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WIND AT 100,000 FT. OVER SOUTH-EAST ENGLAND

Observations and a discussion of the monsoon theory of winds at great heights

BY

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Observations and a discussion of the monsoon theory of wind at great heights

§ 1—SUMMARY

A description is given of the measurement of wind at 100,000 ft. by observation of the drift of smoke bursts produced by a high-velocity gun at that level over south-east England in 1944–45.

The results indicated that the wind was mainly strong SW. to NW. in winter and moderate NE. to SE. in summer.

The mean temperature values up to 60,000 ft. over Salisbury Plain and the Shetlands indicate that in winter at these high levels it is colder to the north and in summer warmer to the north, which will explain the seasonal variation of wind direction at these levels. The relation ships between the horizontal temperature gradients, the vector mean winds over the British Isles, and the wind values at 100,000 ft. are discussed.

§ 2—INTRODUCTION

The amount of experimental data on the magnitudes and directions of the winds at heights above about 60,000 ft., the normal limit of observation by the balloon method, is very scanty. The purpose of the present investigation was to extend the measurements by making observations at 100,000 ft.

The existing information on winds above the balloon-observation limit is summarised briefly in §8.

§ 3—EXPERIMENTAL METHOD

A high-velocity gun located near Dover was used to fire shells to about 100,000 ft. The shells were filled with a smoke mixture and were fused to burst at the top of the trajectory. The drift of the smoke cloud thus produced was observed from several positions, and from the observations it was possible to calculate the wind speed and direction at this height. The observations had to be made in clear weather with no cloud in the area of the burst. In these conditions the smoke cloud was visible to the naked eye, and could usually be seen for about three minutes before it finally dispersed. In some cases the cloud was followed and photographed with kiné-theodolites.

Thirty-five rounds were observed between February 1944 and May 1945. Although the disposition of the observation posts and the direction of fire of the gun were altered from time to time for operational reasons the method of observation was the same throughout. Four or more observation posts were arranged about 10 miles apart so that a large angle was subtended at the burst point by the " lines " from the observation posts, hence giving an accurate location of the burst. The posts were accurately surveyed, and were in telephonic communication with a control centre. The observing instruments were standard service-type flash-spotting theodolites with a wide field of view (6–7°). When the cloud was first formed in the glass the readings were accurate to about one minute of arc, but the error increased as the cloud expanded. Synchronous half-minute readings of the azimuth and elevation by all observers were made until the cloud dispersed, usually about three minutes after its formation. The kiné-theodolites photographed the cloud every five or ten seconds, and the films were generally too indefinite to read 60–90 seconds after the burst.

A given set of simultaneous azimuth readings, corrected for refraction and curvature, produced a number of rays, one from each post, from which the plan position of the cloud at the instant of observation could be found. In general these rays did not intersect in a point but formed a small " cat's-cradle " from which the plan position was assessed. The wind speed and direction were calculated from the successive plan positions. Mean heights were calculated from these plan positions and the corresponding angles of elevation.

§ 4—RESULTS

The results from the observations made in the period February 1944 to May 1945 are collected in Table I. A short description of the pressure situation over the firing area is included; details of the synoptic situation can be extracted from the relevant daily weather reports. There is no obvious correlation between the present results and the highest winds (usually about 60,000 ft.) obtainable from radio-sonde data on the day of measurement. The number of observations given includes all measurements of successive positions of the smoke cloud.

The variations of the north–south and east–west components are shown in Figs. 1 and 2, all the measurements being plotted together although the heights varied from 90,000 ft. to 110,000 ft. Where several measurements were made on the same day they have all been plotted, and the graph drawn through the mean point for the day. In many cases a large number of observations were made on each cloud, all reasonably consistent, and it is considered that in most cases the results are accurate to $\pm 5^{\circ}$ in direction and $\pm$ 10 kt. in speed.

The results show that the wind at 100,000 ft. was mainly easterly in summer and westerly in winter, with a change-over in spring and autumn. The time of change-over appeared to be a month earlier in 1945 than in 1944. The winds in summer were comparatively light, but in winter they were as much as 130 kt. and varied rapidly between SW and NW. On one occasion there appeared to be a rapid change within 24 hours.

§ 5—"MONSOON" WINDS IN THE UPPER ATMOSPHERE

The theory that in these latitudes the wind between 50,000 and 150,000 ft. height is mainly W. in winter and E. in summer was discussed by the late Dr. F. J. W. Whipple in a lecture to the Royal Meteorological Society[2]*. He described how the audibility of the anomalous sound wave from large explosions in north-west Europe was generally good to the east of an explosion source in winter and to the west in summer, and explained this by a seasonal change in wind direction at high levels. In addition he compared a series of temperature determinations up to a height of 50,000 ft. over Lapland with those over England throughout the year, and was able to show that in the lower stratosphere Lapland is warmer than England in summer and colder in winter. Furthermore he calculated that this would produce a reversal in the north to south pressure gradient at 50,000 ft. and hence east to west wind components in summer, and west to east in winter at these heights. As the observations that were available to him in 1935 may have been to some extent invalidated by the effect of direct solar radiation on the instruments then available it was decided to repeat this part of his investigation utilising all the radio-sonde observations of temperature made at Larkhill (Salisbury Plain) and Lerwick (Shetlands) from

* The index figures refer to the bibliography on p. 14.

