SIO 117: The Physical Climate System

Spring 2007

Homework #2

Due April 17 in class

The model in Hartmann Fig. 2.3 assumes that all radiation emitted by the surface is absorbed by the atmosphere and that the atmosphere emits radiation as a perfect blackbody. We will now consider the situation where the atmosphere absorbs only a fraction of the radiation emitted by the surface and allows the remainder to be transmitted to space. Let ε be the fraction absorbed and $1 - \varepsilon$ be the fraction transmitted. Because absorptivity equals emissivity under conditions of thermodynamic equilibrium, the atmosphere now only emits $\varepsilon \times \sigma T_a^4$ radiation upward and downward. We will still assume that the surface is a perfect blackbody at wavelengths of terrestrial radiation.

1. (*a*) Write down an equation describing the radiation budget at the top of the atmosphere (incoming radiation on the left, outgoing radiation on the right).

   (*b*) Write down an equation describing the radiation budget for the atmosphere (absorbed radiation on the left, emitted radiation on the right).

   (*c*) Write down an equation describing the radiation budget for the surface (absorbed radiation on the left, emitted radiation on the right).

2. (*a*) Derive an expression for ε as a function of S_0, α_p, and T_s.

   (*b*) Calculate the value of ε for $S_0 = 1367$ W m^{-2}, $\alpha_p = 0.3$, and $T_s = 288$ K (the observed global mean surface temperature).

3. Imagine that the burning of fossil fuels increases the emissivity of the model atmosphere such that T_s increases to 291 K. If S_0 and α_p remain the same, what is the new value of ε?

4. Derive an expression for T_s as a function of S_0, α_p, and ε.

5. (*a*) Imagine that the polar ice caps partially melt with global warming such that α_p decreases to a value of 0.29. Using this value of α_p and the value of ε calculated in Problem 3, what is the value of T_s? Is it larger or smaller than 291 K?

   (*b*) Imagine that cloud reflectivity increases with global warming such that α_p increases to a value of 0.31. Using this value of α_p and the value of ε calculated in Problem 3, what is the value of T_s? Is it larger or smaller than 291 K?

   As you can see, the internal response of the climate system can exacerbate or mitigate global warming caused by an increase in atmospheric emissivity.