San Francisco State University **Name** ____________________________________
Department of Earth & Climate Sciences **ERTH 260: Physical Processes of the Atmosphere**

Laboratory Exercise 7: Adjusting the Gas Law for Variations in Gas Constant: Virtual Temperature Differences Across the Dry Line (100 pts)

Due Wednesday 28 March 2018

A. Which is denser, warm moist air at a given pressure, or warm dry air at the same pressure?

It's an interesting question, because it involves the gas law. Note that the question simplifies the gas law by removing one of the variables. Which variable is made into a constant by the constraints of the question?

It turns out that gas constant is often defined for an air parcel with NO water vapor. We've been treating the gas constant as just that, a constant.

What impact on the density of air parcel would adding water vapor have? Or, to put it another way, suppose there were two air parcels, one with a temperature of 97F and a dew point of 15F and another with the same temperature of 97F but a dew point of 70F. Which do you think is denser?

It turns out that water vapor molecules are very "bulky" for their weight. In other words, a gram of water vapor takes up much more space than a gram of diatomic oxygen or diatomic nitrogen. That should give you a clue

B. Virtual Temperature

To make the Ideal Gas Law as we've discussed it work, we can define a temperature, Virtual Temperature, that works this way. The Gas Law is very complicated when you consider the effects of the density of water vapor. But one can (not you, but one can) solve the more complicated Gas Law for density (including water vapor) and then put that density back into the familiar Gas Law and solve for temperature. That temperature is called Virtual Temperature. In other words, the impact of water vapor is to make a kilogram air parcel LESS dense. The virtual temperature of a moist air parcel is the temperature at which a theoretical dry air parcel would have a total pressure and density equal to the moist parcel of air. As long as there is a dew point (water vapor is present), the Virtual Temperature is always greater than the actual temperature.

$$T_v = T(1 + [am]) \qquad (1)$$

where T_v is virtual temperature (in Kelvin), T is the actual temperature (in Kelvin), a= 0.61, and m is mixing ratio ($g_{\text{water vapor}}/g_{\text{dry air}}$). As Stull points out (p. 15), moist air of temperature T behaves as dry air (whose properties are expressed in the simplified Ideal Gas Law) with temperature T_v.

C. Mixing Ratios

Recall that the amount of water vapor in a mass of dry air can be determined experimentally and by equation. We will explore this when we get to Humidity in the class discussion list. Here is a table of mixing ratios for various dew point temperatures.

Table for Fahrenheit Temperature	
Temperature (°F) Or Dew Point Temperature (°F)	Saturation Mixing Ratio (g / kg) Or Mixing Ratio (g / kg)
-40	0.12
-30	0.21
-20	0.35
-10	0.58
0	0.94
10	1.52
15	1.89
20	2.34
25	2.88
30	3.54
35	4.33
40	5.28
45	6.40
50	7.74
55	9.32
60	11.19
65	13.38
70	15.95
75	18.94
80	22.43
85	26.48
90	31.16
95	36.56
100	43.22

Table for Celsius Temperature	
Temperature (°C) Or Dew Point Temperature (°C)	Saturation Mixing Ratio (g / kg) Or Mixing Ratio (g / kg)
-40	0.1
-30	0.3
-20	0.8
-10	1.8
0	3.8
5	5.4
10	7.6
15	10.6
20	14.7
25	20.1
30	27.2
35	36.6
40	49.0

Table 1. Mixing Ratios (g/kg) for various dew point temperatures

D. Lab Exercises

1. Examine Figs. 1 and 2, the surface plots for 1300 and 2300 UTC, respectively, 6 March 2017. Notice the two stations highlighted by the boxes.
   a. Calculate the Virtual Temperature at the two stations for the two synoptic times given on the basis of Equation 1. To do this determine the mixing ratio from Table 1. Be sure to transform the units (g/kg) to (g/g) and F temperatures to C (using the Table on the class website's first week's schedule). Show all work.

   b. Record all the data in Table 2 and Table 3.

13 UTC	Temperature	Dew Point	Mixing Ratio	Virtual Temperature
Station A				
Station B				

Table 2: 13 UTC Temperature, Dew Point Temperature, Mmixing Ratio, and Virtual Temperature

23 UTC	Temperature	Dew Point	Mixing Ratio	Virtual Temperature
Station A				
Station B				

Table 3: 23 UTC Temperature, Dew Point Temperature, Mmixing Ratio, and Virtual Temperature

2. Assume that the atmospheric pressure is the same at both stations at both times. Using the concept (no calculations) embedded in the Ideal Gas Law (now including the impact of water vapor), comment on which side of the Dry Line is found the denser air.

