**ATS 620**
**Fall 2011**
**Problem Set #9**
**Due 5 December 2011**

**Problem 1** (20 points)

**Stratocumulus-topped marine boundary layer**

The problem works with the observations presented in Shu et al. (2005), based on Research Flight 1 from DYCOMS II (Dynamics and Chemistry of Marine Stratocumulus) and modified for use as model initialization profiles for a GEWEX model intercomparison exercise (findings from which are reported in Zhu et al.).

"Based on observations, the initial thermodynamic profiles are

$$\theta_l = \begin{cases} 289\ \mathrm{K}, & \text{if} \quad z < z_i \\ 297.5 + (z - z_i)^{1/3}\ \mathrm{K}, & \text{otherwise} \end{cases} \qquad (3)$$

$$q_t = \begin{cases} 9.0\ \mathrm{g\ kg^{-1}}, & \text{if} \quad z < z_i \\ 1.5\ \mathrm{g\ kg^{-1}}, & \text{otherwise} \end{cases} \qquad (4)$$

where $\theta_l$ is the liquid water potential temperature; $q_t$, the total specific humidity; $z$, the height above the surface; and $z_i$ = 840 m the base of the inversion, equivalent to the top of the cloud layer. These profiles compare well with the observed vertical thermodynamic structure shown in Fig. 1, which remained nearly constant throughout RF01 (Stevens et al. 2003b)." Surface pressure was 1017.8 hPa.

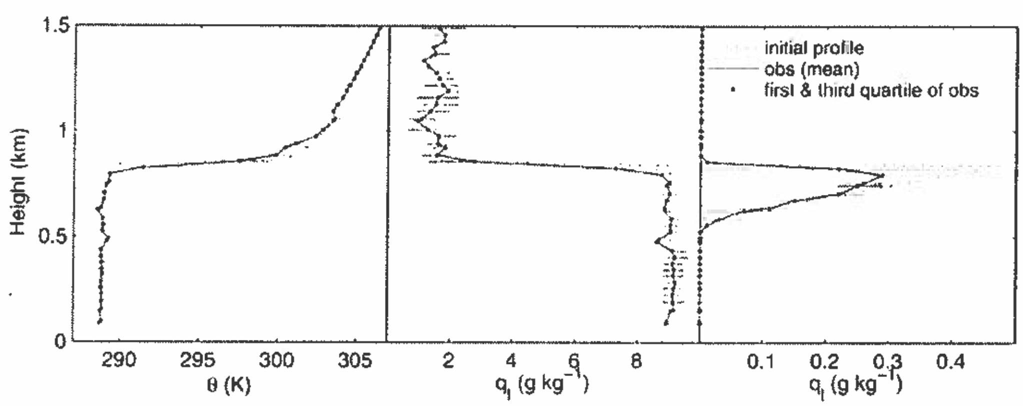



FIG. 1. Observed vertical thermodynamic profiles from RF01 along with profiles used for model initialization (superposed dotted line). Dark lines with dots are the average values over all profiles during the flight. Light horizontal lines indicate the first and third quartiles of the observed values.

See attached figure for all plots

(a) Using your choice of calculation method (a spreadsheet works well), set up a vertical profile (values of height variable $z$) from 0 m to 1000 m, using at least 50 m resolution (i.e., $z_1$=0 m; $z_2$ = 50 m; $z_3$ = 100 m; ....) Plot the vertical profiles of $\theta_l$ and $q_t$.

Equations used are:

Watch units for all calculations

(b) Plot the vertical profile of temperature (K).

$$\theta = T\left(\frac{P_0}{P}\right)^{R/c_p}$$

$$h = Z_2 - Z_1 = \frac{R\bar{T}}{g} \ln\left[\frac{P_1}{P_2}\right]$$

$P_0 = 1000$ hPa

$\bar{T}$ = mean Temp in layer

(c) Plot the vertical profile of relative humidity with respect to liquid water. Where is cloud base?

