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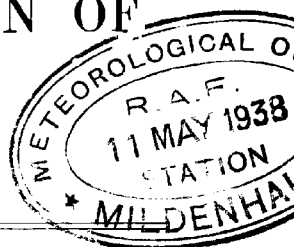
**PROFESSIONAL NOTES, No. 42**

*(Second Number of Volume IV.)*

**THE INVESTIGATION  
OF THE  
WINDS IN THE UPPER AIR  
FROM INFORMATION  
REGARDING THE PLACE OF  
FALL OF PILOT BALLOONS  
AND THE DISTRIBUTION OF  
PRESSURE**

BY

**J. DURWARD, M.A.**



**Published by the Authority of the Meteorological Committee.**



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# THE INVESTIGATION OF THE WINDS OF THE UPPER AIR FROM INFORMATION REGARDING THE PLACE OF FALL OF PILOT BALLOONS AND THE DISTRIBUTION OF PRESSURE

By J. DURWARD, M.A.

**The method employed.**—It has been suggested from time to time that additional information could be derived from the pilot balloon ascents which now form part of the routine work at many meteorological stations if arrangements were made for collecting information regarding the place of fall of the balloons. Postcards (Form 3638) were accordingly issued to the co-operating stations in December 1922 for attachment to the balloons. A specimen form is shown below. As it was anticipated that some of the cards might fall on the Continent, the text is printed both in French and English. The serial number of the ascent, date, time and place of origin are entered on the card in waterproof ink, and the finder is requested to fill in the place and date of finding and to return the card by post to the Director, Meteorological Office, Air Ministry, Kingsway, W.C.2.

Form 3638.

(Approx. 780 miles, 110°)

## INVESTIGATION OF THE UPPER AIR.

This postcard was attached to a small balloon which was released at SHOTWICK (CHESTER) on 8th Oct. 1923 at 1645m. (Ascent No. 673).

In order that information about the wind currents in the upper air on that day may be obtained, the finder is asked to fill in the blanks in the statement below and to post this postcard. NO STAMP  
NEED BE AFFIXED.

This postcard was found in the parish or town of .....  
.....in the county of.....  
.....on.....19.....

## EXPLORATION DE LA HAUTE ATMOSPHERE.

Cette carte postale était attachée à un ballon-sonde lâché à SHOTWICK (CHESTER) le 8 octobre 1923 à 1645 m. (Sondage No. 673).

Afin de permettre l'étude des courants dans la haute atmosphère à cette date, la personne ramassant cette carte est priée de donner les indications demandées ci-dessous et de mettre cette carte à la poste. IL N'EST PAS NECESSAIRE D'AFFRANCHIR CETTE CARTE.

Cette carte a été ramassée dans la Commune ou Ville de PRICRAM dans le Département de TEHÈGUOSLOBENIE. BOHÈME, en date du le 9 octobre 1923 à 16 heures.



The specimen on the previous page is a copy of the postcard attached to the balloon which accomplished the longest run during 1923.

The card is attached to the neck of the balloon by means of a short piece of thread or string. It is weighed with the balloon, and the free lift calculated from the total weight of the balloon and postcard.

The balloons used are either 70-inch or 90-inch, generally the former, except for night ascents or when a long ascent is expected by day. The free lift employed is such that balloons rise 500 ft/min in accordance with the formula

$$V(\text{ft/min}) = 275 \frac{W^{\frac{1}{2}}}{(W + L)^{\frac{1}{2}}}.$$

Where  $W$  = dead weight in grammes, and  
 $L$  = free lift.

This method of investigation is naturally attended by many uncertainties; the height to which the balloon ascends is uncertain, and its behaviour when it springs a leak or bursts is uncertain. Also the time at which the balloon actually falls is very rarely known; out of 1,000 cards returned only three have been seen falling—one in Ireland, one in Holland and one in Germany.

**The data available.**—The present report deals with the cards returned during 1923. Form 3638 was brought into use in December 1922, and the cards received up to the end of February 1923 were discussed in an unpublished report by L. H. G. Dines.<sup>1</sup> Only the exceptional cases noted by him during January and February have been included in this discussion; cards for these occasions, together with those received during the period March–December 1923, make a total of nearly 1,000.

**The height reached by pilot balloons.**—Mr. Dines in his report says that “an ordinary upper limit to the height reached by pilot balloons can be guessed at from past experience with pilot balloons; it is probably 10–15 kilometres, but a good many must burst or leak much below this.”

Johnson<sup>2</sup> concludes from experiments and actual measurements of the height of balloons that ordinary 90-inch balloons inflated to rise at 500 ft/min will rarely rise above 40,000 feet. The limiting height of 70-inch balloons would be lower still—probably 30–35,000 feet.

**Behaviour of balloons after attaining their maximum height.**—Balloons may burst or develop pin-holes, large or small; their behaviour after the maximum height is attained is thus uncertain. If a balloon bursts, the rate of fall of the remains appears to be between 600 and 800 ft/min. Johnson gives a case in which a burst balloon fell 2,430 feet in 4 minutes; some experiments made at Calshot by throwing burst balloons with a card attached out of an aeroplane showed that the time taken to fall 2,000 feet was  $2\frac{1}{2}$  to  $2\frac{3}{4}$  minutes, giving a rate of descent of about 750 ft/min.

An 8-gramme balloon, with a pendant attached, was observed to fall 500 ft/min after bursting.

The majority of balloons, however, probably develop pin-holes, and it is more difficult in this case to give the speed of the descent. The figures given by Johnson show rates of descent varying from 100 to 500 ft/min; in two of his examples the balloons descended at about 200 ft/min. The 100 ft/min rate of descent is a mean over about 50 minutes: actually the balloon kept level for 30 minutes, and then descended at 200–250 ft/min.

The rate of descent will depend on the size of the hole: a small one will tend to close up as the balloon descends, and so prevent the efflux of gas. A large one will not do so to the same extent. Also, at the low temperature at 30,000 to 40,000 feet, the hole in many balloons must be more like a rent.

**Time of flight of pilot balloons.**—A balloon which bursts on reaching a height of, say, 40,000 feet will have a time of flight of approximately 130 minutes—80 minutes ascent and 50 minutes descent. But the majority of balloons probably develop leaks and float or descend slowly for some considerable time. Dines says that “it is fairly safe to say that in most of the long runs (500 miles or more) the balloon was floating 5–10 hours at least”—this, however, overlooks the possibility of the balloons having encountered a very high wind near the base of the stratosphere. In one case a run of 570 miles was accomplished in 4 hours, and there was nothing in the observations of that day to indicate that a high wind was in evidence.

During the period March–December 1923 the following long runs were noted:—

Date	Station	Run	Remarks
		Miles	
Mar. 2	Croydon	393	Calshot: Cirrus 110 m.p.h.
„ 10	Calshot	435	—
Aug. 3	S. Farnboro'	400	Calshot: Cirrus 100 m.p.h.
„ 15	„	440	Cranwell: Cirrus 80 m.p.h. Renfrew: Cirrus 120 m.p.h.
Oct. 8	Shotwiek	780	Cirrus 110 m.p.h.
„ „	Cranwell	620	„ „
„ 22	Calshot	570	4 hrs. run.
Nov. 8	Larkhill	415	Calshot: Cirrus 80 m.p.h.
Dec. 6	Calshot	460	—

In seven out of the nine cases of long runs observations of cirrus are available, and they tend to show that the time of flight need not as a rule exceed 4–5 hours. The three definite cases when the balloons were observed during their descents give times of flight of 3 hrs. 10 mins. (220 miles), 4 hrs. (570 miles), and 4 hrs. 44 mins. (210 miles).

On the assumption that a balloon flies for  $4\frac{1}{2}$  hours, the most probable course of events is as follows:—The balloon rises to 25,000 feet (cirrus level) in 50 minutes; in another 30 minutes it will have reached 40,000 feet. It then descends slowly and afterwards more rapidly, the bottom 25,000 feet probably taking about 50 minutes. The time below the cirrus level will thus be 100 minutes, and the time above the cirrus level 170 minutes; or roughly 40 per cent. of the time is spent below 25,000 feet and 60 per cent. above this height.

**The point of fall of balloons.**—That the majority of balloons spend a considerable time at or above the cirrus level is borne out by a study of the falling points of balloons, the direction of the point of fall being generally closely connected with the direction of movement of high cloud.

On 26th May 1923 a balloon liberated at Calshot fell at a point  $275^\circ$  from Calshot, indicating a wind with a considerable Ely component, but cirro-cumulus was observed from  $350^\circ$ , and the lower winds were also Nly. This indicates that the balloon spent a considerable time well above the cirrus level where a S.-SE. wind was in evidence.