3. Examine Figs. 3, 4, and 5, the soundings for El Paso TX (KEPZ), Midland TX (KMAF), and Oklahoma City (KOUN) for 12 UTC 6 March 2017.
4. Of the three soundings shown, which appears definitely to be characteristic of the dry air west of the Dry Line and why?
5. Of the three soundings shown, which appears definitely to be characteristic of the Loaded Gun sounding and why?

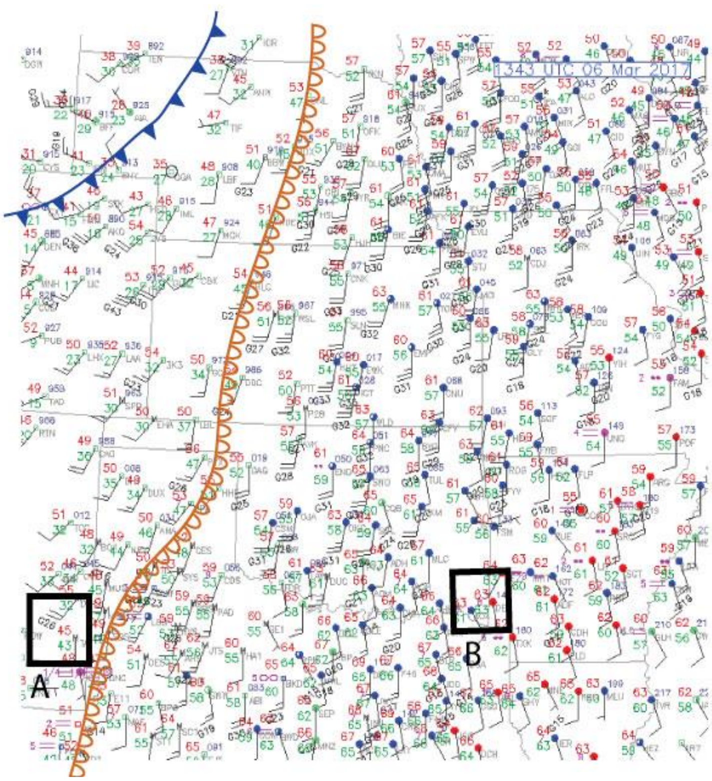

Figure 1. Surface plot at 13 UTC 6 March 2017. Boxes indicate two stations on either side of the Dry Line.

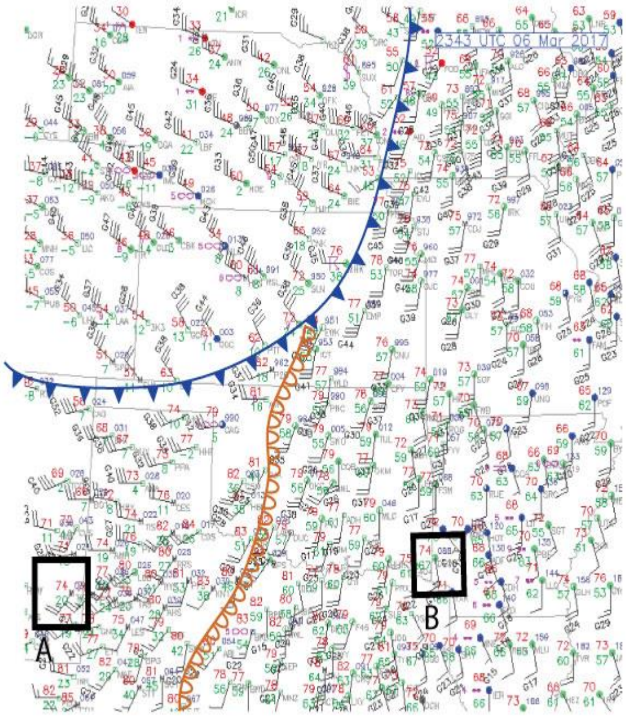

Figure 2. Surface plot at 23 UTC 6 March 2017. Boxes indicate two stations on either side of the Dry Line.

