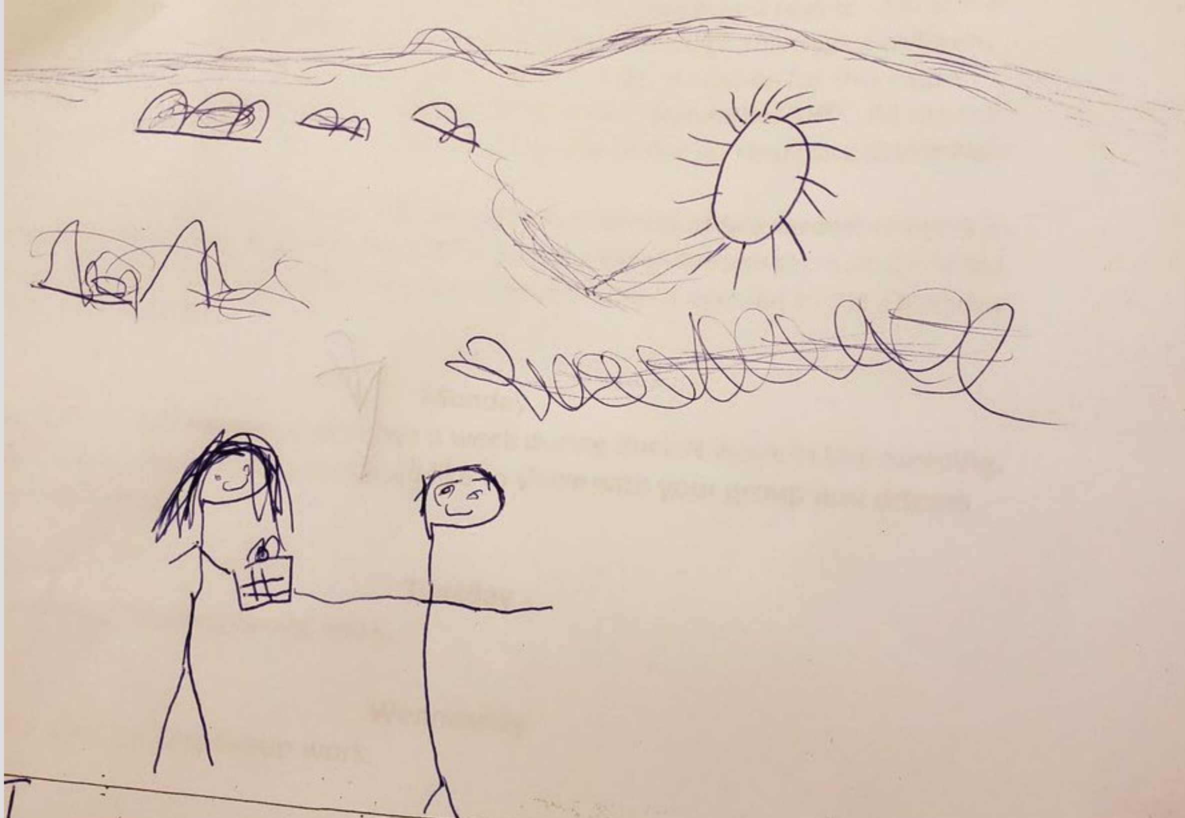
A primer on the Skew-T, log-p diagram

Diagnosis of potential for convection


clouds
clouds
stratus clouds

Giving

Name________________________



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Outline

Review of basic atmospheric stability concepts

Rationale and format of thermodynamic diagrams

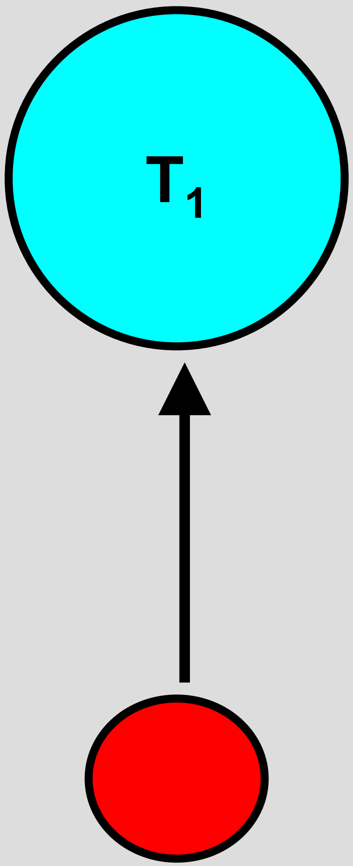
Some basic derived diagnostic measures on Skew-T

Characterizing the potential for convection

Latent Heat Release by Condensation

Temperature LESS than dew point

Parcel unsaturated.

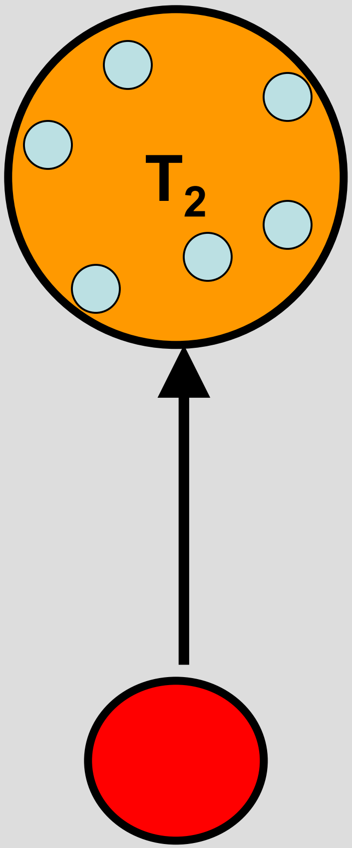


Temperature AT the dew point

Parcel saturated and RH = 100%

Condensation RELEASES latent heat and warms the parcel.

$T_1 < T_2$



DRY ADIABATIC PROCESS
LAPSE RATE = 9.8 °C per km

MOIST ADIABATIC PROCESS
LAPSE RATE < 9.8 °C per km

What happens to a rising air parcel?

1. Parcel rising and no condensation:

   Temperature decreases at the dry adiabatic lapse rate of 9.8 °C per kilometer

2. Parcel rising, saturated, and there is condensation:

   Temperature decreases at the moist adiabatic lapse rate, about 6-7 °C per kilometer.

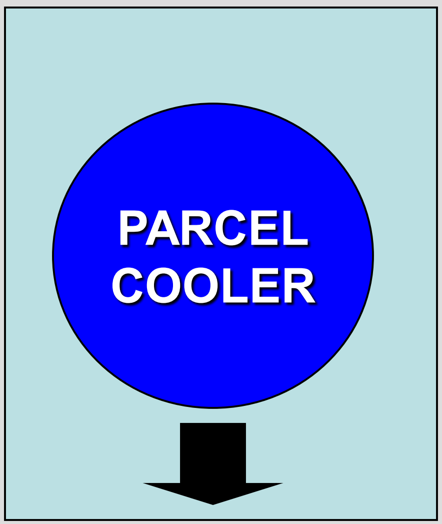
3. Parcel sinking:

   Temperature increases at the dry adiabatic lapse rate, since the parcel is warming and no condensation is taking place.

Stability and Buoyancy

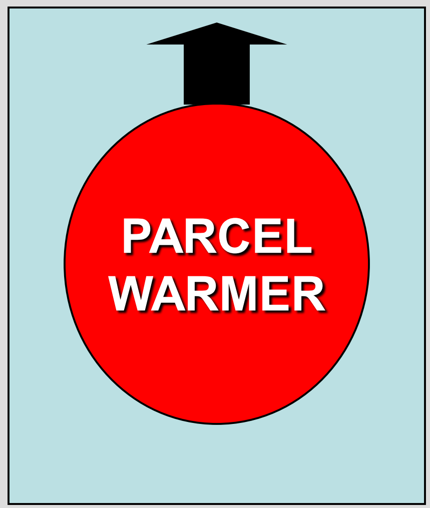
In the atmosphere, the stability is related to the *__buoyancy__*, the upward force exerted on the air parcel by virtue of the temperature difference between the parcel and the surrounding air.

ABSOLUTELY STABLE



$\Gamma_{env} < \Gamma_{moist}$

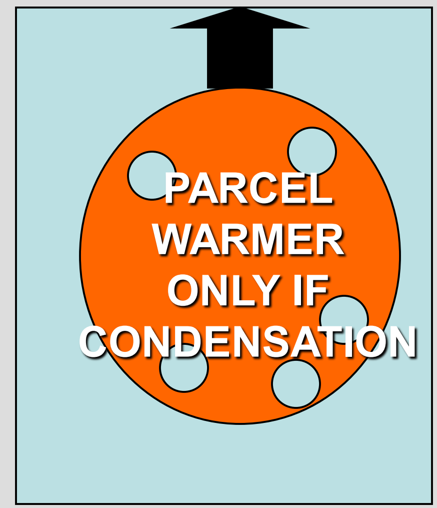
ABSOLUTELY UNSTABLE



$\Gamma_{env} > \Gamma_{dry}$

Superadiabatic

CONDITIONALLY UNSTABLE



$\Gamma_{env} < \Gamma_{env} < \Gamma_{dry}$

What 'unstable' means operationally

Clouds in a Stable Environment

RADIATION FOG

Forms in inversion caused by surface radiational cooling. The inversion acts like a "lid"

STRATUS

NIBMOSTRATUS

Form because air is being forced up and over something, for example a front or terrain barrier.

Clouds in a Conditionally Unstable Environment

Cumulus Congestus

Cumulus Humilis

Cumulonimbus

Basically any type of cumulus cloud indicates conditional instability somewhere in the atmosphere.

Causes of Instability in the Atmosphere

Occurs by any process which increases the environmental lapse rate.

<u>Cooling Aloft</u>

Winds bringing in colder air
Clouds (radiational cooling)

<u>Warming of the surface</u>

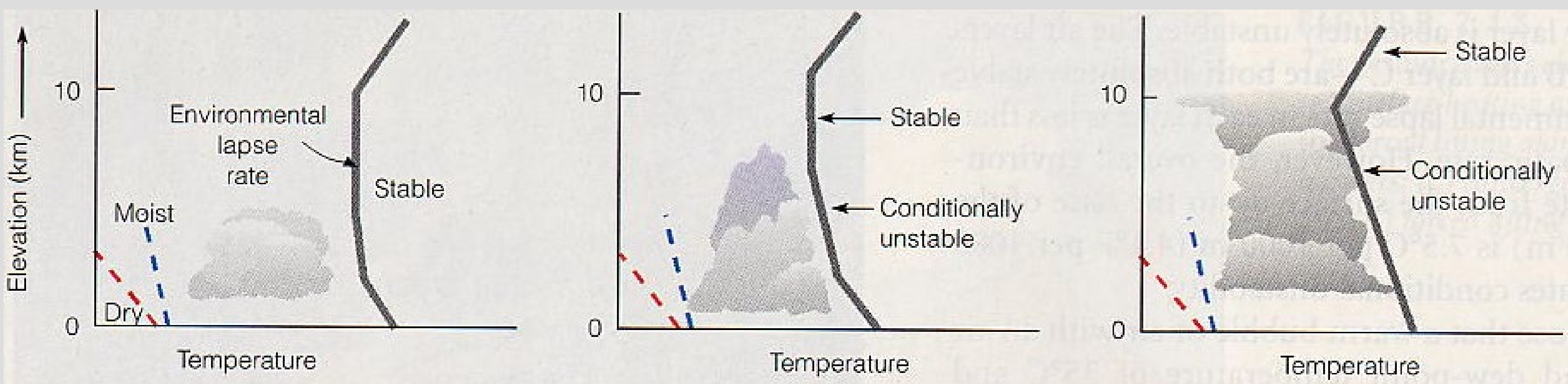
Daytime solar heating
Winds bringing in warmer air
Air moving over a warm surface.