A point which is perhaps worthy of mention in connexion with the behaviour of balloons is the remarkable closeness of the points of fall of balloons released within an hour or so of each other. For example, two balloons from Larkhill released at 1115 and 1215 on the same day fell at points  $78^\circ$  from Larkhill, 91 and 94 miles away respectively; two balloons from the same place at 1015 and 1245 were found in the town of Reading; four balloons, again released from the same place at hourly intervals, were found at  $259^\circ$ , 30 miles;  $247^\circ$ , 26 miles;  $270^\circ$ , 28 miles and  $270^\circ$ , 28 miles, respectively. This shows that there is a certain amount of consistency of behaviour on the part of balloons.

**The resultant horizontal displacement of balloons and wind direction at high levels.**—By finding the distance and bearing of the point of fall of a balloon the resultant horizontal motion during the time the balloon was in flight can be obtained. What this represents with regard to the wind direction at any particular level is open to some considerable doubt. In most cases the direction of the point of fall is intimately connected with the wind at some high level probably near the base of the stratosphere; and the stronger the wind at high levels, the more nearly will this be so.

But there are cases in which the bearing of the point of fall does not give the direction of the upper wind at all. For example, on 20th April a balloon released at Andover at 1220 fell at  $248^\circ$ , 12 miles, indicating an ENE. wind; a balloon released at Larkhill at 1220 fell at  $116^\circ$ , 12 miles, indicating a WNW. wind. On this particular day the wind at the cirrus level was Wly, but the balloon from Andover does not reveal the fact.

Also on 26th May 1923 the morning balloon from Calshot was picked up in Cowes, indicating a Nly wind, but the wind

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at high levels on that day was not Nly but Sly, as other evidence shows; in fact, the midday balloon from Calshot on the same day was picked up in Southampton, and the Sly upper wind thereby revealed.

Examples of the falling-place of a balloon not revealing the upper wind direction seem to be most frequent on the north side of depressions. Provided the centre is not too far away, the winds at high levels are generally between S and W. In 1923 the cirrus observations available generally indicate *light* S to W winds, but the resultant displacement of balloons more often indicates Ely winds (*i.e.*, the wind at lower levels).

The direction of the mean point of fall for 1923 balloons is about  $100^\circ$ , or the resultant wind direction is W by N. This result, however, whilst in agreement with the accepted notion that the atmospheric circulation at or near the tropopause is from the west with a northerly component, is not conclusive. A very large number of balloons have been sent up in the westerly circulation, south of depressions, and there is not much reason to expect any great difference between upper and lower winds in this case. Long runs to the westward (if they occurred) would bring the balloons into the Atlantic, whereas long runs to the eastward mean that the balloon has a chance of being recovered. The number of balloon ascents on the north side of depressions is very small, though, as already pointed out, most of them do not reveal the upper westerly circulation even when it exists.

#### **Horizontal travel of balloons in relation to surface isobars.—**

The direction of the point of fall of each balloon has been considered in conjunction with the synoptic chart nearest in point of time, in order to see how far the resultant displacement of the balloon agrees with the run of the isobars. That certain marked divergences will occur is to be expected, seeing that the surface pressure distribution is not an exact replica of the distribution at, say, 30,000 feet.

The number of occasions, however, on which the bearing of the falling-place of a balloon agrees closely with the run of the surface isobars is large, as the table below shows. This table has been constructed by taking all occasions on which the direction of the isobars was definite (978 in number) and measuring the angle between the isobars and the line which represents the balloon's horizontal displacement.

*Table showing the percentage number of occasions on which the direction of a balloon's travel differed by a given amount from the run of the surface isobar.*

0-10°	11-20°	21-40°	41-60°	61-90°	91-135°	136-180°
39	21	17	8	6	5	4

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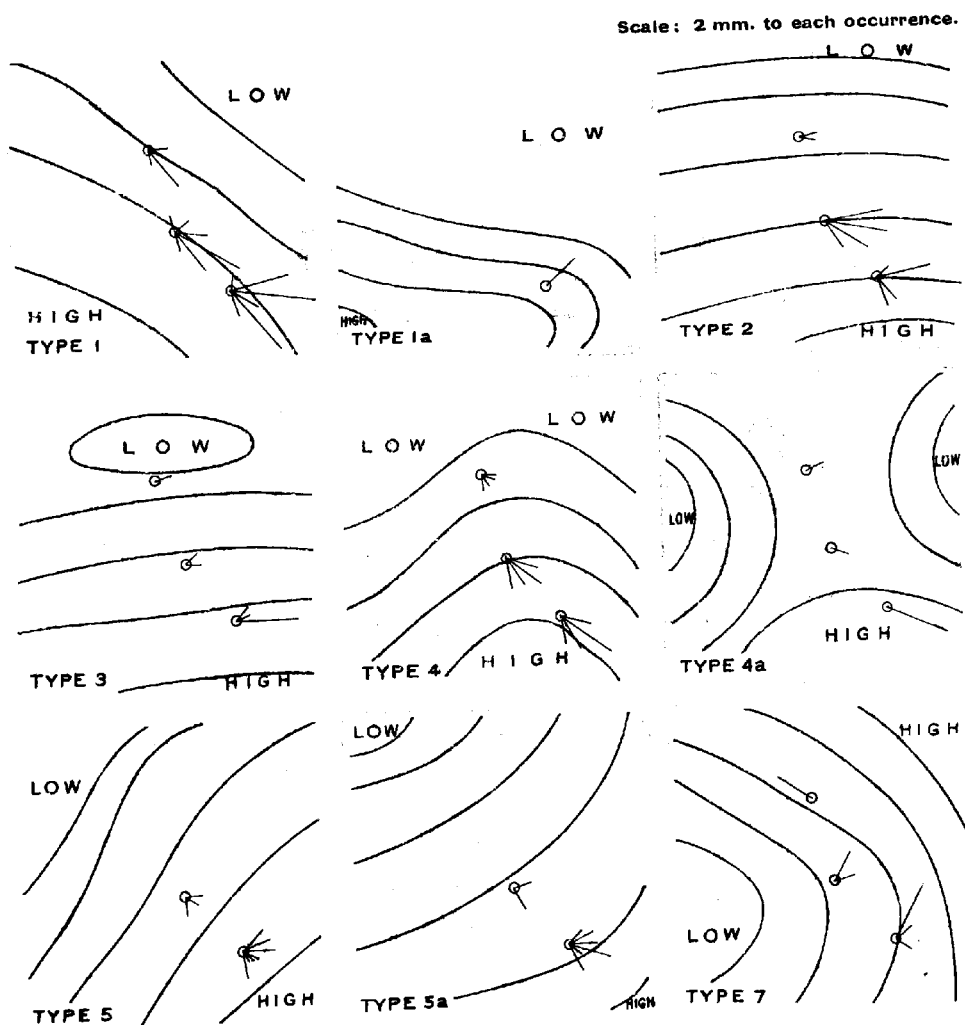
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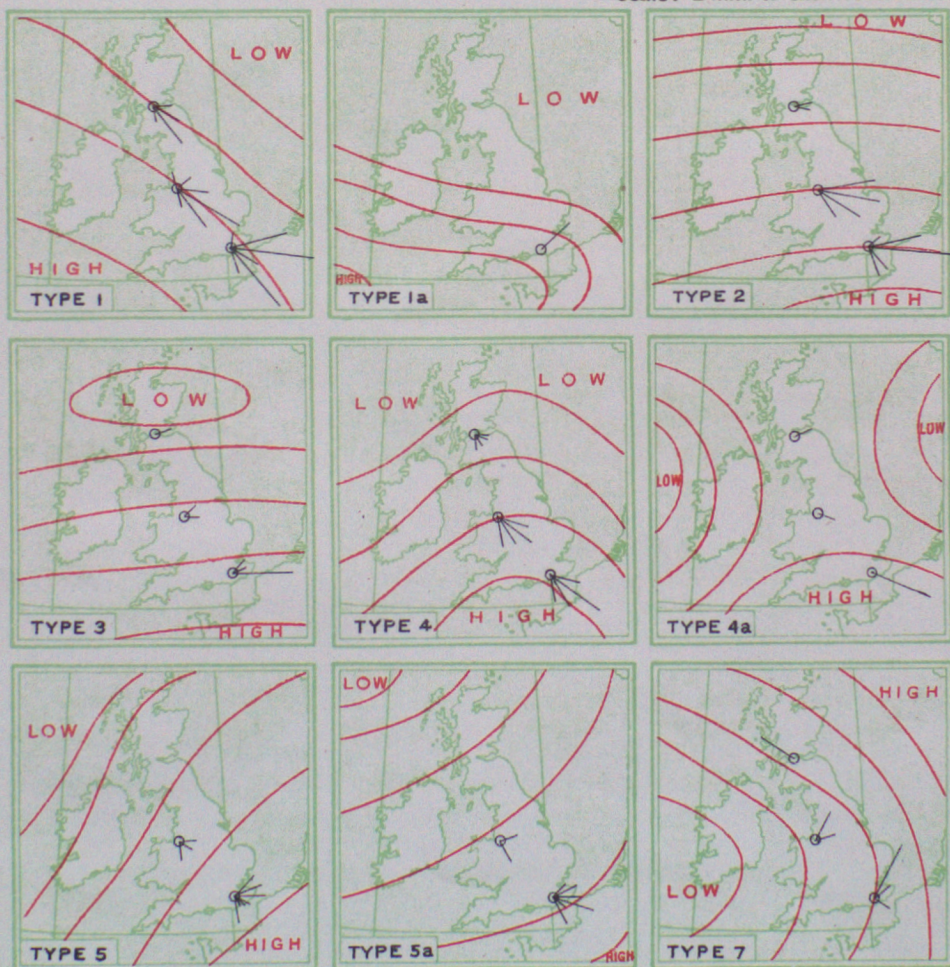




