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THE USE OF PRESSURE ALTITUDE AND ALTIMETER CORRECTIONS IN METEOROLOGY

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ABSTRACT

This discussion presents a scheme that has been found to be very convenient for the three-dimensional representation of the pressure and temperature fields in the atmosphere both for forecasting and for aircraft operations. The terms pressure altitude (z_p), altimeter correction (D) and specific temperature anomaly (S) are defined and their physical interpretation discussed. The hydrostatic equation, the geostrophic and gradient wind equations, and the thermal wind equations are stated in terms of these parameters. All necessary tables and calculation diagrams including a thermodynamic chart called the pastagram are presented. Applications of the proposed scheme to pressure-height computations, wind calculations, aircraft operations and general synoptic analysis are given together with a number of examples.

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1. Introduction. This article presents the results of a search for convenient parameters with which to describe the atmospheric pressure and temperature fields. In this search the following factors were considered:

1. Ease of conversion, if required, from the parameters with which actual measurements of pressure and temperature are made (or can easily be made) to those parameters which are convenient for the meteorologist to use.
2. Simplification of calculations involving the hydrostatic and gradient wind equations. Particular attention was given to this point since both of these equations are almost always used at the present time, either qualitatively or quantitatively, for the determination, representation and forecasting of the wind. Also it seems probable that they will always be useful as the first approximation to the solution of the equations of motion.
3. Simplicity, clearness and convenience of graphically representing the pressure and temperature fields on charts and diagrams. Here the primary consideration was the simplicity of the relationships between the graphical representations and the hydrostatic and gradient wind equations, since it is felt that the primary meteorological use of these fields is the determination and representation of the wind field. Secondary consideration was given to the usefulness of these representations for pilots, navigators, surveyors, etc., so that a minimum of effort and time is required for the meteorologist to give them the desired information.

From these considerations it seems that the pressure altitude, z_p, and a quantity called the altimeter correction, D, are the most convenient parameters with which to represent pressure quantitatively in most routine meteorological work. Also, a quantity called the specific temperature anomaly, S, is a convenient parameter with which to represent temperature quantitatively for many meteorological considerations. These parameters are defined and a detailed description of their properties and use is given below.

2. Definitions and theory.

Pressure altitude z_p. The pressure altitude represents the quantitative value of the pressure at a given point by giving the height above a given standard pressure at which that pressure occurs in a standard atmosphere. Thus, the physical concept of pressure altitude is very similar to that commonly used with other parameters of pressure, such as the height of a standard mercury column which can be supported by that pressure, or the depth (pressure head) of water in a standard water column at which that pressure occurs. The dissimilarity between pressure altitude and the most commonly used pressure parameters is a result of the compressibility of the air. Thus pressure altitude is not linearly related to such common pressure parameters as inches of mercury, feet of water, millibars, pounds per square inch, etc., which are linearly related to each other. Also, since the height of zero pressure in a compressible fluid is indeterminate, pressure altitude is essentially measured from the bottom of the column up, instead of from the top of the column down as is the case with mercury or water columns. Hence, when the value of the pressure altitude increases, the values of these other common pressure parameters decrease and vice versa. However, as will be seen later, incorporation of the compressibility of the air into the pressure parameter results in a simplification of routine hydrostatic and gradient wind calculations.

Even at present upper-air pressures are commonly measured and thought of in terms of the pressure altitude used to calibrate aircraft altimeters (the pressure altitude obtained with the N.A.C.A. or U. S. Standard Atmosphere). Because of this, and since this standard atmosphere is sufficiently representative of mean world wide conditions, the U. S. Standard pressure altitude, z_p, is used throughout this work.

The U. S. Standard Atmosphere can be defined as follows:

1. The standard pressure at zero value of the pressure altitude ($z_p = 0$) is that pressure which will support a standard mercury column 760 mm high. Hence, the zero of pressure altitude is merely defined as being that point at which the pressure can be expressed as 760 mm of mercury and can be at any height above mean sea level.
2. The standard temperature, T_p, is 15°C at $z_p = 0$ and decreases upward with a uniform lapse rate of 6.5°C/km (1.9812°C/1000 ft) until it becomes equal to $-$ 55°C at $z_p =$ 10,769.2 m or 35,332.0 ft, above which point it is constant at this value.
3. The air is assumed to obey the perfect-gas laws and to contain no water vapor, the acceleration of gravity is assumed to be constant at $g_p = 980$ cm/sec^2, and it is assumed that no vertical accelerations of the air are present.

Using this definition of the standard atmosphere and the hydrostatic relationship with the equation of state, a one-to-one relationship between pressure altitude and the absolute pressure units, such as millibars, pounds per square inch, etc., can be derived. The formulae obtained in this way can then be considered as being a mathematical definition of a new pressure parameter, pressure altitude, so that the quantitative value of the pressure at a given point can be specified completely by giving the value of the pressure altitude of that point. For example, saying that the value of the pressure altitude at a given point is 10,000 feet denotes that the pressure at that point has a given value equal to the pressure which occurs at 10,000 feet above the zero point in the standard atmosphere. This pressure could be measured directly with an aircraft altimeter set at 29.92, and its value could be, but usually need not be, converted to a value of 697 millibars, or 20.58 inches of mercury, etc. It is, of course, very important to keep in mind that the actual level at which the pressure altitude is 10,000 feet can be at almost any height (but probably fairly close to 10,000 feet) and usually is *not* exactly 10,000 feet. Similarly, if it is desired to give the time sequence of the pressure at a given point, for instance at an airport, it could be given as measured 29.90, 29.92 and 29.94 inches of mercury, or equally completely as + 20 feet, 0 feet and $-$ 20 feet of pressure altitude. The calculations and a graphical table of the conversion between pressure altitude and millibars, inches of mercury and millimeters of mercury are given later.

Since the standard atmosphere is used solely as a means of providing parameters for expressing the intensity of *pressure*, the *pressure* at any point in the actual atmosphere is used to determine the corresponding point at which that pressure occurs in the standard atmosphere. Thus the various other properties at that point in the standard atmosphere can be used to state the intensity of this pressure. For example, for pressures that occur in the standard troposphere ($T \geq -$ 55°C) one can specify the intensity of pressure by giving the value of the standard temperature, T_p (instead of giving the pressure altitude), which occurs at that pressure, since a one-to-one relationship exists between the pressure, the standard temperature and the pressure altitude. Since the standard atmosphere used here has an isothermal stratospheric region the standard temperature cannot be used as a parameter of pressure above the tropopause. However, in this region the hydrostatic equation still provides that the pressure altitude is a continuous single-valued function of the pressure, so that the use of a standard isothermal stratosphere does not essentially affect the use of pressure altitude as a pressure parameter. Similarly, since the pressure and temperature are defined at all points in the standard atmosphere, the values of thermodynamic quantities such as the standard density ρ_p, the standard potential temperature θ_p, etc., are considered in this way as being essentially parameters with which one could specify the *pressure* at any point in the actual atmosphere.

Altimeter correction D. A very convenient quantity for representing the spacial distribution of pressure is the altimeter correction D, defined as the difference between the height above mean sea level z, of any point in the atmosphere, and the pressure altitude z_p, which occurs at that point, or

$$D = z - z_p. \tag{1}$$

The value of D at any point in the atmosphere thus is a function of both the height of the point and the pressure occurring at that point. Thus, if desired, D can be considered as being a parameter with which to specify the intensity of pressure on any horizontal surface. Conversely, D can also be considered as being a parameter with which to specify the height at which any given constant pressure occurs in the atmosphere.

Considering D as a pressure parameter at a given height z above mean sea level, the intensity of pressure can be thought of as being given by the depth, $z - z_p$, measured from that height *down* to the height above mean sea level at which that pressure occurs in a standard atmosphere (which is in the standard vertical position such that everywhere the value of the pressure altitude is numerically equal to the height above mean sea level). Thus this concept is very similar to that of the pressure head, especially since the *relative* pressure head (i.e., the depth of water measured from the surface of the water on which the atmospheric pressure is acting) is usually used.

Another way of considering D as a pressure parameter is to think of D as being the vertical displacement of the standard atmosphere from its standard position ($z = z_p$ at all points) required to obtain the observed pressure at the height above mean sea level considered. In other words, this vertical displacement of the standard atmosphere is the displacement necessary to obtain the same weight of air above the height considered in both the actual and standard atmospheres.

For example, if the value of D at a point 10,000 feet above mean sea level were to *increase* from 0 feet to + 100 feet, the value of the pressure altitude at that point would *decrease* from 10,000 feet to 9900 feet and the value of the pressure expressed in millibars would *increase* from 697 mb to 699.5 mb. The increase in weight of the air above this point (2.5 mb) is then equivalent to the weight of the standard atmosphere between the values of $z_p = 9900$ feet and $z_p = 10{,}000$ feet, and this increase in weight above the point can be considered as being equivalent to that obtained by raising the standard atmosphere through a distance equal to the change of D, + 100 feet, so that the pressure value $z_p = 9900$ feet occurs at the height $z = 10{,}000$ feet.

The use of D thus provides a pressure parameter which takes account of the compressibility of the air without changing its sense of increase with respect to the absolute pressure units. Lines of constant D on a map of conditions at any constant height z are then merely isobars labeled in terms of the displacement of the standard atmosphere from its standard position required to obtain the same weight of air above that level as in the actual atmosphere.

Considering D as a height parameter specifying the position of a given pressure z_p, this height, $D = z - z_p$, is measured from the height above mean sea level at which that pressure occurs in the standard atmosphere in its standard position instead of from mean sea level. Hence, lines of constant D on a map representing conditions on a surface of constant pressure are merely contour lines of that surface with the origin of vertical measurement at the standard height above mean sea level of that pressure.

Altimeter setting P. The relationship between the altimeter correction D and the altimeter setting P can conveniently be obtained by considering the construction of an aircraft altimeter as schematically represented in Figure 1. Plate A, which is fixed with respect to the aircraft, is marked with a linear height scale z and an Altimeter Setting Index I_p. Plate B, which can be rotated with the knob and gear K with respect to Plate A, has mounted on it an aneroid pressure element and an indicating hand. The linkage between the pressure element and the indicating hand is such that the angular displacement of the hand from a zero ($z_p = 0$) position, marked in the diagram (but not on present altimeters) by the Altimeter Correction Index I_D, is directly proportional to the pressure altitude z_p, and is such that the angular scale of z_p is the same as the angular scale of the z markings on Plate A. Ring C, which can be rotated with respect to Plate A through the same angle, but in the opposite direction, as Plate B, is marked with a Pressure Altitude Variation Index Iz_p and an Altimeter Setting Scale P. The P scale is a pressure scale,

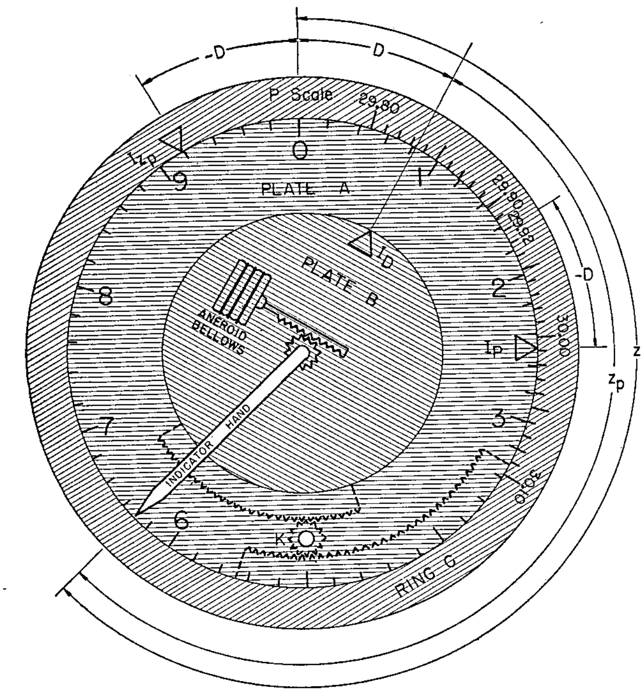


FIGURE 1.

usually marked in terms of the pressure parameter inches of mercury, with angular dimensions the same (but in the opposite direction) as a corresponding pressure altitude scale with the same dimensions as the z markings on Plate A. Plate B and Ring C are so arranged that, when they are rotated (in opposite directions with knob K) so that the indices Iz_p and I_D are opposite each other, they are both opposite the zero of the z scale, and the 29.92-inch ($z_p = 0$) mark of the P scale is opposite the index I_p.

The procedure for setting an altimeter consists of moving the pressure element, Plate B, with knob K, so that the hand points to the height on the height scale z of the position of the altimeter in the atmosphere. The position of Plate B must then be such that the index I_D is opposite the value of $D = z - z_p$ occurring at the point in the atmosphere considered. Thus the process of setting an altimeter can easily be thought of as being a mechanical method of adding the altimeter correction D to the pressure altitude z_p as measured by the altimeter, to obtain the height above mean sea level z. From Figure 1 is seen that when the altimeter is set, the index Iz_p points to the value of $-D$ on the z scale, and the value of P on the P scale, to which the index I_p points, corresponds to a movement of the P scale through a pressure altitude of $-D$. Thus the altimeter setting P can be defined as being the pressure, expressed in inches of mercury, which is equal to a pressure altitude of the negative of the value of D at the point considered.

The usual definition of the altimeter setting can be stated as the pressure, expressed in inches of mercury, which would occur at sea level if a U. S. Standard atmosphere (standard virtual temperature at all values of the *pressure*) were between the point considered and sea level. That these two definitions give the same numerical result is seen by the fact that the value of D can be considered as the vertical displacement of the standard atmosphere from its standard position required to have the observed pressure at the height considered. With this displacement the pressure altitude that would then occur at mean sea level would be equal to $-D$.

The use of the altimeter setting for determinations of the height of an aircraft in the upper air is an indirect procedure. If it is desired to set the altimeter so that it always reads the height of the aircraft, the values of the altimeter settings that apply must be given for the various heights (not pressures) considered, since the reading of the altimeter is then a "height". But the pilot has no direct means of determining his height to determine the altimeter setting that should be used at his particular position. Thus, fundamentally, he must perform a series of successive approximations, such as, guess at the applicable setting, read the indicated height, determine the applicable setting for this height from the meteorological data, reset the altimeter for this setting, determine the applicable setting for the new indicated height, etc., etc. On the other hand, the determination of heights in the upper air by a correction procedure (i.e., adding algebraically the value of D from meteorological data to the indicated pressure altitude with the altimeter always set at 29.92 inches or with I_p and Iz_p at 0) is direct and convenient since the applicable D can be given directly in terms of the measured z_p.

The use of the altimeter-setting procedure for determining when the aircraft gets to a given predetermined elevation (such as in landing procedures) is direct and convenient since then the setting that applies at that point in the atmosphere can be preset into the altimeter. This setting can be given to flying personnel either as the altimeter setting P, to be set under the index I_p, or as the altimeter correction D, to be set under the index I_D if available, or to be set with the index Iz_p opposite $-D$. The use of P has the advantage of eliminating the possible confusion caused by the positive and negative signs of D. The use of D has the advantage that the pilot has the choice of using either the setting or the correction procedure, and the greater simplicity of the concept involved should lead to better understanding of the meaning of the altimeter setting.

Specific temperature anomaly S. A quantity for specifying the temperature, that is convenient for many meteorological uses, is the specific temperature anomaly S defined in terms of the variation of the actual temperature T from the standard temperature T_p at any given pressure, by

$$S = \frac{T - T_p}{T_p}. \tag{2}$$

It is seen that, in general, S is a function of both temperature and pressure since T_p is defined as the standard temperature at a given pressure. However, at any given pressure T_p is a constant and S can then be used as a parameter with which to describe the temperature and is directly proportional to T which in this formula is in degrees of the absolute scale.

The hydrostatic equation. The hydrostatic equation, a very good approximation of the actual relationship connecting height, pressure and temperature, assumes that all vertical forces, such as the vertical component of the Coriolis force or the inertial forces due to vertical accelerations, are small enough to be neglected with respect to the vertical pressure gradient force and the weight of the air. In other words, it is assumed that the weight of a column of air is supported by the difference in pressure force between the bottom and the top of the column.

In the actual atmosphere (with a density ρ and an acceleration of gravity g) the weight of a column of air of unit horizontal cross section and height Δz is $\rho g \Delta z$. This weight must be balanced by the vertical pressure gradient force, which is also the weight of the standard column of air from z_p at the bottom of the column to $z_p + \Delta z_p$ at the top of the column. Thus $\rho g \Delta z = \rho_p g_p \Delta z_p$ or, going to the limit as $\Delta z \to 0$, the hydrostatic equation can be written

$$\frac{\partial z}{\partial z_p} = \frac{\rho_p g_p}{\rho g}. \tag{3}$$

The density of a gas at a given pressure is inversely proportional to the temperature and directly proportional to the molecular weight of the gas, so that

$$\frac{\rho_p}{\rho} = \frac{T}{T_p}\frac{m_d}{m},$$

where m_d is the effective molecular weight of dry (standard) air and m is the effective molecular weight of the actual air. Hence,

$$\frac{\partial z}{\partial z_p} = \frac{T}{T_p}\frac{m_d}{m}\frac{g_p}{g}. \tag{4}$$

If D is used as a pressure parameter, since $D = z - z_p$ and

$$\frac{\partial D}{\partial z} = 1 - \frac{\partial z_p}{\partial z},$$

the hydrostatic equation can be written as

$$\frac{\partial D}{\partial z} = 1 - \frac{T_p m g}{T m_d g_p} = \frac{T\dfrac{m_d g_p}{mg} - T_p}{T\dfrac{m_d g_p}{mg}}. \tag{5}$$

If D is considered as a height parameter, since

$$\frac{\partial D}{\partial z_p} = \frac{\partial z}{\partial z_p} - 1,$$

the hydrostatic equation can also be written as

$$\frac{\partial D}{\partial z_p} = \frac{T m_d g_p}{T_p m g} - 1 = \frac{T\dfrac{m_d g_p}{mg} - T_p}{T_p}. \tag{6}$$

Virtual temperature T^*. The numerical calculation of the hydrostatic equations can be systematized and simplified by the introduction of the virtual temperature T^* which absorbs the small variations of the molecular weight and of gravity in the relatively large variations of the temperature parameter. T^* can be defined by

$$T^* = \frac{m_d g_p}{mg} T. \tag{7}$$

In other words, this virtual temperature is that temperature which dry air at a given pressure and acted upon by a standard gravity must have in order that its weight per unit volume be the same as the weight per unit volume of the actual air at that pressure.*

To express this definition of the virtual temperature in terms of the mixing ratio w of the mass of water vapor to the mass of dry air in a given sample of air, consider the mixture of a unit mass of dry air and a mass w of water vapor. The total pressure of a given volume of this mixture is equal to the sum of the partial pressures due to the dry air and the water vapor, and these pressures are directly proportional to the respective masses and inversely proportional to the respective effective molecular weights. Thus, for the total mass $1 + w$, in any given volume

$$\frac{1+w}{m} = \frac{w}{m_w} + \frac{1}{m_d} \quad \text{or} \quad m = m_d\left(\frac{1+w}{1+\dfrac{m_d}{m_w}w}\right).$$

Hence

$$T^* = T\frac{g_p}{g}\frac{\left(1+\dfrac{m_d}{m_w}w\right)}{1+w}. \tag{8}$$

* It is to be noted that the virtual temperature as used here is different from the usual definition of virtual temperature,

$$T^{*\prime} = \frac{m_d}{m} T.$$

Rearranging this equation for a difference method of calculation,

$$T^* - T = T\left[\left(\frac{m_d}{m_w} - 1\right)\left(\frac{w}{1+w}\right) + \left(\frac{g_p - g}{g}\right) + \right.$$
$$\left. + \left(\frac{m_d}{m_w} - 1\right)\left(\frac{w}{1+w}\right)\left(\frac{g_p - g}{g}\right)\right]. \quad (9)$$

The hydrostatic equation can then be written in terms of T^* as

$$\frac{\partial z}{\partial z_p} = \frac{T^*}{T_p}, \quad (10)$$

or

$$\frac{\partial D}{\partial z} = \frac{T^* - T_p}{T^*}, \quad (11)$$

or

$$\frac{\partial D}{\partial z_p} = \frac{T^* - T_p}{T_p}. \quad (12)$$

These forms are obtained from equations (4), (5) and (6).

Specific virtual temperature anomaly S^*. Analogous to the definition of the virtual temperature, the specific virtual temperature anomaly S^* can be defined by

$$S^* \equiv \frac{T^* - T_p}{T_p} = \frac{T\dfrac{m_d g_p}{mg} - T_p}{T_p}. \quad (13)$$

By using equation (2) it follows that

$$1 + S^* = (1 + S)\frac{m_d g_p}{mg}. \quad (14)$$

By using a process similar to that employed in developing equation (9) one obtains

$$S^* - S = (1 + S)\left[\left(\frac{m_d}{m_w} - 1\right)\left(\frac{w}{1+w}\right) + \right.$$
$$+ \left(\frac{g_p - g}{g}\right) + \left(\frac{m_d}{m_w} - 1\right)\times$$
$$\left. \times \left(\frac{w}{1+w}\right)\left(\frac{g_p - g}{g}\right)\right]. \quad (15)$$

The three forms of the hydrostatic equation can then be written in terms of S^* as

$$\frac{\partial z}{\partial z_p} = 1 + S^*, \quad (16)$$

$$\frac{\partial D}{\partial z} = \frac{S^*}{1 + S^*}, \quad (17)$$

and

$$\frac{\partial D}{\partial z_p} = S^*. \quad (18)$$

Pressure gradient force F_p. The expression for the value of a pressure gradient force F_p (the force per unit mass acting on a parcel due to the spacial pressure variations) in terms of the spacial gradients of the pressure parameter z_p can be obtained by considering that there is a gradient $\partial z_p/\partial \xi$ present at a point where ξ is in the arbitrary direction of the force F_p. The total force per unit cross-sectional area corresponding to a change of pressure altitude of Δz_p equals the weight of the standard air column between the heights of z_p and $z_p + \Delta z_p$, or $\rho_p g_p \Delta z_p$. Since for the limit of a unit length in the ξ direction

$$\Delta z_p = \lim_{\Delta\xi \to 1} \frac{\partial z_p}{\partial \xi}\Delta\xi = \frac{\partial z_p}{\partial \xi},$$

we have that

$$\rho F_p = \rho_p g_p \frac{\partial z_p}{\partial \xi}. \quad (19)$$

The plus sign is used since F_p has the same sense as a positive increase of z_p.*

The horizontal component of the pressure gradient force $(F_p)_n$, using the definition $T^* = Tm_d g_p/mg$ and using n as a horizontal coordinate in the direction of the total horizontal pressure gradient, can then be written as

$$(F_p)_n = g\frac{T^*}{T_p}\left(\frac{\partial z_p}{\partial n}\right)_z = g(1 + S^*)\left(\frac{\partial z_p}{\partial n}\right)_z. \quad (20)$$

Also, since we are considering conditions on a constant level surface so that

$$\left(\frac{\partial z_p}{\partial n}\right)_z = \left[\frac{\partial}{\partial n}(z - D)\right]_z = -\left(\frac{\partial D}{\partial n}\right)_z,$$

$$(F_p)_n = -g\frac{T^*}{T_p}\left(\frac{\partial D}{\partial n}\right)_z = -g(1 + S^*)\left(\frac{\partial D}{\partial n}\right)_z. \quad (21)$$

The horizontal pressure gradient force $(F_p)_n$ can also be expressed in terms of the slope of a constant pressure surface $(\partial z/\partial n)_p$. From Figure 2 it is seen

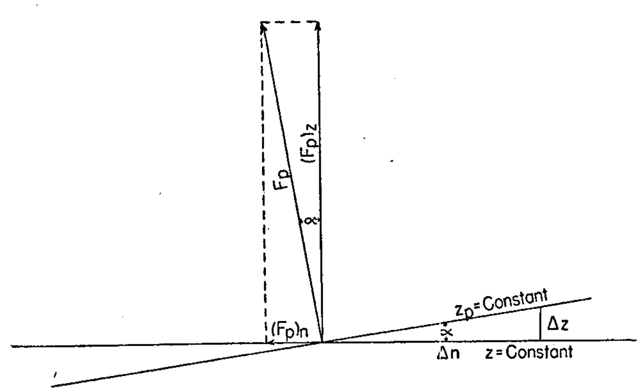


FIGURE 2.

* This formula is very similar to that obtained for other common pressure units. For example, in terms of h, the height of a standard mercury column which can be supported by a given pressure $\rho F_p = \rho_0 g_0(\partial h/\partial \xi)$ where ρ_0 and g_0 are the standard mercury density and the standard acceleration of gravity, respectively.

that

$$(F_p)_n = -(F_p)_z \tan\alpha = -(F_p)_z\left(\frac{\partial z}{\partial n}\right)_p.$$

If we also assume that the hydrostatic equation applies so that $(F_p)_z = g$, we have that

$$(F_p)_n = -g\left(\frac{\partial z}{\partial n}\right)_p. \tag{22}$$

Also, since $(\partial z/\partial n)_p$ is the variation of the height z of a constant pressure surface with respect to n (measured on a horizontal surface) so that $(\partial z/\partial n)_p = (\partial D/\partial n)_p$,

$$(F_p)_n = -g\left(\frac{\partial D}{\partial n}\right)_p. \tag{23}$$

Geostrophic wind equation. Since the horizontal component of the Coriolis force per unit mass at a given latitude ϕ and for a given horizontal component of the wind velocity v is $F_c = -2\Omega v \sin\phi$ where Ω is the angular velocity of the earth, the geostrophic wind equation can be written as

$$2\Omega v\sin\phi = g\frac{T^*}{T_p}\left(\frac{\partial z_p}{\partial n}\right)_z = g(1+S^*)\left(\frac{\partial z_p}{\partial n}\right)_z, \tag{24}$$

$$2\Omega v\sin\phi = -g\frac{T^*}{T_p}\left(\frac{\partial D}{\partial n}\right)_z = -g(1+S^*)\left(\frac{\partial D}{\partial n}\right)_z, \tag{25}$$

$$2\Omega v\sin\phi = -g\left(\frac{\partial z}{\partial n}\right)_p, \tag{26}$$

$$2\Omega v\sin\phi = -g\left(\frac{\partial D}{\partial n}\right)_p. \tag{27}$$

In this notation the positive direction for the distance n is taken to be at right angles to the *left* of the direction of motion so that the geostrophic wind blows with *low values of z_p*, but with *high values of D and z*, to its right in the northern hemisphere.

Gradient wind equation. Inclusion of the centrifugal force per unit mass V^2/R_T, where V is the gradient wind and R_T is the radius of curvature of the trajectories of the air, gives the gradient wind equation in terms of the parameters z, z_p or D,

$$2\Omega V\sin\phi \pm \frac{V^2}{R_T} = g\frac{T^*}{T_p}\left(\frac{\partial z_p}{\partial n}\right)_z = g(1+S^*)\left(\frac{\partial z_p}{\partial n}\right)_z, \tag{28}$$

$$2\Omega V\sin\phi \pm \frac{V^2}{R_T} = -g\frac{T^*}{T_p}\left(\frac{\partial D}{\partial n}\right)_z = -g(1+S^*)\left(\frac{\partial D}{\partial n}\right)_z, \tag{29}$$

$$2\Omega V\sin\phi \pm \frac{V^2}{R_T} = -g\left(\frac{\partial z}{\partial n}\right)_p, \tag{30}$$

$$2\Omega V\sin\phi \pm \frac{V^2}{R_T} = -g\left(\frac{\partial D}{\partial n}\right)_p. \tag{31}$$

In this notation, then, if the radius of curvature is in the direction of the Coriolis force (Fig. 3a), the curvature is *anticyclonic* and the *negative sign* is used. If the radius of curvature is *cyclonic* (Fig. 3b), the *positive sign* is used. Thus a cyclonic gradient wind blows around high values of z_p and low values of z and D; an anticyclonic gradient wind blows around low values of z_p and high values of z and D.

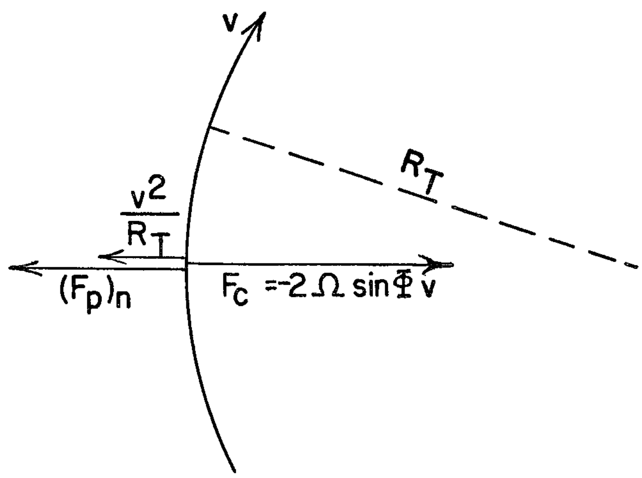


FIG. 3a. Air trajectory with anticyclonic curvature in the northern hemisphere.

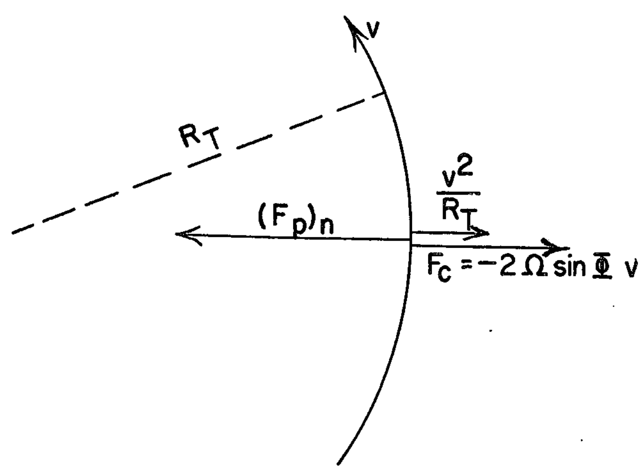


FIG. 3b. Air trajectory with cyclonic curvature in the northern hemisphere.

Thermal wind equation. Since the gradient wind velocity is determined by the horizontal pressure gradients, and since the horizontal pressure gradients change with elevation in a manner determined by the hydrostatic equation, particularly if horizontal temperature gradients are present, the shear of the wind along a vertical line is primarily a function of the horizontal temperature gradients. This combination of the concepts of the gradient wind and hydrostatic equations, namely the thermal wind equation, can then be obtained by vectorial differentiation (i.e., taking account of the changing direction of the horizontal coordinate n) with respect to z of the gradient wind equation (28). This gives

$$\frac{\partial}{\partial z}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) = g\left(\frac{\partial z_p}{\partial n}\right)_z \frac{\partial(1+S^*)}{\partial z} + g(1+S^*)\left(\frac{\partial}{\partial n'}\frac{\partial z_p}{\partial z}\right)_z,$$

or since the hydrostatic equation is $\partial z_p/\partial z = 1/(1+S^*)$, by substitution from equation (28) we get

$$\frac{\partial}{\partial z}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) = \left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) \times \frac{\partial \ln(1+S^*)}{\partial z} - g\left(\frac{\partial \ln(1+S^*)}{\partial n'}\right)_z. \quad (32)$$

Also, since $1 + S^* = T^*/T_p$,

$$\frac{\partial}{\partial z}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) = \left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) \times \frac{\partial}{\partial z}\ln\frac{T^*}{T_p} - g\left(\frac{\partial}{\partial n'}\ln\frac{T^*}{T_p}\right)_z. \quad (33)$$

Similarly, vectorial differentiation of the gradient wind equation (31) with respect to z_p and substitution of the hydrostatic equation $\partial D/\partial z_p = S^*$ gives

$$\frac{\partial}{\partial z_p}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) = -g\left(\frac{\partial S^*}{\partial n'}\right)_p, \quad (34)$$

or

$$\frac{\partial}{\partial z_p}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) = -\frac{g}{T_p}\left(\frac{\partial T^*}{\partial n'}\right)_p. \quad (35)$$

In these equations

$$\frac{\partial}{\partial z}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) \quad \text{and} \quad \frac{\partial}{\partial z_p}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right)$$

are the vectorial shears, with respect to z and z_p, respectively, of the sum of the horizontal Coriolis and centrifugal forces per unit mass.

Furthermore,

$$\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right)\frac{\partial \ln(1+S^*)}{\partial z}$$

or

$$\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right)\frac{\partial}{\partial z}\ln\frac{T^*}{T_p}$$

is the part of this shear in the direction of the sum of the Coriolis and centrifugal forces themselves due to changes in the vertical of the temperature factor $1 + S^*$ or T^*/T_p in the constant level form of the gradient wind equation.

Likewise

$$-g\left(\frac{\partial \ln(1+S^*)}{\partial n'}\right)_z \quad \text{or} \quad -g\left(\frac{\partial}{\partial n'}\ln\frac{T^*}{T_p}\right)_z$$

is the part of this shear of force in the direction n' of the gradient of the quantity $1 + S^*$ or T^*/T_p on a constant level surface, and

$$-g\left(\frac{\partial S^*}{\partial n'}\right)_p \quad \text{or} \quad -\frac{g}{T_p}\left(\frac{\partial T^*}{\partial n'}\right)_p$$

is the value of this shear of force, with respect to z_p, which is then in the direction n' of the horizontal component of the virtual temperature gradient on a constant pressure surface.

Since the Coriolis force is frequently larger than the centrifugal force in general these equations state that the vertical shear of the wind is approximately parallel to the virtual temperature isotherms with the high temperature to the right of this shear in the northern hemisphere.

Advective local temperature changes. If it is assumed that the motion of the air is approximately along a constant pressure surface and that the temperature of any given parcel of air is changing very slowly, the rate of temperature change at any given point in space can be expressed, with the aid of equations (34) and (35), in terms of $V_{n'}$, the horizontal component of the wind normal to the virtual isotherms, as

$$\frac{\partial S^*}{\partial t} = -V_{n'}\left(\frac{\partial S^*}{\partial n'}\right)_p = \frac{V_{n'}}{g}\left|\frac{\partial}{\partial z_p}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right)\right|, \quad (36)$$

or

$$\frac{\partial T^*}{\partial t} = -V_{n'}\left(\frac{\partial T^*}{\partial n'}\right)_p = \frac{V_{n'}}{g}T_p\left|\frac{\partial}{\partial z_p}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right)\right|. \quad (37)$$

Similarly, for approximately horizontal flow, with $V_{n'}$ being the horizontal component of the wind normal to the isolines of $1 + S^*$ or T^*/T_p on a constant level surface,

$$\frac{\partial \ln(1+S^*)}{\partial t} = V_{n'}\left(\frac{\partial \ln(1+S^*)}{\partial n'}\right)_z = \frac{V_{n'}}{g}\left|\frac{\partial}{\partial z}\left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right) - \left(2\Omega V \sin\phi \pm \frac{V^2}{R_T}\right)\frac{\partial \ln(1+S^*)}{\partial z}\right|, \quad (38)$$

or

$$\frac{\partial}{\partial t}\ln\frac{T^*}{T_p} = V_{n'}\left(\frac{\partial}{\partial n'}\ln\frac{T^*}{T_p}\right)_z =$$

$$= \frac{V_{n'}}{g}\left|\frac{\partial}{\partial z}\left(2\Omega V\sin\phi \pm \frac{V^2}{R_T}\right) - \left(2\Omega V\sin\phi \pm \frac{V^2}{R_T}\right)\frac{\partial}{\partial z}\ln\frac{T^*}{T_p}\right|. \quad (39)$$

3. Techniques of calculation.

Conversion of pressure parameters. The definition of the U. S. Standard Atmosphere and the conversion from millimeters and inches of mercury to z_p and T_p are given in the *National Advisory Committee for Aeronautics Technical Reports Number 218* by Walter S. Diehl (2) and *Number 538* by W. G. Brombacher (1). A conversion table (5) from each millibar of p to feet of z_p is given in *USAAF Weather Division Report No. 708*. This mathematical definition of the relationship between the pressure parameters p (inches of mercury, millimeters of mercury or millibars) and the parameters z_p and T_p can be obtained by using the hydrostatic equation and the definition of the U. S. Standard Atmosphere.

The hydrostatic equation in the standard atmosphere can be written as

$$\frac{dp}{dz_p} = -\rho_p g_p, \quad (40)$$

since the vertical pressure-gradient force per unit volume in terms of the pressure parameter p is dp/dz_p and this must balance the weight of a unit volume $\rho_p g_p$. Then, using the concept of a perfect gas for the standard dry atmosphere, $\rho_p = m_d p/RT_p$, where R is the universal gas constant, so that

$$\frac{d\ln p}{dz_p} = -\frac{m_d g_p}{RT_p}. \quad (41)$$

The mathematical definition of the U. S. Standard Atmosphere, which is then the definition of the conversion between the pressure parameters z_p and T_p, can be written as follows:

$$\text{At } z_p = 0\begin{cases}\text{the temperature } T_0 = 288°\text{A},\\ \text{the pressure } P_0 = 1013.25 \text{ mb.}\end{cases} \quad (42)$$

In the standard troposphere $T_p = T_0 - \alpha z_p$. (43)

In the standard stratosphere $T_p = 218°$A. (44)

Substituting these relationships into equation (41) and integrating, we get that in the standard troposphere

$$T_p = T_0\left(\frac{p}{p_0}\right)^{\alpha R/m_d g_p} \quad \text{and} \quad z_p = \frac{1}{\alpha}(T_0 - T_p); \quad (45)$$

in the standard stratosphere

$$z_p = z_{ps} + 2.30259\,\frac{RT_{ps}}{m_d g_p}\log_{10}\frac{p_s}{p}. \quad (46)$$

In these formulae the values of the constants used are

$$T_{ps} = 218°\text{A},$$
$$\alpha = 1.9812°\text{C}/1000 \text{ ft},$$
$$z_{ps} = 35{,}332.0 \text{ ft},$$
$$p_s = 234.511 \text{ mb},$$
$$\frac{\alpha R}{m_d g_p} = 0.190285.$$

These equations have been used for calculating Tables 1 through 3 for the conversion of pressure parameters. These tables are designed to be used as follows:

Tables 1a and 1b—These are graphical tables for two-way conversion between any two of the pressure parameters z_p in feet, z_p in meters, T_p in degrees centigrade, p in millibars, p in inches of mercury, and p in millimeters of mercury. Table 1a covers the range $-3000 \text{ ft} \leq z_p \leq 80{,}000$ ft, and 1b (drawn to a larger scale for greater accuracy) covers the range $-2000 \text{ ft} \leq z_p \leq 10{,}000$ ft. These tables are meant to be used primarily for occasional conversions, such as making up a specific numerical table, since it is felt that numerical tables are usually more convenient for routine work.

Tables 2a through 2f—These tables give the pressure conversions from p in inches of mercury, in millimeters of mercury or in millibars, measured at or reduced to sea level, to the value of D at sea level expressed in feet or meters. Thus they can be used for: 1. converting mercurial pressure observations actually made at sea level to D; 2. conversion of past and present "sea-level" pressure maps in inches, millimeters or millibars to D; 3. conversion of the altimeter setting P expressed in inches, millimeters or millibars, for *any* point in the atmosphere to the corresponding value of the altimeter correction D applying at that point. The specific parameters used in any given table are denoted by the following notation: The vertical position referred to is given in the presuperscript, the unit of measurement used is given in the postsuperscript, and the parameter entered in the body of the table is denoted as being a function of the argument of the table. For example, the notation ${}^{z=0}D^{\text{ft}}$ $({}^{z=0}p^{\text{in}})$ denotes the conversion from the value of p, expressed in inches of mercury,

TABLE 1A.
Conversion of Pressure Parameters (range: $-3000 \text{ ft} \leq z_p \leq 80{,}000 \text{ ft}$)

TABLE FOR CONVERSION OF PRESSURE PARAMETERS

p-mb = millibars.

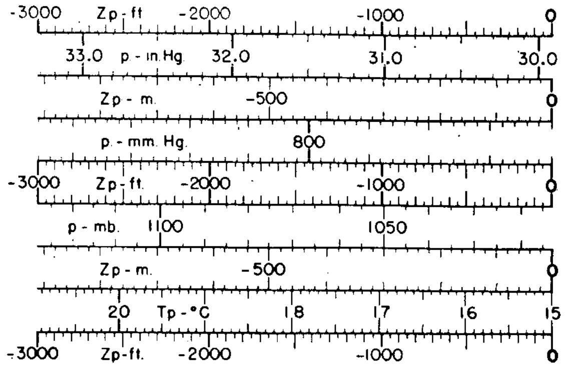
p-in. Hg. = inches of mercury.

p-mm. Hg. = millimeters of mercury.

z_p-ft. = pressure altitude in feet based on the U.S. Standard Atmosphere.

z_p-m. = pressure altitude in meters based on the U.S. Standard Atmosphere.

T_p-°C = standard temperature in degrees Centigrade based on the U.S. Standard Atmosphere



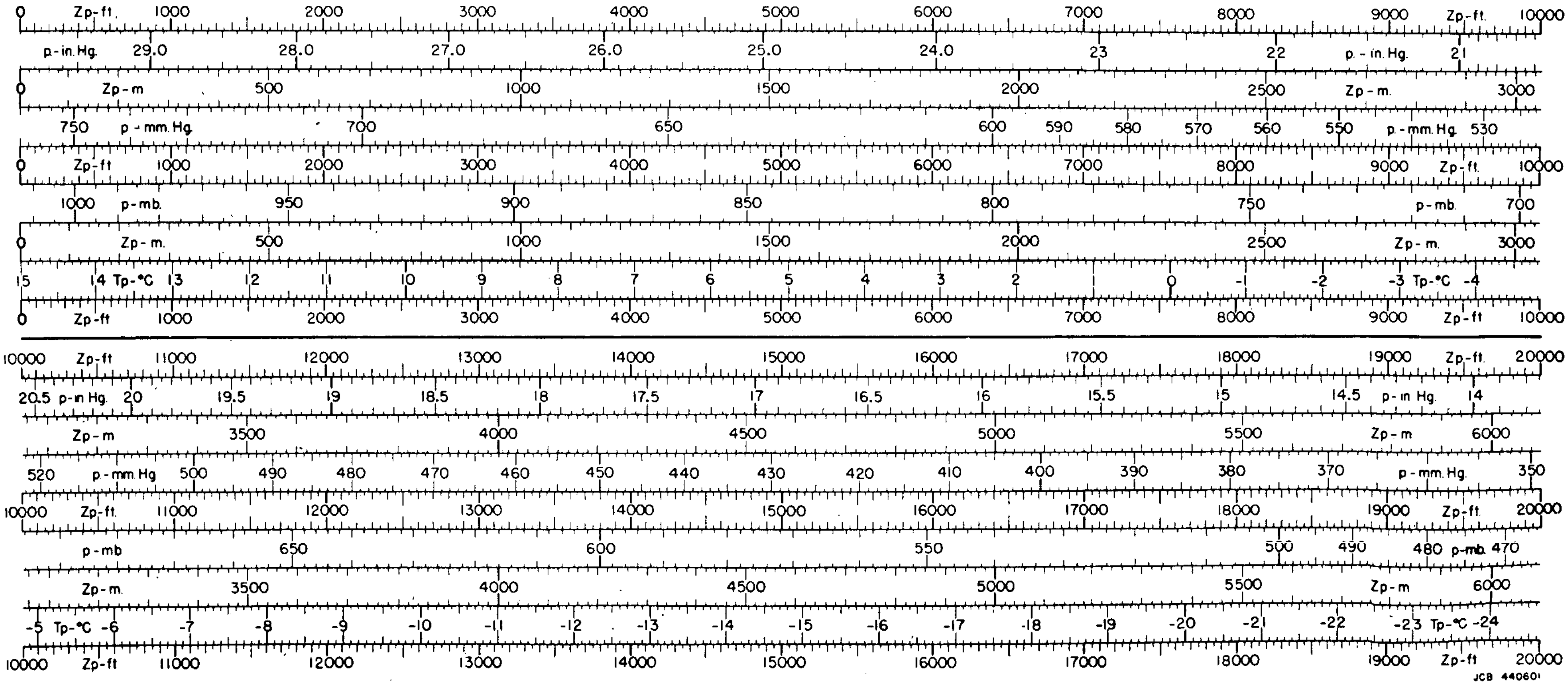


TABLE 1A (*cont.*).