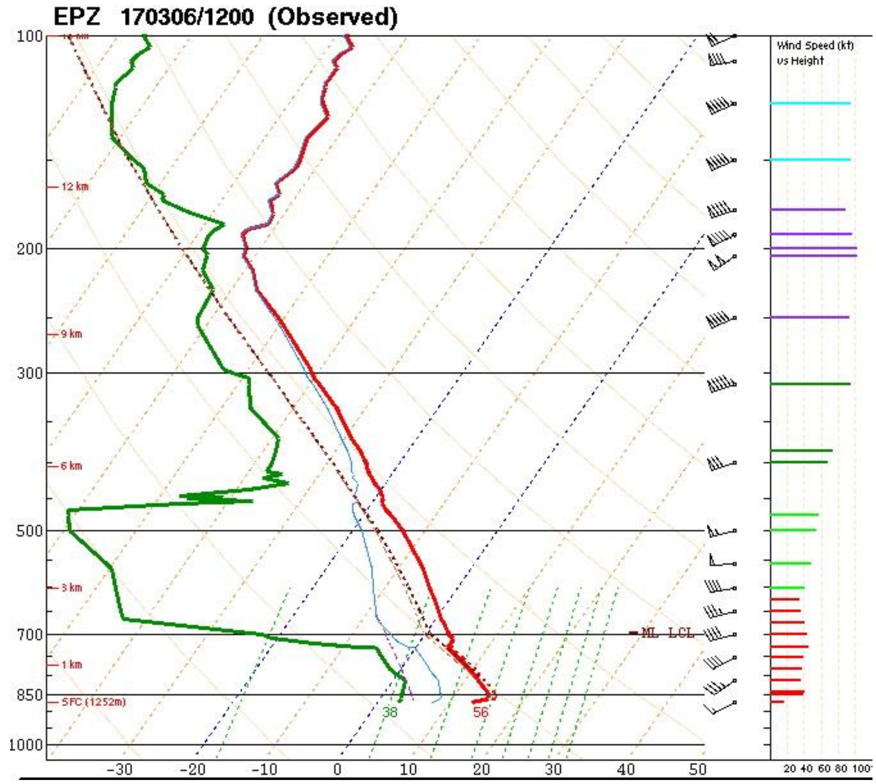

Figure 3. Sounding for El Paso TX at 12 UTC 6 March 2017.

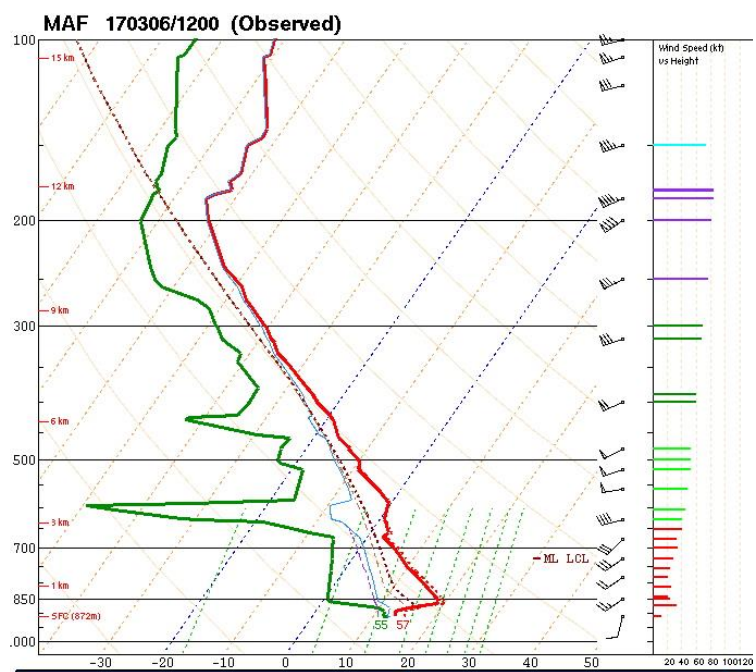

Figure 4. Sounding for Midland TX at 12 UTC 6 March 2017.