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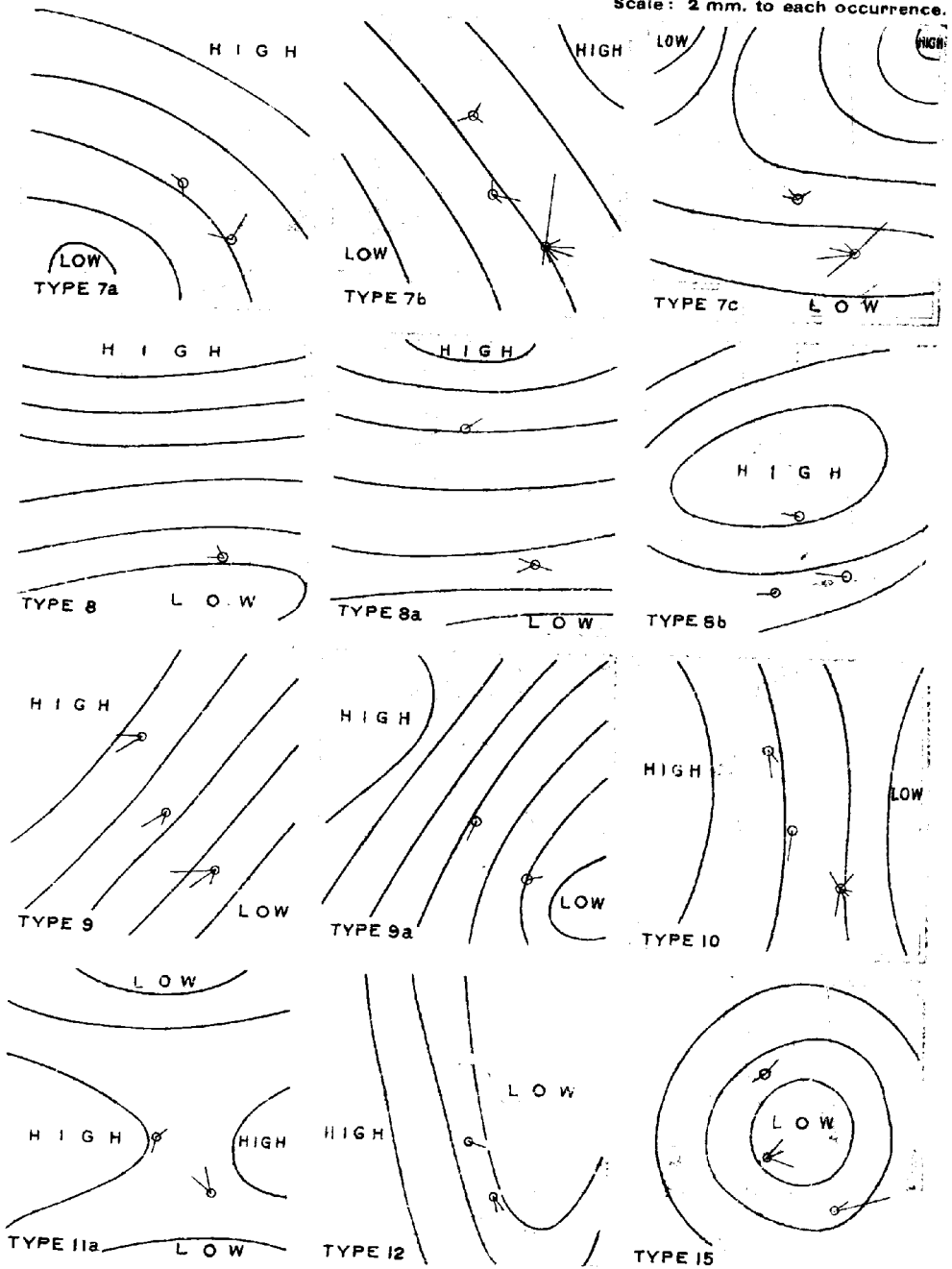
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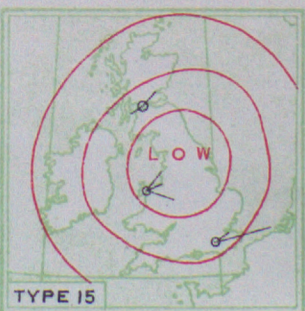
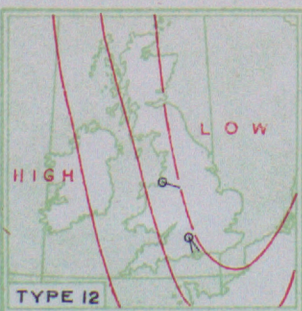
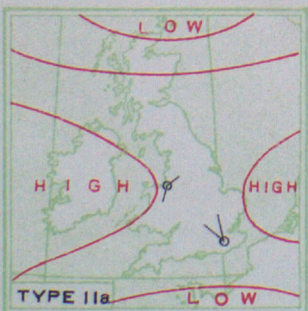
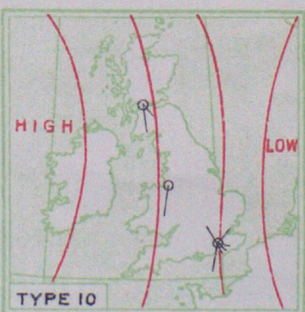
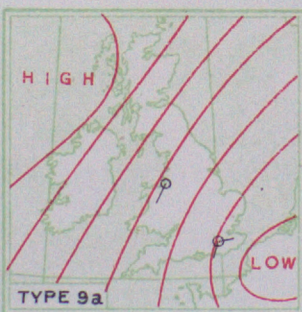
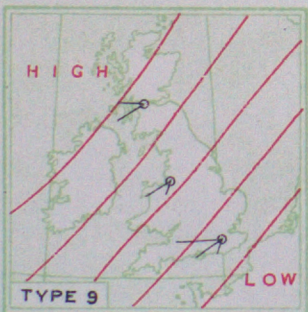
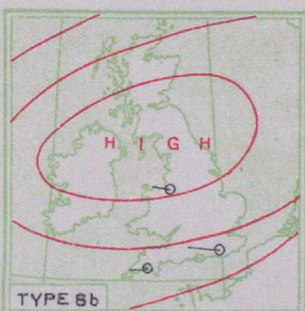
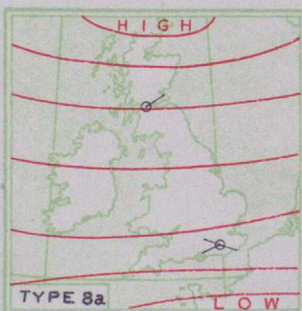
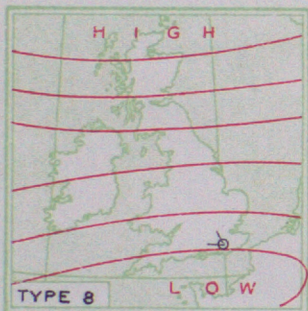
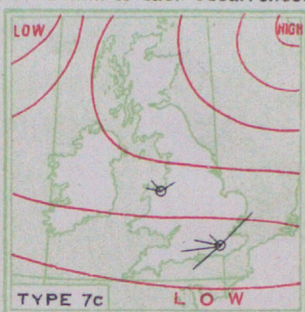
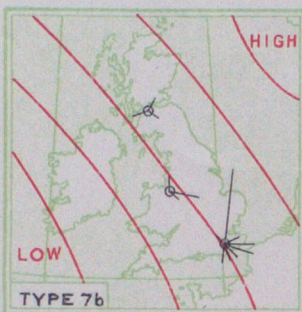
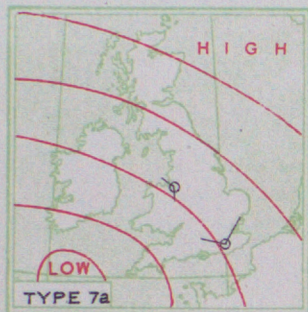
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Scale: 2 mm. to each occurrence.



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It will be seen that 77 per cent. of the balloons *which are found* have a resultant motion which is inclined to the surface isobars by less than  $40^{\circ}$ .

