SKEW-T, LOG-P DIAGRAM
ANALYSIS PROCEDURES

I.   THE SKEW-T, LOG-P DIAGRAM

The primary source for information contained in this appendix was taken from the Air Weather Service Technical Report TR-79/006.[1] The Skew-T, Log-P Diagram is the standard thermodynamic chart in use in most United States weather service offices today. This diagram is a graphic representation of pressure, density, temperature, and moisture, in a manner such that the basic atmospheric energy transformations are visually depicted. A unit of area on the diagram represents a specific quantity of energy. This diagram, when plotted with the various meteorological elements received from an upper air sounding, presents a vertical picture of the atmospheric conditions present at the time of observation and allows for computations of various parameters required by forecasters. The Skew-T, Log-P diagram is preferred because: (a) most of the important isopleths are straight rather than curved, (b) the angle between the adiabats and isotherms is large enough to facilitate estimates of the stability, (c) the ratio of area on the chart to thermodynamic energy is the same over the whole diagram, (d) the vertical in the atmosphere approximates the vertical coordinate of the diagram (i.e. the isobars are plotted to a logarithmic scale and pressure in the atmosphere decreases nearly logarithmically with height), and (e) an entire sounding to levels in the stratosphere can be plotted on one chart.

The "parcel" method is the process used in determination of unmeasured parameters and analysis of the characteristics of the atmosphere above a station. In the parcel method, a small quantity of air is moved upward or downward in the atmosphere and the changes to its characteristics are determined and compared with the surrounding, unchanged air. One might imagine this parcel to behave as a very thin balloon, which expands or contracts as the parcel moves upward or downward, but which does not allow mixing with the surrounding air. This is, of course, somewhat unrealistic since as air rises (e.g., as thermals) or sinks, it mixes, to some extent, with the surrounding air.

The Skew-T, Log-P diagram is also considered a "pseudo-adiabatic diagram" in that it is derived from the assumption that the latent heat of condensation is used to heat the air parcel, and that condensed moisture falls out immediately. Similarly, the above assumption does not represent the observed changes which occur as air is lifted. However, the results are sufficiently accurate to provide estimates in the right order of magnitude, and when used with other forecasting considerations, will prove useful.
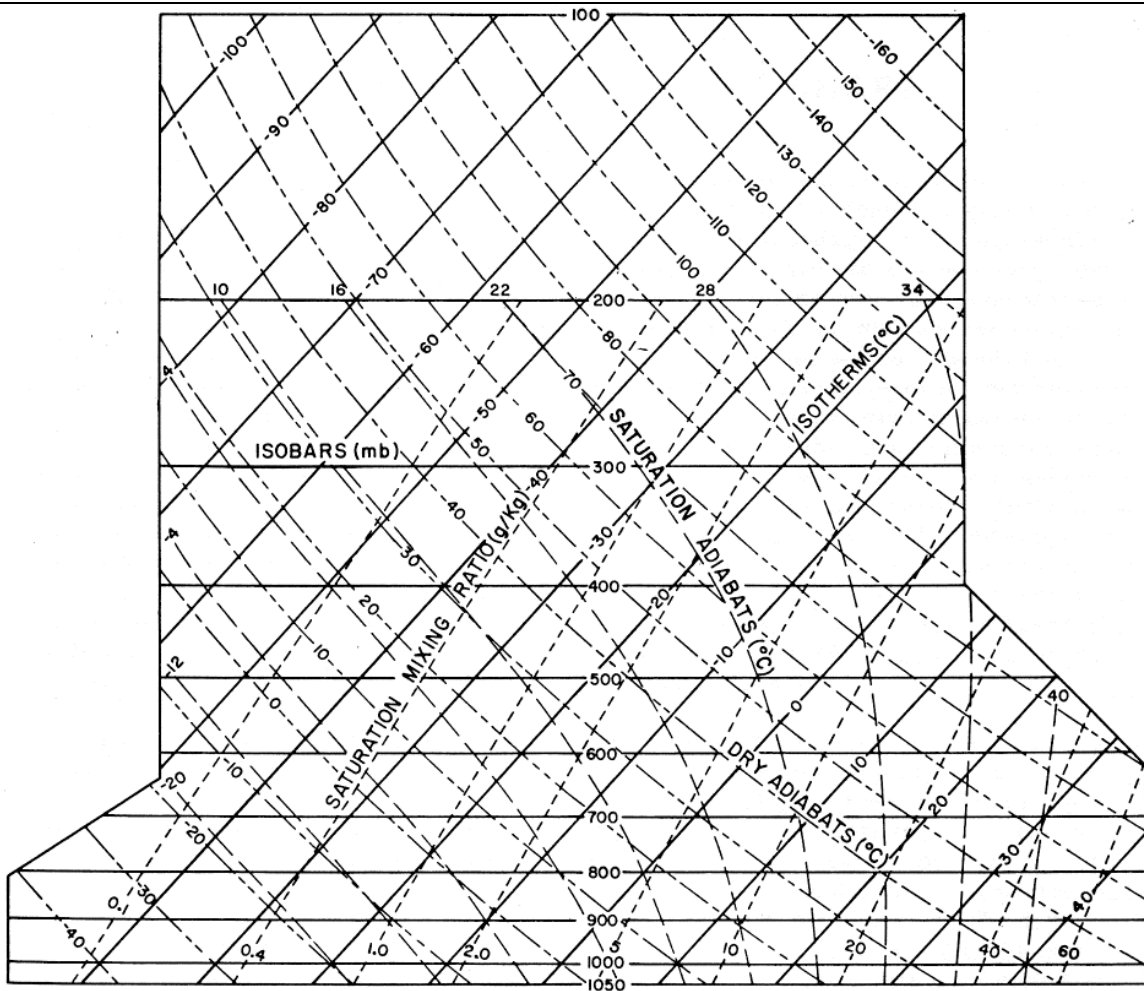
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FIG. 1. Coordinate system of the Skew-T, Log-P Diagram.

A. Diagram Description

    The standard Skew-T, Log-P diagram for general use is a large, multi-colored (brown, green, and black) chart with numerous scales and graphs superimposed upon each other. The five basic lines are shown in figure 1.
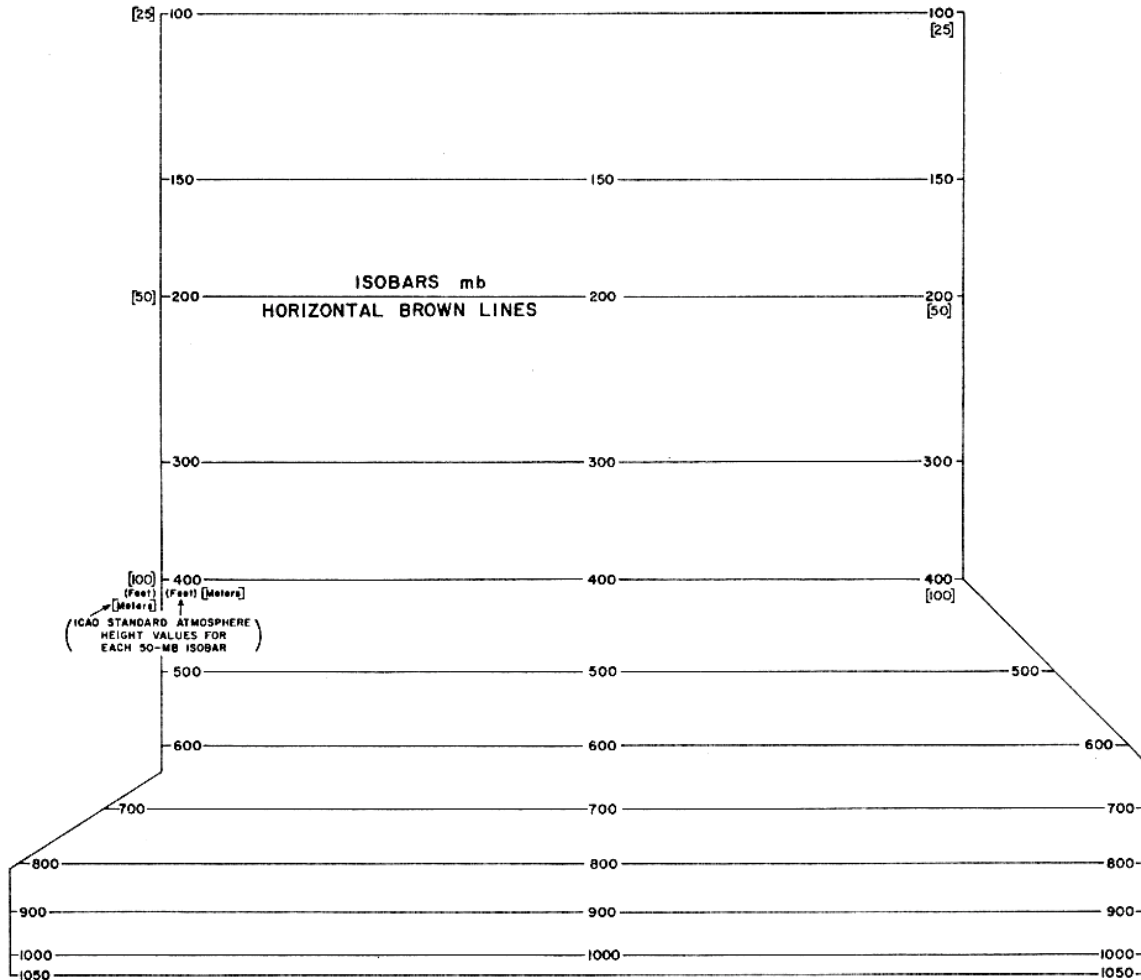
ISOBARS mb
HORIZONTAL BROWN LINES

[25] 100 ... 100 [25]
150 ... 150
[50] 200 ... 200 [50]
300 ... 300
[100] 400 ... 400 [100]
(Feet) (Feet) [Meters]
[Meters]
(ICAO STANDARD ATMOSPHERE
HEIGHT VALUES FOR
EACH 50-MB ISOBAR)
500 ... 500
600 ... 600
700 ... 700
800 ... 800
900 ... 900
1000 ... 1000
1050 ... 1050

FIG. 2. Isobars on the Skew-T, Log-P Diagram.

1. Isobars

Isobars, figure 2, are horizontal, solid, brown lines spaced logarithmically for 10-mb intervals. Pressure-value labels are printed at both ends and in the center of the chart for each 50-mb interval. The upper portion of the chart from 400 to 100 mb is also used for pressure values from 100-25 mb. Labels for the latter range are printed in brackets at the ends of the appropriate isobars. ICAO Standard Atmosphere height values are shown under appropriate isobar labels on the left side. The values are given in both feet (in parentheses) and meters [in brackets]. The height values for the range from 1000 to 100 mb are printed to the right of the left edge of the grid; those for the range from 100 to 25 mb are printed to the left of this boundary.
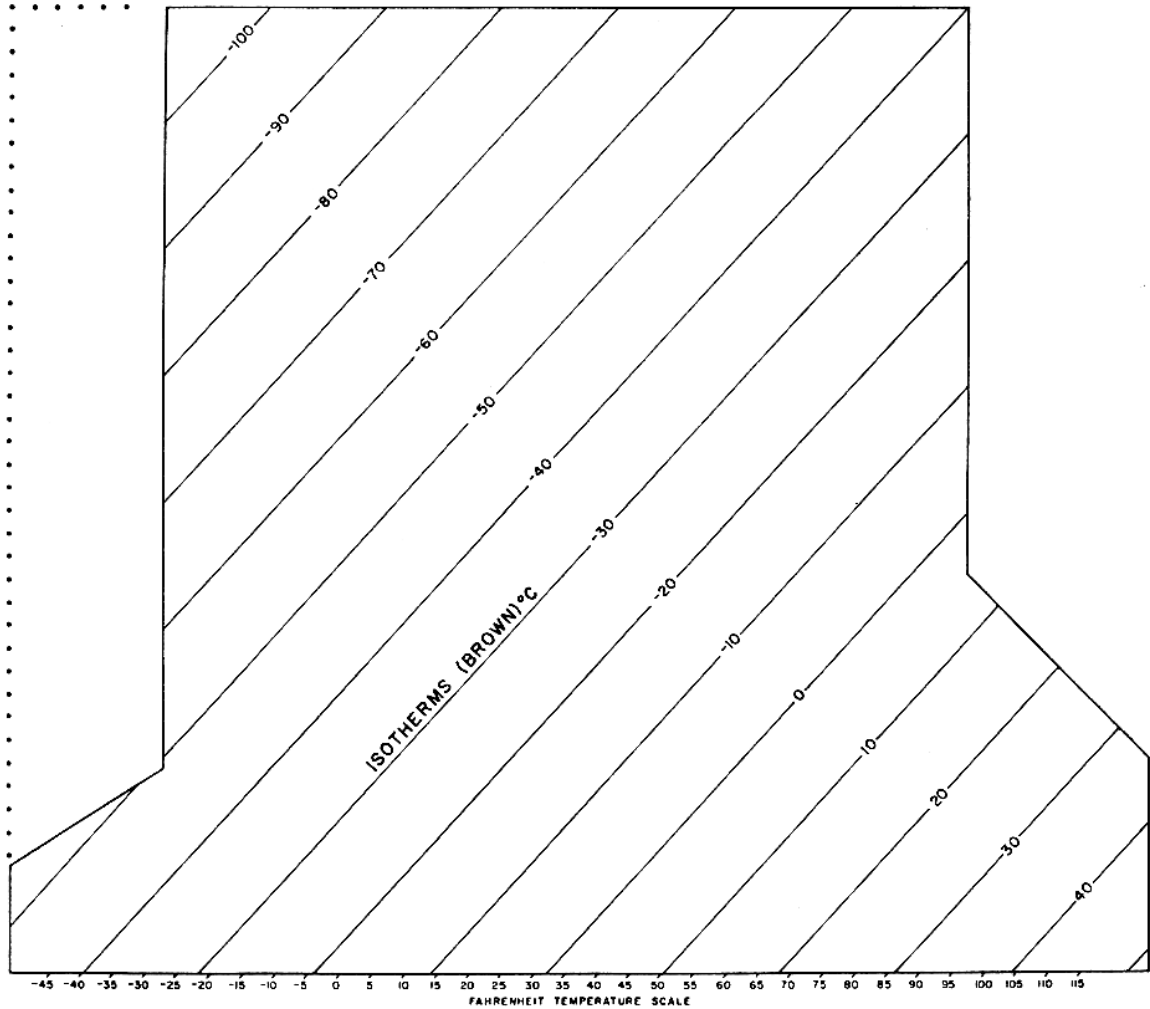
FIG. 3. Isotherms on the Skew-T, Log-P Chart.

