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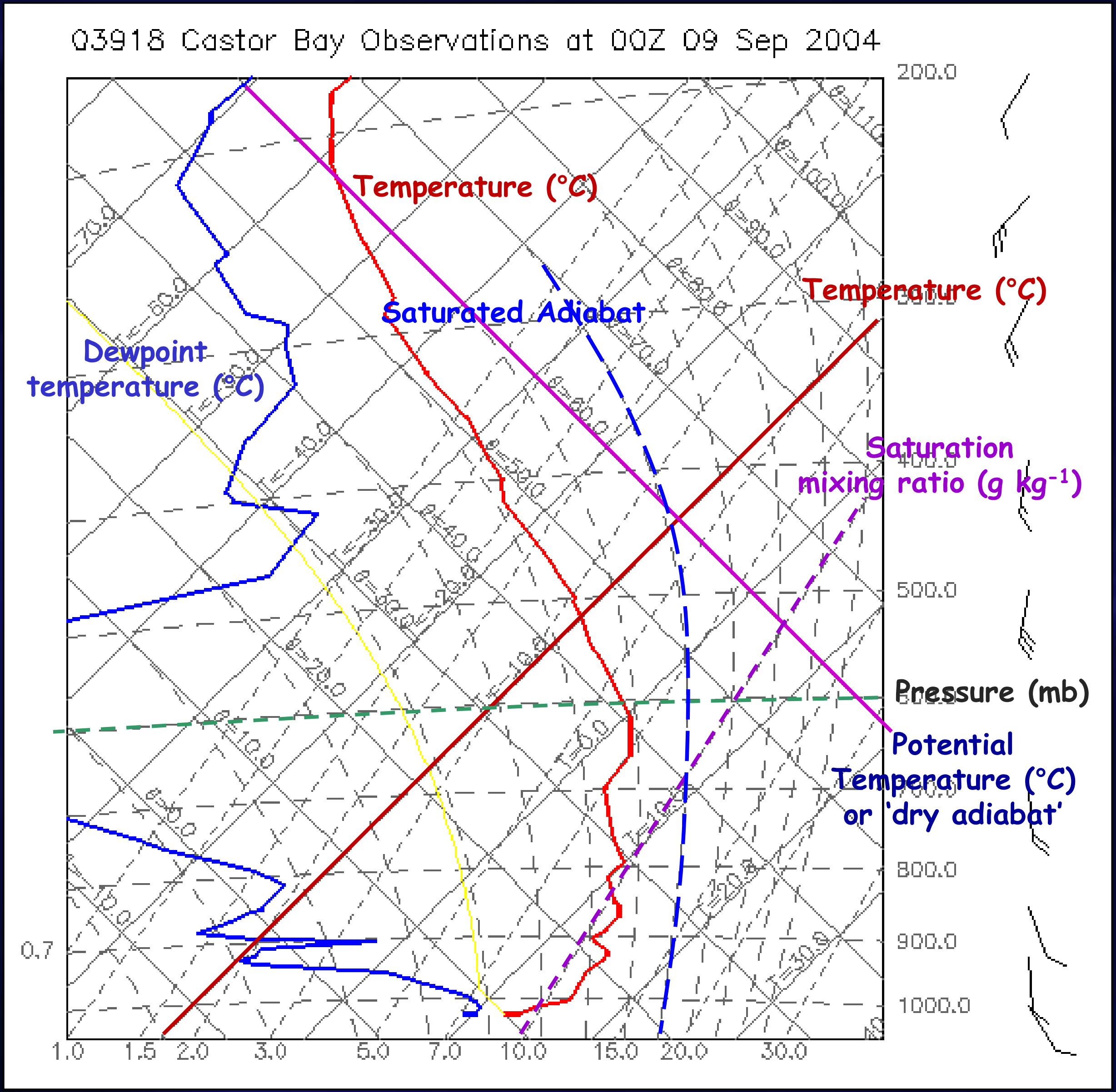
Fundamentals of Atmospheric Physics

Lecture 8

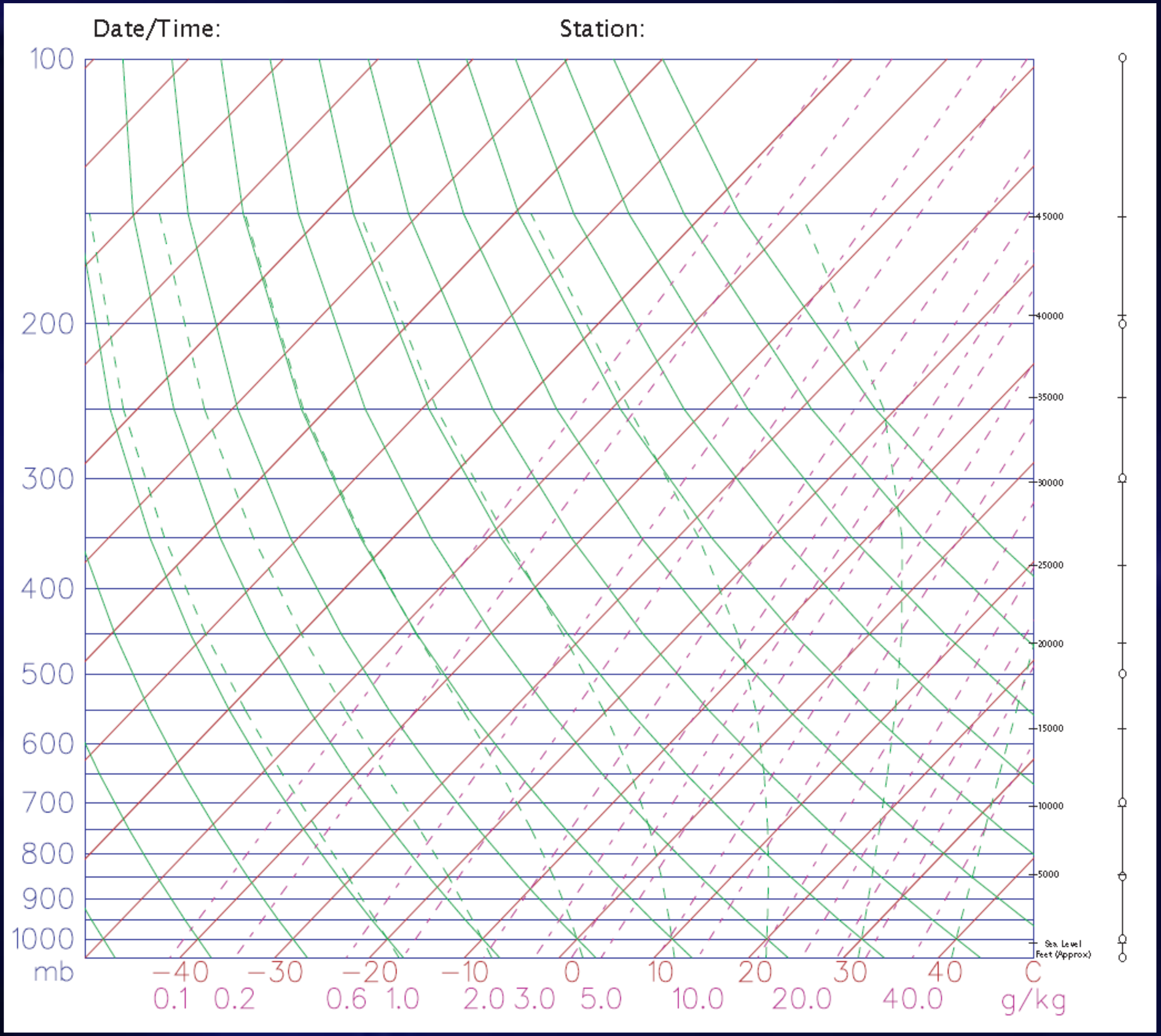
J. Sahraei

Tephigram

Thermodynamic diagram showing the vertical structure of the atmosphere.



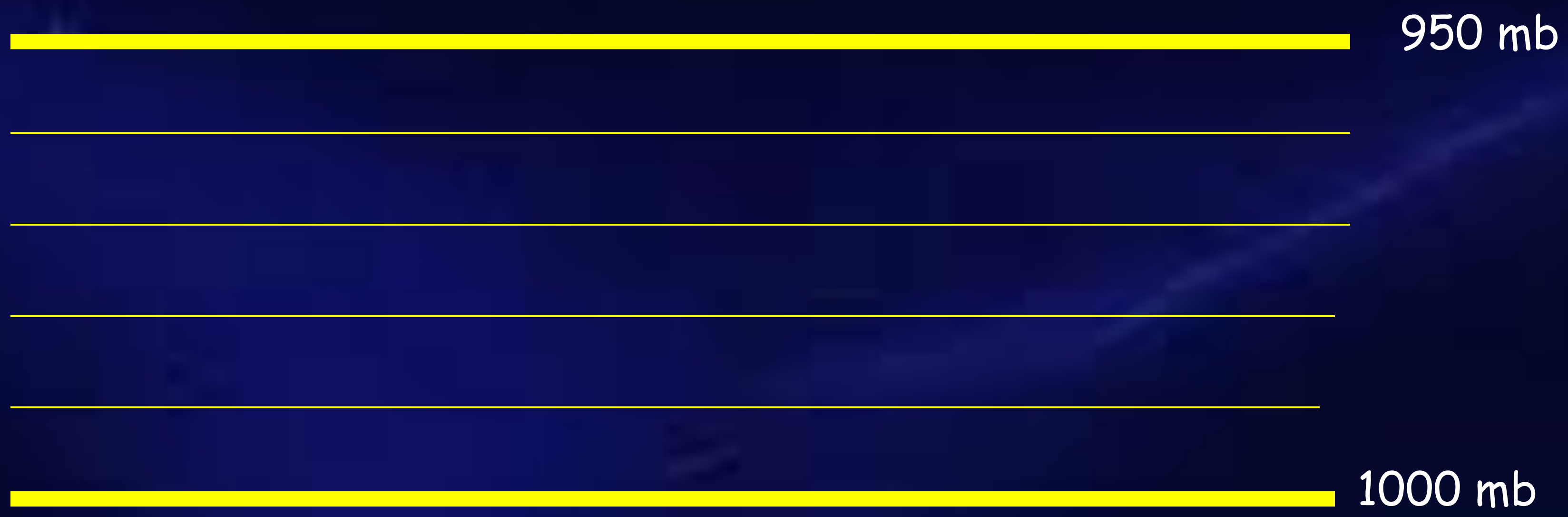
4) The SkewT/Log P diagram (modified emagram)



SKEW-T

Isobars are roughly horizontal lines that represent the pressures on the SKEWT.

They are plotted every 10 mb and are labeled every 50 mb

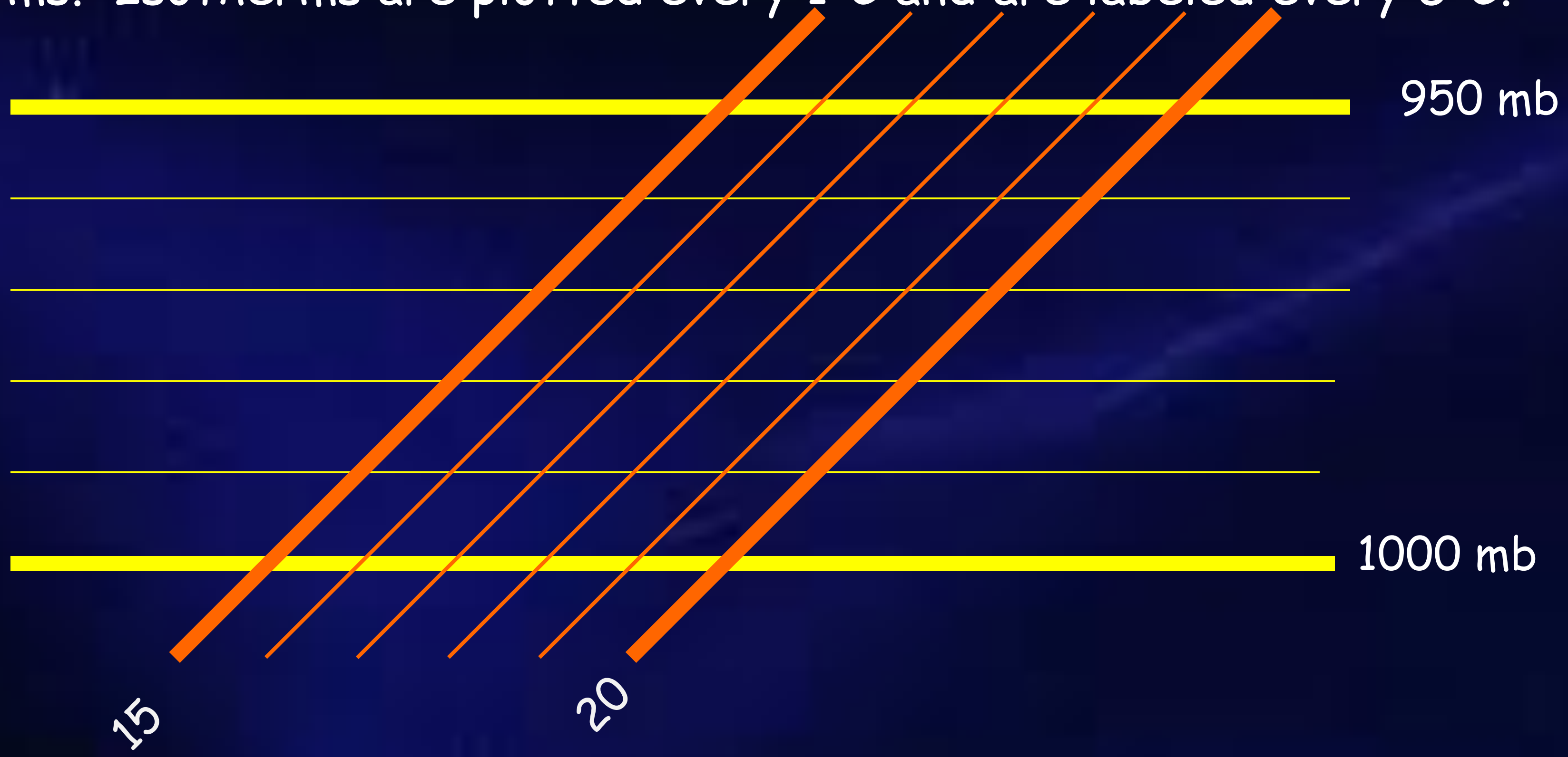


Isobars

Isotherms

Isotherms are nearly straight lines running from the lower left to the upper right that represent the temperatures.

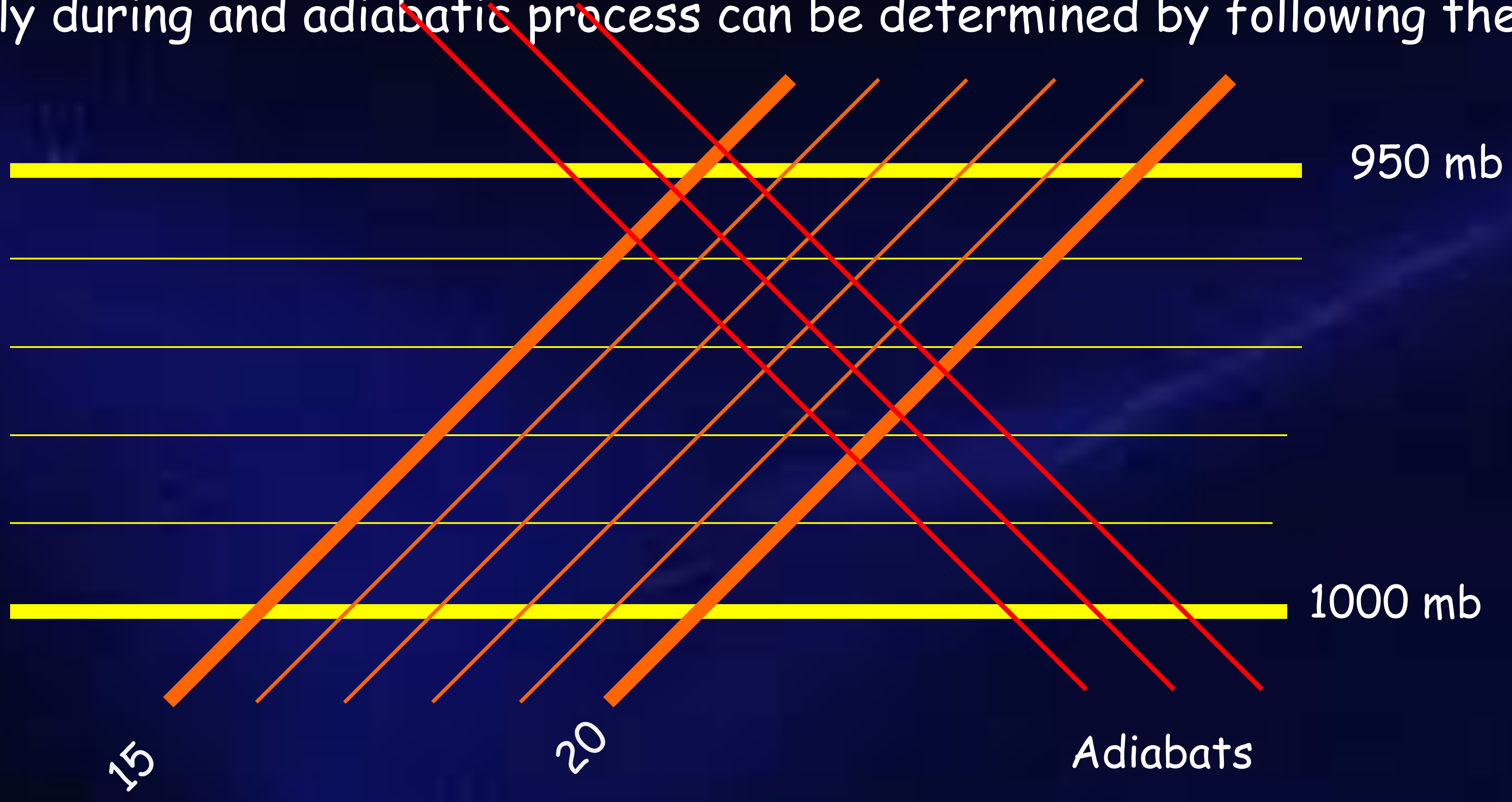
Both temperatures and dew point temperatures are plotted using the isotherms. Isotherms are plotted every 1°C and are labeled every 5°C.



