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A REVIEW OF THE USE OF THE THERMODYNAMIC DIAGRAM AND ITS FUNCTIONS (With the Application Towards AFOS)

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1. INTRODUCTION

A main ingredient for understanding any weather situation is the upper-air sounding. Yet, interest and understanding of this valuable tool has declined over the past years. Maddox (1979) stated the importance of developing a four-dimensional (current structure plus temporal evolution) mental picture of the meteorological situation. One of those dimensions is the vertical. Doswell (1982) stated: **"Nothing can or should replace an examination of the individual soundings. Such an examination can also help to evaluate and correct any erroneous data that may have crept into the constant level analyses".** Many meteorologists give the sounding only a cursory glance, looking for layers of dry or moist air and temperature inversions. Most of us are aware that much additional information can be derived from upper-air soundings, but may have forgotten how to obtain it.

This review combines information from several sources and is intended as a ready reference to the operational meteorologist. Much of the material was obtained from Air Weather Service manuals although other references also provided important contributions. Much information was lifted verbatim. A list of sources is included should more detailed information be required.

This paper will be divided into four sections: 1) Description of the thermodynamic diagram, 2) Meteorological quantities which can be calculated from the thermodynamic diagram, 3) Determination of stability, and 4) Raob analysis and the AFOS ANALYZ program.

Since much of the National Weather Service currently uses the Pseudo-adiabatic chart, all procedures and figures will utilize this diagram. Also, since upper-air sounding data is now routinely plotted by AFOS, all figures will be on the AFOS sounding background.

2. DESCRIPTION OF THE THERMODYNAMIC DIAGRAM

The Pseudo-adiabatic chart used in the National Weather Service is a version of the Stuve diagram. Pressure is the ordinate of the diagram with the pressure ($P^{0.286}$) increasing downward. The abscissa is a linear scale of temperature increasing to the right. The pseudo-adiabats are curved but the saturation mixing ratio lines and dry adiabats are essentially straight. The adiabat-isotherm angle is near 45°. The Stuve (or Pseudo-adiabatic) diagram is <u>not</u> an equal-area transformation of the α, -P diagram. That is, area is not strictly proportional to energy. According to Hess (1959), "this diagram is clearly not as good as the Tephigram or Skew T-log P diagram".

The Skew T-log P diagram is an emagram (energy-per-unit-mass diagram) with the isotherms rotated 45 degrees clockwise to produce greater separation of isotherms and adiabats. The isobars, isotherms and saturation mixing ratio lines are straight, parallel lines but the dry adiabats are gently curved. The psuedo-adiabats are distinctly curved. This is the thermodynamic diagram used by the U.S. Air Force.

The Tephigram was designed by Sir Napier Shaw with temperature and logarithm of potential temperature as coordinates. Isobars are gently curved lines and the chart is rotated so that pressure increases downward. The pseudo-adiabats are appreciably curved but the saturation mixing ratio lines are nearly straight. The angle between isotherms and adiabats is exactly 90°.

Other than the isobars and isotherms, the Pseudo-adiabatic chart contains three additional sets of lines--the dry adiabats, the saturation mixing ratio lines and the pseudo-adiabats.

<u>Dry adiabats</u> are straight lines on the Pseudo-adbiatic chart (Fig. 1) and are labeled (although no labels exist on the AFOS diagram) in degrees Kelvin (or absolute). The Kelvin temperature can be determined by adding 273° to the Celsius temperature. Consequently, the value of any dry adiabat can be determined by adding 273 to the isotherm (degrees Celsius) which the dry adiabat intersects at 1000 mb.

<u>Saturation mixing ratio lines</u> are curves (Fig. 3) labeled in grams of water vapor per kilogram of dry air (assuming saturated conditions).

<u>Pseudo-adiabats</u> are curved lines (fig. 2) and are labeled in equivalent potential temperature (degrees Kelvin) and wet-bulb potential temperature (degrees Celsius). See Section 3 for definitions and procedures for determining equivalent potential temperature and potential pseudo-wet-bulb temperature. NOTE: pseudo-adibats are not labeled on the AFOS diagrams.

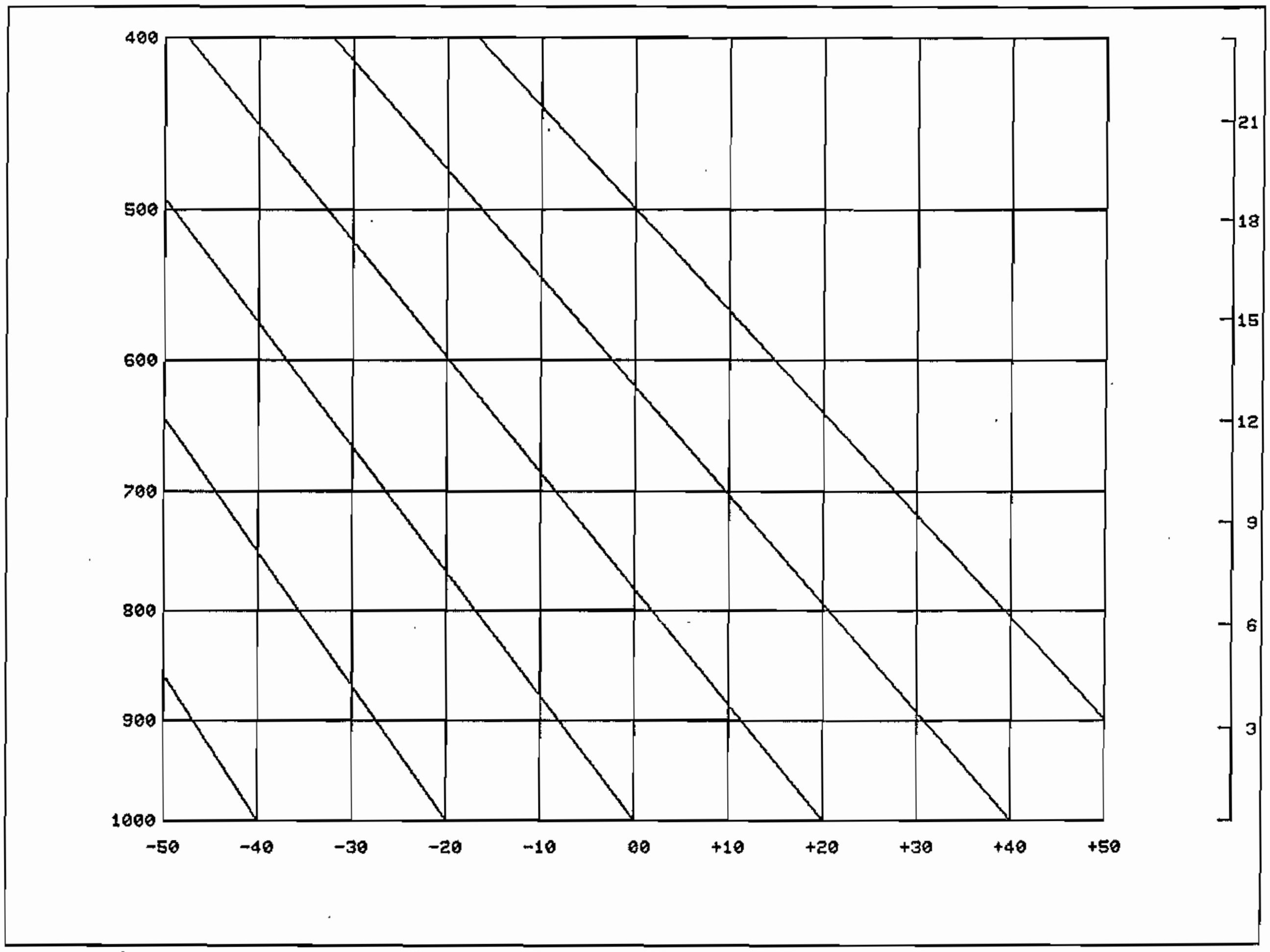

Figure 1. AFOS presentation of the Pseudo-adiabatic diagram. Ordinate is pressure (mb) and abscissa is temperature (^{o}C). Slanting lines are dry adiabats (20^{o} K intervals).

For a parcel of air at a given pressure, temperature and dew point, certain properties of that parcel can be readily obtained from the thermodynamic diagram:

mixing ratio- The ratio of the mass of water vapor to the mass of dry air expressed in terms of grams/kilogram.

procedure - For a given pressure, read the value of the saturation mixing ratio line that crosses the dew point curve.

potential temperature - The temperature a sample of air would have if the sample were brought dry adiabatically to a pressure of 1000 mb.

procedure - For a given pressure, the value of the dry adiabat passing through the temperature curve.

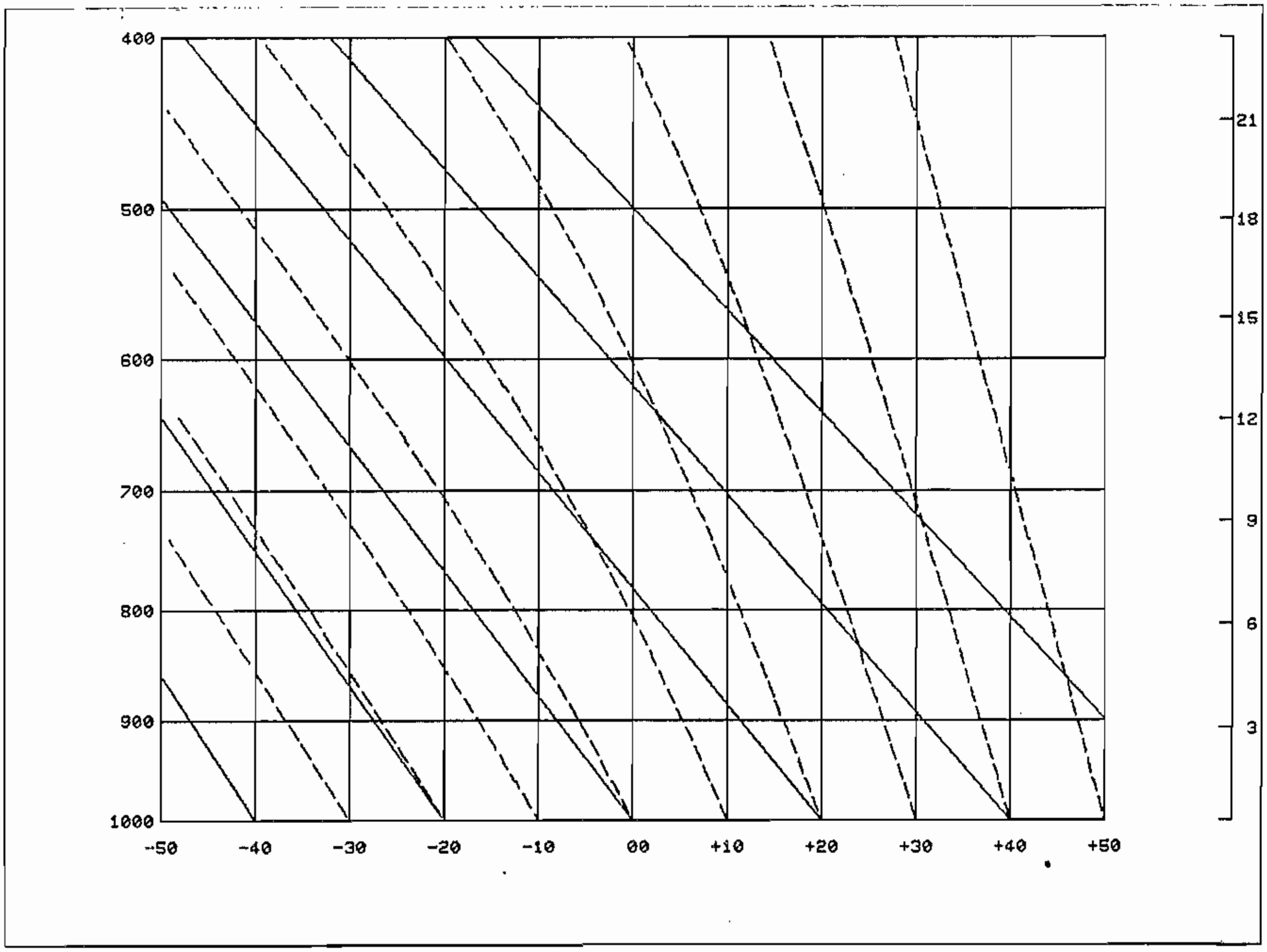

Figure 2. AFOS presentation of the Pseudo-adiabatic diagram. Ordinate is pressure (mb) and abscissa is temperature (^{o}C). Dashed lines are pseudo-adiabats (10^{o} K intervals).

saturation mixing ratio - The mixing ratio a sample of air would have if saturated. Expressed in grams/kilogram.

procedure - for a given pressure, the value of the saturation mixing ratio line passing through the temperature curve.

