PRECISION ALTIMETRY

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THE aneroid barometer has a long history of usefulness for exploration, reconnaissance, and sketch mapping. It is usually considered an instrument which can give only approximate elevations, and it has never been considered as a tool for accurate mapping. With the development of the airplane, altimeters have undergone considerable improvement, both for use in the airplane itself and as an aid to the meteorologist in forecasting weather for airplane operation. With the improved instrument it should be possible to obtain more accurate elevations. If sufficient accuracy could be obtained, the possibility would exist of materially reducing the cost of vertical control for all mapping operations.

For a number of years the Wallace and Tiernan Products Company, of Belleville, New Jersey, have been building high-grade altimeters. One of their recent types was especially designed for ground surveying, and the design indicated the possibility of especially high precision. In order to discover what could be done with this instrument, this company sponsored a pilot project at Princeton University to determine what methods should be employed for barometric leveling and what accuracy could be expected in the results. The research was undertaken by the Civil Engineering Department under the direction of the author. It was not the purpose of the project to conduct an exhaustive study of the problem, but to blaze a trail for further investigation.

The results indicate that two methods of barometric leveling are entirely practical and satisfactory from a standpoint of operation, and that the results obtained are well within the limits of accuracy desirable for high-grade mapping.

The Wallace and Tiernan instruments in question have a range from minus 1,000 feet to plus 3,000 feet. The instrument is illustrated in Figure 1. The graduations are spaced at 10-foot intervals and the nearest foot can be accurately estimated. The 100-foot marks are indicated on the dial while the instrument is held at a standard pressure and the 10-foot marks are interpolated between them. The values in feet are correlated with barometric pressure in accordance with the Smithsonian Meterological Table 51, of 1931, which is based on the density of dry air at 50°F. at sea level at latitude 45°29′. Zero elevation is set at 29.900 inches of mercury. The instruments are operated by metal strips rather than gears. They are jeweled and sensitive to one-foot difference in altitude. They showed no indication of friction or backlash.

Soon after tests had been begun with these instruments, it became apparent that instead of testing the instruments, it was the peculiarities of the atmosphere that were being tested.

The usual method of determining elevations by aneroids is, of course, to place an instrument at a base station (preferably at a known elevation) where readings are taken at frequent intervals. A second instrument is taken to the various field stations where elevations are to be determined. The difference between simultaneous readings of the two instruments gives the difference in altitude between two stations.

Altimeters usually are graduated in feet and, therefore, a fixed relationship must be established for any altimeter between feet of elevation and differences in barometric pressure. Actually this relationship is not fixed but changes in proportion to the change in air density. The density of the air depends chiefly upon its temperature, moisture content, and the force of gravity. Gravity in

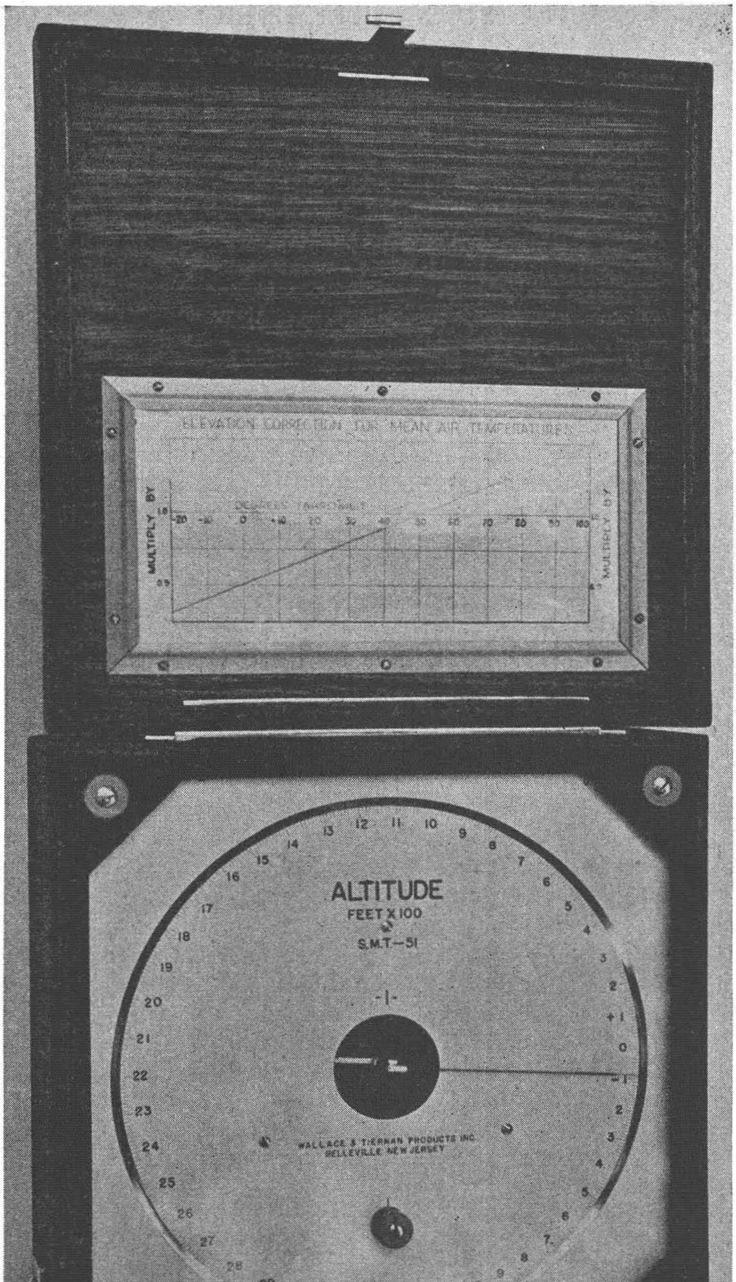

FIG. 1. One of the altimeters used.

turn varies with the latitude and the elevation. Thus when accuracy is desired, corrections must be applied to the altitude differences obtained with the instruments.

It was found that in order to utilize fully the precision of the instruments, corrections for air temperature and moisture were necessary. Obviously some method had to be arranged by which these corrections could be made quickly and easily. This problem was approached in two ways, giving rise to the two methods which are recommended for precise altimetry.

The first method depends on using a single base in accordance with the usual procedure for barometric leveling. A special chart was finally developed which made it practical to apply the various corrections.

The second method utilizes two bases, preferably above and below the elevation range of the field stations. When the true difference in elevation between the base stations is known, and simultaneous indications of the instruments are read, the relationship between altitude difference and differences in elevation is known precisely at that particular moment.