Dry Adiabats

Dry adiabats are nearly straight curves running from the lower right to the upper left that represent the Dry Adiabatic Lapse Rate.

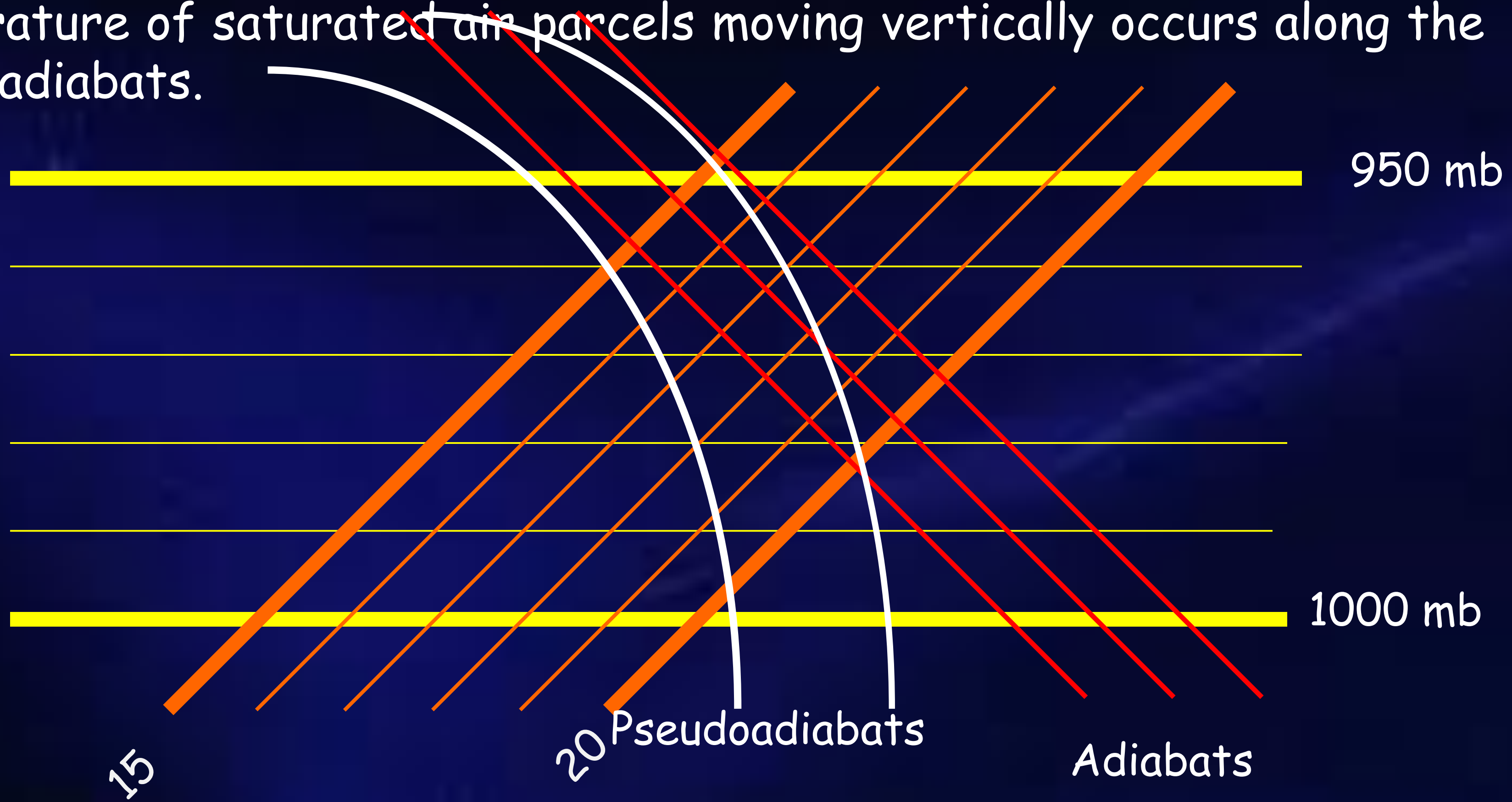
Unsaturated air parcels move vertical along the adiabats as they are lifted or sink. The temperature of an unsaturated air parcel moving vertically during and adiabatic process can be determined by following the adiabat



Pseudoadiabats

Pseudoadiabats are curves running from the bottom of the diagram and gradually curving toward the upper left that ultimately become nearly parallel to the dry adiabats.

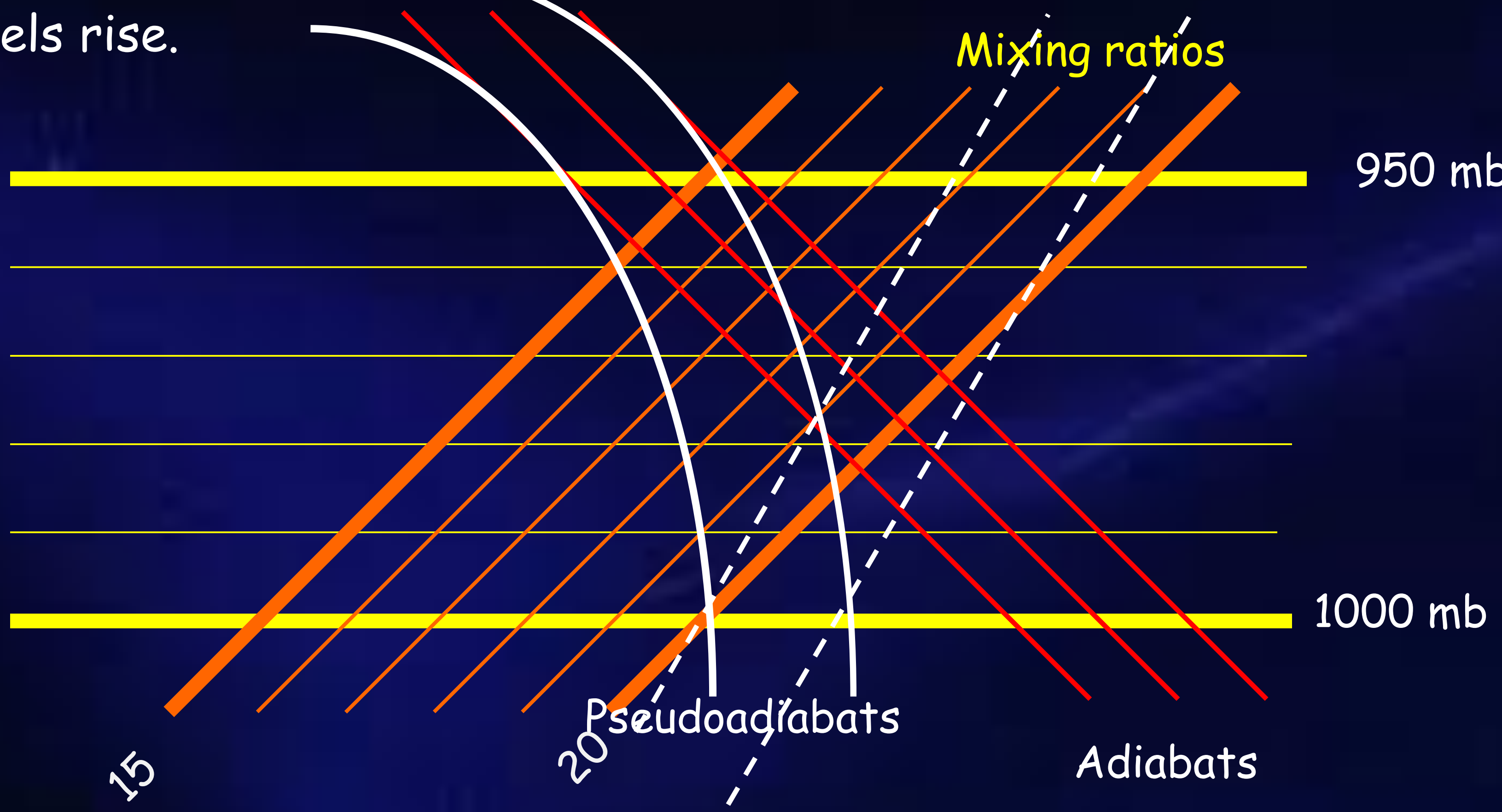
They represent the Saturated Adiabatic Lapse Rate. The change in temperature of saturated air parcels moving vertically occurs along the pseudoadiabats.



Mixing ratios

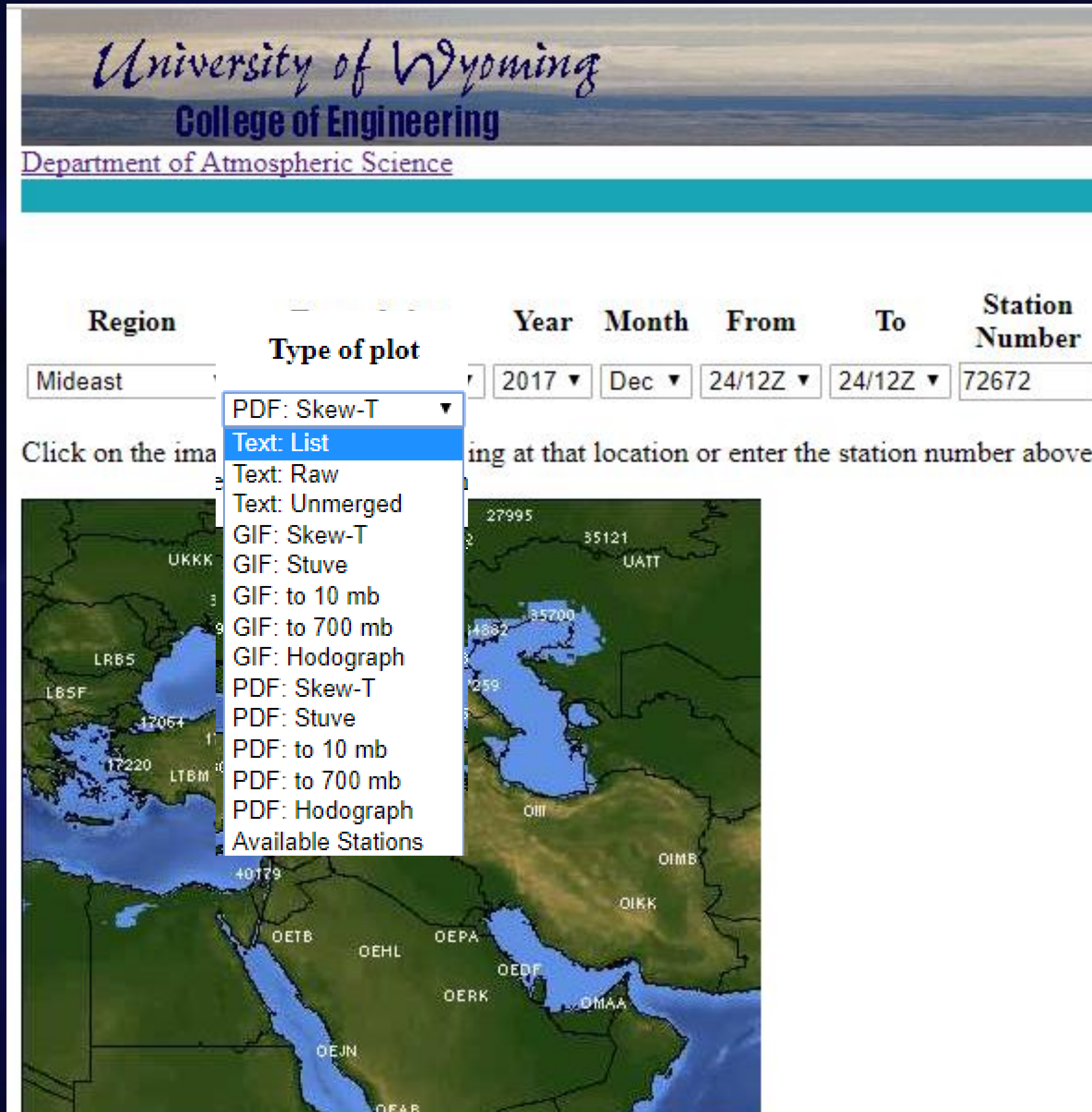
The mixing ratios are also plotted as straight dashed lines running from the lower left to upper right more steeply than the isotherms.

The mixing ratios can be used to find the height at which condensation would occur under various conditions if unsaturated parcels rise.



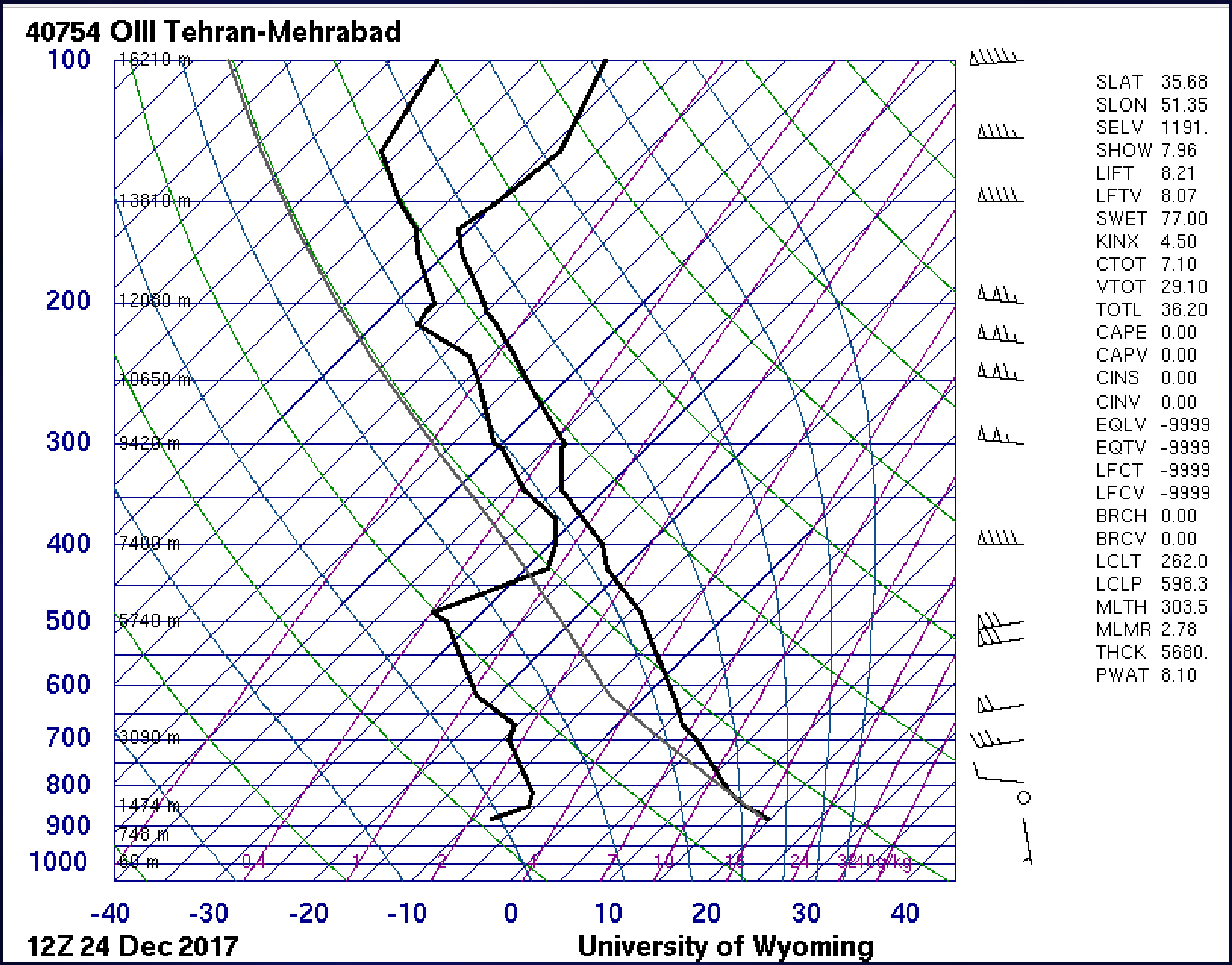
university of wyoming

http://weather.uwyo.edu/upperair/sounding.html

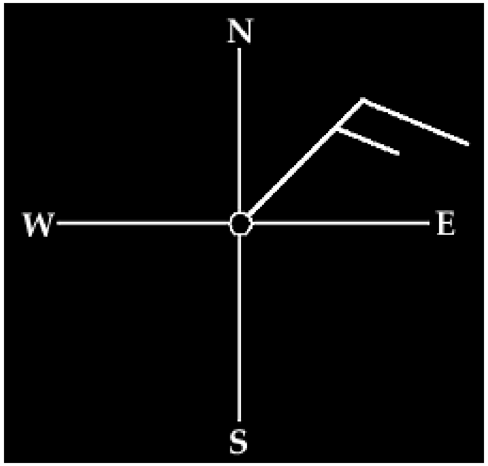

University of Wyoming
College of Engineering
Department of Atmospheric Science
Region
Type of plot
Year
Month
From
To
Station Number
Mideast
PDF: Skew-T
2017
Dec
24/12Z
24/12Z
72672
Text: List
Text: Raw
Text: Unmerged
GIF: Skew-T
GIF: Stuve
GIF: to 10 mb
GIF: to 700 mb
GIF: Hodograph
PDF: Skew-T
PDF: Stuve
PDF: to 10 mb
PDF: to 700 mb
PDF: Hodograph
Available Stations
Click on the ima
ing at that location or enter the station number above.
UKKK
LRBS
LBSF
17064
17220
LTBM
27995
35121
UATT
35700
OIII
OIMB
OIKK
40179
OETB
OEHL
OEPA
OEDF
OERK
OMAA
OEJN
OEAB

