Fundamentals of Atmospheric Physics

Lecture 7

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Letting $\delta z \rightarrow 0$, we get the saturated adiabatic lapse rate (SALR) Γ_s:

$$\Gamma_s = -\frac{dT}{dz} = \frac{g}{c_p} \frac{(1+\frac{L\mu_s}{R_a T})}{(1+\frac{L^2\mu_s}{c_p R_v T^2})}$$

g/c_p ⇨ DALR Γ_a

$$\Gamma_s = \Gamma_a (coefficient)$$

For typical atmospheric values of T and μ_s it is found that $\Gamma_s \leq \Gamma_a$.

Because of the latent heat given to the air by condensation of the water vapour, the temperature drops off less rapidly with height (by about 6–9Kkm^{-1}) at the SALR than it does at the DALR ($\sim$ 9.8Kkm^{-1})

Note that Γs depends on the temperature and pressure, through its dependences on T and μ_s (T, p).

Working in terms of the pressure of the parcel, rather than its height,

$$g\delta z = -\frac{R_a T \delta p}{p}$$

$$dT = -\Gamma_s dz$$

that, following the ascending parcel,

$$\frac{dT}{dp} = \frac{\Gamma_s R_a T}{gp} = \Gamma'_s(T, p)$$

say. Curves in the T, p plane whose slopes at each point are given by this equation are called saturated adiabatics.

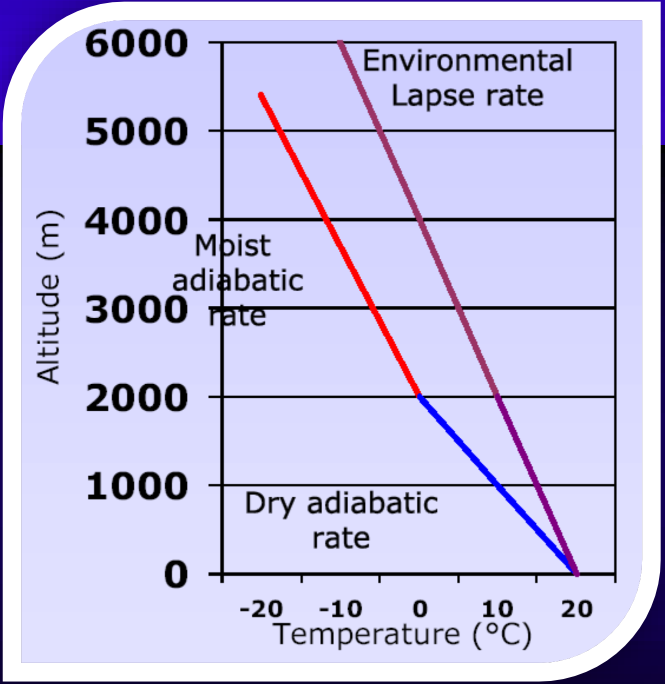
Given the expression for Γ'_s and suitable starting values of T and p, they may readily be calculated numerically.

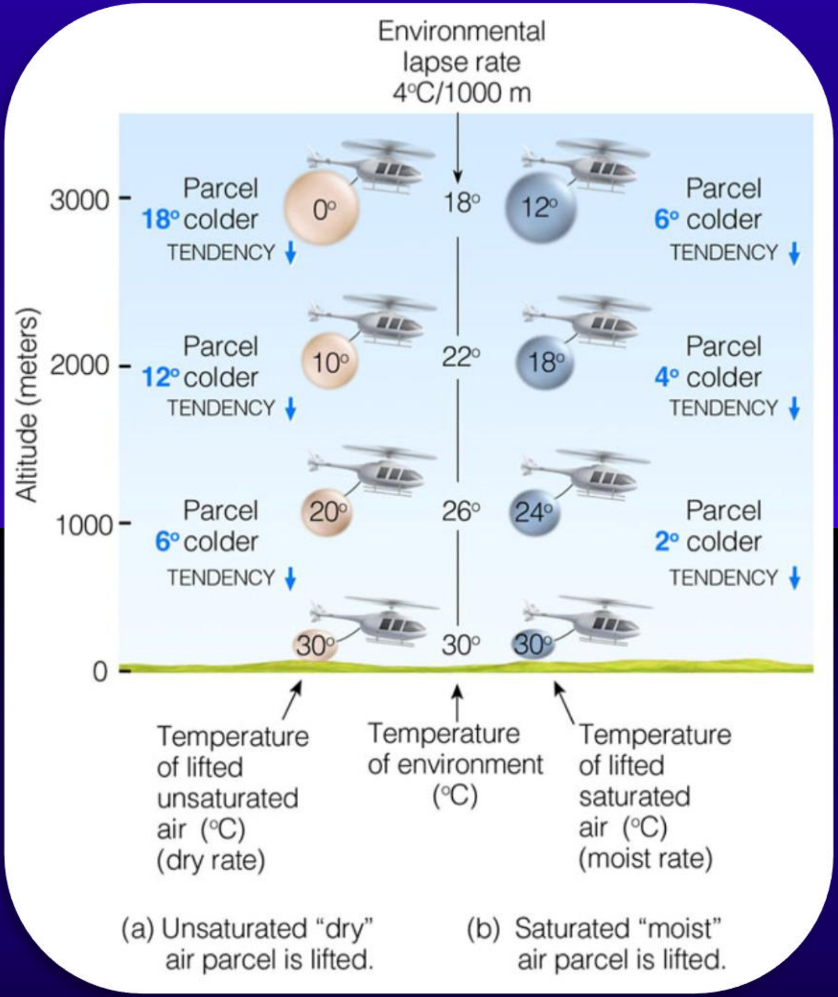
A Stable Atmosphere

stabilizing processes

nighttime surface radiational cooling;

Stable air provides ideal conditions for high pollution levels





Absolute stability

The environmental lapse rate less than the saturated adiabatic lapse rate

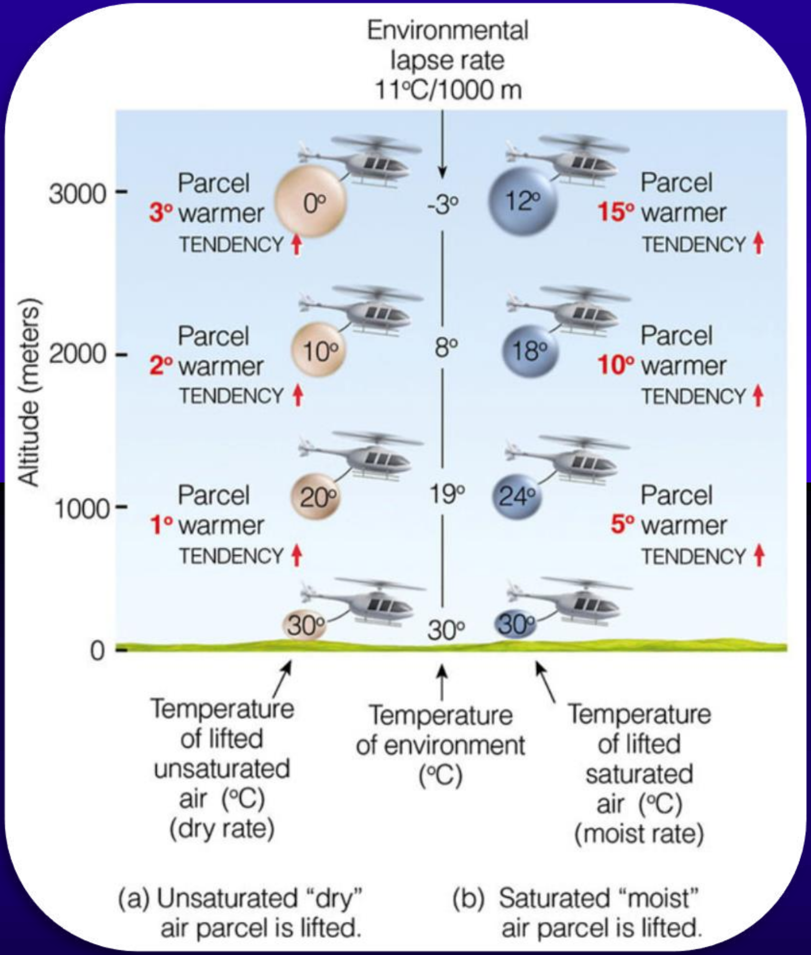
An Unstable Atmosphere

destabilizing processes
daytime solar heating of surface air;

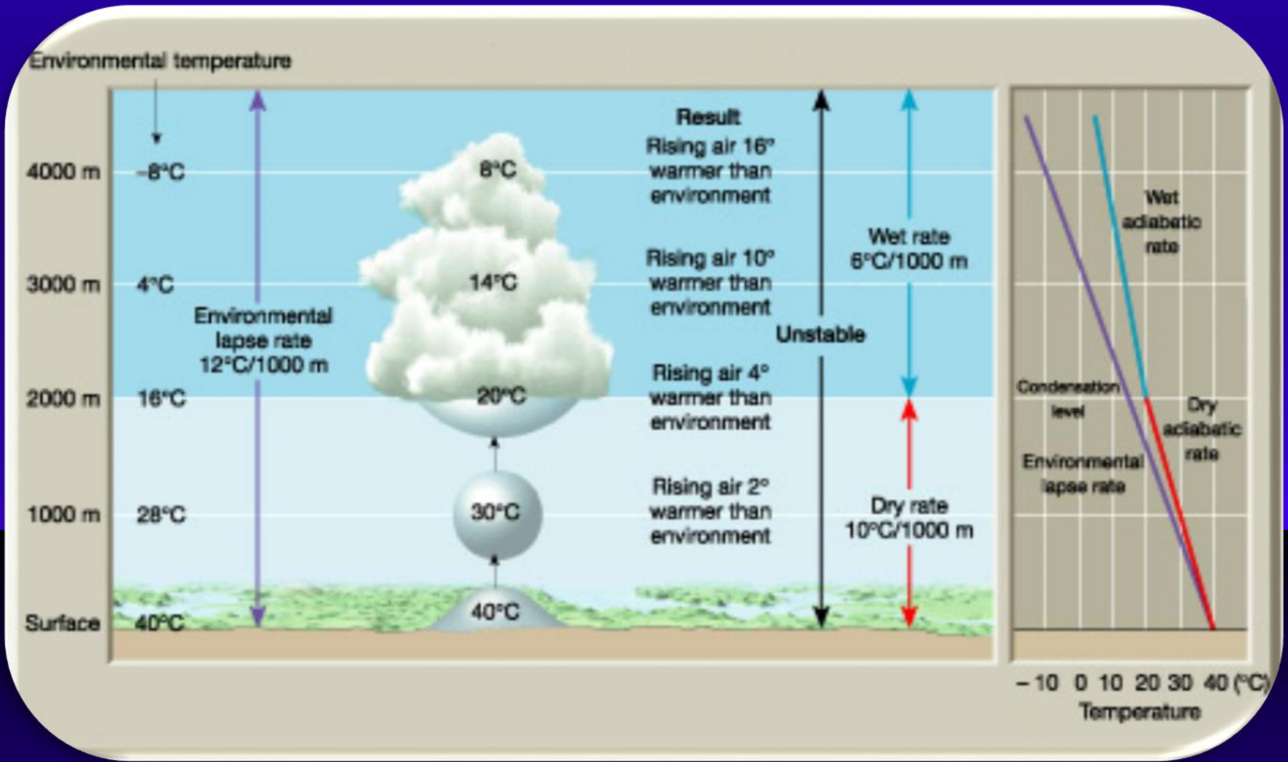
cold air advected to warm Surface

superadiabatic lapse rates (> 10 °C/km)

unstable air tends to be well-mixed



Absolute Instability



The environmental lapse rate is greater than the dry adiabatic lapse rate

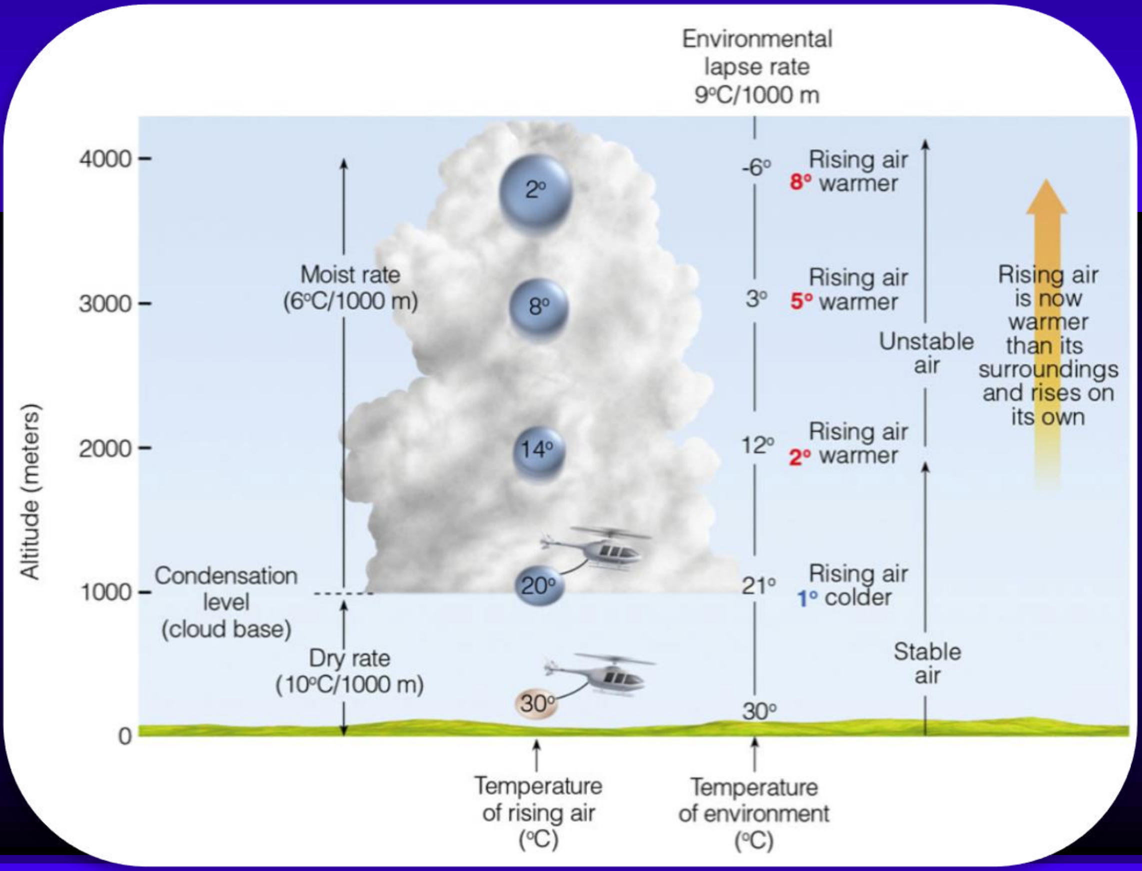
Ascending parcel always less dense than surrounding air, will always rise

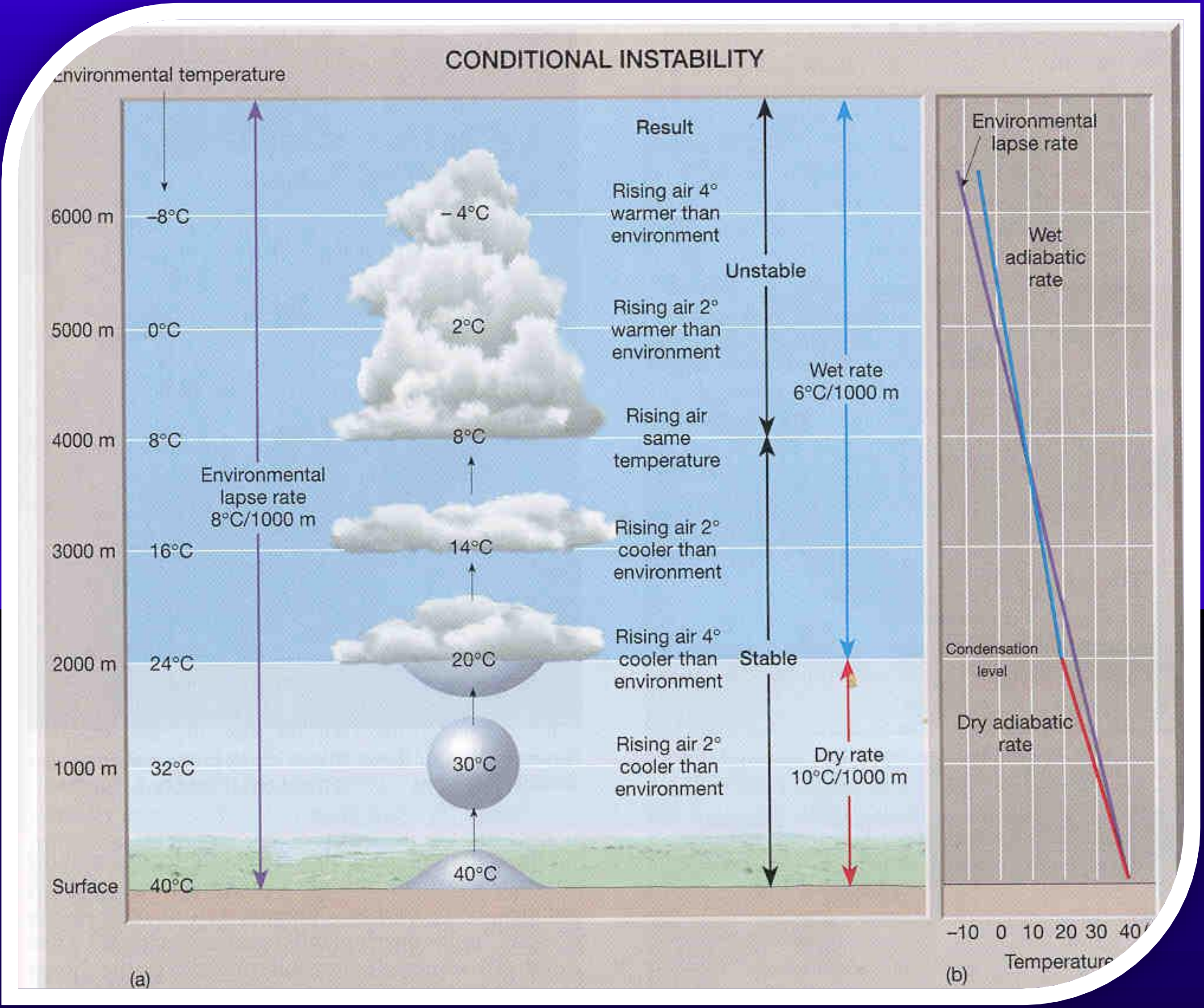

Instability Air

Conditionally Unstable Air

Conditional instability: environmental lapse rate between dry and moist lapse rates

