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A COMPARISON BETWEEN THE GEOSTROPHIC WIND, THE SURFACE WIND, AND THE UPPER WINDS DERIVED FROM PILOT BALLOONS, AT VALENTIA OBSERVATORY, Co. KERRY

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A COMPARISON BETWEEN THE GEOSTROPHIC WIND, THE SURFACE WIND, AND THE UPPER WINDS DERIVED FROM PILOT BALLOONS, AT VALENTIA OBSERVATORY, Co. KERRY

By L. H. G. DINES, M.A.

In several previous publications of the Meteorological Office the relations existing between the surface and gradient winds have been discussed, and tables and graphs given relating to particular stations. References to these will be found in the bibliography on p. 12.

The present note aims at a detailed discussion of the same question for Valentia Observatory, including the results of pilot balloon observations, and considered also in relation to data from certain other stations in Ireland. The comparison refers to the period 1917–21, when the writer was stationed at the Observatory.

The surface data were derived from the readings of a Dines pressure tube anemometer exposed in a grass field, with the head at

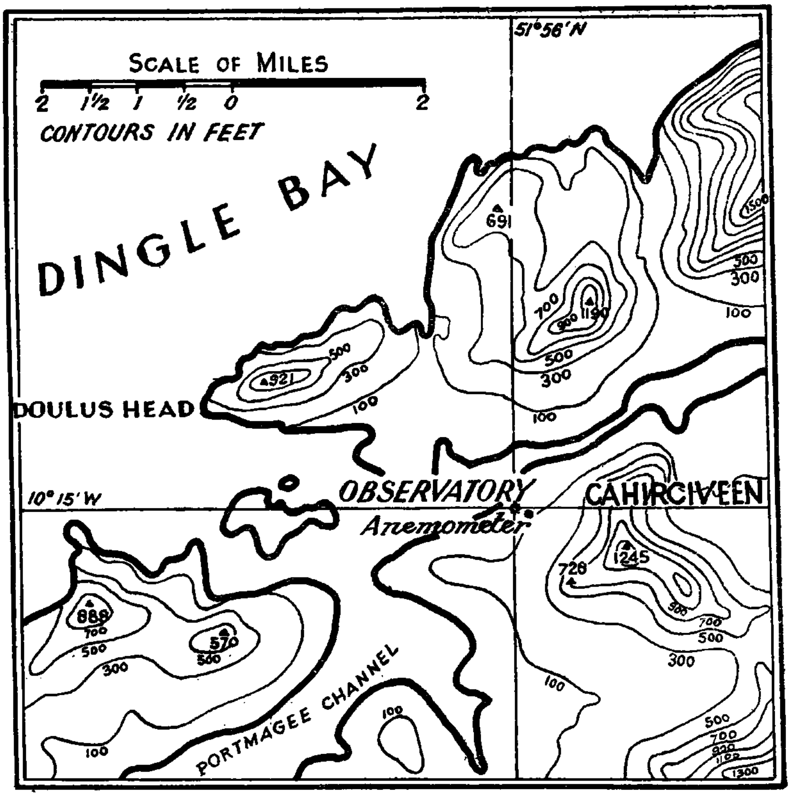

FIG. 1.—MAP OF DISTRICT AROUND VALENTIA OBSERVATORY.

a height of 13 m. above the ground. The position is shown on the map (Fig. 1). As far as immediate local obstructions are concerned the exposure is good, but the locality is surrounded by hills in some directions. Between south-west and west-north-west the obstruction between the site and the open Atlantic is small, but between north-east and south-south-east the country is broken and hilly. Throughout the period concerned the orientation of the direction recorder was regularly checked ; the pressure head also was tested by the National Physical Laboratory, and found to be approximately accurate.

As concerns the surface wind, readings for the hours 1, 7, 13 and 18 G.M.T. were utilised, being those for which synoptic charts were available in the *Daily Weather Report*. The mean wind was read to the nearest 0·1 m/sec. and to the nearest 5° as regards direction, for the hour centred about the epoch chosen ; winds below 1 m/sec. were omitted. The geostrophic wind was determined from the synoptic chart, and every occasion was utilised on which this could reasonably be done. Valentia Observatory being at the western edge of the chart, there were many occasions when it was impossible to determine the geostrophic velocity, but on some of these it was still possible to estimate the geostrophic direction. Unfortunately such difficulties occur more frequently on occasions of light wind, which cause the data to possess selective qualities which will be referred to again later.

