Answers to the first exam

1. [10] Using the following data for Venus [radius= 6052 km, dominant gas CO2, surface gravity 8.87 m/s2, surface pressure 9,300,000Pa, typical atmospheric surface temperature 470C], compute the mass of the Venusian atmosphere.

   Here we use the hydrostatic relation to get the column density; then multiply by the surface area of the planet.

$$M = 4\pi R^2\left(\frac{P}{g}\right) = 4\pi(6052000)^2\left(\frac{9300000}{8.87}\right) = 482.6\times 10^{18}kg$$

2. [10] If the water vapor density is 0.01kg/m3 and the temperature is 20C, find:
   a. The partial pressure of water vapor

   Here we use the perfect gas law with the gas constant for water vapor

$R_W = \frac{8314}{18} = 462$ $\quad P_W = \rho_W R_W T = (0.01)(462)(293.1) = 1354Pa$

   b. The relative humidity

From the Table, the saturation vapor pressure at 20C is 2340Pa, so the relative humidity is $RH = \frac{P_W}{P_{SAT}} = \frac{1354}{2340} = 0.578 \approx 58\%/$

3. [10] Explain why clouds always form in rising air.

   Clouds form when there is more water than can be held in the vapor state. The excess water will condense to form small liquid droplets or ice crystals. In rising air, air cools by adiabatic expansion and the temperature drops. As T drops, the saturation vapor pressure drops and the RH increases. A cloud forms when RH reaches unity.

4. [10] Explain the greenhouse effect on earth; in particular
   a. Why does it warm rather than cool the surface of our planet?

   The greenhouse effect warms rather than cools the planet as it acts as a one-way-valve for radiation trying to penetrate the atmosphere. Our atmosphere is relatively transparent to incoming shortwaves from the sun but more opaque to outgoing longwaves from earth. Thus, the radiation gets in easily but has more difficulty getting out. The planet must warm to compensate.

   b. Which gases contribute and why?

A greenhouse gas is defined as a molecule that can absorb and emit thermal infra-red radiation. Complex molecules with a dipole moment (i.e. a charge separation) can do this: such as CO2, H2O, NO, O3 etc. The air itself (N2, O2 and Argon) consists of molecules without a dipole moment.

5. [10] A small rocky asteroid between earth and sun has a solar constant of 2000W/m2 and an albedo of 0.5. Predict the temperature of the asteroid. Mention your assumptions.

We will assume that the asteroid has reached a steady state heat budget where the radiation absorbed from the sun balances the emitted longwave radiation.

$$T = [\frac{S(1-a)}{4\sigma}]^{\frac{1}{4}} = [\frac{(2000)(1-.5)}{4(5.735\times10^{-8})}]^{\frac{1}{4}} = 257K$$

We also assume that the asteroid has a constant temperature, perhaps maintained by heat conduction within it.

6. [10] Explain why a planet like earth will have lost its light gases over geologic time but retained its heavier gases like N2 and O2.

   The lighter gases like H2 and He move faster than heavier gases (N2 and O2) at the same temperature and thus can more easily exceed the escape velocity for the planet. These fast molecules can escape the gravitational field of the planet.

7. [10] Consider a hot summer day with the earth's surface temperature Ts=30C and a deep cumulo nimbus cloud with a cloud top temperature of T= -60C.
   a. Compute the wavelength most profusely emitted by each surface. Which band of radiation is it in (UV, VIS, NIR, TIR, Radiowave)?

      We estimate the dominant wavelength of emission using Wien's Law.

$$\lambda = \frac{2898}{303K} = 9.56\,microns$$

$$\lambda = \frac{2898}{213K} = 13.6\,microns$$

      Both of these wavelengths fall in the thermal infra-red (TIR) range.

   b. Compute the total power emitted from 1 square kilometer of each surface.

      We estimate the power emitted using the Stefan-Boltzmann Law

$$F = \sigma T^4 = (5.735\times10^{-8})(303)^4 = 483.4W/m2$$
$$F = \sigma T^4 = (5.735\times10^{-8})(213)^4 = 118.0W/m2$$

8. [10] Ten tonnes of methane gas is suddenly released into the earth's atmosphere from a ruptured tank. There is no wind blowing, but the daytime turbulence induced by solar heating of the surface is large: giving a diffusivity of 50m2/s.
    a. Compute the **distance** (in meters) from the source reached by the spreading "cloud" of methane six hours after the release.

       The distance of turbulent diffusion increases as the square root of time according to $d = \sqrt{Kt}$. *In this case,*
       $$d = \sqrt{(50)(6)(3600)} = 1039m$$

    b. What is the **concentration of methane** in the "cloud"? Express your answer in ppmm.

The expanding "cloud" of methane rich air has the shape of a hemisphere. The mass of air in the hemisphere is $Mass = \rho\left(\frac{2}{3}\right)\pi d^3 = 2.8\times10^9 kg$

The concentration (by mass) is then $C = \frac{M_{Methane}}{M_{Air}} = \frac{10^4 kg}{2.8\times10^9 kg} = 3.57ppmm$

9. [10] For Earth, the atmospheric density scale height is about 8400m. If the sea level density is 1.2kg/m3, estimate the air density at an altitude of 30 km?

   We will use the approximate density profile formula derived for an isothermal atmosphere.
   $$\rho(30km) = \rho(z=0)\exp\left(-\frac{z}{Hs}\right) = 1.2\exp\left(-\frac{30}{8.4}\right) = 0.0337kg/m3$$

10. [10] Briefly define and describe each term below.
    a. supercooled water

       Liquid water at a temperature below the normal freezing point (i.e. 0C for freshwater).

    b. unstable lapse rate

       If the lapse rate in the earth's atmosphere is less than the adiabatic lapse rate (-9.8C/km) the air column will be unstable. Convection will ensue. Example, a lapse rate of -12C/km is unstable.

    c. Archimedes Law

       Archimedes Law for buoyancy states that the upward pressure force on a *submerged object is equal to the weight of the fluid displaced.*

d. tropopause

Defined as the point where the air temperature stops decreasing with height, becoming constant or increasing. The upper boundary of the troposphere.

e. advection fog

Fog formed by warm moist air advecting (i.e. moving) over a cold surface. As the air loses heat to the surface, the saturation vapor pressure drops and the RH increases.