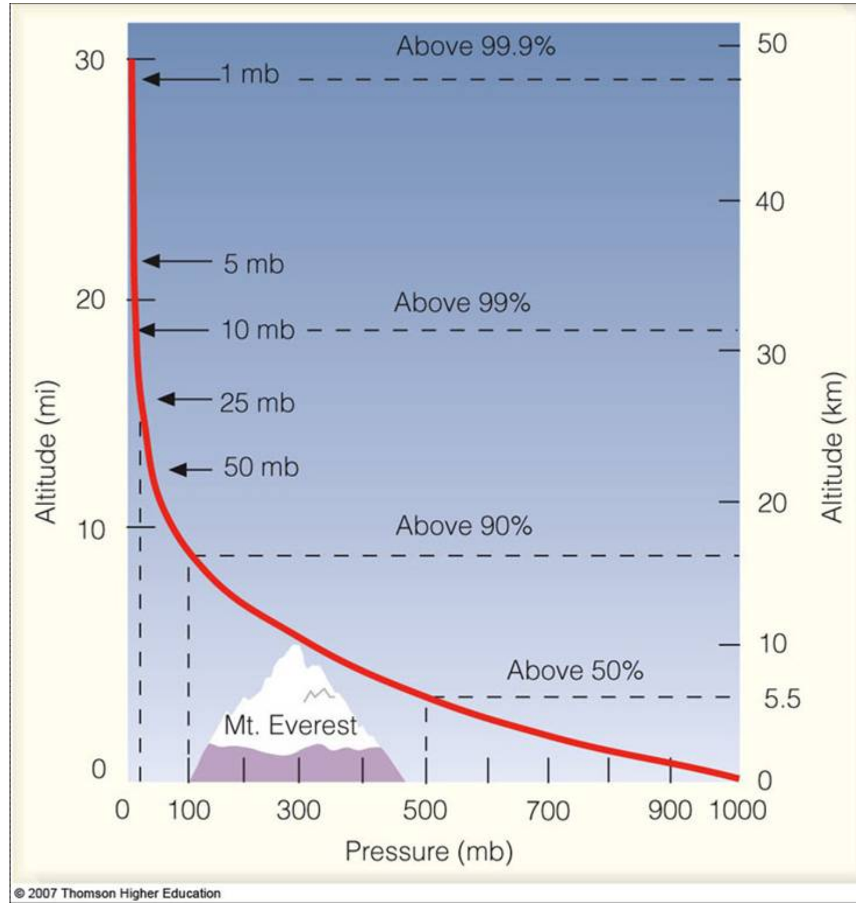
MET 3502/5561
Synoptic Meteorology

Lecture 2: Skew-T Review
(Convection and Cloud formation)

Cloud Formation and Air Parcel

- **Cloud and convection**: are very important weather phenomena.
- ***<u>What does a cloud consist of?</u>***
- **Cloud formation**: starts from the movement of an air **parcel.**
- A ***Parcel*** is a mass of air that moves from one point to another, perhaps changing its properties in reaction to its surroundings.
- **The parcel's pressure changes to the pressure of its surroundings, but its temperature & humidity change according to adiabatic process.**



Vertical Profile of Pressure

The first law of thermodynamics

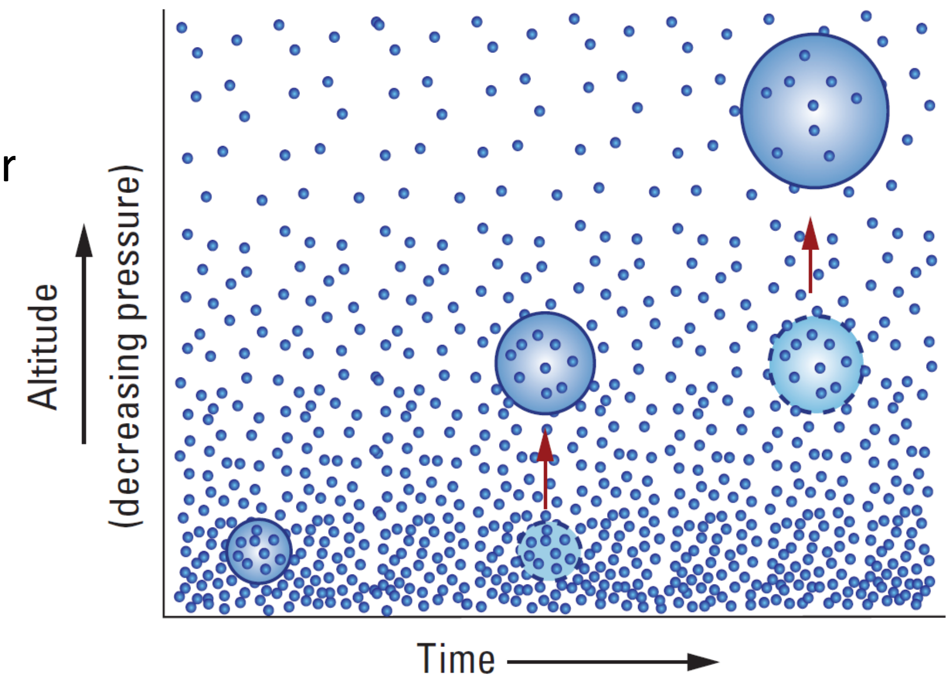
- ***Heat is a form of energy***
- ***Energy is conserved***
  - dQ =dU + dW (Q is heat added or lost, U is internal energy, W is work done or being done)
  - dU=Cv dT (Cv is specific heat at constant volume, T is temperature)
  - dW = p dV (V is volume per unit mass)

Adiabatic Process

- **Definition**: A change in temperature of the air parcel without gain or loss of heat from outside the air parcel.
- **Significance**: Adiabatic processes are very important in the atmosphere, and adiabatic cooling and heating air is the dominant cause of cloud formation.
- **Consequences**: Think about how the air parcel changes temperature when it rises or subsides in adiabatic processes.

Rising: pressure decreases, so the air parcel will expand, which means air molecules are doing work as they expand. Because this is an adiabatic process, no heat in & out, so the work being done are from the air molecule's kinetic energy, which means the air parcel's temperature must drop.

Subsiding: temperature increases



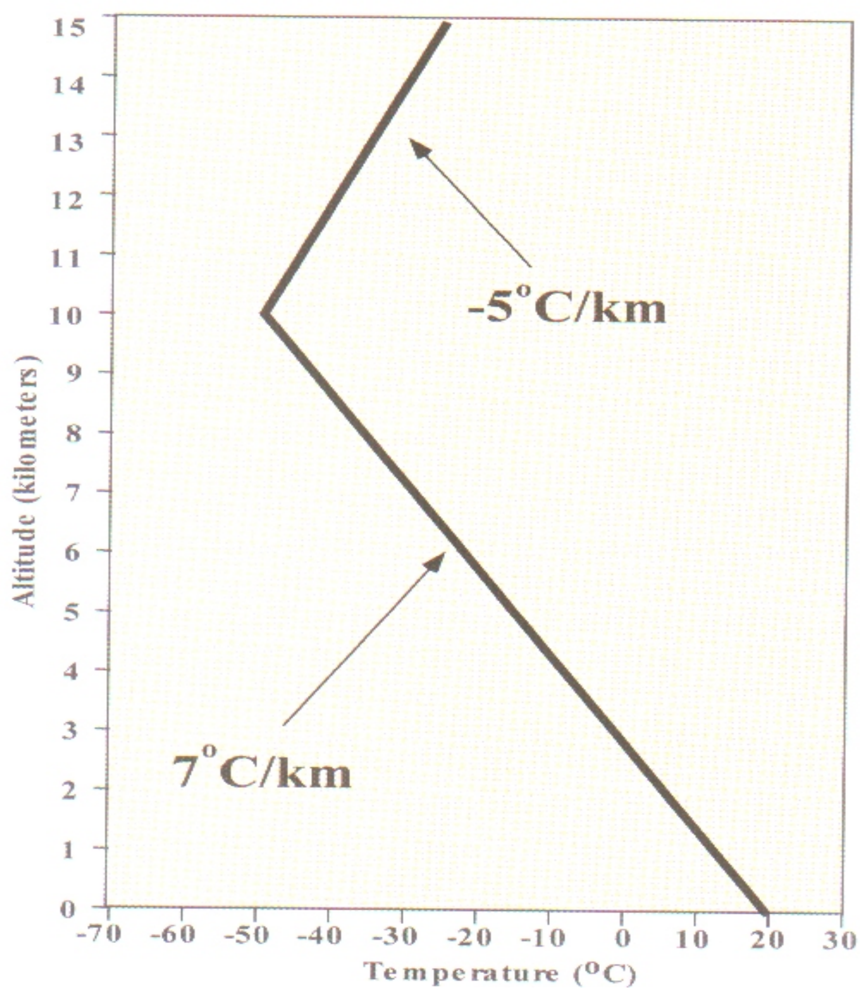
Parcel Thermodynamics

- ***Adiabatic Process***: No heat added or removed, but temperature and/or **water mixing ratio change (*Why?*)** as the parcel
  - Expands into lower pressure using internal energy to do work
  - Is compressed by higher pressure converting work done by its surroundings into internal energy

Lapse Rate

- **Environmental lapse rate**:
  - The change in temperature of still air (not rising or subsiding). Standard air: 6.5 C/km, but it varies.
- **Dry adiabatic lapse rate**:
  - The rate of temperature change of unsaturated rising or subsiding air when no condensation is taking place. ~ 9.8 C/km. **Dry adiabatic lapse rate applies to rising or sinking air when the relative humidity is below 100%.**
- **Saturated (or Moist) adiabatic lapse rate**:
  - The rate of temperature change of in a parcel of air rising (or subsiding) pseudo-adiabatically. Pseudo-adiabatic means all the condensed water vapor is assumed to fall out immediately as the parcel rises adding its latent heat of condensation to the parcel, slowing the cooling rate compared to the dry adiabatic process. **Saturation adiabatic lapse rate applies to rising or sinking air when the relative humidity is 100%.** ~ 5-6 C/km.

Lapse Rate Plot



Parcel Theory (1)

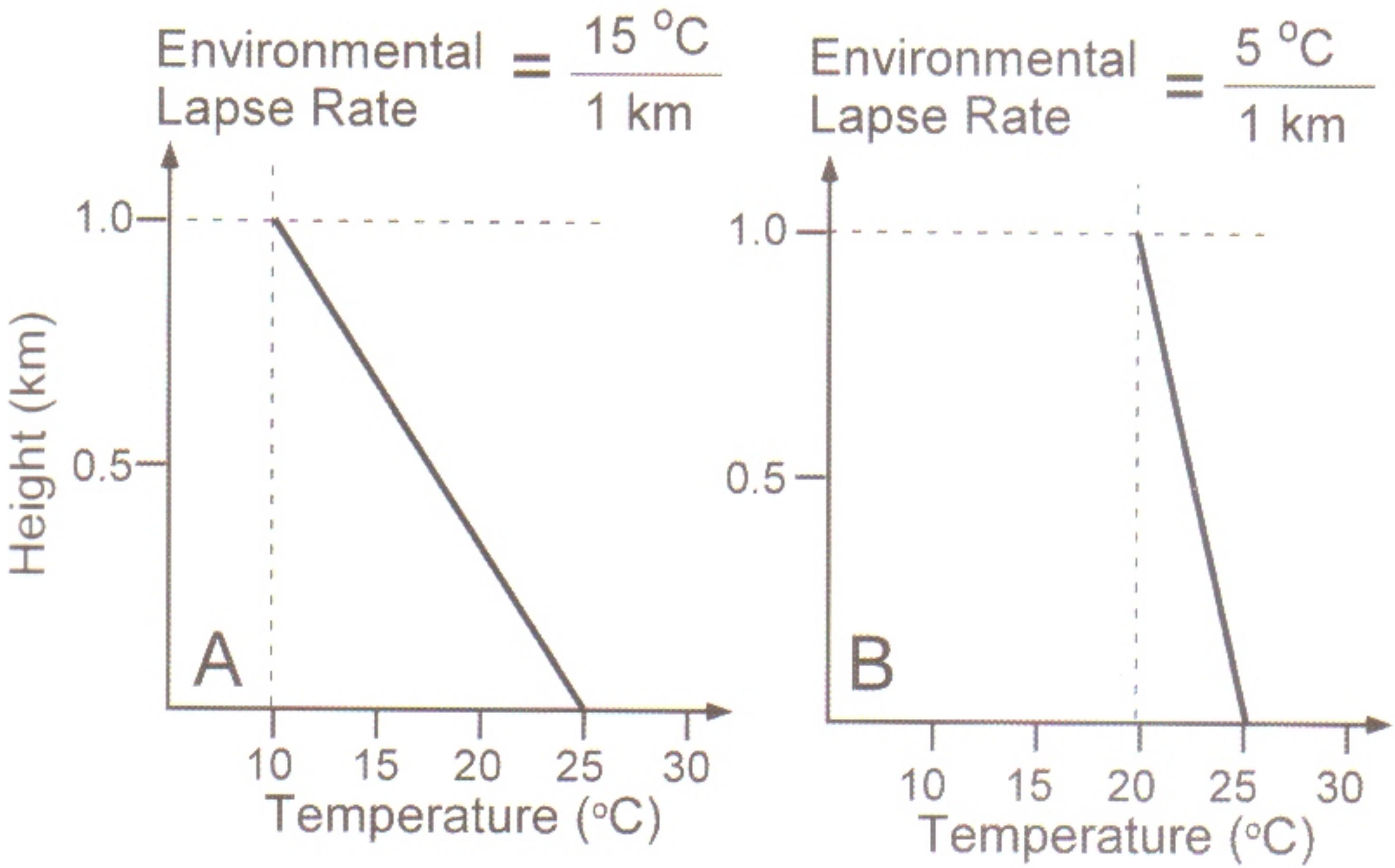
- **What is it for?** It is an assumption (very close to reality) to evaluate and analyze the stability of the atmosphere (if convection will happen).
- **Vertical displacement & temperature change:** The temperature of a small parcel of air is assumed to change adiabatically. If the parcel is unsaturated, its temperature is assumed to change at dry-adiabatic lapse rate: 9.8 °C/km. If the parcel is saturated, the change will occur at saturation-adiabatic lapse rate: about 6°C/km.
- **Positive buoyancy force:** After the vertical displacement, if the parcel temperature is warmer than the surrounding air, it is less dense than the surrounding air and is subjected to a **Positive buoyancy force** and will be accelerated upward.
- **Negative buoyancy force:** After the vertical displacement, if the parcel temperature is colder than the surrounding air, it is more dense than the surrounding air and is subjected to a **negative buoyancy force** and will be pushed downward until it returns its initial or equilibrium position.

Parcel Theory (2)

Physical processes in actual convection which are not counted for by the parcel theory:

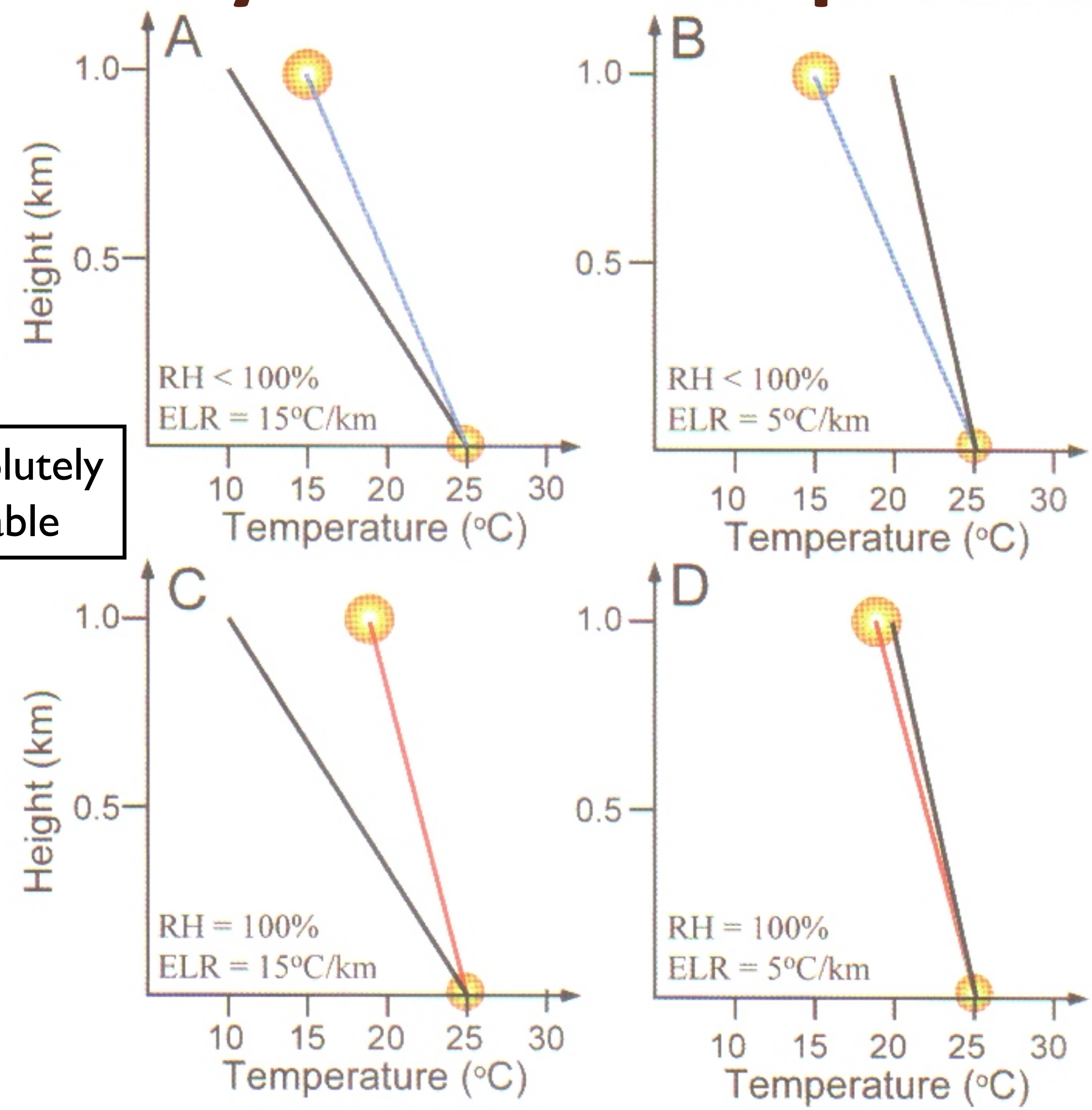
- Mixing of the parcel with environment.
- Cooling from evaporation and/or melting of falling precipitation.
- Drag of precipitation on upward vertical motion.

