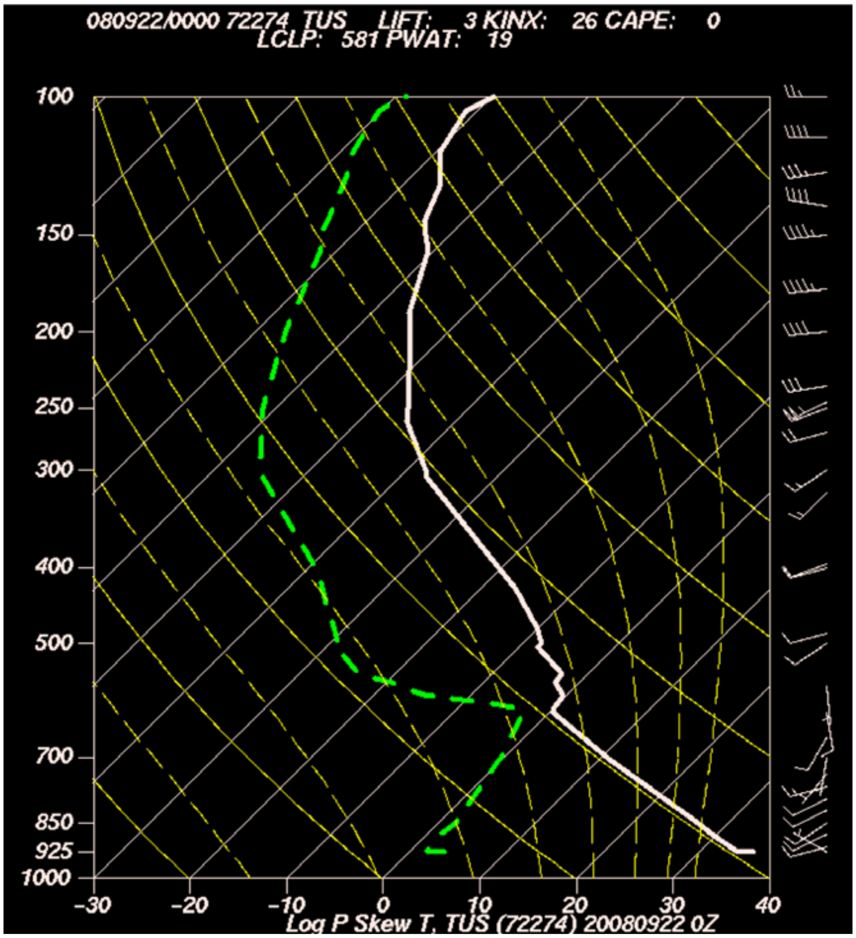
1. Conversion between moisture variables.
   Conditions: Temperature = 75°F. Dew point = 60°F, Pressure = 1000 mb.
   Find the following
   a. water vapor partial pressure
   b. water vapor saturation vapor pressure
   c. relative humidity
   d. specific humidity
   e. saturation specific humidity
   f. absolute humidity

2. The vertical gradient of dew point temperature in a well mixed boundary layer (mixing ratio is constant with altitude)
   a. Show that $\frac{dT_d}{dz} = -\frac{g}{L}\frac{m_d T_d^2}{m_v T} \sim -\frac{g}{L}\frac{m_d T_d}{m_v}$
   b. Show that the value of dT_d/dz is typically in the range from -1.5 to -1.7 K/km.

3. Using the figure below, and assuming a well mixed boundary layer, if the dew point at 1000 mb had been 15°C, approximately at what altitude and pressure level would the air have been saturated such that a cloud formed there



4. Calculate a moist adiabatic atmospheric structure.

You are going to construct approximately the moist adiabatic curve in the figure above that starts at T=22°C and P = 1000 mb.

a. Create a spreadsheet with at least 5 columns titled: altitude (km), temperature(K), pressure (mb), es (mb) and dT/dz (K/km)
b. Setup the altitude column so that the values run from 0 km at the bottom of the sheet to 16.5 km at the top in increments of 0.5 km
c. Set the surface temperature = 293.15K (= 22°C).
d. Set the surface pressure = 1000 mb
e. In the 4th column use the Groff-Gratch equation to calculate e_s:

$$\begin{aligned}\mathrm{Log}_{10}(e_s) = & -7.90298\,(373.16/T-1) \\ & + 5.02808\,\mathrm{Log}_{10}(373.16/T) \\ & - 1.3816\times10^{-7}\,(10^{11.344\,(1-T/373.16)}\ -1) \\ & + 8.1328\times10^{-3}\,(10^{-3.49149\,(373.16/T-1)}\ -1) \\ & + \mathrm{Log}_{10}(1013.246)\end{aligned}$$

with T in [K] and e_s in [hPa=mb]