$$RH = \frac{q_t}{q_{sat}} \times 100\%$$ ← given ($q_t$)

$$q_{sat}(T) = 0.622\left(\frac{e}{p-e}\right) \text{ in } \frac{kg}{kg}$$

$$e = 6.112 \exp\left(\frac{17.67 \cdot T(C)}{243.5 + T(C)}\right)$$

(d) Using the findings from (c), calculate and plot the (idealized) liquid water content (as in panel C in Figure 1) through the depth of the cloud.

$$q_{Liquid} = q_{total} - q_{sat}$$

(e) Assume that this well-mixed boundary layer has 100 cm$^{-3}$ CCN measured at the surface. Convert this to a mixing ratio (number of CCN per kg air).

At sfc, $CCN = 100 \text{ cm}^{-3}$ $\quad T_v = T_{sfc}(1 + 0.61 q_t)$

$\rho_{sfc} = P_{sfc} / (287 \cdot T_v)$ $\quad CCN = CCN/\rho_{sfc}$ in #/kg ← this is constant with height

(f) Using the results from (e) and (d), calculate the average drop radius as a function of height through the cloud layer. $M_{drop} = q_L / CCN$ [g/kg] × 1000 = kg/kg

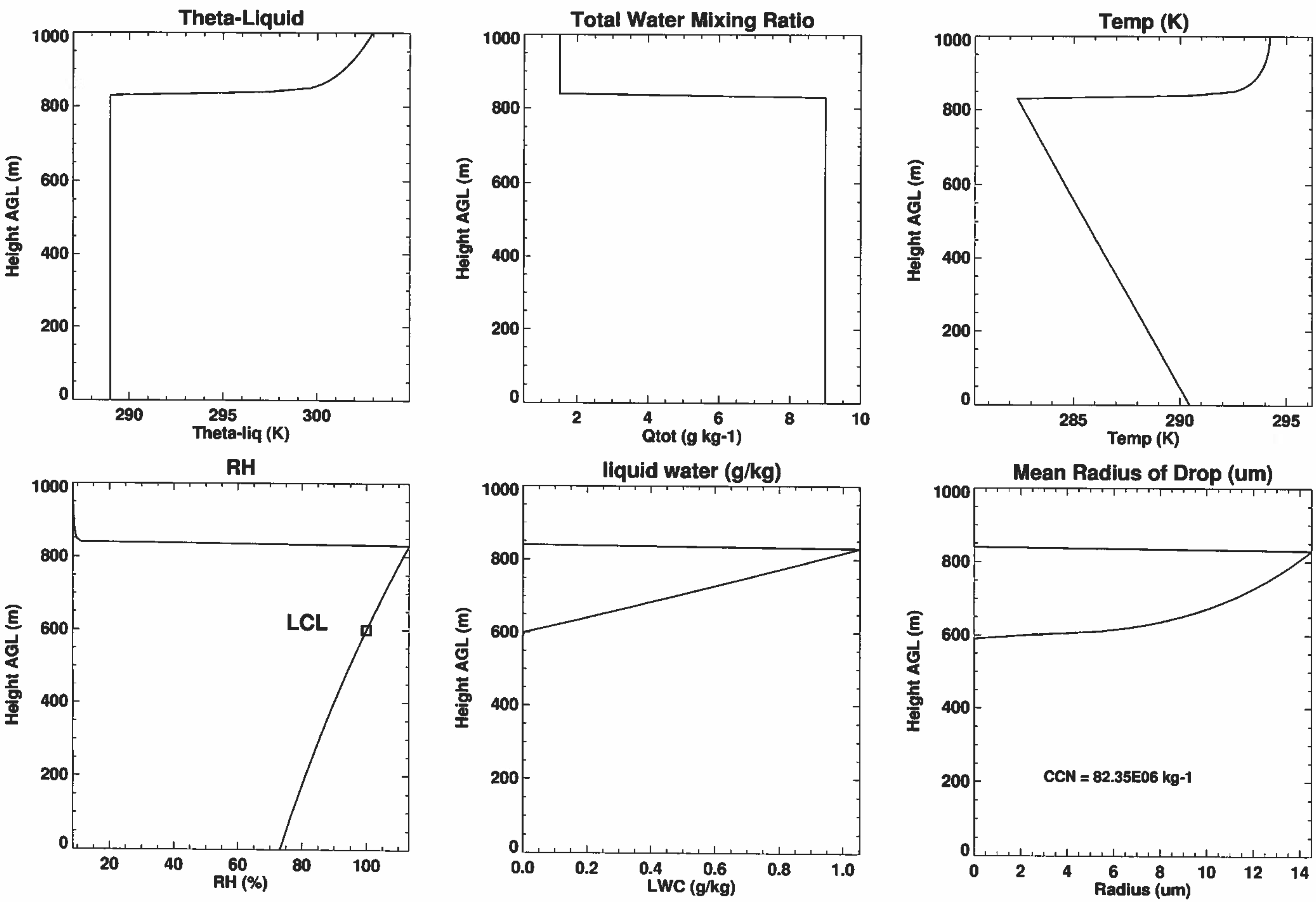
$$r_{drop}[\mu m] = \left[\left(\frac{3}{4\pi}\right)\left(\frac{M_{drop}}{\rho_L}\right)\right]^{1/3} \times 1 \times 10^6 \quad \rho_L = 1000 \frac{kg}{m^3}$$