Even when definite gradients were indicated on the charts, there were many occasions when it was obvious that they could not pretend to great accuracy. The large mass of data available however reduces the risk of serious casual error in the means.

Two statistical methods of analysis were employed. The data of the first covered a period of about 2 years, in which the surface wind was taken as the standard and the observations were grouped according to direction into sectors of 15° each ; the velocity was further grouped into four ranges, 1 to 5 m/sec., 5·1 to 10 m/sec., 10·1 to 15 m/sec., and 15·1 m/sec. upwards. Winds above 15 m/sec. were so few that they were generally included with the group below. The corresponding geostrophic wind, velocity and direction, or in some cases direction only, was entered alongside in a parallel column. Each range of velocity in each sector was treated separately; the surface wind velocity W and the geostrophic velocity G were each meaned and the ratio of the means is denoted by W/G in the tables. In the case of direction, these were all entered in the form of degrees from north, the two means obtained and the difference between them entered in the tables, with the convention that if the geostrophic wind veered from the surface wind the difference was positive. It was found in a few cases that the individual deviation of the geostrophic wind from the surface wind exceeded 100° ; in this part of the investigation such occasions were omitted altogether.

TABLE I.—THE RELATION BETWEEN THE WIND VELOCITY W GIVEN BY THE PRESSURE TUBE ANEMOMETER AND THE GEOSTROPHIC WIND G FOR SURFACE WINDS OF VARIOUS STRENGTHS

Wind direction by Anemometer	Velocity range by anemometer					
	1·0–5·0 m./sec.		5·1–10·0 m./sec.		10·1 m./sec. upwards	
	Ratio W/G	Deviation	Ratio W/G	Deviation	Ratio W/G	Deviation
°		°		°		°
360	·36	− 21	·77	− 4	·83	− 5
15	·32	− 8	·72	+ 1	·64	0
30	·32	− 15	·64	+ 12	·58	+ 30
45	·37	+ 10	·73	0	·92	+ 32
60	·33	− 19	·66	+ 20	(·69)*	+ 10
75	·42	+ 14	·60	+ 31	(·63)*	+ 40
90	·43	+ 15	·82	+ 34	(·85)*	(+ 35)*
105	·56	+ 24	·58	+ 35	·77	+ 34
120	·32	+ 50	·60	+ 41	·57	+ 37
135	·29	+ 39	·62	+ 31	·47	+ 33
150	·30	+ 40	·51	+ 40	·57	+ 35
165	·40	+ 48	·57	+ 36	·61	+ 34
180	·43	+ 50	·55	+ 37	·53	+ 37
195	·42	+ 33	·48	+ 38	·52	+ 30
210	·34	+ 34	·46	+ 27	·54	+ 28
225	·36	+ 17	·47	+ 28	·54	+ 20
240	·35	+ 25	·45	+ 12	·53	+ 13
255	·32	+ 9	·52	+ 13	·50	+ 10
270	·34	+ 4	·48	+ 4	·44	+ 7
285	·33	+ 6	·49	+ 2	·49	+ 2
300	·42	− 7	·51	− 6	·58	− 18
315	·35	− 15	·50	− 11	·59	− 6
330	·32	− 29	·66	− 8	·62	+ 9
345	·42	− 24	·57	− 7	·63	− 11
Means	·37	..	·58	..	·61	..

* No observations were available. The figures in brackets are estimated by comparison with the preceeding range.