Before discussing the exceptional cases, let us explain the series of small maps on which lines have been drawn representing the direction of the resultant motion of various balloons (*see* Fig. 1). The maps represent one or other of Gold's<sup>3</sup> types. The lines have been drawn on all available days for the neighbourhoods of Leuchars and Renfrew, Shotwick and Holyhead, and south-east England. The direction of a line is thus the mean direction of travel of all balloons on the same day or at the same time from the same place, or from neighbouring places; the length of a line gives the number of occasions on which the mean direction of travel was in a particular direction. Only those days have been taken on which the type approximated very closely to one or other of those in *Geophysical Memoirs* No. 16, and naturally the number of occasions represented by the lines is small; but the maps will perhaps serve to show on what occasions large divergences from the surface isobars are to be expected.

The maps reveal the following :—

*Type 1.*—The majority of the balloons follow the isobars, but there are cases of decided incurvature, and at Shotwick and south-east England there is evidence of a complete reversal of wind direction.

*Type 2.*—Tendency to follow the isobars or to be directed out from the low is pronounced.

*Type 4 and 4a.*—These are transitional types, and most of the balloons seem to be controlled by the depression which has passed.

*Type 5 and 5a.*—The tendency for the resultant motion to be towards the east and south is pronounced.

*Type 7, 7a, 7b.*—Cases occur in which the resultant drift is towards east and south (wind between W and N).

*Type 7c.*—The Ely winds on the north side of a depression over France seem very pronounced, but exceptions occur in south-east England, where the resultant drift is sometimes towards the north-east. Reference has already been made to these Ely winds. Upper winds on most occasions were between S and W.

*Type 8a.*—*See under 7c.*

*Type 9a and 10.*—In south-east England cases occur of Sly winds behind a low to the east.

*Type 15.*—At Renfrew the travel in one case is towards the west and in another case towards the east (*see under 7c*).

This classification naturally leaves out many cases which do not readily come under any type classification and we will now proceed to discuss the exceptional cases in greater detail.

These exceptional cases are generally associated with low barometric pressures.

**Divergences from surface isobars.**—(a) *Front of Depressions.* The upper winds in the region of SE-SW surface gradient in front of a depression in the Atlantic or in the south-east sector of a depression centred near Iceland frequently have a large W or N component.

A typical example is that of March 12, 1923. The synoptic chart for 0700 on that day is reproduced in Fig. 2. An attempt has been made to draw the trajectories of air reaching our eastern and western coasts on that morning. These trajectories have been drawn for surface air and air at 2,000 feet. For the 2,000 feet trajectories the winds measured by observations of pilot balloons have been used in tracing the air from the time of one synoptic chart to the previous one; failing these observations, the gradient wind measured from the maps themselves has been employed. The surface trajectories have been drawn in a similar manner, use being made of surface wind observations. Air reaching London at the surface and at 2,000 feet had come from the east, and before that from the north. Air reaching Valencia at these heights had come from the south-west. The surface air reaching eastern Ireland had come from the east, and before that from the north, but the air at 2,000 feet over eastern Ireland had come from the south-west. Somewhere near the west of Ireland, therefore, a surface of discontinuity reached the ground—the Forecast Division to whom questions regarding discontinuities were referred represent it as a line of occlusion in the position indicated by the double line. The slope of the surface of discontinuity appears to be about 1/200–1/250 and over south-east England 350–400 miles away, some sort of discontinuity in the lapse rate should be looked for at about 7,000 feet.

Ascents at Farnboro', Andover and Grain reveal inversions or almost isothermal conditions between 4,000 and 8,000 feet.

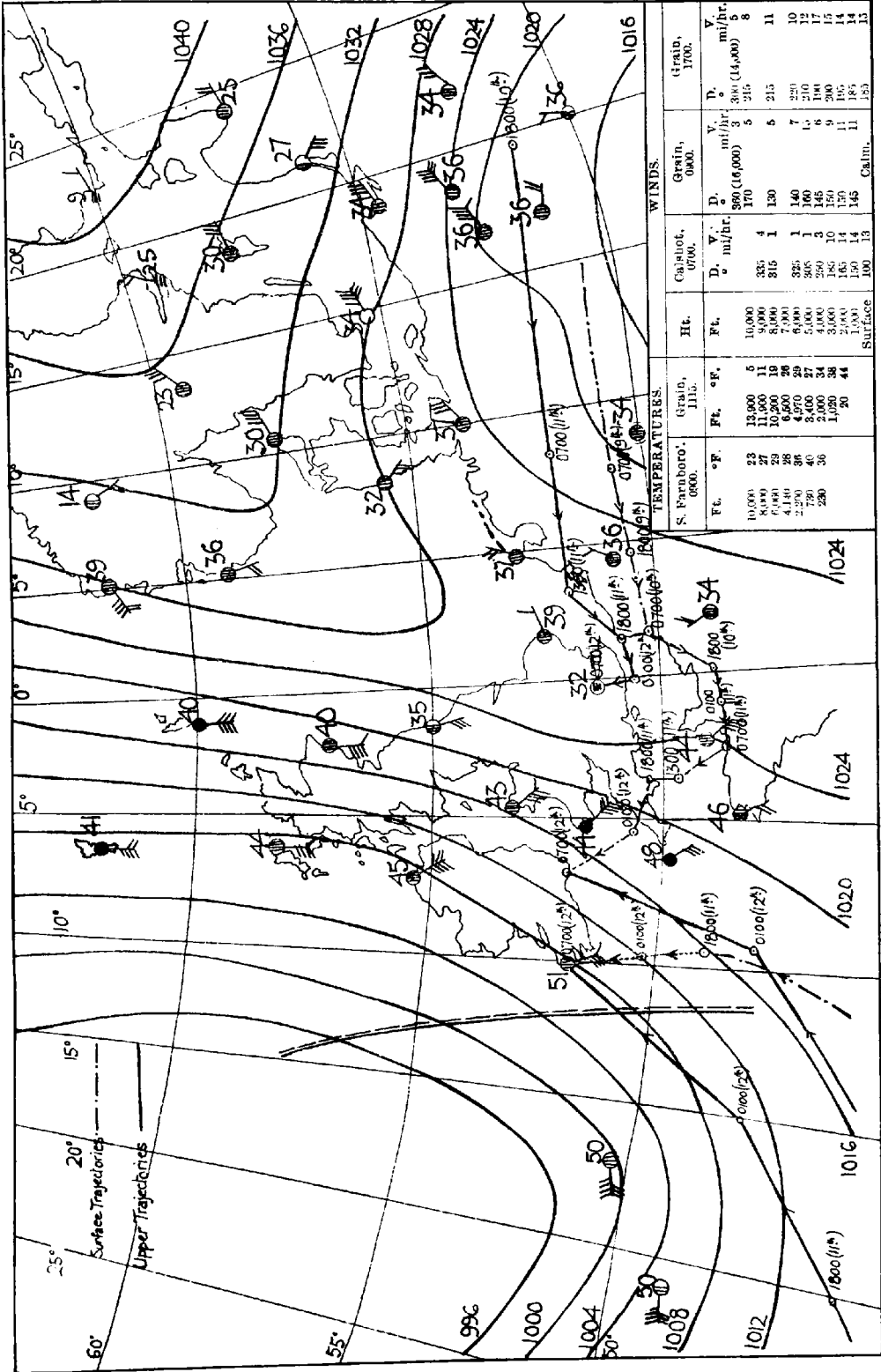
At some English stations pilot balloons were observed up to great heights and show a change from a Sly wind to a Nly one at 15,000 feet (Grain 0900) 6,000–10,000 feet (Calshot 0700), and at 12,000 feet at Shoeburyness. Balloons released at Shoeburyness were found 150 and 24 miles south of the station; one from Lympne 240 miles to the south and one from Andover 20 miles to the south. Balloons from Croydon and Cranwell fell to the north-north-east, and did not reveal the Nly wind, probably because it was light in this case, or perhaps because they did not go high enough.