Two Different Lapse Rates



Stability for These Lapse Rates

Absolutely unstable



Absolutely Stable

Conditional Instability

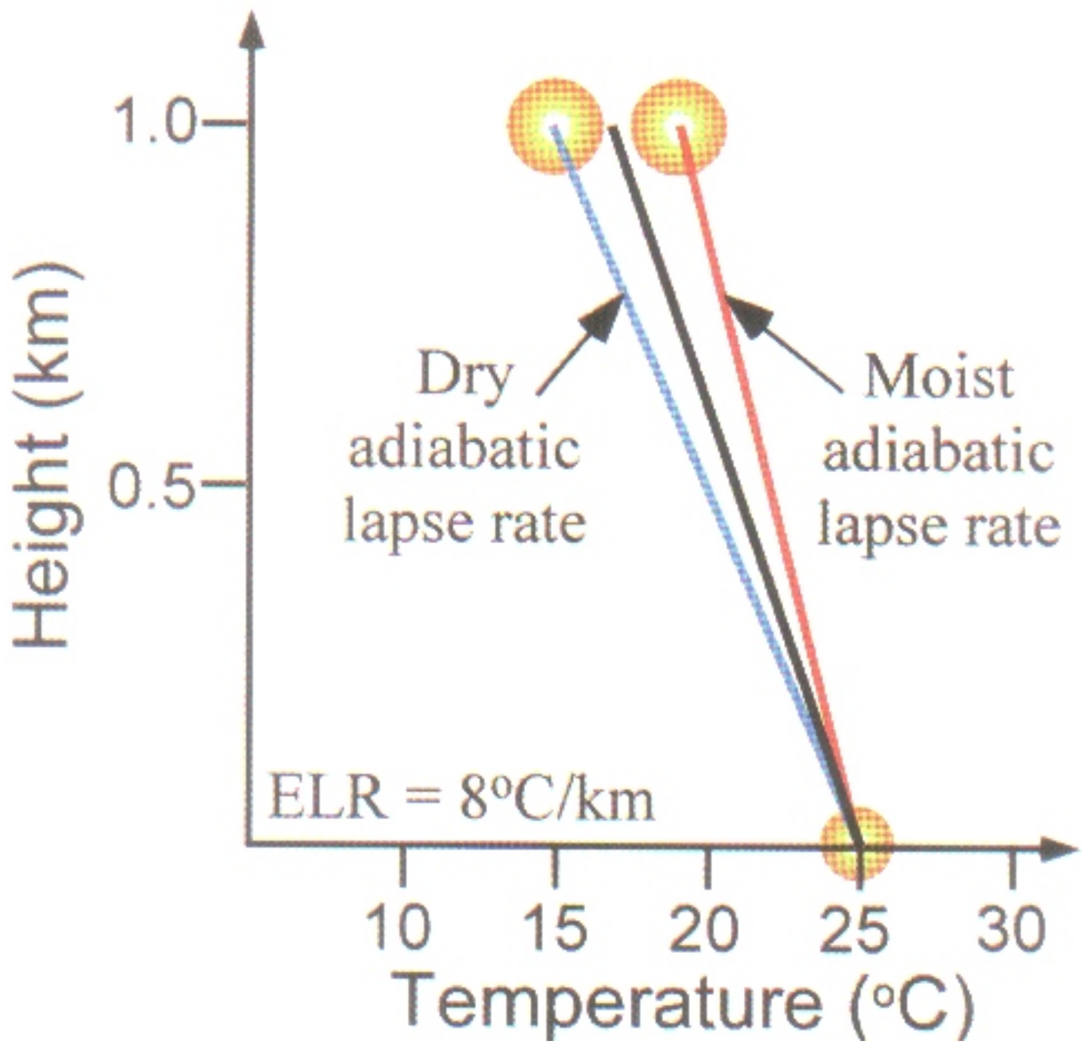


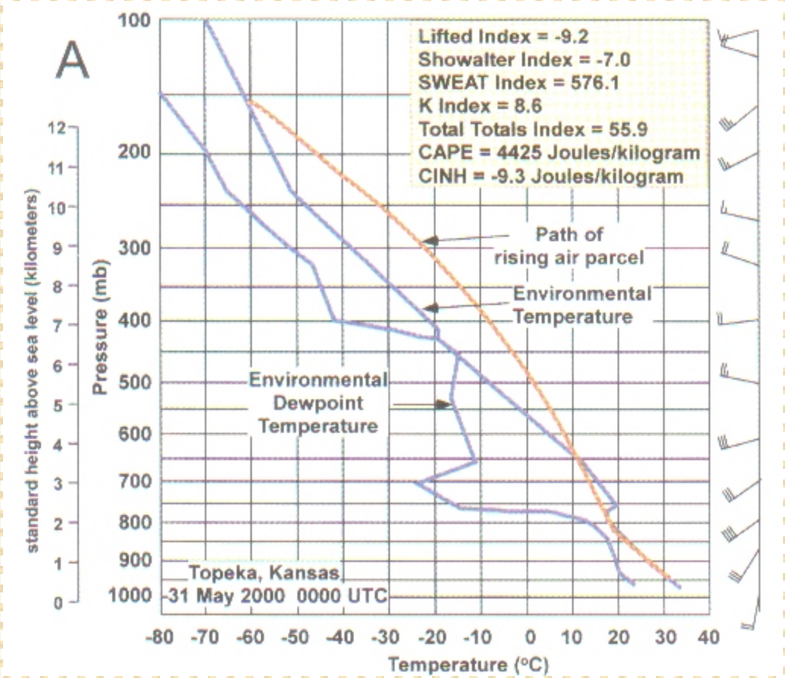
Table 5.1 Summary of Categories of Atmospheric Layer Stability

Environmental Lapse Rate (ELR)	Stability
ELR > 10°C/km	Unstable
6°C/km < ELR < 10°C/km	Conditionally unstable (Unstable if saturated, stable if unsaturated)
ELR < 6°C/km	Stable
ELR = 10°C/km	Neutral if unsaturated, unstable if saturated
ELR = 6°C/km	Neutral if saturated, stable if unsaturated

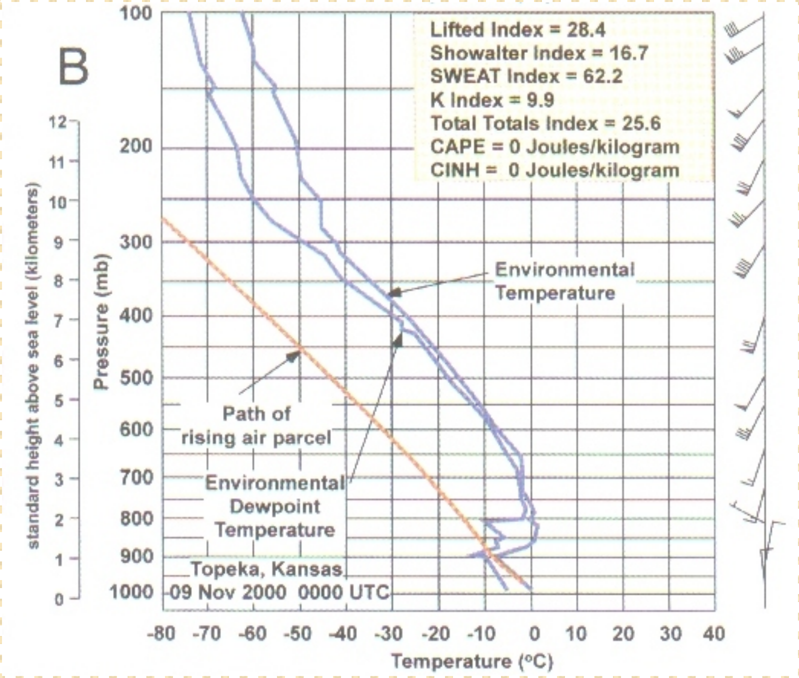
Note: The moist adiabatic lapse rate actually may vary from 4 to 10 ^{o}C km^{-1}

Some Representative Soundings

Unstable



Stable



Thermodynamic Diagrams

A thermodynamic diagram is a graph that shows the relationship between five atmospheric properties: (*Please review these definitions in the "A short course in cloud physics" book ch1-4 handout!*)

Pressure (millibars)
Temperature (°C)
Potential temperature (θ °C – must be converted to K)
Equivalent Potential Temperature (θe °C – must be converted to K)
Saturation Mixing Ratio (g/kg)

Since pressure rapidly decreases with altitude, thermodynamic diagrams are used most commonly to display vertical profiles of atmospheric properties, as measured with rawinsondes.

Wind speed and direction are also displayed as separate variables

Thermodynamic diagrams

Allow meteorologists to determine and quantify:

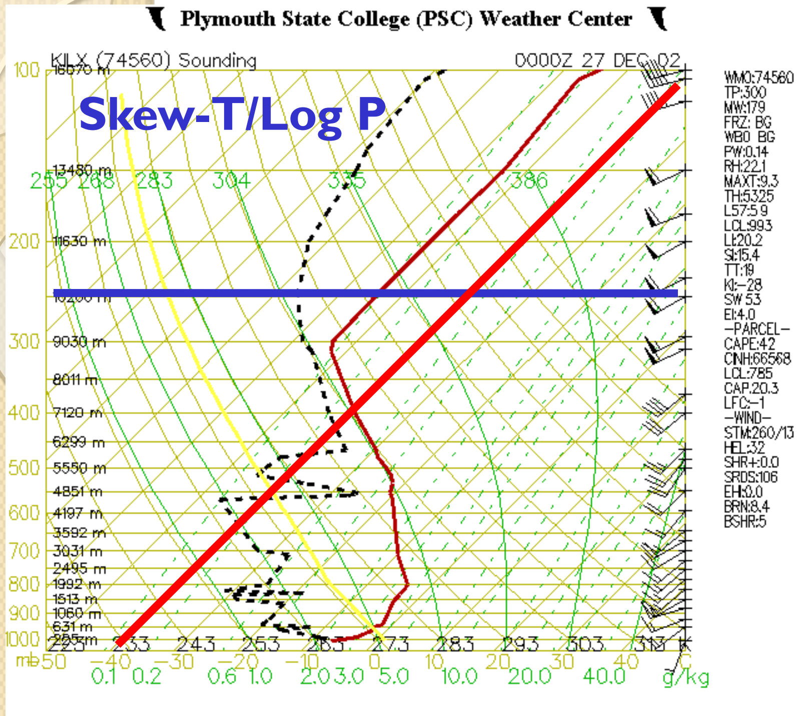
1) Atmospheric Stability
2) Cloud layers
3) Height of the tropopause
4) Cloud top temperatures
5) Frontal zones
6) Vertical wind shear
7) Helicity
8) Location of inversions
9) Precipitation type
10) Height of the freezing level
11) Locations of upper level fronts

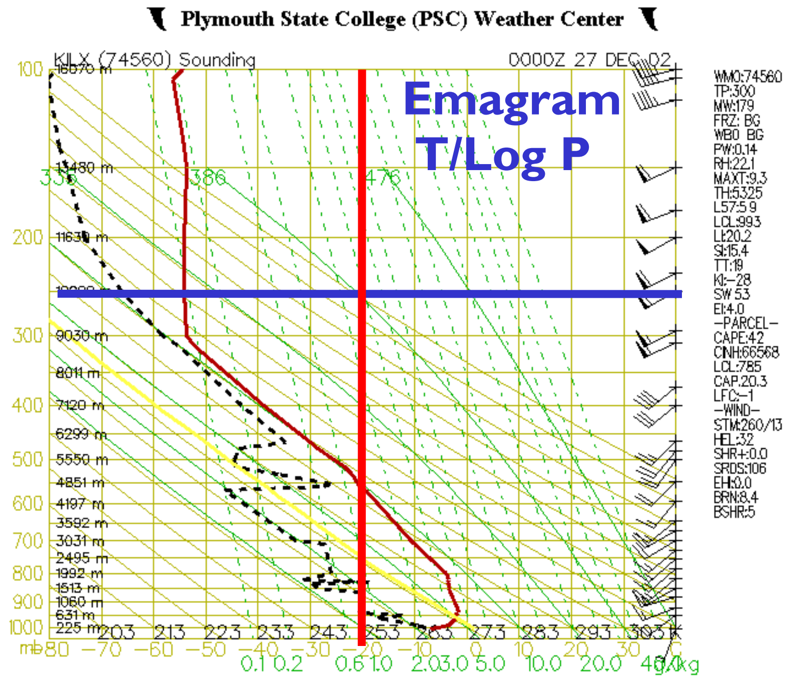
Thermodynamic diagrams

Emagram
Tephigram
Stuve Diagram
Skew-T Log P diagram

- All express the same physical (thermodynamic) relationships
- All show isobars, isotherms, saturation mixing ratio lines dry adiabats, and saturation adiabats.

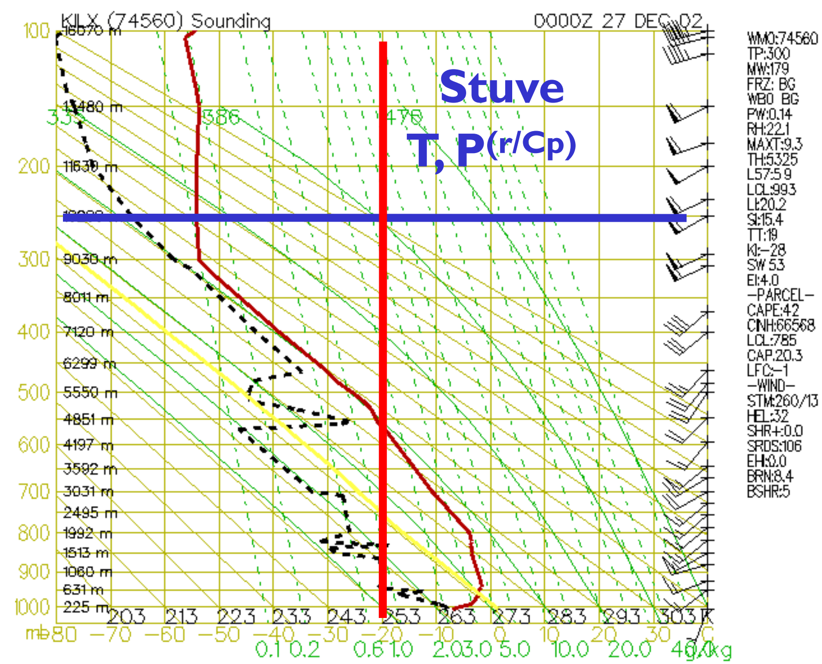
Difference between these diagrams is the choice and orientation of the two fundamental coordinates, which can be any of the five variables or variants of them.





Three common diagrams used in the United States are:

The Skew-T/Log-P
The Emagram
The Stuve Diagram



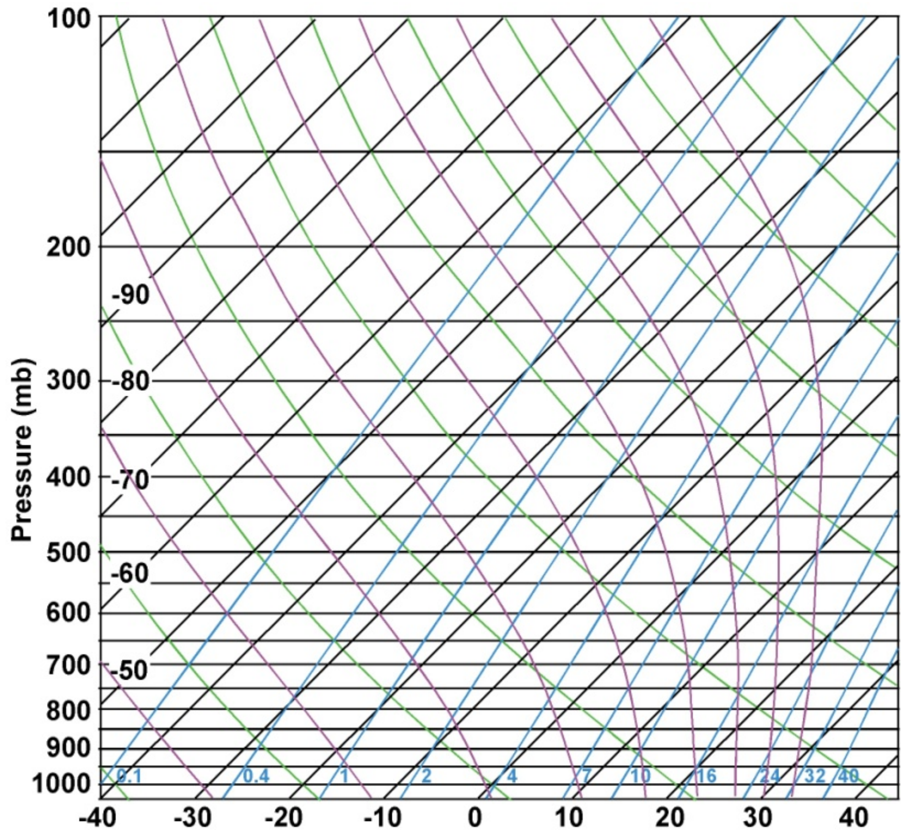
Advantages of Skew-T, Log-P diagram:

- Most of the important isopleths are straight rather than curved.
- The angle between the adiabats and isotherms is large enough to facilitate estimates of the stability
- The ratio of area on the diagram to thermodynamic energy is the same over the whole diagram
- Vertical coordinate proportional to height
- An entire sounding to levels in the stratosphere can be plotted on one chart
- Skew-T Manual online in our class webpage under lecture 2 (http://faculty.fiu.edu/~hajian/MET3502/Skew-T.pdf).

•The Skew T-Log P diagram was selected by the Air Weather Service as the most convenient thermodynamic diagram for general use.

