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HEIGHTS BY ANEROID BAROMETER

by

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1. The Principle of Barometer Heighting

In the mercury barometer, a long test tube completely filled with mercury is inverted with its open lower end in a mercury pool. The mercury column will no longer reach the end of the tube, but will fall, leaving a vacuum above it. The pressure of the atmosphere on the exposed surface of the pool must balance the pressure of the mercury in the tube at the same level, for otherwise mercury would flow from tube to pool or vice versa until exact equilibrium was obtained. If a linear scale is fitted with its zero at pool level, the height of the mercury column can be read directly; we can then say that a column of mercury say 30 inches tall weighs the same as a column of air of the same cross-section, the air column extending from the point of observation upwards to the limit of the earth's atmosphere. If the weight of this air column was always the same at a particular height above sea level it would be possible to deduce altitude from a single reading of the barometer; but weather changes vary atmosphere pressure to such an extent that an altitude thus deduced might be in error by more than 1,000 feet. It is, therefore, always necessary to deduce heights from the difference of two simultaneous readings.

Fig. 1(a) shows diagrammatically two points A and B on a hillside. At the lower point A of altitude h_a, the mercury barometer reads 30 inches; at the same instant another barometer is found to read 29 inches at B, altitude h_b. The mercury column in each case balances the air column upwards from the point to the limit of the atmosphere, as in Fig. 1(b). The difference in length of the two mercury columns can then only be due to the air column between levels h_a and h_b, and a one inch mercury column must exactly balance the air column of length $(h_b - h_a)$. The density of mercury being known, we only require to know the density of air to deduce $(h_b - h_a)$; but since this density is not constant, but varies with pressure, temperature and humidity, the computation is a little more involved; details are given in para. 3.

The substitution of an aneroid barometer for the mercury instrument does not affect the principle; the aneroid is discussed in para. 2.

2. The Aneroid Barometer

The mercury barometer has the advantage that it gives an absolute value for the pressure; direct measurement on a scale gives a reading in inches or centimetres of mercury, only liable to error should the scale be the wrong length or incorrectly located. The instrument is not, however, suitable for field use, since it is bulky, heavy and susceptible to damage. If tilted from its vertical position the mercury will rise in the tube, and may make violent contact with the end to shatter it. This is guarded against in portable mercury barometers, either by arranging to raise the mercury level to fill the tube completely for transit (the Fortin), or to empty it (the George). The latter involves the risk of introducing air bubbles on refilling, and these would vitiate the results.