How deep convection is depends on how far up the instability goes in the atmosphere

Cumulus humilis

Cumulus congestus

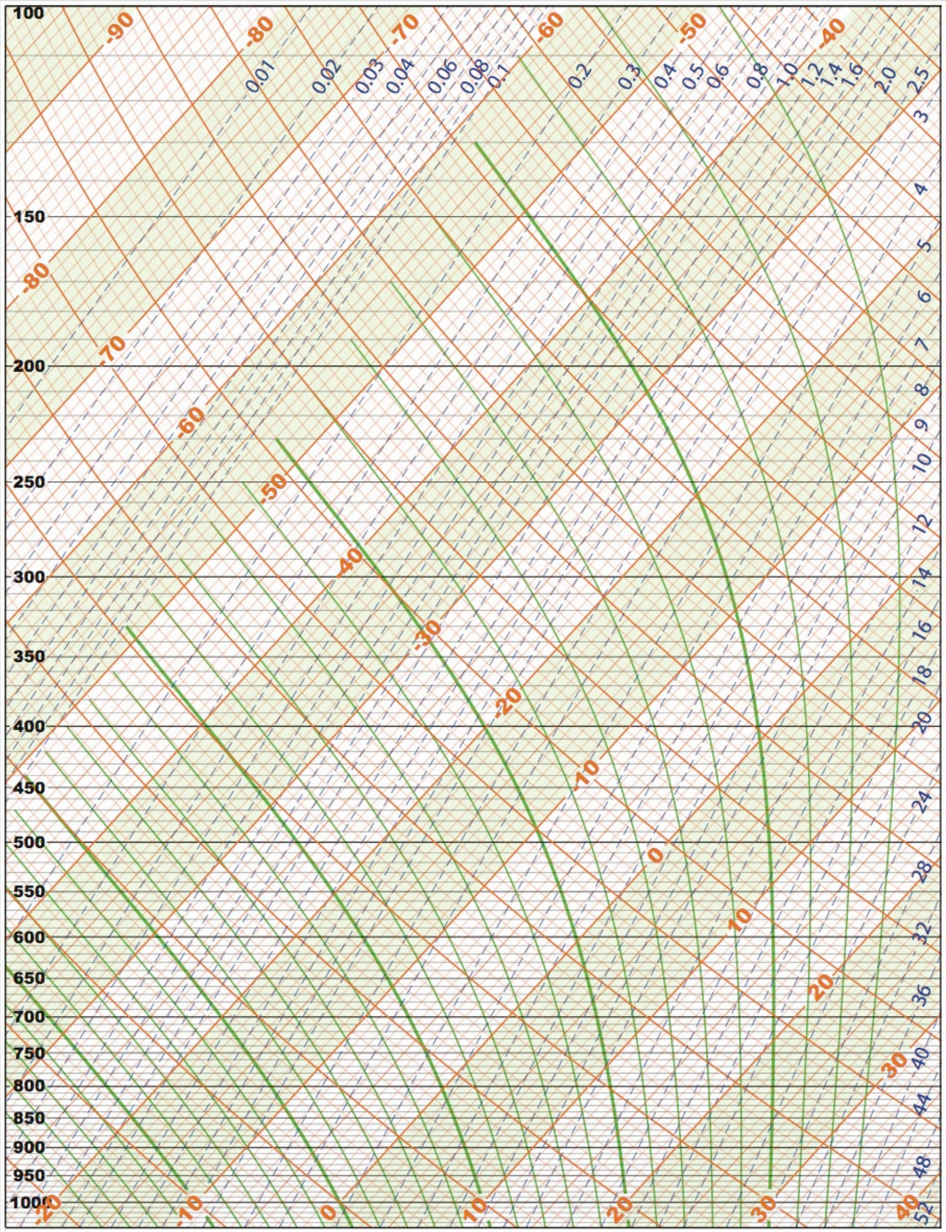
Cumulonimbus



Conditionally unstable in a shallow layer

Conditionally unstable about midway through troposphere

Conditionally unstable nearly to the tropopause

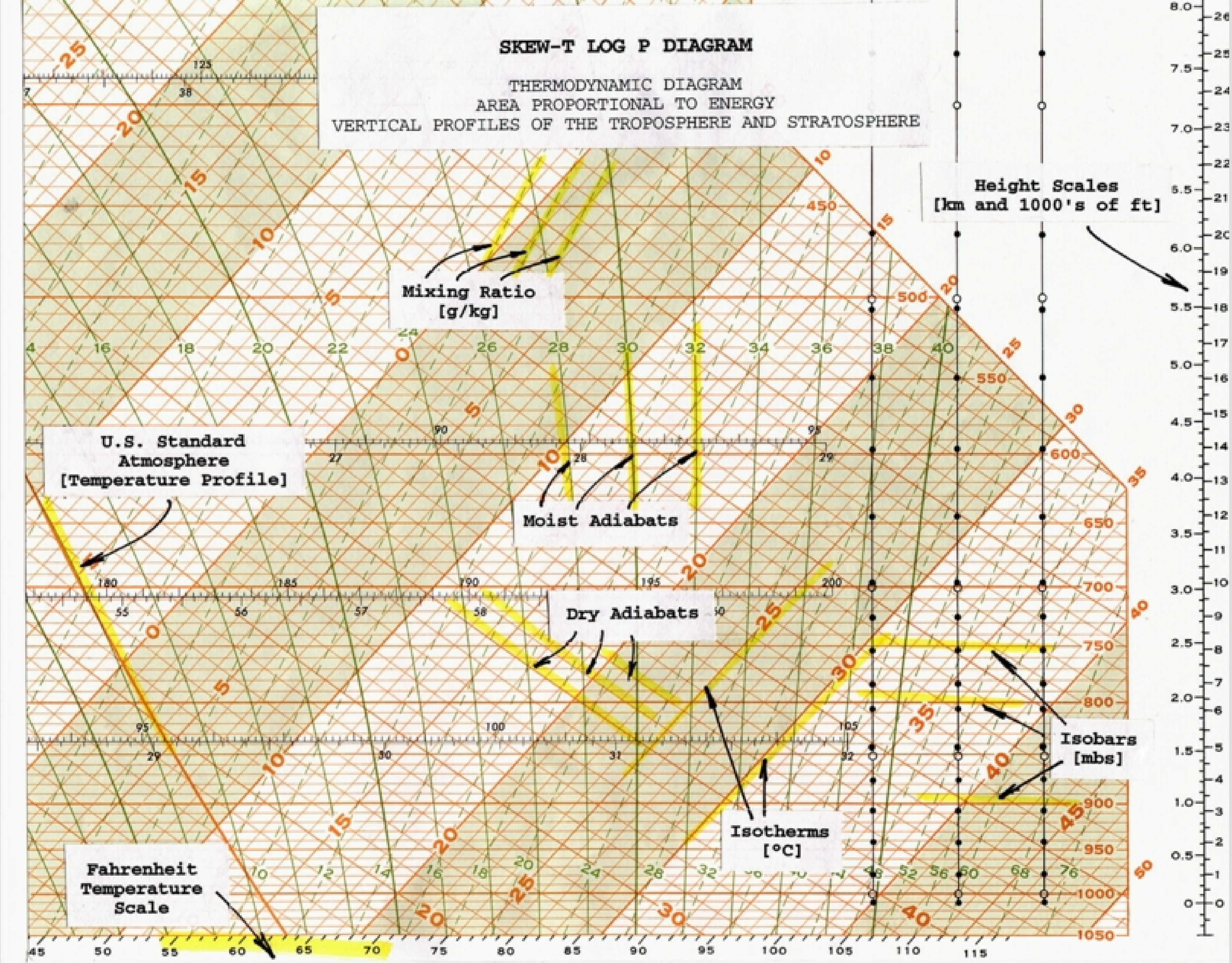


Rationales for the diagram

See the temperature and moisture (dew point) profiles of the observed atmosphere (as recorded from a radiosonde)

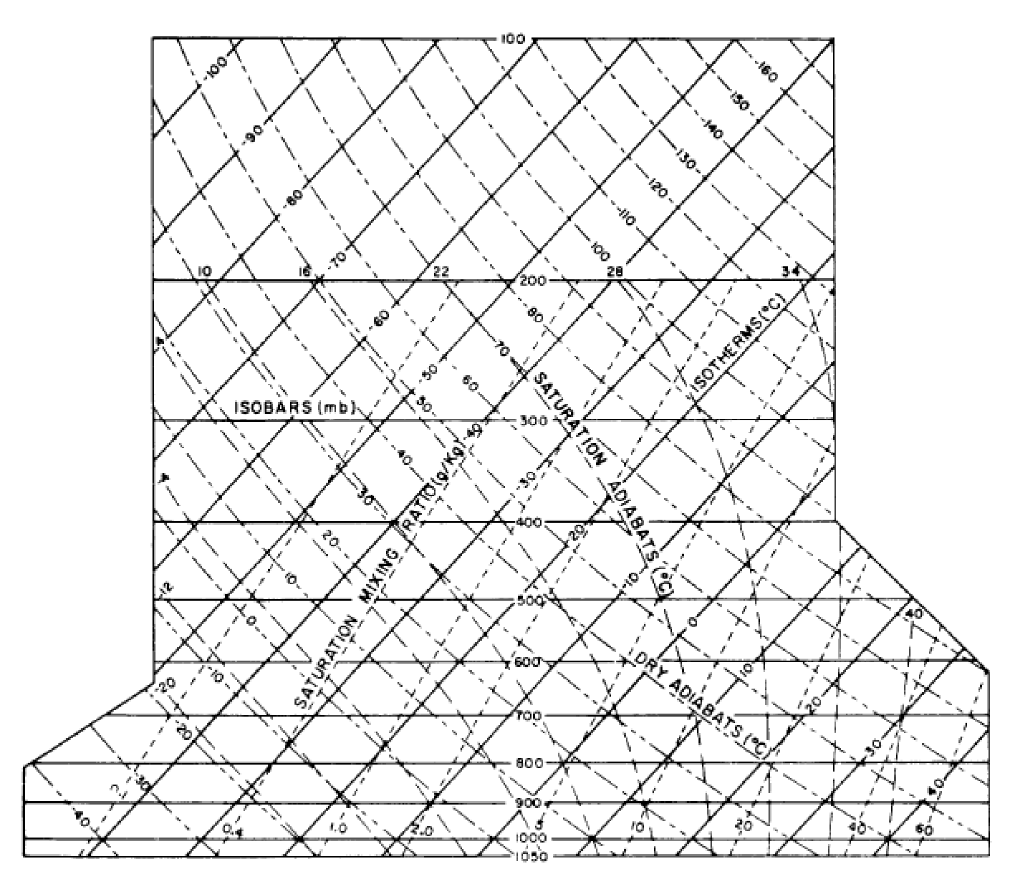
The diagram is, at its essence, a visual depiction of the first law of thermodynamics (dq=du+dw)

Can be used to derive diagnostic quantities associated with both dry and moist adiabatic processes. This can be quickly done graphically without the use of formulas, which can be quite complicated when atmosphere is behaving moist adiabatically.


SKEW-T LOG P DIAGRAM
THERMODYNAMIC DIAGRAM
AREA PROPORTIONAL TO ENERGY
VERTICAL PROFILES OF THE TROPOSPHERE AND STRATOSPHERE
Mixing Ratio [g/kg]
Height Scales [km and 1000's of ft]
U.S. Standard Atmosphere [Temperature Profile]
Moist Adiabats
Dry Adiabats
Isobars [mbs]
Isotherms [°C]
Fahrenheit Temperature Scale

*** SkewT-LogP diagram ***

** The **SkewT/Log(-P)** diagram is also in widespread use in weather services. This is in fact a variation on the original Emagram, first devised in 1884 by H. Hertz.

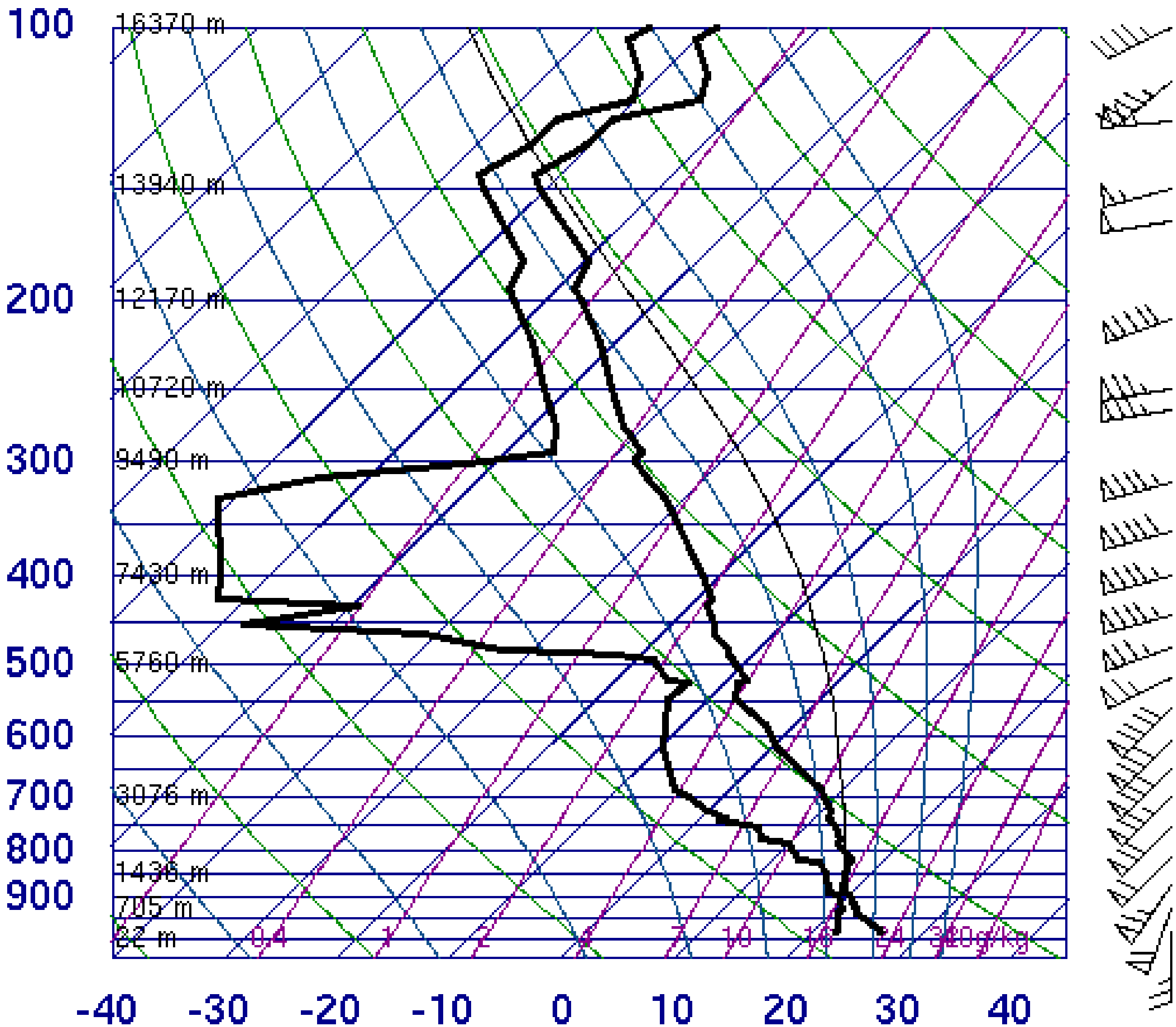


$y = -R\ln P$

$x = T + k\ln P$

k is adjusted to make the angle between isotherms and dry adiabats nearly 90^o.