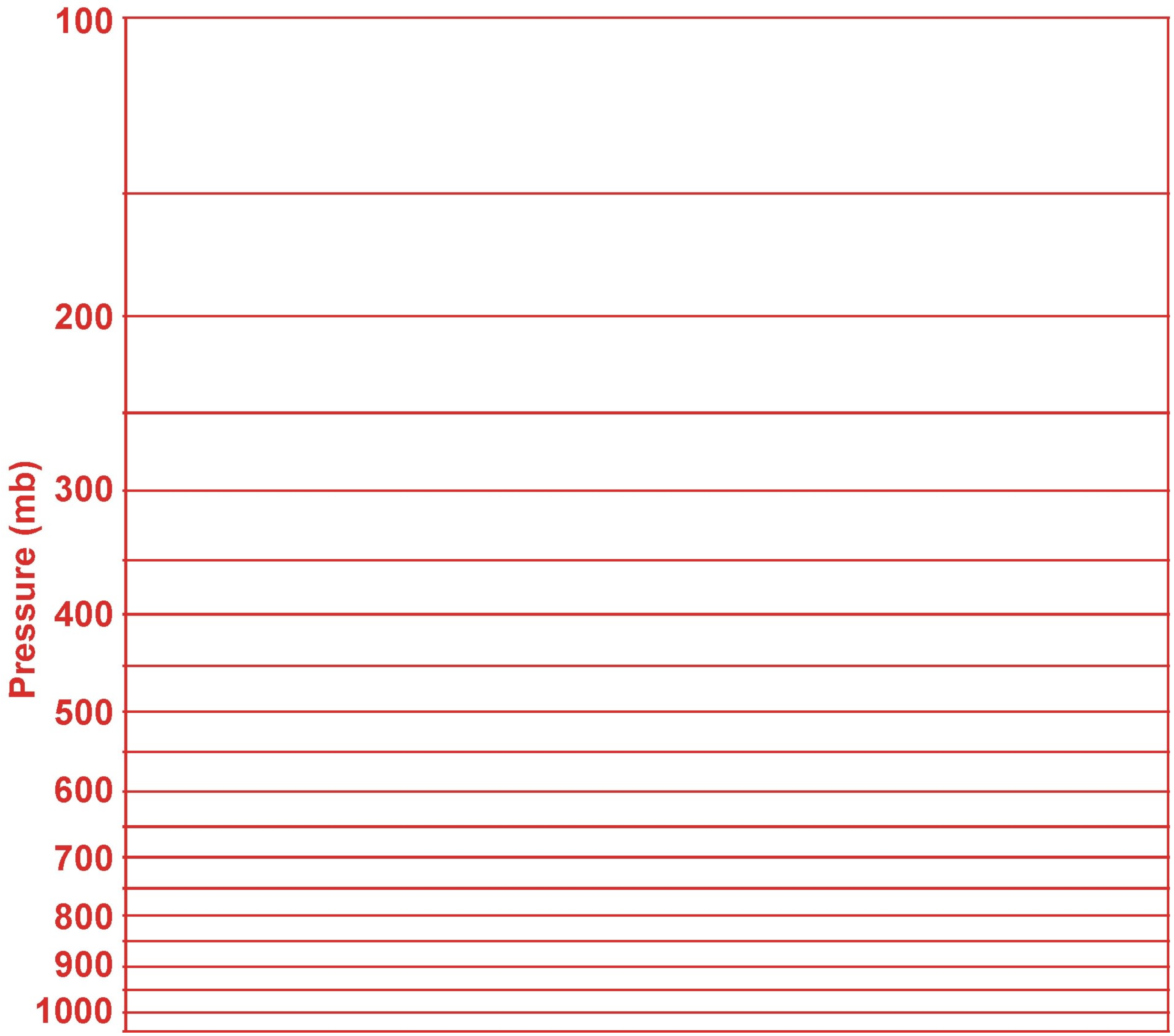
• The most commonly used diagram in the United States.

• Current soundings, model soundings, and archived soundings are available in Skew-T Log-P form at several websites and in analysis programs such as GARP.

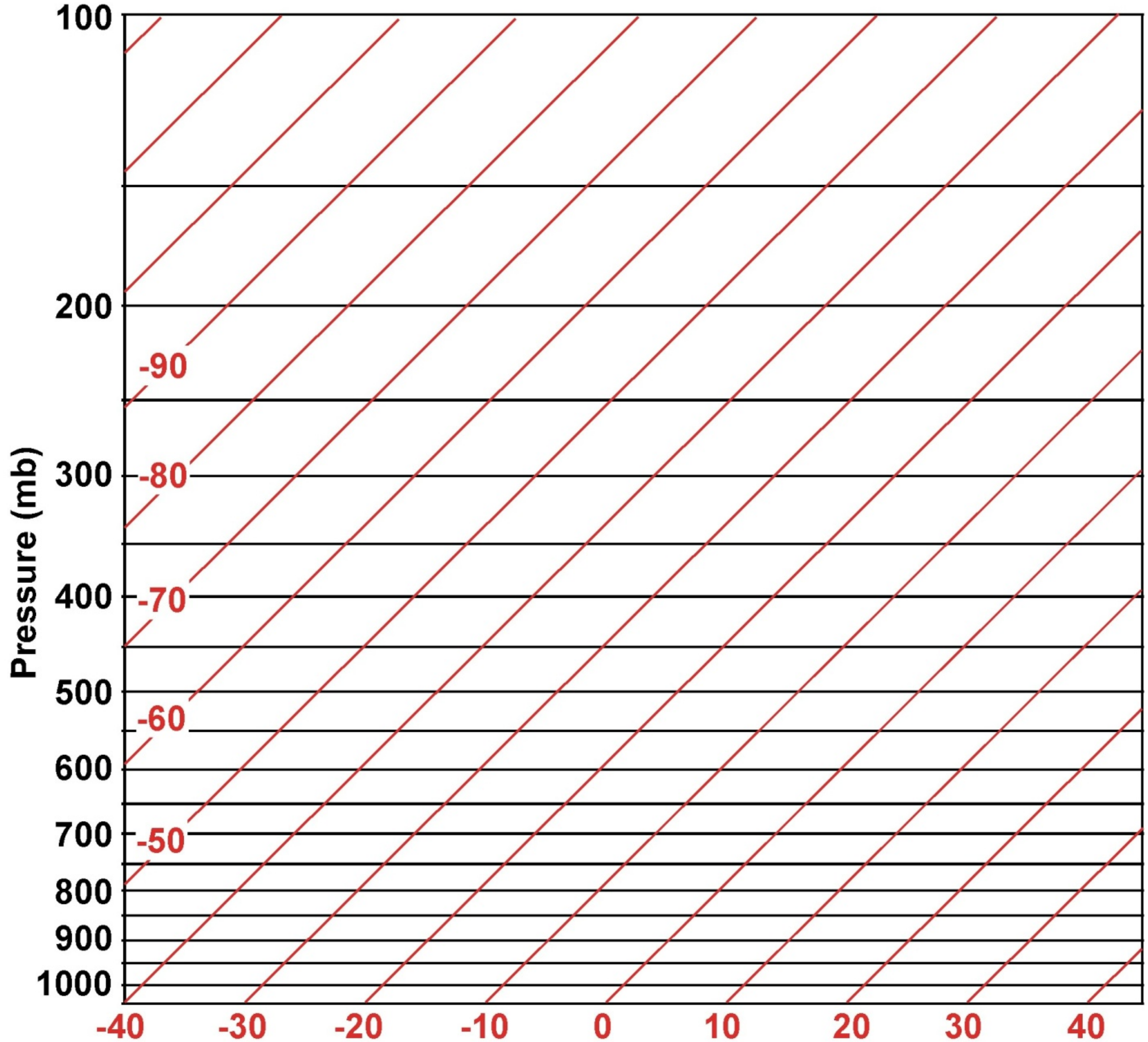


Isobars: Pressure (mb) is the vertical coordinate on a Skew T-Log P

Note that pressure is scaled logarithmically
– making the diagram correspond to the atmosphere

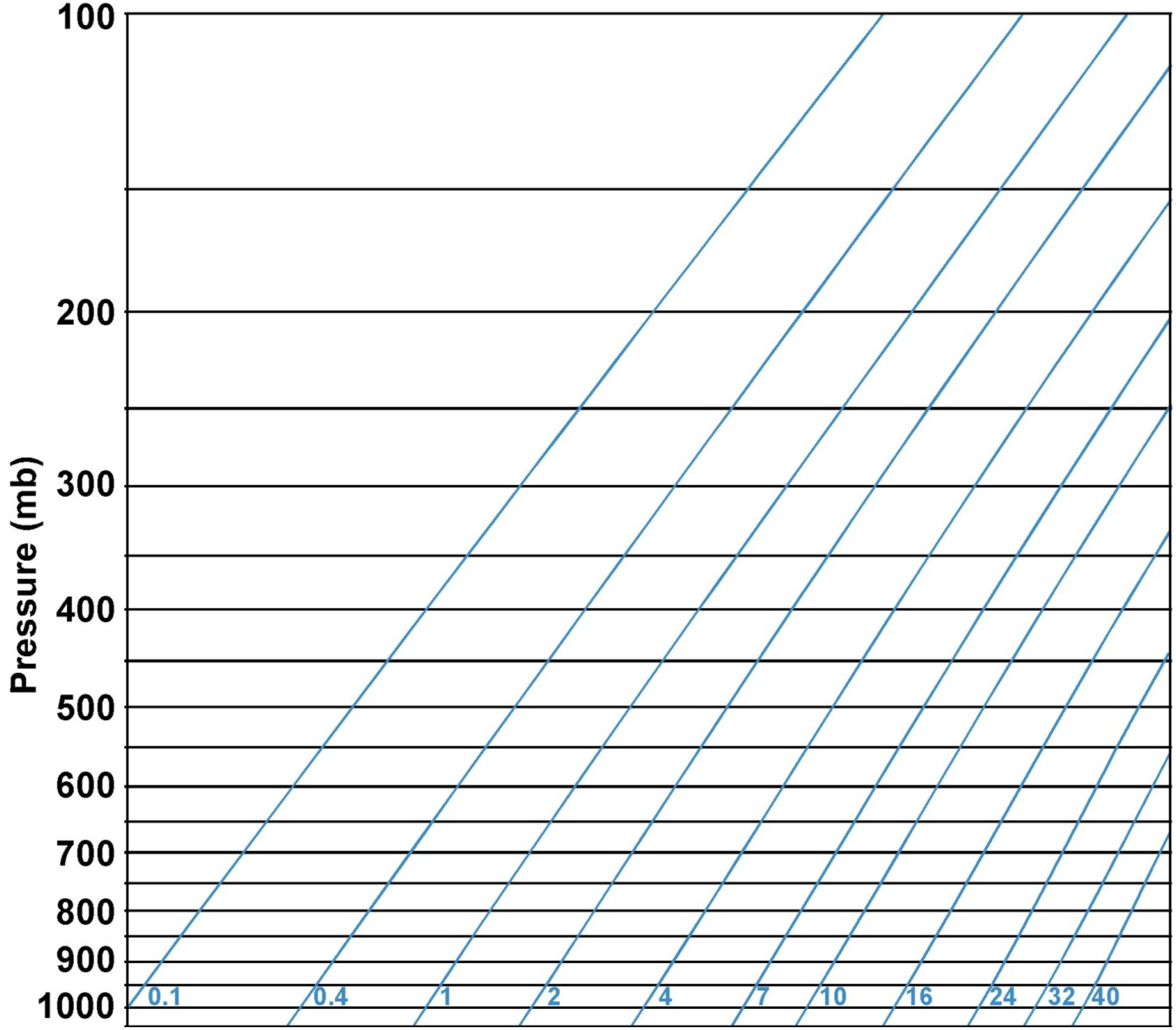


Isotherms: Temperature lines are skewed and labeled in Celsius

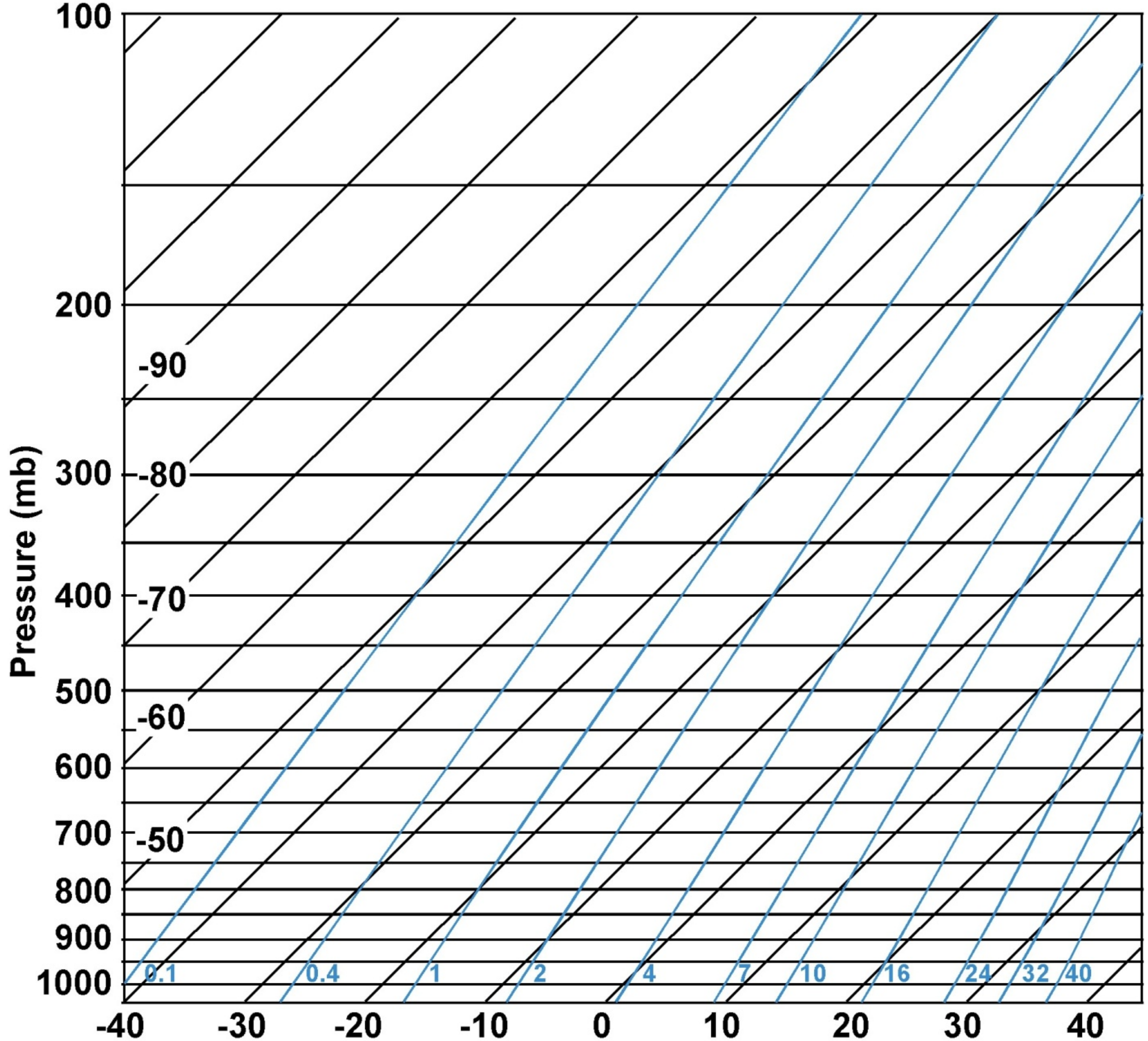


Saturation mixing ratio lines, labeled in g/kg (grams of water vapor per kg of dry air)

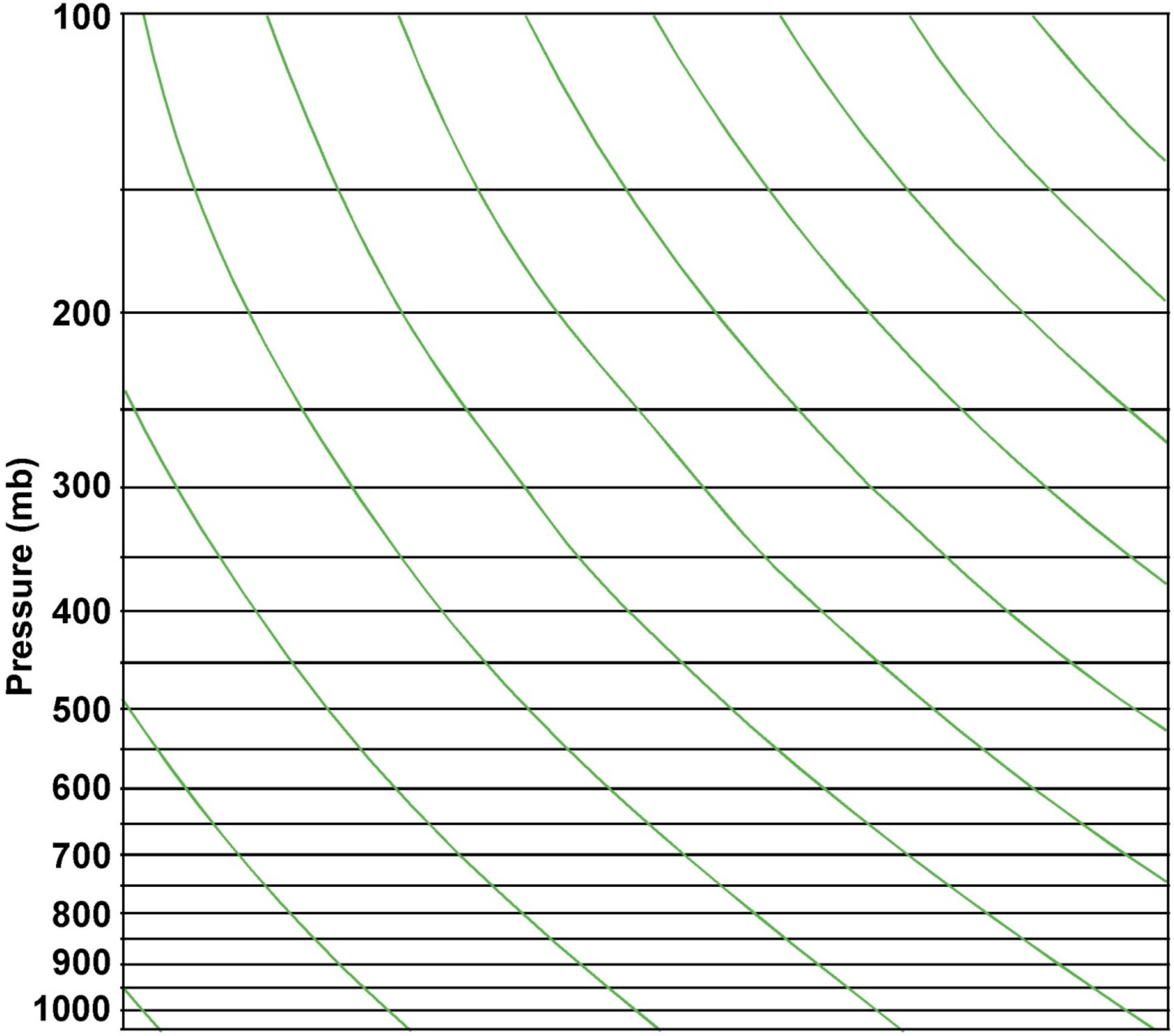
Saturation mixing ratio is a function of air temperature, but the relationship is non-linear.