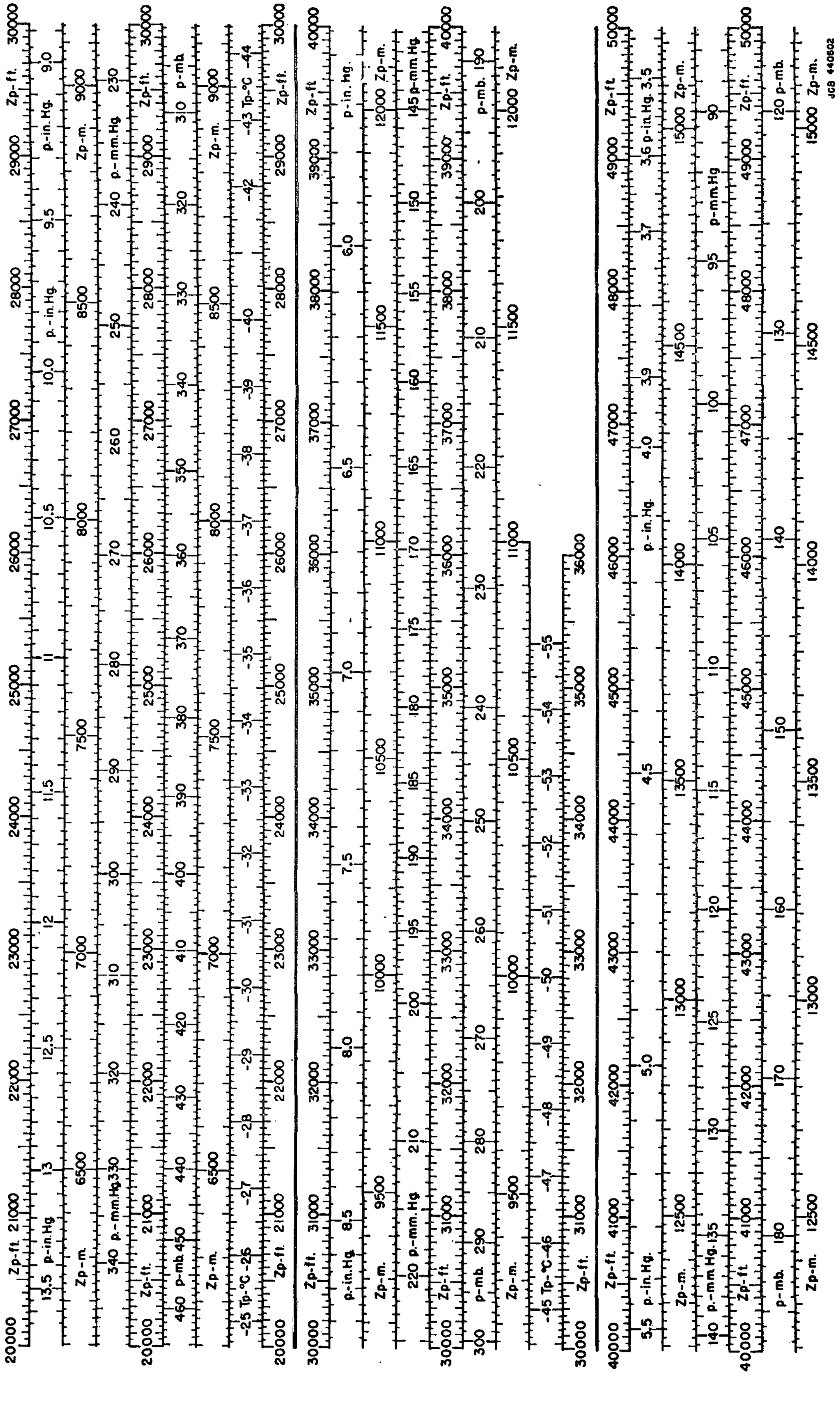


TABLE 1A (*cont.*).

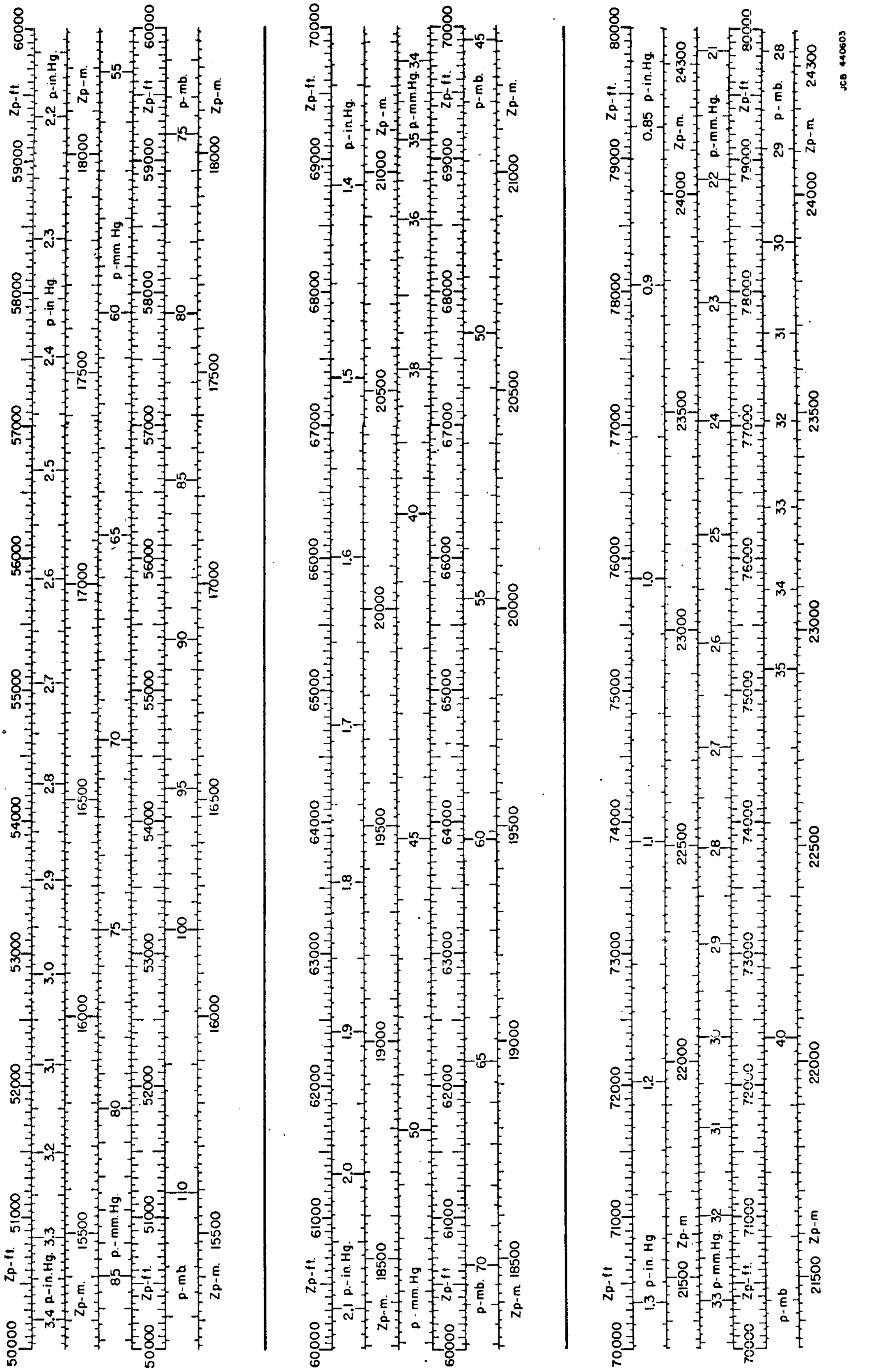


TABLE 1B.

Conversion of Pressure Parameters (range: $-2000 \text{ ft} \leqq z_p \leqq 10{,}000 \text{ ft}$)

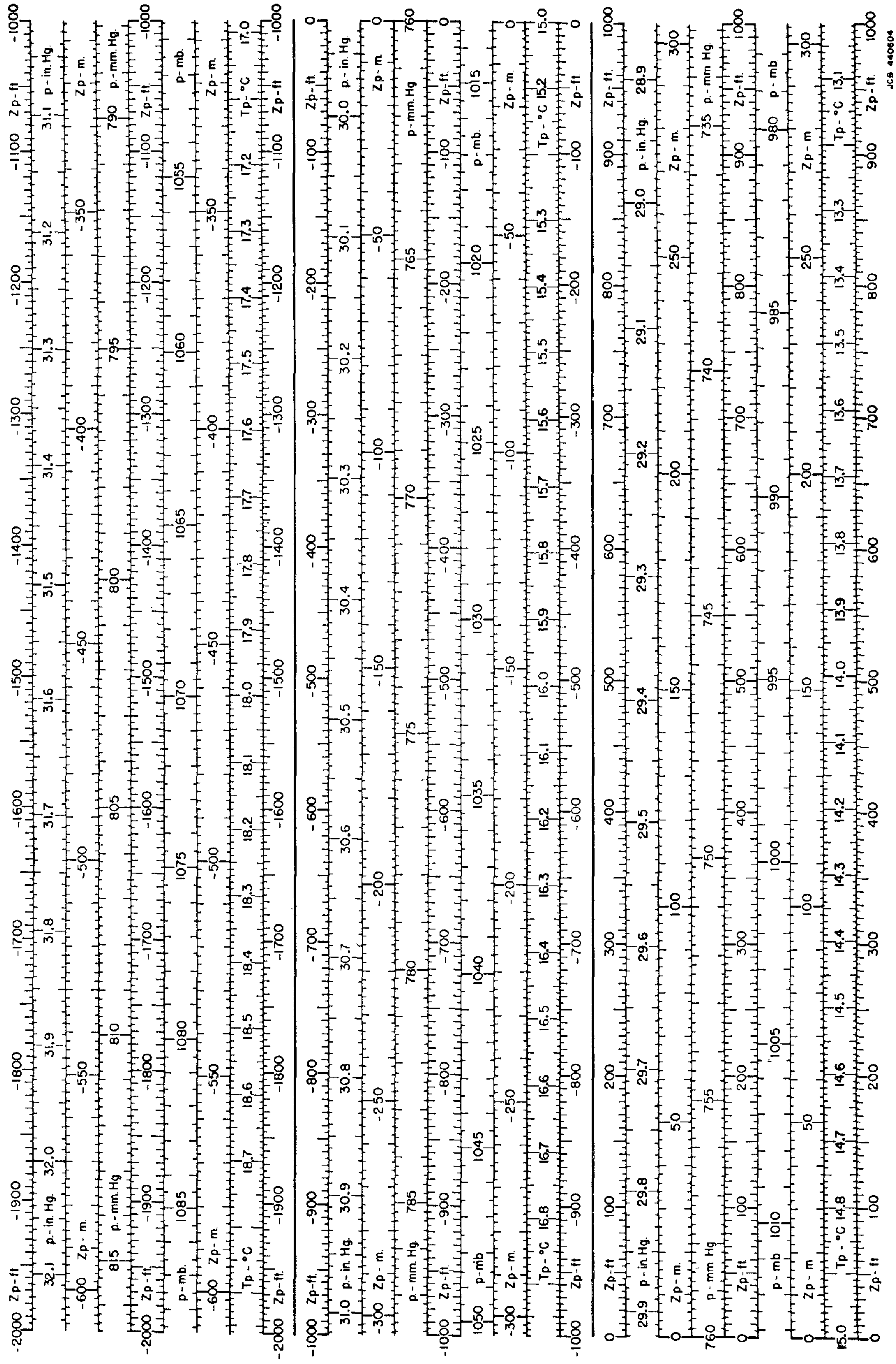


TABLE 1B (*cont.*).

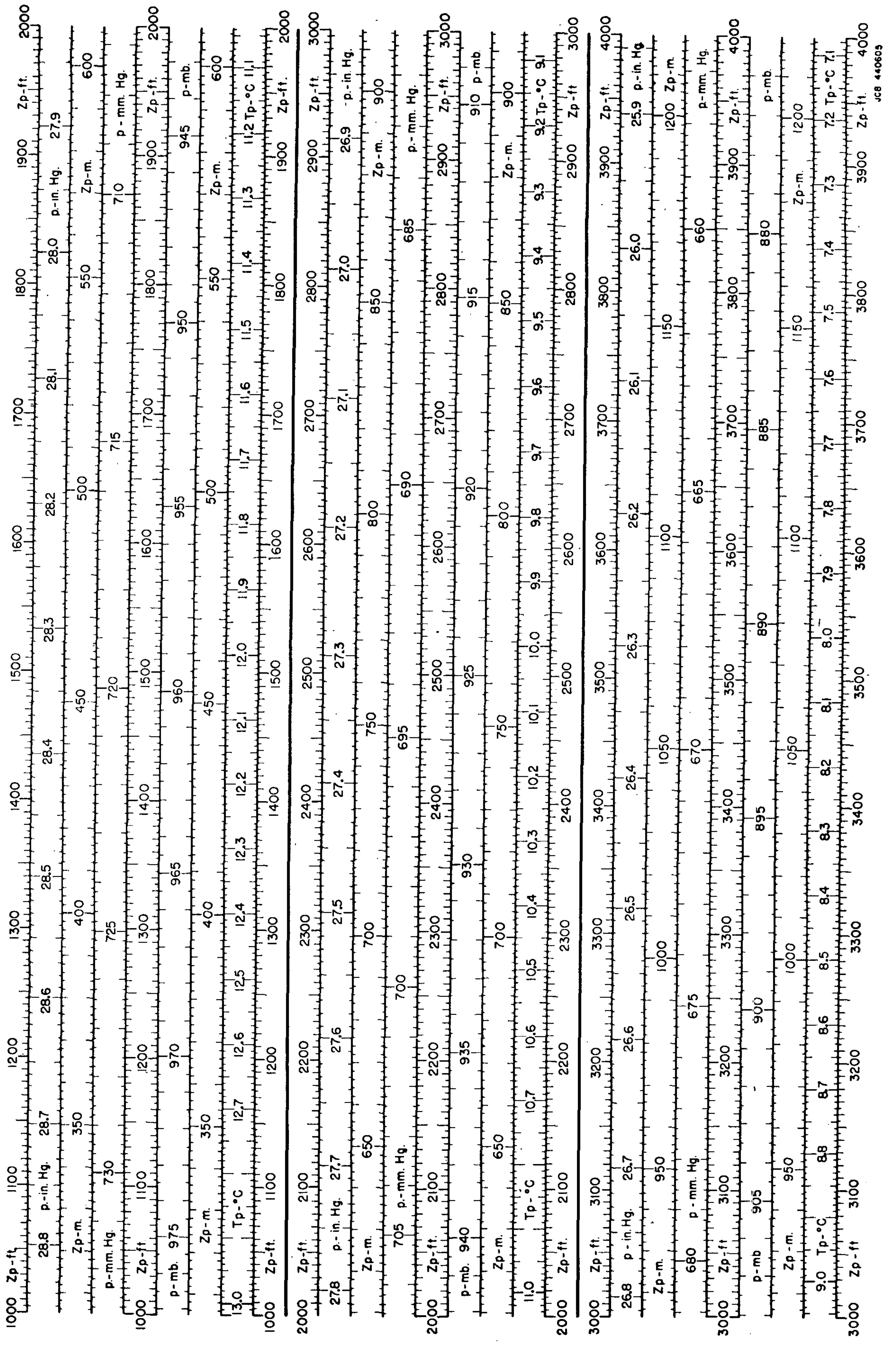


TABLE 1B (*cont.*).

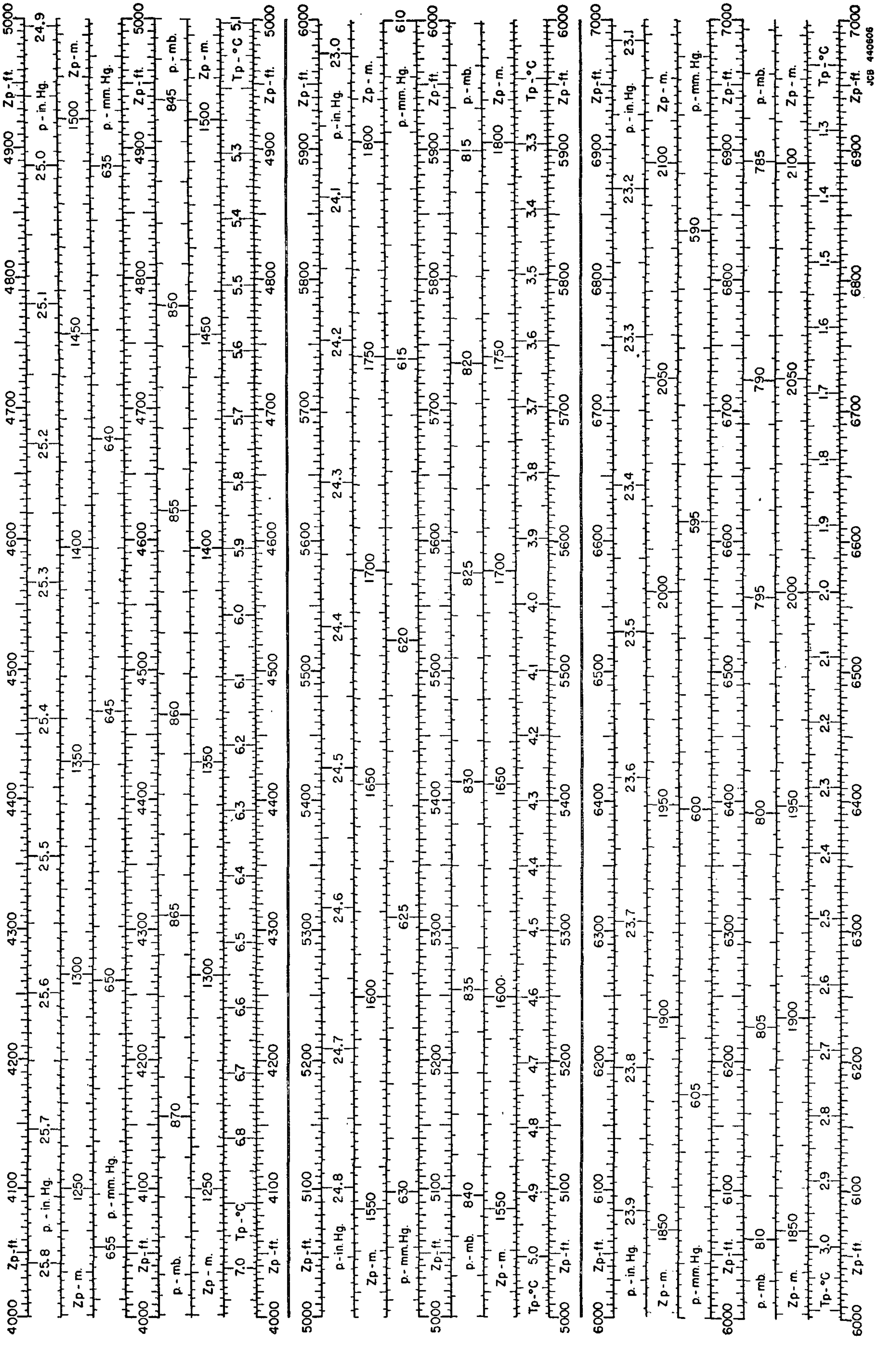


TABLE 1B (*cont.*).

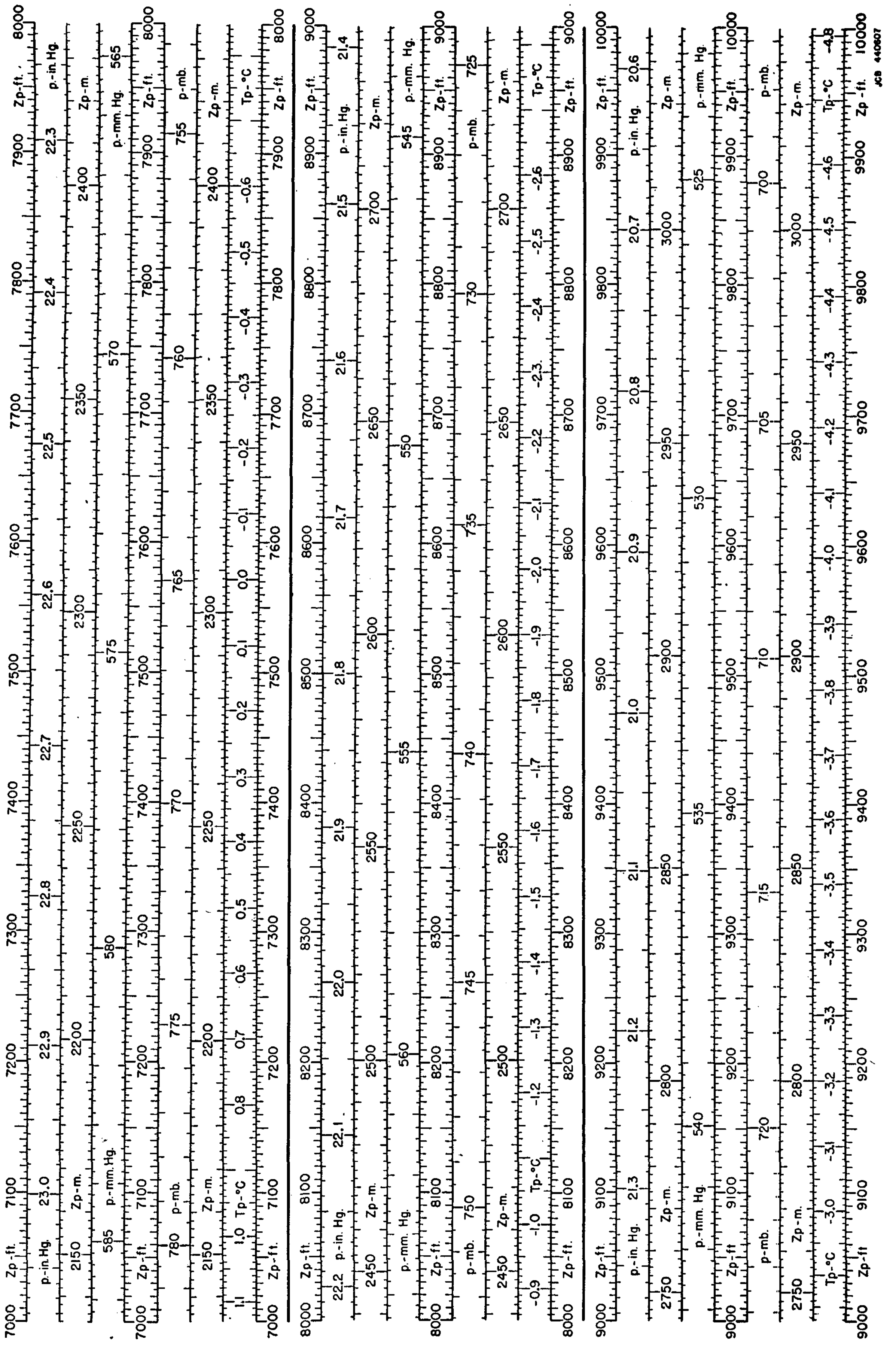


TABLE 2a

Conversion from p in Inches of Mercury to D in Feet at Sea Level

$_{z=0}D^{ft}$ ($_{z=0}p^{in}$)

inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
27.0	−2810	−2800	−2790	−2780	−2770	−2760	−2750	−2740	−2730	−2720
27.1	2710	2700	2690	2680	2670	2660	2650	2640	2630	2620
27.2	2610	2600	2590	2580	2570	2560	2550	2540	2530	2520
27.3	2510	2500	2490	2480	2470	2460	2450	2440	2430	2420
27.4	2410	2400	2390	2380	2370	2360	2360	2350	2340	2330
27.5	−2320	−2310	−2300	−2290	−2280	−2270	−2260	−2250	−2240	−2230
27.6	2220	2210	2200	2190	2180	2170	2160	2150	2140	2130
27.7	2120	2110	2100	2090	2080	2070	2060	2050	2040	2030
27.8	2020	2010	2000	1990	1980	1970	1960	1950	1940	1930
27.9	1920	1910	1900	1890	1880	1870	1860	1850	1840	1830
28.0	−1820	−1810	−1800	−1790	−1780	−1780	−1770	−1760	−1750	−1740
28.1	1730	1720	1710	1700	1690	1680	1670	1660	1650	1640
28.2	1630	1620	1610	1600	1590	1580	1570	1560	1550	1540
28.3	1530	1520	1510	1500	1490	1480	1470	1460	1460	1450
28.4	1440	1430	1420	1410	1400	1390	1380	1370	1360	1350
28.5	−1340	−1330	−1320	−1310	−1300	−1290	−1280	−1270	−1260	−1250
28.6	1240	1230	1220	1210	1210	1200	1190	1180	1170	1160
28.7	1150	1140	1130	1120	1110	1100	1090	1080	1070	1060
28.8	1050	1040	1030	1020	1010	1000	990	990	980	970
28.9	960	950	940	930	920	910	900	890	880	870
29.0	− 860	− 850	− 840	− 830	− 820	− 810	− 810	− 800	− 790	− 780
29.1	770	760	750	740	730	720	710	700	690	680
29.2	670	660	650	640	640	630	620	610	600	590
29.3	580	570	560	550	540	530	520	510	500	490
29.4	480	480	470	460	450	440	430	420	410	400
29.5	− 390	− 380	− 370	− 360	− 350	− 340	− 340	− 330	− 320	− 310
29.6	300	290	280	270	260	250	240	230	220	210
29.7	200	200	190	180	170	160	150	140	130	120
29.8	110	100	90	80	70	70	60	50	40	30
29.9	20	10	00	+ 10	+ 20	+ 30	+ 40	+ 40	+ 50	+ 60
30.0	+ 70	+ 80	+ 90	+ 100	+ 110	+ 120	+ 130	+ 140	+ 150	+ 160
30.1	160	170	180	190	200	210	220	230	240	250
30.2	260	270	280	280	290	300	310	320	330	340
30.3	350	360	370	380	380	390	400	410	420	430
30.4	440	450	460	470	480	480	490	500	510	520
30.5	+ 530	+ 540	+ 550	+ 560	+ 570	+ 580	+ 580	+ 590	+ 600	+ 610
30.6	620	630	640	650	660	670	680	680	690	700
30.7	710	720	730	740	750	760	770	780	780	790
30.8	800	810	820	830	840	850	860	870	870	880
30.9	890	900	910	920	930	940	950	960	960	970
31.0	+ 980	+ 990	+1000	+1010	+1020	+1030	+1040	+1050	+1050	+1060
31.1	1070	1080	1090	1100	1110	1120	1130	1140	1140	1150
31.2	1160	1170	1180	1190	1200	1210	1220	1220	1230	1240
31.3	1250	1260	1270	1280	1290	1300	1300	1310	1320	1330
31.4	1340	1350	1360	1370	1380	1380	1390	1400	1410	1420
31.5	+1430	+1440	+1450	+1460	+1460	+1470	+1480	+1490	+1500	+1510
31.6	1520	1530	1540	1540	1550	1560	1570	1580	1590	1600
31.7	1610	1610	1620	1630	1640	1650	1660	1670	1680	1690
31.8	1690	1700	1710	1720	1730	1740	1750	1760	1760	1770
31.9	1780	1790	1800	1810	1820	1830	1830	1840	1850	1860
32.0	+1870	+1880	+1890	+1900	+1900	+1910	+1920	+1930	+1940	+1950
32.1	1960	1970	1970	1980	1990	2000	2010	2020	2030	2040
32.2	2040	2050	2060	2070	2080	2090	2100	2110	2110	2120
32.3	2130	2140	2150	2160	2170	2170	2180	2190	2200	2210
32.4	2220	2230	2240	2240	2250	2260	2270	2280	2290	2300
32.5	+2300	+2310	+2320	+2330	+2340	+2350	+2360	+2370	+2370	+2380
32.6	2390	2400	2410	2420	2430	2430	2440	2450	2460	2470
32.7	2480	2490	2490	2500	2510	2520	2530	2540	2550	2550
32.8	2560	2570	2580	2590	2600	2610	2610	2620	2630	2640
32.9	2650	2660	2670	2670	2680	2690	2700	2710	2720	2730

TABLE 2b

Conversion from p in Millimeters of Mercury to D in Feet at Sea Level

$_{z=0}D^{\text{ft}}$ ($_{z=0}p^{\text{mm}}$)

mm	0.0	0.2	0.4	0.6	0.8	mm	0.0	0.2	0.4	0.6	0.8
690	−2650	−2640	−2630	−2620	−2620	750	− 370	− 360	− 350	− 340	− 340
691	2610	2600	2590	2580	2580	751	330	320	310	310	300
692	2570	2560	2550	2550	2540	752	290	280	280	270	260
693	2530	2520	2510	2510	2500	753	260	250	240	230	230
694	2490	2480	2480	2470	2460	754	220	210	200	200	190
695	−2450	−2440	−2440	−2430	−2420	755	− 180	− 170	− 170	− 160	− 150
696	2410	2400	2400	2390	2380	756	150	140	130	120	120
697	2370	2370	2360	2350	2340	757	110	100	90	90	80
698	2330	2330	2320	2310	2300	758	70	70	60	50	40
699	2300	2290	2280	2270	2260	759	40	30	20	10	10
700	−2260	−2250	−2240	−2230	−2230	760	+ 0	+ 10	+ 10	+ 20	+ 30
701	2220	2210	2200	2190	2190	761	40	40	50	60	60
702	2180	2170	2160	2160	2150	762	70	80	90	90	100
703	2140	2130	2120	2120	2110	763	110	120	120	130	140
704	2100	2090	2090	2080	2070	764	140	150	160	170	170
705	−2060	−2050	−2050	−2040	−2030	765	+ 180	+ 190	+ 200	+ 200	+ 210
706	2020	2020	2010	2000	1990	766	220	220	230	240	250
707	1990	1980	1970	1960	1950	767	250	260	270	270	280
708	1950	1940	1930	1920	1920	768	290	300	300	310	320
709	1910	1900	1890	1890	1880	769	330	330	340	350	350
710	−1870	−1860	−1850	−1850	−1840	770	+ 360	+ 370	+ 380	+ 380	+ 390
711	1830	1820	1820	1810	1800	771	400	400	410	420	430
712	1790	1790	1780	1770	1760	772	430	440	450	460	460
713	1750	1750	1740	1730	1720	773	470	480	480	490	500
714	1720	1710	1700	1690	1690	774	510	510	520	530	530
715	−1680	−1670	−1660	−1660	−1650	775	+ 540	+ 550	+ 560	+ 560	+ 570
716	1640	1630	1620	1620	1610	776	580	580	590	600	610
717	1600	1590	1590	1580	1570	777	610	620	630	630	640
718	1560	1560	1550	1540	1530	778	650	660	660	670	680
719	1530	1520	1510	1500	1500	779	680	690	700	710	710
720	−1490	−1480	−1470	−1460	−1460	780	+ 720	+ 730	+ 730	+ 740	+ 750
721	1450	1440	1430	1430	1420	781	760	760	770	780	780
722	1410	1400	1400	1390	1380	782	790	800	810	810	820
723	1370	1370	1360	1350	1340	783	830	830	840	850	850
724	1340	1330	1320	1310	1310	784	860	870	880	880	890
725	−1300	−1290	−1280	−1280	−1270	785	+ 900	+ 900	+ 910	+ 920	+ 930
726	1260	1250	1240	1240	1230	786	930	940	950	950	960
727	1220	1210	1210	1200	1190	787	970	980	980	990	1000
728	1180	1180	1170	1160	1150	788	1000	1010	1020	1020	1030
729	1150	1140	1130	1120	1120	789	1040	1050	1050	1060	1070
730	−1110	−1100	−1090	−1090	−1080	790	+1070	+1080	+1090	+1100	+1100
731	1070	1060	1060	1050	1040	791	1110	1120	1120	1130	1140
732	1030	1030	1020	1010	1000	792	1150	1150	1160	1170	1170
733	1000	990	980	970	970	793	1180	1190	1190	1200	1210
734	960	950	940	940	930	794	1220	1220	1230	1240	1240
735	− 920	− 910	− 910	− 900	− 890	795	+1250	+1260	+1260	+1270	+1280
736	880	880	870	860	850	796	1290	1290	1300	1310	1310
737	850	840	830	820	820	797	1320	1330	1330	1340	1350
738	810	800	790	790	780	798	1360	1360	1370	1380	1380
739	770	770	760	750	740	799	1390	1400	1400	1410	1420
740	− 740	− 730	− 720	− 710	− 710	800	+1430	+1430	+1440	+1450	+1450
741	700	690	680	680	670	801	1460	1470	1470	1480	1490
742	660	650	650	640	630	802	1500	1500	1510	1520	1520
743	620	620	610	600	590	803	1530	1540	1540	1550	1560
744	590	580	570	560	560	804	1570	1570	1580	1590	1590
745	− 550	− 540	− 540	− 530	− 520	805	+1600	+1610	+1610	+1620	+1630
746	510	510	500	490	480	806	1630	1640	1650	1660	1660
747	480	470	460	450	450	807	1670	1680	1680	1690	1700
748	440	430	420	420	410	808	1700	1710	1720	1720	1730
749	400	390	390	380	370	809	1740	1750	1750	1760	1770

TABLE 2b (cont.)

mm	0.0	0.2	0.4	0.6	0.8	mm	0.0	0.2	0.4	0.6	0.8
810	+1770	+1780	+1790	+1790	+1800	820	+2120	+2120	+2130	+2140	+2140
811	1810	1810	1820	1830	1840	821	2150	2160	2160	2170	2180
812	1840	1850	1860	1860	1870	822	2190	2190	2200	2210	2210
813	1880	1880	1890	1900	1900	823	2220	2230	2230	2240	2250
814	1910	1920	1920	1930	1940	824	2250	2260	2270	2270	2280
815	+1950	+1950	+1960	+1970	+1970	825	+2290	+2290	+2300	+2310	+2320
816	1980	1990	1990	2000	2010	826	2320	2330	2340	2340	2350
817	2010	2020	2030	2030	2040	827	2360	2360	2370	2380	2380
818	2050	2060	2060	2070	2080	828	2390	2400	2400	2410	2420
819	2080	2090	2100	2100	2110	829	2420	2430	2440	2440	2450

TABLE 2c

Conversion from p in Millibars to D in Feet at Sea Level

${}_{z=0}D^{\mathrm{ft}}\ ({}_{z=0}p^{\mathrm{mb}})$

mb	0	1	2	3	4	5	6	7	8	9
900	−3240	−3210	−3180	−3150	−3120	−3090	−3060	−3030	−3000	−2970
910	2940	2910	2880	2850	2830	2790	2760	2730	2710	2680
920	2650	2620	2590	2560	2530	2500	2470	2440	2410	2380
930	2350	2320	2290	2260	2230	2210	2180	2150	2120	2090
940	2060	2030	2000	1970	1940	1920	1890	1860	1830	1800
950	−1770	−1740	−1710	−1690	−1660	−1630	−1600	−1570	−1540	−1510
960	1490	1460	1430	1400	1370	1340	1310	1290	1260	1230
970	1200	1170	1140	1120	1090	1060	1030	1000	980	950
980	920	890	860	840	810	780	750	720	700	670
990	640	610	580	560	530	500	470	450	420	390
1000	− 360	− 340	− 310	− 280	− 250	− 230	− 200	− 170	− 140	− 120
1010	90	60	30	10	+ 20	+ 50	+ 70	+ 100	+ 130	+ 160
1020	+ 180	+ 210	+ 240	+ 260	290	320	350	370	400	430
1030	450	480	510	530	560	590	620	640	670	690
1040	720	750	780	800	830	860	880	910	940	960
1050	+ 990	+1010	+1040	+1070	+1090	+1120	+1150	+1170	+1200	+1230
1060	1250	1280	1310	1330	1360	1380	1410	1440	1460	1490
1070	1510	1540	1570	1590	1620	1650	1670	1700	1720	1750
1080	1780	1800	1830	1850	1880	1900	1930	1960	1980	2010
1090	2030	2060	2090	2110	2140	2160	2190	2210	2240	2270
1100	+2290	+2320	+2340	+2370	+2390	+2420	+2440	+2470	+2490	+2520

TABLE 2d

Conversion from p in Inches of Mercury to D in Meters at Sea Level

$^{z=0}D^{m}\ (^{z=0}p^{in})$

inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
27.0	−858	−855	−852	−849	−846	−842	−839	−836	−833	−830
27.1	827	824	821	818	815	812	809	806	803	800
27.2	797	794	791	787	784	781	778	775	772	769
27.3	766	763	760	757	754	751	748	745	742	739
27.4	736	733	730	727	724	721	718	715	712	709
27.5	−706	−703	−700	−697	−694	−691	−688	−685	−682	−679
27.6	676	673	670	667	664	661	658	655	652	649
27.7	646	643	640	637	634	631	628	625	622	619
27.8	615	613	610	607	604	601	598	595	592	589
27.9	586	583	580	576	574	571	568	565	562	559
28.0	−556	−553	−550	−547	−544	−541	−538	−535	−532	−529
28.1	526	523	520	517	514	511	508	505	502	499
28.2	496	493	490	487	485	482	479	476	473	470
28.3	467	464	461	458	455	452	449	446	443	440
28.4	437	434	432	429	426	423	420	417	414	411
28.5	−408	−405	−402	−399	−396	−394	−391	−388	−385	−382
28.6	379	376	373	370	367	364	361	358	356	353
28.7	350	347	344	341	338	335	332	329	326	323
28.8	320	318	315	312	309	306	303	300	297	294
28.9	292	289	286	283	280	277	274	271	268	266
29.0	−263	−260	−257	−254	−251	−248	−245	−243	−240	−237
29.1	234	231	228	225	222	219	217	214	211	208
29.2	205	202	199	196	194	191	188	185	182	179
29.3	176	173	171	168	165	162	159	156	153	151
29.4	148	145	142	139	136	133	131	128	125	122
29.5	−119	−116	−113	−111	−108	−105	−102	− 99	− 96	− 93
29.6	91	88	85	82	79	76	74	71	68	65
29.7	62	59	58	54	51	48	45	42	39	37
29.8	34	31	28	25	22	20	17	14	11	8
29.9	5	3	0	+ 3	+ 6	+ 9	+ 12	+ 15	+ 17	+ 20
30.0	+ 23	+ 26	+ 28	+ 31	+ 34	+ 37	+ 40	+ 42	+ 45	+ 48
30.1	51	53	56	59	62	65	67	70	73	76
30.2	79	81	84	87	90	93	95	98	101	104
30.3	107	109	112	115	118	120	123	126	129	132
30.4	134	137	140	143	146	148	151	154	157	160
30.5	+162	+165	+168	+171	+173	+176	+179	+182	+184	+187
30.6	190	193	195	198	201	204	207	209	212	215
30.7	218	220	223	226	229	231	234	237	240	242
30.8	245	248	251	253	256	259	262	264	267	270
30.9	273	275	278	281	283	286	289	291	294	297
31.0	+300	+302	+306	+308	+310	+313	+316	+319	+321	+324
31.1	327	330	332	335	338	341	343	346	349	351
31.2	354	357	360	362	365	368	370	373	376	379
31.3	381	384	387	390	392	395	398	400	403	406
31.4	408	411	414	417	419	422	425	427	430	433
31.5	+436	+438	+441	+444	+446	+449	+452	+454	+457	+460
31.6	463	465	468	471	473	476	479	481	484	487
31.7	489	492	495	498	500	503	506	508	511	514
31.8	516	519	522	524	527	530	532	535	538	540
31.9	543	546	549	551	554	557	559	562	565	567
32.0	+570	+573	+575	+578	+581	+583	+586	+589	+591	+594
32.1	597	599	602	605	607	610	612	615	618	620
32.2	623	626	628	631	634	636	639	642	644	647
32.3	650	652	655	658	660	663	666	668	671	673
32.4	676	679	681	684	687	689	692	695	697	700
32.5	+702	+705	+708	+710	+713	+716	+718	+721	+723	+726
32.6	729	731	734	737	739	742	745	747	750	752
32.7	755	758	760	763	766	768	771	773	776	779
32.8	781	784	786	789	792	794	797	800	802	805
32.9	807	810	813	815	818	820	823	826	828	831

TABLE 2e

Conversion from p in Millimeters of Mercury to D in Meters at Sea Level

$_{z=0}D^{\mathrm{m}}$ ($_{z=0}p^{\mathrm{mm}}$)

mm	0.0	0.2	0.4	0.6	0.8	mm	0.0	0.2	0.4	0.6	0.8
690	−807	−805	−802	−800	−798	750	−112	−109	−107	−105	−103
691	795	793	790	788	786	751	101	98	96	94	92
692	783	781	778	776	774	752	89	87	85	83	80
693	771	769	766	764	762	753	78	76	74	71	69
694	759	757	754	752	750	754	67	65	62	60	58
695	−747	−745	−743	−740	−738	755	− 56	− 54	− 51	− 49	− 47
696	735	733	731	728	726	756	45	42	40	38	36
697	724	721	719	717	714	757	33	31	29	27	24
698	712	709	707	705	702	758	22	20	18	15	13
699	700	698	695	693	690	759	11	9	7	4	2
700	−688	−686	−683	−681	−678	760	+ 0	+ 2	+ 4	+ 7	+ 9
701	676	674	671	669	666	761	11	13	14	17	19
702	664	662	659	657	655	762	22	24	27	29	31
703	652	650	648	645	643	763	33	35	38	40	42
704	641	638	636	633	631	764	44	47	49	51	53
705	−629	−626	−624	−622	−619	765	+ 55	+ 58	+ 60	+ 62	+ 64
706	617	615	612	610	608	766	67	69	71	73	75
707	605	603	601	598	596	767	77	80	82	84	86
708	594	591	589	586	584	768	88	90	93	95	97
709	582	579	577	575	572	769	99	101	104	106	108
710	−570	−568	−565	−563	−560	770	+110	+112	+115	+117	+119
711	558	556	554	551	549	771	121	123	125	128	130
712	547	544	542	539	537	772	132	134	136	139	141
713	535	532	530	528	525	773	143	145	147	150	152
714	523	521	518	516	514	774	154	156	158	161	163
715	−512	−509	−507	−505	−502	775	+165	+167	+169	+172	+174
716	500	498	495	493	491	776	176	178	180	182	185
717	488	486	484	481	479	777	187	189	191	193	195
718	477	474	472	470	467	778	198	200	202	204	206
719	465	463	460	458	456	779	208	211	213	215	217
720	−454	−451	−449	−447	−444	780	+219	+221	+224	+226	+228
721	442	440	437	435	433	781	230	232	234	237	239
722	431	428	426	423	421	782	241	243	245	247	250
723	419	416	414	412	409	783	252	254	256	258	260
724	407	405	402	400	398	784	263	265	267	269	271
725	−396	−393	−391	−389	−386	785	+273	+276	+278	+280	+282
726	384	382	379	377	375	786	284	287	289	291	293
727	373	370	368	366	363	787	295	297	300	302	304
728	361	359	357	354	352	788	306	308	310	312	315
729	350	348	345	343	341	789	317	319	321	323	325
730	−338	−336	−334	−332	−329	790	+327	+330	+332	+334	+336
731	327	325	322	320	318	791	338	340	343	345	347
732	315	313	311	309	306	792	349	351	353	355	358
733	304	302	299	297	295	793	360	362	364	366	368
734	292	290	288	286	283	794	370	372	375	377	379
735	−281	−279	−277	−274	−272	795	+381	+383	+385	+387	+390
736	270	268	265	263	261	796	392	394	396	398	400
737	259	256	254	252	250	797	403	405	407	409	411
738	247	245	243	240	238	798	413	415	418	420	422
739	236	233	231	229	227	799	424	426	428	430	432
740	−224	−222	−220	−217	−215	800	+435	+437	+439	+441	+443
741	213	211	208	206	204	801	445	447	450	452	454
742	202	199	197	195	193	802	456	458	460	462	464
743	190	188	186	184	181	803	467	469	471	473	475
744	179	177	175	172	170	804	477	479	481	483	486
745	−168	−166	−164	−161	−159	805	+488	+490	+492	+494	+496
746	157	155	152	150	148	806	498	500	502	504	507
747	146	143	141	139	137	807	509	511	513	515	517
748	134	132	130	127	125	808	519	521	524	526	528
749	123	121	118	116	114	809	530	532	534	536	538

TABLE 2e (cont.)

mm	0.0	0.2	0.4	0.6	0.8	mm	0.0	0.2	0.4	0.6	0.8
810	+541	+543	+545	+547	+549	820	+645	+647	+649	+651	+653
811	551	553	555	557	559	821	655	657	660	662	664
812	561	563	566	568	570	822	666	668	670	672	674
813	572	574	576	578	580	823	676	678	680	682	685
814	583	585	587	589	591	824	687	689	691	693	695
815	+593	+595	+597	+599	+601	825	+697	+699	+701	+703	+705
816	603	605	608	610	612	826	707	709	712	714	716
817	614	616	618	620	622	827	718	720	722	724	726
818	624	626	628	630	633	828	728	730	732	734	737
819	635	637	639	641	643	829	739	741	743	745	747

TABLE 2f

Conversion from p in Millibars to D in Meters at Sea Level

$_{z=0}D_{\text{m}}$ ($_{z=0}p_{\text{mb}}$)

mb	0	1	2	3	4	5	6	7	8	9
900	−988	−979	−970	−961	−951	−942	−933	−924	−915	−906
910	897	888	879	870	860	851	842	833	824	815
920	806	797	788	779	770	761	752	744	735	726
930	717	708	699	690	681	672	663	654	645	637
940	628	619	610	601	593	584	575	566	557	549
950	−540	−531	−522	−514	−505	−496	−488	−479	−470	−461
960	453	444	435	427	418	410	401	392	384	375
970	366	358	349	341	332	323	315	306	298	289
980	281	272	263	255	246	238	229	221	212	204
990	195	187	179	170	162	153	145	136	128	120
1000	−111	−103	− 94	− 86	− 78	− 69	− 61	− 52	− 44	− 36
1010	27	19	11	2	+ 6	+ 14	+ 22	+ 31	+ 39	+ 47
1020	+ 56	+ 64	+ 72	+ 80	89	97	105	113	122	130
1030	138	146	154	163	171	179	187	195	203	212
1040	220	228	236	244	252	260	269	277	285	293
1050	+301	+309	+317	+325	+333	+341	+349	+357	+365	+373
1060	381	389	397	406	414	422	430	438	446	454
1070	462	470	477	485	493	501	509	517	525	533
1080	541	549	557	565	572	580	588	596	604	612
1090	620	627	635	643	651	659	667	674	682	690
1100	+698	+706	+713	+721	+729	+737	+745	+752	+760	+768