In the second method of analysis the geostrophic wind was taken as the standard. The work was carried out at a later stage than the first method, by which time a great many more observations were available. The period covered was about 3½ years. The geostrophic wind was grouped according to direction into sectors of 15° as before, and the velocity was grouped into three ranges 0 to 10 m/sec., 10·1 to 17 m/sec., and 17·1 m/sec. upwards. On occasions when the geostrophic wind could not be completely determined the whole item was omitted, but all other occasions were included, irrespective of the magnitude of the deviation. As before mean values were

TABLE II.—THE RELATION BETWEEN THE WIND VELOCITY W GIVEN BY THE PRESSURE TUBE ANEMOMETER AND THE GEOSTROPHIC WIND G FOR VARIOUS STRENGTHS OF THE GEOSTROPHIC WIND

Geostrophic Wind Direction	Velocity range of the Geostrophic Wind					
	0–10 m./sec.		10·1–17 m./sec.		17 m./sec. and upwards	
	Ratio W/G	Deviation	Ratio W/G	Deviation	Ratio W/G	Deviation
°		°		°		°
360	·81	− 7	·58	− 8	·62	− 5
15	·68	− 4	·48	0	·52	+ 2
30	·67	+ 2	·62	+ 8	·50	0
45	·64	+ 7	·68	+ 11	·56	+ 28
60	·66	+ 22	·56	+ 17	·42	+ 27
75	·62	+ 14	·55	+ 18	(·48)*	..
90	·63	+ 10	·50	+ 24	(·43)*	..
105	·56	+ 19	·34	+ 35	(·27)*	..
120	·57	+ 24	·55	+ 26	·37	+ 23
135	·46	+ 36	·58	+ 29	·50	+ 23
150	·62	+ 39	·43	+ 41	·42	+ 45
165	·80	+ 26	·44	+ 50	·32	+ 38
180	·60	+ 22	·46	+ 26	·45	+ 34
195	·72	+ 34	·60	+ 25	·46	+ 26
210	·68	+ 42	·59	+ 31	·46	+ 26
225	·54	+ 45	·52	+ 31	·41	+ 26
240	·51	+ 36	·47	+ 28	·41	+ 29
255	·44	+ 24	·45	+ 22	·43	+ 21
270	·44	+ 22	·43	+ 17	·44	+ 18
285	·49	+ 2	·47	+ 7	·42	+ 9
300	·50	− 8	·52	+ 4	·44	+ 6
315	·52	− 9	·49	− 6	·40	+ 5
330	·66	− 12	·55	− 8	·47	+ 3
345	·64	− 7	·54	− 6	·51	− 2
Means	·60	..	·52	..	·45	..

* No observations were available. The figures in brackets are estimated by comparison with the preceeding range.

determined for each range of velocity in each sector, but the method adopted was somewhat different. The geostrophic winds were dealt with by forming arithmetic means of velocity, and of direction expressed in the form of degrees from north. The surface winds were treated as vectors and vector means formed for each subdivision. It may be observed that the means of the geostrophic winds differ little from true vector means, since the range of direction in each sector is small.

The results of the two methods of analysis are given in Tables I and II. In them and in what follows the term " deviation " denotes the angle by which the direction of the geostrophic wind veers from that of the surface wind. A cursory examination of the tables shows that the deviations are much the same in both, but that the mean values of the ratio W/G are widely different.

Considering first the points of resemblance, both tables show a remarkable variation of the deviation as between different wind directions. The greatest value of the deviation occurs with a geostrophic wind from about SSE., and it is possible that this may be a local feature caused by the high ridge of the hill to the south-east of the site. One outstanding feature is the manner in which the direction of the geostrophic wind backs from that of the surface wind in the north-west quadrant and around north ; another feature is that the lowest values of W/G occur with westerly winds. The latter is the more remarkable in that there is little obstruction between the site and the Atlantic Ocean to the west, while on the eastern side the country is systematically hilly.

Both of these peculiar phenomena have been confirmed by comparison with other stations in Ireland. S.P. Wing (3) found that at Ballybunnion on the west coast about 45 miles north-north-east of Cahirciveen the ratio W/G had a much higher value for winds from NNE. than from S., and rather higher than for winds from W.

The manner in which the deviation of the geostrophic wind becomes negative in the north-west quadrant was investigated further, and found to have its counterpart at many Irish stations. Graphs of the deviation of the geostrophic wind for these stations will be found in Fig. 2. The observations at Valentia Island were made by coastguards at the wireless station, the site being a few miles to the west of Cahirciveen. Blacksod Point, Malin Head, Donaghadee and Roches Point are all coast stations, while Birr Castle is in the centre of Ireland. The numbers of observations on which the graphs are based are shown in the small circles. These graphs clearly indicate a systematic tendency which has more than a local significance (4) and (5).