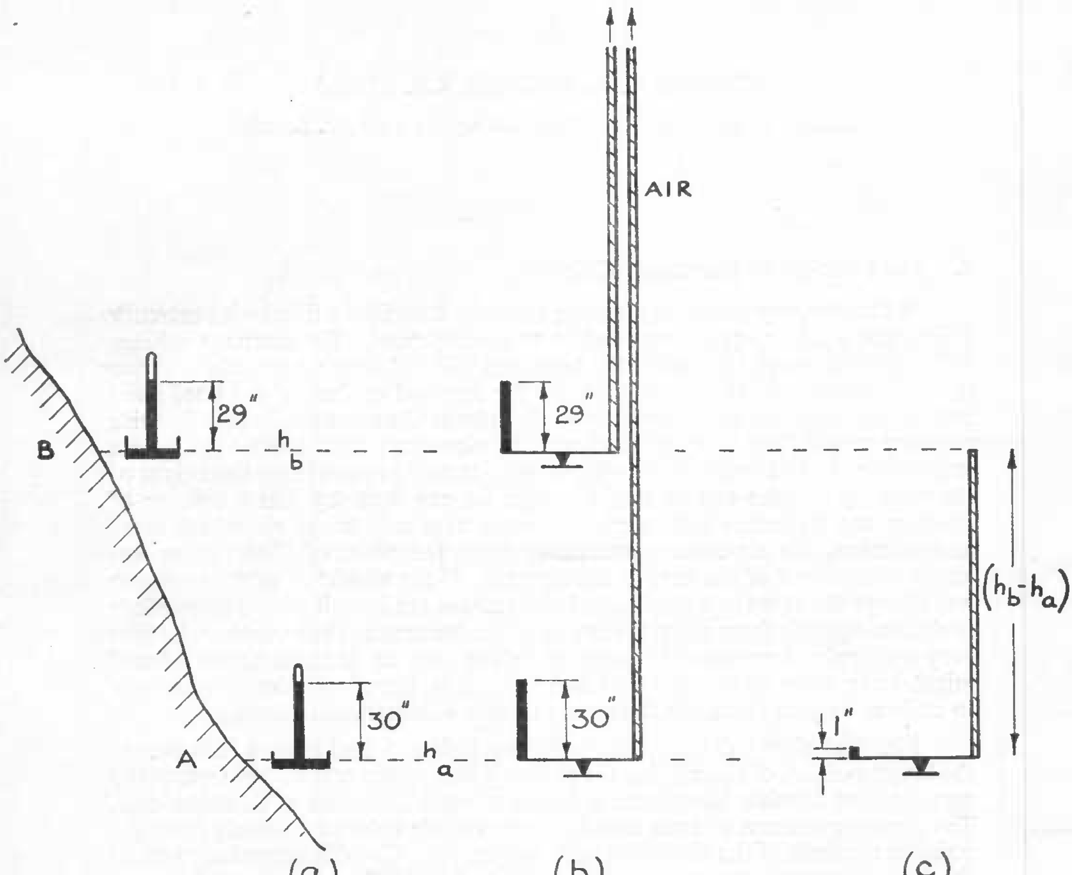


FIG. 1.

For field use, the aneroid barometer is much more suitable; it operates on a principle entirely different. One or more capsules of thin metal are evacuated of air and sealed. Under atmospheric pressure on its outer surfaces the capsule tends to collapse inwards, and its natural resistance may be assisted by a coil or leaf spring. One side of the capsule will be anchored to the instrument case; the other side then tends to move inwards under increased atmospheric pressure, or outwards as pressure falls. The range of movement is very small, of the order of 0·01 inches for a pressure change of 1 inch of mercury; very precise measurement is therefore necessary. In conventional designs the movement has generally been magnified by some system of levers; in the Baromec, a micrometer is used instead of a pointer, with electronic assistance to detect exact contact.

An aneroid is graduated in the same units as a mercury barometer: i.e., in inches or centimetres of mercury, or in millibars. A millibar is a pressure of 1,000 dynes per square centimetre. The scale would be set by the manufacturer after comparison in a pressure chamber against a mercury standard. The absolute value of pressure read by an aneroid will depend on the accuracy of this setting, or subsequent calibration; but since aneroid heighting always depends on the differences of readings, this is not a serious matter. A modern precision aneroid will detect smaller pressure differences than will the best mercury barometer.

An aneroid may be given a scale reading altitude direct, in which case it is properly termed an altimeter. This is not necessarily an advantage. The scale will certainly not read true heights above sea level, and it is still essential to take readings with two instruments to find a height difference. The difference thus obtained will only be true under certain standard conditions assumed when graduating, temperature of the air column being the most significant; for any air temperature other than the standard, a correction would have to be applied, and it is not much more laborious to compute height differences direct from pressure readings with an aneroid than to apply the necessary corrections to altimeter readings.

3. Computation of Height Differences

If simultaneous readings of pressure have been obtained at two points, A, B, as in Fig. 1(a), the text book relation connecting their height difference ($h_b - h_a$) with the pressure readings p_a and p_b is usually given in the form

$$h_b - h_a = c \log\frac{p_a}{p_b} \times \frac{T_m}{T_s} \times (1 + x)(1 + y)$$

where c is some constant

T_m is the absolute mean temperature of the air column between A and B

T_s is a standard temperature

x is a small correction for the humidity of the air column

y is a very small correction for the change of gravity with latitude.

This formula can be considerably simplified.

Since T_s is a constant, we can write $\frac{c}{T_s} = K$; also, an increase in humidity has a similar effect to an increase in T_m. Instead of using the separate multiplying factor $(1 + x)$ for a humidity correction, we may add to T_m the small temperature correction T_h which would have the same effect. Similarly, we may replace the gravity change factor $(1 + y)$ by adjusting the temperature again by the correction T_l of equivalent effect. The adjusted temperature $T_m + T_h + T_l$ may then be known as the virtual temperature T_v; it is the temperature of the air column of zero humidity at standard latitude which would exert the same pressure as the actual column of temperature T_m. For most purposes the humidity and latitude corrections may be neglected altogether; the former will be insignificant at low temperatures, the latter in latitudes between 30° and 60°. Instructions for determining them are given in para. 4.

The formula thus reduces to

$$(h_b - h_a) = KT_v \log \frac{p_a}{p_b}$$

$$= KT_v(\log p_a - \log p_b)$$

Since log. tables are required for one term above, it will be most convenient to complete the computation by logs.:

$$\log (h_b - h_a) = \log KT_v + \log (\log p_a - \log p_b)$$

Log KT_v, to give height differences in feet for values of T_v from 0°F to 100°F, is tabulated in Table A at the end of the booklet; if heights are required in metres, add $\bar{1}{\cdot}48401$.