TABLE 3a

Conversion from p in Millibars to D in Feet at Standard Levels

$_{z\text{ in ft}}D_{\text{ft}}$ ($_{z\text{ in ft}}p_{\text{mb}}$)

mb	0	1	2	3	4	5	6	7	8	9
					z = 5,000 feet.					
760	−2740	−2710	−2670	−2640	−2600	−2570	−2530	−2500	−2470	−2430
770	2400	2360	2330	2300	2260	2230	2200	2160	2130	2090
780	2060	2030	1990	1960	1920	1890	1860	1820	1790	1760
790	1720	1690	1660	1620	1590	1560	1520	1490	1460	1420
800	−1390	−1360	−1330	−1290	−1260	−1230	−1190	−1160	−1130	−1090
810	1060	1030	1000	960	930	900	870	830	800	770
820	740	710	670	640	610	580	540	510	480	450
830	410	380	350	320	290	250	220	190	160	130
840	90	60	30	0	+ 30	+ 60	+ 100	+ 130	+ 160	+ 190
850	+ 220	+ 250	+ 280	+ 320	+ 350	+ 380	+ 410	+ 440	+ 470	+ 500
860	530	560	600	630	660	690	720	750	780	810
870	840	870	910	940	970	1000	1030	1060	1090	1120
880	1150	1180	1210	1240	1270	1300	1330	1360	1400	1430
890	1460	1490	1520	1550	1580	1610	1640	1670	1700	1730
900	+1760	+1790	+1820	+1850	+1880	+1910	+1940	+1970	+2000	+2030
910	2060	2090	2120	2150	2180	2210	2240	2270	2290	2320
920	2350	2380	2410	2440	2470	2500	2530	2560	2590	2620

TABLE 3a (cont.)

mb	0	1	2	3	4	5	6	7	8	9
					z = 10,000 feet					
630	−2570	−2530	−2490	−2450	−2410	−2370	−2330	−2290	−2250	−2210
640	2170	2130	2090	2050	2010	1970	1930	1890	1850	1810
650	−1780	−1740	−1700	−1660	−1620	−1580	−1540	−1500	−1460	−1430
660	1390	1350	1310	1270	1230	1190	1160	1120	1080	1040
670	1000	960	930	890	850	810	770	740	700	660
680	620	590	550	510	470	440	400	360	320	290
690	250	210	170	140	100	60	30	+ 10	+ 50	+ 80
700	+ 120	+ 160	+ 200	+ 230	+ 270	+ 300	+ 340	+ 380	+ 410	+ 450
710	490	520	560	600	630	670	700	740	780	810
720	850	880	920	960	990	1030	1060	1100	1140	1170
730	1210	1240	1280	1310	1350	1380	1420	1460	1490	1530
740	1560	1600	1630	1670	1700	1740	1770	1810	1840	1880
750	+1910	+1950	+1980	+2020	+2050	+2090	+2120	+2150	+2190	+2220
760	2260	2290	2330	2360	2400	2430	2460	2500	2530	2570
					z = 15,000 feet					
510	−2800	−2750	−2710	−2660	−2610	−2560	−2520	−2470	−2420	−2380
520	2330	2280	2240	2190	2140	2100	2050	2000	1960	1910
530	1860	1820	1770	1730	1680	1630	1590	1540	1500	1450
540	1410	1360	1320	1270	1220	1180	1130	1090	1040	1000
550	− 960	− 910	− 870	− 820	− 780	− 730	− 690	− 640	− 600	− 550
560	510	470	420	380	330	290	250	200	160	120
570	70	30	+ 10	+ 60	+ 100	+ 140	+ 190	+ 230	+ 270	+ 320
580	+ 360	+ 400	440	490	530	570	610	660	700	740
590	780	830	870	910	950	1000	1040	1080	1120	1160
600	+1200	+1250	+1290	+1330	+1370	+1410	+1450	+1500	+1540	+1580
610	1620	1660	1700	1740	1780	1820	1870	1910	1950	1990
620	2030	2070	2110	2150	2190	2230	2270	2310	2350	2390
630	2430	2470	2510	2550	2590	2630	2670	2710	2750	2790
					z = 20,000 feet					
410	−2990	−2930	−2880	−2820	−2760	−2710	−2650	−2600	−2540	−2480
420	2430	2370	2320	2260	2210	2150	2100	2040	1990	1930
430	1880	1820	1770	1710	1660	1600	1550	1500	1440	1390
440	1330	1280	1230	1170	1120	1070	1020	960	910	860
450	− 800	− 750	− 700	− 650	− 590	− 540	− 490	− 440	− 390	− 330
460	280	230	180	130	80	20	+ 30	+ 80	+ 130	+ 180
470	+ 230	+ 280	+ 330	+ 380	+ 430	+ 480	530	580	630	680
480	730	780	830	880	930	980	1030	1080	1130	1180
490	1230	1280	1330	1380	1430	1480	1530	1570	1620	1670
500	+1720	+1770	+1810	+1860	+1910	+1960	+2010	+2050	+2100	+2150
510	2200	2250	2290	2340	2390	2440	2480	2530	2580	2620

TABLE 3b

Conversion from p in Millibars to D in Feet at Standard Levels

z in km D ft (z in km p mb)

mb	0	1	2	3	4	5	6	7	8	9
					z = 0.5 km					
870	−2520	−2480	−2450	−2420	−2390	−2360	−2330	−2300	−2270	−2240
880	2210	2180	2150	2120	2090	2060	2020	1990	1960	1930
890	1900	1870	1840	1810	1780	1750	1720	1690	1660	1630
900	−1600	−1570	−1540	−1510	−1480	−1450	−1420	−1390	−1360	−1330
910	1300	1270	1240	1210	1180	1150	1120	1090	1070	1040
920	1010	980	950	920	890	860	830	800	770	740
930	710	680	650	620	590	570	540	510	480	450
940	420	390	360	330	300	280	250	220	190	160
950	− 130	− 100	− 70	− 50	− 20	+ 10	+ 40	+ 70	+ 100	+ 130
960	+ 150	+ 180	+ 210	+ 240	+ 270	300	320	350	380	410
970	440	470	490	520	550	580	610	640	660	690
980	720	750	780	800	830	860	890	920	940	970
990	1000	1030	1050	1080	1110	1140	1170	1190	1220	1250
1000	+1280	+1300	+1330	+1360	+1390	+1410	+1440	+1470	+1500	+1520
1010	1550	1580	1610	1630	1660	1690	1710	1740	1770	1800
1020	1820	1850	1880	1900	1930	1960	1990	2010	2040	2070
1030	2090	2120	2150	2170	2200	2230	2250	2280	2310	2330
1040	2360	2390	2420	2440	2470	2500	2520	2550	2580	2600
					z = 1 km					
820	−2460	−2420	−2390	−2360	−2330	−2290	−2260	−2230	−2200	−2170
830	2130	2100	2070	2040	2010	1970	1940	1910	1880	1850
840	1810	1780	1750	1720	1690	1660	1620	1590	1560	1530
850	−1500	−1470	−1440	−1400	−1370	−1340	−1310	−1280	−1250	−1220
860	1180	1150	1120	1090	1060	1030	1000	970	940	910
870	870	840	810	780	750	720	690	660	630	600
880	570	540	510	480	440	410	380	350	320	290
890	260	230	200	170	140	110	80	50	20	+ 10
900	+ 40	+ 70	+ 100	+ 130	+ 160	+ 190	+ 220	+ 250	+ 280	+ 310
910	340	370	400	430	460	490	520	550	570	600
920	630	660	690	720	750	780	810	840	870	900
930	930	960	990	1020	1050	1070	1100	1130	1160	1190
940	1220	1250	1280	1310	1340	1360	1390	1420	1450	1480
950	+1510	+1540	+1570	+1590	+1620	+1650	+1680	+1710	+1740	+1770
960	1790	1820	1850	1880	1910	1940	1970	1990	2020	2050
970	2080	2110	2140	2160	2190	2220	2250	2280	2300	2330
980	2360	2390	2420	2440	2470	2500	2530	2560	2580	2610
					z = 1.5 km					
770	−2480	−2440	−2410	−2380	−2340	−2310	−2270	−2240	−2210	−2170
780	2140	2100	2070	2040	2000	1970	1940	1900	1870	1840
790	1800	1770	1740	1700	1670	1640	1600	1570	1540	1500
800	−1470	−1440	−1400	−1370	−1340	−1310	−1270	−1240	−1210	−1170
810	1140	1110	1080	1040	1010	980	950	910	880	850
820	820	780	750	720	690	650	620	590	560	530
830	490	460	430	400	370	330	300	270	240	210
840	170	140	110	80	50	20	+ 20	+ 50	+ 80	+ 110
850	+ 140	+ 170	+ 200	+ 240	+ 270	+ 300	+ 330	+ 360	+ 390	+ 420
860	450	490	520	550	580	610	640	670	700	730
870	760	800	830	860	890	920	950	980	1010	1040
880	1070	1100	1130	1160	1190	1220	1260	1290	1320	1350
890	1380	1410	1440	1470	1500	1530	1560	1590	1620	1650
900	+1680	+1710	+1740	+1770	+1800	+1830	+1860	+1890	+1920	+1950
910	1980	2010	2040	2070	2100	2130	2160	2190	2210	2240
920	2270	2300	2330	2360	2390	2420	2450	2480	2510	2540

TABLE 3b (cont.)

mb	0	1	2	3	4	5	6	7	8	9
					$z = 2$ km					
720	−2590	−2550	−2520	−2480	−2440	−2410	−2370	−2340	−2300	−2270
730	2230	2190	2160	2120	2090	2050	2020	1980	1950	1910
740	1880	1840	1810	1770	1740	1700	1670	1630	1600	1560
750	−1530	−1490	−1460	−1420	−1390	−1350	−1320	−1280	−1250	−1210
760	1180	1140	1110	1080	1040	1010	970	940	900	870
770	840	800	770	730	700	670	630	600	560	530
780	500	460	430	400	360	330	290	260	230	190
790	160	130	90	60	30	0	+ 40	+ 70	+ 100	+ 140
800	+ 170	+ 200	+ 240	+ 270	+ 300	+ 330	+ 370	+ 400	+ 430	+ 470
810	500	530	560	600	630	660	690	730	760	790
820	820	860	890	920	950	990	1020	1050	1080	1110
830	1150	1180	1210	1240	1280	1310	1340	1370	1400	1430
840	1470	1500	1530	1560	1590	1620	1660	1690	1720	1750
850	+1780	+1810	+1840	+1880	+1910	+1940	+1970	+2000	+2030	+2060
860	2100	2130	2160	2190	2220	2250	2280	2310	2340	2370
870	2410	2440	2470	2500	2530	2560	2590	2620	2650	2680
					$z = 2.5$ km					
670	−2800	−2760	−2720	−2690	−2650	−2610	−2570	−2530	−2500	−2460
680	2420	2380	2350	2310	2270	2230	2200	2160	2120	2080
690	2050	2010	1970	1930	1900	1860	1820	1780	1750	1710
700	−1680	−1640	−1600	−1570	−1530	−1490	−1460	−1420	−1380	−1350
710	1310	1270	1240	1200	1160	1130	1090	1060	1020	980
720	950	910	880	840	800	770	730	700	660	630
730	590	550	520	480	450	410	380	340	310	280
740	240	200	170	130	100	60	30	+ 10	+ 40	+ 80
750	+ 110	+ 150	+ 180	+ 220	+ 250	+ 290	+ 320	+ 360	+ 390	+ 430
760	460	490	530	560	600	630	670	700	730	770
770	800	840	870	900	940	970	1010	1040	1070	1110
780	1140	1180	1210	1240	1280	1310	1340	1380	1410	1440
790	1480	1510	1540	1580	1610	1640	1680	1710	1740	1780
800	+1810	+1840	+1880	+1910	+1940	+1970	+2010	+2040	+2070	+2110
810	2140	2170	2200	2240	2270	2300	2330	2370	2400	2430
820	2460	2500	2530	2560	2590	2630	2660	2690	2720	2750
					$z = 3$ km					
630	−2720	−2680	−2640	−2600	−2560	−2520	−2480	−2440	−2410	−2370
640	2330	2290	2250	2210	2170	2130	2090	2050	2010	1970
650	−1930	−1890	−1850	−1820	−1780	−1740	−1700	−1660	−1620	−1580
660	1540	1500	1470	1430	1390	1350	1310	1270	1240	1200
670	1160	1120	1080	1050	1010	970	930	890	860	820
680	780	740	700	670	630	590	560	520	480	440
690	410	370	330	290	260	220	180	150	110	70
700	− 40	+ 0	+ 40	+ 70	+ 110	+ 150	+ 180	+ 220	+ 260	+ 290
710	+ 330	370	400	440	480	510	550	580	620	660
720	690	730	760	800	840	870	910	940	980	1010
730	1050	1090	1120	1160	1190	1230	1260	1300	1330	1370
740	1400	1440	1470	1510	1540	1580	1610	1650	1680	1720
750	+1750	+1790	+1820	+1860	+1890	+1930	+1970	+2000	+2030	+2070
760	2100	2140	2170	2200	2240	2270	2310	2340	2380	2410
770	2440	2480	2510	2550	2580	2610	2650	2680	2720	2750

mb	0	1	2	3	4	5	6	7	8	9
					z = 4 km					
550	−2830	−2790	−2740	−2700	−2650	−2610	−2560	−2520	−2480	−2430
560	2390	2340	2300	2260	2210	2170	2120	2080	2040	1990
570	1950	1910	1860	1820	1780	1730	1690	1650	1600	1560
580	1520	1470	1430	1390	1350	1300	1260	1220	1180	1130
590	1090	1050	1010	960	920	880	840	800	750	710
600	− 670	− 630	− 590	− 550	− 500	− 460	− 420	− 380	− 340	− 300
610	260	220	170	130	90	50	10	+ 30	+ 70	+ 110
620	+ 150	+ 190	+ 230	+ 270	+ 310	+ 350	+ 390	430	470	510
630	550	590	630	670	710	750	790	830	870	910
640	950	990	1030	1070	1110	1150	1190	1230	1270	1310
650	+1350	+1390	+1430	+1460	+1500	+1540	+1580	+1620	+1660	+1700
660	1740	1770	1810	1850	1890	1930	1970	2000	2040	2080
670	2120	2160	2200	2230	2270	2310	2350	2390	2420	2460
					z = 5 km					
480	−2860	−2810	−2760	−2710	−2660	−2610	−2560	−2510	−2460	−2410
490	2360	2320	2270	2220	2170	2120	2070	2020	1970	1930
500	−1880	−1830	−1780	−1730	−1680	−1640	−1590	−1540	−1490	−1440
510	1400	1350	1300	1250	1210	1160	1110	1070	1020	970
520	920	880	830	780	740	690	650	600	550	510
530	460	410	470	320	280	230	180	140	90	50
540	0	+ 40	+ 90	+ 130	+ 180	+ 220	+ 270	+ 310	+ 360	+ 400
550	+ 450	+ 490	+ 540	+ 580	+ 630	+ 670	+ 720	+ 760	+ 800	+ 850
560	890	940	980	1020	1070	1110	1160	1200	1240	1290
570	1330	1370	1420	1460	1500	1550	1590	1630	1680	1720
580	1760	1810	1850	1890	1930	1980	2020	2060	2100	2150
590	2190	2230	2270	2320	2360	2400	2440	2480	2530	2570
					z = 6 km					
420	−2740	−2690	−2630	−2580	−2520	−2470	−2410	−2360	−2300	−2250
430	2190	2140	2080	2030	1970	1920	1870	1810	1760	1700
440	1650	1600	1540	1490	1440	1380	1330	1280	1220	1170
450	−1120	−1070	−1010	− 960	− 910	− 860	− 800	− 750	− 700	− 650
460	600	540	490	440	390	340	290	240	190	130
470	80	30	+ 20	+ 70	+ 120	+ 170	+ 220	+ 270	+ 320	+ 370
480	+ 420	+ 470	520	570	620	670	720	770	820	870
490	920	960	1010	1060	1110	1160	1210	1260	1310	1350
500	+1400	+1450	+1500	+1550	+1600	+1640	+1690	+1740	+1790	+1840
510	1880	1930	1980	2030	2070	2120	2170	2210	2260	2310
520	2360	2400	2450	2500	2540	2590	2630	2680	2730	2770
					z = 7 km					
360	−3020	−2950	−2890	−2830	−2760	−2700	−2640	−2580	−2510	−2450
370	2390	2330	2270	2210	2150	2080	2020	1960	1900	1840
380	1780	1720	1660	1600	1540	1480	1420	1360	1300	1240
390	1180	1120	1070	1010	950	890	830	770	710	660
400	− 600	− 540	− 480	− 420	− 370	− 310	− 250	− 200	− 140	− 80
410	20	+ 30	+ 90	+ 140	+ 200	+ 260	+ 310	+ 370	+ 430	+ 480
420	+ 540	590	650	700	760	810	870	920	980	1030
430	1090	1140	1200	1250	1310	1360	1410	1470	1520	1580
440	1630	1680	1740	1790	1840	1900	1950	2000	2060	2110
450	+2160	+2210	+2270	+2320	+2370	+2420	+2480	+2530	+2580	+2630
					z = 8 km					
310	−3080	−3010	−2940	−2870	−2800	−2730	−2660	−2590	−2520	−2450
320	2380	2310	2240	2170	2100	2040	1970	1900	1830	1760
330	1700	1630	1560	1490	1430	1360	1290	1220	1160	1090
340	1030	960	890	830	760	700	630	570	500	440
350	− 370	− 310	− 240	− 180	− 120	− 50	+ 10	+ 70	+ 140	+ 200
360	+ 260	+ 330	+ 390	+ 450	+ 520	+ 580	640	700	770	830
370	890	950	1010	1070	1130	1200	1260	1320	1380	1440
380	1500	1560	1620	1680	1740	1800	1860	1920	1980	2040
390	2100	2160	2210	2270	2330	2390	2450	2510	2570	2620

TABLE 3b (cont.)

mb	0	1	2	3	4	5	6	7	8	9
					$z = 9$ km					
270	−2810	−2730	−2650	−2570	−2500	−2420	−2340	−2260	−2180	−2110
280	2030	1950	1870	1800	1720	1640	1570	1490	1420	1340
290	1270	1190	1120	1040	970	890	820	740	670	600
300	− 520	− 450	− 380	− 310	− 230	− 160	− 90	− 20	+ 50	+ 120
310	+ 200	+ 270	+ 340	+ 410	+ 480	+ 550	+ 620	+ 690	760	830
320	900	970	1040	1110	1180	1240	1310	1380	1450	1520
330	1580	1650	1720	1790	1850	1920	1990	2060	2120	2190
340	2250	2320	2380	2450	2520	2580	2650	2710	2780	2840
					$z = 10$ km					
230	−2930	−2840	−2750	−2660	−2570	−2480	−2390	−2300	−2210	−2130
240	2040	1950	1860	1780	1690	1600	1520	1430	1350	1260
250	−1180	−1090	−1010	− 920	− 840	− 760	− 670	− 590	− 510	− 420
260	340	260	180	100	20	+ 60	+ 150	+ 230	+ 310	+ 390
270	+ 470	+ 550	+ 630	+ 700	+ 780	860	940	1020	1100	1170
280	1250	1330	1400	1480	1560	1630	1710	1790	1860	1940
290	2010	2090	2160	2240	2310	2390	2460	2530	2610	2680
					$z = 11$ km					
200	−2580	−2470	−2370	−2260	−2160	−2060	−1960	−1860	−1750	−1650
210	1550	1460	1360	1260	1160	1060	960	870	770	680
220	580	490	390	300	200	110	20	+ 70	+ 170	+ 260
230	+ 350	+ 440	+ 530	+ 620	+ 710	+ 800	+ 890	980	1070	1150
240	1240	1330	1420	1500	1590	1680	1760	1850	1930	2020
250	+2100	+2190	+2270	+2360	+2440	+2520	+2610	+2690	+2770	+2860
					$z = 12$ km					
170	−2700	−2570	−2450	−2330	−2210	−2090	−1970	−1850	−1730	−1620
180	1500	1380	1270	1150	1040	930	810	700	590	480
190	370	260	150	40	+ 70	+ 170	+ 280	+ 390	+ 490	+ 600
200	+ 700	+ 810	+ 910	+1010	+1120	+1220	+1320	+1420	+1530	+1630
210	1730	1820	1920	2020	2120	2220	2320	2410	2510	2600
					$z = 13$ km					
140	−3480	−3330	−3180	−3040	−2890	−2750	−2600	−2460	−2320	−2180
150	−2040	−1900	−1760	−1620	−1490	−1350	−1220	−1080	− 950	− 820
160	690	560	430	300	170	40	+ 80	+ 210	+ 330	+ 460
170	+ 580	+ 710	+ 830	+ 950	+1070	+1190	1310	1430	1550	1660
180	1780	1900	2010	2130	2240	2350	2470	2580	2690	2800
					$z = 14$ km					
120	−3430	−3260	−3080	−2910	−2740	−2570	−2410	−2240	−2080	−1910
130	1750	1590	1430	1280	1120	960	810	650	500	350
140	200	50	+ 90	+ 240	+ 390	+ 530	+ 680	+ 820	+ 960	+1100
150	+1240	+1380	+1520	+1660	+1890	+1930	+2060	+2200	+2330	+2460
					$z = 15$ km					
100	−3960	−3760	−3550	−3350	−3140	−2940	−2740	−2550	−2350	−2160
110	1970	1780	1590	1410	1220	1040	860	680	500	320
120	150	+ 20	+ 200	+ 370	+ 540	+ 710	+ 870	+1040	+1200	+1370
130	+1530	1690	1850	2000	2160	2320	2470	2630	2780	2930

TABLE 3b (cont.)

mb	0	1	2	3	4	5	6	7	8	9
					z = 16 km					
90	−2890	−2660	−2430	−2200	−1980	−1760	−1540	−1320	−1110	− 890
100	− 680	− 480	− 270	− 70	+ 140	+ 340	+ 530	+ 730	+ 930	+1120
110	+1310	+1500	+1690	+1870	2060	2240	2420	2600	2780	2960
					z = 17 km					
70	−4870	−4570	−4280	−3990	−3710	−3430	−3150	−2880	−2610	−2340
80	2080	1810	1560	1310	1050	810	560	320	80	+ 160
90	+ 390	+ 620	+ 850	+1080	+1300	+1520	+1740	+1960	+2170	2390
					z = 18 km					
60	−4820	−4470	−4130	−3800	−3470	−3140	−2820	−2510	−2200	−1890
70	1590	1290	1000	710	430	150	+ 130	+ 400	+ 670	+ 940
80	+1200	+1470	+1720	+1970	+2230	+2470	2720	2960	3200	3440
					z = 19 km					
50	−5360	−4940	−4530	−4130	−3740	−3360	−2980	−2610	−2250	−1890
60	1540	1190	850	520	190	+ 140	+ 460	+ 770	+1080	+1390
70	+1690	+1990	+2280	+2570	+2850	3130	3410	3680	3950	4220
					z = 20 km					
40	−6750	−6230	−5720	−5230	−4750	−4280	−3820	−3370	−2930	−2500
50	2070	1660	1250	850	460	80	+ 300	+ 670	+1030	+1390
60	+1740	+2090	+2430	+2760	+3090	+3420	3740	4050	4360	4670

TABLE 3c

Conversion from p in Millibars to D in Meters at Standard Levels

$_{z\text{ in km}}D_{\text{m}}$ ($_{z\text{ in km}}p_{\text{mb}}$)

mb	0	1	2	3	4	5	6	7	8	9
					z = 0.5 km					
870	−766	−757	−747	−738	−729	−719	−710	−701	−691	−682
880	673	663	654	645	636	626	617	608	598	589
890	580	571	561	552	543	534	525	515	506	497
900	−488	−479	−470	−461	−451	−442	−433	−424	−415	−406
910	397	388	379	370	360	351	342	333	324	315
920	306	297	288	279	270	261	252	244	235	226
930	217	208	199	190	181	172	163	154	145	137
940	128	119	110	101	93	84	75	66	57	49
950	− 40	− 31	− 22	− 14	− 5	+ 4	+ 12	+ 21	+ 30	+ 39
960	+ 47	+ 56	+ 65	+ 73	+ 82	90	99	108	116	125
970	134	142	151	159	168	177	185	194	202	211
980	219	228	237	245	254	262	271	279	288	296
990	305	313	321	330	338	347	355	364	372	380
1000	+389	+397	+406	+414	+422	+431	+439	+448	+456	+464
1010	473	481	489	498	506	514	522	531	539	547
1020	556	564	572	580	589	597	605	613	622	630
1030	638	646	654	663	671	679	687	695	703	712
1040	720	728	736	744	752	760	769	777	785	793

TABLE 3c (cont.)

mb	0	1	2	3	4	5	6	7	8	9
					z = 1 km					
820	−749	−739	−729	−719	−709	−699	−690	−680	−670	−660
830	650	641	631	621	611	601	592	582	572	563
840	553	543	534	524	514	504	495	485	476	466
850	−456	−447	−437	−428	−418	−409	−399	−390	−380	−371
860	361	352	342	333	323	314	304	295	285	276
870	266	257	247	238	229	219	210	201	191	182
880	173	163	154	145	136	126	117	108	98	89
890	80	71	61	52	43	34	25	15	6	+ 3
900	+ 12	+ 21	+ 30	+ 39	+ 49	+ 58	+ 67	+ 76	+ 85	+ 94
910	103	112	121	130	140	149	158	167	176	185
920	194	203	212	221	230	239	248	256	265	274
930	283	292	301	310	319	328	337	346	355	363
940	372	381	390	399	407	416	425	434	443	451
950	+460	+469	+478	+486	+495	+504	+512	+521	+530	+539
960	547	556	565	573	582	590	599	608	616	625
970	634	642	651	659	668	677	685	694	702	711
980	719	728	737	745	754	762	771	779	788	796
					z = 1.5 km					
770	−755	−745	−734	−724	−714	−704	−693	−683	−673	−662
780	652	642	631	621	611	601	590	580	570	560
790	550	539	529	519	509	499	489	478	468	458
800	−448	−438	−428	−418	−408	−398	−388	−378	−368	−358
810	348	338	328	318	308	298	288	279	269	259
820	249	239	229	219	209	199	190	180	170	160
830	150	141	131	121	111	101	91	82	72	63
840	53	43	34	24	14	4	+ 5	+ 15	+ 24	+ 34
850	+ 44	+ 53	+ 63	+ 72	+ 82	+ 91	+101	+110	+120	+129
860	139	148	158	167	177	186	196	205	215	224
870	234	243	253	262	271	281	290	299	309	318
880	327	337	346	355	364	374	383	392	402	411
890	420	429	439	448	457	466	475	485	494	503
900	+512	+521	+530	+539	+549	+558	+567	+576	+585	+594
910	603	612	621	630	640	649	658	667	676	685
920	694	703	712	721	730	739	748	756	765	774
					z = 2 km					
720	−789	−778	−767	−756	−745	−734	−723	−712	−702	−691
730	680	669	658	647	637	626	615	604	593	583
740	572	561	551	540	529	519	508	497	486	476
750	−465	−455	−444	−433	−423	−412	−402	−391	−380	−370
760	359	349	338	328	318	307	297	286	276	266
770	255	245	234	224	214	204	193	183	173	162
780	152	142	131	121	111	101	90	80	70	60
790	50	39	29	19	9	+ 1	+ 11	+ 22	+ 32	+ 42
800	+ 52	+ 62	+ 72	+ 82	+ 92	+102	+112	+122	+132	+142
810	152	162	172	182	192	202	212	221	231	241
820	251	261	271	281	291	301	310	320	330	340
830	350	359	369	379	389	399	408	418	428	437
840	447	457	466	476	486	496	505	515	524	534
850	+544	+553	+563	+572	+582	+591	+601	+610	+620	+629
860	639	648	658	667	677	686	696	705	715	724
870	734	743	753	762	771	781	790	799	809	818

Table 3c (cont.)

mb	0	1	2	3	4	5	6	7	8	9
					$z = 2.5$ km					
670	−854	−842	−830	−819	−807	−796	−784	−772	−761	−749
680	738	726	715	703	692	681	669	658	646	635
690	624	612	601	590	578	567	556	544	533	522
700	−511	−499	−488	−477	−466	−455	−444	−433	−422	−411
710	399	388	377	366	355	344	333	322	311	300
720	289	278	267	256	245	234	223	212	201	191
730	180	169	158	147	137	126	115	104	93	83
740	72	61	51	40	29	19	8	+ 3	+ 14	+ 24
750	+ 35	+ 45	+ 56	+ 67	+ 77	+ 88	+ 98	+109	+120	+130
760	141	151	162	172	182	193	203	214	224	234
770	245	255	266	276	286	296	307	317	327	338
780	348	358	369	379	389	399	410	420	430	440
790	450	461	471	481	491	501	511	522	532	542
800	+552	+562	+572	+582	+592	+602	+612	+622	+632	+642
810	652	662	672	682	692	702	712	721	731	741
820	751	761	771	781	791	801	810	820	830	840
					$z = 3$ km					
630	−830	−818	−806	−794	−782	−769	−757	−745	−733	−721
640	709	697	685	673	661	649	637	625	613	601
650	−589	−577	−565	−553	−541	−530	−518	−506	−494	−482
660	471	459	447	435	424	412	400	389	377	365
670	354	342	330	319	307	296	284	272	261	249
680	238	226	215	203	192	181	169	158	146	135
690	124	112	101	90	78	67	56	44	33	22
700	− 11	+ 1	+ 12	+ 23	+ 34	+ 45	+ 56	+ 67	+ 78	+ 89
710	+101	112	123	134	145	156	167	178	189	200
720	211	222	233	244	255	266	277	288	298	309
730	320	331	342	353	363	374	385	396	407	417
740	428	439	449	460	471	481	492	503	514	524
750	+535	+545	+556	+567	+577	+588	+598	+609	+620	+630
760	641	651	662	672	682	693	703	714	724	734
770	745	755	766	776	786	796	807	817	827	838
					$z = 4$ km					
550	−863	−850	−836	−822	−809	−795	−782	−768	−755	−741
560	728	714	701	687	674	660	647	634	620	607
570	594	580	567	554	541	528	515	501	488	475
580	462	449	436	423	410	397	384	371	358	345
590	332	319	307	294	281	268	255	243	230	217
600	−204	−192	−179	−166	−154	−141	−128	−116	−103	− 91
610	78	66	53	41	28	16	3	+ 9	+ 22	+ 34
620	+ 46	+ 59	+ 71	+ 84	+ 96	+108	+120	133	145	157
630	170	182	194	206	218	231	243	255	267	279
640	291	303	315	327	339	351	363	375	387	399
650	+411	+423	+435	+447	+459	+470	+482	+494	+506	+518
660	529	541	553	565	576	588	600	611	623	635
670	646	658	670	681	693	704	716	728	739	751
					$z = 5$ km					
480	−872	−856	−841	−826	−811	−796	−781	−766	−750	−735
490	720	705	690	676	661	646	631	616	601	587
500	−572	−557	−543	−528	−513	−499	−484	−470	−455	−440
510	426	411	397	383	368	354	339	325	311	296
520	282	268	253	239	225	211	197	182	168	154
530	140	126	112	98	84	70	56	42	20	14
540	1	+ 13	+ 27	+ 41	+ 55	+ 68	+82	+ 96	+109	+123
550	+137	+150	+164	+178	+191	+205	+218	+232	+245	+259
560	272	286	299	313	326	340	353	366	380	393
570	406	420	433	446	459	472	485	499	512	525
580	538	551	564	577	590	603	616	629	642	655
590	668	681	693	706	719	732	745	757	770	783

TABLE 3c (cont.)

mb	0	1	2	3	4	5	6	7	8	9
					z = 6 km					
420	−836	−819	−802	−785	−768	−751	−735	−718	−701	−684
430	668	651	635	618	601	585	568	552	535	519
440	502	486	470	454	437	421	405	389	373	357
450	−341	−325	−309	−293	−277	−261	−245	−229	−213	−197
460	181	166	150	134	119	103	87	72	56	41
470	25	10	+ 6	+ 21	+ 36	+ 52	+ 67	+ 83	+ 98	+113
480	+128	+144	159	174	189	204	219	234	250	265
490	280	295	310	324	339	354	369	384	399	413
500	+428	+443	+457	+472	+487	+501	+516	+530	+545	+560
510	574	589	603	617	632	646	661	675	689	704
520	718	732	747	761	775	789	803	818	832	846
					z = 7 km					
360	−919	−900	−881	−862	−843	−824	−805	−786	−767	−748
370	729	710	691	673	654	635	617	598	580	561
380	543	524	506	488	470	451	433	415	397	379
390	361	343	325	307	289	271	253	235	218	200
400	−182	−165	−147	−129	−112	− 94	− 77	− 59	− 42	− 25
410	7	+ 10	+ 27	+ 45	+ 62	+ 79	+ 96	+113	+130	+147
420	+164	181	198	215	232	249	265	282	299	316
430	332	349	365	382	399	415	432	448	465	481
440	498	514	530	546	563	579	595	611	627	643
450	+659	+675	+691	+707	+723	+739	+755	+771	+787	+803
					z = 8 km					
310	−940	−918	−897	−875	−854	−832	−811	−790	−768	−747
320	726	705	684	663	642	621	600	579	558	537
330	517	496	476	455	435	414	394	373	353	333
340	313	293	273	253	233	213	193	173	153	133
350	−114	− 94	− 74	− 55	− 35	− 16	+ 4	+ 23	+ 42	+ 62
360	+ 81	+100	+119	+138	+157	+176	195	214	233	252
370	271	290	309	327	346	365	383	402	420	439
380	457	476	494	512	530	549	567	585	603	621
390	639	657	675	693	711	729	747	765	782	800
					z = 9 km					
270	−858	−833	−809	−785	−761	−737	−713	−689	−666	−642
280	618	595	571	548	525	501	478	455	432	409
290	386	363	340	318	295	272	250	227	205	182
300	−160	−138	−115	− 93	− 71	− 49	− 27	− 5	+ 17	+ 38
310	+ 60	+ 82	+103	+125	+146	+168	+189	+210	232	253
320	274	295	316	337	358	379	400	421	442	463
330	483	504	524	545	565	586	606	627	647	667
340	687	707	727	747	767	787	807	827	847	867
					z = 10 km					
230	−893	−866	−838	−811	−783	−756	−729	−702	−675	−648
240	621	595	568	542	516	489	463	437	411	385
250	−359	−333	−307	−282	−256	−231	−205	−180	−155	−130
260	104	79	55	30	5	+ 20	+ 45	+ 69	+ 94	+118
270	+142	+167	+191	+215	+239	263	287	311	334	358
280	382	405	429	452	475	499	522	545	568	591
290	614	637	660	682	705	728	750	773	795	818
					z = 11 km					
200	−785	−753	−721	−690	−658	−627	−596	−565	−535	−504
210	474	444	414	384	354	324	295	265	235	206
220	177	148	119	91	62	34	5	+ 23	+ 51	+ 79
230	+107	+134	+162	+189	+217	+244	+271	298	325	352
240	379	405	432	458	484	511	537	563	589	615
250	+641	+667	+693	+718	+744	+769	+795	+820	+845	+870

TABLE 3c (cont.)

mb	0	1	2	3	4	5	6	7	8	9
					z = 12 km					
170	−822	−785	−748	−711	−674	−637	−601	−565	−529	−493
180	458	422	387	352	317	282	248	214	180	146
190	112	79	45	12	+ 21	+ 54	+ 86	+119	+151	+183
200	+215	+247	+279	+310	+342	+373	+404	+435	+465	+496
210	526	556	586	616	646	676	705	735	765	794
					z = 13 km					
140	−1061	−1016	− 971	− 926	− 882	− 838	− 794	− 750	− 707	− 664
150	621	579	537	495	454	413	372	331	290	250
160	209	170	130	91	52	13	+ 25	+ 64	+ 102	+ 140
170	+ 178	+ 215	+ 252	+ 289	+ 326	+ 363	399	435	471	507
180	542	578	613	648	683	718	752	786	820	854
					z = 14 km					
120	−1045	− 992	− 940	− 888	− 836	− 785	− 734	− 683	− 633	− 584
130	535	486	437	389	341	294	247	200	153	107
140	61	16	+ 29	+ 74	+ 118	+ 162	+ 206	+ 250	+ 293	+ 336
150	+ 379	+ 421	463	505	546	587	628	669	710	750
					z = 15 km					
100	−1209	−1146	−1083	−1021	− 959	− 898	− 837	− 777	− 718	− 659
110	600	543	486	429	373	318	262	207	153	99
120	45	+ 8	+ 60	+ 112	+ 164	+ 215	+ 266	+ 317	+ 367	+ 416
130	+ 465	514	563	611	659	706	753	800	847	893
					z = 16 km					
90	− 881	− 810	− 741	− 672	− 603	− 536	− 469	− 403	− 338	− 273
100	209	146	83	21	+ 41	+ 102	+ 163	+ 223	+ 282	+ 341
110	+ 400	+ 457	+ 514	+ 571	627	682	738	793	847	901
					z = 17 km					
70	−1485	−1394	−1305	−1217	−1130	−1044	− 960	− 876	− 794	− 714
80	634	554	476	399	322	247	172	98	25	+ 48
90	+ 119	+ 190	+ 259	+ 328	+ 397	+ 464	+ 531	+ 597	+ 662	727
					z = 18 km					
60	−1469	−1363	−1259	−1157	−1057	− 958	− 860	− 764	− 670	− 577
70	485	394	305	217	130	44	+ 40	+ 124	+ 206	+ 286
80	+ 366	+ 446	+ 524	+ 601	+ 678	+ 753	828	902	975	1048
					z = 19 km					
50	−1632	−1506	−1382	−1260	−1141	−1024	− 909	− 796	− 685	− 576
60	469	363	259	157	57	+ 42	+ 140	+ 236	+ 330	+ 423
70	+ 515	+ 606	+ 695	+ 783	+ 870	956	1040	1124	1206	1286
					z = 20 km					
40	−2056	−1899	−1745	−1595	−1448	−1305	−1164	−1027	− 893	− 761
50	632	506	382	260	141	24	+ 91	+ 204	+ 315	+ 424
60	+ 531	+ 637	+ 741	+ 843	+ 943	+1042	1140	1236	1330	1423

TABLE 4

Relation between S and T (in degrees centigrate) for Various Pressure Altitudes in Feet

z_p \ S	−0.20	−0.19	−0.18	−0.17	−0.16	−0.15	−0.14	−0.13	−0.12	−0.11
− 3000	−37.8	−34.9	−32.0	−29.0	−26.1	−23.1	−20.2	−17.3	−14.3	−11.4
2000	39.4	36.5	33.6	30.7	27.7	24.8	21.9	19.0	16.1	13.1
1000	41.0	38.1	35.2	32.3	29.4	26.5	23.6	20.7	17.8	14.9
+ 0	−42.6	−39.7	−36.8	−34.0	−31.1	−28.2	−25.3	−22.4	−19.6	−16.7
1000	44.2	41.3	38.5	35.6	32.7	29.9	27.0	24.2	21.3	18.4
2000	45.8	42.9	40.1	37.2	34.4	31.6	28.7	25.9	23.0	20.2
3000	47.3	44.5	41.7	38.9	36.1	33.2	30.4	27.6	24.8	22.0
4000	48.9	46.1	43.3	40.5	37.7	34.9	32.1	29.3	26.5	23.7
+ 5000	−50.5	−47.7	−45.0	−42.2	−39.4	−36.6	−33.8	−31.1	−28.3	−25.5
6000	52.1	49.3	46.6	43.8	41.1	38.3	35.5	32.8	30.0	27.3
7000	53.7	50.9	48.2	45.5	42.7	40.0	37.2	34.5	31.8	29.0
8000	55.3	52.6	49.8	47.1	44.4	41.7	38.9	36.2	33.5	30.8
9000	56.9	54.2	51.5	48.7	46.0	43.3	40.6	37.9	35.2	32.5
+10000	−58.4	−55.8	−53.1	−50.4	−47.7	−45.0	−42.4	−39.7	−37.0	−34.3
11000	60.0	57.4	54.7	52.0	49.4	46.7	44.1	41.4	38.7	36.1
12000	61.6	59.0	56.3	53.7	51.0	48.4	45.8	43.1	40.5	37.8
13000	63.2	60.6	58.0	55.3	52.7	50.1	47.5	44.8	42.2	39.6
14000	64.8	62.2	59.6	57.0	54.4	51.8	49.2	46.6	44.0	41.4
+15000	−66.4	−63.8	−61.2	−58.6	−56.0	−53.5	−50.9	−48.3	−45.7	−43.1
16000	68.0	65.4	62.8	60.3	57.7	55.1	52.6	50.0	47.4	44.9
17000	69.5	67.0	64.5	61.9	59.4	56.8	54.3	51.7	49.2	46.7
18000	71.1	68.6	66.1	63.5	61.0	58.5	56.0	53.5	50.9	48.4
19000	72.7	70.2	67.7	65.2	62.7	60.2	57.7	55.2	52.7	50.2
+20000	−74.3	−71.8	−69.3	−66.8	−64.4	−61.9	−59.4	−56.9	−54.4	−51.9
21000	75.9	73.4	71.0	68.5	66.0	63.6	61.1	58.6	56.2	53.7
22000	77.5	75.0	72.6	70.1	67.7	65.2	62.8	60.4	57.9	55.5
23000	79.1	76.6	74.2	71.8	69.3	66.9	64.5	62.1	59.7	57.2
24000	80.7	78.2	75.8	73.4	71.0	68.6	66.2	63.8	61.4	59.0
+25000	−82.2	−79.8	−77.5	−75.1	−72.7	−70.3	−67.9	−65.5	−63.1	−60.8
26000	83.8	81.4	79.1	76.7	74.3	72.0	69.6	67.2	64.9	62.5
27000	85.4	83.0	80.7	78.3	76.0	73.7	71.3	69.0	66.6	64.3
28000	87.0	84.7	82.3	80.0	77.7	75.3	73.0	70.7	68.4	66.0
29000	88.6	86.3	84.0	81.6	79.3	77.0	74.7	72.4	70.1	67.8
+30000	−90.1	−87.9	−85.6	−83.3	−81.0	−78.7	−76.4	−74.1	−71.9	−69.6
31000	91.7	89.5	87.2	84.9	82.7	80.4	78.1	75.9	73.6	71.3
32000	93.3	91.1	88.8	86.6	84.3	82.1	79.8	77.6	75.3	73.1
33000	94.9	92.7	90.5	88.2	86.0	83.8	81.5	79.3	77.1	74.9
34000	96.5	94.3	92.1	89.9	87.6	85.4	83.2	81.0	78.8	76.6
+35000	−98.1	−95.9	−93.7	−91.5	−89.3	−87.1	−84.9	−82.8	−80.6	−78.4
≥35332	−98.6	−96.4	−94.2	−92.1	−89.9	−87.7	−85.5	−83.3	−81.2	−79.0

Δz_p	Interpolations									
100	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
200	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
300	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
400	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7
500	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9
600	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1
700	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2
800	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4
900	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.6

TABLE 4 (cont.)