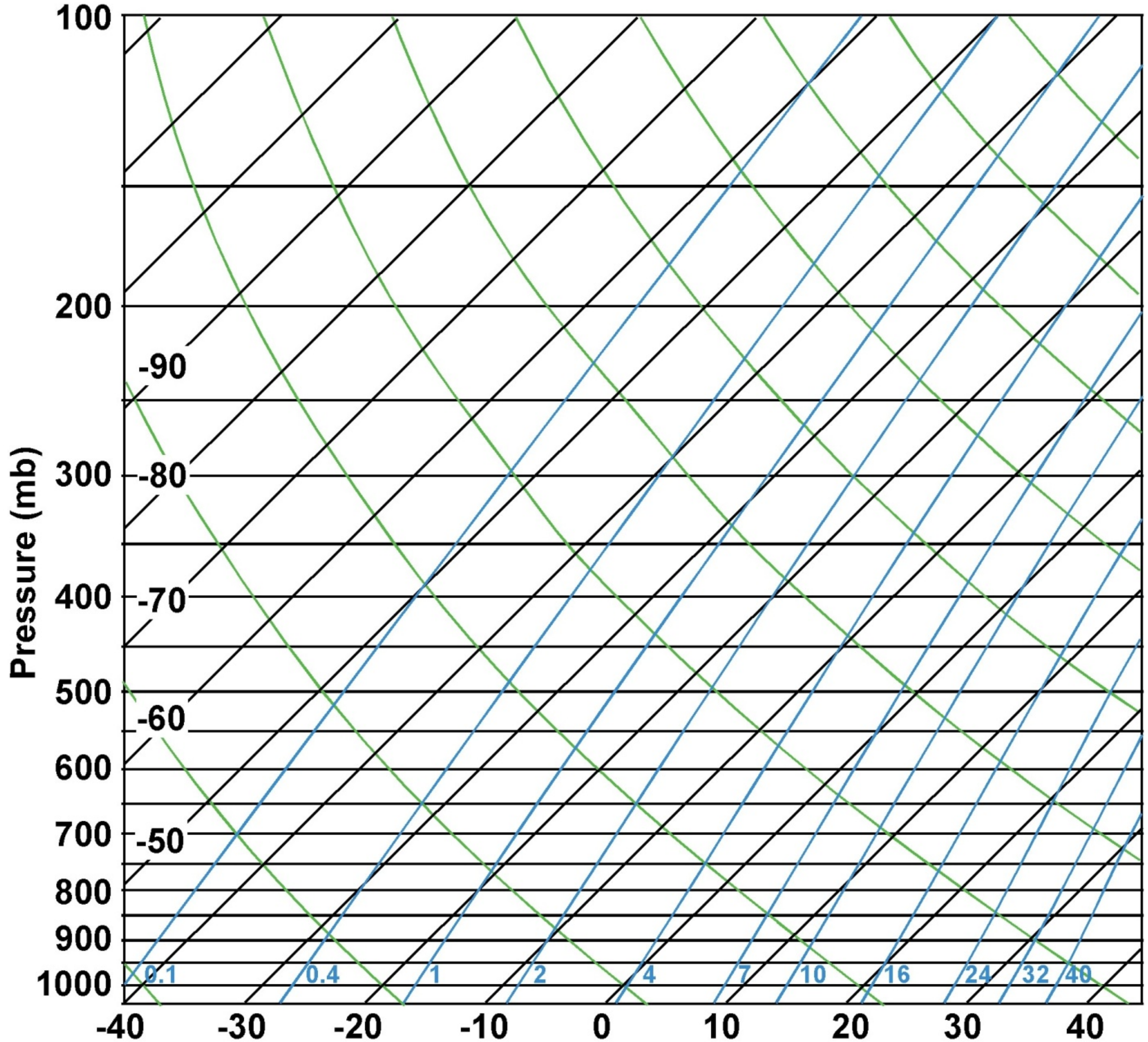
Isobars, Isotherms, and Saturation mixing ratio lines



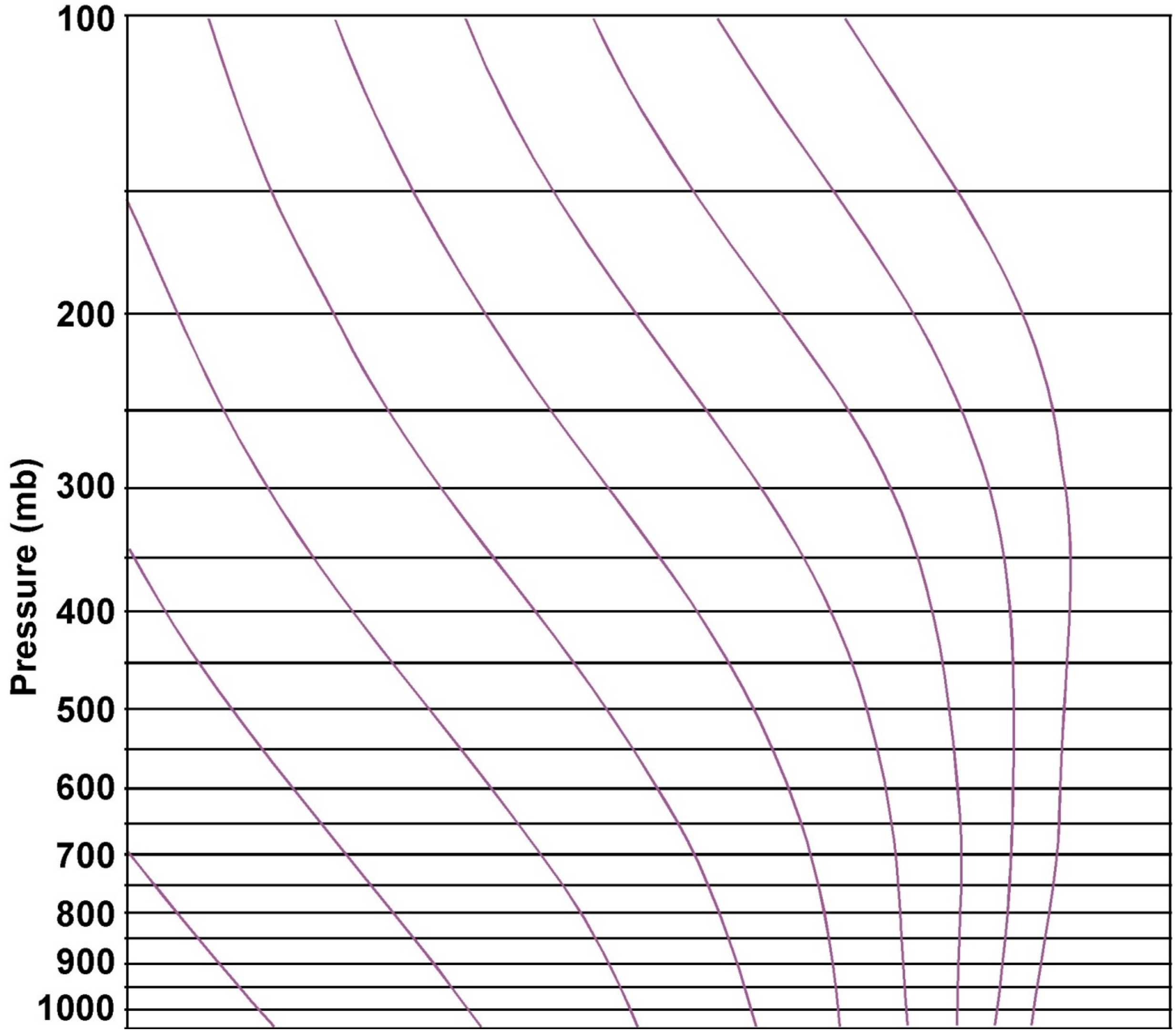
Dry adiabats (Constant Potential Temperature θ curves): indicate rate of change of temperature of a parcel of air ascending or descending dry adiabatically



Isobars, Isotherms, Saturation mixing ratio lines, and Dry Adiabats

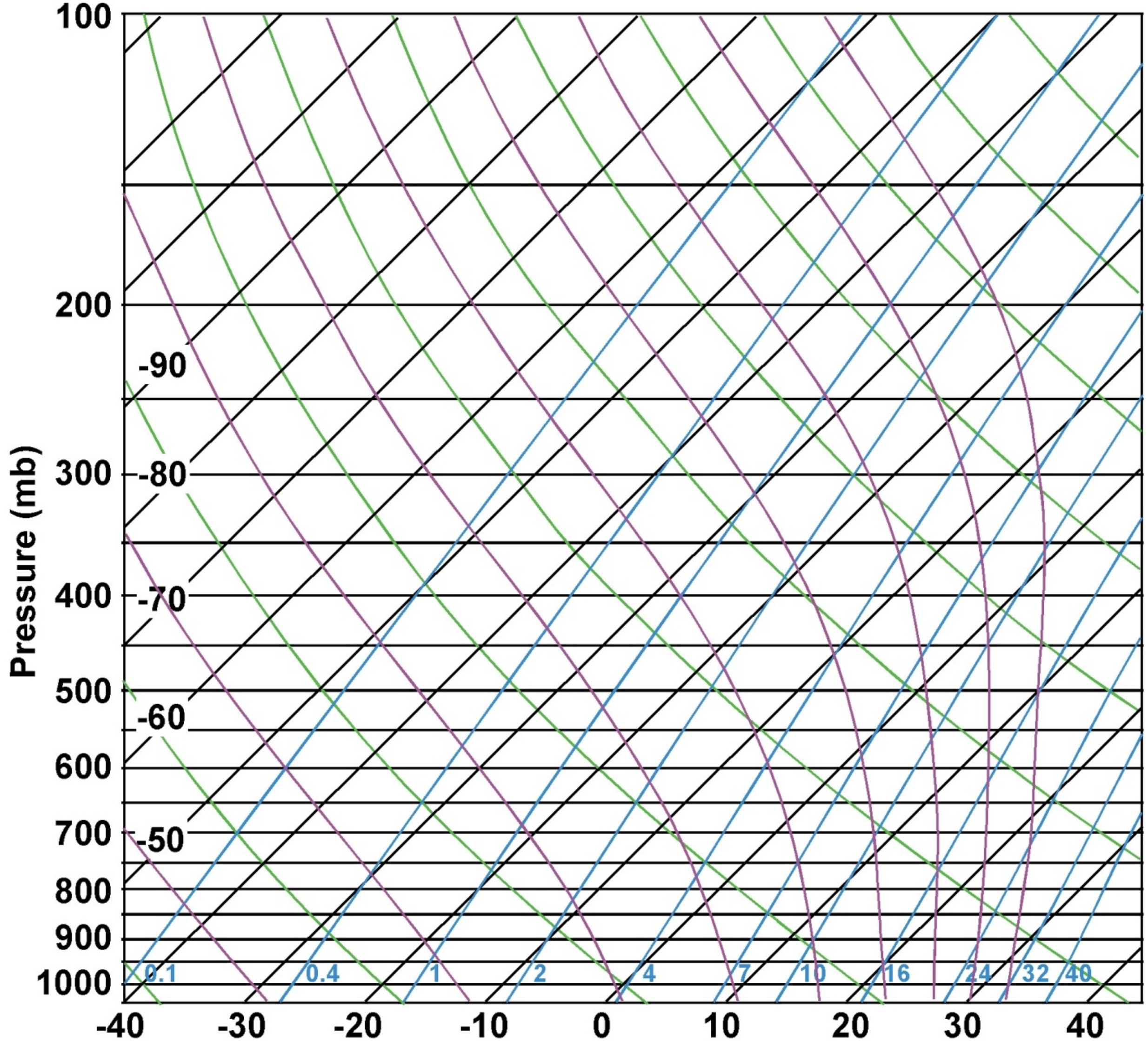


Saturation Adiabats: the path that a saturated air parcel follows as it rises pseudo-moist-adiabatically through the atmosphere.

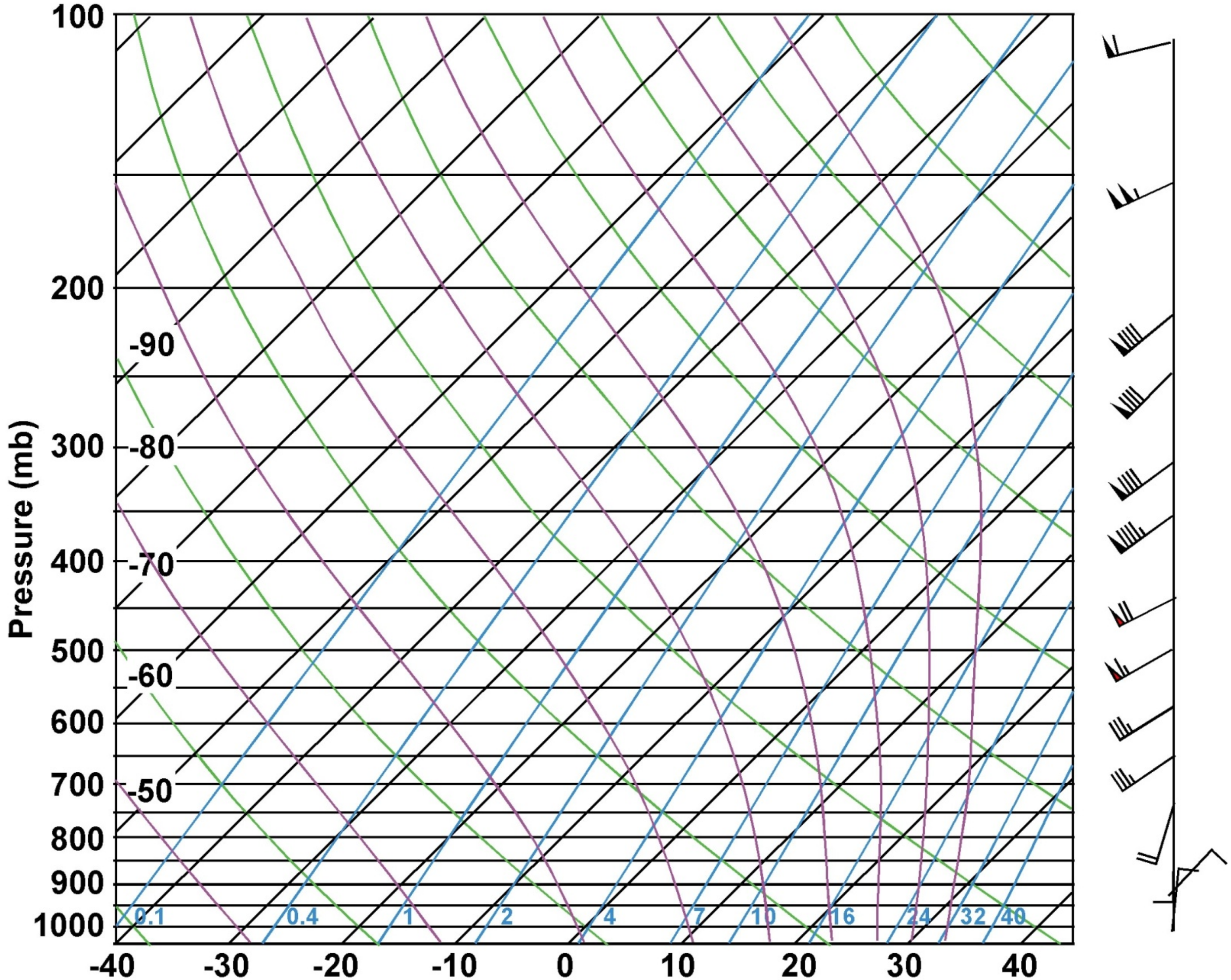


Pseudo-moist-adiabatically: All condensed moisture immediately precipitates from parcel.
Moist adiabatically: All condensed moisture remains in parcel.

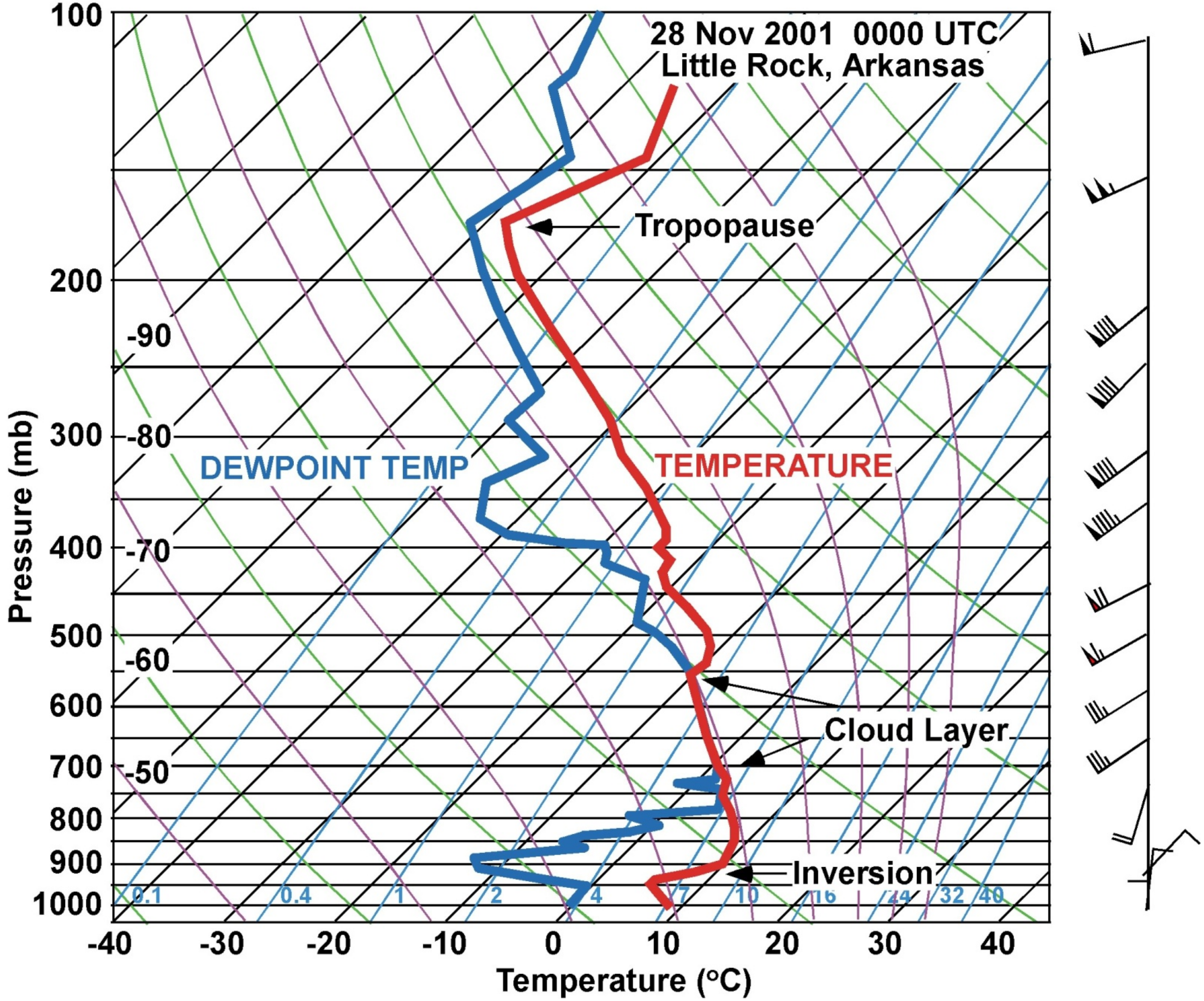
Isobars, Isotherms, Saturation mixing ratio lines, Dry Adiabats, and Saturation Adiabats



Winds are plotted in standard staff/barb format on the line to the right of the diagram



Temperature/Dewpoint temperature from a sounding are plotted as two lines on a Skew-T

