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METEOROLOGICAL OFFICE

Scientific Paper No. 15

The Errors of the Meteorological Office Radiosonde, Mark 2B

by D. N. HARRISON, O.B.E., D.Phil.

LONDON: HER MAJESTY'S STATIONERY OFFICE

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INTRODUCTION

It is known that the errors of radiosonde observations are significant in relation to the uses to which they are put; that is to say, the radiosonde is not a good enough instrument for its purpose.

The errors arise from many different causes, and it is important to know how consistent or how variable they are. They cannot be classified unambiguously as systematic or random, but for the present purpose three types are recognized:

(i) The systematic error, of which the best estimate is the mean value for a particular series of trials. This may be a function of height (or pressure), and the series may be subdivided to show the differences between stations or different times of day or different manufacturers or batches of sondes. Errors of this type affect the absolute accuracy of the readings and can give rise to discontinuities between networks using different sondes or inconsistency between radiosonde and other (for example aircraft) observations. One always hopes to find mean values which are statistically significant and constant enough over long periods of time to be used as corrections in routine work. This was the chief aim of the international trials held in Switzerland in 1950 and 1956. This hope, however, has not so far been realized, but these trials, and others of the type now to be described, have at least been useful in showing the magnitude of the errors which can occur.

(ii) Errors which are more or less systematic, in the sense that they change only gradually during a flight, for a given sonde, but different for different sondes of the same type. These are called "sonde errors" in this paper. They are responsible for the scatter of the upper air observations in space and time.

(iii) Errors which are random or uncorrelated between consecutive readings. Provided that they are small compared with the sonde errors, the random errors are not very important, since most of the results of a sounding depend upon several readings; the chief instances of an observation depending on individual readings without smoothing are the pressure and temperature at an inversion and the lapse rate between two points.

The errors arise not only from changes in the instrument after calibration but also from the inevitable differences between conditions during calibration and those during flight, chiefly (*a*) changes in ambient temperature combined with differences in thermal lag and temperature coefficient between different parts of the sonde, (*b*) the decrease of air density, and (*c*) radiation, mainly of solar but also of terrestrial origin. (These factors affect different types of sonde differently.) It is impossible to measure the errors directly on a given sounding since a repeat calibration does not provide the necessary information and there is no other type of instrument which can be used for comparison.* The idea of a very accurate

* Aircraft observations cannot be co-ordinated with the radiosonde closely enough in place and time, and have not been found to provide a satisfactory comparison. They have, however, a certain value statistically.

"reference sonde" has appealed to many workers, but at present it is not practicable to make, in useful numbers, a sonde which could be proved to be significantly better than those in common use. Indirect methods have therefore to be used to assess the errors.

These methods fall into two categories:

(i) A comparison of two or more instruments of the same or different type in flight. This, if repeated many times, provides a measure of the mean value and standard deviation of the difference between two instruments, and hence of the standard deviation of the error of a single instrument, but not of the errors which they have in common.

(ii) A study of a quantity derived from the radiosonde observations of pressure, temperature and humidity. The quantity used is either the height of a standard pressure level or the height of the sonde at predetermined times. An estimate of the standard deviation, though not of the systematic error, of the height of a standard pressure level can be made for a network of stations by comparing the winds derived from the contours with those measured by radar, while the height of the sonde can be compared directly with the simultaneous value measured by radar. The limitation of this method is that the height is a function of both pressure and temperature, with a small correction for humidity, and their contributions to the total error cannot be separated with certainty.

SUMMARY OF RESULTS

This paper presents the results of a series of trials made at the stations of the British network in the years 1954–55, with later additions. The trials consisted of two parts, (i) a comparison over a whole year's routine soundings of heights derived from radiosonde observations with those measured by radar, and (ii) a series of "twin" soundings, in which two sondes were carried by the same balloon. Later sections of this paper deal separately with these parts (i) and (ii), the second of which was designed to fulfil Recommendation 32 (3) of the first session of the Commission for Instruments and Methods of Observation of the World Meteorological Organization.[1]*

These results have not been published before, but they have been used by the Meteorological Office in attempts to improve the sonde. As is explained below, the systematic errors of pressure found from a particular series of trials cannot be taken as representative of sondes at other times, but it seems probable that the sonde errors and random errors of pressure, temperature and humidity have been much less affected by instrumental changes and may be taken as characteristic of the system.

The results may be summarized as follows:

(i) The mean pressure errors are given in full in Tables 1–8 in Appendix IV and Figures 1 and 2. Those for the 1954–55 series have a characteristic distribution with height, of which the broad features are similar at all stations, though individual stations show variations which appear to be significant. There is also a difference between day and night. The errors are mainly positive up to the 80 mb level, but tend to become negative at higher levels. After these trials, minor changes were made in the sonde in two stages, and further series of trials were made at stations in the United Kingdom

* The superscript figures refer to the bibliography on page 23.

in November 1958 and December 1960. The results, while equally self-consistent, are quite different from those of the first series, having become predominantly negative, and different also from one another. This indicates that trials made over a limited period have some significance, but that over a period of years large changes in performance can be caused unintentionally by variations in the circuits, component values or methods of manufacture. It is probable that these pressure errors have their origin in temperature coefficients of various components.

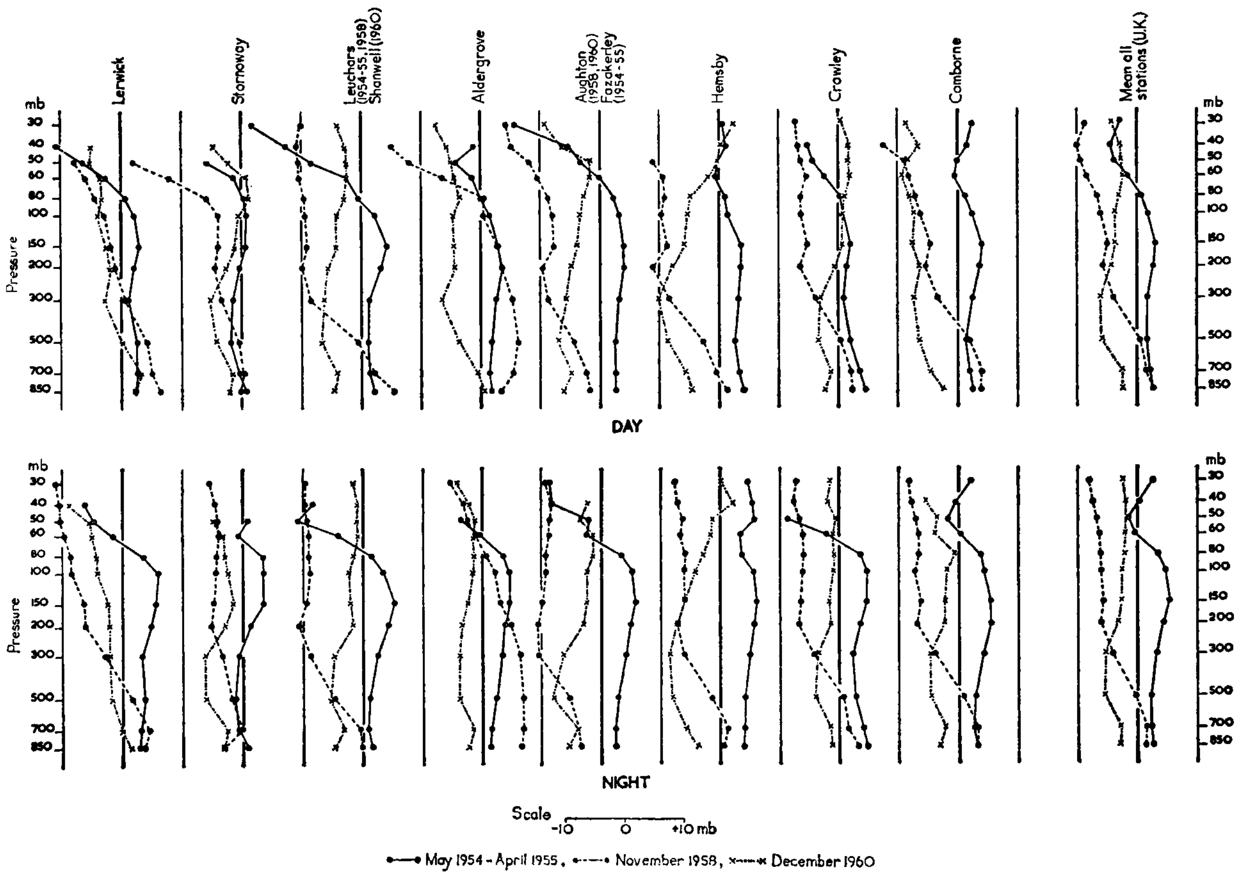

FIGURE 1. Mean pressure errors for United Kingdom stations, May 1954–April 1955, November 1958 and December 1960

(ii) The sonde errors and random errors are deduced from the twin soundings, and are given in Tables 15–17 and 18–20 for pressure, temperature and humidity. The sonde errors of pressure may be compared with the standard deviations derived from the radar height comparisons (Tables 9 and 10); they are of approximately the same magnitude. Probably the most important measure of the observational errors to the synoptic meteorologist is the standard deviation of the height of a pressure surface. The values of this for all levels are given in Tables 21–23. It will be seen that a standard deviation of about 20 metres, which is probably not far from an acceptable value at present, occurs at the 300 mb level. At 100 mb the standard deviation is twice as great, so that it would be necessary to reduce the sonde errors by a half in order to obtain contour charts of the same consistency at 100 mb as is found at present at 300 mb.

On the other hand it has been stated[2] that the deviation of the actual wind from the geostrophic wind could be obtained up to 700 mb if the geopotential at that level could be computed with a probable error of about 3 gpm* (standard deviation 4·5 gpm). The standard deviation of height at 700 mb is found (Table 23) to be 3·8 metres.

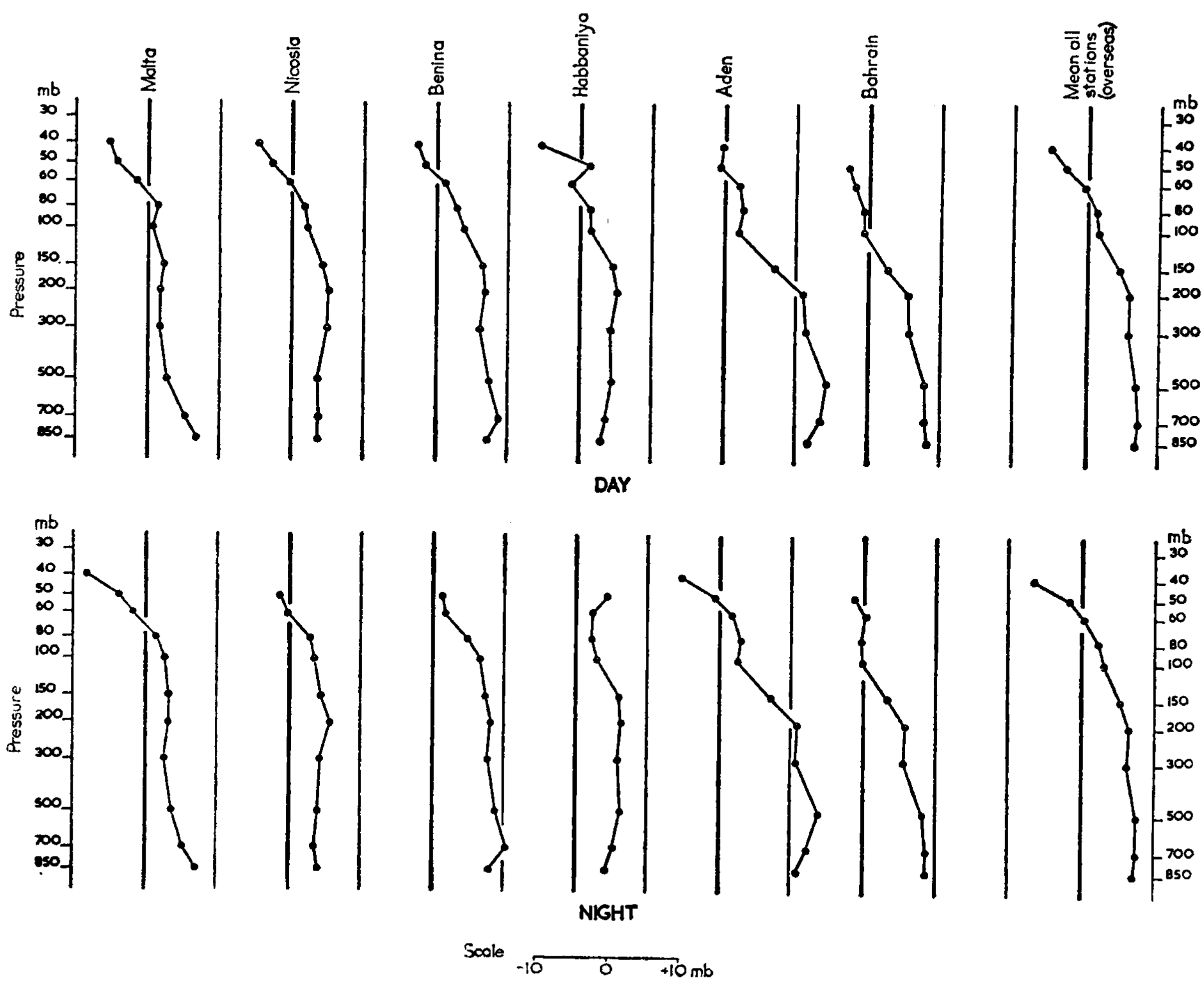

FIGURE 2. Mean pressure errors for overseas stations, June 1954–May 1955

The random errors are in general much smaller than the sonde errors; their effect can be assessed in the case of an inversion or other selected point by adding the variance to that of the sonde error, and in the case of a lapse rate between two points by assuming the sonde error to be constant and multiplying the random errors of pressure and temperature by $\sqrt{2}$.