Then $\log (h_b - h_a) = \text{Table A} + \log (\log p_a - \log p_b)$

The pressures p_a, p_b must be measured in, or converted to, the same units; since it is only their ratio which is used, it is irrelevant what the units are, and the relation is equally applicable to pressures in millibars, centimetres or inches of mercury. In evaluating $(\log p_a - \log p_b)$, five figure log. tables must be used to give answers to a foot; thereafter, four figure logs. would suffice for the rest of the computation, but Table A has been given to five figures as some computers may prefer to keep the same number throughout. It is not worth while giving final height differences more accurately than to the nearest foot.

Example:

Given $p_a = 990{\cdot}31$ mb

$p_b = 960{\cdot}15$ mb

$h_a = 123$ ft.

$T_m = 40°$F.

It is required to find h_b, neglecting humidity and latitude corrections; i.e., taking $T_v = 40°$

Log 990·31 = 2·99577

Log 960·15 = 2·98234

Difference = 0·01343

Log 0·01343 = $\bar{2}{\cdot}1281$

Table A for 40° = 4·7878

Sum = $\log (h_b - h_a)$ = 2·9159

Antilog = $h_b - h_a$ = 824 ft.

h_a = 123

Sum = h_b = 947 ft.

4. Virtual Temperature

The virtual temperature T_v required for computation in para. 3 is derived from

$$T_v = T_m + T_h + T_l$$

where T_m = Air column temperature

T_h = Adjustment for humidity

T_l = Adjustment for latitude.

T_m must always be known or estimated, except in the two-base method, para. 7. It will usually be derived from the mean of the shade temperatures at both stations of observation; if only one temperature has been taken, the other may be estimated, allowing a fall of 4° for 1,000 ft. of altitude. The temperatures should not be measured too close to the ground, where the temperature gradient may be high.

The fact that an aneroid is "compensated for temperature" in no way alters the need for recording T_m. Such compensation only means that the instrument would still give the same reading whether warmed or cooled, and that no extra instrumental error is thus introduced on account of varying instrument temperature.

The humidity correction T_h is always positive; it is only significant at higher temperatures. Omission of T_h cannot affect a height difference by 1% at temperatures below 70°F, even with maximum humidity. The humidity data will normally be derived from readings of wet and dry bulb thermometers. These will be exposed to the air by whirling, or by a small fan driving air past them. The wet bulb, cooled by evaporation, will normally read lower than the dry bulb; only in saturated air would both readings be identical. Since the wet bulb can only be read when whirling ceases, and the temperature will then at once start to rise with less evaporation, the wet bulb must be read first, and very promptly. Several whirlings should be made, and the lowest of the readings obtained after each accepted.

Chart B at the end of the booklet is used to find T_h when such observations have been made. The chart is entered on the left-hand side at the temperature shown by the dry bulb thermometer; the line is followed to the right until it intersects the curve of recorded wet and dry bulb difference. From this point the vertical line is followed downwards until it meets the scale showing additive temperature correction T_h. The vertical line on the left of the diagram, for which T_h is zero, shows the state of dry air; the right-hand curve of zero dry-wet difference shows the state of saturated air. If the humidity is known as a percentage other than by wet and dry bulb readings, it may be interpolated between these lines.

The humidity correction is also affected by the altitude. If this is appreciable the dry bulb temperature with which the chart is entered should be increased by 1° for each 1,000 ft. of height, but the dry-wet difference should not be corrected in any way. The most accurate result will be obtained if wet and dry bulb readings are taken at both stations; a value of T_h is found for each, and the mean of these values used to adjust T_m.

The small correction T_l for latitude arises from the variation of gravity with latitude; gravity is greater by about one part in 200 at the poles than at the equator. Constants being used for a standard latitude of 45°, the maximum correction for polar or equatorial observations is only about one part in 400, and it is usually disregarded altogether. In case it is required for precise work, the values of the equivalent temperature change T_l are given in Table C;

note that the correction changes sign and is negative for latitudes above 45°.

Example of height computation with full corrections:

Station X, height 105 ft. latitude 20°	Pressure 1,010·42 mb Wet bulb 70°F Dry bulb 75°F
Station Y, height unknown (about 2,500 ft.)	Pressure 928·37 mb Wet bulb 61·5°F Dry bulb 65·5°F
From Table C for Latitude 20°	T_l = +1·0°
For Station X, using Chart B for 75° dry, 5° dry-wet	T_h = +4·3°
For Station Y, using 65·5° plus 2·5° for 2,500 ft., and 4° dry-wet	T_h = +3·7
Mean	T_h = +4·0
	$T_m = \frac{75° + 65·5°}{2}$
	= 70·2°
Hence T_v	= 70·2° + 4·0° + 1·0°
	= 75·2°
Log 1010·42	= 3·00450
Log 928·37	= 2·96772
Difference	= 0·03678
Log Difference	= $\bar{2}$·56561
Table A for 75·2°	= 4·81744
Sum	= 3·38305
Antilog = $h_y - h_x$	= 2,416 ft.
h_x	= 105
h_y	= 2,521 ft.