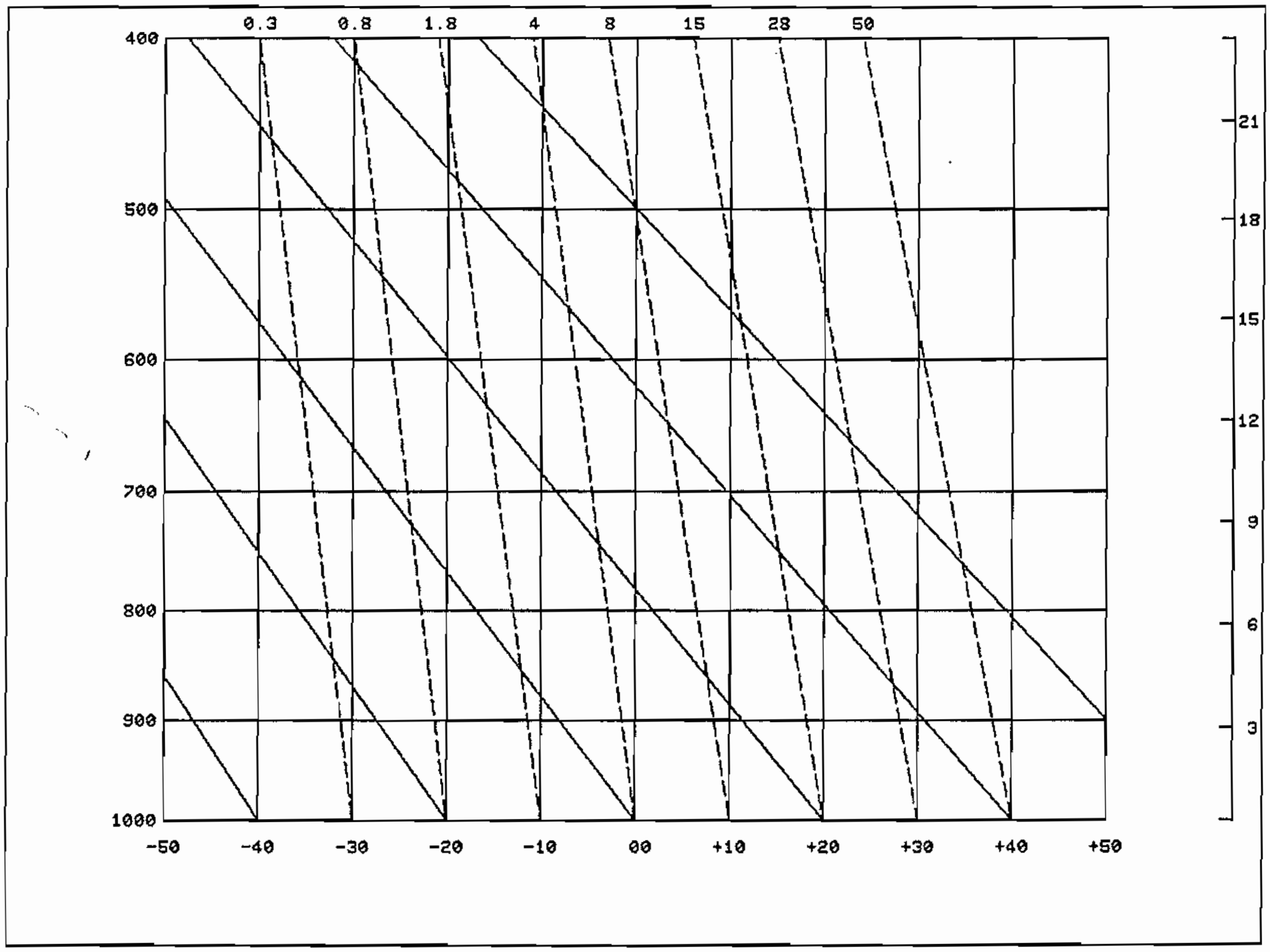

Figure 3. AFOS presentation of the Pseudo-adiabaic diagram. Ordinate is pressure (mb) and abscissa is temperature (°C). Dashed lines are saturation mixing ratio lines (g/kg).

3. METEOROLOGICAL QUANTITIES WHICH CAN BE CALCULATED FROM THE THERMODYNAMIC DIAGRAM

Equivalent temperature - The temperature a parcel of air would have if all the moisture were condensed out by a pseudo-adiabatic process, and the parcel was then brought dry-adiabatically to its original pressure. NOTE: The above definition is actually the adiabatic equivalent temperature (or pseudo-equivalent temperature). The isobaric equivalent temperature is the temperature an air parcel would possess if all water vapor were condensed out at constant pressure with the latent heat released being used to heat the air. The adiabatic equivalent temperature is the value obtained from a thermodynamic diagram and is always greater than the isobaric equivalent temperature.

procedure: From the dew-point curve at a given pressure (Fig. 4), draw a line upward along a saturation mixing-ratio line. Also, from the temperature curve at the given pressure, draw a line upward along a dry adiabat until it intersects the line drawn first. The point of intersection is also the Lifted Condensation Level (LCL). From the LCL follow a pseudo-adiabat upward to where the pseudo-adiabat parallels a dry adiabat. Follow the dry adiabat back to the original pressure. The isotherm value at this point is equal to the equivalent temperature.

Equivalent potential temperature - The temperature a parcel of air would have if all moisture were condensed out by a pseudo-adiabatic process, and the parcel was brought dry-adiabatically to 1000 mb. **This temperature is conservative with respect to dry- and pseudo-adiabatic processes.** The equivalent potential temperature can be changed only by the addition or removal of moisture or by diabatically adding or removing heat from the air parcel.

procedure: The equivalent potential temperature is obtained in the same manner as the equivalent temperature (see procedure indicated above) except the parcel is brought to 1000 mb (Fig. 4). The isotherm value at this point is equal to the equivalent potential temperature (since the equivalent potential temperature is usually expressed in degrees Kelvin, 273 must be added to the value of the isotherm). NOTE: The pseudo-adiabats of many diagrams (unfortunately, not the AFOS diagram) are labeled in values of equivalent potential temperature.

Relative humidity - The ratio (in percent) of the amount of water vapor in a given volume of air to the amount that volume would hold if the air were saturated.

procedure: For a parcel of air divide the mixing ratio by the saturation mixing ratio.

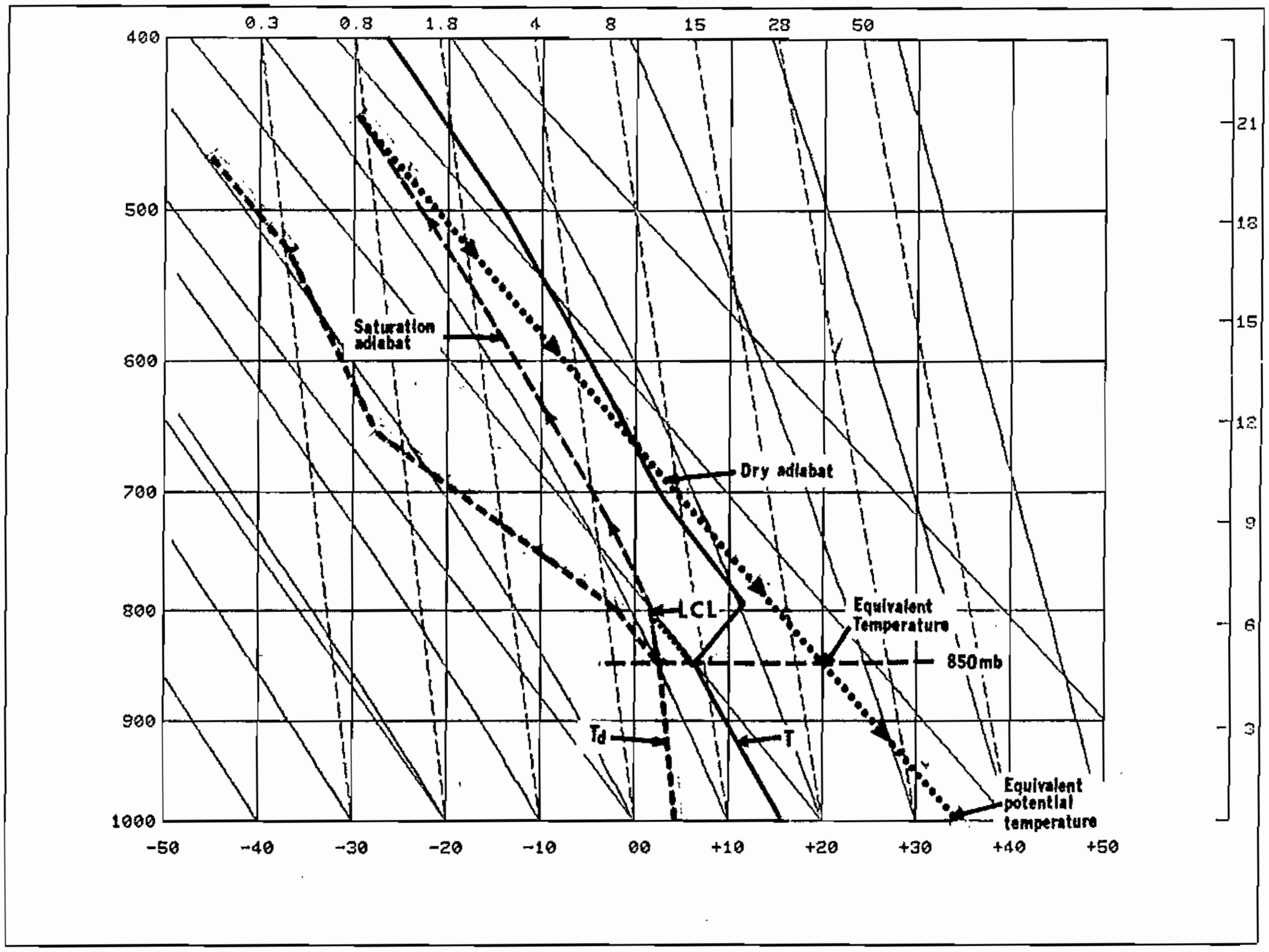

Figure 4. Determination of equivalent temperature and equivalent potential temperature.