The two methods were given a final field check which consisted of over 100 observations spread out over an area 20 miles square. The observations were made at stations the elevations of which had been determined by spirit leveling. The errors which resulted are shown later in a table. Compiled, they are the following:

	Errors in Feet	
Method	*Average Error*	*Maximum Error*
Single-Base	2.08	11.6
Two-Base	1.76	6.7

In the course of the research work it was found that this high accuracy could not be maintained unless certain specifications for the operation were followed. These are described later.

Single-Base Method

In order to utilize a single base the air temperature had to be determined so that the proper correction could be applied. Thermometers were read at the base and at the field station and the average used. Various methods were tried to obtain the moisture content. Humidity indicators, depending upon the expansion of the human hair with moisture, could not be calibrated successfully. A dew point cup required a supply of ether, which was thought to be impractical. The simplest field method proved to be the use of the wet-bulb thermometer. These values were taken at the field and the base stations and the average used.

With the usual formulas and tables it would have been impossible to determine whether or not the wet-bulb thermometers were giving the desired results, because it would have taken too long to make the necessary computations. This was accomplished, however, through the assistance rendered by Mr. Ralph M. Berry, of the United States Coast and Geodetic Survey. Mr. Berry supplied charts which he had designed for temperature corrections and a splendid set of nomographs for the computation of the effect of humidity measured by the wet- and dry-bulb thermometers.

It was found that corrections for humidity were necessary. This was to be expected as the altitude-pressure relationship of the instrument is based on dry air.

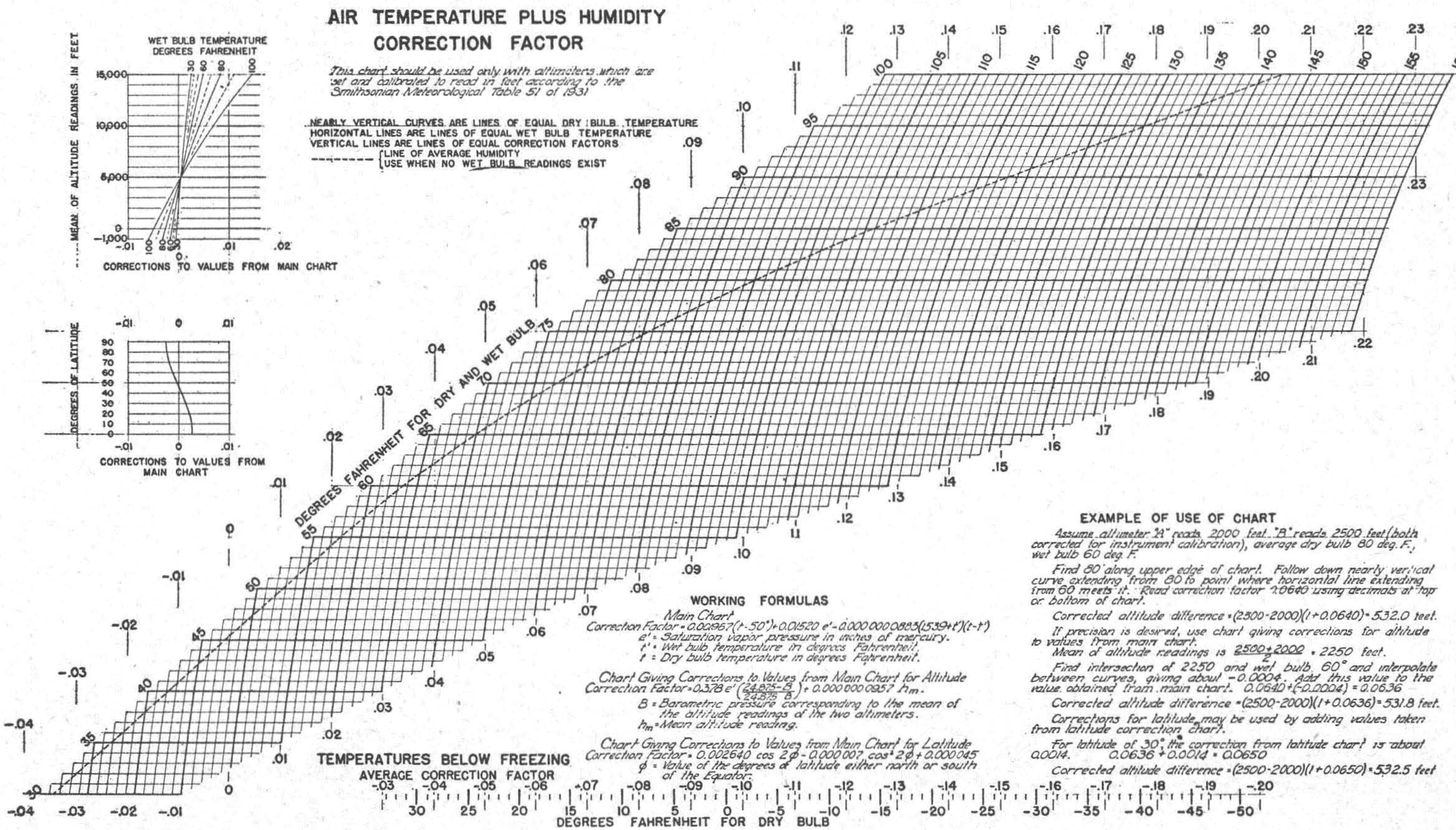

FIG. 2. Correction chart designed to have no corrections to main chart at altimeter readings of 5,000 feet.