(g) The measured liquid water profile does not look quite like the one you calculated. Why not? Could you estimate an entrainment rate from the difference, and why or why not?

The liquid water content calculated here is a theoretical maximum amount of liquid. This assumes no entrainment and no supersaturation. Because the clouds investigated here generally have small supersaturations (weak updrafts), we can assume the differences between our calculations and observations are mainly due to entrainment. Therefore, we can estimate entrainment by,

$$\varepsilon = \frac{q_{L,theory} - q_{L,actual}}{q_{L,theory}} \times 100\%$$ where $q_{L,theory}$ is our maximum possible LWC

$$\varepsilon = \frac{\sim 1 \text{ g/kg} - \sim 0.3 \text{ g/kg}}{\sim 1 \text{ g/kg}} \approx 0.7 \times 100\% \approx 70\%$$


Theta-Liquid
Height AGL (m)
Theta-liq (K)
Total Water Mixing Ratio
Qtot (g kg-1)
Temp (K)
RH
LCL
RH (%)
liquid water (g/kg)
LWC (g/kg)
Mean Radius of Drop (um)
CCN = 82.35E06 kg-1
Radius (um)

**Problem 2** (30 points)

See attached figures for these answers.
Also, the plotted skew-T uses the $T_v$ correction.

**Parcel calculations**

This problem works with the environment simulated in the bubble experiments shown in class. Download the text file containing the simulated base state profile from the class website. The file contains 59 vertical levels and the associated temperature (°C), water vapor mixing ratio (g/kg), and height (meters) at each level. Using your programming language of choice write your own script that performs the following calculations.

(a) Calculate the LCL, LFC, CAPE, and EL

$$CAPE = \int_{LFC}^{EL} g \frac{T_{v,p} - T_{v,E}}{T_{v,E}} dz$$

(b) Plot the environmental sounding and associated parcel calculations on a Skew-T log-p diagram. You can use the IDL program given in Homework #2 to plot your sounding.

See plot  Red = $T_v$  Blue = $T_d$  Green = $T_{p,v}$

(c) From class we saw that during peak intensity of the simulated convective bubble our observed profile within the bubble did not match up perfectly with parcel theory. Please explain some possible mechanisms for this mismatch.

