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THE VARIATION OF WIND

WITH

PLACE.

BY

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THE VARIATION OF WIND WITH PLACE.

BY CAPTAIN J. DURWARD, M.A.

1. A question often asked by those who have to allow for meteorological conditions is, "How does the wind measured at one place compare with the wind measured at another place?" or "In what area does the wind measured at a place agree with the wind measured at another place in the area to within 5 ft./s. or to within 5 per cent.?" Thus, a gunner wants to know how accurate the Meteorological Reports are which may have to be computed at some distance from his battery; and an airman wants to know the changes which may be expected within a certain radius of his aerodrome. It is with the object of endeavouring to answer these questions that the following investigation was undertaken.

2. **Preliminary Investigation.**—In order to answer the question as to the accuracy of "Meteor" reports to artillery, the winds measured during 1918 at the same time at Hazebrouck and Bernaville (two stations in N.E. France about 50 miles apart) were extracted, and it was found that for heights between 2,000 feet and 10,000 feet the winds measured agreed in about 70 per cent. of cases to within 5 ft./s., and in about 90 per cent. of cases to within 10 ft./s.; so that, on the average, the errors arising from the neglect of the variation with place are comparable with those arising from other causes.

3. In order to investigate the question in greater detail, the results for seven stations along the British Front in France were treated as follows. One station was adopted as a standard as regards wind direction, and the winds at the other six places were resolved along and at right angles to the wind direction at the standard station. The winds over the area are thus resolved into components along (following wind) and at right angles to (cross wind) a certain direction, the object being to see whether the agreement is closer in the case of the following wind or in the case of the cross wind.

The stations selected are as follows:—

| <i>Station.</i> | <i>Distance from 1 in miles.</i> | <i>Height above M.S.L. (Metres)</i> |
|----------------------------|--------------------------------------|---|
| 1. Vogeltje (Standard) ... | — | 35 |
| 2. Hazebrouck ... | 13 | 45 |
| 3. Aire ... | 19 | 20 |
| 4. Camblain L'Abbe ... | 35 | 125 |
| 5. Noyelle Vion ... | 41 | 140 |
| 6. Montreuil ... | 51 | 60 |
| 7. Bernaville ... | 57 | 140 |

A map showing the relative positions of these stations is given below.

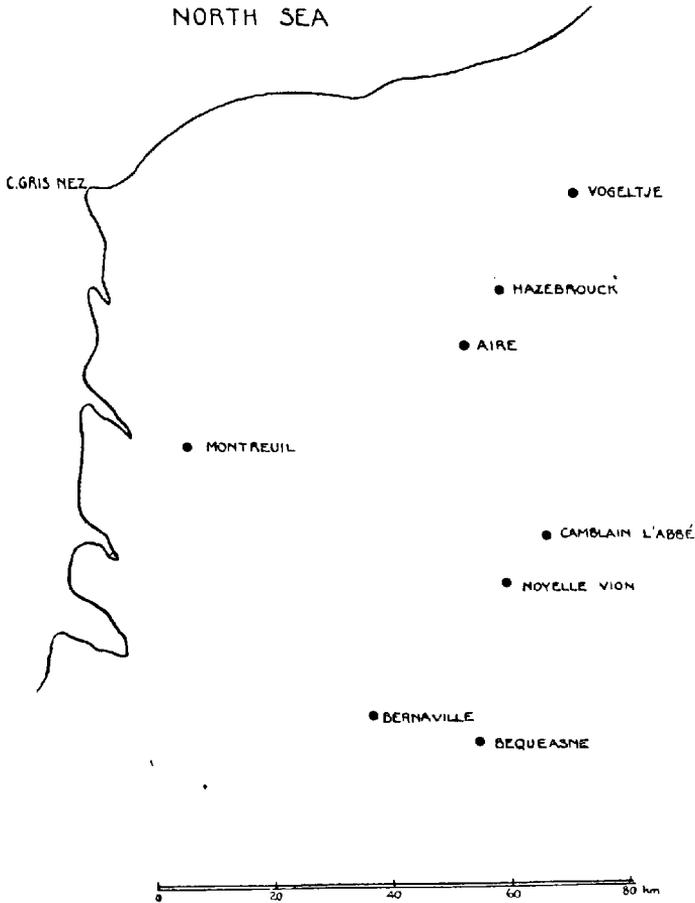


FIG. 1.

Results for these places are available from May, 1918, to September, 1918. From September onwards other stations had to be substituted for Bernaville, but the distance from the standard station was maintained approximately constant.