72230 BMX Shelby County Airport



SLAT	33.16
SLON	-86.76
SELV	178.0
SHOW	-6.26
LIFT	-8.05
LFTV	-8.78
SWET	601.9
KINX	32.70
CTOT	26.90
VTOT	28.50
TOTL	55.40
CAPE	2944.
CAPV	3172.
CINS	-6.19
CINV	-5.23
EQLV	143.0
EQTV	142.9
LFCT	890.2
LFCV	891.4
BRCH	14.24
BRCV	15.35
LCLT	293.7
LCLP	917.5
MLTH	301.0
MLMR	16.98
THCK	5738.
PWAT	41.83

00Z 28 Apr 2011 University of Wyoming

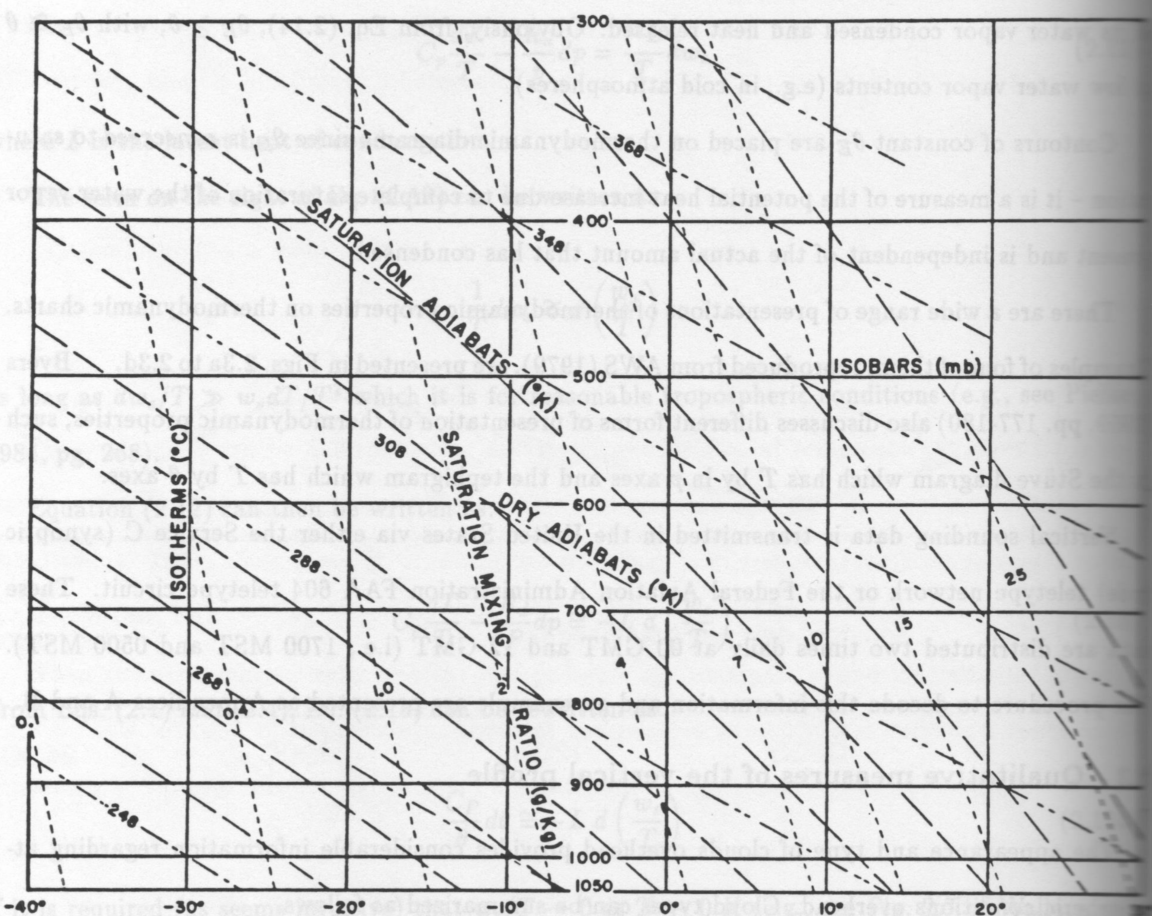
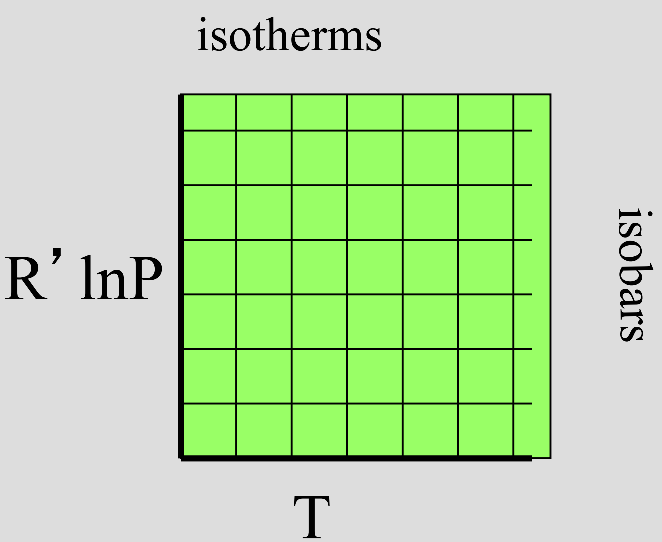


Figure 2.3: (a). Coordinate system of the emagram (from AWS, 1979).

*** Emagram ***

The **emagram** was devised in 1884 by H. Hertz. In this, the dry adiabats make an angle of about 45° with the isobars; isopleths of saturation mixing ratio are almost straight and vertical. In 1947, Herlofson proposed a modification to the emagram which allows straight, horizontal isobars, and provides for a large angle between isotherms and dry adiabats. Area on emagram denotes total **work** done in a cyclic process.

<u>Energy-per-unit-mass-diagram</u> $\oint w = -R' \oint T \, d\ln P$



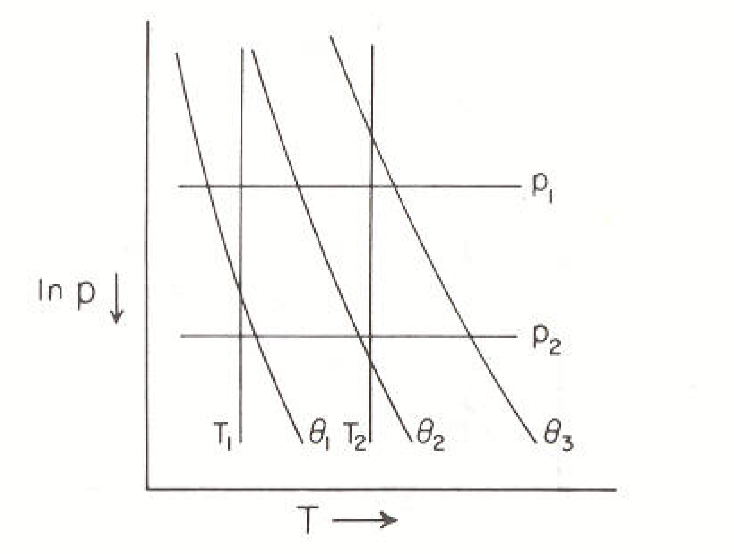
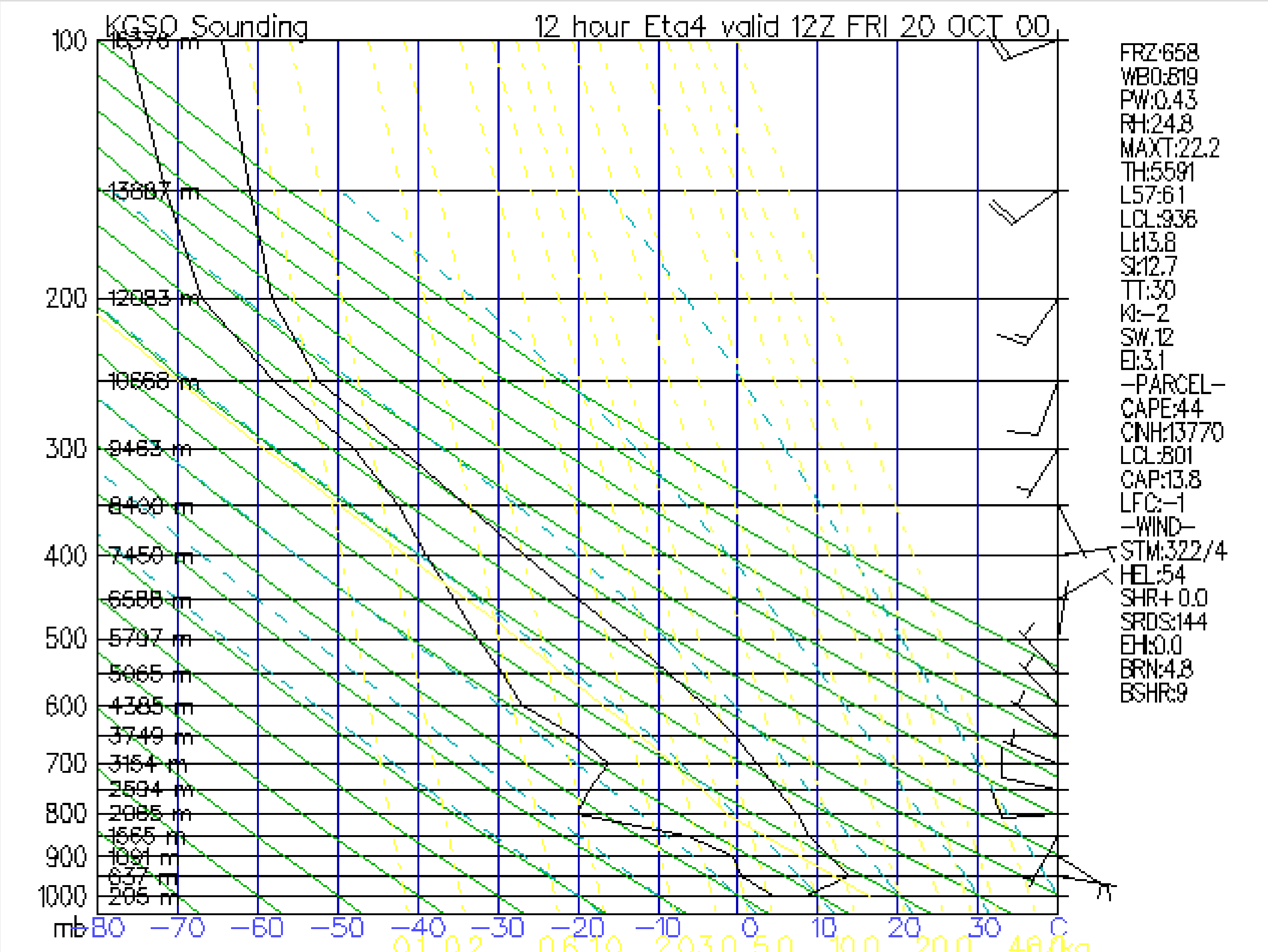


FIG. 1.5. Schematic emagram.

A true thermodynamic diagram has <u>Area</u> α <u>Energy</u>


KGSO Sounding
12 hour Eta4 valid 12Z FRI 20 OCT 00
100
16570 m
13887 m
200
12083 m
10668 m
300
9463 m
8400 m
400
7450 m
6588 m
500
5797 m
5065 m
600
4385 m
3749 m
700
3154 m
2594 m
800
2065 m
1565 m
900
1091 m
637 m
1000
205 m
mb
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 C
0.1 0.2 0.6 1.0 2.0 3.0 5.0 10.0 20.0 40.0 g/kg
FRZ:658
WB0:819
PW:0.43
RH:24.8
MAXT:22.2
TH:5591
L57:6.1
LCL:936
LI:13.8
SI:12.7
TT:30
KI:-2
SW:12
EI:3.1
-PARCEL-
CAPE:44
CINH:13770
LCL:801
CAP:13.8
LFC:-1
-WIND-
STM:322/4
HEL:54
SHR+0.0
SRDS:144
EH:0.0
BRN:4.8
BSHR:9

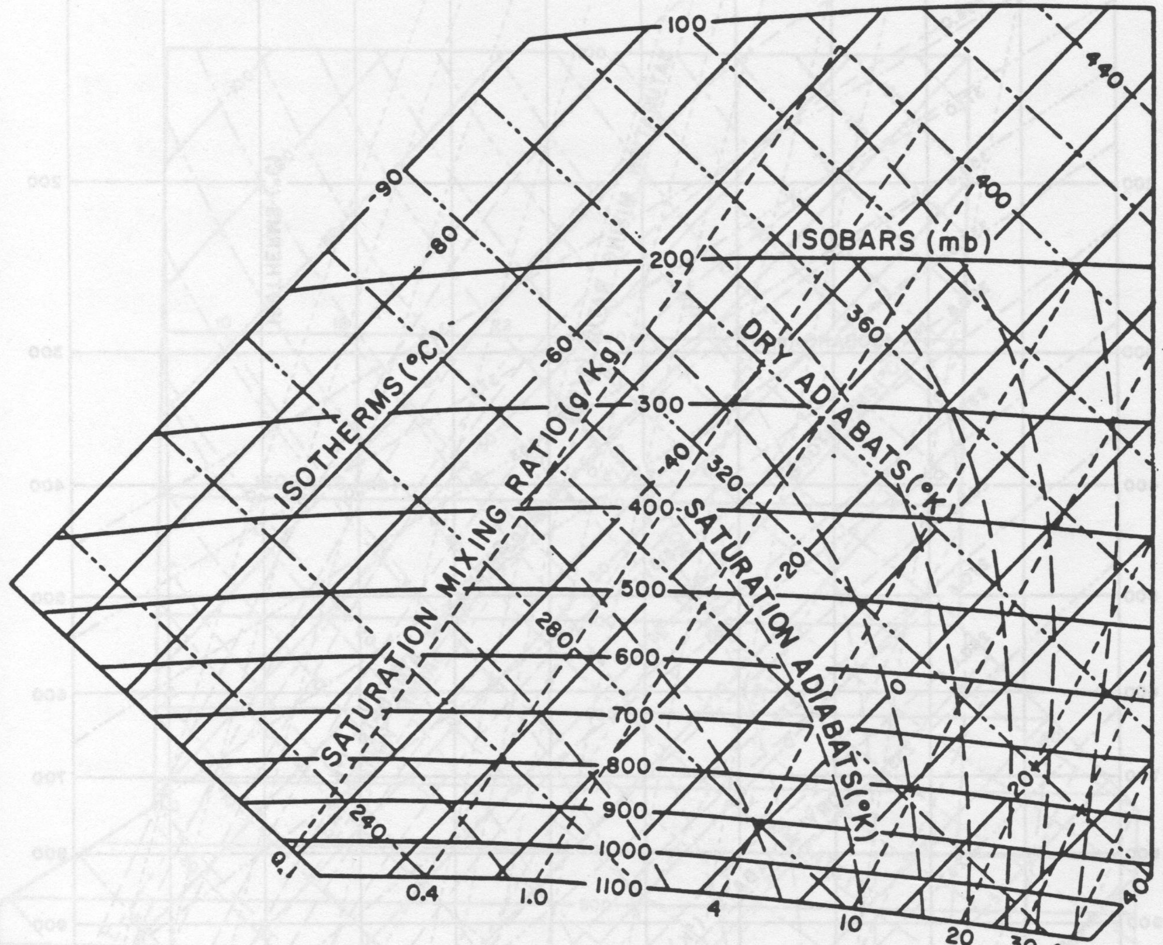


Figure 2.3: (b). Coordinate system of the tephigram (from AWS, 1979).