2. Isotherms

Isotherms, figure 3, are the straight, solid, brown lines sloping from the lower left to the upper right with the spacing equal throughout the diagram. Isotherms are labeled for 5°C intervals, with alternate 10°C temperature bands tinted green. A Fahrenheit temperature scale is printed along the bottom edge of the chart to coincide with the appropriate Celsius isotherms.
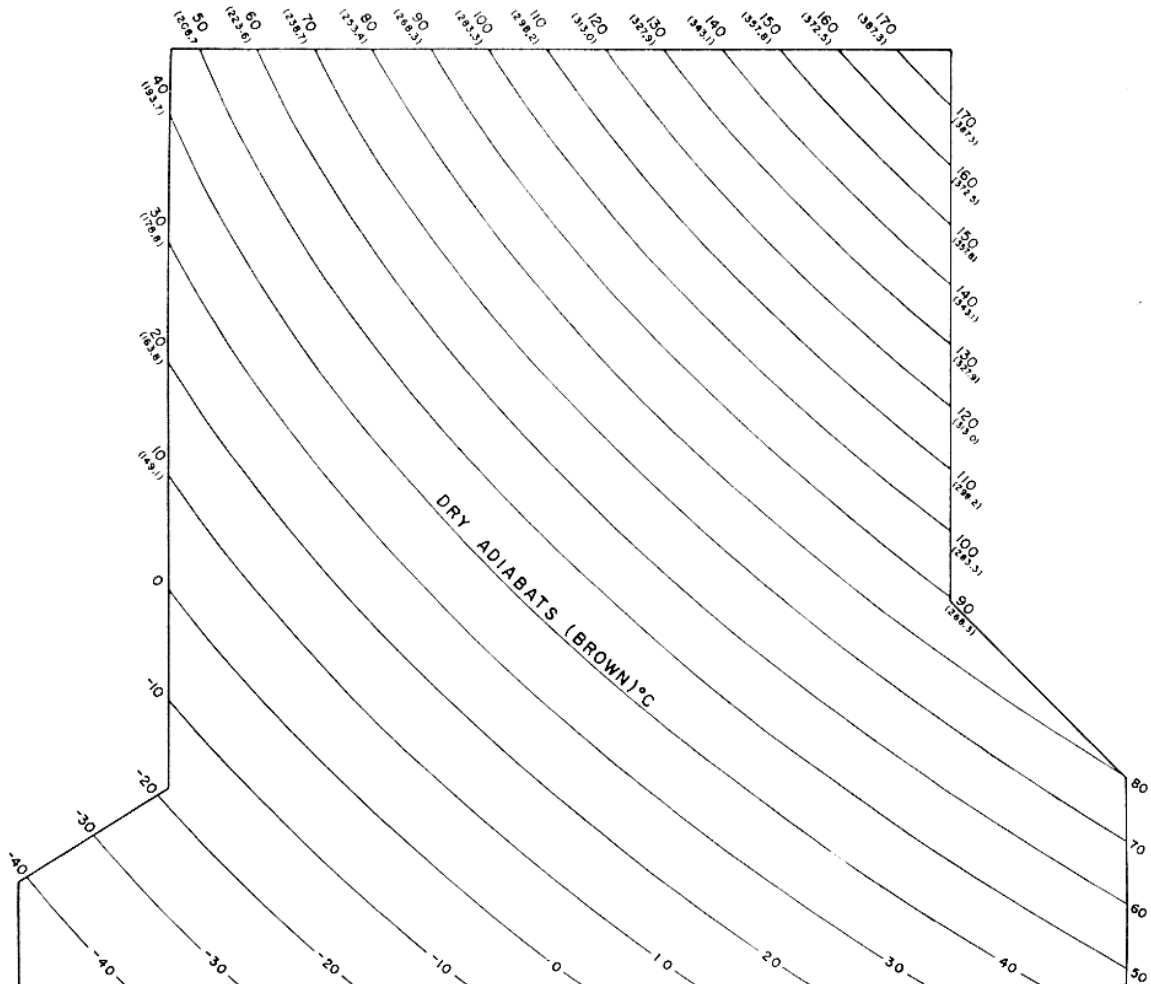
FIG. 4. Dry adiabats on the Skew-T, Log-P Diagram.

3. Dry Adiabats (Γ_d) or Lines of Constant Potential Temperature

Dry adiabats, figure 4, are the slightly curved, solid, brown lines that slope from the lower right to the upper left. They indicate the rate of temperature change in a parcel of dry air which is rising or descending adiabatically when no change of state is occurring with water; e.g., no moisture is changing from vapor to liquid or solid, or solid to liquid to vapor, i.e. with no loss or gain of heat by the parcel. Dry adiabats are labeled for each multiple of 10^oC along the bottom of the chart between 1000-mb and 1050-mb. The dry adiabats are also labeled along the right side of the chart above 400-mb, along the right side of the chart above 800-mb and along the top of the chart. Along the top, the adiabats are labeled twice, to include values (in parentheses) for the 100- to 25-mb pressure range.
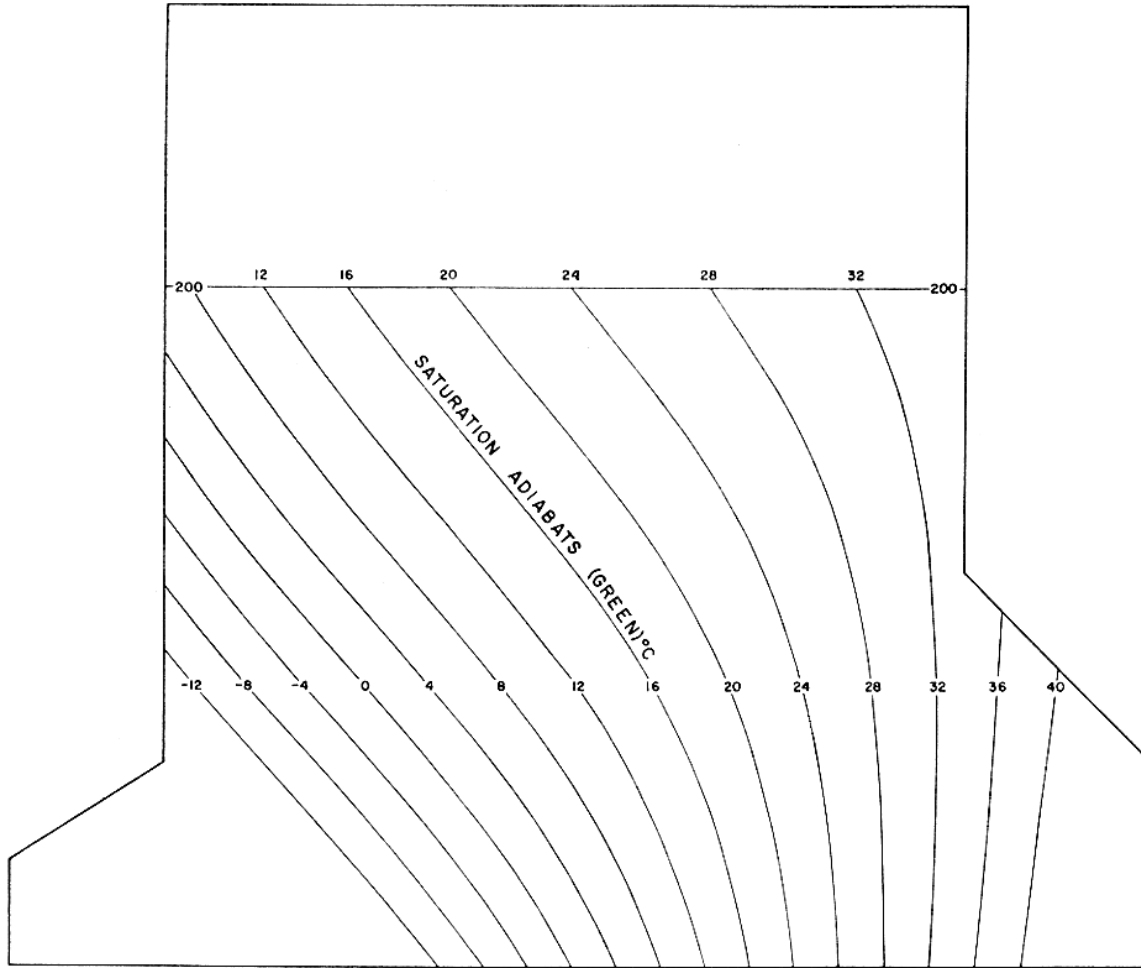
FIG. 5. Saturation adiabats on the Skew-T, Log-P Diagram.

4. Saturation Adiabats (Γ_S)

Saturation adiabats, also called moist or wet adiabats, figure 5, are the slightly curved, solid, green lines sloping from the lower right to the upper left, except those on the extreme right. They indicate the temperature change experienced by a saturated parcel of air rising pseudo-adiabatically through the atmosphere. Pseudo-adiabatic means all the condensed water vapor is assumed to fall out (precipitate) immediately as the air rises. Saturation adiabats intersect the 1000-mb isobar at intervals of 2^{O}C and are labeled in green with the value of the temperature at the point of intersection. Values are printed between the 500-mb and the 550-mb isobars and increase from left to right. Saturation adiabats tend to become parallel to the dry adiabats at low values of moisture, temperature, and pressure. They extend only to the 200-mb isobar because humidity observations are not routinely obtainable from higher altitudes with present standard instruments.
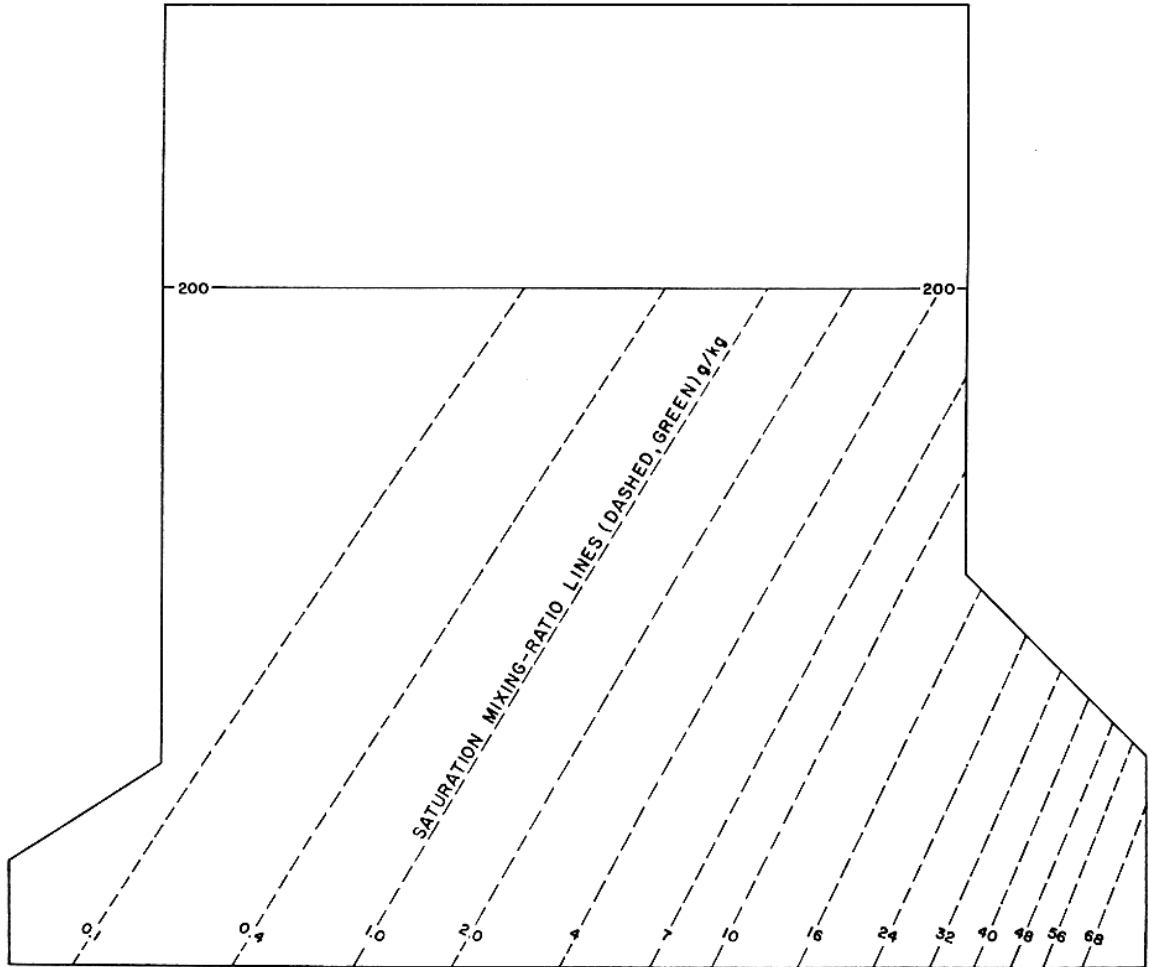
FIG. 6. Saturation Mixing-Ratio lines on the Skew-T, Log-P Diagram.