(Note: this is a complicated equation prone to error when entering it. To verify you have entered this equation properly, make sure it yields a value of ~6.1 mb for a temperature of 0°C = 273.15 K)

The equation should produce e_s at the surface of 26.4 mb for the surface temperature of 295.15 K

f. In the 5th column calculate the moist adiabatic lapse rate using

$$\frac{dT_s}{dz} = -\frac{g}{C_p}\frac{\left[1+\frac{e_s}{P}\frac{L_v}{R_v T}\right]}{\left[1+\frac{L_v^2}{C_p R_v T^2}\frac{\mu_v}{\mu_d}\frac{e_s}{P}\right]} \qquad (15)$$

To make things simple, assume L_v = 2.5e6 J/kg.

Now construct the vertical atmospheric structure using dT/dz

In the row above the surface row

g. Set the temperature in column 2 equal to the surface temperature plus the moist adiabatic dT/dz from the surface row times the height difference between the second and first row
h. To determine the pressure in this row use the hypsometric equation

$$P(z_2) = P(z_1)\exp\left[-\frac{(z_2-z_1)}{H}\right] = P(z_1)\exp\left[-\frac{(z_2-z_1)g}{RT}\right]$$

using T from the surface row or the average of the T in the surface row and T in this row from item g.

i. Using T in this row from item g, calculate e_s.
j. Calculate dT/dz in the 5th column

Repeat steps g-j for the next row up. Continue until you fill all rows

Compare your results with the curve in the figure to verify they are approximately right. Your result should look similar to the following:

z	T		P	es	dT/dz
16.5	176.63	-96.52	98.00	5.09622E-05	-9.80
16	181.53	-91.62	107.66	0.000136736	-9.80
15.5	186.43	-86.72	117.99	0.000339882	-9.79
15	191.32	-81.83	129.00	0.000791464	-9.79
14.5	196.21	-76.94	140.73	0.00174135	-9.78
14	201.09	-72.06	153.20	0.003643459	-9.76
13.5	205.95	-67.20	166.44	0.007285328	-9.73
13	210.79	-62.36	180.48	0.013972504	-9.68
12.5	215.59	-57.56	195.36	0.025770291	-9.60
12	220.34	-52.81	211.10	0.04578768	-9.50
11.5	225.01	-48.14	227.74	0.078460592	-9.35
11	229.59	-43.56	245.32	0.12976228	-9.15
10.5	234.05	-39.10	263.88	0.207257414	-8.91
10	238.35	-34.80	283.48	0.319944686	-8.62
9.5	242.50	-30.65	304.15	0.477902096	-8.29
9	246.47	-26.68	325.97	0.691826377	-7.93
8.5	250.25	-22.90	348.99	0.972594859	-7.57
8	253.85	-19.30	373.27	1.330953463	-7.21
7.5	257.28	-15.87	398.88	1.777371601	-6.85
7	260.54	-12.61	425.89	2.322045398	-6.52
6.5	263.65	-9.50	454.38	2.975000058	-6.21
6	266.61	-6.54	484.43	3.746240245	-5.93
5.5	269.45	-3.70	516.12	4.645910706	-5.68
5	272.18	-0.97	549.53	5.684445514	-5.45
4.5	274.79	1.64	584.76	6.872697018	-5.24
4	277.32	4.17	621.89	8.222043304	-5.05
3.5	279.76	6.61	661.02	9.744476725	-4.89
3	282.13	8.98	702.26	11.4526774	-4.74
2.5	284.43	11.28	745.70	13.36007551	-4.60
2	286.68	13.53	791.46	15.48090574	-4.48
1.5	288.86	15.71	839.65	17.83025651	-4.37
1	291.00	17.85	890.39	20.42411581	-4.28
0.5	293.10	19.95	943.80	23.27941541	-4.19
0	295.15	22.00	1000.00	26.41407416	-4.11

5. Sensitivity of the moist adiabat to the surface temperature

a. In your table, increase the surface temperature by 1K
b. Show that the temperature at 12 km has increased by about 3.5 K.
c. Why has the upper troposphere temperature increased more than the surface temperature change
d. What is the ratio of the new e_s at 12 km to the old e_s at 12 km.

This moist adiabatic behavior is why climate models predict the upper troposphere should be warming faster than the lower troposphere and should be getting wetter in a fractional sense than the lower troposphere, effects that researchers are searching for in observations.