AWSM 105-124

AIR WEATHER SERVICE MANUAL

WEATHER

USE OF THE SKEW T, LOG P DIAGRAM IN ANALYSIS AND FORECASTING

15 JULY 1969

UNITED STATES AIR FORCE

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AWS MANUAL 105-124

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USE OF THE SKEW T, LOG P DIAGRAM IN ANALYSIS AND FORECASTING

This manual provides guidance on the use of the "Skew T, Log P Chart," DOD WPC 9-16, and on the principles of radiosonde analysis for forecasting of clouds and convection-weather phenomena. Chapter 3 establishes standard methods to be used when entering data on Skew T Charts. This manual will serve all AWS forecasters and observers as a general reference up dating and revising previous publications on the subject, as study material for use in OJT and school training, seminars, etc., and as a source of hints on parameters and approaches for local forecast studies or techniques.

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Chapter 1

INTRODUCTION

1.1. Organization of the Manual. This manual is issued in one volume. A planned second volume to cover the use of atmospheric soundings in forecasting proved impracticable to compile. Also, the general use of computer-produced analysis and prognostic charts has greatly decreased the direct application of soundings in forecasting. However, Chapter 8 is added to note some uses of soundings in techniques for forecasting certain phenomena. The manual opens with a description of the DOD Skew T, Log P Diagram (chapters 1 and 2) and instructions for plotting soundings on it (chapter 3). The procedures for evaluating, on the diagram, certain basic quantities from the sounding are then outlined in chapter 4. Up to this point, the treatment is designed for guidance of both observers and forecasters. The rest of the manual is a text for forecasters on the principles and procedures of analyzing raobs on the Skew T, Log P Diagram for stability, fronts, inversions, and clouds. This material is not a review of the conventional standard textbook approach, but a selection and evaluation of topics which recent experience and empirical studies indicate are of direct application to practical forecasting under present operating conditions in ordinary detachments. In chapter 8 various empirical forecasting procedures involving use of the soundings plotted on Skew T, Log P Diagrams are mentioned with respect to clouds, fog, precipitation, showers, temperature, hail, icing, contrails, and turbulence.

1.2. Reason for Choosing the Skew T, Log P Diagram. The Skew T, Log P Diagram was selected by AWS as the most convenient thermodynamic diagram for general use. It was chosen in preference to numerous other diagrams because it is easier to use in many meteorological procedures and computations.

Such thermodynamic diagrams as the Emagram, Tephigram, Stüve Diagram[1] and the Skew T, Log P Diagram all express the same physical relationships [33] and show isobars, isotherms, dry adiabats, saturation adiabats, and saturation mixing-ratio lines. They differ only in the arrangement of these coordinates (see Figures 1a through 1d).

For convenience and utility, it is desired to have a diagram on which: a) the important isopleths are straight rather than curved, b) the angle between 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) an entire sounding to levels inside the stratosphere can be plotted, and e) the vertical in the atmosphere approximates the vertical coordinate of the diagram. Both the skewed version of the Tephigram and the Skew T, Log P Diagram have most of these advantages, but the latter is preferred because its isobars are straight, which makes it easier to estimate pressure altitudes. The Skew T, Log P Diagram was developed[2] from the Emagram by "skewing" the isotherms of that diagram to nearly 45 degrees

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[1] In the United States, the Stüve Diagram came to be known as "The Pseudo-Adiabatic Diagram." Actually, all of the diagrams mentioned are "pseudo-adiabatic diagrams," in that they are derived by assuming that the latent heat of condensation is used to heat the air parcel, and that condensed moisture falls out immediately (see pars. 2.4 and 5.3).

[2] The coordinate system of the Skew T, Log P Diagram was first suggested by N. Herlofson [30], a Norwegian meteorologist.

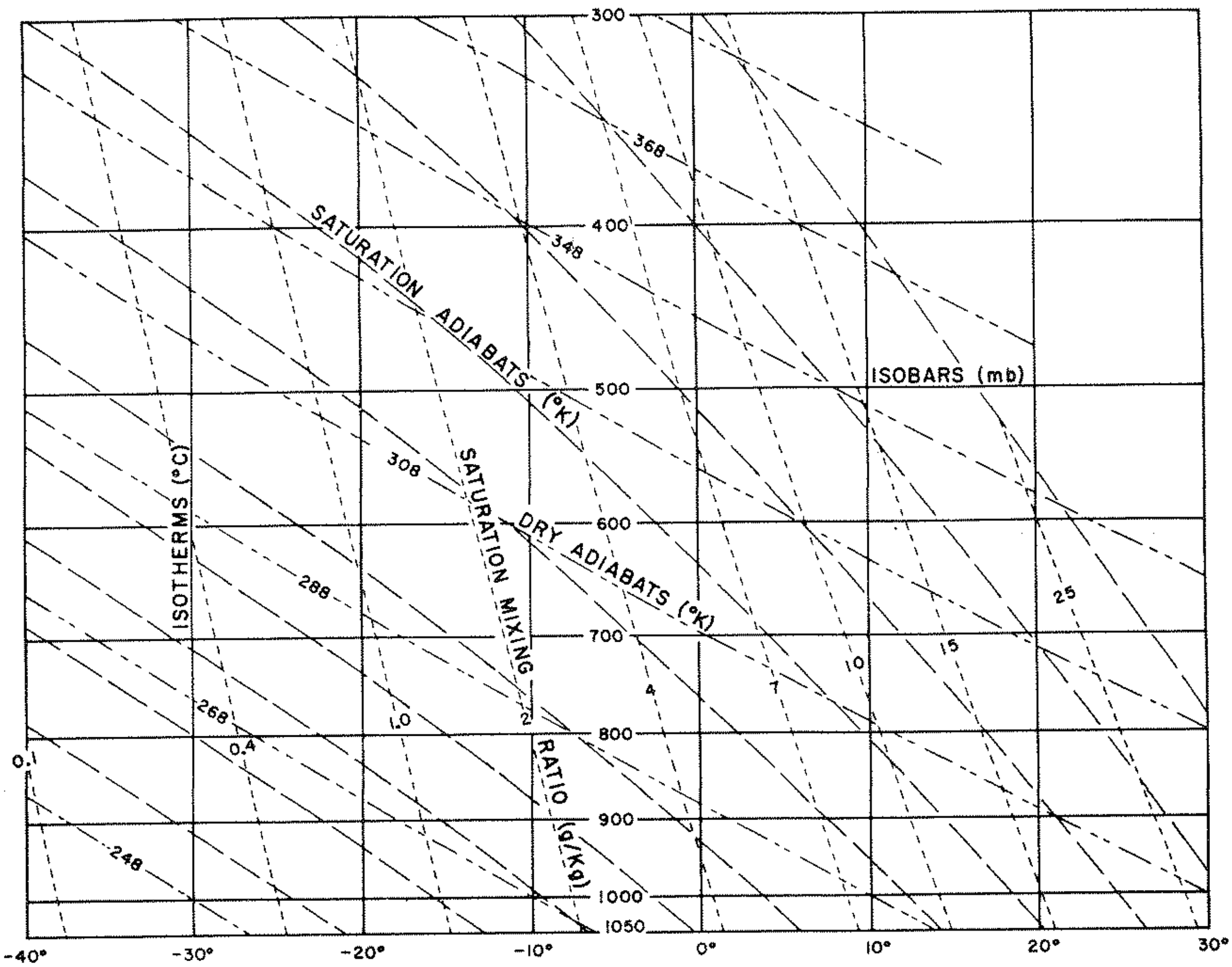

Figure 1a. Coordinate System of the Emagram.

from the vertical to increase the angle between isotherms and adiabats. On the Skew T, Log P Diagram, both the isotherms and isobars are straight lines. The desired relationship between energy and diagram area is also essentially fulfilled, so that thickness scales are easily prepared for any given layer. In addition, a convenient color scheme has been selected, and auxiliary scales have been added to further enhance the value of the diagram. A detailed description of the Skew T, Log P Diagram is given in Chapter 2.

1.3. Different Versions of the DOD Skew T, Log P Diagram. The DOD Skew T, Log P Diagram - hereafter referred to as the "Skew-T Chart" - is printed by the Aeronautical Chart and Information Center (ACIC), and can be requisitioned by USAF activities in accordance with instructions in the DOD *Catalog of Weather Plotting Charts* published by ACIC. The Skew-T Chart is available in six versions:

a. A full-scale chart for general use (DOD WPC 9-16), printed on a sheet 28 x 30 inches. This version now includes the Appleman contrail forecasting curves (see AWSM 105-100) which were on the formerly issued WPC 9-16B.

b. A small-scale chart (DOD WPC 9-16-1), photographically reduced from the full-scale chart, and printed on a sheet 17 x 15

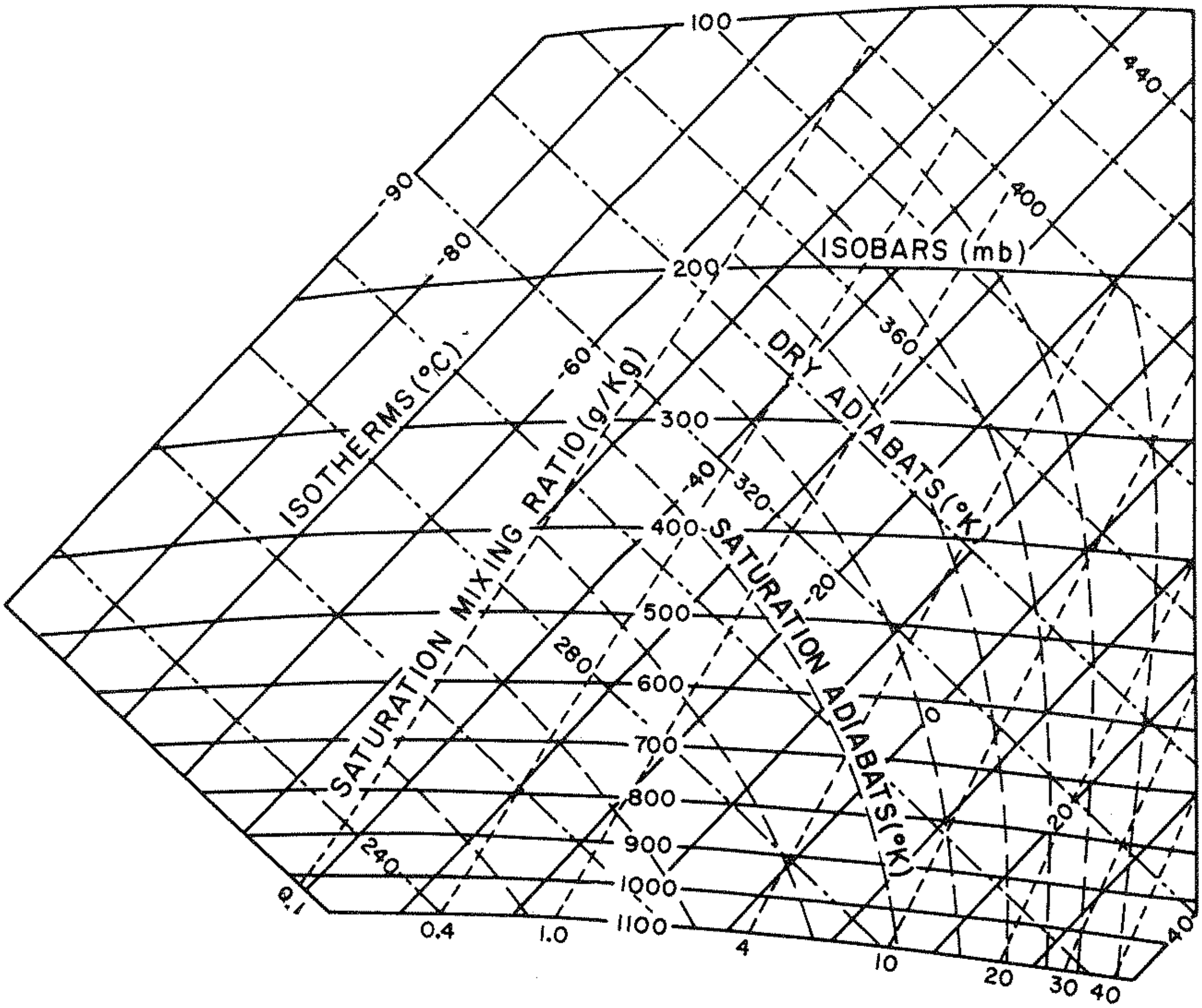

Figure 1b. Coordinate System of the Tephigram.

inches. This version eliminates several of the auxiliary scales and overprints, and is intended for use where these scales are not required and display or handling problems make a smaller sheet essential. Overlays designed for use on the full-scale version must be reduced by one-third to adapt them to this small-scale chart.

c. A "modified" version (DOD WPC 9-16A), printed on a sheet 20.5 x 15.5 inches. This is a cut-out from the full-scale chart, enlarged (but not photographically), and extending only from 1050 to 400 mb, and from -20°C to +50°C at the base. The auxiliary scales on the left and top are omitted, and of the overprinted material only the virtual temperature marks are included. This version was designed for the special requirements of the Military Weather Warning Center.

d. A "High Altitude" version (DOD WPC 9-16-3) printed on a sheet 24.7 x 24.3 inches. It extends the chart up to 1 mb starting at 150 mb, thus overlapping the basic version from 150 to 100 mb. The analysis block overprints and the scale are the same as on the WPC 9-16-1. The standard atmosphere curve reaches to the stratopause (47 km). This chart is designed for special activities concerned with analysis of the upper portion of high radiosonde flights and the lower portion of rocketsonde flights.

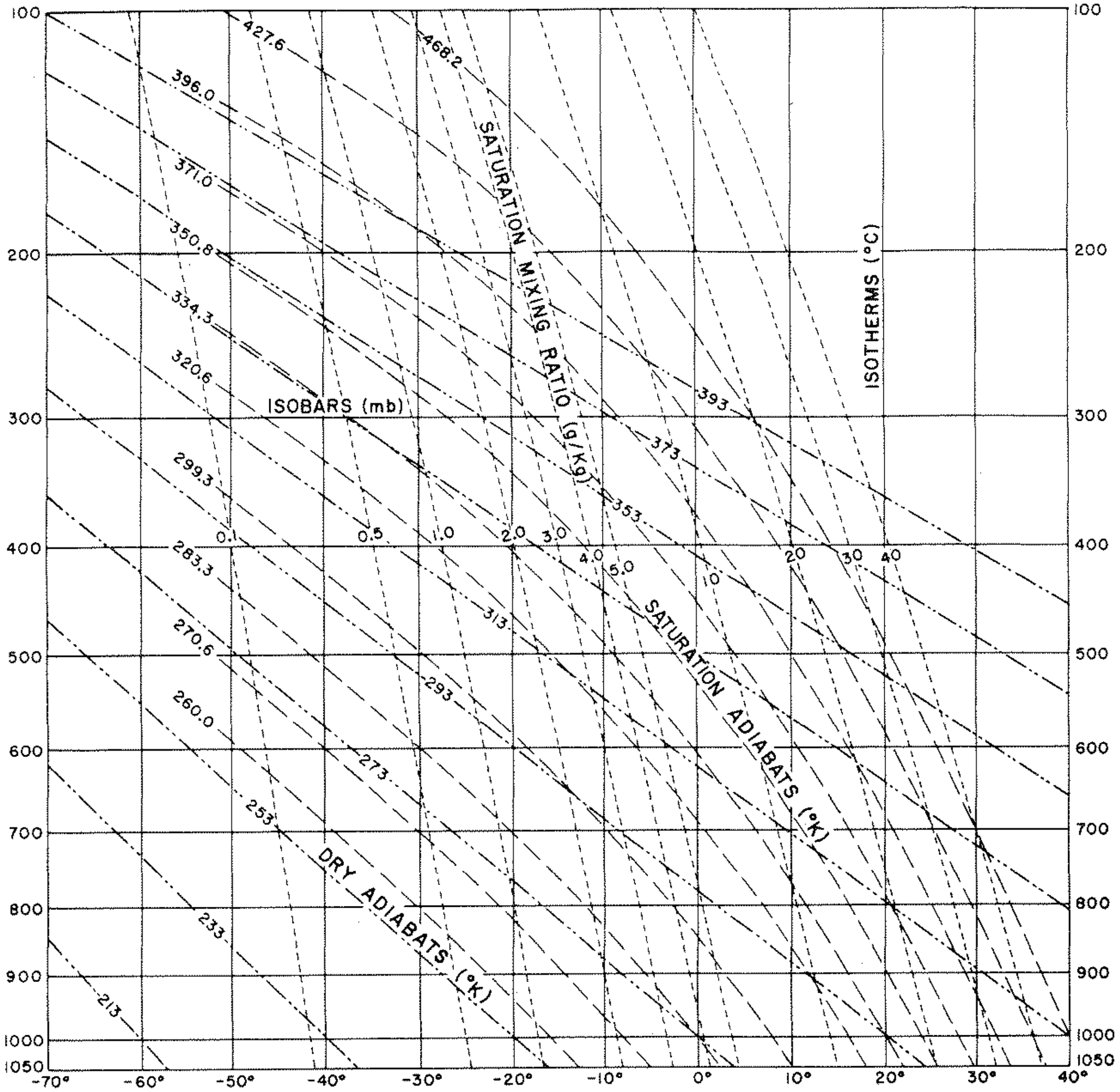

Figure Ic. Coordinate System of the Stüve ("Pseudo-Adiabatic") Diagram.

e. A version of WPC 9-16, identified as DOD WPC 9-16-2, with a refractivity overprint. This is an aid in computing estimates of anomalous radar propagation. The basis and use of the overprint is described in AWS TR 169 and in AWS TR 183.

f. A version of WPC 9-16, available as AWS TR 105-101A (requisition from HQ AWS (DDA)) with an overprint for use as a density-altitude nomogram. The application of this chart is explained in AWS TR 105-101 (Rev. 2).