Condensation level cloud base





Saturated parcel is unstable, unsaturated parcel is stable

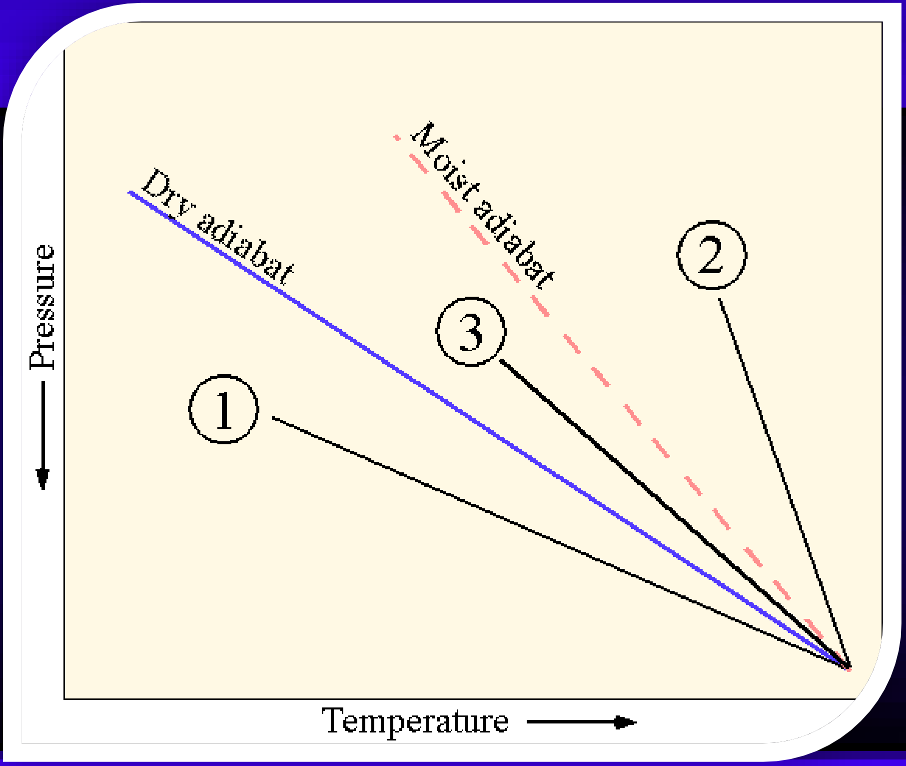
Depend on whether or not the rising air is saturated

In general

(1) is Absolutely Unstable Air

(2) is Absolutely Stable Air

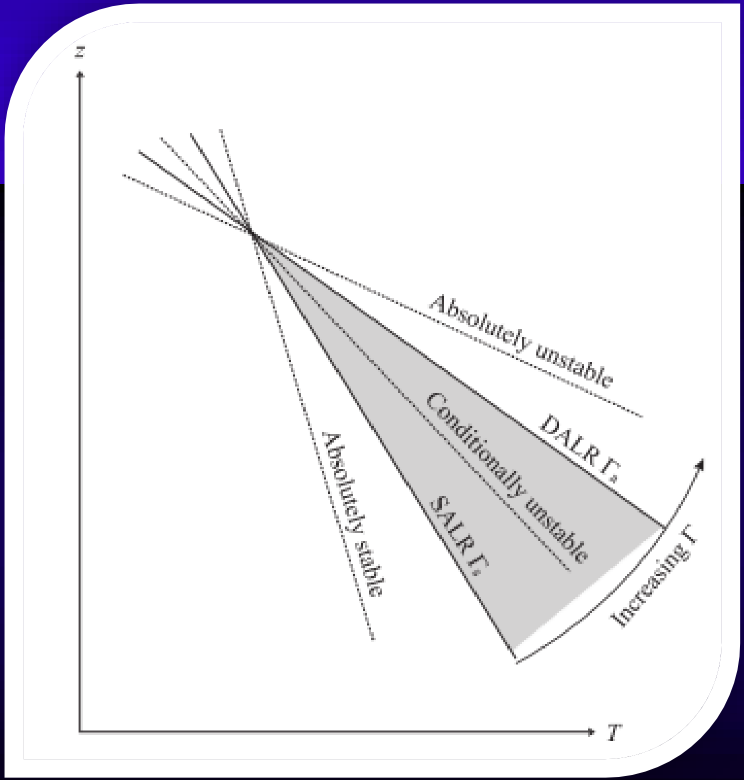
(3) is Conditionally Unstable Air.



if the actual lapse rate $\Gamma < \Gamma_s$ then the region is statically stable even if the air is saturated.

if $\Gamma > \Gamma_s$ a saturated parcel will be unstable.

if $\Gamma_s < \Gamma < \Gamma_a$ a saturated parcel is unstable but an unsaturated one is not: this situation is called conditional instability.



a graphical representation of the various cases

Under a certain approximation, the saturated adiabatic can be calculated explicitly,

First, note that, for reversible processes, $T\,dS = dQ$,

so equation $$\delta S = c_p \frac{\delta T}{T} - R_a \frac{\delta p}{p} = c_p \delta(\ln T) - R_a \delta(\ln p)$$

can be written $$c_p \delta(\ln T) - R_a \delta(\ln p) = \frac{\delta Q}{T} = -\frac{L\delta\mu_s}{T}$$

Provided that the expression on the extreme right-hand side of this equation can be approximated by

$$-\delta(\frac{L\mu_s}{T})$$

$$\delta(c_p \ln T - R_a \ln p + \frac{L\mu_s}{T}) = 0$$

On integrating, dividing by c_p ,using $\kappa = R_a/c_p$

and taking exponentials, we get

$$\theta_e(T,p) \equiv T(\frac{p}{p_0})^{-k} \exp(\frac{L\mu_s}{c_p T}) = constant$$

The quantity θ_e is called the equivalent potential temperature.

equation $\theta = T(\frac{p_0}{p})^k$ and above equation we see that

$$\theta_e(T,p) \equiv \theta(T,p) \exp\left(\frac{L\mu_s(T,p)}{c_p T}\right)$$

Under the given approximation, we have therefore integrated equation

$$\frac{dT}{dp} = \frac{\Gamma_s R_a T}{gp} = \Gamma_s'(T,p)$$ explicitly,

so the curves of constant θ_e closely approximate the saturated adiabatics.

It may be shown that, as we follow a saturated adiabatic

$$\theta_e = \theta_0$$

say, to low pressure (and low temperature), it approaches the dry adiabatic

$$\theta = \theta_0$$

The relationship between the three types of potential temperature can be described as follows

$\mu = \mu_s$ (saturated environment): $\theta_e = \theta_{es}$,

$\mu = 0$ (dry environment): $\theta_e = \theta$,

$0 < \mu < \mu_{sat}$ (unsaturated moist parcel): $\theta < \theta_e < \theta_{es}$.

THERMODYNAMIC DIAGRAMS

which helps us represent atmospheric states and processes on a chart

Purpose:

A thermodynamic diagram is to provide a graphic display of the lines representing major processes to which air may be subject, namely isobaric, isothermal, dry adiabatic, and pseudoadiabatic processes

Thermodynamic diagrams are particularly useful for examining the effects of moisture, for which there are no simple formula allowing easy analytical calculations.

Fundamental lines:

a) isobars,

b) isotherms,

c) dry adiabats,

d) pseudoadiabats,

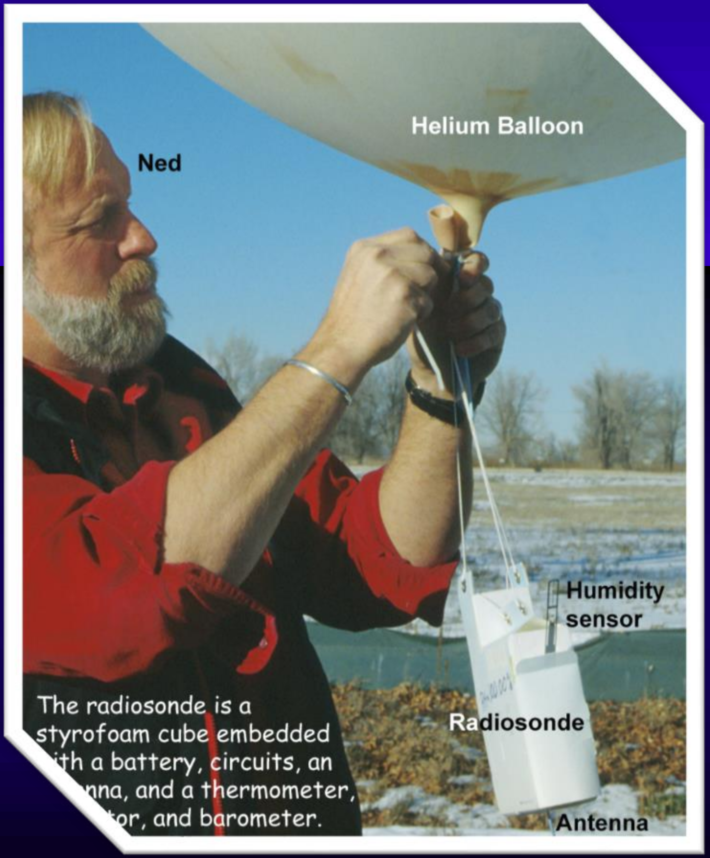
e) saturation mixing ratio

Data to be represented:

the data to be represented are obtained from soundings and consist of temperature, pressure, and humidity

Radiosondes

An instrument package lifted by a balloon with sensors for pressure, temperature, humidity



There are four such diagrams called :

1) The Emagram

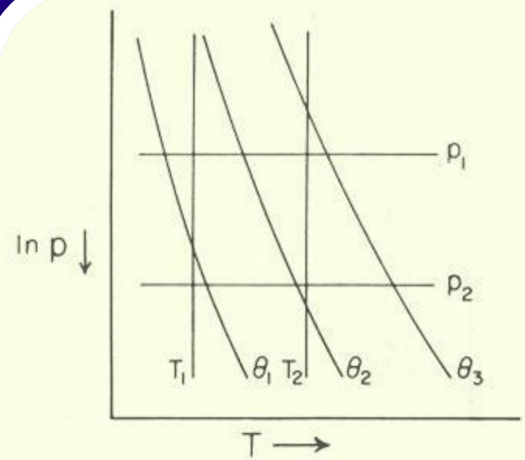


FIG. 1.5. Schematic emagram.

2) The Tephigram

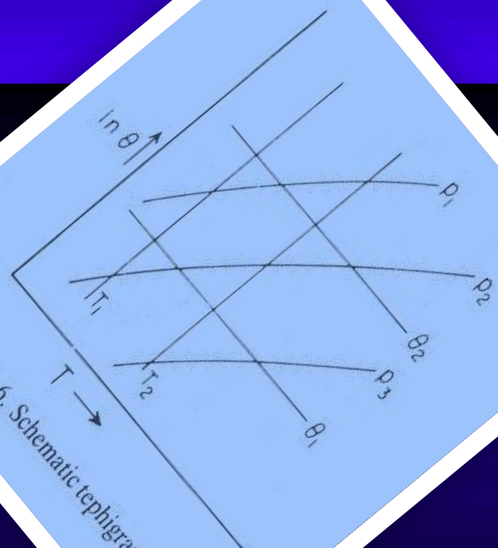
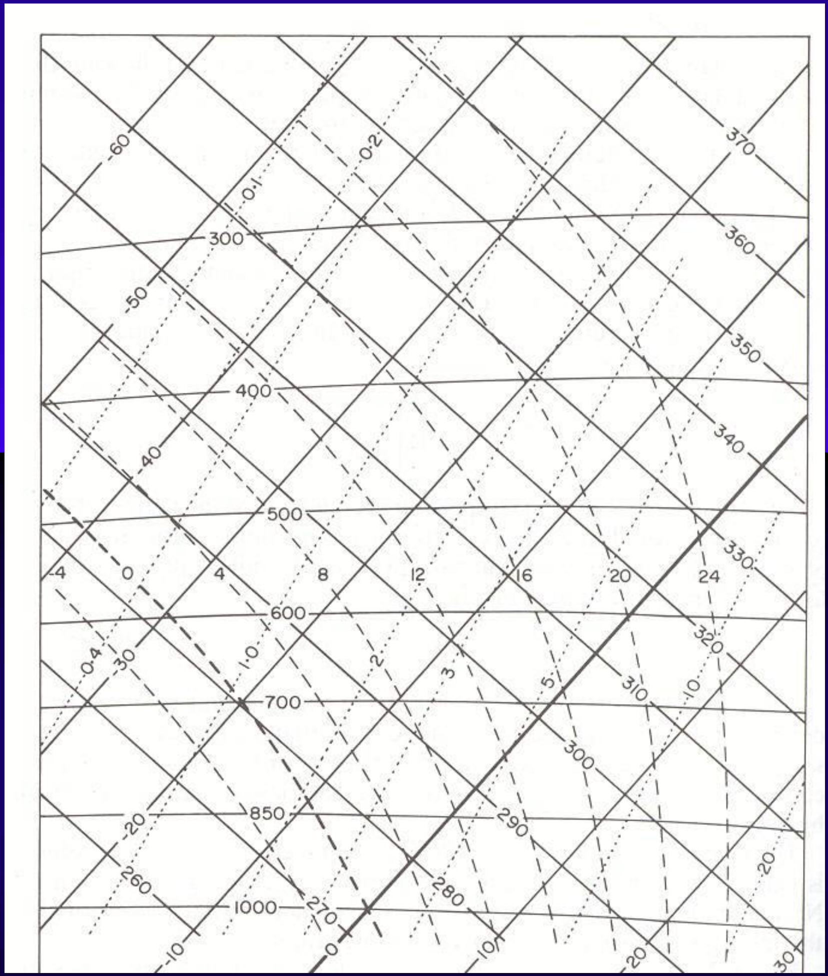


FIG. 1.6. Schematic tephigram.

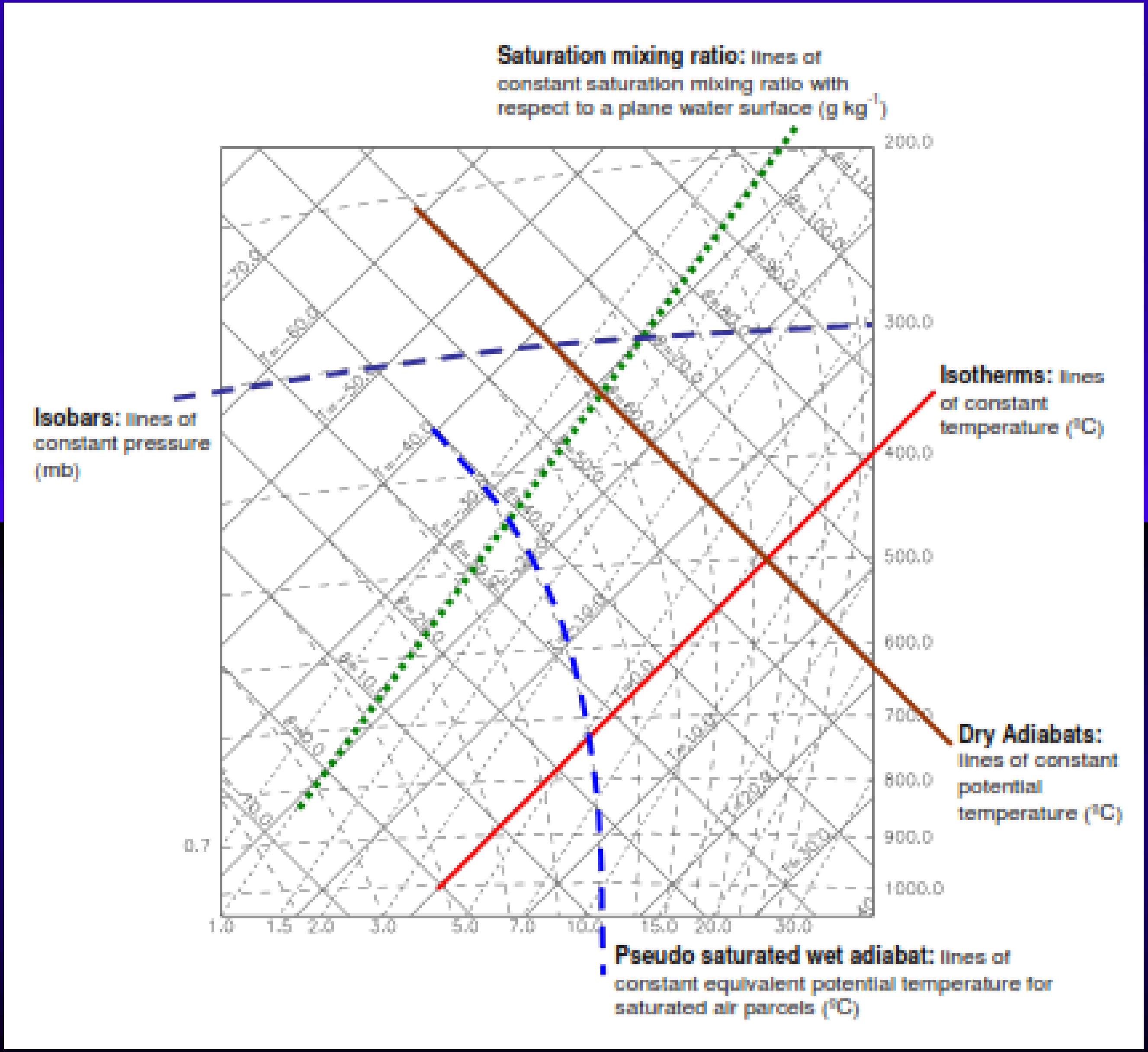
The tephigram

The Tephigram takes its name from the rectangular Cartesian coordinates : temperature and entropy.

The Greek letter 'phi' was used for entropy, hence Te-phi-gram (or T-Φ-gram)



Meteorologists find it convenient to represent the vertical profiles of atmospheric temperature and moisture on thermodynamic diagrams.