Start 9/16/14
Tephigram***

** The **Tephigram** takes its name from the rectangular Cartesian coordinates : temperature and **entropy**. Entropy is denoted by Greek letter 'phi' was used, hence Te-phi-gram (or T-Φ-gram). The diagram was developed by Sir William Shaw, a British meteorologist about 1922, and was officially adopted by the International Commission for the Exploration of the Upper Air in 1925. An area in the Tephigram denotes total HEAT or ENERGY added to a cyclic process

$$\oint đq = \oint T\, d\varphi = c_p \oint T d\theta / \theta = c_p \oint T d(\ln\theta)$$

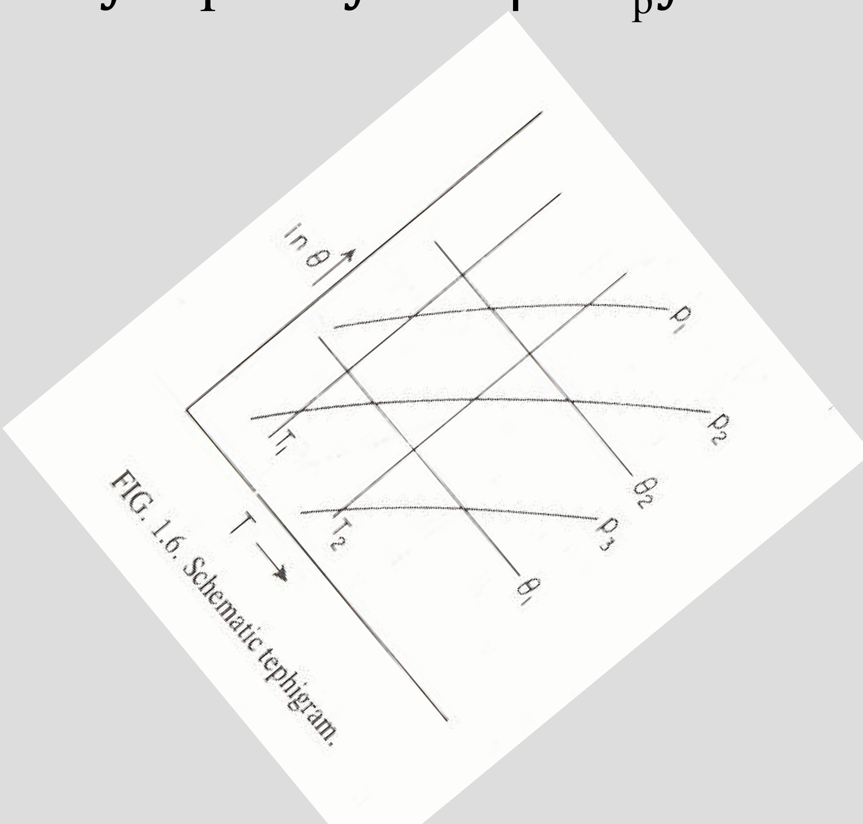
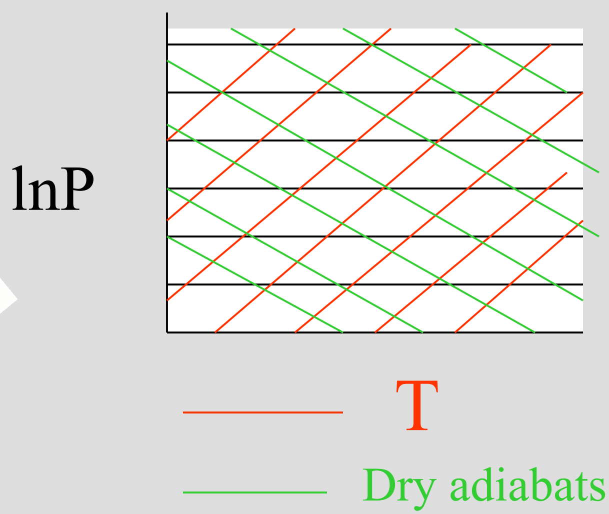
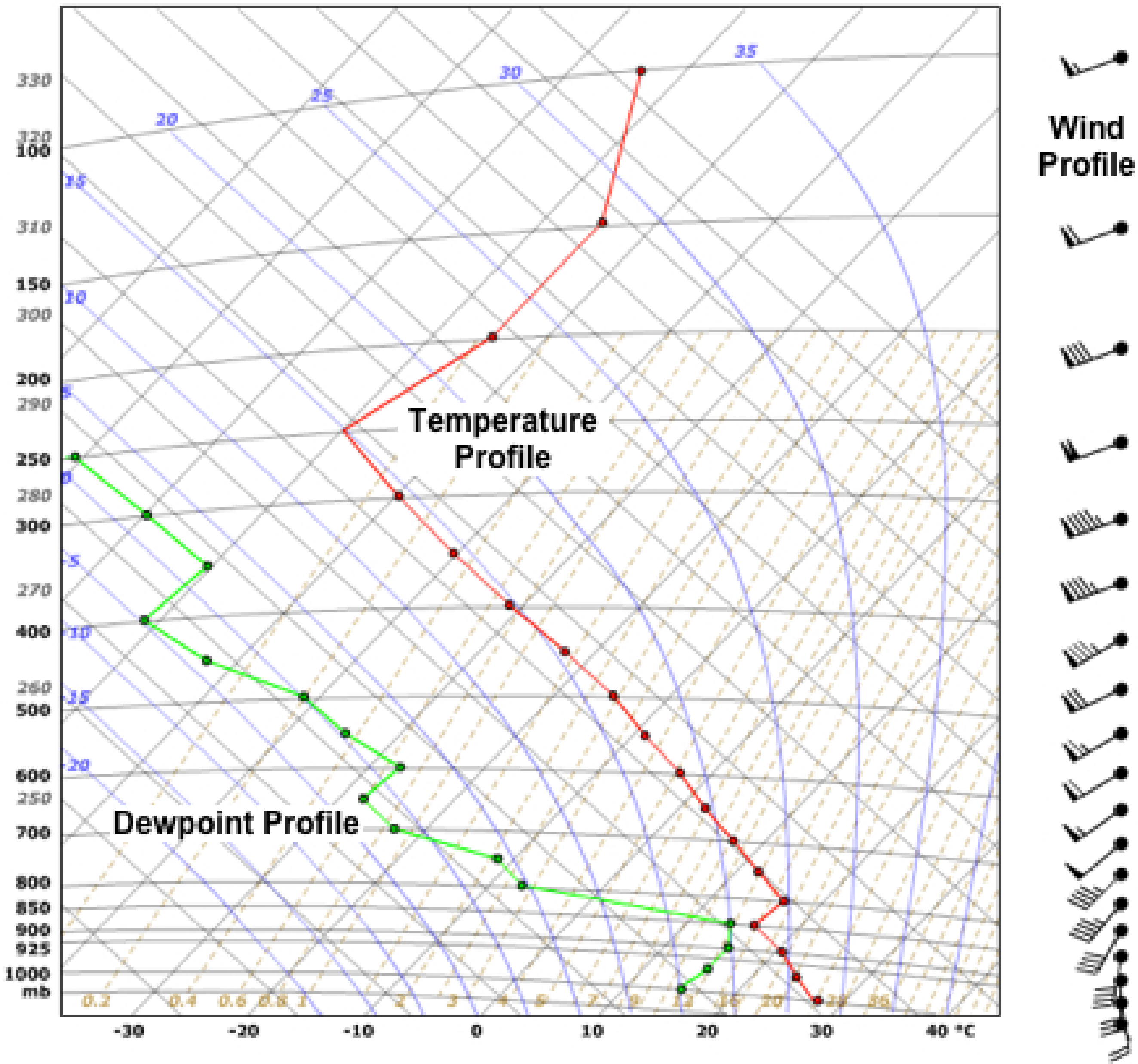


FIG. 1.6. Schematic tephigram.



Profiles Plotted on a Tephigram



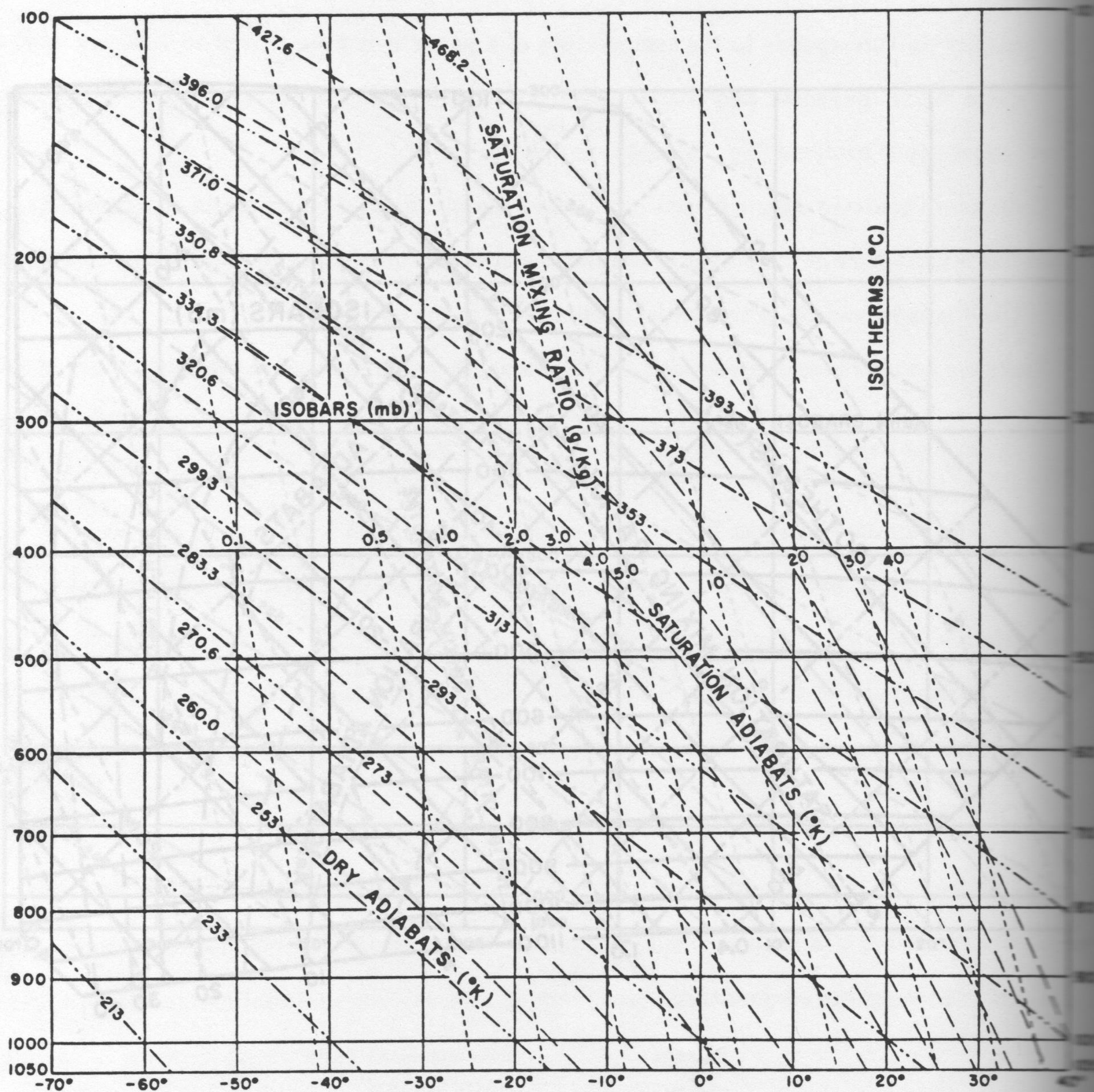


Figure 2.3: (c). Coordinate system of the Stüve ("pseudo-adiabatic) diagram (from AWS, 1979).