TABLE I—SUMMARY OF RESULTS OBTAINED FROM OBSERVATIONS OF WIND AT 100,000 FT. IN SOUTH-EAST ENGLAND BY MEANS OF HIGH-ALTITUDE SMOKE BURSTS

F.S. = Flash-spotting theodolite. K.T. = Kiné-theodolite

Round No.	Date	Time	Height	Wind speed	Wind direction	W.-E. component	S.-N. component	No. of observations	Synoptic situation	No. of posts observing
		G.M.T.	ft.	kt.		kt.	kt.			
1	12. 2.44	1030	95,000	104	256°	+101	+ 25	5	col	1 F.S.
2	14. 2.44	1200	100,000	64	280°	+ 63	− 11	10	col	3 F.S.
3	14. 2.44	1436	100,000	61	273°	+ 61	− 3	19	col	4 F.S.
4	14. 2.44	1512	97,000	46	271°	+ 46	0	16	col	4 F.S.
5	14. 2.44	1618	95,000	61	270°	+ 61	0	14	col	3 F.S.
6	18. 4.44	1120	102,000	23	246°	+ 21	+ 9	58	col	9 F.S.
7	18. 4.44	1145	104,000	37	254°	+ 35	+ 10	46	col	9 F.S.
8	19. 4.44	1120	99,000	37	261°	+ 37	+ 6	24	SW. air stream	4 F.S.
9	19. 4.44	1140	99,500	42	253°	+ 40	+ 12	52	depression to north-west	6 F.S.
10	7. 5.44	1300	95,000	7	266°	+ 7	0	18	high	4 F.S.
11	7. 5.44	1330	99,500	8	271°	+ 8	0	52	high	9 F.S.
12	24. 6.44	1600	106,000	25	103°	− 24	+ 6	26	ridge	5 F.S.
13	24. 6.44	1643	106,900	31	095°	− 31	+ 3	30	ridge	5 F.S.
14	17. 7.44	1530	106,500	25	087°	− 25	− 1	20	high	5 F.S.
15	17. 7.44	1610	100,500	23	103°	− 22	+ 5	19	high	5 F.S.
16	28. 7.44	1807	109,000	18	084°	− 18	− 2	20	W. air stream, high to south	5 F.S.
17	14. 8.44	0525	104,500	18	073°	− 17	− 5	27	high	5 F.S.
18	14. 8.44	0548	103,000	16	080°	− 16	− 3	25	high	5 F.S.
19	26. 8.44	1712	100,700	16	062°	− 14	− 8	14	col	4 F.S.
20	9. 9.44	0718	101,500	10	046°	− 7	− 7	32	shallow trough	5 F.S.
21	2.10.44	0832	100,200	4	variable	0	0	21	high	4 F.S. 2 K.T.
22	13.11.44	1107	95,000	89 (doubtful)	250°	+ 84	+ 30	5	NW. air stream, low to north-east	3 F.S. (Poor intersections)
23	6.12.44	0950	106,000	105	258°	+103	+ 22	17	westerly air stream	4 F.S. 2 K.T.
24	6.12.44	1020	104,500	97	269°	+ 97	+ 2	36	low to north	
25	24.12.44	0857	101,000	85	307°	+ 68	− 51	43	high	4 F.S. 2 K.T.
26	6. 1.45	1010	98,500	114	322°	+ 70	− 90	16	col	4 F.S.
27	20. 1.45	1144	99,000	118	242°	+104	+ 55	34	NW. air stream	5 F.S. 2 K.T.
28	3. 2.45	0840	101,000	128	285°	+123	− 33	44	ridge	5 F.S. 2 K.T.
29	21. 2.45	0904	97,000	38	276°	+ 38	− 4	40	high	5 F.S. (Seen through thin veils of cirrus) 2 K.T.
30	9. 3.45	0827	96,500	119	272°	+119	− 4	40	high	4 F.S. 2 K.T.
31	9. 3.45	1604	94,500	121	278°	+119	− 17	24	high	4 F.S. 2 K.T.
32	18. 3.45	0912	96,500	52	250°	+ 49	+ 18	24	high	3 F.S. 2 K.T.
33	9. 4.45	1345	99,500	34	111°	− 32	+ 12	22	high, S. air stream	5 F.S.
34	16. 4.45	0705	92,500	18	074°	− 17	− 5	14	high to east	4 F.S.
35	13. 5.45	1033	97,000	31	099°	− 31	+ 5	18	W. air stream, low to north-west	4 F.S.

1942 to 1946. Over this period routine ascents were made daily at 0000, 0600, 1200 and 1800 G.M.T. at both stations up to heights approaching 50,000 ft. Monthly means were extracted for both stations at the four times of observation, and then corresponding differences between values at Lerwick and Larkhill were found. The results are shown in Fig. 3, and, in general, confirm Dr. Whipple's results over this smaller distance, Lerwick being only about 600 miles north of