Saturation mixing ratio: lines of constant saturation mixing ratio with respect to a plane water surface (g kg^{-1})
Isobars: lines of constant pressure (mb)
Isotherms: lines of constant temperature (°C)
Dry Adiabats: lines of constant potential temperature (°C)
Pseudo saturated wet adiabat: lines of constant equivalent potential temperature for saturated air parcels (°C)
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
0.7
1.0
1.5
2.0
3.0
5.0
7.0
10.0
15.0
20.0
30.0

Tephigram

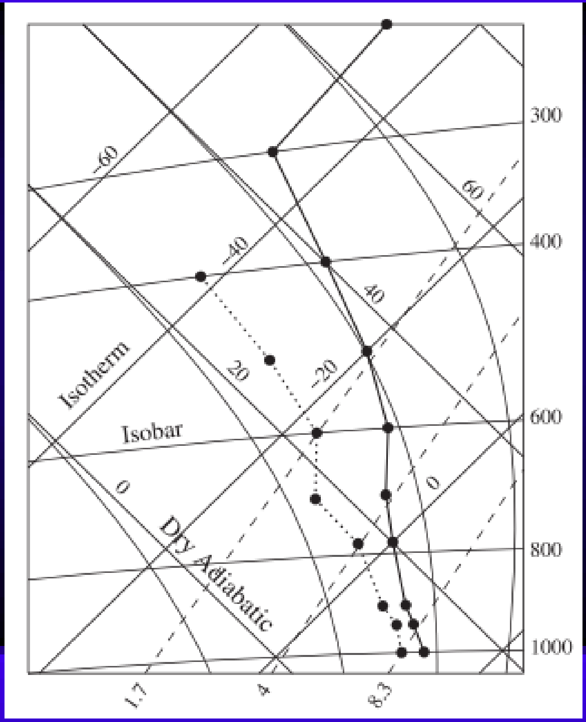
This uses the temperature T and entropy per unit mass S as orthogonal coordinates

The lines of constant S are labelled with the corresponding values of the potential temperature θ

$$S = c_p \ln\theta$$

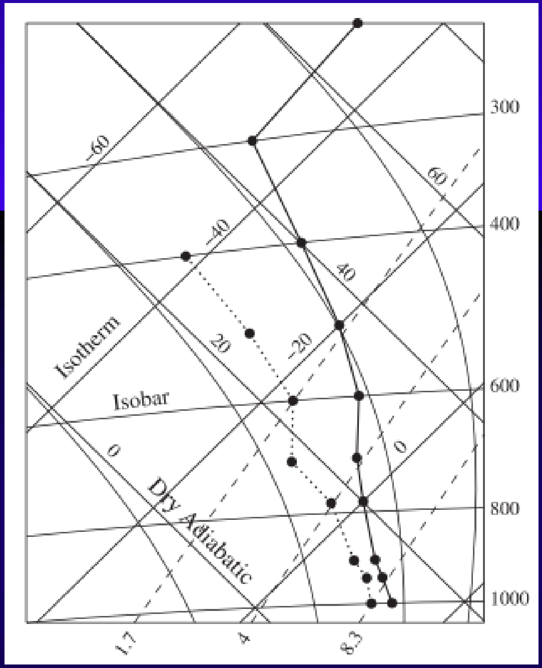
They are called dry adiabatics, the lines of constant T are called isotherms

Since $p = p_0 (\frac{T}{\theta})^{1/k}$



Curves of constant pressure can also be plotted; in the range of T and θ relevant for the lower atmosphere, these are almost straight.

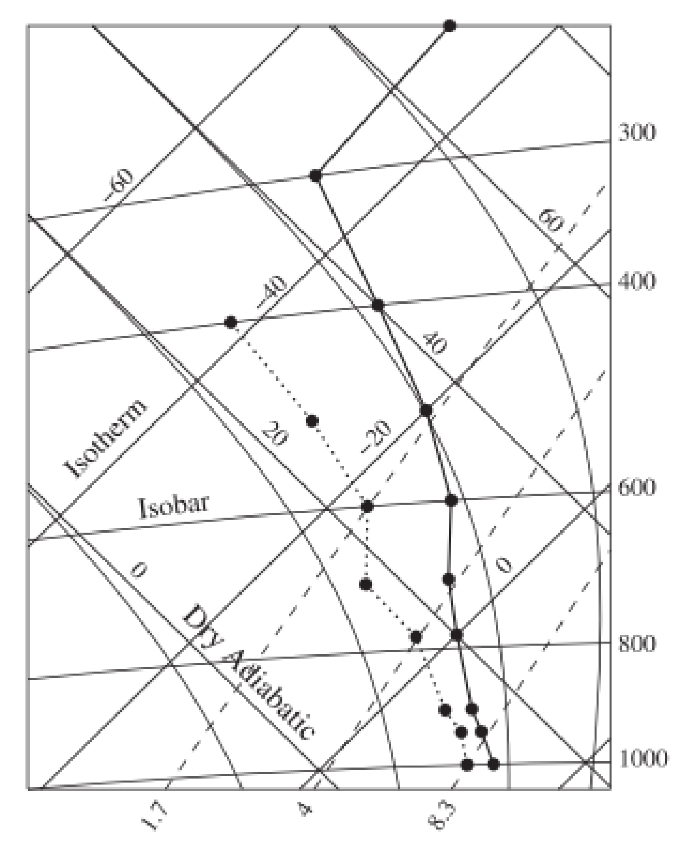
The isotherms (parallel to the S axis) and the dry adiabatics (parallel to the T axis) are chosen to point at 45° above and below the horizontal, respectively, so that the curves of constant p (isobars) become roughly horizontal.



Also included in the figure are two other sets of curves, related to moisture.

The first are the lines of constant saturation mixing ratio $\mu_s(T, p)$: these are almost straight and are drawn dashed.

(Note that we can if we wish use T and p as independent variables for plotting points on the tephigram, instead of T and S.)



They can be plotted using equation

$$\mu_s(T,p) = \frac{es(T)\varepsilon}{p}$$

if an accurate expression for $e_s(T)$ is known

Also plotted are the saturated adiabatics, these are noticeably curved

Each saturated adiabatic can be labelled by the temperature at which it cuts the p = 1000 hPa surface

(the wet-bulb potential temperature θ_w)

or the potential temperature which it approaches at low p

(the equivalent potential temperature θ_e)

During the ascent of a radiosonde the temperature T is measured at a series of pressure levels p, and these can be plotted on the tephigram, to give the environment curve

Straight-line segments are drawn between each point, rather than a smooth curve

This gives a representation of a vertical column of atmosphere, but note that this may be slightly misleading, since the balloon takes some time to ascend and also blows some distance downwind as it does so

The dew point is also plotted at each pressure level, giving a separate curve

Equation $$\mu_s(T_d, p) = \mu$$

then allows us to find the mixing ratio μ at any pressure level on the environment curve, given the corresponding dew point: we just read off the value of μ at the same pressure on the dew point curve.

Many useful results can be obtained from the environment and dew point curves, including inferences about the onset of instability and the formation of clouds:

see Problems 2.12 and 2.13

The tephigram

Allows a radiosonde profile to be analysed for stability

Allows calculations involving moisture content (e.g. saturated adiabatic lapse rate) to be performed graphically

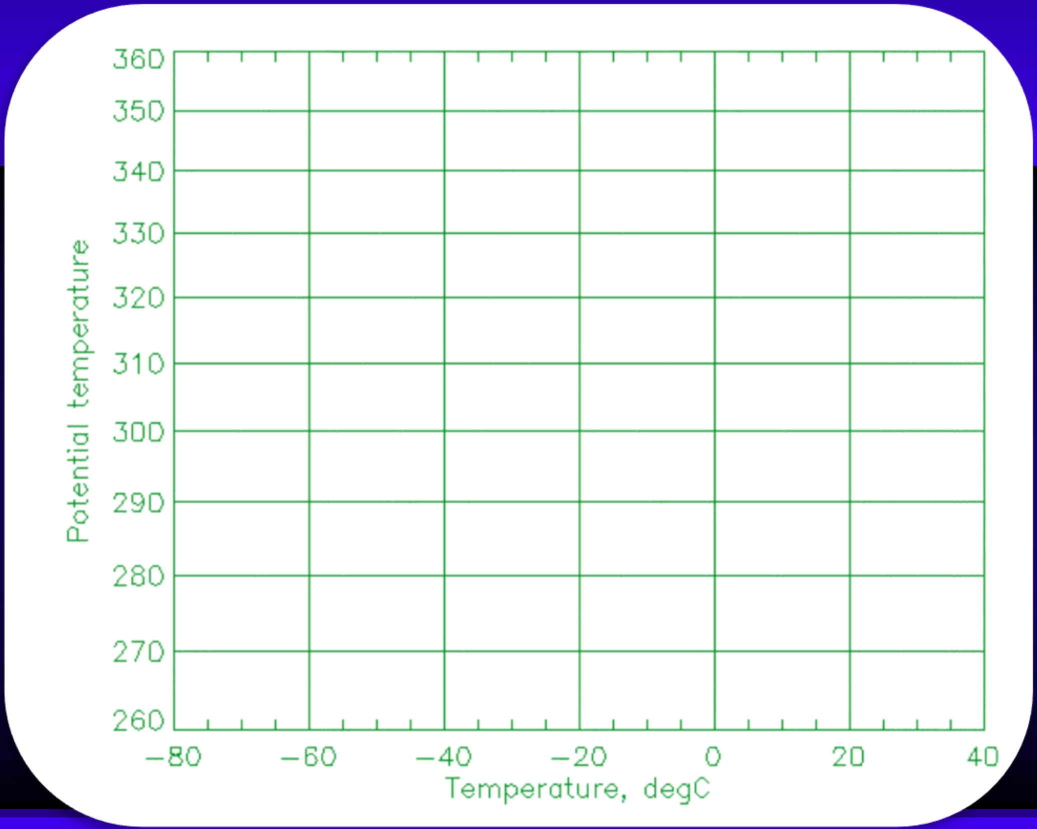
Is very confusing at first sight!

Basic idea

Plot temperature as x-axis and entropy as y

$$S = c_p \ln\theta$$

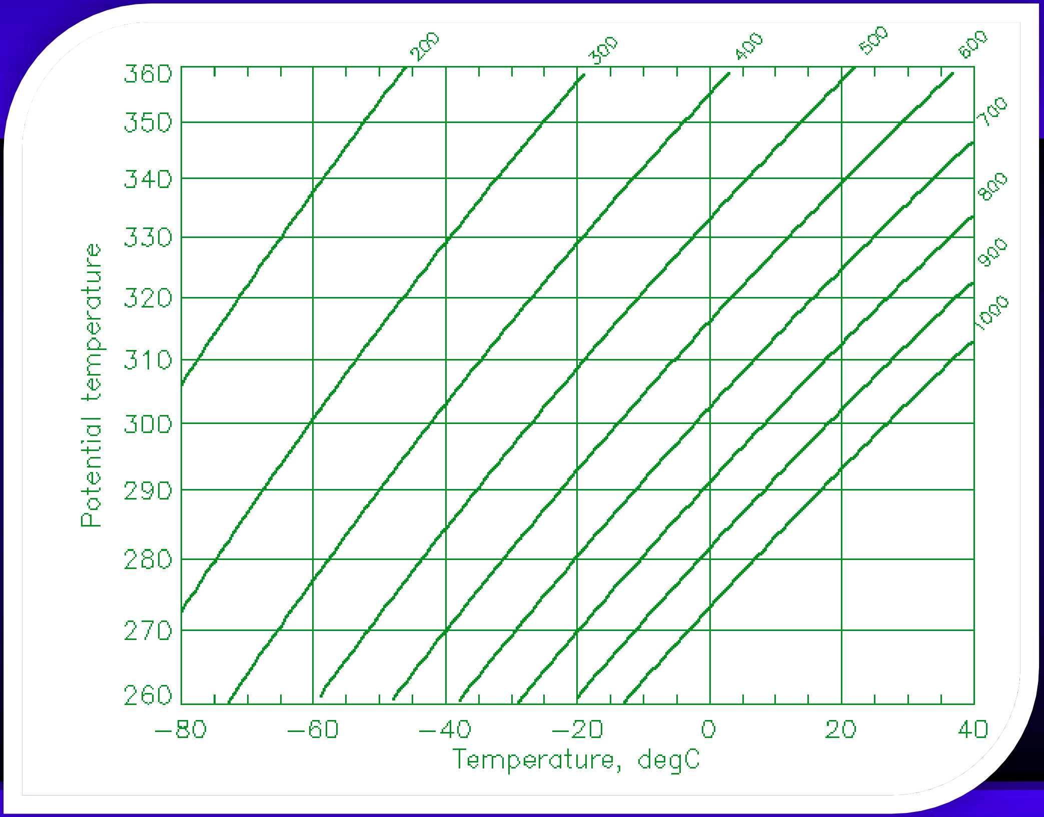
so we plot temperature versus lnθ



Adding pressure

Our measurements are of temperature and pressure, so we want to represent pressure on the plot

The curved lines are isopleths of constant pressure, in mb

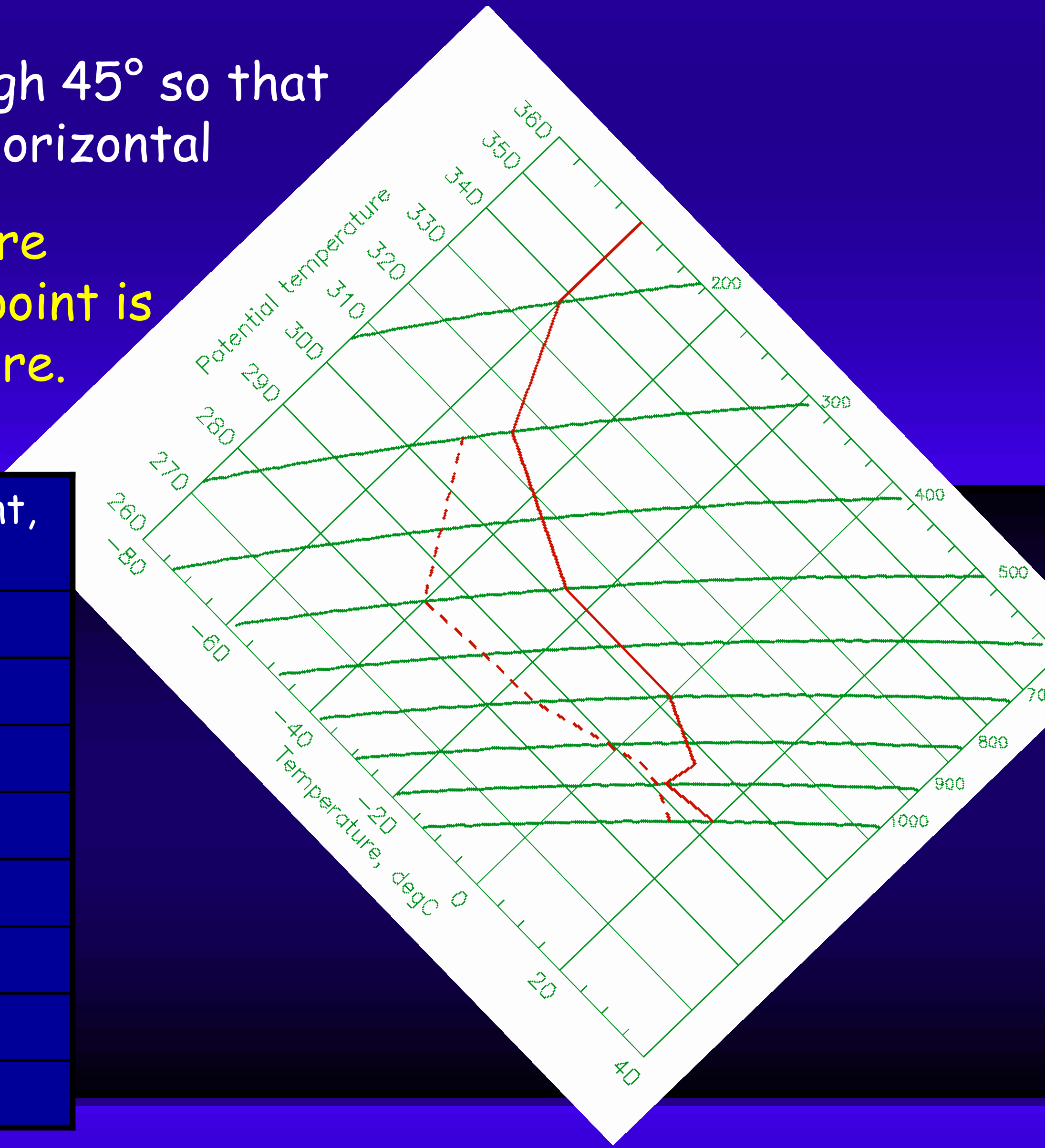


Rotating plot and plotting profile

The diagram is rotated through 45° so that the pressure lines are quasi-horizontal

Temperature and Dew point are plotted on the diagram. Dew point is simply plotted as a temperature. Here:

Pressure,, mb	Temp., °C	Dew point, °C
1000	20	15
900	10	9
850	11	5
700	0	-15
500	-25	-40
300	-50	-55
200	-60	
100	-60	



Adding Moisture information

Dew point is a measure of moisture content. The tephigram can be used to convert (T_D, T) to mixing ratio

Mass mixing ratio isopleths are light dashed lines. Units are $g\ kg^{-1}$

Curved lines are saturated adiabats – the path a saturated parcel of air follows on adiabatic ascent

