

Supplementary Exercises I

1. Over a period of a day, 3 cm of rain falls from a cloud layer that extends from 850 to 500-hPa. The latent heat released in the condensing precipitation warms the cloud layer. (a) Estimate the heating rate in deg K per day. (b) If the temperature at the base of the cloud layer is 5 °C, estimate the upward velocity at this level required to supply the necessary mass of liquid water to the cloud.

Hint: There can be no mass of water vapor through the cloud top: if there were, the cloud would have to grow. Hence the amount of water that rains out of the cloud is equal to the mass of water vapor entering the cloud from below. Use the pseudo-adiabatic chart to estimate the mixing ratio at cloud base. (I get 6.2 g/kg). Calculate the air density at cloud base from the equation of state. (I get 1.06 kg per cubic meter.) The product of these two numbers is the density of water vapor at cloud base. The water vapor density times the upward velocity must equal the rate at which mass of water is condensing out of the cloud. For reference, there are 86,400 seconds in a day.

Answers (a) 21°C per day (b) 6.55 cm per second

2. The environmental lapse rate, as deduced from a radiosonde ascent, is 7.8 °C per km from sea level up to 1 km and 8.8 per km above 1 km. For a parcel at air sea level with a lifting condensation level of 1.5 km, estimate the level of free convection.

Answer 4 km

3. The following conditions are typical of the trade wind belt. (a) at sea-level: $T = 25^\circ\text{C}$, $\text{RH} = 75\%$, (b) just above the trade inversion 1.5 km above sea-level: $T = 18^\circ\text{C}$, $\text{RH} = 20\%$ (c) in the upper troposphere 14 km above sea-level: $T = -70^\circ\text{C}$, $\text{RH} = 100\%$.

Compare the moist static energy of the air at the three levels. (Ignore the small variation of g with height and the small difference between mixing ratio and specific humidity.)

Answers (a) $3.36 \text{ m}^2 \text{ s}^{-2}$; (b) $2.79 \text{ m}^2 \text{ s}^{-2}$; (c) $3.41 \text{ m}^2 \text{ s}^{-2}$

4. The current mean surface air temperature of the tropics is $\sim 25^\circ\text{C}$ and the lapse-rate is observed to be close to moist adiabatic. Assuming that the lapse-rate remains close to moist adiabatic, use the skew $T - \ln p$ chart to estimate how much would the temperature warm at the 200 hPa level if the Earth's surface were to warm by 1°C .

Answer $\sim 2^\circ\text{C}$