THE UNIVERSITY OF UTAH

ATMOS 5130

Lecture 12

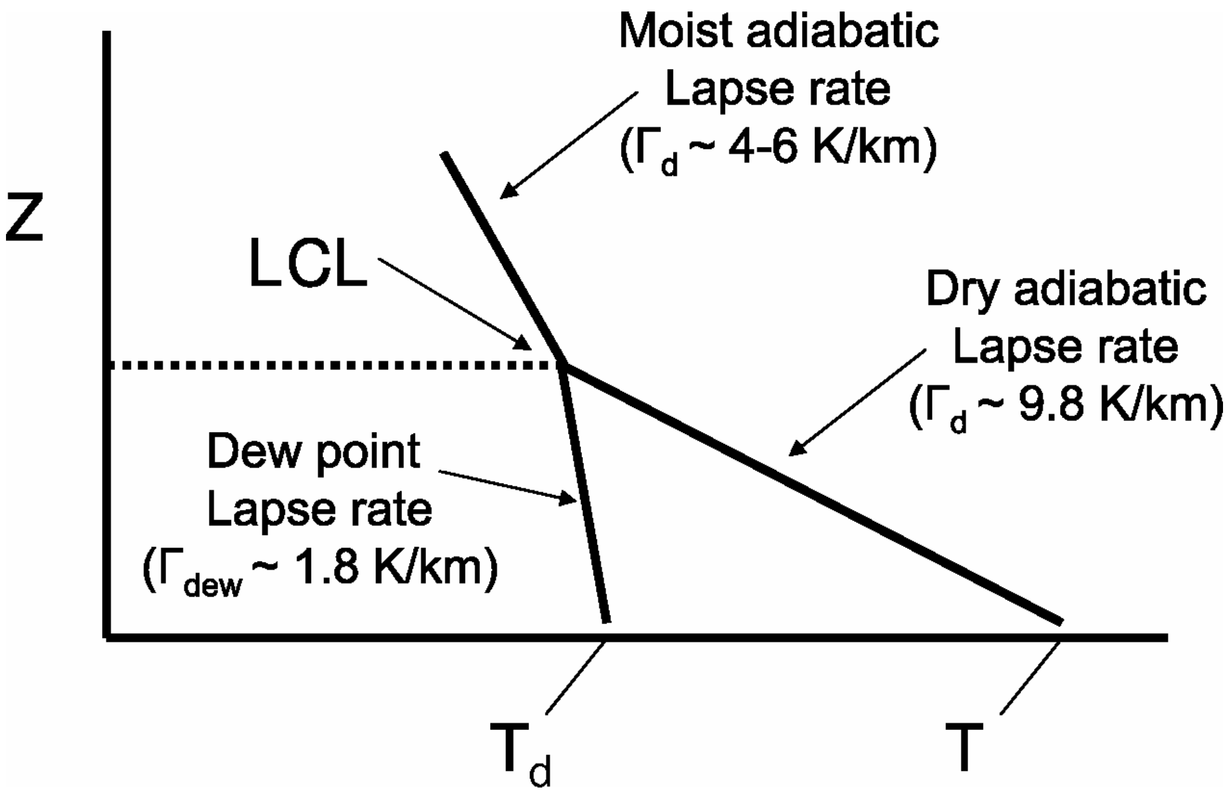
- Moist Processes – Part 3
  - Lifting Condensation Level
  - Equivalent Potential Temperature
    - Review Potential Temperature
    - Isobaric equivalent potential temperature
    - Adiabatic equivalent potential temperature
  - Wet-bulb Temperature
    - Isobaric
    - Adiabatic
    - Normand Rule
    - Wet bulb potential temperature

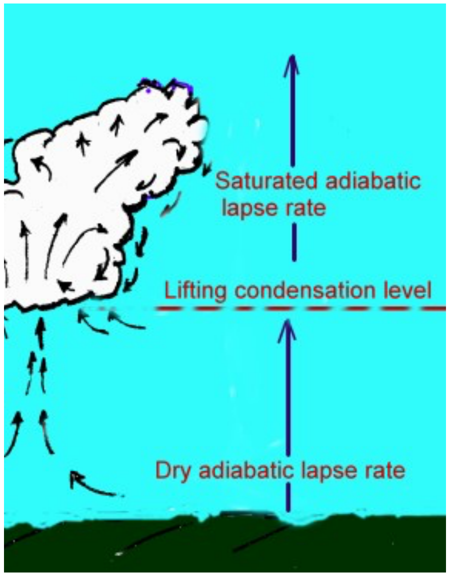
Lifting Condensation Level (LCL)