5. Saturation Mixing-Ratio Lines (ω_S)

Saturation mixing-ratio lines, figure 6, are the slightly curved, dashed, green lines sloping from the lower left to the upper right. Saturation mixing-ratio lines are labeled in parts of water vapor per 1000 parts of dry air (grams/kilogram). Values are printed in green between the 1000-mb line and the 950-mb line.
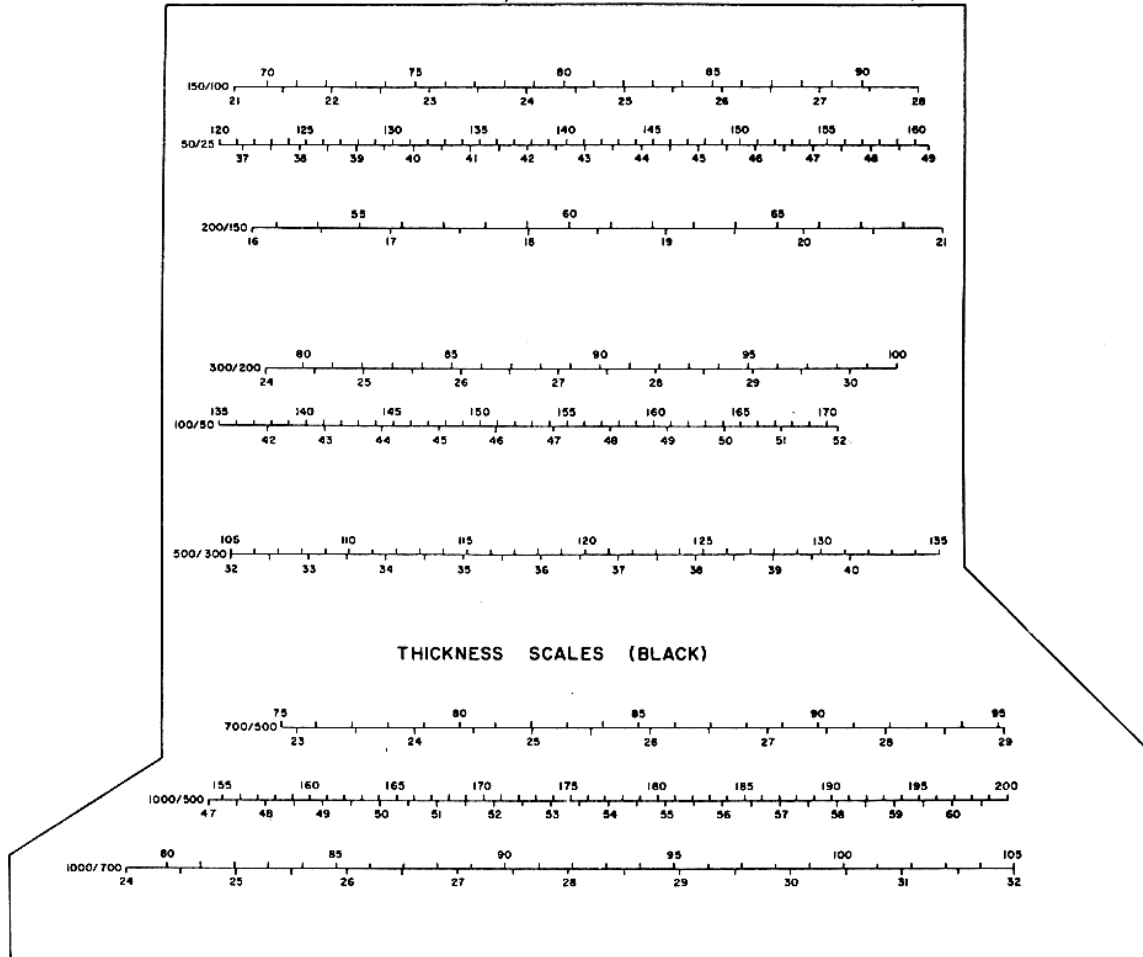
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FIG. 7. Thickness Scales on the Skew-T, Log-P Chart

6. Thickness Scales

The nine thickness scales on the Skew-T, Log-P diagram, see figure 7, are the horizontal, graduated, black lines, each of which is placed midway between the two standard-pressure isobars to which it applies. The bounding pressures of the layer for each scale are labeled at its left end. Scales are included for the following layers: 1000 to 700 mb, 1000 to 500 mb, 700 to 500 mb, 500 to 300 mb, 300 to 200 mb, 200 to 150 mb, 150 to 100 mb, 100 to 50 mb, and 50 to 25 mb. The scales are graduated along the top in 20's or 10's and labeled in hundreds of geopotential feet. Along the bottom they are graduated in 10's and labeled in 100's of geopotential meters.

Geopotential height is the height of a given point in the atmosphere in units proportional to the potential energy of a unit mass at this height, relative to sea level.

$$H = \frac{1}{9.8 \, m/s^2} \int_0^z g \, dz$$

where g is the acceleration of gravity. Geopotential is defined to compensate for the decrease of the acceleration of gravity, g, above the earth's surface. The following equations convert between geopotential height, H, and true height, z.

$$H = R_0 \cdot \frac{z}{(R_0 + z)} \text{ and } z = R_0 \cdot \frac{H}{R_0 - H}$$

where R_0 = 6356.766 km, the radius of the earth. An air parcel raised to height z would have the same potential energy as if lifted only to height H under constant gravitational acceleration. By using H instead of z, we can use g = 9.8m/s^2 as a constant in our equations; however, the height obtained, H, would be slightly lower than the true height.
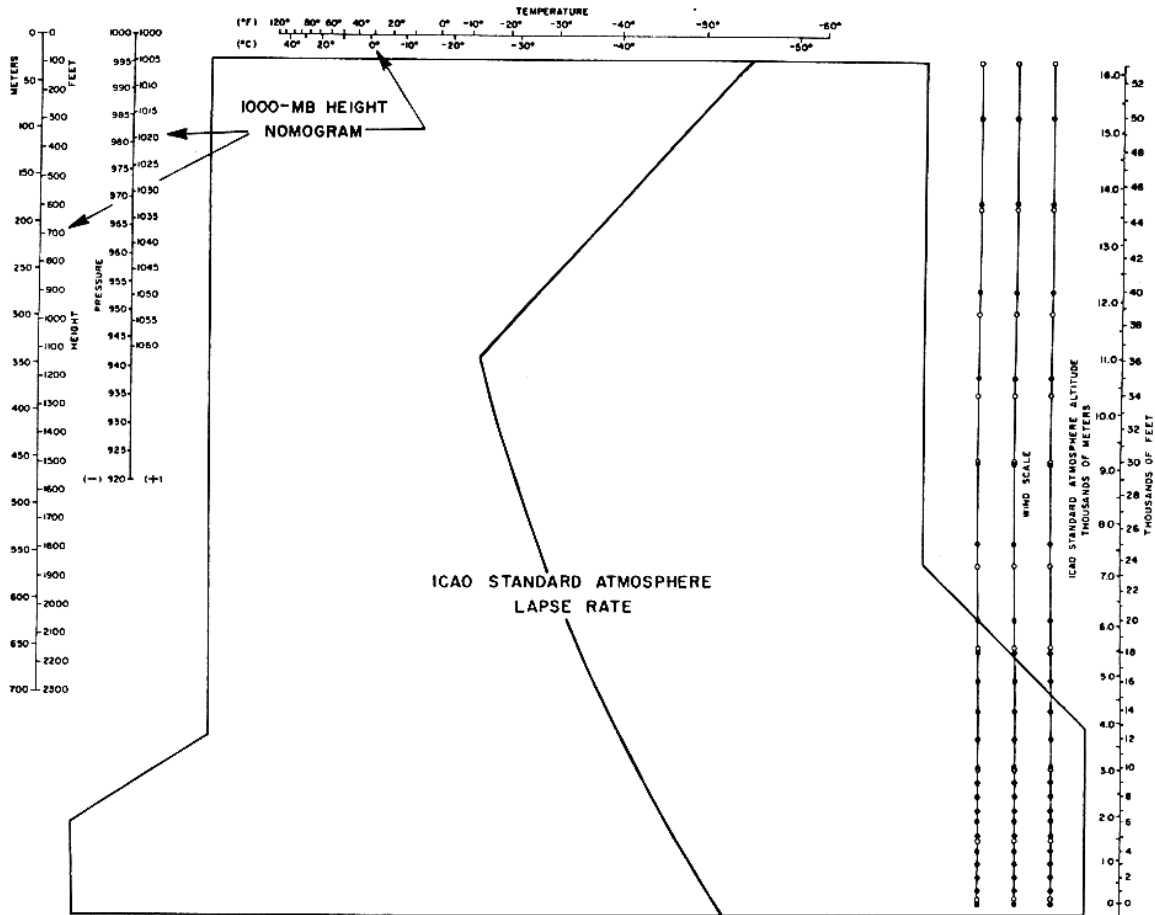

FIG. 8. Auxiliary Scales on the Skew-T, Log-P Chart

7. 1000-mb Height Nomogram

The 1000-mb height nomogram, printed on the full-scale version only, is shown in figure 8. It consists of three black scales:

    a. A temperature scale in whole °C and °F, extending horizontally along the top of the chart.

b. A pressure scale in whole millibars, extending vertically along the left side of the chart.

c. A height scale in geopotential whole feet and meters, parallel to the pressure scale.

The 100-mb height nomogram is used to determine the height of the 1000-mb surface in geopotential feet above mean sea level.

8. ICAO Standard Atmosphere

The ICAO standard atmosphere (temperature vs. height) is printed on the chart as a thick, solid, brown line passing through the point at 1013 mb and 15°C. The position of the line is also illustrated in figure 8. The height of pressure surfaces in this standard atmosphere up to 100 mb are indicated on the vertical scale (labeled ICAO STANDARD ATMOSPHERE) printed on the right side of the chart. This scale is graduated in geopotential meters and feet. The heights of standard-pressure surfaces are also printed at the left margin of the chart beneath each pressure value as indicated previously.

9. Wind Scale

Three vertical staffs labeled WIND SCALE are printed along the right side of the chart for use in plotting upper-wind data. Solid circles on the staffs indicate heights for which wind data are usually reported; the open circles on the staffs are for wind data for mandatory pressure surfaces. See figure 8.

10. Contrail Formation Curves

Contrail formation curves are printed only on the full-scale version of the chart. Contrail formation curves are represented by slightly curved, thin, solid black lines sloping from the lower left to the upper right between the 500 and 100-mb lines and by dashed, thin black lines between the 100 and 40-mb lines. Curve values appear between the 160 and 150-mb lines.

11. Refractivity Grid

On the full-scale version of the Skew-T, Log-P chart, the refractivity grid is represented by heavy black lines. This black grid is used to compute refractivity from the formula $N = N_D + N_W = 77.6 \text{ p/T} + 373256 \text{ e/T}^2$. N_D is read at the dry-bulb temperature against the heavy black lines sloping down from the upper left to the lower right and labeled from 350 to 40. To find N_W, go from the dry-bulb temperature along the light, black lines sloping upwards to the left to intersect with the mixing-ratio line through the dew point and read N_W against the heavy black lines sloping steeply upwards from the lower left to the upper right and labeled from 340 to 1. Add N_D and N_W to obtain the refractivity. For pressures lower than 100 mb, multiply by 10, plot 80 mb at 800 mb, etc., and use one-tenth of the N_D values on the grid.

II.   PLOTTING THE DIAGRAM

The data used for plotting on the Skew-T, Log-P chart are obtained from a variety of sources, including radiosondes, dropsondes, aircraft soundings, rocketsondes, and upper-wind reports of pibals or rawinsondes.

In normal operations, one chart is used for each reporting station, and not more than two soundings from new data are plotted on it. In addition, a trace from a previous sounding should be entered on the chart for continuity purposes. There should be a 12-hour time interval between each set of curves. Thus, if four soundings per day are plotted, two charts would be used, one for the 0000Z and 1200Z sounding plus the trace of the previous day's 1200 sounding, and one chart for the 0600Z and 1800 sounding plus the preceding day's 1800Z trace. This procedure permits the analyst to see from one chart the changes in air mass that occur at a particular station between successive primary upper-air analysis times.

A. Choice of Color

The temperature and dew-point curves from the preceding (continuity) sounding should be traced in black ink or pencil without transcription of data or circling of any point. This is usually done before the first new sounding is plotted. The sounding after the "trace" should be plotted in blue pencil, and the sounding 24 hours after the "trace" should be plotted in red pencil. Thus the latest data is plotted in red.

B. Plotting the Data

Next obtain the upper air data for the station being plotted. After decoding the message, the plotting procedures are as follows.