* The geopotential in gpm is obtained by taking $g=980$ cm sec^{-2} in the integration of the static equation. In the trials under discussion the value $g=980{\cdot}62$ cm sec^{-2} was used. The difference is entirely negligible for the present purpose. (See p. 11)

TECHNICAL NOTES

The following notes on the radiosonde system are intended to help the reader to make use of the results presented.

A full description of the principles and construction of the Mark 1A sonde and an account of the sources of error in the observations are given by Dymond,[3] and a more popular account is given by Lander.[4] In 1946, owing to the need for larger numbers, the sonde was redesigned for mass production. The new design was known as Mark 2. No change was made in the electrical or meteorological components but only in the lay-out and methods of construction. In 1950–52 the half-wavelength aerial was replaced by a quarter-wavelength aerial in order to reduce the risk of short-circuiting overhead power lines, and certain changes calculated to improve stability were made in the radio frequency circuit; this modification is the Mark 2B, and again no change likely to affect the meteorological performance of the sonde was intentionally introduced.

The signal given by the sonde consists of a varying modulation frequency, produced by variable inductors actuated by the meteorological sensing elements, aneroid, bimetal and gold-beaters' skin. The inductors are switched into circuit in turn at intervals of about six to seven seconds, so that a complete cycle of readings—pressure (P), temperature (T) and humidity (U)—is obtained three times per minute, and the atmosphere is sampled at height intervals of 120 metres. (At high levels the switching rate falls considerably.) The observation consists in measuring the modulation frequency, converting this to P, T and U by means of calibration graphs and applying certain corrections.

The calibration data are obtained by subjecting the meteorological units, that is, the sensing elements with their inductors, while connected to their sondes, to varying pressure, temperature or humidity, and measuring the resulting oscillation frequency. The process has been described by Painter.[5]

Ideally, each signal frequency depends only on the response of the controlling sensing element to one of the meteorological variables—the pressure, temperature or humidity of the air—and measures the instantaneous value of that variable. In practice, however, the performance of the instrument departs from this in four different ways:

(i) The response of the sensing elements is not instantaneous, but lags appreciably behind the variations of P, T and U; this is important in the case of T and U, much less so in the case of P.

(ii) The aneroid capsule and gold-beaters' skin have temperature coefficients.

(iii) Other circuit components which determine the frequency—inductors, capacitors and resistors—have temperature coefficients and large thermal time-constants.

(iv) Thermal equilibrium is affected by radiation.

Each of these is a source of error, since it is impossible to reproduce flight conditions in the calibration equipment.

A correction is applied to the pressure readings on account of the temperature coefficient of the pressure unit as a whole. The units differ greatly among themselves, owing mainly to the variability of the magnetic material, but for practical reasons the correction is based not on full knowledge of the characteristics of each unit but on standard data derived from detailed tests of a limited sample. These tests are made in a calibration chamber, in which care is taken to secure uniformity of temperature. During a sounding it is assumed that the temperature of the pressure unit is that indicated by the temperature unit. There are thus two chief sources of uncertainty in the correction and of residual error in the pressure readings, namely departure of the individual unit from the assumed mean characteristic and non-uniformity of temperature in those components which contribute to the temperature coefficient of frequency. This is a basic limitation of the system. At low pressures and low temperatures the correction is large, so that a small percentage error in the correction may mean a large residual error of pressure.

The chief correction applied to the temperature readings is for solar radiation. The system has been described by Scrase[6,7]* and by Hawson.[8] In applying the theory the values of certain "constants" have to be assumed, notably the absorption coefficients for visible and infra-red radiation of the bimetal and aluminium shield of the temperature unit, and the earth's albedo. Mean values are used, although the absorption coefficients of different instruments may differ since they depend on the condition of the metal surfaces, and the albedo certainly varies significantly from time to time and from place to place. Variations of albedo must introduce temperature errors which are not included in those discussed in this report. Certain parts of the temperature unit have time-constants much greater than that of the bimetallic element, so that an error sufficiently systematic to escape detection by twin flight trials must be introduced, just as in the case of the pressure unit (see page 18).

No correction for lag, temperature coefficient or radiation is applied to the humidity readings.

It is a pleasure to acknowledge the help given in the preparation of this paper by Mr. A. L. Maidens and Mr. A. P. Taylor of the Meteorological Office, who were responsible for the organization of the trials, by the members of the staff, too numerous to name, who made the observations, and by Mr. F. W. Inman, by whom much of the computation for the last part of the paper was done.

SYSTEMATIC PRESSURE ERRORS

The first and longest series of trials occupied a year. The pressure errors revealed were so large that it was thought necessary to investigate their origin, and this involved a long programme of laboratory work. Certain changes were made in the sonde, notably an improvement in the mumetal used in the inductors of the meteorological units, and the trials were repeated at stations in the United Kingdom in November 1958. The errors found on this occasion were quite different from, and numerically larger than, those of 1954–55. It was then found that the increased permeability of the mumetal had had unexpected adverse results; further changes in circuit component values and manufacturing methods were introduced, and a third series of trials was made in December 1960. The errors in this case are different from those of the first two series.

The possible sources of error in the trials themselves are discussed below, and it is shown that there can be little doubt that the results represent mainly the pressure errors of the sonde. It would not be profitable now to discuss the instrumental origin of the errors, and therefore the results are put on record, not with any claim that they can be used as corrections for past observations but in order to show the magnitude of the pressure (or height) errors which have been present, their relative consistency from station to station and their variability with time. Trials made at other dates might have given different results again.

* Corrections for radiation and lag have been applied to all radiosonde observations at Meteorological Office stations in the United Kingdom from 1 February 1956, and at overseas stations from 1 March 1956. Observations for January and (overseas) February 1956 have been corrected in climatological statistics, but not in the *Daily Aerological Record.*

Plan of the trials

Routine combined radiosonde and radarwind soundings for one year at 02–03h and 14–15h GMT at eight stations in the United Kingdom (May 1954–April 1955) and six stations overseas (June 1954–May 1955) were used. The radar equipment used was the A.A. No. 3, Mark 2/4 (G.L. III), modified by the Meteorological Office. The procedure followed in the trials of November 1958 and December 1960 was the same.

The heights of the standard pressure levels, 850, 700, 500, 300, 200, 150, 100, 80, 60, 50, 40 and 30 mb, were calculated from the radiosonde observations in the usual way. The times at which the sonde indicated these pressures were found by interpolation to the nearest 0·1 minute, and the heights obtained from the radar readings at one-minute intervals were interpolated for these times. The differences between these two values of height are the raw material for this analysis. Since pressure errors are the most likely source of error in height, the mean height differences and standard deviations for the year have been converted into equivalent pressure differences on the basis of the ICAN atmosphere, but other possible sources of error have to be considered in due course. A positive sign means that the height given by radar was greater than that given by the radiosonde.

It should be noted that the height differences are not the same as the errors in the heights of the standard pressure levels computed from the radiosonde observations. The latter are much smaller (see below).

Theory and procedure of comparison

The height above station level derived from the radiosonde observations is

$$z_1 = k \int_p^{p_0} T \frac{dp}{p},$$

where $k = \frac{R'}{g}$, R' being the gas content per gram and g the value of gravity. p_0 is the observed surface pressure and p has the fixed values of the standard levels. The following values of the constants in c.g.s. units and degrees Celsius were used: $R' = 2{\cdot}8703 \times 10^6$ for dry air, $g = 980{\cdot}62$. A correction was applied for humidity.

The height above station level derived from the radar observations is

$$z_2 = R \sin E + \frac{R^2 \cos^2 E}{2r},$$

where R is the slant range, E the elevation and r the radius of curvature of the earth's surface.

The difference between the two simultaneous values of height, corrected for the distance between radar target and sonde,* should be zero but is found to be

$$A = z_2 - z_1 = \Delta z_2 - \Delta z_1,$$

where Δ is the observational error. If the error z_2 is negligible,

$$A = - \Delta z_1$$

$$= k \int_p^{p_0} \left(\Delta T - \frac{dT}{dp} \Delta p \right) \frac{dp}{p} + \frac{kT}{p} \Delta p, \qquad \dots (1)$$

the right-hand side of this equation being the error in z_1 arising from the observational errors

* The small difference in height between radar aerial and station barometer is ignored.

Δp and ΔT. (The term $-\frac{dT}{dp}\Delta p$ is the effective temperature error due to assigning the observed temperatures to erroneous pressures.)

The complete integral term in equation (1) represents the error in the height of the level p, while the second term $\frac{kT}{p}\Delta p$ represents the distance of the sonde from this level due to Δp. An approximate limit can be set to the probable magnitude of the first of these terms, and if the height difference found is much greater than this it may reasonably be attributed to the second: this is the basis of the method. For example, an error of 2·5°C in the mean temperature of the layer from p_0 to p will cause an error of about one per cent in the layer thickness. The mean differences are much greater than this. It has therefore been assumed as a first approximation that they are due to the pressure error Δp at the level p, and they have been converted into the equivalent pressure errors by the relation

$$\Delta p = \frac{p}{kT} A,$$

the temperature at a given pressure being taken as the ICAN value. The conversion factors used were as follows:

p	$\frac{dp}{dz}$	p	$\frac{dp}{dz}$	p	$\frac{dp}{dz}$
mb	*mb* m^{-1}	*mb*	*mb* m^{-1}	*mb*	*mb* m^{-1}
850	0·1043	200	0·0316	60	0·0095
700	0·0892	150	0·0237	50	0·0079
500	0·0679	100	0·0158	40	0·0063
300	0·0449	80	0·0126	30	0·0047

For each station the values of A were tabulated for every level for day and night soundings throughout the year. Mean values and standard deviations for the year were found and then converted into the equivalent pressure differences. The mean values are given in Tables 1–4 (1954–55), Tables 5 and 6 (November 1958) and Tables 7 and 8 (December 1960), and the standard deviations in Tables 9–14. In deriving the general means for groups of stations, equal weight was given to each ascent (not each station). In Tables 9 and 10 two values of the standard deviation for groups of stations are given, (*a*) the standard deviation of the data as a whole from the general means shown in Tables 1–4, and (*b*) the square root of the mean of the variances for the stations. Normally, (*a*) is larger than (*b*), since (*a*) contains the systematic differences between stations, which have been eliminated from (*b*), though it is possible for (*b*) to be greater than (*a*) if the numbers of soundings at different stations are very unequal.

The mean pressure errors are shown graphically in Figures 1 and 2.*

Results

Mean pressure errors.—The trials of 1954–55 show a highly systematic error, which is positive for levels below 60 mb and larger by night than by day. Above the 60 mb level there is a tendency for the pressure error to become negative, but the number of soundings falls off rapidly. Individual stations have characteristic curves, which are similar for day and night but differ from one another; for instance, Lerwick, Leuchars and Fazakerley are

* The pressure levels in the tables and the ordinates in Figures 1 and 2 are the observed, not the true, pressures.

markedly different from Hemsby and Camborne. At overseas stations the positive errors are generally much larger than at stations in the United Kingdom, and larger by night than by day.

The trials of November 1958 show very different results, with large negative pressure errors from the 300 mb level upwards. The change between 1954–55 and 1958 is systematic at all stations except Aldergrove, the curve for Lerwick day (but not night) soundings being intermediate between those of Aldergrove and the rest. Moreover, Aldergrove and (by day) Lerwick are the only stations which do not show a pronounced negative maximum at 200 mb.

The December 1960 results are again different, being almost entirely negative, with maximum values at 500–300 mb. The errors at Hemsby are particularly large.

These differences between stations are undoubtedly connected with the origin and history of the sondes. Sondes of different manufacture were used at all stations, and no detailed analysis has been made. At Aldergrove, however, the sondes used during November 1958 were mainly sondes which had been used before and recalibrated after recovery; a certain proportion of such sondes was also used at Lerwick by day.

Sufficient experiments have been made in the laboratory to show that these peculiarities are critically dependent on the temperature coefficients of the different parts of the *P* unit inductor, which in turn depend on details in the manufacturing processes which are very difficult to control. Uncertainty as to the distribution of temperature in the unit during flight makes it impossible to reduce these errors by calibration or correction.*

Other possible sources of the systematic differences between stations are discussed on page 10.

Standard deviations.—The values for 1954–55 are for the year as a whole, and therefore contain a contribution from any long-period fluctuations that may have been present. This contribution is, however, small, as may be seen from Table I, which illustrates the effect in the case of three stations which have particularly large standard deviations of the monthly mean height difference at 200 mb.

TABLE I. *Standard deviation of pressure error at 200 mb*

	Camborne		Benina		Bahrain	
	Day	Night	Day	Night	Day	Night
			millibars			
s.d. for year	14·2	12·2	9·3	9·4	12·2	11·1
s.d. of monthly mean	4·3	4·8	4·1	4·7	3·5	3·8
Square root of mean monthly variance	13·6	11·3	8·4	8·3	11·8	10·5

These standard deviations of the monthly mean are about twice those which would be expected from samples of 27 or 28 daily values taken from a population having the standard deviation shown for the year. This indicates that some factor other than random selection was operating. At other stations, however, the standard deviation of the monthly mean is smaller and at some practically equal to that which would be expected to occur by chance.

* The same standard corrections (see p. 5), known as *Q*6, were used in the three series of trials.

The standard deviations may be compared with the standard deviations of pressure found from twin radiosonde soundings (six by day and six by night) at the eight United Kingdom stations. These are given in Tables 15 and 16, and are reproduced in Tables 9 and 10. Comparing the values for twin soundings with the (*b*) means, we find fairly good agreement, the latter being generally the larger, as would be expected, since there are additional sources of error in this experiment; but the great increase in the scatter shown by the twin trials at high levels by day is not reproduced in the present results, which seems to indicate some undisclosed source of error in the twin trials. Comparing Tables 9 to 14, we find at most levels a progressive decrease in the standard deviation.