*** Stüve diagram ***

** The **Stüve** diagram uses straight lines for the three primary variables, **pressure**, **temperature** and **potential temperature**. In doing so sacrifices the equal-area requirements (from the original Clapeyron diagram) that are satisfied in the other two diagrams. See Salby, Figure 5.5.

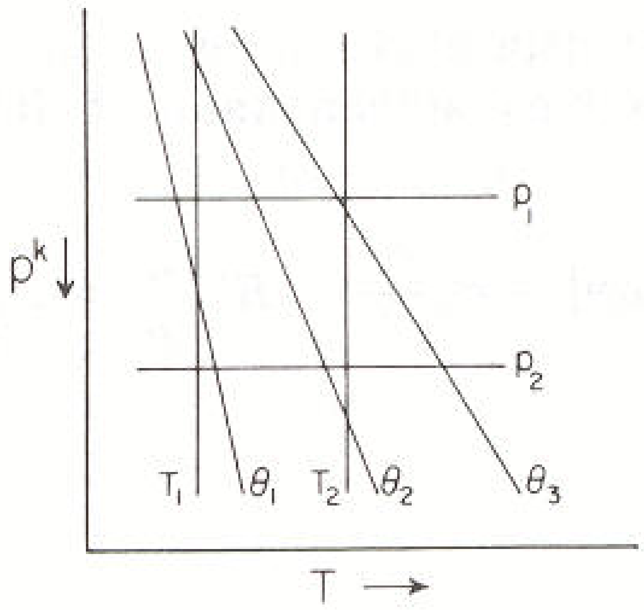
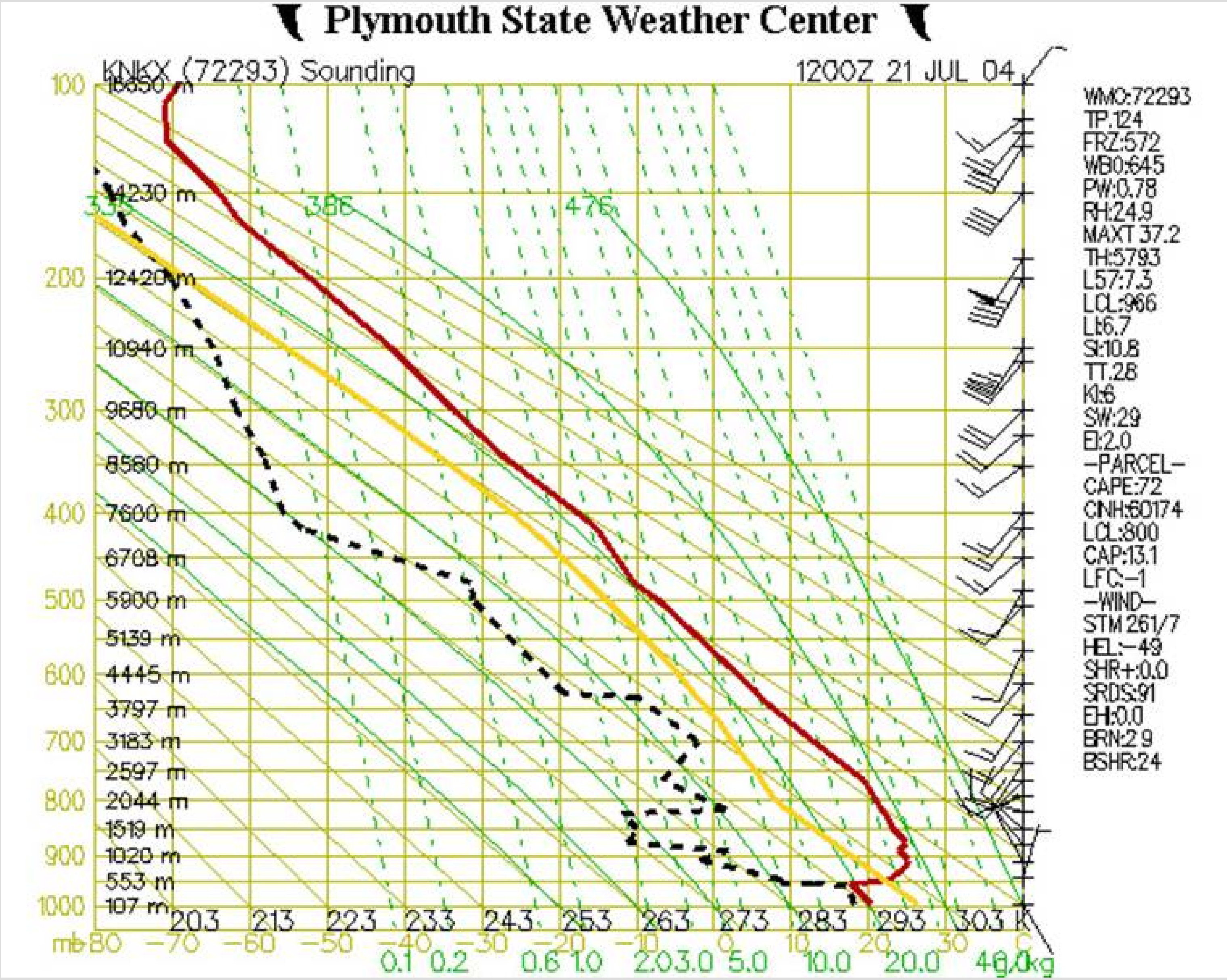


FIG. 1.4. Stüve diagram.

For an **adiabatic** process:

$$\boldsymbol{\theta = T\,(1000/p)^K}$$

The **Stüve** diagram is also simply called adiabatic chart



Plymouth State Weather Center
KNKX (72293) Sounding
1200Z 21 JUL 04
WMO:72293
TP:124
FRZ:572
WBO:645
PW:0.78
RH:24.9
MAXT 37.2
TH:5793
L57:7.3
LCL:966
LI:6.7
SI:10.8
TT:28
KI:6
SW:29
EI:2.0
-PARCEL-
CAPE:72
CINH:60174
LCL:800
CAP:13.1
LFC:-1
-WIND-
STM 261/7
HEL:-49
SHR+:0.0
SRDS:91
EH:0.0
BRN:2.9
BSHR:24

Where are the different thermodynamic diagrams used?

Emagram: Europe

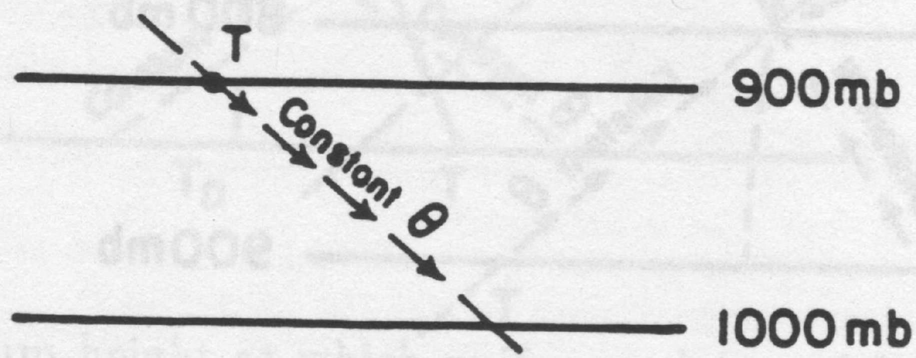
Tephigram: United Kingdom, Ireland, Canada

Stuve: United States, Europe

Skew-T: United States (standard) and most elsewhere in world

Some basic thermodynamically derived quantities on Skew-T

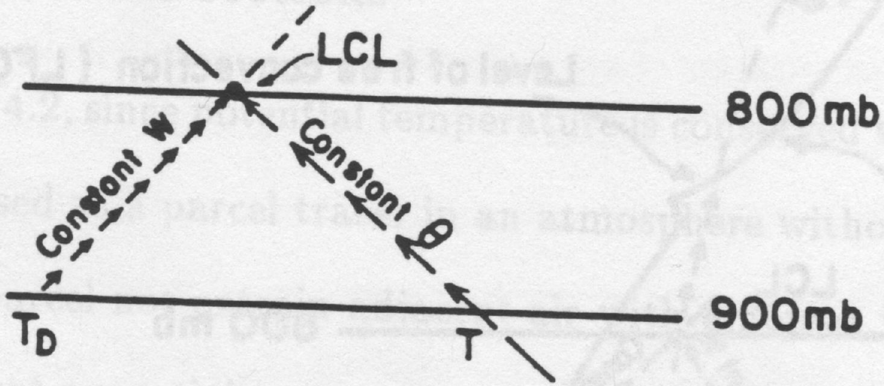
4.2.1 Potential temperature, (θ)



<u>Potential Temperature:</u> Temperature that a parcel of air would potentially have following a dry adiabat to the reference level of 1000-mb.

<u>Utility:</u> Absent any phase change of water, potential temperature will be conserved as a parcel moves vertically in the atmosphere.

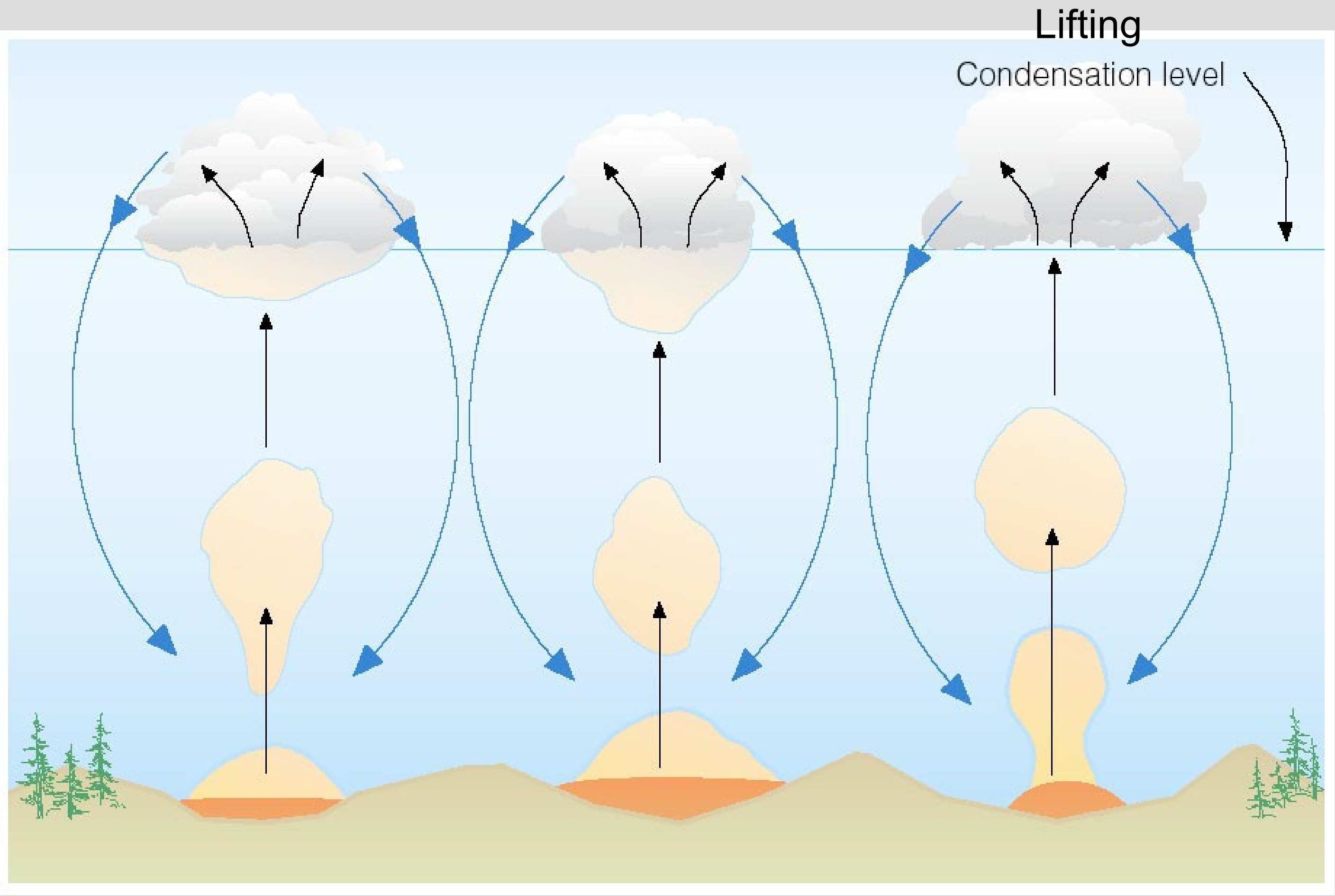
4.2.2 Lifted condensation level (LCL)



Lifting condensation level: Assuming dry adiabatic rise of a parcel with its mixing ratio conserved, defines the point at which the temperature of the parcel = dew point temperature and RH = 100%.

Utility: Defines where (the flat) cloud base is going to occur, especially for any cumuliform cloud. Also nominally defines the height of the planetary boundary layer, because potential temperature and mixing ratio nearly constant in PBL.

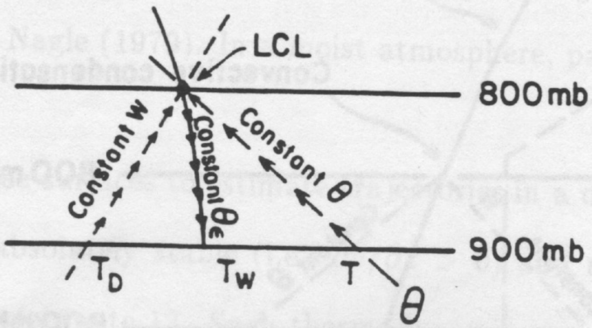
Cloud development by convection



RH = 100%

Convection starts with rising bubbles of warm air or thermals. When these reach the point in the atmosphere where RH =100% a cloud begins to form.