(1) Parcel theory does not include entrainment. This means that CAPE is an upper bound

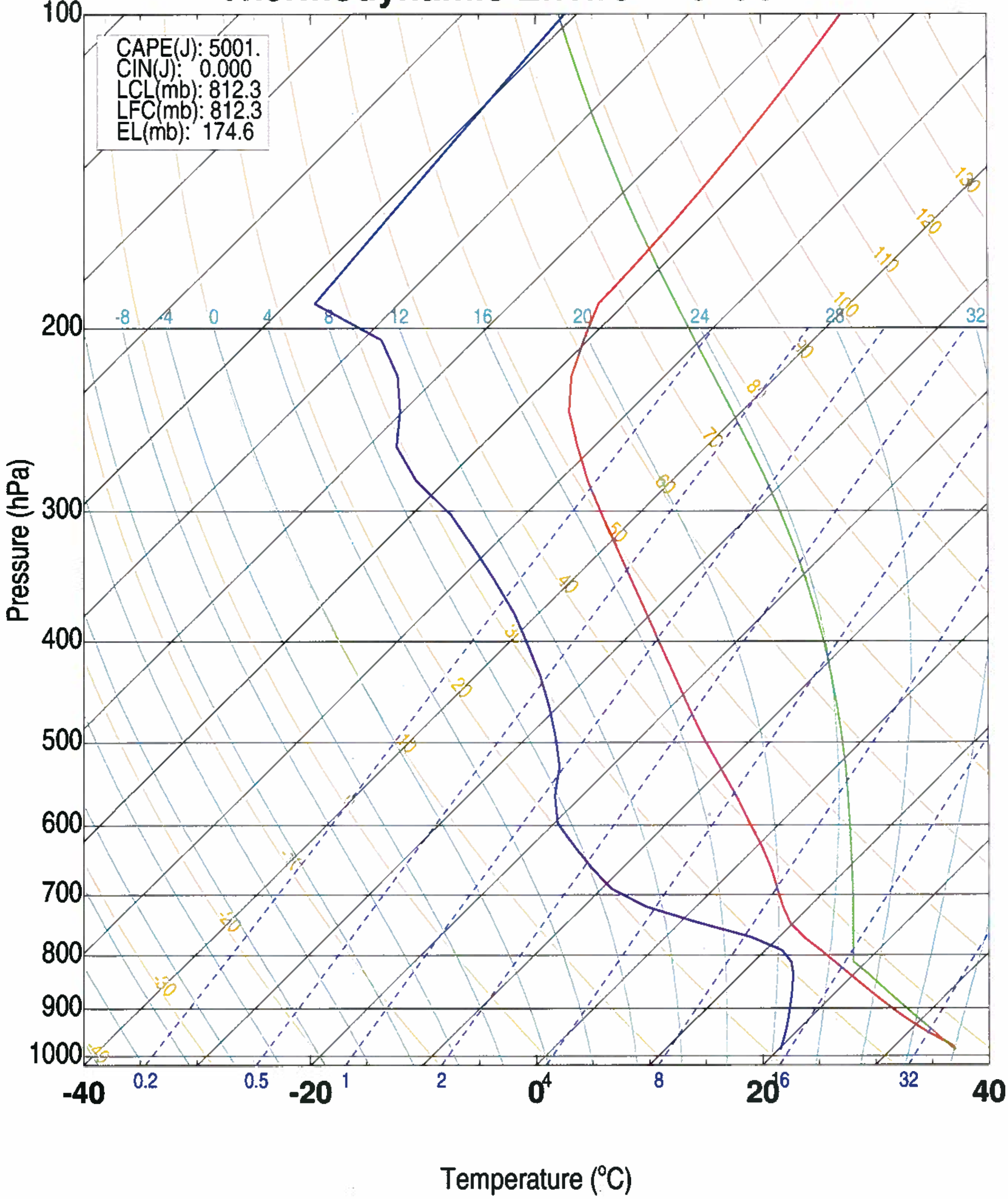
(2) Parcel theory does not include $L_f$, although it is an order of magnitude less than $L_c$, so it is only a minor adjustment