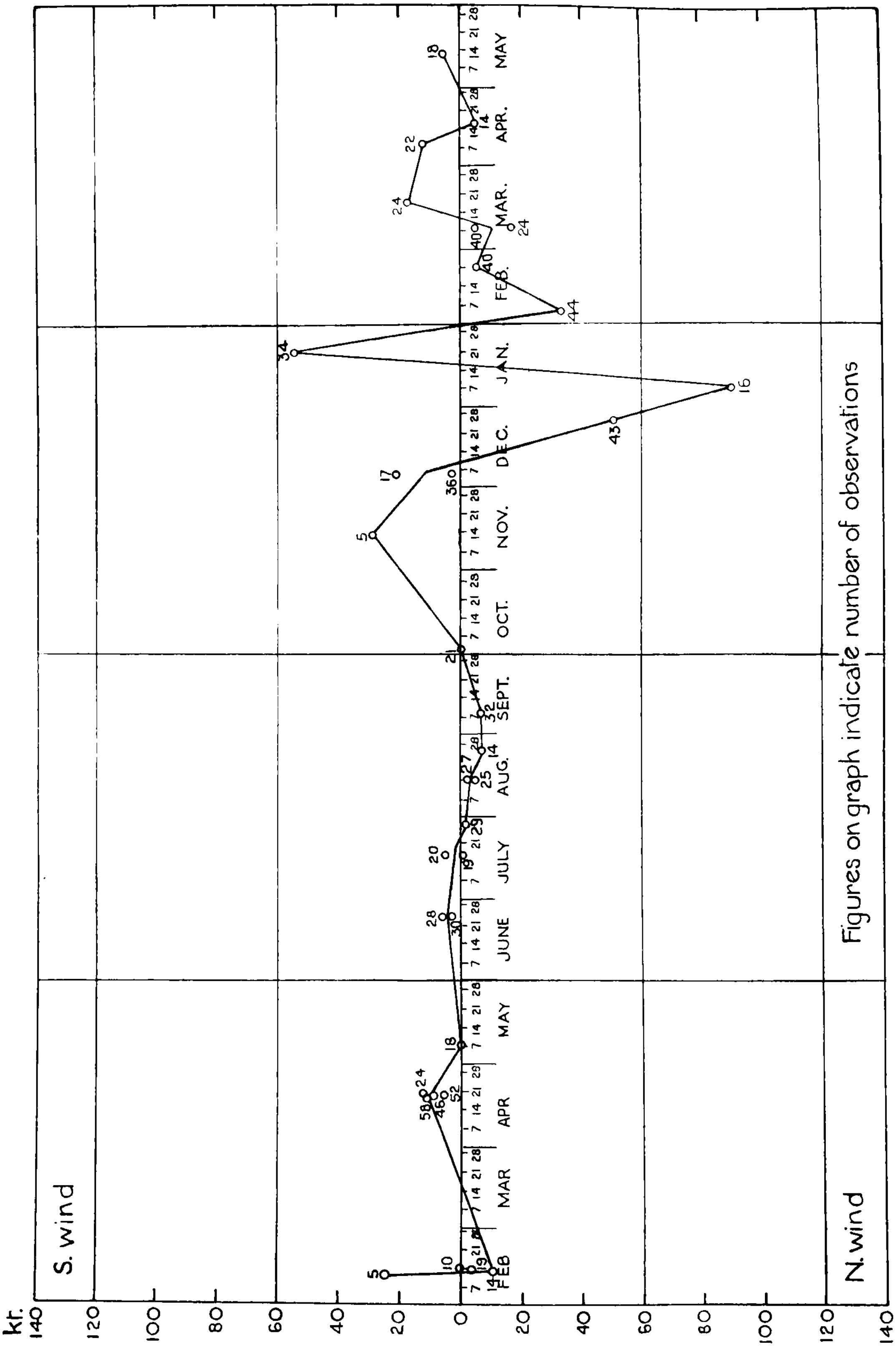

FIG. 1—SOUTH-NORTH WIND COMPONENTS AT 100,000 FT., FEBRUARY 1944—MAY 1945

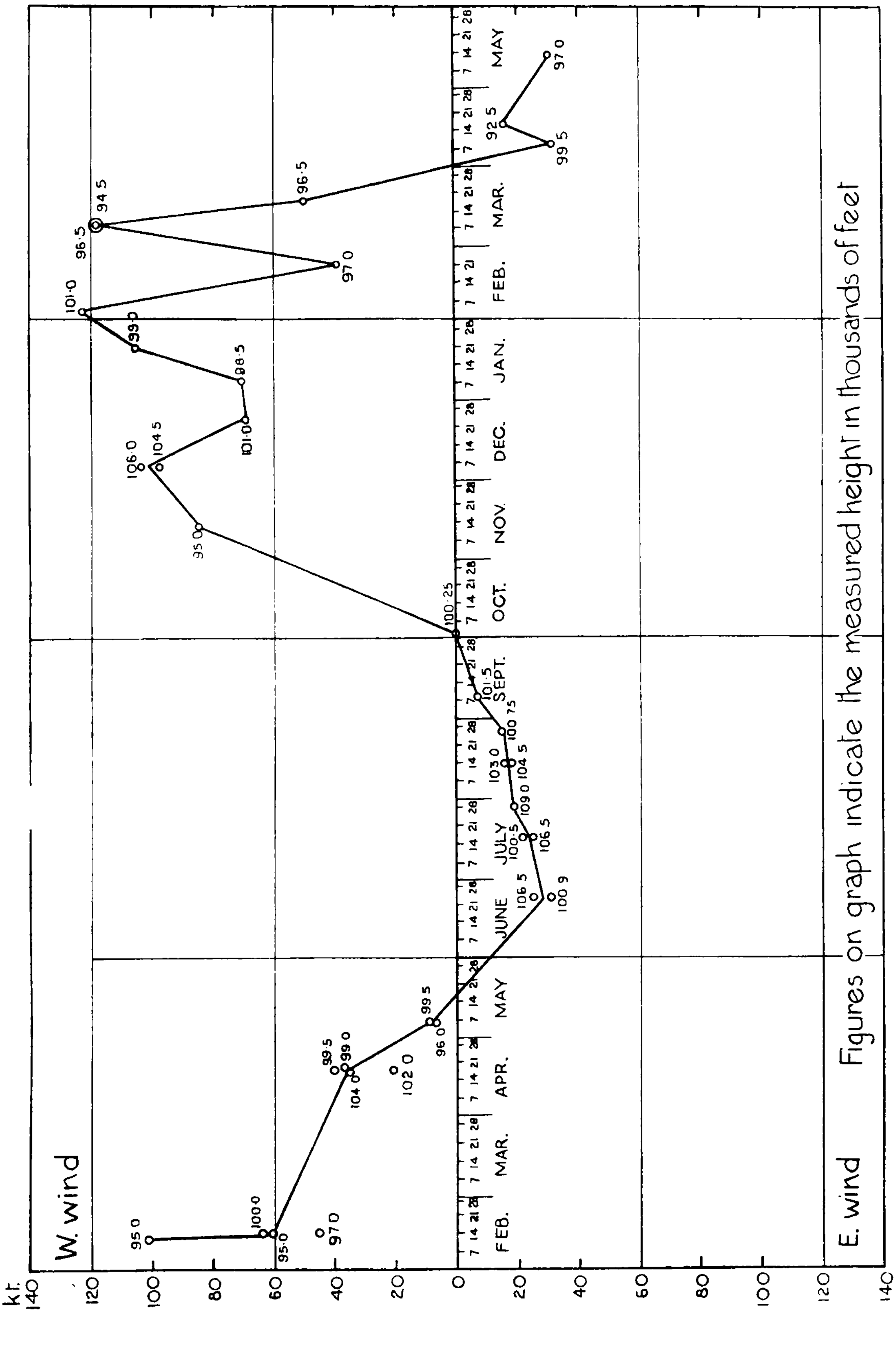

FIG. 2.—WEST-EAST WIND COMPONENTS AT 100,000 FT., FEBRUARY 1944—MAY 1945

Larkhill. The seasonal reversal of temperature gradient in the stratosphere occurs even in the observations based on the midnight ascents when there is no solar radiation on the instruments. Certain other information is given incidentally in these diagrams :—

(1) The troposphere above Larkhill is always warmer than that above Lerwick.

(2) In general the stratosphere is only isothermal in spring and autumn. In winter there appears to be generally a lapse and in summer an inversion of temperature at the highest levels.

(3) Probably at a pressure level of about 200 mb. Lerwick is warmer than Larkhill at all seasons (although it may be about the same temperature in mid winter). At greater heights though, Lerwick is always warmer than Larkhill in summer and colder in winter.

TABLE II—VECTOR MEAN WINDS

Pressure level	December–February					June–August				
	No. of obs.	Wind direction	Wind speed	E.–W. component	N.–S. component	No. of obs.	Wind direction	Wind speed	E.–W. component	N.–S. component
mb.		°	kt.				°	kt.		
				LARKHILL (November 1939–May 1945)						