Saturation vapor pressure - The partial pressure which water vapor would contribute to the total atmospheric pressure if the air were saturated.

procedure: From the temperature curve at a given pressure level, follow the isotherm to the 622 mb level. The value of the saturation mixing-ratio line through this point at 622 mb gives the saturation vapor pressure in millibars at the given pressure.

Specific humidity - The ratio (dimensionless) of the mass of water vapor to the mass of moist air.

procedure: The specific humidity and **mixing-ratio** are nearly equal and have similar properties.

Vapor pressure - The partial pressure which water vapor contributes to the total atmospheric pressure.

procedure: From the dew point curve at a given pressure level, follow the isotherm to the 622 mb level. The value of the saturation mixing-ratio line through this point at 622 mb gives the vapor pressure (in millibars) for the original pressure.

Virtual temperature - In a system of moist air, the temperature dry air would be to have the same density as the moist air. The virtual temperature is always greater than the actual temperature.

procedure: At a given pressure on a sounding, the difference (in degrees Celsius) between the observed and virtual temperatures is approximately equal to 1/6 of the numerical value of the saturation mixing ratio line passing through the dew-point curve at that pressure.

Wet-bulb temperature - (Isobaric) The temperature an air parcel would have if cooled adiabatically to saturation at constant pressure by evaporation of water into it, all latent heat being supplied by the parcel.
(Adiabatic) The temperature an air parcel would have if cooled adiabatically to saturation and then compressed adiabatically to the original pressure in a saturation-adiabatic process. This is the wet-bulb temperature as read off the **thermodynamic diagram** and is always less than the isobaric wet-bulb temperature, usually by a fraction of a degree Celsius.

procedure - From the dew-point curve at the given pressure (Fig 5), draw a line upward along a saturation mixing-ratio line. From the temperature curve at the given pressure, draw a line upwards along a dry adiabat until it intersects the line drawn along the saturation mixing-ratio line. This intersection is the lifted condensation level (LCL). From the LCL follow the pseudo-adiabat back to the given pressure. The isotherm value at this pressure is equal to the wet-bulb temperature.

Wet-bulb potential temperature - (Also called pseudo wet-bulb potential temperature) The temperature an air parcel would have if cooled from its initial state adiabatically to saturation, and then brought to 1000 mb by a saturation-adiabatic process. This temperature is conserved during both moist and dry adiabatic processes just at the **equivalent potential temperature** is conserved during these processes. Consequently, which of the two is used is usually a matter of personal preference.

procedure: Find the wet-bulb temperature as indicated above except follow the pseudo-adiabat to 1000 mb and read the intersecting isotherms (Fig. 5). NOTE: The pseudo-adiabats on many thermodynamic diagrams (unfortunately not the AFOS diagram) are labeled in values of wet-bulb potential temperature.

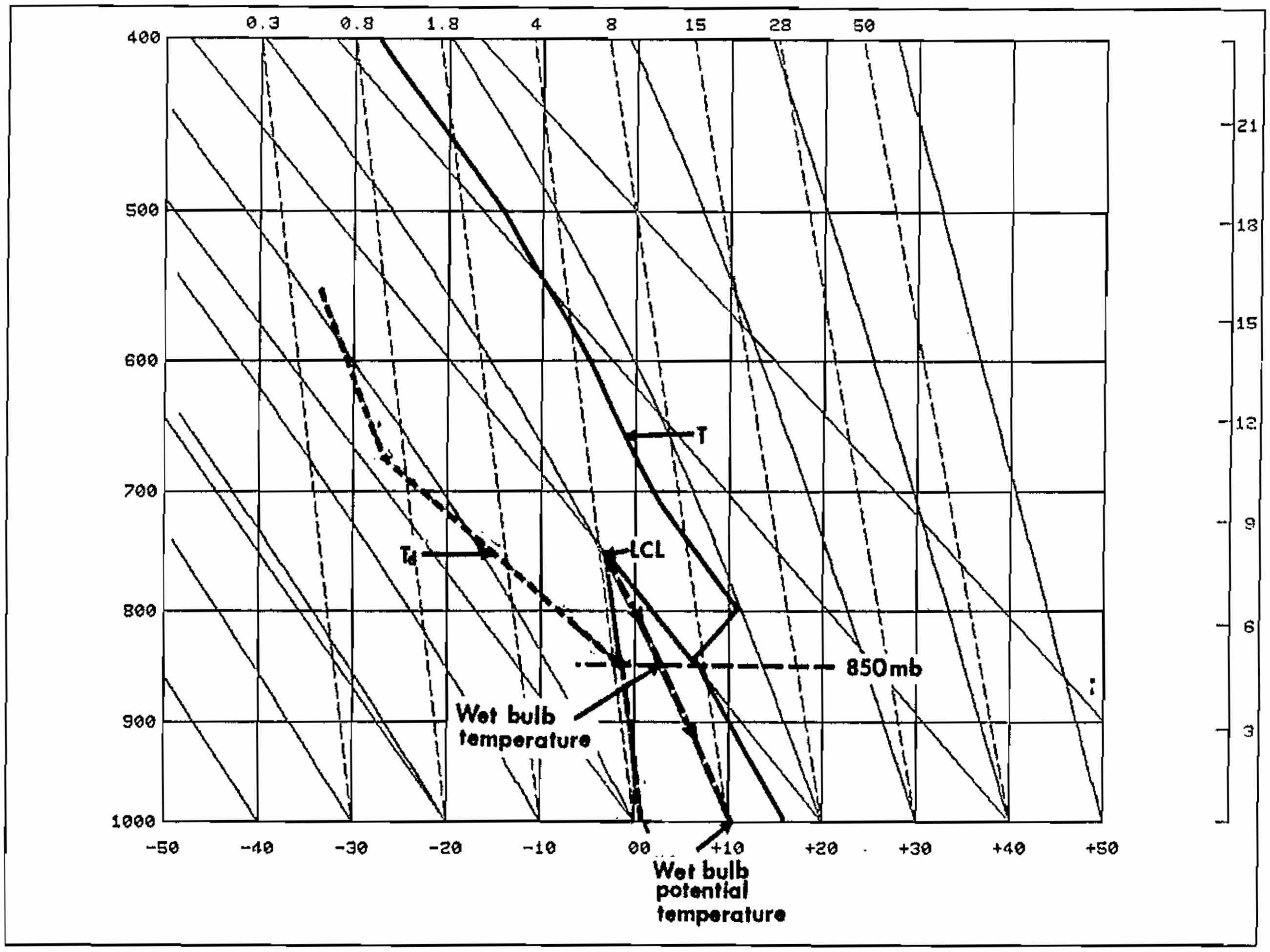

Figure 5. Determination of wet-bulb temperature and wet-bulb potential temperature.

4. DETERMINATION OF STABILITY

Nearly all the procedures routinely used to evaluate and analyze the stability of the atmosphere are manipulations of the so-called "parcel" method. The temperature of a minute parcel of air is assumed to change adiabatically as the parcel is displaced a small distance vertically from its original position. If the parcel is unsaturated, its virtual temperature is assumed to change at the dry adiabatic rate (9.767 ^{o}C per km or about 5.4 ^{o}F per thousand feet); if the parcel is saturated, the change will occur at the saturation-adiabatic rate. In addition, it is assumed that the moving parcel neither affects, nor is affected by, the atmosphere through which it moves.

If, after the vertical displacement, the parcel has a higher virtual temperature than the surrounding atmosphere, the parcel is subjected to a positive buoyancy force and will be further accelerated upwards. If the virtual temperature of the parcel is lower than that of the surrounding air, the parcel will be subjected to a negative buoyancy force and will eventually return to the initial or equilibrium position.

The atmosphere surrounding the parcel is said to be stable if the displaced parcel tends to return to its original position; unstable if the displaced parcel tends to move farther away from its original position. The atmosphere is in neutral equilibrium when the displaced parcel has the same density as its surroundings.

The behavior of a parcel which, once it is saturated, becomes warmer than its environment through the release of the latent heat of condensation, is as follows. The parcel ascends under acceleration from the positive buoyancy force. If the saturated parcel continues to rise through an atmosphere in which the lapse rate exceeds the saturation adiabatic, the speed of ascent increases. This acceleration persists until the height is reached where the saturation-adiabatic path of the parcel crosses the temperature sounding curve; i.e., where the parcel temperature becomes equal to the environment temperature. This height is the equilibrium level (EL).

If the lapse rate of the temperature curve is less than the lapse rate of the saturation adiabat, the layer is absolutely stable; i.e., stable regardless of its moisture content. If the lapse rate of the temperature curve is greater than the dry adiabat, the layer is absolutely unstable; i.e., unstable regardless of its moisture content. This condition is also referred to as a superadiabatic lapse rate. If the lapse rate of the temperature curve is greater than the saturation adiabat but less than the dry adiabat, the layer is conditionally unstable, meaning that it is stable if unsaturated and unstable if saturated. Other important terms are:

convective instability (also called potential instability) - The state of an unsaturated layer or column of air in the atmosphere whose wet-bulb potential temperature (or equivalent potential temperature) decreases with elevation. If such a column is lifted bodily until completely saturated, it will become unstable (i.e., its temperature lapse rate will exceed the saturation-adiabatic lapse rate) regardless of its initial stratification.

gravitational instability - That static instability in a system in which buoyancy or reduced gravity is the only restoring force on displacements. For the atmosphere, when lifting is assumed to be adiabatic, it requires the lapse rate (of temperature) to be greater than the adiabatic lapse rate.

static stability (also called hydrostatic stability, vertical stability) - The stability of an atmosphere in hydrostatic equilibrium with respect to vertical displacements, usually considered by the parcel method.

STABILITY INDICES

The overall stability or instability of a sounding is frequently expressed in the form of a single numerical value called a stability index. Such indices have been introduced mainly as aids in connection with particular forecasting techniques or studies. The stability indices have the advantage of ease of computation, flexible choice of the layer most pertinent to the particular problem or area, and a numerical form convenient for ready use in objective studies. On the other hand, details of the lapse-rate structure important to the problem at hand may be smoothed out or completely missed. Also, these indices are generally useful only when combined with other synoptic considerations. Used alone, they are less useful than the standard stability analyses of the complete sounding by the parcel method. The greatest value of an index lies in alerting the forecaster to those areas which should be more closely examined by other procedures.

Perhaps the earliest index was the algebraic difference between the 500 mb thermal field and the 850 mb thermal field. The advantage was graphical subtraction could be quickly and easily performed with the resulting field an indication of instability. The main disadvantage was the vertical moisture profile was not considered.

Showalter Index (also called stability index) - Developed in the early 50s and published in 1953, this index is a measure of the local static stability of the atmosphere, expressed as a numerical index. This index is determined by raising an air parcel from 850 mb (higher levels are used over higher terrain) dry-adiabatically to the point of saturation, then wet-adiabatically to 500 mb. At the 500 mb level, the temperature of the parcel is compared to that of the environment; the magnitude of the index is the difference between the two temperatures. If the parcel is colder than its new environment, the index is positive; if warmer, the index is negative. NOTE: Another index, the Gardner-Scherhag Index, was developed in 1949. This index was quite similar to the Showalter Index except Gardner and Scherhag subtracted the actual temperature from the lifted temperature at the 500 mb level thus obtaining positive values as compared to negative values for the Showalter Index.