1. Legend Block

Enter the station index number (or location identifier), station name, time (UTC), and date (UTC) in the identification box. Use the same color for legend entries as was used for the corresponding sounding curves.

2. Temperature Curve

On each mandatory and significant level isobar, plot the temperature to the nearest tenths of degree Celsius. Each temperature point is represented by a small dot located at the proper temperature - pressure intersection. A small circle, no more than one-eighth inch in diameter, should be drawn around each dot plotted. A sample curve is shown in figure 9.

The **mandatory levels** are: Surface, 1000-mb, 850-mb, 700-mb, 500-mb, 400-mb, 300-mb, 250-mb, 200-mb, 150-mb, 100-mb, 70-mb, 50-mb, 30-mb, 20-mb, 10-mb, 7-mb, 5-mb, 3-mb, 2-mb, 1-mb.

Significant levels are levels other than the mandatory levels which are required for the reasonable accurate reproduction of a pressure, temperature, or dew-point profile. Usually it represents a change in the slope of the profile.

After plotting all levels for which data was given in the message, connect each point to the next with a solid black, blue or red line, as appropriate. Use a straight edge when drawing the connecting lines between the plotted points.

Where there is a region of missing data, terminate the connecting line at the lower boundary of the missing data region, and start the line again at the upper boundary of the missing data region. Enter the symbol MISDA in the middle of the region of *missing data* in the same color as is used for plotting the connecting line.
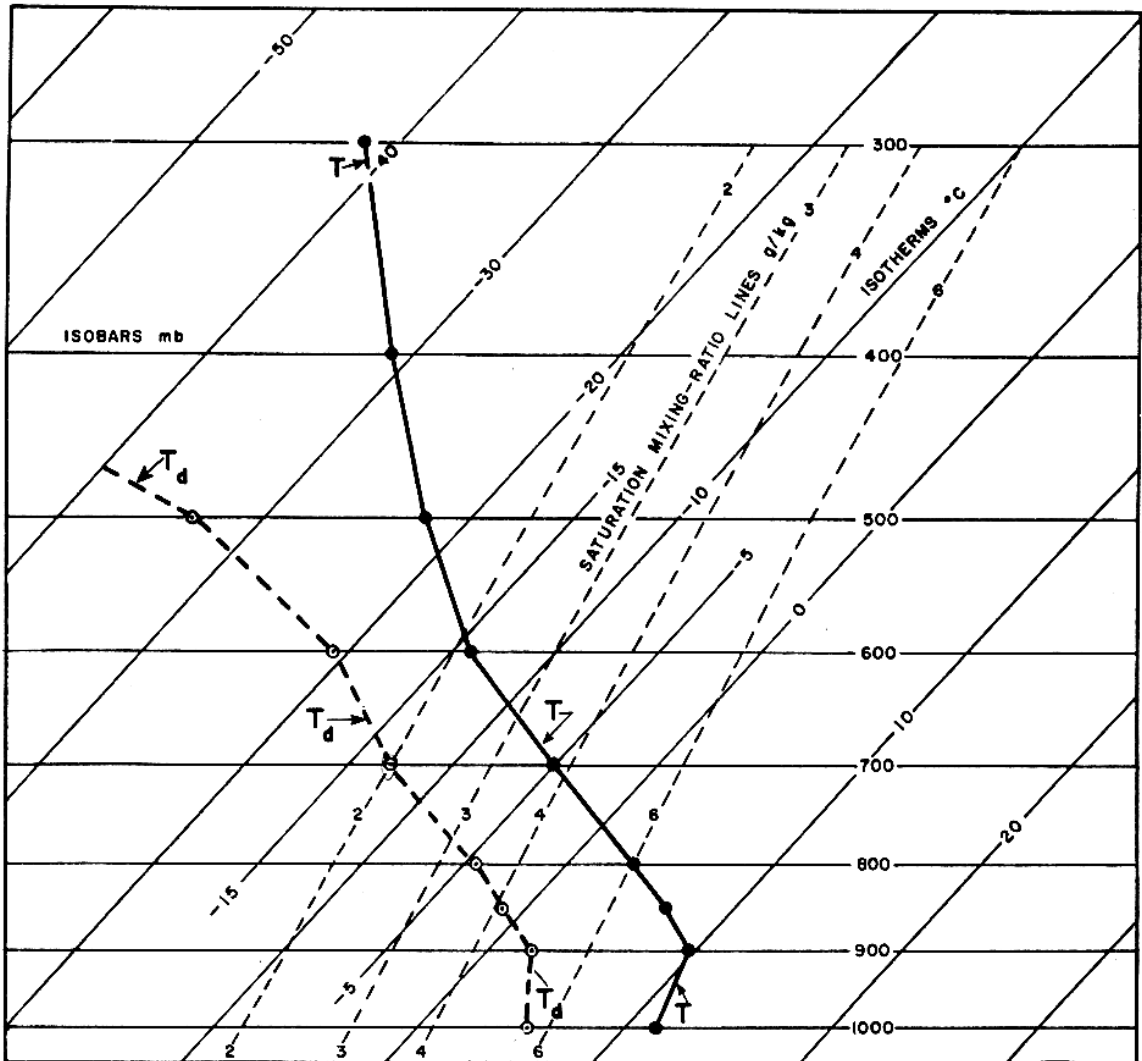

FIG. 9. Sample Sounding on the Skew-T Chart.

3. Dew-Point Temperature Curve

On each mandatory and significant-level isobar for which data is available, plot the dew-point temperature to the nearest tenth of degree Celsius. To obtain the dew-point value, subtract the dew-point depression from the temperature for each level. Each dew-point temperature is represented by a small dot at the proper dew-point temperature-pressure level isobar intersection. A small circle, no more than one-eights in diameter, is drawn about each dot plotted.

The dew-point temperature points are connected by a dashed line in either black ink, blue or red as appropriate. Use a straight edge to draw the connecting line.

For regions of missing data, terminate the line at the lower boundary of the stratus of missing data, and start the curve again at the upper boundary. Enter **MISDA** in the middle of the stratum of missing data in the same color as which the line is plotted. When humidity data is missing due to humidity values being too low for the sensor to measure enter **MB** (meaning "motorboating"). Above the last reported dew-point value enter **MB ABOVE**.

4. Pressure-Altitude Curve

Since the atmosphere above a station is not equivalent to the ICAO standard atmosphere, a pressure altitude curve must be plotted which represents the actual heights of pressure surfaces in the atmosphere. To plot the pressure altitude curve, a modification of the chart must be made. Starting with the 40- degree isotherm on the right side of the chart, label it 0 meters and for every succeeding 10-degree isotherm, label in 1500 meter increments (30° = 1500 meters, 20° = 3000 meters, etc.). See figure 10. Next, for each mandatory level, enter the height value, from the message, on its respective isobar along the right side of the chart. Now, plot each height along the appropriate isobar at the point where the correct re-labeled isotherm line intersects the isobar. Remember, every isoheight (re-labeled isotherm) line now equals 150 meters. Enclose each plotted point in a square box. In many cases you will have to interpolate between two isotherm-isoheight lines to arrive at the reported height. Finally, connect all the plots with a solid black, blue, or red line.
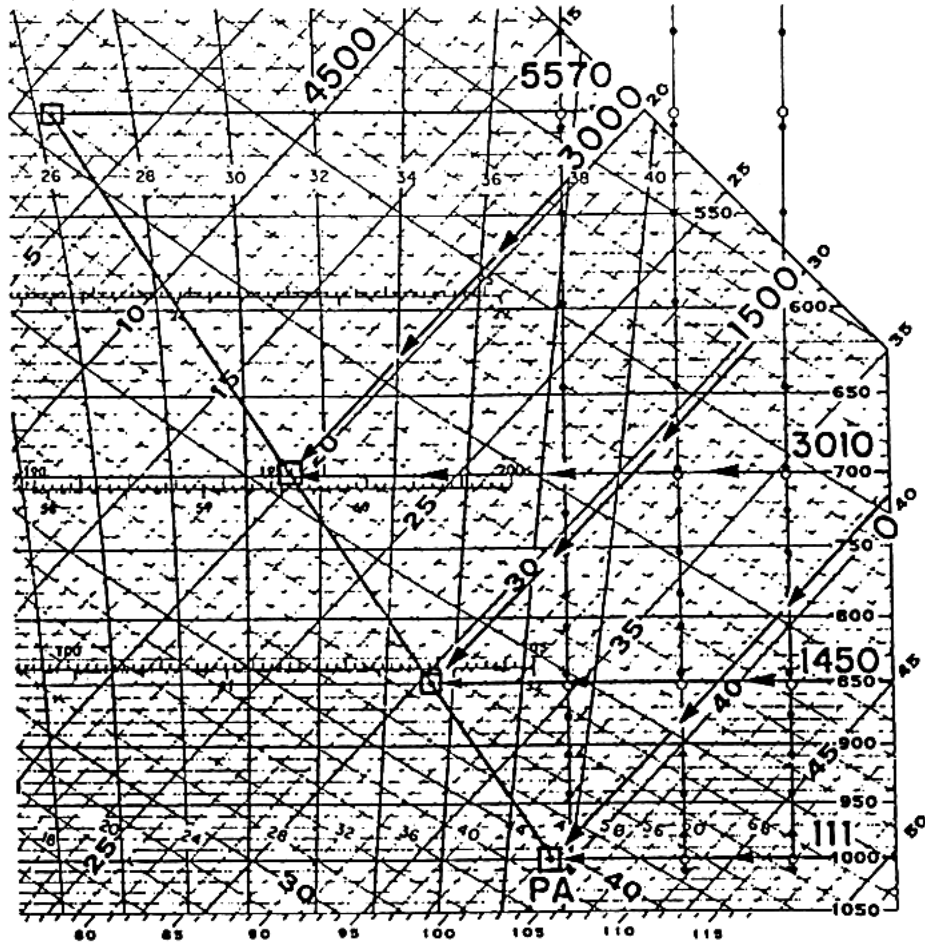
FIG. 10. Plotted Pressure-Altitude Curve

III. DETERMINATION OF UNREPORTED METEOROLOGICAL ELEMENTS FROM PLOTTED SOUNDING DATA

A. Mixing Ratio (ω)

The mixing ratio is the mass of water vapor in a volume of air to the mass of dry air in the same volume, expressed in parts-per-thousand of mass (as, gram per kilogram).

1. Procedure: At the intersection of the environmental dew-point temperature line and the desired pressure level, interpolate the mixing ratio value horizontally along the pressure level line between the value of the dashed green saturation mixing-ratio line (ω_s) on either side of the intersection. The dew-point temperature is used since it gives a measure of how much moisture actually is in the air. On the sounding shown in figure 9, T_d at 700 mb is -13°C; and the saturation mixing-ratio line passing through -13°C is 2.0 g/kg. Hence, the mixing ratio of the air at the 700-mb level on the sounding is 2.0 g/kg.

B. Saturation Mixing Ratio (ω_S)

The saturation mixing ratio is the mixing ratio a parcel of air would have if it were saturated. Thus, it is the mass of water vapor in a volume of air to the mass of dry air in the same volume when the air is saturated.

1. Procedure: At the intersection of the environmental temperature line and the desired pressure level, interpolate the saturation mixing ratio value horizontally along the pressure level between the value of the dashed, green saturation mixing ratio lines (ω_S) on either side of the intersection. The temperature value is use since it gives an indication of the amount of moisture the air could hold. On the sounding shown in figure 9, T at 700 mb is -5°C; and the saturation mixing-ratio value at 700 mb and -5°C is interpolated to be 3.8 g/kg. Hence the saturation mixing ratio (the amount of moisture the air could hold) at the 700-mb level is 3.8 g/kg.

C. Relative Humidity (RH)

Relative humidity is the ratio (in percent) of the mixing ratio, or vapor pressure, of water vapor in a given volume of air to the saturation mixing ratio, or saturation vapor pressure of the same volume.