The Nly wind is thus found in the region between polar and equatorial air or in advance of a warm or occluded front. These Nly winds are generally in evidence 700–1,000 miles from the centre of a depression and at heights between 10,000 and 30,000 feet. Their appearance ought to signify rain—"warm front rain"; in most of the cases during 1923 they were followed



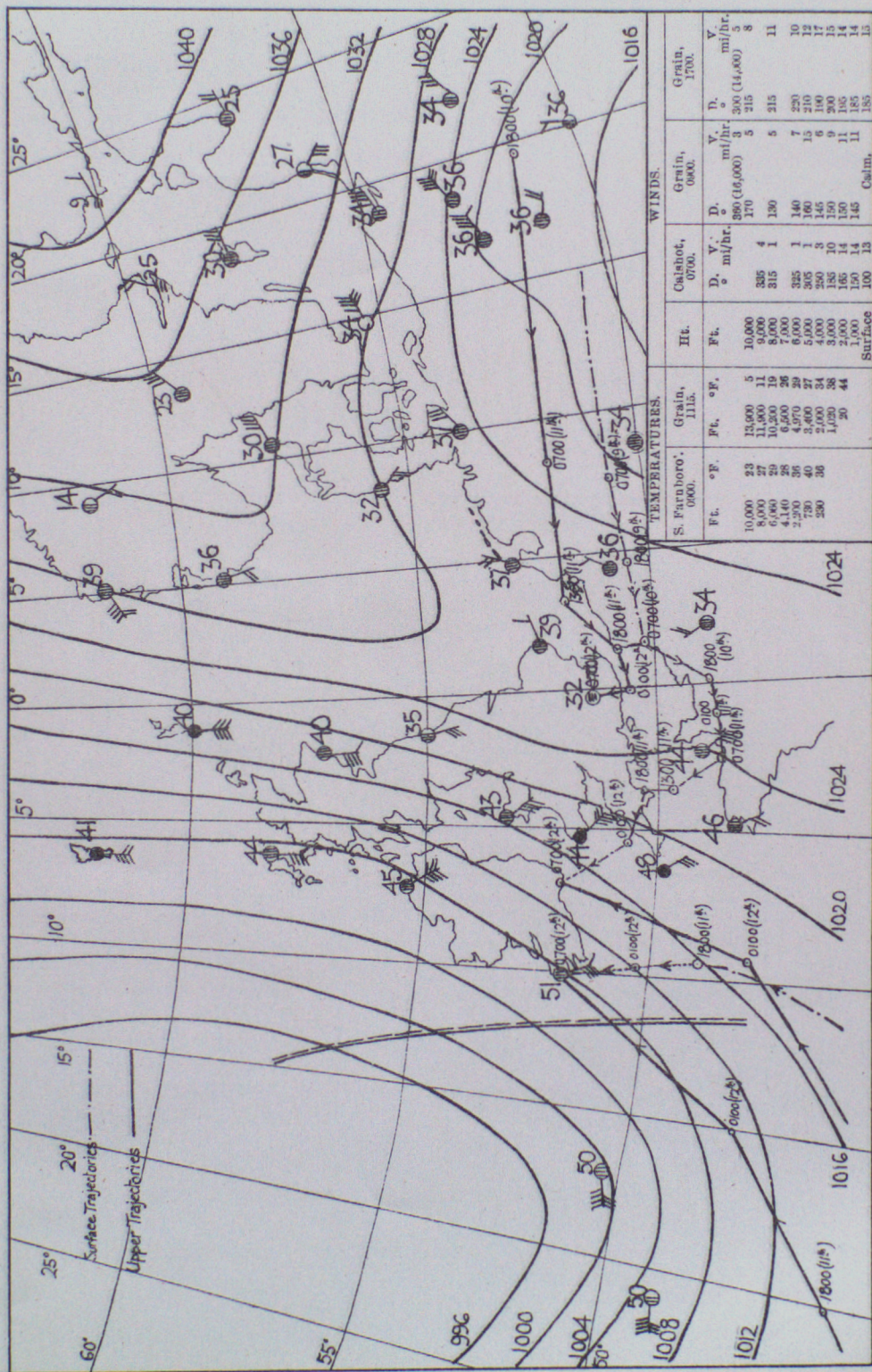
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CHART FOR 0700, 12th MARCH, 1923.

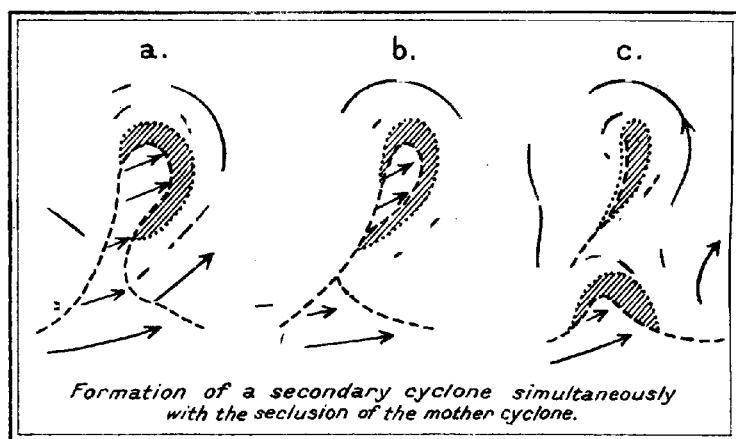


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CHART FOR 0700, 12th MARCH, 1923.



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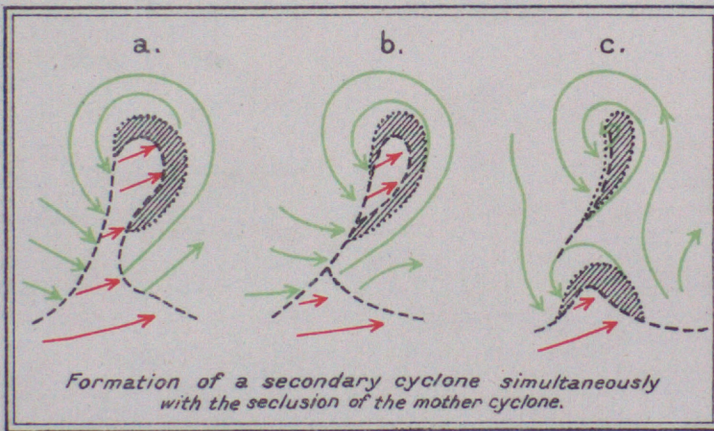


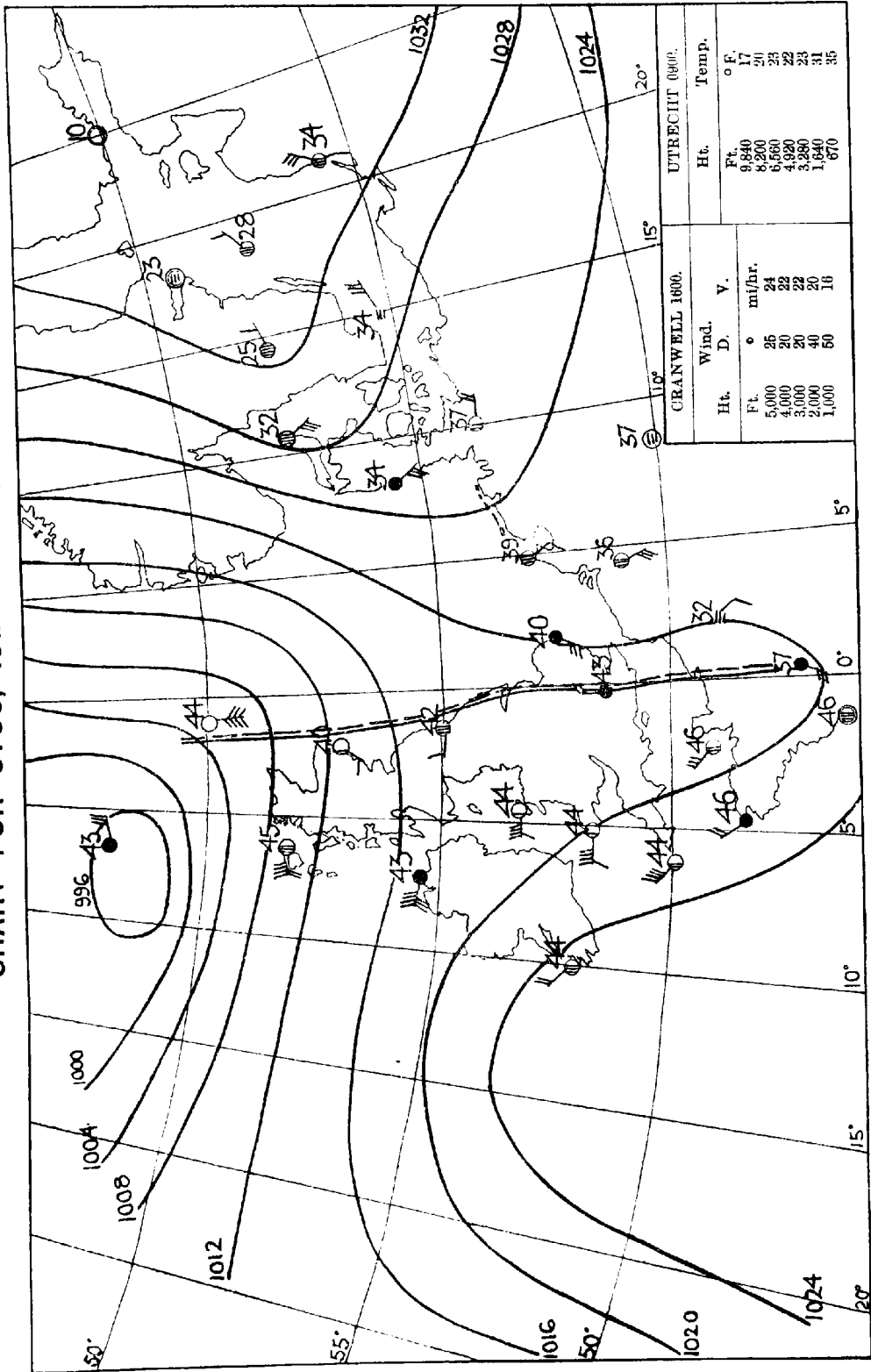


Figure 4.