Some general guidelines to follow are:

1. When the index is +3 or less, showers are probable and some thunderstorms may be expected.

2. The chance of thunderstorms increases rapidly for Index values in the range +1 to -2.

3. Index values of -3 or less are associated with severe thunderstorms.

It should be remembered that the Showalter Index considers conditions at only two levels--850 and 500 mb. This makes it difficult to use on a detailed synoptic time and space basis when, as often happens, there is an inversion or rapid drop of moisture which passes through the 850 mb level between stations or between two successive sounding times. The Showalter Index can be advantageous at certain times, such as when considering the stability above a shallow front; but the index has limited value at other times.

procedure: Draw a line parallel to the dry adiabat upwards from the 850 mb temperature and draw a line parallel to the saturation mixing ratio line upwards from the 850 mb dew point (Fig. 6). The point of intersection is the Lifted Condensation Level (LCL). From the LCL draw a line parallel to the pseudo-adiabat upward until it intersects the 500 mb level. Read the isotherm at this intersection (500 mb). Algebraically subtract the lifted 500 mb temperature from the observed 500 mb temperature to obtain the Showalter Index.

Lifted Index - Because of the limitations of the Showalter Index, the Lifted Index was developed by Joseph G. Galway in the mid 50s. The Lifted Index uses a parcel of air with the moisture content equal to the mean mixing ratio of the lowest 3000 feet (or 100 mb) of the sounding and the temperature equal to the forecast maximum surface temperature. This parcel is lifted to its LCL and then parallel to the pseudo-adiabat to the 500 mb level. The temperature of the parcel at 500 mb is assumed to be the updraft temperature within the cloud. The 500 mb temperature of the parcel is algebraically subtracted from the observed or ambient 500 mb temperature to give the Lifted Index. Lifted Index values are usually algebraically less than Showalter Index values.

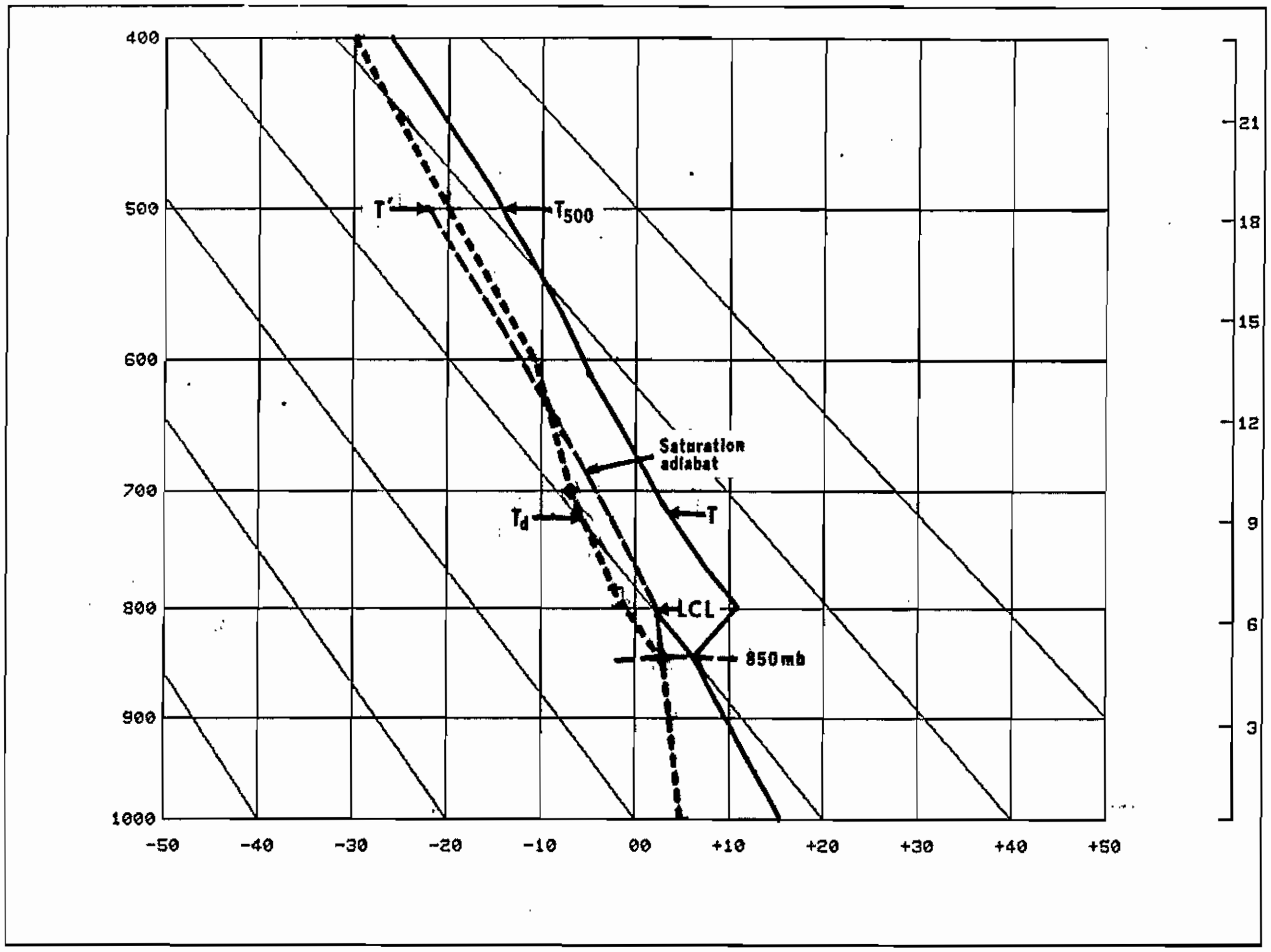

Figure 6. Determination of the Showalter Index.

procedure: Determine the mean mixing ratio of the lowest 100 mb of the sounding and plot on the sounding the expected maximum surface temperature (Fig. 7). The intersection of the dry adiabat intersecting the expected maximum temperature with the mean mixing ratio line depicts the LCL. From the LCL follow the pseudo-adiabat to the 500 mb level. The algebraic difference between this computed 500 mb temperature and the observed or ambient 500 mb temperature represents the Lifted Index.

NOTE: The method of determining the Lifted Index indicated on the stability and moisture composite chart is different than indicated above. This method uses the mean temperature and mean dew point of the lowest 50 mb of the sounding as determined from the levels reported in the RAOB message, including an interpolated value at the top of the layer. These values are considered as defining the characteristic of a parcel at 25 mb above the surface (the mean level of the layer). The remainder of the computation is the same.

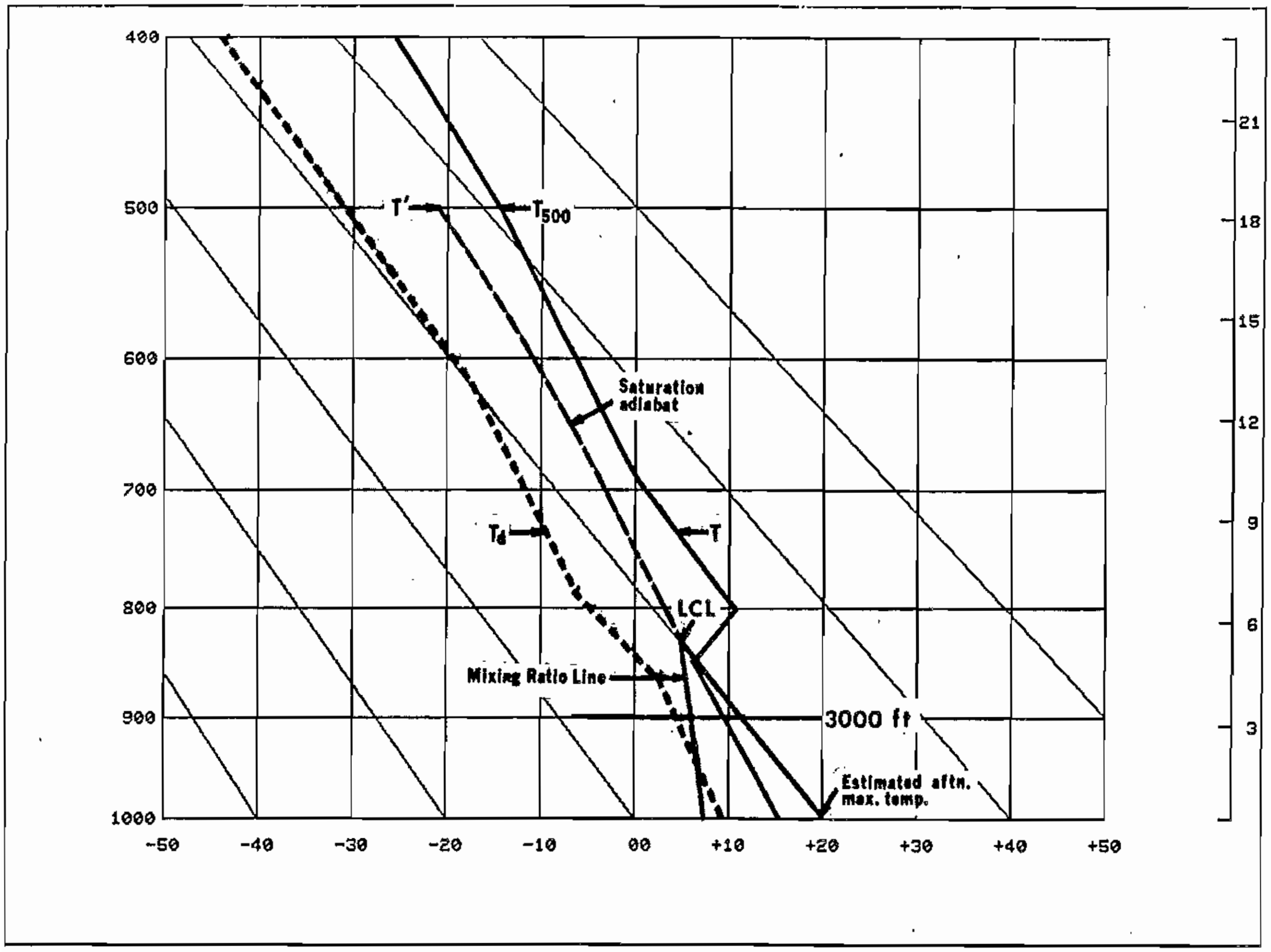

Figure 7. Determination of the Lifted Index.

Best Lifted Index The concept of the Best Lifted Index was introduced by Fujita who noted that a lifted index computed from a fixed level, such as the surface, might not represent the stability of the air mass. The Best Lifted Index is simply the lowest Lifted Index computed separately for each of a series of points (usually two) from the surface to 1600 meters.

Model Lifted Index The Model Lifted Index computation procedure follows the method used in computing the Best Lifted Index as much as possible. This calculation uses parameters available at initial and forecast times in the NMC primitive equation models. The lowest sigma layer of the modeled atmosphere is designed as a boundary layer (50 mb thick). The boundary layer mean temperature and relative humidity values apply at mid-layer and are used to determine the dew point and temperature of a parcel 25 mb above the model terrain at each of the grid points. These parcels are lifted to saturation (LCL), and then moist adiabatically to the 500 mb level. The resultant 500 mb temperatures are compared to the initialized or forecast 500 mb level temperatures at each grid point to give the initial and forecast Model Lifted Index.

Although the Lifted Index (and variations) is more representative than the Showalter Index through a more elaborate consideration of the low-level moisture field, a major disadvantage lies in the fact that only two sections of the sounding are considered--the boundary layer and 500 mb. Low Lifted Indices could be more than offset by stable layers in the middle troposphere.

K Index - The K Index is a measure of thunderstorm potential based on the vertical temperature lapse rate, the moisture content of the lower atmosphere, and the vertical extent of the moist layer. The temperature difference between 850 and 500 mb is used to parameterize the vertical temperature lapse rate. The 850 mb dew point provides information on the moisture content of the lower atmosphere. The vertical extent of the moist layer is represented by the 700 mb temperature-dew point depression. The combination of these parameters to yield the K Index is performed as follows:

K = (850 temp - 500 temp) + 850 dew point - 700 dew point dep
(dep stands for depression)

Note: K values are primarily applicable to the prediction of air mass thunderstorms. The K Index is also an important index for the forecasting of heavy rains. Caution should be exercised when the 850 mb level is near the surface.