Sources of error in the experiment and reliability of results

As explained under "Theory and procedure of comparison" (page 7), it is assumed that the height differences found represent the errors of interpolated pressure readings, but other sources of error may contribute to the mean differences or to the standard deviations. These possible sources of error will be considered under the following headings:*

(i) radiosonde observations,
(ii) computation of height from radiosonde observations and conversion of height differences to pressure,
(iii) measurement of height by radar.

It will be found that the uncertainty arising from these sources is small compared with the observed height differences, which must therefore be attributed to pressure errors. If, however, in any future trials better results were obtained, it would be necessary to take these other factors into account.

Radiosonde observations. Systematic and random errors.—The error of a given pressure reading, though arising from a variety of causes, may be considered as the sum of three types of error: (*a*) the systematic error common to all sondes (or to a particular station or time of day or other specified conditions), (*b*) the "sonde error", which is characteristic of the individual instrument, and (*c*) the random error, which is uncorrelated between successive readings. No doubt this over-simplifies the matter, but it is convenient for the present purpose.

Errors of types (*b*) and (*c*) are effectively removed by taking the mean of some 200–350 soundings per station, and the assumption is that these mean values represent (*a*), the systematic errors.

For any given station the standard deviation from the yearly mean is compounded of (*b*) and (*c*). The contribution of (*c*), however, is small, as may be seen by comparing the values given in Tables 18–20 and Tables 15–17, and it is further reduced by interpolation. The standard deviations given in Tables 9–14 may therefore be taken as representing the sonde error.

Temperature errors.—These must affect the result since temperature enters into the computation of height. In addition to errors of the type considered in the section on non-systematic errors (page 14), those due to lag and radiation must have a quasi-systematic

* In addition to the observational errors, there are meteorological factors which can cause errors in the heights calculated from radiosonde observations, namely (*a*) change of surface pressure with place and time during the sounding, (*b*) differences between the temperature (and humidity) structure as sampled by the sonde and that of the atmosphere beneath the sonde at a given moment, and (*c*) any departure from the static equation. These are not discussed here.

effect, depending on the solar elevation (that is, on the latitude of the station and the time of year and time of day), on the earth's albedo as seen by the sonde, on cloud in the lower part of the ascent and to a small extent on the rate of ascent. Thus the effect will be partly systematic throughout (but different by day and by night), partly systematic on the average for a given station and partly random as between sounding and sounding.

The effect of a given temperature error is, however, more complicated than would appear at first sight from equation (1) on page 7, since the temperature affects the pressure reading through the correction system employed (the "Q" corrections); it does so in such a way that temperature errors are to a large extent compensated on the average in the computed heights, though on any sounding the degree of compensation depends on the "factor" of the sonde (that is, the temperature coefficient of the pressure unit) and on the degree to which the source of temperature error (for example, radiation or variations of battery voltage) also affects the pressure unit.

Upper limits can be set to the probable magnitude of these effects. For instance, the standard deviation of the height of the standard pressure levels given in Table 23, expressed as the equivalent pressure error, is:

Pressure level (mb)	850	700	500	300	200	150	100	80
s.d. of height (mb)	0·2	0·3	0·6	0·9	0·9	0·8	0·6	0·6

These errors, which enter into the present investigation through the first term in equation (1), are negligible in comparison with the standard deviations found. Again, lag and radiation errors* equal to those given for solar elevation 60° in the Meteorological Office correction tables would, if not compensated in the pressure readings as indicated above, give rise to errors in the heights of the standard pressure levels (first term of equation (1)) and hence to the following apparent pressure errors:

Pressure level (mb)	850	700	500	300	200	150	100	80
Pressure error (mb)	—0·3	—1·0	—1·6	—2·2	—2·4	—2·3	—2·2	—2·0

It is clear that the pressure errors found must arise from some other cause.

Humidity errors.—The correction to height for humidity even at a tropical station amounts to only about 30 metres. This therefore cannot be a significant source of error.

Errors in computation of height. Gravity.—The value of gravity used was 980·62 cm sec^{-2}. The resulting heights are nearly all too low by an amount depending on the latitude of the station and the height of the sonde (and to a negligible extent on the height of the station above mean sea level). Table II illustrates the equivalent pressure errors.

TABLE II. *Equivalent pressure error due to use of g=980·62 cm sec^{-2}*

Latitude	Pressure level (mb)			
	700	300	100	50
		millibars		
0°	+0·8	+1·7	+1·3	+0·9
30°	+0·5	+1·1	+1·0	+0·7
45°	+0·1	+0·6	+0·6	+0·5
60°	—0·2	+0·1	+0·3	+0·3

* At the time of the 1954–55 trials no correction was applied for lag or radiation. In November 1958 and December 1960 the correction system adopted in 1956 was in use.

These pressure errors are systematic and are important for low latitudes. The appropriate corrections would make the positive errors of 1954–55 slightly smaller, but the negative errors of November 1958 and December 1960 would become larger.

Printed scales.—The layer thicknesses are computed by means of forms on which the thickness is marked as a function of temperature. The forms used during these trials (1950 edition) have been re-examined and found to be very accurate. They cannot be a significant source of error.

Conversion of height differences to pressure equivalent.—The factors used were those given on page 8, which were based on the ICAN temperatures. Strictly, the actual mean temperatures should have been used. For stations where the mean temperature was above the ICAN value the pressure equivalent computed is too large, and where the mean temperature was below the ICAN value the pressure equivalent is too small, by about 3·6 per cent at 850 mb and 4·6 per cent in the stratosphere for each 10°C. Thus at stations in low latitudes the mean pressure errors and standard deviations may be numerically too large in the lower levels and too small at high levels, possibly by as much as ten per cent in some cases.

Errors in height measured by radar. Radar errors.—The error in height (see page 7) due to observational errors ΔR and ΔE is

$$\Delta z_2 = \sin E . \Delta R + R \cos E . \Delta E,$$

the error in curvature correction being negligible. This has a maximum value at low elevations for all probable values of ΔR and ΔE, and since ΔR is only a very few decametres at the most the first term is negligible and

$$\Delta z_2 = R \cos E . \Delta E = z \cot E . \Delta E \text{ approx.}$$

Experience has shown that with careful maintenance the zero error of elevation is less than 0·1°. At a given time it may be constant or it may be a function of azimuth, but it varies from time to time and from one radar set to another. Superposed on this error, which may be approximately constant for a given ascent, is a random error of setting and reading which has a standard deviation less than 0·1° and is further reduced by interpolation. We may thus say that the observations as a whole are subject to a standard deviation considerably less than $0{\cdot}1° \times \sqrt{2}$. Table III shows the pressure equivalent of the height error arising from an elevation error of 0·1° under various geometrical conditions:

TABLE III. *Pressure equivalent of height error due to elevation error of 0·1°*

	Pressure level (mb)			
	700	300	100	50
		millibars		
cot E=4, E=14°	1·9	2·7	1·8	1·1
cot E=2, E=27°	0·9	1·4	0·9	0·6
cot E=1, E=45°	0·5	0·7	0·4	0·3

There can be no question of a significant systematic error, but a very small part of the standard deviations found must arise from this cause.

Curvature correction.—The corrections applied are based on a constant value of 6360 km for the radius of curvature of the earth's surface. In fact, the principal radii of curvature of the ellipsoidal surface vary from 6336 and 6378 km at the equator to 6383 and 6394 km at latitude 60° (and 6399 km at the pole). The substitution of any of these values for the value used would make only an insignificant difference to the height correction.

Refraction.—Refraction makes the radar elevations too high, but no correction has been applied. This results in an apparent pressure error which is systematically positive. Hooper and Taylor, in a paper of the Meteorological Research Committee,[9] have calculated the height correction for an "ICAN moist" atmosphere. From their figures it can be shown that, within the range of the radar sets, the greatest error in terms of pressure occurs in the layer 300–200 mb at the lowest angles of elevation, and amounts to 0·4 mb. Variations in the height correction due to different atmospheric conditions are negligible in comparison with the standard deviations found.

Synchronization.—A possible source of scatter in the results, though not of systematic error, would be lack of synchronism between radar and radiosonde readings. It is hardly possible that the timing error could exceed 0·1 minute, which is equivalent to about 40 metres in height, and the standard deviation must be much smaller than this. It can be seen by reference to the conversion factors given above (page 8) that this source of error can be ignored.

Slide-rule.—The value of $R \sin E$ was found* by means of a Meteorological Office pilot-balloon slide-rule. Three operations are involved: (i) setting R to the zero of the E scale, (ii) setting the cursor to E on the $\sin E$ scale, (iii) reading $R \sin E$ on the range scale. The result will depend on the accuracy of the rule and the skill of the operator. Errors due to the slide-rule itself may be to some extent systematic, but from an examination of specimens it seems certain that these are negligible. As regards setting errors, it seems reasonable to suppose that under working conditions there is a standard error of 0·2 mm at each operation. The result is therefore subject to a standard deviation of $0{\cdot}2 \times \sqrt{3} = 0{\cdot}35$ mm, which on the scale of the slide-rule corresponds to 0·43 per cent in the height. This will be reduced by a factor $\sqrt{(2/3)}$ by interpolation (see Appendix I) to 0·34 per cent. The corresponding pressure errors are as follows:

Pressure level (mb)	700	500	300	100	50
Pressure error (mb)	0·9	1·3	1·4	0·9	0·6

These are very small compared with the standard deviations found (Tables 9–14).

The effect of a combination of all the possible errors in the experimental method considered in this section is small compared with the mean pressure errors and standard deviations given in the tables. These must therefore be taken as the errors of the sonde, and the very large variation found over a period of six years renders any further discussion profitless.

Comparison with other work

Similar trials on a smaller scale were made by day at one station in 1943 and 1944. The sonde then in use was the Mark 1, which was similar in principle and general design to the Mark 2B. The results, which are contained in a paper of the Meteorological Research Committee,[10] are shown in Table IV. These results show a distribution of errors very different from those reported in the present paper.

The differences in pressure reading between the Mark 2B sonde and the mean of all 14 types taking part in the Payerne trials of 1956[11] are shown in Table V.

* In 1954–55. An improved slide-rule was introduced subsequently.

TABLE IV. *Mean pressure errors obtained in trials during 1943 and 1944*

Height	ICAN pressure	Mean error 1943*	1944†	Height	ICAN pressure	Mean error 1943	1944
km		*millibars*		*km*		*millibars*	
1	899	+1	+3	11	266	—4	0
2	795	+6	+4	12	193	—2	—1
3	701	+9	+7	13	165	+3	0
4	616	+11	+7	14	141	+4	+1
5	540	+8	+6	15	120	+3	+2
6	472	+5	+5	16	103	+3	+1
7	411	+3	+4	17	88	0	0
8	356	+1	+3	18	75	—3	+1
9	307	0	+2	19	64	—5	+1
10	264	—2	0	20	55	—2	+1

* 11 ascents; † 43 ascents.

TABLE V. *Differences in pressure reading between Mark 2B sonde and mean of all 14 types of sonde*

Pressure level	Pressure difference Day	Night	Pressure level	Pressure difference Day	Night
	millibars			*millibars*	
850	0	0	100	+3	+5
700	0	+2	70	+2	+5
500	—1	+3	50	—1	+7
300	+1	+5	30	+3	+6
200	+2	+6			

Little weight can be attached to such differences as a measure of the error of any one type, but it may be noted that in the case of the Mark 2B there is a general tendency for the difference to be positive, in agreement with the results of the 1954–55 trials.

NON-SYSTEMATIC ERRORS

As was explained earlier, the non-systematic errors of the sonde, which have been called "sonde errors" and "random errors", were investigated by means of "twin" soundings.

The two sondes on a twin sounding were rigged one beneath the other at a distance of 4·0 metres. They were tuned to different radio frequencies and were followed by two observers with independent equipment but with identical time scales. It was verified that there was no measurable interaction between the sondes. In all other respects procedure was normal; the sondes were taken from ordinary stock, no special selection being made, and the two records of each flight were computed independently by different operators. Six twin soundings were made by day (14–15h GMT) and six by night (02–03h GMT) at eight stations. A comparison of the simultaneous readings of the two sondes provides statistical information on the errors of the system.

Since the readings of two sondes cannot be synchronized exactly, values of pressure P (mb), temperature T (°F*) and relative humidity U (per cent) were read by linear inter-

* At the time when these trials were made temperature was measured in degrees Fahrenheit, but in this paper the results have been converted into degrees Celsius.

polation at one-minute intervals between the computed points as plotted on the "radio-sounding chart". The heights Z of the standard pressure levels were also computed by the normal method. The differences X between these values of P, T, U and Z for the two sondes (lower — upper) are the raw material for this analysis.

Statistical scheme

General theory.—We distinguish two types of error affecting the observations of P, T and U:

(i) The "sonde error", which is characteristic of the individual instrument and varies slowly during the ascent. It will be assumed that the sondes are drawn from a population having a standard deviation from the mean of σ_1, at a given height. (The trials give no information about the mean error for all sondes.)

(ii) A random error, for which there is no correlation between successive readings, with standard deviation σ_2. This may vary during the ascent.

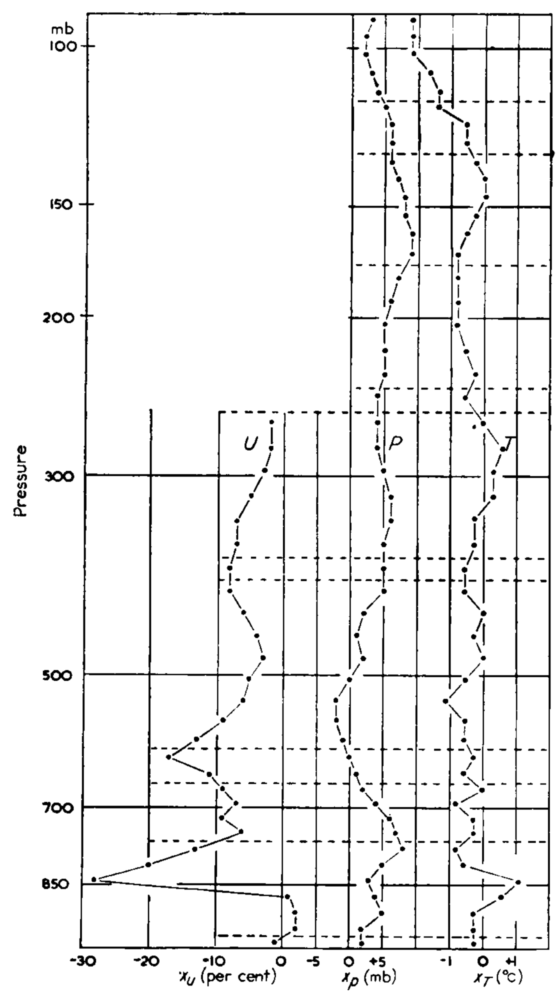

FIGURE 3. Values of X at one-minute intervals for a typical sounding

X represents the difference between values of humidity (U), pressure (P) and temperature (T) for two sondes, subtracting the upper from the lower.