1. Procedure: The relative humidity can be calculated from the mixing ratio (ω) and the saturation mixing ratio (ω_S) by the following equation:

$$\textbf{Relative Humidity} = \frac{\omega}{\omega_s} \times \textbf{100}$$

2. Alternate Procedure:

The alternate procedure for determining relative humidity is shown graphically in figure 11, and described below:

a. At the pressure level for which relative humidity is desired, start at the dew point temperature value and follow parallel to the saturation mixing ratio line (ω_S) to the 1000-mb pressure level.

b. From this intersection, draw a line upward parallel to the isotherm lines.

c. From the pressure level for which relative humidity is desired, start at the temperature value and draw a line parallel to the saturation mixing ratio line (ω_S) to the intersection with the line drawn in step b. The numerical value of the isobar through this last intersection divided by ten is the percent relative humidity.
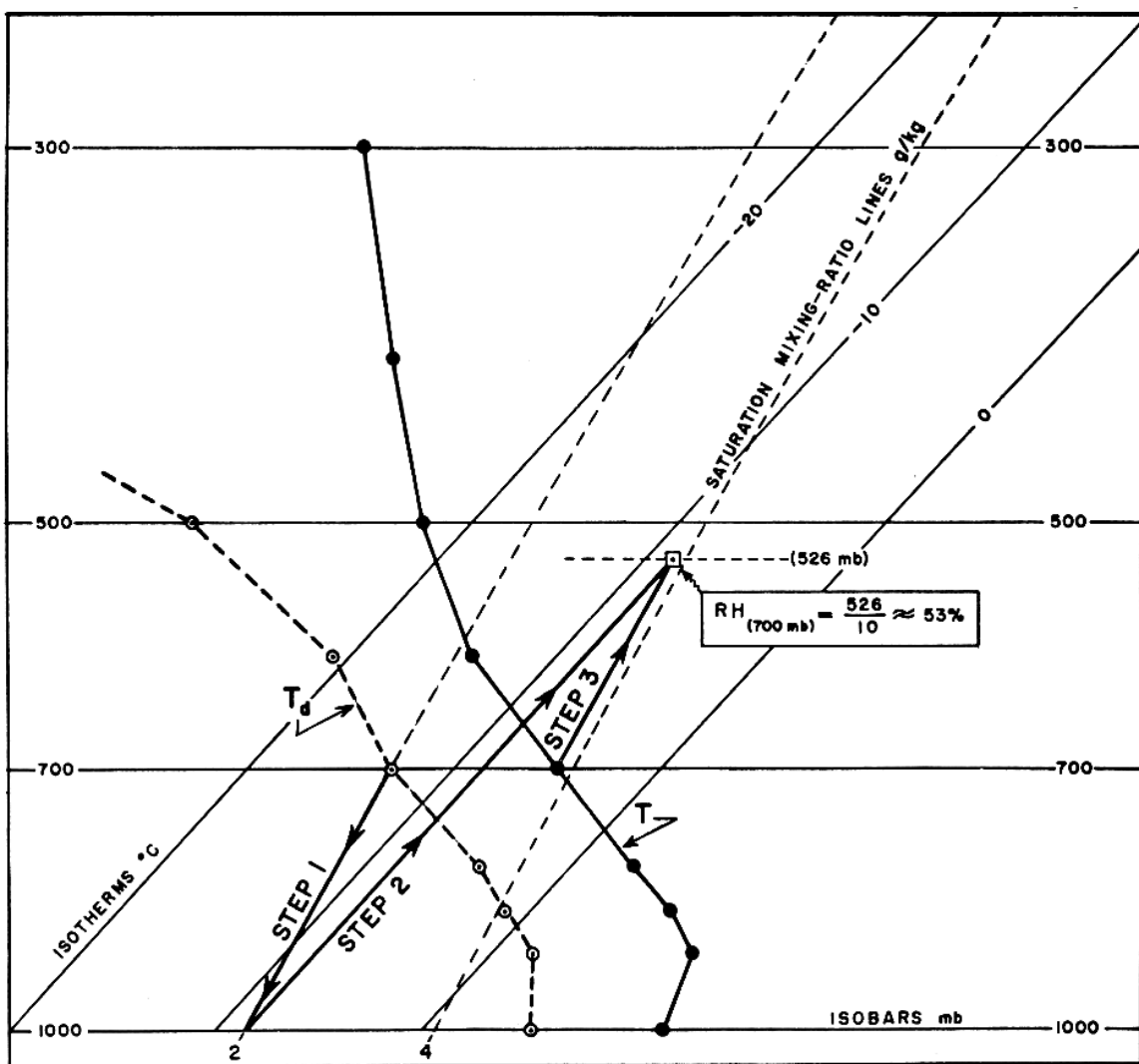

FIG. 11. Alternate Procedure for finding Relative Humidity

D. Vapor Pressure (e)

Vapor pressure is the partial pressure exerted by water vapor molecules in a given volume of air.

1. Procedure: As shown by figure 12, from the pressure level at which e is desired, start at the environmental dew-point temperature value (T_d), and go parallel to the isotherm lines to the 622-mb isobar. Read the saturation mixing ratio value at this point. This value is the vapor pressure in millibars for the original level, since:

$$e = \frac{\omega P}{.622}$$

The value .622 is the ratio of the gas constant for dry air (287.053J/$^\circ$K·kg)and that for water vapor (461J/$^\circ$K·kg). The example in figure 12 shows the dew point temperature at 700 mb to be approximately -13°C. Following upward, parallel to the isotherms to 622 mb and interpolating the saturation mixing ratio value gives a value of 2.3 mb for the vapor pressure.

E. Saturation Vapor Pressure (e_S)

The saturation vapor pressure is the partial pressure exerted by water vapor in a given volume of air when the vapor is saturated at the current temperature.

1. Procedure: The procedure is the same as with determination of the vapor pressure except the starting point is the temperature value at the desired level. See figure 12. From the pressure level at which e_S is desired, start at the environmental temperature value, (T) and go parallel to the isotherms to the 622-mb level. Read the saturation mixing ratio value at this point. This is the saturation vapor pressure in millibars for the original level.
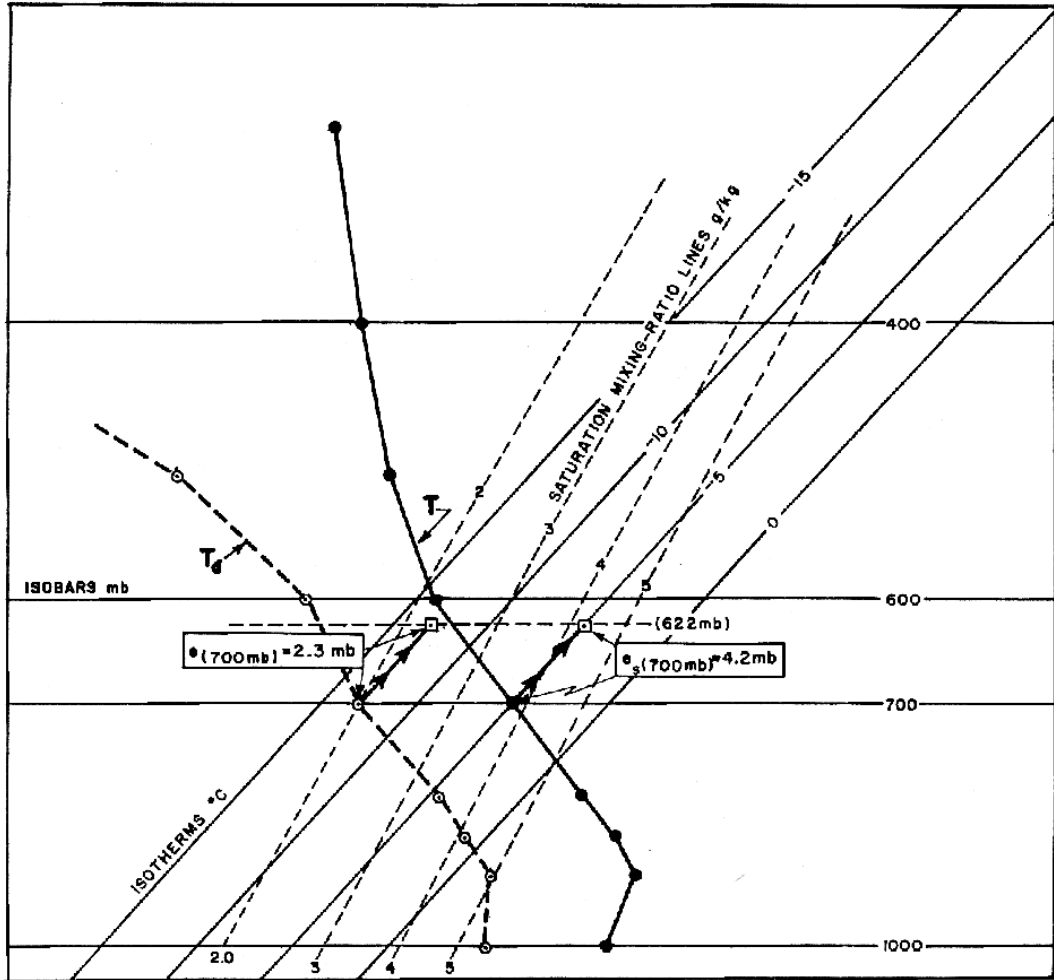
FIG. 12. Determination of the vapor pressure and the saturation vapor pressure

F. Potential Temperature (θ)

Potential temperature (θ) is the temperature that a parcel of dry air would have if it were brought dry-adiabatically from its initial state to a pressure of 1000 mb.[2]

1. Procedure: From the environmental temperature value at the pressure level for which potential temperature is desired, follow parallel to the dry adiabats to the 1000-mb level, as shown in figure 13. The value of the temperature at the intersection of the dry adiabat and the 1000-mb isobar is the potential temperature. Since the dry adiabats are labeled with the value of the isotherm they intersect at the 1000-mb surface, the potential temperature is also the value of the dry adiabat which passes through the environmental temperature value at the desired pressure level.   It is customary to expresses potential temperature in ^{O}K.   Convert the potential temperature to ^{O}K by adding 273° to the Celsius temperature value.
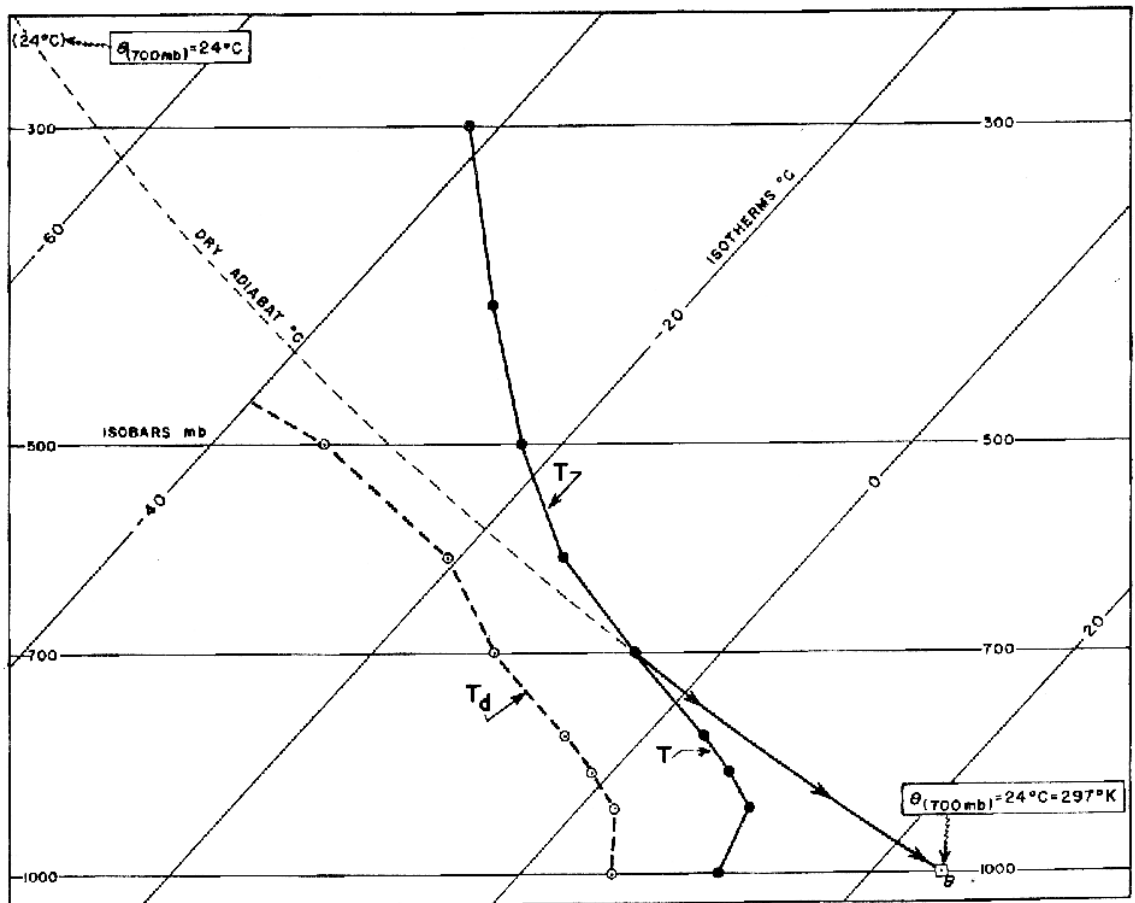

FIG. 13. Determination of the potential temperature

G. Wet-Bulb Temperature (T_W)

The wet-bulb temperature is the lowest temperature to which a volume of air at constant pressure can be cooled by evaporating water into it. Physically, the wet-bulb temperature is the temperature of the wet-bulb thermometer rather than of the air.

1. Procedure: Figure 14 illustrates the method of finding the wet-bulb temperature for a given pressure level.

a. From the dew-point at the level for which the wet-bulb temperature is desired, draw a line upward parallel to the saturation mixing-ratio lines.

b. From the temperature value at the desired pressure level, draw a line upward parallel to the dry adiabat lines to where it intersects the line drawn in 1.

c. From this intersection point, follow parallel to the saturation adiabats back to where it intersects the original pressure level. The temperature value at this last intersection is the wet-bulb temperature.