- The LCL is the height at which the RH of an air parcel will reach 100% when it is cooled by dry adiabatic lifting.
- The RH of air increases when it is cooled, since the amount of water vapor in the air (i.e., specific humidity) remains constant, while the saturation vapor pressure decreases almost exponentially with decreasing temperature.
- If the air parcel is lifting further beyond the LCL, water vapor in the air parcel will begin condensing.
- The LCL is a good approximation of the height of the cloud base on days when air is lifted mechanically from the surface to the cloud base (e.g., due to convergence of air masses).

Forecasting Tool

Lifting Condensation Level (LCL)





Key fact: When a parcel moves through the atmosphere dry adiabatically, its temperature follows a dry adiabat and the dewpoint follows a saturation mixing ratio line. The lifting condensation level (LCL) of the parcel is defined by the pressure level where these two lines intersect. If the parcel reaches the LCL adiabatically, it will become saturated. If it continues to rise adiabatically, its temperature and dewpoint will be the same, both following a moist adiabat.

Lifting Condensation Level Approximations

- It is possible to derive a mathematical relationship between T, p, w, and LCL.
- Yet, it is not easily solved (i.e. using a calculator).
- Thus, approximate relationships are used (and accurate enough) for meteorology. These relationships work over the range T and P commonly observed in the atmosphere.

Forecasting Tool

Lifting Condensation Level Approximations

$$LCL \approx p\, exp[-0.044\, \Delta T_d]$$

Provides approximate pressure of LCL

“Rule of Thumb”

$$LCL\ [km] \approx (T - T_d)/8$$

Provides approximate alitude of LCL

Special Cases of the First Law

$$\delta q = c_v\, dT + p\, d\alpha$$

$$\delta q = c_p\, dT - \alpha\, dp$$

Review

Special Significance in Meteorology!!

Dry Adiabatic Process: (δq = 0) negligible change of heat between the system and environment

$$c_v\, dT = -p\, d\alpha$$

$$c_p\, dT = \alpha\, dp$$

No condensation or evaporation occurs and no heat is added to or removed from the parcel of air, as the parcel moves up and down in atmosphere!

Potential Temperature - Poisson's Equation

IS CONSERVED (no heat exchanged)

$$\frac{T}{T_0} = \left(\frac{p}{p_0}\right)^{\kappa}$$

Review

Set p_0 = 1000 hPa

$$\frac{T}{\theta} = \left(\frac{p}{1000\ hPa}\right)^{\kappa}$$

$$\theta = T\left(\frac{1000\ hPa}{p}\right)^{\kappa}$$

$$\kappa = \frac{R_d}{c_p} \approx 0.286$$

Potential temperature of a parcel at pressure (*p*) is the temperature that the parcel would acquire if **dry adiabatically** brought to 1000 hPa.

Equivalent Potential Temperature

- New Regime – add water

- Now, if condensation does take place, latent heat is released.

- Equivalent Potential Temperature corresponds to the **maximum** potential temperature a parcel could achieve via condensation of **all** the water vapor content, when brought to 1000 hPa. .

- Whereas, the potential temperature (θ) is conserved only for dry adiabatic processes, the equivalent potential temperature is conserved for both dry and moist adiabatic processes