For comparison, neglecting humidity and latitude, and using T_v = 70·2

Log Difference	= $\bar{2}$·56561
Table A for 70·2°	= 4·81336
Sum	= 3·37877
$h_y - h_x$	= 2,393 ft., an error of 0·8%.

5. Field Precautions

Whatever field procedure is used (paras. 6, 7, 8) precautions are necessary to avoid inaccuracy due to meteorological causes, and instrumental errors.

Errors due to meteorological causes will arise if pressure changes are not simultaneous at the stations for which the height difference is being determined. Work will be unreliable if pressure is changing fast or suddenly, as under storm conditions. It is advisable to use stations not too far apart; a base station is preferably central in the area where heights are required, and should not be separated from any part of it by ranges of hills, on the opposite sides of which pressure may differ significantly. Windy days are likely to give poor results, since wind indicates pressure variations; a weather map with isobars will indicate change of pressure with position. Wind will also have a local effect on readings, since pressure will be lower in the lee of a body; it is recommended that readings in windy conditions should be taken with the observer always facing the wind. Pressure will also be low in a car or aircraft past which an airstream flows. A very light wind may, however, give better results than a complete calm, since the air movement prevents the formation of unstable static masses of air, the temperature of which may differ significantly from that recorded for the air column.

Instrumental errors have been a fruitful source of inaccuracy in the past, but should now require much less attention. The invention of the beryllium copper capsule has virtually eliminated hysteresis—the tendency of an aneroid to delay in reaching its true reading; this need only be guarded against (by comparing readings over several minutes) when working under exceptional conditions, e.g., when visiting each station by helicopter, with rapid descents before each reading. Temperature compensation has been much improved, but it is still prudent not to rely on it unnecessarily; if the instrument is protected from extremes of temperature and not left exposed to the sun, it will not matter if compensation is not quite perfect.

It is not recommended that any precautions are taken against graduation error, such as by obtaining N.P.L. calibration certificates for each instrument. If an aneroid reads high, by say 1 millibar, it is of no particular consequence; it is more troublesome if, for a particular pressure change, the aneroid records 10·1 millibars instead of 10·0, for height differences would be proportionally affected; but this is a matter for the initial setting up of the instrument by the manufacturer. A simple test can be made by reading several instruments together at two points of considerable height difference. With an instrument read by micrometer, there would be none of the instrumental errors inherent in mechanical magnification systems.

6. Single Base Method

In the single base method, a "field" aneroid is read in succession at a number of points, the height of which are to be determined, while a second "base" aneroid is read at frequent intervals at a base station; this will normally, but not necessarily, be a station of known height; it is ideally at the centre of the area for survey, and at its mean height. The field observer starts by taking readings of his aneroid (or aneroids, if he is using several) at the base station alongside the instrument there. Since any error in this comparison affects every height determined, it is worth while taking more readings than at field stations, where an error affects one station only. At the end of the visits to field stations, a second comparison between base and field instruments should be made. Each comparison will give a value for the index correction; that is, the correction to be applied to readings of one instrument (normally the field) to give the reading which would have been obtained had the instruments been initially adjusted to read identically. If the starting index correction differs from the closing correction, and the former was applied to all readings, there would be a height misclosure for subsequent adjustment; it is usually more convenient to determine the two index corrections, and to interpolate between them to find the correction to be used for any intermediate time; there will then be no misclosure for adjustment later. The time and temperature may be recorded for the base comparisons; but time is only required here for interpolating index corrections, and temperature as a check on the agreement of the field and base thermometers.

After the starting comparison, the field observer proceeds to his first field station, recording there the aneroid reading, the shade air temperature, and the time by a watch previously checked against that of the base observer. It will generally be impossible to predict in advance the exact times at which field observations will be made; the base observer should, therefore, read his aneroid and air thermometers at frequent intervals—say every 5 minutes—so that the base readings applicable to any other instant may be interpolated; it may help to plot a graph showing base aneroid reading against time. Alternatively, it may be arranged that field observations are taken only at multiples of 5 minutes on the watch, so that there will always be a base reading to correspond without interpolation. If a walkie-talkie set is available, the readings could be synchronised with its help, and no extra base readings would be required. When each field station has been visited, the height traverse is closed by the second comparison at the base station.