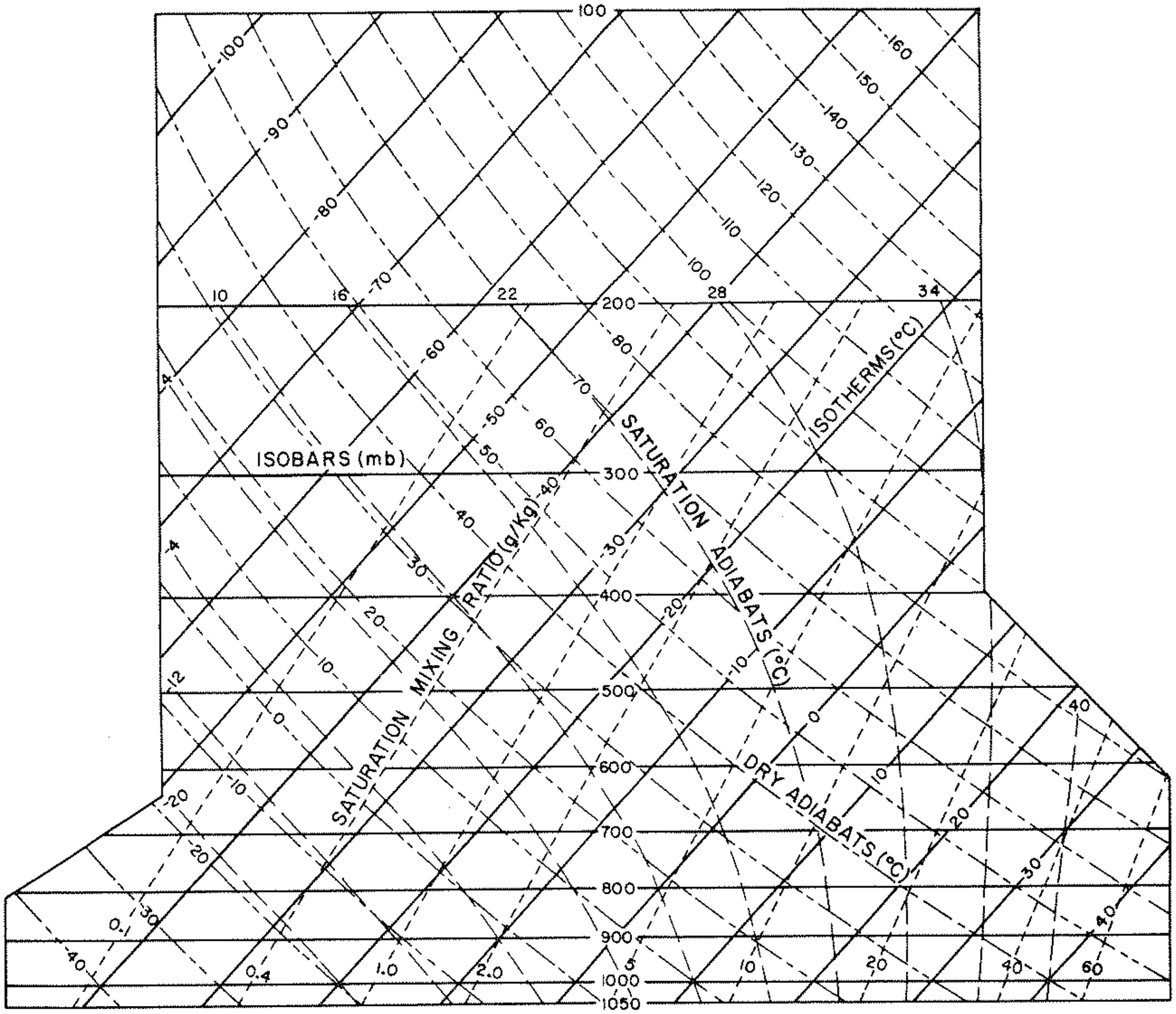

Figure Id. Coordinate System of the Skew T, Log P Diagram.

Chapter 2

DESCRIPTION OF THE SKEW-T CHART

2.1. Isobars. Isobars on the Skew-T Chart are horizontal, solid, brown lines spaced logarithmically for 10-mb intervals. Pressure-value labels are printed at both ends and in the center of isobars for each 50-mb interval from 1050 to 100 mb as shown in Figure 2. The upper portion of the chart from 400 to 100 mb is also used for pressure values from 100 to 25 mb. Labels for the latter range are printed in brackets at the ends of the appropriate isobars. In case it should be desired to plot as high as 10 mb it is suggested that the range 1000 mb to 100 mb be used for the range 100 to 10 mb, and the scale values for the latter be written by hand beside the printed 1000- to 100-mb values at the left of the diagram. One present version of the Skew-T Chart, DOD WPC 9-16-3, does away with this cumbersome procedure and permits the extension of soundings to 1 mb.

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.

2.2. Isotherms. Isotherms (see Figure 3) are straight, solid, brown lines, sloping from the lower left to upper right. The isotherm spacing is the same over the entire chart. Isotherms are labeled for 5°C intervals, and alternate 10°C temperature bands are tinted green. A Fahrenheit temperature scale is printed along the bottom edge of the chart to coincide with the appropriate isotherms.

The scale of temperature in the region around 100 mb does not extend to values low enough to accommodate some of the colder soundings that occur in the tropical-tropopause region. To plot such soundings, it is suggested that for the upper part of the sounding (above 100 mb) the temperature scale be shifted to the right by 10°C or 20°C and the isotherms in the area concerned be relabeled accordingly by hand. The slope of the dry adiabats will no longer be exactly correct for such a shifted scale, but the resultant error is small and of no consequence because one seldom is interested in detailed stability analysis at such heights (usually in the stratosphere). Where the plot of a sounding passes off the left side of the chart, start the continuation of the sounding at the pressure where this occurs but offset 10° or 20°C to the right on the temperature scale.

2.3. Dry Adiabats. The dry adiabats (see Figure 4) are the slightly-curved, solid, brown lines sloping from the lower right to upper left. They indicate the rate of temperature change in a parcel of dry air rising or descending adiabatically, i.e., with no loss or gain of heat by the parcel. The dry adiabat for each multiple of 10°C is labeled, as shown in the figure, with the Celsius temperature value of its point of intersection with the 1000-mb isobar. (Note that the dry adiabats are labeled in °C, rather than °K as on many other thermo dynamic diagrams, and care must be taken not to confuse these labels with those for the ordinary isotherms which are also labeled in °C.) The dry adiabats for the upper portion of the chart are labeled twice, to include the values (in parentheses) for the 100- to 25-mb pressure range. On the chart, the spacing between the dry adiabats decreases as their numerical value increases.

2.4. Saturation Adiabats. Saturation adiabats (illustrated in Figure 5) are the

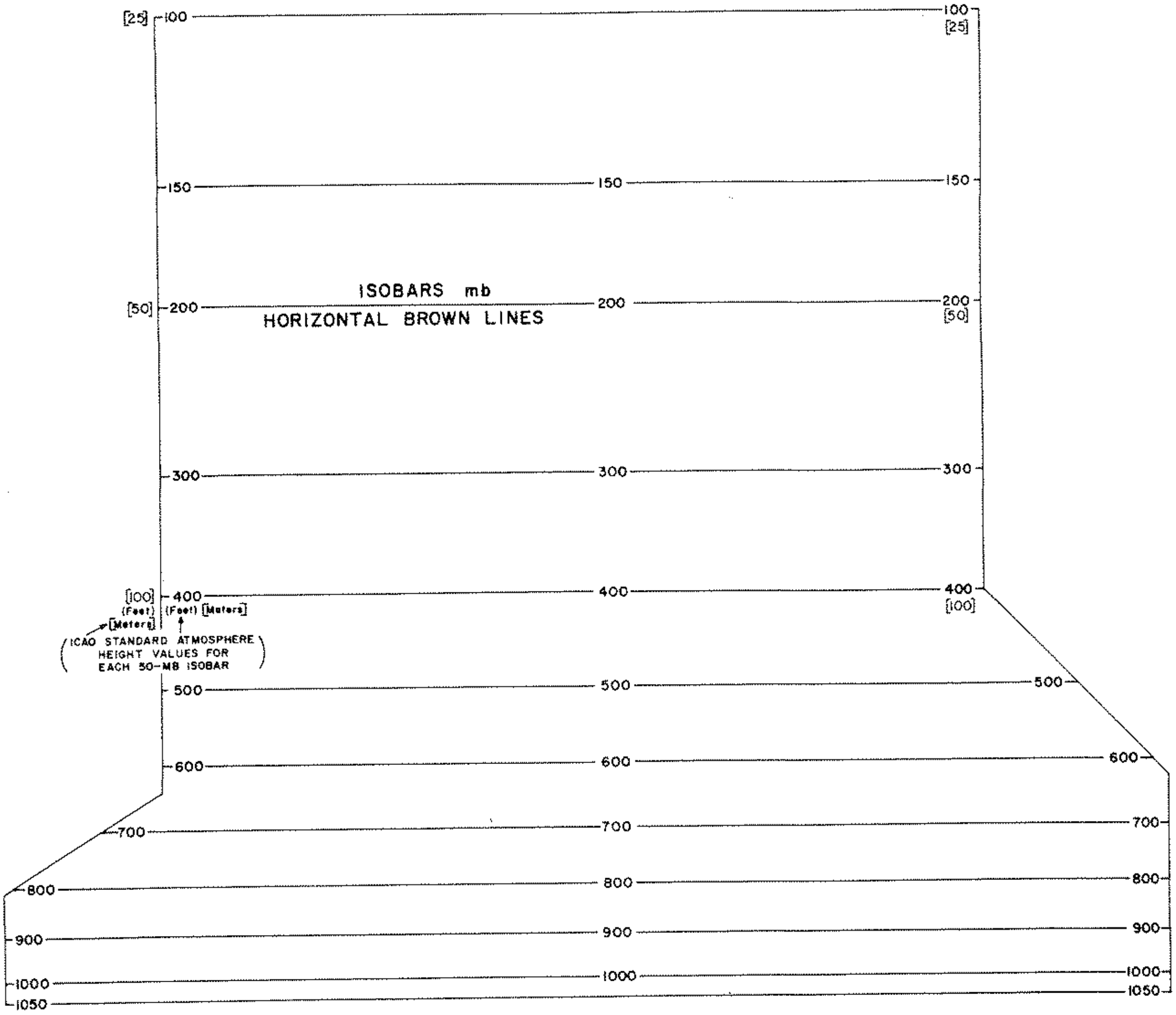

Figure 2. Isobars on the Skew-T Chart.

slightly-curved, solid, green lines sloping from the lower right to upper left. They are paths that the saturated air follows, and represent the rate of temperature change in a parcel of saturated air rising pseudo-adiabatically — pseudo-adiabatic means all the condensed water vapor is assumed to fall out immediately as the parcel rises (see par. 5.3 of this manual, and pp. 68-70 of [33]). The condensation at all temperatures is assumed to be liquid water and therefore no latent heat of fusion is included (see par. 5.3). Each saturation adiabat is labeled with the Celsius temperature value of its point of intersection with the 1000-mb isobar. The 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 equipment.

2.5. Saturation Mixing-Ratio Lines. The saturation mixing-ratio lines (see Figure 6) are the slightly-curved, dashed, green lines sloping from the lower left to upper right. They are labeled in grams per kilogram; i.e.,

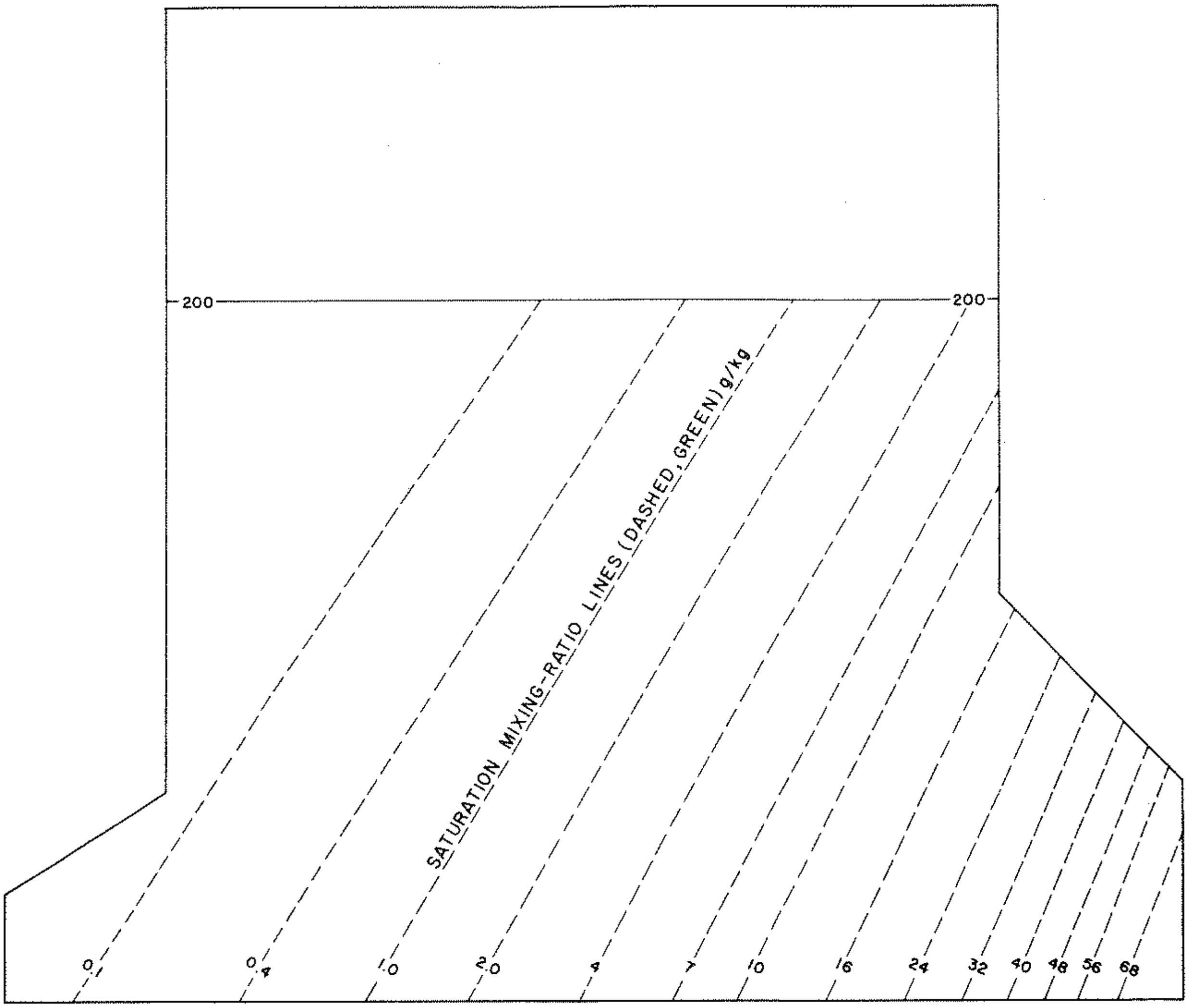

Figure 6. Saturation Mixing-Ratio Lines on the Skew-T Chart.

2.9. 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.

2.10. Contrail-Formation Curves. Printings following the May 1959 edition of the full-scale version (DOD WPC 9-16) of the Skew-T Chart are overprinted in thin black lines with two sets of four lines each, taken from *AWSM 105-100*. These are labeled with the theoretical critical relative-humidity values separating the categories for forecasting probability or absence of contrails from jet aircraft. The solid set of lines is for use between the 500- and 100-mb surfaces, and the dashed set for use between the 100- and 40-mb surfaces. The application of these "curves" is explained in *AWSM 105-100*.

