

Chapter One

Review of Atmospheric Thermodynamics (Part II)

Lapse Rate of a Saturated Parcel

-) If an air parcel is saturated, then as it rises and cools the relative humidity will exceed 100%.
 - Any excess vapor will condense and release latent heat back into the parcel.
 - The lapse rate in saturated ascent will be less than the dry-adiabatic lapse rate.

-) The value of the lapse rate in saturated ascent will depend on what assumptions are made as to:
 - whether or not the liquid water remains in the parcel for falls out immediately.
 - whether or not the correction to the specific heat, $c_p v$, for the water vapor is included or ignored.

-) The three different lapse rates for saturated ascent are:
 -) **Reversible moist-adiabatic lapse rate:** This assumes that any condensed liquid remains with the air parcel. The specific heats of the dry air, water vapor, and liquid water are all included.
 -) **Pseudoadiabatic lapse rate:** This assumes that any condensed liquid immediately leaves the parcel. The specific heat of water vapor is still explicitly included.
 - ✓ Since the liquid water leaves the parcel, this process is *irreversible*.
 -) **Saturation-adiabatic lapse rate:** This is the same as the pseudoadiabatic lapse rate except it does not include the specific heat of the water vapor is ignored. This process is also irreversible.

-) The lapse rate for an ascending saturated air parcel is given by

$$\Gamma_s = \Gamma_d - \frac{1 \Gamma \frac{L_v r_s}{R_d T}}{1 \Gamma \frac{L_v^2 r_s}{R_d c_p T^2}} \quad (1.28)$$

where L_v is the latent heat of vaporization, r_s is the saturation mixing ratio, and $\Gamma = R_d/R_v$.

- At colder temperatures, such as those found in the upper troposphere, the moisture content of the air is very small, and there is little latent heating added to a rising air parcel. Thus, in the upper troposphere the moist adiabatic lapse rate approaches the dry adiabatic lapse rate.

Adiabatic Mixing of Air Parcels

) If two air parcels are adiabatically mixed together, many thermodynamics properties of the mixture are a *mass-weighted mean* of their properties before mixing.

- A mass-weighted mean of some property s of two air parcels of masses m_1 and m_2 is given by the formula

$$\bar{s}_m = \frac{m_1}{m_1 + m_2} s_1 + \frac{m_2}{m_1 + m_2} s_2 \quad (1.29)$$

) Formula (1.29) applies exactly if s is specific humidity q , and approximately for mixing ratio r and potential temperature θ .

) If the air parcels being mixed are also at the same pressure (isobaric mixing), then temperature and vapor pressure also mix as mass-weighted means, and (1.29) also applies.

) Adiabatic mixing of two initially unsaturated air parcels may actually result in a saturated air parcel

- This is why we can sometimes ‘see our breath’ on cold days.

) The concept of mass-weighted mean can be applied to a continuous layer of air as follows:

- We imagine the layer consisting of a series of N very thin air parcels, each having a horizontal area A and thickness z_i .
- The mass-weighted mean is given by the sum

$$\bar{s}_m = \frac{\sum_i m_i s_i}{\sum_i m_i} \quad (1.30)$$

- Each parcel has a mass given by $\rho_i A z_i$, so that (1.30) becomes

$$\bar{s}_m = \frac{\sum_i \rho_i A z_i s_i}{\sum_i \rho_i A z_i} = \frac{\sum_i \rho_i z_i s_i}{\sum_i \rho_i z_i} \quad (1.31)$$

- In the limit as the thicknesses of the air parcels go to zero the summation turns into an integral, and the formula for the mass-weighted mean of a layer becomes

$$\bar{s}_m = \frac{\int_{z_1}^{z_2} s dz}{\int_{z_1}^{z_2} dz} \quad (1.32)$$

) Formula (1.32) applies only to those parameters s that do not change as the air parcel moves up or down.

- Thus, it can be applied to specific humidity, mixing ratio, and potential temperature.
- Formula (1.32) cannot be applied to temperature.

) Formula (1.32) can be written as a derivative with respect to pressure. The hydrostatic equation allows us to write $dz = -gdp$, so that (1.32) becomes

$$\bar{s}_m = \frac{\int_{p_2}^{p_1} s g dp}{\int_{p_2}^{p_1} g dp} = \frac{\int_{p_2}^{p_1} s dp}{\int_{p_2}^{p_1} dp} \quad (1.33)$$

where $p = p_1 - p_2$.