z_p \ S	−0.10	−0.09	−0.08	−0.07	−0.06	−0.05	−0.04	−0.03	−0.02	−0.01
− 3000	− 8.4	− 5.5	− 2.6	+ 0.4	+ 3.3	+ 6.2	+ 9.2	+12.1	+15.1	+18.0
2000	10.2	7.3	4.4	− 1.5	1.4	4.4	7.3	10.2	13.1	16.0
1000	12.0	9.1	6.2	3.3	− 0.4	2.5	5.4	8.3	11.2	14.1
+ 0	−13.8	−10.9	− 8.0	− 5.2	− 2.3	+ 0.6	+ 3.5	+ 6.4	+ 9.2	+12.1
1000	15.6	12.7	9.9	7.0	4.1	− 1.3	1.6	4.4	7.3	10.1
2000	17.4	14.5	11.7	8.8	6.0	3.2	− 0.3	2.5	5.3	8.2
3000	19.1	16.3	13.5	10.7	7.9	5.0	2.2	0.6	3.4	6.2
4000	20.9	18.1	15.3	12.5	9.7	6.9	4.1	− 1.3	1.5	4.3
+ 5000	−22.7	−19.9	−17.1	−14.4	−11.6	− 8.8	− 6.0	− 3.2	− 0.5	+ 2.3
6000	24.5	21.7	19.0	16.2	13.4	10.7	7.9	5.2	2.4	0.3
7000	26.3	23.5	20.8	18.1	15.3	12.6	9.8	7.1	4.3	− 1.6
8000	28.1	25.3	22.6	19.9	17.2	14.5	11.7	9.0	6.3	3.6
9000	29.8	27.1	24.4	21.7	19.0	16.3	13.6	10.9	8.2	5.5
+10000	−31.6	−28.9	−26.3	−23.6	−20.9	−18.2	−15.5	−12.8	−10.2	− 7.5
11000	33.4	30.7	28.1	25.4	22.8	20.1	17.4	14.8	12.1	9.5
12000	35.2	32.5	29.9	27.3	24.6	22.0	19.3	16.7	14.1	11.4
13000	37.0	34.4	31.7	29.1	26.5	23.9	21.2	18.6	16.0	13.4
14000	38.8	36.2	33.6	31.0	28.3	25.7	23.1	20.5	17.9	15.3
+15000	−40.5	−38.0	−35.4	−32.8	−30.2	−27.6	−25.0	−22.5	−19.9	−17.3
16000	42.3	39.8	37.2	34.6	32.1	29.5	26.9	24.4	21.8	19.3
17000	44.1	41.6	39.0	36.5	33.9	31.4	28.8	26.3	23.8	21.2
18000	45.9	43.4	40.8	38.3	35.8	33.3	30.7	28.2	25.7	23.2
19000	47.7	45.2	42.7	40.2	37.7	35.2	32.6	30.1	27.6	25.1
+20000	−49.5	−47.0	−44.5	−42.0	−39.5	−37.0	−34.6	−32.1	−29.6	−27.1
21000	51.2	48.8	46.3	43.8	41.4	38.9	36.5	34.0	31.5	29.1
22000	53.0	50.6	48.1	45.7	43.2	40.8	38.4	35.9	33.5	31.0
23000	54.8	52.4	50.0	47.5	45.1	42.7	40.3	37.8	35.4	33.0
24000	56.6	54.2	51.8	49.4	47.0	44.6	42.2	39.8	37.4	34.9
+25000	−58.4	−56.0	−53.6	−51.2	−48.8	−46.5	−44.1	−41.7	−39.3	−36.9
26000	60.2	57.8	55.4	53.1	50.7	48.3	46.0	43.6	41.2	38.9
27000	61.9	59.6	57.2	54.9	52.6	50.2	47.9	45.5	43.2	40.8
28000	63.7	61.4	59.1	56.7	54.4	52.1	49.8	47.4	45.1	42.8
29000	65.5	63.2	60.9	58.6	56.3	54.0	51.7	49.4	47.1	44.7
+30000	−67.3	−65.0	−62.7	−60.4	−58.1	−55.9	−53.6	−51.3	−49.0	−46.7
31000	69.1	66.8	64.5	62.3	60.0	57.7	55.5	53.2	50.9	48.7
32000	70.9	68.6	66.4	64.1	61.9	59.6	57.4	55.1	52.9	50.6
33000	72.6	70.4	68.2	66.0	63.7	61.5	59.3	57.1	54.8	52.6
34000	74.4	72.2	70.0	67.8	65.6	63.4	61.2	59.0	56.8	54.6
+35000	−76.2	−74.0	−71.8	−69.6	−67.5	−65.3	−63.1	−60.9	−58.7	−56.5
≥35332	−76.8	−74.6	−72.4	−70.3	−68.1	−65.9	−63.7	−61.5	−59.4	−57.2
Δz_p	Interpolations									
100	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
200	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
300	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
400	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8
500	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
600	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2
700	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4
800	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.6
900	1.6	1.6	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.8

TABLE 4 (cont.)

z_p \ S	0.00	+0.01	+0.02	+0.03	+0.04	+0.05	+0.06	+0.07	+0.08	+0.09	+0.10
−3000	+20.9	+23.9	+26.8	+29.8	+32.7	+35.6	+38.6	+41.5	+44.5	+47.4	+50.3
2000	19.0	21.9	24.8	27.7	30.6	33.6	36.5	39.4	42.3	45.2	48.2
1000	17.0	19.9	22.8	25.7	28.6	31.5	34.4	37.3	40.2	43.1	46.0
+0	+15.0	+17.9	+20.8	+23.6	+26.5	+29.4	+32.3	+35.2	+38.0	+40.9	+43.8
1000	13.0	15.9	18.7	21.6	24.5	27.3	30.2	33.0	35.9	38.8	41.6
2000	11.0	13.9	16.7	19.6	22.4	25.2	28.1	30.9	33.8	36.6	39.4
3000	9.0	11.9	14.7	17.5	20.3	23.2	26.0	28.8	31.6	34.4	37.3
4000	7.1	9.9	12.7	15.5	18.3	21.1	23.9	26.7	29.5	32.3	35.1
+5000	+5.1	+7.9	+10.7	+13.4	+16.2	+19.0	+21.8	+24.6	+27.3	+30.1	+32.9
6000	3.1	5.9	8.6	11.4	14.2	16.9	19.7	22.4	25.2	28.0	30.7
7000	1.1	3.9	6.6	9.4	12.1	14.8	17.6	20.3	23.1	25.8	28.5
8000	−0.8	1.9	4.6	7.3	10.0	12.8	15.5	18.2	20.9	23.7	26.4
9000	2.8	−0.1	2.6	5.3	8.0	10.7	13.4	16.1	18.8	21.5	24.2
+10000	−4.8	−2.1	+0.6	+3.2	+5.9	+8.6	+11.3	+14.0	+16.6	+19.3	+22.0
11000	6.8	4.1	−1.5	1.2	3.8	6.5	9.2	11.8	14.5	17.2	19.8
12000	8.8	6.1	3.5	−0.8	1.8	4.4	7.1	9.7	12.4	15.0	17.6
13000	10.7	8.1	5.5	2.9	−0.3	2.4	5.0	7.6	10.2	12.9	15.5
14000	12.7	10.1	7.5	4.9	2.3	0.3	2.9	5.5	8.1	10.7	13.3
+15000	−14.7	−12.1	−9.5	−7.0	−4.4	−1.8	+0.8	+3.4	+5.9	+8.5	+11.1
16000	16.7	14.1	11.6	9.0	6.4	3.9	−1.3	1.2	3.8	6.4	8.9
17000	18.7	16.1	13.6	11.0	8.5	6.0	3.4	−0.9	1.7	4.2	6.7
18000	20.7	18.1	15.6	13.1	10.6	8.0	5.5	3.0	−0.5	2.1	4.6
19000	22.6	20.1	17.6	15.1	12.6	10.1	7.6	5.1	2.6	−0.1	2.4
+20000	−24.6	−22.1	−19.6	−17.2	−14.7	−12.2	−9.7	−7.2	−4.8	−2.2	+0.2
21000	26.6	24.1	21.7	19.2	16.7	14.3	11.8	9.4	6.9	4.4	−2.0
22000	28.6	26.1	23.7	21.2	18.8	16.4	13.9	11.5	9.0	6.6	4.1
23000	30.6	28.1	25.7	23.3	20.9	18.4	16.0	13.6	11.2	8.7	6.3
24000	32.5	30.1	27.7	25.3	22.9	20.5	18.1	15.7	13.3	10.9	8.5
+25000	−34.5	−32.1	−29.8	−27.4	−25.0	−22.6	−20.2	−17.8	−15.5	−13.0	−10.7
26000	36.5	34.1	31.8	29.4	27.0	24.7	22.3	20.0	17.6	15.2	12.9
27000	38.5	36.1	33.8	31.4	29.1	26.8	24.4	22.1	19.7	17.4	15.0
28000	40.5	38.1	35.8	33.5	31.2	28.8	26.5	24.2	21.9	19.5	17.2
29000	42.4	40.1	37.8	35.5	33.2	30.9	28.6	26.3	24.0	21.7	19.4
+30000	−44.4	−42.1	−39.9	−37.6	−35.3	−33.0	−30.7	−28.4	−26.2	−23.8	−21.6
31000	46.4	44.2	41.9	39.6	37.4	35.1	32.8	30.6	28.3	26.0	23.8
32000	48.4	46.2	43.9	41.7	39.4	37.2	34.9	32.7	30.4	28.2	25.9
33000	50.4	48.2	45.9	43.7	41.5	39.2	37.0	34.8	32.6	30.3	28.1
34000	52.4	50.2	47.9	45.7	43.5	41.3	39.1	36.9	34.7	32.5	30.3
+35000	−54.3	−52.2	−50.0	−47.8	−45.6	−43.4	−41.2	−39.0	−36.8	−34.7	−32.5
≥35332	−55.0	−52.8	−50.6	−48.5	−46.3	−44.1	−41.9	−39.7	−37.6	−35.4	−33.2
Δz_p	Interpolations										
100	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
200	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
300	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
400	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9
500	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1
600	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3
700	1.4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5
800	1.6	1.6	1.6	1.6	1.6	1.7	1.7	1.7	1.7	1.7	1.7
900	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	2.0

TABLE 5

Relation between S and T (in Degrees Centigrade) for Various Pressure Altitudes in Meters

z_p \ S	−0.20	−0.19	−0.18	−0.17	−0.16	−0.15	−0.14	−0.13	−0.12	−0.11
− 1000	−37.4	−34.4	−31.5	−28.6	−25.6	−22.7	−19.7	−16.8	−13.8	−10.9
900	37.9	35.0	32.0	29.1	26.2	23.2	20.3	17.3	14.4	11.5
800	38.4	35.5	32.6	29.6	26.7	23.8	20.8	17.9	15.0	12.0
700	39.0	36.0	33.1	30.2	27.2	24.3	21.4	18.5	15.5	12.6
600	39.5	36.6	33.6	30.7	27.8	24.9	22.0	19.0	16.1	13.2
− 500	−40.0	−37.1	−34.2	−31.3	−28.3	−25.4	−22.5	−19.6	−16.7	−13.8
400	40.5	37.6	34.7	31.8	28.9	26.0	23.1	20.2	17.3	14.4
300	41.0	38.1	35.2	32.3	29.4	26.5	23.6	20.7	17.8	14.9
200	41.6	38.7	35.8	32.9	30.0	27.1	24.2	21.3	18.4	15.5
100	42.1	39.2	36.3	33.4	30.5	27.6	24.8	21.9	19.0	16.1
+ 0	−42.6	−39.7	−36.8	−34.0	−31.1	−28.2	−25.3	−22.4	−19.6	−16.7
100	43.1	40.2	37.4	34.5	31.6	28.7	25.9	23.0	20.1	17.3
200	43.6	40.8	37.9	35.0	32.2	29.3	26.4	23.6	20.7	17.8
300	44.2	41.3	38.4	35.6	32.7	29.8	27.0	24,1	21.3	18.4
400	44.7	41.8	39.0	36.1	33.3	30.4	27.6	24.7	21.8	19.0
+ 500	−45.2	−42.3	−39.5	−36.6	−33.8	−31.0	−28.1	−25.3	−22.4	−19.6
600	45.7	42.9	40.0	37.2	34.3	31.5	28.7	25.8	23.0	20.1
700	46.2	43.4	40.6	37.7	34.9	32.1	29.2	26.4	23.6	20.7
800	46.8	43.9	41.1	38.3	35.4	32.6	29.8	27.0	24.1	21.3
900	47.3	44.4	41.6	38.8	36.0	33.2	30.4	27.5	24.7	21.9
+ 1000	−47.8	−45.0	−42.2	−39.3	−36.5	−33.7	−30.9	−28.1	−25.3	−22.5
1100	48.3	45.5	42.7	39.9	37.1	34.3	31.5	28.7	25.8	23.0
1200	48.8	46.0	43.2	40.4	37.6	34.8	32.0	29.2	26.4	23.6
1300	49.4	46.5	43.8	41.0	38.2	35.4	32.6	29.8	27.0	24.2
1400	49.9	47.1	44.3	41.5	38.7	35.9	33.1	30.4	27.6	24.8
+ 1500	−50.4	−47.6	−44.8	−42.0	−39.3	−36.5	−33.7	−30.9	−28.1	−25.3
1600	50.9	48.1	45.4	42.6	39.8	37.0	34.3	31.5	28.7	25.9
1700	51.4	48.7	45.9	43.1	40.4	37.6	34.8	32.1	29.3	26.5
1800	52.0	49.2	46.4	43.7	40.9	38.1	35.4	32.6	29.9	27.1
1900	52.5	49.7	47.0	44.2	41.4	38.7	35.9	33.2	30.4	27.7
+ 2000	−53.0	−50.2	−47.5	−44.7	−42.0	−39.2	−36.5	−33.7	−31.0	−28.2
2100	53.5	50.8	48.0	45.3	42.5	39.8	37.1	34.3	31.6	28.8
2200	54.0	51.3	48.6	45.8	43.1	40.3	37.6	34.9	32.1	29.4
2300	54.6	51.8	49.1	46.4	43.6	40.9	38.2	35.4	32.7	30.0
2400	55.1	52.3	49.6	46.9	44.2	41.5	38.7	36.0	33.3	30.6
+ 2500	−55.6	−52.9	−50.2	−47.4	−44.7	−42.0	−39.3	−36.6	−33.9	−31.1
2600	56.1	53.4	50.7	48.0	45.3	42.6	39.9	37.1	34.4	31.7
2700	56.6	53.9	51.2	48.5	45.8	43.1	40.4	37.7	35.0	32.3
2800	57.2	54.5	51.8	49.1	46.4	43.7	41.0	38.3	35.6	32.9
2900	57.7	55.0	52.3	49.6	46.9	44.2	41.5	38.8	36.1	33.4
+ 3000	−58.2	−55.5	−52.8	−50.1	−47.5	−44.8	−42.1	−39.4	−36.7	−34.0
3100	58.7	56.0	53.4	50.7	48.0	45.3	42.6	40.0	37.3	34.6
3200	59.2	56.5	53.9	51.2	48.5	45.9	43.2	40.5	37.9	35.2
3300	59.8	57.1	54.4	51.8	49.1	46.4	43.8	41.1	38.4	35.8
3400	60.3	57.6	55.0	52.3	49.6	47.0	44.3	41.7	39.0	36.3
+ 3500	−60.8	−58.1	−55.5	−52.8	−50.2	−47.5	−44.9	−42.2	−39.6	−36.9
3600	61.3	58.7	56.0	53.4	50.7	48.1	45.4	42.8	40.1	37.5
3700	61.8	59.2	56.6	53.9	51.3	48.6	46.0	43.4	40.7	38.1
3800	62.4	59.7	57.1	54.5	51.8	49.2	46.6	43.9	41.3	38.7
3900	62.9	60.2	57.6	55.0	52.4	49.7	47.1	44.5	41.9	39.2
+ 4000	−63.4	−60.8	−58.2	−55.5	−52.9	−50.3	−47.7	−45.1	−42.4	−39.8
4100	63.9	61.3	58.7	56.1	53.5	50.8	48.2	45.6	43.0	40.4
4200	64.4	61.8	59.2	56.6	54.0	51.4	48.8	46.2	43.6	41.0
4300	65.0	62.4	59.8	57.1	54.5	51.9	49.4	46.7	44.2	41.5
4400	65.5	62.9	60.3	57.7	55.1	52.5	49.9	47.3	44.7	42.1
+ 4500	−66.0	−63.4	−60.8	−58.2	−55.6	−53.1	−50.5	−47.9	−45.3	−42.7
4600	66.5	63.9	61.4	58.8	56.2	53.6	51.0	48.4	45.9	43.3
4700	67.0	64.5	61.9	59.3	56.7	54.2	51.6	49.0	46.4	43.9
4800	67.6	65.0	62.4	59.8	57.3	54.7	52.2	49.6	47.0	44.4
4900	68.1	65.5	63.0	60.4	57.8	55.3	52.7	50.1	47.6	45.0

TABLE 5 (cont.)

z_p \ S	−0.20	−0.19	−0.18	−0.17	−0.16	−0.15	−0.14	−0.13	−0.12	−0.11
+ 5000	−68.6	−66.0	−63.5	−60.9	−58.4	−55.8	−53.3	−50.7	−48.2	−45.6
5100	69.1	66.6	64.0	61.5	58.9	56.4	53.8	51.3	48.7	46.2
5200	69.6	67.1	64.5	62.0	59.5	56.9	54.4	51.8	49.3	46.8
5300	70.2	67.6	65.1	62.5	60.0	57.5	54.9	52.4	49.9	47.3
5400	70.7	68.1	65.6	63.1	60.6	58.0	55.5	53.0	50.4	47.9
+ 5500	−71.2	−68.7	−66.1	−63.6	−61.1	−58.6	−56.1	−53.5	−51.0	−48.5
5600	71.7	69.2	66.7	64.2	61.6	59.1	56.6	54.1	51.6	49.1
5700	72.2	69.7	67.2	64.7	62.2	59.7	57.2	54.7	52.2	49.6
5800	72.8	70.3	67.7	65.2	62.7	60.2	57.7	55.2	52.7	50.2
5900	73.3	70.8	68.3	65.8	63.3	60.8	58.3	55.8	53.3	50.8
+ 6000	−73.8	−71.3	−68.8	−66.3	−63.8	−61.3	−58.9	−56.4	−53.9	−51.4
6100	74.3	71.8	69.3	66.9	64.4	61.9	59.4	56.9	54.4	52.0
6200	74.8	72.3	69.9	67.4	64.9	62.4	60.0	57.5	55.0	52.5
6300	75.4	72.9	70.4	67.9	65.5	63.0	60.5	58.1	55.6	53.1
6400	75.9	73.4	70.9	68.5	66.0	63.6	61.1	58.6	56.2	53.7
+ 6500	−76.4	−73.9	−71.5	−69.0	−66.6	−64.1	−61.7	−59.2	−56.7	−54.3
6600	76.9	74.4	72.0	69.6	67.1	64.7	62.2	59.8	57.3	54.9
6700	77.4	75.0	72.6	70.1	67.7	65.2	62.8	60.3	57.9	55.4
6800	78.0	75.5	73.1	70.6	68.2	65.8	63.3	60.9	58.5	56.0
6900	78.5	76.0	73.6	71.2	68.7	66.3	63.9	61.5	59.0	56.6
+ 7000	−79.0	−76.6	−74.1	−71.7	−69.3	−66.9	−64.4	−62.0	−59.6	−57.2
7100	79.5	77.1	74.7	72.3	69.8	67.4	65.0	62.6	60.2	57.7
7200	80.0	77.6	75.2	72.8	70.4	68.0	65.6	63.1	60.7	58.3
7300	80.6	78.1	75.7	73.3	70.9	68.5	66.1	63.7	61.3	58.9
7400	81.1	78.7	76.3	73.9	71.5	69.1	66.7	64.3	61.9	59.5
+ 7500	−81.6	−79.2	−76.8	−74.4	−72.0	−69.6	−67.2	−64.8	−62.5	−60.1
7600	82.1	79.7	77.3	75.0	72.6	70.2	67.8	65.4	63.0	60.6
7700	82.6	80.3	77.9	75.5	73.1	70.7	68.4	66.0	63.6	61.2
7800	83.2	80.8	78.4	76.0	73.7	71.3	68.9	66.5	64.2	61.8
7900	83.7	81.3	78.9	76.6	74.2	71.8	69.5	67.1	64.7	62.4
+ 8000	−84.2	−81.8	−79.5	−77.1	−74.8	−72.4	−70.0	−67.7	−65.3	−63.0
8100	84.7	82.4	80.0	77.6	75.3	72.9	70.6	68.2	65.9	63.5
8200	85.2	82.9	80.5	78.2	75.8	73.5	71.2	68.8	66.5	64.1
8300	85.8	83.4	81.1	78.7	76.4	74.1	71.7	69.4	67.0	64.7
8400	86.3	83.9	81.6	79.3	76.9	74.6	72.3	69.9	67.6	65.3
+ 8500	−86.8	−84.5	−82.1	−79.8	−77.5	−75.2	−72.8	−70.5	−68.2	−65.8
8600	87.3	85.0	82.7	80.3	78.0	75.7	73.4	71.1	68.7	66.4
8700	87.8	85.5	83.2	80.9	78.6	76.3	74.0	71.6	69.3	67.0
8800	88.4	86.0	83.8	81.4	79.1	76.8	74.5	72.2	69.9	67.6
8900	88.9	86.6	84.3	82.0	79.7	77.4	75.1	72.8	60.5	68.2
+ 9000	−89.4	−87.1	−84.8	−82.5	−80.2	−77.9	−75.6	−73.3	−71.0	−68.7
9100	89.9	87.6	85.3	83.0	80.8	78.5	76.2	73.9	71.6	69.3
9200	90.4	88.2	85.9	83.6	81.3	79.0	76.7	74.5	72.2	69.9
9300	91.0	88.7	86.4	84.1	81.8	79.6	77.3	75.0	72.8	70.5
9400	91.5	89.2	86.9	84.7	82.4	80.1	77.9	75.6	73.3	71.1
+ 9500	−92.0	−89.7	−87.5	−85.2	−82.9	−80.7	−78.4	−76.2	−73.9	−71.6
9600	92.5	90.3	88.0	85.7	83.5	81.2	79.0	76.7	74.5	72.2
9700	93.0	90.8	88.5	86.3	84.0	81.8	79.5	77.3	75.0	72.8
9800	93.6	91.3	89.1	86.8	84.6	82.3	80.1	77.9	75.6	73.4
9900	94.1	91.8	89.6	87.4	85.1	82.9	80.7	78.4	76.2	73.9
+10000	−94.6	−92.4	−90.1	−87.9	−85.7	−83.4	−81.2	−79.0	−76.8	−74.5
10100	95.1	92.9	90.7	88.4	86.2	84.0	81.8	79.5	77.3	75.1
10200	95.6	93.4	91.2	89.0	86.8	84.5	82.3	80.1	77.9	75.7
10300	96.2	93.9	91.7	89.5	87.3	85.1	82.9	80.7	78.5	76.3
10400	96.7	94.5	92.3	90.1	87.9	85.7	83.5	81.2	79.0	76.9
+10500	−97.2	−95.0	−92.8	−90.6	−88.4	−86.2	−84.0	−81.8	−79.6	−77.4
10600	97.7	95.5	93.3	91.1	88.9	86.8	84.6	82.4	80.2	78.0
10700	98.2	96.0	93.9	91.7	89.5	87.3	85.1	82.9	80.8	78.6
≥10769	−98.6	−96.4	−94.2	−92.1	−89.9	−87.7	−85.5	−83.3	−81.2	−79.0

TABLE 5 (cont.)

z_p \ S	−0.10	−0.09	−0.08	−0.07	−0.06	−0.05	−0.04	−0.03	−0.02	−0.01
−1000	−7.9	−5.0	−2.1	+0.9	+3.8	+6.8	+9.7	+12.7	+15.6	+18.5
900	8.5	5.6	2.7	0.3	3.2	6.1	9.1	12.0	15.0	17.9
800	9.1	6.2	3.3	−0.3	2.6	5.5	8.5	11.4	14.3	17.3
700	9.7	6.8	3.8	0.9	2.0	4.9	7.8	10.8	13.7	16.6
600	10.3	7.4	4.4	1.5	1.4	4.3	7.2	10.1	13.1	16.0
−500	−10.9	−8.0	−5.0	−2.1	+0.8	+3.7	+6.6	+9.5	+12.4	+15.3
400	11.5	8.5	5.6	2.7	0.2	3.1	6.0	8.9	11.8	14.7
300	12.0	9.1	6.2	3.3	−0.4	2.4	5.3	8.2	11.2	14.0
200	12.6	9.7	6.8	3.9	1.1	1.8	4.7	7.6	10.5	13.4
100	13.2	10.3	7.4	4.5	1.7	1.2	4.1	7.0	9.9	12.8
+0	−13.8	−10.9	−8.0	−5.2	−2.3	+0.6	+3.5	+6.4	+9.2	+12.1
100	14.4	11.5	8.6	5.8	2.9	−0.0	2.8	5.7	8.6	11.5
200	15.0	12.1	9.2	6.4	3.5	0.6	2.2	5.1	8.0	10.8
300	15.6	12.7	9.8	7.0	4.1	1.3	1.6	4.5	7.3	10.2
400	16.1	13.3	10.4	7.6	4.7	1.9	1.0	3.8	6.7	9.5
+500	−16.7	−13.9	−11.0	−8.2	−5.3	−2.5	+0.4	+3.2	+6.1	+8.9
600	17.3	14.5	11.6	8.8	5.9	3.1	−0.3	2.6	5.4	8.3
700	17.9	15.1	12.2	9.4	6.6	3.7	0.9	1.9	4.8	7.6
800	18.5	15.6	12.8	10.0	7.2	4.3	1.5	1.3	4.1	7.0
900	19.1	16.2	13.4	10.6	7.8	5.0	2.1	0.7	3.5	6.3
+1000	−19.6	−16.8	−14.0	−11.2	−8.4	−5.6	−2.8	+0.0	+2.9	+5.7
1100	20.2	17.4	14.6	11.8	9.0	6.2	3.4	−0.6	2.2	5.0
1200	20.8	18.0	15.2	12.4	9.6	6.8	4.0	1.2	1.6	4.4
1300	21.4	18.6	15.8	13.0	10.2	7.4	4.6	1.8	1.0	3.7
1400	22.0	19.2	16.4	13.6	10.8	8.0	5.2	2.5	0.3	3.1
+1500	−22.6	−19.8	−17.0	−14.2	−11.4	−8.6	−5.9	−3.1	−0.3	+2.5
1600	23.2	20.4	17.6	14.8	12.1	9.3	6.5	3.7	0.9	1.8
1700	23.7	21.0	18.2	15.4	12.7	9.9	7.1	4.3	1.6	1.2
1800	24.3	21.6	18.8	16.0	13.3	10.5	7.7	5.0	2.2	0.5
1900	24.9	22.2	19.4	16.6	13.9	11.1	8.4	5.6	2.9	−0.1
+2000	−25.5	−22.7	−20.0	−17.2	−14.5	−11.7	−9.0	−6.2	−3.5	−0.7
2100	26.1	23.3	20.6	17.8	15.1	12.4	9.6	6.9	4.1	1.4
2200	26.7	23.9	21.2	18.5	15.7	13.0	10.2	7.5	4.8	2.0
2300	27.2	24.5	21.8	19.1	16.4	13.6	10.9	8.1	5.4	2.7
2400	27.8	25.1	22.4	19.7	17.0	14.2	11.5	8.8	6.0	3.3
+2500	−28.4	−25.7	−23.0	−20.3	−17.7	−14.8	−12.1	−9.4	−6.7	−4.0
2600	29.0	26.3	23.6	20.9	18.3	15.4	12.7	10.0	7.3	4.6
2700	29.6	26.9	24.2	21.5	18.9	16.1	13.4	10.6	7.9	5.2
2800	30.2	27.5	24.8	22.1	19.5	16.7	14.0	11.3	8.6	5.9
2900	30.8	28.1	25.4	22.7	20.1	17.3	14.6	11.9	9.2	6.5
+3000	−31.3	−28.7	−26.0	−23.2	−20.6	−17.9	−15.2	−12.5	−9.9	−7.2
3100	31.9	29.2	26.6	23.9	21.2	18.5	15.9	13.2	10.5	7.8
3200	32.5	29.8	27.2	24.5	21.8	19.2	16.5	13.8	11.1	8.5
3300	33.1	30.4	27.8	25.1	22.4	19.8	17.1	14.4	11.8	9.1
3400	33.7	31.0	28.4	25.7	23.0	20.4	17.7	15.1	12.4	9.8
+3500	−34.3	−31.6	−29.0	−26.3	−23.7	−21.0	−18.4	−15.7	−13.0	−10.4
3600	34.9	32.2	29.6	26.9	24.3	21.6	19.0	16.3	13.7	11.0
3700	35.4	32.8	30.2	27.5	24.9	22.2	19.6	17.0	14.3	11.7
3800	36.0	33.4	30.8	28.1	25.5	22.8	20.2	17.6	15.0	12.3
3900	36.6	34.0	31.4	28.7	26.1	23.5	20.8	18.2	15.6	13.0
+4000	−37.2	−34.6	−32.0	−29.3	−26.7	−24.1	−21.5	−18.9	−16.2	−13.6
4100	37.8	35.2	32.6	29.9	27.3	24.7	22.1	19.5	16.9	14.3
4200	38.4	35.8	33.2	30.5	27.9	25.3	22.7	20.1	17.5	14.9
4300	38.9	36.3	33.7	31.1	28.5	25.9	23.3	20.7	18.1	15.5
4400	39.5	37.0	34.3	31.8	29.2	26.6	24.0	21.4	18.8	16.2
+4500	−40.1	−37.5	−35.0	−32.4	−29.8	−27.2	−24.6	−22.0	−19.4	−16.8
4600	40.7	38.1	35.5	33.0	30.4	27.8	25.2	22.6	20.0	17.5
4700	41.3	38.7	36.1	33.6	31.0	28.4	25.8	23.3	20.7	18.1
4800	41.9	39.3	36.7	34.2	31.6	29.0	26.5	23.9	21.3	18.8
4900	42.5	40.0	37.3	34.8	32.2	29.6	27.1	24.5	22.0	19.4

TABLE 5 (cont.)

z_p \ S	−0.10	−0.09	−0.08	−0.07	−0.06	−0.05	−0.04	−0.03	−0.02	−0.01
+ 5000	−43.0	−40.5	−37.9	−35.4	−32.8	−30.3	−27.7	−25.2	−22.6	−20.1
5100	43.6	41.1	38.5	36.0	33.4	30.9	28.3	25.8	23.2	20.7
5200	44.2	41.7	39.1	36.6	34.0	31.5	29.0	26.4	23.9	21.3
5300	44.8	42.3	39.7	37.2	34.7	32.2	29.6	27.1	24.5	22.0
5400	45.4	42.9	40.3	37.8	35.3	32.7	30.2	27.7	25.1	22.6
+ 5500	−46.0	−43.4	−40.9	−38.4	−35.9	−33.3	−30.8	−28.3	−25.8	−23.3
5600	46.6	44.0	41.5	39.0	36.5	34.0	31.5	28.9	26.4	23.9
5700	47.1	44.6	42.1	39.6	37.1	34.6	32.1	29.6	27.1	24.6
5800	47.7	45.2	42.7	40.2	37.7	35.2	32.7	30.2	27.7	25.2
5900	48.3	45.8	43.3	40.8	38.3	35.8	33.3	30.8	28.3	25.8
+ 6000	−48.9	−46.4	−43.9	−41.4	−38.9	−36.4	−34.0	−31.5	−29.0	−26.5
6100	49.5	47.0	44.5	42.0	39.5	37.1	34.6	32.1	29.6	27.1
6200	50.1	47.6	45.1	42.6	40.2	37.7	35.2	32.7	30.3	27.8
6300	50.6	48.2	45.7	43.2	40.8	38.3	35.8	33.4	30.9	28.4
6400	51.2	48.8	46.3	43.8	41.4	38.9	36.4	34.0	31.5	29.1
+ 6500	−51.8	−49.4	−46.9	−44.4	−42.0	−39.5	−37.1	−34.6	−32.2	−29.7
6600	52.4	50.0	47.5	45.1	42.6	40.1	37.7	35.2	32.8	30.3
6700	53.0	50.5	48.1	45.7	43.2	40.8	38.3	35.9	33.4	31.0
6800	53.6	51.1	48.7	46.3	43.8	41.4	39.0	36.5	34.1	31.6
6900	54.2	51.7	49.3	46.9	44.4	42.0	39.6	37.1	34.7	32.3
+ 7000	−54.7	−52.3	−49.9	−47.5	−45.0	−42.6	−40.2	−37.8	−35.3	−32.9
7100	55.3	52.9	50.5	48.1	45.7	43.2	40.8	38.4	36.0	33.6
7200	55.9	53.5	51.1	48.7	46.3	43.9	41.4	39.0	36.6	34.2
7300	56.5	54.1	51.7	49.3	46.9	44.5	42.1	39.7	37.3	34.9
7400	57.1	54.7	52.3	49.9	47.5	45.1	42.7	40.3	37.9	35.5
+ 7500	−57.7	−55.3	−52.9	−50.5	−48.1	−45.7	−43.3	−40.9	−38.5	−36.1
7600	58.3	55.9	53.5	51.1	48.7	46.3	43.9	41.6	39.2	36.8
7700	58.8	56.5	54.1	51.7	49.3	46.9	44.6	42.2	39.8	37.4
7800	59.4	57.1	54.7	52.3	49.9	47.5	45.2	42.8	40.4	38.1
7900	60.0	57.6	55.3	52.9	50.5	48.2	45.8	43.4	41.1	38.7
+ 8000	−60.6	−58.2	−55.9	−53.5	−51.2	−48.8	−46.4	−44.1	−41.7	−39.4
8100	61.2	58.8	56.5	54.1	51.8	49.4	47.1	44.7	42.4	40.0
8200	61.8	59.4	57.1	54.7	52.4	50.0	47.7	45.3	43.0	40.6
8300	62.3	60.0	57.7	55.3	53.0	50.6	48.3	46.0	43.6	41.3
8400	62.9	60.6	58.3	55.9	53.6	51.3	48.9	46.6	44.3	41.9
+ 8500	−63.5	−61.2	−58.9	−56.5	−54.2	−51.9	−49.6	−47.2	−44.9	−42.6
8600	64.1	61.8	59.5	57.1	54.8	52.5	50.2	47.9	45.5	43.2
8700	64.7	62.4	60.1	57.7	55.4	53.1	50.8	48.5	46.2	43.9
8800	65.3	63.0	60.7	58.4	56.0	53.7	51.4	49.1	46.8	44.5
8900	65.9	63.6	61.3	59.0	56.7	54.3	52.0	49.7	47.4	45.1
+ 9000	−66.4	−64.1	−61.9	−59.6	−57.3	−55.0	−52.7	−50.4	−48.1	−45.8
9100	67.0	64.7	62.5	60.2	57.9	55.6	53.3	51.0	48.7	46.4
9200	67.6	65.3	63.1	60.8	58.5	56.2	53.9	51.6	49.4	47.1
9300	68.2	65.9	63.6	61.4	59.1	56.8	54.5	52.3	50.0	47.7
9400	68.8	66.5	64.2	62.0	59.7	57.4	55.2	52.9	50.6	48.4
+ 9500	−69.4	−67.1	−64.8	−62.6	−60.3	−58.0	−55.8	−53.5	−51.3	−49.0
9600	70.0	67.7	65.4	63.2	60.9	58.7	56.4	54.2	51.9	49.7
9700	70.5	68.3	66.0	63.8	61.5	59.3	57.0	54.8	52.5	50.3
9800	71.1	68.9	66.6	64.4	62.2	59.9	57.7	55.4	53.2	50.9
9900	71.7	69.5	67.2	65.0	62.8	60.5	58.3	56.1	53.8	51.6
+10000	−72.3	−70.1	−67.8	−65.6	−63.4	−61.1	−58.9	−56.7	−54.5	−52.2
10100	72.9	70.7	68.4	66.2	64.0	61.8	59.5	57.3	55.1	52.9
10200	73.5	71.2	69.0	66.8	64.6	62.4	60.2	57.9	55.7	53.5
10300	74.0	71.8	69.6	67.4	65.2	63.0	60.8	58.6	56.4	54.2
10400	74.6	72.4	70.2	68.0	65.8	63.6	61.4	59.2	57.0	54.8
+10500	−75.2	−73.0	−70.8	−68.6	−66.4	−64.2	−62.0	−59.8	−57.6	−55.4
10600	75.8	73.6	71.4	69.2	67.0	64.8	62.7	60.5	58.3	56.1
10700	76.4	74.2	72.0	69.8	67.7	65.5	63.3	61.1	58.9	56.7
≥10769	−76.8	−74.6	−72.4	−70.3	−68.1	−65.9	−63.7	−61.5	−59.4	−57.2

TABLE 5 (cont.)

z_p \ S	0.00	+0.01	+0.02	+0.03	+0.04	+0.05	+0.06	+0.07	+0.08	+0.09	+0.10
− 1000	+21.5	+24.4	+27.4	+30.3	+33.3	+36.2	+39.2	+42.1	+45.1	+48.0	+51.0
900	20.8	23.8	26.7	29.7	32.6	35.5	38.5	41.4	44.4	47.3	50.2
800	20.2	23.1	26.1	29.0	31.9	34.9	37.8	40.7	43.7	46.6	49.5
700	19.5	22.5	25.4	28.3	31.2	34.2	37.1	40.0	43.0	45.9	48.8
600	18.9	21.8	24.7	27.6	30.6	33.5	36.4	39.3	42.2	45.2	48.1
− 500	+18.2	+21.2	+24.1	+27.0	+29.9	+32.8	+35.7	+38.6	+41.5	+44.5	+47.4
400	17.6	20.5	23.4	26.3	29.2	32.1	35.0	37.9	40.8	43.7	46.7
300	16.9	19.8	22.7	25.6	28.5	31.4	34.3	37.2	40.1	43.0	45.9
200	16.3	19.2	22.1	25.0	27.9	30.8	33.6	36.5	39.4	42.3	45.2
100	15.6	18.5	21.4	24.3	27.2	30.1	33.0	35.8	38.7	41.6	44.5
+ 0	+15.0	+17.9	+20.8	+23.6	+26.5	+29.4	+32.3	+35.2	+38.0	+40.9	+43.8
100	14.3	17.2	20.1	23.0	25.8	29.7	31.6	34.5	37.3	40.2	43.1
200	13.7	16.6	19.4	22.3	25.2	29.0	30.9	33.8	36.6	39.5	42.4
300	13.0	15.9	18.8	21.6	24.5	28.3	30.2	33.1	35.9	38.8	41.7
400	12.4	15.2	18.1	21.0	23.8	27.7	29.5	32.4	35.2	38.1	40.9
+ 500	+11.7	+14.6	+17.4	+20.3	+23.1	+27.0	+28.8	+31.7	+34.5	+37.4	+40.2
600	11.1	13.9	16.8	19.6	22.5	26.3	28.1	31.0	33.8	36.7	39.5
700	10.4	13.3	16.1	19.0	21.8	25.6	27.4	30.3	33.1	36.0	38.8
800	9.8	12.6	15.6	18.3	21.1	24.9	26.8	29.6	32.4	35.2	38.1
900	9.1	12.0	14.8	17.6	20.4	23.2	26.1	28.9	31.7	34.5	37.4
+ 1000	+ 8.5	+11.3	+14.1	+16.9	+19.8	+22.6	+25.4	+28.2	+31.0	+33.8	+36.6
1100	7.8	10.6	13.5	16.3	19.1	21.9	24.7	27.5	30.3	33.1	35.9
1200	7.2	10.0	12.8	15.6	18.4	21.2	24.0	26.8	29.6	32.4	35.2
1300	6.5	9.3	12.1	14.9	17.7	20.5	23.3	26.1	28.9	31.7	34.5
1400	5.9	8.7	11.5	14.3	17.0	19.8	22.6	25.4	28.2	31.0	33.8
+ 1500	+ 5.2	+ 8.0	+10.8	+13.6	+16.4	+19.2	+21.9	+24.7	+27.5	+30.3	+33.1
1600	4.6	7.4	10.1	12.9	15.7	18.5	21.2	24.0	26.8	29.6	32.4
1700	3.9	6.7	9.5	12.2	15.0	17.8	20.6	23.3	26.1	28.9	31.6
1800	3.3	6.1	8.8	11.6	14.3	17.1	19.9	22.6	25.4	28.2	30.9
1900	2.6	5.4	8.2	10.9	13.7	16.4	19.2	21.9	24.7	27.5	30.2
+ 2000	+ 2.0	+ 4.7	+ 7.5	+10.2	+13.0	+15.7	+18.5	+21.2	+24.0	+26.7	+29.5
2100	1.3	4.1	6.8	9.6	12.3	15.1	17.8	20.5	23.3	26.0	28.8
2200	0.7	3.4	6.2	8.9	11.6	14.4	17.1	19.9	22.6	25.3	28.1
2300	0.0	2.8	5.5	8.2	11.0	13.7	16.4	19.2	21.9	24.6	27.4
2400	− 0.6	2.1	4.8	7.6	10.3	13.0	15.7	18.5	21.2	23.9	26.6
+ 2500	− 1.2	+ 1.5	+ 4.2	+ 6.9	+ 9.6	+12.3	+15.0	+17.8	+20.5	+23.2	+25.9
2600	1.9	0.8	3.5	6.2	8.9	11.6	14.4	17.1	19.8	22.5	25.2
2700	2.5	0.1	2.9	5.6	8.3	11.0	13.7	16.4	19.1	21.8	24.5
2800	3.2	− 0.5	2.2	4.9	7.6	10.3	13.0	15.7	18.4	21.1	23.8
2900	3.8	1.2	1.5	4.2	6.9	9.6	12.3	15.0	17.7	20.4	23.1
+ 3000	− 4.5	− 1.8	+ 0.9	3.5	+ 6.2	+ 8.9	+11.6	+14.3	+17.0	+19.7	+22.3
3100	5.1	2.5	0.2	2.9	5.6	8.2	10.9	13.6	16.3	18.9	21.6
3200	5.8	3.1	− 0.5	2.2	4.9	7.6	10.2	12.9	15.6	18.2	20.9
3300	6.4	3.8	1.1	1.5	4.2	6.9	9.5	12.2	14.9	17.5	20.2
3400	7.1	4.4	1.8	0.9	3.5	6.2	8.8	11.5	14.2	16.8	19.5
+ 3500	− 7.7	− 5.1	− 2.4	+ 0.2	+ 2.9	+ 5.5	+ 8.2	+10.8	+13.5	+16.1	+18.8
3600	8.4	5.8	3.1	− 0.5	2.2	4.8	7.5	10.1	12.8	15.4	18.1
3700	9.0	6.4	3.8	1.1	1.5	4.1	6.8	9.4	12.1	14.7	17.3
3800	9.7	7.1	4.4	1.8	0.8	3.5	6.1	8.7	11.4	14.0	16.6
3900	10.3	7.7	5.1	2.5	0.2	2.8	5.4	8.0	10.7	13.3	15.9
+ 4000	−11.0	− 8.4	− 5.8	− 3.1	− 0.5	+ 2.1	+ 4.7	+ 7.3	+10.0	+12.6	+15.2
4100	11.6	9.0	6.4	3.8	1.2	1.4	4.0	6.6	9.3	11.9	14.5
4200	12.3	9.7	7.1	4.5	1.9	0.7	3.3	5.9	8.6	11.2	13.8
4300	12.9	10.3	7.7	5.1	2.5	0.0	2.6	5.2	7.8	10.4	13.1
4400	13.5	11.0	8.4	5.8	3.2	− 0.6	2.0	4.5	7.1	9.7	12.3
+ 4500	−14.1	−11.7	− 9.1	− 6.5	− 3.9	− 1.3	+ 1.3	+ 3.9	+ 6.4	+ 9.0	+11.6
4600	14.8	12.3	9.7	7.2	4.6	2.0	0.6	3.2	5.7	8.3	10.9
4700	15.4	13.0	10.4	7.8	5.2	2.7	− 0.1	2.5	5.0	7.6	10.2
4800	16.1	13.6	11.1	8.5	5.9	3.4	0.8	1.8	4.3	6.9	9.5
4900	16.7	14.3	11.7	9.2	6.6	4.1	1.5	1.1	3.6	6.2	8.8

TABLE 5 (cont.)