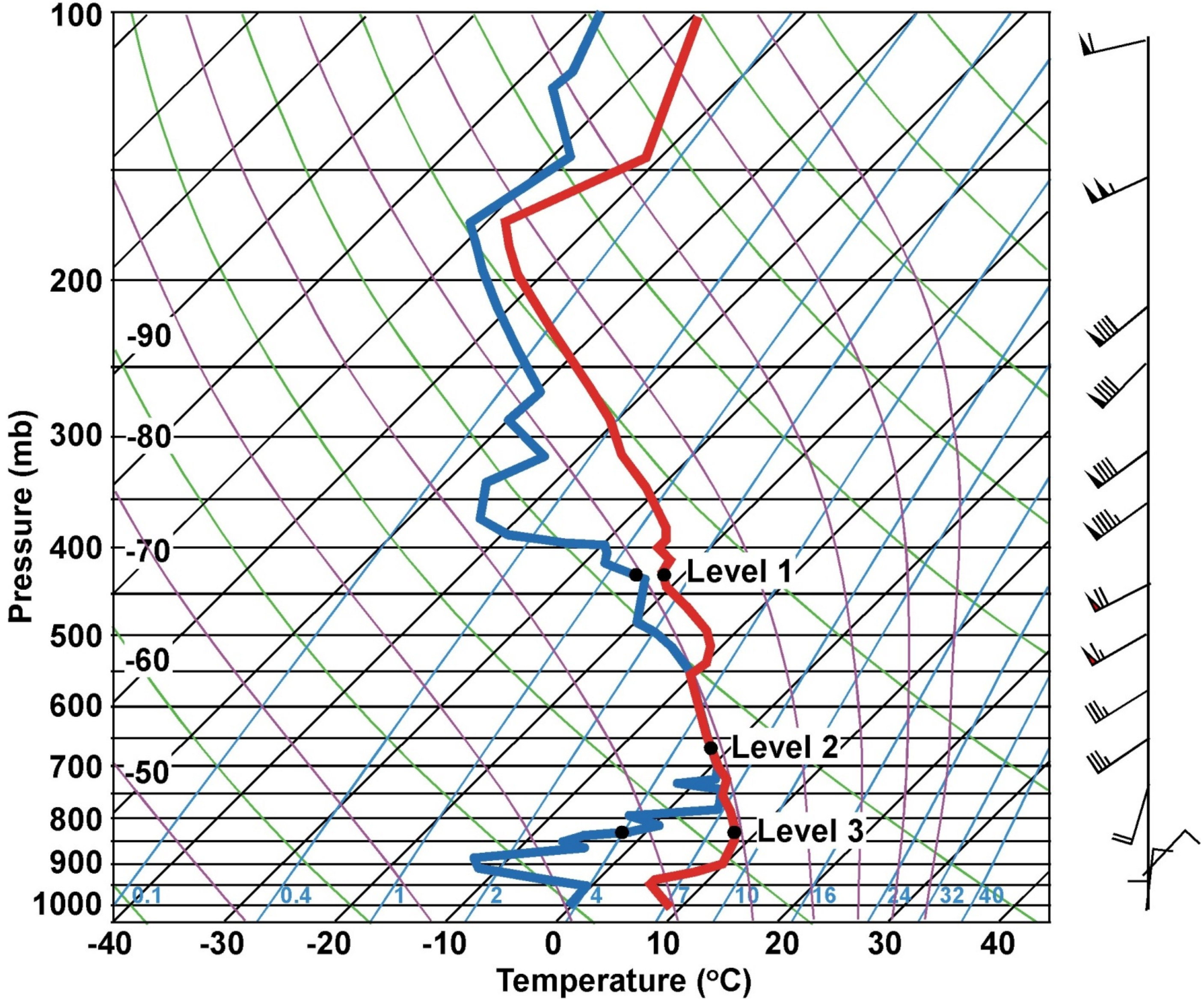


Many other thermodynamic properties of the atmosphere can be determined from a Skew-T/ Log-P diagram

- **Variables for moisture/humidity:**
  - **Absolute humidity or vapor density:** mass of water vapor (m_v)/volume of the total air
  - **Specific humidity:** ***q*****=**(m_v)/mass of the total air ($m_v + m_d$)
  - **Mixing ratio:** ***w*****=**(m_v)/mass of dry air (m_d)
  - **Vapor pressure** (***e***): That part of the total atmospheric pressure contributed by water vapor molecules
  - **Dew point temperature (T_d):**
  - **Wet bulb temperature (T_w):**
  - **Equivalent temperature (T_e):**
  - **Relative humidity (*RH*):**

Ways of reaching saturation

- Ways to reach saturation: 1) Add water vapor to the air; or 2): Cool the sir
- A sample of air may undergo several processes that lead to saturation. Some of these processes are of theoretical importance, and introduce certain new temperatures that reflect the moisture content of the air.
  - **Dew point temperature T_d**, defined as the temperature to which moist air must be cooled, with pressure & mixing ratio held constant, for it to reach saturation.
  - **Wet-bulb temperature T_w**: defined as the lowest temperature to which air may be cooled by evaporating water vapor into it at constant pressure (mixing ratio is not held constant), until saturation is reached.
  - **Equivalent temperature T_e**, defined as the temperature a sample of air would attain if all the moisture (water vapor) were condensed out & all latent heat added to increase the T.



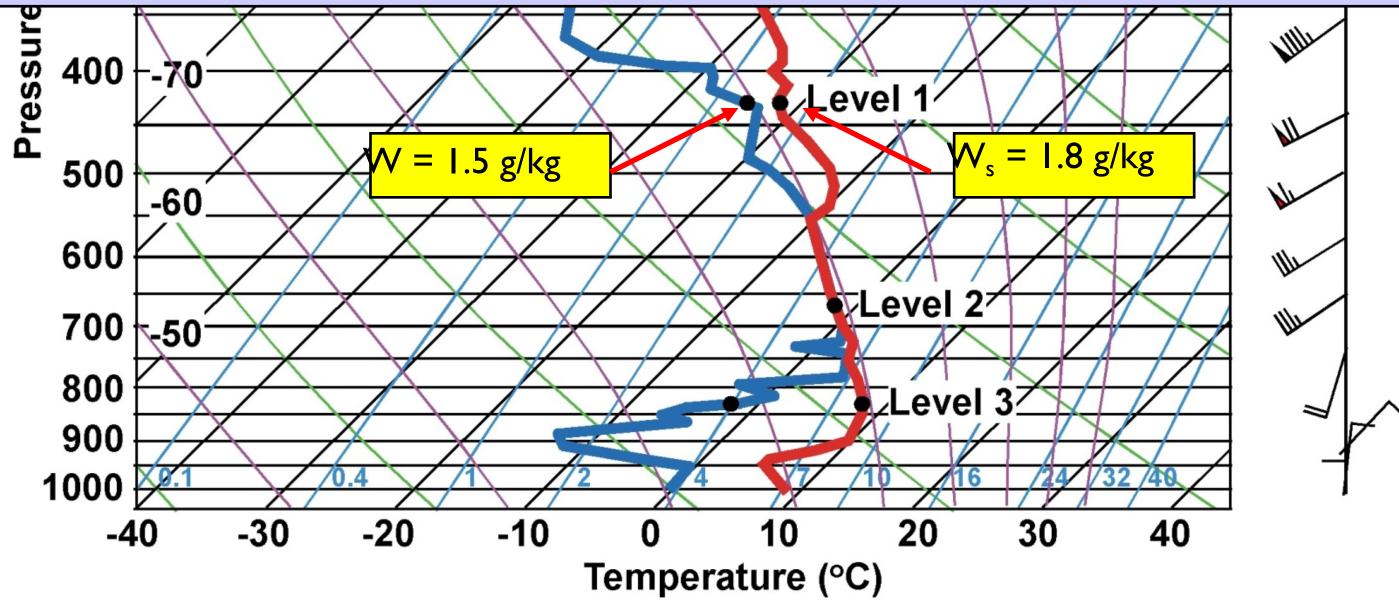
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
-90
-80
-70
-60
-50
0.1
0.4
1
2
4
7
10
16
24
32
40
Level 1
Level 2
Level 3
-40
-30
-20
-10
0
10
20
30
40
Temperature (°C)

Mixing ratio (w): ratio of the mass of water vapor (m_v) to the mass of dry air (m_d) in a sample of air.

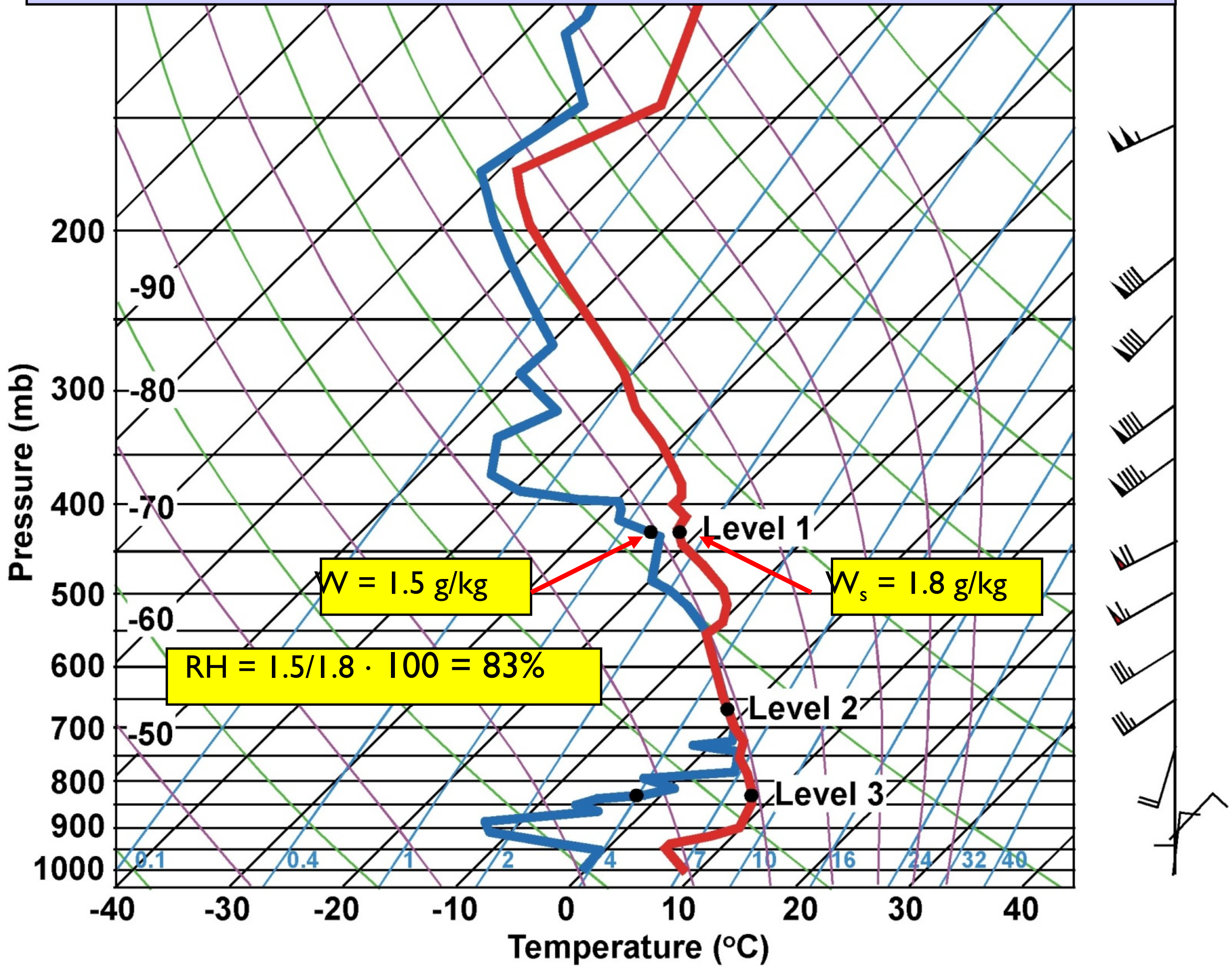
ON THE SKEW-T: READ VALUE, EITHER DIRECTLY OR BY INTERPOLATION, OF THE SATURATION MIXING RATIO LINE THAT CROSSES T_D CURVE.

Saturation mixing ratio (w_s): The mixing ratio a sample of air would have if it were saturated

ON THE SKEW-T: READ VALUE, EITHER DIRECTLY OR BY INTERPOLATION, OF THE SATURATION MIXING RATIO LINE THAT CROSSES T CURVE.



Relative Humidity (RH): ratio of the mixing ratio to the saturation mixing ratio · 100% (RH = w/w_s · 100).

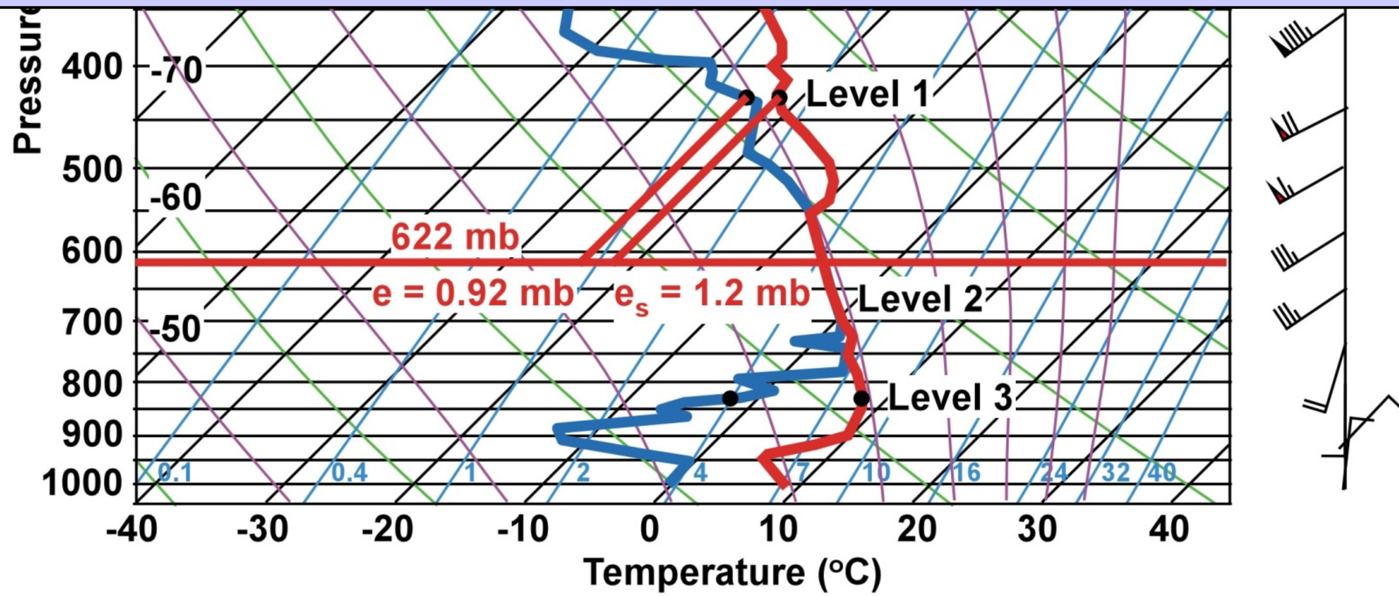


Vapor pressure (e): That part of the total atmospheric pressure contributed by water vapor molecules.

ON THE SKEW-T: FOLLOW THE ISOTHERM THROUGH THE DEWPOINT OF INTEREST TO THE 622 MB LEVEL. VALUE OF saturation mixing ratio W_S LINE IS VAPOR PRESSURE IN mb.

Saturation vapor pressure (e_s): The vapor pressure a sample of air would have if it were saturated.

ON THE SKEW-T: FOLLOW THE ISOTHERM THROUGH THE TEMPERATURE OF INTEREST TO THE 622 MB LEVEL. VALUE OF WS LINE IS VAPOR PRESSURE IN MB.



From Basic Thermodynamics….

$$w = \frac{0.622e}{P-e} \approx \frac{0.622e}{P}$$

Use P = 622 mb

$$w = \frac{0.622e}{622} \approx 0.001e$$ in kg/kg

$$w = e$$ in g/kg

Where *W* is mixing ratio, P is pressure, e is vapor pressure.

More basics…

$$w = \frac{m_v}{m_d} = \frac{\rho_v}{\rho_d}$$

$$\rho_v = \frac{e}{R_v T}$$

$$\rho_d = \frac{p-e}{R'T}$$

$$w = \varepsilon \frac{e}{p-e} \approx \varepsilon \frac{e}{p}$$

Where m is mass, ρ is density,

R_v is the individual gas constant for water vapor (=461.5 J kg^{-1} K^{-1})

R' is the the individual gas constant for dry air (=287 J kg^{-1} K^{-1})

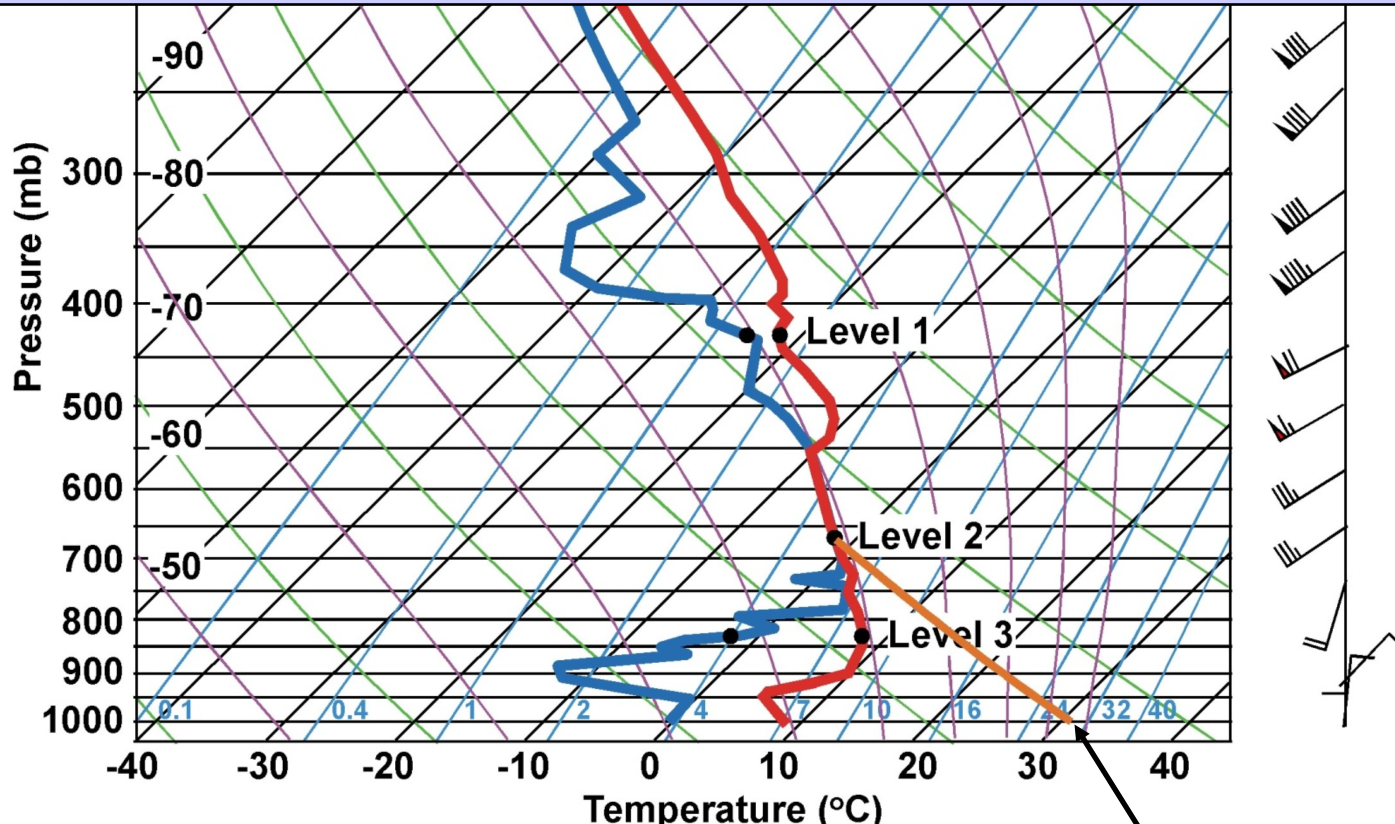
$$\varepsilon = \frac{R'}{R_v} = \frac{Mv}{M_d} = 0.622$$

Mv is the molecular weight of water vapor =18

Md is the molecular weight of dry air =29

Potential Temperature (θ): The temperature a parcel of air would have if it were brought dry adiabatically to a pressure of 1000 mb. (as a variable of state, θ is constant for adiabatic process. It's a function of T & P.)