Vertical, Cross and Total Totals - The Total Totals Index has proven useful in locating potential areas of thunderstorm development. While the Vertical Totals (VT) may prove to be a better indicator of thunderstorm activity in one region or during certain situations, and the Cross Totals (CT) may carry more weight in another, the Total Totals (TT) has proven to be a more reliable predictor of severe weather activity in both warm and cold air situations.

Vertical Totals = 850 temp - 500 temp

General threshold for VT for convection is 26, with higher values more favorable for the formation of thunderstorms.

Cross Totals = 850 dew point - 500 temp

General threshold for CT for convection is 18, with higher values more favorable for the formation of thunderstorms.

Total Totals = Cross Totals + Vertical Totals
or
Total Totals = (850 temp + 850 dew point) - 2(500 temp)

General threshold for TT for convection is 44. Weak potential for severe thunderstorms is 50, moderate is 50 to 55, and strong is greater than 55. Note: Total Totals must be used with careful attention to either the Cross Totals or the low-level moisture since it is possible to have large Total Totals due to the temperature lapse rate with little supporting low-level moisture.

Sweat Index - Severe WEAther Threat Index

$$SWEAT = 12D + 20(T-49) + 2f_8 + f_5 + 125(S+0.2)$$

where D = 850 mb dew point; T = Total Totals Index
f_8 = 850 mb wind speed; f_5 = 500 mb wind speed
S = sin(500 wind dir - 850 mb wind dir)

Restrictions: D must be $> 0^\circ$ C
T must be > 49

Omit S term if a) 500 mb wind direction is not $210^\circ - 310^\circ$
b) 850 mb wind direction is not $130^\circ - 250^\circ$
c) S < 0

Sweat Table

300 - 400	Chc Svr Tstms
400 - 500	Svr Tstms likely chc tornado
500 - 600	Svr Tstms and tornadoes likely
600 - 800	Tornadoes nearly always occur
> 800	No Svr weather - too much wind

Fawbush-Miller Stability Index - This index involves consideration of a surface "moist layer". This "moist layer" is defined as a surface stratum whose upper limit is the pressure surface where the relative humidity first becomes less than 65%. If its vertical extent exceeds 6000 feet, only the lowest 150 mb layer is used to determine the mean wet bulb temperature of the moist layer. (Soundings sometime contain shallow dry layers within this defined "moist layer" such as in the lowest 30 mb, or in the top layers of a surface inversion. In such cases, the assumption is made that the normal convective mixing of moisture will wipe out such shallow dry layers, so they are ignored in identifying the "moist layer").

procedure: a) Compute the relative humidity for enough points in the lower part of the sounding to identify the "moist layer".

b) Plot the wet bulb curve for the "moist layer". Draw a straight line to approximate the mean wet bulb temperature for the layer (equal-area averaging).

c) From the mid-point of the straight line approximation, proceed upward parallel to the saturation adiabats to 500 mb. Algebraically subtract the isotherm value at this new position from the observed 500 mb temperature. Positive values indicate stability and negative values indicate instability. Note: The values of the Fawbush-Miller Index and the Showalter Index are usually quite similar. Significant differences occur when the moisture value at 850 mb is not representative of the layer below that pressure surface. Since the Fawbush-Miller Index considers more information about the moisture values, it appears to be more representative than the Showalter Index. However, computation of the Showalter Index is much easier, and in many cases is of comparable utility.

Martin Index - Claimed to be more "sensitive" to the low-level moisture than either the Showalter or Fawbush-Miller Indices.

procedure: Draw the saturation adiabat intersecting the temperature-sounding curve at 500 mb past the height of maximum mixing ratio. Find the intersection of this line with the saturation mixing-ratio line through the maximum mixing-ratio value in the sounding. From this intersection, draw a dry adiabat to intersect the 850 mb level. Algebraically subtract the sounding temperature at 850 mb from the temperature at the latter intersection. The resulting number (including its algebraic sign) is the Martin Index.

Dynamic Index - Works best for air mass thunderstorms.

procedure: Determine the mean mixing ratio of the lowest 100 mb of the sounding. From the surface temperature ascend dry adiabatically until the dry adiabat intersects the mean mixing ratio. This point is the lifted condensation level (LCL). From the LCL, follow along the mean mixing ratio line until it intersects with the temperature curve. This point is the convective condensation level (CCL). From the CCL follow the saturated adiabat upward to the 500 mb level. Algebraically subtract the 500 mb temperature of the parcel from the observed 500 mb temperature. Negative numbers indicate conditional instability and positive numbers indicate stability. Note: The condition necessary for instability is that the surface temperature be high enough to allow an air parcel to rise dry adiabatically to at least the height of the CCL before intersecting the temperature curve. If this condition is met, then free convection will occur and thunderstorms will develop.

As indicated above, stability (or instability) indices serve to alert the meteorologist of areas with the potential for convection. The meteorological conditions of these areas should then be closely examined. Much information can be obtained through a thorough analysis of the thermodynamic sounding. This technique will be covered in the following section along with the RAOB ANALYZ program available in AFOS.

5. RAOB ANALYSIS AND THE AFOS ANALYZ PROGRAM

Stability indices are best used as alerting devices to warn the meteorologist of possible trouble spots. The meteorologist should then carefully examine the horizontal and vertical atmospheric structure to delineate areas of possible thunderstorm formation. A detailed analysis of the applicable thermodynamic soundings is a necessary procedure. The AFOS RAOB PLOT program does not lend itself to detailed sounding analysis due to the simplified background and the compact sounding. However, the ANALYZ program offers much to the meteorologist in this area. This section describes the AFOS ANALYZ program and offers suggestions as to how this program can be fully utilized.

AFOS ANALYSIS PROGRAM

The RAOB ANALYSIS Program, ANALYZ, is an interactive analysis of the significant levels (CCCSGLXXX) of the RAOB data. If the significant levels are not available, the mandatory levels (CCCMANXXX) are used. ANALYZ plots the RAOB data, and by using the ENTER CURSOR button, the user may plot selected dry adiabatic lines, moist adiabats, and calculate various indices and derived values.

Although the run command may vary from office to office, RUN:XXXANALYZ (where XXX is the identifier of the RAOB station) is used at WSFO San Antonio. This command should be typed at an ADM with a GDM. After striking ENTER, the ADM will respond with JOB QUEUED FOR PROCESSING. Clear the ADM with the DISPLAY CLEAR key. The sounding and menu will appear on the graphics screen. The program allows the following functions:

- DRY - Creates a dry adiabat (solid line)
- WET - Creates a moist adiabat (dashed line)
- VALUE - Displays pressure and temperature at a selected point
- CALC - Displays table of various indices and derived values and draws a mean mixing ratio line for the lowest 100 mb of the sounding
- CLEAR - Clears screen and redraws sounding
- ASL - Displays height above sea level at a selected point
- END - Terminates the program

To select an option, place the cursor in the appropriate box and hit the ENTER CURSOR key. Place the cursor at the location you wish to perform this function and strike the ENTER CURSOR key again. This function can be repeated until another function is selected. To terminate the program, put the cursor in the END box and strike ENTER CURSOR. Should the user not terminate the program, AFOS will terminate the program after two minutes.

Program Cautions

1. Always erase the command line after initiating the ANALYZ program. This will ensure the command is not accidently initiated later.

2. AFOS will run slower because the background is tied up. No PLOT or ALEMBIC programs can be run while the ANALYZ program is being utilized.

3. The graphics product will not be stored. If you wish to save the sounding, you must make a hard copy.

The three most important AFOS controls for utilizing the ANALYZ program are: the ENTER CURSOR button, the CURSOR ball and the ZOOM buttons. After AFOS has displayed the plotted sounding, a function (dry adiabat, wet adiabat, etc.) can be displayed by the following procedure:

1. Using the CURSOR ball, locate the cursor in the desired block in the upper right part of the graphics. Press the ENTER CURSOR button.

2. Using the CURSOR ball, move the cursor to the desired level of the sounding and press the ENTER CURSOR button again. The appropriate function will be displayed.

3. When the cursor is positioned in the CALC box and the ENTER CURSOR button depressed, the following information will be displayed on the sounding:

a. Average mixing ratio (lowest 100 mb of the sounding).
b. Precipitable water (in inches)
c. Moisture depth (number of millibars with the temperature - dew point spread less than 5° Celsius from the surface to 600 mb)
d. Tropopause height (in feet)
e. Showalter Stability Index

4. The ZOOM buttons can be used to expand any part of the sounding.

Before we can advance into the use of the ANALYZ program a few definitions must be reviewed:

Lifted Condensation Level - The height at which a parcel of air becomes saturated when it is lifted dry-adiabatically. The LCL for a surface parcel is always found at or below the Convective Condensation Level (CCL, see definition below). When the lapse rate is dry adiabatic from the surface to the cloud base, the LCL and CCL are identical.

procedure: The LCL is located on a sounding at the intersection of the saturation mixing ratio line representing the parcel's original pressure and dew point with the dry adiabat representing the parcel's original temperature (Fig. 8). NOTE: The LCL is normally determined for a parcel with the moisture characteristics of the lowest 100 mb of the sounding and the observed (or forecast maximum) surface temperature.