Example

Single Base Aneroid Heights

Date: 7th July, 1960	Base Observer: A.B. Aneroid No.: 101
Weather: Fine	Field Observer: C.D. Aneroid No.: 102
Wind: Light N.W.	Base Station: Height: 202 ft.

1. Field aneroid at	Base	1	2	3	Base
2. Time	1105	1132	1156	1230	1255
3. Field air temperature		59	60	58	
4. Base air temperature		62	62	63	
5. Mean of (3) and (4)		60·5	61	60·5	
6. Base aneroid reading	1002·34	1002·20	1002·12	1002·08	1002·02
7. Field aneroid reading	1002·85	980·64	972·69	983·55	1002·47
8. Index correction to (7)	—·51*	—·49	—·48	—·47	—·45*
9. Corrected field reading	1002·34	980·15	972·21	983·08	1002·02
10. Log (6)		3·00095	3·00092	3·00091	
11. Log (9)		2·99129	2·98776	2·99259	
12. (10) − (11) ±		+·00966	+·01316	+·00832	
13. Log (12)		$\bar{3}$·9850	$\bar{2}$·1193	$\bar{3}$·9201	
14. Table A for (5)		4·8053	4·8057	4·8053	
15. (13) + (14)		2·7903	2·9250	2·7254	
16. Antilog (15) ±		+617	+841	+531	
17. Height of base station		202	202	202	
18. (16) + (17) = field height		819	1043	733	

Note: (a) Line 16 has the same sign as line 12.

(b) In line 8, corrections are interpolated between opening and closing corrections.

(c) For more precise work, lines 3, 4 and 5 may record virtual temperatures.

The example above shows a suitable method of computing a height traverse to determine the heights of three unknown stations. The readings of the field observer could be recorded direct on this form, those of the base observer being added later. The form shows a correction for air column temperature only; if humidity readings have also been taken, virtual temperatures may be used in lines 3, 4 and 5. In line 8, two values of the index correction are obtained from comparisons of the field and base instruments; these have been starred in the example. The remaining values have been interpolated by time. In this example, all field stations are above the base, and field pressures in line 9 are therefore lower than base pressures in line 6. If a field station is below the base, line 12 will have a negative value, and the same sign must be applied to the corresponding height difference in line 16. If the height of the base station is not known, the height difference in line 16 must be combined with whatever height is known to determine base height.

7. Two Base Method

In this method control readings are taken at frequent intervals at two base stations, preferably so sited that all heights to be determined lie between them. The heights of these base stations, the upper and lower base, must be known, and the index corrections to two of the three aneroids must be found. It may be convenient for the upper and lower base aneroids to be read together before or after work, to assess the upper base index correction; alternatively, the field aneroid might be separately compared against both, thus obtaining the same index correction indirectly via the field instrument.

Field procedure will be to start at one base station, visit the unknown stations in turn and finally to close at either base station. Readings to be taken at each station by the field observer will be time and aneroid only; it is not necessary to record air temperature. Observers are necessary at both base stations, to read aneroids at frequent intervals—preferably 5 minutes—so that readings corresponding to the field observation times may be obtained, if necessary after plotting graphs of base readings against time. In the example below, the field instrument started at the lower base, visited two unknown stations, the upper base to determine its index correction, another unknown station and finally closed at the lower base again.

In computing this method, the assumption is made that the air column temperature is uniform between the bases. This would mean that the Table A value would be constant, and a height difference would be directly proportional to the difference of log. pressures.

If upper base height and pressure is h_u, p_u
lower base height and pressure is h_l, p_l
field height and pressure is h_f, p_f

Then $(h_u - h_l) = K(\log p_l - \log p_u)$

$(h_f - h_l) = K(\log p_l - \log p_f)$

$$\text{Whence } h_f - h_l = \frac{\log p_l - \log p_f}{\log p_l - \log p_u} \times (h_u - h_l)$$

The logarithm portion of this expression must be evaluated by five figure logs., the answers being most conveniently expressed in units of the fifth place; the further computation may be by four figure logs. or by slide rule; a 10 in. slide rule should give an answer to 1 ft. if the height difference of the bases does not exceed 500 ft.

This method may be expected to give more accurate values than the single base method, but it has the disadvantage of requiring a further observer.