The standard deviation of the difference between the sonde errors of two sondes is $\sqrt{2}.\sigma_1$. It is shown in Appendix I that for an interpolated reading the random error is reduced to $\sqrt{\tfrac{2}{3}}.\sigma_2$, and thus the random error of X is $\sqrt{\tfrac{4}{3}}.\sigma_2$.

The estimates of σ_1 and σ_2 made from the observations will be denoted by S_1 and S_2.

Each sounding was divided into layers centred at the standard levels 850, 700, 500, 300, 200, 150, 100, 80 and 60 mb, the criterion for this purpose being the pressures derived from height measured by radar, not the sonde pressure readings. About four to eight values of X, centred at the given level, were taken for P, T and U in such a way that most of the values were used, but none was used more than once. Figure 3 shows the values of X for a typical sounding, with the division into layers.

For a given level we thus have for each sounding a mean difference

$$\bar{X} = \frac{\sum X}{n}, \qquad \dots (2)$$

where n is the number of observations (that is, four to eight). $\bar{X}$ is subject to a standard error

$$\sqrt{\frac{4}{3n}}\,.\sigma_2.$$

Estimate of σ_2.—The best estimate of the variance σ_2^2 from a single sounding is

$$S_2^2 = \frac{3}{4}\frac{\sum (X - \bar{X})^2}{n-1}. \qquad \dots (3)$$

The standard error of S_2 is

$$\frac{\sigma_2}{\sqrt{(2n)}}.$$

From m soundings the best estimate of σ_2^2 (see Appendix II) is

$$S_2^2 = \frac{3}{4}\frac{\sum^{m}\sum^{n}(X - \bar{X})^2}{\sum^{m}(n-1)}. \qquad \dots (4)$$

Estimate of σ_1.—The variance of $\bar{X}$ is due to both the sonde error and the random error. The variance due to the sonde error is $2\sigma_1^2$. That due to random error is $4\sigma_2^2/3n$ for soundings with n observations, but, since n is not the same for all soundings at a given level, the actual value is

$$\frac{4}{3m}\sum^{m}\left(\frac{1}{n}\right).\sigma_2^2.$$

$\frac{1}{m}\sum^{m}\left(\frac{1}{n}\right)$ is the average value of $\frac{1}{n}$. The n's, however, do not differ greatly, and therefore we take this contribution to the variance of $\bar{X}$ as approximately equal to $4\sigma_2^2/3\bar{n}$, where $\bar{n} = \sum^{m} n/m$, the average number of observations per sounding. Thus

$$\sigma_{\bar{X}}^2 = 2\sigma_1^2 + \frac{4\sigma_2^2}{3\bar{n}}. \qquad \dots (5)$$

Since the position (upper or lower) in which the sondes are placed is chosen at random, the true mean value of $\bar{X}$ for all sondes, after correction for the distance of four metres between them, is zero. Therefore the best estimate of the variance of $\bar{X}$ from m soundings is not $\sum\bar{X}^2/(m-1)$ but

$$S_{\bar{X}}^2 = \frac{\sum^{m} \bar{X}^2}{m}. \qquad \ldots (6)$$

Combining equations (5) and (6), we find for the sonde error*

$$S_1^2 = \frac{1}{2}\left(\frac{\sum^{m} \bar{X}^2}{m} - \frac{4\sigma_2^2}{3\bar{n}}\right). \qquad \ldots (7)$$

Standard deviation of heights of pressure levels.—In the above analysis P, T and U are treated separately, and an independent value of S_1 is found for each level. The results give no information as to any correlation that may exist between the sonde errors at different levels, or between those of P, T and U. This information would be required before the standard deviation of the height could be calculated from those of P, T and U, but it is unnecessary to do this as we obtain directly†

$$S_z^2 = \frac{\sum^{m} X_z^2}{2m}. \qquad \ldots (8)$$

Results

The values of S_1 and S_2 were computed from equations (7) and (4) for each station and for all together. The value for σ_2^2 used in the second term of equation (7) was in each case the corresponding value of S_2^2; a constant value might have been used, but this term is very small compared with the first‡ so that any uncertainty in the value used for σ_2^2 makes little difference to S_1. The results, expressed in millibars, degrees Celsius and per cent, for day (14–15h GMT) and night (02–03h GMT), separately and combined, are given in Tables 15–20. The values of S_z, in metres, derived from equation (8) are given in Tables 21–23.

It is immediately obvious that the stations differ greatly among themselves, and it is of interest to inquire whether the differences are "real" or only the result of chance. If real, they would indicate differences of practice, such as the care taken in the preparation of sondes and in the observations, or differences in the treatment received by the sondes during transport, or in the length of time between calibration and flight.

The statistical significance of the differences may be tested by the F-test,[12] which depends on a comparison of the ratio of two variances with the ratios which would occur by chance.

* The correction to X for the distance between the sondes is: for P, −0·4 mb at 850 mb, and less at higher levels; for T, −0·03°C in the troposphere. Thus the computed values of S_1^2 should be reduced by $\frac{(0{\cdot}4)^2}{2}$ or less for P, and by $\frac{(0{\cdot}03)^2}{2}$ for T. These corrections are negligible, and have been omitted.

† The heights of the standard pressure levels are obtained by integrating the static equation between fixed limits. The height error is proportional to the error in the mean temperature, that is, to the mean value of $(\Delta T - \frac{dT}{dP}\Delta P)$ over the layer, where ΔT and ΔP are the errors of observation. The error in the height of the sonde at a given time, for example, at a "significant point", contains in addition a term proportional to the instantaneous value of ΔP, since this now occurs in one of the limits of integration. This last term is in general much larger than the other, and therefore the variance of the height derived from a single pressure reading is approximately proportional to $(\sigma_1^2 + \sigma_2^2)$ for P at that level.

‡ This means that the uncertainty arising from random error in the value of P, T or U obtained as the mean of about six readings is small compared with the sonde error.

When this test is applied to the extreme values in any one column of Tables 15–23 a number of highly significant ratios are found, but these occur in a somewhat random manner and are by no means consistent between the different stations at different levels, between P, T, U and Z, or between day and night. The conclusion seems to be that the differences between stations do not reflect any permanent characteristics of the stations, even though the probability of a given value arising as the mean of a sample of six or twelve from a population having a standard deviation equal to the mean for all stations is low.

Origin of errors

Origin of sonde errors.—The instrumental aspects of this question will not be discussed in detail, but the following points which are inherent in the system may be noted:

(i) The corrections to the pressure readings for changing temperature are obtained from a set of standard curves, which are derived from calibration of a limited number of sondes. There is a certain scatter in the calibration data, and the curves represent approximate mean values. Any departure of an individual sonde from the law of variation of frequency represented by the curves will result in a residual error of pressure; this will be partly random but may also—especially after a long time—contain a systematic component.

(ii) It is assumed that the pressure unit is at a uniform (though changing) temperature during flight, and that this is the temperature measured by the temperature unit. In fact, the several parts of the pressure unit in which changes of frequency can arise are at different temperatures, and there is some uncertainty as to the effective mean temperature. The resulting error of pressure may be systematic in sign, but it will differ in magnitude between sonde and sonde since there are large differences in temperature coefficient of frequency. It will be seen that the sonde pressure errors are much larger by day than by night (Tables 15 and 16).

(iii) Errors of temperature, from whatever cause they arise, will give rise to pressure errors through the correction system, and these again will depend on the temperature coefficient of the individual unit.

(iv) It is assumed that in these trials the radiation error of temperature is the same for the two sondes on any one flight. Any difference in the absorption coefficients of the radiation shields or the bimetallic elements will cause a difference between the temperature readings of the two sondes, and non-uniformity of temperature within the unit, combined with differences of temperature coefficient, will have the same effect. It seems, however, that these cannot be significant sources of error, since the sonde errors at the higher levels are actually slightly smaller by day than by night.

(v) Errors of computation are probably not important as far as P, T and U are concerned, but they may be significant in the heights of standard levels. An experiment was made to test this. The original frequency graphs and sonde calibration charts for eight soundings were passed in turn to the eight stations, where the soundings, including the heights of the standard levels, were computed by the normal method. For any one sounding the variance of the computed height was taken as $\frac{1}{7}\sum(Z-\bar{Z})^2$ where $\bar{Z}=\frac{1}{8}\sum Z$, and the mean of this for the eight soundings is the variance for the given level. The root mean square values are shown in Table 23 as the standard error of computation. Subtracting this variance from the total variance* and taking the square root, we obtain the standard instrument error. At 850 mb the two standard errors are practically equal; at higher levels the error of computation becomes progressively larger but less important in comparison with the instrumental error.

Origin of random error.—The following sources of error contribute to σ_2:

(i) Any short-period instability in the sonde (for example, due to swinging).

(ii) Any irregular errors of the oscillator scale remaining after the normal corrections have been applied.

(iii) The operator's errors of setting the oscillator and plotting the reading.

(iv) The rounding off to the nearest ½ c/s and 0·05 minute in plotting.

(v) The application of various corrections also to the nearest ½ c/s.

(vi) The final reading of the calibration graphs to the nearest whole millibar, ½°F† and one per cent.

(vii) Inaccuracy in reading from the calibration graphs‡ over and above (vi).

(viii) When the relative humidity is changing very rapidly, as at a temperature inversion, the random sampling due to the rotation of the switch, together with differences in the speed of response of the goldbeaters' skins, introduces a high degree of uncertainty into the interpolated values of U.

(ix) In addition, since S_2 is derived from the differences of the individual observations from the layer mean, the values found will be increased if the sonde error is not constant throughout the layer.

Of these sources of error, (i) and (ii) are believed to be negligible; in any case, (ii) will be indistinguishable from (iii).

The error of the recorded frequency, (iii), was tested by an experiment. Routine soundings with a single sonde were followed by two operators using independent equipment, and the differences between the recorded readings were tabulated, a correction being made for any significant differences of time. About 7000 pairs of readings of P and of T were obtained at eight stations, with several different pairs of operators at each station. The variance of a single reading (half the variance of the differences between two readings) and the root mean square error are:

	P	T
Variance	0·061	0·074
rms error (c/s)	0·25	0·27

The records extended over complete soundings, and no account has been taken of the distance of the sonde or the signal strength. It is probable that the root mean square error is somewhat smaller at the beginning of a sounding and larger at the end, but for a normal sounding the variation is negligible. The readings were, as always, plotted to the nearest ½ c/s. If there were no other source of error, the rounding off involved would be the same for the two operators and the difference would always be zero; but if there are other sources of

* It is believed that the twin-sounding procedure ensured that the computation error was included in the variance of height. If the two soundings of each flight had been computed by the same person the computation error would have been partially eliminated.

† Since 1 January 1956 readings have been made to the nearest ¼°C.

‡ Errors in the drawing of the graphs will give rise to a sonde error.

error, the variance due to reading to ½ c/s may be added partially or completely. It is shown in Appendix III that this variance is 1/48, or 0·02, and the fact that the variances found are three times as large as this indicates that the other sources of error predominate and that the variance due to reading to ½ c/s is probably included in the values given above. Dividing these root mean square errors by the sensitivity, we obtain the root mean square observational errors of *P* and *T*. Table VI shows the approximate sensitivity for *P* and *T* (c/s per mb and per degree C) and the corresponding errors in millibars and degrees C.

TABLE VI. *Sensitivity and root mean square observational error of pressure and temperature*

Pressure level	Sensitivity		rms observational error	
	P	*T*	*P*	*T*
mb	*c/s per mb*	*c/s per °C*	*mb*	*°C*
850	0·145	1·50	1·7	0·18
700	0·172	1·56	1·4	0·17
500	0·213	1·70	1·2	0·16
300	0·257	1·93	1·0	0·14
200	0·281	2·08	0·9	0·13
150	0·294	2·08	0·8	0·13
100	0·308	2·08	0·8	0·13
80	0·312	2·08	0·8	0·13

Comparing these figures with those in Table 20, we see that the observational error is responsible for roughly half of the total random error (about one sixth to half of the variance), except in the case of *P* at 80 mb, where the two figures are equal.

The effect of the rounding off is dealt with theoretically in Appendix III. Only (iv) and (vi) need be considered. The effect of (v)—the application of corrections in units of ½ c/s—can be ignored, as the corrections change only slowly and are usually constant for several successive values of *P* or *T*. The root mean square errors calculated in Appendix III are so much smaller than the random errors of Table 20 that we may conclude that rounding off is not a significant source of error, except for *P* at the highest levels where it accounts for half the total variance.

It is estimated that (vii)—the inaccuracy of reading *P* and *T* from the calibration graphs—contributes a variance of the order of 0·1 and 0·001, or root mean square errors 0·3 mb and 0·03°C. These are negligible in comparison with other errors.

The effect of (viii) cannot be estimated numerically, but it is obvious from the records that in a few instances it has given rise to very large differences in individual values of humidity.