Isobaric Equivalent Potential Temperature (θ_e')

$$\delta q = c_v\, dT + p\, d\alpha$$
$$\delta q = c_p\, dT - \alpha\, dp$$

isobaric

$$\delta q = c_p\, dT$$

$$-Ldw = c_p dT$$

$$-L \int_w^0 dw = c_p \int_T^{T_e} dT$$

w = initial water vapor (Temp T)
0 = remove all water vapor (Temp T_e)

$$-Lw = c_p(T_e - T)$$

$$T_e = \left(1 + \frac{Lw}{c_p T}\right) T$$

Isobaric Equivalent Potential Temperature (θ_e')

$$T_e = \left(1 + \frac{Lw}{c_p T}\right) T$$

Definition: $\theta_e' = T_e \left(\frac{1000\ hPa}{p}\right)^{\kappa}$ Where: $\kappa = \frac{R_d}{c_p} \approx 0.286$

$$\theta_e' = \left(1 + \frac{Lw}{c_p T}\right) T \left(\frac{1000\ hPa}{p}\right)^{\kappa}$$

$$\boxed{\theta_e' = \left(1 + \frac{Lw}{c_p T}\right) \theta}$$

Isobaric Equivalent Potential Temperature (θ_e')

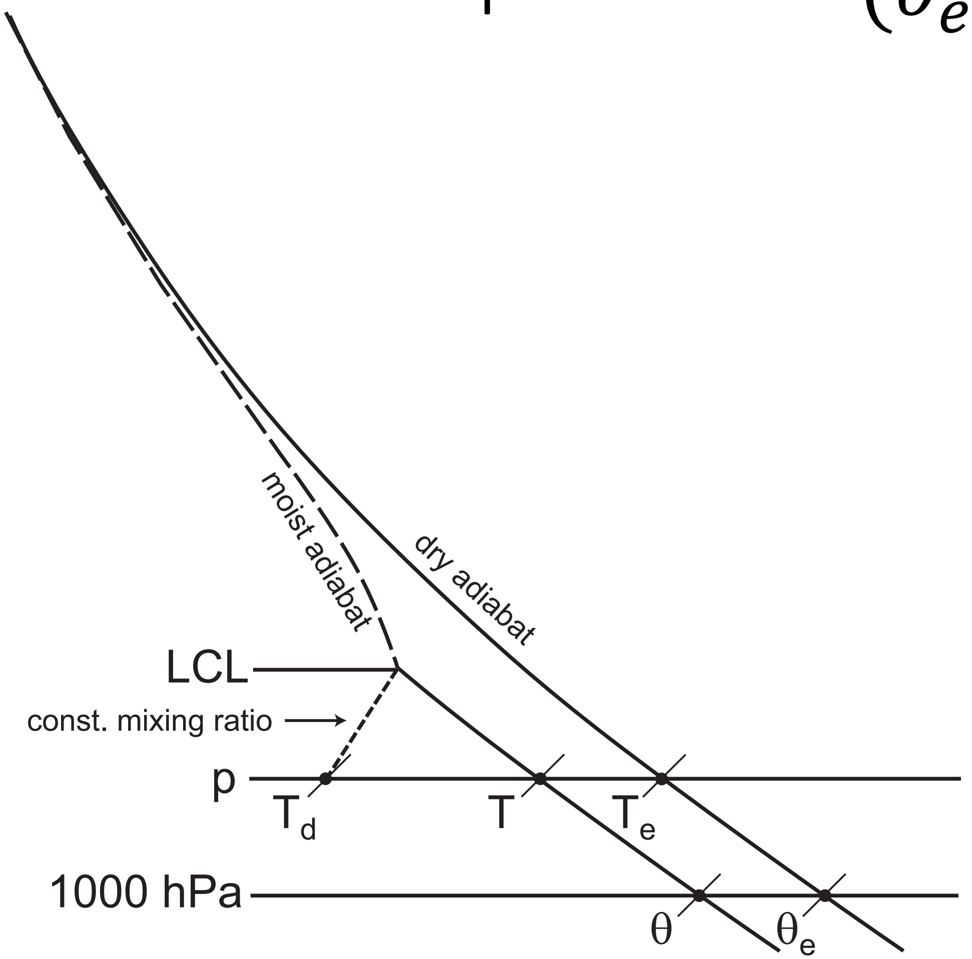
$$\theta_e' = \left(1 + \frac{Lw}{c_p T}\right)\theta$$

- Although mathematically straightforward, this represents a physically impossible process
- You can not warm a parcel isobarically by condensing water from it.
- You can not get isobaric condensation without cooling.