3) The Psuedoadiabatic (or Stüve) diagram

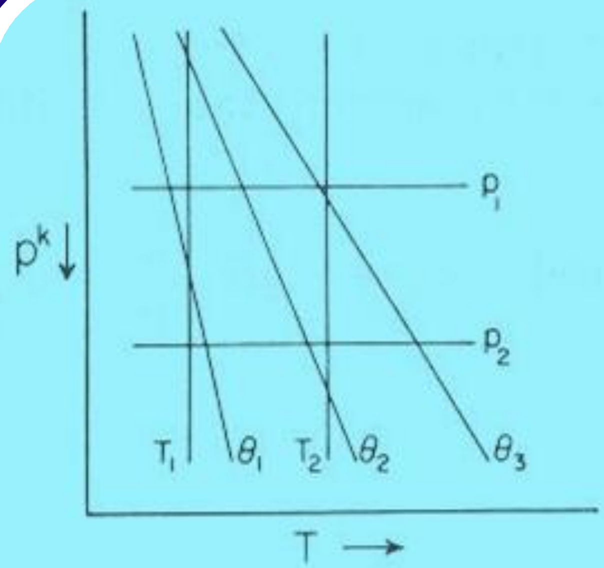
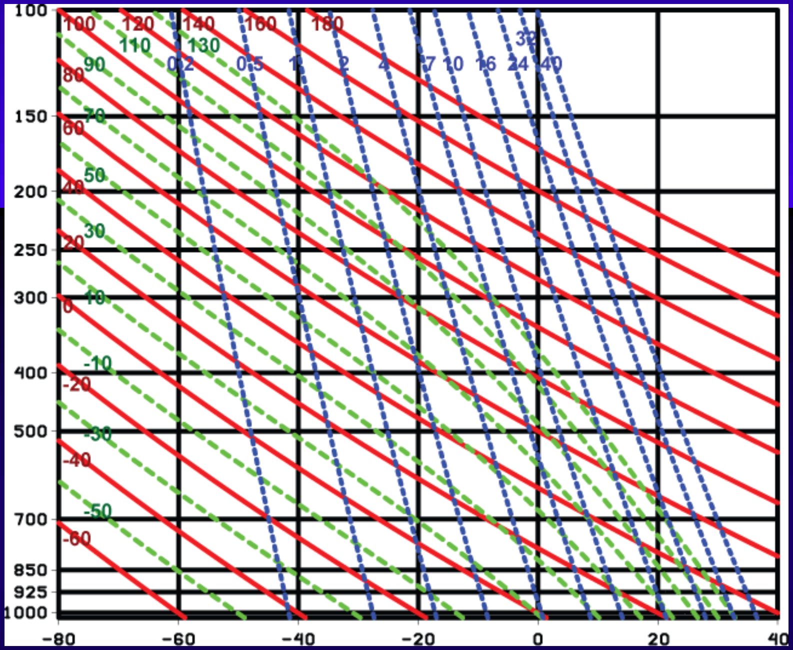


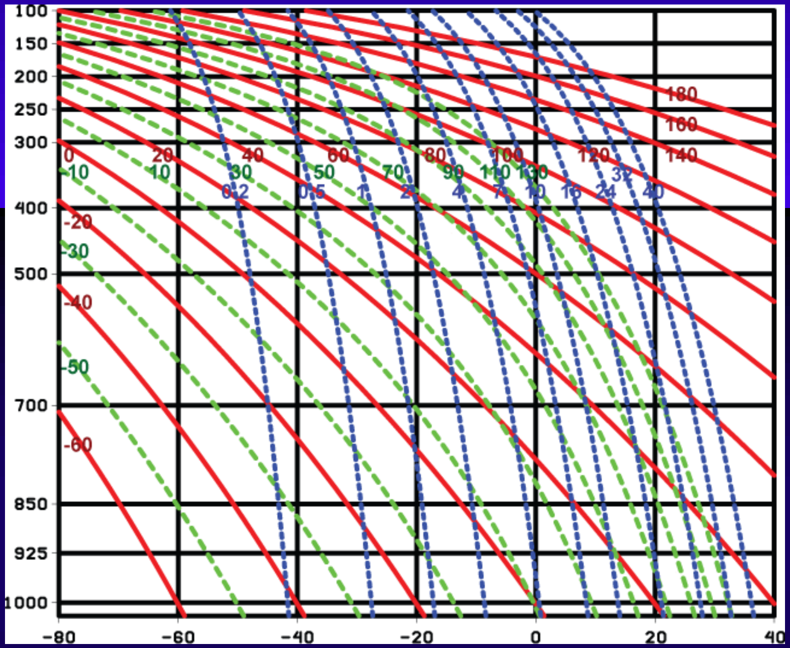
FIG. 1.4. Stüve diagram.

Pressure may be plotted on a linear vertical scale, or on a logrithmic vertical scale.

Temperature is plotted on the horizontal axis, opposite to the convention of plotting data which puts the independent parameter on the horizontal axis.



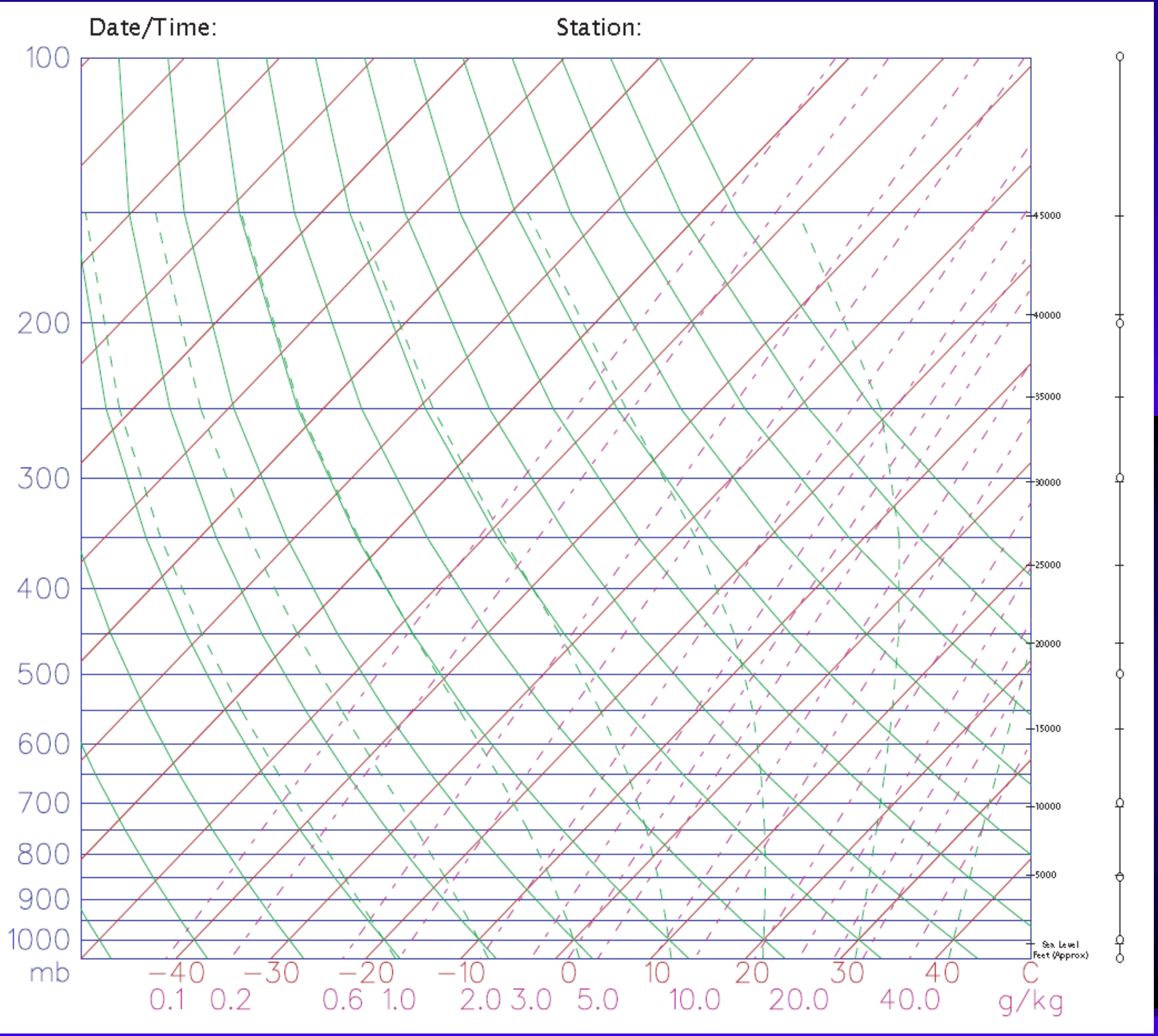
A Log-pressure diagram



A linear pressure diagram

A Stuve diagram

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



SKEW-T

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

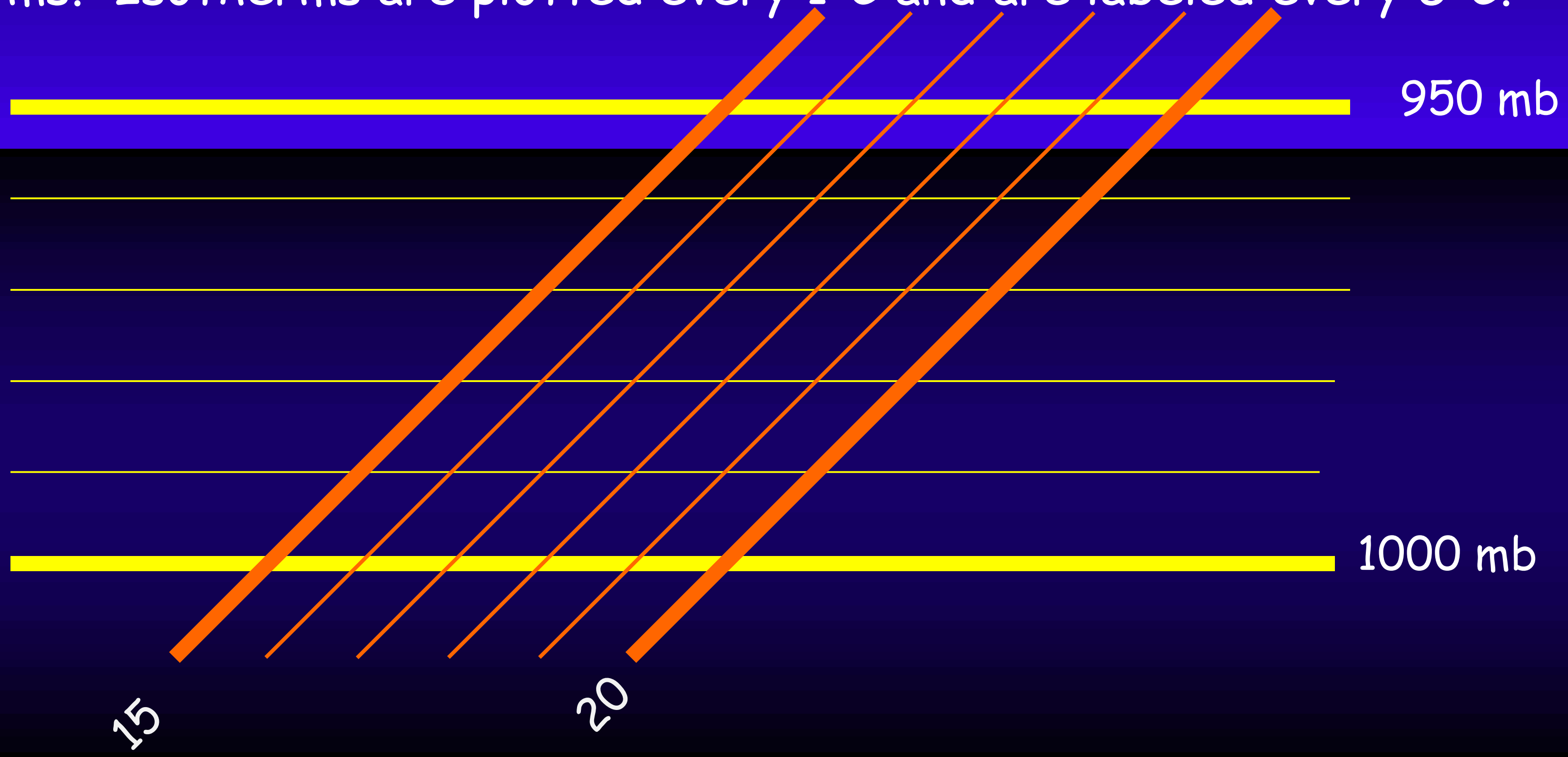
They are plotted every 10 mb and are labeled every 50 mb

Isobars

Isotherms

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

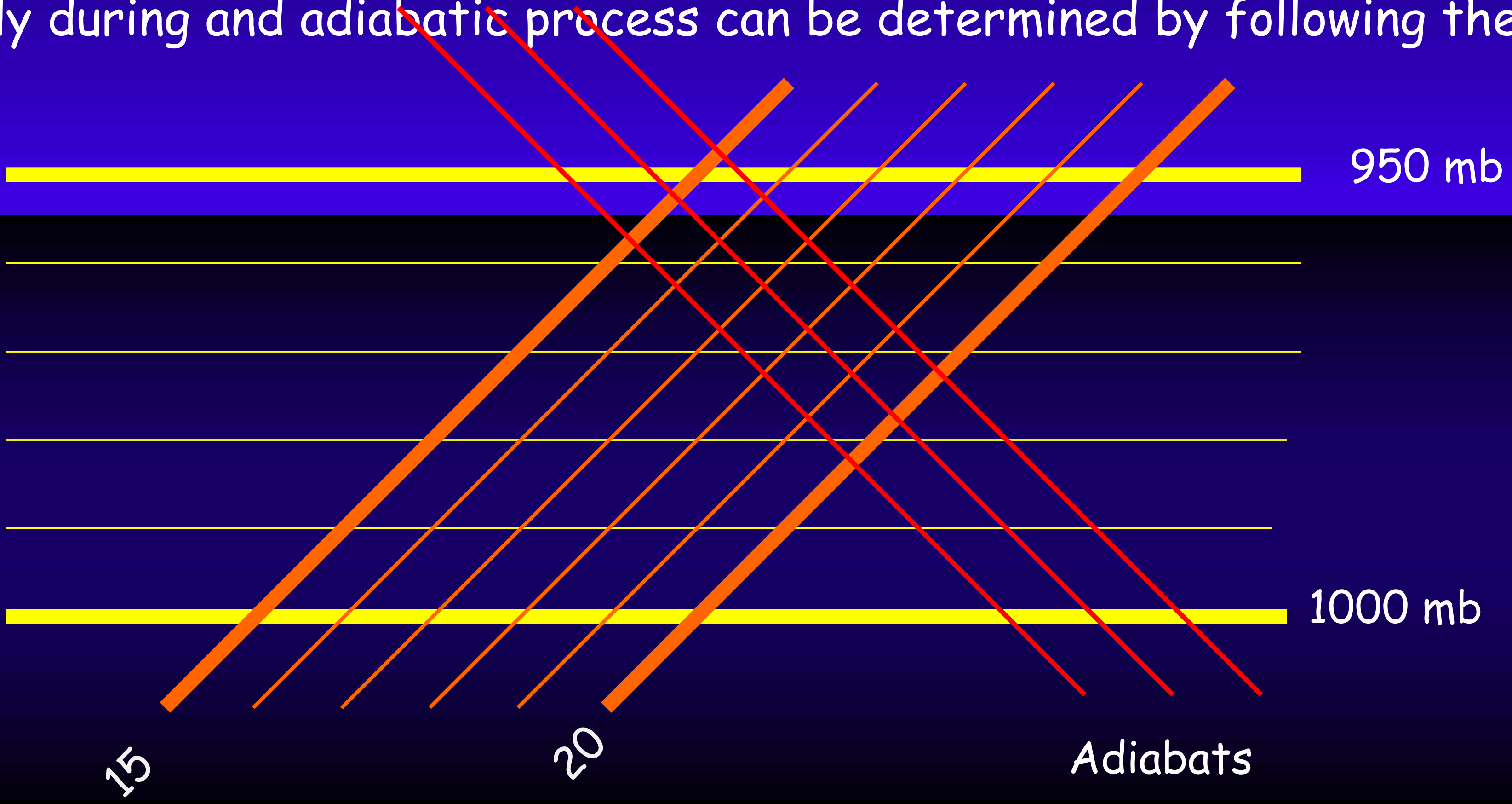
Both temperatures and dew point temperatures are plotted using the isotherms. Isotherms are plotted every 1°C and are labeled every 5°C.



Dry Adiabats

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

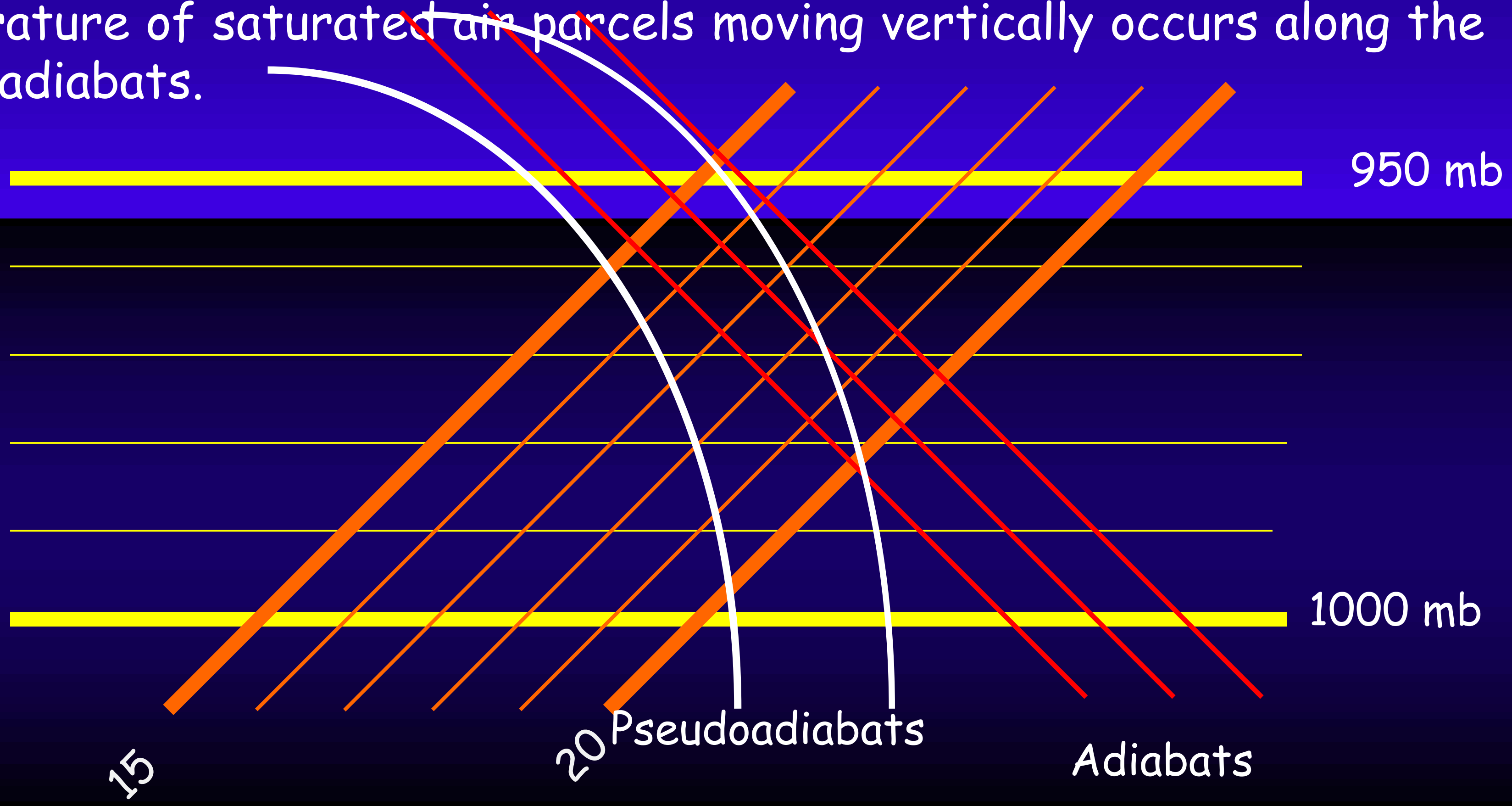
Unsaturated air parcels move vertical along the adiabats as they are lifted or sink. The temperature of an unsaturated air parcel moving vertically during and adiabatic process can be determined by following the adiabat



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.