The effect of (ix)—changing sonde error—on the apparent random error in special cases can be calculated as follows. If the difference *X* between the two sondes is changing uniformly at a rate of *a* units per minute, the resulting variance for *n* consecutive observations calculated from equation (3) is:

n	4	5	6	7	8
Variance (unit a^2)	1·25	1·87	2·63	3·50	4·50

It is obvious in some soundings that this is happening to a significant extent, but the effect on the mean values of S_2 cannot be estimated. To eliminate it would require a more elaborate and subjective method of smoothing than the simple one adopted of taking deviations from the mean of the layer.

To sum up: the known sources of error do not account for the values of S_2 found. The explanation may be that (i) and (iii) were larger than has been supposed, or that significant errors have arisen in the process of interpolation, or that (ix) has resulted in values which are too large.

Comparison with other work

Seven twin soundings were made in daylight with Mark 2 sondes in 1947. These sondes were similar to the Mark 2B, except that they had half-wavelength aerials, whereas the Mark 2B has a quarter-wavelength aerial. The errors found were approximately as shown in Table VII.

TABLE VII. *Errors in Mark 2 sonde during seven twin soundings in 1947*

	Low levels			200 mb	
	P	*T*	*U*	*P*	*T*
	mb	*C°*	*per cent*	*mb*	*C°*
Sonde error	2	0·4	3	7	0·7
Random error	2	0·3	2	1	0·3

These figures, which are in approximate agreement with those reported by Dymond[3] for Mark 1 sondes, are slightly smaller than those shown in Tables 15 and 18, though the difference is probably not significant. The best that can be said is that there is no evidence of any improvement during the interval of seven years.

Rossi,[13] from 15 soundings by day and 16 by night with the Finnish sonde, found the standard deviation of the sonde error to be as shown in Table VIII.

TABLE VIII. *Standard deviation of sonde error of Finnish sonde*

Pressure level	Sonde error			
	Day		Night	
	P	*T*	*P*	*T*
mb	*mb*	*°C*	*mb*	*°C*
790	4·8	0·52	4·4	0·46
275	4·4	0·76	4·1	0·68
96	3·6	0·69	3·2	0·78

These pressure errors at high levels are much smaller than those in Tables 15 and 16; the temperature errors are about the same. The standard deviations of the heights of standard pressure levels from the mean were as given in Table IX.

TABLE IX. *Standard deviation of height (Finnish sonde)*

Pressure level	Standard deviation	
	Day	Night
mb	*gpm*	*gpm*
850	2	2
300	22	19
100	31	35

Certain systematic differences between upper and lower sonde were found, and the root mean square errors would be slightly larger than the standard deviations and not significantly different from those shown in Tables 21 and 22.

This work of Rossi's was done at Ilmala Observatory and may not be representative of other stations using the Finnish sonde.

In a report on the Payerne (1956) radiosonde comparisons,[11] the Royal Netherlands Meteorological Institute gives (under the heading *S* in the tables) an estimate of the scatter of individual sondes of all types together after elimination of the systematic type differences. These were based on the means of five consecutive readings at one-minute intervals, and have the same significance as the sonde errors of the present paper. The figures in Table X are taken from the Netherlands report.

TABLE X. *Root mean square errors of pressure and temperature found from the Payerne radiosonde comparisons*

Pressure level	Root mean square error			
	Day		Night	
	P	*T*	*P*	*T*
mb	*mb*	°*C*	*mb*	°*C*
850	4·4	0·54	4·7	0·53
300	5·1	0·76	4·7	0·70
100	5·5	1·27	4·9	0·80

These figures are not very different from those of Tables 15 and 16, except at 100 mb by day, where the temperature error is larger and the pressure error much smaller than the corresponding values in Table 15.

From this and Rossi's results (see above) it appears that the British sonde is—or was at the time of these trials—subject to particularly large pressure errors at high levels by day (compare the section on standard deviations on page 9).

Malet, in an unpublished report to the Commission for Instruments and Methods of Observation Working Group on Comparison of Radiosondes, calculates from the Payerne (1956) data the root mean square differences between the heights of the standard pressure levels given by any two sondes of different type. Dividing his figures by $\sqrt{2}$, we find the root mean square errors given in Table XI.

TABLE XI. *Root mean square error of height*

Pressure level	Root mean square error		Pressure level	Root mean square error	
	Day	Night		Day	Night
mb	*gpm*		*mb*	*gpm*	
850	5	4	200	46	35
700	7	10	100	57	50
500	20	14	70	70	54
300	27	22			

These are a little larger than the values in Tables 21 and 22, but they contain the systematic type differences which are also given by Malet. It may be noted incidentally that both Malet and Harmantas[14] have calculated the mean type differences of height, and find very close agreement both by day and by night between the Meteorological Office Mark 2B, the United States sonde AN/AMT–4 and the German Graw H50. The same result is shown in the table prepared by the Commission for Instruments and Methods of Observation.[15] This agreement, however, is probably fortuitous, since there are quite large differences in pressure and temperature between the British sonde and the other two; it appears that these differences happen to compensate each other in the computed heights.

It is of interest to compare the variance of the heights of standard levels due to instrumental error (Table 23) with the values found by Lugeon and Ackermann[16] for the variance over 12 hours and 24 hours of the thickness of different layers as reported by European stations. These are much larger. The contribution of instrumental error to the total variance is therefore small and the reality of Lugeon and Ackermann's results is confirmed.

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APPENDIX I—RANDOM ERROR OF AN INTERPOLATED VALUE

If p and q are two observations, the interpolated value at a fraction x of the interval between them is

$$r = (1 - x)p + xq.$$

If the errors of p and q are uncorrelated and subject to a standard deviation S, the variance of r for a given value of x is

$$(1 - x)^2S^2 + x^2S^2 = (1 - 2x + 2x^2)S^2.$$

All values of x from 0 to 1 are equally probable, and therefore the mean variance of r is

$$S^2 \int_0^1 (1 - 2x + 2x^2)dx = \tfrac{2}{3}S^2$$

The factor 2/3 is not strictly correct in the present case since successive interpolations are not always independent, the same pair of observations being sometimes used twice. It is, however, probably a good enough approximation since S_2 is of secondary importance in comparison with S_1.

APPENDIX II—DERIVATION OF S_2 FROM m SOUNDINGS

For one sounding, S_2 is given by equation (3). It is assumed that the true value of σ_2 is the same for all soundings, while the mean difference $\bar{X}$ due to sonde error is different for different soundings. The factor 3/4 will be omitted for convenience.

Let M be the true difference between the sonde errors. We do not know M, but we obtain the most probable value as $\bar{X} = \sum X/n$, which is subject to a standard error $\sigma_2/\sqrt{n}$. Then

$$\sum (X - M)^2 = \sum (X - \bar{X})^2 + n(\bar{X} - M)^2.$$

The mean value of $(\bar{X} - M)^2$ for a large number of soundings with the same number of observations n is σ_2^2/n, and the mean value of $n(\bar{X} - M)^2$ is σ_2^2. Therefore, for a large number m of soundings with different n's, the mean value of $n(\bar{X} - M)^2$ is again σ_2^2; that is to say

$$\sum^m n(\bar{X} - M)^2 = m\sigma_2^2.$$

In the limit, when m is infinite, we have (by definition)

$$\sigma_2^2 = \frac{\sum^m \sum^n (X - M)^2}{\sum^m n}.$$

$$\therefore \sum^m n.\sigma_2^2 = \sum^m \sum^n (X - \bar{X})^2 + \sum^m n(\bar{X} - M)^2$$

$$= \sum^m \sum^n (X - \bar{X})^2 + m\sigma_2^2.$$

$$\therefore \sigma_2^2 = \frac{\sum^m \sum^n (X - \bar{X})^2}{\sum^m n - m}.$$

APPENDIX III—ERROR DUE TO ROUNDING OFF

Suppose that readings are made to the nearest y units. Then, provided that y is very small compared with the range of variation of the quantity measured, the true value may lie anywhere between the limits $-y/2$ and $+y/2$ with equal probability, and therefore the error due to rounding off is uniformly distributed between these limits. The error function is a constant C, where

$$\int_{-y/2}^{+y/2} C\,dx = Cy = 1.$$

The variance of the error is

$$S^2 = \int_{-y/2}^{+y/2} Cx^2.dx = \frac{y^2}{12}.$$

In radiosonde observations there is a rounding off in reading frequencies to the nearest $\frac{1}{2}$ c/s, and a further rounding off in reading P, T and U from the calibration curves to the nearest one mb, $\frac{1}{2}$°F and one per cent. These two processes are independent, and therefore the variances are added. Thus, if the slopes of the calibration curves are K_P mb, K_T °F and K_U per cent for 1 c/s, the total variance from this source is $\left(\frac{K_P^2}{48} + \frac{1}{12}\right)$ for P in mb, $0{\cdot}31\left(\frac{K_T^2}{48} + \frac{1}{48}\right)$ for T in degrees C and $\left(\frac{K_U^2}{48} + \frac{1}{12}\right)$ for U (per cent). Taking average conditions, we find the following values for the root mean square error:

Pressure level mb	Root mean square error P mb	T °C	U per cent
850	1·03	0·13	0·3
500	0·74	0·12	0·3
80	0·54	0·11	—

It can easily be shown that the error due to rounding off the time of reading to 0·05 minute is quite negligible.

APPENDIX IV—TABLES

TABLE 1—*Mean pressure error (mb) and number of day-time soundings at United Kingdom stations, 1954–55*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	+2·4	+2·7	+2·7	+1·2	+2·1	+3·0	+2·2	+0·8	−2·5	−6·1	−10·6	—
	273	273	273	271	269	262	239	194	104	37	11	—
Stornoway	+0·7	−0·3	−1·9	−1·5	−0·3	+0·6	+0·8	+0·4	−1·3	−5·8	—	—
	275	276	276	275	272	254	224	181	82	19	—	—
Leuchars	+2·2	+1·4	+1·1	+1·4	+3·2	+4·1	+2·1	−0·4	−2·5	−8·2	−12·6	−18·1
	323	322	316	313	309	273	219	168	97	36	18	4
Aldergrove	+1·8	+1·4	+1·9	+2·6	+3·6	+2·8	+1·5	+0·1	−2·4	−4·2	−1·2	—
	348	348	347	344	336	313	273	225	111	27	2	—
Fazakerley	+2·6	+2·8	+2·6	+3·3	+4·1	+4·1	+3·2	+2·3	0·0	−3·1	−5·1	−14·2
	350	352	352	351	345	333	304	271	158	65	18	5
Hemsby	+4·1	+3·3	+2·7	+3·2	+3·7	+3·8	+1·5	+1·0	−0·7	−0·1	+1·1	+0·6
	341	341	341	339	335	312	253	199	93	35	16	9
Crawley	+4·5	+3·5	+1·9	+0·8	+1·3	+2·0	+0·8	+0·2	−2·4	−4·4	−5·3	—
	249	249	249	247	244	230	194	165	107	36	9	—
Camborne	+2·5	+2·0	+1·4	+2·5	+3·6	+4·0	+2·4	+1·2	−0·6	−0·1	+1·5	+2·4
	342	342	342	342	339	315	271	210	113	40	25	16
All U.K. stations	+2·6	+2·1	+1·6	+1·8	+2·8	+3·1	+1·9	+0·8	−1·5	−3·8	−4·4	−2·9
	2501	2503	2496	2482	2449	2292	1977	1613	865	295	99	34

TABLE 2—*Mean pressure error (mb) and number of night-time soundings at United Kingdom stations, 1954–55*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	+3·0	+3·1	+3·8	+3·2	+4·9	+5·7	+6·0	+3·6	−1·5	−4·7	−6·1	—
	275	277	277	276	276	267	215	134	29	9	3	—
Stornoway	+0·8	−0·6	−1·1	−0·6	+1·3	+3·5	+3·4	+3·3	−0·6	+0·9	—	—
	260	264	265	265	260	234	184	118	27	1	—	—
Leuchars	+1·6	+0·9	+1·2	+2·6	+4·3	+5·3	+3·4	+1·5	−4·0	−10·8	−8·4	—
	325	325	323	321	315	280	207	135	40	7	2	—
Aldergrove	+1·3	+1·5	+2·4	+3·3	+3·9	+4·5	+4·5	+3·5	−0·5	−3·5	—	—
	346	346	346	343	337	320	257	182	36	7	—	—
Fazakerley	+2·3	+2·4	+2·8	+4·1	+4·9	+5·8	+5·1	+3·3	−2·4	−2·0	−8·1	−8·8
	347	349	349	347	341	327	288	199	59	12	3	1
Hemsby	+3·9	+4·0	+4·1	+5·0	+5·7	+6·1	+5·6	+3·6	+3·3	+5·7	+5·4	+4·6
	350	350	350	347	343	323	257	167	46	19	13	6
Crawley	+4·7	+4·0	+2·7	+2·2	+3·4	+4·5	+4·6	+3·4	−2·2	−8·7	—	—
	253	253	253	252	247	232	188	119	38	4	—	—
Camborne	+3·0	+2·6	+2·9	+4·2	+5·4	+5·3	+4·2	+3·6	+0·2	−1·9	−0·6	+2·0
	343	343	343	342	337	311	247	134	43	8	5	3
All U.K. stations	+2·5	+2·3	+2·4	+3·2	+4·3	+5·2	+4·7	+3·3	−0·5	−1·6	+0·3	+2·5
	2499	2507	2506	2493	2456	2294	1843	1188	318	67	26	10