z_p \ S	0.00	+0.01	+0.02	+0.03	+0.04	+0.05	+0.06	+0.07	+0.08	+0.09	+0.10
+ 5000	−17.5	−14.9	−12.4	− 9.8	− 7.3	− 4.7	− 2.2	+ 0.4	+ 2.9	+ 5.5	+ 8.0
5100	18.1	15.6	13.0	10.5	8.0	5.4	2.9	− 0.3	2.2	4.8	7.3
5200	18.8	16.3	13.7	11.2	8.6	6.1	3.5	1.0	1.5	4.1	6.6
5300	19.4	16.9	14.4	11.8	9.3	6.8	4.2	1.7	0.8	3.4	5.9
5400	20.1	17.6	15.0	12.5	10.0	7.5	4.9	2.4	0.1	2.7	5.2
+ 5500	−20.7	−18.2	−15.7	−13.2	−10.7	− 8.1	− 5.6	− 3.1	− 0.6	+ 1.9	+ 4.5
5600	21.4	18.9	16.4	13.9	11.3	8.8	6.3	3.8	1.4	1.2	3.7
5700	22.0	19.5	17.0	14.5	12.0	9.5	7.0	4.5	2.0	0.5	3.0
5800	22.7	20.2	17.7	15.2	12.7	10.2	7.7	5.2	2.7	− 0.2	2.3
5900	23.4	20.8	18.4	15.9	13.4	10.9	8.4	5.9	3.4	0.9	1.6
+ 6000	−24.0	−21.5	−19.0	−16.5	−14.0	−11.5	− 9.1	− 6.6	− 4.1	− 1.6	+ 0.9
6100	24.6	22.2	19.7	17.2	14.7	12.2	9.7	7.3	4.8	2.3	0.2
6200	25.3	22.8	20.3	17.9	15.4	12.9	10.4	8.0	5.5	3.0	− 0.5
6300	25.9	23.5	21.0	18.5	16.1	13.6	11.1	8.7	6.2	3.7	1.2
6400	26.6	24.1	21.7	19.2	16.7	14.3	11.8	9.4	6.9	4.4	2.0
+ 6500	−27.2	−24.8	−22.3	−19.9	−17.4	−15.0	−12.5	−10.0	− 7.6	− 5.1	− 2.7
6600	27.9	25.4	23.0	20.5	18.1	15.6	13.2	10.7	8.3	5.8	3.4
6700	28.5	26.1	23.7	21.2	18.8	16.3	13.9	11.4	9.0	6.5	4.1
6800	29.2	26.7	24.3	21.9	19.4	17.0	14.6	12.1	9.7	7.3	4.8
6900	29.8	27.4	25.0	22.6	20.1	17.7	15.3	12.8	10.4	8.0	5.5
+ 7000	−30.5	−28.1	−25.6	−23.2	−20.8	−18.4	−15.9	−13.5	−11.1	− 8.7	− 6.2
7100	31.1	28.7	26.3	23.9	21.5	19.1	16.6	14.2	11.8	9.4	7.0
7200	31.8	29.4	27.0	24.6	22.1	19.7	17.3	14.9	12.5	10.1	7.7
7300	32.4	30.0	27.6	25.2	22.8	20.4	18.0	15.6	13.2	10.8	8.4
7400	33.1	30.7	28.3	25.9	23.5	21.1	18.7	16.3	13.9	11.5	9.1
+ 7500	−33.7	−31.4	−29.0	−26.6	−24.2	−21.8	−19.4	−17.0	−14.6	−12.2	− 9.8
7600	34.4	32.0	29.6	27.2	24.9	22.5	20.1	17.7	15.3	12.9	10.5
7700	35.0	32.7	30.3	27.9	25.5	23.1	20.8	18.4	16.0	13.6	11.2
7800	35.7	33.3	30.9	28.6	26.2	23.8	21.5	19.1	16.7	14.3	12.0
7900	36.3	34.0	31.6	29.3	26.9	24.5	22.2	19.8	17.4	15.0	12.7
+ 8000	−37.0	−34.6	−32.3	−29.9	−27.6	−25.2	−22.8	−20.5	−18.1	−15.8	−13.4
8100	37.6	35.3	32.9	30.6	28.2	25.9	23.5	21.2	18.8	16.5	14.1
8200	38.3	35.9	33.6	31.3	28.9	26.6	24.2	21.9	19.5	17.2	14.8
8300	38.9	36.6	34.3	31.9	29.6	27.2	24.9	22.6	20.2	17.9	15.5
8400	39.6	37.3	34.9	32.6	30.3	27.9	25.6	23.3	20.9	18.6	16.3
+ 8500	−40.2	−37.9	−35.6	−33.3	−30.9	−28.6	−26.3	−24.0	−21.6	−19.3	−17.0
8600	40.9	38.6	36.3	33.9	31.6	29.3	27.0	24.6	22.3	20.0	17.7
8700	41.5	39.2	36.9	34.6	32.3	30.0	27.7	25.3	23.0	20.7	18.4
8800	42.2	39.9	37.6	35.3	33.0	30.7	28.4	26.0	23.7	21.4	19.1
8900	42.8	40.5	38.2	35.9	33.6	31.3	29.0	26.7	24.4	22.1	19.8
+ 9000	−43.5	−41.2	−38.9	−36.6	−34.3	−32.0	−29.7	−27.4	−25.1	−22.8	−20.5
9100	44.1	41.9	39.6	37.3	35.0	32.7	30.4	28.1	25.8	23.6	21.3
9200	44.8	42.5	40.2	38.0	35.7	33.4	31.1	28.8	26.5	24.3	22.0
9300	45.4	43.2	40.9	38.6	36.3	34.1	31.8	29.5	27.2	25.0	22.7
9400	46.1	43.8	41.6	39.3	37.0	34.8	32.5	30.2	27.9	25.7	23.4
+ 9500	−46.7	−44.5	−42.2	−40.0	−37.7	−35.4	−33.2	−30.9	−28.6	−26.4	−24.1
9600	47.4	45.1	42.9	40.6	38.4	36.1	33.9	31.6	29.3	27.1	24.8
9700	48.0	45.8	43.5	41.3	39.0	36.8	34.6	32.3	30.1	27.8	25.5
9800	48.7	46.4	44.2	42.0	39.7	37.5	35.2	33.0	30.8	28.5	26.3
9900	49.3	47.1	44.9	42.6	40.4	38.2	35.9	33.7	31.5	29.2	27.0
+10000	−50.0	−47.8	−45.5	−43.3	−41.1	−38.8	−36.6	−34.4	−32.2	−29.9	−27.7
10100	50.6	48.4	46.2	44.0	41.8	39.5	37.3	35.1	32.9	30.6	28.4
10200	51.3	49.1	46.9	44.7	42.4	40.2	38.0	35.8	33.6	31.3	29.1
10300	51.9	49.7	47.5	45.3	43.1	40.9	38.7	36.5	34.3	32.1	29.8
10400	52.6	50.4	48.2	46.0	43.8	41.6	39.4	37.2	35.0	32.8	30.6
+10500	−53.2	−51.0	−48.9	−46.7	−44.5	−42.3	−40.1	−37.9	−35.7	−33.5	−31.3
10600	53.9	51.7	49.5	47.3	45.1	42.9	40.8	38.6	36.4	34.2	32.0
10700	54.5	52.4	50.2	48.0	45.8	43.6	41.4	39.3	37.1	34.9	32.7
≥10769	−55.0	−52.8	−50.6	−48.5	−46.3	−44.1	−41.9	−39.7	−37.6	−35.4	−33.2

TABLE 6a

Virtual Temperature Corrections
$T^* - T$ in degrees centigrade

w gm/kg \ T °C	−20	0	+20	+40
1	0.2	0.2	0.2	0.2
2	0.3	0.3	0.3	0.4
3	0.5	0.5	0.5	0.6
4	0.6	0.7	0.7	0.8
5	0.8	0.8	0.9	0.9
6	0.9	1.0	1.1	1.1
7	1.1	1.1	1.2	1.3
8	1.2	1.3	1.4	1.5
9	1.4	1.5	1.6	1.7
10	1.5	1.6	1.8	1.9
11		1.8	1.9	2.1
12		2.0	2.1	2.2
13		2.1	2.3	2.4
14		2.3	2.4	2.6
15		2.4	2.6	2.8
16		2.6	2.8	3.0
17		2.7	2.9	3.1
18		2.9	3.1	3.3
19		3.1	3.3	3.5
20		3.2	3.5	3.7
21		3.4	3.6	3.9
22		3.5	3.8	4.1
23		3.7	4.0	4.2
24		3.9	4.1	4.4
25		4.0	4.3	4.6
26		4.2	4.5	4.8
27		4.3	4.7	5.0
28		4.5	4.8	5.2
29		4.7	5.0	5.3
30		4.8	5.2	5.5
31		5.0	5.3	5.7
32		5.1	5.5	5.9
33		5.3	5.7	6.1
34		5.4	5.9	6.2
35		5.6	6.0	6.4
36		5.7	6.2	6.6
37		5.9	6.4	6.8
38		6.1	6.5	7.0
39		6.2	6.7	7.2
40		6.4	6.9	7.3

TABLE 6b

Virtual Temperature Anomaly Corrections
$S^* - S$

w gm/kg \ S	−0.10	−0.05	0.00	+0.05	+0.10
1	0.001	0.001	0.001	0.001	0.001
2	.001	.001	.001	.001	.001
3	.002	.002	.002	.002	.002
4	.002	.002	.002	.002	.003
5	.003	.003	.003	.003	.003
6	.003	.003	.004	.004	.004
7	.004	.004	.004	.004	.005
8	.004	.005	.005	.005	.005
9	.005	.005	.005	.006	.006
10	.005	.006	.006	.006	.007
11		.006	.007	.007	.007
12		.007	.007	.007	.008
13		.007	.008	.008	.008
14		.008	.008	.009	.009
15		.008	.009	.009	.010
16		.009	.009	.010	.010
17		.009	.010	.011	.011
18		.010	.011	.011	.012
19		.011	.011	.012	.012
20		.011	.012	.012	.013
21			.012	.013	.014
22			.013	.014	.014
23			.014	.014	.015
24			.014	.015	.016
25			.015	.015	.016
26			.015	.016	.017
27			.016	.017	.017
28			.016	.017	.018
29			.017	.018	.019
30			.018	.019	.019
31			.018	.019	.020
32			.019	.020	.021
33			.019	.020	.021
34			.020	.021	.022
35			.021	.022	.023
36			.021	.022	.023
37			.022	.023	.024
38			.022	.023	.025
39			.023	.024	.025
40			.023	.025	.026

which occurs at $z = 0$ to the value of D, expressed in feet, at $z = 0$. The specific tables included are

Table 2a $^{z=0}D^{\mathrm{ft}}(^{z=0}p^{\mathrm{in}})$ or $D^{\mathrm{ft}}(P^{\mathrm{in}})$,
Table 2b $^{z=0}D^{\mathrm{ft}}(^{z=0}p^{\mathrm{mm}})$ or $D^{\mathrm{ft}}(P^{\mathrm{mm}})$,
Table 2c $^{z=0}D^{\mathrm{ft}}(^{z=0}p^{\mathrm{mb}})$ or $D^{\mathrm{ft}}(P^{\mathrm{mb}})$,
Table 2d $^{z=0}D^{\mathrm{m}}(^{z=0}p^{\mathrm{in}})$ or $D^{\mathrm{m}}(P^{\mathrm{in}})$,
Table 2e $^{z=0}D^{\mathrm{m}}(^{z=0}p^{\mathrm{mm}})$ or $D^{\mathrm{m}}(P^{\mathrm{mm}})$,
Table 2f $^{z=0}D^{\mathrm{m}}(^{z=0}p^{\mathrm{mb}})$ or $D^{\mathrm{m}}(P^{\mathrm{mb}})$.

Tables 3a through 3c—These tables give the pressure conversions from p, in millibars, which occurs at various constant elevations above sea level to the values of D in feet or meters at those levels. They are convenient for conversion of past and present radiosonde reports and climatic summaries such as the U. S. Weather Bureau Form No. 1109. The specific tables which are included are the conversion to D in feet at $z = 5000$, 10,000, 15,000 and 20,000 feet and to D in feet and meters at $z = 0.5$, 1.0, 1.5, 2.0, 2.5, 3.0, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20 km. The specific tables are indicated by a notation similar to that described above. For example, the notation $^{z=5000\ \mathrm{ft}}D^{\mathrm{ft}}\ (^{z=5000\ \mathrm{ft}}p^{\mathrm{mb}})$ denotes the table of conversion from p, expressed in millibars, which occurs at $z = 5000$ ft to the value of D, expressed in feet, at $z = 5000$ ft.

Relation between S and T at various pressure altitudes. Table 4 gives the value of T, in degrees centigrade, for each value of S which is an integral multiple of 0.01 and for each value of z_p which is an integral multiple of 1000 feet. Table 5 is the same as Table 4 except that the values of z_p used in Table 5 are integral multiples of 100 meters. Linear interpolation in either direction is possible since the defining equation for S can be written as $T = (1 + S)(T_0 - \alpha z_p)$.

Tables 4 and 5 have been found to be most useful for converting meteorological analyses of temperature distribution in terms of the parameter S to the parameter T for dissemination to pilots, etc. This use is discussed more fully in the sections on space cross sections and mean temperature charts. Usually the conversion from T to S is most convenient on thermodynamic diagrams upon which lines of constant S have been entered. Tables 4 and 5 are convenient for plotting these S lines on such thermodynamic diagrams as the adiabatic chart, the tephigram, the Stüve diagram, etc. A special thermodynamic diagram, the "*pastagram*," which is described in the next section, has been found to be especially convenient for these conversions.

Both of these tables could be used for numerical pressure-height computations, but, since graphical pressure-height computations are usually more convenient, such numerical computations are not discussed in this article.

4. The pastagram. The pastagram is a thermodynamic chart designed to facilitate meteorological work with the parameters z_p and D, especially for pressure-height computations. On this chart the ordinate represents the pressure altitude z_p on a linear scale, and the abscissa represents the specific temperature anomaly S also on a linear scale. Its use in pressure-height computations is described in the next section.

In the standard stratospheric region the standard temperature T_p is defined to be constant, so that $S = (T - T_p)/T_p$ is a linear function of the temperature T. Also in this region $dz_p = (RT_p/m_d g_p)d \ln p$ so that, since T_p is constant, z_p is a logarithmic function of the pressure p. Hence in the standard stratospheric region the pastagram is merely an adiabatic diagram (coordinates of $\ln p$ and T) with isobars drawn for round values of a constant times the logarithm of p. For all pressures, since

$$\oint Td \ln p = \oint \frac{Tm_d g_p}{T_p R} dz_p = $$
$$= \frac{m_d g_p}{R} \oint (1 + S)dz_p = \frac{m_d g_p}{R} \oint S dz_p,$$

the pastagram is a "true" thermodynamic diagram, that is, the heat energy released in any thermodynamic cycle undergone by a parcel of air is proportional to the area enclosed by a plot of that cyclic process on the pastagram.

Charts of various thermodynamic quantities have been drawn in such a way as to provide underlays or transparent overlays to be used in conjunction with basic pastagrams upon which only z_p, S and sometimes T are entered. This arrangement eliminates the confusion caused by many sets of lines on one diagram and is convenient since it has been found that a great deal of useful information can be obtained from plots of soundings on the basic pastagrams without the necessity of using overlays or underlays. The underlays are used primarily for plotting soundings on the basic pastagrams and are most efficient if the basic pastagrams are printed on transparent (tracing) paper although a light table can be used for this plotting. Specific transparent overlays are desirable for such thermodynamic calculations as determining numerical values of various thermodynamic quantities such as potential temperature, equivalent potential temperature, stability studies, cloud analysis, etc. Illustrations of the basic pastagrams and some underlays or overlays are given in Plates I through VIII. The theory of construction of these charts is not given since the pastagram is essentially just a reorientation of the coordinates which occur on most other thermodynamic diagrams. A description of the plates follows. The description of the soundings shown is given in the discussion of Plate VI.

Plate I. This is a basic pastagram upon which soundings can be plotted with the use of underlays. The 0°C isotherm is entered so that the pressure altitude of the freezing level is immediately apparent and so that a reference line for the shape of an isothermal lapse rate in the standard troposphere is available. The standard tropopause (z_p = 35,332.0 ft) is entered since the appearance and interpretation of soundings on the pastagram change abruptly at this line. For example, isotherms above this line are straight vertical lines. This change of interpretation at the standard tropopause is discussed more fully in connection with Plate III.

Plate II. This is a basic pastagram like Plate I but is for work in terms of meters instead of feet.

Plate III. This is a basic pastagram which is convenient for much routine work, especially pressure-height computations in terms of feet. The conversion scale from millibars to pressure altitude on the left side has been included as an aid in plotting data which are reported in terms of millibars. An underlay, such as described in the discussion of Plate IV, is a further aid for this conversion when a great deal of routine plotting is required.

Since there is an abrupt change of the slope of the isotherms at the standard tropopause, simple straight-line interpolations of the pressure-temperature relationship between points on opposite sides of this line cannot be made. A convenient method of interpolating between such points, as A (z_p = 33,000 ft, $T = -44°C$) and B (z_p = 37,000 ft, $T = -52°C$) on Plate III, is demonstrated by the following example.

Locate point A' at the same pressure as point A (z_p = 33,000 ft) and at the value of S (+ 0.05) corresponding to the value of T, in the standard stratosphere, that occurs at point A. Thus point A' can be obtained by following the isotherm through point A to the standard tropopause, and then vertically down to point A' at the same pressure as point A. Then point C is located at the standard tropopause on the straight line joining points A' and B, and the broken line ACB represents the interpolation between points A and B. This interpolation process would be eliminated if a mandatory level (such as 400 mb in present procedures) were provided at the pressure altitude of 35,332 ft (10,769 m).

Plate IV. This is a basic pastagram exactly similar to Plate III but for work in terms of meters instead of feet.

Plate V. This plate is designed primarily as an underlay for plotting soundings reported in terms of millibars on Plate I or II. A similar plate without the isotherms can be used for plotting such soundings on Plate III or IV. Another similar plate without the millibar lines is convenient for plotting aircraft soundings (or any other soundings with pressures reported in terms of pressure altitude) and, as a transparent overlay, for determining temperatures in °C or °F from such plots as given on Plates I and II.

Plate VI. The values of the potential temperature θ on the dry adiabats, which slope from lower right to upper left, are given in degrees of the absolute scale. A change from the usual quantitative definition of potential temperature was made so that the value of θ as given here is the value of the temperature of a given parcel of air if that parcel were to be moved dry adiabatically to the pressure of the zero of the pressure-altitude scale (1013.25 mb) instead of to 1000 mb. It is felt that this change is desirable since the location of the 1000-mb pressure value is inconvenient if most routine work is done in terms of pressure altitude. Also, the zero of the pressure-altitude scale, 760 mm or 1013.25 mb, is the standard pressure usually used in physics and chemistry. The relationship between θ as used here and θ' (in terms of 1000 mb) is then

$$\theta = \left(\frac{1013.25}{1000}\right)^{0.288} \theta' = 1.003808\theta'.$$

The following table gives the difference $\theta - \theta'$ for various values of θ' or θ in °A.

TABLE 7

θ' or θ	240	260	280	300	320	340	360	380	400	420	440	460	480	500
$\theta - \theta'$	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9

The lines which slope from lower left to upper right represent round values of the mixing ratio w in grams of water vapor per kilogram of dry air, corresponding to a saturated parcel at the temperature and pressure of any given point of the pastagram. The third set of lines are the moist adiabats, drawn for each ten degrees of equivalent potential temperature θ_E as defined by Rossby (4) except that, in harmony with the definition of θ, the standard pressure for θ_E is taken to be the zero of the pressure-altitude scale instead of 1000 mb. Plate VI can be used as a transparent overlay for detailed thermodynamic calculations, such as determining the values of w, θ or θ_E, stability or energy calculations, etc., with soundings plotted on basic pastagrams.

The w and θ lines have been placed on the same diagram to facilitate plotting the lifting condensation levels of the points of a sounding, as illustrated by the plots on Plates I, II and IV. It has been found convenient to use the following procedure for routine plotting:

1. Plot the pressure-temperature relationship with Plate V used as an underlay.
2. Using Plate VI as an underlay, draw lines (in some distinctive color) from each reported point of step 1 along the dry adiabats through these points to the corresponding lifting condensation levels. These condensation levels will then be at the intersections of the dry adiabats and the lines for the actual mixing ratios of the points considered.

Some of the information which can be obtained from such plots on Plates I, II, III or IV, without using overlays, is:

1. A qualitative idea of the relative humidity at any point can be gotten because this quantity is approximately inversely proportional to the length of the lines along the dry adiabats.
2. The stability of the column is indicated since the dry adiabatic lapse rate is given by the lines along the dry adiabats and the moist adiabatic lapse rate can be estimated with a little experience because the moist adiabats tend to be vertical.
3. The height of the base of convective clouds is obtained directly from the lifting condensation plot. This height is conveniently expressed in terms of the pressure altitude in conformity with the needs of aircraft operations.
4. The position of the freezing (0°C) isotherm, again conveniently given in terms of pressure altitude, is immediately apparent.

5. Air-mass identification is convenient on a pastagram since the vertical (S) lines represent temperature departures from standard (average middle-latitude) conditions and the departures that occur in the actual air are clearly represented by the mean horizontal positions of the soundings. For example, the $S = 0$ line is a plot of the standard (average middle-latitude) pressure-temperature relationship; the sounding on Plate I, approximately along the $S = 0$ line, is a typical middle-latitude sounding, slightly on the tropical side; the sounding on Plate II, far to the right in the troposphere and to the left in the stratosphere, is a typical mT sounding; the sounding on Plate IV, far to the left in the troposphere and far to the right in the stratosphere, is a typical cP sounding.

6. Since most soundings appear on the average as approximately vertical lines (except perhaps in the region of the tropopause), the S lines of the pastagram provide convenient reference lines with which changes, in space or time, between soundings plotted on separate sheets of paper can be easily determined. The examples given in the time cross section of Figure 10 illustrate the ease with which even the moderate changes in that sequence are seen.

Plate VII. This plate is designed for use as an underlay or overlay for conversion between the relative humidity h of a given parcel of air and the mixing ratio w of that parcel.

Using e_s as the saturation vapor pressure at a given temperature and w_s as the saturation mixing ratio of a given parcel of air, we can write

$$w = \frac{\rho_w}{\rho_d} = \frac{\dfrac{m_w h e_s}{RT}}{\dfrac{m_d(p - he_s)}{RT}} = \frac{m_w}{m_d\left(\dfrac{p}{he_s} - 1\right)},$$

and

$$w_s = \frac{m_w}{m_d\left(\dfrac{p}{e_s} - 1\right)}.$$

Thus, eliminating the factor p/e_s from these equations, the relationship between the variables w, w_s and h can be written as

$$h\left(\frac{m_w}{m_d w} + 1\right) = \left(\frac{m_w}{m_d w_s} + 1\right).$$

This relationship was then used, with $m_w/m_d = 0.622$, for plotting the h values corresponding to the various values of w along any given θ line, since the value of w_s occurring at the intersection of that θ line and the zero pressure-altitude line ($h = 100$ per cent) is determined by the θ and w coordinates.

As an example of the use of this diagram, suppose that it is known that the relative humidity h at some point such as point A (this would actually be plotted on the basic pastagram but is shown on Plate VII) is 50 per cent. Then the saturation mixing ratio ($w = 10$ gm/kg) at that point is given by the w line through it, so that point B on this w line and the zero pressure-altitude line can be determined. Then, following along the θ line through point B (287.2°A) to point C at the 50 per cent h line, the actual mixing ratio at point A (5 gm/kg) can be read from the w lines. The lifting condensation level (point E), for the parcel at point A, can then be determined by following the w line through point C until it intersects the θ line through point A. Similarly, the dew point (point D), for the parcel at point A, can be determined by following the w line through point C until it intersects the pressure-altitude line (on the basic pastagram) through point A.

5. Pressure-height computations.

General remarks. An attempt has been made to transform the hydrostatic equation so that routine pressure-height calculations can be made with maximum accuracy in a minimum of time. It is felt that this has been accomplished in the transformation of the hydrostatic equation into

$$\frac{\partial D}{\partial z_p} = S^* \tag{18}$$

or, in an integrated form,

$$^{z_{p2}}D - {}^{z_{p1}}D = \int_{z_{p1}}^{z_{p2}} S^* dz_p. \tag{47}$$

In the physical interpretation of this equation, D is considered as a height parameter which gives the height of any given pressure surface; z_p is the pressure parameter with which the intensity of pressure is specified; and $S^* = (T^* - T_p)/T_p$ is the temperature parameter with which the temperature of the air at any given pressure is specified. Thus it has been assumed that the distribution of temperature as a function of pressure, not height, has been measured or estimated so that the conversion from the temperature parameter T in °C to S can be accomplished. This assumption is consistent with present procedures since all present upper-air soundings, made with radiosondes or airplanes, give the distribution of temperature as a function of pressure, not height. Even in cases in which the temperature is measured or estimated as a function of height and not pressure, a convenient procedure is to use successive approximations of the temperature as a function of pressure (starting with $z \approx z_p$) and the techniques described here.

Determination of heights of pressure surfaces from soundings. The determination of the heights of any desired pressure surfaces, in terms of z_p and D, from soundings which give the temperature as a function of the pressure can conveniently be accomplished by the following steps. (This procedure is described in terms of using a pastagram, but it applies equally well to the use of any thermodynamic diagram on which lines of z_p and S are entered.)

1. Plot the observed temperature-pressure relationship on Plates I, II, III or IV with an underlay of Plate V if required. This step then effectively makes the conversion of the temperature parameter from T to S, and the conversion of the pressure parameter from millibars to pressure altitude if required. This work could thus be simplified for future radiosonde observations by calibrating the pressure elements and reporting soundings in terms of pressure altitude instead of millibars.

2. Plot the virtual temperature-pressure relationship. Since the mixing ratio at each significant level is usually determined, this can be accomplished from equation (9) or (15).

In these equations $|g_p - g|$ is never much greater than 2 cm/sec² so that $|(g_p - g)/g|$ is usually less than 0.002. Hence the virtual temperature correction due to variations of gravity is usually less than 0.6°C so that it can be neglected for any but the most accurate work. In any case, for one station this correction sensibly amounts to a shift of the entire temperature-pressure curve a constant amount $(1 + S)|(g_p - g)/g|$ units of S to the right if $g > 980$ cm/sec² and to the left if $g < 980$ cm/sec², since for this purpose percentage variations of $1 + S$ and g in the vertical are negligible.

Neglecting (or applying separately) the effect of $(g_p - g)/g$ and neglecting the last term in the brackets of equation (9) or (15), which is less than 0.002 times the value of $(m_d/m_w - 1)w/(1 + w)$, the virtual temperature correction can be expressed (with $m_d/m_w = 1.6077$) as

$$T^* - T \approx 0.6077T\frac{w}{1 + w}, \tag{48}$$

or

$$S^* - S \approx 0.6077(1 + S)\frac{w}{1 + w}. \tag{49}$$

For very accurate work small cardboard scales for several values of $(1 + S)$, giving the correction $S^* - S$, to be *added* to S to obtain S^* for any given value of w can be made. The virtual temperature pressure curve can then be mechanically plotted with these scales as a function of the mixing ratios at the significant levels. These corrections, or the cardboard scales, can conveniently be made with the aid of Table 6b. For most work, however, the approximation

$$S^* - S \approx 0.6w \tag{50}$$

is sufficiently accurate. Thus the temperature-pressure curve should be shifted to the right approximately 0.006 units of S (six-tenths of the distance between S lines on the pastagram) for each ten grams per kilogram actual mixing ratio to get the virtual temperature-pressure curve.

3. Determine the thickness of the layers between all desired pressure surfaces using equation (47).

The quantity $({}^{z_{p2}}D - {}^{z_{p1}}D)$ can be written as ${}^{z_{p2}}D - {}^{z_{p1}}D = ({}^{z_{p2}}z - {}^{z_{p1}}z) - (z_{p2} - z_{p1})$. Thus $({}^{z_{p2}}D - {}^{z_{p1}}D)$ is the actual geometric thickness between these two pressure surfaces, $({}^{z_{p2}}z - {}^{z_{p1}}z)$, minus the thickness of the standard atmosphere between the same two pressure surfaces, $(z_{p2} - z_{p1})$. Since z_p is used as the pressure parameter, the conversion from $({}^{z_{p2}}D - {}^{z_{p1}}D)$ to $({}^{z_{p2}}z - {}^{z_{p1}}z)$ can be accomplished by mentally adding $(z_{p2} - z_{p1})$ to $({}^{z_{p2}}D - {}^{z_{p1}}D)$. Thus the actual numerical conversion is seldom required and $({}^{z_{p2}}D - {}^{z_{p1}}D)$ is used as a parameter with which the thickness of the layer of air between any two pressure surfaces is described.

The value of this thickness anomaly $({}^{z_{p2}}D - {}^{z_{p1}}D)$ is then determined by the area $\int_{z_{p1}}^{z_{p2}} S^* dz_p$ enclosed on the pastagram between the horizontal lines for the two pressures considered, the vertical line for $S = 0$, and the line representing the actual distribution of S^* (the virtual temperature-pressure sounding) as a function of z_p. On pastagrams drawn in terms of feet (Plates I and III), since lines are drawn for each 1000 feet of z_p and each 0.01 of S, the area in each square formed by the z_p and S lines corresponds to a thickness anomaly $({}^{z_{p2}}D^{\text{ft}} - {}^{z_{p1}}D^{\text{ft}})$ of $1000 \times 0.01 = 10$ feet. Similarly on the pastagrams drawn in terms of meters (Plates II and IV) the area in each rectangle formed by the z_p and S lines corresponds to a thickness anomaly of $100 \times 0.01 = 1$ meter. This thickness anomaly between any two pressures can then be easily determined by counting the rectangles of the z_p and S lines enclosed between those pressures, the $S = 0$ line and the virtual temperature sounding.

This counting process is many times simplified if an average virtual temperature anomaly, $\bar{S}^*$ is determined and used with the equation

$${}^{z_{p2}}D - {}^{z_{p1}}D = \bar{S}^*(z_{p2} - z_{p1}). \tag{51}$$

$\bar{S}^*$ is then that value of S^* such that as much area is included, between z_{p1} and z_{p2} and the S^* sounding, to the right of the $\bar{S}^*$ line as to the left of the $\bar{S}^*$ line. This is of the greatest advantage when the thickness between round values of z_p is desired since then the multiplication process can be automatically accomplished by imagining the S lines to be labeled in terms of $(z_{p2} - z_{p1})S$. For example, if the thickness between each multiple of 5000 feet of z_p is desired it can be imagined that the $S = +0.01$ line is labeled as $5000(+0.01) = +50$ ft, the $S = -0.02$ line as -100 ft, etc. Then the determination of any thickness such as $({}^{z_{p1}+5000\text{ft}}D - {}^{z_{p1}}D)$ can be determined by inspection from the $\bar{S}^*$ line extending vertically from z_p to $z_p + 5000$ ft.

4. Determine the value of D at one point of the sounding. For radiosonde work the only place that *both* the height and pressure are known, hence the only place that D can be determined without using the hydrostatic equation, is the surface. The value of D at the surface is obtained by converting the station pressure, in say inches of mercury as measured with a mercurial barometer at the time of release, to pressure altitude, with some table such as Table 1, and algebraically subtracting this pressure altitude z_p from the height above sea level z of the ivory point of the barometer. For any particular radiosonde station it would be advantageous to construct a table of the form of Tables 2a–2f for the direct conversion from inches of mercury to D at the height of the barometer. Table 1 could be used to construct this additional table. For airplane soundings, especially when the height of at least one point is determined with a radio altimeter, the value of D can be determined directly as the difference of the height above sea level z, as determined with the radio altimeter, and the pressure altitude z_p, as determined with the pressure altimeter.

5. Determine the heights D of all desired pressure surfaces by successively adding the thickness anomalies as determined in 3. to the value of D at the one known point. D is thus determined as a function of z_p so that the conversion to the heights above sea level z can be very simply obtained by adding z_p to D. However, since this is such a simple process, and since, as described later, it is convenient to use D directly in meteorological map analysis, this determination of D at the desired pressure surfaces can usually be considered as representing the completion of the pressure-height computations.

It has been found convenient in routine work with maps analyzed in terms of D to make the following physical interpretation of this process. One can write

$$ {}^{z_{p2}}D = {}^{z_{p1}}D + ({}^{z_{p2}}D - {}^{z_{p1}}D). \tag{52} $$

${}^{z_{p1}}D$ and ${}^{z_{p2}}D$ are the heights, measured up from $z = z_{p1}$ and $z = z_{p2}$, of the constant pressure surfaces z_{p1} and z_{p2}, respectively. $({}^{z_{p2}}D - {}^{z_{p1}}D)$ is the geometric thickness of the layer between these two pressure surfaces minus the "standard thickness" $(z_{p2} - z_{p1})$, and is used as the parameter with which the mean virtual temperature between the two pressure surfaces is specified, since this thickness can vary only if the mean virtual temperature between these two *fixed* pressure surfaces varies. Thus for most purposes, such as drawing charts of mean isotherms, it is convenient to label these mean isotherms in terms of the parameter $({}^{z_{p2}}D - {}^{z_{p1}}D)$, instead of in °C, since then the pressure-height calculations can be performed with maximum ease.

The sounding plotted on Plate I provides a sample of this technique of pressure-height calculation. The steps for this calculation are:

1. The sounding was plotted with Plates V and VI as an underlay from the reported values of T, p and w.
2. The virtual temperature-pressure curve (the light dashed curve) was plotted 0.06 units of S to the right of the temperature-pressure curve for each 10 gm/kg of w.
3. The thickness anomalies in feet between the various pressure surfaces were determined and entered in parentheses to the right of the diagram. For example, the value of $({}^{5000\text{ ft}}D - {}^{Sfc}D)$, from the surface to $z_p = 5000$ ft, is $+40$ ft since 4 squares (to the nearest integral number of squares) are enclosed between the $S = 0$ line, the z_p line for the surface point, the $z_p = 5000$ ft line and the virtual temperature curve. Also, the value of $({}^{10000\text{ ft}}D - {}^{5000\text{ ft}}D) = +30$ ft was determined by locating a mean S line from $z_p = 5000$ ft to $z_p = 10{,}000$ ft. This line occurred about three-tenths of the way from the $S = 0$ line to the $S = 0.02$ line which was imagined as being labelled $+100$ ft.
4. The value of ${}^{Sfc}D = {}^{Sfc}z - {}^{Sfc}z_p$ was determined from the reported surface pressure, ${}^{Sfc}p = 974$ mb or ${}^{Sfc}z_p = 1090$ ft (from Table 1e), and the height above sea level of this station, ${}^{Sfc}z = 1250$ ft, as ${}^{Sfc}D = 1250 - 1090 = +160$ ft.
5. The values of D in feet at each integral multiple of $z_p = 5000$ ft were then determined by successive additions of the thickness anomalies, as shown at the right of the diagram.

The soundings plotted on Plates II and IV were evaluated in exactly similar fashion, with the values of the thickness anomaly and D entered in meters, for each kilometer of z_p. For the sounding on Plate II, ${}^{Sfc}z = 5$m, ${}^{Sfc}p = 1018$ mb, ${}^{Sfc}z_p = -39$ m from Table 1d, so ${}^{Sfc}D = 5 - (-39) = +44$ m. For the sounding on Plate IV ${}^{Sfc}z = 506$ m, ${}^{Sfc}p = 960$ mb, ${}^{Sfc}z_p = 453$ m from Table 1e, so ${}^{Sfc}D = 506 - 453 = +53$ m.

This technique of pressure-height evaluation thus provides for very accurate pressure-height computations by simple addition and subtraction of small numbers. This is possible since the accurate calculations involving logarithms or large numbers have been done once and for all in the definition of pressure altitude as the pressure parameter. Thus it is in general as convenient to make these calculations between arbitrary pressure surfaces as between predetermined standard pressure surfaces since the difficult calculations in the definition of pressure altitude have already been made for *all* pressure values. This is to be contrasted with the common procedures in terms of millibars in which the thicknesses between standard isobaric levels (say each 100 mb) have been similarly calculated and tabulated for convenience, but in which the calculations involving nonstandard pressure surfaces are in general much more difficult. This consideration is becoming more important since a great deal of data at arbitrary pressure values is becoming available from aircraft equipped with radio altimeters. Also the possibility of easily obtaining the height of *any* desired pressure surface, not just a few predetermined surfaces, seems to be very desirable.

Determination of pressures at constant-level surfaces from soundings. The pressures at predetermined constant-level surfaces, determined from soundings in which the temperature is measured as a function of the pressure, must essentially be calculated by successive approximations since the temperature distribution as a function of height is not known at the outset. This problem can conveniently be solved almost directly with very little error by the following procedure.

1. Determine the heights, expressed in terms of D, of those constant pressure surfaces for which the numerical value of the pressure altitude is equal to the numerical value of the height above sea level at which the pressure is desired. For example, the first step in determining pressures at $z = 5000$ ft, 10,000 ft, 15,000 ft, etc., is to determine the value of D at the pressure surfaces where $z_p = 5000$ ft, 10,000 ft, 15,000 ft, etc. This step is accomplished by the previously described technique.

2. Convert the value of D at these constant pressure surfaces, ${}^{z_p=a}D$, to the value of D at the corresponding constant level surfaces, ${}^{z=a}D$. Since ${}^{z=a}D$ can conveniently be thought of as a parameter with which to describe the pressure at the level $z = a$, this usually completely solves the problem, although, if desired, the value of ${}^{z=a}D$ can be converted to millibars by means of Table 3c.

A rapid method of making this conversion is

a. Locate the approximate pressure altitude $z_p = a - {}^{z_p=a}D$ of the point on the pastagram.

b. Determine the area enclosed by this pressure-altitude line and the lines for $z_p = a$, $S = 0$ and the S^* sounding. This area then approximately represents the value of $({}^{z=a}D - {}^{z_p=a}D)$.

c. Add this approximate value of the area to the value of ${}^{z_p=a}D$. This result is then the approximate value of ${}^{z=a}D$, and except in very extreme cases it will not be in error by more than 10 feet.

d. For very accurate work a more exact value of $({}^{z=a}D - {}^{z_p=a}D)$ could then be obtained by using the result of step c to locate the pressure altitude line corresponding to the level $z = a$ and repeating the process.

As an example, the calculation for the pressure at $z = 15{,}000$ ft for the sounding on Plate I is

a. Locate a point at $z_p = 15{,}000 - 300 = 14{,}700$ ft on the sounding.

b. Then $({}^{z=15000\ \mathrm{ft}}D - {}^{z_p=15000\ \mathrm{ft}}D) = -10$ ft (to the nearest 10 ft) since slightly more than one half of a square is enclosed by the sounding between $z_p = 15{,}000$ ft and $z_p = 14{,}700$ ft.

c. Then ${}^{z=15000\ \mathrm{ft}}D = +300 + (-10) = +290$ ft. By Table 3c this can be converted, if desired, to ${}^{z=15000\ \mathrm{ft}}p = 578$ mb.

The convenience of this technique in comparison with the method of determining these pressures from a pressure-height curve constructed from the heights of each round 100-mb pressure surface results primarily from the possibility of easily finding the height of those particular pressure surfaces which are on the average at nearly the same vertical position in the atmosphere as the desired constant level surfaces. Thus it is not necessary to draw a pressure-height curve to obtain a first approximation. Also the dual interpretation of D as either a height or pressure parameter saves considerable time in routine work because unit conversions are not necessary.

Pressure-height extrapolations. The extrapolation of the pressure-height relationship in regions where temperature soundings are not available is usually very easy in terms of D and z_p. Some examples of such extrapolations are

1. The simplest assumption for extrapolation in terms of D is that $S^* = 0$, in other words that $T^* = T_p$ or that the virtual temperature of the actual air is the same at all pressures as in the standard atmosphere. For such an assumption $\partial D/\partial z_p = 0$ or D is a constant in the vertical equal to its value at the point at which it is known.

This concept is commonly used in the usual definition of the altimeter setting in which the pressure at a point is reduced to sea level by use of the assumption that the standard atmosphere exists between the point considered and sea level. Thus in this case, as seen before, the value of D at sea level is assumed to be the same as at the point considered. This concept is also useful in representing the pressure distribution on the surface of the earth and will be described more fully under the discussion of the surface chart.

The assumption that D does not vary in the vertical is quite accurate when extrapolations through small vertical distances are required since, for any probable values of S^*, $({}^{z_{p2}}D - {}^{z_{p1}}D) = \bar{S}^* (z_{p2} - z_{p1})$ becomes very small for small values of $(z_{p2} - z_{p1})$. For example, in the majority of actual conditions $|\bar{S}^*| \leq 0.05$ so that, for an accuracy of extrapolation of 10 feet a range of $|z_{p2} - z_{p1}|$ of about 200 feet can be used, while for an accuracy of extrapolation of 100 feet a range of $|z_{p2} - z_{p1}|$ of about 2000 feet can be used. This type of extrapolation is very important in the determination of drift in aircraft and is discussed more fully in the section on that subject.

2. Extrapolations from points at which the height, pressure and temperature are known can conveniently be made by assuming that the value of S^* throughout the column considered is equal to its value at the known point. This assumption is then equivalent to assuming that the lapse rate is roughly moist adiabatic (6.5°C/km) in the troposphere and isothermal in the stratosphere. The general extrapolation formula for this assumption is then

$$ {}^{z_p}D - {}^{z_{p0}}D = {}^{z_{p0}}S^*(z_p - z_{p0}), \tag{53} $$

where ${}^{z_{p0}}D$, ${}^{z_{p0}}S^*$ and z_{p0}. are the values of these quantities at the known point and ${}^{z_p}D$ is the value of the height (or pressure) parameter at the desired point of extrapolation where the pressure altitude is equal to z_p.

As an extreme example of the vertical distance through which such an extrapolation can safely be made, consider that the actual lapse rate in the troposphere is isothermal, as represented by line $EFGH$ in Plate III. Then, assuming that the value of ${}^{z_{p0}}D$ at point E is equal to $-$ 200 feet, the actual values, the extrapolated values, and the errors in the extrapolation of D, to the nearest ten feet, at the various points are given in Table 8.

TABLE 8.

Point	E	F	G	H
Range of z_p in ft	0	1000	2000	5000
Actual D in ft	-200	-190	-170	-60
Extrapolated D in ft	-200	-190	-180	-150
Error in ft	0	0	10	90

Conversion between constant level and constant pressure data. The extrapolation assumption that S^* is constant is very convenient for converting the value of the pressure (and temperature) at a constant level surface to the value of the height of the numerically corresponding pressure-altitude (constant pressure) surface, or vice versa when it is impossible or inconvenient to obtain a plot of the sounding between these two surfaces. Since these two surfaces are seldom separated by more than 2000 feet, this approximation of the *lapse rate* should seldom lead to an error of more than 20 feet. ${}^{z=a}D$, a parameter of the pressure at $z = a$, can be considered to be the distance, *measured in the standard atmosphere*, from a height where the pressure is ${}^{z=a}z_p$ to the height of the pressure surface $z_p = a$. Similarly ${}^{z_p=a}D$, a parameter of the height of the pressure surface $z_p = a$, can be considered as being the distance, *measured in the actual atmosphere*, from the height $z = a$ where the pressure is ${}^{z=a}z_p$ to the height of the pressure surface $z_p = a$. Hence these two distances are measured between the same two pressure surfaces, one in the standard atmosphere and the other in the actual atmosphere. Thus, since we are assuming that S^* (hence T^*/T_p) is constant between these surfaces, we can write

$$ {}^{z_p=a}D = {}^{z=a}D\frac{T^*}{T_p} = {}^{z=a}D(1 + S^*). \tag{54} $$

Plate VIII has been drawn to solve this equation directly. It consists of a transparent overlay of quasi-horizontal lines for ${}^{z=a}D$, superimposed on Plate I to be used with the S^* values of Plate I (or Plate III). This overlay is so constructed that the values of ${}^{z_p=a}D$ are represented by the horizontal lines on Plate I (or III). Numerically corresponding ${}^{z=a}D$ and ${}^{z_p=a}D$ lines intersect each other at $S^* = 0$. Hence the labels of the ${}^{z=a}D$ lines also apply to the ${}^{z_p=a}D$ lines through these intersection points. It follows that this plate can be used to convert ${}^{z_p=a}D$ to ${}^{z=a}D$ and vice versa for any level (any value of a) since the value of S^* for any level can easily be determined on Plate III with the values of z_p and T^*. As an example of the use of this plate, the value of ${}^{z=15000\ \mathrm{ft}}D$ for the sounding plotted on Plate I is given by locating point A at the value of ${}^{z_p=15000\ \mathrm{ft}}D = +\ 300$ ft and at the value of ${}^{z_p=15000\ \mathrm{ft}}S^* = 0.015$, determined from the sounding on Plate I. Thus ${}^{z=15000\ \mathrm{ft}}D = +\ 290$ ft read from the slanting lines of Plate VIII. Similarly for some other levels in this sounding, the values are given in Table 9.

TABLE 9

Point	a	${}^{z_p=a}D$	S^*	${}^{z=a}D$
B	35,000	+520 ft	0.031	+500 ft
C	40,000	+650 ft	0.020	+630 ft

Plates IX and X are conversions of Plate VIII in which the values of ${}^{z=a}D$ have been converted to millibars and the values of S^* have been converted to T^* at either the constant level or constant pressure surface. The description of the construction and use of these plates is given on Plate IX. They have been designed primarily for the conversion from pressures in millibars at the various constant level surfaces to the heights of the corresponding pressure surfaces, so that these constant pressure charts can easily be drawn from present and past U. S. radiosonde reports. It has been found that a very efficient method of calculating the pressures in millibars at these constant level surfaces for the original encoding of this type of data consists of calculating the heights (in D) of the numerically corresponding pressure-altitude surfaces and using these plates (or the previously described method) for the final conversion. Some examples of the use of these plates are

1. Given: ${}^{z=10000\ \text{ft}}p = 707$ mb, ${}^{z=10000\ \text{ft}}T = +10°\text{C}$; then ${}^{z_p=10000\ \text{ft}}D = +400$ ft.
2. Given: ${}^{z=20000\ \text{ft}}p = 445$ mb, ${}^{z=20000\ \text{ft}}T = -50°\text{C}$; then ${}^{z_p=20000\ \text{ft}}D = -970$ ft.
3. Given: ${}^{z_p=10\ \text{km}}D = +1000$ ft, ${}^{z_p=10\ \text{km}}T = -53°\text{C}$; then ${}^{z=10\ \text{km}}p = 277$ mb.

Utilization of aircraft reports of pressure-height data. One of the best sources of pressure-height data over oceanic areas are data from aircraft equipped with radio and pressure altimeters. The reporting of D at the corresponding values of the pressure altitude is an efficient method of distributing these data. This system has several advantages, namely:

1. D is easily obtainable by subtracting the pressure-altimeter reading (corrected for instrumental errors) from the radio-altimeter reading.
2. D is useful in itself for navigators in drift determinations.
3. The vertical position of the observation can be given with sufficient accuracy to the nearest 100 feet since the variations of D in 100 feet are almost always less than 10 feet.
4. When vertical position is given in terms of pressure altitude (in contrast to geometric altitude) no change in the form of aircraft reports is necessitated when the flight is over land or when no radio altimeter is available.
5. When vertical position is given in terms of pressure altitude (in contrast to millibars) geometric heights are apparent by adding D, and conversion from the observational pressure parameter is eliminated.
6. Reports in terms of D (in contrast to almost any other common parameter) are immediately applicable to analysis of the pressure distribution on vertical cross sections.
7. The vertical extrapolation of these reports (as seen in this section) to standard surfaces for "horizontal" analysis is convenient.