Arising out of this discovery attempts were made to discover by statistical analysis whether any relation could be discovered between the deviation of the geostrophic wind and various other meteorological elements. A limited range of wind direction about NNW. was chosen, and 128 occasions found on which the surface wind exceeded 5 m./sec. Correlation coefficients were then worked out between the deviation at Cahirciveen and the following quantities :—(*a*) the difference of air temperature between Cahirciveen and Roches Point, (*b*) the difference between the air temperature at Cahirciveen and the temperature of the Atlantic, (*c*) the barometric pressure, and (*d*) the barometric tendency. In no case was any significant correlation coefficient found.

The differences between Tables I and II are considerable and not easy to explain, they chiefly concern the ratio W/G. In Table I W/G increases with W, in Table II it decreases with G. It is possible to account for a low value with light winds in Table I by the operation of a selective error previously referred to. Small barometric gradients cannot readily be measured on the maps in the *Daily Weather Report*, and therefore occasions when they occurred were usually rejected ; such small gradients tend to be associated with light

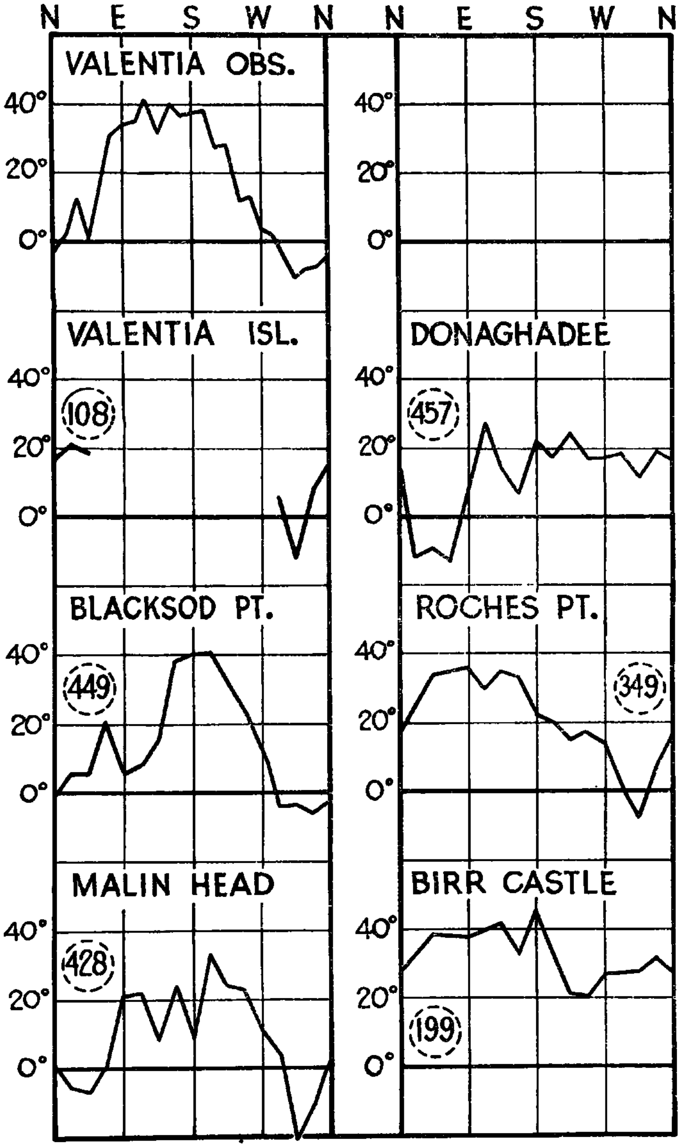

FIG. 2.—DEVIATION PLOTTED AGAINST THE SURFACE WIND DIRECTION FOR TELEGRAPHIC REPORTING STATIONS IN IRELAND.

surface winds, and therefore the mean of W/G based on light surface winds must inevitably be too small. Fairgrieve (6) obtained a similar result, doubtless for the same reason. Another possibility of a physical nature is that a light surface wind may be associated with a low surface temperature and an inversion, with a comparatively large geostrophic wind blowing above. An examination of the data showed that when the surface wind was less than 1 m./sec. there existed on about one occasion in eight a geostrophic wind exceeding 7 m./sec. Table III shows for a limited range of direction at the surface how the individual values of W/G vary within the several ranges of surface velocity.