TABLE 3—*Mean pressure error (mb) and number of day-time soundings at overseas stations, 1954–55*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Malta	+6·9	+5·3	+2·9	+1·7	+1·8	+2·2	+0·6	+1·2	−1·6	−4·3	−5·4	—
	334	334	334	334	334	323	295	247	160	84	28	—
Nicosia	+3·7	+3·7	+3·7	+4·9	+5·1	+4·3	+2·1	+1·7	−0·2	−2·7	−4·7	—
	319	319	320	320	316	269	211	160	84	37	9	—
Benina	+7·3	+8·9	+7·5	+6·2	+6·9	+6·5	+3·9	+3·0	+1·2	−1·4	−2·6	—
	343	342	338	335	320	279	220	157	70	19	2	—
Habbaniya	+3·1	+3·8	+4·6	+4·4	+5·3	+4·6	+1·5	+1·4	−1·1	+1·3	−5·3	—
	339	339	339	333	324	270	169	93	27	4	2	—
Aden	+12·0	+13·6	+14·4	+11·5	+11·0	+7·1	+2·1	+2·6	+2·1	−0·5	−0·1	—
	333	332	332	331	332	310	284	223	95	26	1	—
Bahrain	+8·3	+7·9	+7·9	+5·8	+5·6	+2·7	−0·6	−0·6	−1·8	−2·8	—	—
	336	336	336	332	320	269	182	120	40	12	—	—
All overseas stations	+6·9	+7·2	+6·9	+5·8	+6·0	+4·6	+1·6	+1·4	−0·2	−2·9	−5·0	—
	2004	2002	1999	1985	1946	1720	1361	1000	476	182	42	—
All U.K. and overseas stations	+4·5	+4·4	+4·0	+3·6	+4·2	+3·8	+1·8	+1·0	−1·0	−3·4	−4·5	(−2·9)
	4505	4505	4495	4467	4395	4012	3338	2613	1341	477	141	(34)

TABLE 4—*Mean pressure error (mb) and number of night-time soundings at overseas stations, 1954–55*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Malta	+7·2	+5·3	+3·8	+2·7	+3·3	+3·3	+2·8	+1·4	−1·7	−3·7	−8·1	—
	353	353	354	353	352	335	299	227	104	37	4	—
Nicosia	+4·1	+3·6	+4·1	+4·4	+5·8	+4·5	+3·6	+3·0	−0·1	+1·2	—	—
	323	323	323	322	320	281	206	133	36	7	—	—
Benina	+8·1	+10·3	+8·9	+7·9	+8·2	+7·5	+6·7	+4·9	+1·9	+1·3	—	—
	340	340	338	337	326	291	234	162	32	4	—	—
Habbaniya	+4·3	+5·4	+6·4	+6·0	+6·5	+6·1	+3·0	+2·2	+2·4	+4·4	—	—
	339	339	339	334	323	254	156	91	22	3	—	—
Aden	+10·9	+12·3	+13·9	+10·8	+10·8	+7·2	+2·6	+3·0	+1·7	−0·6	−5·2	—
	333	333	333	333	331	316	297	220	75	20	5	—
Bahrain	+8·7	+8·7	+8·2	+5·7	+5·8	+3·3	0·0	−0·2	+0·4	−1·2	—	—
	329	329	328	327	326	275	211	138	58	9	—	—
All overseas stations	+7·2	+7·6	+7·5	+6·2	+6·7	+5·3	+3·1	+2·4	+0·3	−1·7	−6·5	—
	2017	2017	2015	2006	1978	1752	1403	971	327	80	9	—
All U.K. and overseas stations	+4·6	+4·6	+4·7	+4·5	+5·4	+5·2	+4·0	+2·9	−0·1	−1·6	−1·5	(+2·5)
	4516	4524	4521	4499	4434	4046	3246	2159	645	147	35	(10)

TABLE 5—*Mean pressure error (mb) and number of day-time soundings at United Kingdom stations, November 1958*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	+6·5	+5·1	+4·3	+0·9	−0·9	−1·6	−2·8	−4·2	−5·9	−7·6	—	—
	27	27	27	27	27	27	26	21	15	10	—	—
Stornoway	−0·1	0·0	−0·5	−3·5	−4·5	−4·0	−3·9	−5·9	−12·0	−17·9	—	—
	27	27	28	28	28	26	23	20	7	3	—	—
Leuchars	+5·3	+2·1	−0·5	−8·4	−9·9	−9·1	−9·3	−9·5	−10·3	−10·5	−10·6	−9·9
	29	29	29	29	29	29	29	28	25	24	23	21
Aldergrove	+3·4	+5·4	+6·2	+5·3	+3·5	+3·0	+0·4	+0·3	−6·5	−12·0	−15·0	—
	26	26	26	26	26	26	22	17	8	2	1	—
Aughton	−1·6	−2·1	−4·3	−8·8	−9·7	−7·8	−8·0	−8·7	−10·5	−11·9	−14·9	−15·7
	26	27	27	27	26	26	26	26	20	15	8	2
Hemsby	+1·3	−0·4	−2·6	−8·3	−11·0	−8·8	−9·7	−9·1	−9·4	−11·1	—	—
	30	30	30	30	30	29	28	25	19	10	—	—
Crawley	+2·2	+2·0	+0·2	−3·9	−6·4	−5·3	−6·3	−6·4	−5·5	−6·4	−6·9	−7·2
	27	27	27	27	27	27	27	27	26	26	22	20
Camborne	+3·8	+3·9	+1·9	−3·5	−5·4	−4·6	−6·4	−7·1	−8·2	−9·0	−12·4	—
	29	29	29	29	29	29	27	27	18	11	2	—
All U.K. stations	+2·6	+2·0	+0·5	−3·9	−5·7	−4·9	−6·0	−6·7	−8·4	−9·5	−10·0	−8·9
	221	222	223	223	222	219	208	191	138	101	58	43

TABLE 6—*Mean pressure error (mb) and number of night-time soundings at United Kingdom stations, November 1958*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	+3·6	+4·5	+1·6	−2·8	−6·1	−6·3	−8·3	−8·5	−9·5	−10·1	−10·2	−10·9
	29	29	29	29	29	29	27	27	26	25	24	17
Stornoway	−3·1	−0·4	−1·5	−3·4	−5·3	−4·9	−4·5	−4·3	−4·0	−4·2	−4·7	−5·6
	30	30	30	30	30	30	30	28	28	28	24	18
Leuchars	−0·1	−0·4	−4·8	−8·7	−10·7	−9·4	−8·8	−9·1	−9·0	−9·4	−9·6	−9·6
	27	27	27	27	27	27	26	25	25	25	25	22
Aldergrove	+6·5	+6·9	+6·9	+6·4	+4·8	+3·0	+2·1	+0·6	−1·0	−2·5	−3·2	−5·4
	28	28	28	28	28	27	27	26	25	23	18	13
Aughton	−3·3	−3·8	−5·4	−10·5	−10·6	−9·9	−9·4	−9·4	−8·8	−8·7	−8·4	−9·5
	29	29	28	28	28	28	28	26	26	26	26	19
Hemsby	+0·5	+1·2	−1·5	−6·1	−7·2	−5·9	−6·1	−5·9	−6·7	−6·2	−7·1	−7·7
	29	29	29	29	29	29	29	29	26	23	22	17
Crawley	+3·2	+1·4	+0·7	−4·3	−6·9	−6·5	−6·4	−6·1	−6·2	−6·9	−7·6	−6·9
	28	28	28	28	28	28	28	27	25	23	20	16
Camborne	+3·1	+2·8	+0·8	−4·0	−7·0	−6·4	−7·4	−6·8	−6·8	−7·2	−7·9	−8·4
	29	29	29	29	29	27	26	26	25	24	21	19
All U.K. stations	+1·3	+1·5	−0·4	−4·1	−6·1	−5·8	−6·1	−6·2	−6·5	−6·9	−7·5	−8·2
	229	229	228	228	228	225	221	214	206	197	180	141

TABLE 7—*Mean pressure error (mb) and number of day-time soundings at United Kingdom stations, December 1960*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	+2·3	+3·0	+0·1	−2·8	−1·6	−2·1	−3·9	−3·3	−3·3	−5·3	−4·9	—
	29	29	29	29	29	29	23	20	15	10	3	—
Stornoway	−2·2	−1·7	−4·2	−5·4	−2·8	−1·3	−0·5	+1·1	+0·7	−2·3	−4·8	—
	28	28	28	28	28	26	22	17	11	6	2	—
Shanwell	−4·7	−4·1	−6·7	−6·3	−5·7	−4·3	−4·3	−3·1	−2·4	−2·6	−2·8	−4·1
	29	29	30	29	29	28	26	25	20	18	17	13
Aldergrove	+0·4	−0·6	−3·7	−6·7	−4·4	−4·5	−4·7	−3·6	−4·6	−5·0	−5·7	−7·7
	29	29	29	29	29	27	26	26	24	19	16	10
Aughton	−6·3	−4·9	−7·2	−5·7	−4·9	−3·8	−3·1	−2·8	−1·6	−1·7	−6·2	−9·3
	24	24	24	23	22	21	19	16	12	10	4	2
Hemsby	−4·7	−5·7	−8·6	−10·1	−7·8	−5·8	−5·2	−4·8	−1·9	−0·2	+0·3	+2·5
	28	28	28	28	27	26	24	21	11	8	7	4
Crawley	−2·4	−1·3	−3·4	−3·1	−0·7	+0·6	+0·5	+1·0	+1·9	+1·5	+1·7	+0·3
	27	27	27	27	26	26	25	22	21	17	13	7
Camborne	−2·5	−4·6	−6·4	−7·3	−6·3	−7·6	−7·3	−8·0	−9·4	−8·7	−6·5	−8·7
	30	29	31	31	28	24	21	17	7	6	4	2
All U.K. stations	−2·4	−2·4	−5·9	−6·0	−4·3	−3·5	−3·6	−2·9	−2·2	−2·7	−2·9	−4·1
	224	223	226	224	218	207	186	164	121	94	66	38

TABLE 8—*Mean pressure error (mb) and number of night-time soundings at United Kingdom stations, December 1960*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	+1·0	−0·4	−2·0	−2·7	−2·3	−2·5	−4·3	−4·4	−5·1	−5·5	−8·9	—
	26	26	26	26	25	23	18	16	8	7	2	—
Stornoway	−3·5	−2·9	−6·4	−6·5	−3·1	−1·7	−2·7	−3·2	−3·6	−4·7	—	—
	27	27	27	27	27	27	20	18	10	4	—	—
Shanwell	−4·9	−3·4	−5·3	−5·0	−1·8	−2·3	−2·6	−1·8	−1·0	−1·2	−1·1	−1·7
	30	30	30	31	31	29	25	24	22	20	14	10
Aldergrove	−2·2	−1·6	−4·0	−4·0	−3·5	−2·6	−1·6	−1·5	−1·4	−1·3	−2·5	−4·5
	29	29	29	29	28	28	27	23	21	19	16	8
Aughton	−5·7	−4·0	−8·3	−6·5	−3·1	−2·6	−2·6	−1·6	−1·4	−3·6	−2·3	—
	26	26	26	25	25	22	19	16	9	4	1	—
Hemsby	−4·1	−5·9	−8·2	−8·7	−7·4	−5·7	−4·4	−3·0	−1·7	−1·3	+2·0	0·0
	29	29	29	29	29	28	25	20	18	12	5	1
Crawley	−1·4	−1·7	−4·1	−3·8	−1·4	−1·8	−1·0	−1·0	−1·4	−0·6	−2·1	−1·5
	30	30	30	30	30	28	27	26	21	15	12	8
Camborne	−3·2	−2·2	−4·7	−4·5	−2·2	−2·3	−2·0	−0·6	−4·1	−3·7	−5·5	—
	29	29	30	28	27	23	16	12	6	5	1	—
All U.K. stations	−3·0	−2·8	−5·4	−5·2	−3·1	−2·7	−2·6	−2·1	−2·0	−1·9	−1·9	−2·4
	226	226	227	225	222	208	177	155	115	86	51	27

TABLE 9—*Standard deviation of pressure error (mb) from day-time soundings, United Kingdom and overseas stations, 1954–55*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	6·0	6·0	6·8	8·1	10·0	10·0	9·6	8·2	7·1	5·9	4·9	—
Stornoway	4·5	5·2	6·2	7·3	9·2	8·9	7·8	6·9	6·4	2·5	—	—
Leuchars	5·1	5·2	6·8	8·8	10·9	10·2	11·0	8·6	8·1	6·5	5·7	4·9
Aldergrove	5·7	5·7	6·4	8·8	11·2	10·4	9·8	8·9	6·7	6·0	4·8	—
Fazakerley	6·7	5·2	6·2	7·9	9·0	9·2	9·5	9·0	8·1	7·5	8·4	7·8
Hemsby	4·8	5·4	6·0	8·6	9·9	10·3	8·7	8·2	7·0	7·5	9·2	4·1
Crawley	5·1	5·2	5·6	8·4	9·6	9·3	9·1	9·0	6·8	6·3	7·8	—
Camborne	5·4	6·3	7·5	11·6	14·2	12·6	11·3	10·1	10·3	10·0	8·8	8·7
All U.K. stations (*a*)*	5·4	5·7	6·6	8·9	10·8	10·3	9·7	8·7	7·9	7·6	9·5	10·7
(*b*)*	5·4	5·5	6·5	8·8	10·7	10·2	9·7	8·7	7·7	6·8	7·6	6·7
Sonde errors	4·3	3·9	5·4	8·1	10·0	10·6	10·7	11·4	7·8	—	—	—
Malta	6·7	5·7	6·4	7·0	8·9	9·3	8·2	7·5	6·0	4·9	5·2	—
Nicosia	6·0	6·3	7·0	8·6	10·2	8·7	7·9	8·4	7·2	7·1	4·6	—
Benina	5·1	6·0	6·4	8·8	9·3	9·0	9·4	8·8	7·4	6·8	2·6	—
Habbaniya	5·4	5·4	6·6	8·1	9·6	8·9	7·3	8·8	8·4	9·4	2·7	—
Aden	7·6	7·9	8·3	8·2	9·1	9·0	9·6	10·3	8·0	6·0	—	—
Bahrain	6·4	7·3	7·9	9·9	12·2	10·5	10·1	9·6	8·3	8·9	—	—
All overseas stations (*a*)	7·0	7·3	8·1	9·0	10·3	9·5	9·0	9·0	7·3	5·9	4·9	—
(*b*)	6·3	6·5	7·1	8·5	10·0	9·3	8·8	8·9	7·6	7·3	3·9	—
All stations (*a*)	6·7	6·9	7·7	9·0	10·7	10·0	9·5	8·9	7·7	7·0	8·4	(10·7)
(*b*)	5·8	5·9	6·8	8·6	10·4	9·8	9·3	8·8	7·6	6·2	6·4	(6·7)