A convenient general assumption for the lapse rate between the observation point and the standard "horizontal" surface is that S^* is equal to its value, as determined by z_p and T at the observation point, throughout this column. Thus the general equation for this assumption (53) applies to this problem and can conveniently be solved on the pastagram. As an example, assume that it was determined that at some point $z_{p0} = 21{,}000$ ft, ${}^{z_p0}T = -17°\text{C}$ and ${}^{z_p0}D = +1080$ ft (point J, Plate III). Then the value of D at $z_p = 20{,}000$ ft (for analysis of the contours of the $z_p = 20{,}000$-ft surface) would be estimated as ${}^{z_p=20000\ \text{ft}}D \approx +1080 - 40 = +1040$ ft, where the -40 feet corresponds to the area $JJ'K'K$ since $z_p - z_{p0}$ is negative. Further, the value of D at $z = 20{,}000$ ft (for analysis of the isobars in terms of D at $z = 20{,}000$ ft) would be estimated as ${}^{z=20000\ \text{ft}}D = 1040 - 40 = +1000$ ft (by area $KK'L'L$ since this extrapolatión is to be taken to a pressure altitude of $z_p \approx 20{,}000 - 1040 \approx 19{,}000$ ft). Finally, the value of p at $z = 20{,}000$ ft (for analysis of the isobars in terms of millibars at 20,000 ft) would be ${}^{z=20000\ \text{ft}}p^{\text{mb}}({}^{z=20000\ \text{ft}}D\ {}^{\text{ft}}) = 485$ mb from Table 3a.

Plate XI has been constructed as an aid in making large numbers of these extrapolations to the value of D at the nearest round 5000-foot pressure-altitude surface. The hyperbolae of equal areas on the pastagram can conveniently be placed on a transparent overlay (or printed in a different color) and used with Plate III as shown. Some examples of the use of Plate XI are

1. Given: $z_p = 9{,}000$ ft, $T = +8°\text{C}$, $D = +320$ ft; then ${}^{z_p=10000\ \text{ft}}D = +320 + 40 = +360$ ft.
2. Given: $z_p = 11{,}000$ ft, $T = +9°\text{C}$, $D = +410$ ft; then ${}^{z_p=10000\ \text{ft}}D = +410 - 60 = +350$ ft.
3. Given: $z_p = 2{,}000$ ft, $T = -2°\text{C}$, $D = -200$ ft; then ${}^{z_p=0}D = -200 + 90 = -110$ ft.
4. Given: $z_p = 23{,}000$ ft, $T = -38°\text{C}$, $D = -1140$ ft; then ${}^{z_p=25000\ \text{ft}}D = -1140 - 60 = -1200$ ft.

If constant level analysis is desired, the conversion from ${}^{z_p=a}D$ to ${}^{z=a}D$ can then be made directly on the pastagram by means of Plate VIII. Similarly the conversion to ${}^{z=a}p$ can be made from this last step with Table 3a or directly from the first step with Plate IX or X.

Extrapolations from surface data. In the general case any type of temperature distribution can be assumed and the extrapolations can be carried out by means of the methods given for evaluation of soundings. For other specific assumptions special diagrams can be made to facilitate the extrapolations.

A very convenient scale for extrapolating surface observations to the 10,000-ft and 20,000-ft levels, the "Isobaric Contour Extrapolation Scale" shown on Plate XII, has been designed by Capt. William J.

Plumley, Capt. Reid A. Bryson and Lt. John W. Bookston, U. S. Army Air Forces. It has been designed for use in connection with observations in oceanic areas where the reporting stations are close to sea level. The scale relates sea-level pressure (in millibars), mean virtual temperature (in degrees centigrade or Fahrenheit), surface temperature (in degrees centigrade or Fahrenheit), low cloud type, height of low cloud base, and the value of D (in feet) at z_p = 10,000 ft or 20,000 ft.

Sea-level pressure lines are horizontal and labelled along the left-hand border. The large numbers increasing upward are used for calculations of D at z_p = 10,000 ft. The small numbers decreasing upward are used for calculations of D at z_p = 20,000 ft. Temperature lines are vertical and the temperature increases from left to right in degrees Fahrenheit or centigrade. The diagonal lines which extend upward from right to left are lines of constant D (in feet) at z_p = 10,000 ft. The diagonal lines which extend upward from left to right are lines of constant D (in feet) at z_p = 20,000 ft.

A sliding strip (the portion between the double lines on Plate XII) contains the scales of temperature and three index indicators I_0, I_{10000}, and I_{20000}. When I_0 on the sliding scale is set opposite I_0 on the fixed scale (as printed in Plate XII), the value of D at both z_p = 10,000 ft and z_p = 20,000 ft is determined for any selected mean virtual temperature (read on the temperature scale) and sea-level pressure.

When I_{10000} on the sliding scale is set opposite I_{10000} on the fixed scale, the temperature scale is used to indicate surface temperature rather than mean virtual temperature. The use of the I_{20000} indicator is analogous to the use of the I_{10000} indicator. The additional symbols below the sliding scale are the cloud indicators. The numbers below each cloud symbol denote the height of the cloud base in the international code. If I_{10000} on the sliding scale is set opposite any cloud indicator in the I_{10000} fixed group, a correction is introduced for the difference between the lapse rate for a particular cloud type and the U. S. Standard lapse rate of minus 6.5° C/km. Sea-level pressure and surface temperature then determine the value of D at z_p = 10,000 ft.

The following assumptions have been made as to lapse rates for particular low cloud types. A dry adiabatic lapse rate was assumed to exist up to the base of the cloud, a moist adiabatic lapse rate through the cloud, a two-degree centigrade inversion at the top of the cloud (four-degree centigrade inversion for stratus or stratocumulus) and the U. S. Standard lapse rate above the inversion. To correct for the moisture in the atmosphere two degrees centigrade were added to the mean temperature of the column from sea level to z_p = 10,000 ft, and one degree centigrade was added to the mean temperature of the column from sea level to z_p = 20,000 ft. Fair weather cumulus clouds were assumed to have tops at 4000 feet if the height of their base is 3, 4, or 5 in terms of the international code. If the height of the base is 6 the tops were assumed to be at 6100 feet and if it is 8 the tops were placed at 9300 feet. Swelling cumulus were assumed to have tops at 8000 feet if the cloud bases are coded 3, 4 or 5, at 9000 feet if the bases are coded as 6, and at 11,000 feet if the bases are coded as 8. Cumulonimbus were assumed to have tops higher than 20,000 feet. Stratus or stratocumulus were assumed to have a thickness of 1500 feet for height of bases coded as 1 through 6.

Example 1.

Given:

Sea-level pressure, 1010 mb.
Surface temperature, 80°F.
Cloud type, swelling cumulus, height of bases 5.
Find D at z_p = 10,000 ft and at z_p = 20,000 ft.

Procedure:

1. Set I_{10000} of sliding scale opposite symbol for swelling cumulus with base marked 5 in the I_{10000} fixed group.
2. At the intersection of the T equal 80°F line and the sea-level pressure line for 1010 mb, read the value of D = + 400 ft at z_p = 10,000 ft.
3. Set I_{20000} of sliding scale opposite the appropriate cloud symbol in the I_{20000} fixed group.
4. At the intersection of the T equal 80°F line and the sea-level pressure line for 1010 mb (on the outer pressure scale), read the value of D = + 1050 ft at z_p = 20,000 ft.

Example 2.

Given:

Sea-level pressure, 1010 mb.
Mean virtual temperature between sea level and z_p = 10,000 ft is 7°C.
Mean virtual temperature between sea level and z_p = 20,000 ft is − 6°C.
Find D at z_p = 10,000 ft and at z_p = 20,000 ft.

Procedure:

1. Set I_0 of the sliding scale opposite I_0 of the fixed scale (as in Plate XII). At the intersection of + 7°C and 1010 mb (on the inner pressure scale), read D = − 10 ft at z_p = 10,000 ft.
2. At the intersection of − 6°C and 1010 mb (on the outer pressure scale), read D = − 150 ft at z_p = 20,000 ft.

6. Theoretical wind calculations.

Geostrophic wind calculations. Using $\Omega = 0.2625\ \text{hr}^{-1}$ and $g = 980\ \text{cm/sec}^2$ and expressing v in knots, z and D in feet and n in degrees of latitude, equations (26) and (27) for conditions on a constant pressure surface can be written

$$\frac{v \sin \phi}{0.357} = -\left(\frac{\partial D}{\partial n}\right)_p = -\left(\frac{\partial z}{\partial n}\right)_p. \tag{55}$$

The similar equation for conditions on a constant level surface is

$$\frac{v \sin \phi}{0.357} = -(1 + S^*)\left(\frac{\partial D}{\partial n}\right)_z. \tag{56}$$

This latter equation thus contains the additional factor, $(1 + S^*)$, which, if set equal to one, can cause an error of at most about 10 per cent ($S^* = 0.1$) but in most cases would cause an error of less than about 5 per cent. Hence (in harmony with common practice in which density variations at *one* level are neglected) if $(1 + S^*)$ is set equal to one the numerical calculation of the geostrophic wind (in terms of D) on either constant level or constant pressure surfaces is the same and independent of vertical position. This is in contrast with the ordinary methods of geostrophic wind calculation (in terms of pressure) which necessitate the use of different constants for different levels. Thus D as a *pressure parameter* at constant levels provides for added convenience in these calculations.

Plate XIII gives the solution of these equations (neglecting S^* in the constant level case) in terms of the horizontal distance corresponding to a change of D (or z) of 100 feet. Some examples of its use are:

1. The spacing of 100-foot contour lines for a 25-knot (29 mi/hr or 13 m/s) wind at a latitude of 35° is 2.5 degrees of latitude (150 nautical miles, 172 statute miles or 278 kilometers).
2. The geostrophic wind component normal to a line along which the value of D changes at a rate of 100 feet per 60 nautical miles (1 degree of latitude) at a latitude of 25° is 85 knots (98 mi/hr, 44 m/s or 34 degrees of latitude per 24 hours).

Other techniques of solving the geostrophic wind equation are given under the sections on drift determinations and space cross sections.

Gradient wind calculations. It has been found convenient to calculate the gradient wind speed V in terms of the geostrophic wind speed v. Substituting $2\Omega v \sin \phi$ for the various expressions of the pressure gradient force in the gradient wind equations (28)–(31), one obtains

$$\frac{V^2}{v - V} = \pm\, 2\Omega R_T \sin \phi. \tag{57}$$

With V and v expressed in knots, R_T expressed in degrees of latitude and Ω set equal to $0.2625\ \text{hr}^{-1}$ this becomes

$$\frac{V^2}{v - V} = \pm\, 3.15 R_T \sin \phi. \tag{58}$$

Plate XIV has been drawn according to this equation with the left portion for the minus sign (anticyclonic curvature) and the right portion for the plus sign (cyclonic curvature). The speed scales can be used as indicating miles per hour instead of knots if the auxiliary R_T scale at the bottom is used. Some examples of solving the gradient wind equation with Plate XIV are

1. Given: At latitude 40° a radius of curvature of 20 degrees of latitude and a geostrophic wind velocity (from Plate XIII) of 50 knots. Point A is located at $R_T = 20$ degrees of latitude and $\phi = 40°$. If the curvature is cyclonic, the gradient wind velocity at point B is 45 knots. If the curvature is anticyclonic, the gradient wind velocity at point C is 60 knots.
2. Given: An observed wind of 50 knots at 30° latitude and an estimated cyclonic radius of curvature of 5 degrees of latitude. Point D is located at $R_T = 5$ degrees of latitude and $\phi = 30°$. The geostrophic wind (point E for $V = 50$ knots) is 83 knots. The spacing of 100-foot D lines from Plate XIII is 0.85 degrees of latitude or 60 miles.

Thermal wind calculations. The usual simplifications of the thermal wind equation (34), that is, neglecting the effect of V^2/R_T and neglecting the temperature factors in the constant level scheme, result in the simplified equation,

$$\frac{\partial 2\Omega v \sin \phi}{\partial z_p} = -g\left(\frac{\partial S^*}{\partial n'}\right)_p. \tag{59}$$

Expressing v in knots, z_p in feet and n' in degrees of latitude and integrating through a finite difference of pressure altitude $z_{p2} - z_{p1}$, this can then be written

$$\frac{\Delta v \sin \phi}{0.357} = \left(\frac{\partial S^*(z_{p2} - z_{p1})}{\partial n'}\right)_p = \left(\frac{\partial({}^{z_{p2}}D - {}^{z_{p1}}D)}{\partial n'}\right)_p. \tag{60}$$

This formula is very similar to that for the geostrophic wind equation and Plate XIII can conveniently be used to solve it. For this purpose

1. The velocity scale is used as the scale of the magnitude of the shear of the wind, in knots, which occurs through a vertical distance corresponding to an arbitrary change of pressure altitude.

2. The spacing scale is used as the scale for the spacing of isolines of the quantity ${}^{z_{p2}}D - {}^{z_{p1}}D$ drawn for intervals of 100 ft. It is apparent from equation (60) that the pattern of these lines is the same as the pattern of the mean isotherms for the same layer. It follows, therefore, that the quantity ${}^{z_{p2}}D - {}^{z_{p1}}D$ can be used directly as a temperature parameter making it unnecessary, for most purposes, to convert its values into values of the mean temperature in degrees.

An example of this use of Plate XIII is as follows: If at latitude 30° the magnitude of the shear of the wind between the pressure altitude $z_p = 5000$ ft and $z_p = 10{,}000$ ft is 20 knots, the spacing of isolines of ${}^{z_p=10000\text{ ft}}D - {}^{z_p=5000\text{ ft}}D$ drawn for 100-ft intervals is 3.6 degrees of latitude or 250 miles. Since this scale applies to an arbitrary range of pressure altitude, the calculation in this example could also be used to give, for a shear of 20 knots from $z = 5000$ ft to $z = 10{,}000$ ft, the approximate spacing of 100-ft lines of the quantity ${}^{z=10000\text{ ft}}D - {}^{z=5000\text{ ft}}D$ which can be used as an approximate parameter of the mean isotherms between these constant-level surfaces.

7. Applications to aircraft operations.

Drift determinations with radio and pressure altimeters. In general the value of D can easily be determined in an airplane at any given instant by subtracting the value of the pressure altitude, as determined with a pressure altimeter, from the value of the height above sea level as measured with a radio altimeter. If such determinations are made at two different times the component of the geostrophic wind normal to the track over which the airplane has travelled between these two observations can be calculated. The drift angle of the airplane can then be determined with the aid of this value of the cross wind and the true air speed of the airplane.

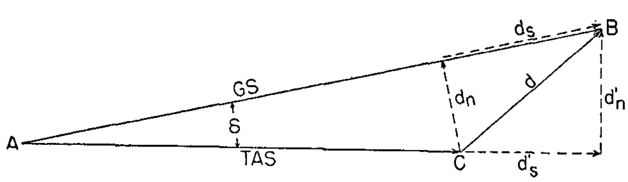


FIGURE 4.

Figure 4 illustrates the geometry involved in this problem.

Point A is the position of the airplane at the time of the first observation of the altimeter correction, D_1.

Point B is the position of the airplane at the time of the second observation, D_2.

Point C is the position the airplane would have at the later time if there were no wind.

d is the wind distance travelled between readings and is proportional to the wind speed and in the direction of the wind.

Since a geostrophic wind is assumed, so that the wind blows parallel to lines of constant D (isobars or contour lines), the value of D at point C is also equal to D_2.

TAS is the air distance travelled between observations which is proportional to the true air speed and is in the direction of the heading of the airplane.

GS is the ground distance or track actually travelled between readings which is proportional to the ground speed.

δ is the drift angle.

d_n is the component of the wind distance normal to the track.

d_s is the component of the wind distance parallel to the track.

d_n' is the component of the wind distance normal to the heading.

d_s' is the component of the wind distance parallel to the heading.

The geostrophic wind relationship gives the component of the wind normal to *any* distance, x, along which a given pressure gradient occurs. Thus, if x is taken as the ground distance GS, d_n is determined. The drift angle δ is then given by the formula $\sin \delta = d_n/TAS$. On the other hand, if x is taken as the air distance TAS, d_n' is determined. The drift angle is then given by the formula $\sin \delta = d_n'/GS$. Thus an accurate determination of the drift angle requires an estimate of the ground speed in both procedures. The choice of which of these two procedures should be used (they both give the same result) seems to be primarily one of personal preference. The first procedure will be used in the rest of this article.

When no other navigational aid is available for obtaining the ground speed the value of the drift angle must be approximated by using TAS instead of GS. The error due to this approximation is, however, usually quite small since the head or tail component of ordinary winds has little effect on the drift angle for high-speed aircraft. Even a rough estimate of the head or tail wind component from, say, a wind forecast sensibly eliminates this error in the drift angle. It is possible to use a double-drift procedure with this technique to determine the total geostrophic wind vector, but usually the time involved in flying off course makes this impractical.

The geostrophic wind equation for this purpose can be expressed as

$$v_n = \frac{21.4}{\sin \phi} \frac{D_2 - D_1}{x}, \tag{61}$$

where v_n is expressed in knots, x (the ground distance) is expressed in nautical miles, D_2 and D_1 are expressed in feet, ϕ is the mean latitude of points A and B, and the differential expression $(\partial D/\partial n)_p$ has been replaced by the finite difference expression $(D_2 - D_1)/x$. A calculation diagram which has been found to be convenient for these computations is given in Plate XV. Instructions and an example of its use are given in the diagram.

It has been found that in most cases in temperate and arctic latitudes it is necessary to obtain the values of D_1 and D_2 to a relative accuracy of about 10 feet in order to obtain satisfactory accuracy in the drift angles. This can be accomplished with careful use of present equipment since it is the *relative* accuracy that is important, that is, any *constant* error in either or both of the altimeters is eliminated in the subtraction process. Thus it is possible to make most of these calculations directly from the readings of the two altimeters. However, since absolute observations of D are very important as meteorological data for other uses, and since in some cases it is necessary to make hydrostatic calculations in the drift determinations, it is usually desirable to apply the available instrumental corrections to the readings of the altimeters to obtain as great an accuracy as possible for z and z_p before they are subtracted to give D. Since such (even relative) accuracy is very difficult to obtain when flying over land this method of drift determination is limited to use over oceans or large lakes. Close to the equator the pressure gradients are very small for usual wind speeds so that excessive flight times between observations are required to obtain measurable values of $D_2 - D_1$. Thus the usefulness of this method is limited in tropical regions. Some cases have been observed, however, in which at least the direction of drift has been given as near to the equator as 5 degrees of latitude.

Since the geostrophic wind equation used refers to conditions on a constant pressure surface the successive determinations of D should be adjusted, using the hydrostatic equation, to the same pressure surface. In usual "level" flight the airplane is kept approximately at a constant value of the pressure altitude (pressure-altimeter reading set at 29.92) but slight variations (of the order of 300 feet) from the flight "level" are constantly occurring due to turbulence, etc. For such "level" flight the necessary hydrostatic calculations are automatically accomplished by using D in the computations since D seldom varies in a vertical distance of this amount by more than 10 feet. In climbs or descents the necessary hydrostatic calculations can conveniently be made by using the following procedure with a pastagram such as Plate III.

1. Locate the points on the pastagram corresponding to the pressure altitudes, z_{p1} and z_{p2}, and temperatures, T_1 and T_2, of the air at the two times of observation.
2. Determine the value of ${}^{zp2}D_1 - {}^{zp1}D_1$, the change of D at the horizontal position of the first observation, from the pressure altitude of the first observation to the pressure altitude of the second observation. This quantity is the area enclosed by the lines $z_p = z_{p1}$, $z_p = z_{p2}$, $S = 0$ and the line joining the two points of step 1, and is equal to the number of enclosed squares of the z_p and S lines multiplied by 10 feet. The algebraic sign of this quantity is

   a. Positive if the points of step 1 are to the right of the $S = 0$ line and $z_{p1} < z_{p2}$.
   b. Positive if the points of step 1 are to the left of the $S = 0$ line and $z_{p1} > z_{p2}$.
   c. Negative if the points of step 1 are to the right of the $S = 0$ line and $z_{p1} > z_{p2}$.
   d. Negative if the points of step 1 are to the left of the $S = 0$ line and $z_{p1} < z_{p2}$.

3. Determine the value of ${}^{zp2}D_1$ by algebraically adding the value of ${}^{zp2}D_1 - {}^{zp1}D_1$ to the observed value of ${}^{zp1}D_1$.
4. Use $D_2 - {}^{zp2}D_1$ for $D_2 - D_1$ in the drift angle calculations.

Two examples of the hydrostatic calculation, shown on Plate III, are given in Table 10.

TABLE 10

	Point	z feet	z_p feet	T °C	D feet	${}^{zp2}D_1 - {}^{zp1}D_1$ feet	${}^{zp2}D_1$ feet	$D_2 - {}^{zp2}D_1$ feet
First observation	P	9870	9220	−15	−650	−70	−720	+110
Second observation	Q	11460	10850	−16	−610			
First observation	S	15910	15300	0	+610	−70	+540	+ 60
Second observation	R	14720	14120	0	+600			

*Pressure-pattern flying.** The determination of D with radio and pressure altimeters while in flight provides a method for the continual adjustment of flight plans to take fullest advantage of winds in long flights over water. The original flight plans can best be made from the meteorologist's forecast of the wind distribution. If these forecasts are given to the navigator in the form of a map analyzed in terms of D at the flight pressure altitude, the values of D observed in flight can conveniently be used to make relatively small corrections. Slight changes in flight plan can then be made en route to take fullest advantage of the actual wind conditions. It is felt that the development and use of these procedures will prove to be very valuable since minimum flight times and minimum fuel con-

* This is the term applied by H. E. Hall (3) and associates of Transcontinental and Western Air, Inc. in their extensive work of choosing flight paths which use the winds to fullest advantage.

sumption can thus be obtained. Furthermore, the increased amount of observational data and the more direct and detailed verification of forecasts should result in better general forecasting procedures.

Height determinations. As seen in the discussion of altimeter settings, the altimeter correction D is a very convenient parameter with which the meteorologist can give pressure-height data to flying personnel for use over land or when radio altimeters are not available. These data can conveniently be given in the form of constant pressure maps, vertical space cross sections or vertical time cross sections, all analyzed in terms of D with the vertical position indicated in terms of pressure altitude.

The following procedure can be used for determining elevations of aircraft above sea level over land in coastal regions when a radio altimeter is available. This method is often needed since it is usually quite difficult to determine accurately the height of the particular land surface beneath the airplane at any given instant. If an observation of the value of D with both radio and pressure altimeters is made over the water, and direct wind observations at the flight level are made, the change in D along the flight level (constant pressure surface) from this observational point to any desired point over the land can be calculated by using the geostrophic wind equation,

$$v_n = \frac{21.4}{\sin\phi}\left(\frac{\partial D}{\partial n}\right)_p. \tag{62}$$

In this equation ∂D is the value of this "horizontal" change in D, in feet, ∂n is the distance in nautical miles between the two points, ϕ is the average latitude of the two points and v_n is the component of the wind in knots normal to the line joining the two points. Thus a value of D at the desired point over land is determined. This value is independent of forecast errors and of any constant instrumental errors of the pressure altimeter. The value of z is then obtained by adding D to z_p.

This procedure also offers the possibility of determining the elevation of land surfaces in unsurveyed regions. For this purpose several approximately simultaneous wind observations and readings of radio and pressure altimeters over a known elevation and the unknown point could be made. These observations would be made at some convenient constant pressure surface which is everywhere above the terrain and above the level of frictional influences, so that the geostrophic (or gradient) wind equation could be used to determine the applicable value of D over the desired point. Such determinations could probably be made quite accurately, even far inland under favorable weather conditions, with two or more airplanes in which the altimeters are carefully calibrated with respect to each other.

Weather chart analysis in terms of altimeter corrections.

It has been found that the altimeter correction D is a very convenient parameter with which to represent the spacial distribution of pressure and temperature on maps and cross sections. In fact the concept of the altimeter correction originated in a search for some such parameter with which one could conveniently represent the continuous pressure distribution in the vertical as well as in the horizontal.

The representation of the spacial distribution of pressure can conveniently be accomplished with either the constant pressure scheme or the constant level scheme. As shown in this section the similarity of the two schemes and the convenience of either for routine work become more marked if z_p and D are used as parameters of pressure and height respectively in the constant pressure scheme and if D and z are used as the parameters of pressure and height respectively in the constant level scheme.

Figure 5 is an example of the similarity of these two schemes in a "horizontal" representation. The solid lines are contours, in terms of D, of the constant pressure surface, $z_p = 20{,}000$ ft measured from $z = 20{,}000$ ft. The dotted lines are isobars at $z = 20{,}000$ ft measured by the displacement D, of the standard atmosphere required to obtain the observed pressure at any given point on the map. In order to show the correspondence of this representation with the common one in millibars at $z = 20{,}000$ ft, a constant level chart analyzed in terms of millibars was prepared for the same data (Fig. 6). The solid lines are isobars in terms of millibars while the dotted lines are isobars in terms of D and are identical with the dotted lines in Figure 5.

The constant pressure scheme is used in this article to illustrate analysis in terms of D since it is felt that it is usually more convenient than the constant level scheme. As seen in the section on pressure-height extrapolations, the conversion from the constant pressure scheme to the constant level scheme, especially if z_p is used as the pressure parameter in the constant pressure scheme and D is used as the pressure parameter in the constant level scheme, can easily be accomplished. Some of the reasons why the constant pressure scheme was chosen are

1. Since most upper-air observations made with radiosonde or aircraft record pressure, not height, these observations are directly applicable to representation in the constant pressure scheme without requiring pressure-height computations or estimations.

2. Calculations of height and of geostrophic, gradient and thermal winds are in general more convenient in the constant pressure scheme. In fact

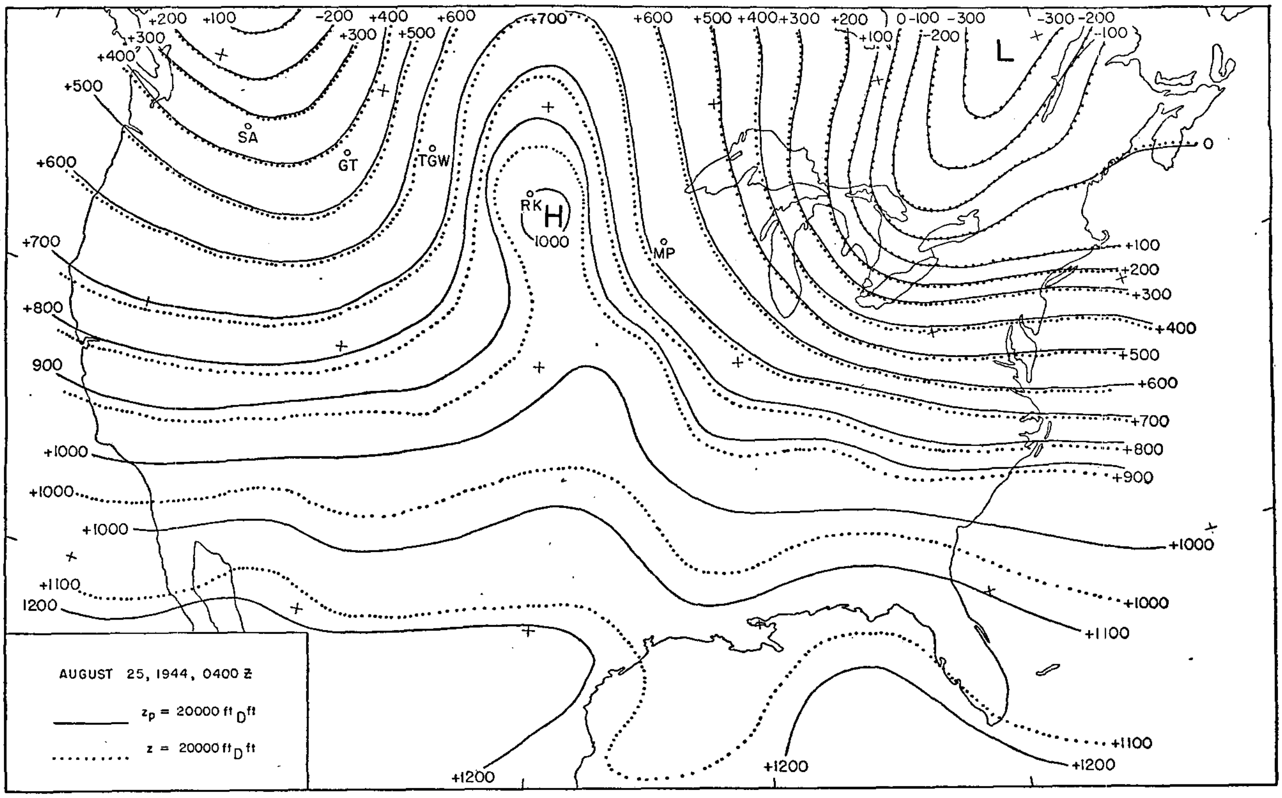


FIGURE 5.

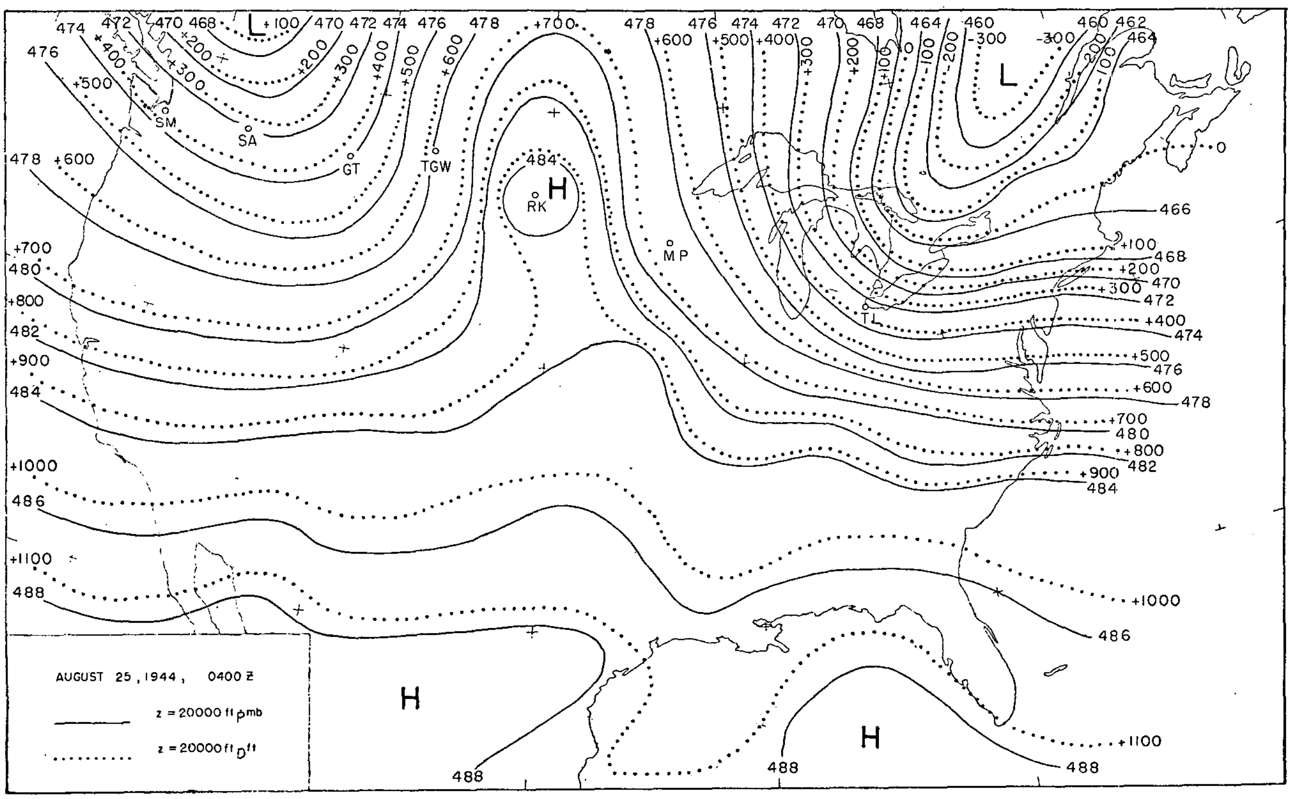


FIGURE 6.

it seems that the most convenient method of making these calculations in the constant level scheme is to use the formulae for the constant pressure scheme as the first approximate solution by substituting z for z_p in the formulae.

3. Thermodynamic representations and calculations are more convenient in the constant pressure scheme since then the independent variable in the spacial representations is itself a thermodynamic quantity. Thus immediate correlation between the spacial representations and the thermodynamic diagram is obtained; in many cases the spacial representations can then be used directly as thermodynamic diagrams. This point is illustrated by the time cross section described below.

4. The constant pressure scheme (in terms of z_p) is more directly useable by flying personnel since in the upper air direct determination of the pressure altitude, and hence the corresponding positions on the charts, is always convenient while the direct determination of height is usually more inconvenient or even impossible.

Constant pressure charts. Figures 5, 7 and 8 are synoptic examples of contour analysis (solid lines in terms of D) of constant pressure surfaces for the respective values $z_p = 20{,}000$ ft, $z_p = 10{,}000$ ft and $z_p = 5000$ ft. These charts then have, in general, the same interpretation as any other contour map of a constant pressure surface; for instance, the gradient wind blows parallel to the contour lines and the speed of the geostrophic wind is inversely proportional to the spacing of the contour lines. The latter relationship is independent of the particular surface considered, so that the analysis in terms of D has the added convenience that numerical comparison of the intensity of the circulations at various levels is obtained from the numerical values of D. Also these charts directly provide flight personnel with the altimeter correction (which can also easily be used as an altimeter setting) that applies to an *interval* of elevation near the respective pressure altitudes drawn for.

The above choice of constant pressure surfaces provides several conveniences such as the following:

1. The winds, as reported at round values of z, can conveniently be placed directly on the map for the corresponding value of z_p, since on the average z_p occurs at z. This point is of primary importance since accurate contour analysis requires the use of wind reports with the gradient wind relationship. Also most upper-air wind forecasts are desired at round values of z_p or z.

2. It is convenient to determine by means of pressure-height computations, the heights of *any* round value of the pressure altitude for use with the winds already reported at the corresponding values of z. In general, the pressure-height computations to such arbitrary levels are relatively much more difficult by ordinary methods.

3. Contour analysis in terms of D for round values of z_p is efficient since z can be obtained by simple addition without conversion of units.

4. The conversion from constant level charts to constant pressure charts, and vice versa, for *any* desired level, is in general convenient only if the constant pressure charts are drawn for those surfaces for which the pressure altitude is numerically equal to the height above sea level of the constant level considered. This is very important for preserving the usefulness of past constant level charts when a change to the constant pressure scheme of analysis is made.

Mean temperature charts. Figures 7 and 8 are examples of mean virtual temperature charts drawn in terms of the thickness of the layer between the respective constant pressure surfaces. The dotted lines on Figure 7 represent the thickness between $z_p = 10{,}000$ ft and $z_p = 20{,}000$ ft and are labelled in terms of the thickness parameter ${}^{z_p=20000\text{ ft}}D - {}^{z_p=10000\text{ ft}}D$. This quantity is also a parameter for the mean virtual temperature. Similarly the dotted lines on Figure 8 are drawn for ${}^{z_p=10000\text{ ft}}D - {}^{z_p=5000\text{ ft}}D$.

These charts can be interpreted either as thickness charts with the lines labelled in terms of ${}^{z_{p2}}z - {}^{z_{p1}}z$ or as mean virtual temperature charts with the lines labelled in terms of °C. Thermal wind computations in terms of ${}^{z_{p2}}D - {}^{z_{p1}}D$ can conveniently be made with Plate XIII.

A comparison of numerical values of ${}^{z_{p2}}D - {}^{z_{p1}}D$ in the vertical provides a representation of the average lapse rate. For example, assuming that ${}^{15000\text{ ft}}D - {}^{10000\text{ ft}}D = +200$ ft, then if ${}^{10000\text{ ft}}D - {}^{5000\text{ ft}}D = +200$ ft the lapse rate is the same as the U. S. Standard (approximately moist adiabatic). If ${}^{10000\text{ ft}}D - {}^{5000\text{ ft}}D = +100$ ft the lapse rate is relatively stable; and if ${}^{10000\text{ ft}}D - {}^{5000\text{ ft}}D = +300$ ft the lapse rate is relatively unstable.

For most purposes mean temperature charts seem to be more convenient than actual temperature charts for given pressures. This is primarily a result of the greater ease with which wind reports and the thermal wind equation can be used as aids in making accurate analyses. The winds that are ordinarily plotted on the constant pressure charts can then also be used to determine the shears applying to the mean temperature charts. This work is facilitated if the winds are plotted on the constant pressure charts as vectors. The shears applying to the mean temperature charts are then immediately available by superposition of the respective constant pressure charts. The mean temperature analysis can be obtained by graphically sub-

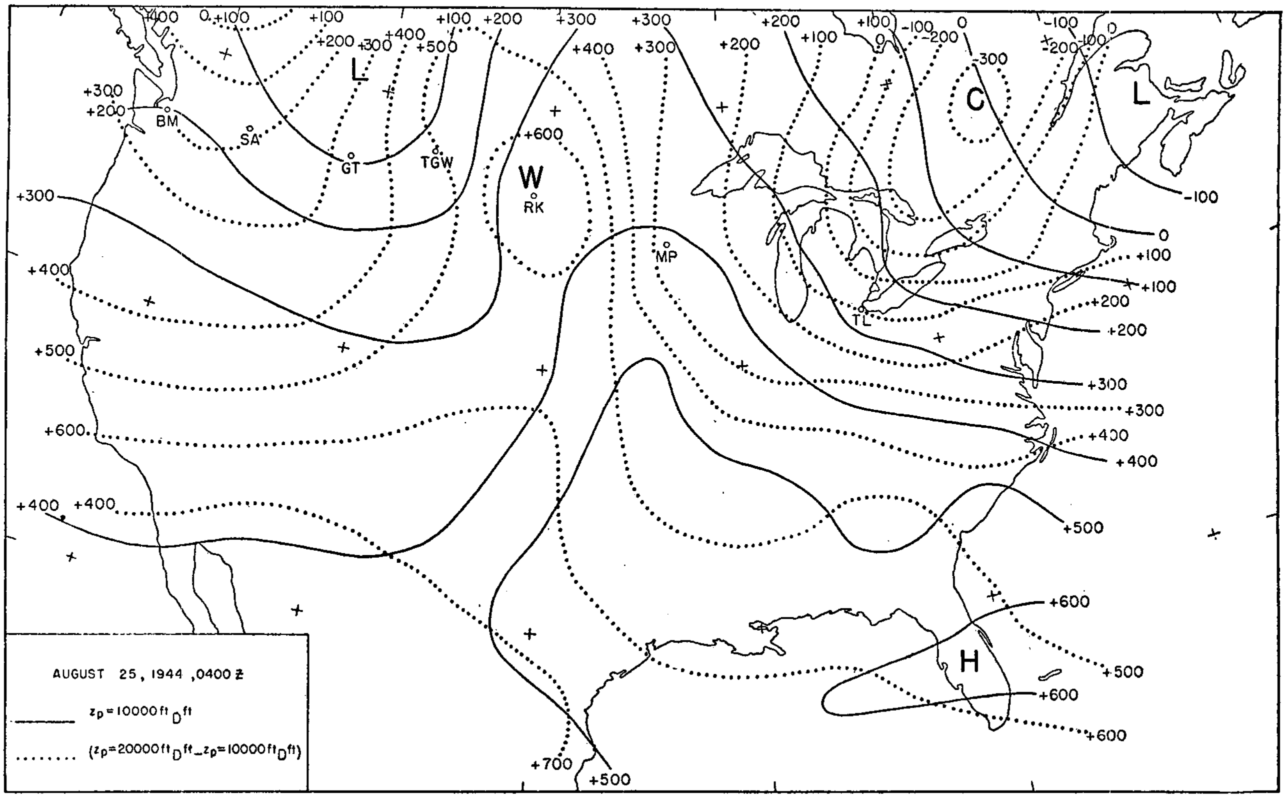


FIGURE 7.

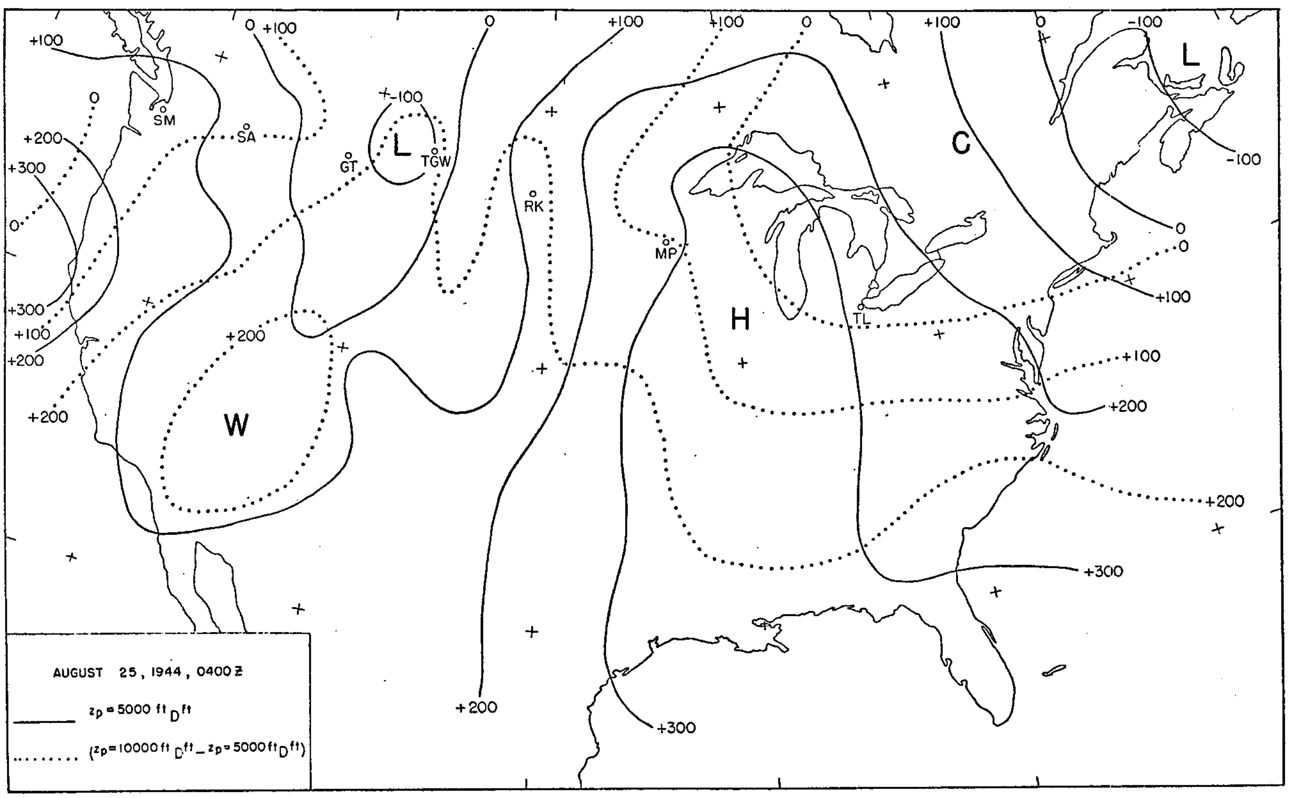


FIGURE 8.

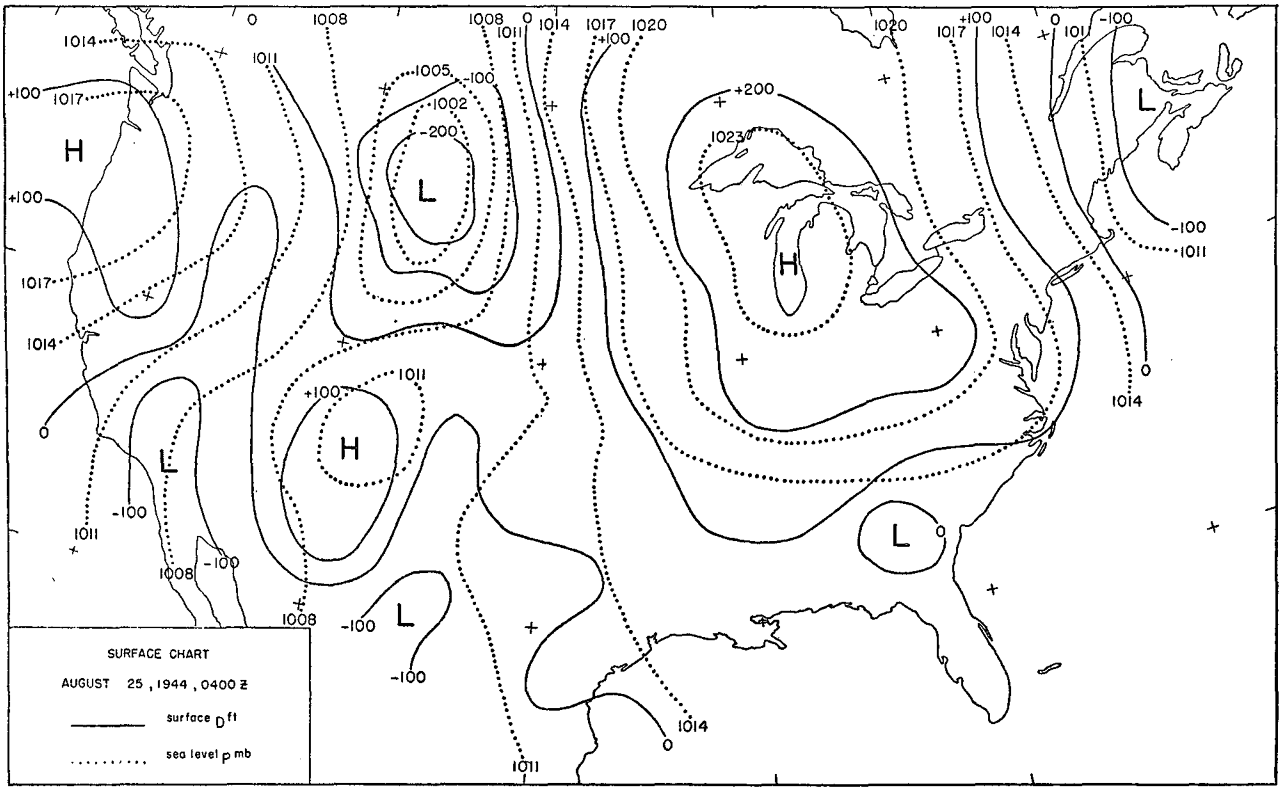


FIGURE 9.