2.11. Analysis Blocks. To facilitate and standardize entry of sounding analyses, a form as shown in Figure 9 has been printed on the right-hand side of DOD WPC 9-16, 9-16-2, and 9-16-3, and on the left-hand side of DOD WPC 9-16-1. The DOD WPC 9-16A does not have this feature.

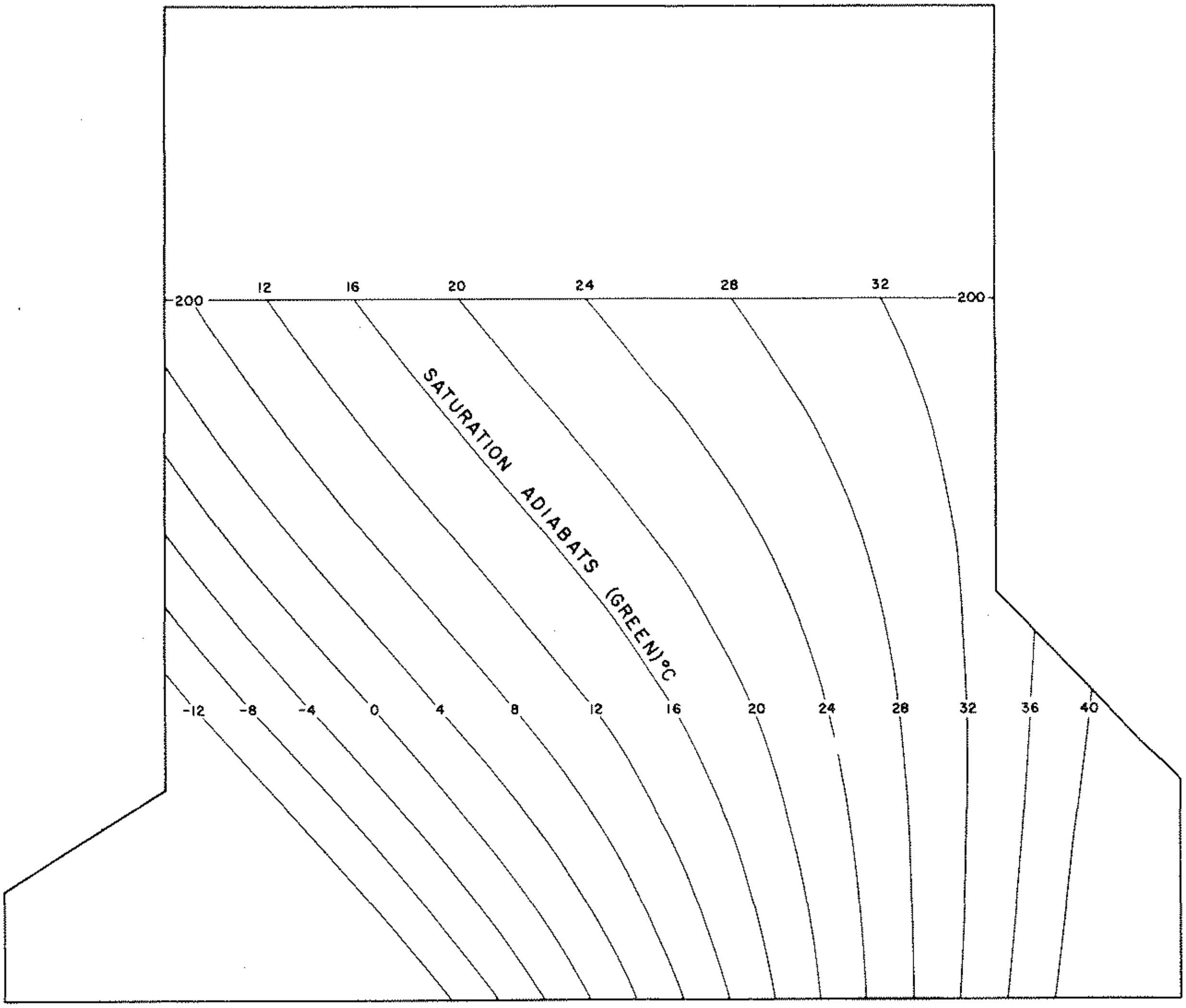

Figure 5. Saturation Adiabats on the Skew-T Chart.

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.

2.8. Standard Atmosphere Data. The ICAO Standard Atmosphere lapse rate is shown on the Skew-T Chart as a heavy brown line passing through the point at 1013 mb and 15°C.[5] The position of this line is also illustrated in Figure 8. The heights of pressure surfaces in this standard atmosphere up to 100 mb are indicated on the vertical scale (labeled ICAO STANDARD ATMOSPHERE ALTITUDE) printed on the right side of the chart. This scale is graduated in geopotential meters and feet (see Footnote 4). The heights of standard-pressure surfaces are also printed at the left margin of the chart beneath each pressure value (1000, 950, 900,...etc., to 10 mb).

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[5] Appendix II of *AWSM 345-1 (Rev.)* gives additional data on the ICAO Standard Atmosphere.

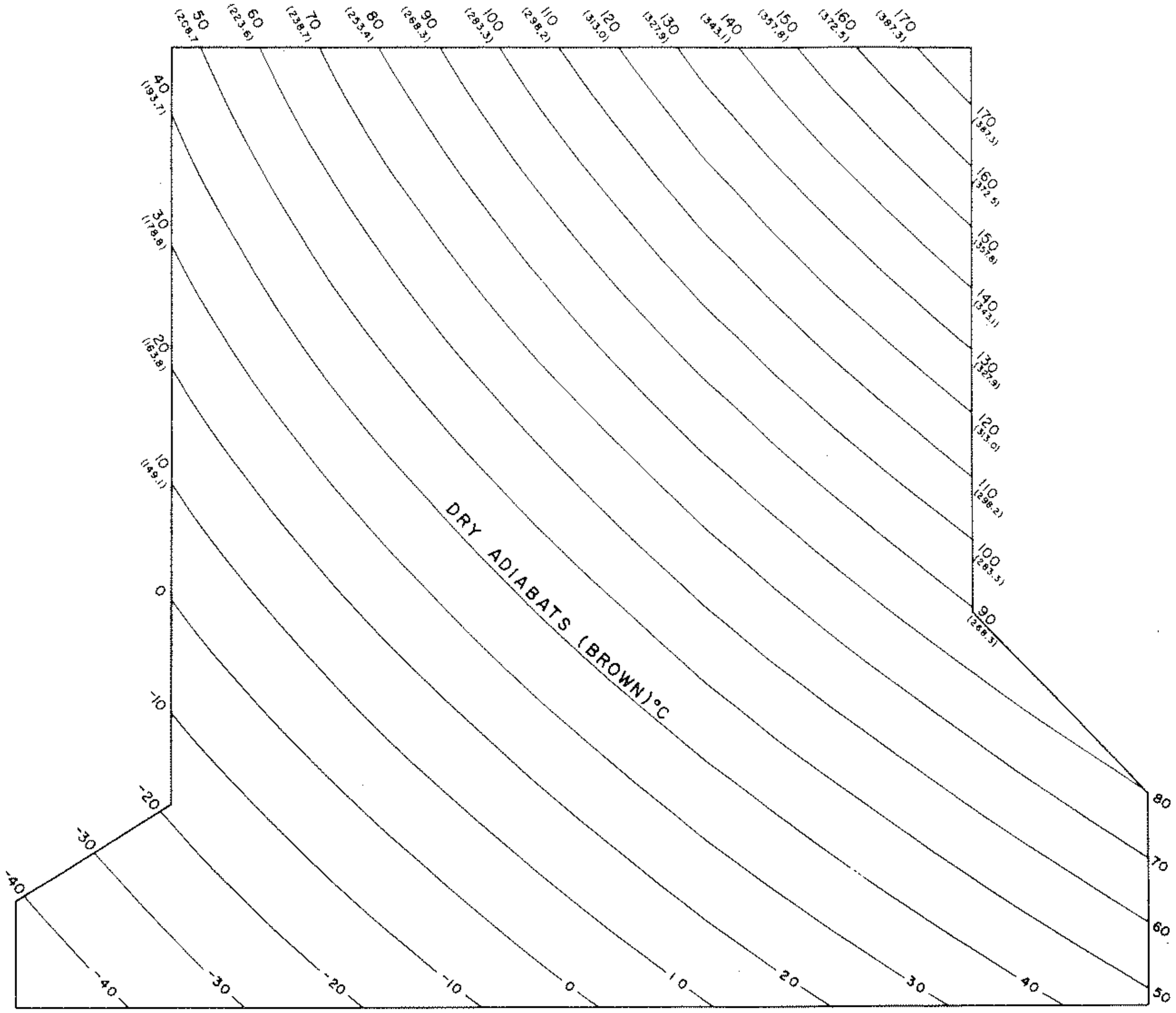

Figure 4. Dry Adiabats on the Skew-T Chart.

100's of geopotential meters.[4] Each thickness scale may be used also for layers other than that for which it is labeled, provided that the ratio of the boundary pressures is the same; paragraph 4.14 explains this procedure. If needed, additional thickness scales may also be constructed locally for any desired layer (see pp. 109-116 of [33]).

2.7. The 1000-mb Height Nomogram. The 1000-mb height nomogram, printed on the full-scale version (DOD WPC 9-16) only, as shown in Figure 8, consists of three black scales:

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

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[4] For meteorological purposes, geopotential feet and meters can be considered as geometric feet or meters with very little error. (The exact relationship is explained in the *Smithsonian Meteorological Tables*, Sixth Revised Edition [60], which tabulates the resulting errors for all heights and latitudes.)

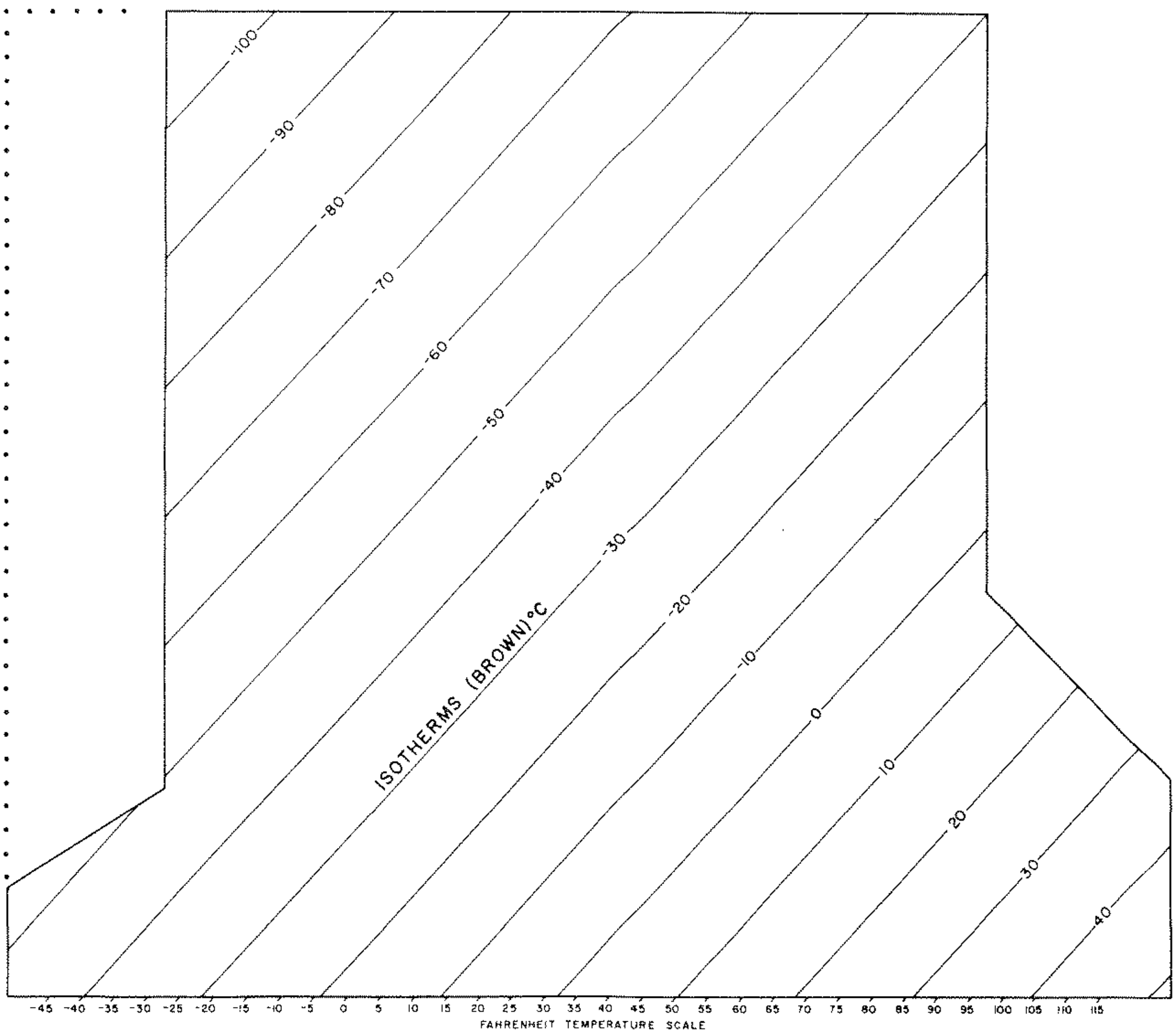


Figure 3. Isotherms on the Skew-T Chart.

in parts of water vapor per 1000 parts of dry air. The spacing between the saturation mixing-ratio lines decreases as their numerical value increases. The mixing ratio at all temperatures is computed from the vapor pressure over a plane water surface. Like the saturation adiabats, the mixing-ratio lines are extended only to the 200-mb isobar.

2.6. Thickness Scales. The nine thickness scales on the Skew-T Chart (illustrated in 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

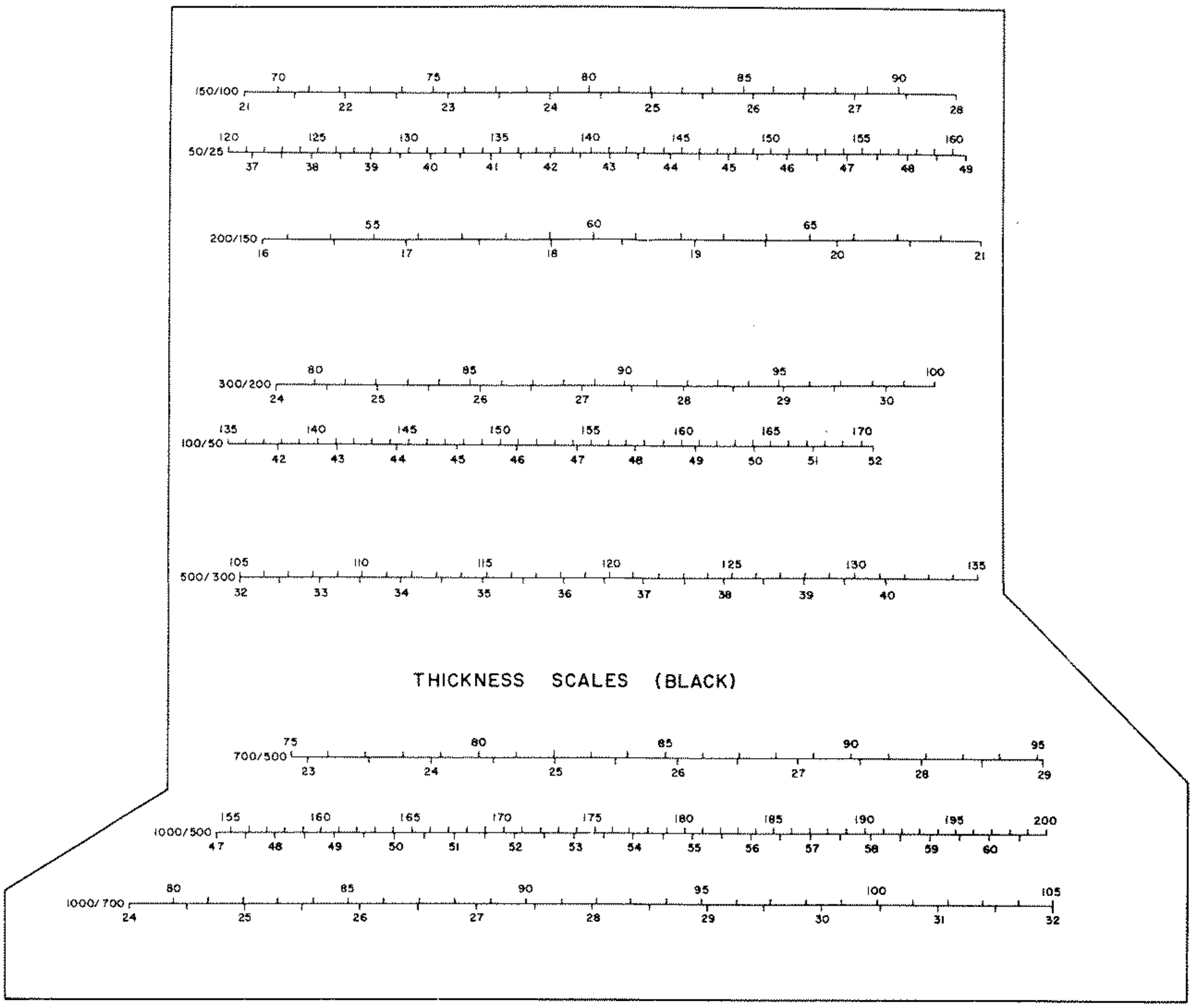


Figure 7. Thickness Scales on the Skew-T Chart.