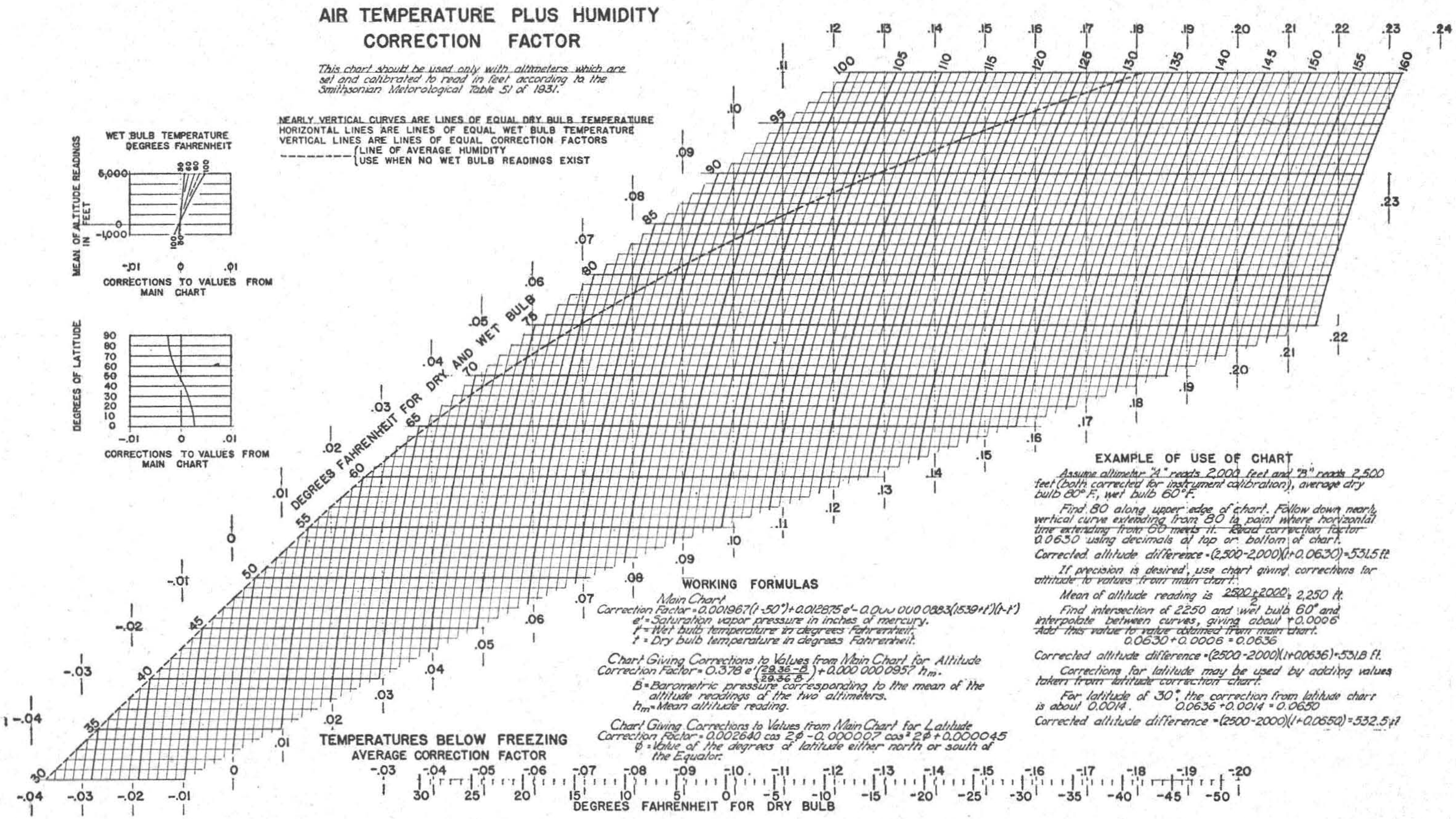

FIG. 3. Correction chart designed to have no correction to the main chart at altimeter readings of 500 feet.

The Correction Factor Chart

Finally a chart was developed by the writer which proved practical. It can be used rapidly and provides for the corrections for temperature, humidity, altitude, and latitude.

The chart is entered with the dry- and wet-bulb temperatures as arguments. From the chart can be read a correction factor to the fourth decimal which corrects for air temperature and humidity. Since the correction for humidity varies slightly with changes in barometric pressure and the actual wet-bulb reading, a small chart was added which is entered with the average altitude and the wet-bulb reading as arguments. Since gravity varies with altitude, the correction for the change in gravity is included. It was found that an approximate average altitude and an average wet-bulb reading for a single day's work was accurate enough to be used for entering this small chart. Thus a certain value could be obtained for a day's work and applied to all the readings of the main chart. A small chart was also added to give the correction factor for the latitude. Thus to use the chart it is necessary only to add the altitude and latitude correction factors for the day and to apply this value to any readings obtained from the main chart. The altitude difference is then multiplied by the correction factor and corrected accordingly. Two main charts, Figures 2 and 3, were prepared having zero correction at 5,000 feet and 500 feet respectively.[1]

Method Utilizing Two Bases

When two base stations are at known elevations, the field instrument reading will give one altitude computed from the lower base and another altitude computed from the upper base. The variation between the two altitudes is proportional between the actual air density and the density for which the instruments were calibrated. It is therefore possible to obtain the correct altitude by adjustment in proportion to the altitude differences. This procedure eliminates all field observations and computations having to do with corrections for variations in air densities, and reduces the necessary computations to merely proportional adjustment.

In actual practice, the altitude is computed from each base without correction, and the variation between these altitudes is obtained. The variation is then multiplied by the ratio of the altitude difference to be corrected divided by the absolute sum of the altitude differences (from the two bases), and the proper altitude corrected by this amount. The same procedure can be applied to the second altitude as a check. (See Fig. 4.)

Specifications

Effect of Wind. It was soon discovered that observations at certain field stations gave erratic results. In particular, there was a station in a railroad cut and a second station directly above it on a bridge. The variation in the differences between these stations alone was considerable and increased with increase in wind velocity. This gave rise to a series of tests by which it was definitely determined that precise altimetry cannot be accomplished when a medium wind is blowing. In general, the wind indicates a barometric gradient which has an unknown and changing direction, but the effect of wind is much more serious because of the following:

Since it was found that when the wind was blowing, certain field stations gave erratic results, a test was designed to measure if possible, what caused this

[1] Coordinates necessary to plot the charts are carried at the end of this article.

erratic behavior. The Palmer Stadium at Princeton University constitutes an obstacle to the wind which presents one vertical face and one sloping face. A day was chosen when a strong wind was blowing and altimeters were placed at different positions on the stadium so that the wind first struck the vertical face. A control altimeter was placed at a considerable distance. The results indicated that, although there was in general a change in pressure which would be ex-