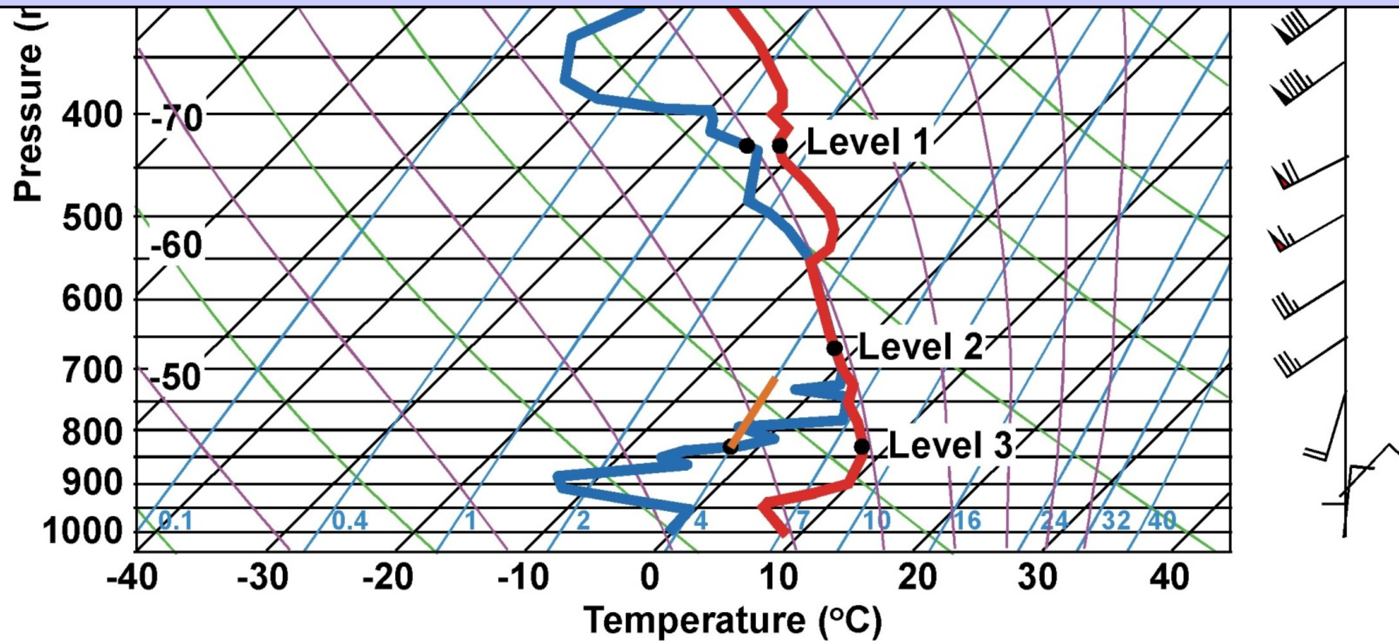
ON THE SKEW-T: FOLLOW THE DRY ADIABAT TO THE 1000 MB LEVEL. VALUE OF TEMPERATURE AT 1000 MB (CONVERT TO K) IS POTENTIAL TEMPERATURE.



θ= 273.1 + 30.5 = 303.6 K

Wet Bulb Temperature (T_w): The lowest temperature to which a volume of air can be cooled at constant pressure by evaporating water into it.

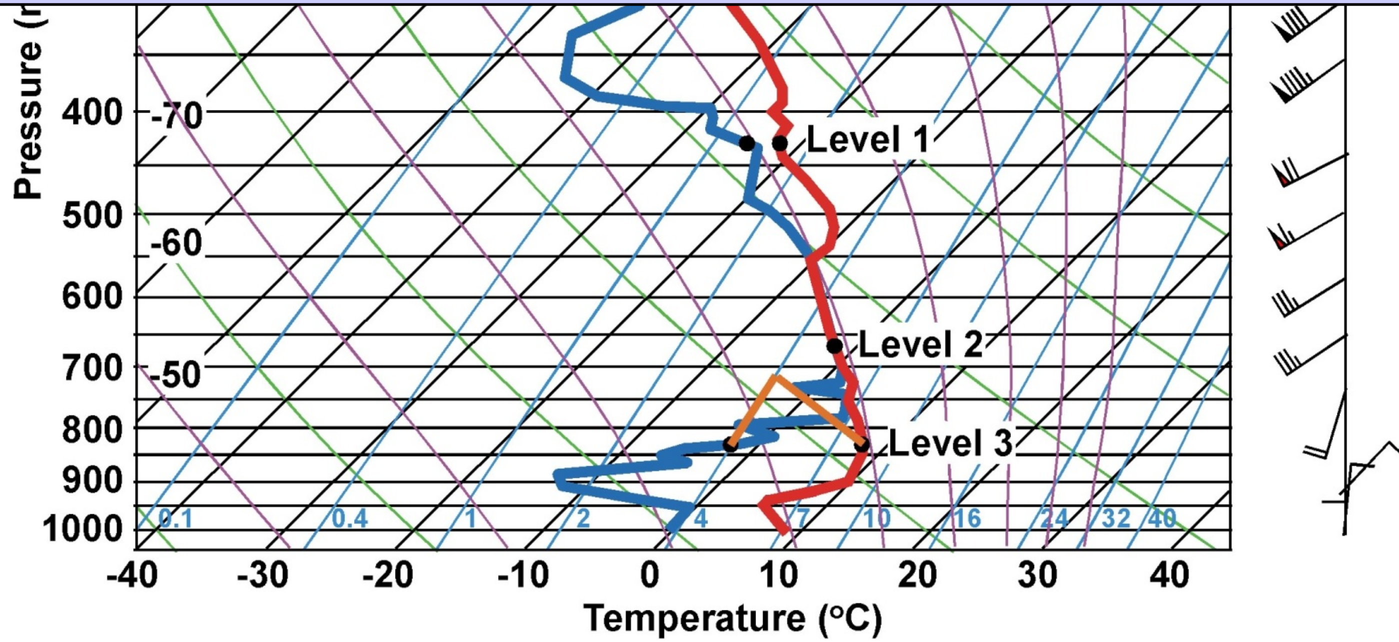
ON THE SKEW-T: 1) FOLLOW THE SATURATION MIXING RATIO LINE UPWARD FROM THE DEWPOINT TEMPERATURE



Wet Bulb Temperature (T_w): The lowest temperature to which a volume of air can be cooled at constant pressure by evaporating water into it.

ON THE SKEW-T: 1) FOLLOW THE SATURATION MIXING RATIO LINE UPWARD FROM THE DEWPOINT TEMPERATURE

2) FOLLOW THE DRY ADIABAT UPWARD FROM THE TEMPERATURE UNTIL IT CROSSES THE FIRST LINE

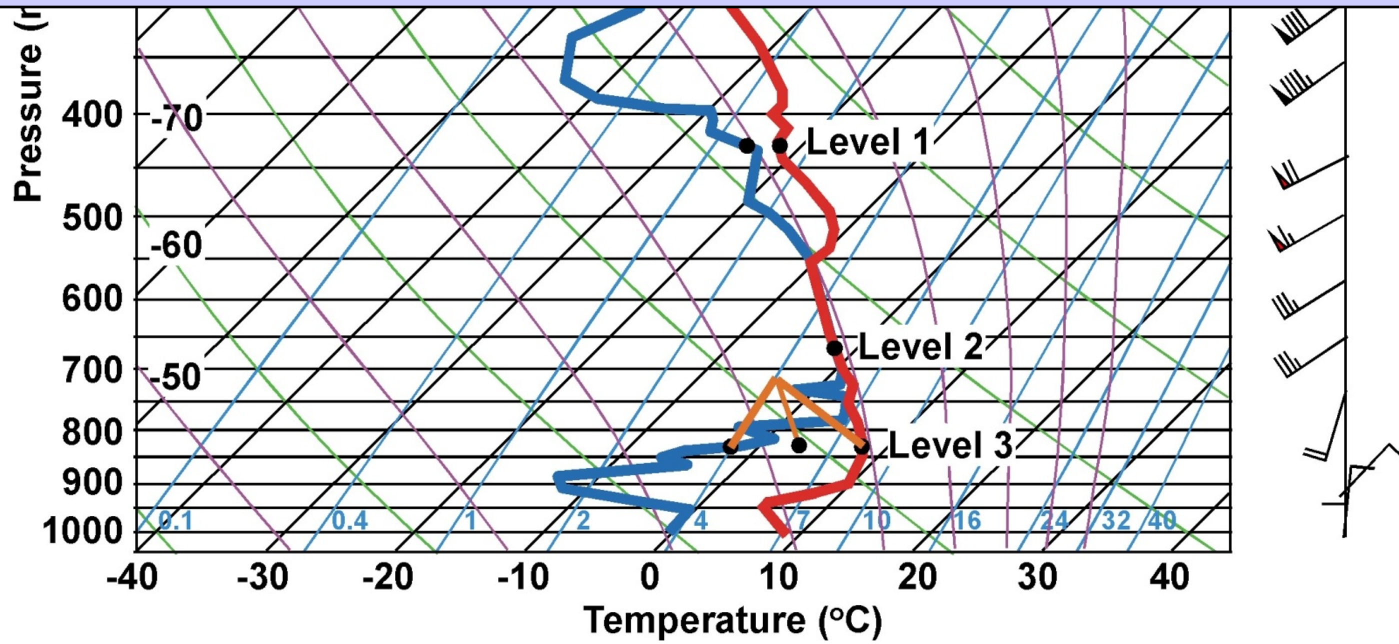


Wet Bulb Temperature (T_w): The lowest temperature to which a volume of air can be cooled at constant pressure by evaporating water into it.

ON THE SKEW-T: 1) FOLLOW THE SATURATION MIXING RATIO LINE UPWARD FROM THE DEWPOINT TEMPERATURE

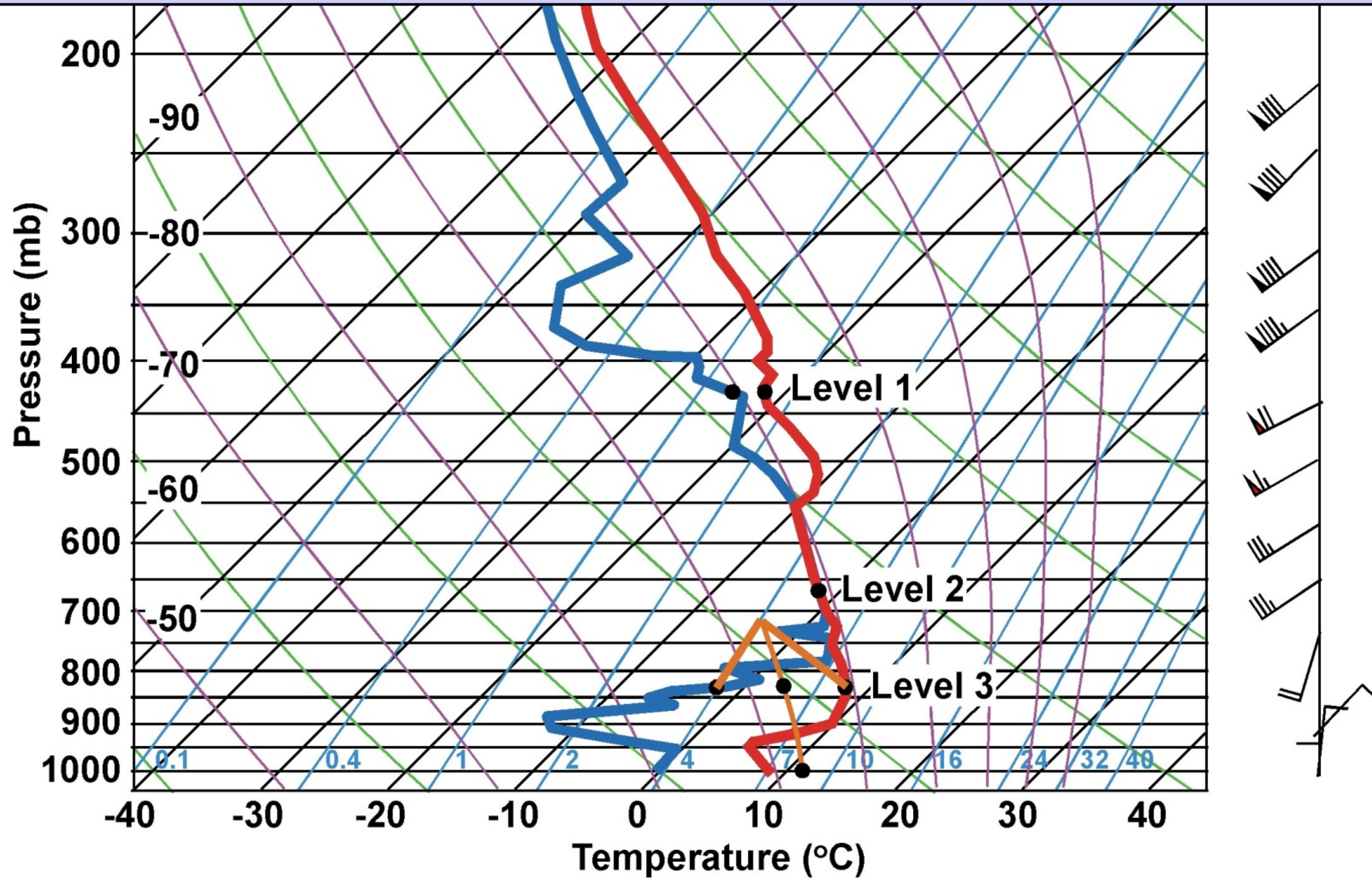
2) FOLLOW THE DRY ADIABAT UPWARD FROM THE TEMPERATURE UNTIL IT CROSSES THE FIRST LINE

3) FOLLOW THE SATURATION ADIABAT DOWN TO THE ORIGINAL LEVEL. TEMPERATURE AT THIS POINT IS THE WET-BULB TEMPERATURE

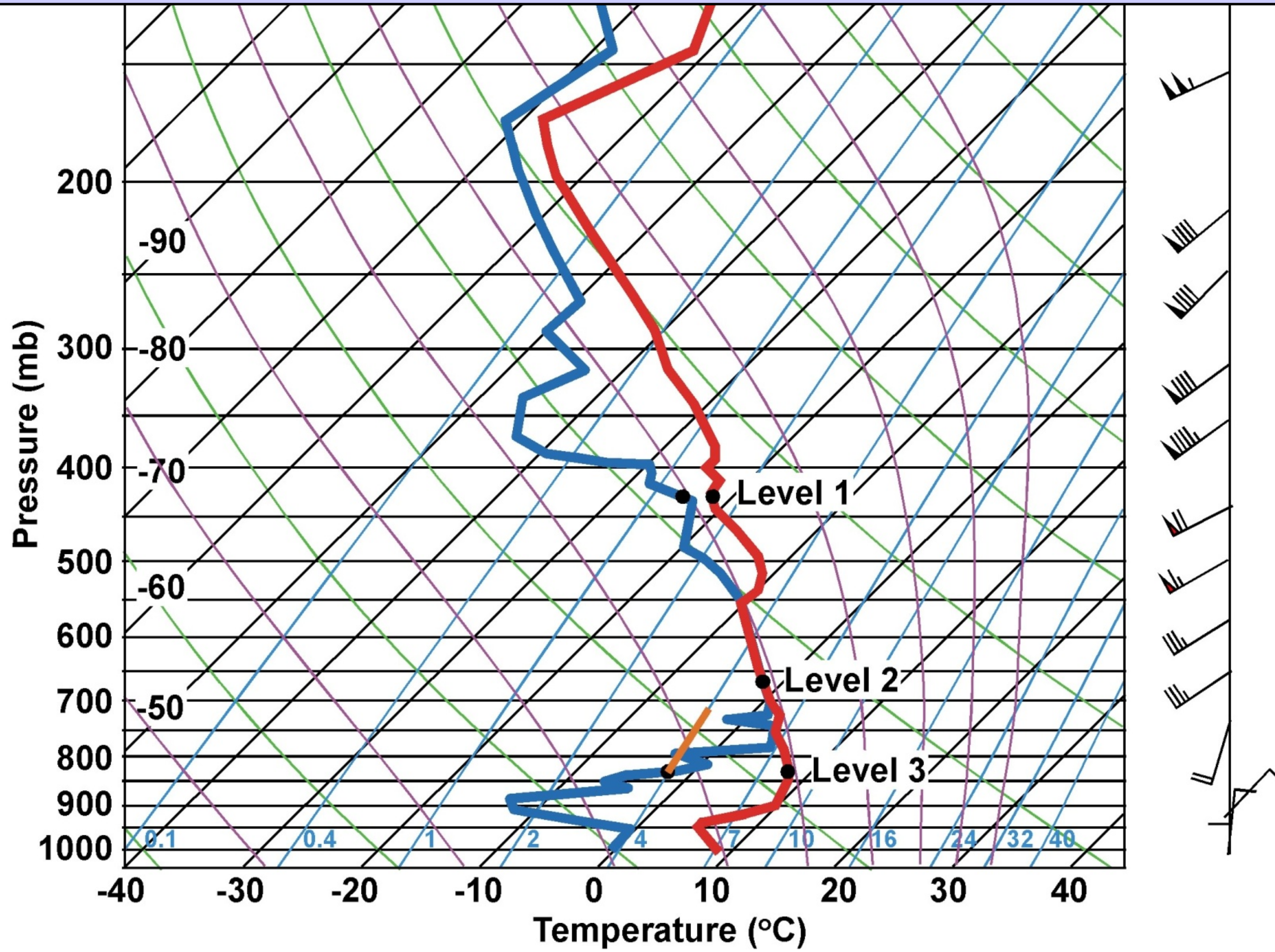


Wet Bulb Potential Temperature (θ_w): The wet bulb temperature a parcel of air would have if it were brought saturation adiabatically to a pressure of 1000 mb.

ON THE SKEW-T: 1) FOLLOW THE SATURATION ADIABAT FROM THE WET BULB TEMPERATURE TO 1000 MB.