TABLE 10—*Standard deviation of pressure error (mb) from night-time soundings, United Kingdom and overseas stations, 1954–55*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	6·0	6·5	6·4	7·9	8·9	8·0	9·1	7·3	5·8	4·6	4·2	—
Stornoway	4·5	5·4	7·0	10·0	10·2	10·3	9·0	7·4	8·0	—	—	—
Leuchars	4·5	4·9	5·8	9·2	9·5	9·9	9·0	8·2	7·2	10·9	1·6	—
Aldergrove	5·4	6·0	6·4	8·4	9·5	9·8	10·1	8·8	7·6	7·6	—	—
Fazakerley	4·8	5·4	6·4	8·9	9·7	10·1	10·0	8·3	7·5	7·6	4·3	—
Hemsby	4·8	5·2	6·6	8·6	9·8	9·3	9·8	9·2	6·9	8·8	7·0	7·3
Crawley	5·1	5·2	6·0	7·7	8·7	8·7	8·9	8·5	7·0	5·2	—	—
Camborne	6·7	7·3	7·9	12·3	12·2	10·4	11·0	10·4	10·0	9·4	6·8	4·4
All U.K. stations (*a*)*	5·4	6·0	6·8	9·5	10·0	9·7	9·8	8·6	7·9	9·2	8·3	7·3
(*b*)*	5·3	5·8	6·6	9·2	9·9	9·6	9·6	8·6	7·6	8·0	5·7	6·0
Sonde errors	3·9	4·2	4·5	5·6	6·8	6·8	5·6	5·5	—	—	—	—
Malta	7·0	6·3	5·8	7·0	8·5	8·7	8·2	6·7	4·9	3·0	3·2	—
Nicosia	6·7	6·5	7·0	8·1	9·2	8·7	8·0	7·4	7·0	5·4	—	—
Benina	5·1	6·0	7·2	8·5	9·4	8·9	10·1	9·0	8·4	5·2	—	—
Habbaniya	5·1	5·4	7·0	8·2	9·4	9·2	7·5	6·9	5·1	2·0	—	—
Aden	7·9	8·7	8·5	8·2	9·2	8·9	10·2	10·7	7·7	5·6	5·9	—
Bahrain	6·0	6·8	7·5	8·9	11·1	9·4	8·6	8·2	7·5	4·5	—	—
All overseas stations (*a*)	7·0	7·3	7·9	8·6	9·8	9·1	9·2	8·6	6·9	4·8	5·1	—
(*b*)	6·4	6·7	7·2	8·2	9·5	8·9	8·9	8·3	6·9	4·5	4·7	—
All stations (*a*)	6·7	7·1	7·7	9·2	10·0	9·4	9·5	8·6	7·4	7·1	8·2	(7·3)
(*b*)	5·8	6·2	6·9	8·8	9·7	9·3	9·3	8·4	7·3	6·6	5·4	(6·0)

* For explanation of (*a*) and (*b*), see page 8.

TABLE 11—*Standard deviation of pressure error (mb) from day-time soundings, United Kingdom stations, November 1958*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	5·5	6·7	8·3	7·0	7·2	8·2	7·1	6·1	6·2	6·4	—	—
Stornoway	5·3	5·0	5·2	6·9	7·9	7·7	8·9	8·1	11·1	14·3	—	—
Leuchars	5·1	4·3	5·2	6·8	6·8	7·6	8·1	7·9	7·5	7·3	6·0	4·3
Aldergrove	6·5	6·4	8·3	10·6	12·4	12·6	9·6	11·4	5·8	3·8	—	—
Aughton	4·5	4·5	6·9	8·8	11·0	11·0	10·1	11·1	6·1	6·4	5·3	1·5
Hemsby	5·3	3·9	4·2	4·3	4·5	4·6	4·0	4·4	4·5	4·5	—	—
Crawley	5·5	4·9	4·3	4·3	5·8	5·2	5·5	5·0	3·8	4·9	4·9	4·3
Camborne	5·4	6·5	4·7	4·1	5·1	6·1	5·0	5·5	3·9	4·3	7·2	—
All U.K. stations	6·0	5·9	6·8	8·3	9·1	9·0	8·1	8·1	6·3	6·8	5·9	4·7

TABLE 12—*Standard deviation of pressure error (mb) from night-time soundings, United Kingdom stations, November 1958*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	4·7	5·9	4·8	4·8	5·7	6·8	5·7	5·5	5·3	5·1	5·5	3·9
Stornoway	5·2	5·3	4·7	6·9	6·5	6·2	5·5	5·7	5·6	5·6	5·9	4·9
Leuchars	4·9	5·3	6·2	6·4	6·2	7·7	7·3	6·8	6·2	5·8	5·6	5·7
Aldergrove	5·2	5·4	6·1	8·1	10·0	7·6	8·5	7·9	7·8	7·9	6·4	5·9
Aughton	4·4	4·5	4·5	7·6	8·9	8·9	8·7	9·5	9·5	9·5	8·9	6·0
Hemsby	5·8	6·7	4·6	4·4	5·5	5·6	5·9	6·7	6·0	5·8	5·6	4·4
Crawley	4·5	5·2	4·4	5·0	6·3	5·8	5·9	6·0	5·6	6·0	5·5	4·3
Camborne	4·9	5·0	3·8	4·4	6·1	5·9	6·1	5·8	5·5	6·3	6·1	6·0
All U.K. stations	5·9	6·2	6·1	7·7	8·3	7·8	7·6	7·5	7·1	7·1	6·7	5·5

TABLE 13—*Standard deviation of pressure error (mb) from day-time soundings, United Kingdom stations, December 1960*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	5·8	5·6	5·0	6·5	6·4	5·8	7·2	7·7	6·2	6·3	4·6	—
Stornoway	4·2	4·5	4·7	5·9	5·9	5·8	6·1	4·1	4·7	4·6	2·4	—
Shanwell	5·5	4·7	5·6	6·0	6·5	7·1	6·8	6·8	5·7	5·8	6·4	5·1
Aldergrove	5·2	5·2	5·9	5·3	6·3	5·4	4·3	4·5	4·6	4·4	3·8	3·6
Aughton	4·1	4·9	3·9	4·9	4·3	4·2	4·5	4·7	5·4	5·9	6·3	6·9
Hemsby	4·0	4·1	3·1	4·2	3·8	4·9	5·1	5·8	5·3	4·8	5·0	2·3
Crawley	3·4	3·3	4·0	4·4	3·9	5·5	3·9	3·5	3·6	3·8	5·0	3·6
Camborne	4·1	4·5	4·0	7·2	6·2	5·7	4·5	4·4	4·2	5·2	4·2	5·2
All U.K. stations	5·3	5·4	4·3	6·1	6·0	6·2	5·9	6·0	5·7	5·8	5·9	5·8

TABLE 14—*Standard deviation of pressure error (mb) from night-time soundings, United Kingdom stations, December 1960*

Pressure level (mb)	850	700	500	300	200	150	100	80	60	50	40	30
Lerwick	4·9	7·4	6·8	8·9	7·0	6·8	5·4	6·1	5·7	6·1	2·3	—
Stornoway	3·1	4·1	5·3	7·0	7·7	8·9	8·6	7·8	8·5	3·3	—	—
Shanwell	4·7	3·3	4·4	6·8	11·0	7·4	5·1	4·9	4·8	4·7	5·0	4·6
Aldergrove	4·7	5·1	4·6	5·2	5·5	5·6	5·8	7·2	6·8	7·3	5·7	3·5
Aughton	4·0	3·8	3·6	3·8	6·2	4·0	4·1	3·7	5·0	1·6	—	—
Hemsby	3·8	4·5	5·1	4·7	6·0	4·6	4·8	5·5	5·7	5·9	2·1	—
Crawley	4·7	4·1	4·3	5·6	5·2	5·4	5·0	6·0	6·7	7·5	5·9	6·0
Camborne	4·0	4·0	4·4	4·7	5·2	5·3	7·6	7·5	4·7	4·7	—	—
All U.K. stations	4·7	4·9	5·3	6·3	7·3	6·3	6·0	6·3	6·3	6·2	5·5	4·9

TABLE 15—*Sonde error of pressure P, temperature T and humidity U, and number of day-time soundings*

Pressure level (mb)	850			700			500			300			200		150		100		80		60	
	P *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*
Lerwick	4·0	0·1	1·7	4·3	0·3	3·4	6·5	0·3	5·1	7·1	0·7	4·8	9·1	0·9	10·1	0·8	10·7	0·8	13·3	1·3	—	—
		6			6			6			6			6		6		5		2		—
Stornoway	3·1	0·2	2·6	4·1	0·5	4·5	3·3	0·4	2·4	5·0	0·6	4·8	6·8	0·7	6·9	0·6	7·8	0·8	9·4	0·7	9·2	0·6
		6			6			6			6			6		6		6		3		3
Leuchars	3·0	0·3	5·2	4·2	0·4	5·7	6·9	0·6	6·2	11·5	0·5	6·9	15·3	0·3	15·9	0·4	15·9	0·6	19·9	0·2	2·1	0·1
		6			6			6			6			5		5		5		3		1
Aldergrove	2·6	0·4	3·2	3·0	0·3	1·9	4·9	0·6	2·6	6·3	0·7	2·5	9·4	0·9	10·5	1·0	12·6	1·5	9·2	0·9	10·4	0·4
		6			6			6			6			6		6		3		2		1
Fazakerley	4·4	0·2	1·0	3·6	0·4	2·0	3·0	0·3	2·5	4·6	0·4	3·5	4·5	0·3	4·7	0·6	5·2	0·5	5·8	0·6	5·5	0·1
		6			6			6			6			6		6		6		4		2
Hemsby	2·9	0·4	1·5	2·8	0·4	2·9	3·5	0·6	2·4	7·8	0·9	3·7	7·8	1·0	8·7	1·0	13·1	0·6	—	—	—	—
		6			6			6			6			5		5		3		—		—
Crawley	5·9	0·3	2·0	5·8	0·3	4·0	9·1	0·8	3·4	12·6	0·8	4·2	15·7	0·8	16·4	0·9	12·7	1·0	9·3	1·5	—	—
		6			6			6			6			6		6		4		2		—
Camborne	6·4	0·8	5·1	2·9	0·7	9·1	2·5	0·4	6·9	5·7	1·2	6·9	5·5	0·8	4·9	0·7	6·8	0·8	5·8	0·2	—	—
		6			6			6			6			5		5		5		2		—
All stations	4·3	0·40	3·2	3·9	0·44	4·7	5·4	0·53	4·3	8·1	0·74	4·9	10·0	0·75	10·6	0·77	10·7	0·81	11·4	0·85	7·8	0·40
		48			48			48			48			45		45		37		18		7

TABLE 16—*Sonde error of pressure P, temperature T and humidity U, and number of night-time soundings*

Pressure level (mb)	850			700			500			300			200		150		100		80	
	P *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*
Lerwick	7·1	0·6	4·1	5·7	0·4	4·5	7·4	0·7	5·2	9·0	1·3	7·8	8·4	1·3	10·6	1·5	6·9	0·5	4·5	0·0
		6			6			6		6	6	5		6		4		2		1
Stornoway	2·5	0·3	1·2	3·1	0·3	3·7	3·8	0·4	2·5	4·4	0·5	2·4	7·3	0·8	7·9	0·6	6·5	0·6	8·9	0·9
		6			6			6			6			6		6		5		2
Leuchars	3·9	0·3	4·8	4·2	0·3	3·5	2·7	0·4	4·1	3·8	0·6	4·5	3·5	0·7	3·1	0·6	—	—	—	—
		6			6			6			6			6		5		—		—
Aldergrove	2·9	0·2	2·8	3·3	0·3	3·5	2·7	0·3	3·3	4·8	0·5	6·1	7·3	1·0	5·1	1·0	3·5	1·2	3·4	1·1
		6			6			6			6			6		5		5		4
Fazakerley	2·0	0·3	2·8	4·0	0·4	4·0	4·5	0·4	4·7	4·7	0·7	5·6	5·4	0·7	6·1	0·8	5·4	0·8	—	—
		6			6			6			6			6		6		5		—
Hemsby	3·4	0·3	0·7	4·9	0·1	1·6	4·7	0·5	1·6	4·3	0·9	1·3	5·0	1·0	5·3	1·0	5·1	1·2	5·4	0·4
		6			6			6			6			6		6		5		2
Crawley	4·5	0·2	2·7	4·4	0·3	4·5	3·1	0·4	5·2	4·9	0·2	4·4	5·8	0·2	7·0	0·3	4·6	0·0	3·9	0·4
		6			6			6			6			6		6		2		1
Camborne	2·8	0·5	5·2	3·4	0·4	2·2	4·8	0·5	1·6	7·2	1·1	2·3	9·3	1·3	7·7	1·0	6·8	1·0	—	—
		6			6			6			6			6		6		4		—
All stations	3·9	0·36	3·4	4·2	0·36	3·6	4·5	0·48	3·8	5·6	0·80	4·7	6·8	0·95	6·8	0·89	5·6	0·93	5·5	0·83
		48			48			48		48	48	47		48		44		28		10

TABLE 17—*Sonde error of pressure P, temperature T and humidity U, and number of day- and night-time soundings*