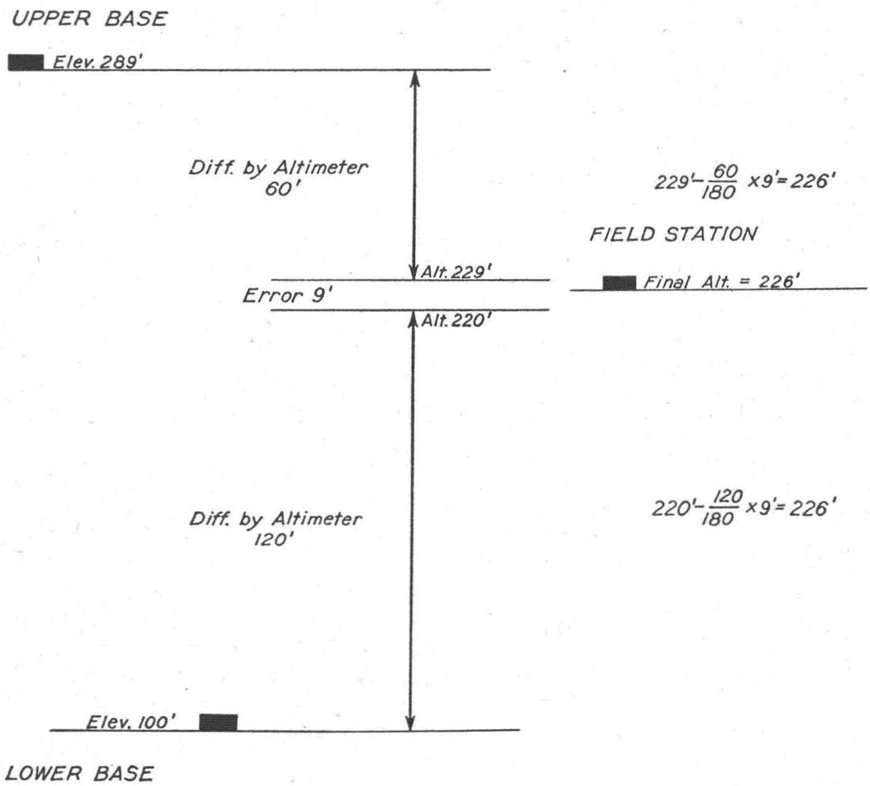

FIG. 4. Proportional adjustment when two bases are used.

pected according to the rules of aerodynamics, the chief effect was that the readings became more and more erratic with the increase in wind velocity. It was shown that in the presence of an obstacle the air pressure increases at the windward base of the obstacle (thus lowering the altitude indication), and decreases very considerably at the top of the obstacle and for a considerable distance behind the obstacle. But more important than this, random eddy currents are set up and this turbulence creates random barometric pressures.

A study was made on a windy day, using three bases separated by approximately twenty-eight, twenty-two, and sixteen miles respectively. The velocity of the wind averaged thirteen miles an hour (N. E.), and the altitude differences between bases varied over the following ranges:

Bases	*Distance*	*Range of Errors*
S—P26	22 miles	73′
S—Mon 144	28 miles	67′
P26—Mon 144	16 miles	51′

The study made in the stadium gave no errors as great as this with much higher wind velocities. Thus it can be assumed that the effect of wind, topography, and distance is to increase the errors at random. When the wind was not blowing, distance and topography had little effect. A final specification, therefore, was established that the maximum distance should be ten miles, and the maximum wind velocity ten miles per hour. This specification has been used in the final test runs, but it should not be assumed that it cannot be safely increased.

A determination of the wind velocity, therefore, has been included as part of the method, but with a little practice it is possible to estimate the wind velocity with sufficient accuracy to make such a determination unnecessary.

Location of Bases. It is obvious upon a moment's thought that quiet air must have exactly the same pressures at exactly the same elevations. The slightest variation from this condition would cause an air movement and thus be indicated by wind.

The rate of change of pressure with respect to increasing altitude in still air, therefore, depends upon the density of the air only. No matter how carefully temperature and humidity are determined, since of necessity they must be determined on the surface of the ground, the actual density of the air must always be slightly in doubt. By setting two bases at different known elevations, it is possible to calibrate the air while the observations are being made. By locating them as near as possible to the center of the area where the work is being carried on, a closer determination of the air densities over the working area is obtained.

Since the unknown quantity is the air density, which can never be positively determined, the less the altitude difference, the less will this unknown factor appear and the more accurate will be the results. In accordance with the above assumptions, it was decided to limit the range of altitude differences to 200 feet.

Use of Field Instruments in Pairs. It was found that more accurate results are obtained when two field instruments are used together. They serve as a check against blunders by the field station observer. Theoretically, they should be used when two bases are used because the field reading comes into the computations twice as often as the base-station readings, and thus the average of the readings of the two field instruments gives a stronger result.

Observational Procedure. The instruments, of course, should be kept in the shade as much as possible so that their temperature will be that of the surrounding air and thus can be determined with accuracy, and the dry-bulb readings can be used for instrument temperature. The readings are made at two-minute intervals because it was found that often a sudden small barometric change will occur, creating a difference of as much as five feet in four minutes. Also, added accuracy is obtained by using an average rather than a single reading.

Swing Corrections. It was found that under the same conditions the instruments differed by amounts up to three feet. It was thought at first that this was due to a form of hysteresis or drift. Tests were made accordingly. Instruments were held in a partial vacuum corresponding to an increase in altitude over atmospheric pressure of 2,500 feet and 600 feet, respectively, and at temperature ranges of 28°F. to 85°F. The vacuum was maintained for at least eight hours. Upon release each instrument was compared with an instrument at atmospheric pressure. It was found that from 2,500 feet the instrument returned to normal in about two hours, and from 600 feet in about four minutes. It was decided that for the usual rates of change of altitude which would obtain in use, the effect is negligible.

The instruments were then placed together and compared from time to time. It was found that occasionally the differences between their readings varied by amounts up to three feet which could not be correlated to any physical conditions. As a result it was decided to apply index corrections to the instruments in