40754 OIII Tehran-Mehrabad Observations at 12Z 24 Dec 2017

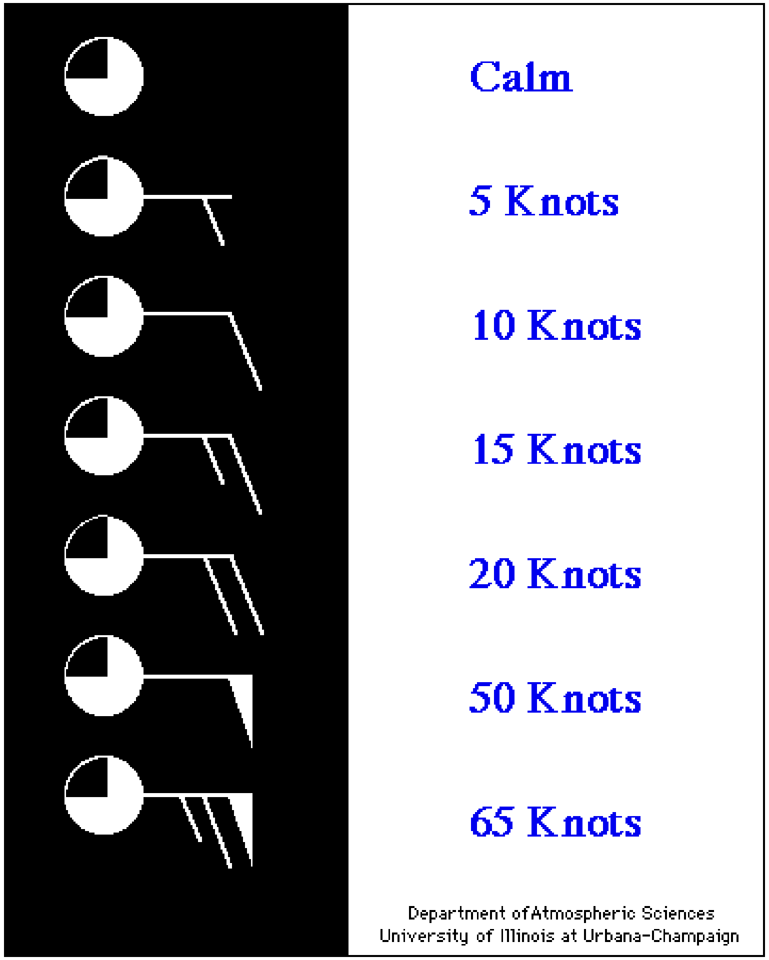
PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K	THTE K	THTV K
1000.0	60									
925.0	748									
879.0	1191	19.8	-8.2	14	2.35	170	4	303.9	311.5	304.4
850.0	1474	16.4	-5.6	22	2.98	155	4	303.3	312.8	303.9
826.0	1716	14.2	-6.3	24	2.90	0	0	303.5	312.7	304.1
817.0	1809	13.4	-6.6	24	2.87	337	3	303.6	312.7	304.1
793.0	2056	11.7	-8.1	24	2.63	275	10	304.4	312.8	304.9
700.0	3090	4.6	-14.4	24	1.80	260	35	307.6	313.5	307.9
671.0	3433	1.6	-15.4	27	1.73	260	45	307.9	313.7	308.2
634.0	3886	-0.9	-20.0	22	1.24	260	59	310.1	314.3	310.3
618.0	4091	-2.1	-22.1	20	1.06	260	61	311.0	314.7	311.2
524.0	5375	-10.3	-30.4	18	0.59	260	72	316.1	318.2	316.2
504.0	5678	-12.3	-32.3	17	0.51	260	69	317.2	319.1	317.4
500.0	5740	-12.7	-32.7	17	0.49	260	69	317.5	319.3	317.6
487.0	5940	-13.9	-34.9	15	0.41	261	71	318.4	319.9	318.5
429.0	6888	-21.7	-27.7	58	0.92	267	82	320.2	323.6	320.4
400.0	7400	-24.7	-29.5	64	0.83	270	88	322.8	325.9	323.0
371.0	7941	-29.3	-32.1	77	0.70	271	93	323.7	326.3	323.9
342.0	8515	-34.3	-38.2	68	0.42	273	98	324.5	326.1	324.6
304.0	9329	-38.5	-44.5	53	0.24	275	105	329.7	330.7	329.8
300.0	9420	-38.7	-45.7	48	0.21	275	106	330.7	331.6	330.8
298.0	9466	-39.1	-46.1	47	0.21	275	106	330.8	331.6	330.8
250.0	10650	-48.9	-53.9	56	0.10	275	115	333.2	333.7	333.2
233.0	11110	-52.7	-57.2	58	0.07	275	116	334.2	334.6	334.3
224.0	11362	-54.9	-60.9	47	0.05	275	116	334.7	334.9	334.7
213.0	11685	-57.7	-65.7	35	0.03	275	115	335.1	335.3	335.1
205.0	11926	-60.1	-66.1	45	0.03	275	114	335.1	335.2	335.1
200.0	12080	-61.1	-66.1	51	0.03	275	113	335.9	336.0	335.9
174.0	12929	-68.3	-72.7	53	0.01	280	111	337.6	337.7	337.6
162.0	13354	-71.1	-75.5	52	0.01	275	97	339.9	339.9	339.9
150.0	13810	-69.9	-79.9	22	0.00	270	92	349.5	349.5	349.5
130.0	14662	-68.7	-86.7	6	0.00	270	87	366.2	366.2	366.2
125.0	14893	-69.4	-87.2	6	0.00	270	85	369.1	369.1	369.1
100.0	16210	-73.3	-90.3	6	0.00	265	93	385.9	385.9	385.9


40754 OIII Tehran-Mehrabad
100
200
300
400
500
600
700
800
900
1000
16210 m
13810 m
12060 m
10650 m
9420 m
7400 m
5740 m
3090 m
1474 m
746 m
60 m
0.4
1
2
4
7
10
16
24
32 40 g/kg
-40
-30
-20
-10
0
10
20
30
40
SLAT 35.68
SLON 51.35
SELV 1191.
SHOW 7.96
LIFT 8.21
LFTV 8.07
SWET 77.00
KINX 4.50
CTOT 7.10
VTOT 29.10
TOTL 36.20
CAPE 0.00
CAPV 0.00
CINS 0.00
CINV 0.00
EQLV -9999
EQTV -9999
LFCT -9999
LFCV -9999
BRCH 0.00
BRCV 0.00
LCLT 262.0
LCLP 598.3
MLTH 303.5
MLMR 2.78
THCK 5680.
PWAT 8.10
12Z 24 Dec 2017
University of Wyoming

Winds on Skew T Log P Charts



wind is 15 knots
coming ***from*** the northeast.



1 Knot = 1.15 Miles Per Hour (MPH)

1 Knot = 1.9 Kilometers Per Hour (KM/HR)

Sounding Station Parameters and Indices

SLAT Station latitude in degrees

SLON Station longitude in degrees; West longitude is negative

SELV Station elevation in meters

SHOW Showalter index

Showalter stability index

$$SHOW = T_{500} - T_{parcel}$$

where T_{parcel} is the temperature (°C) of a parcel lifted from 850 to 500 mb, dry-adiabatically to saturation and moist-adiabatically above that.

As the index decreases to zero and below, the likelihood of showers and thunderstorms is considered to increase (Showalter 1947).

SLAT	35.68
SLON	51.35
SELV	1191.
SHOW	7.96
LIFT	8.21
LFTV	8.07
SWET	77.00
KINX	4.50
CTOT	7.10
VTOT	29.10
TOTL	36.20
CAPE	0.00
CAPV	0.00
CINS	0.00
CINV	0.00
EQLV	-9999
EQTV	-9999
LFCT	-9999
LFCV	-9999
BRCH	0.00
BRCV	0.00
LCLT	262.0
LCLP	598.3
MLTH	303.5
MLMR	2.78
THCK	5680.
PWAT	8.10

LIFT Lifted index

LIFT $= T_{500} - T_{parcel}$

T_{500}= temperature in Celsius of the environment at 500 mb

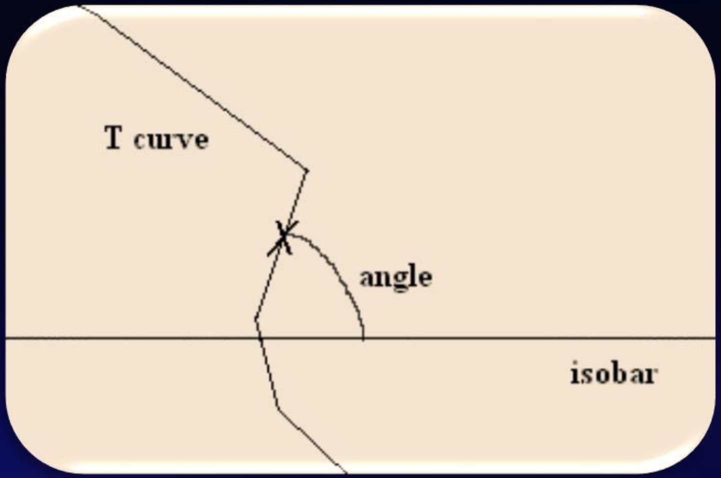
T_{parcel} = 500 mb temperature in Celsius of a lifted parcel with the average pressure, temperature, and dewpoint of the layer 500 m above the surface

LFTV LIFT computed by using virtual temperature

SLAT	35.68
SLON	51.35
SELV	1191.
SHOW	7.96
LIFT	8.21
LFTV	8.07
SWET	77.00
KINX	4.50
CTOT	7.10
VTOT	29.10
TOTL	36.20
CAPE	0.00
CAPV	0.00
CINS	0.00
CINV	0.00
EQLV	-9999
EQTV	-9999
LFCT	-9999
LFCV	-9999
BRCH	0.00
BRCV	0.00
LCLT	262.0
LCLP	598.3
MLTH	303.5
MLMR	2.78
THCK	5680.
PWAT	8.10

Stability

The term "slope" in reference to the Skew-T chart is the angle from the horizontal (the isobars) counter clockwise to a section of the T curve.



For stability, the smaller the angle, the greater stability there will be.

The larger this angle, the more instability there will be.

The stability of air parcels in an atmospheric layer is indicated by comparing the slope of the virtual temperature to the slope of the dry or saturation adiabats.

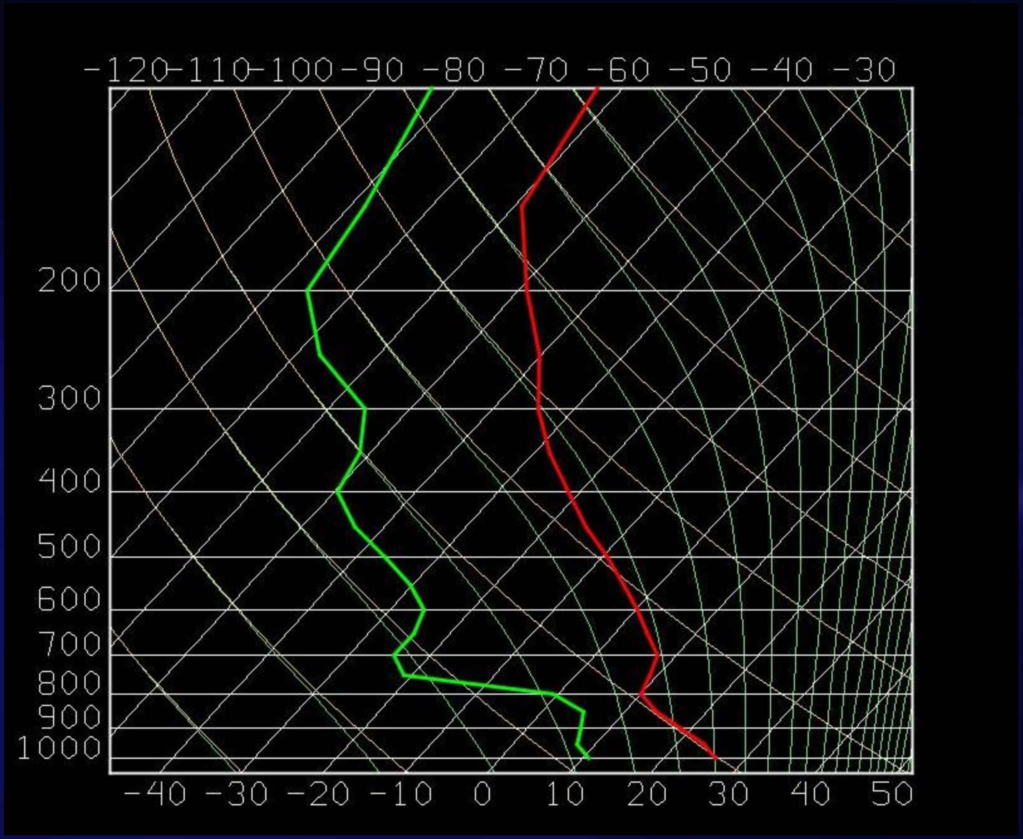
Virtual temperature is compared to the dry adiabats when the parcel is unsaturated and to the saturation adiabats when the parcel is saturated.

The temperature curve is normally used instead of the virtual temperature curve for a quick determination of the stability; however this may cause errors under certain circumstances.

For this reason be sure when looking at stability on a Skew-T to use the virtual temperature.

Absolutely Stable

If the slope of the T curve is less than the slope of the saturation adiabat and the slope of the dry adiabat then the layer is considered absolutely stable.



The area between 700 and 800mb is an example of an absolutely stable layer.

The stability of the atmosphere

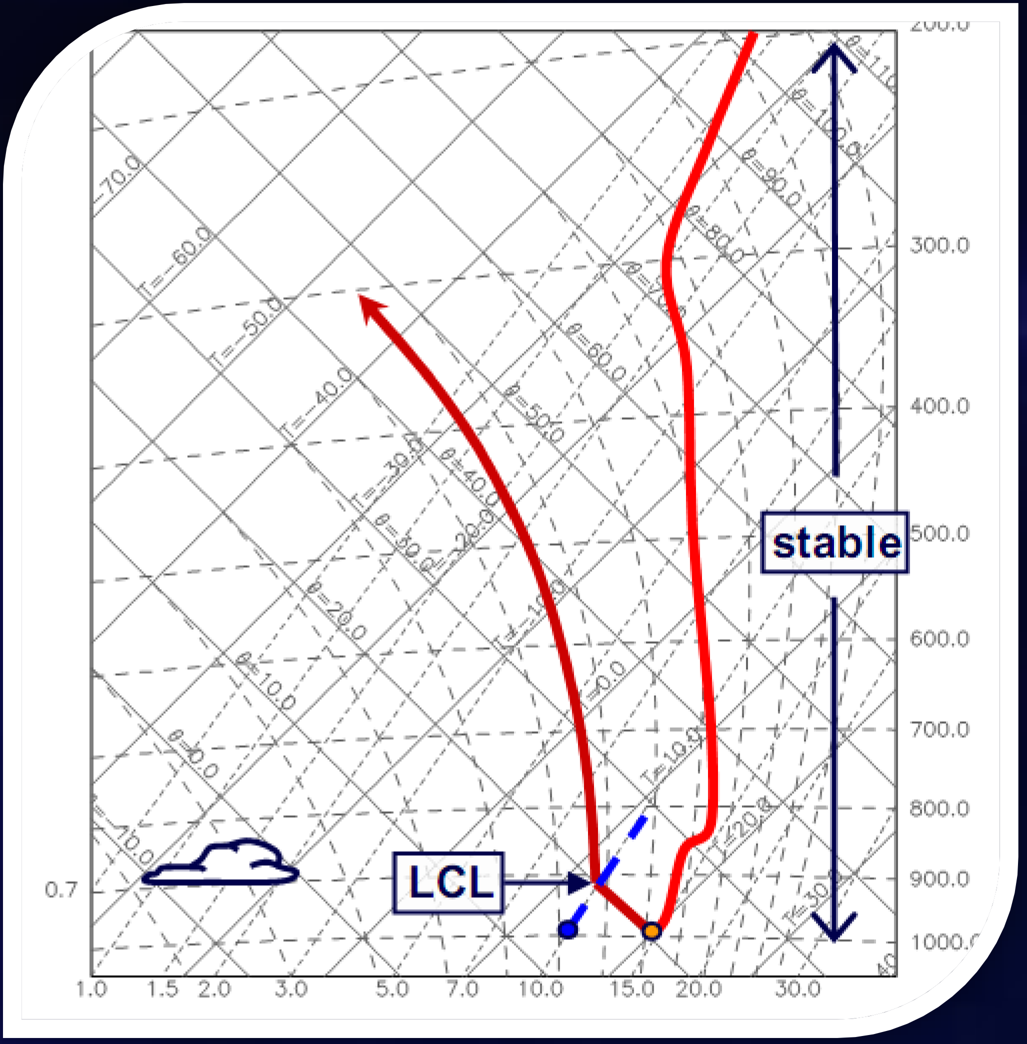
Figure shows a stable temperature profile:

if air at the surface (or in this case from any level) is forced to rise, it cools adiabatically until it reaches its lifting condensation level, and along a saturated adiabat with any further lifting.

At all points the parcel is cooler, and hence denser, than the ambient air at the pressure level at which it has been lifted.

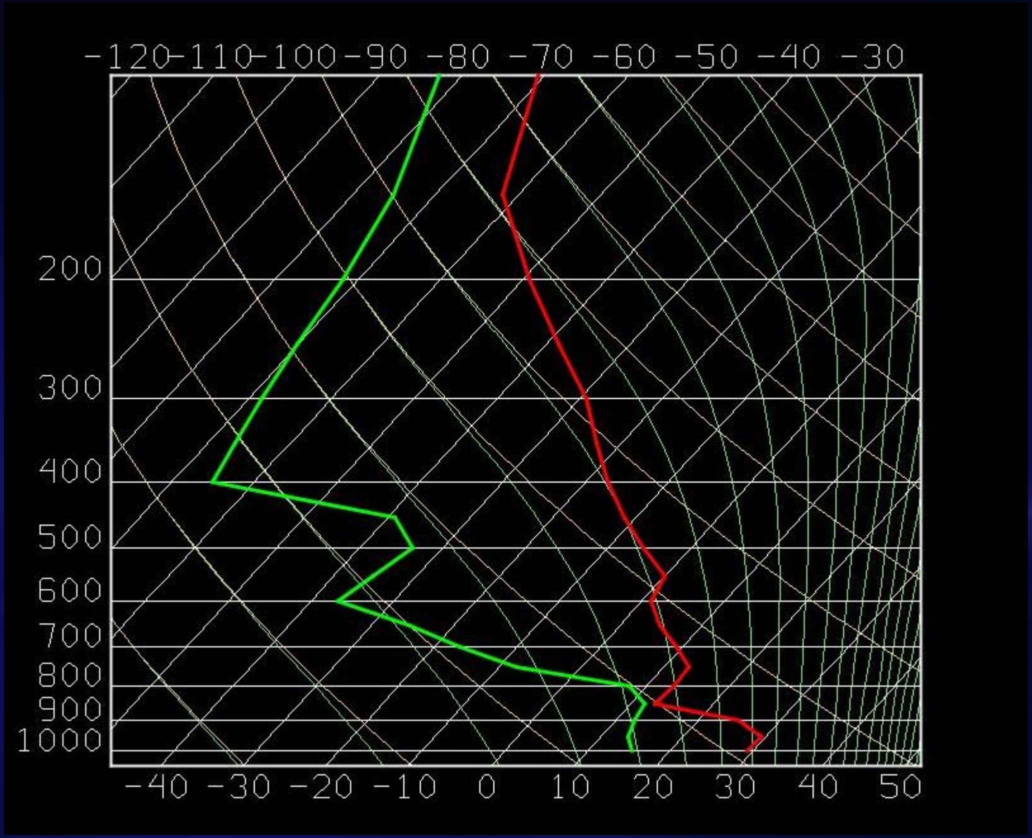
It is thus stable, tending to sink back towards the level at which it started. Lifting here must be externally forced.