Pressure level (mb)	850			700			500			300			200		150		100		80	
	P mb	*T* °C	*U* %	*P* mb	*T* °C	*U* %	*P* mb	*T* °C	*U* %	*P* mb	*T* °C	*U* %	*P* mb	*T* °C	*P* mb	*T* °C	*P* mb	*T* °C	*P* mb	*T* °C
Lerwick	5·8	0·4	3·2	5·0	0·4	4·0	7·0	0·6	5·2	8·1	1·1	6·4	8·8	1·1	10·3	1·1	9·8	0·7	11·2	1·1
		12			12			12		12	12	11		12		10		7		3
Stornoway	2·8	0·3	2·0	3·6	0·4	4·2	3·7	0·4	2·4	4·7	0·5	3·8	7·0	0·8	7·4	0·6	7·2	0·7	9·2	0·8
		12			12			12			12			12		12		11		5
Leuchars	3·5	0·3	5·0	4·2	0·4	4·8	5·2	0·5	5·3	8·6	0·5	5·8	10·7	0·5	11·4	0·5	(15·9)	(0·6)	(19·9)	(0·2)
		12			12			12			12			11		10		5		3
Aldergrove	2·8	0·4	3·0	3·1	0·3	2·9	3·6	0·5	3·0	5·6	0·6	4·5	8·4	0·9	8·5	1·0	8·2	1·3	6·0	1·0
		12			12			12			12			12		11		8		6
Fazakerley	3·4	0·3	2·1	3·8	0·4	3·1	3·8	0·4	3·8	4·6	0·6	4·7	5·0	0·6	5·4	0·7	5·3	0·7	(5·8)	(0·6)
		12			12			12			12			12		12		11		4
Hemsby	3·1	0·3	1·1	4·0	0·3	2·4	4·1	0·6	2·0	6·3	0·9	2·8	6·5	1·0	7·1	1·0	9·0	1·0	(5·4)	(0·4)
		12			12			12			12			11		11		8		2
Crawley	5·2	0·2	2·1	5·1	0·3	4·2	6·8	0·6	4·4	9·5	0·6	4·3	11·8	0·6	12·6	0·7	10·7	0·8	7·9	1·2
		12			12			12			12			12		12		6		3
Camborne	4·9	0·7	5·2	3·2	0·6	6·6	3·8	0·5	5·0	6·5	1·1	5·1	7·8	1·1	6·6	0·9	6·8	0·9	(5·8)	(0·2)
		12			12			12			12			11		11		9		2
All stations	4·1	0·38	3·3	4·1	0·40	4·2	4·9	0·50	4·1	7·0	0·78	4·8	8·5	0·86	8·9	0·83	8·9	0·87	9·7	0·84
		96			96			96		96	96	95		93		89		65		28

Figures in brackets are for day only or night only.

TABLE 18—*Random error of pressure P, temperature T and humidity U, and number of day-time observations**

Pressure level (mb)	850			700			500			300			200		150		100		80		60	
	P *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*
Lerwick	2·1	0·5	4·4	2·3	0·4	2·8	2·4	0·5	2·3	2·0	0·4	1·7	1·4	0·5	1·6	0·4	1·2	0·3	0·6	0·3	—	—
		26			26			44			36			30		38		23		4		—
Stornoway	2·6	0·5	6·3	2·3	0·3	7·2	1·6	0·3	3·3	1·5	0·4	0·9	1·5	0·4	1·3	0·2	1·0	0·5	0·7	0·5	0·8	0·6
		28			30			44			30			24		32		26		16		13
Leuchars	2·3	0·2	2·4	2·0	0·3	2·4	3·1	0·3	2·1	2·1	0·3	1·0	1·0	0·2	1·4	0·3	0·7	0·5	1·2	0·3	2·1	0·1
		30			42			48			32			24		38		22		16		5
Aldergrove	2·1	0·2	4·2	1·6	0·3	2·7	2·0	0·3	2·1	2·0	0·3	0·6	1·1	0·3	1·2	0·4	0·5	0·4	0·5	0·3	1·1	0·4
		26			28			48			37			29		29		14		8		4
Fazakerley	1·7	0·2	1·1	2·5	0·3	2·4	1·9	0·3	3·1	1·4	0·3	0·5	1·3	0·3	1·7	0·3	0·6	0·3	0·6	0·3	0·7	0·3
		23			24			44			34			28		35		27		17		10
Hemsby	2·5	0·2	3·2	2·3	0·3	1·2	1·9	0·3	2·1	1·4	0·3	1·1	1·3	0·2	1·3	0·2	1·3	0·2	—	—	—	—
	31	31	29		27			47			33			25		29		15		—		—
Crawley	2·9	0·3	4·7	3·0	0·2	2·1	2·5	0·4	1·5	1·8	0·3	0·5	1·3	0·3	1·1	0·3	0·9	0·3	0·5	0·3	—	—
		23			25			44			30			25		30		14		10		—
Camborne	2·3	0·4	5·8	1·7	0·4	3·3	2·4	0·5	2·4	2·7	0·5	1·0	1·6	0·3	0·9	0·4	0·9	0·5	0·9	0·3	—	—
		25			30			42			37			25		22		20		8		—
All stations	2·3	0·32	4·3	2·2	0·31	3·5	2·3	0·37	2·4	1·9	0·35	1·0	1·3	0·34	1·3	0·32	0·9	0·40	0·8	0·35	1·1	0·44
	212	212	210		232			361			269			210		253		161		79		32

* The number of observations means the number of values of *X* (see page 15). This is normally the same for *P*, *T* and *U*, but a few values for *U* are missing.

TABLE 19—*Random error of pressure P, temperature T and humidity U, and number of night-time observations**

Pressure level (mb)	850			700			500			300			200		150		100		80	
	P *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*
Lerwick	2·6	0·3	5·8	2·7	0·3	2·6	2·0	0·4	3·5	1·3	0·4	2·5	2·2	0·3	0·7	0·3	0·8	0·3	0·9	0·0
		20			29			45		35	35	28		35		22		7		2
Stornoway	1·9	0·3	4·2	1·7	0·3	3·4	2·1	0·4	2·1	1·4	0·4	0·9	1·2	0·4	1·3	0·4	1·2	0·3	0·6	0·4
		26			32			40			24			24		30		24		9
Leuchars	2·5	0·3	3·1	2·7	0·3	4·8	2·3	0·4	3·3	1·7	0·3	1·7	1·2	0·2	2·3	0·3	—	—	—	—
		24			32			48			38			26		27		—		—
Aldergrove	2·0	0·4	5·9	1·9	0·3	1·5	1·7	0·3	2·3	1·7	0·4	1·6	1·5	0·3	1·3	0·4	0·6	0·3	0·6	0·4
		28			27			47			36			29		27		23		16
Fazakerley	1·2	0·3	2·7	1·7	0·3	3·2	1·7	0·2	1·3	1·8	0·2	0·7	1·8	0·3	0·8	0·2	0·6	0·3	—	—
		26			28			46			36			33		36		18		—
Hemsby	2·2	0·2	1·0	1·9	0·2	1·1	1·7	0·3	1·7	1·5	0·2	0·6	1·7	0·3	1·4	0·3	0·9	0·4	0·9	0·2
		23			27		41	41	40		30			27		26		22		7
Crawley	2·4	0·3	9·8	2·1	0·3	3·1	2·4	0·2	1·5	1·1	0·3	0·9	1·3	0·2	1·3	0·3	0·5	0·2	0·5	0·0
		28			28			42			30			25		32		10		4
Camborne	2·1	0·3	8·5	2·1	0·3	2·4	2·5	0·4	2·2	2·3	0·5	0·7	2·1	0·6	2·1	0·3	0·9	0·3	—	—
		25			26			41			33			28		32		19		—
All stations	2·1	0·30	6·0	2·1	0·29	3·1	2·0	0·33	2·4	1·7	0·34	1·4	1·7	0·35	1·5	0·31	0·9	0·30	0·6	0·34
		200			229		350	350	349	262	262	255		227		232		123		38

* The number of observations means the number of values of *X* (see page 15). This is normally the same for *P*, *T* and *U*, but a few values for *U* are missing.

TABLE 20—*Random error of pressure P, temperature T and humidity U, and number of day- and night-time observations**

Pressure level (mb)	850			700			500			300			200		150		100		80	
	P *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*U* %	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*	*P* *mb*	*T* °*C*
Lerwick	2·4	0·4	5·0	2·5	0·4	2·7	2·2	0·5	3·0	1·7	0·4	2·1	1·9	0·4	1·3	0·3	1·1	0·3	0·7	0·3
		46			55			89		71	71	64	65		60		30		6	
Stornoway	2·3	0·4	5·4	2·0	0·3	5·5	1·9	0·3	2·8	1·5	0·4	0·9	1·4	0·4	1·3	0·3	1·1	0·4	0·7	0·5
		54			62			84			54		48		62		50		25	
Leuchars	2·4	0·3	2·7	2·3	0·3	3·6	2·7	0·3	2·7	1·9	0·3	1·4	1·1	0·2	1·8	0·3	(0·7)	(0·5)	(1·2)	(0·3)
		54			74			96			70		50		65		22		16	
Aldergrove	2·0	0·3	5·2	1·7	0·3	2·2	1·9	0·3	2·2	1·8	0·3	1·2	1·3	0·3	1·2	0·4	0·6	0·3	0·5	0·3
		54			55			95			73		58		56		37		24	
Fazakerley	1·5	0·2	2·1	2·1	0·3	2·9	1·8	0·3	2·4	1·6	0·3	0·6	1·6	0·3	1·3	0·3	0·6	0·3	(0·6)	(0·3)
		49			52			90			70		61		71		45		17	
Hemsby	2·4	0·2	2·5	2·1	0·3	1·1	1·8	0·3	1·9	1·4	0·2	0·9	1·5	0·2	1·3	0·2	1·1	0·3	(0·9)	(0·2)
	54	54	52		54		88	88	87		63		52		55		37		7	
Crawley	2·6	0·3	8·0	2·5	0·3	2·7	2·5	0·3	1·5	1·5	0·3	0·7	1·3	0·3	1·2	0·3	0·8	0·3	0·5	0·3
		51			53			86			60		50		62		24		14	
Camborne	2·2	0·3	7·3	1·9	0·4	2·9	2·5	0·4	2·3	2·5	0·5	0·9	1·8	0·5	1·7	0·4	0·9	0·4	(0·9)	(0·3)
		50			56			83			70		53		54		39		8	
All stations	2·2	0·31	5·2	2·2	0·30	3·3	2·2	0·35	2·4	1·8	0·35	1·2	1·5	0·35	1·4	0·31	0·9	0·36	0·8	0·34
	412	412	410		461		711	711	710	531	531	524	437		485		284		117	

* The number of observations means the number of values of X (see page 15). This is normally the same for P, T and U, but a few values for U are missing.

Figures in brackets are for day only or night only.

TABLE 21—*Standard deviation of height (metres) and number of day-time soundings*

Pressure level (mb)	850	700	500	300	200	150	100	80	60
Lerwick	2·5	5·1	13·8	28	41	39	42	63	—
	6	6	6	6	6	6	5	1	—
Stornoway	3·3	4·4	8·0	13	17	18	22	26	33
	6	6	6	6	6	6	6	3	3
Leuchars	0·9	2·1	6·1	24	25	26	28	20	—
	6	6	6	6	5	5	5	2	—
Aldergrove	2·4	5·0	10·0	20	30	33	56	43	36
	6	6	6	6	6	6	3	2	1
Fazakerley	1·2	2·6	7·4	13	21	23	28	35	5
	6	6	6	6	6	6	6	4	2
Hemsby	1·5	3·7	9·0	26	43	52	75	116	—
	6	6	6	6	5	5	2	1	—
Crawley	2·4	3·0	5·1	20	32	25	32	52	—
	6	6	6	6	6	6	4	1	—
Camborne	2·0	5·6	10·6	15	23	27	39	38	48
	6	6	6	6	5	5	4	3	1
All stations	2·1	4·1	9·1	21	30	32	38	46	31
	48	48	48	48	45	45	35	17	7

TABLE 22—*Standard deviation of height (metres) and number of night-time soundings*

Pressure level (mb)	850	700	500	300	200	150	100	80
Lerwick	2·9	3·0	6·2	16	26	37	21	29
	6	6	6	6	6	4	2	1
Stornoway	1·9	3·5	6·8	13	16	16	19	11
	6	6	6	6	6	6	5	1
Leuchars	1·4	3·8	7·7	15	20	27	—	—
	6	6	6	6	6	4	—	—
Aldergrove	1·6	3·1	5·0	10	22	25	38	55
	6	6	6	6	6	5	5	3
Fazakerley	2·6	4·2	9·4	20	33	41	52	—
	6	6	6	6	6	6	4	—
Hemsby	1·4	2·9	10·8	29	46	52	68	47
	6	6	6	6	6	6	5	2
Crawley	1·4	2·5	3·9	8	14	15	5	9
	6	6	6	6	6	6	2	1
Camborne	2·0	4·5	8·2	20	30	36	39	—
	6	6	6	6	6	6	4	—
All stations	2·0	3·5	7·5	17	28	34	43	43
	48	48	48	48	48	43	27	8

TABLE 23—*Standard deviation of height (metres) and number of day- and night-time soundings*

Pressure level (mb)	850	700	500	300	200	150	100	80
Lerwick	2·7	4·2	10·7	22	34	39	37	49
	12	12	12	12	12	10	7	2
Stornoway	2·7	4·0	7·4	13	16	17	21	23
	12	12	12	12	12	12	11	4
Leuchars	1·2	3·1	6·9	20	22	27	(28)	(20)
	12	12	12	12	11	9	5	2
Aldergrove	2·0	4·2	7·9	16	26	30	46	51
	12	12	12	12	12	11	8	5
Fazakerley	2·0	3·5	8·5	17	28	33	39	(35)
	12	12	12	12	12	12	10	4
Hemsby	1·4	3·4	10·0	28	45	52	70	77
	12	12	12	12	11	11	7	3
Crawley	2·0	2·8	4·5	15	25	21	26	37
	12	12	12	12	12	12	6	2
Camborne	2·0	5·1	9·5	18	27	32	39	(38)
	12	12	12	12	11	11	8	3
All stations	2·1	3·8	8·4	19	29	33	40	45
	96	96	96	96	93	88	62	25
Standard error:								
Computation	1·5	2·3	2·7	3·7	4·0	4·6	5·0	5·2
Instrument	1·4	3·1	7·9	19	29	32	40	45

Figures in brackets are for day only.

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