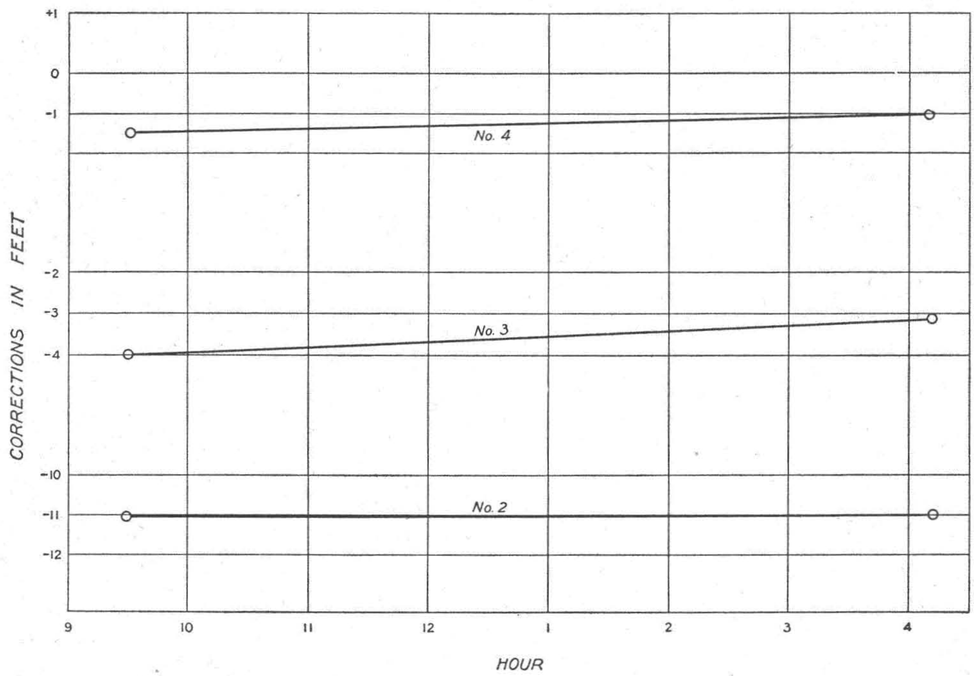

FIG. 5. Chart made for Swing corrections.

proportion to the time elapsed between comparisons. These have been called swing corrections.

SPECIFICATIONS FOR FIELD PROCEDURE

The requirements specified above can be collected into the following specifications:

1. *Definitions of Terms.*
   a. *Base Station.* An instrument position of known elevation at which an instrument is read at frequent intervals while altitude observations are being made.
   b. *Field Station.* Point where altitude is to be obtained.
   c. *Altitudes.* Elevations obtained by altimeters.
   d. *Elevations.* Elevations obtained by spirit leveling.

2. *Location of Base Stations, Two-Base Method.* Two base stations shall be used, and be known as the upper base and the lower base. The upper base shall be higher than any field station and the lower base lower than any field station. The difference in elevation shall not be greater than 200 feet between upper and lower bases. Both stations shall be located as near as possible to the center of the horizontal pattern of field stations.

3. *Location of Base Station, Single-Base Method.* The base station shall be located as nearly as possible at the average horizontal and vertical position of the field stations.

4. *Location of Field Stations.* Field stations shall not be more than ten miles from either base.

5. *Observation at Base Stations.* On altimeter known as the Upper or Lower Base Instrument shall be located at each base station. These instruments shall be kept in the shade and read at two-minute intervals on the even minutes during observations.

A dry- and a wet-bulb (omit wet bulb for two-base method) air temperature shall be read at the quarter hours.

The wind velocity shall be obtained at each hour during the progress of the work. This may be obtained by direct observation with an anemometer in the general vicinity or from local U. S. Weather Bureau stations.

6. *Observations at Field Stations.* Two instruments shall be read simultaneously at each field station. Five readings shall be taken for each instrument at intervals of two minutes on the even minutes. One dry- and one wet-bulb (omit wet bulb for two-base method) air temperature shall be read between the last two instrument readings. Any number of pairs of field instruments can be used while the bases are occupied so that several field observers can be operating together.

7. *Comparison Readings.* Immediately before and immediately after the work all instruments used shall be placed at the same elevation, allowed to attain the air temperature, and five readings shall be taken simultaneously on all instruments. One air temperature shall be taken. Whenever instruments can be brought together during the course of the work comparison readings should be made.

Note: It is best to store all instruments together and to take their comparison readings before taking them outdoors. On returning the comparison readings should be taken outdoors. As little time as possible should intervene between the comparisons and the field observations.

SPECIFICATIONS FOR COMPUTATIONS

General Method of Computation. Briefly the general method is as follows:

1. Select the base-instrument readings made when the field instruments are read.

2. Average each set of instrument readings and correct them for instrument temperature and swing.

3. Compute the altitude differences from each base.

4. Correct the altitude differences for temperature, moisture, content, altitude, and latitude (all by chart). (This step is omitted in the two-base method and paragraph 5 substituted.)

5. Compute the altitude of the field station from each base station, giving two altitudes. Adjust these to agreement in proportion to the altitude differences.

Computations in Field Books. Note: All computations shall be carried to tenths of feet.

1. *Selection of Data.* Among the base-instrument readings, select and mark the sets of five that were taken at the times any field instrument readings were taken. All readings thereafter should be identified by the time of the third reading of the five and the name of the field stations.

2. *Averaging.* Average all sets of five readings both for the base and the field instruments, including the comparison readings. Thereafter only the average readings will be used.

3. *Instrument Temperature Correction.* Correct the averages according to instrument calibration for temperature and pressure, using air temperature for instrument temperature.

4. *Chart for Adjustment for Swing.* For each of the two or more comparisons, after making temperature corrections, determine the corrections necessary to apply to the readings of each of the instruments to make all the readings the same. It will be found that these corrections will usually be different for each of the comparisons. Construct a chart having ordinates showing corrections and abscissas showing the time. Plot the correction readings for each instrument and draw straight lines connecting them so that the corrections for swing adjusted against time can be read for any particular minute, this is illustrated in Figure 5.

5. *Adjustment for Swing.* Correct all instrument readings for swing.

6. *Final Altitude.* Compute the final altitude for each field station according to the proper computation form.

Extension of the Limits Specified

A study of the data was made to determine if possible how far the limits mentioned in the specifications could be extended. The limits called for are 200 feet of altitude, 10 miles in horizontal direction and 10 miles per hour wind velocity.

As a result of this study it was concluded that if the difference in altitude between the bases were increased to 300 feet, the size of the working area increased to 30 miles square, and the wind specification held at 10 miles per hour, the average error would be 2.5 feet.

It is assumed the change in specifications would introduce a 0.4-foot error each for elevation, distance, and wind. Combining these by the square root of the sum of their squares the result of 2.5 is obtained.

Sample Field Notes for the Two-Base Method

In the following pages are shown samples of field notes at the upper base, the field station, and the lower base respectively. The beginning and end of the series of field notes are shown, and the data selected from the base stations notes which correspond to the data obtained for the field station No. 204. Note that two instruments are used at the field station.

Tabulation of Test Runs

Eight runs were made in exact accordance with the specifications. They have been called "test" runs. Using the data obtained by these runs four methods of computations were applied, named A, C, D, E respectively. The computation methods are the following:

Computation A—made in accordance with the Two-Base Method described.

Computation C—made in accordance with the Single-Base Method described using the upper base only.

Computation D—same as C but using lower base only.

Computation E—The principle of adjustment in accordance with altitude differences was applied to the results of C and D. This method was discarded.