Example

Two Base Aneroid Heights

Lower Base: B.M.202.11	Observer: A.B.	Aneroid: 103	Height:	202
Upper Base: B.M.	Observer: C.D.	Aneroid: 104	Height:	775
Date: 12th July, 1960	Field Observer: E.F.	Aneroid: 105	Difference:	573

1. Field aneroid at	L.B.	1	2	U.B.	3	L.B.
2. Time	0935	0953	1027	1045	1102	1120
3. Lower base reading	990·44	990·50	990·59	990·64	990·74	990·80
4. Field reading	990·21	986·27	975·45	970·31	980·33	990·53
5. Index correction to (4)	+0·23	+0·24	+0·25	+0·26	+0·26	+0·27
6. Corrected field reading	990·44	986·51	975·70	970·57	980·59	990·80
7. Upper base reading	970·54	970·58	970·70	970·75	970·88	970·92
8. Index correction to (7)	—·18	—·18	—·18	—·18	—·18	—·18
9. Corrected U.B. reading	970·36	970·40	970·52	970·57	970·70	970·74
10. Log (3) 5 figs.		2·99585	2·99589		2·99596	
11. Log (9)		2·98695	2·98700		2·98708	
12. (10) — (11), × 10^5		890	889		888	
13. (10)		2·99585	2·99589		2·99596	
14. Log (6)		2·99410	2·98932		2·99149	
15. (13) — (14), × 10^5		175	657		447	
16. Log (15) 4 figs.		2·2430	2·8176		2·6503	
17. Log difference of base heights		2·7581	2·7581		2·7581	
18. (16) + (17)		5·0011	5·5757		5·4084	
19. Log (12)		2·9494	2·9489		2·9484	
20. (18) — (19)		2·0617	2·6268		2·4600	
21. Antilog (20) = height difference		115	423		288	
22. Lower base height		202	202		202	
23. Field height (21) + (22)		317	625		490	

Note: By slide rule, obtain line (21) from $\frac{(15)}{(12)}$ × difference of base heights.

8. Leap-frog Method

This method, generally reported as more accurate than the single or two base, requires two observers, who move alternately, so that simultaneous observations are made at each successive pair of stations to determine their height difference. The diagram below shows observers A and B finding the relative heights of stations 11-14. A and B observe together at station 11 to find the index correction to be applied to B's aneroid; B then visits station 12, for a simultaneous observation there while A remains at 11. A then proceeds direct from 11 to 13, for a simultaneous reading there with B at 12.

B then goes to 14, and after the simultaneous readings of A at 13 and B at 14, A joins B at 14 to determine a closing index correction.

Station 11	Station 12	Station 13	Station 14
A, B	—	—	—
A	B	—	—
—	B	A	—
—	—	A	B
—	—	—	A, B

The method is very flexible; any number of pairs of stations may be observed before the observers meet for comparison, but more accurate results are likely if comparisons are frequent.

If the height of one station only is known, it will be necessary for air temperatures to be observed, preferably by both observers; for accurate work at high temperatures, wet and dry readings might also be worth while. If a closing height is also known, and the heights to be found lie roughly between the known heights, temperatures can be omitted. The computation then becomes analogous to that of the two base method, the assumption being made that air column temperature is uniform.

The practical difficulty of the method lies in obtaining simultaneous observations. If the observers have walkie-talkie sets, there should be no delays; otherwise, it may be necessary for each observer to take 5 minute readings until certain that his fellow has reached his next station and started his series of readings. Premature movement of course means an unknown difference of height between successive stations, and entails re-observation.

In order to compute the relative heights of stations 11 to 14 of the traverse illustrated above, the readings of both observers are transferred to a single sheet (see example) and tabulated against time. There will be some gaps in the readings, while an observer is in transit from one station to the next, but each successive pair of stations must be connected by readings on one line. There may be more than one line for each pair, thus station 11 and 12 have been simultaneously observed at 1015 and at 1020, and their height difference will be computed from the mean readings for both times. Stations 12 and 13 are observed at 1030, stations 13 and 14 at 1040. It is not necessary to complete the form in respect of times at which only one observation has been taken, e.g., 1045.

Example

Leap-frog Traverse Record

Observer A				Observer B				
Time	Stn.	Temp.	Aneroid	Stn.	Temp.	Aneroid	Index corrn.	Corrected aneroid
1000	11	54	995·10	11	54	994·80	+·30	995·10
05	11	54	995·05	—	—	—	—	—
10	11	54·5	995·01	—	—	—	—	—
15	11	54·5	994·99 }	12	53	990·72	+·32	991·04 }
20	11	55	994·97 }	12	53·5	990·70	+·32	991·02 }
25	—	—	—	12	53·5	990·66	—	—
30	13	53	986·18	12	54	990·64	+·33	990·97
35	13	53·5	986·12	—	—	—	—	—
40	13	54	986·09	14	53·5	982·37	+·34	982·71
45	—	—	—	14	53·5	982·35	—	—
50	14	—	982·66	14	54	982·31	+·35	982·66