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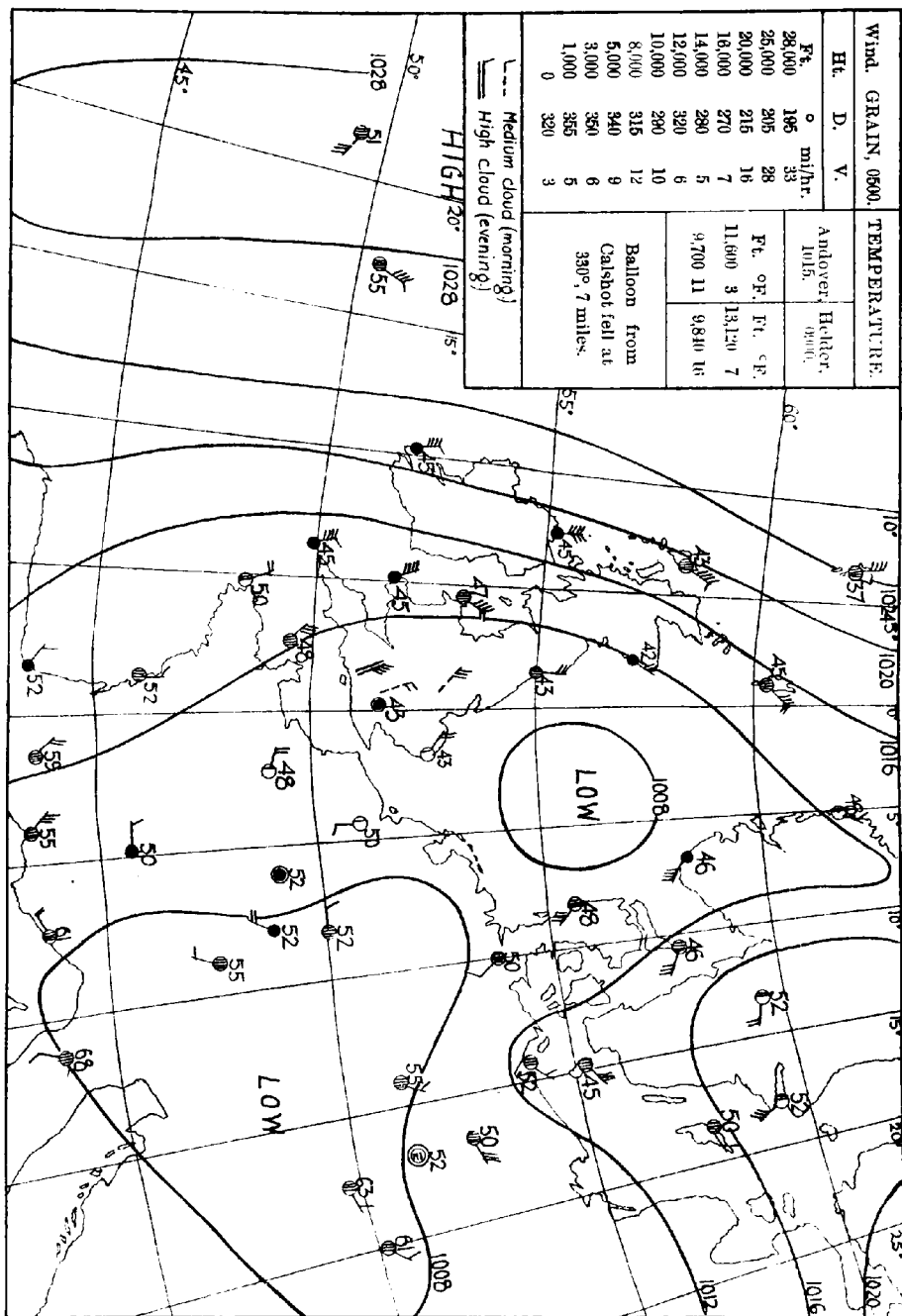
Professional Notes No. 42.

CHART FOR 0700, 13th MARCH, 1923.



Professional Notes No. 42.

CHART FOR 0700, 26th MAY, 1923.



by the formation of a secondary depression over southern England. The tendency for Nly winds over Sly or SWly winds to be followed by the formation of a secondary was pointed out by Shaw<sup>4</sup> in 1913, and the explanation seems to follow naturally from the mechanism suggested by Bjerknes; for if these Nly winds imply a warm or occluded front, there will be a tendency for a "secondary" to form south of the primary centre, as illustrated in the diagram Fig. 3.

The 0700 chart for 13th March 1923 reproduced in Fig. 4 shows a secondary trough over England; some other examples are the secondaries on Jan. 5, Feb. 11, Feb. 13, Feb. 22, March 2, April 18, Sept. 4.

These Nly winds are not always indicated by the travel of the balloon. On the occasions when they are not, the movement of cirrus has been slight from between west and north, showing that there has been a Nly "thermal wind" component introduced; but it has been too light to alter the direction of the balloon's motion sufficiently or else the balloon has not spent sufficient time in the region where it prevailed.

Another example of these Nly winds which may be worthy of mention on account of its historical character is that of Oct. 19, 1917. On this occasion surface winds behind a depression which had passed and in front of another advancing from the west were light W-NW, but at 20,000 feet at Portsmouth the wind was N by W 87 mi/hr. This occasion is memorable on account of the loss of a fleet of Zeppelins due to this unexpected high Nly wind. The situation is fully discussed by Sir Napier Shaw in the *Manual of Meteorology*, Part IV, pp. 110-114.

(b) *Rear of depressions.* In the rear of depressions it is known that cirrus often continues to move from the south or south-west long after the wind in the lower layers has changed to W or NW. Balloons liberated in the rear of well-marked circular depressions seldom fall in a direction  $360^{\circ}$ - $40^{\circ}$  from the point of release, but their courses often indicate that the upper wind differs from the lower by the addition of a marked southerly component. Behind shallow troughs or secondaries, however, the resultant motion often shows that the upper wind is SE-S, because, after travelling a considerable way with a Nly wind, the balloon is picked up to the north of the point of release.

Perhaps a case in point is found in the chart for 13th March 1924 already referred to. The line of occlusion is shown and on this occasion a balloon released at Cranwell, behind the occlusion, travelled until lost to view in a NNE wind, but was ultimately found at  $318^{\circ}$ , 34 miles.

Another case in which actual measurements of wind in the upper layers exist is 26th May, 1923. The synoptic chart for 0700 is reproduced in Fig. 5. No "fronts" are given in their Daily Weather Reports by the Norwegian Meteorologists for this day; an occluded front from between Yarmouth and Cranwell to Scilly shown on the map of the 25th had apparently disappeared.

But above the Nly wind at the ground there was a Sly one. Observations at Grain show a light NNW wind up to 6,000 feet, a light W-NW up to 20,000 feet, but a wind of 33 mi/hr from  $195^{\circ}$  at 28,000 feet. A balloon released from Calshot in the Nly wind was found later in Southampton (bearing  $330^{\circ}$ ). Temperature measurements on this day show that at 12,000 feet the air over Utrecht and Helder was about  $8^{\circ}$  F. warmer than over Andover. This temperature gradient (roughly  $3^{\circ}$  F. per 100 miles) would give a Sly component increasing at the rate of 3 to 3.5 mi/hr per 1,000 feet so long as the temperature gradient was maintained. Between 16,000 feet and 28,000 feet, the S component increased from 0-30 mi/hr—an increase of 2.5 mi/hr per 1,000 feet. Thus the temperature gradient was apparently maintained, and the warm air to the eastward seems to have been that which was secluded some time before from the depression over the North Sea.

Another good example of this is found in the mid-day balloon ascent from Leuchars on 30th August, 1923. The ascent indicated a wind from W to NW up to 10,000 feet, but the balloon ultimately fell in Aberdeenshire, indicating a S or SE wind at higher levels behind a depression over the North Sea.