ABSOLUTE STATIC STABILITY



Absolutely Unstable

If the slope of the T curve is greater than the slope of the dry adiabat and the saturation adiabat, the layer is considered absolutely unstable.

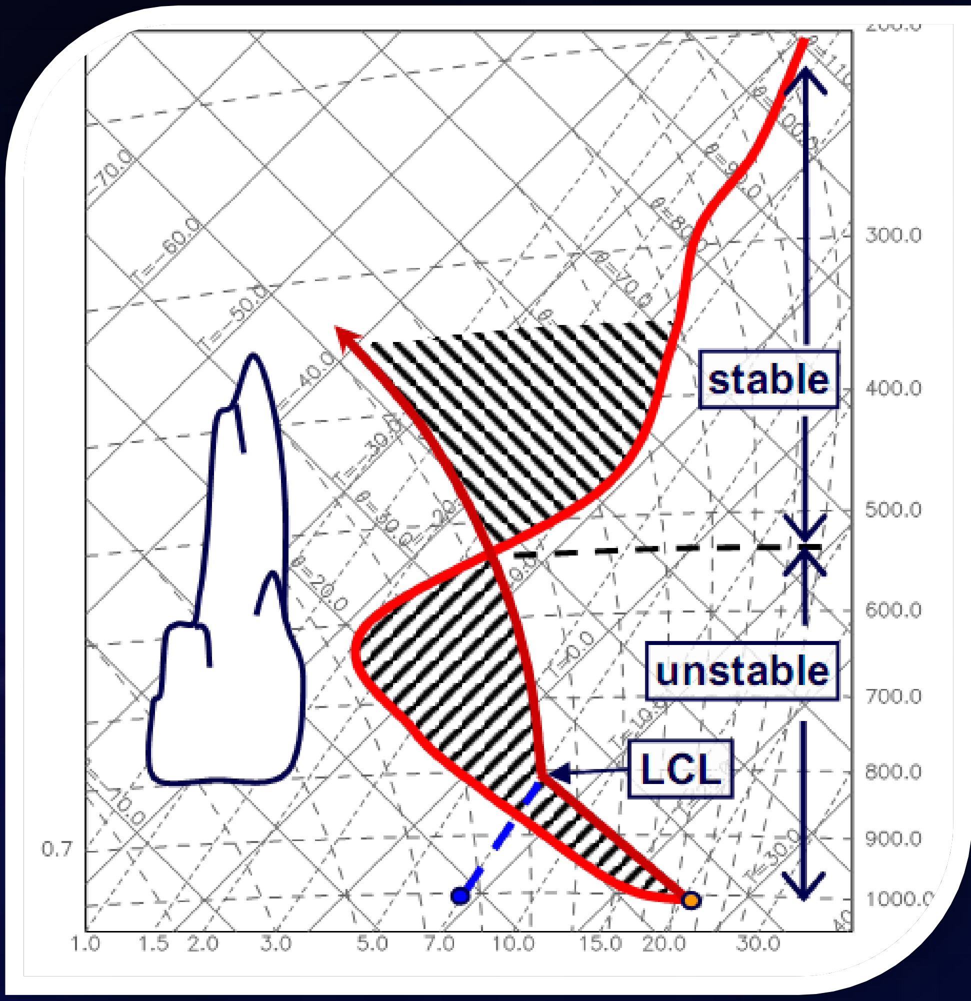


The area between 850 and 950mb is an example of an absolutely unstable layer

Absolute instability

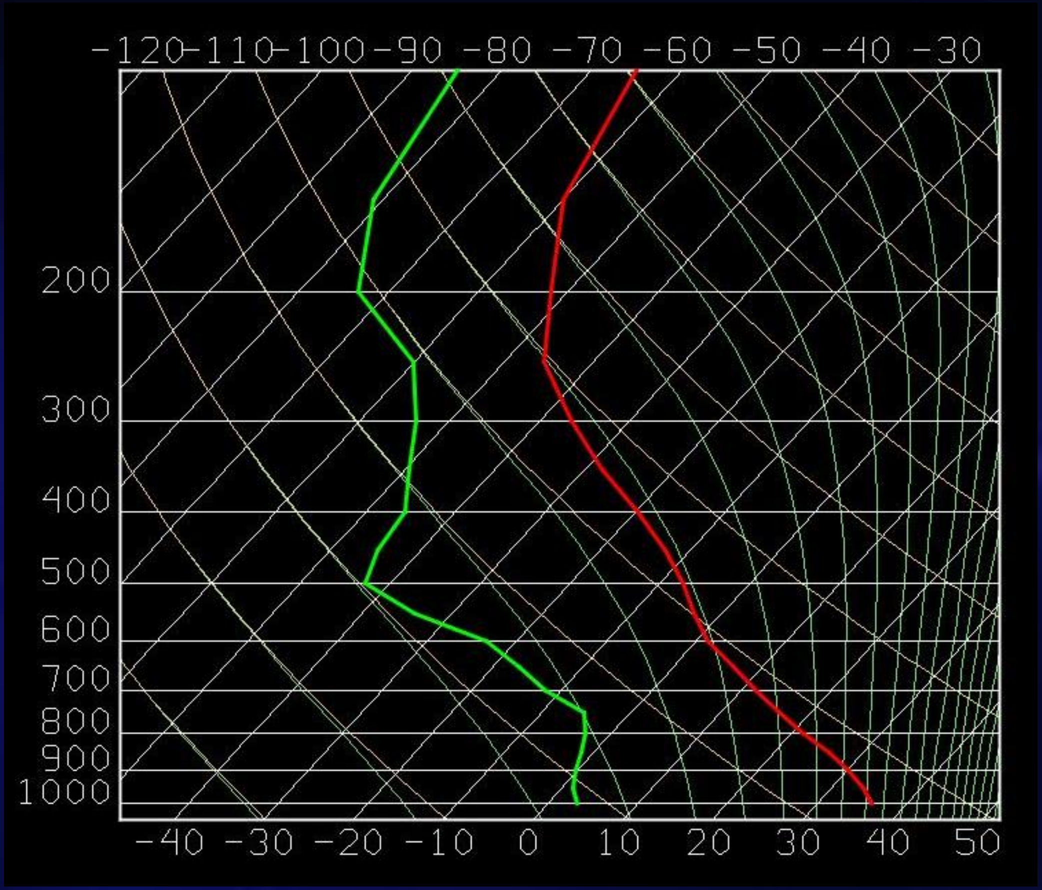
Figure shows a case for which the new-surface air is unstable. Adiabatic lifting results in an air parcel warmer, thus less dense, than the surrounding air;

this will be positively buoyant and will rise upwards as a convective plume. It rises dry adiabatically until its lifting condensation level, then along a saturated adiabat. In the case shown a strong temperature inversion exists at the top of the boundary layer at about 600 hPa; within the inversion the ambient temperature increases with altitude. When the rising plume of air reaches the point at which its temperature equals that of the surrounding air it is no longer positively buoyant,



Conditionally Unstable/Stable

If the slope of the T curve is less than the slope of the dry adiabat but greater than the slope of the saturation adiabat, the layer is conditionally unstable/stable. This means that the layer is stable only if it is unsaturated and unstable if the layer is saturated.

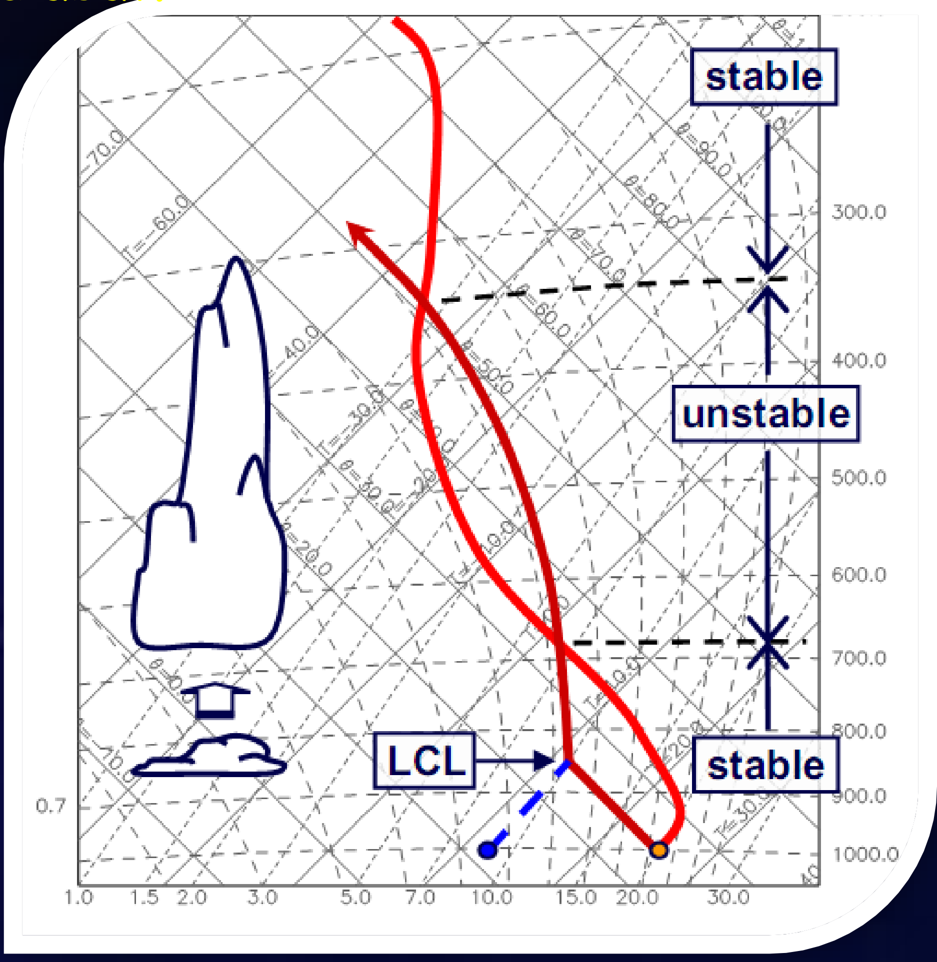


The area between 600 and 700mb is an example of a conditionally unstable layer

conditional instability

A parcel of air lifted adiabatically from the surface remains cooler than its surroundings, and thus stable. If the parcel remains dry, it would remain stable no matter how high it was lifted; however, in this case the LCL is reached at around 850 hPa, and the rate of cooling decreases to that of the saturated adiabat.

The saturated adiabat intersects the environmental temperature profile at about 680 hPa;
if the parcel of surface air is forced to lift past this point it becomes warmer than its surroundings, and thus positively buoyant, and will continue to lift convectively until about the 340 hPa level, above which it becomes negatively buoyant again.
This case is described as conditional instability, because reaching the point of instability is conditional on forced lifting through a region of stability.

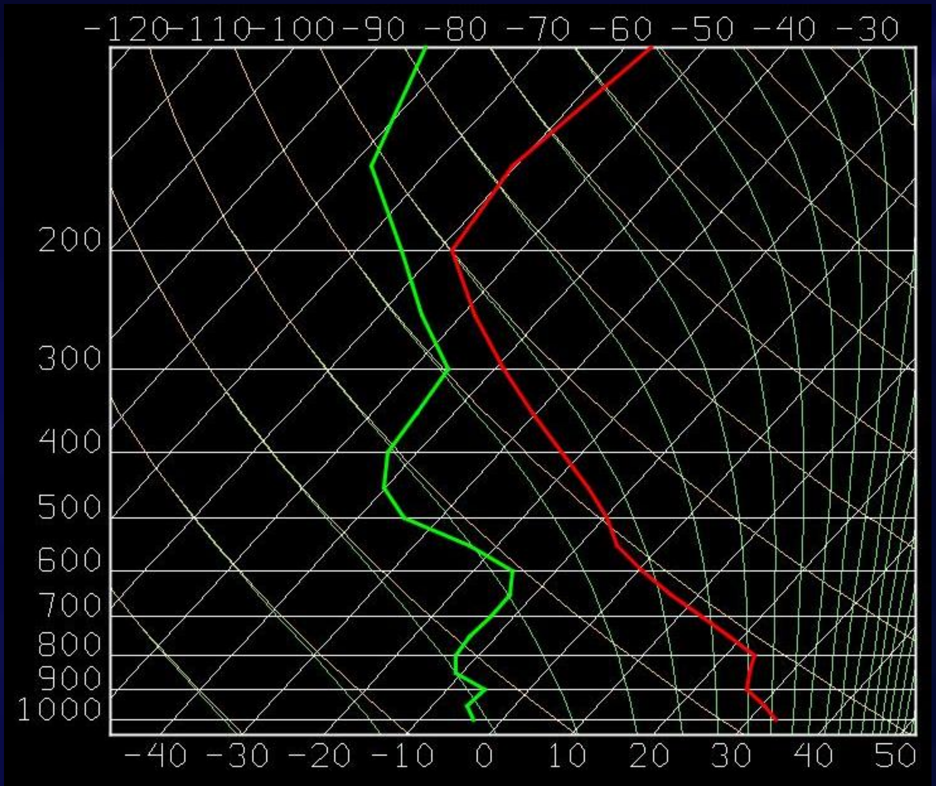


Neutrally Stable

If the T curve is parallel to either a saturation or a dry adiabat, the layer is in neutral equilibrium with the surrounding atmosphere.

If the curve is parallel to a saturation adiabat, then the upward movement of saturated parcels will not be aided or hindered by the environment. Likewise, if the T curve is parallel to a dry adiabat, the parcel's upward displacement of unsaturated parcels is not helped or hindered by the environment.

The area between 600 and 800 mb is an example of a neutral layer with respect to the dry adiabatic lapse rate

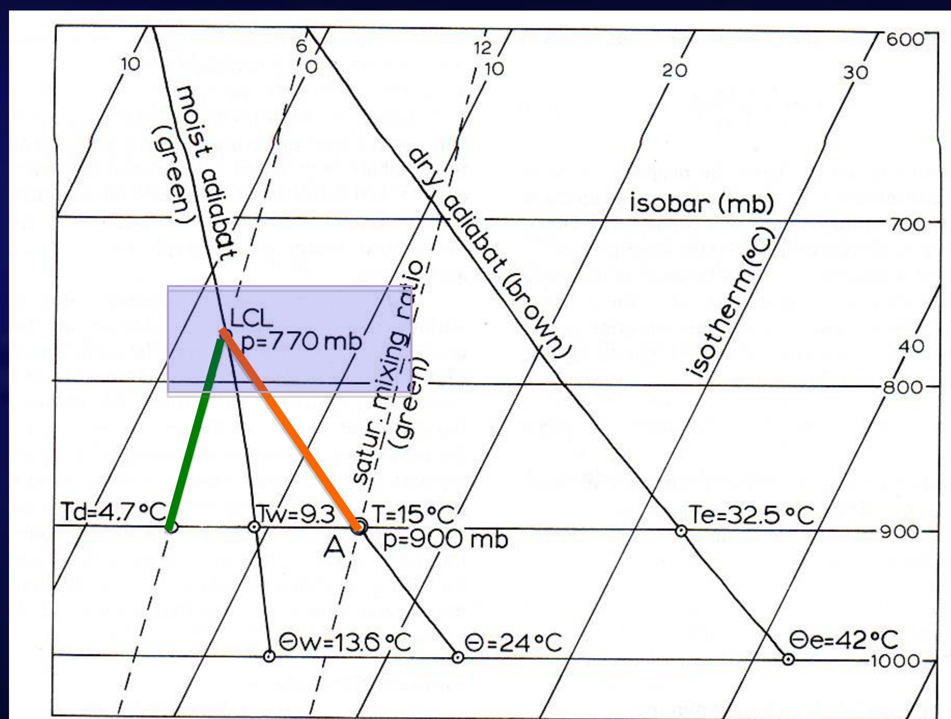


Lifting Condensation Level (LCL)

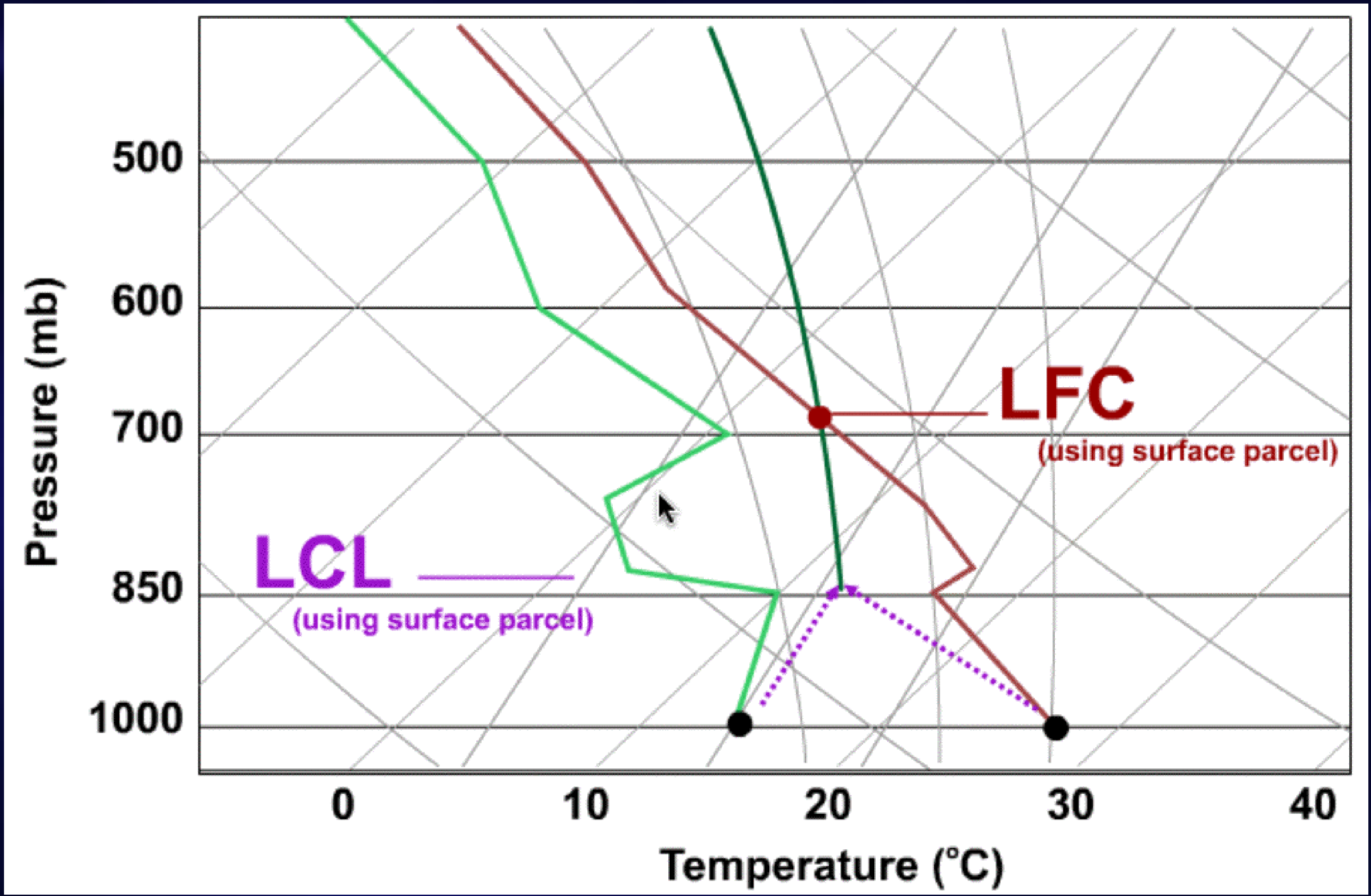
The level at which a parcel lifted dry adiabatically will become saturated.