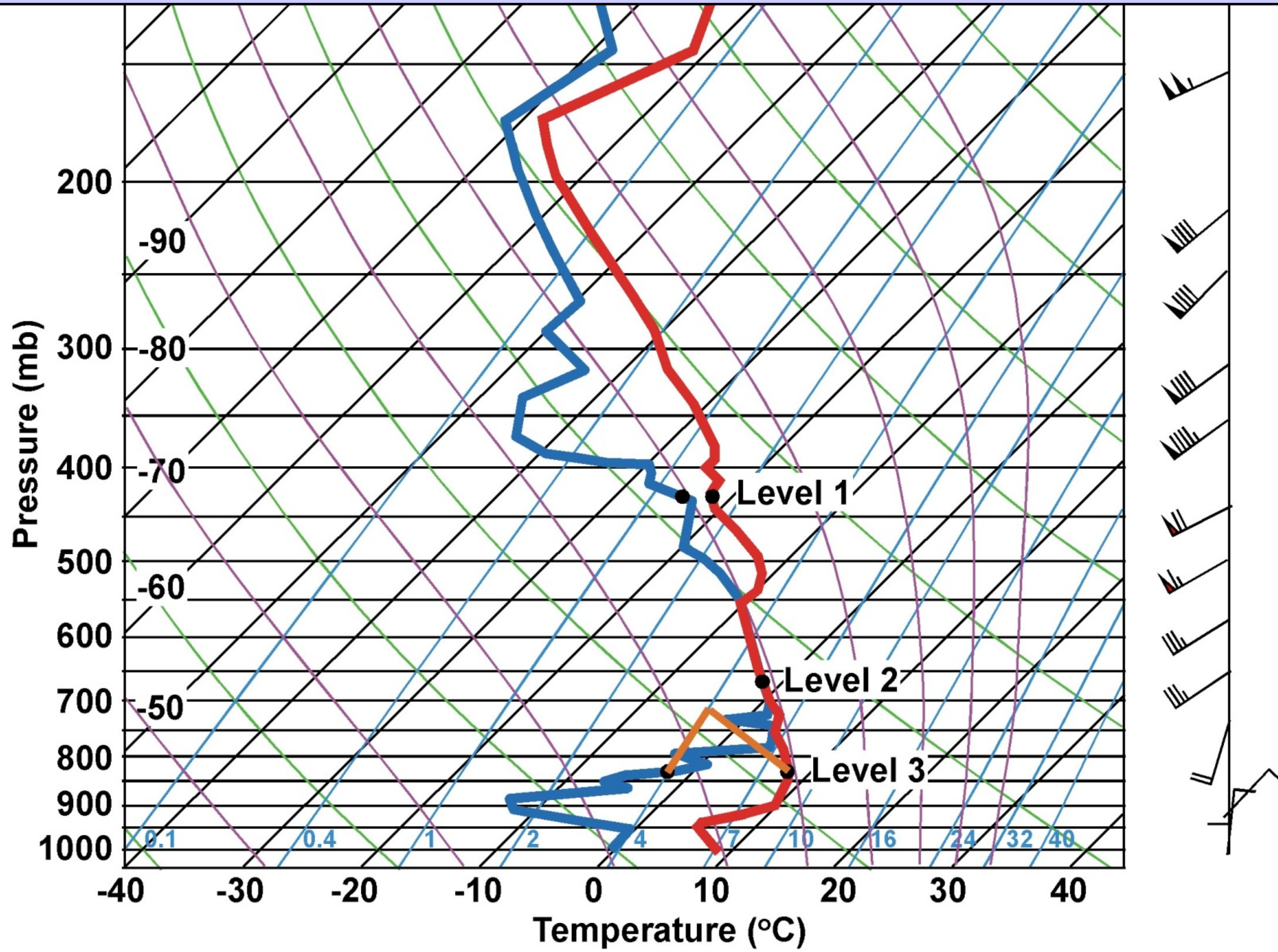


Equivalent Temperature (T_e): The temperature a sample of air would have if all its moisture were condensed out by a pseudo-adiabatic process (with the latent heat of condensation heating the air sample), and the sample then brought dry adiabatically to its original pressure.



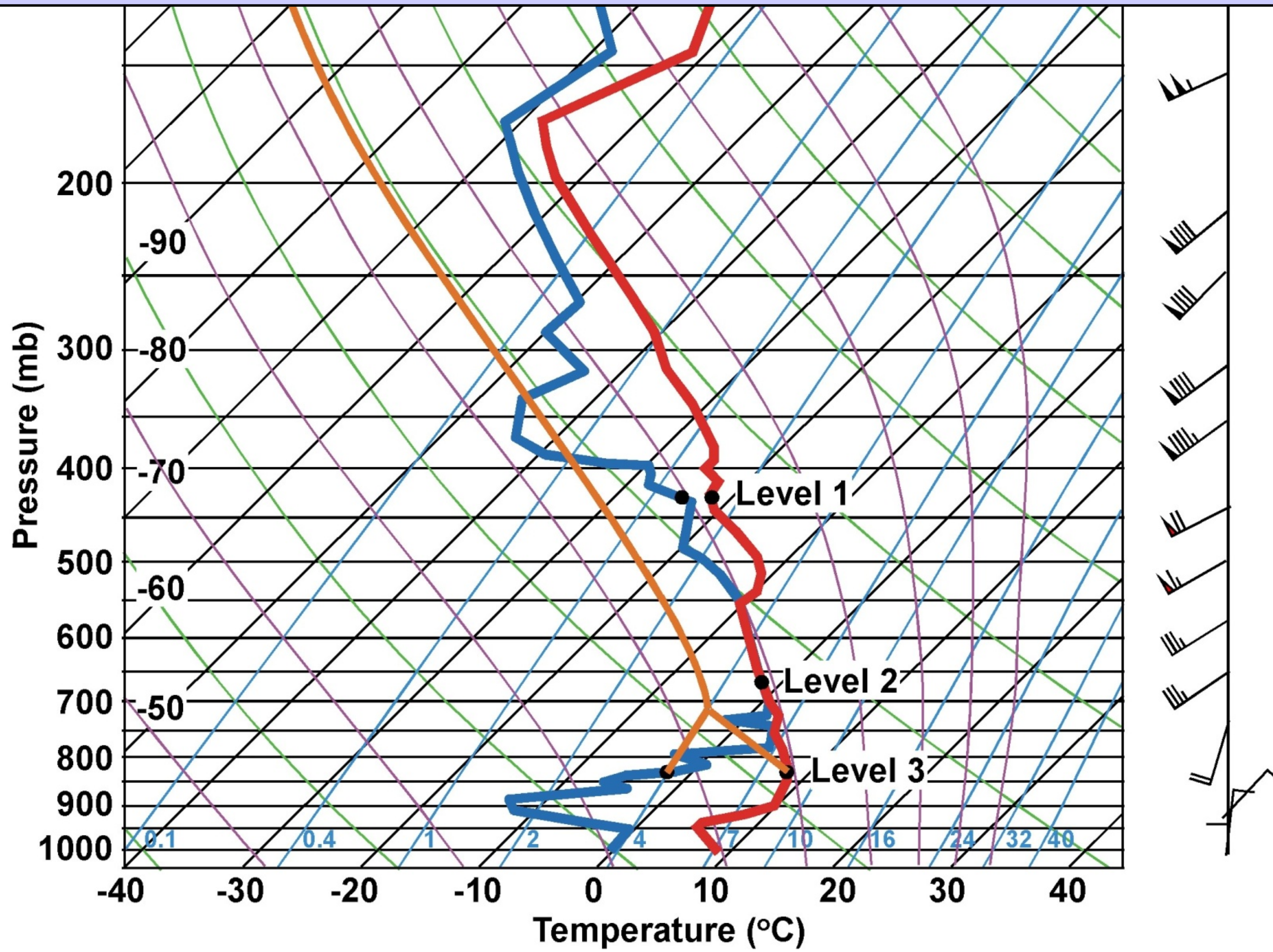
ON THE SKEW-T: 1) FOLLOW THE SATURATION MIXING RATIO LINE UPWARD FROM THE DEWPOINT TEMPERATURE

Equivalent Temperature (T_e): The temperature a sample of air would have if all its moisture were condensed out by a pseudo-adiabatic process (with the Latent heat of condensation heating the air sample), and the sample then brought Dry adiabatically to its original pressure.



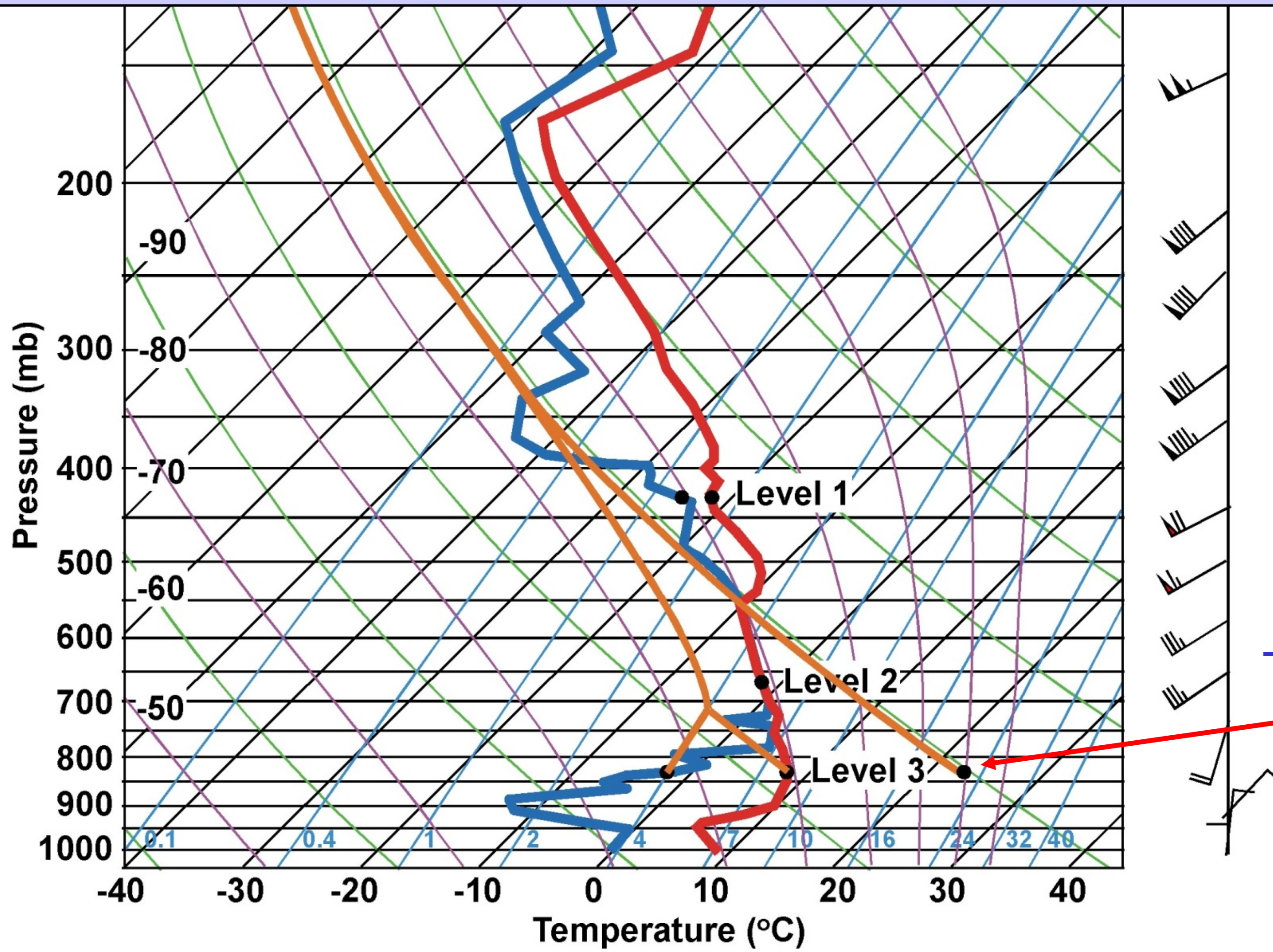
2) FOLLOW THE DRY ADIABAT UPWARD FROM THE TEMPERATURE UNTIL IT CROSSES THE FIRST LINE

Equivalent Temperature (T_e): The temperature a sample of air would have if all its moisture were condensed out by a pseudo-adiabatic process (with the Latent heat of condensation heating the air sample), and the sample then brought Dry adiabatically to its original pressure.



3) FOLLOW THE SATURATION ADIABAT UPWARD UNTIL IT PARALLELS A DRY ADIABAT

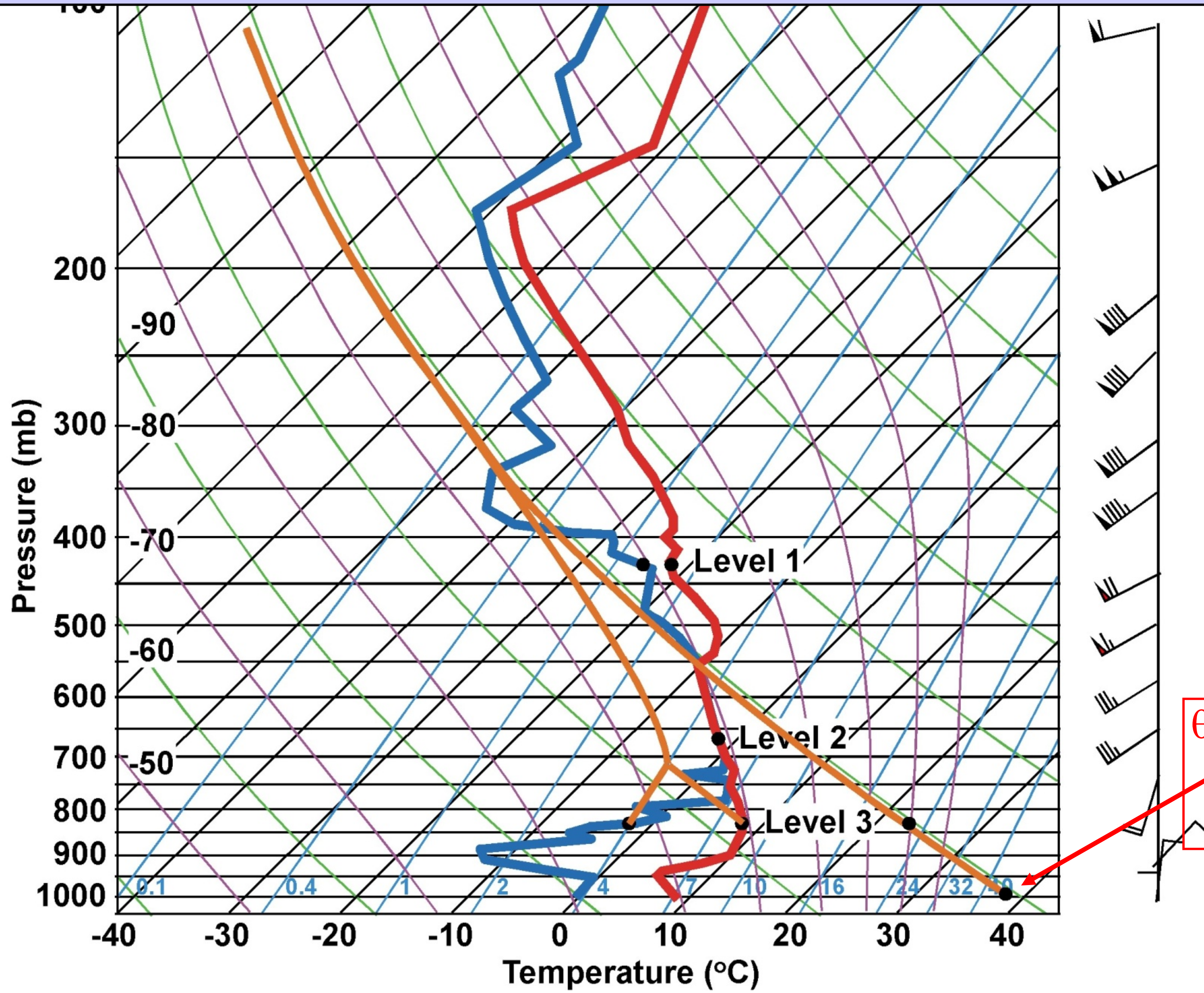
Equivalent Temperature (T_e): The temperature a sample of air would have if all its moisture were condensed out by a pseudo-adiabatic process (with the Latent heat of condensation heating the air sample), and the sample then brought Dry adiabatically to its original pressure.



T_e = 273.1 + 23.0 = 296.1 K

3) FOLLOW THE DRY ADIABAT DOWN TO THE ORIGINAL LEVEL AND READ THE TEMPERATURE AT THAT LEVEL.

Equivalent Potential Temperature (θ_e): The equivalent temperature a sample of air would have if it were compressed dry adiabatically to 1000 mb.



θ_e = 273.1 + 39.0 = 312.1 K

4) FOLLOW THE DRY ADIABAT DOWN FROM EQUIVALENT TEMPERATURE TO THE 1000 MB LEVEL.