The wind velocities were written down for heights of 2,000, 4,000, 6,000 and 10,000 feet whenever possible; but, of course, balloons were not followed to the same height at each station and breaks must necessarily occur in the continuity of observation.

4. Agreement within Limits of Velocity.—Considering, first of all, all measurements of wind made at each station, taking the differences from the wind velocity at the standard station, and arranging the differences according as they lie within the limits 0.5 ft./s., 6-10 ft./s., > 10 ft./s., we have the results as given in Table I. In this table the percentages in ordinary type refer to the following component, those in heavy type to the cross component.

TABLE I.—PERCENTAGE OF CASES OF AGREEMENT WITHIN THE LIMITS OF 0-5 ft/s, 6-10 ft/s, > 10 ft/s.

| Station. | 2,000. | | | No. of Cases. | 4,000. | | | No. of Cases. | 6,000. | | | No. of Cases. | 10,000. | | | No. of Cases. |
|----------|----------|----------|----------|---------------|----------|----------|----------|---------------|----------|----------|----------|---------------|----------|----------|---------|---------------|
| | 0-5. | 5-10. | > 10. | | 0-5. | 5-10. | > 10. | | 0-5. | 5-10. | > 10. | | 0-5. | 5-10. | > 10. | |
| 2 | 72 82 | 20 15 | 8 3 | 515 | 71 77 | 21 19 | 8 4 | 497 | 73 82 | 16 17 | 11 1 | 337 | 81 84 | 16 11 | 3 5 | 90 |
| 3 | 63 73 | 25 20 | 12 7 | 490 | 66 69 | 26 23 | 8 8 | 452 | 68 75 | 21 19 | 11 6 | 308 | 76 69 | 20 20 | 4 2 | 96 |
| 4 | 57 66 | 33 28 | 10 6 | 484 | 56 62 | 28 27 | 16 11 | 438 | 54 62 | 32 28 | 14 10 | 281 | 56 61 | 32 31 | 12 8 | 84 |
| 5 | 49 65 | 30 26 | 21 9 | 457 | 57 62 | 25 29 | 18 9 | 383 | 56 60 | 27 23 | 17 17 | 219 | 63 63 | 31 29 | 6 8 | 49 |
| 6 | 56 62 | 30 29 | 14 9 | 457 | 52 56 | 34 27 | 14 17 | 398 | 55 54 | 30 32 | 15 14 | 264 | 60 69 | 34 23 | 6 8 | 64 |
| 7 | 48 57 | 31 25 | 21 16 | 462 | 47 58 | 32 29 | 21 13 | 417 | 49 54 | 32 28 | 19 18 | 274 | 61 59 | 31 34 | 8 7 | 80 |

Considering the percentage of cases in which the agreement is within 5 ft./s., we see:—

(a) The values decrease with distance, as would be expected. Thus, at 2,000 feet in 72 per cent. of occasions the wind at a given place is within 5 ft./s. of the component of the wind in the same direction at a place about 13 miles away, and in 82 per cent. of occasions the cross component at the latter place will not exceed 5 ft./s. At a distance of 57 miles these percentages are reduced to 48 and 57 respectively.

(b) There is very little difference in the values of the percentages with increase of height up to 6,000 feet. At 10,000 feet, with a comparatively small number of observations, the figures for the following component are slightly higher, indicating better agreement in the winds measured at that height.

(c) The decrease in the percentages is not exactly regular. Apart from the fact that the number of observations is different for each station, there are irregularities introduced by the different exposures of the stations. Thus, stations No. 1 and 3 are low-lying, Nos. 4, 5, 7 are much higher; also, station No. 6 is very near a coast line running North and South and land and sea breezes will materially affect the general wind current. Roughly speaking, we may say that for heights between 2,000 and 6,000 feet the 50 per cent. zone of agreement within 5 ft./s. has a radius of 55 miles in the case of the following component; and in the case of the cross component the 55 per cent. zone will have the same radius.

In Table II. the same thing is given, but the number of observations on which the percentages are based is the same for each station.

