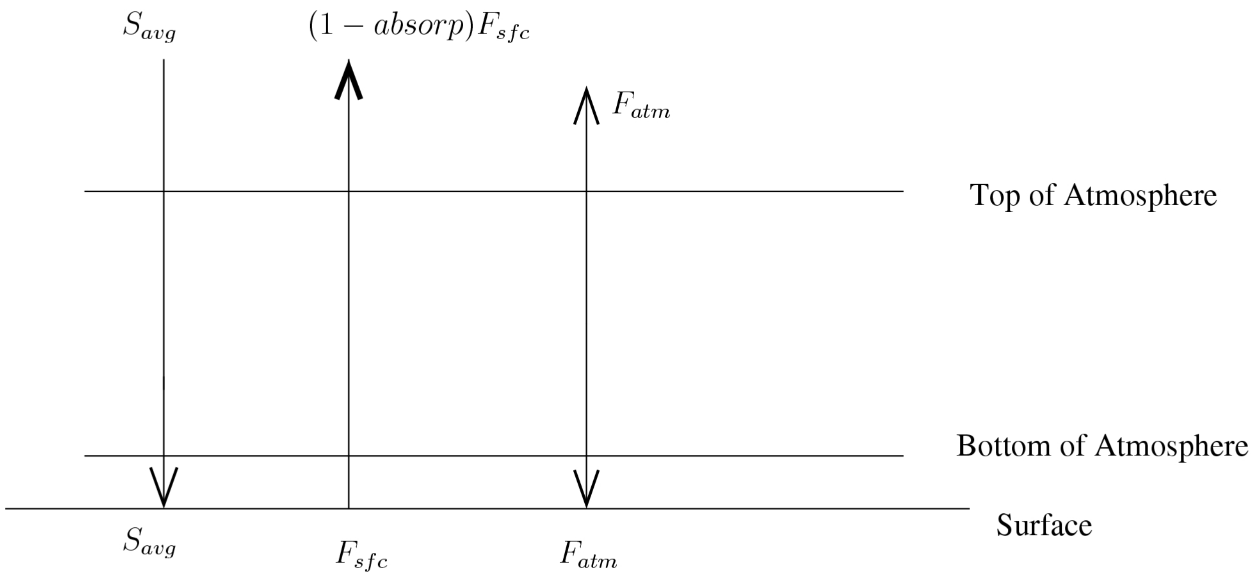

Figure 2: Short (S_{avg}) and longwave (F_{atm}) fluxes for a partially absorbing atmosphere. (Units: $\mathrm{W\,m^{-2}}$). Note that now some of F_{atm} makes it through the top of the atmosphere. (For example, if $absorp = 0.8$, then 20% of F_{sfc} makes it to outer space.)

- Why is this an improvement? If we put in $absorp = 1$ (completely absorbing blackbody) then $(1 - absorp) = 0$ and no F_{sfc} can escape through the top of the atmosphere, and we have the same situations as in Figure 1. If *absorp* is less than 1, though, the surface is going to be able to cool by emission through the atmosphere to space, and the atmosphere will radiate less flux back to the surface. A value of $absorp = 0.8$ is pretty close to the actual value for the Earth's atmosphere.

- I show separately (optional reading, not required – click here if you're interested). that balancing the fluxes for Figure 2 gives the following:

$$F_{atm} = \frac{absorp}{2 - absorp} S_{avg} \tag{4}$$

$$F_{sfc} = \frac{2}{2 - absorp} S_{avg} \tag{5}$$

As before, we can solve for T_{sfc} of a black surface:

$$T_{sfc} = \left(\frac{2 S_{avg}}{\sigma (2 - absorp)} \right)^{1/4} \tag{6}$$

You should convince yourself (by plugging a few numbers into Equation (6)) that as the absorption drops below 1, T_{sfc} decreases as expected. In the lab you'll use a spreadsheet to show that if the albedo A=0.3 and $absorp = 0.8$, $T_{sfc} \approx 289K$ (pretty close to the current observations).