60	89	298	28·9	− 25·9	+ 13·6	154	322	1·9	− 1·2	+ 1·5
80	188	299	27·9	− 24·4	+ 13·5	191	288	5·9*	− 5·6	+ 1·8
100	292	300	29·3*	− 25·4	+ 14·7	274	281	11·3	− 11·1	+ 2·1
130	363	303	30·7	− 25·8	+ 16·8	320	275	14·8	− 14·7	+ 1·3
170	418	307	31·4	− 25·0	+ 18·8	364	281	25·2	− 24·7	+ 4·8
200	445	308	32·7	− 25·7	+ 20·2	395	280	26·8	− 26·5	+ 4·7
250	479	311	32·1	− 24·2	+ 21·1	431	278	27·4	− 27·0	+ 3·8
300	498	309	31·1	− 24·2	+ 19·6	441	278	26·9	− 26·5	+ 3·7
900	516	290	7·3	− 6·8	+ 2·5	442	277	7·9	− 7·8	+ 1·0
				LERWICK (January 1942–May 1945)						
60	24	278	39·8*	− 39·3	+ 5·6	70	318	0·9*	− 0·6	+ 0·1
80	69	279	40·5	− 39·8	+ 6·3	100	262	3·7	− 3·7	− 0·5
100	124	280	36·5	− 35·7	+ 6·3	155	262	7·8	− 7·7	− 1·1
130	182	283	36·8	− 35·7	+ 8·3	198	261	9·7	− 9·6	− 1·5
170	232	283	38·1	− 36·9	+ 8·6	237	264	16·1	− 16·0	− 1·7
200	247	283	38·0	− 36·8	+ 8·5	249	263	19·3	− 19·2	− 2·3
250	254	283	40·1	− 39·0	+ 9·0	259	264	23·2	− 23·0	− 2·4
300	256	271	37·6	− 37·5	+ 1·0	268	260	21·0	− 20·6	− 3·6
900	268	258	14·6	− 14·2	− 3·0	276	244	3·9	− 3·5	− 1·7

Calculated thermal winds (isobaric) E.–W. components Larkhill to Lerwick

Pressure layer	Winter	Summer
mb.	kt.	kt.
150– 50	8·5 W.	19·9 E.
250–150	1·3 E.	10·6 E.
900–250	19·9 W.	16·6 W.

* From this level the summaries were probably " incomplete " in respect of strong winds.