Computation of Height Differences

Station (a)	11	12	13
Station (b)	12	13	14
Mean temp. T_m	54·0	53·5	53·7
p_a	994·98	990·97	986·09
p_b	991·03	986·18	982·71
Log p_a	2·99781	2·99606	2·99392
Log p_b	2·99609	2·99396	2·99247
Difference	0·00172	0·00210	0·00145
Log Difference	$\bar{3}$·2355	$\bar{3}$·3222	$\bar{3}$·1614
Table A for T_m	4·7999	4·7994	4·7996
Sum	2·0354	2·1216	1·9610
Antilog = $h_b - h_a$	108 ft.	132	91

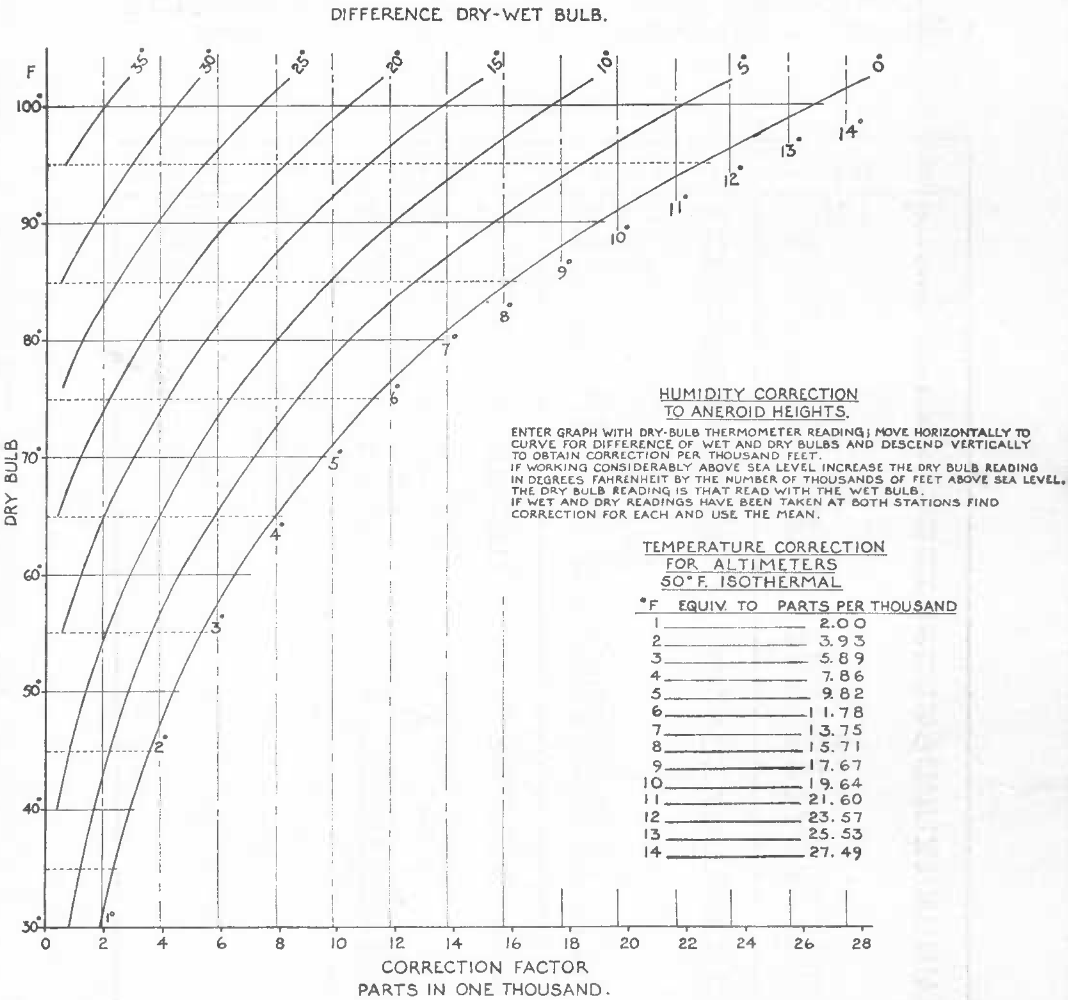
Index corrections are derived from the comparisons at station 11 at 1000, and station 14 at 1050; intermediate index corrections are interpolated between these values, and the corrected readings of B's aneroid taken out. Height differences are then computed on the lower part of the form, as in para. 3, to give differences in feet for each pair of stations; if one height is then known, all heights can be derived.

