ESE 101:

Homework 2 (due October 25):

1. *Greenhouse effect*. Consider an atmosphere consisting of n homogeneous layers in radiative equilibrium with an underlying surface. Assume the atmosphere absorbs no solar radiation, the surface has albedo α, and the atmospheric layers absorb and emit as blackbodies (emissivities ϵ = 1).

   (a) What is the radiative energy balance at the top of the atmosphere and in each atmospheric layer?

   (b) What is the radiative equilibrium temperature for each layer and the surface as a function of n? What are representative values for Earth in the top layer of the atmosphere and at the surface for a few values of n (total solar irradiance $S_0 = 1362\,\mathrm{W\,m^{-2}}$ and albedo $\alpha = 0.3$)?

   (c) Provide a (narrative) physical explanation for the dependence (or lack thereof) of the temperature of the top layer and of the surface on n.

   (d) The atmospheric layer adjacent to the surface may be physically thin. Yet there is a difference between the temperature of the surface and the temperature of this near-surface layer of the atmosphere. What causes it? What are some of its implication?

2. *Radiative cooling*. In your first job fresh after graduating from Caltech, your new boss asks you to study whether it is feasible to create a material with amazing properties: If you put the material in a shed that has the same interior temperature as the ambient air outside the shed, the material, of course, equilibrates to the same temperature as the shed and the ambient air. (You can assume the interior of the shed to be a blackbody cavity.) But once you take the material outside, it cools radiatively and entirely passively—even if the sun is shining directly upon it—to temperatures below the ambient temperature.

   Can such a material possibly exist, and if, so under which conditions? Write a short report that addresses the following questions using the relevant physical laws:

   (a) Under which conditions is it even possible that a material in local thermodynamic equilibrium on Earth is cooler than the ambient air when it is exposed to direct sunlight? Is there a temperature range where this may be possible? (Strong hint: For this problem, assume that the atmosphere is transparent to radiation in a wavelength window centered on $10\ \mu\mathrm{m}$.)

(b) Roughly how would the cooling power of such a material vary (i) with time of day, (ii) with time of year, and (iii) with latitude?

(c) Unreactive gases used in industrial processes, such as perfluorocarbons (e.g., CF_4, C_2F_6, C_3F_8), strongly absorb infrared radiation in the window around $10\ \mu\mathrm{m}$ and have been accumulating in the atmosphere. How is their accumulation affecting the cooling power of the material?