

SIO 117: The Physical Climate System

Spring 2007

Homework #5

Due May 24 in class

Global climate models generally predict that the Hadley circulation will weaken in the future due to global warming. This result is based on two assumptions: 1) the lapse rate of the tropical atmosphere is determined by precipitating clouds rising from the warm ocean surface, and 2) the amount of atmospheric radiative cooling in the dry subtropics will not substantially change. We will now explore this topic.

1. a) If the ocean temperature is 303 K, what is the water vapor mixing ratio of a saturated air parcel at the surface?
b) What is the water vapor mixing ratio if the ocean temperature is 305 K?
2. a) Assume that the saturated air parcel rises from the surface to an elevation of 16 km and that all water vapor in the air parcel rains out (after releasing latent heat). If moist static energy is conserved, what is the temperature of the air parcel at 16 km if the surface temperature is 303 K? What is the average lapse rate between in surface and 16 km?
b) What is the temperature at 16 km if the surface temperature is 305 K? What is the average lapse rate if the surface temperature is 305 K?
c) Does the upper troposphere warm faster than the surface when surface temperature goes from 303 K to 305 K? Does the lapse rate increase or decrease?
3. The air parcel at 16 km returns to the surface under unsaturated conditions. In order to do so, it must lose energy through radiative cooling so that it matches the dry static energy at the surface.
a) What is the difference between dry static energy at 16 km and dry static energy at the surface if the surface temperature is 303 K? (*units are $J kg^{-1}$*)
b) What is the difference if the surface temperature is 305 K?
4. Figure 6.1 indicates that the average rate of radiative cooling in the atmosphere is approximately $100 W m^{-2}$.
a) What is the mass of the atmosphere between the surface and 16 km, where the pressure is about 100 hPa? (*units are $kg m^{-2}$*)
b) If all of the radiative cooling of the atmosphere occurs between the surface and 16 km, what is the average rate of energy loss? (*units are $W kg^{-1}$*)

- c) What is the average rate of tropospheric temperature decrease due to radiative cooling? (*units are $K day^{-1}$*)
- d) How many days does it take for an air parcel to descend from 16 km to the surface if it loses dry static energy via radiative cooling and the surface temperature is 303 K?
- e) How many days does it take to descend if the surface temperature is 305 K?
- f) If descending air returns to the precipitating region via the trade winds, what is the relative reduction in wind speed if surface temperature goes from 303 K to 305 K?