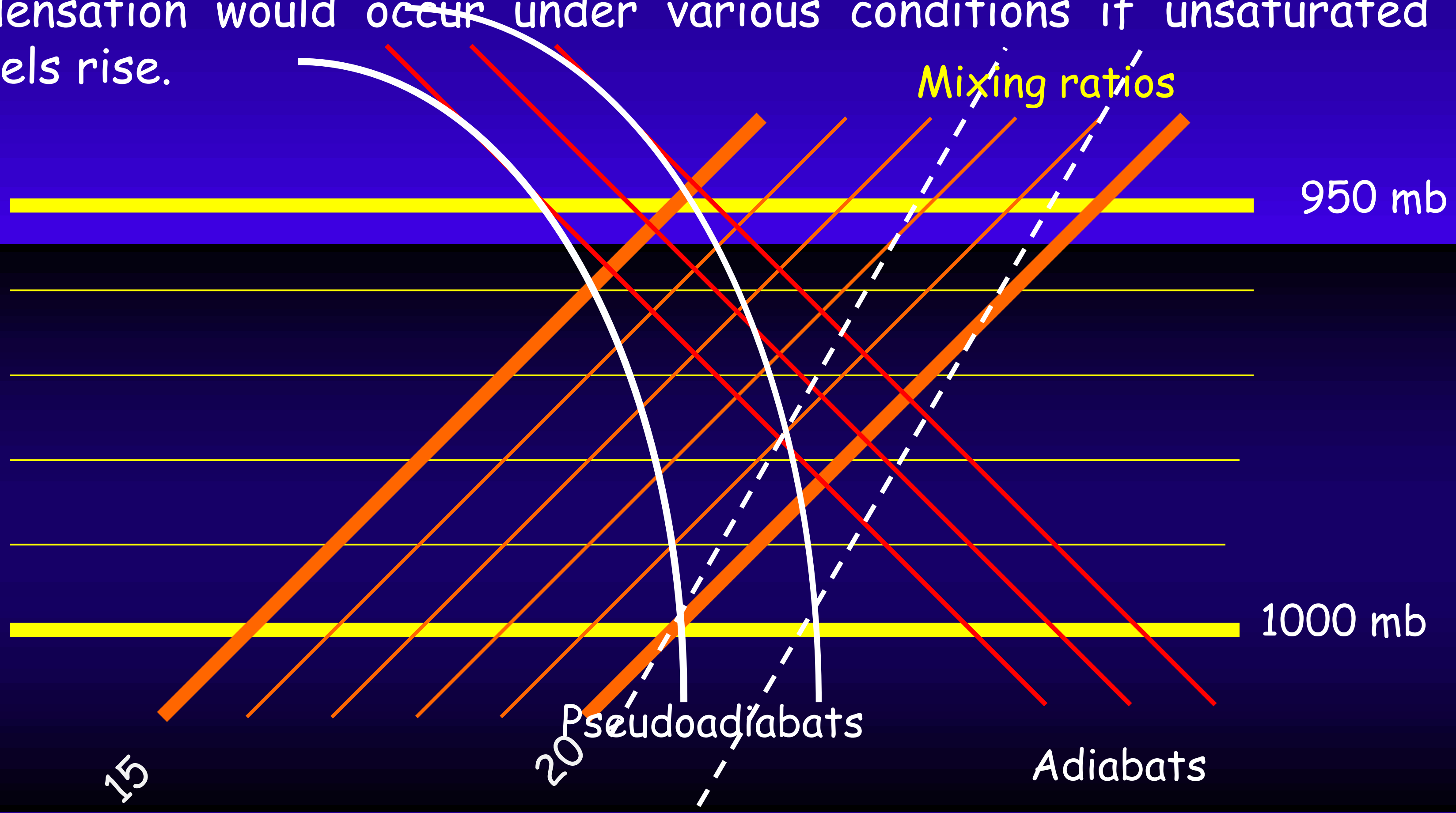
They represent the Saturated Adiabatic Lapse Rate. The change in temperature of saturated air parcels moving vertically occurs along the pseudoadiabats.



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.



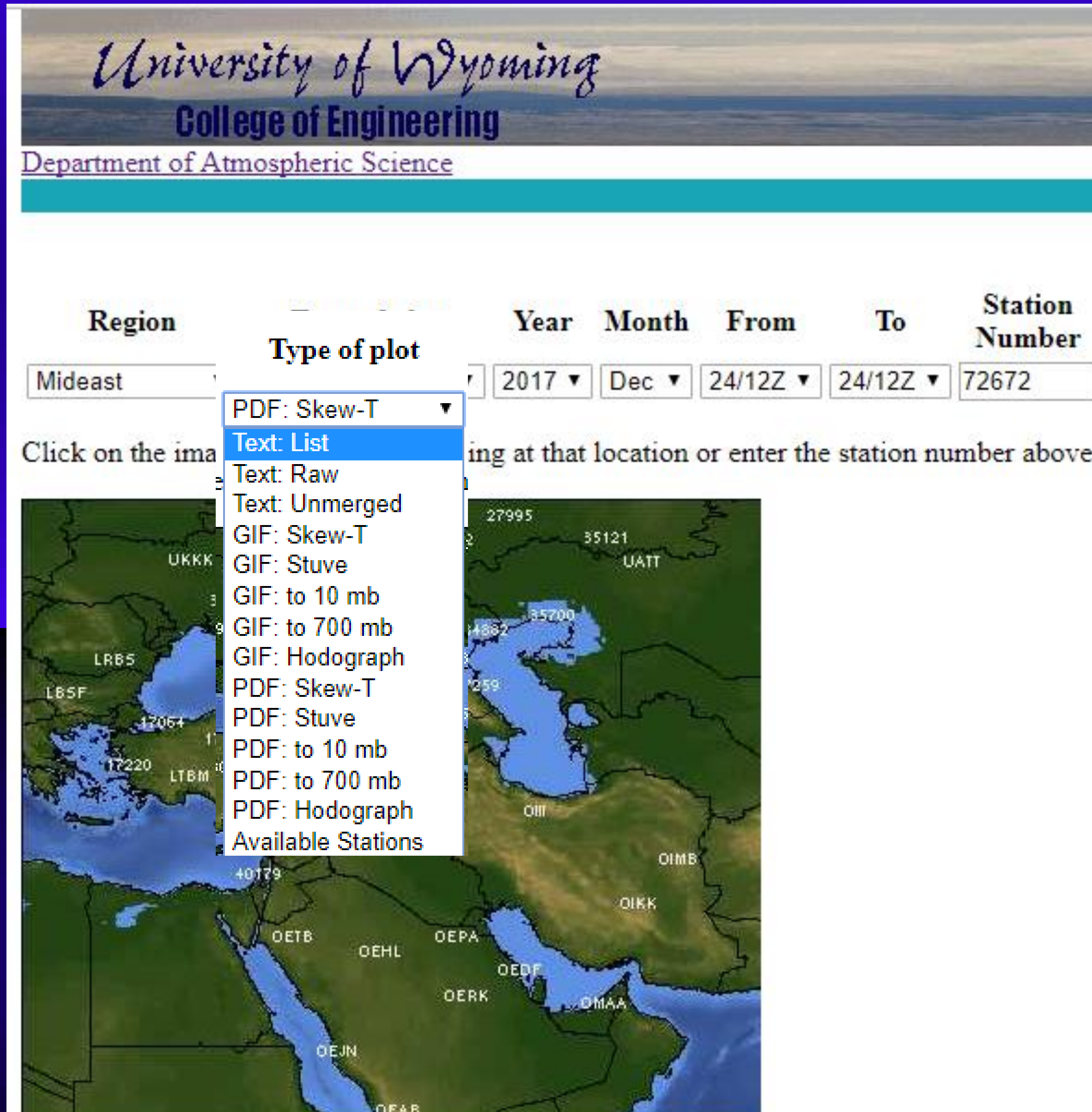
university of wyoming

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
North America	Text: List	2017	Dec	24/12Z	24/12Z	72672

Click on the image to request a sounding at that location or enter the station number above.



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Region
Type of plot
Year
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72672
Text: List
Text: Raw
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GIF: to 10 mb
GIF: to 700 mb
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Available Stations
Click on the ima
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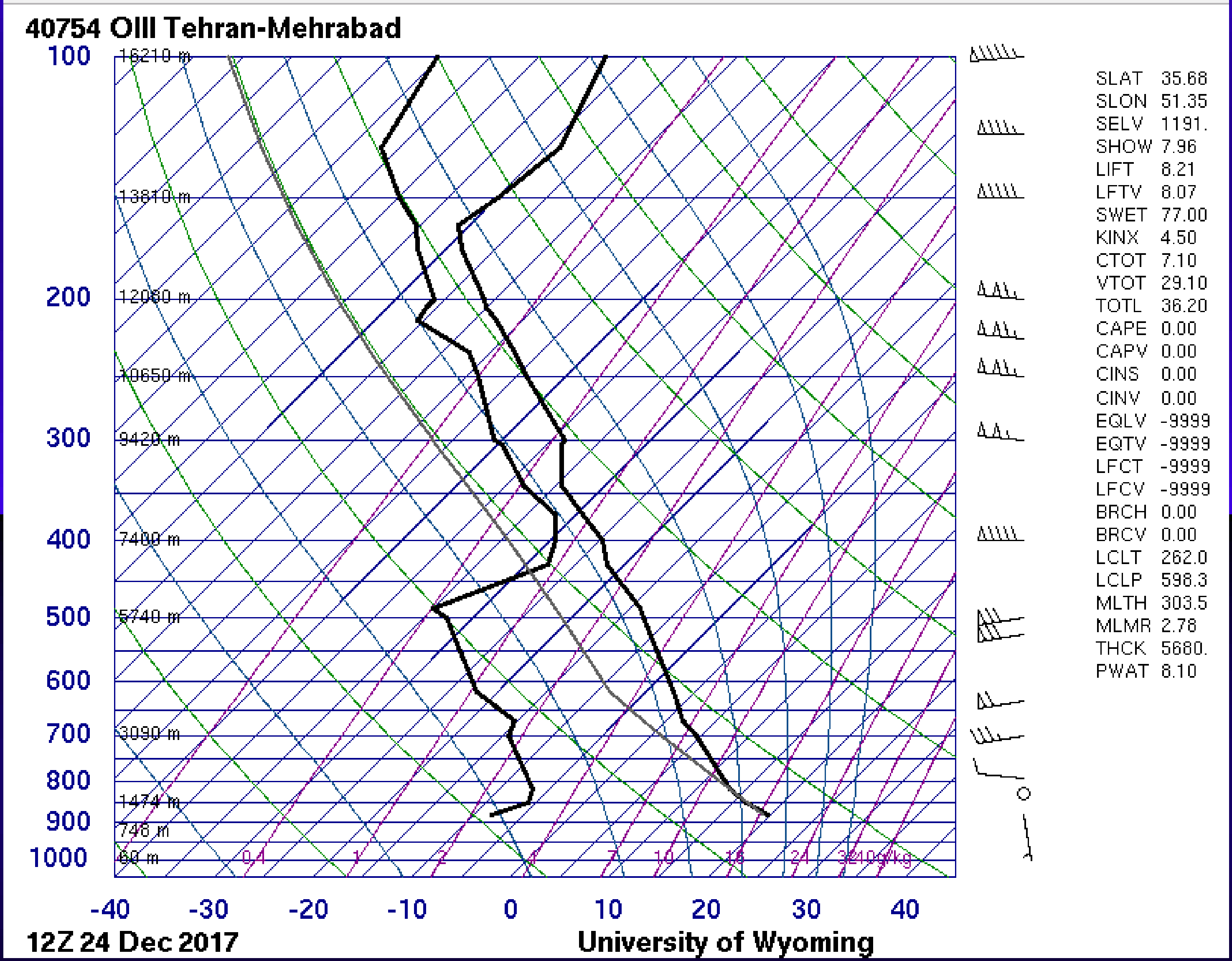
UKKK
LRBS
LBSF
17064
17220
LTBM
27995
35121
UATT
35700
OIMB
OIKK
40179
OETB
OEHL
OEPA
OEDF
OERK
OMAA
OEJN
OEAB

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



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100
200
300
400
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600
700
800
900
1000
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13810 m
12080 m
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7400 m
5740 m
3090 m
1474 m
746 m
60 m
0.4
1
2
4
7
10
16
24
32
40g/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

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

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

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

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).

LIFT   Lifted index

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

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

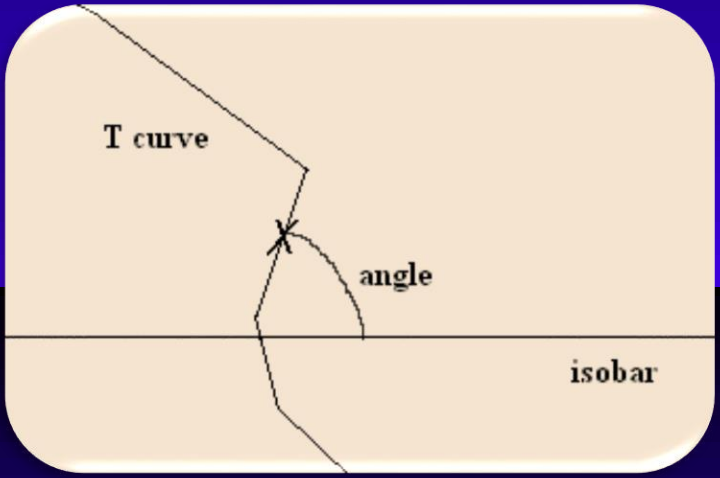
T_{parcel} = 500 mb temperature in Celsius of a lifted parcel with the average pressure, temperature, and dewpoint of the layer 500 m above the surface

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.



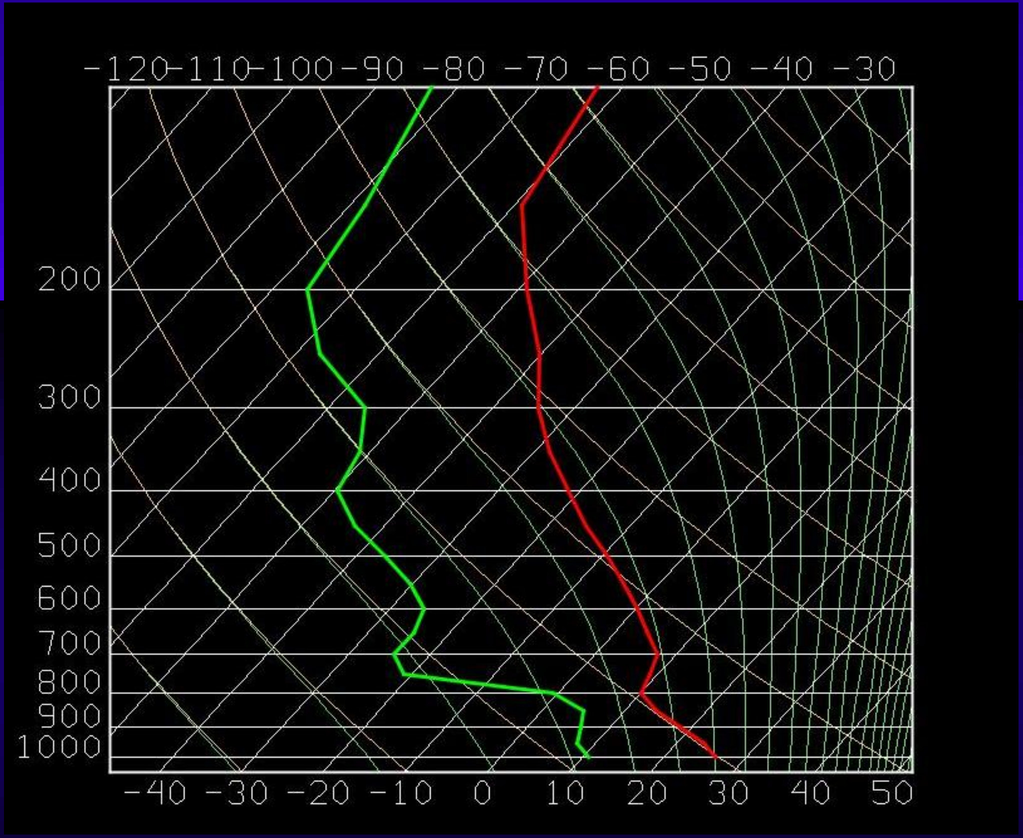
For stability, the smaller the angle, the greater stability there will be. The larger this angle, the more instability there will be.