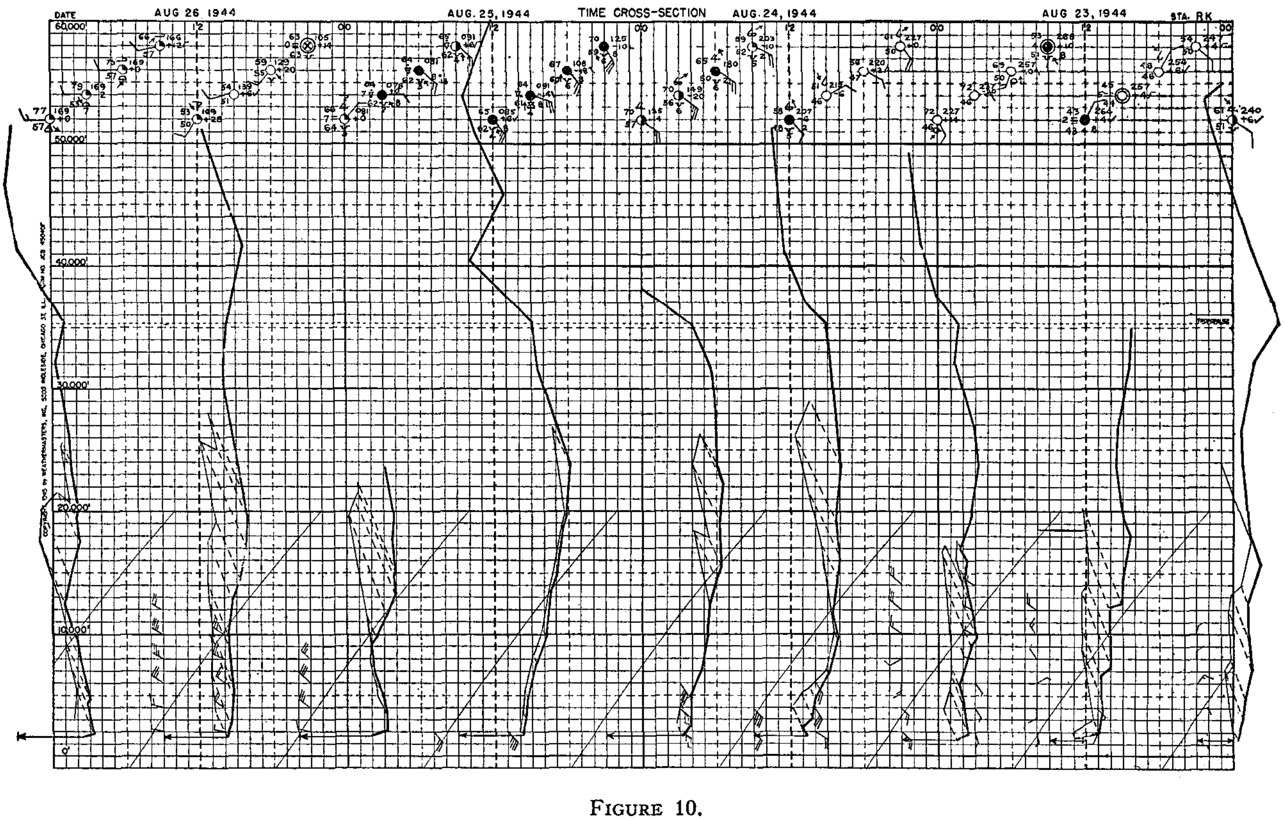


FIGURE 10.

tracting the contour analysis of the lower surface from that of the upper surface after these contour analyses have been made (using the wind reports and the gradient wind equation). This intersection method was used to determine the mean temperature analyses in Figures 7 and 8.

Time cross sections. Time cross sections (with time as abscissa and pressure altitude as ordinate) are very useful in analysis and forecasting. In general it is desirable to enter all the observed meteorological conditions that occur over a given station on this chart, so that they can all be conveniently compared with each other and correlated with representations on various other charts.

Figure 10 is an example of such a time cross section. The surface reports, in this case for each 3-hourly interval, are recorded on station circles near the top. The upper-air wind observations are plotted at the value of z_p equal to the reported value of z with the top of the chart as north. Each full barb corresponds to 10 miles per hour. For accurate analysis it should be remembered that these winds occur at a distance D below the level at which they are plotted on the cross section. The radiosonde observations are plotted as soundings on essentially basic pastagrams similar to Plate I but on a smaller scale. For this purpose each hour of the time scale is also used to represent an interval of S of 0.01; the $S = 0$ lines are taken to be at the 0000- and 1200-time lines; the 0°C isotherms for these values of S and z_p are entered. The soundings are plotted with underlays similar to Plates V and VI and can be examined for thermodynamic details with the aid of an overlay similar to Plate VI although this need not be done for most routine interpretations of the soundings. It has been found that these soundings (with virtual temperature plots not shown here) can be conveniently used for accurate pressure-height computations. The values of ${}^{z_p}D$ and ${}^{z_p+5000\ \mathrm{ft}}D - {}^{z_p}D$ have been calculated for the soundings shown. Their values have been plotted to the left of each sounding curve with ${}^{z_p}D$ entered at the respective values of z_p and with ${}^{z_p+5000\ \mathrm{ft}}D - {}^{z_p}D$ entered in parentheses halfway between these positions.

The analysis entered on the time cross section in Figure 11 consists of isolines of ${}^{z_p}D$. The data were taken from Figure 10. Such an analysis can be directly correlated with the D analysis on various other charts. The D analysis of a time cross section can be interpreted as follows:

1. The D values show directly the height of any pressure surface at any time, since the height above sea level can be determined by adding the value of D to the corresponding value of z_p.

2. The vertical variations in intensity and the slope of the various pressure systems as they pass over the station are shown directly.

3. The vertical spacing of the D lines is inversely proportional to the temperature anomaly of the air (see equation (18)) so that a useful representation of the temperature distribution is also obtained. For example, if the value of D increases with height, the temperature is warmer than the U. S. Standard; and if the D lines come closer together in time, the air is warming over that station in time. Also, whenever the D lines are vertical the temperature is the same as the U. S. Standard temperature.

4. The horizontal spacing of the D lines is inversely proportional to the height tendency $\partial D/\partial t$ at any point considered so that this height tendency is zero when the D lines are horizontal. This height tendency can be considered as an approximate measure of the pressure tendency at a fixed level.

The analysis on the time cross section in Figure 12 is an analysis of S^*, in units of $5000S^*$, for the same data. This S^* analysis can be interpreted as follows:

1. The vertical spacing of the S^* lines is inversely proportional to the lapse rate $\partial S^*/\partial z_p$, so that the lapse rate relative to the U. S. Standard lapse rate, which is approximately moist adiabatic, is apparent. Thus if S^* increases with height the atmosphere is relatively stable, if the S^* lines are vertical the atmosphere has the same stability as the U. S. Standard, and if S^* decreases with height the atmosphere is relatively unstable.

2. The local rate of change of temperature $(\partial S^*/\partial t)_p = (1/T_p)(\partial T^*/\partial t)_p$ is inversely proportional to the horizontal spacing of the S^* lines and the temperature remains constant with time if the S^* lines are horizontal.

At times, especially in the tropics, it has also been found useful to analyze time cross sections in terms of 24-hour pressure (or height D) and temperature (S^* or ${}^{z_p+5000\ \mathrm{ft}}D - {}^{z_p}D$) changes in order to represent more clearly small pressure and temperature changes and to eliminate diurnal effects.

Space cross sections. Figure 13 is an example of a space cross section which is analyzed in terms of D. This cross section is synoptic with the maps discussed previously.

The analysis in terms of D can be given the following interpretations:

1. The height of any pressure surface in the cross section is given directly by the value of D at that point. This can then also be thought of, if desired, as giving the pressure at any height.

2. The vertical extent and orientation of pressure systems are clearly and conveniently shown.

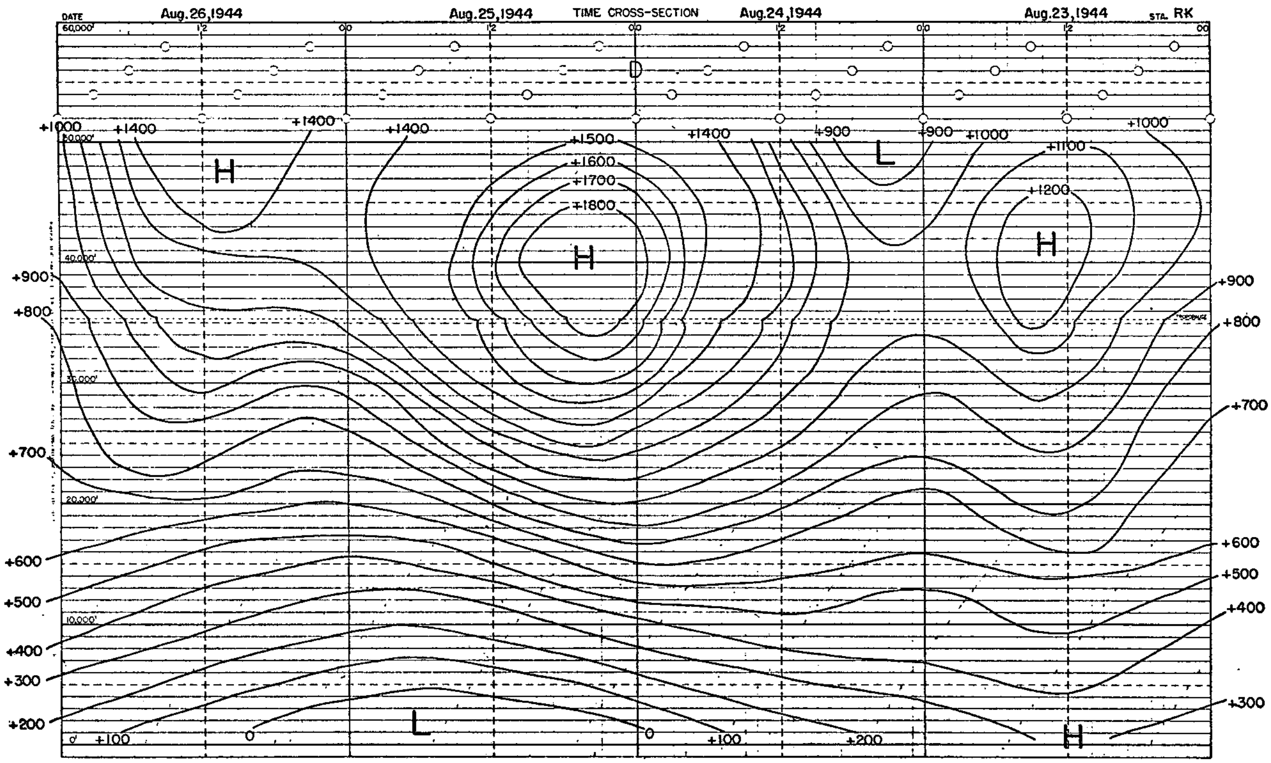


FIGURE 11.

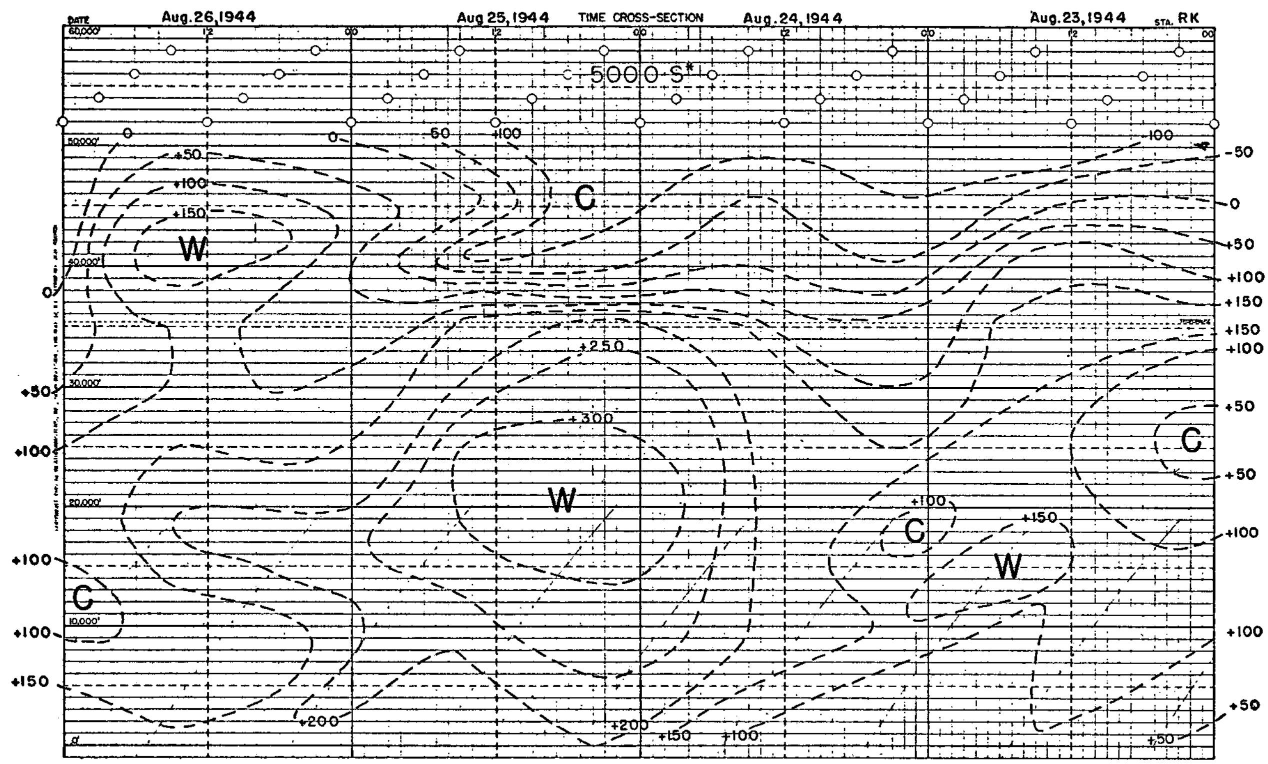


FIGURE 12.

3. The vertical spacing of the D lines is inversely proportional to the temperature parameter S^* so that, as discussed in connection with the time cross section, the D lines also provide a representation of the temperature field.

4. The horizontal spacing of the D lines is inversely proportional to the horizontal component of the geostrophic wind normal to the plane of the cross section. Thus the wind is either calm or parallel to the plane of the cross section if the D lines are horizontal. Space cross sections have proved to be useful as an aid in making wind forecasts, especially when forecasts of the wind at several different levels along one flight path are desired. The geostrophic wind scale given in Plate XIII applies directly to any point of the cross section.

The analysis of the space cross section in Figure 14 is in terms of S^* in units of $5000S^*$ and can be given the following interpretations:

1. Since the hydrostatic equation can be written as

$$_{z_p+5000\text{ ft}}D = {}_{z_p}D + \overline{5000S^*}, \tag{63}$$

the pressure-height calculations between any two pressure surfaces separated by a pressure altitude of 5000 feet can be made by simple addition or subtraction. The pressure-height computations can also very easily be made between arbitrary pressure surfaces by first multiplying the mean value $\overline{5000S^*}$ by an appropriate factor.

2. The value of the temperature in degrees centigrade can be obtained, if desired, directly from Table 4 or Table 5 or from a pastagram. This step is usually not desired, however, since the value of S^* is a quantitative measure of the temperature of the air with respect to the standard temperature at that pressure.

3. The vertical spacing of the S^* lines provides a useful representation of lapse rates and stability as discussed for the time cross section.

4. The horizontal spacing of the S^* lines is inversely proportional to the component of the wind shear in the vertical which is normal to the plane of the cross section. Thus the diagram in Plate XIII can be used directly to compute the shear in 5000-ft layers from the S^* analysis (in units of $5000S^*$) given on the cross section.

As an example of the convenience of using the parameters z_p, D and S^* in the analysis of space cross sections, the following procedure has been found to be profitable for making wind forecasts along one route at several different levels. For this purpose the horizontal scale x of the space cross section is chosen to take into account the variations in the geostrophic and thermal wind due to latitude differences by defining $dx = \sin\phi \, dl$ where dl is the actual length measured on the earth along the cross section. Then, choosing the correct scale for x, the geostrophic wind equation can be written as $v_n = (\partial D/\partial x)_p$ and the thermal wind equation can be written as

$$_{z_p+5000\text{ ft}}v_n - {}_{z_p}v_n = \left(\frac{\partial\, \overline{5000S^*}}{\partial x}\right)_p.$$

In these equations v_n is conveniently expressed in

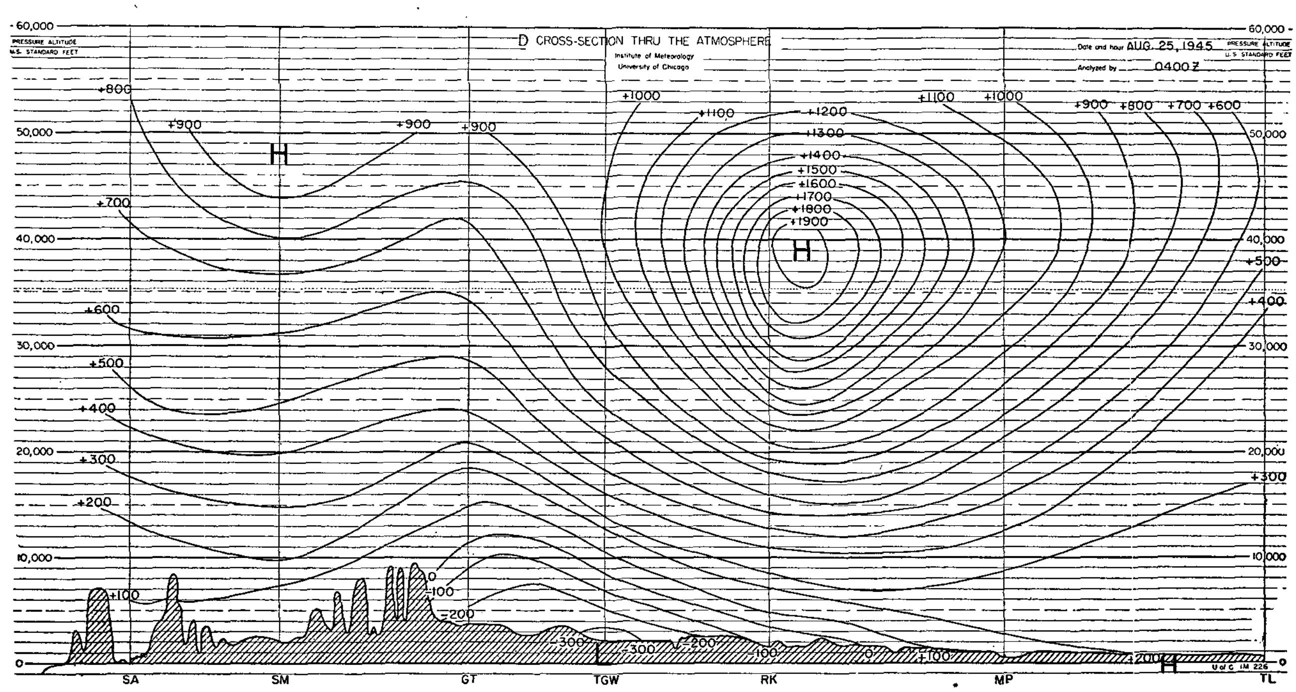


FIGURE 13.

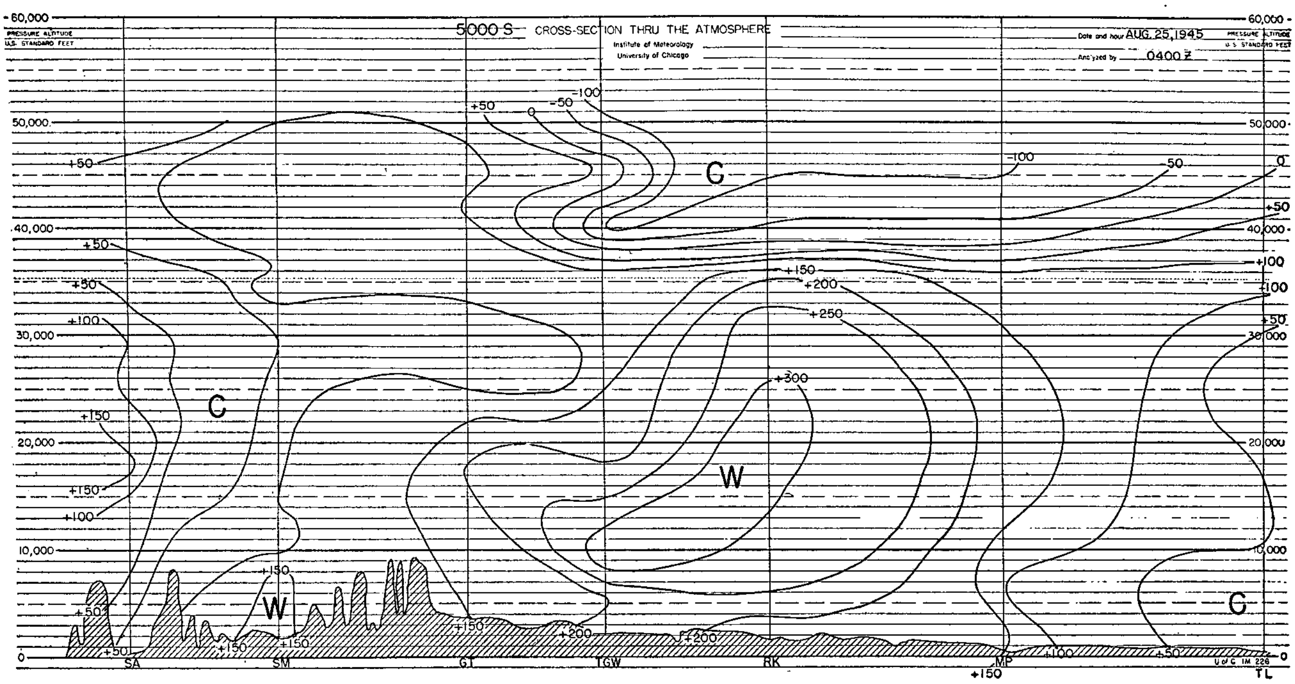


FIGURE 14.

knots, D is expressed in feet, and the values of x are labeled on the space cross section. Thus, these equations apply equally well at *any* point on the cross section, and a given horizontal spacing of D or S lines means a given cross component of the wind or shear, independent of the position on the particular cross section that is considered. For forecasting and other purposes it is convenient to divide the cross section into vertical strips or zones. If the zones are chosen to be suitable values of x in width, all geostrophic and thermal wind calculations are very simply made by additions, subtractions and division or multiplication of small integers. For example, if the difference of D across a zone 10 units of x wide were 100 feet, the mean cross component of the wind in this zone would be ten knots. The steps for making the forecast in this procedure are

1. Analyze the space cross section in terms of S^*. For this all radiosonde and aircraft reports are utilized to determine S^* values at the points of observation and the interpolations are made using the thermal wind equation with all available wind reports. The S^* analysis is labeled in terms of the unit ($5000S^*$) to facilitate hydrostatic calculations of the form given by equation (63).
2. Forecast the mean temperature distribution on this cross section in terms of S^*, using advection as indicated by the various constant pressure and mean temperature charts, as an aid in determining the expected change of the S^* distribution.
3. Check the consistency of this forecast with the forecast values of D on two or more of the constant pressure charts and by constructing pastagrams (usually on the space cross section itself) at several points along the cross section.
4. Determine, by simple addition, the value of D at all desired levels and at the end points of each desired zone.
5. Determine the cross wind, in knots, in the zones by simple subtraction of D values.
6. Determine the direction of the wind at all levels for which prognostic constant pressure charts are drawn, and estimate the directions at all other desired levels.
7. From the direction and cross component, determine the total wind speed.

These calculations are simple enough so that they can be accomplished in a short enough time to make this procedure practical. However, it is very doubtful if that would be the case if, say, millibars were used as the parameter with which to specify pressure, since the conversion of units and multiplicative factors necessarily involved in the calculations are quite time consuming.

Surface chart. If D is used as the parameter with which to express the pressure field in the upper air, D should also be used for analysis of the surface chart so that continuity and direct correlation of surface and upper-air conditions are possible. The use of D as the pressure parameter on the surface chart also has several advantages over using the "sea level" pressure expressed in millibars.

From the principle that the primary purpose of making a pressure analysis is to represent the horizontal wind field, it follows that the pressure analysis should provide as accurate and easy solutions of the gradient wind equation as possible. In general the sea-level pressure map is unsatisfactory for this purpose since the extrapolations to sea level are made by assuming that the mean temperature of the fictitious column down to sea level depends on the temperature observations at the surface. Hence the "sea level" map is a function of the temperature of the air as well as the pressure so that, especially for high plateau regions, the sea-level pressure pattern is distorted by horizontal temperature gradients as compared with the actual pressure pattern occurring at the surface. In contrast to this, for any set of observations made at approximately the same elevation, an analysis in terms of the observed values of D at the surface accurately represents the actual pressure field at that mean elevation, since D remains constant for hydrostatic extrapolations through short vertical distances.

If desired, the surface chart in terms of D can also be considered as a sea-level chart in which the extrapolation assumption is that the temperature of the air is always the same as the standard temperature. Similarly, if desired, the surface D analysis can also be interpreted as a contour chart of the $z_p = 0$ constant pressure surface. It seems, however, that the most direct interpretation, not involving the idea of extrapolations, is to consider the surface D chart as directly representing the conditions occurring at the surface of the earth, and then the geostrophic wind relationship can be directly applied to any approximately horizontal region of the chart. This interpretation of D has direct meaning for flying personnel, surveyors, etc., since the value of D is then the altimeter correction, which can also be used as an altimeter setting applicable to the surface.

The use of D as the pressure parameter on the surface chart also simplifies the required conversions from (or to) the parameters in which pressure is actually measured. For this purpose a table could be made for the particular elevation z of any given station, giving the direct conversion from inches or millimeters of mercury to feet or meters of D, as desired. This conversion is simpler than the customary reduction to sea-level pressure in millibars since the temperature observations need not be considered. Even for mercurial barometer observations actually made at sea level the use of Table 2a or 2b is in general as convenient as a conversion table from inches or millimeters of mercury to millibars. Of greater importance is the possibility of always being able to determine easily the actual pressure observations that were made at any given station from the reports of the value of D at that station. A convenient method of doing this is to subtract the reported value of D from the height of the station, z, and to convert the resulting value of z_p to inches or millimeters of mercury with Table 1. In general this conversion is impossible with surface pressure reports in terms of the sea-level pressure in millibars since the particular reduction tables, and even the temperatures used to enter these tables, are not generally available. This factor is of primary importance since the introduction of the fictitious column of air in all sea-level pressure reports makes it very difficult, and usually even impossible, to obtain accurate continuity and comparison of surface conditions with upper-air conditions.

Figure 9 is an example of a surface chart analyzed in terms of these two pressure parameters. The solid lines are drawn for values of D at the surface and the dotted lines are drawn for values of the sea-level pressure in millibars. This map, and many more, have been constructed by Lt. J. L. Clayton, U. S. Army Air Forces. This work has been quite difficult due to the unknown extrapolations made in the reported data available. Special graphs were constructed to estimate the values of D at the surface from the surface temperature and the sea-level pressure reports in those regions for which altimeter settings were not available. Unfortunately those regions included the mountainous ones in which the only significant variations between the two methods of representation are to be expected. However, from this work it seems that, in general, the analysis in terms of D does more closely represent the gradient wind flow than does the sea-level pressure chart.

Acknowledgment

The author wishes to thank the members of the University of Chicago, especially Mr. V. P. Starr, and the University of Puerto Rico and many officers in the U.S.A.A.F. for their aid and encouragement in this work.

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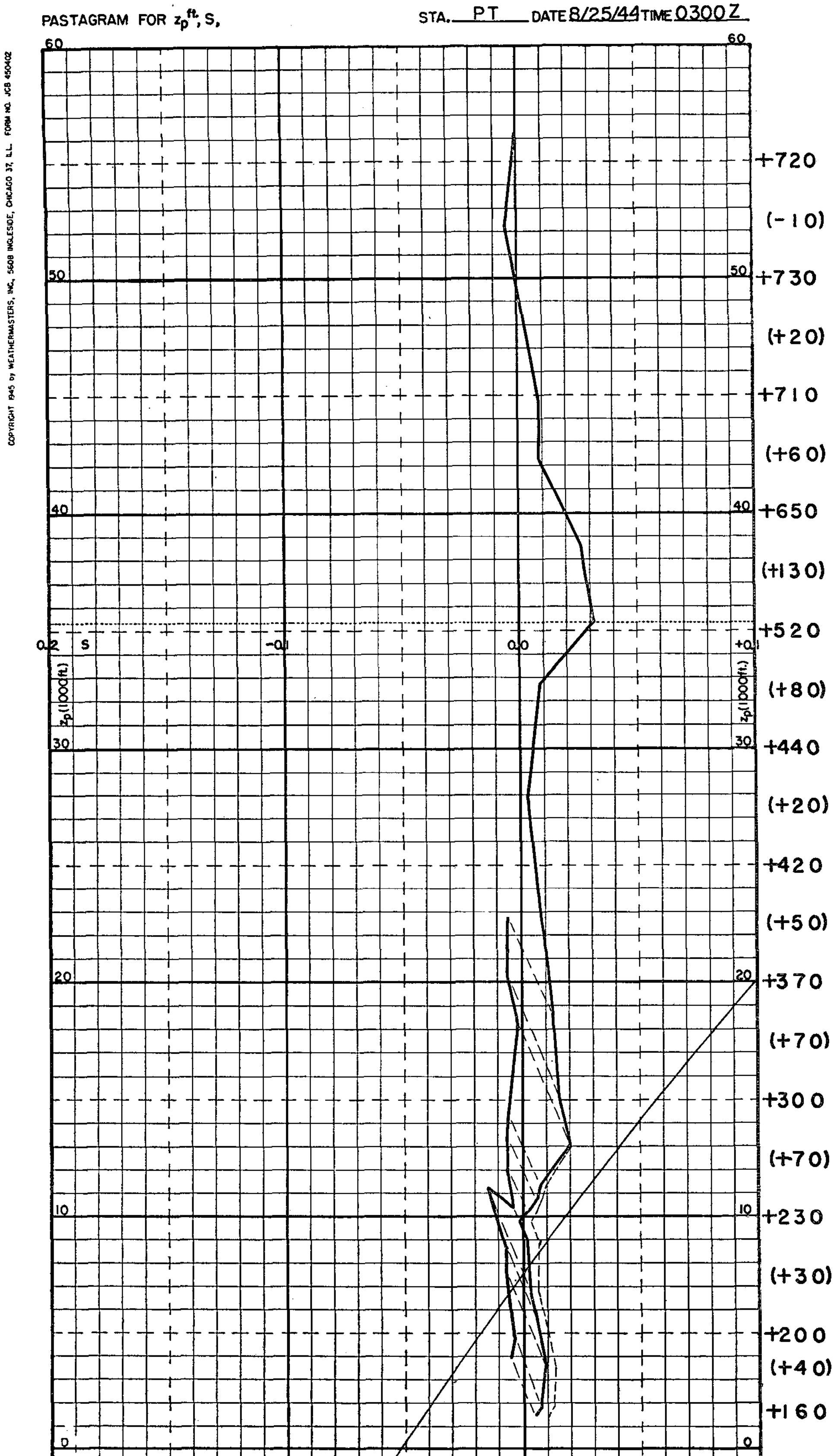
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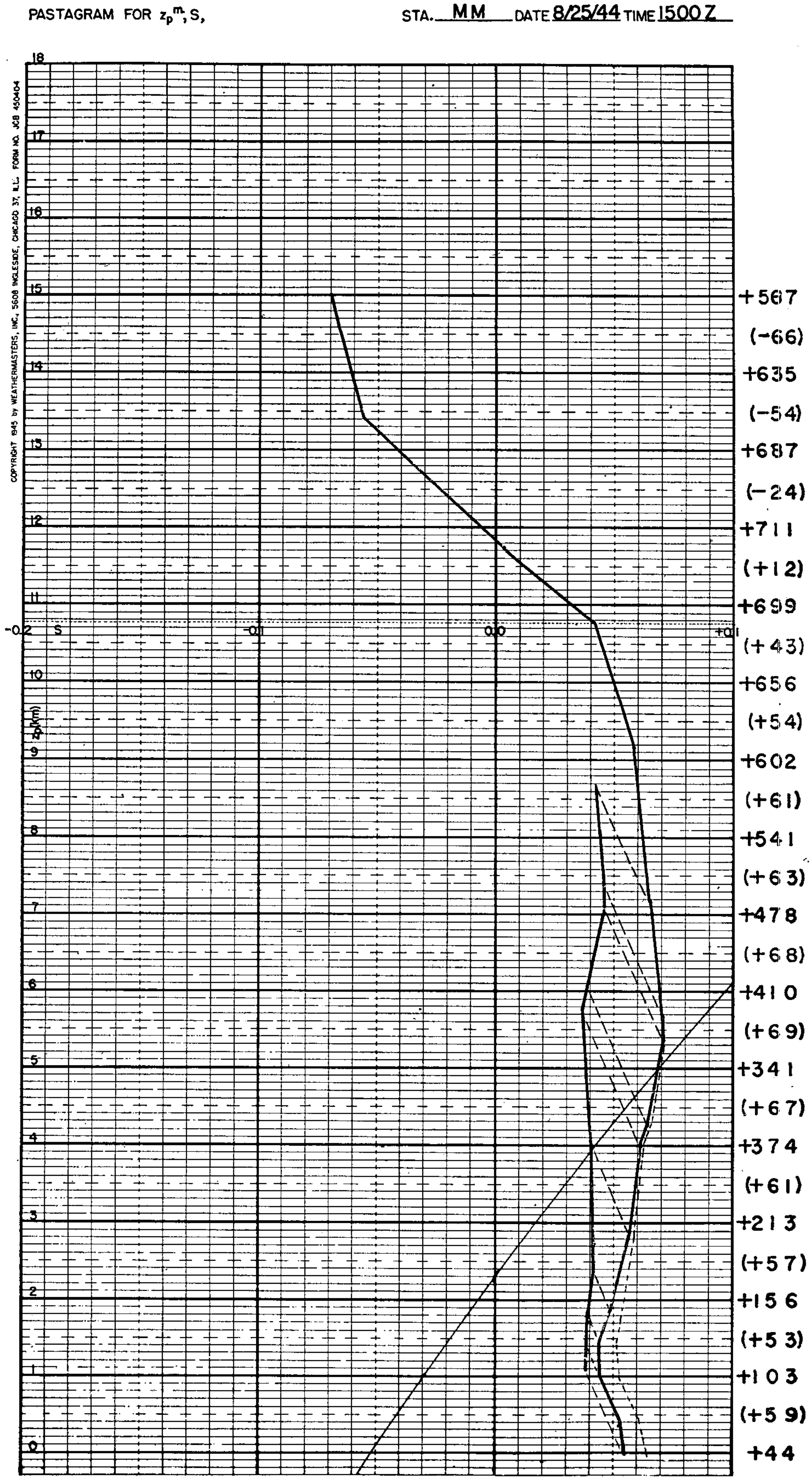
PLATE I.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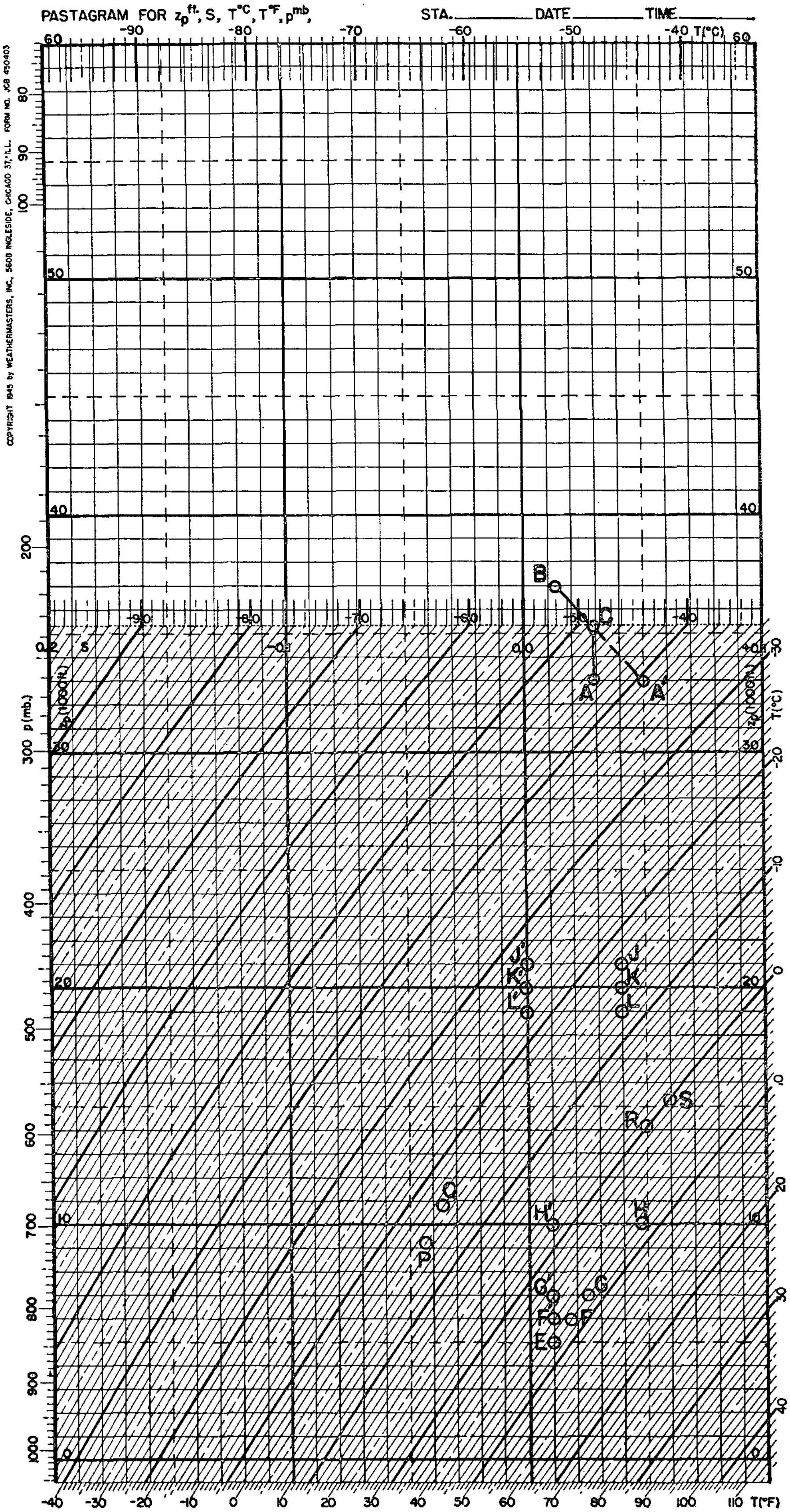
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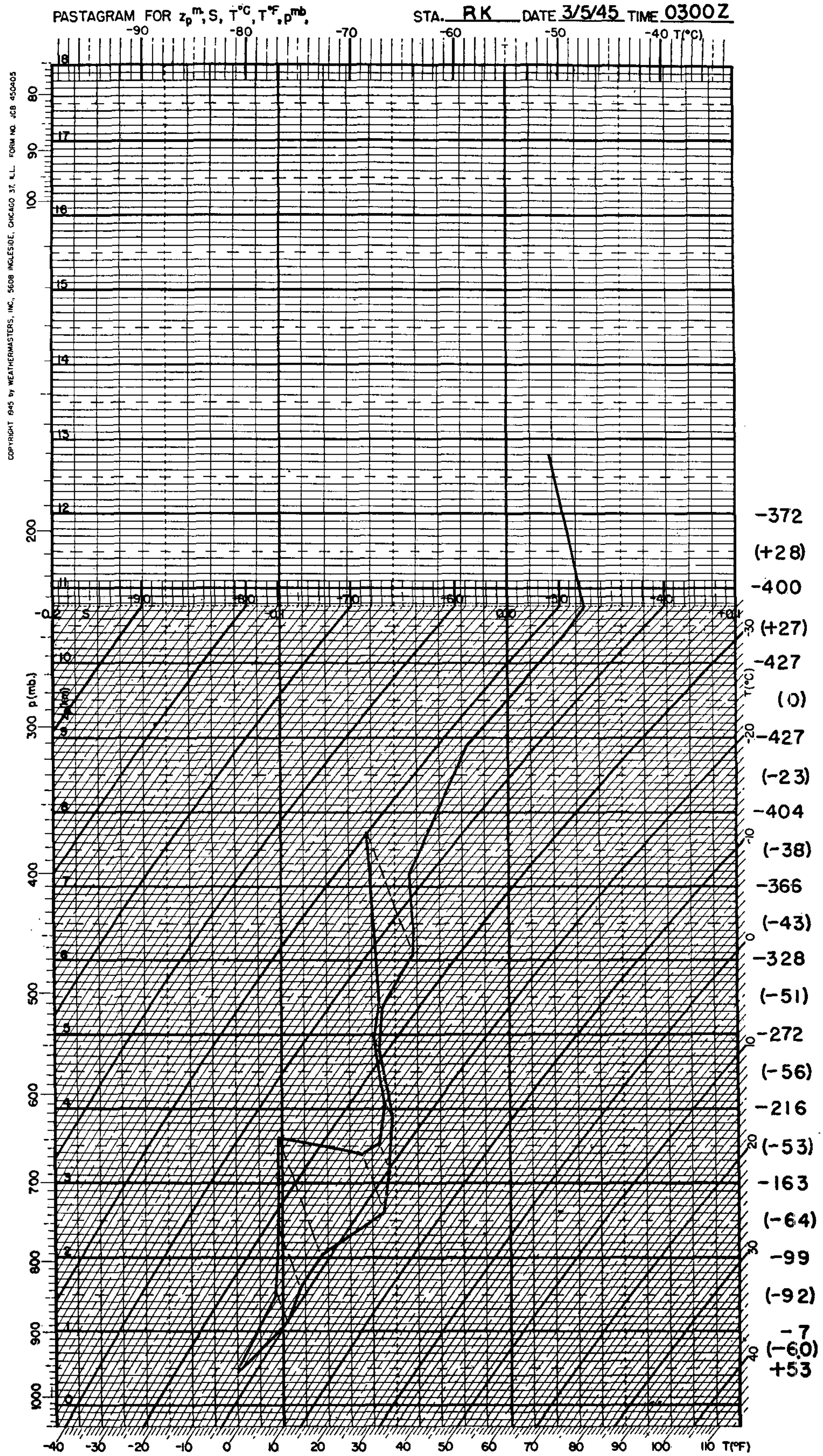
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PLATE IV.