4.2.3 Wet bulb potential temperature (θ_W) and wet bulb temperature (T_W)



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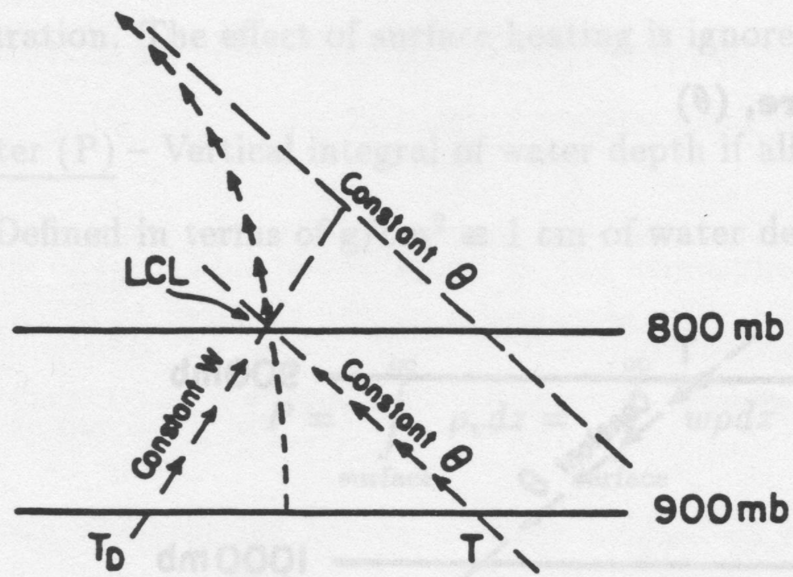
<u>Wet bulb temperature:</u> temperature a parcel of air would have if it were cooled to saturation (100% relative humidity) by the evaporation of water into it. Find by descending along a moist adiabat from LCL. Continue on to 1000-mb to find wet bulb potential temperature.

<u>Utility:</u> Wet-bulb temperature is one of the easiest manual measures of atmospheric moisture to calculate, via use of a sling psychrometer. Also relates to efficiency of evaporative cooling processes (e.g. swamp cooler)

4.2.4 Equivalent potential temperature (θ_E)

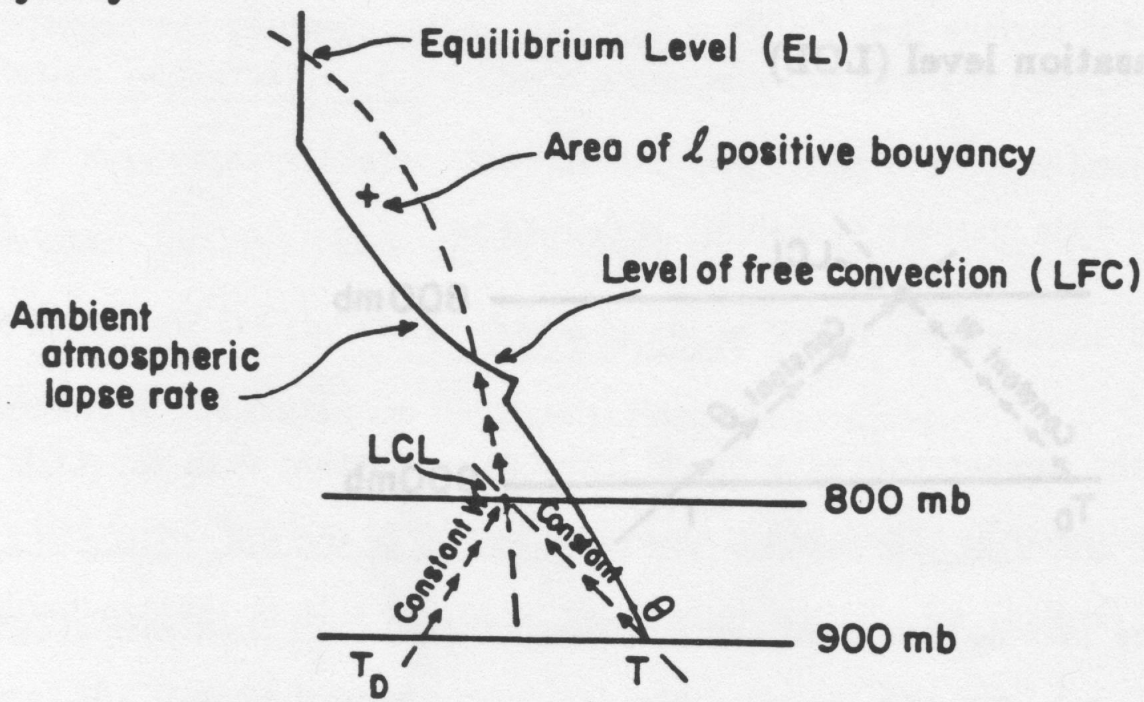


<u>Equivalent potential temperature:</u> follow moist adiabat upward till all moisture is condensed out. Then descend along a dry adiabat to reference level of 1000-mb.

<u>Utility:</u> Potential temperature parcel of air would have if all its moisture were condensed out. Good as a combined metric of heat and moisture, which are requisite conditions in the lower atmosphere for convective initiation. Commonly used in reference to any convective processes (e.g. thunderstorms, tropical cyclones), since saturated air moves along a moist adiabat

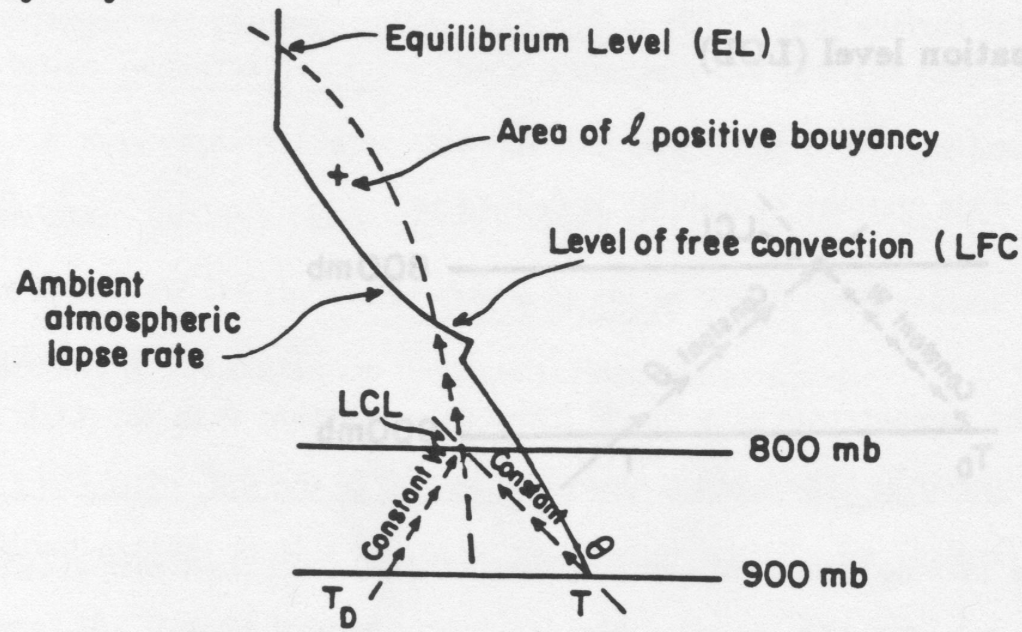
4.2.5 Level of free convection (LFC), equilibrium level (EL), and area of pa[rcel]

buoyancy



4.2.5 Level of free convection (LFC), equilibrium level (EL), and area of po

buoyancy

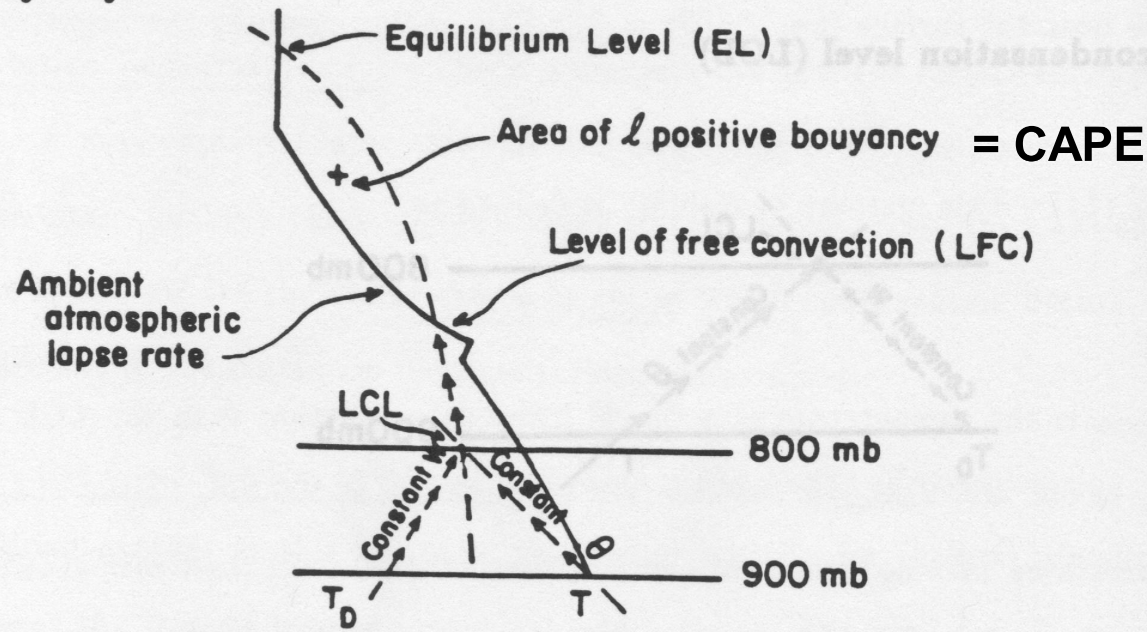


<u>Level of free convection (LFC):</u> Assuming moist adiabatic rise from LCL, defines point at which the temperature of the rising parcel > temperature of the environment. At this point the parcel is conditionally unstable and will spontaneously rise due to its positive buoyancy.

MUST reach this point to utilize any convective available potential energy present in the sounding. So some sort of forced lifting mechanism to trigger the convection on synoptic scale or mesoscale (e.g. a front, differential heating due to terrain, sea breeze circulation, mesoscale convective vortex, etc., etc.).

4.2.5 Level of free convection (LFC), equilibrium level (EL), and area of po

buoyancy



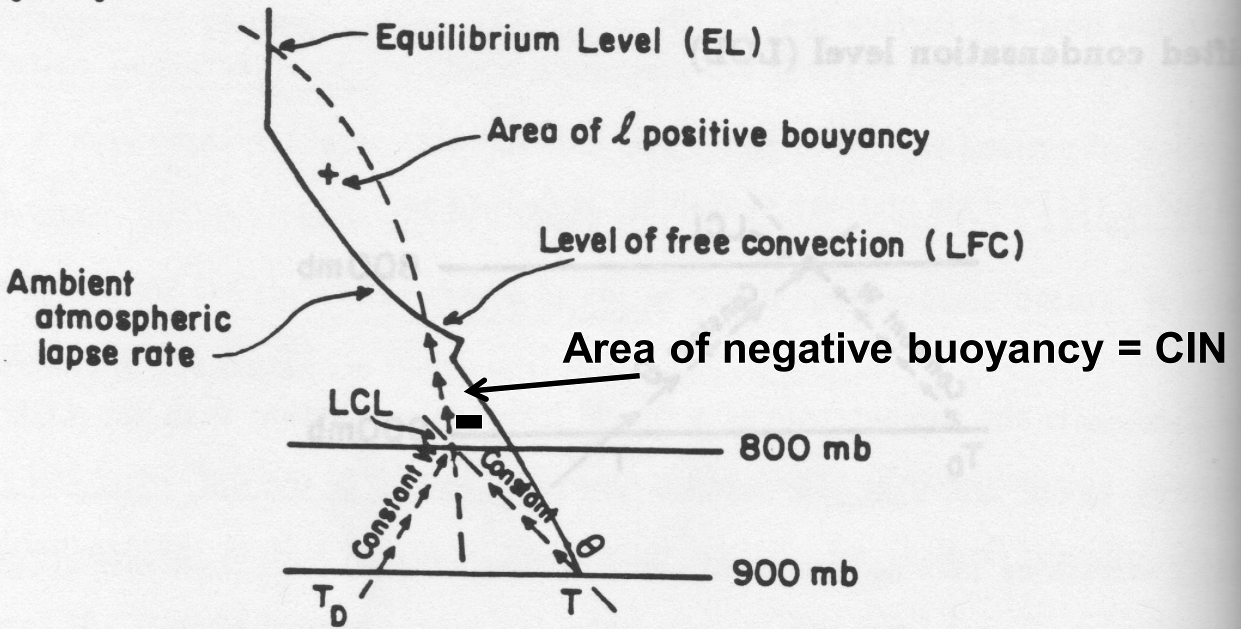
$$\text{CAPE} = g \int_{LFC}^{EL} \frac{\Theta(z) - \bar{\Theta}(z)}{\bar{\Theta}(z)}\, dz$$

Convective available potential energy

Vertically integrated energy due to positive buoyancy in the cloud, calculated from the level of free convection to the equilibrium level. Units J kg^{-1} = m^2 s^{-2}

