ESE 101:

Homework 4 (due November 9):

1. *(9 points)* Suppose a gas that absorbs solar radiation has a uniform mixing ratio of $1\,\mathrm{g\,kg^{-1}}$ and an absorption cross section of $5\,\mathrm{m^2\,kg^{-1}}$. Assume an isothermal atmosphere with $T = 260\,\mathrm{K}$, and a surface pressure of $10^5\,\mathrm{Pa}$.[1]

   (a) At what altitude is the rate of energy absorption per unit volume maximal when the sun is directly overhead?

   (b) At what altitude is the rate of energy absorption per unit volume maximal when the solar zenith angle is $45°$? What difference does the zenith angle make?

   (c) If the frequency range over which absorption takes place contains 5% of the total solar energy flux, what is the heating rate (K day^{-1}) at the level of maximum energy absorption? What is the heating rate one density scale height above and below the level of maximum absorption? (Use globally averaged insolation.)

2. *(11 points)* Stratocumulus clouds cover 23% of the world's oceans. Because they reflect a large portion of the incoming sunlight, they are important for regulating Earth's energy balance. They are unusual among Earth's clouds in that the turbulence that sustains them is driven by longwave radiative cooling at the cloud tops, rather than by heating at the surface.

   (a) Assume a marine stratocumulus deck at 35°N has an albedo of 40%, and the atmosphere above it is transparent to solar radiation. Neglect absorption of shortwave radiation in the cloud, and assume the ocean underneath has an albedo of 10%. By how much does the stratocumulus deck reduce the shortwave radiative energy flux absorbed at the surface as a function of time of year and in the annual average? (You can use the insolation code from the last homework set to calculate insolation.)

   (b) The stratocumulus deck is optically thick for longwave radiation. Assume that the temperature at the cloud top is 280 K. How large is the upwelling longwave radiative energy flux at the cloud top?

[1] From Hartmann, *Global Physical Climatology*.

(c) Assume that the atmosphere above the clouds is dry and cloud-free, so that the downwelling longwave flux that reaches the stratocumulus top originates at a much higher level of the atmosphere, where the temperature is 250 K. What is the net longwave radiative energy flux at the cloud top? How does it drive turbulence?

(d) Discuss qualitatively what happens as the concentration of greenhouse gases in the atmosphere increases. What does that imply about the longwave cooling at the cloud tops? What may it imply about the turbulence in the boundary layer at whose top the stratocumulus clouds sit?