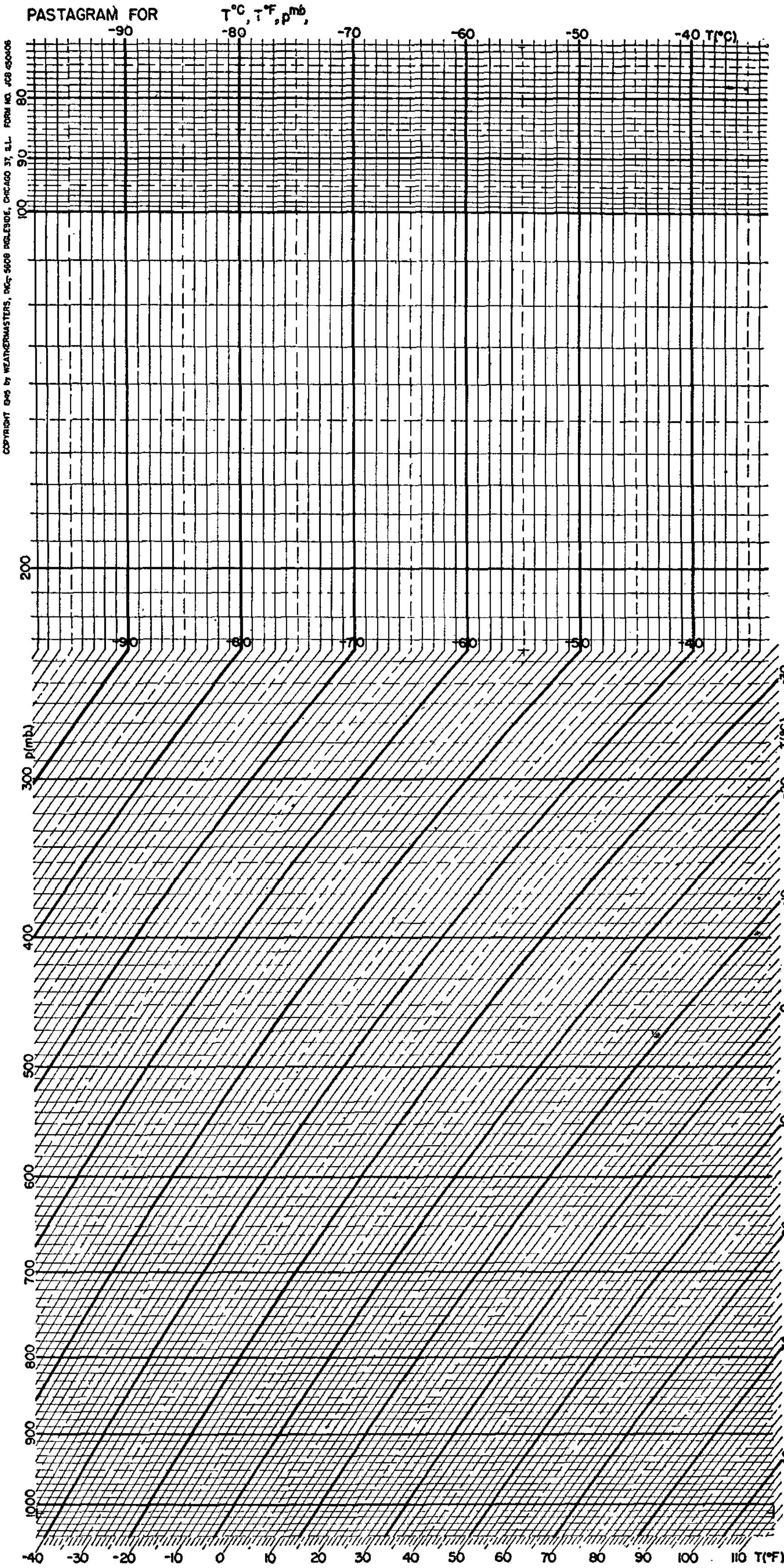
PASTAGRAM FOR $T^{°C}, T^{°F}, p^{mb}$,
COPYRIGHT 1945 by WEATHERMASTERS, INC., 5608 INGLESIDE, CHICAGO 37, ILL. FORM NO. JCB 450406
-90
-80
-70
-60
-50
-40 T(°C)
80
90
100
200
300 p(mb)
400
500
600
700
800
900
1000
-30
T(°C)
-20
-10
0
10
20
30
40
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110 T(°F)

PLATE V.

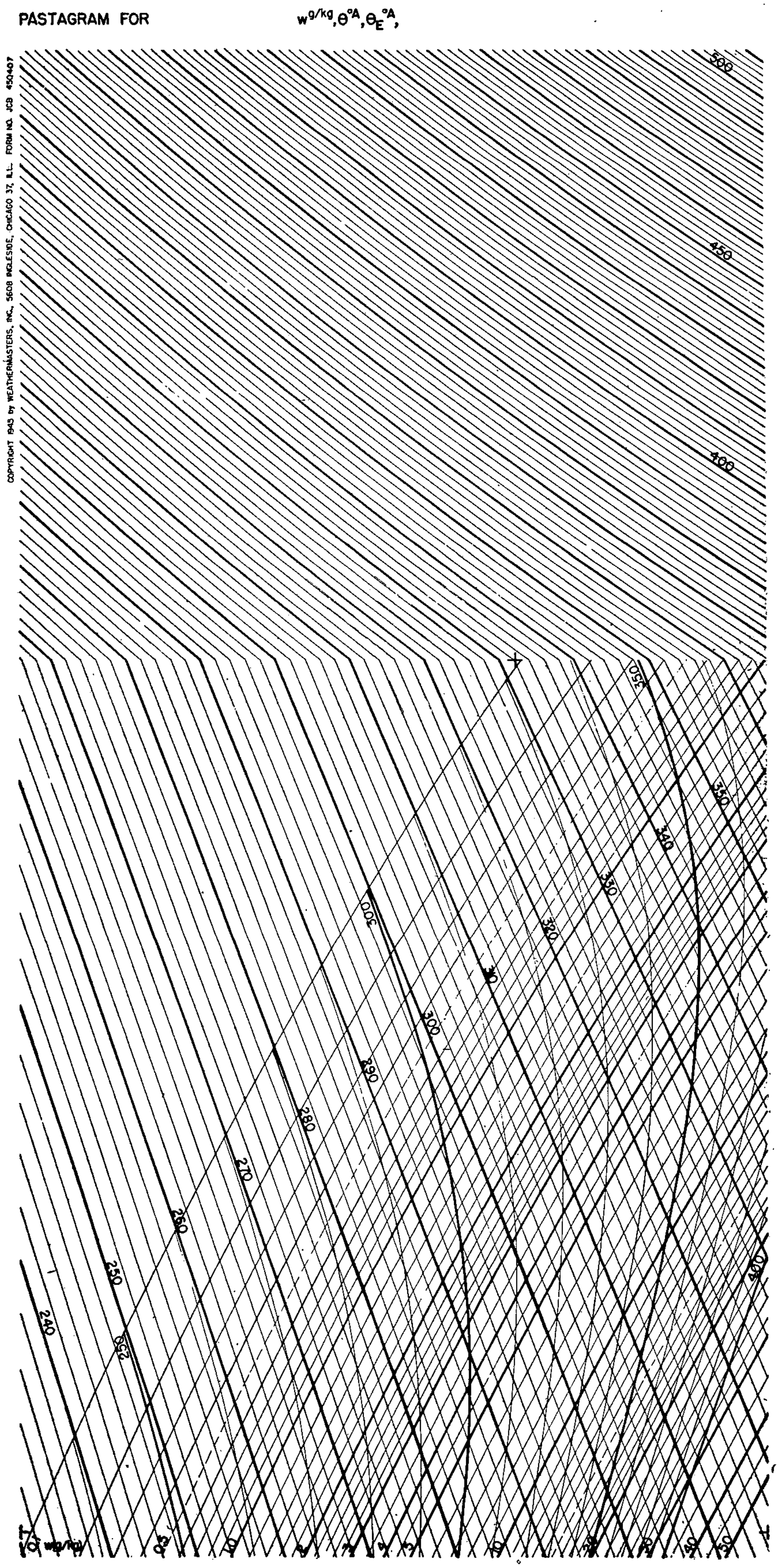
PASTAGRAM FOR $w^{g/kg}, \theta^{°A}, \theta_E^{°A}$,
COPYRIGHT 1945 by WEATHERMASTERS, INC., 5608 INGLESIDE, CHICAGO 37, ILL. FORM NO. JCB 450407
500
450
400
350
350
340
330
320
310
300
300
290
280
270
260
250
250
240
400
w g/kg
10
20
30
40
50

PLATE VI.

PASTAGRAM FOR $w^{g/kg}$, $\theta^{\circ A}$, $h\%$

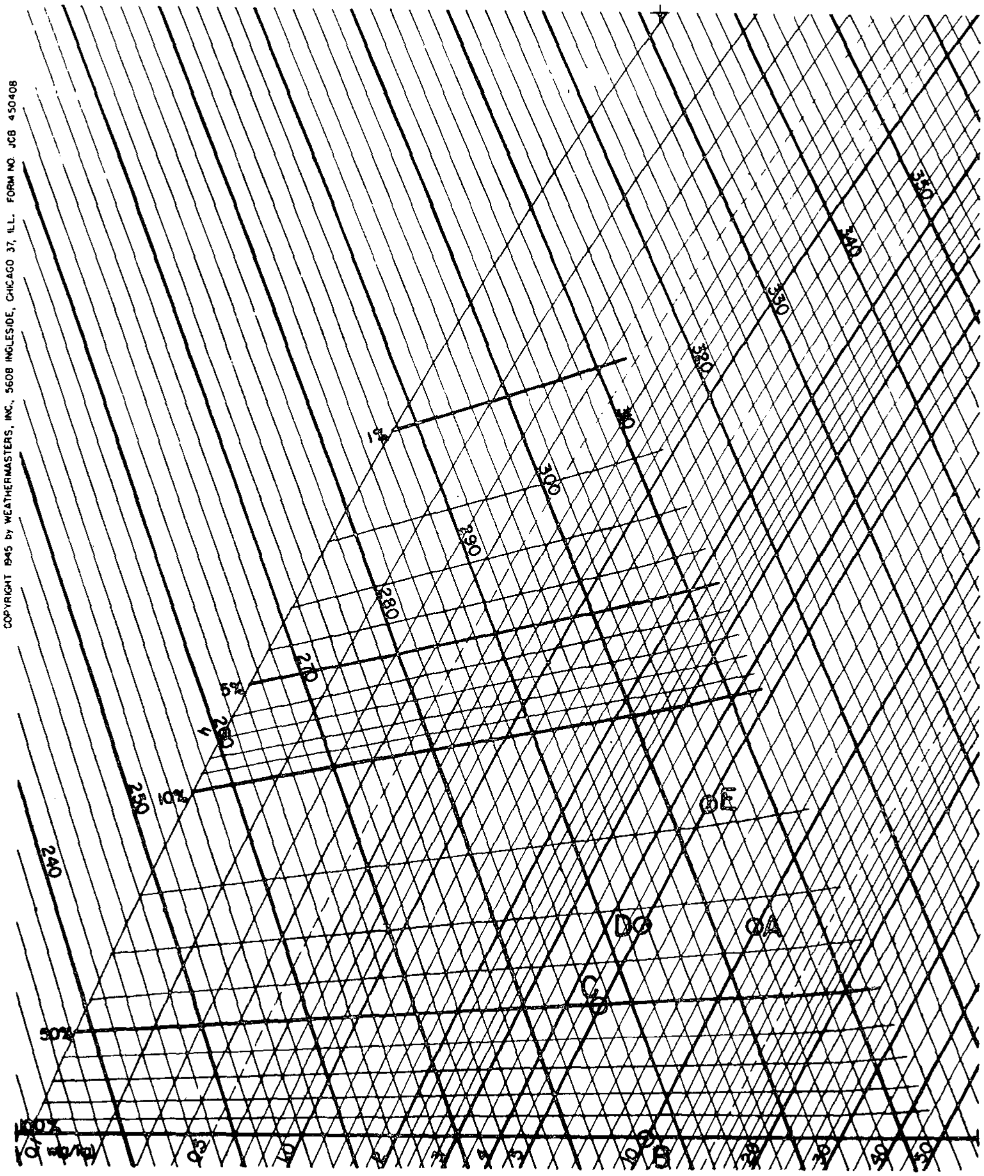

PLATE VII.

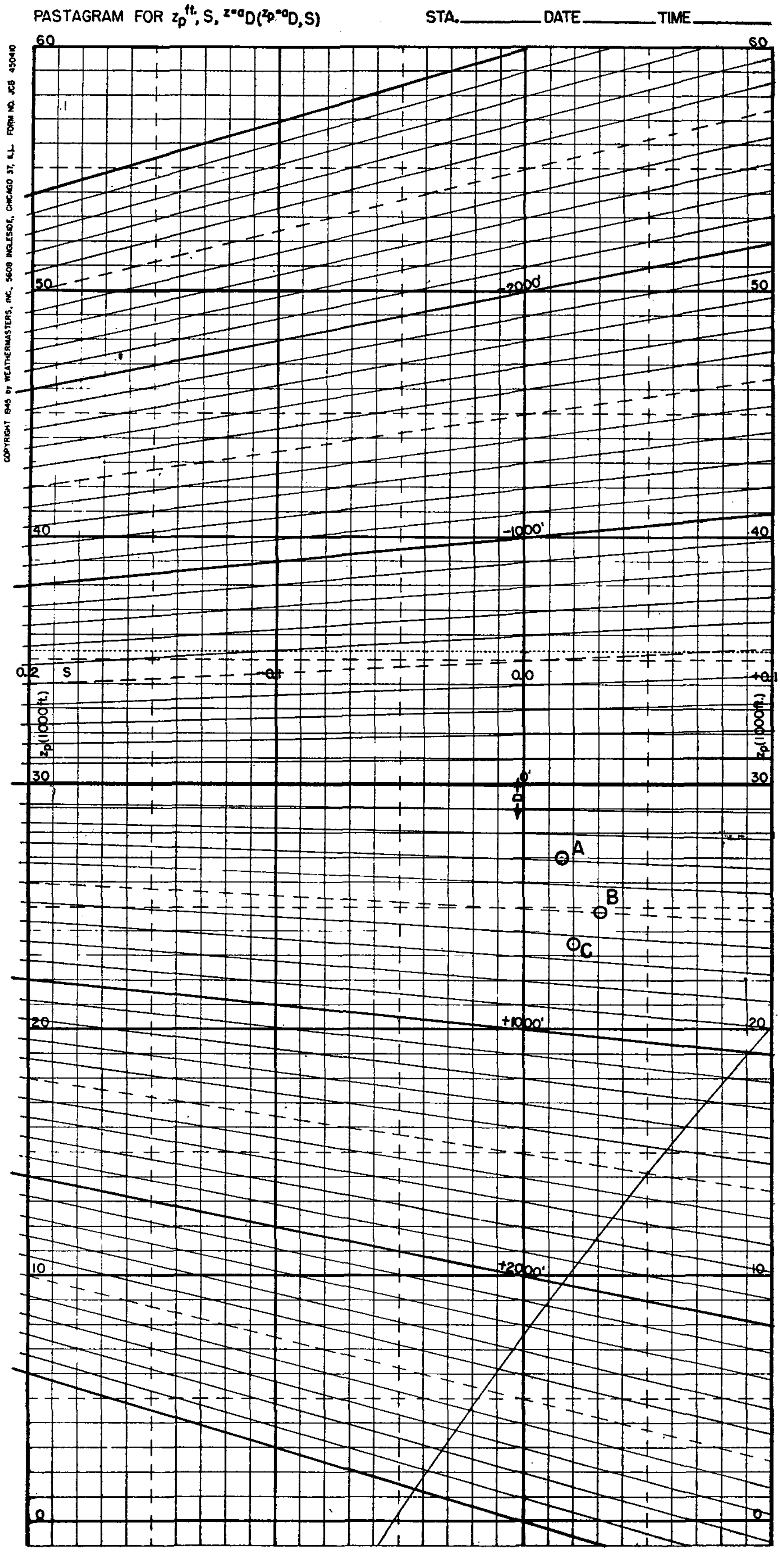
PASTAGRAM FOR z_p^{ft}, S, $^{z=a}D(^{z_p=a}D,S)$
STA. DATE TIME
COPYRIGHT 1945 by WEATHERMASTERS, INC., 5608 INGLESIDE, CHICAGO 37, ILL. FORM NO. JCB 450410
60
50
40
30
20
10
0
-2000'
-1000'
+1000'
+2000'
0.2
S
0.1
0.0
+0.1
z_p(1000 ft.)
D
A
B
C

PLATE VIII.

CONVERSION CHART
BETWEEN
PRESSURES AT STANDARD LEVEL SURFACES
AND
HEIGHTS OF STANDARD PRESSURE SURFACES

PRESSURES, IN MILLIBARS, AT THE STANDARD CONSTANT LEVEL SURFACES ARE INDICATED BY THE SLANTING LINES.
HEIGHTS, IN FEET OF ALTIMETER CORRECTION, OF THOSE CONSTANT PRESSURE SURFACES FOR WHICH THE PRESSURE ALTITUDE IS NUMERICALLY EQUAL TO THE HEIGHT OF THE CORRESPONDING CONSTANT LEVEL SURFACES, ARE INDICATED BY THE VERTICAL LINES.

TEMPERATURES, IN DEGREES CENTIGRADE, AT THE STANDARD CONSTANT LEVEL SURFACES, ARE INDICATED BY THE HORIZONTAL LINES.
TEMPERATURES AT THE STANDARD CONSTANT PRESSURE SURFACES ARE INDICATED BY THE HORIZONTAL ROWS OF DOTS.
THE VALUE OF T^*-T_p/T_p IS ASSUMED TO BE CONSTANT BETWEEN CORRESPONDING CONSTANT LEVEL AND PRESSURE SURFACES.

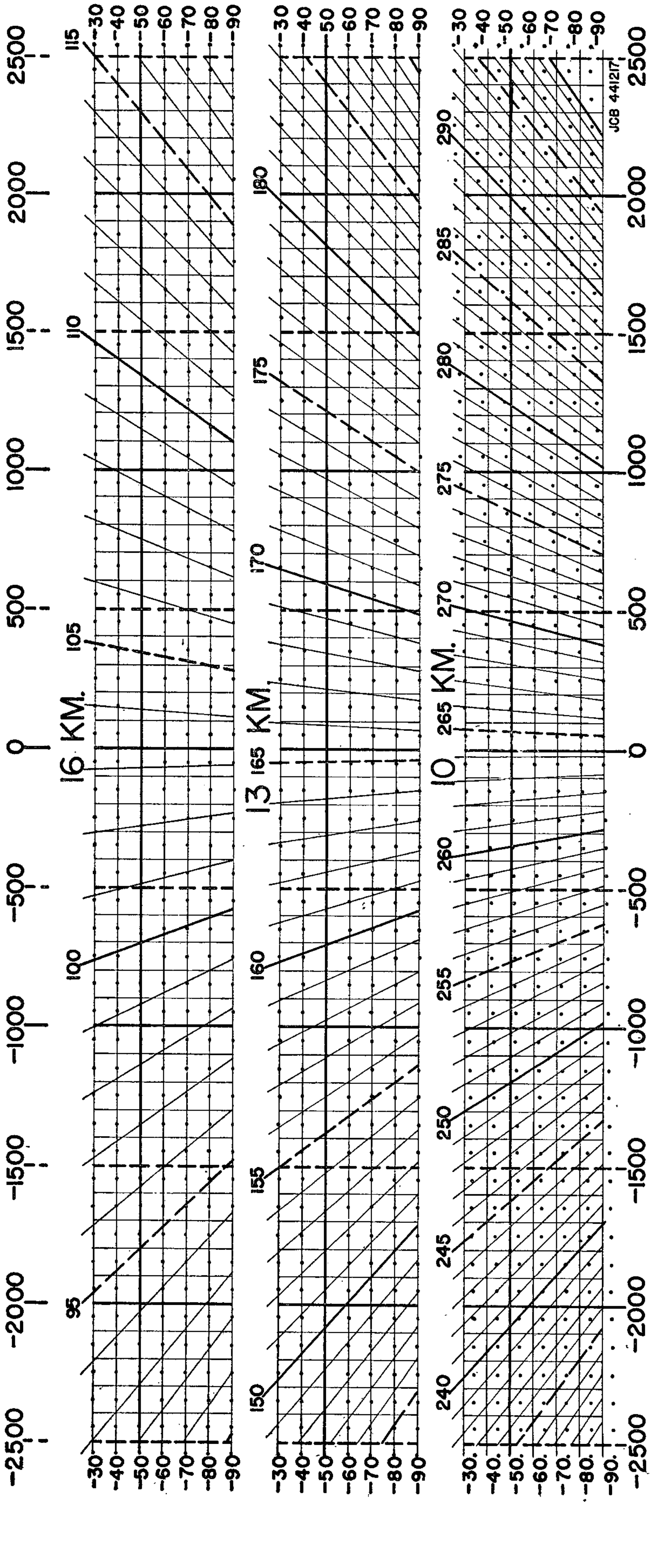

PLATE IX.

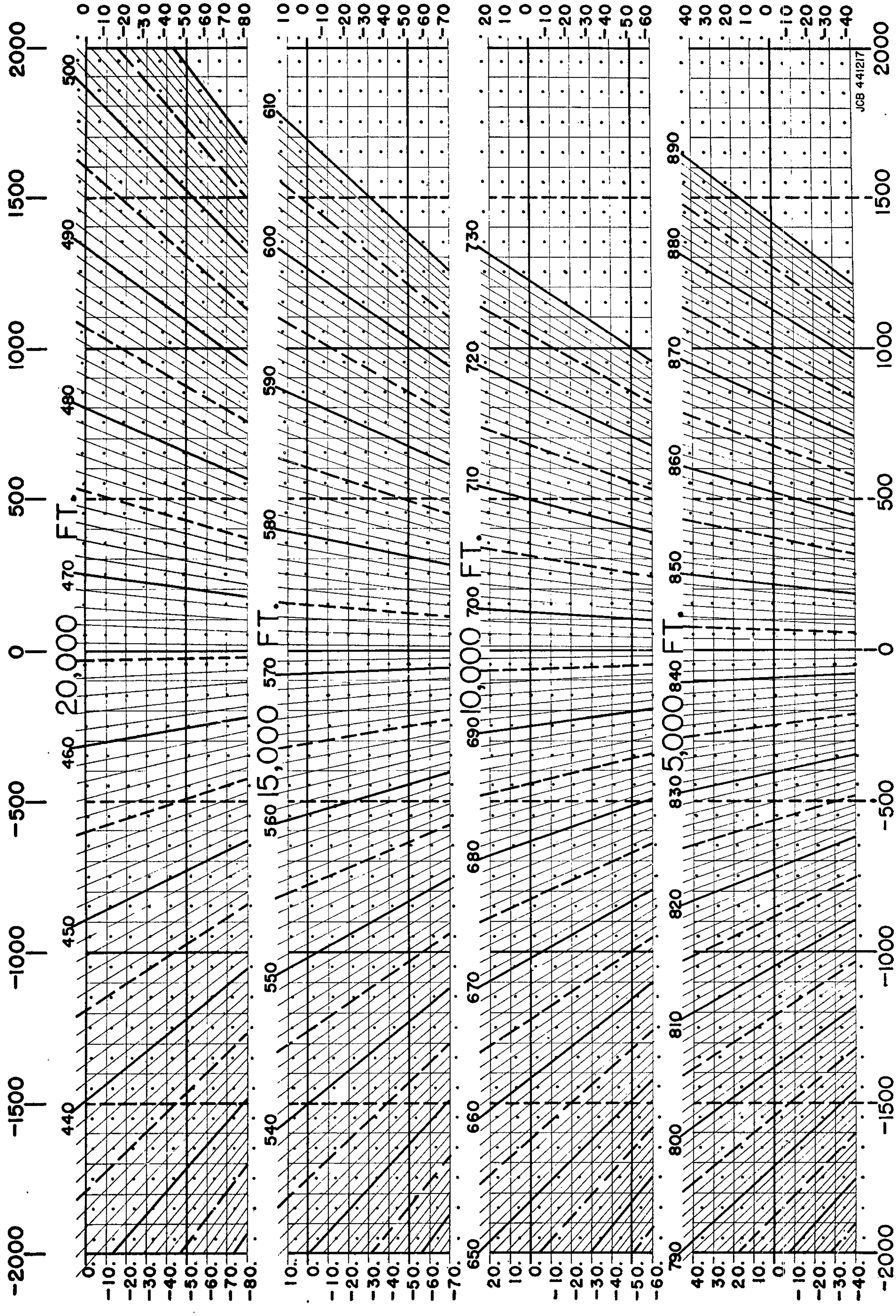

PLATE X.

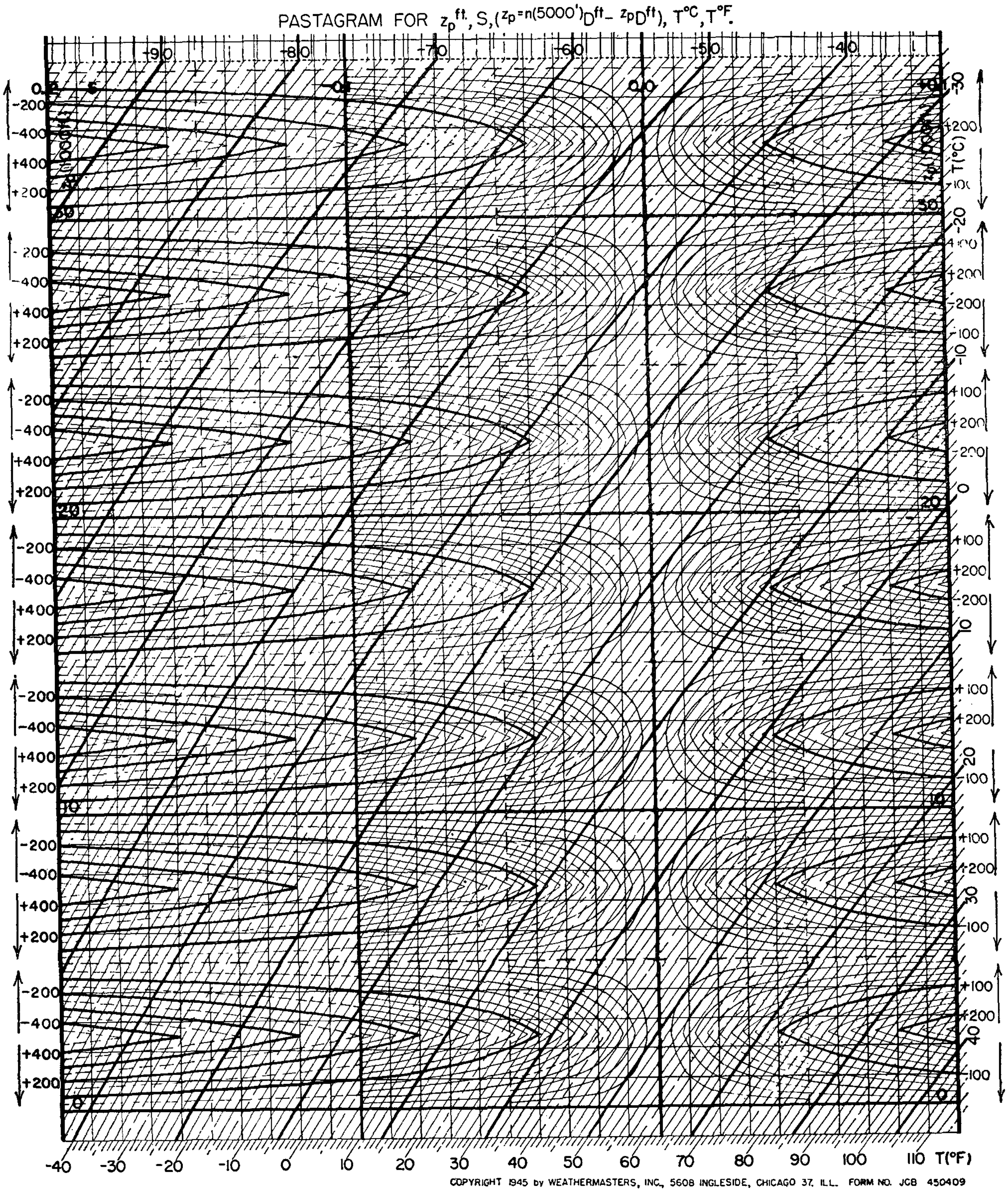
PASTAGRAM FOR z_p^{ft}, S, (z_p=n(5000')D^{ft} − z_pD^{ft}), T°C, T°F.
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 T(°F)
T(°C)
COPYRIGHT 1945 by WEATHERMASTERS, INC., 5608 INGLESIDE, CHICAGO 37, ILL. FORM NO. JCB 450409

PLATE XI.

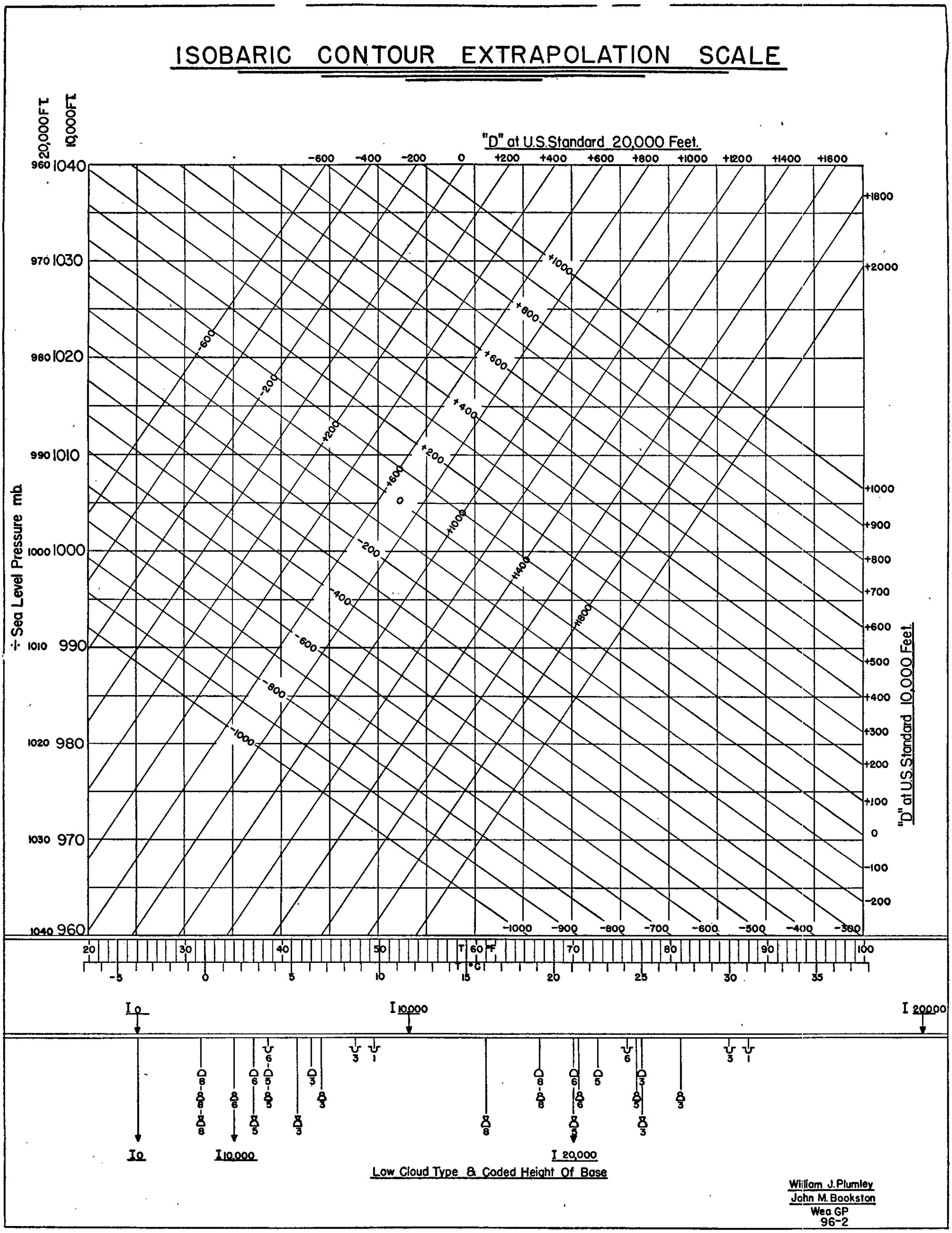
ISOBARIC CONTOUR EXTRAPOLATION SCALE
"D" at U.S. Standard 20,000 Feet.
"D" at U.S. Standard 10,000 Feet.
Sea Level Pressure mb.
20,000 FT.
10,000 FT.
Low Cloud Type & Coded Height Of Base
William J. Plumley
John M. Bookston
Wea GP
96-2

Plate XII.

GEOSTROPHIC AND THERMAL WIND SCALE

NOTE: The dashed latitude lines are to be used with ten times the labeled value of either the spacing or the speed

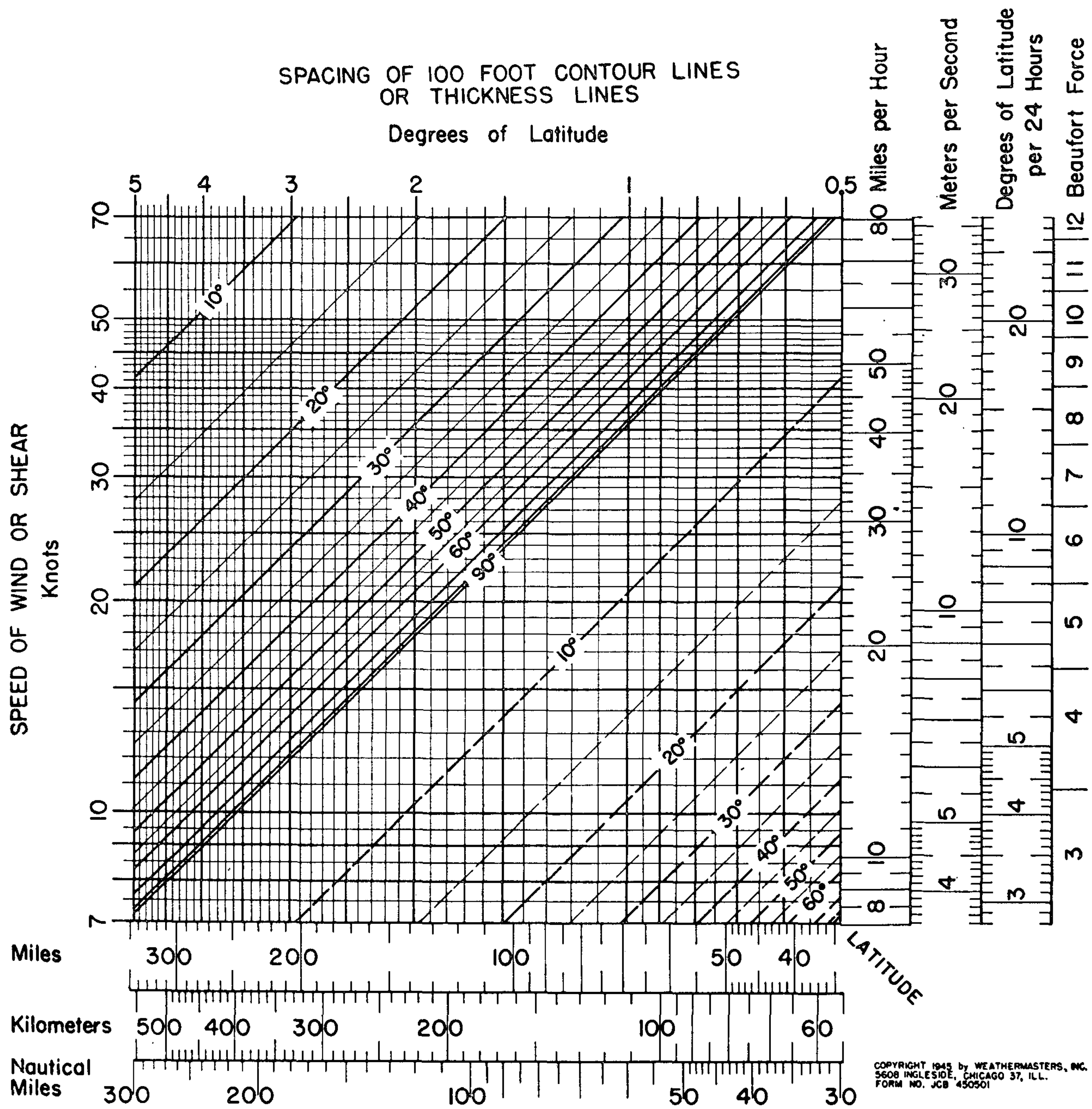

PLATE XIII.

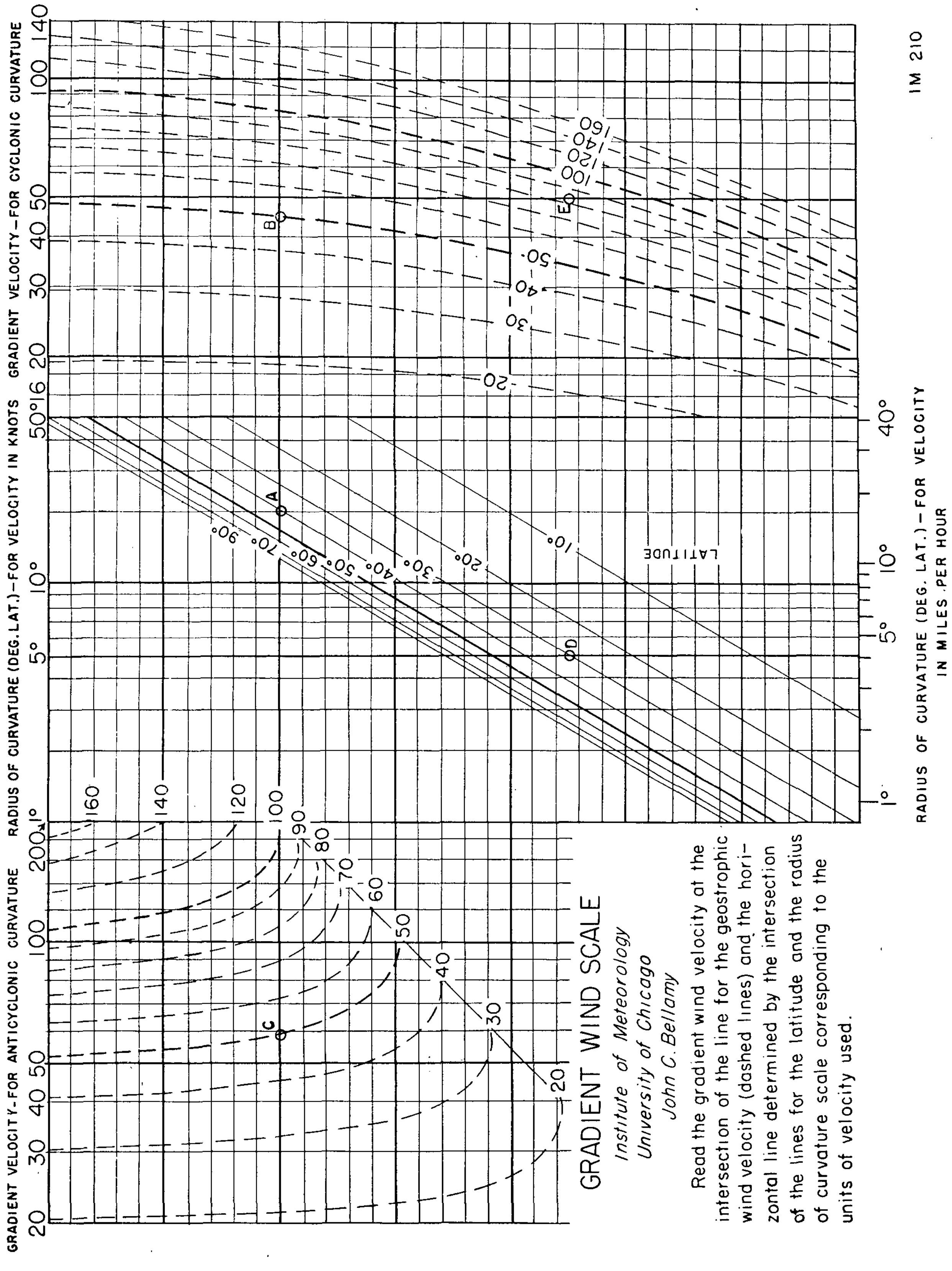
GRADIENT VELOCITY-FOR ANTICYCLONIC CURVATURE
RADIUS OF CURVATURE (DEG. LAT.)-FOR VELOCITY IN KNOTS
GRADIENT VELOCITY-FOR CYCLONIC CURVATURE
RADIUS OF CURVATURE (DEG. LAT.)-FOR VELOCITY IN MILES PER HOUR
LATITUDE
IM 210
GRADIENT WIND SCALE
Institute of Meteorology
University of Chicago
John C. Bellamy
Read the gradient wind velocity at the intersection of the line for the geostrophic wind velocity (dashed lines) and the horizontal line determined by the intersection of the lines for the latitude and the radius of curvature scale corresponding to the units of velocity used.

PLATE XIV.

DRIFT DETERMINATIONS WITH RADIO AND PRESSURE ALTIMETERS

INSTRUCTIONS AND EXAMPLE

1. Determine D_1, the first radio altimeter reading (9410') minus a simultaneous pressure altimeter reading (9260') (or $D_1 = 9410' - 9260' = +150'$)
2. Determine D_2, a later radio altimeter reading (9150') minus a simultaneous pressure altimeter reading (9300') (or $D_2 = 9150' - 9300' = -150'$)
3. Locate point A at the ground distance travelled between readings (130 n.m.) and the mid latitude of the two readings (30°N)
4. Move vertically to point B at the value of $D_2 - D_1$ $(-150' - (+150') = -300')$ to obtain the cross wind (100 knots)
5. Move horizontally to point C at the true air speed (200 knots) to obtain the drift angle (30° Right)

IN THE NORTHERN HEMISPHERE: if $D_2 - D_1$ is positive, drift is to the left
if $D_2 - D_1$ is negative, drift is to the right

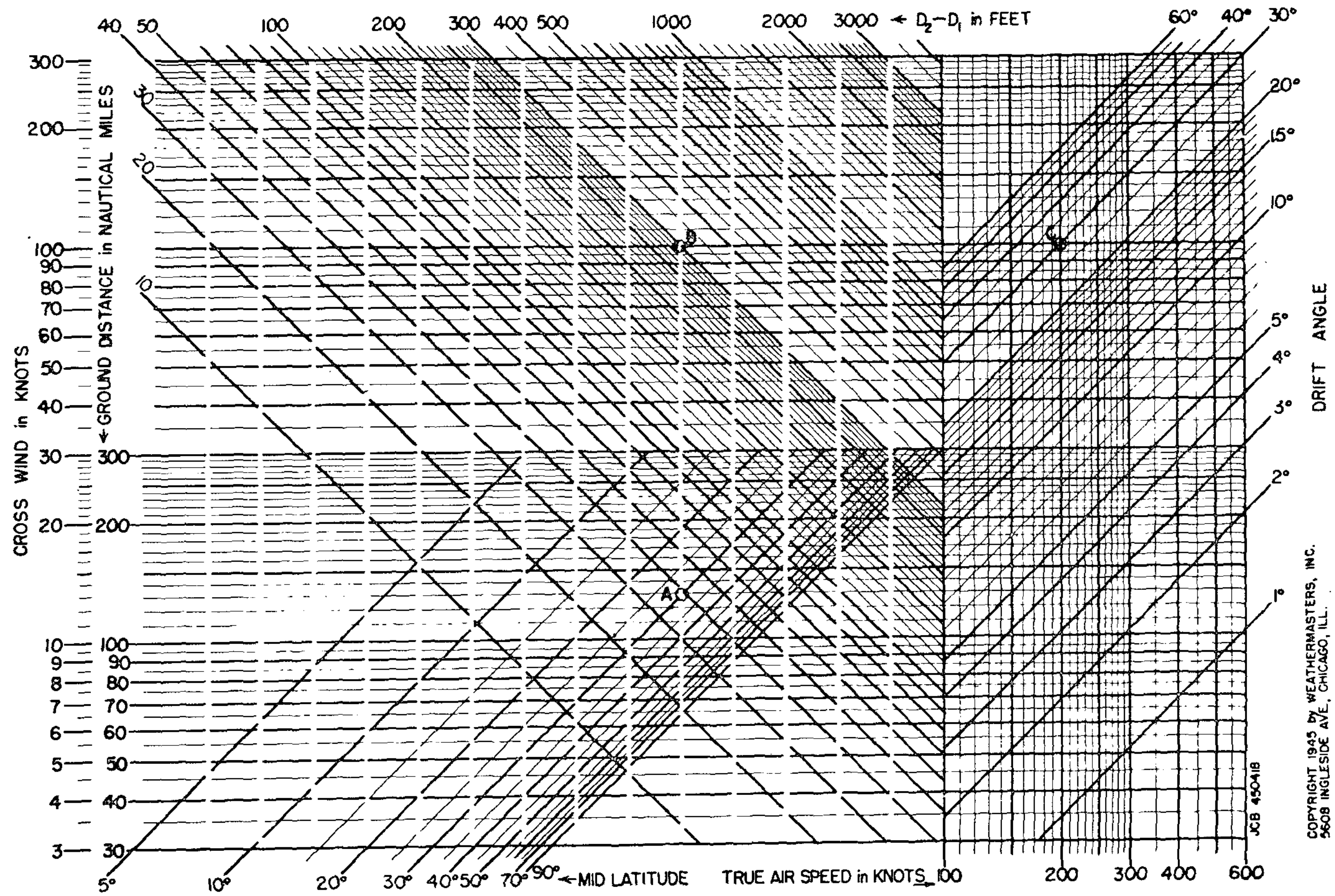

PLATE XV.