Find the temperature and dewpoint of the parcel (at the same level, typically the surface).

Follow the mixing ratio up from the dewpoint, and follow the dry adiabat from the temperature, where they intersect is the LCL.

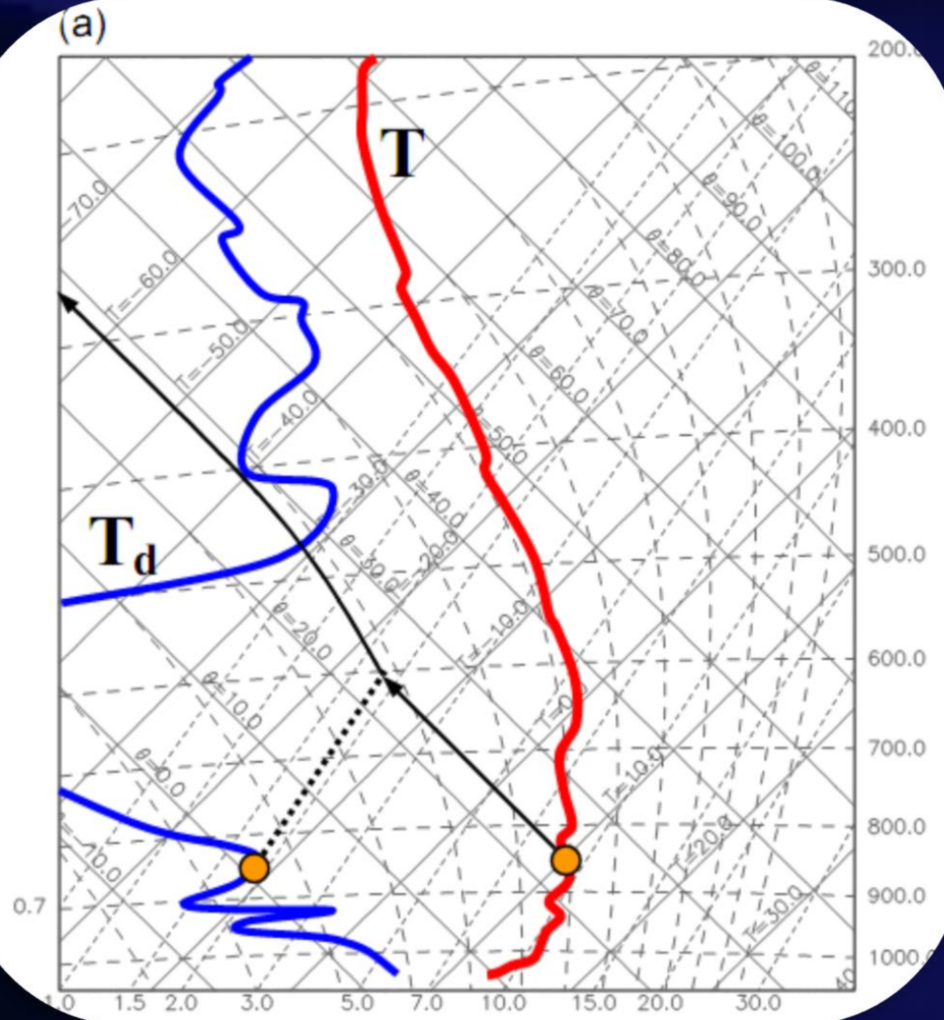


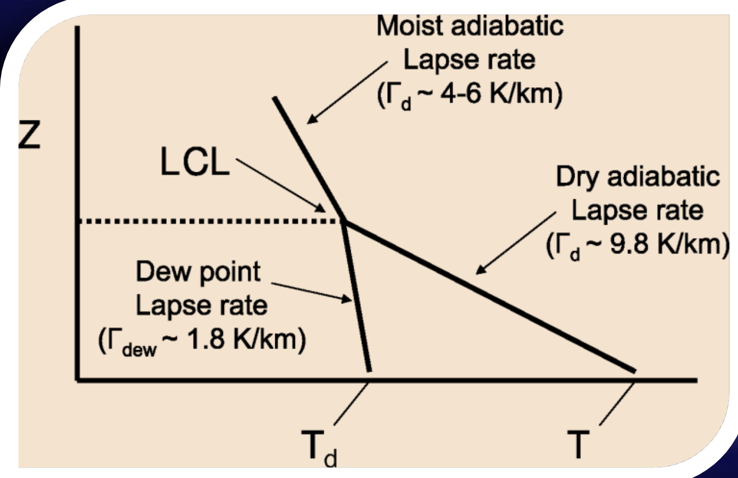
CAPE	0.00
CAPV	0.00
CINS	0.00
CINV	0.00
EQLV	-9999
EQTV	-9999
LFCT	-9999
LFCV	-9999
BRCH	0.00
BRCV	0.00
LCLT	262.0
LCLP	598.3
MLTH	303.5
MLMR	2.78
THCK	5680.
PWAT	8.10



500
600
700
850
1000
Pressure (mb)
LFC
(using surface parcel)
LCL
(using surface parcel)
0
10
20
30
40
Temperature (°C)

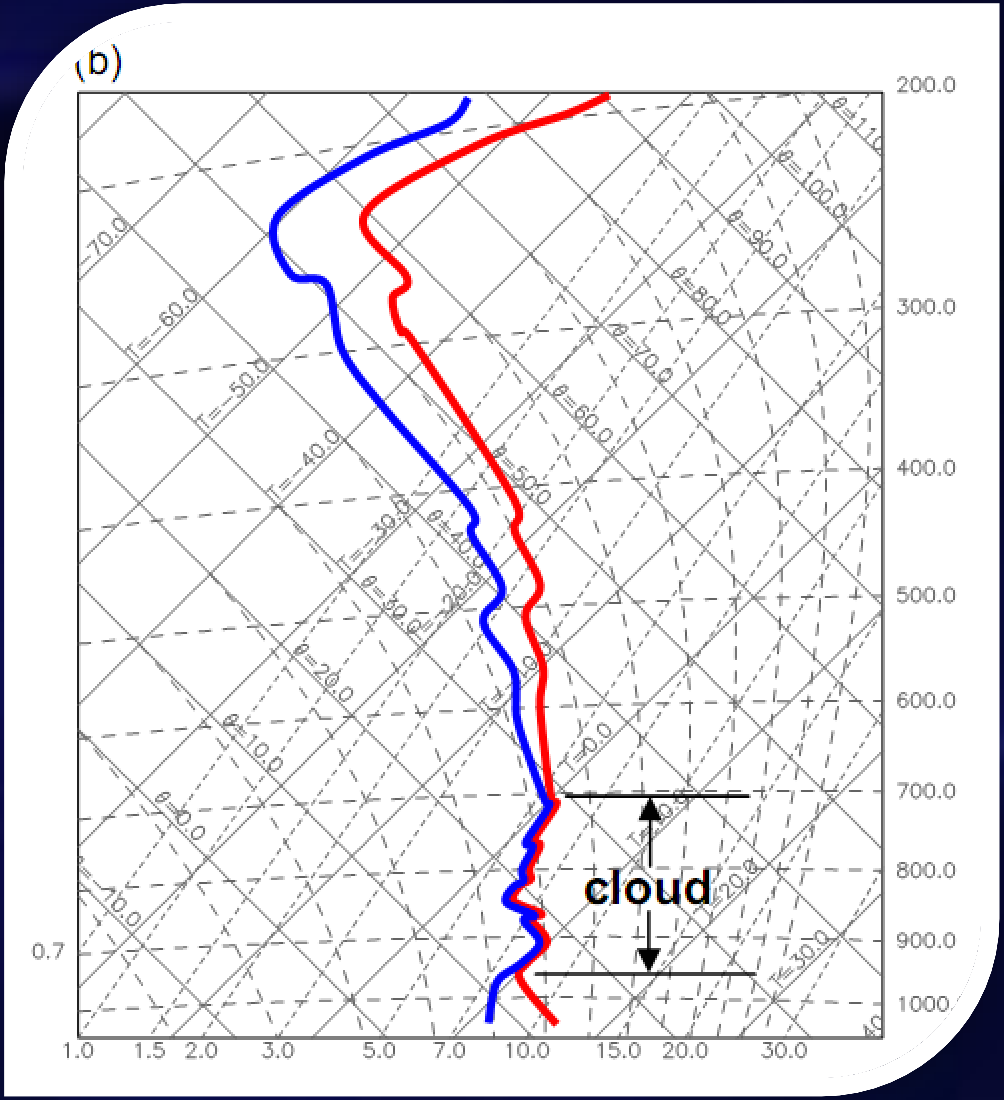
The temperature and dew point curves at the same pressure



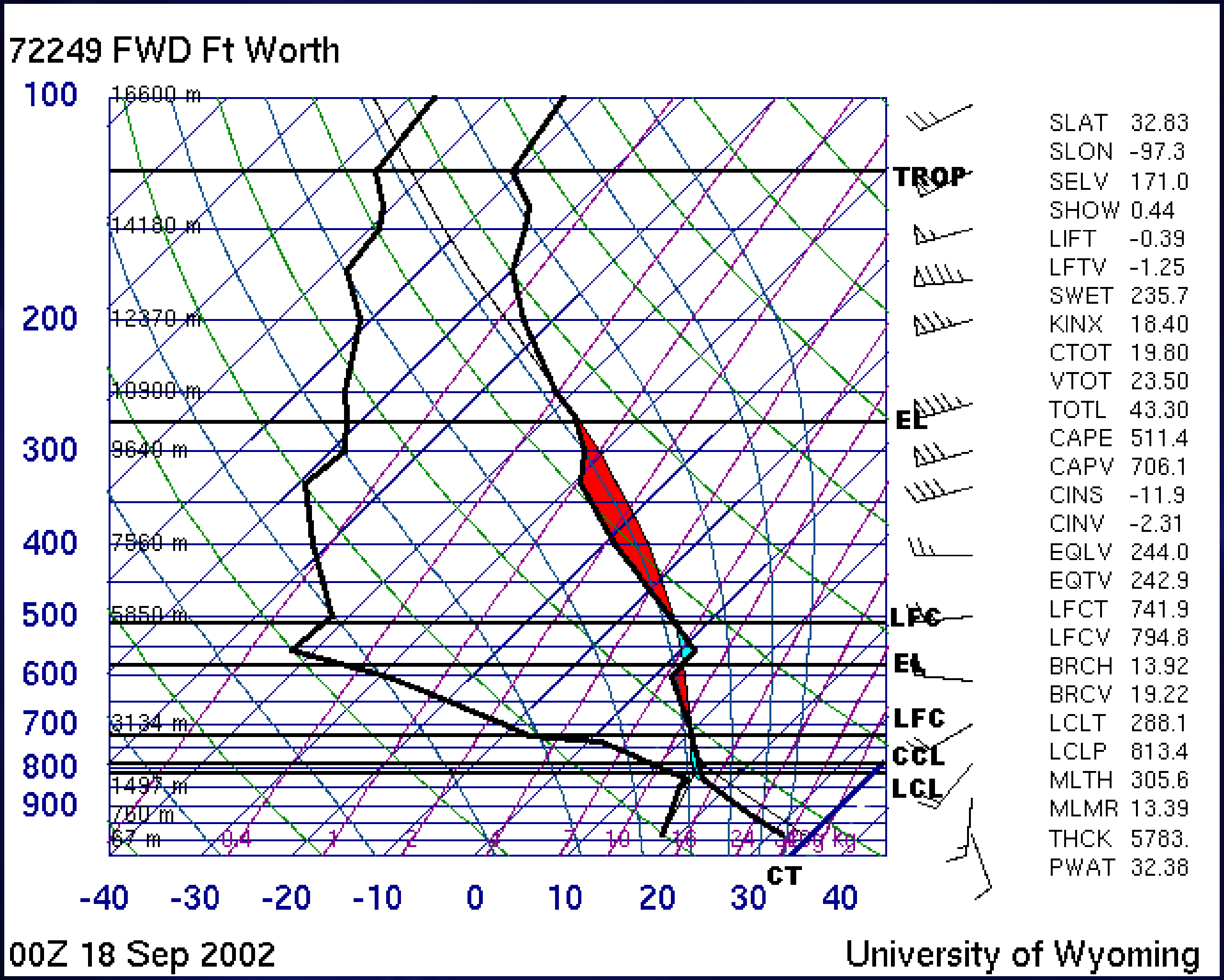


To find LCL graphically on tephigram or skew-T diagram, draw lines upward from the surface temperature and surface dewpoint along the dry adiabat and mixing ratio, respectively. They intersect at the LCL. This determines the cloud base.

Saturated air – cloud



Upper Air Data: Convective Parameters



Level of Free Convection (LFC)

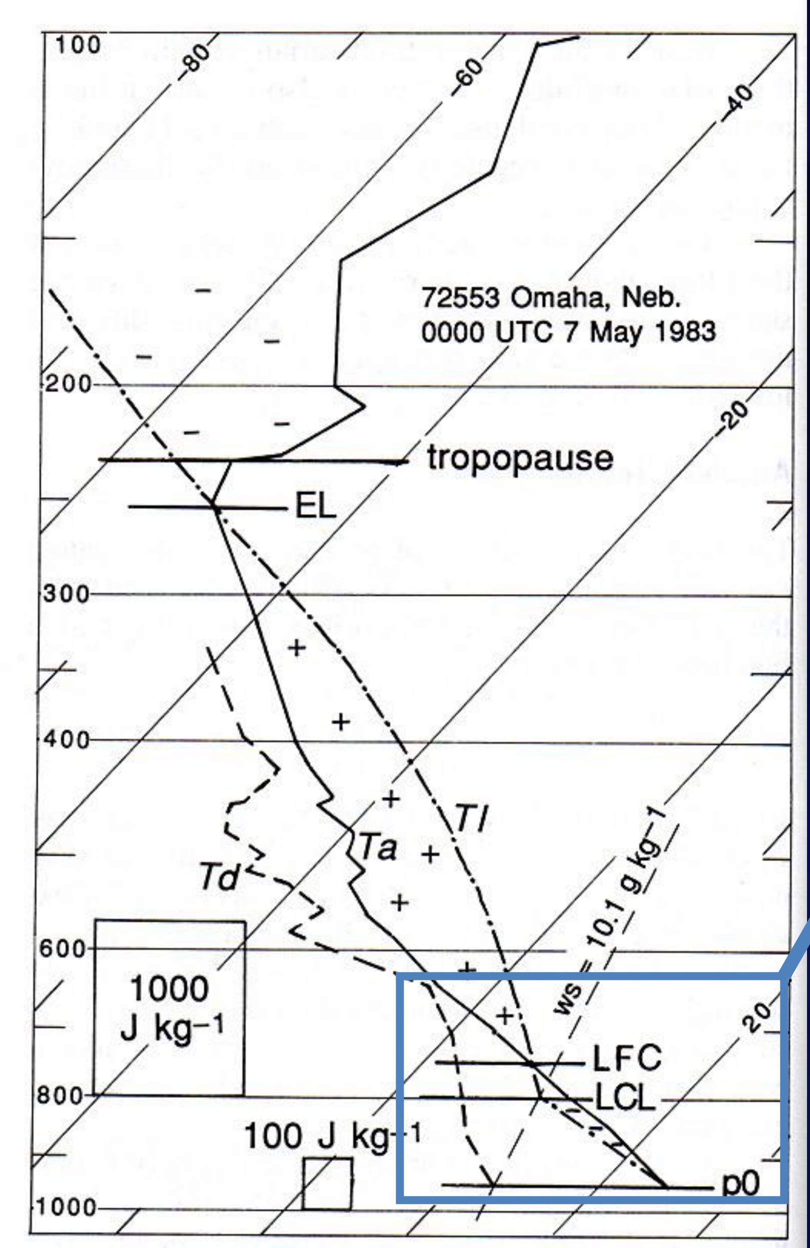
The level above which a parcel will be able to freely convect without any other forcing.