Thus, we introduce the more realistic Adiabatic Equivalent Potential Temperature

Adiabatic Equivalent Potential Temperature (θ_e)

- Temperature that an air parcel would have after undergoing a dry adiabatic expansion until saturation is reached, a saturated adiabatic expansion up to some extremely cold temp ($w \rightarrow 0$). Then a dry adiabatic compression back to 1000 hPa.



Adiabatic Equivalent Potential Temperature (θ_e)

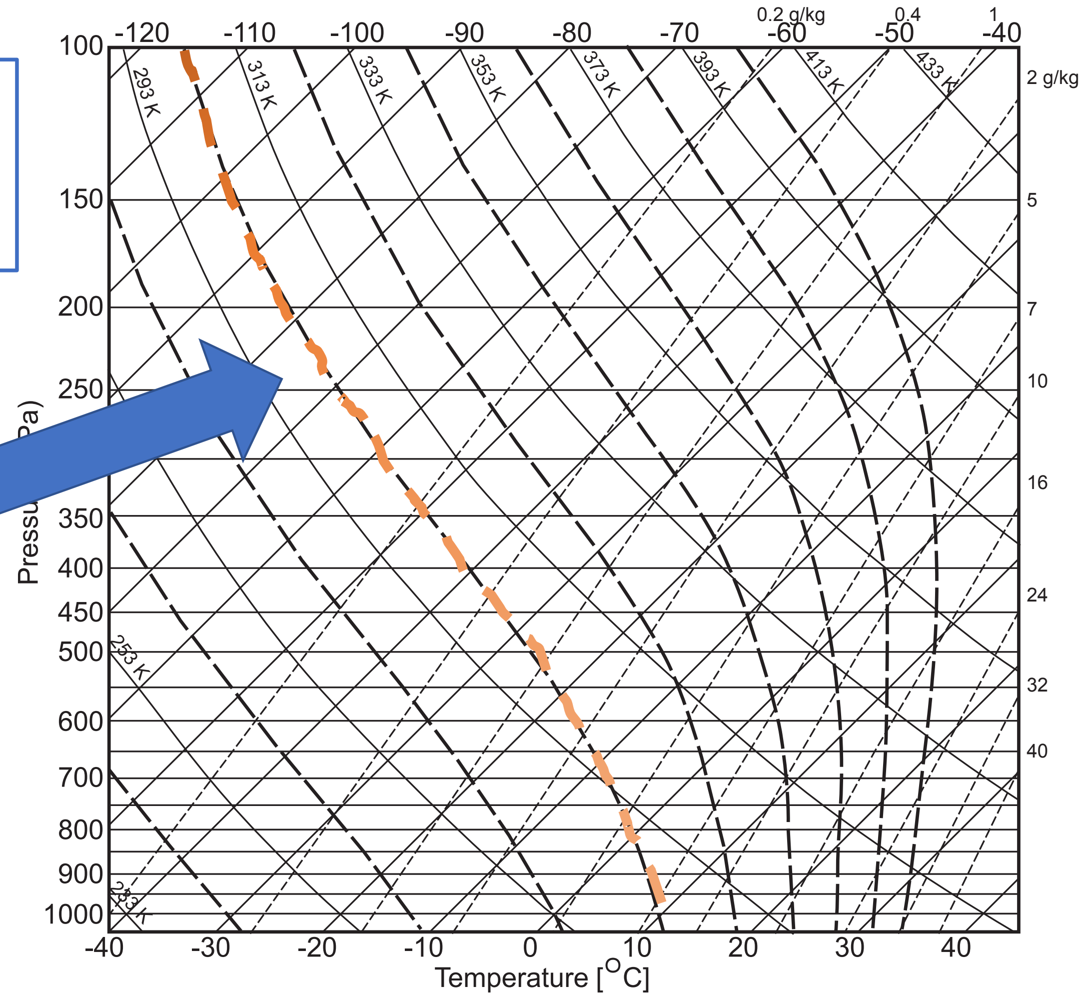
$$\theta_e = \theta \exp\left(\frac{Lw}{c_p T_{LCL}}\right)$$

$$\theta_e' \approx< \theta$$

Adiabatic Equivalent Potential Temperature (θ_e)

$$\theta_e = \theta \exp\left(\frac{Lw}{c_p T_{LCL}}\right)$$

Moist Adiabats are line of constant θ_e for any **saturated** parcel



Wet Bulb Temperature

- Temperature a volume of air attains when water is evaporated into the air exactly to the point of saturation and assuming that all the latent heat of vaporization is supplied by the air

$RH = 100\%$ then $T_v = T$

$RH < 100\%$ then $T - T_v > 0$

$T - T_v$ $\Rightarrow$ Wet Bulb Depression

Temperature is called “dry bulb temperature” in this scenario

What is the difference between dew point temperature and wet bulb temperature?