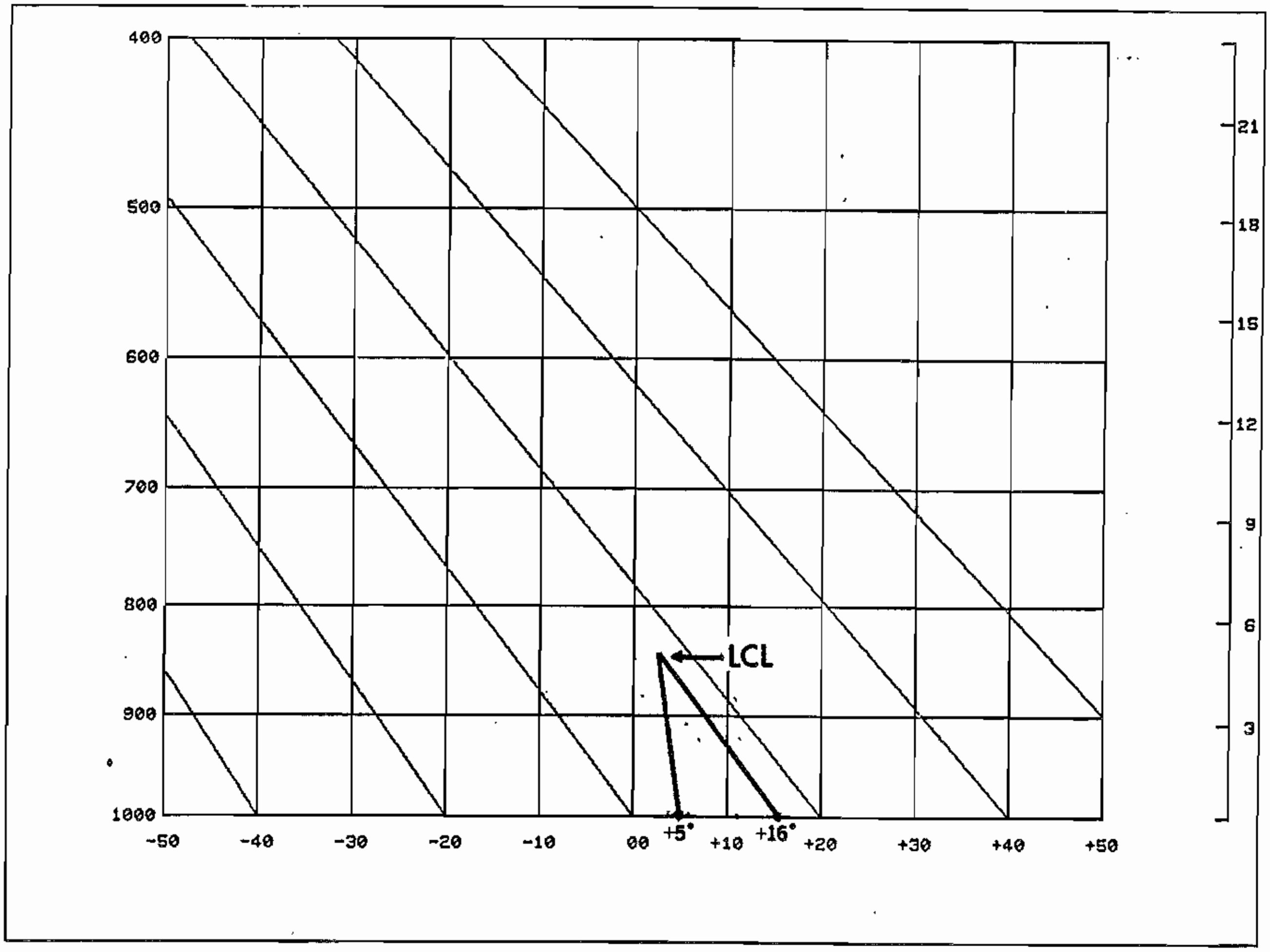

Figure 8. Determination of the Lifted Condensation Level (LCL).

procedure for the ANALYZ program: Place the cursor in the CALC box and press the ENTER CURSOR button. The mean mixing ratio for the lowest 100 mb of the sounding will be displayed (Fig. 9). Place the cursor in the DRY box and press the ENTER CURSOR button. Move the cursor to the expected maximum surface temperature (or any temperature desired) and press the ENTER CURSOR again. A dry adiabat will be displayed--the intersection of this dry adiabat with the mean mixing ratio line is the Lifted Condensation Level. Note: If it is decided the displayed dry adiabat is not the one desired, simply move the cursor to another location and press the ENTER CURSOR button again.

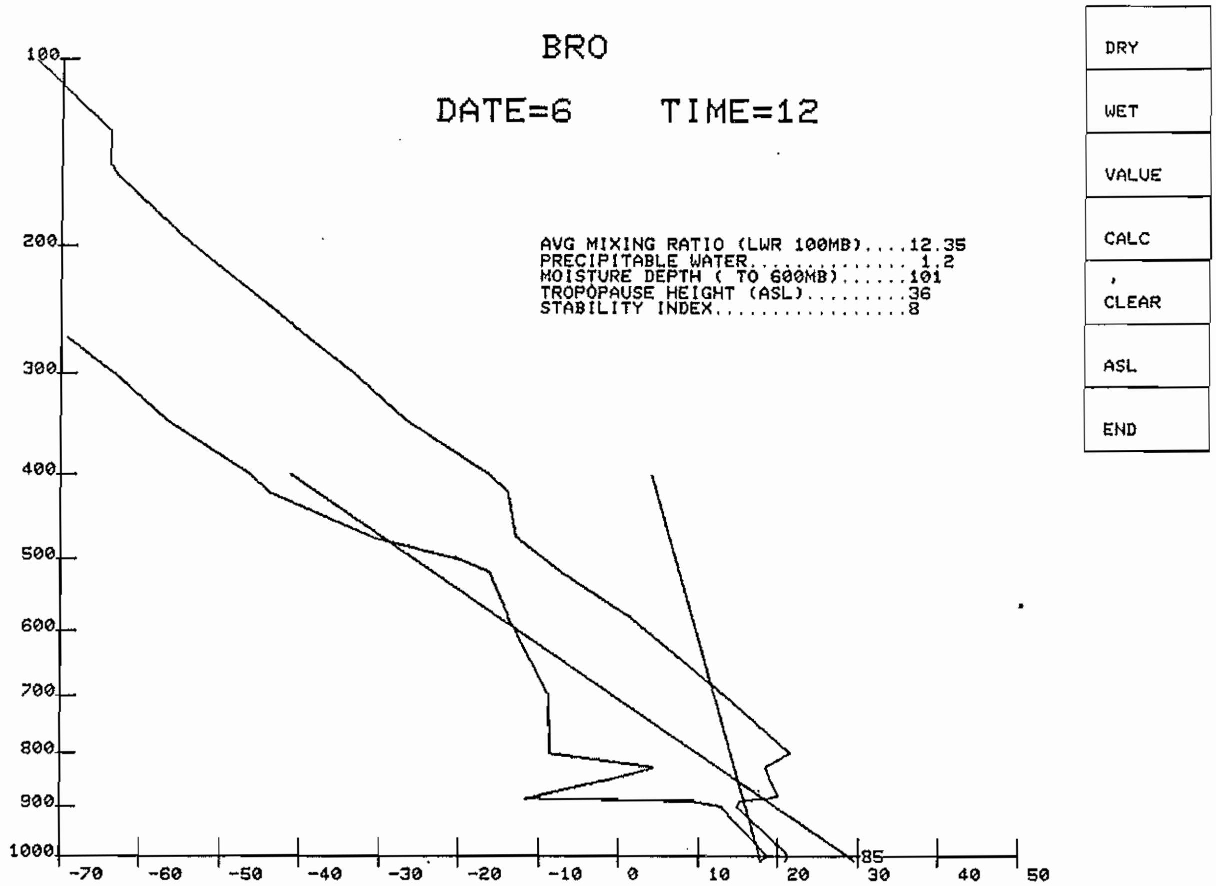

Figure 9. Determination of the Lifted Condensation Level (LCL) using the RAOB ANALYZ AFOS program.

Convective Condensation Level (CCL) - The height to which a parcel of air, if heated sufficiently from below, will rise dry adiabatically until it is just saturated. In the most common case, it is the height of the base of cumuliform clouds which are or would be produced by thermal convection solely from surface heating. The **Convection Temperature** is the surface temperature that must be reached to start the formation of convective clouds by solar heating of the surface air layer.

procedure: Proceed upward along the saturation mixing ratio line through the surface dew point until this line intersects the temperature curve of the sounding. The CCL is at the height of this intersection (Fig. 10). Note: A more common procedure would be to use the mean mixing ratio line of the lowest 100 mb of the sounding. The **Convection Temperature** is obtained by proceeding downward along the dry adiabat from the CCL to the surface pressure level. The temperature at this intersection is the convection temperature.

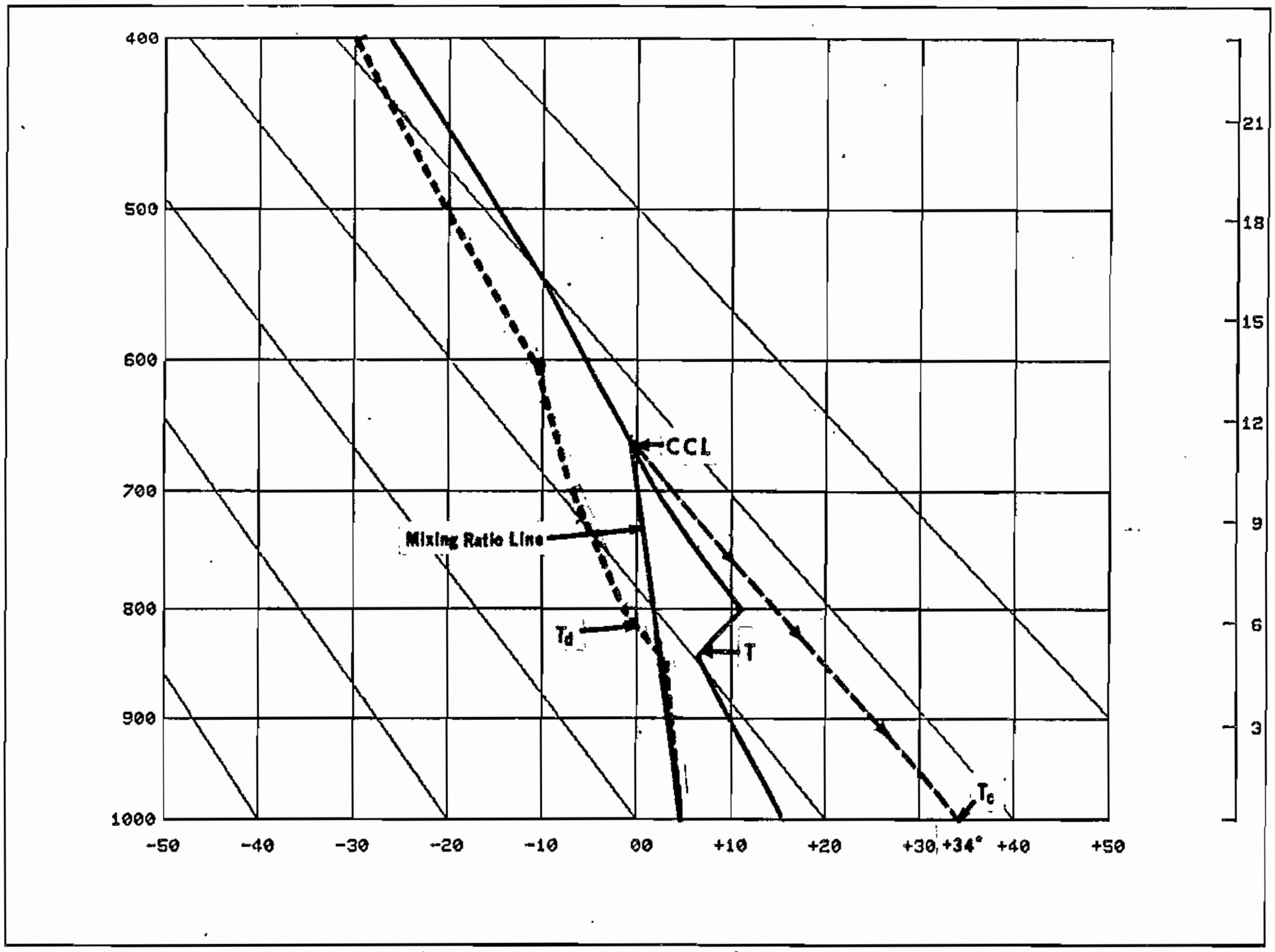

Figure 10. Determination of the Convective Condensation Level (CCL) and convection temperature (T_c).

procedure for ANALYZ program - Place the cursor in the CALC box and strike the ENTER CURSOR button. The intersection of the displayed mean mixing ratio line with the temperature curve is the CCL (Fig. 11). Place the cursor in the DRY box and press the ENTER CURSOR button. Move the cursor to the CCL and strike the ENTER CURSOR button again. The temperature displayed at the base of the dry adiabat will be the **Convection Temperature.**

Level of Free Convection (LFC) - The height at which a parcel of air lifted dry adiabatically until saturated and moist adiabatically afterwards would first become warmer than the surrounding air. The parcel will then continue to rise freely above this level until it becomes colder than the surrounding air. The level at which the parcel once again has the same temperature as the environment is the **Equilibrium Level** (EL, see definition below).