To investigate the effect of this temperature distribution on the east-to-west wind components, the thermal (isobaric) wind was computed between several pressure levels using the expression below which is given in " A note on the thermal wind " by Sverre Petterssen[5] :—

$$U_1 - U_0 = \frac{R}{2\omega g \sin \phi} \log \frac{p_1}{p_0} \cdot \frac{\partial T_M}{\partial y},$$

where $U_1 - U_0$ is the difference in wind components between the pressure levels p_1 and p_0, $\partial T_M/\partial y$ is the mean horizontal temperature gradient of the isobaric layer, ϕ is the latitude, ω the angular velocity of the earth's rotation, g the acceleration of gravity and R the gas constant for air. Mean east–west components at various levels were then calculated from these thermal wind components. The results of these calculations are given and compared with mean wind values in Table II and shown in Fig. 4. It can be seen that the wind at both Lerwick and Larkhill has a westerly component which decreases with height in the stratosphere in summer but remains constant or slightly increases with height in the stratosphere in winter. The calculated winds show reasonable agreement with the mean vector winds. The horizontal lines on the curve of calculated winds show the effect of a $\pm$ 1° F. change in the value of the temperature difference between Larkhill and Lerwick at the various levels. The fact that the observed wind values at the higher levels may be slightly low since the wind observations cannot be continued to the greatest heights when the winds are strong also tends to improve the agreement. It is therefore concluded that the " monsoon " effect of wind begins to take place owing to the seasonal reversal of the north-to-south horizontal temperature gradient from about the 150-mb. level upwards. It should be noted, however, that although the horizontal temperature gradient in summer at levels of 150–50 mb. (if it continues up to a level of 11 mb. approx. 100,000 ft. at the same value) is sufficient to produce the observed summer values of wind at 100,000 ft., this is not true of the winter values. It is necessary for the winter horizontal temperature difference between Larkhill and Lerwick to be considerably greater between 50 and 11 mb. than it is between 150 and 50 mb. in order to produce the observed values of wind at 11 mb. in winter. In order to estimate the magnitude of the horizontal temperature differences between these stations in the layer 50–11 mb., the thermal winds in this layer have been calculated for each wind observation at 100,000 ft. and these are described below.

§ 6—HORIZONTAL TEMPERATURE GRADIENT BETWEEN LERWICK AND LARKHILL IN THE LAYER 100–11 MB.

If we take the pressure level of the wind determinations to be approximately 11 mb. (100,000 ft.) and find the vector wind change between the radio-sonde wind value at 100 mb. (measured at the same time) and this value, we can obtain from the east-west components of this vector change the mean horizontal temperature difference between Lerwick and Larkhill in the layer 100–11 mb. on each occasion. This was done, and the values are given in Table III. These values are compared with the mean differences in the layer 100–50 mb. over the period 1942–46 in Fig. 5, and the following tentative conclusions are suggested :—

(1) In the layer 100–11 mb. during 1944–45 Larkhill was warmer than Lerwick for one or two months longer than it was in the layer 100–50 mb. computed for the years 1942–46. Hence it seems that Larkhill is warmer than Lerwick for a longer part of the year at 100,000 ft. than it is at 50,000 ft.

(2) In the summer months the layers 100–50 mb. and 100–11 mb. both have a temperature difference of 5° to 7° F. between Larkhill and Lerwick, Lerwick being the warmer. Probably this is the general magnitude of the temperature difference within the range 50,000 to 100,000 ft. during the summer. This would explain the moderate easterly winds in summer.