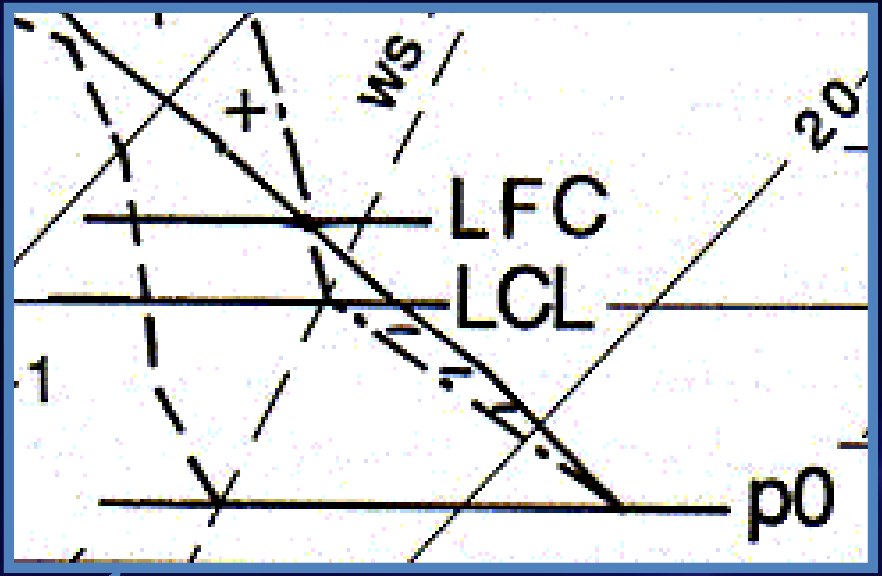
Find the LCL, then follow the moist adiabat until it crosses the temperature profile.

At the LFC the parcel is neutrally buoyant.

At this point, the parcel becomes warmer and more bouyant than it's environment. it will accelerate upwards. Some other lifting mechanism must do work to bring the parcel to this level.

Example of LFC





EL - Equilibrium Level - is found by lifting the parcel from the LFC to where it meets with the ambient temperature curve. At this point, the parcel becomes negatively bouyant, and further convective ascent is suppressed. In the FWD sounding there are two equilibrium levels

Equilibrium Level (EL)

The level above the LFC at which a parcel will no longer be buoyant. (At this point the environment temperature and parcel temperature are the same.)

It is a level of neutral buoyancy.

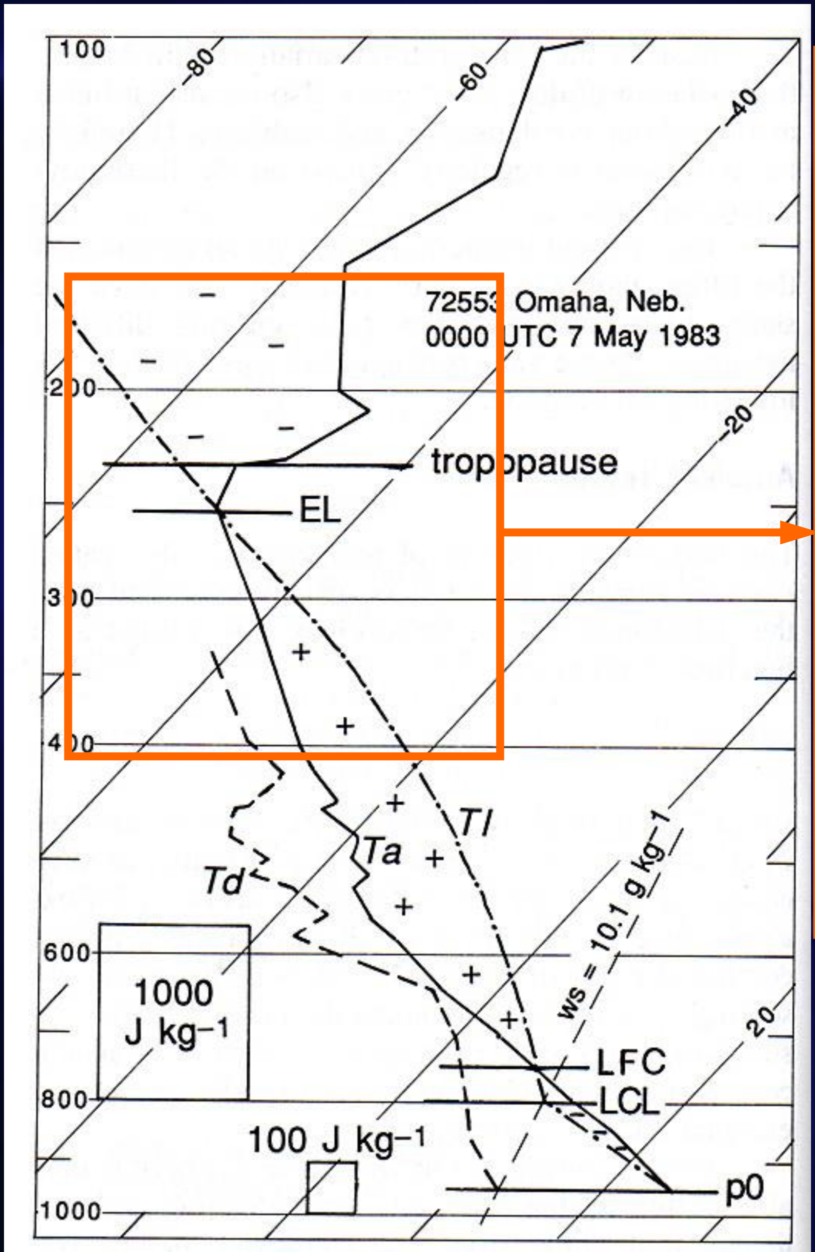
Above this level the parcel is negatively buoyant.

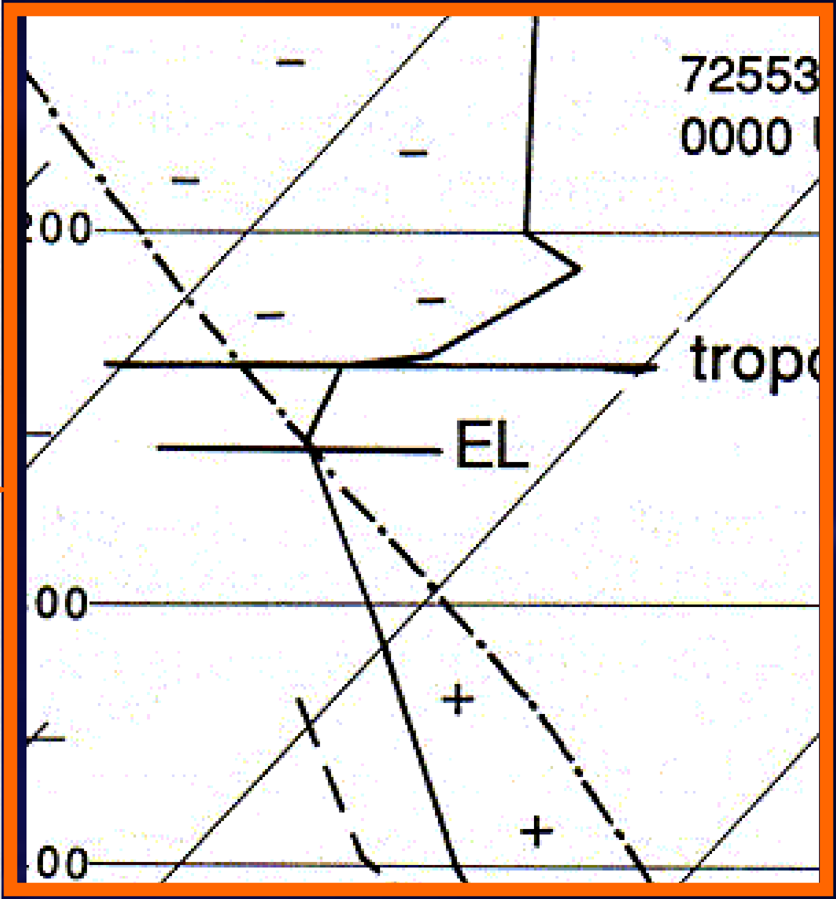
The parcel may still continue to rise due to accumulated kinetic energy of vertical motion.

Find the LFC and continue following the moist adiabat until it crosses the temperature profile again.

The first equilibrium level is associated with a "capping inversion" that prevents parcels from racing to the top of the troposphere.

Example of finding the EL





Convective Condensation Level (CCL)

Level at which the base of convective clouds will begin.

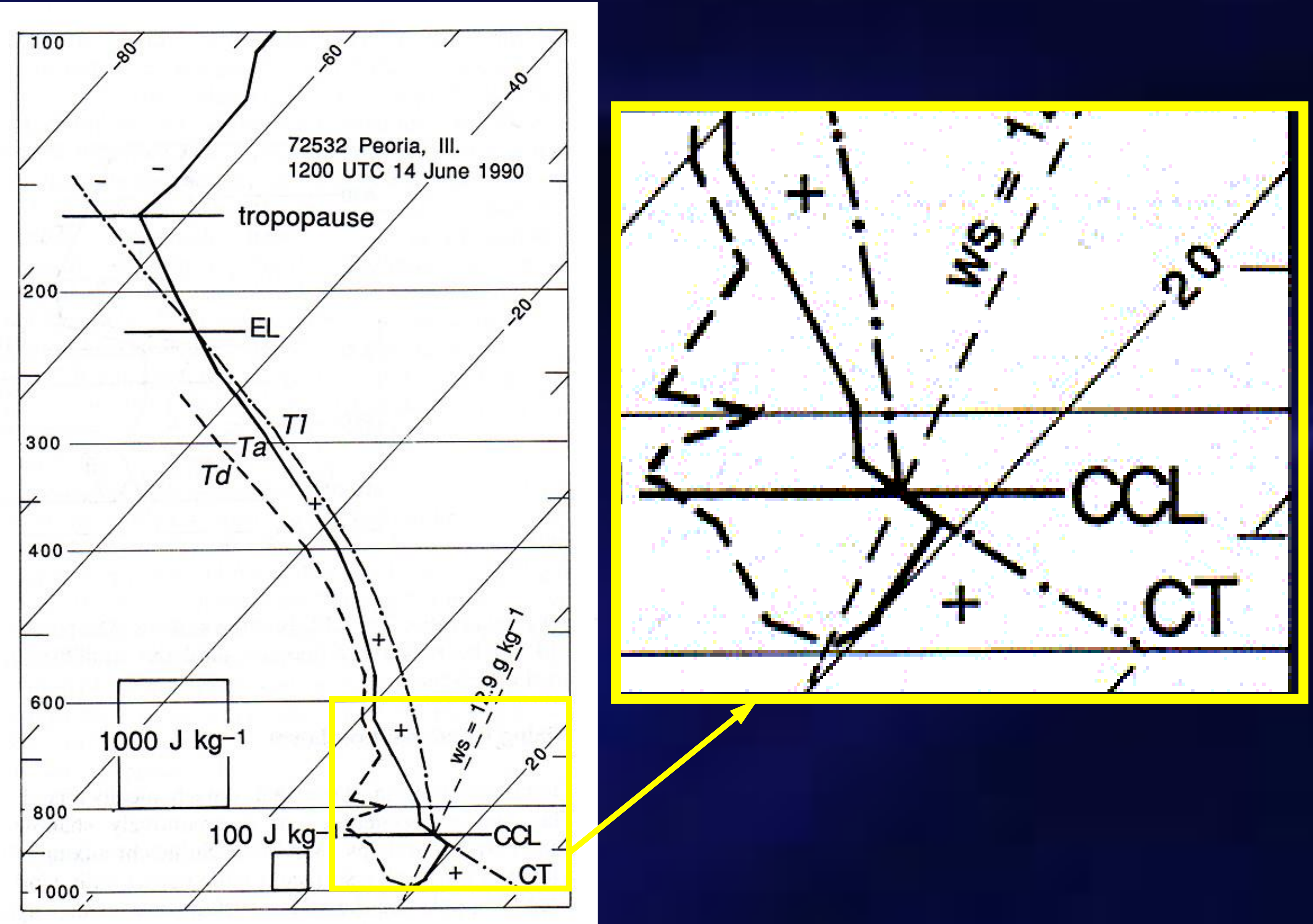
From the surface dew point temperature follow the mixing ratio until it crosses the temperature profile of sounding.

Convective Temperature (CT)

The surface temperature that must be reached for purely convective clouds to develop. (If the CT is reached at the surface then convection will be deep enough to form clouds at the CCL.)

Determine the CCL, then follow the dry adiabat down to the surface.

Finding the CCL and CT



CCL - Convective Condensation Level - is found by following surface w_s up to ambient temperature profile. It is the LCL for a parcel reaching the CT.

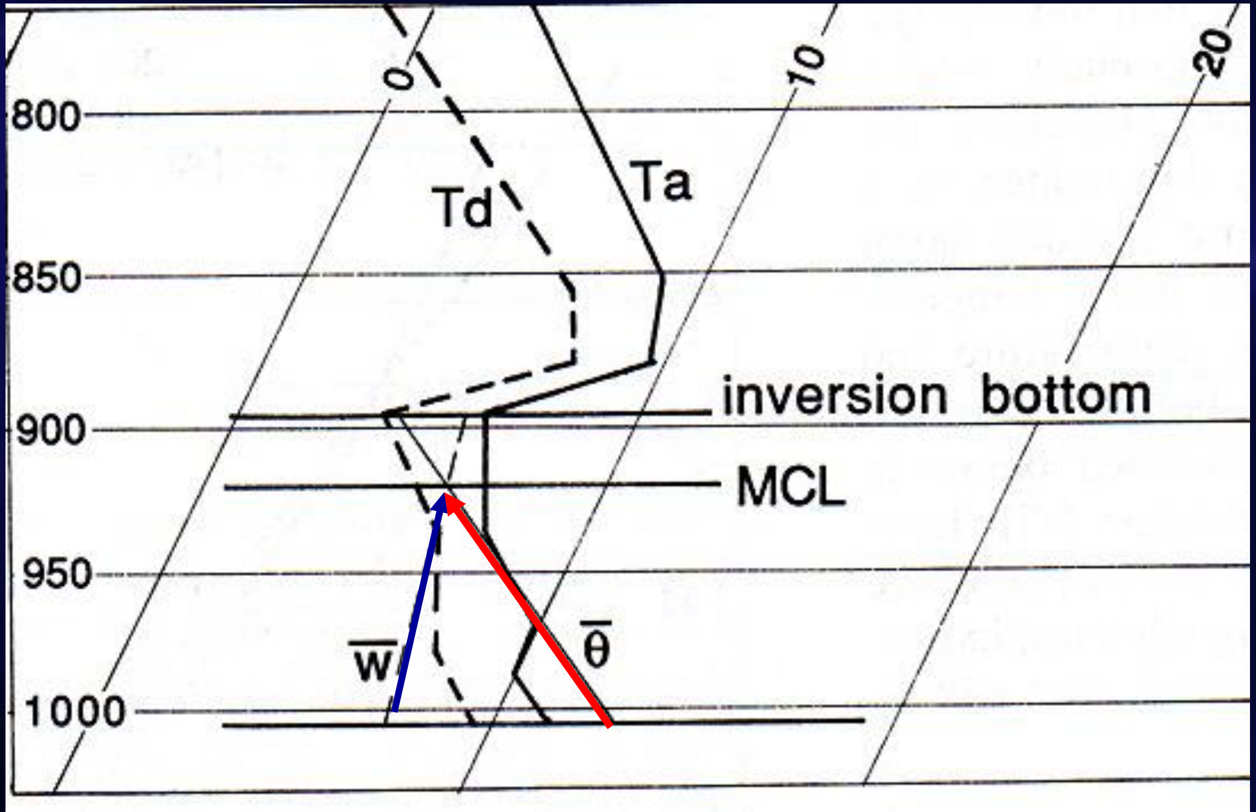
CT - Convective temperature - is found by following the dry adiabat down from the CT. This is the temperature that the surface layer of the atmosphere must reach to initiate spontaneaous convection. On this particular afternoon at FWD, the surface temperature falls short of the CT. Note that convection could still occur if some other mechanism lifted air parcels to the LFC. The convective temperature in the sounding above is about 37 C compared to surface temperature of 32 C.
LI - Lifted Index - difference in temperature between atmosphere and lifted parcel:

$$LI = T - T_{lifted}$$

Mixing Condensation Level (MCL)

This represents the level at which clouds will form when a layer is sufficiently mixed mechanically. (i.e. due to turbulence)

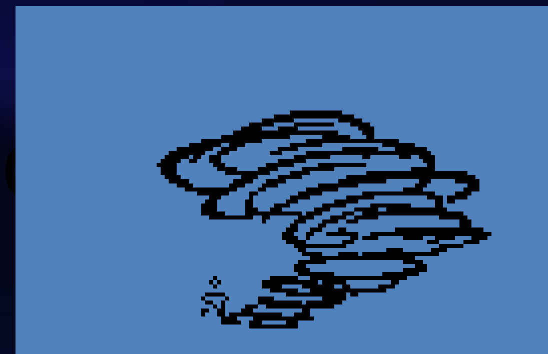
To find the MCL determine the average potential temperature (θ) and average mixing ratio (w) of the layer. Where the average θ and average w intersect is the MCL.



Thermodynamic Diagrams and Severe Weather

What is Severe Thunderstorm?

Tornad



Hail > or = 3/4inch

Wind Gust > 50 knots

Convective Available Potential Energy (CAPE)

Remember: Area on a thermodynamic diagram is proportional to energy.