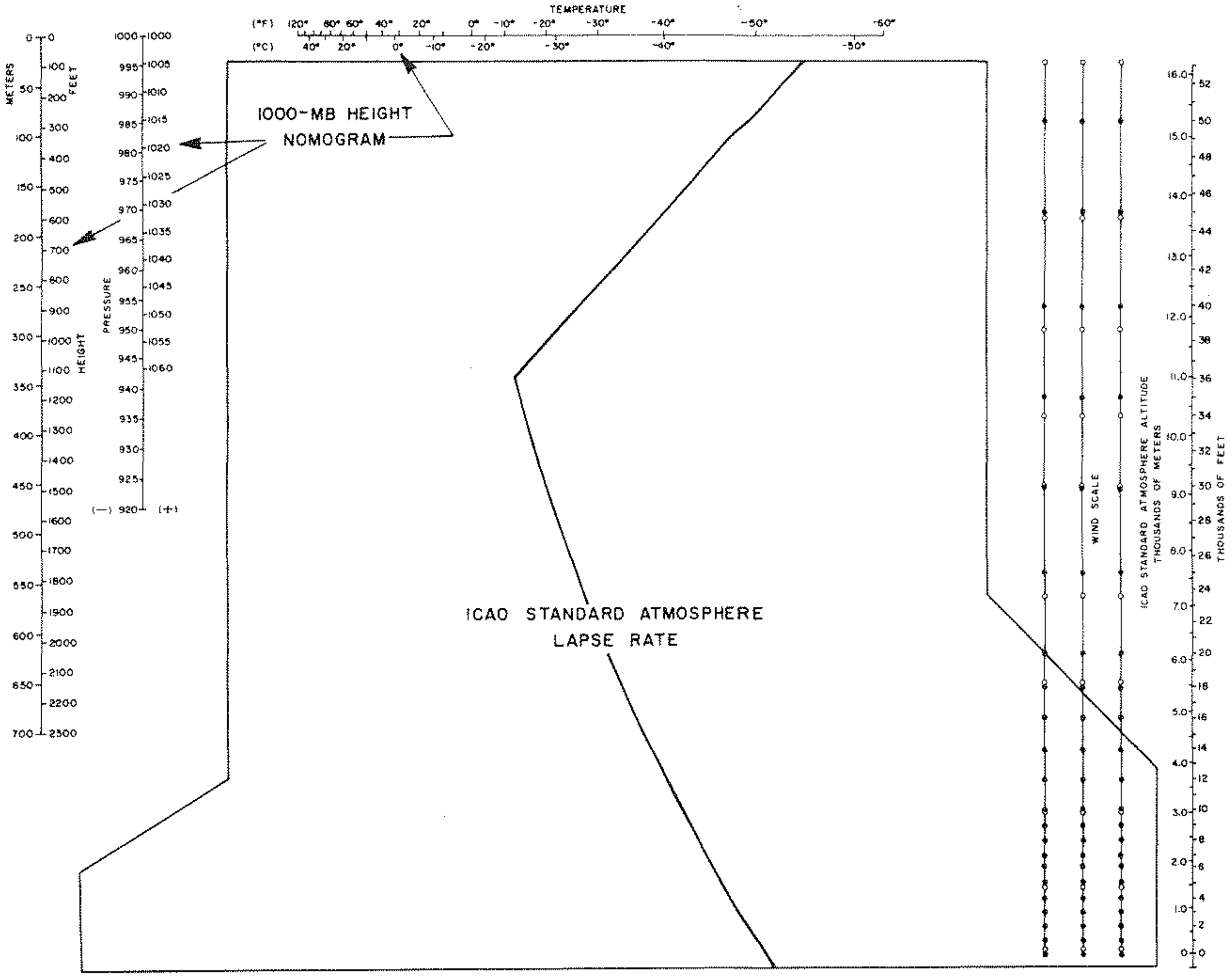
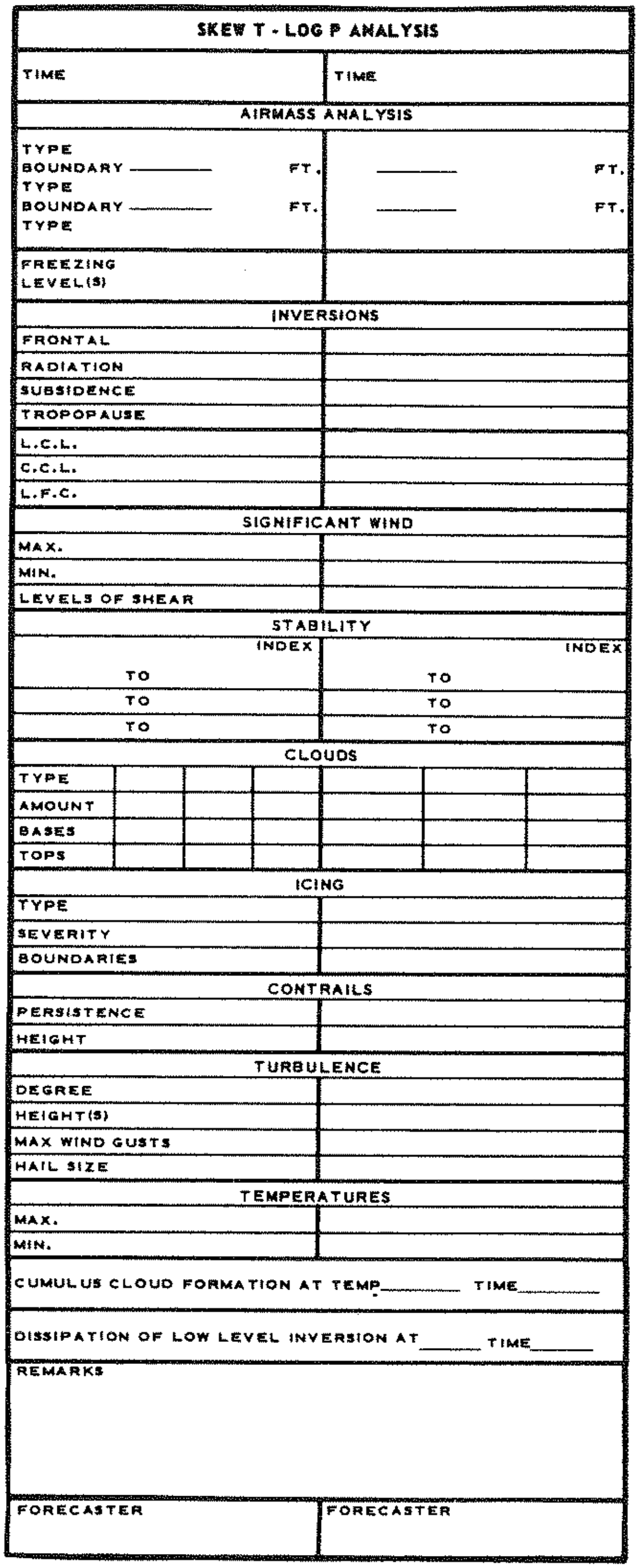


Figure 8. Auxiliary Scales on the Skew-T Chart.



SKEW T - LOG P ANALYSIS	
TIME	TIME
AIRMASS ANALYSIS	
TYPE BOUNDARY ________ FT. TYPE BOUNDARY ________ FT. TYPE	________ FT. ________ FT.
FREEZING LEVEL(S)	
INVERSIONS	
FRONTAL	
RADIATION	
SUBSIDENCE	
TROPOPAUSE	
L.C.L.	
C.C.L.	
L.F.C.	
SIGNIFICANT WIND	
MAX.	
MIN.	
LEVELS OF SHEAR	
STABILITY	
INDEX TO	INDEX TO
TO	TO
TO	TO

CLOUDS						
TYPE						
AMOUNT						
BASES						
TOPS						

ICING	
TYPE	
SEVERITY	
BOUNDARIES	
CONTRAILS	
PERSISTENCE	
HEIGHT	
TURBULENCE	
DEGREE	
HEIGHT(S)	
MAX WIND GUSTS	
HAIL SIZE	
TEMPERATURES	
MAX.	
MIN.	

CUMULUS CLOUD FORMATION AT TEMP________ TIME________

DISSIPATION OF LOW LEVEL INVERSION AT______ TIME______

REMARKS

FORECASTER	FORECASTER

Figure 9. Analysis Block on the Skew-T Chart.

Chapter 3

PLOTTING SOUNDING DATA ON THE SKEW-T CHART

3.1. General. The data used for plotting thermodynamic diagrams such as the Skew-T Chart are obtained from a variety of sources, including radiosondes, dropsondes, aircraft soundings, rocketsondes, and upper-wind reports of pibals or rawins. The plotter should refer to the appropriate FMH, WBAN, or WMO publications for decoding instructions applicable to the type of report in question. The plotting instructions given in this chapter pertain to all six versions of the Skew-T Chart.

3.2. Number of Soundings Plotted Per Chart. One chart is used for each reporting station, and normally no more than two soundings from new data are plotted on it. A trace from a previous sounding should be entered on the chart for continuity purposes. There should be a 6-hour or a 12-hour time interval between each set of curves, determined by the individual forecasting unit. Thus, if four soundings per day from a given station are plotted, two charts would normally be used. For a 12-hour time interval, plot one chart for the 0000Z and 1200Z soundings plus the trace of the previous day's 1200Z sounding and plot one for the 0600Z and 1800Z soundings plus the preceding 1800Z trace. Use of a 12-hour interval 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. For a 6-hour time interval, plot one chart for the 0000Z and 0600Z soundings plus the trace for the previous day's 1800Z trace, and one for the 1200Z and 1800Z soundings plus the preceding 0600Z sounding.

3.3. 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 first new sounding (6 or 12 hours) after the "trace" should be plotted in blue pencil; the second new sounding (12 or 24 hours) after the "trace" in red pencil. This procedure is suggested since the use of red for the third set of curves emphasizes the latest data. All supplementary data for a sounding should be in the same color as the plotted curves; e.g., legend, tropopause, etc.

3.4. Plotting Individual Elements. A free-air temperature curve and a dew-point curve should be plotted for each sounding. Curves of other types of moisture representation may be plotted if desired.

The points to be plotted on the chart are located by reference to the pressure and temperature (either free air or dew point) of the level. Pressures are plotted in whole millibars; temperatures are plotted to the nearest tenth of a degree or whole degree according to local policy and chart scale. Each point on the curve of temperature or dew point is presented by a small dot located at the proper temperature and pressure. A small circle no larger than one-eighth inch diameter should be drawn around each dot on the temperature and dew-point curves (note that, for clarity, the points on temperature curves in the figures in this manual have been indicated by large solid dots). This circle will aid in locating the points when drawing the connecting lines; and the circles further aid in identifying significant points on the curves. If other moisture curves are plotted (for example, the wet-bulb curve) small triangles or other symbols should be drawn around the dots on these curves to distinguish them from the dew-point curve.

The free-air temperature curve will always be represented by a solid line; while the moisture curves will be dashed lines. Use a straightedge when drawing the connecting lines between the plotted points.

Through strata of *doubtful* data, draw the free-air temperature and moisture-representation curves in the normal manner. Indicate the limits of such strata in the space above the legend (e.g., TEMP DBTFL 615-550 MB), in the same color as is used for plotting the curves.

Where there is a stratum of *missing* data, terminate the curves at the lower boundary of the stratum, and start the curves again at the upper boundary of the stratum. Enter the symbol MISDA in the middle of the stratum of missing data in the same color as is used for plotting the curves. When humidity data are missing, it is desirable to enter 10168 or 10169, when applicable, below the symbol MISDA. This procedure will inform the analyst whether the missing humidity data are due to dry, cold air, or are the result of some other factor (frequently non-meteorological). Often, humidity data do not appear again at higher levels after they have been indicated as missing at lower ones. In these cases, it is desirable to enter M ABOVE or 10168 ABOVE, as applicable, just above the last reported humidity point.

Enter the height of each mandatory level on the isobar to which it pertains. Make this entry just inside either edge of the diagram for levels from 1000 mb to 100 mb, and just inside the opposite edge of the diagram for levels above 100 mb.

If necessary, the position of height entries may be adjusted to avoid conflict with other plotted data. Enter height values to the nearest meter for levels up to 500 mb and to the nearest 10 meters for levels at and above 500 mb. For example, plot 1436 for an 850-mb height reported as 85436 and plot 1175 for a 200-mb height reported as 20175. Plot maximum-wind and tropopause data when reported within the levels plotted. For the pressure level of the tropopause, extend the isobar into the margin of the side on which the mandatory-level heights are entered.

3.5. Plotting Wind Data. Wind data at the mandatory levels, as received in the rawinsonde report, should always be plotted on the open circles on the wind staffs in the same color as the corresponding sounding curves. Wind data at other levels, taken from the winds-aloft report for the same time, may be plotted on the solid dots if desired. The conventions specified in *AWSM 105-22* (i.e., north is at the top of the diagram, a full barb equals 10 knots, etc.) should be followed when plotting winds. Use the right-hand staff for the first wind report, and plot succeeding reports on the middle and/or left-hand staffs. The winds for the continuity trace are not normally copied unless the analyst specifically desires them; in which case, they should be located on the right-hand staff.

3.6. Legend. A legend will be entered for each sounding plotted. Enter the station index number (or location identifier), station name, time (Z), and date (Z) in the identification box(es). Use the same color for legend entries as was used for the corresponding sounding curves.

When a scheduled sounding is not received, complete the legend entries and enter the $101A_{df}A_{df}$ group identifying the reason for no observation in the space above the legend in the appropriate color. If a $101A_{df}A_{df}$ group is not received, enter "..... Z MISG."

Chapter 4

DETERMINATION OF UNREPORTED METEOROLOGICAL QUANTITIES FROM PLOTTED SOUNDINGS

4.1. Introduction. In accordance with paragraph 3.4, two curves are usually plotted and drawn on the Skew-T Chart for each sounding, as shown in Figure 10. One represents the free-air temperature *(T)*, the other the dew-point temperature (T_d). This chapter outlines procedures for determining certain unreported meteorological quantities which may be evaluated on the Skew-T Chart from such a plotting sounding.

4.2. Mixing Ratio.

Definition: In a sample of moist air, the mixing ratio *(w)* is the ratio of the mass of water vapor (M_v) to the mass of dry air (M_d), i.e., $w = M_v / M_d$.[6] It is expressed in parts per thousand, usually grams of water vapor per kilograms of dry air.

Procedure: To find the mixing ratio for a given pressure on the plotted sounding, read the value, either directly or by interpolation, of the saturation mixing-ratio line that crosses the T_d curve at that pressure. On the sounding shown in Figure 10, for example, T_d at 700 mb is -13°C; and the saturation mixing-ratio value at 700 mb and -13°C is 2.0 g/kg. Hence, the mixing ratio of the air at the 700-mb level on this sounding is 2.0 g/kg.

4.3. Saturation Mixing Ratio.

Definition: The saturation mixing ratio (w_s) is the mixing ratio a sample of air would have if saturated[7].

Procedure: To find the saturation mixing ratio for a given pressure on the plotted sounding, read the value, either directly or by interpolation, of the saturation mixing-ratio line that crosses the *T* curve at that pressure. On the sounding shown in Figure 10, *T* at 700 mb is -5°C; and the saturation mixing-ratio value at 700 mb and -5°C is 3.8 g/kg. Hence, the saturation mixing ratio of the air at the 700-mb level on this sounding is 3.8 g/kg.

4.4. Relative Humidity.

Definition: Relative humidity (RH) is 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: The relative humidity can be computed from the mixing ratio *(w)* and the saturation mixing ratio (w_s) by the following equation:

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[6] The "specific humidity" *(q)*, where $q = M_v/(M_v + M_d)$, the mass of water vapor per mass of moist air, often is preferable for very precise physical and theoretical work. For synoptic purposes, however, the mixing ratio is sufficiently representative, and is easier to evaluate.