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

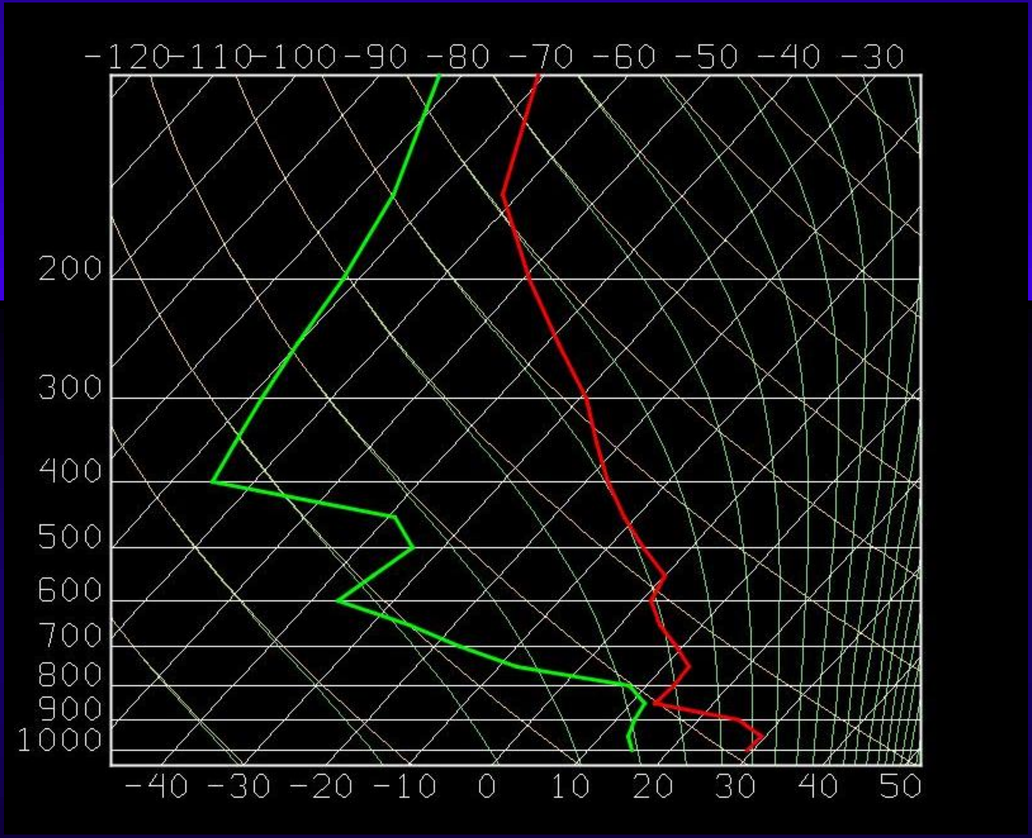
If the slope of the T curve is less than the slope of the saturation adiabat and the slope of the dry adiabat then the layer is considered absolutely stable.



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

Absolutely Unstable

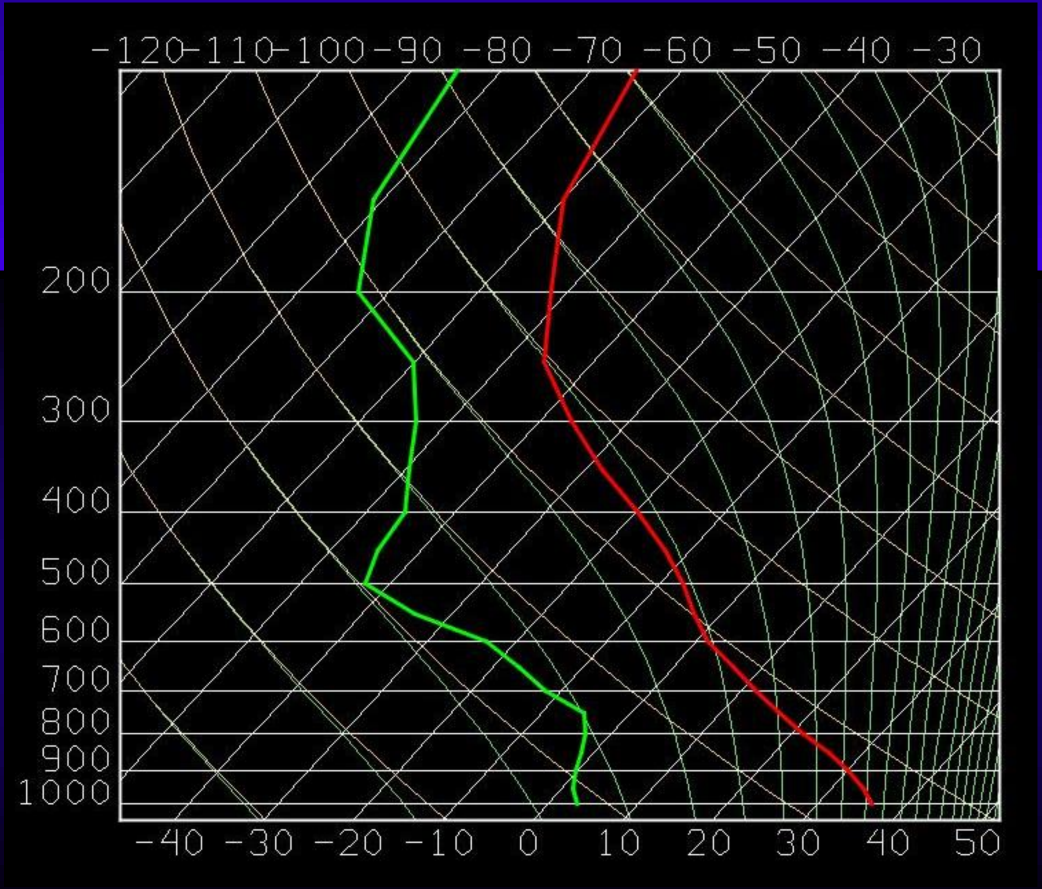
If the slope of the T curve is greater than the slope of the dry adiabat and the saturation adiabat, the layer is considered absolutely unstable.



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

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.

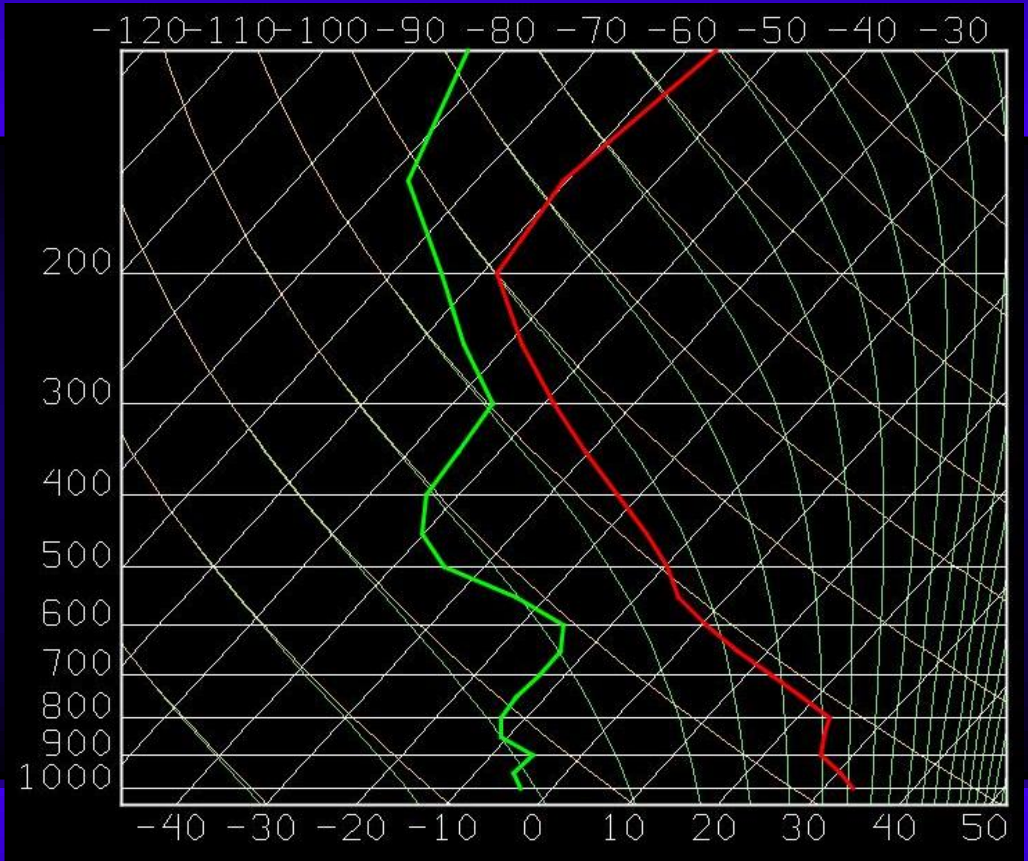


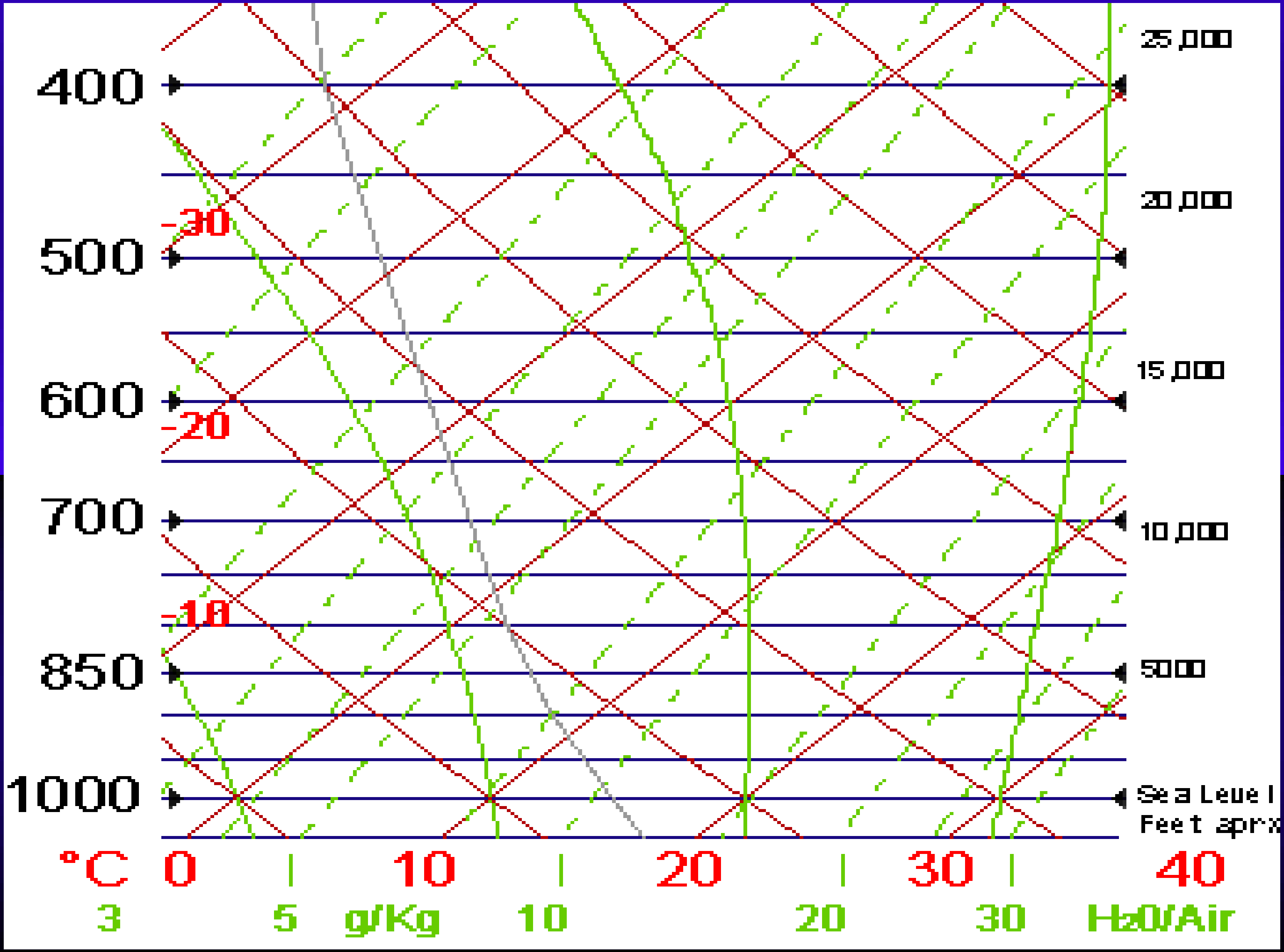
The area between 600 and 700mb is an example of a conditionally unstable layer

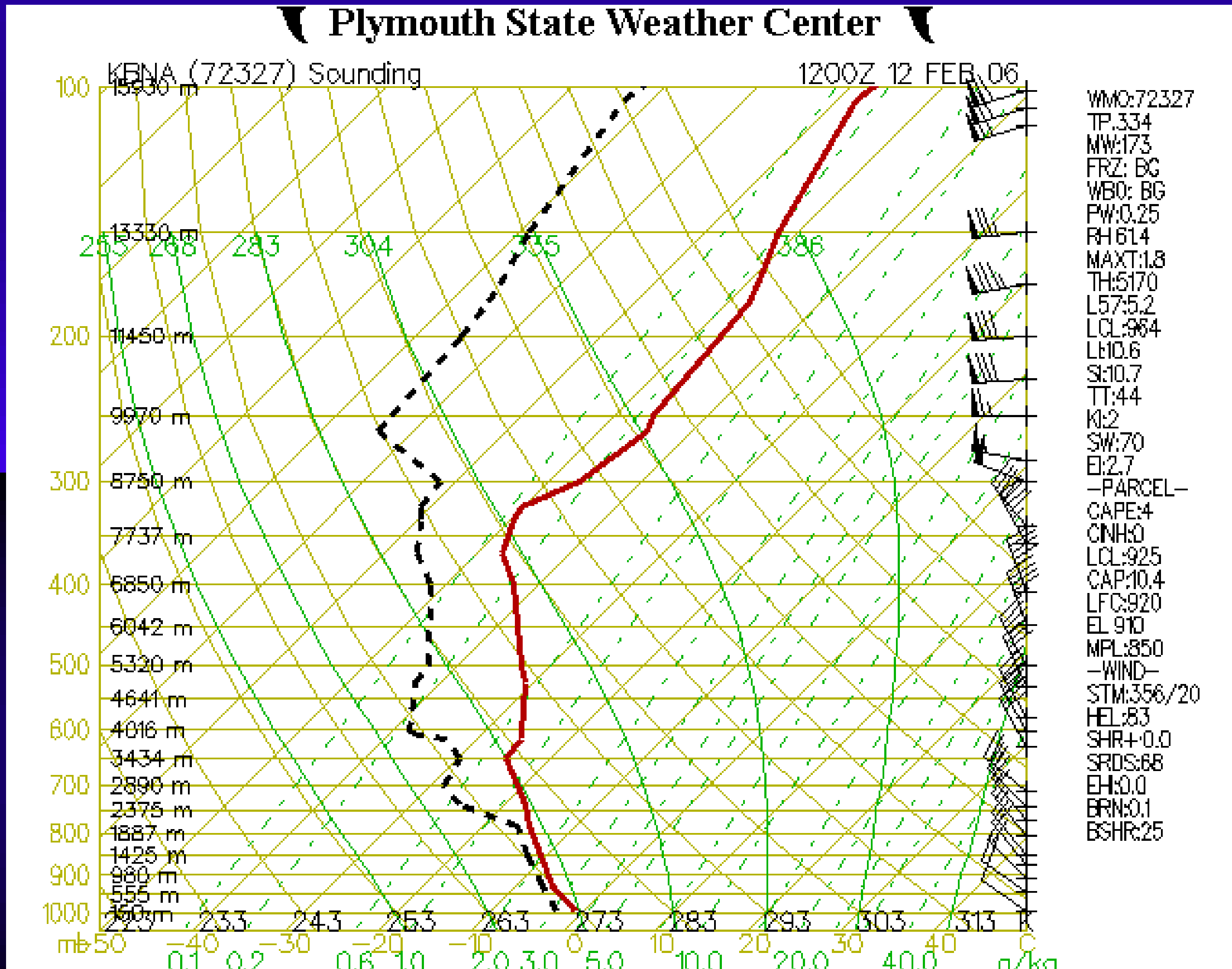
Neutrally Stable

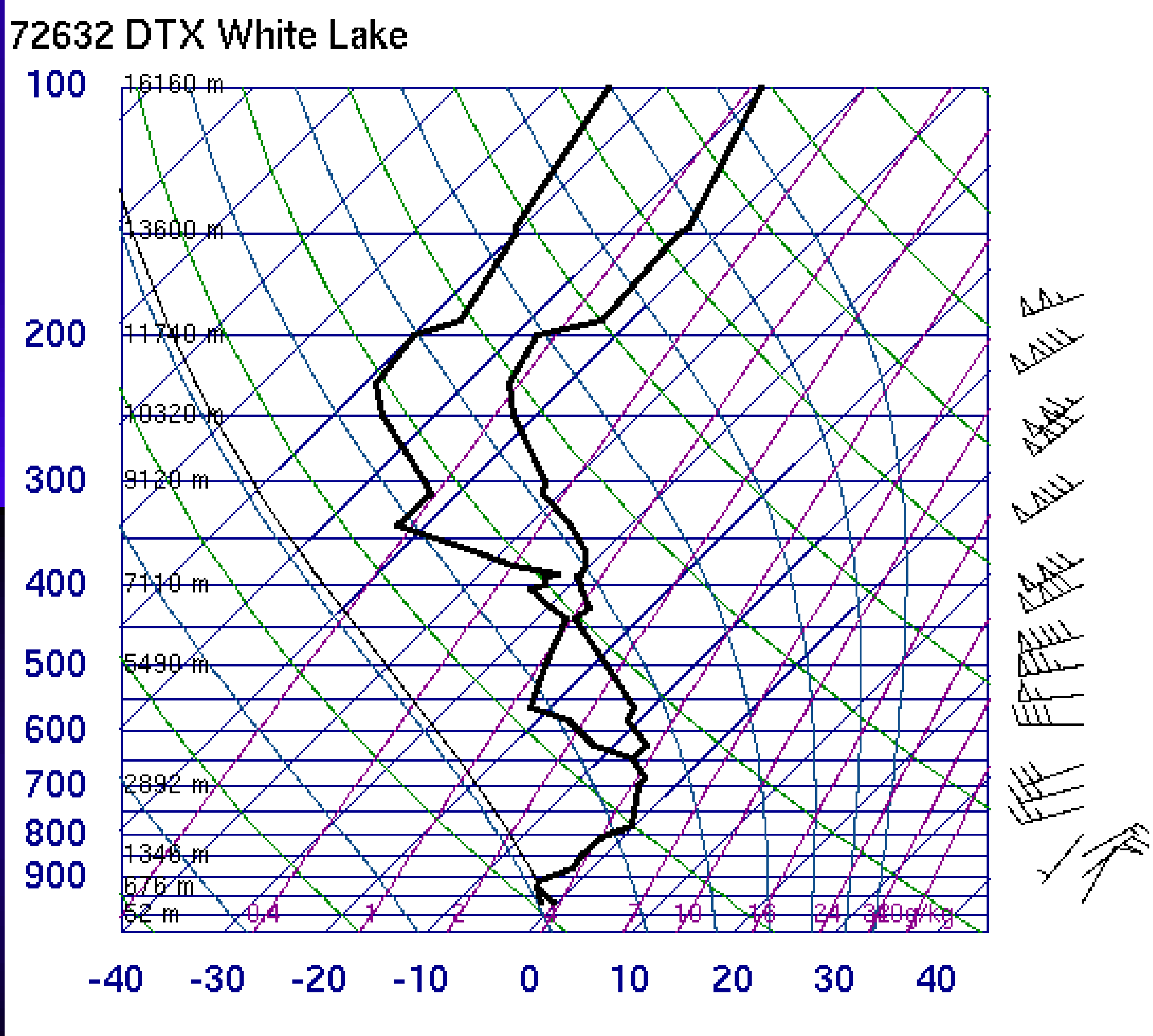
If the T curve is parallel to either a saturation or a dry adiabat, the layer is in neutral equilibrium with the surrounding atmosphere. If the curve is parallel to a saturation adiabat, then the upward movement of saturated parcels will not be aided or hindered by the environment. Likewise, if the T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