CAPE on a thermodynamic diagram is the area between the parcel and the environment temperatures from the LFC to the EL

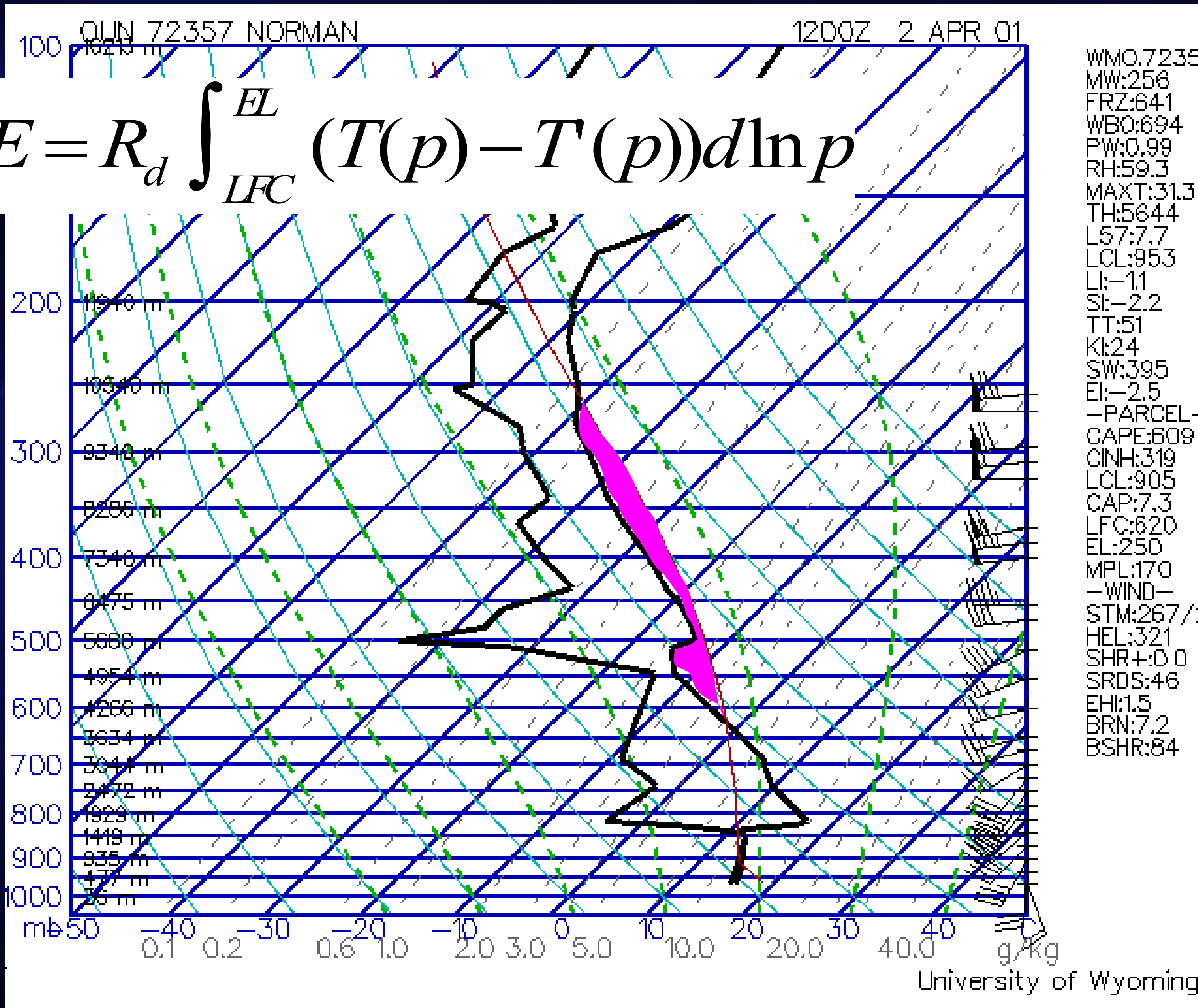
CAPE is also called buoyant energy.

CAPE is a measure of instability

$$CAPE = g\int_{LFC}^{EL} \frac{\theta_{parcel} - \theta_{env}}{\theta_{env}} dz$$

CAPE

$$CAPE = R_d \int_{LFC}^{EL} (T(p) - T'(p))\, d\ln p$$



CAPE

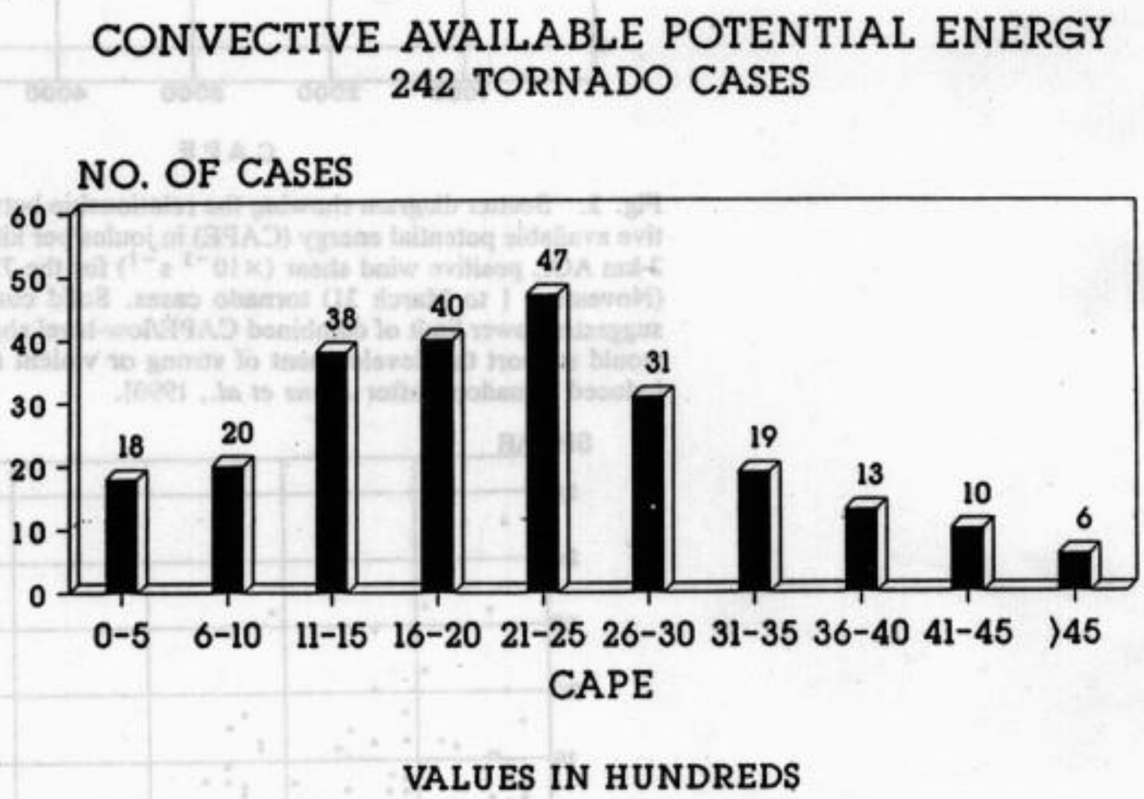


Fig. 1. Distribution of the convective available potential energy (CAPE) values associated with the 242 strong and violent tornado cases in the data set. Number above each bar is the number of cases in that particular range of CAPE values.

CAPE - Convective available potential energy - is the amount of bouyant energy available to air parcels for conversion to kinetic energy. It is proportional to the red shaded area between the lifted parcel and ambient temperature profile. The CAPE of 511 J/kg is not particularly large. CAPE over 1500 J/kg usually yields thunderstorms. CAPE over 3000 J/kg usually yield severe thunderstorms.

$$\mathrm{CAPE} = R \int_{p_{LFC}}^{p_{EL}} [T_{lifted}(p) - T(p)]\, d\ln(p)$$

CIN - Convective Inhibition - defines the work required to bring parcel to the LFC. It is proportional to the light blue shading between the parcel and ambient temperature profile. The convective inhibition of 11.9 J/kg is very small but is enough to prevent convection from occuring. It appears to be too dry for convection.

$$\mathrm{CIN} = R \int_{p_{sfc}}^{p_{LFC}} [T_{lifted}(p) - T(p)]\, d\ln(p)$$

Convective parameters and lifted air parcels: Morning soundings

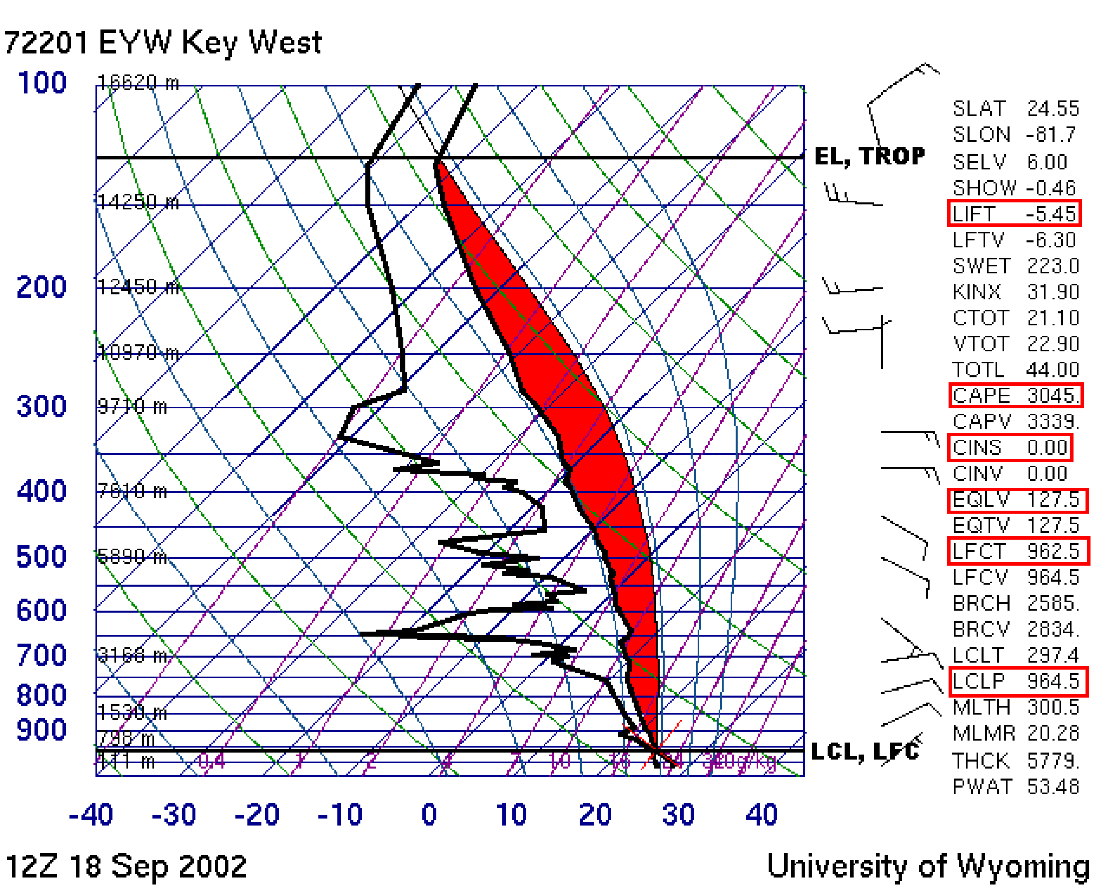
Morning soundings usually feature a stable boundary layer.

They are used to make predictions about afternoon convection in the vicinity. Lifted parameters are calculated using lifted parcels where:

a) a mean mixing ratio of the lowest km of the atmosphere;

b) the estimated high for the day. This is to provide a more meaningful estimate of CAPE, CIN, LFC, EL,etc. than actual surface conditions.

The following is a morning sounding in Key West, Florida.



This is a very unstable sounding. A large CAPE can be infered from the large area of red shading between parcel and ambient temperature profiles. Note that CAPE greater than 3000 J/kg indicates the probability of severe convection. Indeed, hurricane Isadore was not far from Florida at the time of the sounding. The LCL and LFC are at the same level in his sounding. The tropopause and EL also coincide.

This soundingings illustrate the effect of a humid boundary layer on the potential for convection. If the relative humidity near the surface is high, the LCL will be reached sooner, more latent heat will be released, and the parcel lapse rate will be smaller.

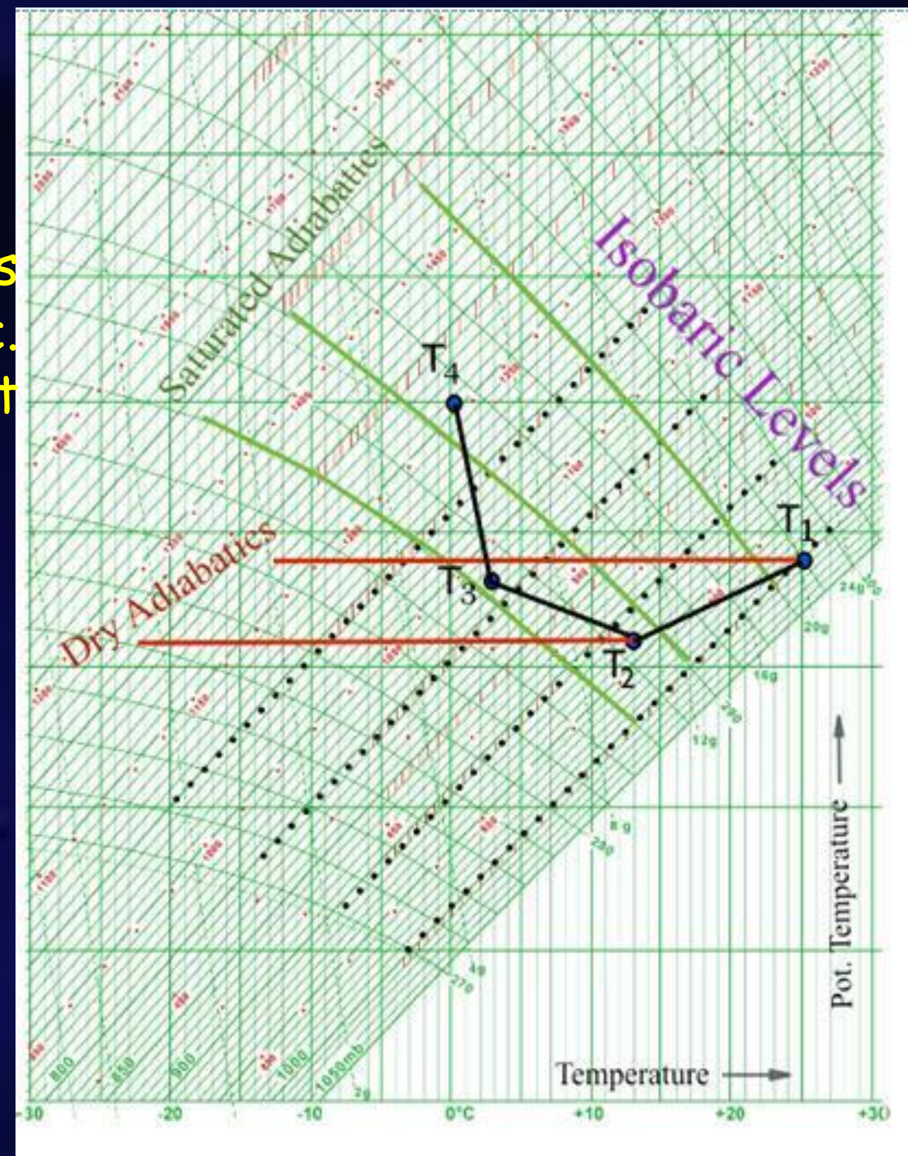
The black curve represented by T_1 $T_2 T_3$ T_4 is a typical temperature profile from a sounding.

The portion T_1 T_2 of the black curve represent super-adiabatic lapse rate

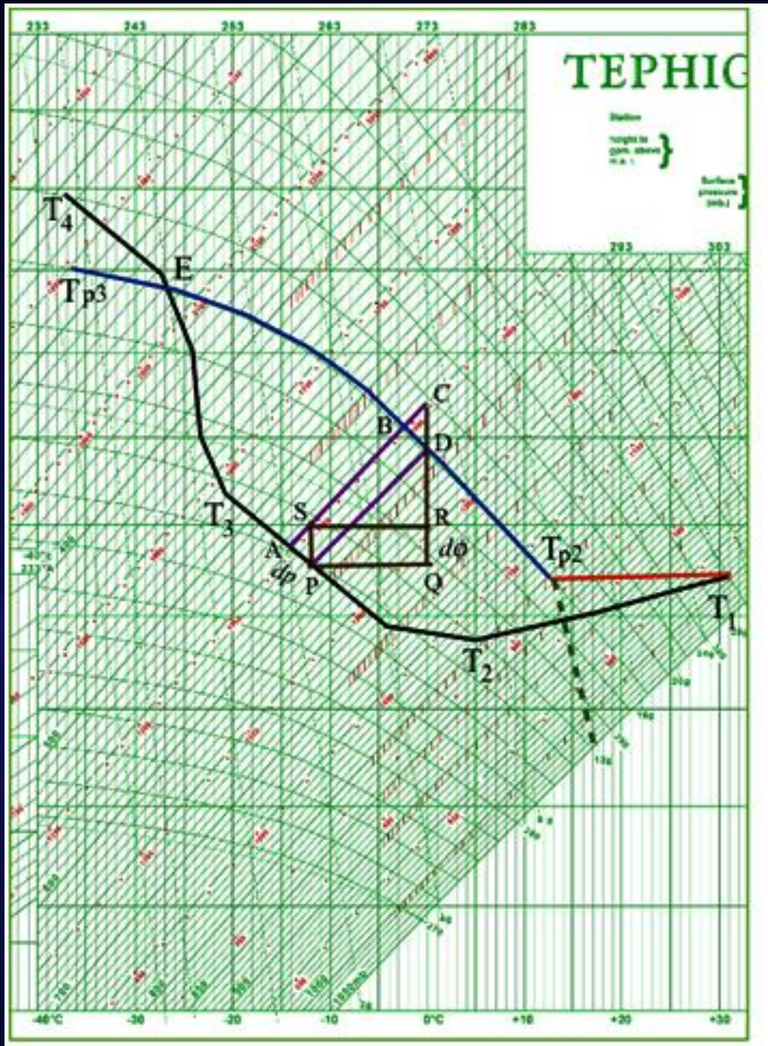
$$(\Gamma > \Gamma_d)$$

The portion T_2 T_3 of the curve slopes upward relative to the dry adiabatic. Lapse rate is less than DALR but exceeds SALR.