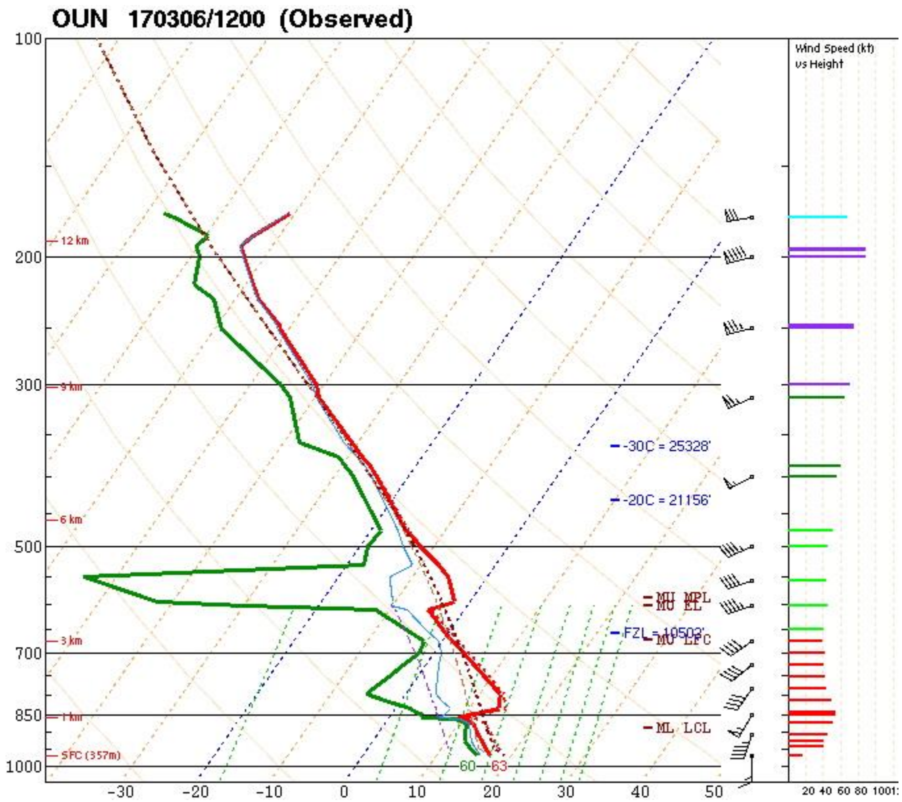

Figure 5. Sounding for Oklahoma City OK at 12 UTC 6 March 2017.

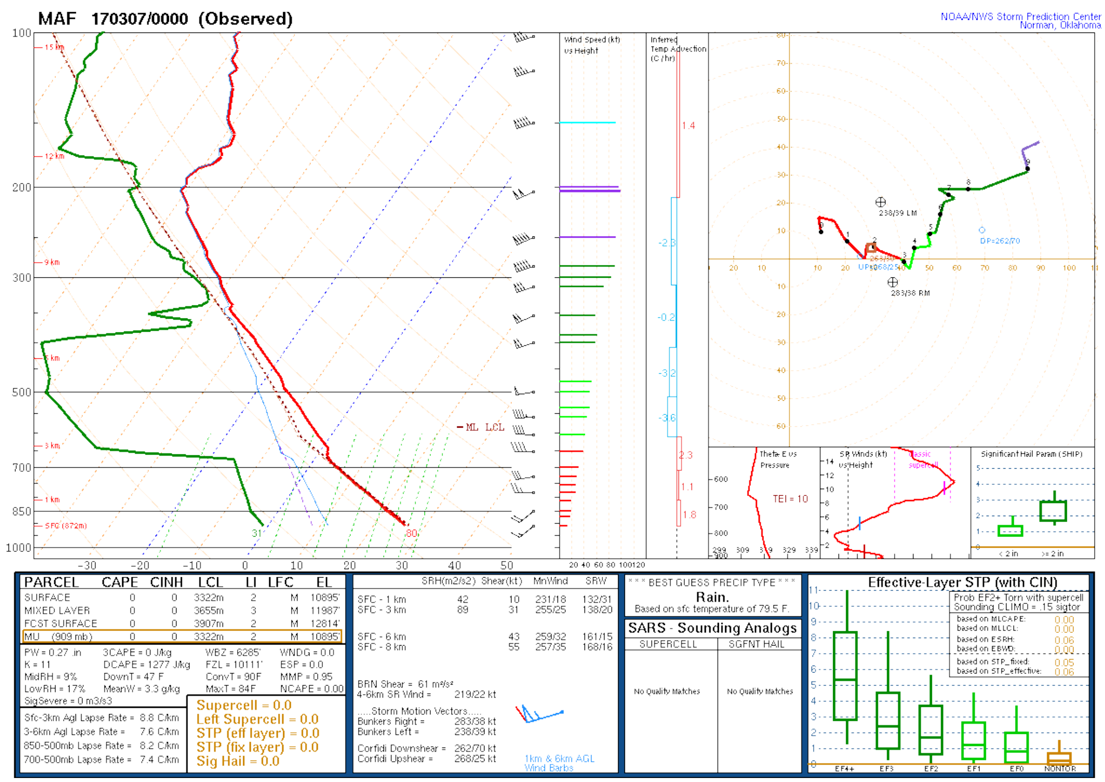

Figure 6. Sounding for Midland TX at 0000 UTC 7 March 2017 (for class discussion)