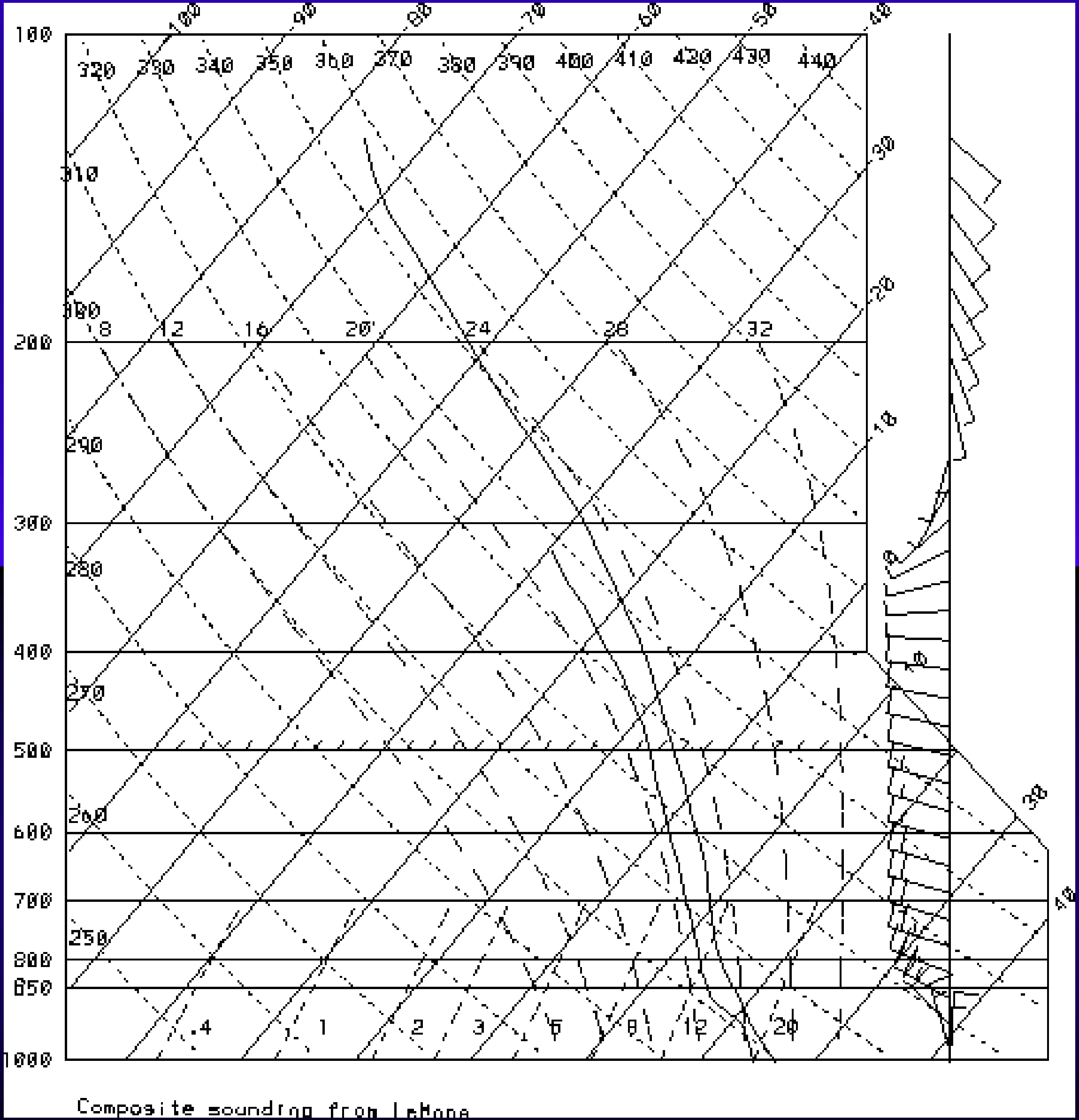
The area between 600 and 800mb is an example of a neutral layer with respect to the dry adiabatic lapse rate

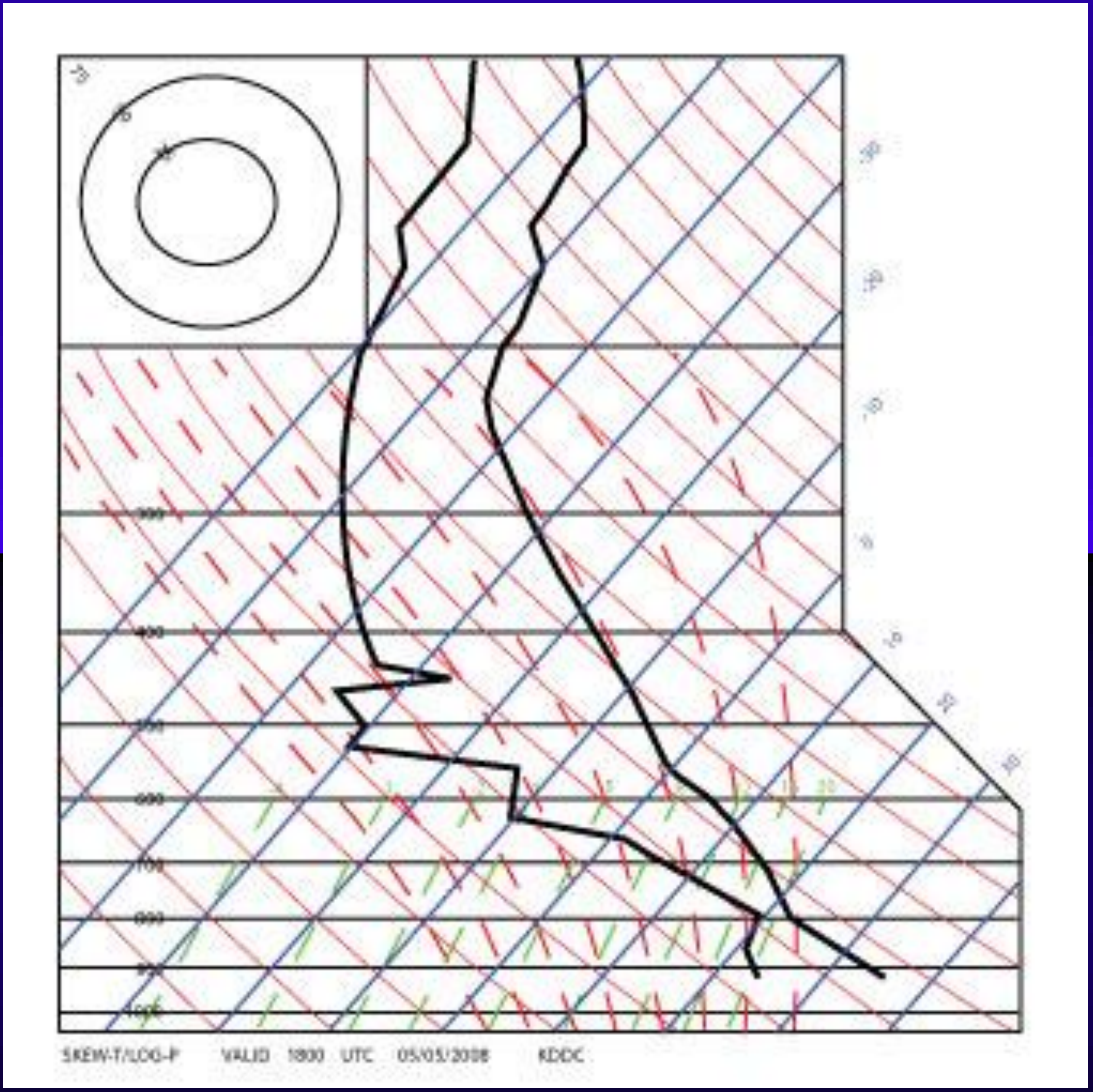



400
500
600
700
850
1000
-30
-20
-10
25,000
20,000
15,000
10,000
5000
Sea Level
Feet aprx
°C
0
10
20
30
40
3
5
g/Kg
10
20
30
H2O/Air

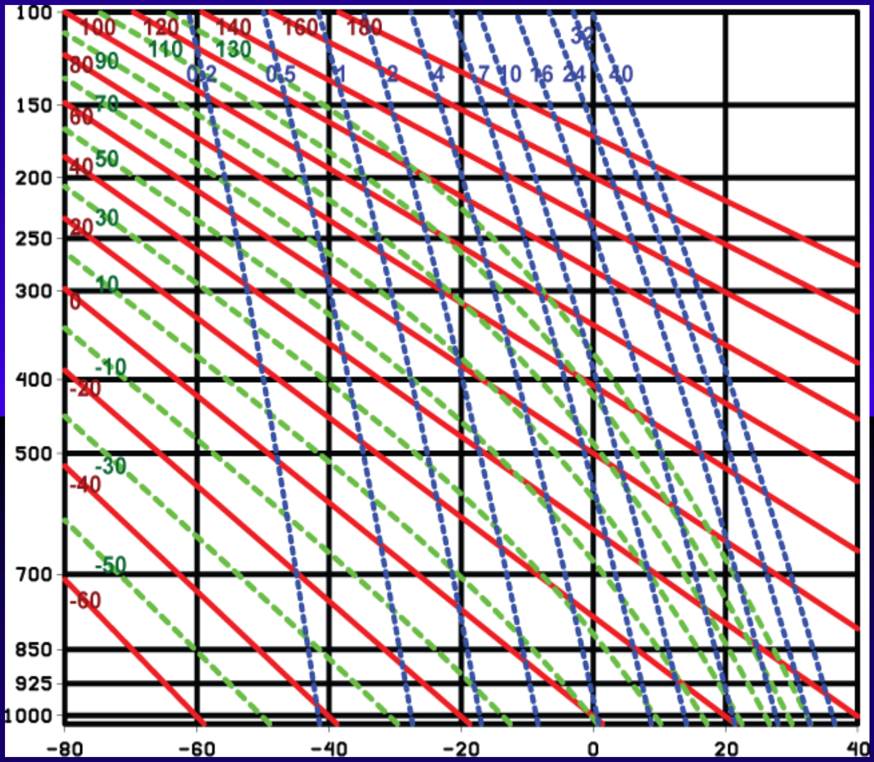

Plymouth State Weather Center
KBNA (72327) Sounding
1200Z 12 FEB 06
WMO:72327
TP:334
MW:173
FRZ: BG
WB0: BG
PW:0.25
RH:61.4
MAXT:1.8
TH:5170
L57:5.2
LCL:964
LI:10.6
SI:10.7
TT:44
KI:2
SW:70
EI:2.7
–PARCEL–
CAPE:4
CINH:0
LCL:925
CAP:10.4
LFC:920
EL:910
MPL:850
–WIND–
STM:356/20
HEL:83
SHR+0.0
SRDS:68
EH:0.0
BRN:0.1
BSHR:25
mb
g/kg


72632 DTX White Lake
100
200
300
400
500
600
700
800
900
16160 m
13600 m
11740 m
10320 m
9120 m
7110 m
5490 m
2892 m
1346 m
676 m
52 m
0.4
1
2
4
7
10
16
24
32
40g/kg
-40
-30
-20
-10
0
10
20
30
40