TABLE III.—FREQUENCIES OF VALUES OF W/G WITH SURFACE WINDS BETWEEN $172\frac{1}{2}°$ AND $202\frac{1}{2}°$

Surface wind between (m./sec.) \ Limits of W/G	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·00 to 1·09	1·10 to 1·19	1·20 to 1·29
1·0 & 5·0	0	15	9	17	7	7	3	2	1	..	..	..
5·1 & 10·0	0	4	28	64	48	35	28	8	4	5	2	1
10·1 & 15·0	0	0	5	19	27	11	8	3	1	0	0	2
>15·1	0	1	0	2	1	..	..	..	..	..	..	..

A special investigation was made into the cases when the surface wind exceeded 15 m./sec. Taking all directions together there were 27 of them, and the mean value of W/G was found to be 0·58. This agrees closely with the middle and upper ranges in Table I, and it is legitimate to conclude that the value of W/G found by the method of analysis under consideration does not, as W increases from 5 m./sec. upwards, differ much from 0·60. By way of comparison S.P. Wing (3) has given figures for Ballybunnion. He found for all wind velocities and directions taken together a mean value of W/G of 0·58. The geographical conditions in the two cases are not very dissimilar.

An attempt was made to discover if there is any relation between the ratio W/G and the deviation of the direction of the geostrophic wind from that of the surface wind. Table IV refers to a limited range of direction and to occasions when the surface wind exceeded 5 m/sec. No entries were made unless at least 8 observations were available. It will be seen that there is little correlation between W/G and the deviation.

Turning to Table II, if the pressure gradient may be regarded as the ultimate cause of the surface wind, then Table II will give the best estimate of the surface wind when the pressure gradient is known. A special investigation was made also in this case when G exceeded 30 m./sec., and it was found that there were 36 cases for all directions taken together with a mean value of W/G of 0·40. In the preparation of the tables no allowance was made for the curvature of the path of the air. Assuming that the air follows the contour of the isobars, the 36 cases referred to above were worked out again and a mean value of 0·50 found for W/G. Since the majority of high winds are associated with cyclonic disturbances and the correction for curvature regarded as a percentage increases with the gradient, it would appear that if corrections were applied in every case the values of W/G in Table II for the range of G from 17 m./sec. upwards would also have been increased, but not by nearly so large an amount. For the lower ranges the effect is inappreciable. The application of the correction for curvature would therefore appreciably smooth out the peculiarities of Table II, leaving a value of about 0·50 for W/G in the middle and upper ranges. There is however no reason why the same correction should not be applied to Table I, with the result that the peculiarities found therein would become worse, and the values of W/G in the upper ranges greater than before.

TABLE IV.—MEAN VALUES OF W/G ASSOCIATED WITH DIFFERENT VALUES OF THE DEVIATION, FOR CERTAIN DIRECTIONS OF THE SURFACE WIND

Deviation / Surface wind direction	− 5 and − 10	Nil.	5 and 10	15 and 20	25 and 30	35 and 40	45 and 50	55 and 60
°								
180	..	..	..	·67	·63	·56	·53	·58
195	..	..	..	·59	·54	·55	·50	·53
210	..	..	·56	·52	·53	·52	·49	..
225	..	..	·48	·52	·58	·50	·53	..
240	·60	..	·52	·51	·54	..	..	..
255	·59	·50	·55	·57	·59	·61	..	..
270	·49	·49	·53	·53	..	..	..	..

It is possible to account for a part of the difference between Tables I and II by allowing for the fact that the magnitude of a vector mean is less than the arithmetic mean of the scalar magnitude of its component vectors. In this particular case a difference of about 5 per cent. is to be expected, so that for comparative purposes we may add 5 per cent. to the values in Table II. So small a correction does little to reconcile the discrepancies between the two tables, which as they stand serve to emphasise the fact that if an attempt is made to determine an average value of the ratio W/G, it is essential to define precisely the conditions under which it is made.