[7] Moist air at temperature *T* and at total pressure *p* is said to be saturated if its composition is such that it can co-exist in neutral equilibrium with a plane surface of pure condensed phase (water or ice) at the same temperature and pressure [65].

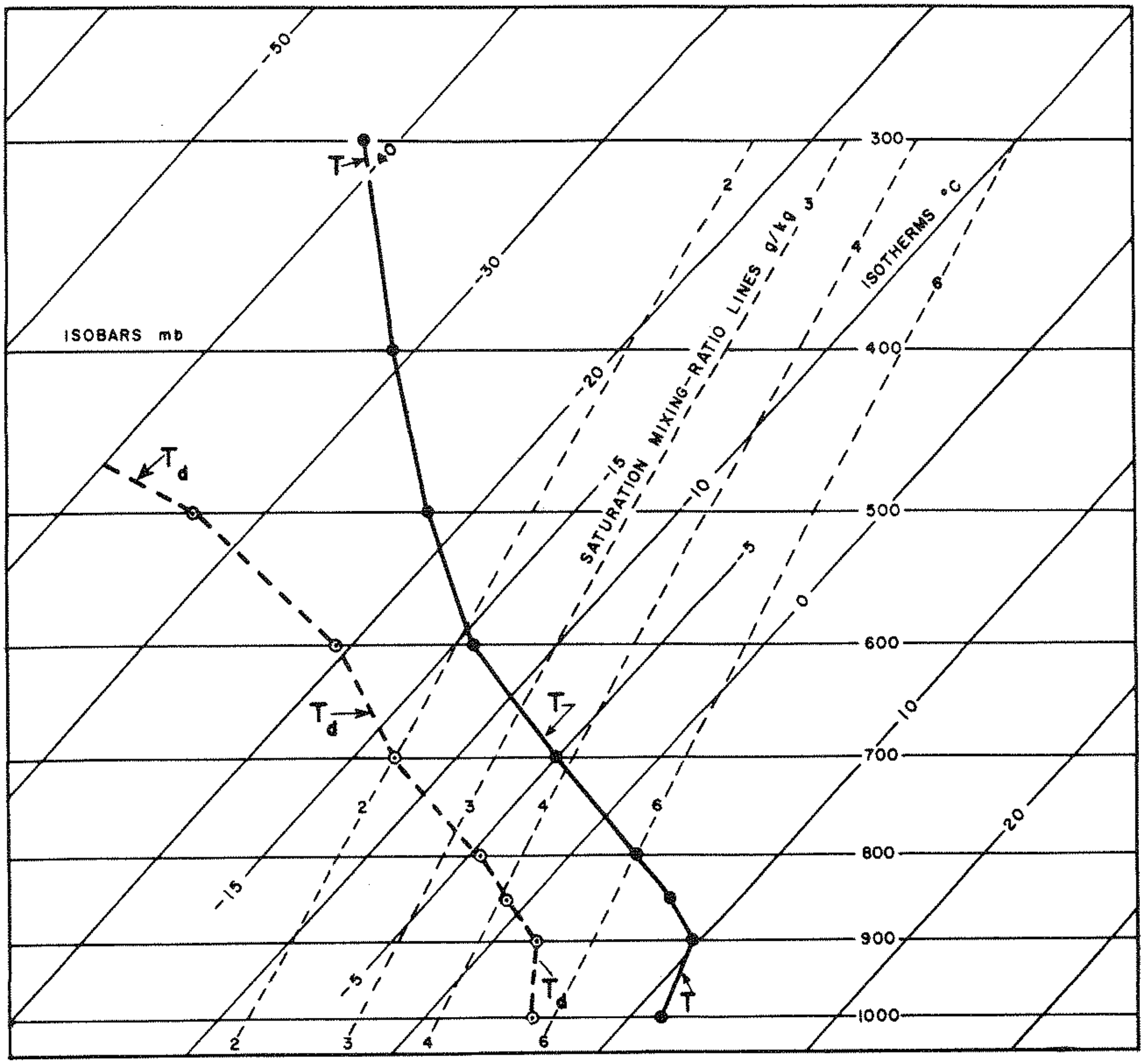

Figure 10. Sample Sounding on the Skew-T Chart.

$$RH = 100(w/w_s)$$

On the sounding shown in Figure 10, w and w_s at 700 mb are 2.0 and 3.8 g/kg, respectively. Therefore the relative humidity at the 700-mb level on that sounding is $100 \frac{2.0}{3.8} = 53\%$.

Alternate Procedure: There is also a procedure, shown in Figure 11 to find graphically on the Skew-T Chart the relative humidity for a given pressure on the sounding. It is as follows:

Step 1. From the T_d curve at the given pressure, follow the saturation mixing-ratio line to the 1000-mb isobar.

Step 2. From this intersection, draw a line parallel to the isotherms.

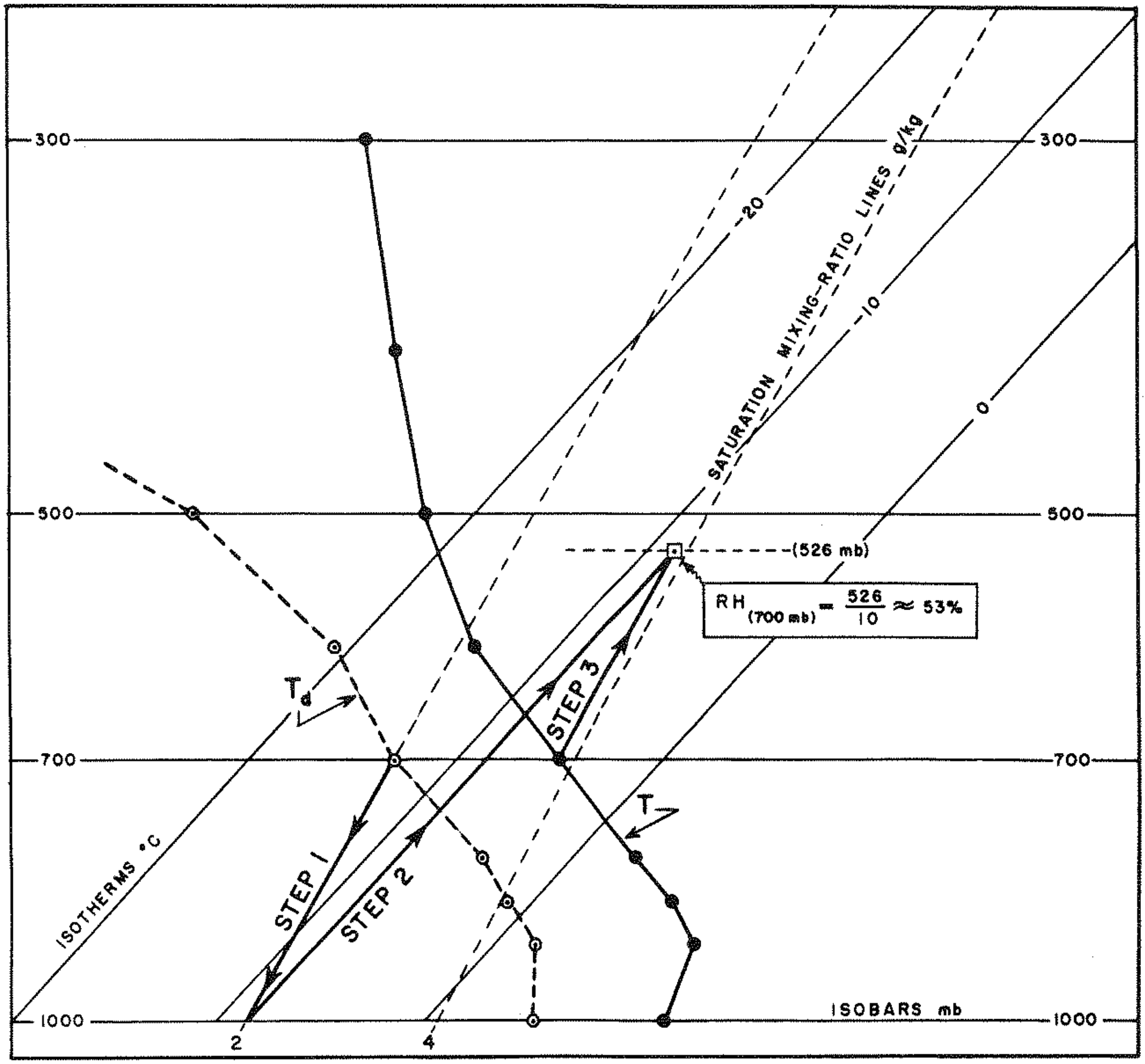

Figure 11. Alternate Procedure for Finding Relative Humidity (RH).

Step 3. From the *T* curve at the given pressure, follow the saturation mixing-ratio lines to the intersection with the line drawn in Step 2. The numerical value of the isobar through this last intersection point is divided by ten. The quotient is the relative humidity at the given pressure.

4.5. Vapor Pressure.

Definition: The vapor pressure *(e)* is that part of the atmospheric pressure which water vapor contributes to the total atmospheric pressure.

Procedure: From the T_d curve at the given pressure on the sounding (for example, at 700

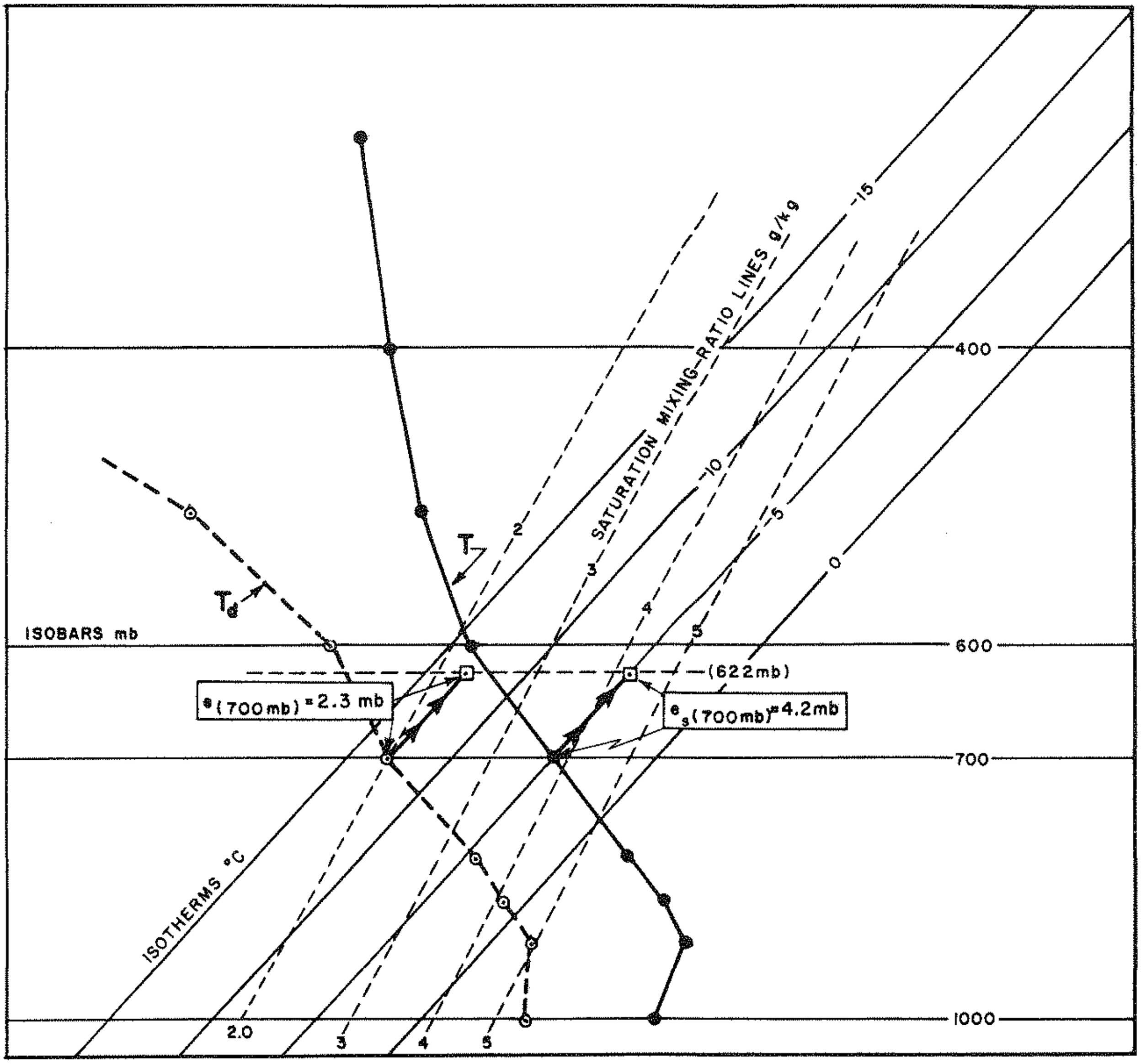

Figure 12. Determination of the Vapor Pressure (e) and the Saturation Vapor Pressure (e_s).

mb in Figure 12), follow the isotherms to the 622-mb isobar[8]. The value of the saturation mixing-ratio line, read by interpolation if necessary, through this point at 622 mb gives the vapor pressure in millibars at the given pressure.

4.6. Saturation Vapor Pressure.

Definition: The saturation vapor pressure (e_s) is the partial pressure which water vapor would contribute to the total atmospheric pressure if the air were saturated.

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[8] The theoretical basis for choosing this particular isobar is explained on pages 60-63 of[33].

Procedure: Referring again to Figure 12, from the T curve at the given pressure (700 mb), follow the isotherms to the 622-mb isobar. The value of the saturation mixing-ratio line, read by interpolation if necessary, through this point at 622 mb gives the saturation vapor pressure in millibars at the given pressure.

4.7. Comments on Temperature Parameters.

At times in the past, various authors have given a slightly different name and definition to the same temperature parameter. This has resulted in a confusion which is more annoying than serious. The names and definitions for the various temperature parameters used in this manual were taken from the WMO standard names and definitions [65] whenever possible, or from the most logical and practical designations now in use.

4.8. Potential Temperature.

Definition: The potential temperature (θ) is the temperature that a sample of air would have if it were brought dry-adiabatically to a pressure of 1000 mb.

Procedure: For any given pressure, for example 700 mb on the sounding shown in Figure 13, the potential temperature in °C is equal to the value of the dry adiabat passing through the T curve at that level. However, the potential temperature is customarily expressed in °K, which can be converted from °C by adding 273 to the Celsius temperature value.

Alternate Procedure: Another procedure is also shown in Figure 13. From the T curve at the given pressure (700 mb), follow the dry adiabat to the 1000-mb isobar. The isotherm value of this adiabat at 1000 mb is equal to the potential temperature of the air parcel at the given pressure.

In the example shown in Figure 13, $\theta_{(700)} = 24°C$ or $297°K$.

4.9. Wet-Bulb Temperature.

Definition: The wet-bulb temperature (T_w) is the lowest temperature to which a volume of air at constant pressure can be cooled by evaporating water into it. This assumes that the heat required for evaporation is taken from the air itself. (WMO definition [65].) Physically, the wet-bulb temperature is the temperature of the wet-bulb thermometer rather than of the air.

Procedure[9]*:* Figure 14 illustrates the method of finding the wet-bulb temperature at a given pressure on the sounding. The steps are:

Step 1. From the T_d curve at the given pressure, in this case 700 mb, draw a line upward along a saturation mixing-ratio line.

Step 2. From the T curve at the given pressure (700 mb), draw a line upward along a dry adiabat until it intersects the line drawn in Step 1. (The height of this intersection is the "lifting condensation level," as described in par. 4.20.)

Step 3. From this point of intersection, follow a saturation adiabat back to the given pressure, 700 mb. The isotherm value at this pressure is equal to the wet-bulb temperature.

In the example shown in Figure 14, $T_{w(700)} = -8°C$.

4.10. Wet-Bulb Potential Temperature.

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

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[9] The procedure given here is for the adiabatic wet-bulb temperature. The "true" (i.e., isobaric) wet-bulb temperature is almost identical (see p. 78 of [33]).