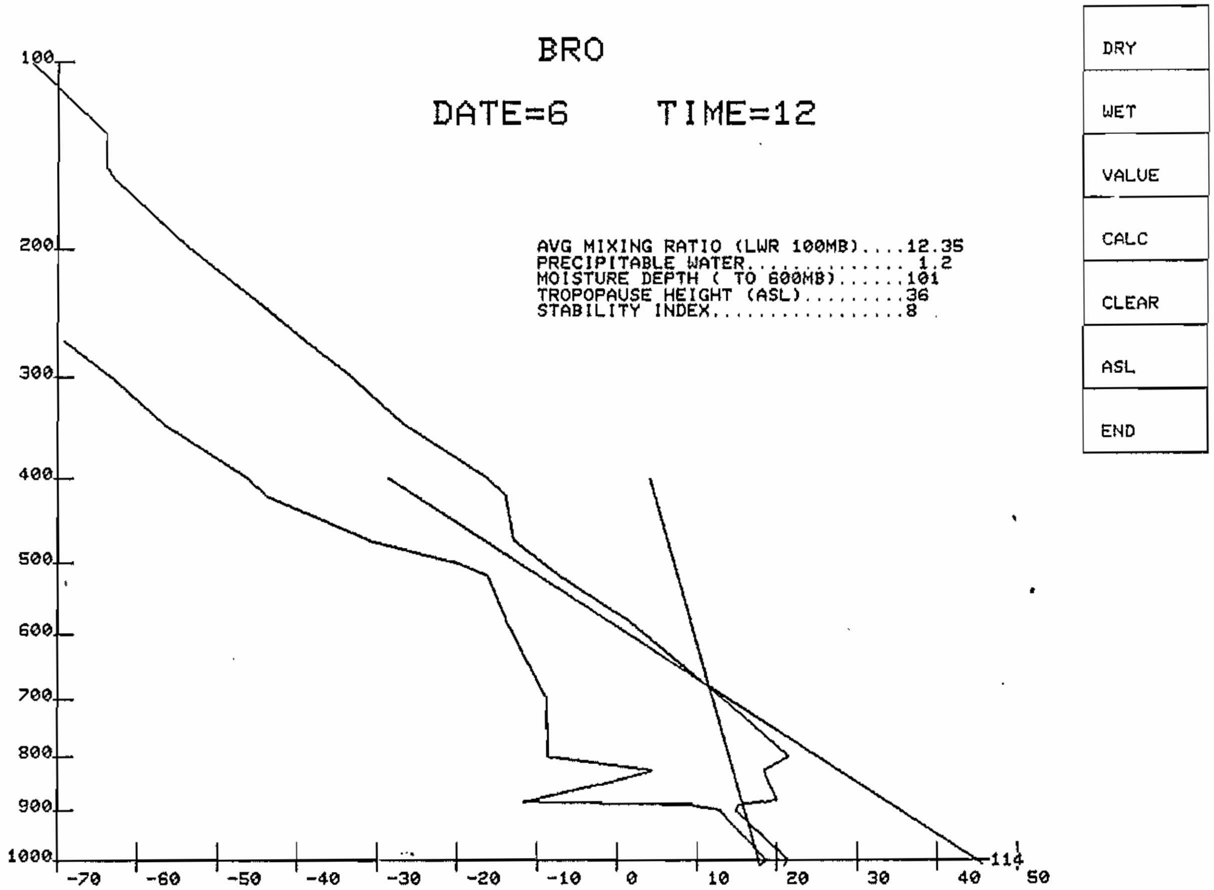

Figure 11. Determination of the Convective Condensation Level (CCL) and convection temperature using the RAOB ANALYZ AFOS program.

procedure: After determining the LCL, follow the pseudo-adiabat until it crosses the temperature sounding curve. This intersection is the LFC (Fig. 12). If the parcel is to be raised by diabatic heating, then the CCL should be used as opposed to the LCL.

procedure for ANALYZ program: After determining the LCL or CCL, place the cursor in the WET box and press the ENTER CURSOR button. Move the cursor to the LCL or CCL and press the ENTER CURSOR button again. A pseudo-adiabat will be drawn upward from the cursor. The point where this pseudo-adiabat intersects the temperature curve (with the pseudo-adiabat to the right of the temperature curve above the intersection) is the LFC. NOTE: Under certain conditions, the LFC may be at the same point as the LCL or CCL.

Negative Area - When a parcel on a sounding lies in a stable layer, energy has to be supplied to the parcel to move it either up or down. The area between the path of such a parcel moving along an adiabat and the sounding curve is proportional to the amount of kinetic energy that must be supplied to move it. This is called **Negative Area** (Fig. 13).

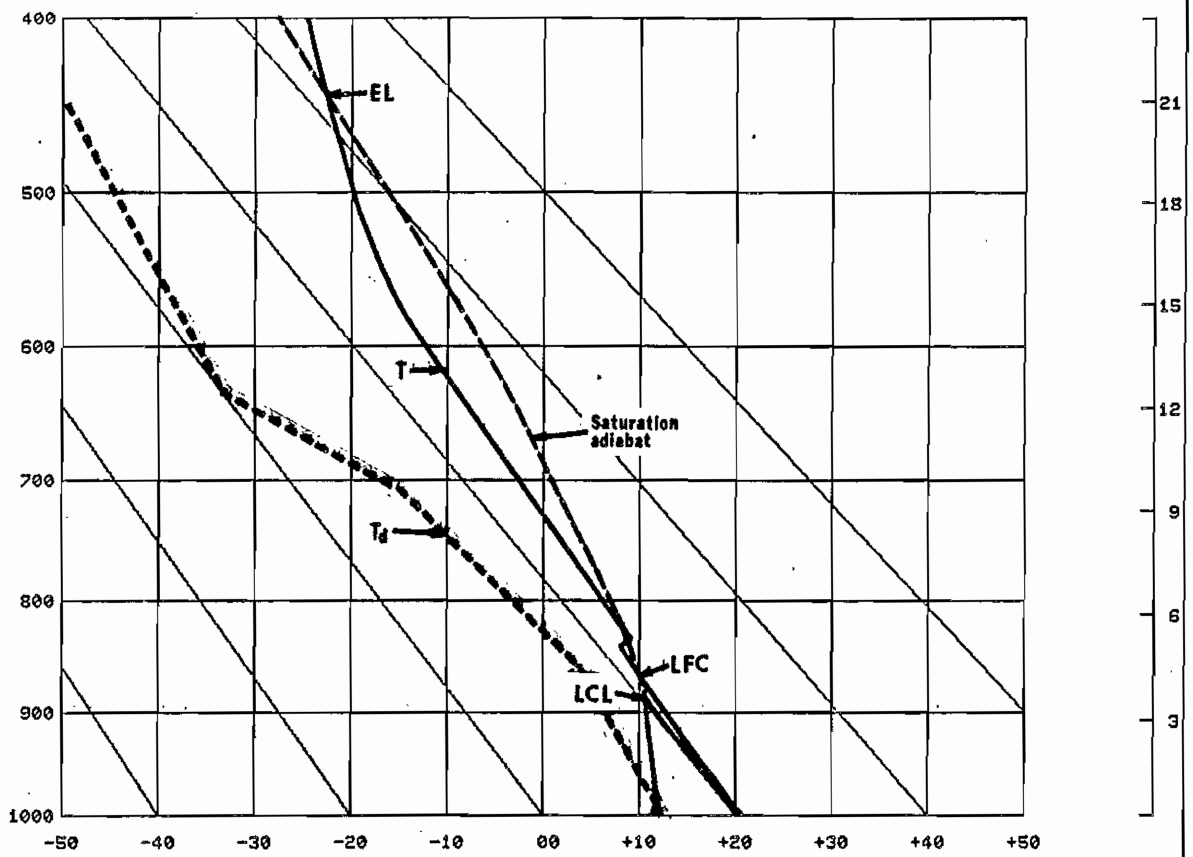

Figure 12. Determination of the Level of Free Convection (LFC).

Positive Area - When a parcel can rise freely because it is in a layer where the adiabat it follows is warmer than the surrounding environment, the area between the adiabat and the sounding is proportional to the amount of kinetic energy the parcel gains from the environment. This is called **Positive Area** (Fig. 13).

Note: The negative and positive areas are not uniquely defined on any given sounding. They depend on the parcel chosen and whether the movement of the parcel is assumed to result from diabatic heating or forcible lifting. If destabilization is expected to result from diabatic heating, parcels should be lifted upward from the Convective Condensation Level along the pseudo-adiabats. If destabilization is expected to result from forced lifting, parcels should be lifted upward from the Lifted Condensation Level along the pseudo-adiabats. That part of the parcel path which is colder than the temperature sounding defines the negative area and that part of the parcel path warmer than the temperature sounding defines the positive area.

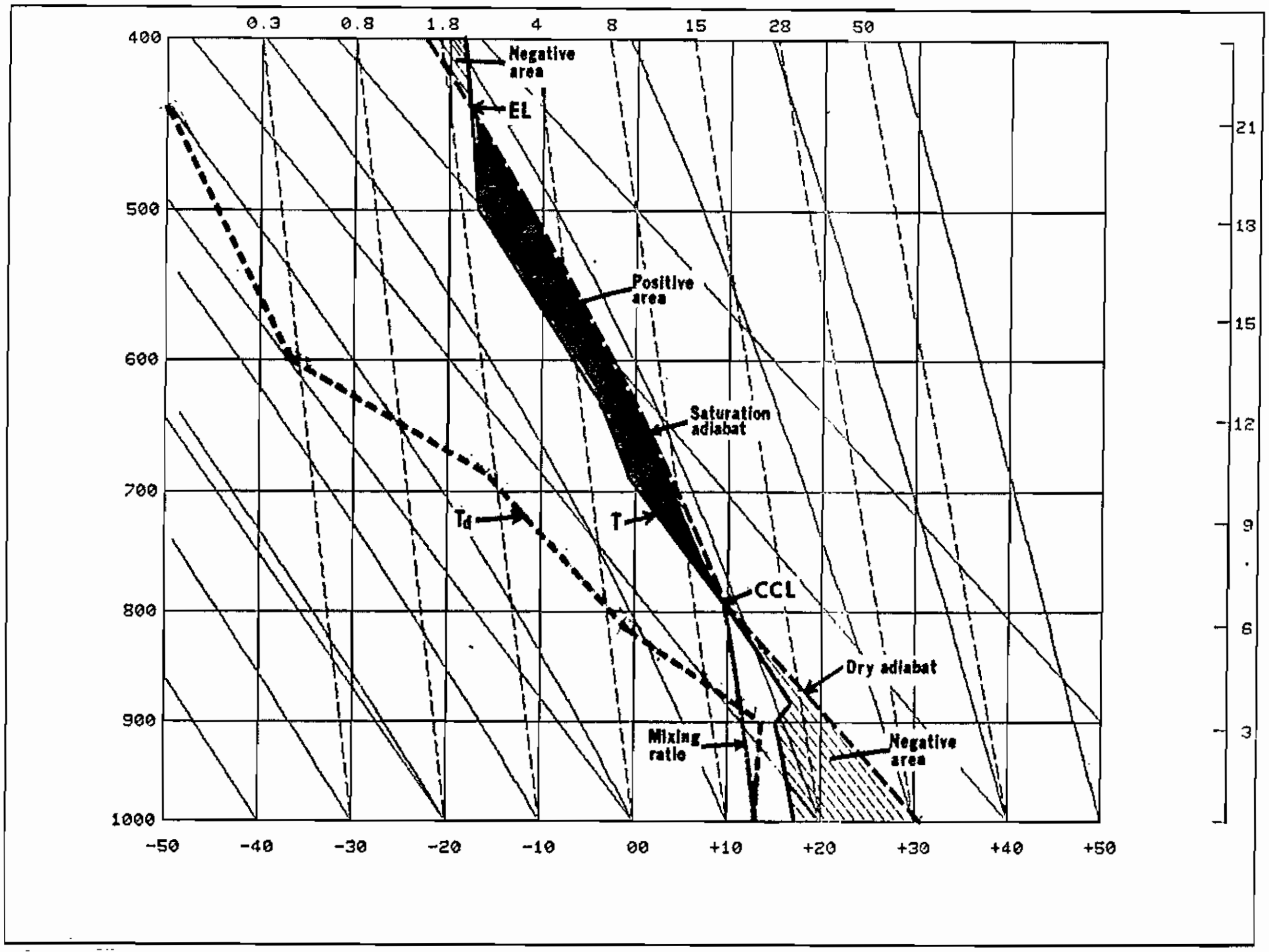

Figure 13. Determination of the Positive and Negative areas and Equilibrium Level (EL) on a sounding due to the heating of a surface parcel.