(c) *North side of depressions.* The evidence disclosed by the motion of a balloon is somewhat conflicting. For instance, on 20th April, 1923, with a low over Spain and an ENE current over the British Isles, most of the balloons travelled a short distance to the south-west, but one balloon from Larkhill fell at  $116^{\circ}$ , indicating that the wind at some high level was between W and N. On 9th November, 1923, a balloon from Calshot fell at  $270^{\circ}$ , but the cirrus movement over south-east England was SSE-S. The synoptic chart for this occasion is reproduced in Fig. 6. On 5th December, 1923, a balloon from Larkhill fell at  $290^{\circ}$ , but cirrus movement was from the west. On 13th July, 1923, the movement of balloons indicated SE-S winds, in agreement with the observed movements of high cloud. On the 27th and 28th November, 1923, the falling points lay between  $360^{\circ}$  and  $20^{\circ}$ , indicating upper winds between S and SW or WSW; actually the cirrus movement was SW-WSW, 20-40 mi/hr.

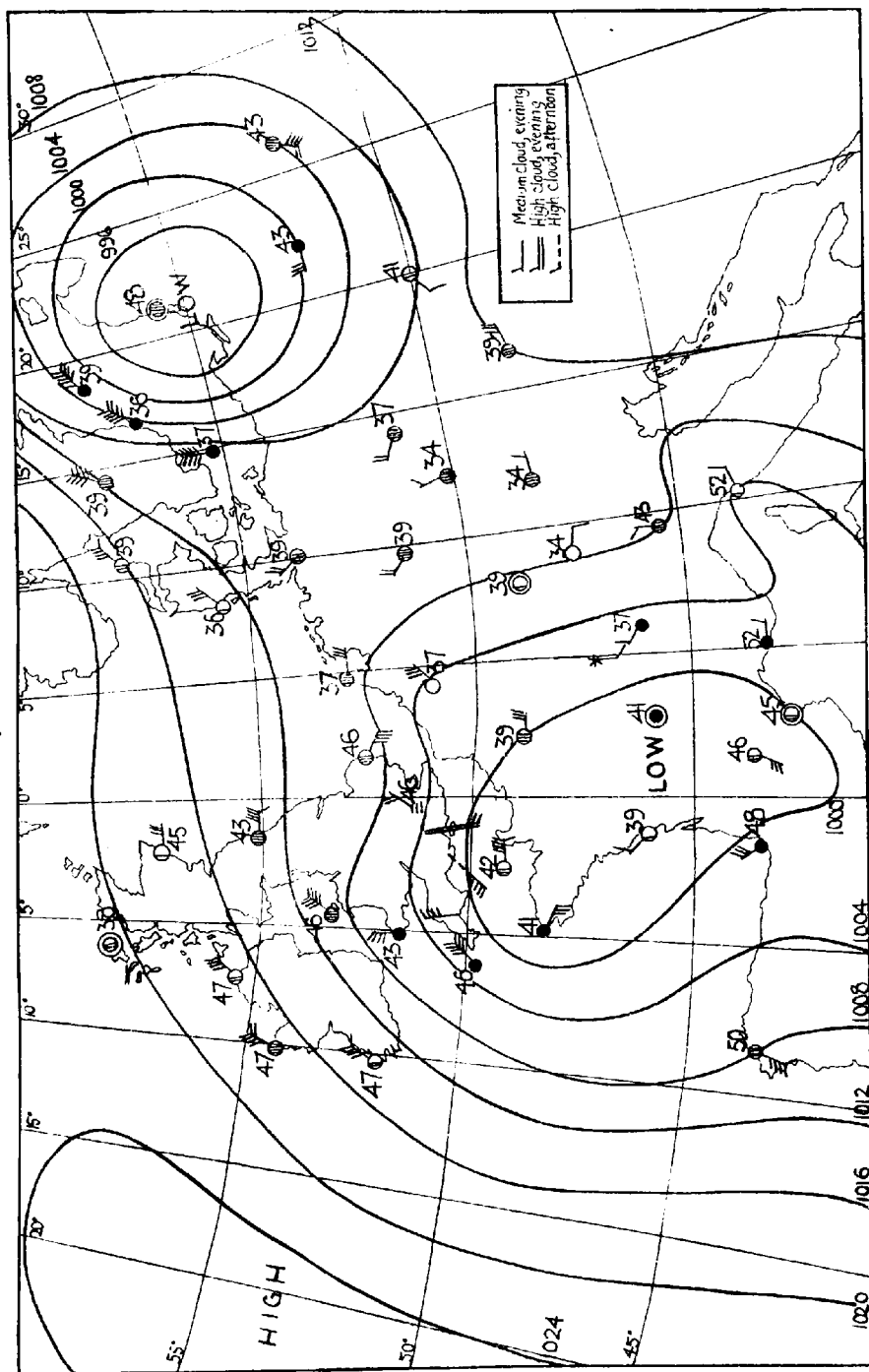
It seems that the upper winds on the north side of depressions are mostly Wly, but often from S or SE; but during 1923 these upper winds were fairly light, and the direction of the point of fall of balloons does not indicate them.

(d) *South side of depressions.* Here the resultant displacement of balloons reveals that the SW or W winds are generally continued to great heights. In the south-west section, SE winds are occasionally found over the surface Wly circulation; perhaps the case at Leuchars on 30th August, 1923, already mentioned above, might be cited as an example.

The other point which is worthy of mention is the high speed which the Wly circulation may assume at or above the cirrus

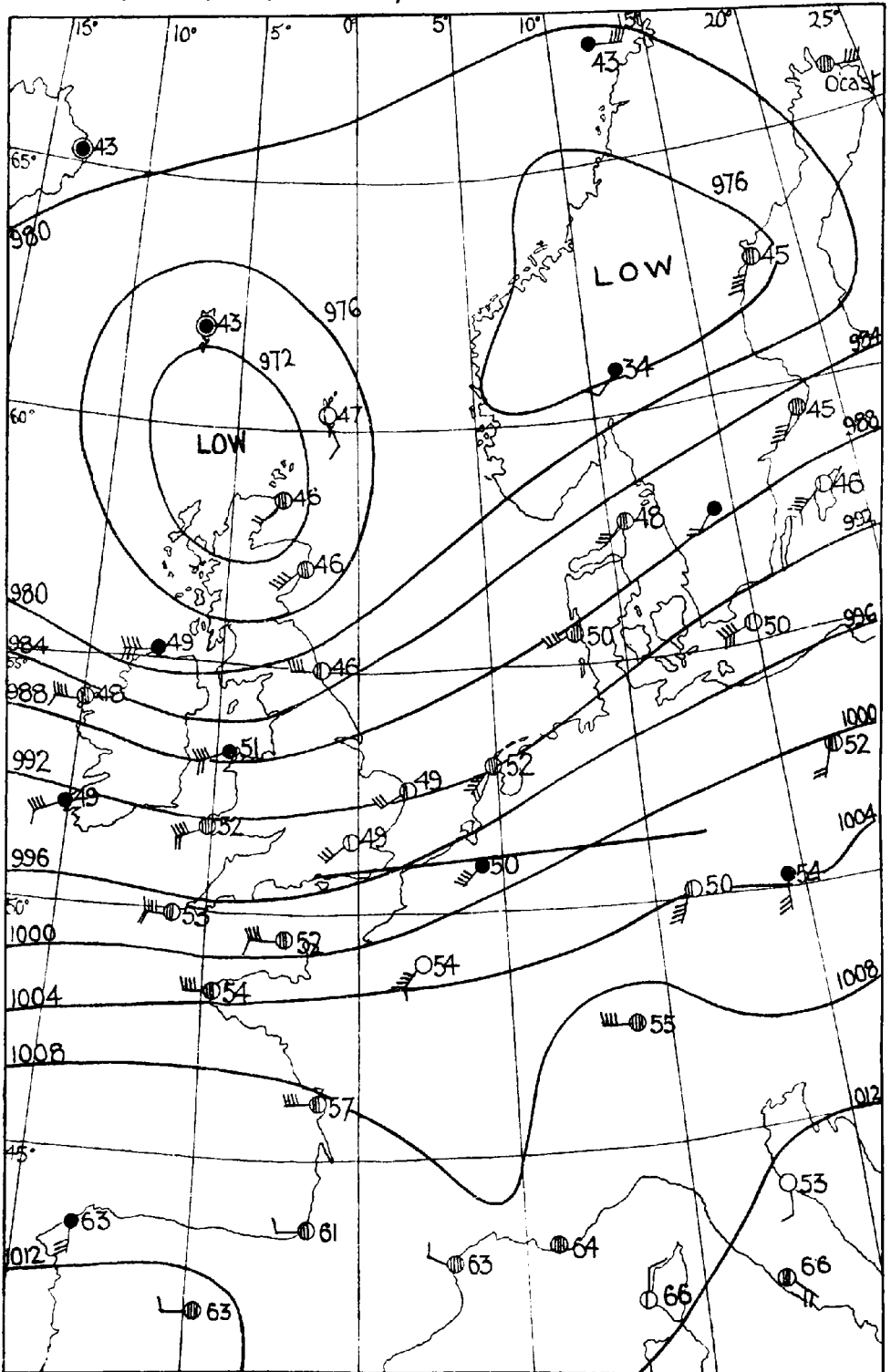
Professional Notes No.