A table has been included showing the results of these various computations. The values in the table are the errors in feet which resulted.

SAMPLE COMPUTATIONS
Field Notes

Upper Base Inst. | Observer King | June 8, 1943.

Time	Sta.	Alt. No. 4	Dry	Averages and Corrections	
9:26	Eng.	−83			−85.0
9:28	Bld.	−84		temp. cor.	+ .6
9:30	Comparison	−86			−84.4
9:32		−86	75.2	cor. to No. 1	− .5
9:34		−86			−84.9
11:54	R 124	−36			−35.2
11:56	R 124	−36		temp. cor.	+ .9
11:58	R 124	−35			−34.3
12:00	R 124	−35 204	65.8	cor. to No. 1	.3
12:02	R 124	−35			−34.6
12:04	R 124	−35			
12:06	R 124	−35			
4:10	Eng.	−87			−87.0
4:12	Bld.	−87	70.1	temp. cor.	+ .8
4:14	Steps	−87			−86.2
4:16	Comparison	−87		cor. to No. 1	0
4:18		−87			−86.2

Note: The observations were taken at the field station 204 at 11:56–12:04 inclusive. Only those observations taken at the base stations at those times are used in the average.

SAMPLE COMPUTATIONS
Field Notes

Field Instruments | Observer Jones | June 8, 1943

Time	Sta.	Alt. No. 1	Alt. No. 3	Dry	Averages and corrections			
9:26	Eng.	−85	−82			Alt. 1	Alt. 3	
9:28	Bld.	−87	−84			− 88.2	− 85.2	
9:30	Comparison	−90	−86		temp. cor.	+ 3.3	+ 4.3	
9:32		−90	−87	74.9		− 84.9	− 80.9	
9:34		−89	−87		cor. to 1		− 4.0	
							84.9	
11:56	204	−182	−182			−184.0	−183.8	
11:58		−184	−184		temp. cor.	+ 3.2	+ 4.5	Aver. two inst.
12:00		−185	−185			−180.8	−179.3	
12:02		−185	−185	74.0	cor. to 1		− 3.7	−181.9
12:04		−184	−183					
							−183.0	
4:10	Eng.	−90	−88			− 90.0	− 88.0	
4:12	Bld.	−90	−88		temp. cor.	+ 3.8	+ 5.0	
4:14	Steps	−90	−88			− 86.2	− 83.0	
4:16	Comparison	−90	−88	70.1	cor. to 1		− 3.2	
4:18		−90	−88				− 86.2	

SAMPLE COMPUTATIONS

Field Notes

Lower Base Inst. — Observer Smith — June 8, 1943.

Time	Sta.	Alt. No. 2	Dry	Averages and Corrections	
9:26	Eng.	−74			− 77.0
9:28	Bld.	−76		temp. cor.	+ 3.2
9:30	Comparison	−78	74.9		− 73.8
9:32		−79		cor. to no. 1	− 11.1
9:34		−78			− 84.9
11:54	A	−238			
11:56	A	−237			−238.2
11:58	A	−238		temp. cor.	+ 4.2
12:00	A	−238 204	66.7		−234.0
12:02	A	−239		cor. to no. 1	− 11.1
12.04	A	−239			
12:06	A	−238			−245.1
4:10	Eng.	−79			− 79.0
4:12	Bld.	−79		temp. cor.	+ 3.8
4:14	Steps	−79			− 75.2
4:16	Comparison	−79	70.1	cor. to no. 1	− 11.0
4:18		−79			− 86.2

Note: The observations were taken at the field station 204 at 11:56–12:04. Only those observations taken at the base station at these times are used in the average.

Two Base Method

Sample Altitude Computation

Each column is used for the computation of the altitude of one field station. The numbers give the order of computation and refer to the explanation below.

F. Sta. Name	204	5				
Time	12:00	6				
U. B. Name	R 124	1				
L. B. Name	A	3				
Alt.	122.0	17				
Adj. Inc.	− 5.6	16				
Alt. (U. B.)	127.6	11				
Elev. U. B.	274.9	2				
Alt. Diff.	−147.3	10				
−Read. U. B.	+ 34.6	8				
Read. F. Sta.	−181.9	7				
−Read. L. B.	+245.1	9				
Alt. Diff.	+ 63.2	12				
Elev. L. B.	56.4	4				
Alt. (L. B.)	119.6	13				
Adj. Inc.	+ 2.4	18				
Alt.	122.0	19				
Error	+ 8.0	14				
Abs. Sum	210.5	15				

(1) Designation of Upper base (same for all columns).
(2) Elevation Upper Base (same for all columns)
(3) Designation of Lower base (same for all columns).
(4) Elevation Lower Base (same for all columns).
(5) Designation of Field Station.
(6) Time of third Observation (the average of the five).
(7) Corrected Altitude Reading at Field Station.
(8) Corrected Altitude Reading at Upper Base sign changed.
(9) Corrected Altitude Reading at Lower Base sign changed.
(10) Sum of two below = Altitude Difference.
(11) Sum of two below = Altitude from Upper Base.
(12) Sum of two above = Altitude Difference.
(13) Sum of two above = Altitude from Lower Base.
(14) Altitude from Upper Base minus Altitude from Lower Base.
(15) Absolute Sum of Differences.
(16) Adjustment Increment.*
(17) Sum of two below = Final Altitude.
(18) Adjustment Increment.*
(19) Sum of two above = Final Altitude.