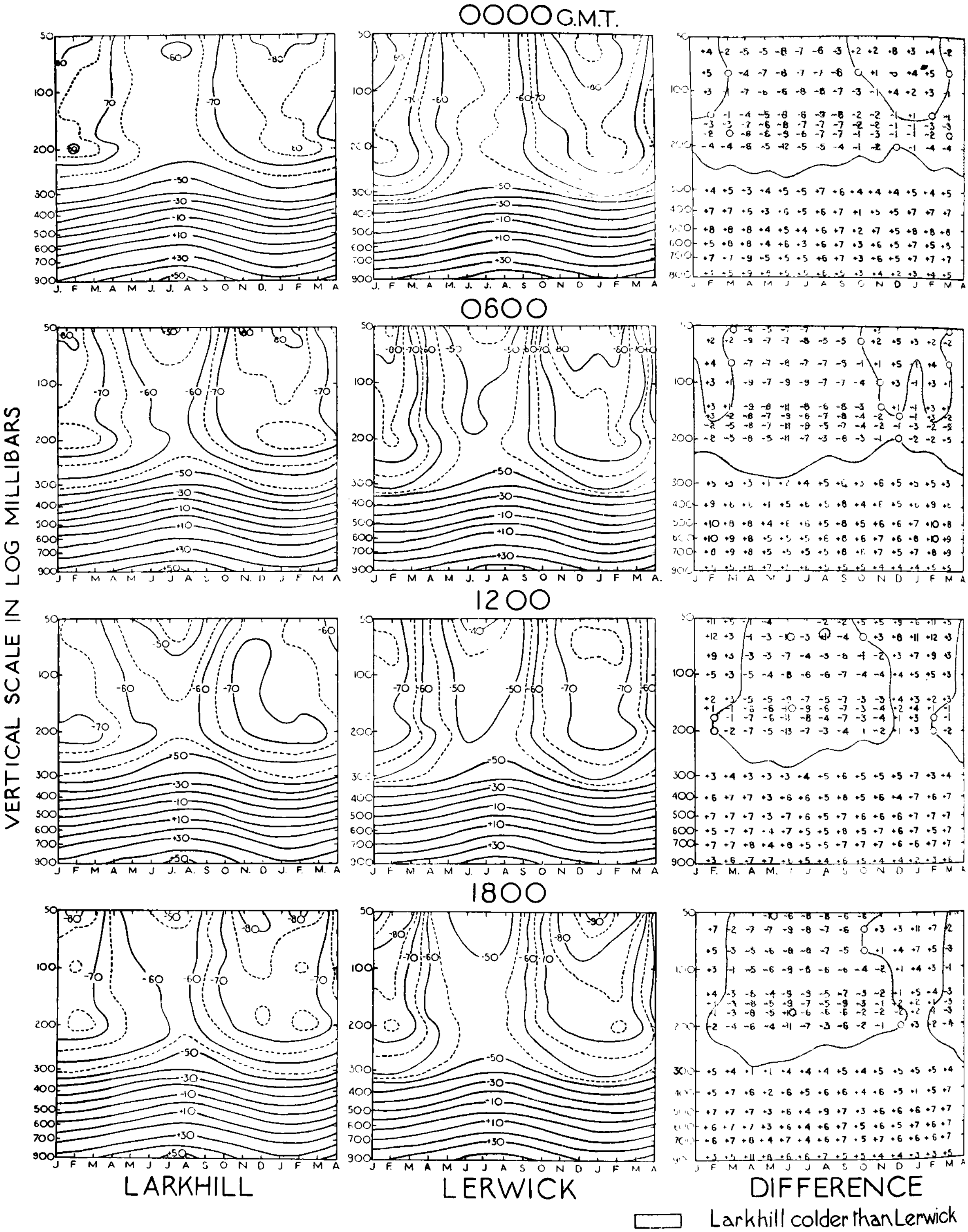

FIG. 3—MEAN MONTHLY TEMPERATURES OVER LARKHILL AND LERWICK, 1942–46
Temperatures in degrees Fahrenheit

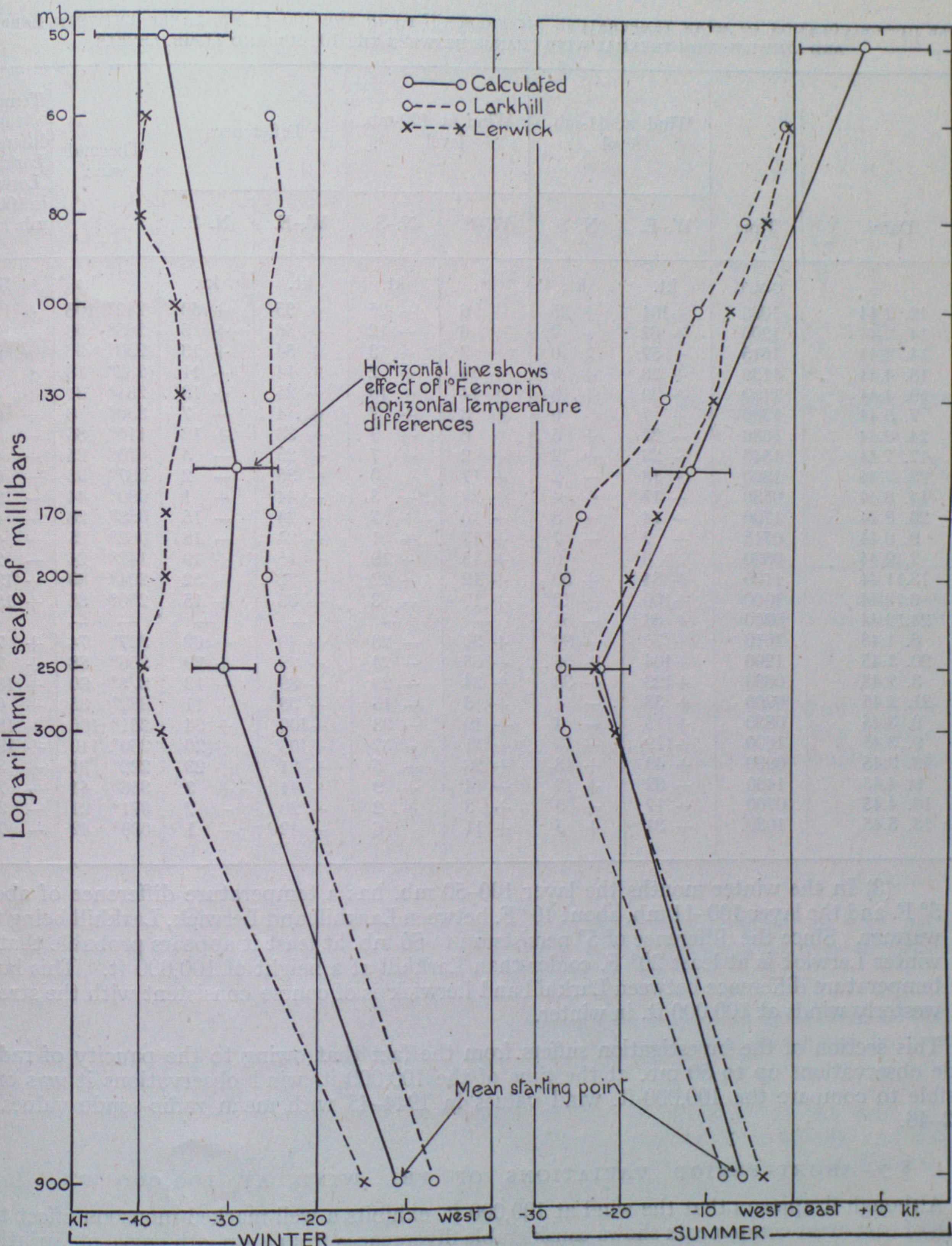

FIG. 4—EAST-WEST COMPONENTS OF VECTOR MEAN WIND FOR LARKHILL AND LERWICK COMPARED WITH EAST-WEST WIND COMPONENTS CALCULATED FROM HORIZONTAL TEMPERATURE DIFFERENCES BETWEEN LARKHILL AND LERWICK