As a supplement to the investigation described above the results of pilot balloon soundings made at the Observatory at about the same time have been analysed by Mr. N. H. Smith, and to him I am indebted for the data of the concluding section of this note.

The soundings were made with a single theodolite, assuming a constant ascensional velocity. They were made at or near the hours of 7 and 18 G.M.T. at all times of the year, and the object aimed at was to compare the winds at different heights with the geostrophic wind. Only those occasions were utilised when a reliable value could be assigned to the latter. A total number of 371 soundings remained, all of which reached a height of at least 2 Km.

The results are classified under three groups according to the maximum height reached by the balloon, namely 2 to 4 Km., 4 to 6 Km. and 6 Km. upwards. The data of a sounding reaching a height between 2 and 4 Km. has been utilised up to 2 Km. but no higher, and similarly with the greater heights. Also those entered in the higher groups have been included in those below.

TABLE V.—MEAN WINDS IN EACH SECTOR AT VARIOUS HEIGHTS, AND THE CORRESPONDING MEAN GEOSTROPHIC WINDS

Sector	NNE.	ENE.	ESE.	SSE.	SSW.	WSW.	WNW.	NNW.
Soundings reaching 2 Km.								
Number	22	68	17	32	35	85	53	59
Height above Ground	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø
m.	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °
13	5·2 18	3·6 63	3·5 97	4·5 126	4·7 193	5·0 242	4·7 308	5·0 352
500	7·2 27	6·7 69	5·3 113	6·9 146	7·7 220	9·1 244	8·4 300	8·5 345
1,000	9·4 19	6·9 69	8·0 126	10·2 148	9·9 222	11·1 251	10·8 303	10·0 345
2,000	9·2 19	7·7 62	8·5 120	7·9 142	10·7 237	11·3 251	13·0 297	11·5 339
Geostrophic velocity and direction ..	9·4 30	7·9 72	6·9 117	7·6 161	9·7 216	11·4 252	11·1 296	9·8 341
Soundings reaching 4 Km.								
Number	12	40	4	15	7	20	13	11
Height above Ground	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø
m.	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °
13	4·8 23	3·1 67	3·3 123	3·3 127	4·9 164	4·1 249	3·2 326	2·2 8
500	6·8 33	5·5 79	5·2 115	6·5 152	6·1 230	6·6 238	4·4 288	5·1 14
1,000	7·9 21	5·9 77	5·9 120	7·8 151	6·9 217	8·4 253	6·9 308	6·7 11
2,000	8·8 14	6·3 67	6·2 100	6·8 130	7·6 272	11·0 261	8·1 302	7·3 350
3,000	9·3 6	7·8 57	8·2 109	6·0 152	8·2 267	12·8 264	11·0 297	9·7 348
4,000	10·8 347	8·8 53	6·7 101	9·3 124	9·9 292	15·2 264	14·5 298	11·7 348
Geostrophic velocity and direction ..	8·6 34	7·8 75	7·0 126	6·3 159	9·0 216	9·2 252	7·2 291	6·9 349
Soundings reaching 6 Km.								
Number	5	23	2	9	0	3	3	3
Height above Ground	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø	*V* ø
m.	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °	m/sec. °
13	3·7 326	2·9 66	2·8 113	3·5 135	.. ..	1·9 341	0·9 13	2·5 3
500	6·1 345	5·4 83	5·8 113	6·3 146	.. ..	3·8 216	1·7 296	4·3 57
1,000	8·9 328	5·8 76	4·8 133	6·5 144	.. ..	4·8 236	8·4 296	4·4 60
2,000	8·2 324	6·7 75	6·2 90	6·1 141	.. ..	5·1 285	7·8 296	3·0 20
3,000	6·3 317	7·9 64	6·8 93	6·0 144	.. ..	10·6 291	11·8 305	4·4 20
4,000	11·1 290	8·4 60	7·2 67	7·9 141	.. ..	18·6 293	15·7 300	3·8 7
5,000	13·8 293	8·9 54	7·3 75	8·5 134	.. ..	26·3 293	20·5 303	4·4 312
6,000	20·3 279	9·8 37	8·0 67	9·6 127	.. ..	29·5 296	27·2 321	9·8 8
Geostrophic velocity and direction ..	8·6 340	7·9 73	6·5 130	6·7 163	.. ..	6·3 248	7·0 293	6·3 350