$$* \text{ Adjustment Increment} = \frac{(14)}{(15)} \times \text{Alt. Diff.}$$

Thus:—

$$(16)\ \frac{8.0}{210.5} \times (-147.3) = -5.6.$$

$$(18)\ \frac{8.0}{210.5} \times (+63.2) = +2.4.$$

TABULATION OF TEST RUNS

Errors in Feet

Runs		July 6, 1943				July 8, 1943			
Sta.		A	C	D	E	A	C	D	E
Mon	1316	−2.5	−2.0	−2.7	−2.5	+1.3	+0.8	+1.6	+1.3
RV	133	−2.4	−1.8	−2.5	−2.4	−0.1	+1.5	−0.2	0
RV	126	−1.2	−0.9	−1.4	−1.2	−4.2	−0.8	−5.9	−4.3
Mon	204	−1.4	−1.7	−1.6	−1.6	−1.5	+0.1	−2.1	−1.5
Mon	107	−2.0	−2.2	−2.5	−2.2	+6.2	+6.2	+3.5	+6.1
RV	105	−0.1	−2.6	+0.5	−0.2	−1.0	+1.5	−2.0	−1.2
Mon	177	+2.3	+2.0	+2.1	+1.9	−0.8	−1.3	−0.3	−0.9
Mon	118	−1.6	−1.5	−2.0	−2.1	−1.0	−0.1	−2.4	−1.2
Mon	122	+1.8	+1.5	+1.8	+1.7	−2.0	−0.8	−2.5	−2.1
Mon	124	+0.9	−1.5	+1.3	+0.8	−2.0	−3.3	−1.6	−1.9
Mon	149	−1.2	−3.2	−0.7	−1.3	0	−0.5	+0.1	0
P.R.R.		+1.9	+0.2	+1.9	+1.7	+0.1	−1.3	+1.1	−0.8
Mon	145	+0.4	+0.8	−0.2	+0.3	−3.5	−3.0	+3.7	−3.6
Max.		−2.5	−3.2	−2.7	−2.5	+6.2	+6.2	−5.9	+6.1
Aver.		1.52	1.69	1.63	1.53	1.82	1.63	2.08	1.92
Wind (An)			8.23				3.51		
Wind (W.B.)			7.57				4.72		

(An) indicates anemometer readings.
(W.B.) indicates Weather Bureau data.

TABULATION OF TEST RUNS

Errors in Feet

Runs		July 9, 1943				July 10, 1943			
Sta.		A	C	D	E	A	C	D	E
Mon	1316	−6.7	−1.9	−8.1	−6.7	+1.1	−0.5	+1.2	+0.8
RV	133	−0.4	+3.0	−1.2	−0.7	+3.2	+3.4	+3.2	+3.2
RV	126	−0.4	+2.4	−1.8	−0.4	−1.5	−0.5	−2.0	−1.5
Mon	204	−1.3	+1.9	−2.5	−1.3	−2.4	−2.2	−2.6	−2.5
Mon	107	−0.6	−0.3	−7.1	−0.7	+0.2	+0.2	−1.3	+0.1
RV	105	−0.2	+3.5	−1.4	−0.2	0.0	−1.2	+0.2	−0.1
Mon	177	−0.4	+1.4	−3.3	−0.3	−1.4	−1.7	−1.3	−1.6
Mon	118	+5.7	+11.6	−2.0	+5.7	−4.9	−5.4	−3.3	−4.4
Mon	122	+1.7	+4.9	+0.6	+1.7	−3.3	−2.4	−3.4	−3.2
Mon	124	+2.8	+4.0	+2.5	+2.8	−0.9	−0.9	−1.0	−1.0
Mon	149	−0.6	+1.6	−1.3	−0.6	−1.7	−2.8	−1.5	−1.8
P.R.R.		−0.1	+3.1	+0.3	+0.1	+0.3	+1.3	+0.2	+0.3
Mon	145	−0.7	+1.1	+1.2	−0.7	−1.8	−1.8	−1.9	−1.9
Max.		−6.7	+11.6	−8.1	−6.7	−4.9	−5.4	−3.4	−4.4
Aver.		1.66	3.13	2.56	1.68	1.75	1.87	1.78	1.73
Wind (An)			2.27				2.36		
Wind (W.B.)			3.5				5.0		

(An) indicates anemometer readings.
(W.B.) indicates Weather Bureau data.

TABULATION OF TEST RUNS

Errors in Feet

Runs		June 8, 1943				June 12, 1943			
Sta.		A	C	D	E	A	C	D	E
Mon	1316	+3.8	+2.2	+4.4	+3.8	−0.5	+0.2	−1.0	−0.7
RV	133	+0.3	−2.0	+0.6	+0.3	−0.2	+1.9	−0.4	−0.1
RV	126	+1.1	−1.0	+2.1	+1.0	+1.6	+2.6	+1.0	+1.6
Mon	204	+1.7	+0.2	+2.7	+2.0	−1.4	+0.7	−2.5	−1.6
Mon	107	+3.3	+2.7	+3.8	+2.7	+0.1	+0.3	−3.7	+0.1
RV	105	+0.1	−0.7	+0.6	+0.3	−1.6	−0.6	−2.4	−2.0
Mon	177	+2.2	+2.9	+1.2	+2.3	+0.8	+1.5	−1.0	+0.6
Mon	118	+1.4	+2.2	+1.6	+1.9	+0.8	+2.6	−0.6	+1.2
Mon	122	−2.0	−2.3	−1.8	−2.1	+1.7	+3.1	+0.7	+1.3
Mon	124	+1.2	+4.0	+0.6	+1.2	+1.5	+1.2	+1.6	+1.5
Mon	149	−0.8	−0.6	−0.7	−0.7	−1.6	−1.6	−1.8	−1.8
P.R.R.		+1.2	+2.6	+1.1	+1.3	−2.1	+0.4	−2.4	−2.1
Mon	145	+1.6	+2.4	+1.3	+1.6	−1.0	−1.0	−1.0	−1.0
Max.		+3.8	+4.0	+4.4	+3.8	−2.1	+3.1	−3.7	−2.1
Aver.		1.59	1.99	1.73	1.63	1.15	1.36	1.55	1.20
Wind (An)			2.21				3.10		
Wind (W.B.)			3.57				5.83		

(An) indicates anemometer readings.
(W.B.) indicates Weather Bureau data.

TABULATION OF TEST RUNS

Errors in Feet

Runs		July 15, 1943				July 16, 1943			
Sta.		A	C	D	E	A	C	D	E
Mon	1316	+2.3	+1.6	+2.5	+2.3	0.0	+3.5	−1.1	0.0
RV	133	0.0	+0.7	−0.4	−0.3	−1.7	+1.5	−2.2	−1.8
RV	126	−0.9	0.0	−1.6	−1.1	−0.9	+4.1	−3.7	−1.1
Mon	204	+1.7	+3.8	+0.5	+1.5	+0.4	+2.2	−0.7	+0.1
Mon	107	+2.4	+2.5	+0.1	+2.4	+2.4	−2.5	−2.2	+2.3
RV	105	−1.4	−0.2	−2.1	−1.7	−1.2	0.0	−1.6	−1.2
Mon	177	−0.5	−0.4	−1.4	−0.8	−1.0	−0.7	−2.5	−1.4
Mon	118	−3.0	−3.3	−4.2	−3.4	−2.8	−0.9	−5.5	−3.1
Mon	122	−4.2	−2.5	−4.9	−4.4	−3.0	−1.1	−3.8	−3.2
Mon	124	−6.3	−6.3	−6.4	−6.4	−6.0	−7.1	−6.1	−6.2
Mon	149	−4.0	−3.4	−4.5	−4.3	−3.2	−1.4	−4.0	−3.4
P.R.R.		−1.7	−1.0	−2.0	−1.9	−2.0	+2.0	−2.1	−2.1
Mon	145	−3.2	−3.5	−3.5	−3.5	−4.4	−2.5	−5.2	−4.7
Max.		−6.3	−6.3	−6.4	−6.4	−6.0	−7.1	−6.1	−6.2
Aver.		2.43	2.24	2.62	2.62	2.23	2.27	3.13	2.35
Wind (An)			3.16				2.78		
Wind (W.B.)			6.5				7.67		

(An) indicates anemometer readings.
(W.B.) indicates Weather Bureau data.

