EART164 Homework #3 Due Wednesday 24th April 2013

Show all your working for full credit

1.The moist adiabatic lapse rate is given by

$$\frac{dT}{dz} = \frac{g}{C_p + L_s \frac{dm}{dT}}$$

where g is the acceleration due to gravity (10 ms^{-2}), C_p is the specific heat capacity of air (1 kJ/kg K), L_s is the latent heat (in J/kg) and dm/dT tells you how the mass fraction of condensed water changes with temperature.

a) Calculate the lapse rate (in K/km) for dry air. [1]

b) For water, the saturation vapour pressure (SVP) curve is described by

$$P_{vap} = C_L \exp\left(-\frac{L_s}{RT}\right)$$

where P_{vap} is the SVP, C_L is a constant (3x10^7 bar), and L_s is the latent heat (here expressed as J/mol).

b) If L_s=50 kJ/mol, what is the SVP at 280 K? [1]

c) What is the value of dP_{vap}/dT at 280K? (in bars/K) [4]

d) You can convert from partial pressure of water (in bars) to the mass of condensed water (per unit mass of air) by multiplying by the ratio (molar mass of water : molar mass of air). Hence deduce dm/dT and the moist lapse rate. You can assume that air has a molar mass of 30. (**Hint**: watch out for the units of latent heat!). [3]

e) How does your answer to d) compare with the dry lapse rate? [1] [9 total]

2. a) Clouds on Venus consist mainly of H_2SO_4 droplets. The thickness of the main cloud layer is about 10 km and the bulk density is 0.01 kg m^{-3}. What is the total mass of H_2SO_4 present in the atmosphere of Venus? (radius 6000 km). [1]

b) What liquid thickness would this layer form at the surface if it all rained out? Assume a liquid density of 1000 kg m^{-3}. [2]

c) The *optical depth* of opaque objects is given by $\tau = \frac{3}{4}\frac{d\rho}{r\rho_s}$ where d is the layer thickness, ρ is the bulk density, r is the object radius and ρ_s is the object density.

If the average droplet size is 10 μm, what is the optical depth at the base of the cloud layer? What does this mean about our ability to see the surface of Venus from Earth? [3]

d) How long would it take one of these drops to cross the cloud layer? Take the viscosity to be 10^{-3} Pa s, g=9 ms^{-2} and neglect the density of the atmosphere when calculating the density contrast. [2] [8 total]

3. Martian clouds form when the polar caps sublimate.

a) If the temperature of early Mars were higher, what would happen to 1) the sublimation rate 2) the fraction of Mars that was cloud-covered and 3) the Martian albedo? [3]

b) Is this a positive or a negative feedback? [1] [4 total]

4. We saw in class that the terminal velocity of a particle sinking through a fluid is given by $v \approx \frac{r^2 \rho g}{\eta}$ where r is the particle radius, ρ is the density of the particle (we're neglecting the fluid density here, because it's small) and η is the fluid viscosity. An important complication for raindrops is that as they fall through the atmosphere, they grow by colliding with other raindrops.

a) As a raindrop grows, what happens to its terminal velocity and the rate at which it collides with other raindrops? [1]

b) Write down the relationship between the rate at which the radius of a raindrop increases, *dr/dt*, and the rate at which its mass increases, *dm/dt*. [1]

b) The rate at which a raindrop increases in mass via collisions is given by $\frac{dm}{dt} = \pi r^2 \rho_b v$ where m is the raindrop mass and ρ_b is the bulk density of raindrops in the atmosphere (a constant). Using the information given above, find an expression for r as a function of time. Take the boundary condition to be $r=r_0$ at $t=0$. [5]

c) How does the value for r at a particular time change if you increase g, ρ_b and η? Do these effects make physical sense? [3]

d) In the limit that $g\rho_b t r_0/4\eta$ is small, write down an approximate expression for $r(t)$ which is linear in t. [1] [11 total]

5. List one thing you like about the class, and one thing that could be improved [2]