In the example shown in figure 14, T_W (700 mb) = -8°C.
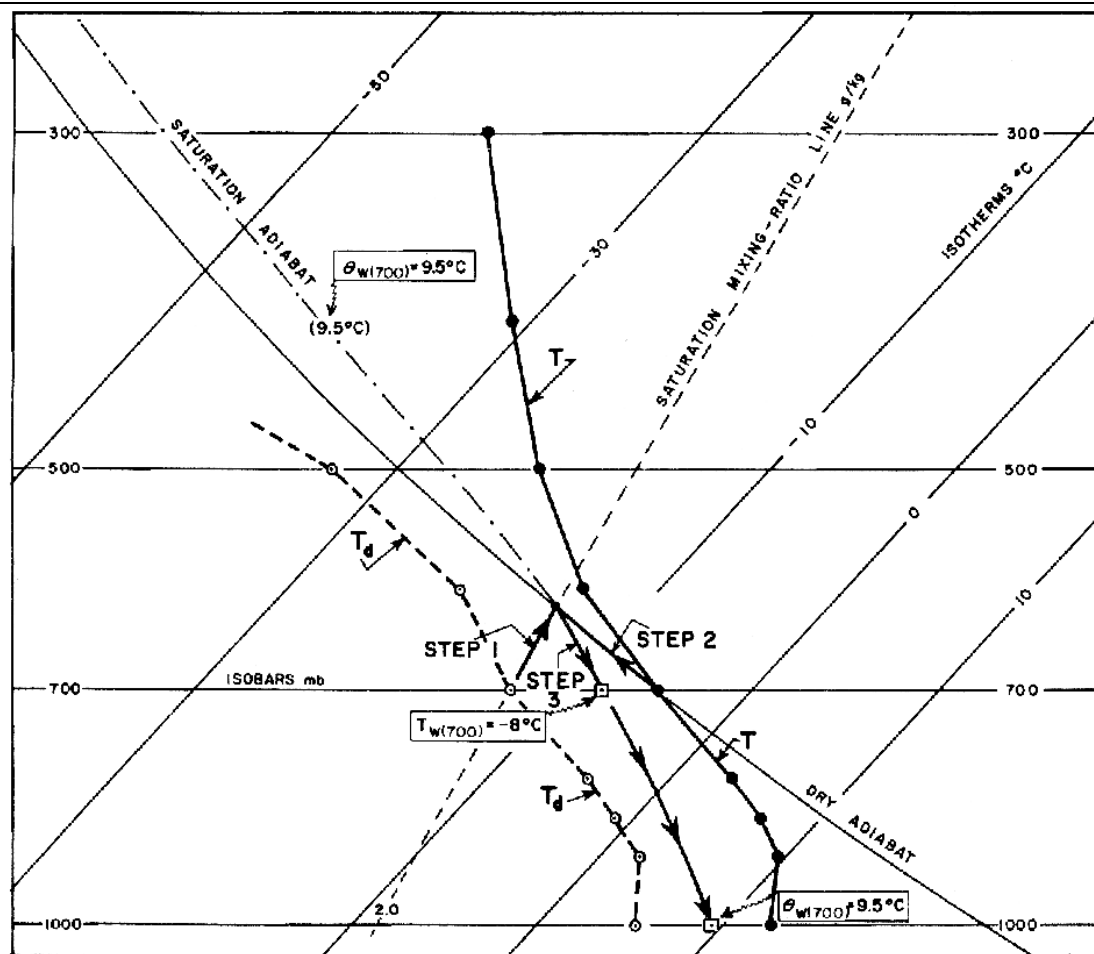

FIG. 14. Determination of the wet-bulb temperature and the wet-bulb potential temperature.

H. Wet-Bulb Potential Temperature (θw)

The wet-bulb potential temperature is the wet-bulb temperature a sample of air would have if it were brought saturation-adiabatically to a pressure of 1000 mb.

1.   Procedure: From the wet-bulb temperature follow down parallel to the saturation adiabat lines to the 1000-mb level. The temperature value at this intersection is the potential wet-bulb temperature. It is normally expressed in ^{O}K, so add 273° to the Celsius value to obtain the value in ^{O}K. In figure 14, the wet-bulb potential temperature is 9.5^{O}C (282.5^{O}K).

I. Equivalent Temperature (T$_E$)

The equivalent temperature is the temperature a parcel of air would have if all its moisture were condensed out by a pseudo-adiabatic process (i.e., with the latent heat of condensation being used to heat the air sample), and the sample then brought dry-adiabatically to its original pressure. This equivalent temperature is sometimes termed the "adiabatic equivalent temperature."

1.   Procedure: Figure 15 illustrates the method of finding T$_E$ for a given pressure on the sounding.

   a. From the dew-point temperature at the pressure level for which the equivalent temperature is desired, (in the example, 700-mb is used), draw a line upward paralleling the saturation mixing-ratio lines.

   b. From the temperature at the desired pressure level (700-mb in the example), draw a line upward paralleling the dry adiabat lines until it intersects the line drawn in a. This is the LCL for the 700-mb level.

   c. From this LCL point, draw a line upward following the saturation adiabat lines to a pressure level where both the saturation and dry adiabats are parallel; i.e., to a pressure where all moisture has been condensed out of the parcel.

   d. From this pressure, follow the dry adiabat lines back to the original pressure (700-mb in the example). The isotherm value at this point is equal to the equivalent temperature. In the example shown in figure 15, T$_E$(700) = +0.5^{O}C.
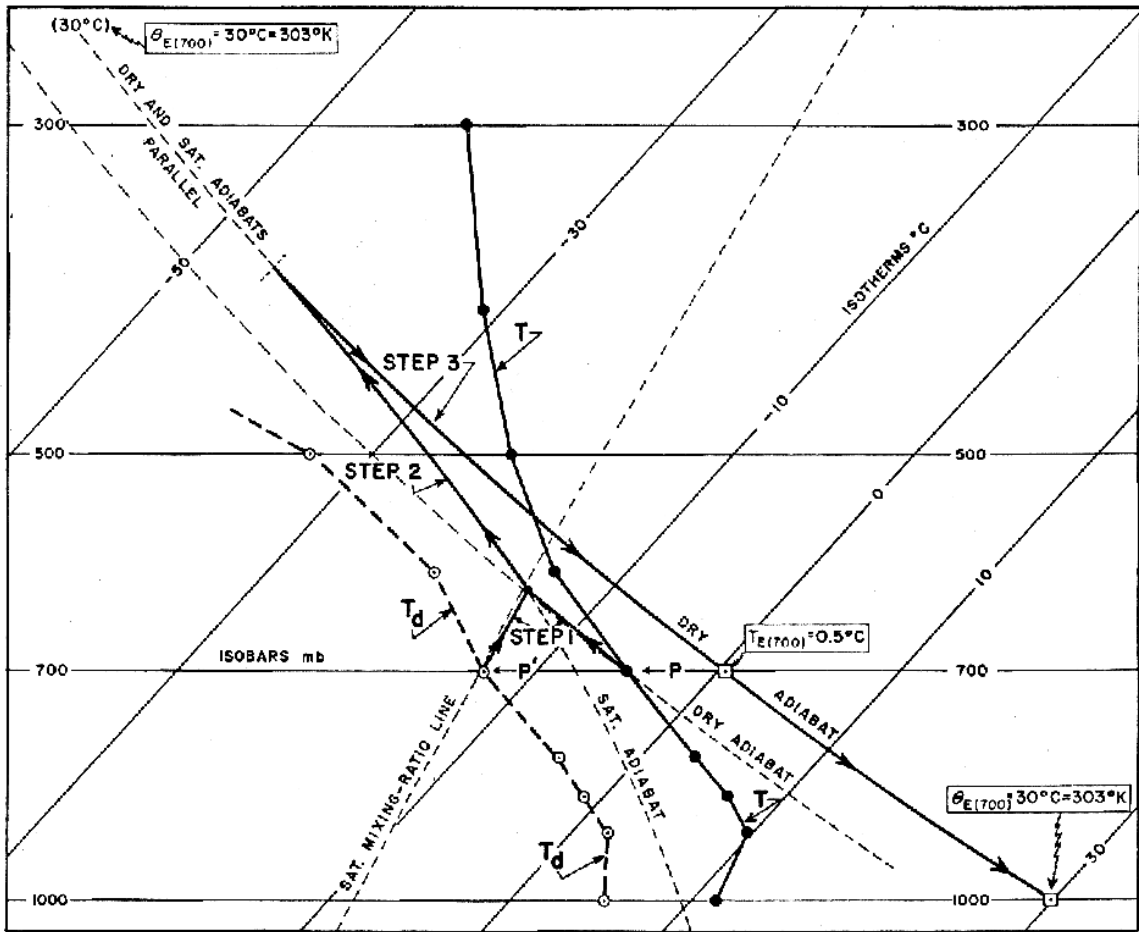
FIG. 15. Determination of the Equivalent Temperature
and the Equivalent Potential Temperature

J. Equivalent Potential Temperature (θ_E)

The equivalent potential temperature is the temperature a parcel of air would have if all its moisture were condensed out by a pseudo-adiabatic process and the sample were brought dry adiabatically to 1000 millibars.

1. Procedure: From the equivalent temperature, follow the dry adiabat lines to the 1000-mb isobar. The isotherm value at this point is equal to the equivalent potential temperature. In the example shown in figure 15, (θ_E) = 30°C or 303°K.
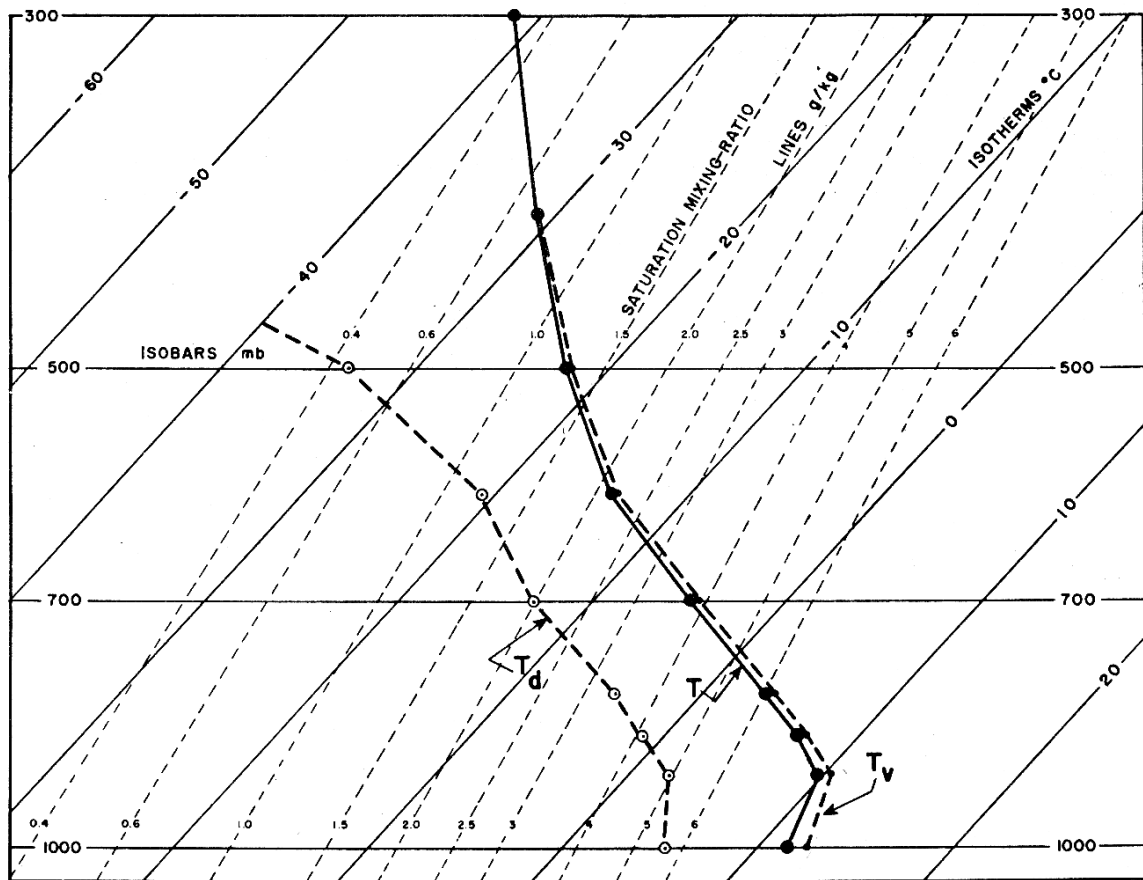
FIG. 16. Comparison between the observed-temperature
and Virtual-temperature Curves.

K. Virtual Temperature (T_V)

The virtual temperature of a moist air sample is defined as the temperature at which dry air at the same pressure, would have the same density as the moist air.

1. Procedure: At a given pressure level on a sounding, the difference (in °C) between the observed and virtual temperatures (i.e., T_V - T) is approximately equal to 1/6 of the numerical value of the saturation-mixing ratio line passing through the dew-point temperature at that pressure. Hence, the virtual temperature may be computed at each appropriate pressure by adding this numerical difference (w/6) to that pressure's temperature (T). An example of the relationship between the T and T_V curves is shown in figure 16. At the lower moisture values; i.e., above 500 mb, the T and T_V curves are almost identical.
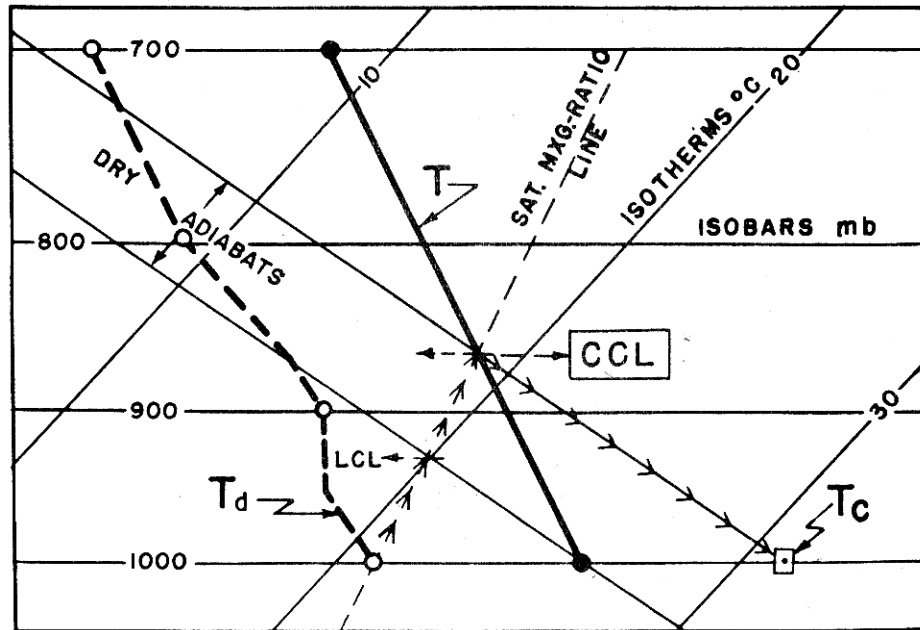
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FIG. 17. Procedure for locating the Lifting Condensation Level,
Convection Condensation Level, and the Convection Temperature

L. Lifting Condensation Level (LCL)

The height at which a parcel of air becomes saturated when it is lifted dry
adiabatically is the Lifting Condensation Level.   When a parcel of air is forced upward,
as by being forced upward across land, a mountain, or over a layer of colder air, the air
cools dry adiabatically.   This is called mechanical lifting.   If the air is lifted high enough,
and cools enough, the parcel is saturated and any further cooling will result in
condensation of moisture.   This is the Lifting Condensation Level.