CHART FOR 1800, 9th NOVEMBER, 1923.



Professional Notes No. 42.

CALSHOT TO LEIPZIG IN FOUR HOURS.  
CHART FOR 1800, OCTOBER 22nd, 1923.



level. One of the few balloons picked up just as it fell affords positive evidence on this point.

The balloon in question was released at Calshot at 1630 on 22nd October, 1923, and was picked up four hours later at Meresburg, near Leipzig. It thus travelled approximately 570 miles, at an average speed of 143 mi/hr.

The synoptic chart for 1800 on that date (Fig. 7) indicates an area of low pressure over Scandinavia and the north of Scotland and a general Wly circulation further south. The actual ascent revealed a wind of 51 mi/hr at 7,000 feet, the wind beneath this height being about 40 mi/hr. Observations from France show winds of 45-50 mi/hr. between 6,000 and 7,000 feet.

In the morning high clouds over England were moving from the west at 50-60 mi/hr (estimated height 26,000 feet). No great change took place during the day so far as the layers 0-10,000 feet were concerned, but there were no high cloud observations published for the afternoon or evening.

It seems that a very high wind must have been experienced between 25,000 and 35,000 feet. If the observations of high cloud over England in the morning are applicable, the average speed up to 25,000 feet was about 50 mi/hr, and allowing 50 minutes of ascent and 30 minutes of descent, this means that in 80 minutes the balloons covered about 70 miles, leaving 500 miles to be done in 2 hrs. 40 mins., or at an average speed of 188 mi/hr. This would imply a maximum speed of nearly 250 mi/hr.

Probably, however, the morning observations did not apply to this ascent at 1630, and perhaps the following represented the course of events more accurately. It was apparently cold over Norway—snow was reported at 0700 and at 1800, one Norwegian station had a temperature of 34° F. Assume that there was a temperature gradient from south to north of approximately 4° F. per 100 miles. This would cause an increase in the Wly component of the wind by about 4 mi/hr per 1,000 feet, and we have now got to fit the velocities to suit the present case.

Let the speed at 10,000 feet be	80 mi/hr
then „ „ „ 15,000 „ will be	100
and „ „ „ 35,000 „ „	180

Up to the height of 15,000 feet the mean speed was about 70 mi/hr, and the balloon travelled for 30 minutes (that is 35 miles) ascending, and 20 minutes (or 23 miles) descending, total 58 miles.

In the interval 15,000-35,000 feet the mean speed was 140 mi/hr. and the balloon travelled 40 minutes, or 93 miles (ascending), and, say, 40 minutes, or 93 miles (descending), total 186 miles.

Accordingly at or near the 35,000 feet level the balloon spent 1 hour 50 minutes and travelled 326 miles, or had an average speed of roughly 180 mi/hr.

The figures suggested thus fit very well, as no great increase should be met with above 35,000 feet or even some lesser height depending on the height at which the stratosphere was reached.

It is probable, then, that the maximum speed was between 180 and 200 mi/hr and that this was due to a gradient of temperature between Norway and northern Germany of about  $4^{\circ}$  F. per 100 miles. The large temperature gradient in this region was due to the existence of a boundary surface separating polar and tropical air of approximately the same direction of motion. This boundary surface as it existed on October 9–14th, 1923, is discussed fully by Bergeron and Swoboda.<sup>6</sup>

**Conclusion.**—(a) The investigation of the upper air by means of Form 3638 attached to pilot balloons is attended by so many uncertainties that the method cannot possess any exactness, but the facts disclosed as to wind direction in the upper layers have been confirmatory of those already found by a study of upper cloud movements such as is given by Douglas<sup>5</sup> in "Observations of Upper Cloud Drift." The diagram given there on p. 347, especially that referring to cyclones well advanced towards the "dying" stage, meets all the points which have been raised; the appropriate isobaric distribution over such a low would be as on p. 349 of the same paper. Some temperature figures for 1921, 1922, supplied by Major Goldie indicate that the mean difference in temperature between "polar" and "equatorial" air between 950 and 600 millibars (roughly 1,500 to 13,500 feet) is generally  $10$ – $15^{\circ}$  F., but may amount to  $20^{\circ}$  F. The temperature distribution given by Douglas in the pressure distribution diagram is thus verified, and the result is that the circular form of the isobars is replaced by a trough of low pressure displaced westwards and northwards.

(b) It is doubtful whether this method is any better or even as good as the careful observation of high cloud, except of course that the method is available in all kinds of weather if observers put cards on every balloon sent up, no matter how short an ascent is expected.

(c) The Wly circulation south of regions of low pressure in the north attains a very high speed on occasions, and it is suggested that many of the long runs may be due to this fact, rather than that the balloon floated for many hours.

## REFERENCES

- <sup>1</sup> M.O. Correspondence File 369872/22.
- <sup>2</sup> N. K. Johnson, B.Sc.: "The Behaviour of Pilot-Balloons at Great Heights." *Q.J.R. Meteor. Soc.* Jan 1922, pp. 49–59.
- <sup>3</sup> E. Gold, F.R.S.: "Types of Pressure Distribution." *Meteorological Office Geophysical Memoirs*, No. 16.
- <sup>4</sup> Sir Napier Shaw: *Forecasting Weather*. 1st Edition, pp. 61–62.
- <sup>5</sup> C. K. M. Douglas, B.A.: "Observation of Upper Cloud Drift as an aid to research and to weather forecasting." *Q.J.R. Meteor. Soc.*, pp. 342–356.
- <sup>6</sup> T. Bergeron and G. Swoboda: "Wellen und Wirbel an einer quasistationären Grenzfläche über Europa" *Veröff. Geophys. Inst.* Leipzig, 2 Ser., Bd. III., H. 2.



## ADDENDUM

It has been suggested that useful information regarding sites for "balloon sonde" stations might be derived from a study of the travel of pilot balloons. If two or three stations exist, discretion can be used as to which is the best one according to the meteorological conditions prevailing at the time from which to release the "balloon sonde."

Accordingly for each station a table was made showing the number of occasions on which the direction of travel of a balloon differed by a given amount from the direction of the surface isobars, eight directions being considered. This amount was reckoned positive if the resultant direction was veered from the direction of the isobar and negative if backed. The total number of balloons recovered is known and also the total number sent up. Assuming that each balloon sent up had a postcard attached, the percentage of balloons recovered can be calculated and a "figure of merit" assigned to each station.

The tables for individual stations are not given here. They show that from 70 to 80 per cent. of the recovered balloons are found in a direction inclined to the isobars at an angle of less than  $40^\circ$  and that this angle is generally positive with gradient winds between E and SW and negative with gradient winds between W and N.

The following table amplifies that given on p. 6 but gives in addition information regarding the percentage number of balloons recovered. Eskdalemuir, it will be observed, has the highest percentage of recovered balloons, but perhaps it is unfair to include this station in view of the small number of balloons released during the period under consideration. Shotwick (now Sealand) has the next highest percentage, then Larkhill, and then Croydon and Renfrew. Farnborough, Cranwell, Calshot, Andover and Holyhead are about equal. Stations near the sea such as Grain, Shoeburyness, Cattewater and Lympne have a very small percentage of balloons recovered.

TABLE SHOWING THE PERCENTAGE NUMBER OF OCCASIONS ON WHICH THE DIRECTIONS OF THE FALLING-POINTS OF BALLOONS DIFFERED BY A GIVEN AMOUNT FROM THE DIRECTIONS OF THE SURFACE ISOBARS, also the number of balloons recovered, and the total number of pilot balloon ascents at various stations (period March 1923-Feb. 1924).

Station	Divergence from surface isobars							No. of balloons recovered	No. of balloon ascents	Percentage of balloons recovered
	0-10°	11-20°	21-40°	41-60°	61-90°	91-135°	136-180°			
Andover	31	16	26	10	5	5	7	64	702	9
Calshot	39	17	14	10	9	6	5	129	1069	11
Cattewater	27	9	18	9	9	28	0	11	435	3
Cranwell	42	24	13	4	10	5	2	102	857	12
Croydon	41	20	21	6	5	5	2	135	930	15
Farnborough	32	32	16	11	6	3	0	43	367	12
Grain	41	18	23	9	5	4	0	24	630	4
Holyhead	49	27	11	3	5	3	2	58	656	9
Leuchars	50	9	25	16	0	0	0	15	494	3
Lympne	41	25	16	3	9	3	3	35	883	4
Renfrew	34	29	16	7	5	5	4	55	304	15
Shotwick	38	23	21	7	4	7	0	192	790	24
Eskdalemuir	35	24	12	18	4	3	0	18	50	36
Shoeburyness	25	31	13	25	0	6	0	16	741	2
Biggin Hill	40	20	0	0	0	20	20	5	—	—
Larkhill	41	18	14	10	8	4	5	141	669	21