4.2.5 Level of free convection (LFC), equilibrium level (EL), and area of po

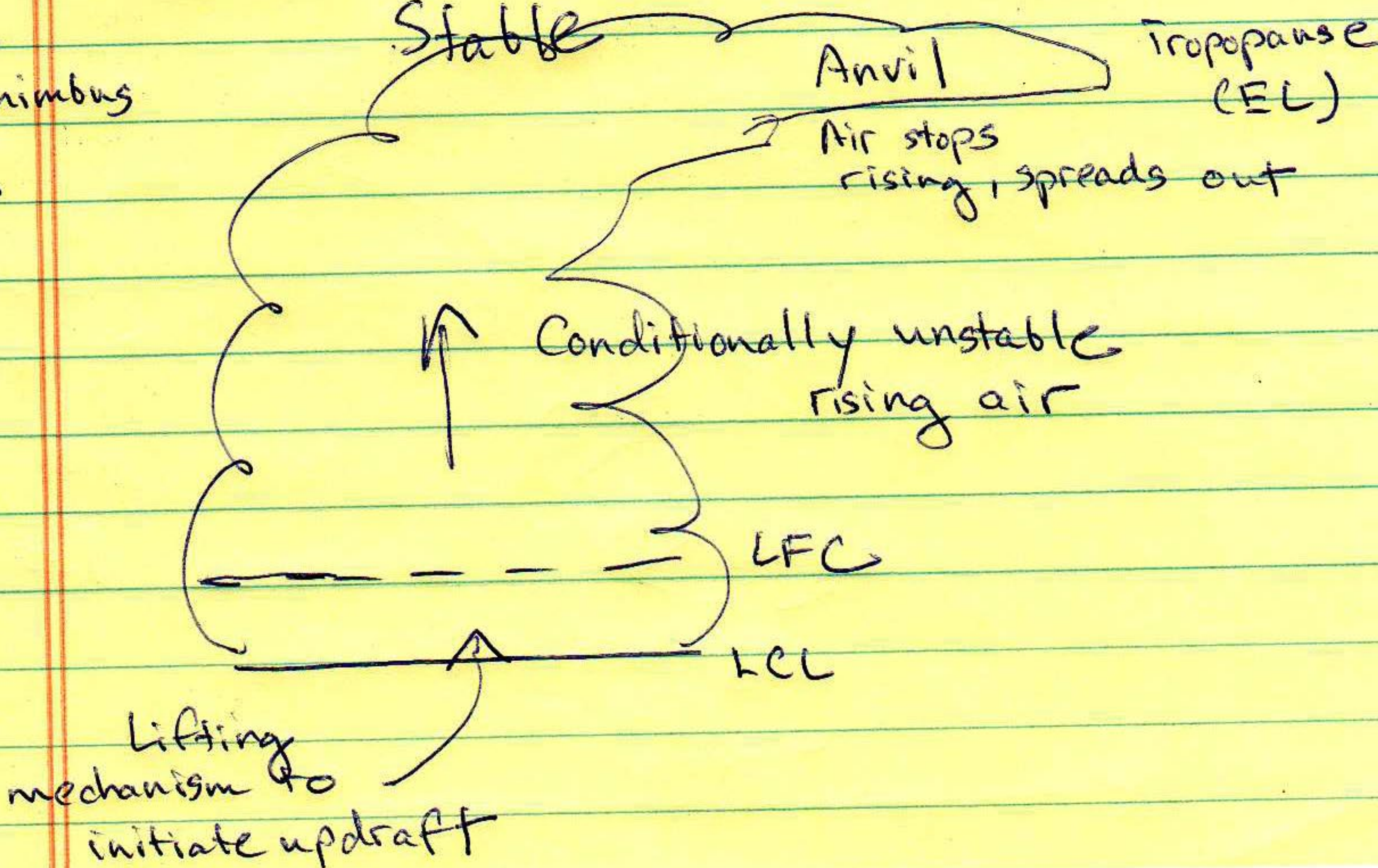
buoyancy

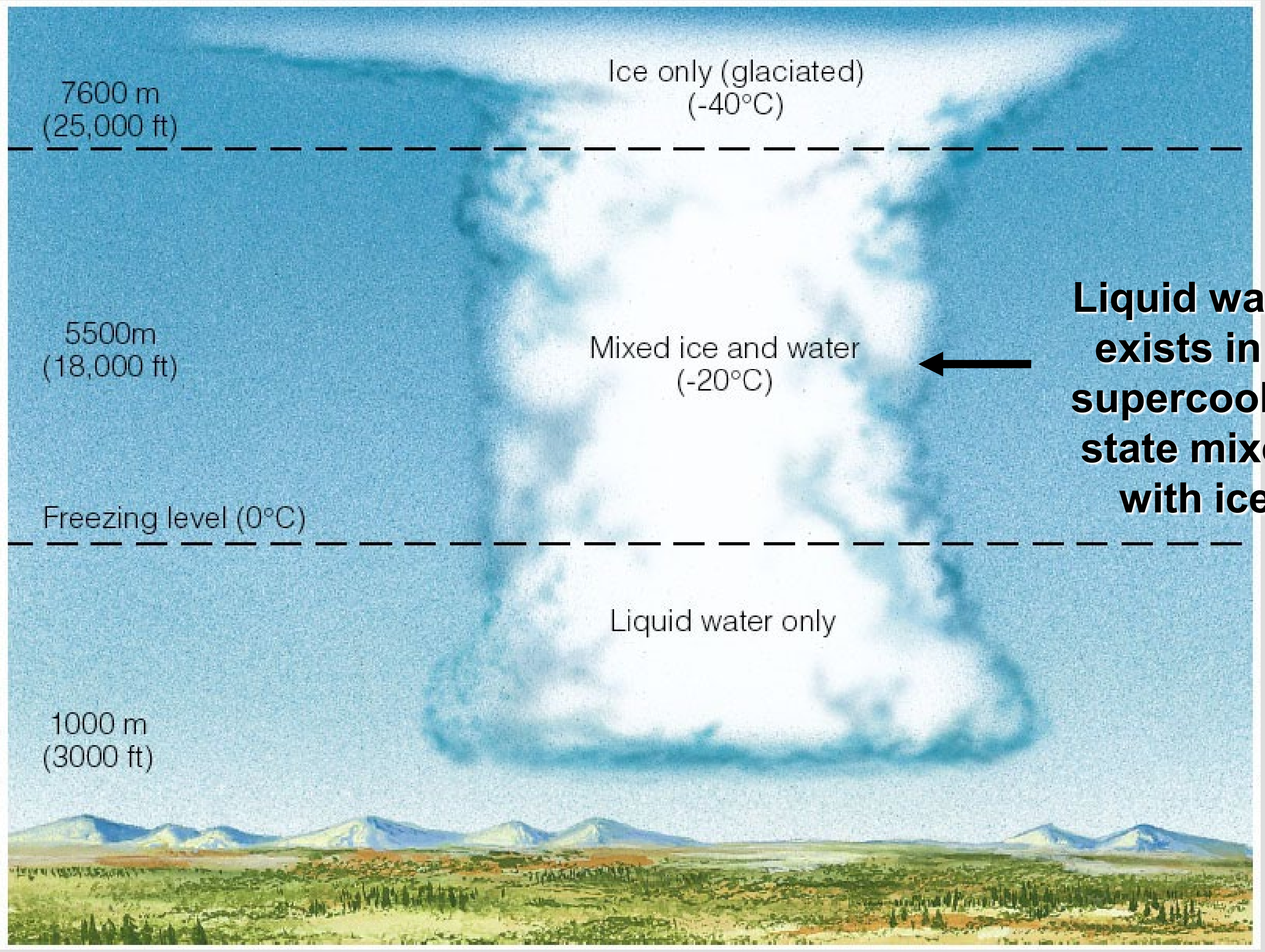


$$CIN = -g\int_{LCL}^{LFC} \frac{\theta(z)-\bar{\theta}(z)}{\bar{\theta}(z)}\,dz$$ Convective inhibition.

Vertically integrated negative buoyancy in the cloud, calculated from the LCL to LFC. Initiating updraft must overcome this barrier for spontaneous convection. Some CIN is necessary for the most severe types of thunderstorms (e.g. supercells).

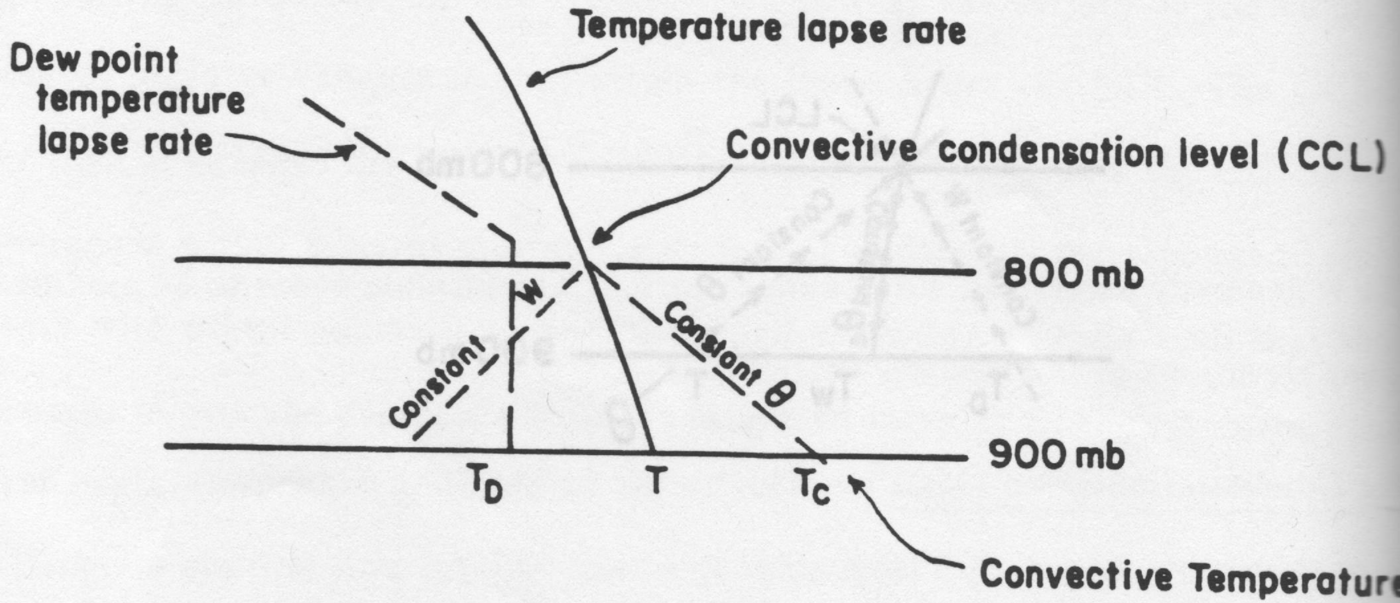
Typical cumulonimbus cloud





Liquid water exists in a supercooled state mixed with ice

4.2.6 Convective temperature (T_c) and convective condensation level (CCL)



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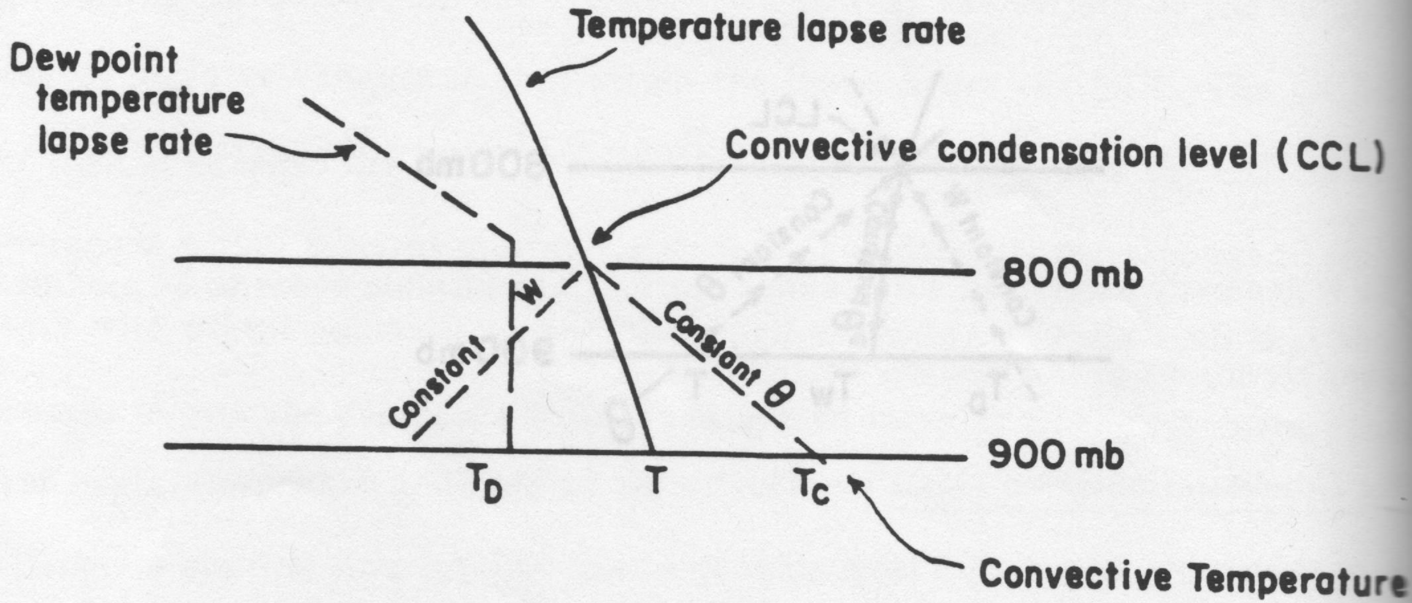
<u>Convective Temperature:</u> Temperature near the surface corresponding to a dry adiabatic lapse rate creating by heating and upward expansion of the boundary layer during the day. Closely matches maximum daytime temperature.

<u>Utility:</u> If considering a morning sounding, the convective temperature is what is more appropriate to consider as the surface temperature, as it will define the maximum height of the PBL.