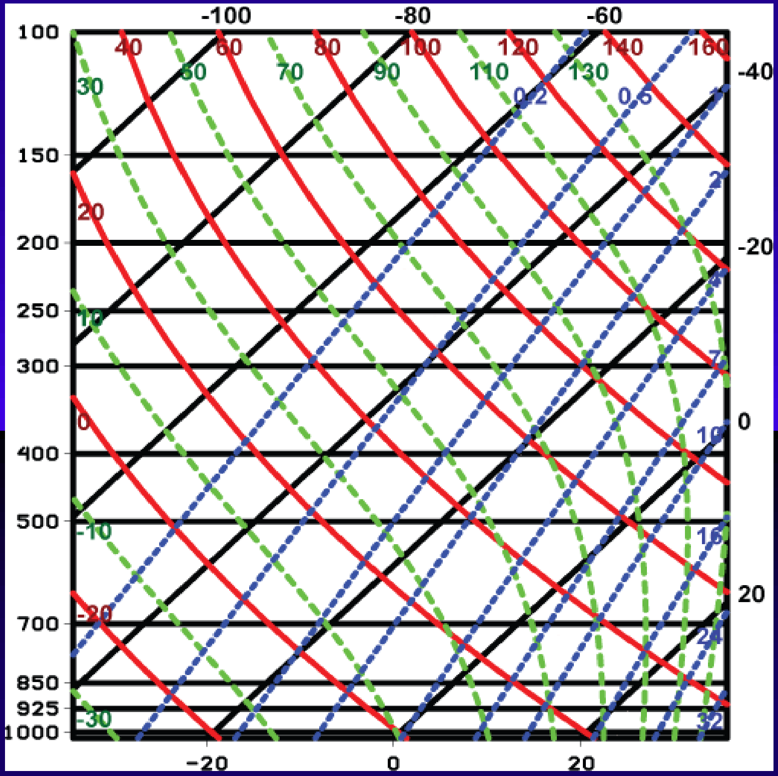

100
200
300
400
500
600
700
800
850
1000
Composite sounding from LeMone

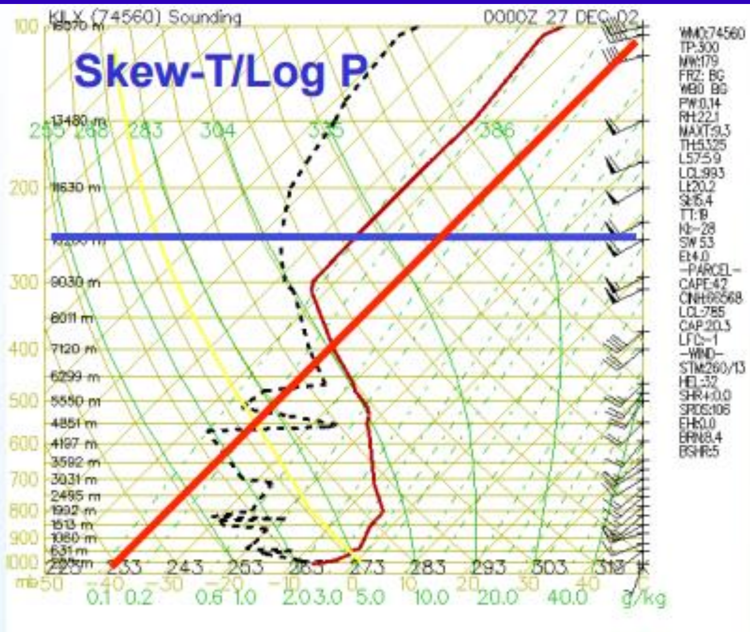

SKEW-T/LOG-P VALID 1800 UTC 05/05/2008 KDDC

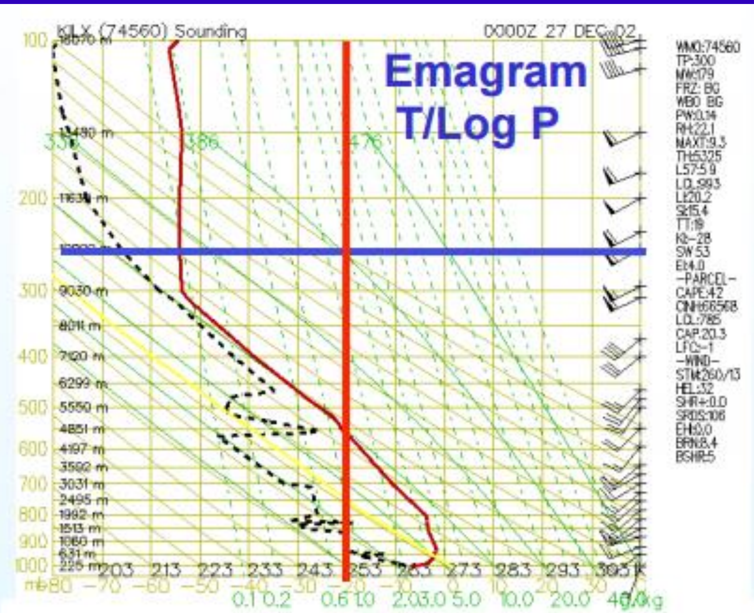
A Stuve diagram

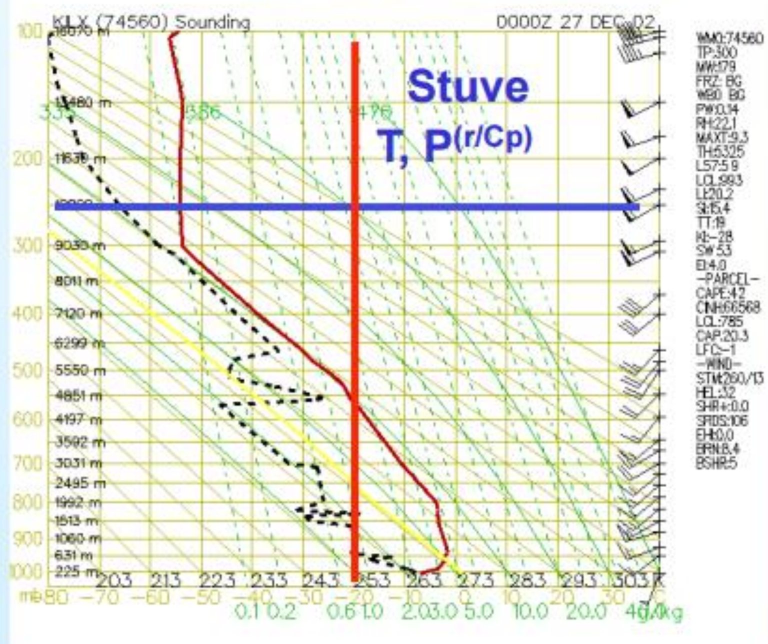


A Skew-T log-P diagram



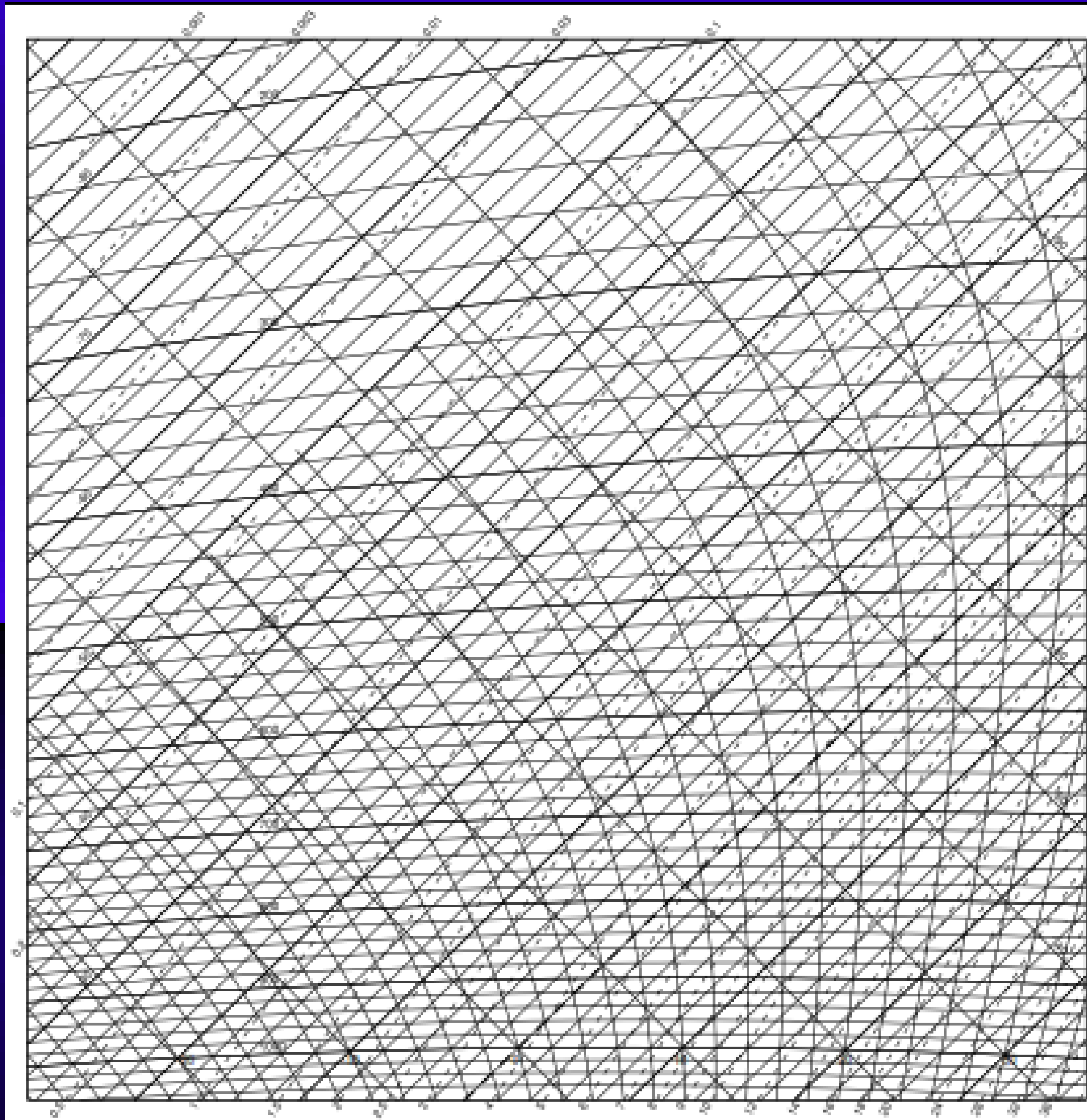






Three common diagrams used in the United States are:

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



TEPHIGRAM
pressures in millibars
temperatures in degrees Celsius
saturated mixing ratios in grams per kilogram

Application of Tephigram to Determine T_d

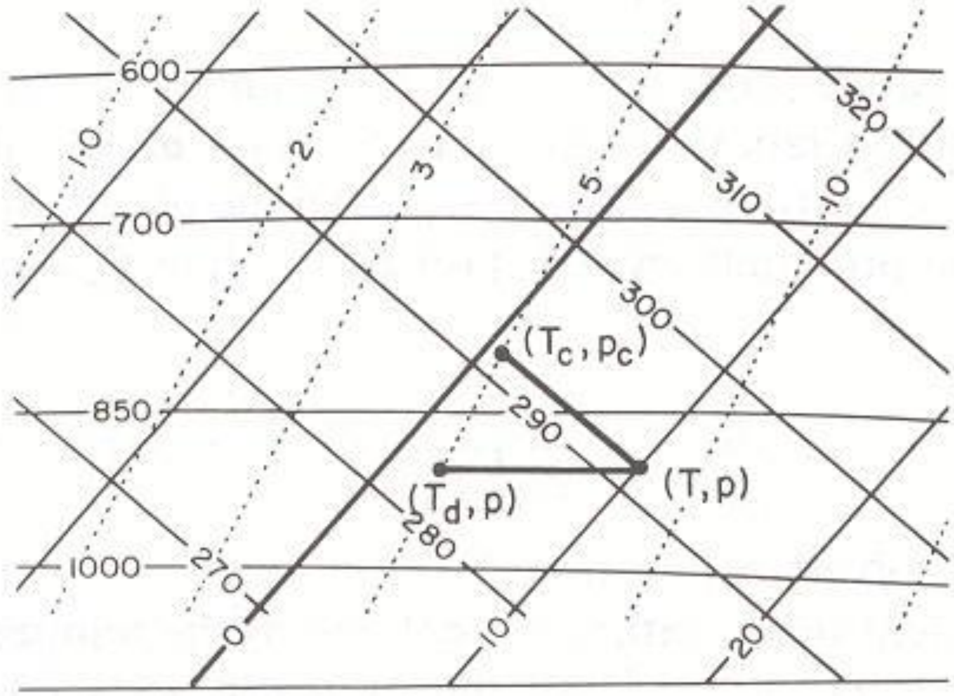


FIG. 2.2. Temperature, dew point, and isentropic condensation temperature, indicated on a tephigram. In the example shown the sample of air at 10°C, 900 mb, is assumed to have a mixing ratio of 5 g/kg. Its dew point, found from the intersection of the 900 mb isobar and the 5 g/kg vapor line, is 2.2°C. Its isentropic condensation point, found from the intersection of the adiabat through (T, p) with the 5 g/kg vapor line, is at 0.7°C and approximately 800 mb.

Application of Tephigram to Determine different tempertures

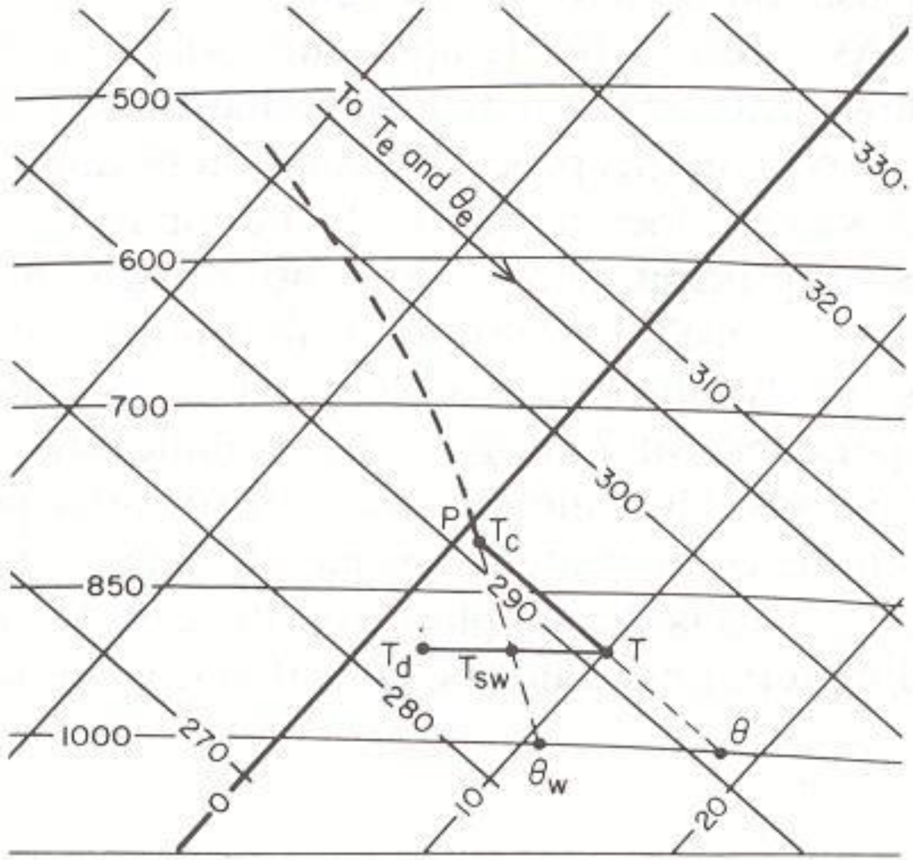
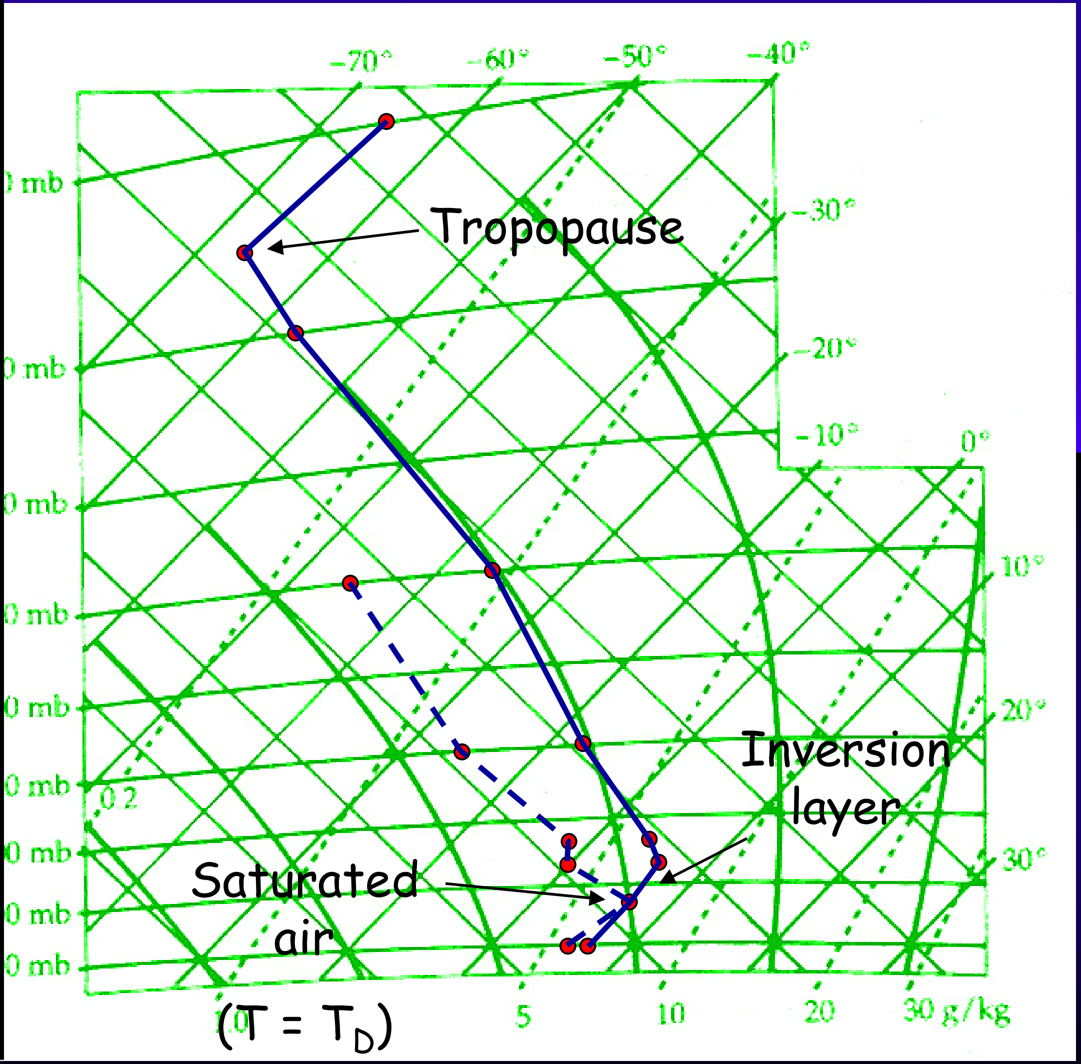


FIG. 2.3. Continued expansion of the air sample of Fig. 2.2 beyond point *P*, the isentropic condensation point. The dashed line is the pseudoadiabat through *P*. This diagram indicates the graphical determination of some of the important theoretical temperatures that characterize an air sample.

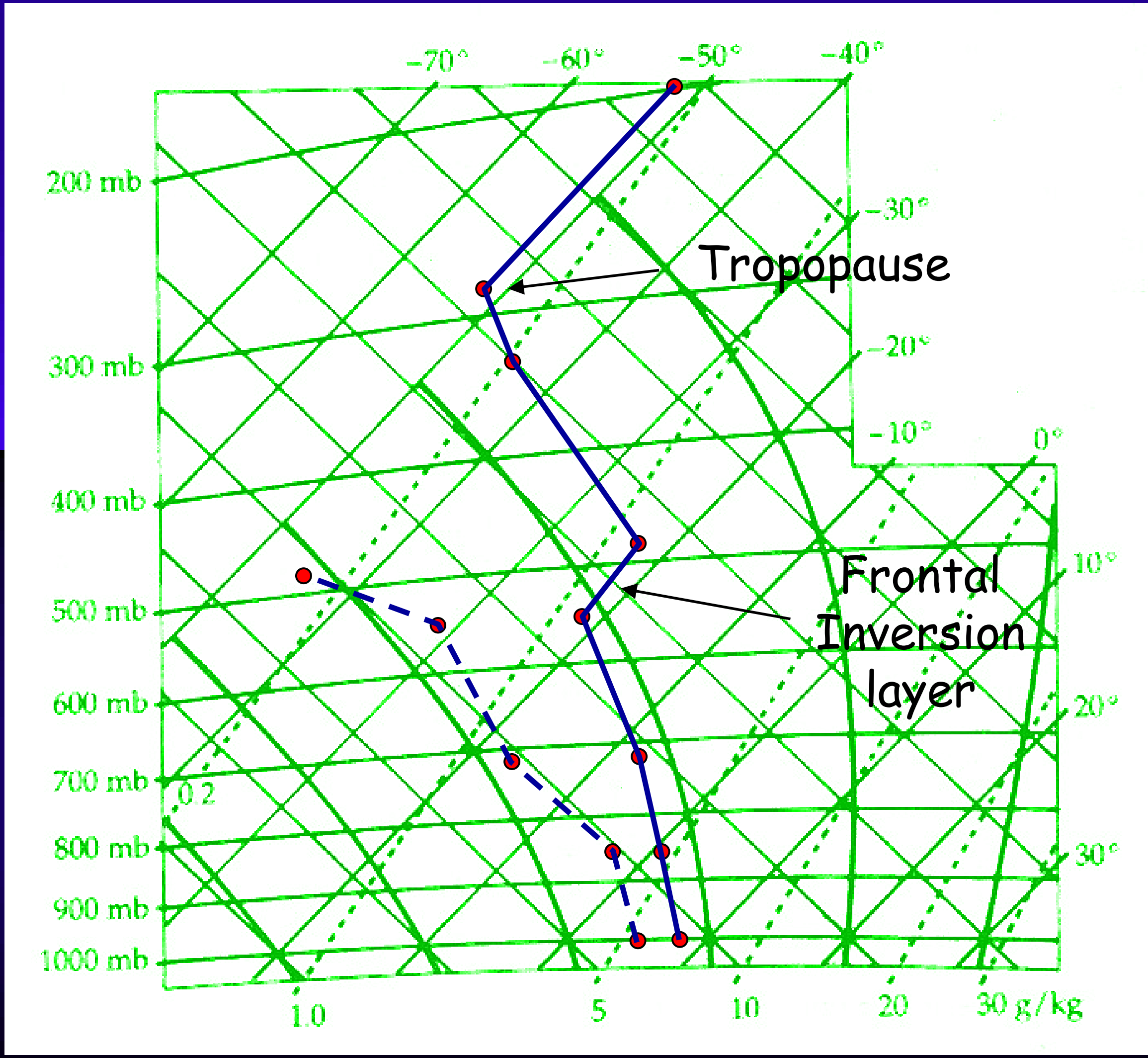
Example 1

Pressure, mb	Temp. °C	Dew point, °C
1000	7	6
920	7	7
870	6	0
840	3.5	-1.5
700	-8	-16
500	-27	-36
300	-58	
250	-67	
200	-65	



Example 2

Pressure, mb	Temp. °C	Dew point, °C
1000	8.5	5.5
860	0.5	-3
710	-8	-17
550	-21.5	-31.5
490	-22.5	-45
330	-45	
285	-51	
200	-51	



Global water cycle
precipitation = evaporation