

SIO 117: The Physical Climate System

Spring 2007

Homework #3

Due April 24 in class

1. The most obvious impact of increasing CO₂ on Earth's climate actually occurs in the stratosphere rather than at the surface. We will now explore what that is.

Assume that the stratosphere is in radiative equilibrium (no transport of energy except through radiative transfer). Ozone in the stratosphere absorbs fraction ϵ_{O_3} of incoming solar energy $S_0/4$, and CO₂ absorbs fraction ϵ_{CO_2} of upwelling terrestrial energy from the troposphere F_{trop} . The stratosphere also emits energy upward and downward with a magnitude that is equal to fraction ϵ_{CO_2} of what a perfect blackbody would emit. Let T_{strat} be the temperature of the stratosphere, and assume that S_0 and F_{trop} are constant.

- (a) Write down an equation describing the radiation budget for the stratosphere (absorbed radiation on the left, emitted radiation on the right).
- (b) Derive an expression for T_{strat} as a function of the other parameters.
- (c) If the burning of fossil fuels causes the concentration of CO₂ in the stratosphere to increase, how will ϵ_{CO_2} change? How will T_{strat} change in response to the change in ϵ_{CO_2} ?
- (d) Provide a brief physical explanation for your answer to (c).

2. An aircraft measures the properties of a stratocumulus cloud off the coast of San Diego. The cloud is 150 m thick and has an average liquid water content of 0.5 g m⁻³. The average radius of the cloud droplets is 15 μm.

- (a) What is the optical thickness of the cloud at visible wavelengths?
- (b) What is the approximate albedo of the cloud at visible wavelengths? (Assume that the asymmetry parameter g is 0.87 and ignore reflection from the ocean surface.)
- (c) Tiny particles from the exhaust produced by a ship traveling underneath the cloud act as condensation nuclei such that the number of cloud droplets increases by a factor of eight. If there is no change in liquid water content, what is the new average cloud droplet radius?
- (d) What is the ratio of new cloud optical thickness to old cloud optical thickness? What is the ratio of new cloud albedo to old cloud albedo? As you can see, anthropogenic pollution on a large scale might affect Earth's cloud albedo.
- (e) Repeat all of the calculations in (a) - (d) using a cloud thickness of 300 m instead of 150 m.
- (f) Provide a brief physical explanation for why an increase in the number of droplets has more impact on the albedo of a thin cloud than on the albedo of a thick cloud.