1. Procedure:

a. From the dew-point temperature of the level for which the LCL is desired to
be determined, draw a line upward parallel to the saturation mixing ratio lines.

b. From the temperature value of the level for which the LCL is desired, draw a
line upward parallel to the dry adiabat lines. The level where these two lines
intersect is the LCL. See figure 17.

M. Convection Condensation Level (CCL)

The convection condensation level, figure 17, is the height at which a parcel of
air, if heated sufficiently from below, will rise dry adiabatically until it is just saturated.
This is the height of the base of cumuliform clouds which are, or would be, produced by
thermal convection from surface heating.   Thus, the procedure always starts with
temperature and dew-point temperature values of the surface air.

1. Procedure: From the surface dew-point temperature, draw a line up the saturation mixing ratio line to where it intersects the environmental temperature curve. The level where these two lines intersect is the CCL. See figure 17.

N. Convection Temperature (T$_C$)

The T$_C$ is the surface temperature that must be reached to start formation of convective clouds by heating of the surface air layer. When this temperature is reached, air can rise dry adiabatically to the convection condensation level.

1. Procedure: Start at the CCL and follow down the dry adiabat to the surface pressure isobar. The temperature at this intersection is the convection temperature. See figure 17.

O. Level of Free Convection (LFC)

The level of free convection is the height at which a parcel of air lifted dry adiabatically until saturated and then moist adiabatically thereafter, would first become warmer (less dense) than the surrounding environmental air. The parcel would then continue to rise freely above this level until it becomes colder (more dense) than the surrounding air. Note, a LFC may not be present for all atmospheres.

1. Procedure: Start at the lifting condensation level (LCL) of the level for which the LFC is desired, (i.e., if the LFC for air at 700 mb is desired, the calculate the LCL for 700 mb). From the LCL go upwards parallel to the saturation adiabats until you intersect the temperature curve. The level where the intersection occurs is the LFC. See figure 18. Note, a parcel which is forced upward will first cool at the dry adiabatic lapse rate until it is saturated, (follow the dry adiabat to the LCL). Thereafter as it is forced upward, it cools at the saturation adiabatic lapse rate, (moisture is condensing out of the parcel; follow the saturation adiabat from the LCL upward). The parcel must be forced upward as long as it is cooler than the surrounding air. Once the parcel becomes warmer than the surrounding air it rises by itself.

P. Equilibrium Level (EL)

The equilibrium level is the height where a buoyantly rising parcel, (rising freely because it is warmer than the surrounding air), again becomes equal to the temperature of the surrounding environmental air. Above this level, the parcel is cooler, (denser) than the surrounding air and will not rise freely. Note, an equilibrium level may not be present for some atmospheres.

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1. Procedure:

 For mechanical lifting. From the LFC, continue drawing a line upward paralleling the saturation adiabat lines until the drawn line intersects the temperature curve. This is the equilibrium level. See figure 18.
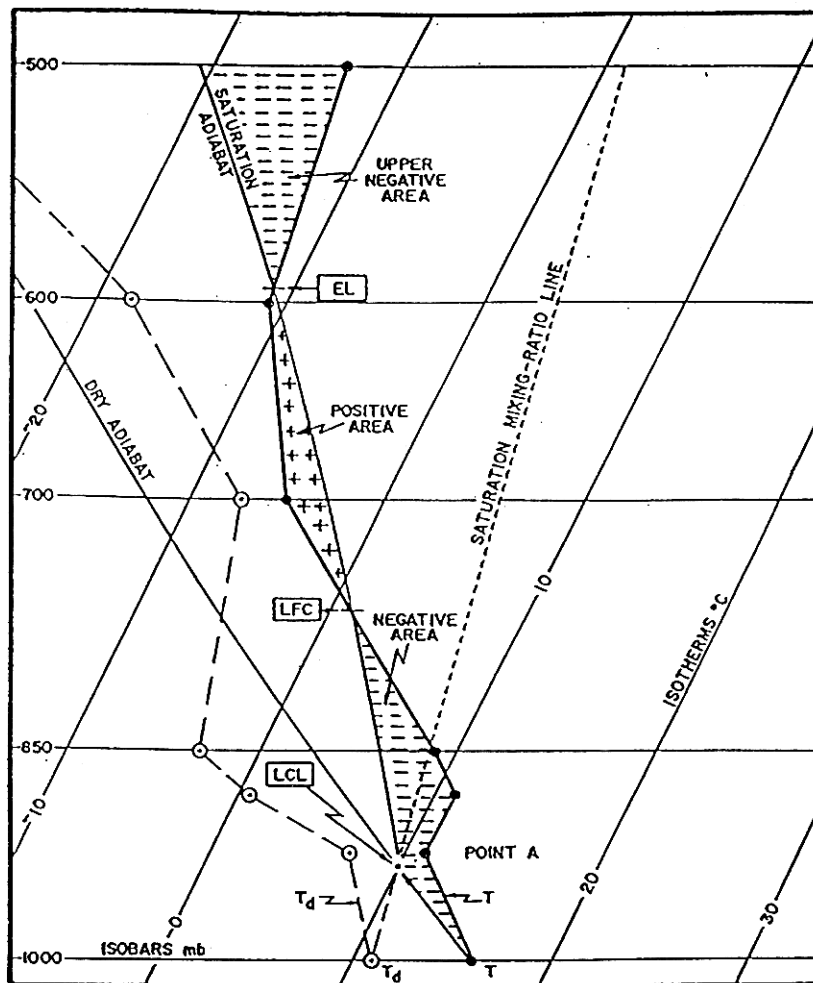

FIG. 18. Determination of the Level of Free Convection, Equilibrium Level, and Positive and Negative Energy Areas.

 For convection lifting. From the CCL, continue drawing a line upward paralleling the saturation adiabat lines until the drawn line intersects the temperature curve. This is the equilibrium level. See figure 19.

Q. Positive and Negative Areas

 On a thermodynamic diagram, such as the Skew-T, Log-P Chart, a given area can be considered proportional to a certain amount of energy of a vertically and adiabatically moving air parcel.

1. Positive Area: When a parcel can rise <u>freely</u> because it is in a layer where the adiabat it follows is warmer than the surrounding environment, the area between the adiabat and the environmental temperature curve is proportional to the **Convective Available Potential Energy (CAPE)**, also called <u>positive</u> areas, which is available for conversion to kinetic energy of motion of the parcel. A parcel rising in these CAPE or positive areas finds itself warmer than the surrounding air and continues to rise freely. These are considered unstable areas and are regions where clouds of greater vertical extent can form. See figure 18.
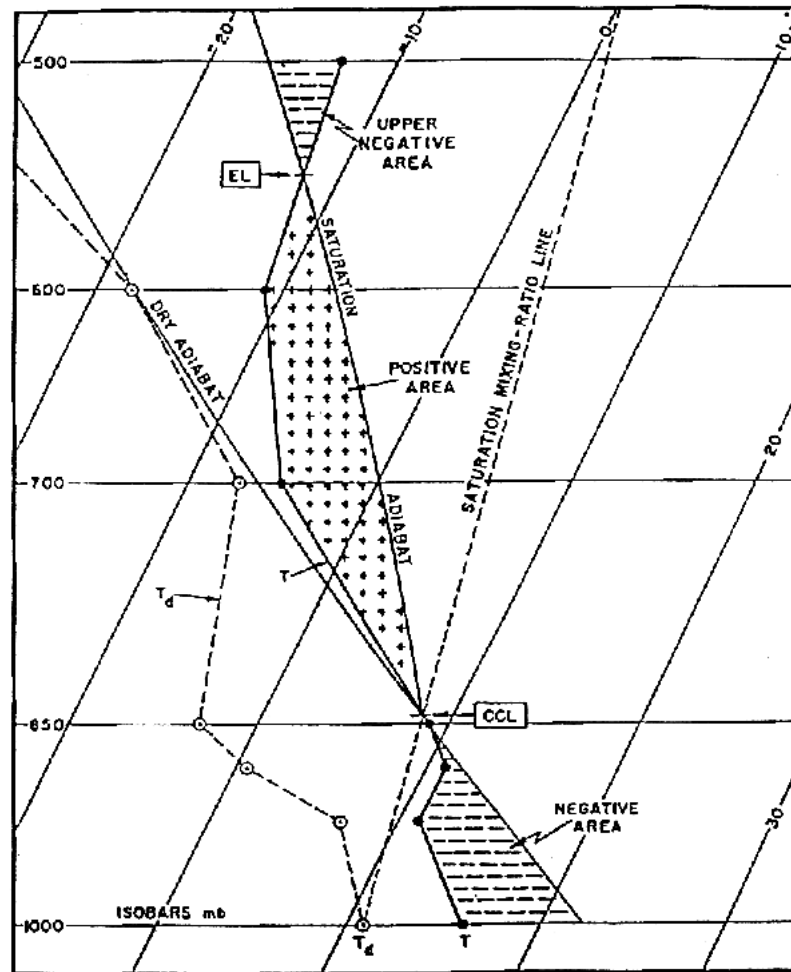

FIG. 19. Determination of Positive and Negative Areas on a sounding
due to heating of the surface parcel.

2. Negative Area: When a parcel on a sounding lies in a <u>negative</u> area, energy has to be supplied to it to move it either up or down. The area between the path of such a parcel moving along an adiabat and the environmental temperature curve is proportional to the amount of <u>energy that must be supplied</u> to move the parcel. For this reason, this negative area is called a region of **Convective Inhibition (CIN)**. See figure 19.

The negative and positive areas are not uniquely defined on any given sounding. They depend on the parcel chosen and on whether the movement of the chosen parcel is assumed to result from surface heating, (insolation), release of latent heat of condensation, or from forcible lifting, (i.e., convergence, orographic lifting, etc.).

3. **Procedure for the Surface-Parcel-Heating Case:**

   a. From the CCL, draw a line upward paralleling the saturation adiabats to the top of the sounding. From the CCL, draw a line downward paralleling the dry adiabat to the surface-pressure isobar. Figure 19 shows an example.

   b. The area below the CCL is labeled as a negative area, since energy must be added to the parcel (by surface heating) to get it to rise to the CCL. For the area above the CCL, label those areas positive if the line drawn in 1 above lies to the right of the environmental temperature curve, and negative if the line drawn lies to the left.

4. **Procedure for the Lifted Surface-Parcel Case:**

   a. In this instance, the surface parcels are lifted by some mechanical process, such as orographic, or frontal lifting, or convergence. From the LCL for the lifted surface parcel, draw a line upward parallel to the nearest saturation adiabat to the top of the sounding. From the LCL, draw a line down parallel to the dry adiabats to the surface-pressure isobar. An example is shown in figure 18.

   b. Those areas in which the line drawn in 1 is to the right of the environmental temperature curve are labeled as positive areas. Positive areas represent the energy gained by the lifting parcel after it rises above the LFC. The areas in which the line drawn in "a" are to the left of the environmental temperature curve are labeled as negative areas. Negative areas represent the energy that must be supplied to the lifted surface parcel to force it to rise.

5. **Procedure for the Lifted Upper-Level Parcel Case:**

   The procedure to be used in the event the analyst wishes to determine the positive and negative areas that will result when an air parcel initially at some upper level is lifted by a mechanism such as frontal over-running, upper-level convergence, etc., the procedure is exactly the same to that used in the lifted surface-parcel case, except that the LCL is first determined for the upper level where the parcel originates. From the upper-level LCL, a line is drawn upward paralleling the nearest saturation adiabat, and a line is drawn downward from the upper-level LCL a line is drawn downward to the upper-level isobar line where the parcel originated. Positive and negative areas are labeled following the same procedure as in the lifted surface-parcel case.

R. Energy Determinations on the Skew-T, Log-P Chart.

When positive or negative areas have been located on the Skew-T chart, the energies involved may be computed by the following relationship:

   a. One square centimeter on the DOD WPC 9-16 chart equals 0.280×10^6 ergs, or 0.0280 joules, per gram of air in the sample under consideration.

   b. One square inch on the chart equals $1,808 \times 10^6$ ergs, or 0.1808 joules, per gram of air in the sample.

S. Determination of Cloud Tops and Bases

Cloud tops and bases present in the air mass measured by the sounding are determined from the saturation of the layers in the sounding. A level is saturated if the dew-point temperature is equal to the environmental.