Correction Factor Chart for Altimeters

By Philip Kissam

Based on Altitude of 5,000 feet

Table to Abscissas of 5° Intersections

Wet bulb temperatures	Dry bulb temperatures															
	160°	155°	150°	145°	140°	135°	130°	125°	120°	115°	110°	105°	100°	95°	90°	85°
100°	2371	2280	2189	2098	2007	1916	1824	1733	1642	1551	1460	1369	1278			
95°	2322	2231	2140	2049	1958	1867	1776	1684	1593	1502	1411	1320	1229	1138		
90°	2279	2188	2097	2006	1915	1824	1732	1641	1550	1459	1368	1276	1185	1094	1003	
85°	2241	2150	2058	1967	1876	1785	1694	1602	1511	1420	1329	1238	1147	1056	0964	0873
80°	2206	2115	2024	1933	1842	1750	1659	1568	1477	1386	1294	1203	1112	1021	0930	0838
75°	2176	2085	1993	1902	1811	1720	1628	1537	1446	1355	1264	1172	1081	0990	0899	0807
70°				1874	1783	1692	1601	1509	1418	1327	1236	1145	1053	0962	0871	0780
65°							1576	1485	1394	1302	1211	1120	1029	0937	0846	0755
60°										1280	1189	1098	1006	0915	0824	0732
55°													0986	0895	0804	0712
50°																0694
45°																
40°																
35°																
30°																

Note: A decimal point should precede each value in the table, i.e., the value given in the table should be divided by ten thousand.

Correction Factor Chart for Altimeters

By Philip Kissam

Based on Altitude of 5,000 feet

Table to Abscissas of 5° Intersections

Wet bulb temperatures	Dry bulb temperatures 80°	75°	70°	65°	60°	55°	50°	45°	40°	35°	30°
100°											
95°											
90°											
85°											
80°	0747										
75°	0716	0625									
70°	0688	0597	0506								
65°	0664	0572	0481	0390							
60°	0641	0550	0459	0367	0276						
55°	0621	0530	0439	0347	0256	0165					
50°	0603	0512	0420	0329	0238	0147	0055		Minus Values		
45°		0495	0404	0313	0221	0130	0039	0053			
40°				0298	0206	0115	0024	0068	0159		
35°						0102	0010	0081	0173	0264	
30°								0094	0185	0277	0368

Note: A decimal point should precede each value in the table, i.e., the value given in the table should be divided by ten thousand.

Corrections to Values from Main Chart

By Philip Kissam

Based on Altitude of 5,000 feet

Table of abscissas of curves for wet bulb temperatures

Mean of Altitude readings in feet	100°	90°	80°	70°	60°	50°	40°	30°
− 1000	−0059	−0044	−0032	−0023	−0017	−0012	−0008	−0006
0	−0050	−0036	−0026	−0019	−0013	−0009	−0006	−0004
+ 1000	−0039	−0029	−0020	−0014	−0010	−0006	−0004	−0002
+ 2000	−0029	−0021	−0014	−0010	−0006	−0004	−0002	−0001
+ 3000	−0018	−0012	−0008	−0005	−0003	−0001	0000	+0001
+ 4000	−0007	−0004	−0002	0000	+0001	+0002	+0002	+0003
+ 5000	+0005	+0005	+0005	+0005	+0005	+0005	+0005	+0005
+ 6000	+0017	+0014	+0012	+0010	+0009	+0008	+0007	+0007
+ 7000	+0029	+0023	+0019	+0015	+0013	+0011	+0010	+0009
+ 8000	+0042	+0033	+0026	+0021	+0017	+0014	+0012	+0011
+ 9000	+0055	+0043	+0034	+0026	+0021	+0017	+0015	+0013
+10000	+0069	+0053	+0041	+0032	+0026	+0021	+0017	+0015
+11000	+0083	+0064	+0049	+0038	+0030	+0024	+0020	+0017
+12000	+0098	+0075	+0058	+0045	+0035	+0028	+0023	+0019
+13000	+0113	+0086	+0066	+0051	+0040	+0031	+0025	+0021
+14000	+0129	+0098	+0075	+0058	+0044	+0035	+0028	+0023
+15000	+0145	+0111	+0084	+0064	+0050	+0039	+0031	+0026

Note: A decimal point should precede each value in the table, i.e., the value given in the table should be divided by ten thousand.

Correction Factor Chart for Altimeters

By Philip Kissam

Based on Altitude of 495 feet

Table of Abscissas of 5° Intersections

Wet bulb temperatures	Dry Bulb temperatures															
	160°	155°	150°	145°	140°	135°	130°	125°	120°	115°	110°	105°	100°	95°	90°	85°
100°	2326	2235	2144	2053	1962	1871	1780	1688	1597	1506	1415	1324	1233			
95°	2284	2193	2102	2010	1919	1828	1737	1646	1555	1464	1373	1281	1190	1099		
90°	2246	2155	2064	1973	1882	1790	1699	1608	1517	1426	1335	1243	1152	1061	0970	
85°	2212	2121	2030	1939	1848	1757	1666	1574	1483	1392	1301	1210	1118	1027	0936	0845
80°	2182	2091	2000	1909	1818	1726	1635	1544	1453	1362	1270	1179	1088	0997	0906	0814
75°	2155	2064	1973	1882	1790	1699	1608	1517	1426	1334	1243	1152	1061	0970	0878	0787
70°				1857	1766	1675	1584	1492	1401	1310	1219	1127	1036	0945	0854	0762
65°							1562	1470	1380	1288	1197	1105	1014	0923	0832	0740
60°										1268	1177	1086	0994	0903	0812	0720
55°													0976	0885	0794	0702
50°																0686
45°																
40°																
35°																
30°																

Note: A decimal point should precede each value in the table, i.e., the value given in the table should be divided by ten thousand.