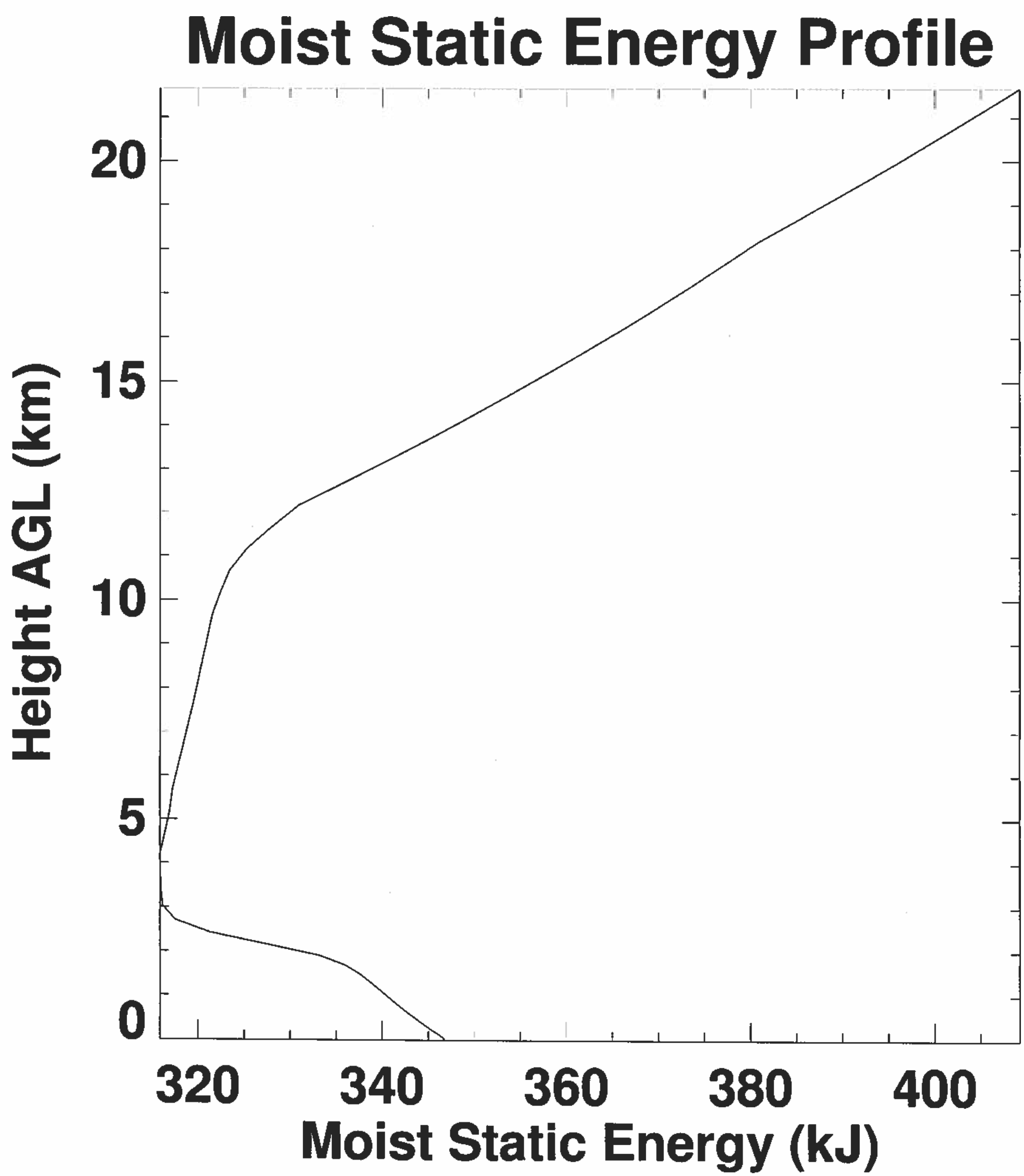
(d) Plot the environmental sounding in terms of moist static energy (MSE). Discuss the physical meaning of MSE with respect to your plot.

See figure.

This MSE profile represents the energetics of the atmosphere. From this initial state, you can see that the lower troposphere and "boundary layer" contain high energy. This means that if a perturbation could lead to convection (i.e. a warm bubble) then the energy would prefer to travel from high to low and the bubble would rise. This would help to lead to a redistribution of energy and this is the purpose of convection.

# Thermodynamic Environment 0 min




Moist Static Energy Profile
Height AGL (km)
0
5
10
15
20
320
340
360
380
400
Moist Static Energy (kJ)