4.2.6 Convective temperature (T_c) and convective condensation level (CCL)



<u>Convective condensation level:</u> Estimate the average dewpoint within a well mixed boundary layer to define PBL-averaged mixing ratio. The intersection of the modified value of w and dry adiabat from the surface convective temperature.

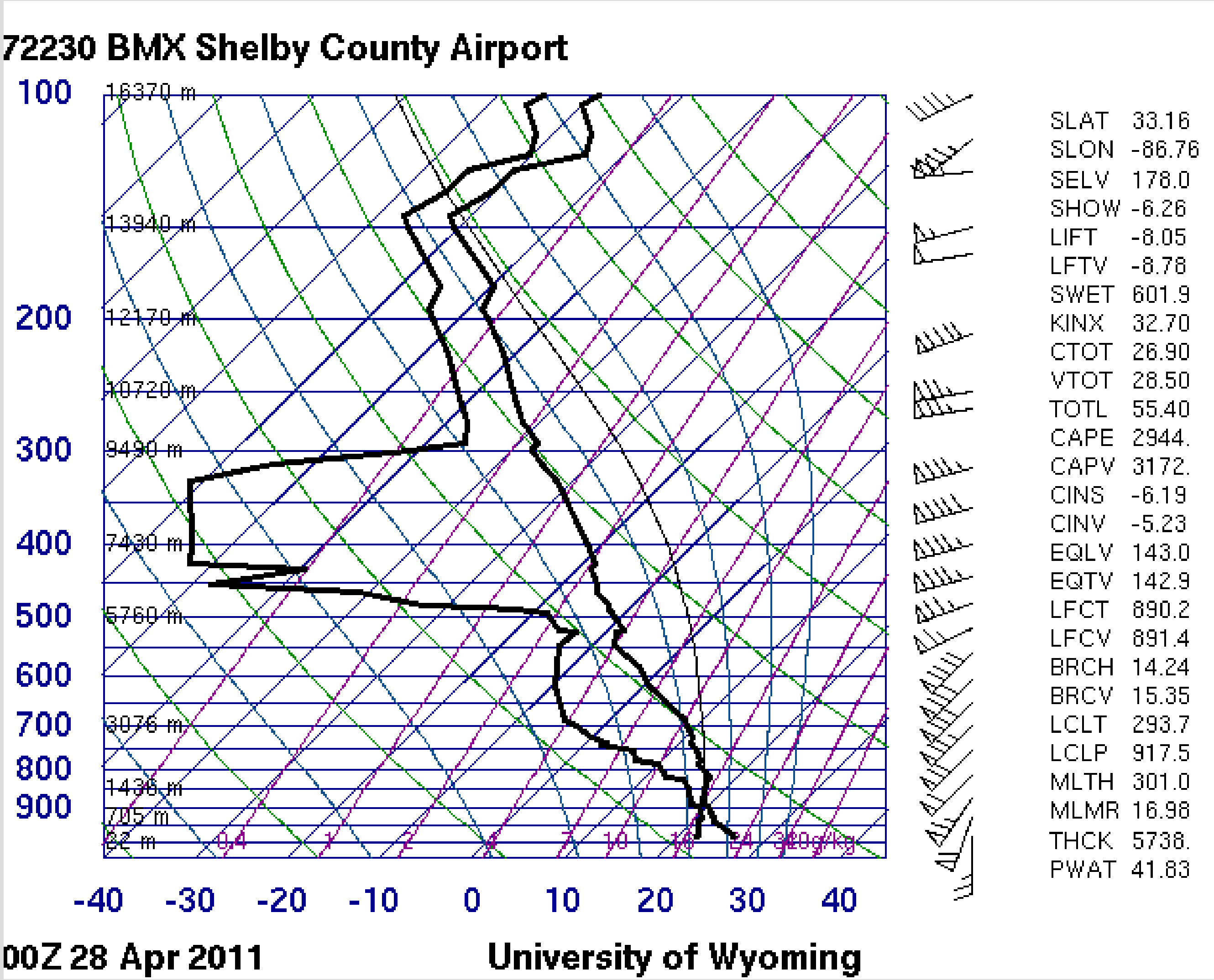
<u>Utility:</u> Most accurate metric for cloud base height and height of the PBL during the day. BUT…its dependent on the particular forecaster!

Typical steps (by forecaster)
to determine potential for convection :

- Estimate afternoon temperature (T_c)
- Determine lifting cond. level and level of free convection, assuming adiabatic rise to LCL and then psuedo adiabatic after that.
- Determine if parcel has sufficient upward motion to overcome any convective inhibition (i.e. break cap)
- If parcel can rise to point where its temperature > environment, parcel is unstable and keeps rising till it reaches equilibrium level
- As it rises, latent heat release, condensation, (may be sublimation), entrainment / detrainment of/to surrounding air.
- More CAPE = deeper convection
- Organization depends on the wind profile (i.e. is there shear, rotation?)

Diagnosing potential for convection from CAPE and other indices

LOTS of potential indices…we'll just focus on most commonly used ones.



Which one of these do you use???

Whatever one you choose, I suggest look at CAPE and CIN first.

Those are the most fundamental metrics which have most firm basis in physics (my opinion).

No one “right” answer on indices…frankly depends on the preference of the forecaster. Lots of indices because there’s a lot of regional, seasonal dependencies on how they perform.

Convective available potential energy. The acceleration induced by the buoyancy force in moist air, in the absence of liquid water or ice, is

$$B = g\,\frac{T_v(z) - \bar{T}_v(z)}{\bar{T}_v(z)}. \qquad (3.4.35)$$

The dynamical effect of B [Eq. (3.4.12)] alone when w is steady state and independent of x and y is as follows:

$$\frac{Dw}{Dt} = w\frac{dw}{dz} = \frac{d}{dz}\left(\tfrac{1}{2}w^2\right) = B. \qquad (3.4.36)$$

(We are not including here the effects of the vertical, perturbation pressure-gradient force, which opposes the buoyancy force.) Integrating Eq. (3.4.36) from the level of free convection (LFC) to the equilibrium level (EL), we find that if the air parcel is at rest at the LFC, and if the air parcel does not "entrain" any cooler, drier environmental air, then the updraft at the equilibrium level, the maximum vertical velocity (w_{max}), is

$$w_{max} = \sqrt{2\,\mathrm{CAPE}}, \qquad (3.4.37)$$

where CAPE, the *convective available potential energy* (also known as the *buoyant energy*), is given by

$$\mathrm{CAPE} = \int_{\mathrm{LFC}}^{\mathrm{EL}} g\,\frac{T_v(z) - \bar{T}_v(z)}{\bar{T}_v(z)}\,dz. \qquad (3.4.38)$$

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Moderate to strong convection = CAPE of 1000 to 3000 J kg^{-1}

Yields a maximum vertical velocity of 70 ms^{-1} for CAPE = 2500 J kg^{-1}.
Close to what is actually observed!

Showalter Index

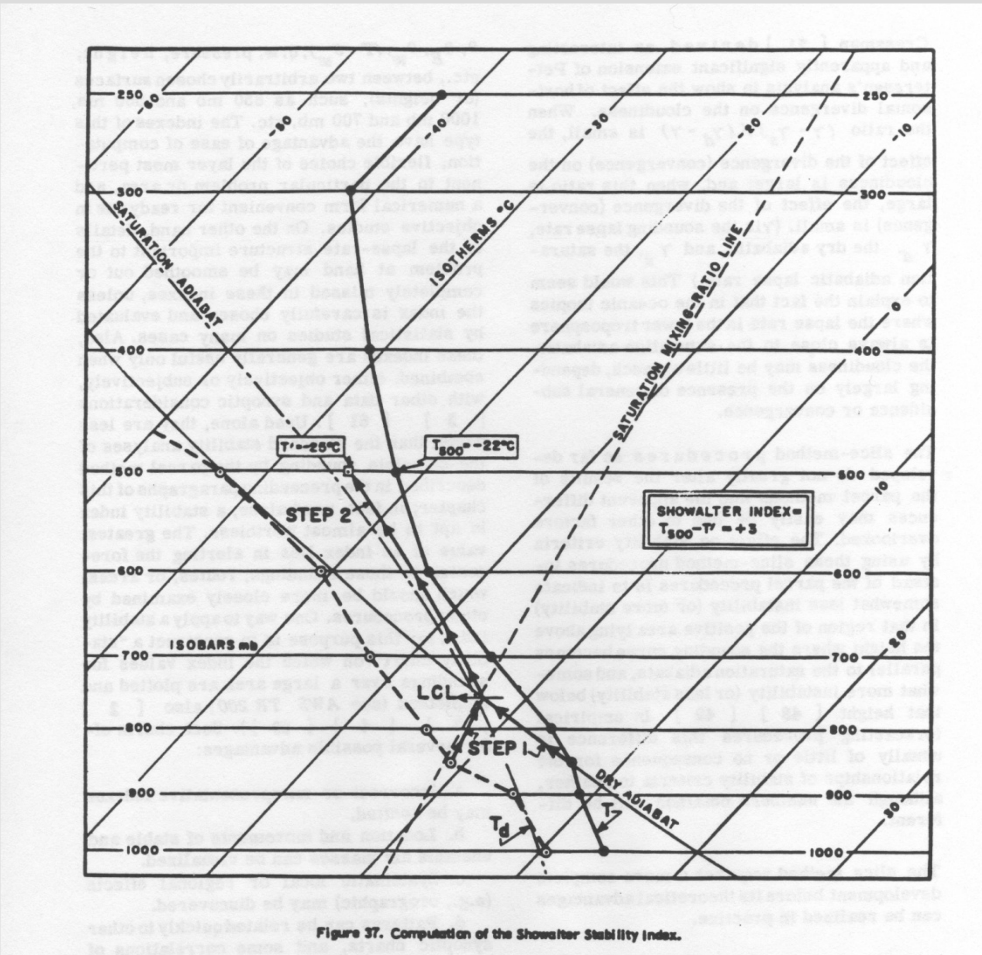

Figure 37. Computation of the Showalter Stability Index.

1. From 850-mb temperature, draw line parallel to dry adiabats upward to LCL
2. From LCL draw line parallel to moist adiabat upward to 500-mb. Call this value T'
3. Subtract T' from 500-mb environmental T to define index.

SHOWALTER INDEX (SI)[1]	Thunderstorm Indications
3 to 1	Thunderstorm possible--strong trigger needed
0 to -3	Unstable--thunderstorms probable
-4 to -6	Very unstable--good heavy thunderstorm potential
less than -6	Extremely unstable--good strong thunderstorm potential

Not very good for high based convection, when source air for convective clouds is above 850-mb

Lifted Index

Temperature excess at 500-mb of the environment, with respect to an air parcel in the PBL lifted to LCL and then lifted moist adiabatically to 500-mb

LIFTED INDEX (LI)[1]	Thunderstorm Indications
0 to -2	Thunderstorms possible--good trigger mechanism needed
-3 to -5	Unstable--thunderstorms probable
less than -5	Very unstable--heavy to strong thunderstorm potential

Similar to the idea of the convective temperature, need to forecast PBL characteristics in the afternoon from the morning sounding. Similar to Showalter index but more regionally adaptable.

"K" index

K = 850-mb temperature – 500-mb temperature
+ 850-mb dew point – 700-mb dew point depression

K INDEX West of Rockies[1]	K INDEX East of Rockies[2]	Airmass Thunderstorm Probability
less than 15	less than 20	None
15 to 20	20 to 25	Isolated thunderstorms
21 to 25	26 to 30	Widely scattered thunderstorms
26 to 30	31 to 35	Scattered thunderstorms
above 30	above 35	Numerous thunderstorms

Note: K value may not be representative of airmass if 850-mb level is near surface. Western U.S. values are forced to approximate area coverage used by George.[2]

Designed to capture the potential instability in the lower half of the atmosphere, availability of moisture in PBL, and reduction in buoyancy through dry air entrainment. Useful in the absence of strong synoptic-scale forcing.

Totals-Totals (TT) Index

TT= Sum of Vertical Totals (VT) and Cross Totals (CT)

VT = 850-mb temperature minus 500-mb temperature
→ lapse rate between two pressure surfaces

CT = 850-mb dew point minus 500-mb temperature
→ Combines measure of low-level moisture with temperature aloft

Does NOT involve the use of any dry or moist adiabatic lapse rates

WEST OF THE ROCKIES (with adequate moisture):

VERTICAL TOTALS (VT)	Expect:
<28	No thunderstorms
29 to 32	Few thunderstorms
>32	Scattered thunderstorms

WEST OF THE ROCKIES:

TOTAL TOTALS (TT)[1]	Expect:
48	Isolated or few thunderstorms
52	Scattered thunderstorms, few of moderate intensity
55	Scattered thunderstorms, few of moderate intensity, isolated severe
58	Scattered thunderstorms, few severe, isolated tornadoes
61	Scattered to numerous thunderstorms, few to scattered severe, few tornadoes
64	Numerous thunderstorms, scattered severe, scattered tornadoes

EAST OF THE ROCKIES[3] (Total Totals Most Important):

CROSS TOTALS	VERTICAL TOTALS	TOTAL TOTALS	Expect:
18-19*	26 or more*	44	Isolated or few thunderstorms
20-21	26 or more	46	Scattered thunderstorms
22-23	26 or more	48	Scattered thunderstorms,isolated severe thunderstorms
24-25	26 or more	50	Scattered thunderstorms, few severe thunderstorms, isolated tornadoes
26-29	26 or more	52	Scattered to numerous thunder-storms, few to scattered severe thunderstorms, few tornadoes
30	26 or more	56	Numerous thunderstorms, scattered severe thunderstorms, scattered tornadoes

*Except along the immediate Gulf Coast and over the Gulf Stream, where the CT value is only 16 or more, and the VT value is only 23 or more.