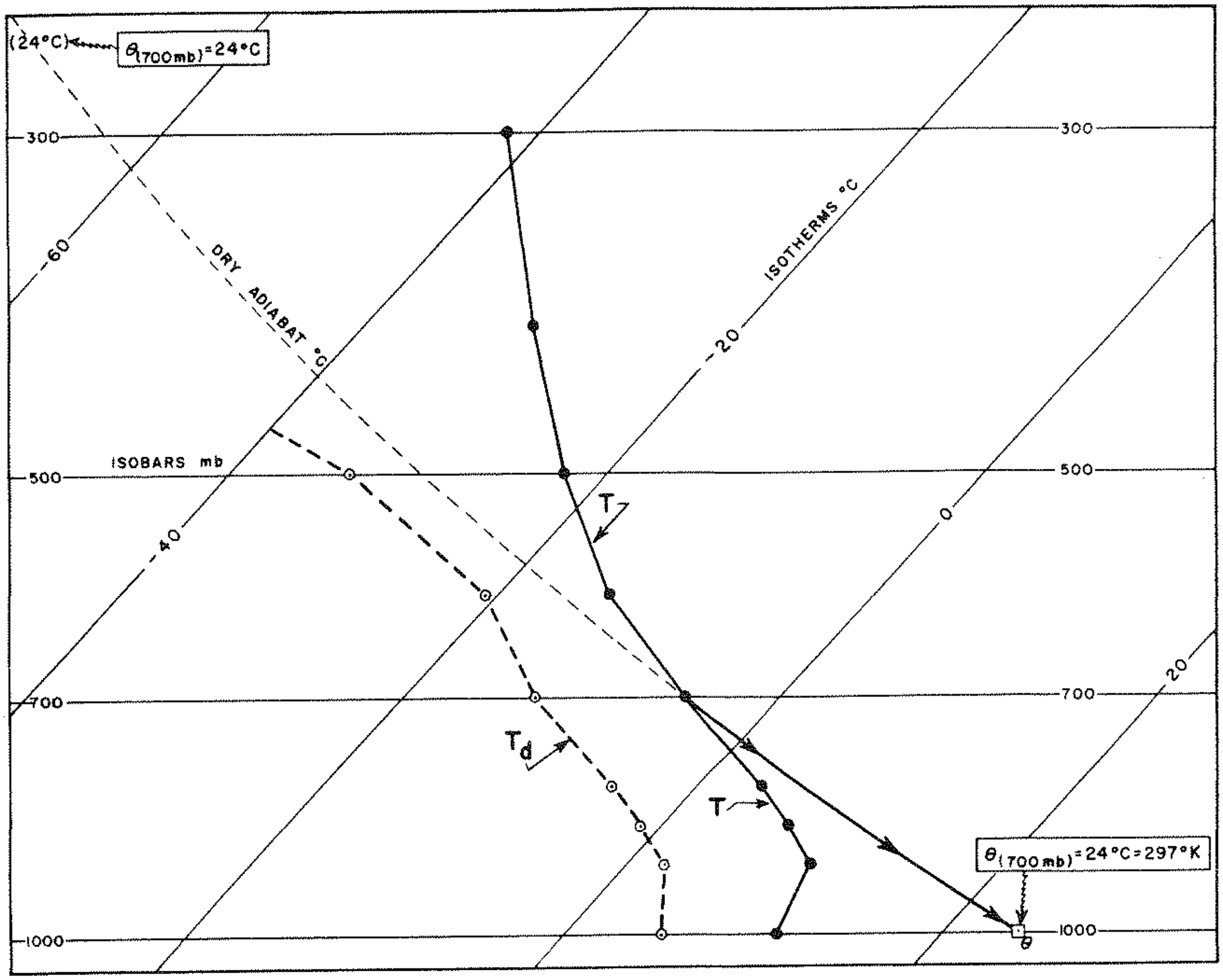

Figure 13. Determination of the Potential Temperature (θ).

Procedure: Find the wet-bulb temperature as in paragraph 4.9 and shown in Figure 14. The value of the saturation adiabat through this wet-bulb temperature point is equal to the wet-bulb potential temperature.

Alternate Procedure: Another procedure is also illustrated in Figure 14. Find the wet-bulb temperature as in paragraph 4.9. From the T_w point, follow the saturation adiabat to the 1000-mb isobar. The isotherm value at this intersection is equal to the wet-bulb potential temperature at the given pressure.

In the example shown in Figure 14, $\theta_{w(700)} = 9.5°C$.[10]

4.11. Equivalent Temperature.

Definition: The equivalent temperature (T_E) is the temperature a sample 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

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[10] In theoretical and physical meteorology it is customary to express θ_w in °K (i.e., by adding 273° to the Celsius temperature value).

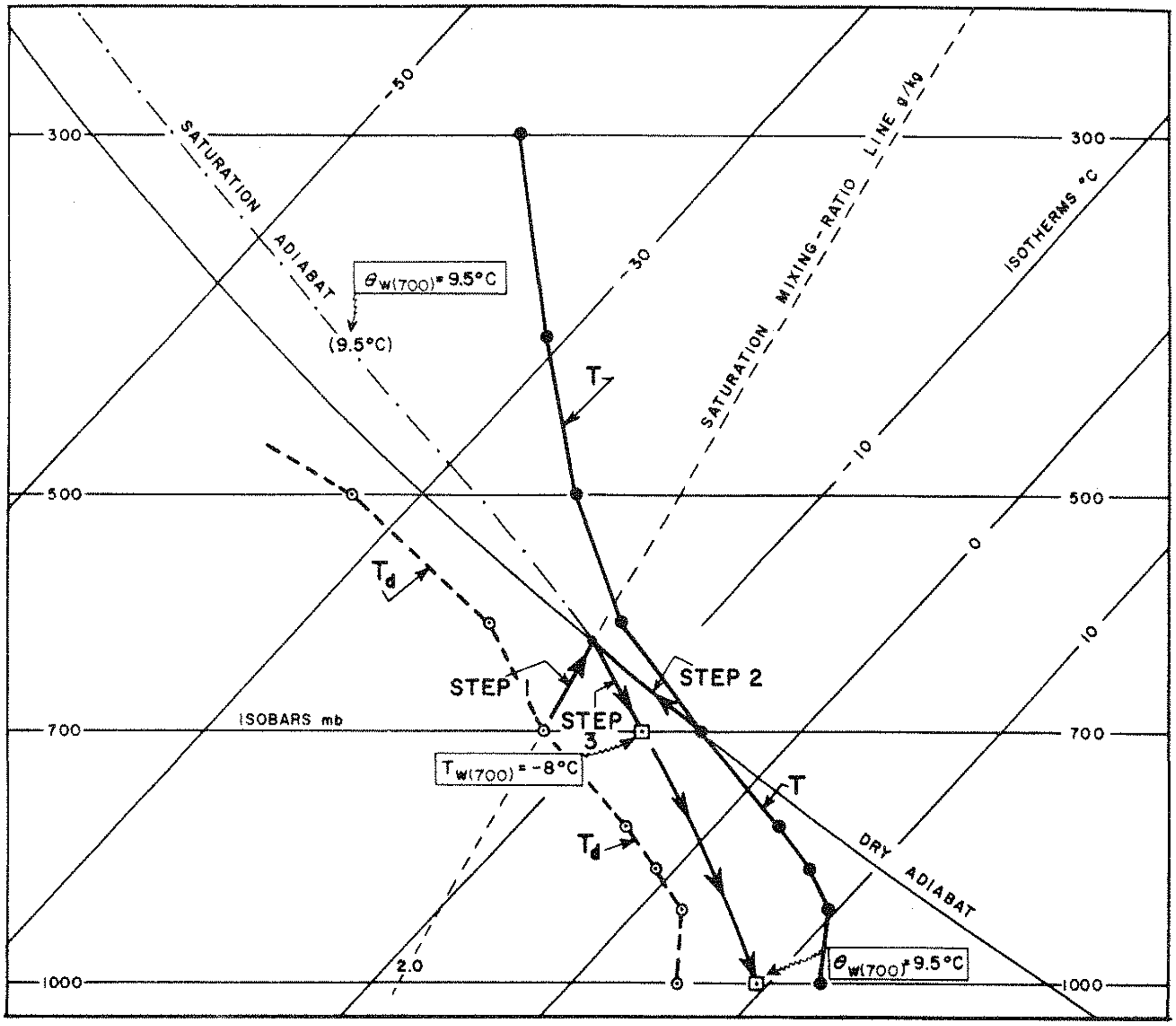

Figure 14. Determination of the Wet-Bulb Temperature (T_w) and the Wet-Bulb Potential Temperature (θ_w).

termed the "adiabatic equivalent temperature," and should not be confused with the "isobaric equivalent temperature" which is always slightly lower.

Procedure: Figure 15 illustrates the method of finding T_E for a given pressure on the sounding. The steps are:

Step 1. From the T_d curve at the given pressure, in this case 700 mb (Point P'), draw a line upward along a saturation mixing-ratio line. Also, from the T curve at the given pressure (Point P), draw a line upward along a dry adiabat until it intersects the line drawn first. (The height of this intersection is the "lifting condensation level," see par. 4.20.)

Step 2. From this intersection, follow a saturation adiabat upward to a pressure where both the saturation and dry adiabats become parallel; i.e., to a pressure where all the moisture has been condensed out of the sample.

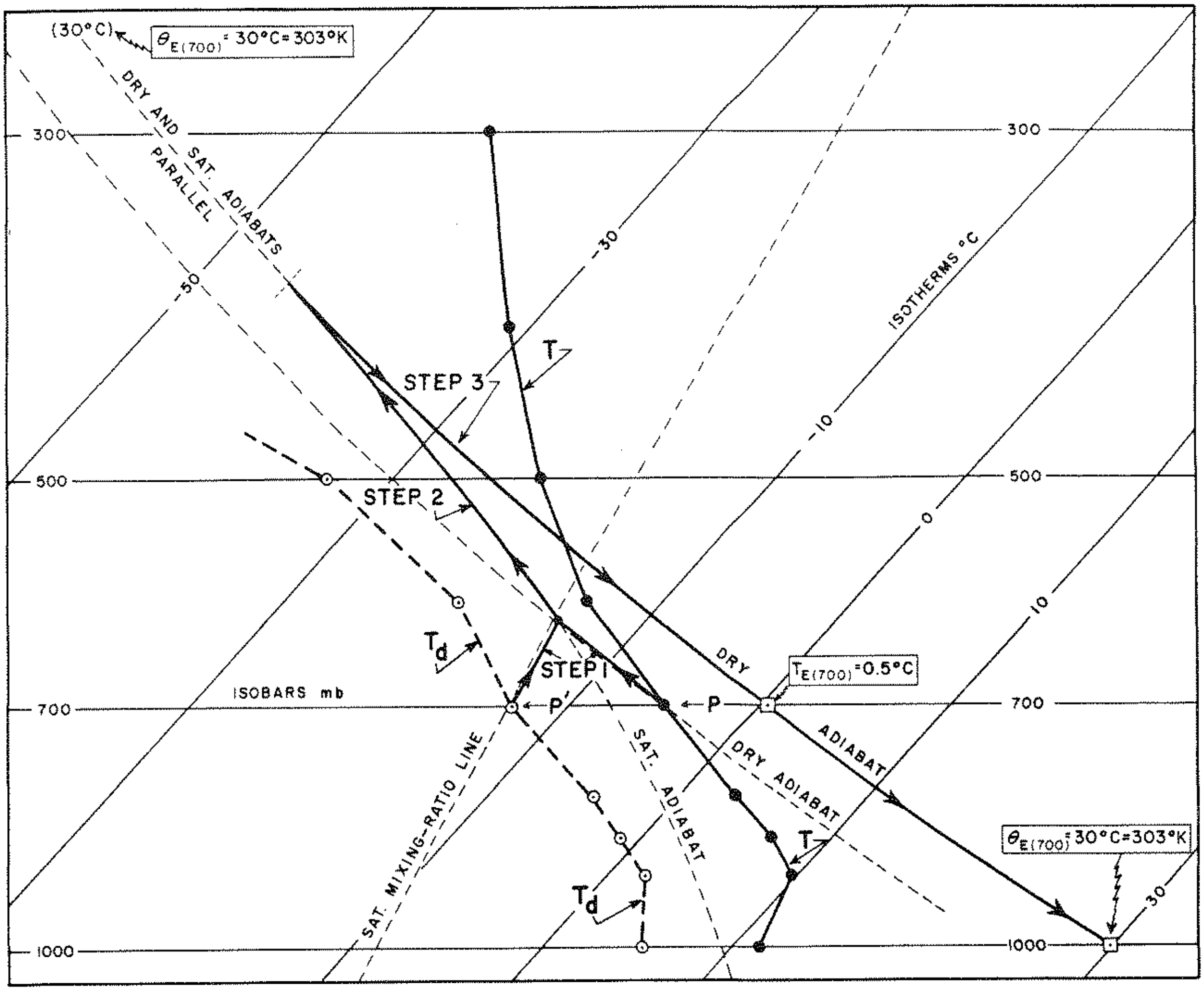

Figure 15. Determination of the Equivalent Temperature (T_E) and the Equivalent Potential Temperature (θ_E).

Step 3. From this pressure, follow a dry adiabat back to the original pressure, 700 mb. The isotherm value at this point is equal to the equivalent temperature (T_E).

In the example shown in Figure 15, $T_{E(700)} = +0.5°C$.

4.12. Equivalent Potential Temperature.

Definition: The equivalent potential temperature (θ_E) is the temperature a sample 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 back to 1000 mb.

Procedure: Find the equivalent temperature for the given pressure, in this case 700 mb, as described in paragraph 4.11, and as shown in Figure 15. From the T_E point, follow the dry adiabat to the 1000-mb isobar. The isotherm value at this point is equal to the equivalent potential temperature (θ_E) at the given pressure. θ_E can also be read directly from the value of the dry adiabat through the T_E point at the given pressure.

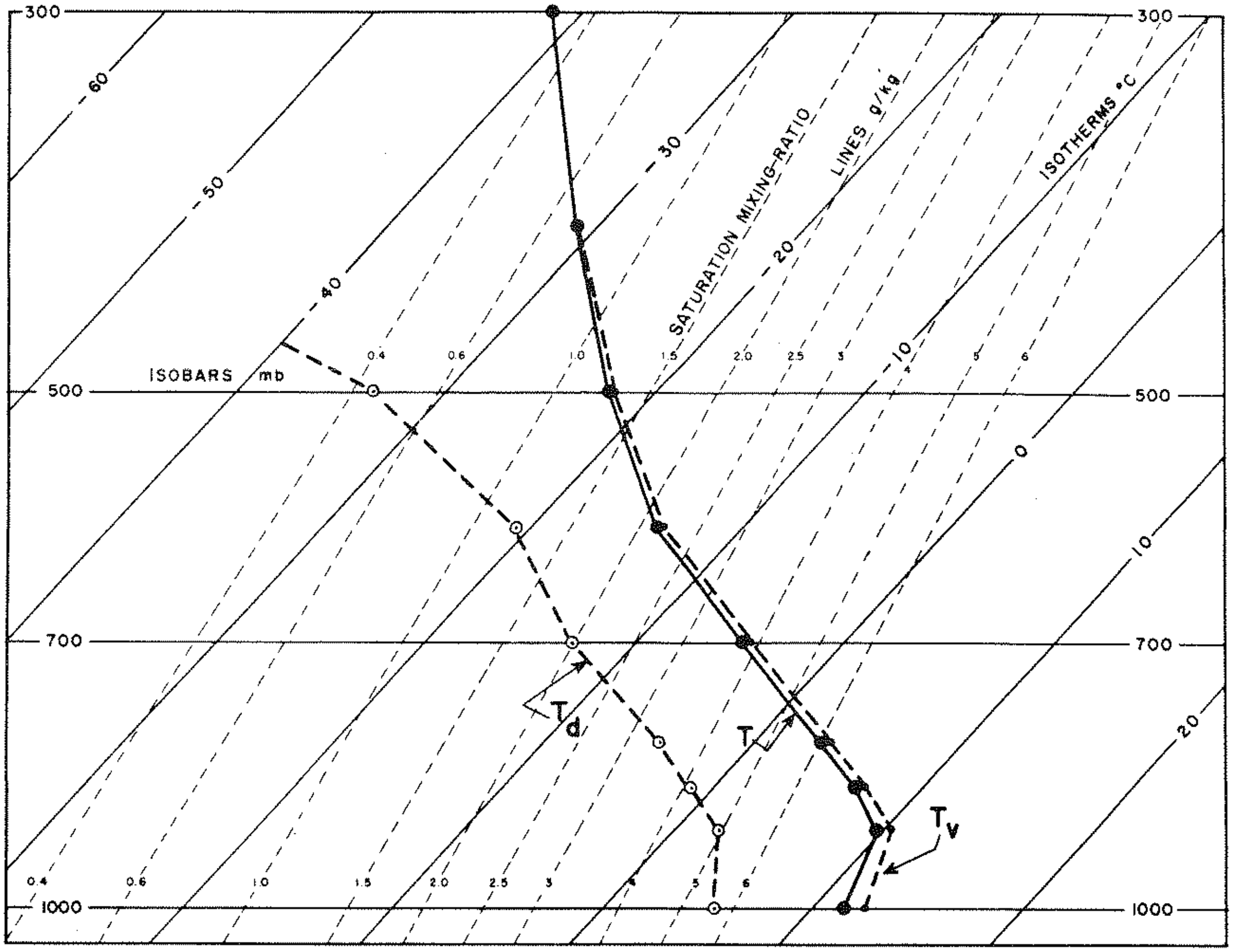

Figure 16. Comparison Between the Observed-Temperature and Virtual-Temperature Curves.