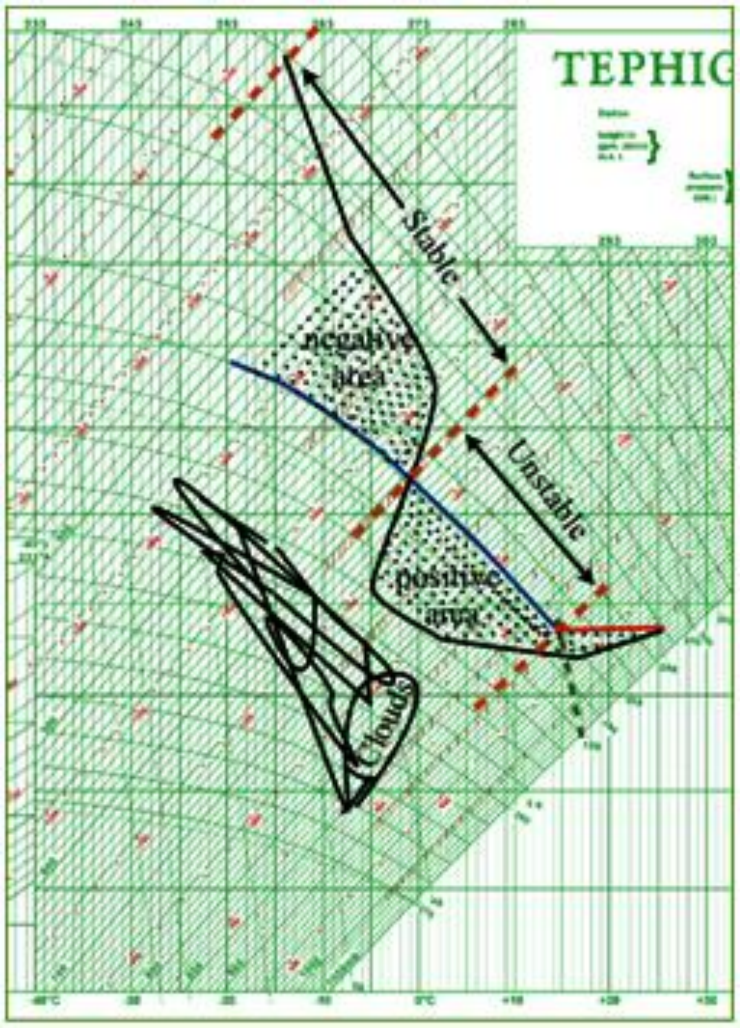
For the portion T_3 T_4 of the curve, lapse rate is less than SALR.



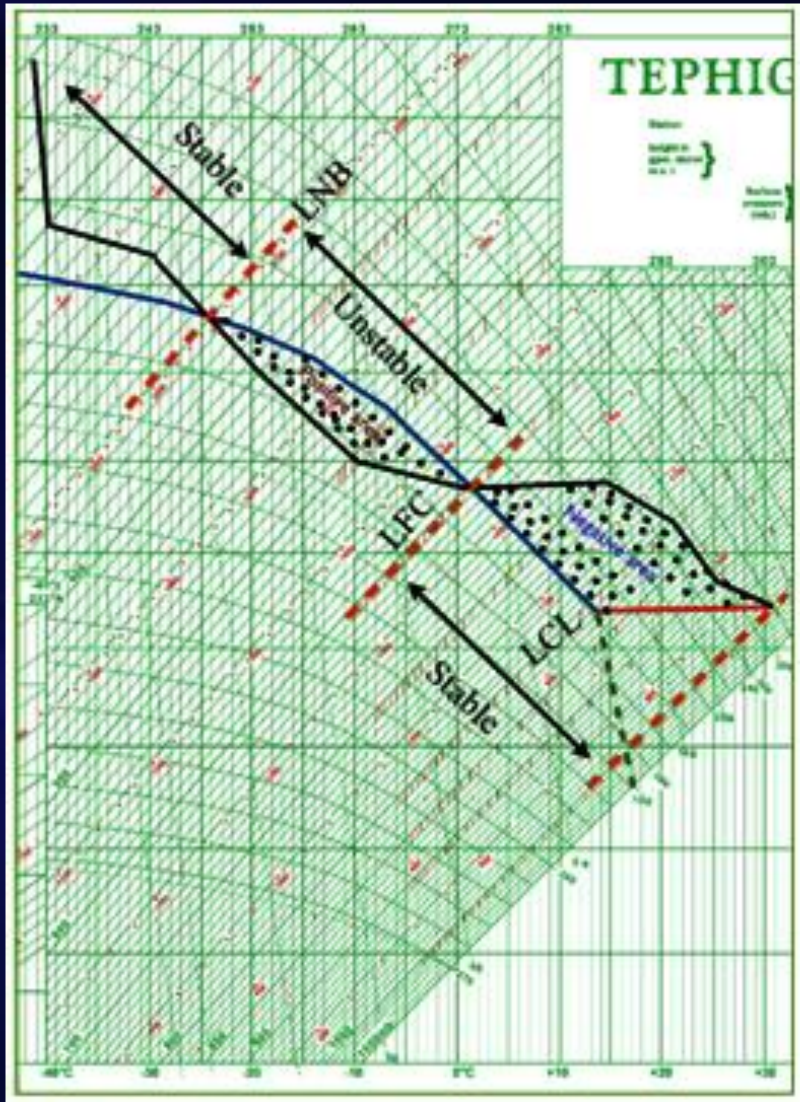
ENERGY LIBERATED DURING THE ASCENT OF AIR



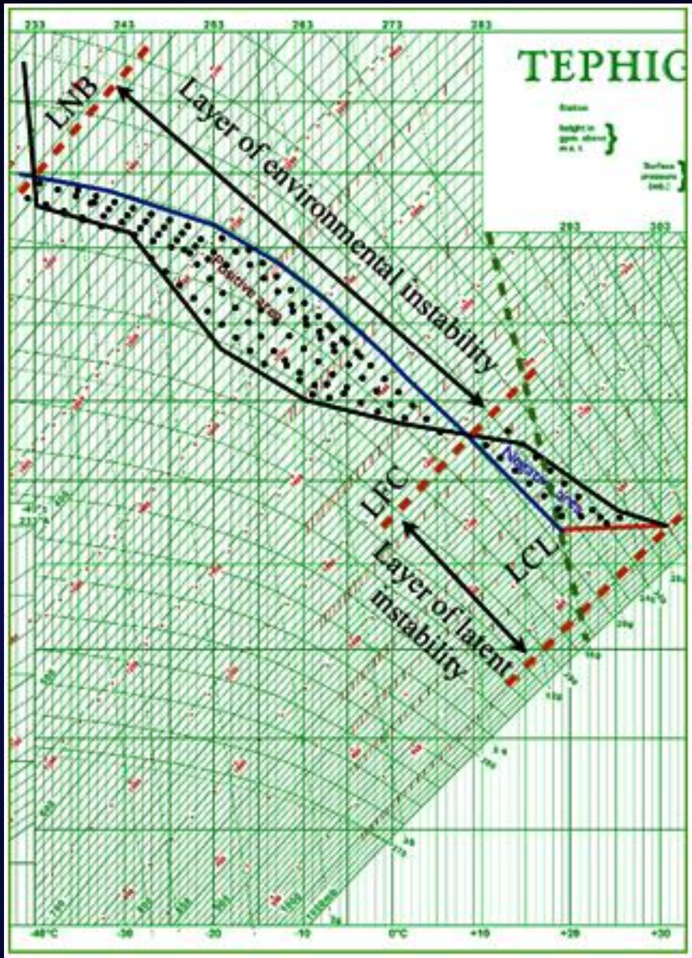
ABSOLUTE INSTABILITY



CONDITIONAL INSTABILITY



CONDITIONAL INSTABILITY



We close this discussion on conditional instability by taking another example where there is a low level inversion, but air mass above is absolutely unstable. The observed temperatures and the corresponding wet-bulb temperatures at different pressure levels on a typical day characterizing the above situation at an observing station are as follows:

p (mb)	1000	950	900	850	800	700	600	500	400	450
T °C	26.0	24.0	27.0	20.0	18.5	8.0	1.0	-9.0	-14.0	-14.0
T_w°C	21.0	21.0	20.0	16.0	12.0	4.0	-9.0	-	-	-

the positive and negative areas shaded in red and in blue respectively

Since the positive area (red) is much smaller than the negative area (blue), there is no possibility of deep convection, though a very strong surface heating could offset this stable situation with an inversion at 900 hPa. Such situations are a common sight during winters. Clearly an inversion will prevent mixing in the vertical with the result that the thickness of the layer of latent instability will not reduce rapidly. The possibility of persistent haze in urban clusters is very high in situations of contemporaneous occurrence of higher moisture content and trapping of pollutants below inversion over such regions.

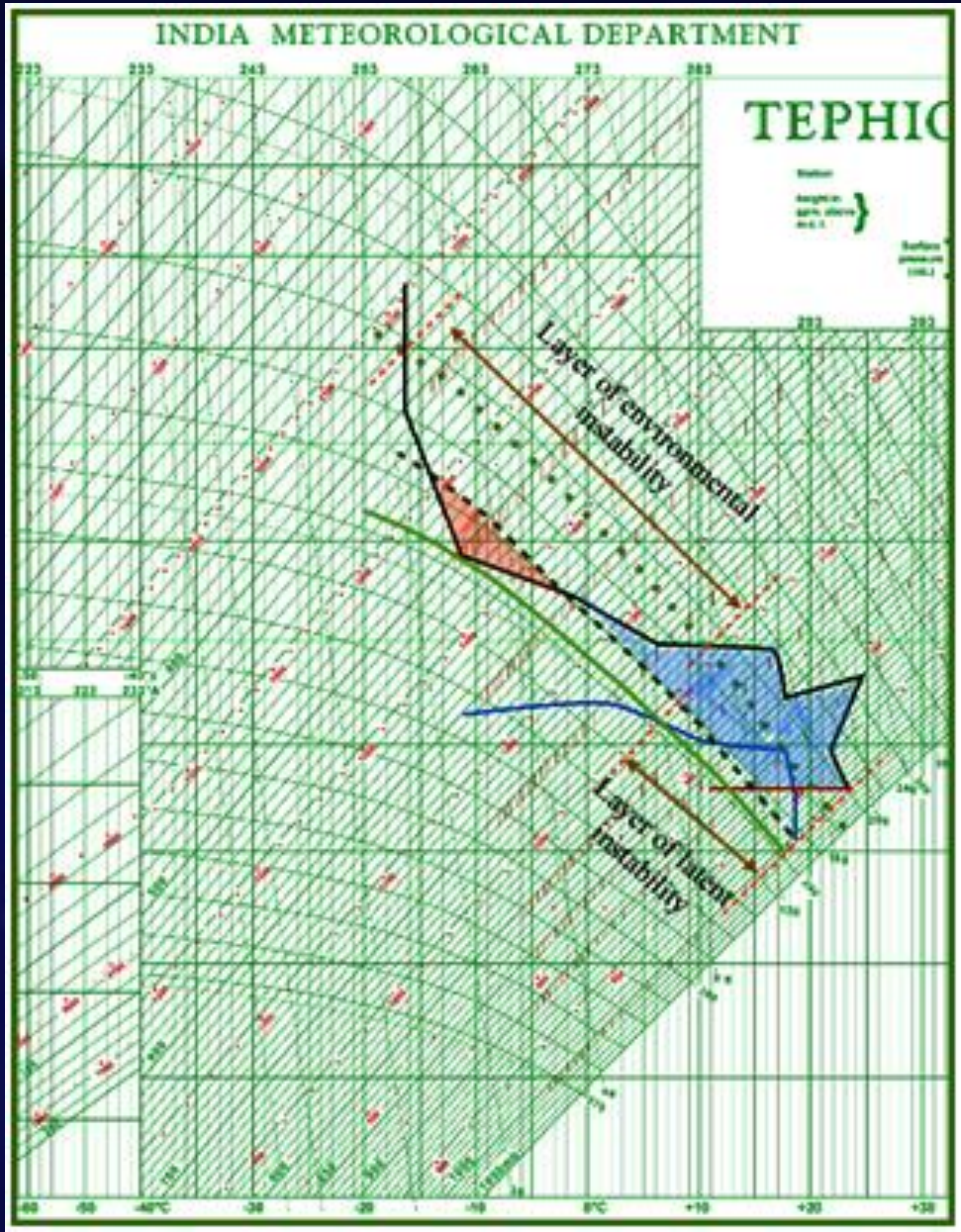
CONDITIONAL INSTABILITY

The positive area is much smaller than the negative area. The potential energy barrier to raise a parcel from LCL to its LFC is high.

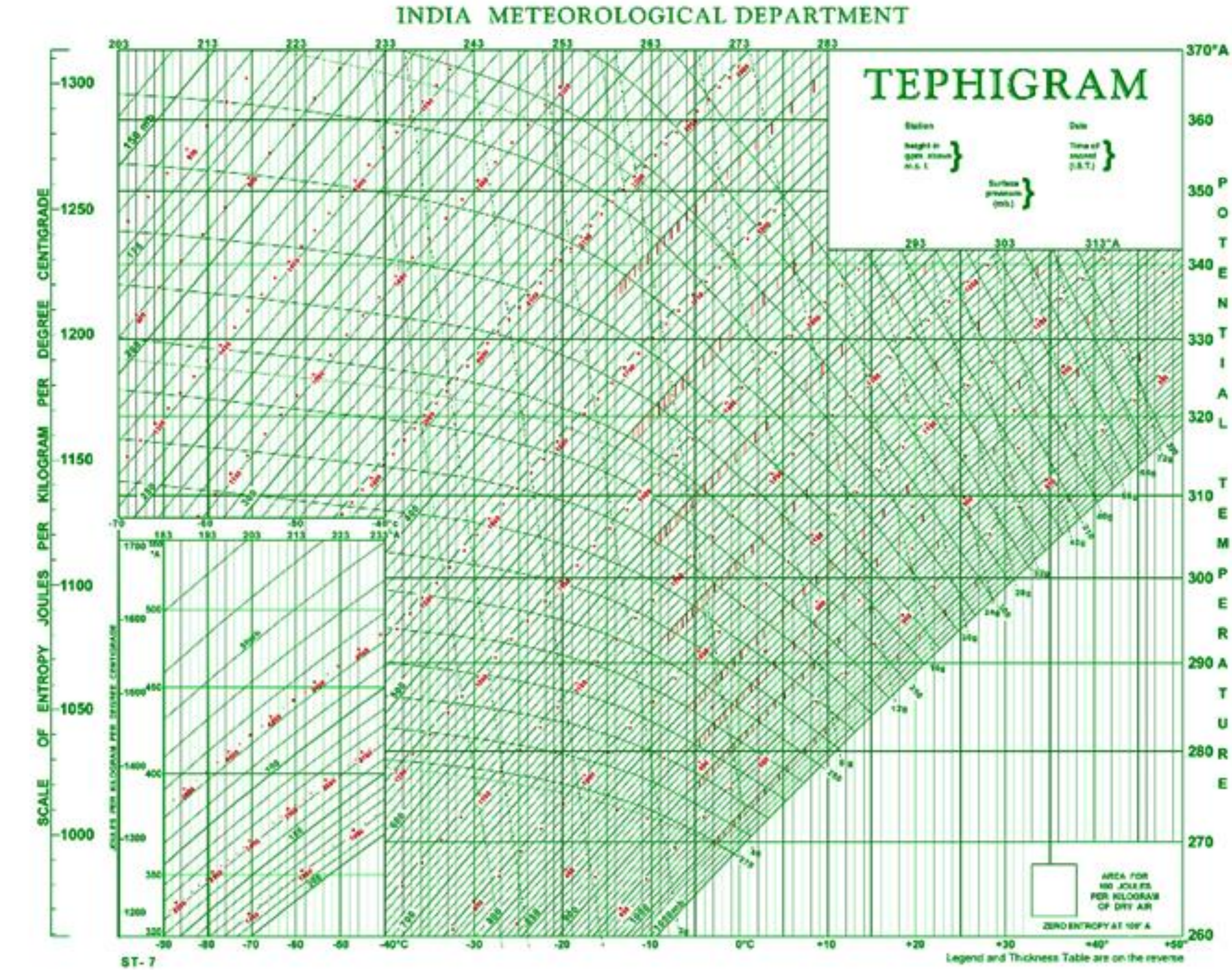
This typical tephigram shows positive area (CAPE) much smaller than negative area (CIN), therefore there is no possibility of any deep convection to develop. Convective Inhibition Energy (CIN) exceeds 100 J kg $^{-1}$.

Positive area = CAPE (<100 J kg^{1})

Negative area = CIN(>400 J kg^{-1})



Then temperatures increasing with height as shown in Fig. 5.8 give rise to an inversion at 900 hPa. The mixing ratio of the surface air mass is 12 g kg^{-1} while *16 g* kg^{-1} dew-point line passes through the T_w=20°C. This means that air is unsaturated at the inversion level but near to saturation. Above the inversion, the tephigram (Fig. 5.8) shows the lapse rate sloping downward on the left with reference to DALR. Further up, super-adiabatic lapse rate exists in a layer that is topped by an isothermal layer. Note that from LCL to LFC, the parcels are negatively buoyant, and energy must be supplied to parcels for them to reach LFC in such situations. Moreover, the negative area (shaded blue in Fig. 5.8) between the environmental temperature profile and the saturated adiabatic passing through the LCL is substantially larger than the positive area (shaded red). The atmospheric layer between LCL and LFC is stable which inhibits convection. The existence of a stable layer below the cloud base (i.e. LFC) is a very characteristic feature of moist convection. However, if CIN exceeds 100 Jkg^{-1}, a parcel will not reach LFC unless substantial amount of energy is supplied. The existence of a layer of environmental instability may give rise to some cloud formation either in the upper atmosphere (cirrus clouds) or some middle level cloud might form in the region shaded red in Fig. 5.8, but these clouds may not be very thick.


INDIA METEOROLOGICAL DEPARTMENT
TEPHIGRAM
Station
Height in gpm above m.s.l.
Date
Time of ascent (I.S.T.)
Surface pressure (mb)
SCALE OF ENTROPY JOULES PER KILOGRAM PER DEGREE CENTIGRADE
POTENTIAL TEMPERATURE
370°A
360
350
340
330
320
310
300
290
280
270
260
1300
1250
1200
1150
1100
1050
1000
203
213
223
233
243
253
263
273
283
293
303
313°A
-40°C
-30
-20
-10
0°C
+10
+20
+30
+40°
+50°
150 mb
1000mb
AREA FOR 100 JOULES PER KILOGRAM OF DRY AIR
ZERO ENTROPY AT 100° A
ST- 7
Legend and Thickness Table are on the reverse