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12.003 Atmosphere, Ocean and Climate Dynamics  
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## 12.003 Physics of Atmospheres, Ocean and Climate

### Problem set 2: Emission temperatures and greenhouse models

Due date: September 24, 2008

1. Suppose that the Earth is, after all, flat. Specifically, consider it to be a thin circular disk (of radius 6370km), orbiting the Sun at the same distance as the Earth; the planetary albedo is 30%. The vector normal to one face of this disk always points directly towards the Sun, and the disk is made of perfectly conducting material, so both faces of the disk are at the same temperature. Calculate the emission temperature of this disk, and compare with the result we obtained for a spherical Earth.
2. Consider the thermal balance of Jupiter. You will need the following information about Jupiter: mean planetary radius = 69,500km; mean radius of orbit around the Sun = 5.19A.U. (where 1A.U. is the mean radius of the Earth's orbit); planetary albedo = 0.51.

- (a) Assuming a balance between incoming and outgoing radiation, calculate the emission temperature for Jupiter.
- (b) In fact, Jupiter has an internal heat source resulting from its gravitational collapse. The measured emission temperature  $T_e$  defined by

$$\sigma T_e^4 = (\text{outgoing flux of planetary radiation per unit surface area}) \quad (1)$$

is 130K. Comment in view of your theoretical prediction in part (a). Calculate the magnitude of Jupiter's internal heat source.

3. The haze containing organic molecules in Titan's upper atmosphere absorbs 90% of the solar radiation reaching Titan, but is inefficient at trapping infrared radiation generated by the surface. Adapt the greenhouse model sketched in Fig. 2.7 of the textbook to an atmosphere that is opaque to shortwave radiation, but is transparent to infrared radiation. Compute the emission and surface temperatures for such an atmosphere (assume that the incoming radiation per unit area is  $S_0$  and the albedo is  $\alpha_p$ ). Is Titan's surface temperature warmer or colder as a result of its peculiar atmosphere?
4. For the one-layer leaky greenhouse model we considered in class suppose that, all else being fixed, the atmospheric absorption depends linearly on atmospheric  $CO_2$  concentration as

$$\epsilon = \epsilon_0 + [CO_2]\epsilon_1 \quad (2)$$

where  $[CO_2]$  is  $CO_2$  concentration (in ppm),  $\epsilon_0 = 0.734$ , and  $\epsilon_1 = 1.0 \times 10^{-4}$  (ppm) $^{-1}$ . Calculate, for this model, the surface temperature:

- (a) for the present atmosphere, with  $[CO_2] = 360$  ppm

(b) in pre-industrial times, with  $[CO_2] = 280$  ppm; and

(c) in a future atmosphere with  $[CO_2]$  doubled from its present value.

Calculate the expression for the climate sensitivity using the leaky greenhouse model with the emissivity  $\epsilon = \epsilon_0 + [CO_2]\epsilon_1$ . Is the climate sensitivity larger or smaller in the presence of  $CO_2$ ?