In the example shown in Figure 15, $\theta_{E(700)} = 30^{\circ}C$ or $303^{\circ}K$.

4.13. Virtual Temperature.

Definition: The virtual temperature (T_v) 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.

Procedure: At a given pressure 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 T_d curve 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.

For detailed work, a more accurate determination of the virtual temperature can be made by using the following formula (see p. 63 of [33] for the derivation of this equation):

$$T_v = T(1 + 0.6w)$$

4.14. Thickness of a Layer.

Definition: The thickness of a layer between any two pressure surfaces is equal to the difference in the geopotential heights of these surfaces.

Procedure: Figure 17 illustrates the procedure for finding the thickness of a given layer:

Step 1. Construct a T_v curve for the given layer, in this case the 1000- to 700-mb layer, based upon the corresponding T and w values at the appropriate points of the original sounding (see paras. 4.2 and 4.13).

Step 2. 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 the left of 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.

Step 3. The thickness of the layer is read at the point where the straight line of Step 2 crosses the thickness scale for the given layer.

The label at the left end of each thickness scale on the Skew-T Chart specifies the layer for which that scale is primarily intended. However, each scale is also applicable in determining the thickness of certain other layers, namely, layers for which the numerical ratio of the boundary-pressure values is equal to the ratio indicated by the label of the printed scale. For example, the scale for the 500- to 300-mb layer (labeled "500/300") can also be used to determine the thickness of the layers 50 to 30 mb, 250 to 150 mb, 1000 to 600 mb, etc. The thickness scales printed on the Skew-T Chart thus provide for a thickness determination of any layer whose boundary-pressures ratio is equal to 2/1, 3/2, 4/3, 5/3, 7/5, or 10/7; there are six unique ratios.

The thickness of the layer between any two pressure surfaces is directly proportional to the mean virtual temperature[11] of the layer. This can be seen from the hypsometric equation, upon which all thickness computations are based, and which may be written in the form:

$$\text{Thickness} = \frac{R_d}{g}\,\overline{T_v}\ \text{Ln}\left(\frac{P_1}{P_2}\right)$$

where $\overline{T_v}$ is the mean virtual temperature of the layer (in °K); R_d is the gas constant for dry air; g is the gravity constant; P_1 and P_2 are the boundary pressures of the layer; and Ln indicates the natural logarithm (to the base e). Once the boundary-pressure values are chosen, the natural logarithm of their ratio becomes a constant; and thus the thickness varies only with the mean virtual temperature. This may also be shown on the Skew-T Chart. For example, the thickness of the 1000- to 500-mb layer with a mean virtual temperature of -40°C is read from that thickness scale as 15,540 feet. The thicknesses of both the 100- to 50-mb and 50- to 25-mb layers (which each have the same ratio of pressures, 2/1) with the same mean virtual temperature of -40°C are also read from their thickness scales

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[11] Although the T and T_v curves are almost the same for layers of low moisture content, the difference between T and T_v becomes more important when warm, moist air is involved. If thickness calculations for the summer soundings at Miami, Fla., for instance, were based on T values, rather than T_v values, thickness errors in a moist 1000- to 700-mb layer of as much as 100 feet could result.

as 15,540 feet. Thus, if the boundary-pressures ratio of a nonstandard layer fits one of the six unique thickness-scale pressure ratios printed on the Skew-T Chart and if the mean virtual temperature of the nonstandard layer is known, its thickness can be read from that particular thickness scale at the intersection of the proper isotherm value.

In the example shown in Figure 17, the thickness of the 1000- to 700-mb layer is approximately 9550 geopotential feet, or 2910 geopotential meters when read from the bottom scale.

4.15. Height of the 1000-mb Surface.

Definition: This is the height of the 1000-mb pressure surface in geopotential feet above mean sea level (MSL).

Procedure: The 1000-mb Height Nomogram described in paragraph 2.7, printed in the upper left-hand corner of the Skew-T Chart, is used to obtain this value. An example of the use of this nomogram is shown in Figure 18. Locate the surface-air temperature value (40°F) on the TEMPERATURE scale along the top of the chart. Then locate the *sea-level* pressure (1025 mb) on the PRESSURE scale at the left side of the chart. Next, lay a straightedge between these two points so that it intersects the HEIGHT scale. The value at this point of intersection of the HEIGHT scale (660 feet) is the height of the 1000-mb surface above MSL. When the sea-level pressure is less than 1000 mb, the indicated height value is negative; i.e., the 1000-mb surface is below MSL.

The height of the 1000-mb surface above the station can also be calculated from this nomogram. To do this, the station pressure is used on the PRESSURE scale instead of the sea-level pressure. The height read is then the height above the station (or below the station, if the station pressure is less than 1000 mb).

4.16. Pressure Altitude.

Definition: Pressure altitude is defined as the altitude at which a given pressure is found in a standard atmosphere[12]. When an aircraft altimeter is set at 29.92 inches (1013 mb), its height-scale reading indicates the pressure altitude in the particular standard atmosphere upon which its calibration is based. (Most U.S. aircraft altimeters are based on the old NACA standard atmosphere, which does not differ significantly from the ICAO standard atmosphere except above the tropopause.)

Procedure: To find the pressure altitude at a given pressure on a sounding, read the value, in feet or meters as desired, of the ICAO STANDARD ATMOSPHERE ALTITUDE scale (at the right side of the chart) at that pressure. The exact heights of pressures divisible by 50 mb are given in geopotential feet (in parentheses) and in geopotential meters [in brackets] below the pressure-surface values printed along the left border of the chart. For example, the pressure-altitude height for 500 mb is 18,289 feet; for 700 mb it is 9,882 feet.

4.17. Density Altitude. Density altitude is defined as the altitude in a standard atmosphere at which a given density is found. This parameter is frequently used in meteorological and operational problems related to aircraft performance, airport design, etc.

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[12] A standard atmosphere is a hypothetical vertical distribution of atmospheric temperature, pressure, and density which, by national or international agreement, is taken to be representative of the atmosphere for purposes of pressure-altimeter calibration, aircraft-performance calculations, aircraft and missile design, ballistic tables, etc. (refer to the *Glossary of Meteorology* for further discussion). The scales on the Skew-T Chart are based on the ICAO Standard Atmosphere, adopted in November 1952 (see *AWSM 345-1 (Rev.)* and *U. S. Standard Atmosphere, 1962*, for a table of height values.

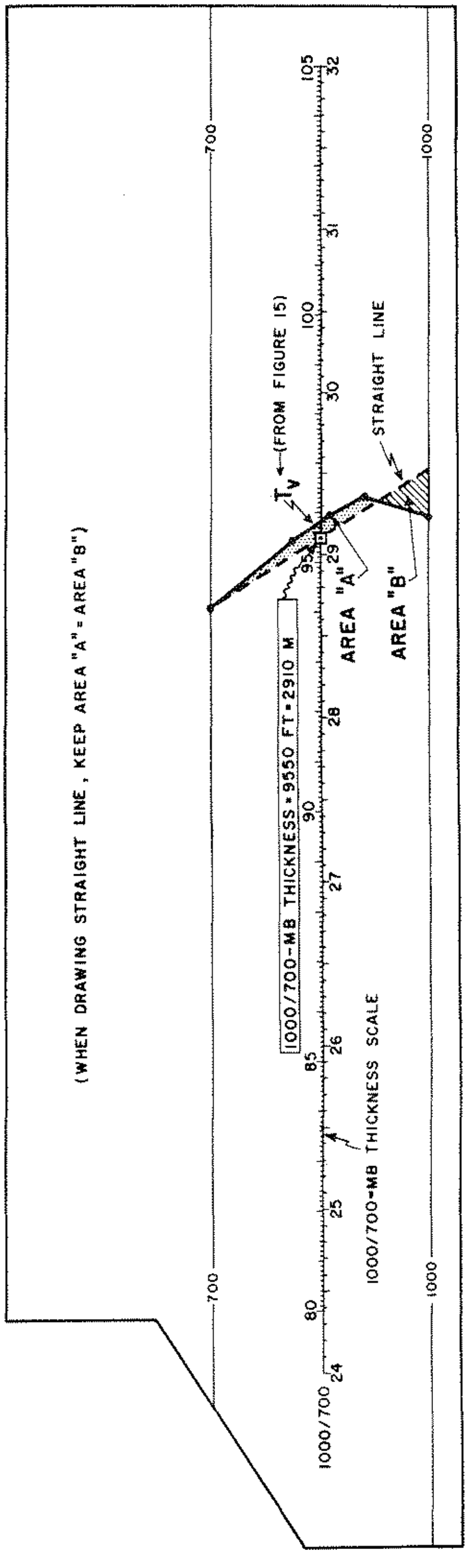

Figure 17. Determination of the Thickness of the 1000- to 700-mb Layer.

Computation of the density altitude can be easily accomplished on an edition of the full-scale Skew-T Chart which has a density-altitude nomogram overprinted on it. This edition and instructions for its use are available in *AWS TR 105-101.* (See para. 1.3f)

4.18. Convection Condensation Level.

Definition: The convection condensation level (CCL) is the height to which a parcel of air, if heated sufficiently from below, will rise adiabatically until it is just saturated (condensation starts). In the commonest case, it is the height of the base of cumuliform clouds which are or would be produced by thermal convection solely from surface heating.

Procedure: To determine the CCL on a plotted sounding, proceed upward along the saturation mixing-ratio line through the surface dew-point temperature until this line intersects the *T* curve on the sounding. The CCL is at the height of this intersection. Figure 19 illustrates this procedure.

When there is much variation in moisture content in the layers near the surface, an average moisture value of the lower layer may be used in place of the surface-parcel moisture value in computing the CCL (see for examples, paras. 5.24.1 through 5.24.3).

4.19. Convection Temperature.

Definition: The convection temperature (T_c) is the surface temperature that must be reached to start the formation of convection clouds by solar heating of the surface-air layer.

Procedure: Determine the CCL on the plotted sounding, as described in paragraph 4.18. From the CCL point on the *T* curve of the sounding, proceed downward along the dry adiabat to the surface-pressure isobar. The temperature read at this intersection is the

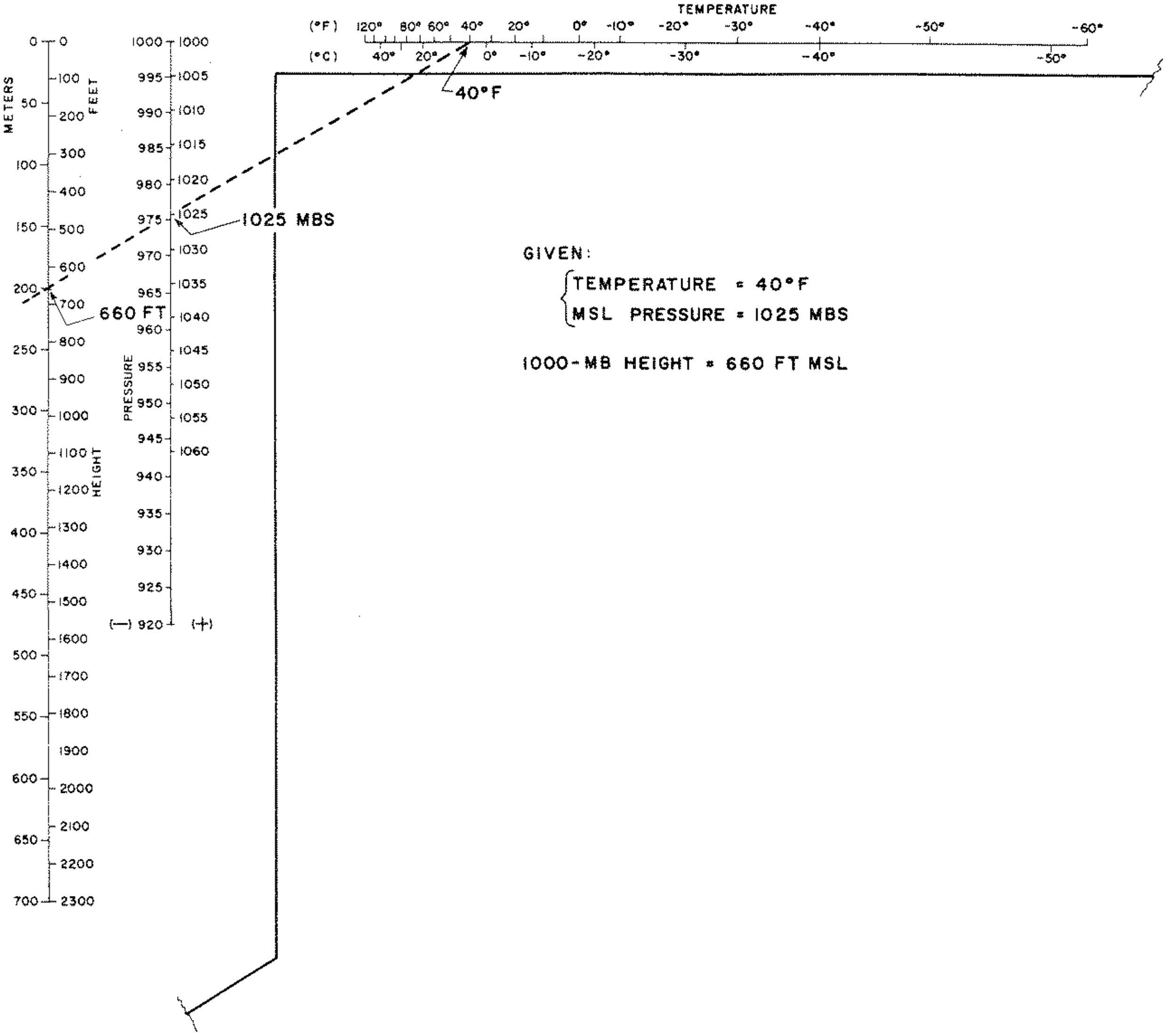

Figure 18. Determination of the Height of the 1000-mb Surface Above (or Below) Mean Sea Level.

convection temperature (T_c). This procedure is illustrated in Figure 19.

4.20. Lifting Condensation Level.

Definition: The lifting condensation level (LCL) is 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 CCL; note that when the lapse rate is, or once it becomes, 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 through the surface dew-point temperature with the dry adiabat through the surface temperature. This procedure is also illustrated in Figure 19.

4.21. Mixing Condensation Level.

Definition: The mixing condensation level (MCL) is the lowest height, in a layer to be mixed by wind stirring, at which saturation occurs after the *complete* mixing of the layer; it is located at the intersection of the saturation mixing-ratio line through the mean mixing ratio of the layer with the mean dry adiabat of the mixed layer.

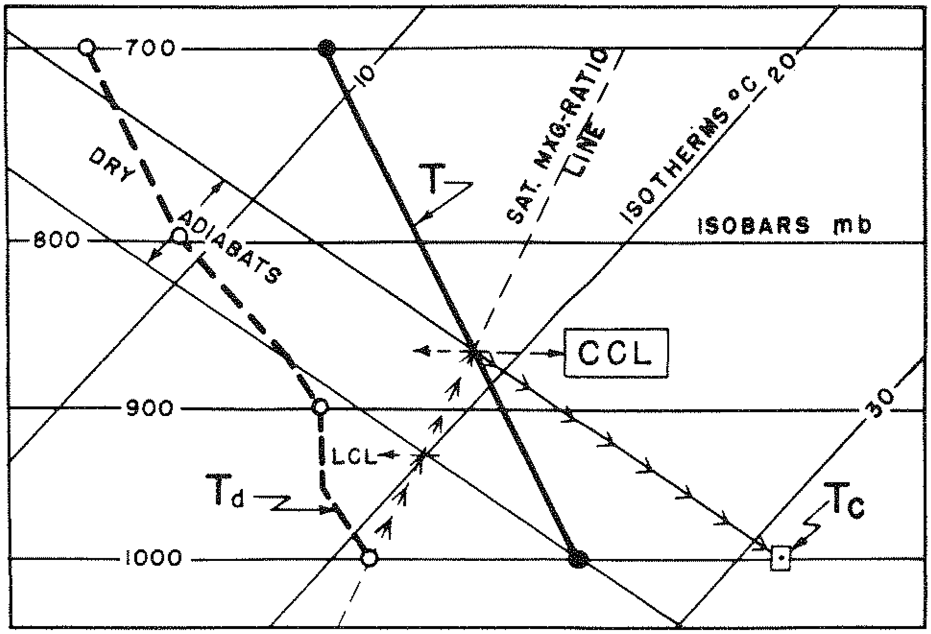

Figure 19. Procedure for Locating the Convection Condensation Level, the Convection Temperature, and the Lifting Condensation Level.

