Natural Hazards - Geology 209 - **Severe Weather Systems**
Due Date: April, 7th **Name____________**

This exercise explores some of the atmospheric properties and processes that are associated with severe weather such as violent thunderstorms, hail storms, tornados and hurricanes. The main objective is to investigate how temperature, air density, moisture and heat interact within the atmosphere to produce buoyant uplift in severe storms. Using Excel will greatly expedite the completion of this problem set.

1. Derive a temperature profile, from 0 to 10 km height in the atmosphere, based on a temperature-cooling rate (environmental lapse rate) of –6.5°C/km. Use a starting temperature of 25°C - a good estimate for average surface temperatures. Make a graph showing temperature vs. height from the surface (O km) up to 10 km. Use Kelvin (K) for the temperature scale, not °C (0^{o} C is equivalent to 273.15 K – a Kelvin degree represents the same magnitude temperature change as a Celsius degree).

2. Now calculate air density (kg/m^3) for the same elevation profile - 0 to 10 km. To do this use the following “Gas Law” equation: pressure P = density × $R_{\text{gas constant}}$ × temp. T

$P = \rho R T$ where the Specific Gas Constant, R = 287 J kg^{-1} K^{-1} (m^2 sec^{-2} K^{-1})

REMEMBER to use Kelvin (K) not °C. The necessary data on atmospheric pressure vs. height is given below, which should be used to calculate the density profile. I would suggest plotting the data below in Excel and fitting the data with a best-fit trend line. Then, use the trendline equation to determine which of the mathematical expressions best represents the data (i.e., which best-fit line best approaches an R^2 value closest to one). Finally, use the best-fit equation to compute a new dataset that goes from an elevation of zero to 10 km. This new dataset should have at least 500-meter increments between each calculation (i.e., 0, 500, 1000, 1500, 2000, etc.). After you have calculated the appropriate pressure gradient, use the pressures to calculate a density gradient using the Gas Law above. Although atmospheric pressures are usually reported in millibars (mb) in the US, for simplicity we’ll stick with the SI units ($\frac{kg}{ms^2}$). These are Pascals; 100 Pa=1 mb.

Height (m)	Pressure (kg m^{-1} s^{-2}).
0	101325
500	95461
1000	89876
2000	79501
4000	61660
7000	41105

You should now have produced a graph of pressure vs. height, temperature vs. height and air density vs. height.

3. Thunderstorms, tornados and hurricanes all involve high wind velocities resulting from strong centralized updrafts (unstable rising air). These updrafts result from central areas of lower atmospheric pressure that in turn are caused by reduced air densities. One reason these storms persist and strengthen is that they draw in moist air, which rises, encounters cooler temperatures, and condense. As condensation occurs, latent heat is released. This heat warms the air within the storm, reduces the local air density, which causes further convective uplift that draws in more moist air. As the system develops, inflowing wind speeds can achieve highly destructive velocities.

Below, you will compute the effect of latent heat transfer on the density (ρ) of a cubic meter (m^3) of air as it travels from the Earth's surface to 10 km into the atmosphere. Use a water vapor concentration of 5 g H_2O / m^3 in the upward-flowing moist air; assume that the entire H_20 quantity condenses. **Latent Heat of condensation for H_2O equals 2501 x 10^3 J / kg**. In other words, condensation of a kilogram of water vapor releases 2,501,000 Joules of heat. The **Specific Heat of dry air at constant pressure is 1005 J kg^{-1} K^{-1}**, i.e., it takes 1005 J of heat to raise the temperature of 1 kg of air by 1 K.

Remember, that although an entire air parcel (1 m^3) <u>receives</u> the heat, only the water <u>contributes</u> latent heat. Also, recall that the water vapor does not begin to condense until the dew point (or temperature of saturation) is reached. The dew point is a function of air temperature and water vapor concentration per volume of air. For a water vapor concentration of 5 g/m^3, the dew point temperature is about 2^o C.

To breakdown the problem, consider first the heat released from the small (5 g) quantity of water (step 1, below). This released heat then warms the batch of dry air that held the water (1 m^3). Steps 3 & 4 consider how much the air is warmed by that heat. Step 5 looks at how that warming affects the air parcel's density. Step 6 has you plot the data. You will need to look at the units of the variables at each step below to figure out how to proceed with the calculation - e.g., if you are looking for the unit (J) and you have two variables (J/K, and K), then you must multiply your two variables to get (J).

Step 1. Convert H_2O vapor mass to kg. Use latent heat given above (J/kg) to <u>calculate</u> heat (in J) yielded to a local air parcel by condensation of 5 g of H_2O vapor.

Step 2. Figure out the mass of (kg) of total air in a cubic meter (m^3) based on the initial dry air <u>density</u> for each of your elevation points in question #2 (previous page).

Step 3. Use the mass (kg) of the cubic meter air parcel (from step 2) and the Specific Heat given above (J kg^{-1} K^{-1}) to determine a specific heating rate (in J / K) for the 1 m^3 parcel of air you are considering. This calculation should be done for each elevation step.

Step 4. Use the Latent Heat released (in J) from step 1 and the specific heat rate (J/K) determined in step 3 to determine the local air parcel temperature increase (in K) due to release of latent heat by condensation for each elevation step.

Step 5. Use the Gas Equation from question #2 (previous page) to compute a **new** air density (kg/m^3) after warming due to latent heat of condensation. You will need to use the temperature and pressure calculated in question #2. Remember to add the temperature increase to the prior temperature in K.

Step 6. Make a plot of the new density profile relative to the dry air profile.

4. From your calculations above, explain in words how the release of Latent Heat helps explain surface wind convergence and intensification of a centralized surface low-pressure zone into a hazardous storm system.

5. What eventually happens to the condensed water droplets? Why couldn't they just evaporate again, now that temperature is warmed up?

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6. Download a weather map for the US that shows pressure zones and fronts. Write a paragraph about the general motion of air masses that have resulted in the present configuration of your weather map - pay close attention to the air masses that are likely moist or dry, and the air masses that are likely hot or cold. On the map of North America provided, label the high and low pressure zones (if not already labeled) and draw the general winds direction (air mass motion) that the current pressure citation is producing. Make a prediction on were storms might occur in the near future given the current configuration of air masses and fronts.