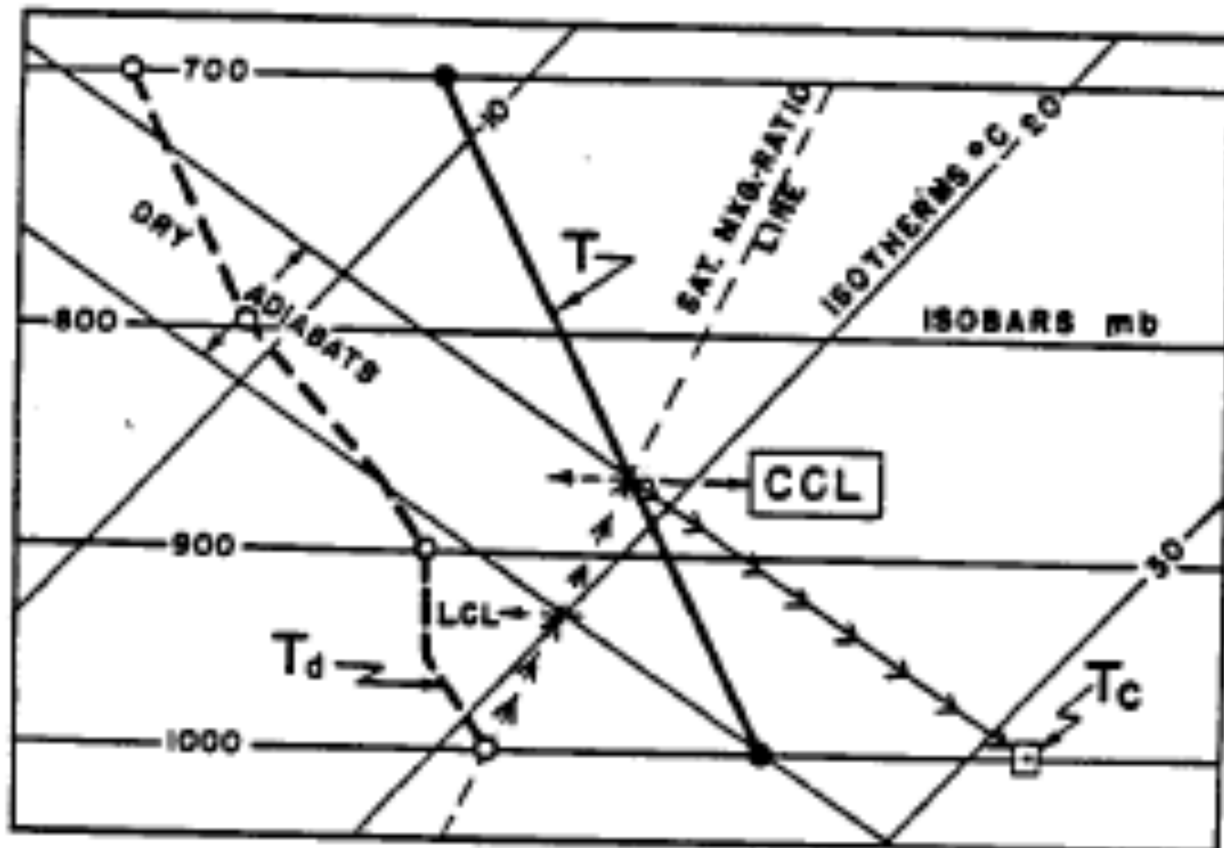
Find/draw the path of an air parcel on the sounding (Skew-T) diagram

- **How does a rising air parcel reach saturation?** There are two ways:
  - ***Lifting: lifting condensation level (LCL)***
  - ***Heating: Convective condensation level (CCL)***
- **How to draw the path of a parcel:**
  - Before saturation: follow dry adiabats
  - After saturation: follow moist adiabats

Lifting condensation level (LCL)

- **Definitions**: Height at which a parcel of air becomes saturated by lifting dry-adiabatically. If there is mechanical lifting, such as being forced upward across land, a mountain, or over a layer of cool air, the air parcel will **cools** dry adiabatically. If the air is lifted high enough and cools enough, the parcel is saturated and any further cooling will result in condensation of moisture.
- **Procedure:**

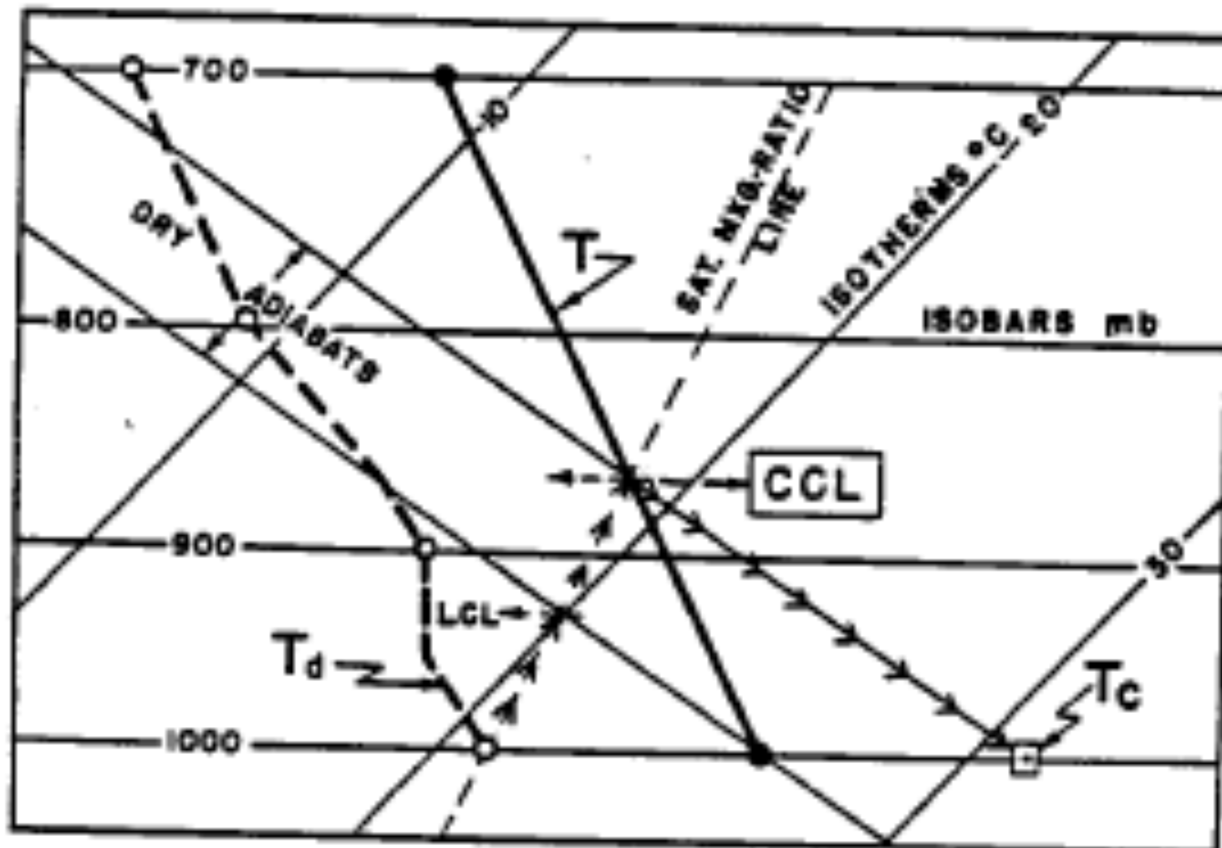
1. From dew point, draw a line upward and parallel to the saturation mixing-ratio line,.
2. From the temperature, draw a line upward and parallel to the dry adiabatic. The point of intersection of these two lines is the LCL.



Convective condensation level (CCL)

- **Definitions**: Height to which a parcel of air, if heated sufficiently from below, will rise adiabatically until it is just saturated. This is the height of the base of cumuliform clouds which are, or would be, produced by thermal convection from surface heating.
- **Procedure:**

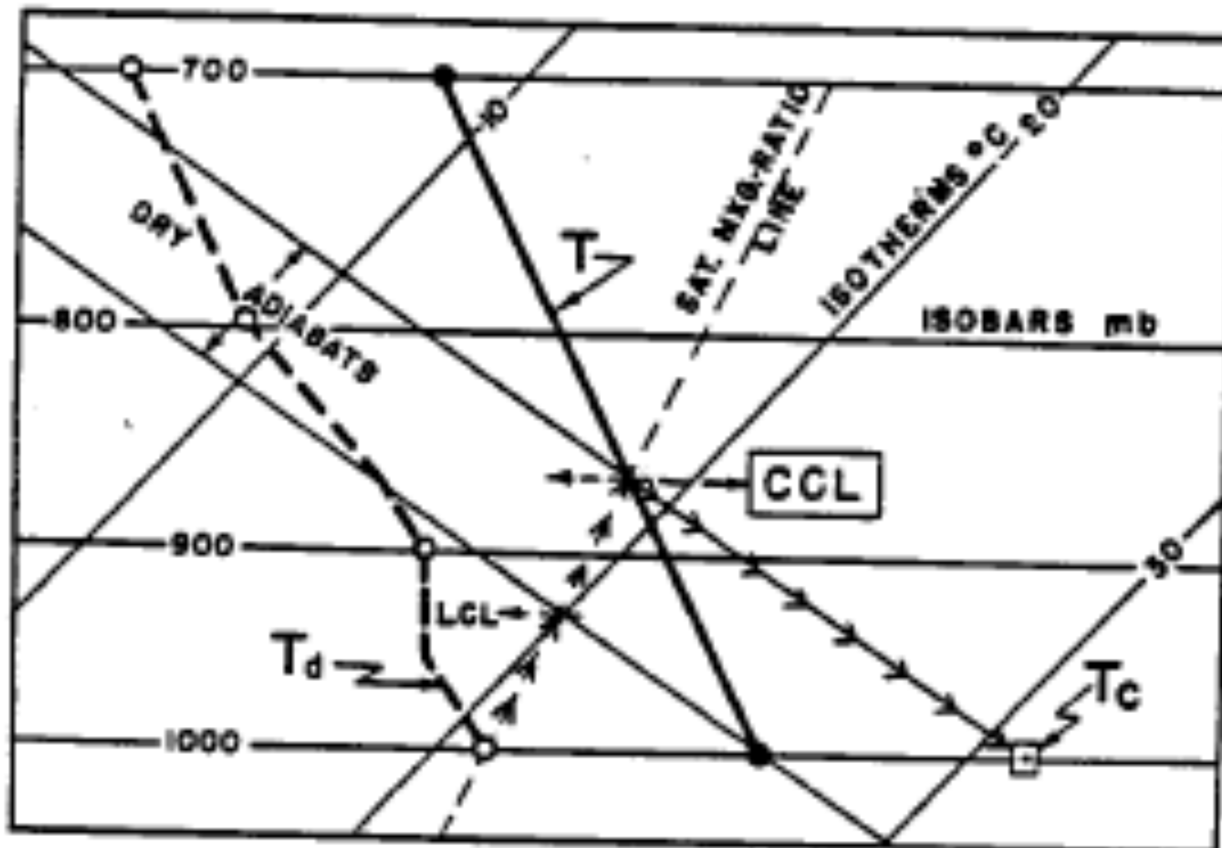
From the surface dew- point temperature, draw a line upward along or parallel to a mixing-ratio line, until it intersects the T curve.



Convective temperature (T_c)

- **Definitions**: Tc is the surface temperature that must be reached to start to form convective clouds by solar heating of the surface air layer. When this temperature is reached, air can rise dry adiabatically to the convection condensation level (CCL).
- **Procedure:**

From CCL, then proceed downward along dry-adiabat until it intersects the surface pressure.



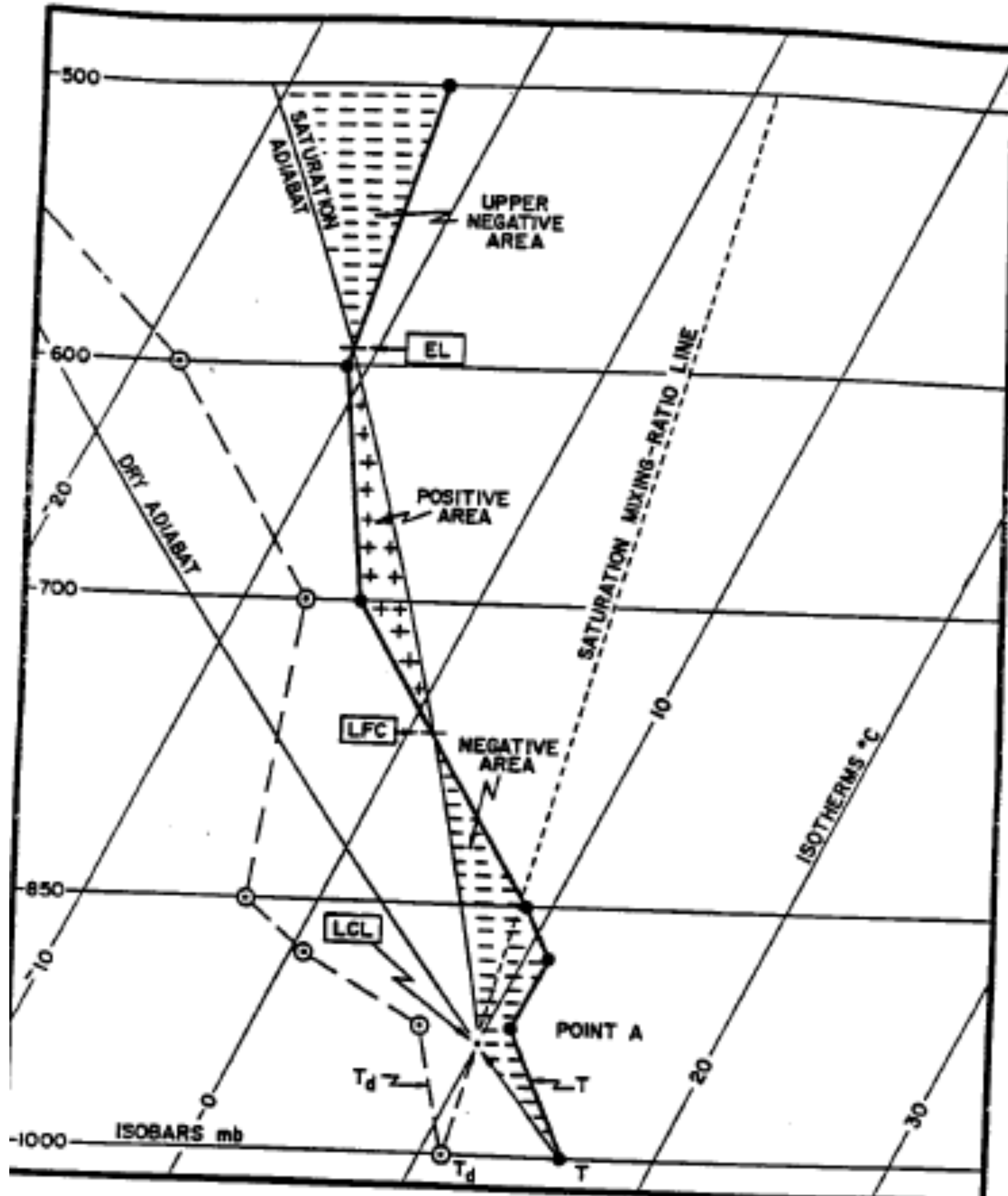
Skew-T Log-P Diagram (cont.)

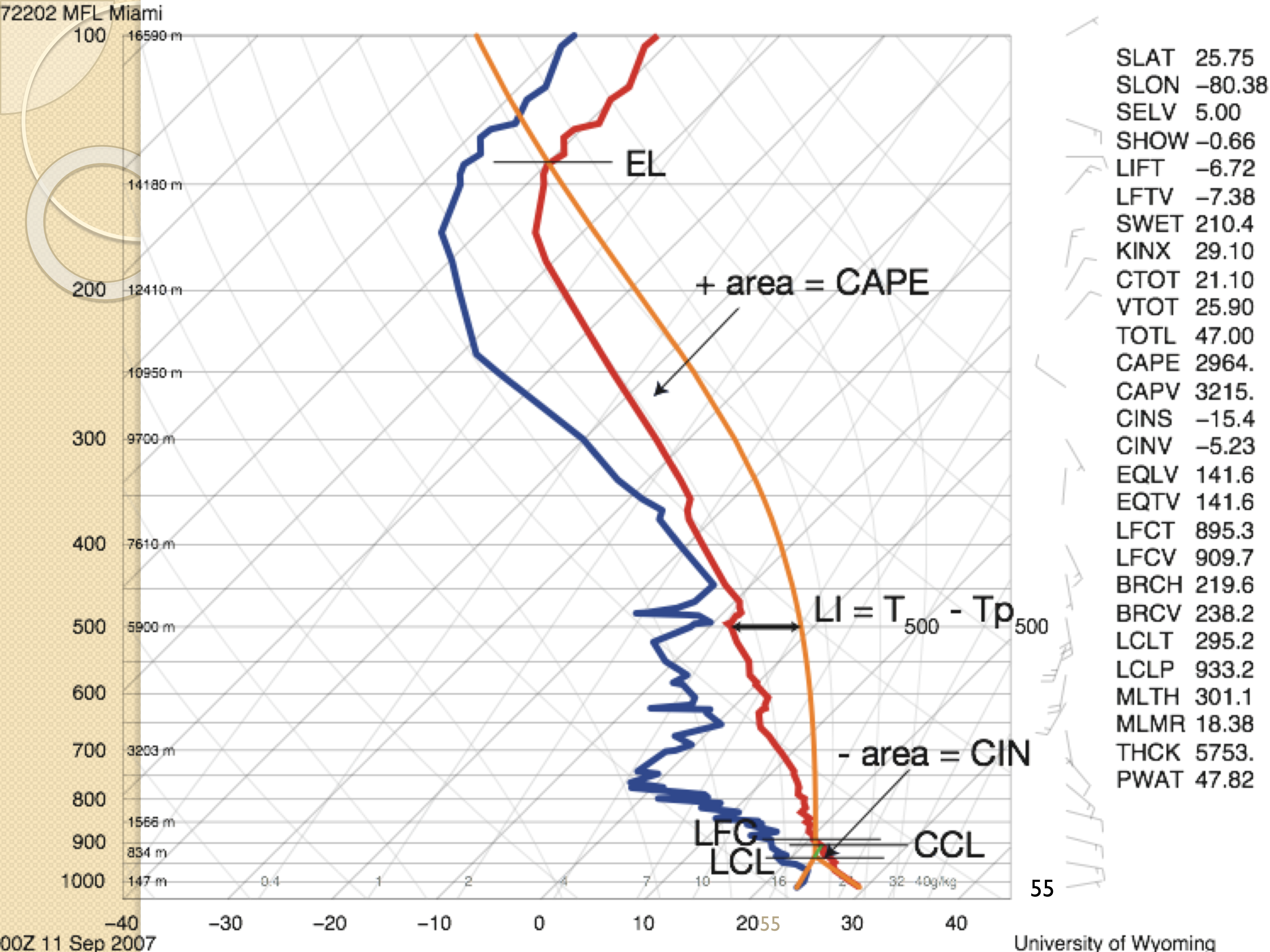
- Other Basic Definitions
  - ***Level of free convection*** (LFC)
    - Height where parcel lifted dry-adiabatically until saturated, then moist-adiabatically, first becomes warmer than the surrounding air. The parcel would then continue rise freely until it becomes cooler than the environment.
  - ***Positive area*** (or CAPE--Convective Available Potential Energy)
    - Area between the sounding and the moist adiabat when the parcel is warmer than the surrounding environment. Proportional to the amount of energy the parcel gains from the environment.
  - ***Negative area*** (or CIN—Convective Inhibition)
    - Area between the sounding and the adiabat when the parcel is colder than the surrounding environment. Proportional to the energy needed to move the parcel.
  - ***Equilibrium level*** (EL)
    - Height where the temperature of a buoyant parcel again becomes equal to the temperature of the environment.

Procedure for LFC:

1. Start at the LCL of the level for which the LFC is desired (i.e. if the LFC for air at 700 mb is desired, then calculate the LCL for 700 mb).

2. From the LCL go upwards parallel to the saturation-adiabats. The point where the line intersects the plotted T curve is the LFC. (Note, a LFC may not be present for all atmosphere.)




72202 MFL Miami
100
16590 m
14180 m
200
12410 m
10950 m
300
9700 m
400
7610 m
500
5900 m
600
700
3203 m
800
1566 m
900
834 m
1000
147 m
EL
+ area = CAPE
LI = T_{500} - Tp_{500}
- area = CIN
LFC
LCL
CCL
SLAT 25.75
SLON −80.38
SELV 5.00
SHOW −0.66
LIFT −6.72
LFTV −7.38
SWET 210.4
KINX 29.10
CTOT 21.10
VTOT 25.90
TOTL 47.00
CAPE 2964.
CAPV 3215.
CINS −15.4
CINV −5.23
EQLV 141.6
EQTV 141.6
LFCT 895.3
LFCV 909.7
BRCH 219.6
BRCV 238.2
LCLT 295.2
LCLP 933.2
MLTH 301.1
MLMR 18.38
THCK 5753.
PWAT 47.82
−40
−30
−20
−10
0
10
20
30
40
00Z 11 Sep 2007
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