Procedure: The determination of the MCL first requires an estimate or forecast of the height of the top of the layer to be mixed. There is no known objective way to determine this height. However, a subjective estimate based on local experience which considers such things as the expected lower-level wind speeds, the terrain roughness, and the original sounding through the lower layers, will usually suffice (see par. 6.7 for a discussion of this).

Once the top of the mixed layer is estimated, the procedure is as follows. Since the potential temperature and the mixing ratio of a completely mixed unsaturated layer are constant from the ground to the top of the layer, an equal-area approximation of its mean temperature and moisture can be used. Determine the mean dry adiabat (an isotherm of potential temperature) of the mixed layer from the original T curve on the sounding by the equal-area method shown in Figure 20. Then, determine for the mixed layer the mean saturation mixing-ratio line through the T_d curve by the equal-area method as shown in Figure 20. If an MCL exists, it will be found at the point of intersection (*within* the mixed layer) of the mean saturation mixing-ratio line with the mean dry adiabat of the mixed layer. If there is no intersection of these two lines *within* the mixed layer, then the mixed air is too dry to reach saturation by the mixing process.

4.22. Level of Free Convection.

Definition: The level of free convection (LFC) is the height at which a parcel of air lifted dry-adiabatically until saturated and saturation-adiabatically thereafter would first become warmer (less dense) than the surrounding air. The parcel will then continue to rise freely above this level until it becomes colder (more dense) than the surrounding air.

Procedure: The LFC for a given parcel which becomes saturated by *lifting* is located at the height where the saturation adiabat through the initial wet-bulb temperature of the parcel intersects the sounding temperature curve at a higher level. If the parcel is to be *heated* to make it rise, then the wet-bulb temperature corresponding to the convection temperature must be used (see par. 4.9 for

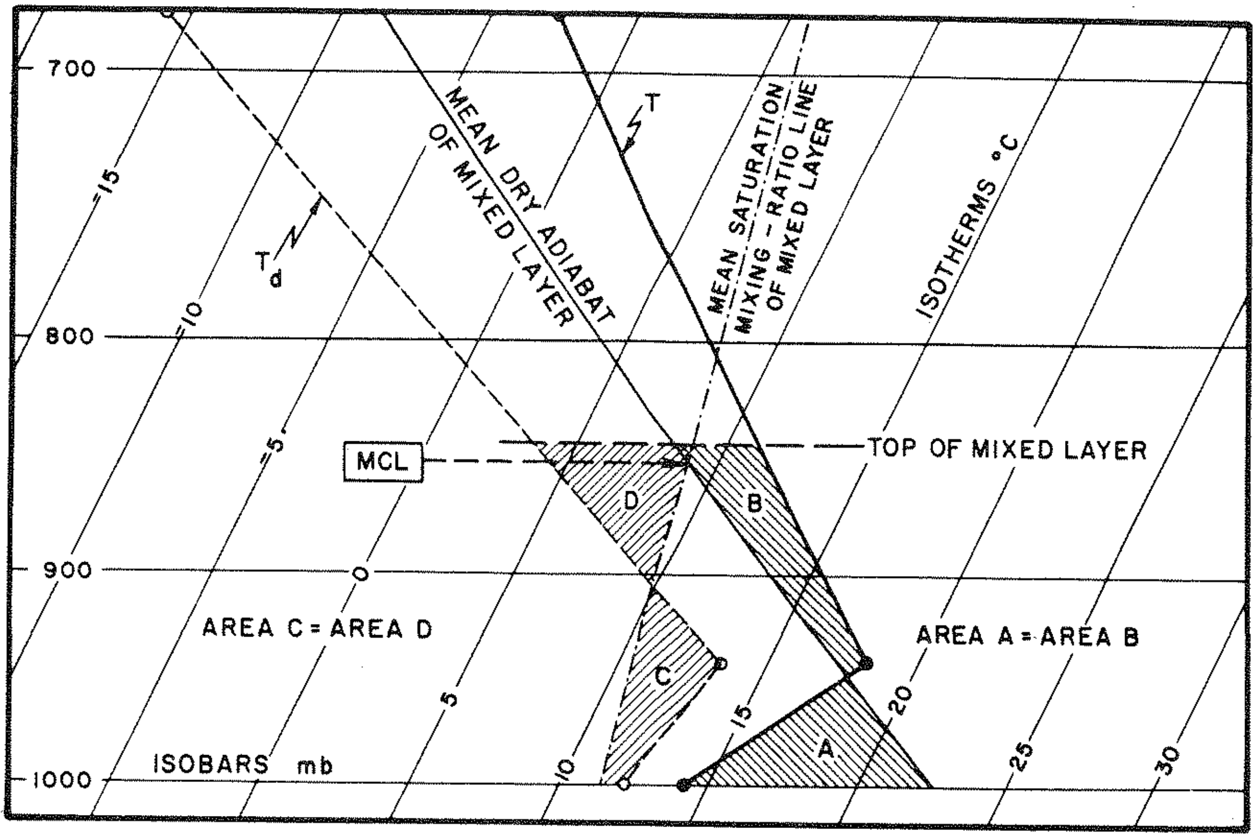

Figure 20. Determination of the Mixing Condensation Level on a Sounding.

graphical determination of wet-bulb temperature).

For determining the LFC, the result is often more realistic if one uses the wet-bulb temperature corresponding to the moisture content of the lower layer(s) of the atmosphere instead of the surface wet-bulb temperature (see for examples, pars. 5.24.1 through 5.24.3).

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

Definition of NEGATIVE Area: When a parcel on a sounding lies in a stable layer, 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 sounding curve is proportional to the amount of kinetic energy that must be supplied to move it. This is called a "negative (energy) area."

Definition of 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 a "positive (energy) area."

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 heating (insolation at the ground, release of latent heat of condensation, etc.), or from forcible lifting (convergence, orographic effects, etc.).

Procedure for the Surface-Parcel-Heating Case: The plotted sounding is analyzed to find the CCL according to procedure of paragraph 4.18. A saturation adiabat is then constructed upwards from the CCL to well beyond the point where it intersects the sounding again the equilibrium level (EL - see par. 4.24); and a dry adiabat is constructed through the CCL down to its intersection with the surface-pressure isobar. The negative and positive areas are then labelled and colored or shaded as in the example in Figure 21. (Note that many soundings have no lower negative area, as when the lower layers are already adiabatic, but only a positive area; and also that many soundings show only a deep negative area without any positive area as when the CCL is extremely high.) The areas determined by the above procedure are indicative of conditions under the assumption that the surface temperature does not rise after the CCL has been reached - if the surface temperature does rise further then it is readily seen that the areas change somewhat because the cloud base rises and the surface humidity decreases.

Procedure for the Lifted Surface-Parcel Case: In this instance, the surface parcels are lifted by some mechanical process, such as orographic or frontal lifting or convergence. The first step is a determination, from the plotted sounding, of the LCL for the lifted surface parcel by the procedure given in paragraph 4.20. Then, from this LCL draw a line upward parallel to the nearest saturation adiabat (i.e., construct the saturation adiabat through the LCL) to well beyond the EL. An example is shown in Figure 22. The point at which this line first intersects the T curve of the sounding is the LFC. Then the negative area is the area on the chart below the LFC bounded on the right by the sounding curve, at the bottom by the surface point, and on the left by the dry adiabat from the surface point to the LCL and by the saturation adiabat from the LCL to the LFC. This negative area represents the energy that the lifting mechanism must supply to the lifted surface parcel to raise it to the LFC. The positive area is the area above the LFC bounded on the left by the sounding curve, on the right by the saturation adiabat through the LFC, and terminated at the top by the EL. This positive area represents the energy gained by the lifted parcel after it rises above the LFC. There is also an upper negative area above the EL.

Procedure for the Case Where an Upper-Level Parcel is Lifted: In the event that 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 overrunning, upper-level convergence, etc., the procedure is exactly analogous to that used in the lifted surface-parcel case. That is, first determine the LCL for the parcel in question, then construct the saturation adiabat upward through this LCL through the LFC to well beyond the EL. The negative area, representing the energy that must be supplied to the parcel to raise it to its LFC, is the area below the LFC bounded by the sounding curve on the right, and by the dry and saturation adiabats on the left. The positive area, representing the energy gained by the parcel after it rises above the LFC, is the area above the LFC bounded by the sounding curve on the left, and the saturation adiabat through the LFC on the right, and terminating at the EL.

4.24. Equilibrium Level.

Definition: The equilibrium level (EL) is the height where the temperature of a buoyantly rising parcel again becomes equal to the temperature of the environment.

Procedure: Determine the positive area for the parcel of interest according to the proper procedure outlined in paragraph 4.23. The EL is then found at the top of the positive area where the T curve and the saturation adiabat through the LFC again intersect. The location of an EL is shown in both Figures 21 and 22.

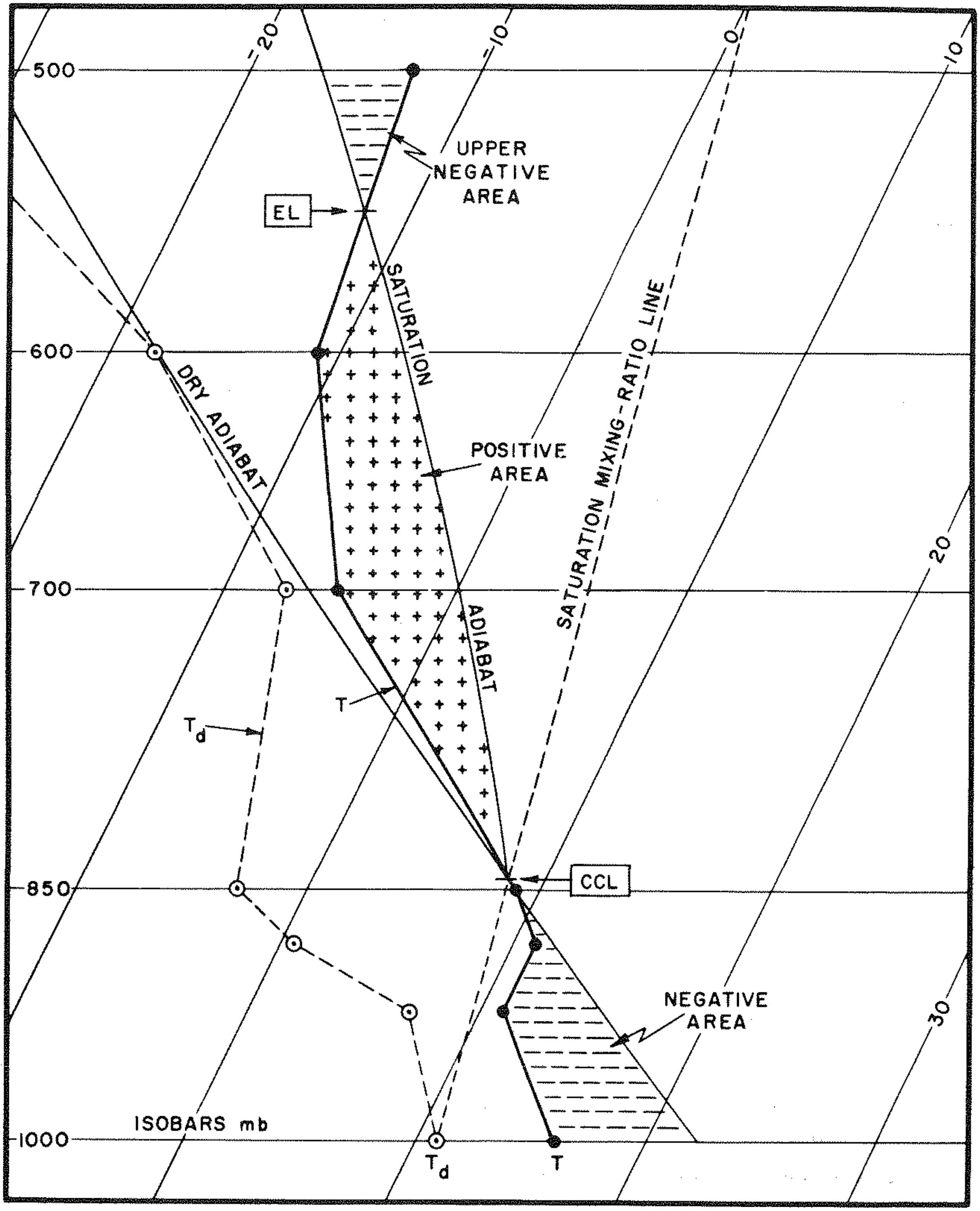

Figure 21. Determination of the Positive and Negative Areas on a Sounding Due to the Heating of a Surface Parcel.

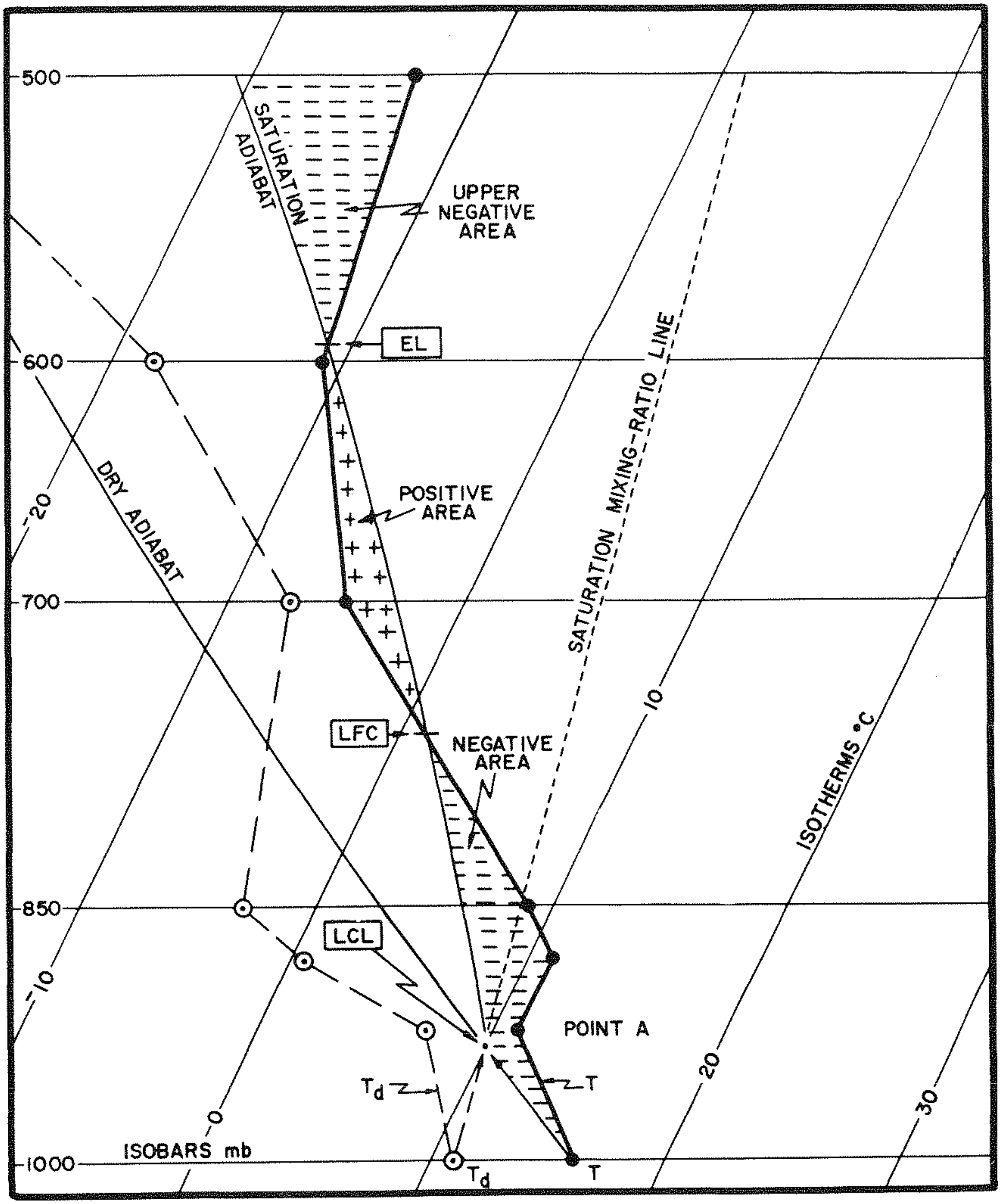

Figure 22. Determination of the Positive and Negative Areas on a Sounding Due to the Lifting of a Surface Parcel.

4.25. Energy Determinations on the Skew-T Chart. When positive or negative areas have been located on the Skew-T Chart in accordance with the procedures given in paragraph 4.23, the energies involved may be computed by the following relationships:

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 DOD WPC 9-16 chart equals 1.808×10^6 ergs, or 0.1808 joules, per gram of air in the sample.