If the heights of the first and last stations, 11 and 14, had been known, it would not have been necessary to record temperatures. On the assumption that there is a constant temperature between these stations, height differences will be directly proportional to (log p_a — log p_b), for which values are in units of the fifth decimal place, 172, 210 and 145, total 527. If the height difference of stations 11 and 14 was 328 ft., the difference of stations 11 and 12 would be $\frac{172}{527} \times 328$, or 107 ft. Alternatively, a temperature may be guessed with which to enter Table A; if the guess happens to be correct, there will be no misclosure; if incorrect, a small misclosure will require proportional adjustment, and the same answer as above will result.

9. Single Aneroid Work

An observer working alone with a single aneroid may achieve useful results by taking a reading at a station of unknown height between two readings at a known station, provided the time interval between these readings is not so long as to make it inaccurate to interpolate the known station reading for the time at which the unknown station was visited. Speed is therefore important, as is settled weather. The result may be improved if the process is repeated; alternate readings at the two stations being plotted against time, and a succession of pairs of pressure values obtained from the graphs. Long intervals must be avoided; it will be better to find the height of B from A, and then C from B, rather than visit B and C in a single longer traverse from A.

In tropical countries only, a diurnal wave may be used. The pressure variations are there very regular in periods of good weather, and a graph of pressure against clock time can be plotted from the mean values of some days or weeks of static observations; this graph then being accepted as the base station pressure while field stations are visited. Even in the tropics, this method will give results much inferior to those from occupied base stations; outside the tropics weather changes swamp the regular variation, and the method is quite useless.



HUMIDITY CORRECTION TO ANEROID HEIGHTS.

ENTER GRAPH WITH DRY-BULB THERMOMETER READING; MOVE HORIZONTALLY TO CURVE FOR DIFFERENCE OF WET AND DRY BULBS AND DESCEND VERTICALLY TO OBTAIN CORRECTION PER THOUSAND FEET.
IF WORKING CONSIDERABLY ABOVE SEA LEVEL INCREASE THE DRY BULB READING IN DEGREES FAHRENHEIT BY THE NUMBER OF THOUSANDS OF FEET ABOVE SEA LEVEL. THE DRY BULB READING IS THAT READ WITH THE WET BULB.
IF WET AND DRY READINGS HAVE BEEN TAKEN AT BOTH STATIONS FIND CORRECTION FOR EACH AND USE THE MEAN.

TEMPERATURE CORRECTION FOR ALTIMETERS 50° F. ISOTHERMAL

°F EQUIV. TO	PARTS PER THOUSAND
1	2.00
2	3.93
3	5.89
4	7.86
5	9.82
6	11.78
7	13.75
8	15.71
9	17.67
10	19.64
11	21.60
12	23.57
13	25.53
14	27.49

CHART B.

10. Acknowledgments

For incorporation in a new edition of Vol. I of R.G.S. "Hints to Travellers", the author has compiled notes on heighting both by aneroid and altimeter, using the virtual temperature method. Thanks are due to the Council of the R.G.S. for permission to make use of portions of those notes in this booklet.

Chart B has been modified by permission of Col. D. R. Crone, C.I.E., O.B.E., from one first published by him in the Empire Survey Review.

TABLE A

t	Log KT	t	Log KT	t	Log KT	t	Log KT
0°	4·75155	30°	4·77905	60°	4·80491	90°	4·82931
1	250	31	994	61	574	91	4·83010
2	344	32	4·78082	62	658	92	089
3	438	33	171	63	741	93	168
4	532	34	259	64	824	94	247
5	626	35	347	65	907	95	325
6	719	36	435	66	990	96	403
7	813	37	522	67	4·81073	97	481
8	906	38	610	68	155	98	560
9	999	39	697	69	237	99	637
10	4·76091	40	784	70	320	100°	4·83715
11	184	41	871	71	402		
12	276	42	958	72	483		
13	368	43	4·79044	73	565		
14	460	44	131	74	647		
15	552	45	217	75	728		
16	643	46	303	76	809		
17	735	47	389	77	890		
18	826	48	475	78	971		
19	917	49	560	79	4·82052		
20	4·77008	50	646	80	133		
21	098	51	731	81	213		
22	189	52	816	82	294		
23	279	53	901	83	374		
24	369	54	986	84	454		
25	459	55	4·80070	85	534		
26	548	56	155	86	614		
27	638	57	239	87	693		
28	727	58	323	88	773		
29	816	59	407	89	852		

TABLE C

Adjustment T_l to air column temperature equivalent to correction for change of gravity with latitude.

Latitude	T_l in F°
0°	+1·4°
10°	+1·3
20°	+1·0
30°	+0·7
40°	+0·2
45°	0
50°	−0·2
60°	−0·7
70°	−1·0
80°	−1·3
90°	−1·4