TABLE III—CALCULATION OF MEAN TEMPERATURE DIFFERENCE (° F.) IN THE 100–11 MB. LAYER BETWEEN LARKHILL AND LERWICK FROM THERMAL WIND CHANGE BETWEEN THE 100-MB. AND 11-MB. LEVELS

Date	Time	Wind at 11-mb. level		Wind at 100-mb. level		Differences		Thermal wind	Temperature difference, Larkhill–Lerwick in 100–11 mb. layer
		W.–E.	N.–S.	W.–E.	N.–S.	W.–E.	N.–S.		
	G.M.T.	kt.	kt.	kt.	kt.	kt.	kt.	kt.	°F.
12. 2.44	1030	+101	+ 25	+ 6	− 25	+ 95	+ 50	242° 108	+ 16·6
14. 2.44	1200	+ 62	− 7	+ 6	− 12	+ 56	+ 5	265° 56	+ 10·3
14. 2.44	1615	+ 57	0	+ 3	− 13	+ 54	+ 13	256° 56	+ 9·9
18. 4.44	1130	+ 28	+ 9	+ 14	− 2	+ 14	+ 11	232° 18	+ 2·5
19. 4.44	1130	+ 39	+ 8	+ 14	− 10	+ 25	+ 18	234° 31	+ 4·6
7. 5.44	1300	+ 7	0	+ 3	+ 7	+ 4	− 7	330° 8	+ 0·8
24. 6.44	1630	− 27	+ 5	+ 6	− 7	− 33	+ 12	110° 35	− 6·1
17. 7.44	1545	− 23	+ 2	+ 2	+ 7	− 25	− 5	079° 25	− 4·6
28. 7.44	1800	− 18	− 2	+ 17	0	− 35	− 2	087° 35	− 6·4
14. 8.44	0530	− 17	− 4	+ 27	− 5	− 44	+ 1	090° 44	− 8·1
26. 8.44	1700	− 14	− 8	+ 10	+ 7	− 24	− 15	058° 28	− 4·4
9. 9.44	0715	− 7	− 7	+ 17	+ 1	− 24	− 18	062° 25	− 4·4
2.10.44	0830	0	0	+ 15	− 19	− 15	+ 19	142° 24	− 2·8
13.11.44	1100	+ 84	+ 30	+ 12	− 22	+ 72	+ 52	234° 89	+ 13·3
6.12.44	1000	+100	+ 12	+ 17	− 3	+ 83	+ 15	260° 85	+ 15·2
24.12.44	0900	+ 68	− 51	—	—	—	—	— —	—
6. 1.45	1010	+ 70	− 90	+ 30	− 28	+ 40	− 62	327° 74	+ 7·4
20. 1.45	1200	+104	+ 55	+ 65	− 24	+ 39	+ 79	206° 88	+ 7·2
3. 2.45	0830	+123	− 33	+ 34	− 20	+ 89	− 13	278° 90	+ 16·4
21. 2.45	0900	+ 38	− 4	+ 5	− 15	+ 33	+ 11	252° 35	+ 6·1
9. 3.45	0830	+119	− 4	+ 19	− 38	+100	+ 34	251° 106	+ 18·5
9. 3.45	1600	+119	− 17	+ 11	− 37	+108	+ 20	260° 110	+ 19·9
18. 3.45	0900	+ 49	+ 18	+ 28	− 5	+ 21	+ 23	222° 31	+ 3·9
9. 4.45	1400	− 32	+ 12	− 14	+ 9	− 41	+ 3	356° 41	− 7·5
16. 4.45	0700	− 17	− 5	+ 3	+ 2	− 20	− 7	071° 21	− 3·7
13. 5.45	1030	− 31	+ 5	+ 11	+ 6	− 42	− 1	089° 42	− 7·7

(3) In the winter months the layer 100–50 mb. has a temperature difference of about 5° F. and the layer 100–11 mb. about 10° F. between Larkhill and Lerwick, Larkhill being the warmer. Since the difference of 5° persists up to 50 mb. at least it appears probable that in winter Lerwick is at least 20° F. colder than Larkhill at a height of 100,000 ft. This large temperature difference between Larkhill and Lerwick is of course consistent with the strong westerly winds at 100,000 ft. in winter.

This section of the investigation suffers from the fact that owing to the paucity of radio-sonde observations up to 50 mb. at the time of the 100,000-ft. wind observations it was only possible to compare the 100,000-ft. wind values in 1944–45 with mean radio-sonde values in 1942–46.

§ 7—SHORT-PERIOD VARIATIONS OF THE WIND AT 100,000 FT.