Equilibrium Level (EL) - The height where the temperature of a buoyantly rising parcel again becomes equal to the temperature of the environment.

procedure: From the CCL or LCL determine the path a parcel will follow. If the parcel is warmer than the environment the parcel will pass through the Level of Free Convection (LFC) and the path of the parcel will be to the right of the temperature sounding curve and will describe a positive area. The EL is found at the top of the positive area where the temperature curve and the pseudo-adiabat through the LFC again intersect (Fig. 12).

Using the ANALYZ program to analyze RAOB soundings

Perhaps the most important feature of the ANALYZ program is the ability to perform various functions, clear the sounding and begin again. Another important feature is vertical extent of the sounding (to 100 mb) which enables the Equilibrium Level to be determined. We have already described the methods for determining the LCL, CCL, LFC, EL and positive and negative areas utilizing the ANALYZ program. Below are suggestions which may assist in using the ANALYZ program to perform a detailed RAOB analysis.

1. Assuming the command has been executed and the sounding plotted, the first step is to exercise the CALC function to provide the various parameters and the mean mixing ratio of the lowest 100 mb of the sounding.

2. Determine if destabilization will be accomplished by diabatic heating or forced lifting (of course diabatic heating will act to destabilize the atmosphere even if forced lifting is occurring). If destabilization will be the result of only diabatic heating place the cursor at the CCL (intersection of the mean mixing ratio line with the temperature curve) and using the DRY function, locate the Convection Temperature. Using the WET function (with the cursor still at the CCL) display the pseudo-adiabat the parcel will follow from the CCL. Locate the LFC and EL.

If forced lifting is the primary destabilization force the LCL should be utilized. However, it should be emphasized that diabatic heating of the low levels will have a pronounced effect even if forced lifting is the primary destabilization force.

1. Using the CALC button, display the mean mixing ratio line of the lowest 100 mb of the sounding. Assuming the sounding is taken at 1200 GMT, forecast three surface temperatures (late morning, early afternoon and maximum).

2. For each forecast surface temperature locate the dry adiabat extending through the surface pressure and forecast temperature using the DRY function (this may take some practice since the cursor must be placed on the surface temperature at the surface pressure).

3. Place the cursor at the intersection of the dry adiabat and the mean mixing ratio line (LCL) and using the WET function, display the pseudo-adiabat extending upward from the LCL. Note the negative (or positive area) between this pseudo-adiabat and the temperature curve.

4. By performing the above procedure for the three forecast temperatures an estimate can be made as to the amount of forced lifting required to destabilize the atmosphere as the low level is heated (Fig. 14). If the path of the parcel for the maximum temperature (or any of the other temperatures) contains no negative area, thunderstorms could be triggered by surface heating alone (Fig. 14).

5. After the LCL, CCL, LFC, and EL have been determined, the ASL and VALUE functions can be used to determine the heights, temperatures and pressures of the various levels.

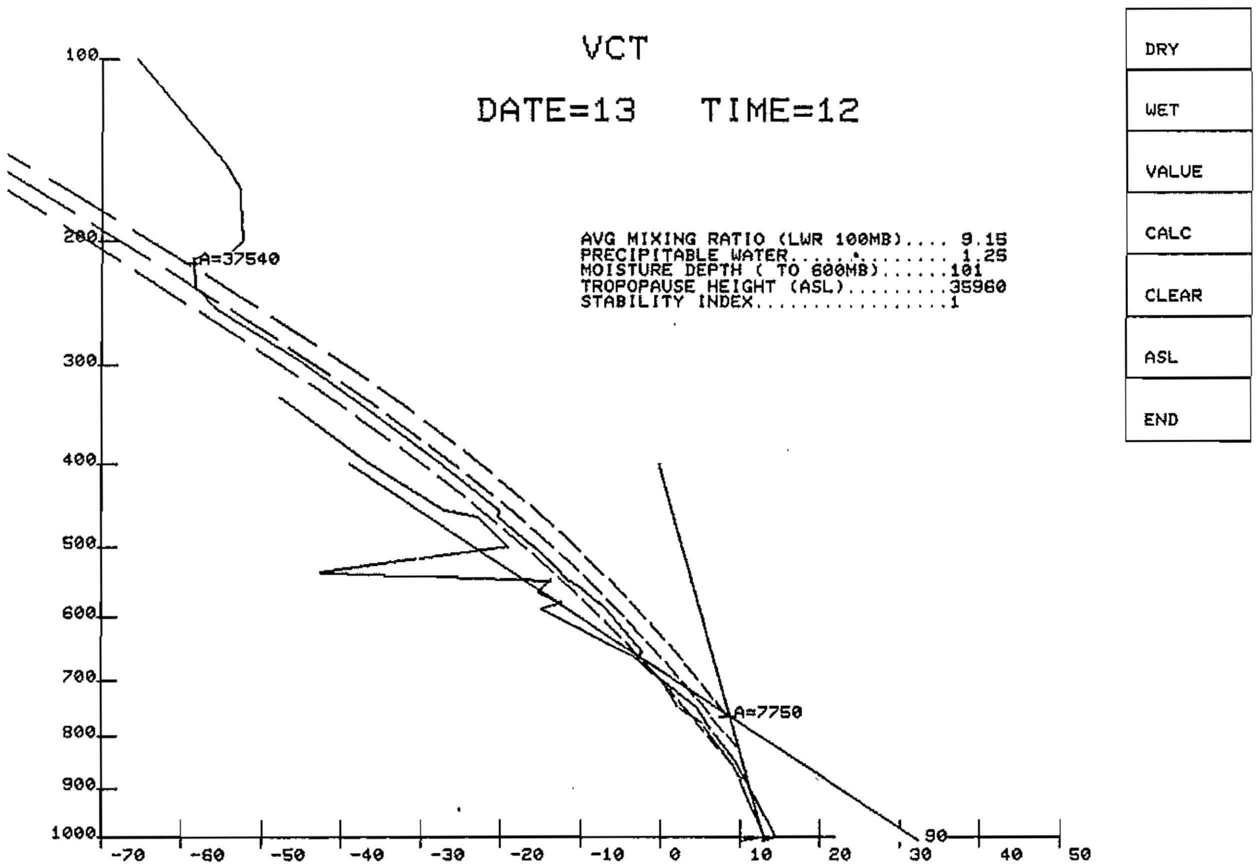

Figure 14. Determination of parcel paths resulting from diabatic heating. The three dashed lines are pseudo-adiabats which correspond to three forecast surface temperatures.

6. CONCLUDING REMARKS

A review of the thermodynamic diagram, its description and meteorological quantities which can be obtained from this chart have been reviewed. No new material has been presented. Rather, information from a number of sources has been combined in the form of a review or reference paper. Related areas have not been covered--areas such as modifying morning soundings to reflect diabatic and advective changes and preparing soundings for locations between upper air observation sites. This will be left for future study.

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SOURCES

Air Weather Service, 1969: Use of the Skew T, log P diagram in analysis and forecasting. AWSM 105-124. Hdqrtrs. Air Weather Service, Scott AFB, Ill., 120 pp.

American Meteorological Society, 1959: Glossary of Meteorology. American Meteorological Society, 638 pp.

Doswell, C.A. III, 1982: The operational meteorology of convective weather, Volume I: Operational mesoanalysis. NOAA Tech. Memo., NWS NSSFC-5, Kansas City, Mo.

Galway, J.G., 1956: The lifted index as a predictor of latent instability. Bull. Amer. Meteor. Soc., 37, 528-529.

Hess, S.L., 1959: Introduction to Theoretical Meteorology. Henry Holt and Co., 362 pp.

Maddox, R.A., 1979: A methodology for forecasting heavy convective precipitation and flash flooding. Nat. Wea. Digest, No. 4, 32-42.

Miller, R.C., 1972: Notes on analysis and severe-storm forecasting procedures of the Air Force Global Central. AWS TR 200(Rev). Hdqrtrs. Air Weather Service, Scott AFB, Ill., 101 pp.

National Weather Service: Raob analysis program. AFOS Southern Region Program Note 13. Fort Worth, Tex, 4 pp.

National Weather Service, 1977: Stability Indices. NOAA Tech. Proc. Bull. No. 207, Silver Spring, Md, 8 pp.

Showalter, A.K., 1953: A stability index for thunderstorm forecasting. Bull. Amer. Meteor. Soc., 6, 250-252.

QUESTIONS

1. Dry adiabats on the Pseudo-adbiatic chart are labeled in degrees Kelvin (or absolute). How are these values of the dry adiabats derived?

2. Pseudo-adiabats on the Pseudo-adbiatic chart generally contain two labels. What are those labels?

3. What two factors will change the equivalent potential (or wet-bulb potential) temperature of a parcel of air.

4. Can the specific humidity be approximated from the Pseudo-adiabatic chart? How?

5. Explain the difference between isobaric equivalent temperature and adiabatic equivalent temperature. Which is larger?

6. What factor is responsible for the virtual temperature being greater than the actual temperature? When would the two be the same?

7. Equivalent potential temperature and wet-bulb potential temperature are both conservative during moist and dry adiabatic processes. Are they equal?

8. Nearly all the procedures routinely used to evaluate the stability of the atmosphere are manipulations of the so-called "parcel method". Briefly explain this concept.

9. Explain the difference between stable and unstable.

10. Dry adiabats have a greater slope (temperature lapse rate) than pseudo-adiabats in the lower part of the Pseudo-adiabatic chart. However, the two become parallel in the upper part of the chart. What causes this? Explain.

11. What is the equilibrium level. Do you think the equilibrium level may be more significant than the height of the tropopause for determining overshooting tops with thunderstorms? Why?

12. Define conditional instability.

13. Define convective instability.

14. What is the greatest value of a stability index?

15. What is the greatest disadvantage of the Showalter Index? Under what conditions can this disadvantage actually become an advantage?

16. What do you feel is the importance of considering the surface layer in the development of an index such as the Lifted Index. What is the chief disadvantage of the Lifted Index?

17. The K Index is generally applicable to what type of convection?

18. Is a Total Totals Index of 58 necessarily indicative of severe weather? What other factors or indices must be considered?

19. Which index is best indicative of convection in your area? Why?

20. What is the chief advantage of the AFOS RAOB ANALYSIS Program ANALYZ?

21. The Convective Condensation Level is the best indicator of what?

22. The LCL for a surface parcel is always found at or below the CCL. True or False?

23. The Level of Free Convection and the Equilibrium Level both consider the environmental temperature and the parcel temperature. What are the differences?

24. What does negative area infer with respect to a parcel of air? Positive area?

25. Assuming a detailed analysis is made of the early morning soundings. Does this mean the analysis will be correct six hours later? Why?