   1. Procedure:

Compare the dew-point temperature with the environmental temperature. If they are the same, the air is saturated and a cloud is assumed to exist at that level. The cloud base is normally found where there is a sharp decrease in the dew-point depression value to a value of 6°C or less. The air does not necessarily indicate saturation, since the humidity sensor may be slow in responding and (2) droplets may form on hygroscopic nuclei when the humidity is only 75% to 80%. The top of the cloud is usually where there is a sharp decrease in the dew-point temperature. The height in feet, or meters, of the cloud base and top is determined by following the pressure level of the base and top to the right to the pressure altitude curve and reading the height from the scale. Figures 20 and 21 show examples of soundings through a warm front and a cold front, respectively.

   2. Forecasting Convective Cloud Tops and Bases.

The base for convective clouds expected to form due to surface heating, is at the CCL. The top of the cloud layer is near the Equilibrium Level. A little overshooting generally occurs, sometimes as much as 1000 to 2000 feet. An approximation for convective cloud bases can be made using the equations below. Since rising, dry air cools at about 10°C/1000 meters, and the dew-point decreases at about 2°C/1000 meters, the air temperature and the dew-point temperature approach each other at 8°C/1000 meters. For every 1°C difference between the surface air temperature and the dew-point temperature, the surface air must rise 125 meters for the two to be equal. Thus,

$$H_{(meters)} \quad = \quad 125(T\text{-}T_d)$$

$$T \text{ and } T_d \text{ in } °C$$

$$H_{(feet)} \quad = \quad 222(T\text{-}T_d)$$

$$T \text{ and } T_d \text{ in } °F$$

3. Forecasting Stratiform Cloud Tops and Bases.

When mechanical lifting is expected to occur, stratiform clouds may form at the LCL. The cloud top will continue upward as long as mechanical lifting forces the air upward, unless the air passes the LFC. Then, the cloud will continue upward to the equilibrium level as a convective cloud.
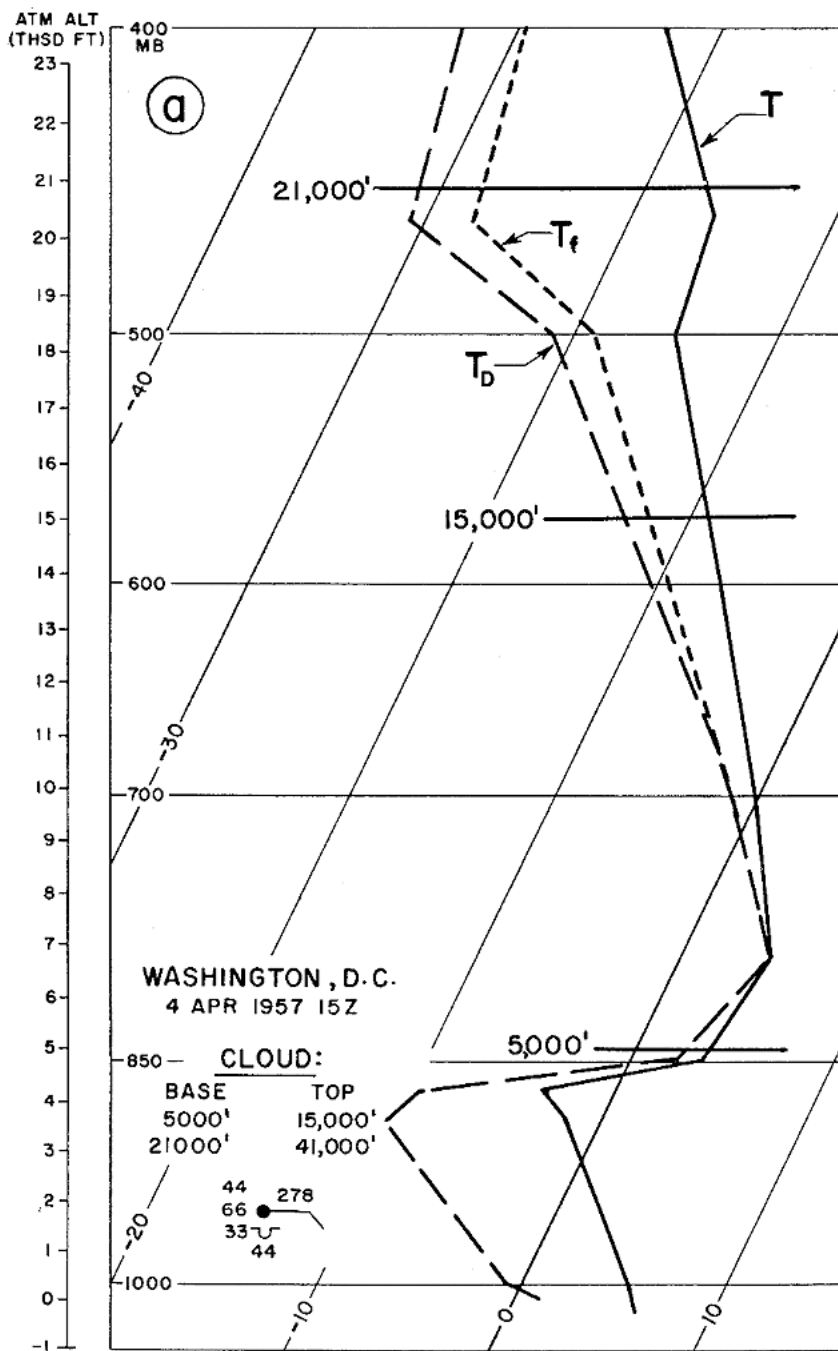

FIG. 20. Sounding showing a marked warm front

Figure 20 shows a sounding which indicates a marked warm front. Two clouds layers are indicated. A marked warm front was approaching from the south. Moderate, continuous rain fell two hours later. At 1830Z, an aircraft reported solid cloud from 1000 to 44,000 feet (tropopause).   The 15Z sounding shows an increasing dew-point depression with height, with no discontinuity at the reported cloud top of 15,000 feet. A definitely dry layer is indicated between 18,300 and 20,000 feet. The second reported cloud layer is indicated by a decrease in dew-point depression, but the humidity element obviously is slow in responding. The dew-point depression at the base of the cloud at 21,000 feet is 14$^{\text{O}}$C and at 400-mb after about a 3-minute climb through cloud is still 10$^{\text{O}}$C. From the sounding, clouds should be inferred from about 4,500 feet (base of rapid humidity increase) to 500 mb and a second layer from 20,000 feet up. The line marked, T_f, is the frost point and indicates the temperature at which the air is saturated with respect to ice.

Figure 21, below, shows a cold front with a cloud layer thinner than indicated by the sounding. A cold front lay E-W across North Dakota at 15Z. The reported cloud layer was much thinner than would be inferred from the sounding. Using the rule that a cloud base is indicated by a fairly rapid decrease in dew-point depression to a dew-point depression of 6$^{\text{O}}$C or less, the base should be somewhere between 12,100 to 14,900 feet. Similarly, the cloud should be expected to extend to 19,300 feet where the dew-point depression starts increasing again. The surface report places the base at 12,000 feet. Of the two possibilities, 12,100 and 14,900, the latter should be chosen as the base height from the rule. If a decrease in dew-point depression is followed by a much stronger decrease, choose the height of the base of the stronger decrease as the cloud-base height.
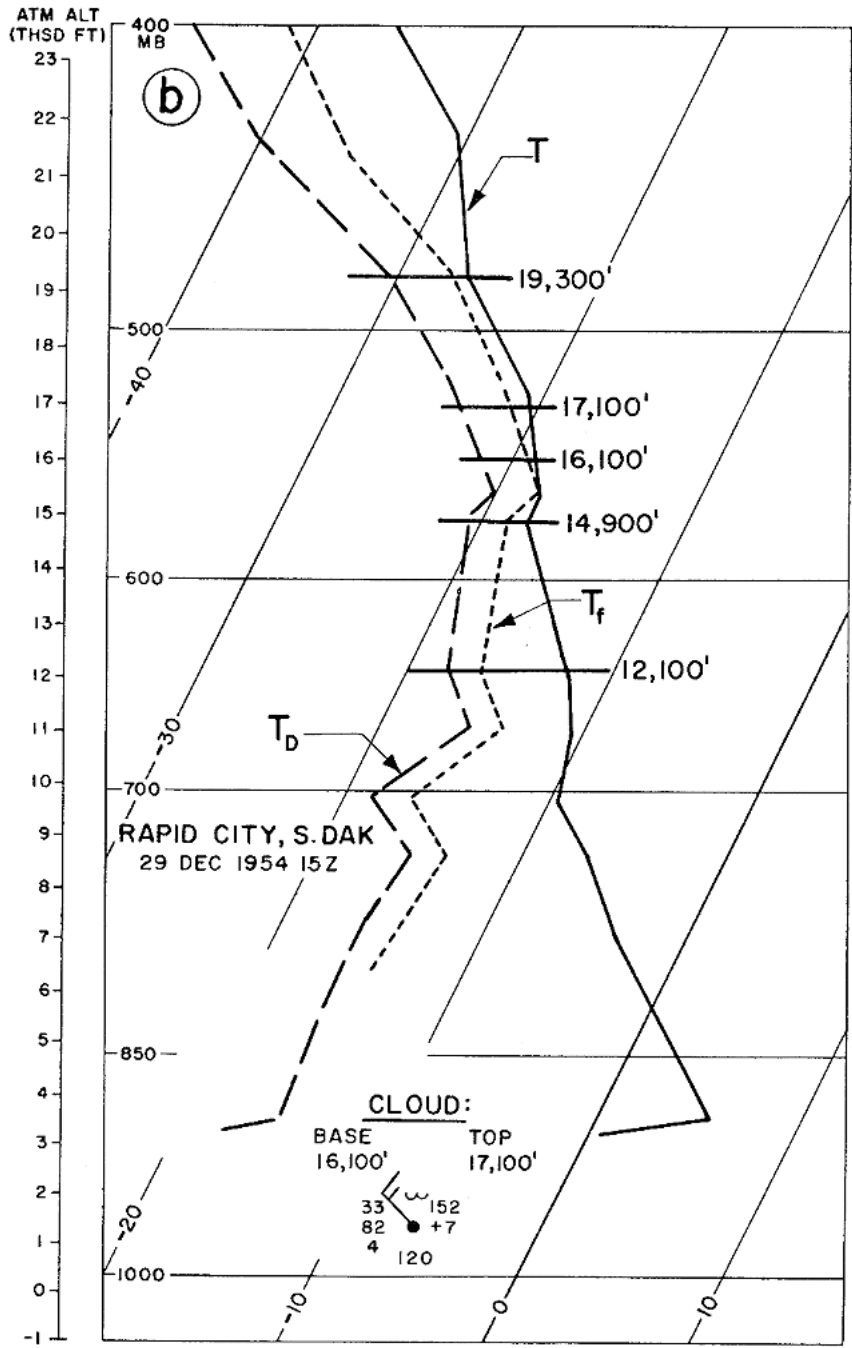
FIG. 21. Sounding showing a cold front

T. Thickness of a Layer

The thickness of a layer between any two pressure surfaces is equal to the difference in the geopotential heights of these surfaces. This can be determined by:

$$\text{Thickness} \quad = \quad \frac{R_d}{g} \, \overline{T_v} \, \ln\left[\frac{P_1}{P_2}\right]$$

$\overline{T_v}$ =   Mean virtual temperature
R_d =   Gas constant for dry air
g   =   Acceleration of gravity
P_1, P_2 =   Pressure surfaces

1. Procedure. See figure 22.

a. Construct a T_v curve for the given layer; in the example, the 1000 to 700 mb layer, based on the corresponding temperature and mixing ratio values at the appropriate points on the original sounding.

b. Draw a straight line through the given layer, so that the areas confined by the T_v curve and the straight line balance to the right and left of the line. The straight line can have any orientation, but it is easiest to balance the areas when they are small, so choose an orientation that minimizes the areas.

c. The thickness of the layer is read at the point where the straight line of step b crosses the thickness scale for a given layer.
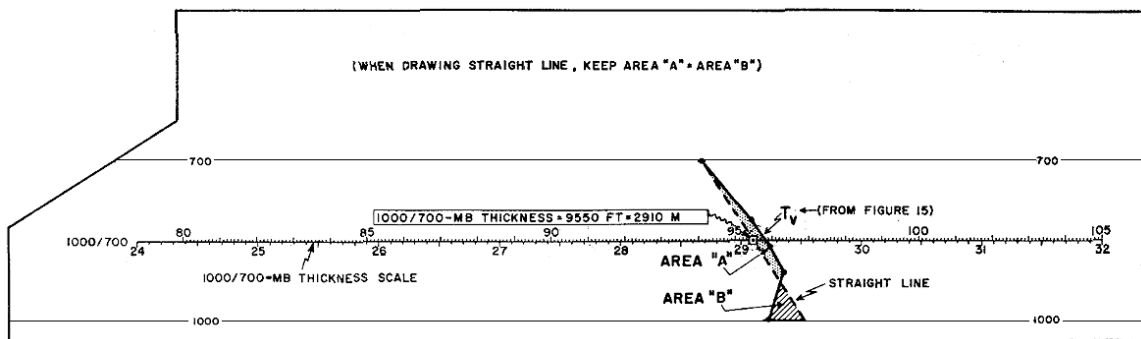

FIG. 22. Determination of the thickness of the
1000- to 700-mb layer.