Although it appears that the wind at 100,000 ft. exhibits a well marked monsoon effect the graph of east–west components shows considerable divergences from a smooth curve of variation from summer to winter. An attempt was therefore made to find if some correlation existed between these irregularities and that of meteorological elements at lower levels. The most likely

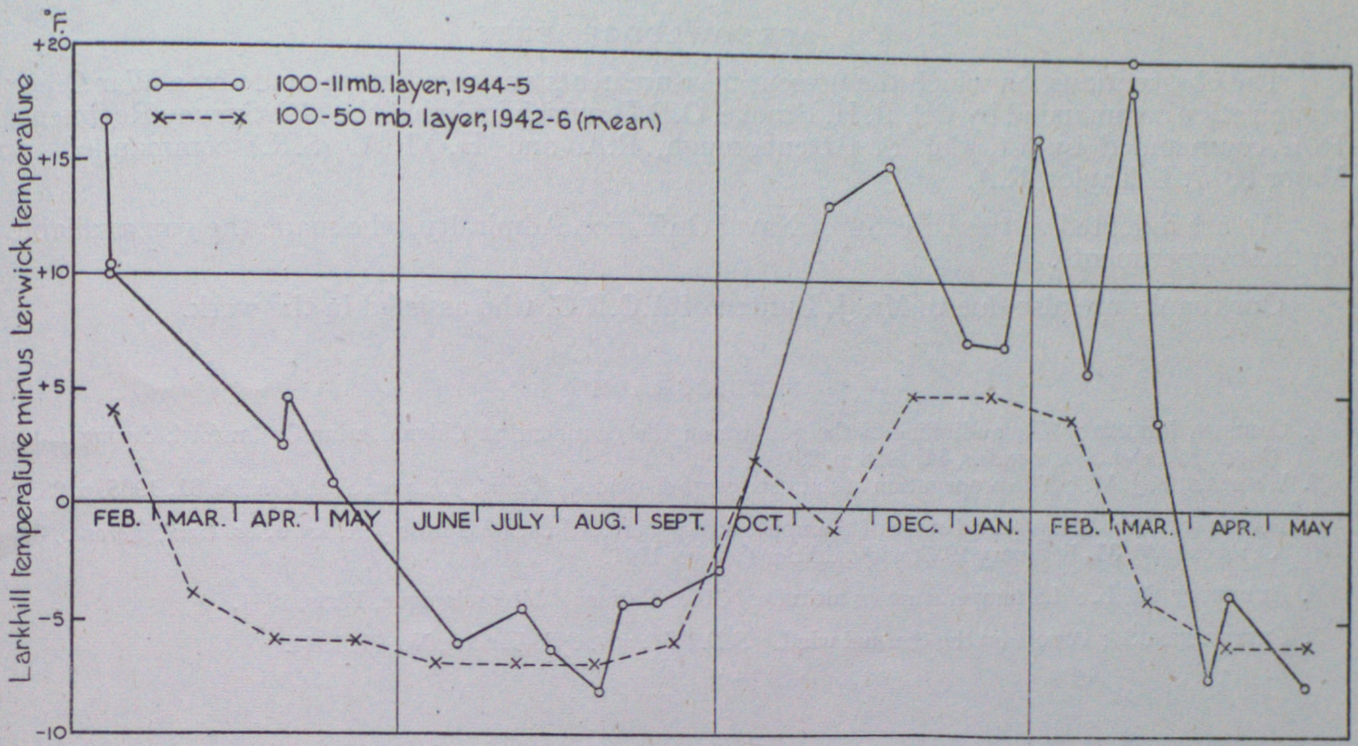

FIG. 5—COMPARISON OF THE MEAN (1942–46) TEMPERATURE DIFFERENCE BETWEEN LERWICK AND LARKHILL IN THE LAYER 100–50 MB. WITH THE TEMPERATURE DIFFERENCE IN THE LAYER 100–11 MB. CALCULATED FROM THE WIND CHANGE BETWEEN 100 AND 11 MB. 1944–45

element to show any correlation was thought to be the wind at 100 mb. or 300 mb. Although the agreement appeared to be striking at some points it was not considered that any definite correlation was obtained. All that can be said is that the wind at 100,000 ft. is probably subject to the same type of short-period variations as that at these lower levels.

§ 8—OTHER INFORMATION ON WINDS AT VERY HIGH LEVELS

Balloon ascents.—There have been very few successful measurements of wind by balloons above heights of about 60,000 ft. As far as is known none of these form a consistent series and so do not allow a comparison to be made with the results above.

Movement of mother-of-pearl clouds.—These clouds are seen occasionally between 60,000 ft. and 100,000 ft. above Scandinavia and Canada. Their drifts have usually shown north-westerly winds with varying velocities at this level in winter.

Movement of meteor trains.—The various series of observations of the drift of meteor trains have produced somewhat contradictory results for winds between 100,000 and 400,000 ft. On the whole it appears likely that the wind is mainly easterly up to about 250,000 ft. and perhaps westerly above this level. The velocities quoted vary considerably.

Movement of noctilucent clouds.—These clouds are seen occasionally at about 250,000 ft. also above Scandinavia and Canada. Their drifts have usually shown easterly or north-easterly winds with greatly varying velocities at this level.

§ 9—ACKNOWLEDGEMENTS

The observations, on which the present measurements are based, were made by a War Office organization commanded by Col. B. H. Brooke, O.B.E., which included the 11th Survey Regiment, R.A. commanded by Lt. Col. S. Attenborough, R.A. and H.Q.R.A. (S.R.) commanded by Major P. W. E. Taylor, R.A.

We are indebted to the Director of Naval Ordnance, Admiralty, who made the gun available for these experiments.

Our thanks are also due to Mr. J. Bunten of A.O.R.G. who assisted in the work.

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