Each height group is subdivided according to the direction of the geostrophic wind, and for this purpose eight sectors of 45° have been taken. The first extends from 0 to 45° and is designated NNE., and so on. The data are set out in Table V, where the means of velocity *V* and direction ø are set out in parallel columns for each sector, with the number of observations (at the top) and the corresponding means for the geostrophic wind and surface wind by the anemometer.

It is necessary to remember in dealing with pilot balloon data of this kind, first that the stronger the wind the less the height to which the balloon can be followed; secondly that when the balloon springs a leak, fictitiously high wind velocities are likely to be recorded. Therefore the means of velocity at the lower heights in any group are lower than the true means, while the means at the upper heights in the higher groups are liable to uncertain error both positive and negative and need to be treated with great caution.

Considering the directions first, the tables show that with geostrophic winds between N. and S. through E. the directions do not show any very striking features, though neither do they show the type of approach to the geostrophic direction which would be expected on theoretic grounds. In the west-south-west sector the 2 Km. group has a normal type of variation with height, but from between W. and N. there is a systematic tendency for the wind to back from the surface upwards.

In regard to the velocities two points call for comment. In the south-south-east sector the wind velocity decreases as between 1 and 2 Km.; this is probably due to vertical currents caused by the local hills, which, with the assumption of a constant vertical velocity of the balloon, are capable of producing systematic errors in the calculation of velocity in the sectors involved. It was frequently noticed with south-easterly winds that the elevation of the balloon was abnormally low soon after the start, followed by a recovery later. The high velocities at the higher levels with westerly winds are based on a small number of soundings, and it seems almost certain that a few cases of leaking balloons have artificially inflated the computed velocities.

Table VI is summarised from Table V and shows the variations of velocity and direction with height for all directions taken together, referred to geostrophic wind as the standard. The same nomenclature is employed as in Tables I and II, but here *W* refers to winds at other levels besides the surface. The general result seems to be that the geostrophic velocity is reached at a height of about 900 m. for all wind directions. The approach to the geostrophic direction is not so readily summarised since it varies greatly with different directions, but on the whole it appears that the geostrophic direction is reached at a height rather greater than 900 m. The outstanding peculiarity is the way in which between west and north the winds veer from the geostrophic direction.

TABLE VI.—MEAN VARIATION OF VELOCITY AND DIRECTION WITH HEIGHT, FOR ALL DIRECTIONS OF THE GEOSTROPHIC WIND TAKEN TOGETHER

Height above Ground	371 soundings reaching 2 Km.		122 soundings reaching 4 Km.	
	W/G	Deviation	*W/G*	Deviation
m.		°		°
13	·49	11	·46	7
500	·81	3	·75	− 1
1,000	1·05	0	·92	− 2
2,000	1·08	2	1·00	1
3,000	..	..	1·18	0
4,000	..	..	1·41	4
Mean geostrophic velocity ..	9·6 m/sec.		7·8 m/sec.	

Conclusion.—The value of the ratio *W/G* for Valentia Observatory has been exhaustively tabulated, but the results are rather difficult to understand in spite of the abundant data available. The conclusion reached is that if an attempt is made to evaluate such a " constant " for a station, it is necessary to know precisely the conditions under which the analysis is made.

The value of the ratio has been shown to vary with direction, but surface obstruction of the air flow does not appear to be the important factor.

The deviation of the geostrophic wind from the surface wind has been shown to vary with direction in a remarkable manner. Particularly, the geostrophic wind backs from the surface wind in the north-west quadrant, and a somewhat similar phenomenon has been found to exist at all the coast stations in Ireland.

A study of the upper winds has shown that the geostrophic velocity from all directions is reached at about 900 m.; the geostrophic direction is reached at a rather greater height, but with less consistency.

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(42870) Wt. 1214/813 625 11/38 Hw. G. 371 S.O. Code No. 40–9999