) During adiabatic mixing the specific humidity and potential temperature mix as mass-weighted means, and take on constant values in the mixed layer. The mixing ratio also mixes to a close approximation as a mass-weighted mean from (1.33) these values are

$$\bar{q}_m = \frac{\int_{p_2}^{p_1} q dp}{\int_{p_2}^{p_1} dp} \quad (1.34)$$

$$\bar{r}_m = \frac{\int_{p_2}^{p_1} r dp}{\int_{p_2}^{p_1} dp} \quad (1.35)$$

$$\bar{\theta}_m = \frac{\int_{p_2}^{p_1} \theta dp}{\int_{p_2}^{p_1} dp} \quad (1.36)$$

) On a diagram using a logarithmic pressure axis the averages for (1.34), (1.35), and (1.36) can be approximated graphically, by using the *method of equal areas*.

- The mass-weighted mean mixing ratio, r_m , is the isohume that splits the dewpoint profile into two equal areas, as shown in Figure 1.
- The mass-weighted mean potential temperature, θ_m , is the adiabat that splits the temperature profile into two equal areas, as shown in Figure 1

) Adiabatic mixing is why surface temperatures on a windy night will be warmer than on a calm night.

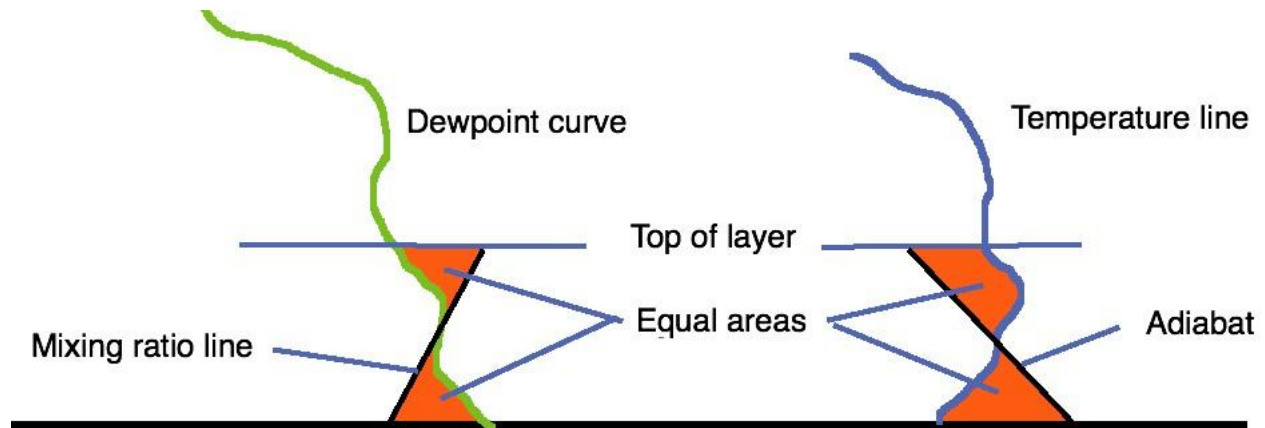


Figure 1: Equal-area method for determining mass-weighted mean of mixing ratio and potential temperature.

Convective Mixing and the Convective Condensation Level

-) Another important mixing process for the atmosphere is *convective mixing*, which occurs when a layer of air is heated from below and the upward and downward overturning of the layer mixes the air parcels.
-) Convective mixing is *not adiabatic*.
- In a convectively mixed layer r still takes on a constant value, but it is not given by (1.36).
 - Instead, r in a convectively mixed layer will be the value of the adiabat through the surface temperature.
 - Mixing ratio in a convectively mixed layer will still be given by (1.35).
-) A morning sounding usually has a surface inversion
-) The *convective temperature*, T_c , is the temperature that the surface must reach in order for an air parcel to ascend dry adiabatically to reach the CCL.

- The convective temperature is found by following a dry adiabatic downward from the CCL to the surface, and reading the temperature at that point.
- Figure 2 illustrates the determination of the convective temperature.

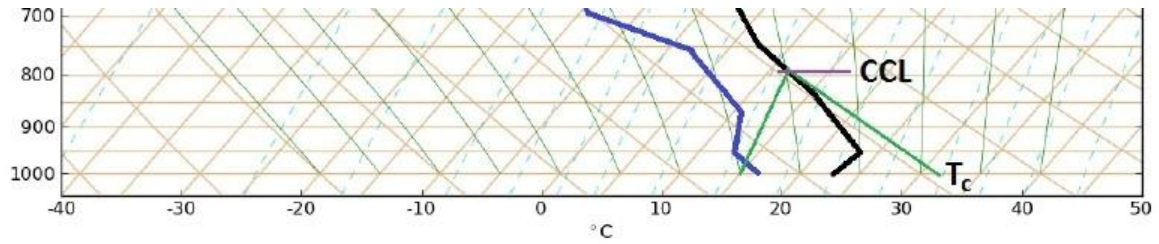


Figure 2: Example Skew-T showing how to find the convective temperature, T_c .