Difference between dew point temperature and wet bulb temperature

- Dew Point = Cool a volume of air until saturation is reached *<u>while keeping the moisture content constant</u>*

- Wet Bulb = Cool a volume of air until saturation is reached *<u>by evaporating water into it</u>*

$$T_d \leq T_w \leq T$$

When are these three terms equal?

Difference between dew point temperature and wet bulb temperature

- Dew Point = Cool a volume of air until saturation is reached *while keeping the moisture content constant*

- Wet Bulb = Cool a volume of air until saturation is reached *by evaporating water into it*

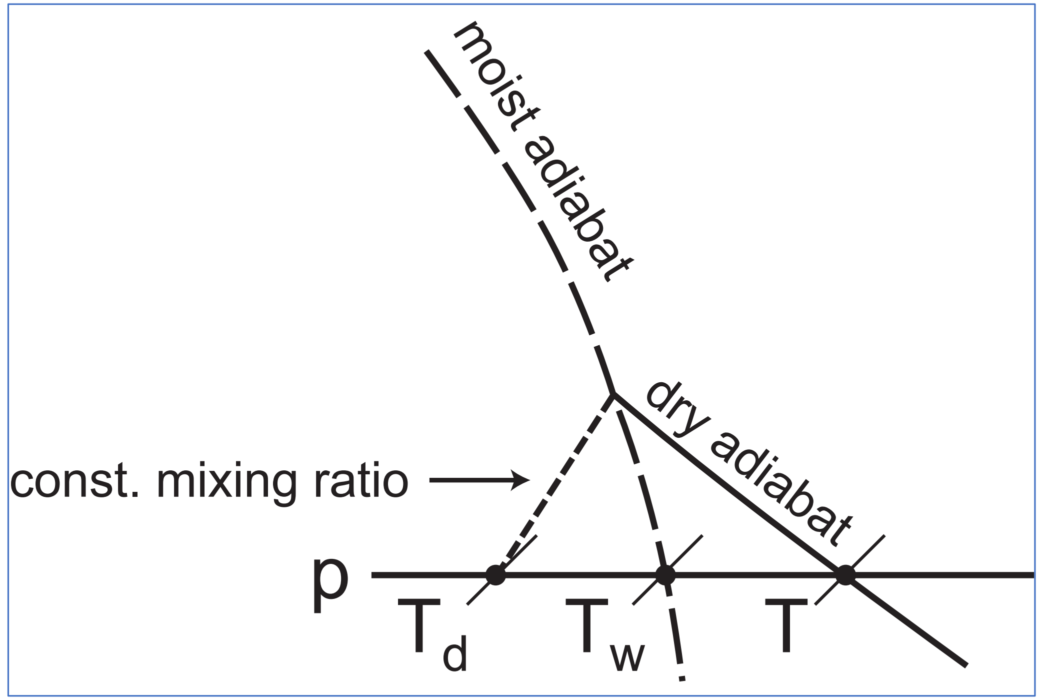
$$T_d \leq T_w \leq T$$

When are these three terms equal? At Saturation

Normand's Rule

Forecasting Tool

- Wet Bulb temp determined by lifting a parcel of air adiabatically to its LCL and then following moist adiabat from that temperature back down to parcel's actual pressure
- Gives you the adiabatic wet bulb temp
- Wet bulb thermometer gives you isobaric wet-bulb temp



Wet Bulb Potential Temperature (θ_w)

- Wet Bulb Temperature a parcel would have after adiabatic compression (or expansion) to the 1000 hPa pressure level.
- Use Normand Rule – find T_w
- Then follow moist adiabat until it intersects 1000 hPa