TABLE II.—PERCENTAGE OF CASES OF AGREEMENT WITHIN THE LIMITS OF 0-5 ft/s, 6-10 ft/s, > 10 ft/s.

| Station. | 2,000. | | | No. of Cases. | 4,000. | | | No. of Cases. | 6,000. | | | No. of Cases. | 10,000. | | | No. of Cases. |
|----------|----------|----------|----------|---------------|----------|----------|----------|---------------|----------|----------|----------|---------------|----------|----------|---------|---------------|
| | 0-5. | 6-10. | > 10. | | 0-5. | 6-10. | > 10. | | 0-5. | 6-10. | > 10. | | 0-5. | 6-10. | > 10. | |
| 2 | 74 83 | 18 13 | 8 4 | 350 | 77 77 | 17 19 | 6 4 | 255 | 80 89 | 13 10 | 7 1 | 105 | 79 86 | 21 7 | 0 7 | 14 |
| 3 | 67 74 | 24 21 | 9 5 | 350 | 67 73 | 25 20 | 6 7 | 255 | 72 77 | 20 16 | 8 7 | 105 | 79 93 | 21 7 | 0 0 | 14 |
| 4 | 54 65 | 31 28 | 15 7 | 350 | 57 65 | 27 24 | 16 11 | 255 | 56 62 | 30 27 | 14 11 | 105 | 43 56 | 43 7 | 14 7 | 14 |
| 5 | 54 65 | 28 24 | 18 11 | 350 | 56 61 | 27 27 | 17 12 | 255 | 55 62 | 25 25 | 20 13 | 105 | 79 64 | 14 22 | 7 14 | 14 |
| 6 | 58 65 | 28 23 | 14 12 | 350 | 55 59 | 35 25 | 10 16 | 255 | 61 62 | 25 24 | 14 14 | 105 | 50 71 | 43 22 | 7 7 | 14 |
| 7 | 52 61 | 30 24 | 18 15 | 350 | 49 56 | 33 28 | 18 16 | 255 | 50 52 | 31 25 | 19 23 | 105 | 79 57 | 21 43 | 0 0 | 14 |

These figures agree very closely with those in Table I. For the following component in the column 0-5 ft./s. the figures are slightly greater for the shorter distances than the corresponding figures in Table I. ; but the 50 per cent. zone is again reached at about 55 miles in the case of the following component and at a greater distance in the case of the cross component. For the height of 10,000 feet the number of observations is small and the figures are irregular.

5. **Average Velocities.**—In Table III. the average wind velocities are given for the same number of observations as in Table II. ; in the case of Stations 2-7, the figure given first refers to the following component, and the other to the cross component.

TABLE III.—AVERAGE WIND VELOCITIES.

| Height. | No. of Cases. | 1. | | 2. | | 3. | | 4. | | 5. | | 6. | | 7. | |
|---------|---------------|------|------|-----|------|-----|------|-----|------|-----|------|-----|------|-----|----|
| | | 1. | 2. | 1. | 2. | 1. | 2. | 1. | 2. | 1. | 2. | 1. | 2. | 1. | 2. |
| 2,000 | 350 | 22.9 | 23.4 | 3.3 | 22.7 | 3.9 | 23.0 | 4.8 | 22.8 | 5.0 | 22.9 | 5.2 | 22.6 | 5.5 | |
| 4,000 | 255 | 23.0 | 24.0 | 3.7 | 22.6 | 4.1 | 22.4 | 5.1 | 22.5 | 5.3 | 23.3 | 5.7 | 21.8 | 6.0 | |
| 6,000 | 105 | 22.1 | 21.9 | 3.1 | 22.0 | 4.0 | 20.7 | 4.4 | 20.3 | 5.5 | 20.6 | 5.8 | 19.3 | 7.1 | |
| 10,000 | 14 | 17.6 | 16.6 | 2.9 | 15.6 | 2.7 | 17.9 | 4.7 | 17.1 | 4.2 | 16.5 | 5.2 | 17.0 | 4.8 | |

It can thus be seen that the following components are, on the average, in close agreement. At 2,000 feet the greatest difference from Station 1 is 0.5 ft./s.; at 4,000 feet, 1.2 ft./s.; at 6,000 feet, 2.8 ft./s.; and at 10,000 feet, 2.0 ft./s. This represents approximately agreement to within 2 per cent., 5 per cent., 12 per cent., 11 per cent. At 4,000 and 6,000 feet the greatest differences occur at the greatest distance away.

The average value of the cross component increases with distance, at first quickly and then more slowly. At 2,000 feet, for instance, the average cross component of the wind 13 miles away is about 14 per cent. of the velocity at Station 1; at 57 miles it is about 24 per cent.

6. **Vector Changes.**—If $A_1B_1, A_1B_2, A_1B_3,$ etc. (fig. 2) represent the wind velocity in magnitude and direction at stations 1, 2, 3, etc., the average values of $B_1B_2, B_1B_3,$ etc., in ft./s., and of the angles $B_1\hat{A}_1B_2, B_1\hat{A}_1B_3,$ etc., in degrees, are as follows:—

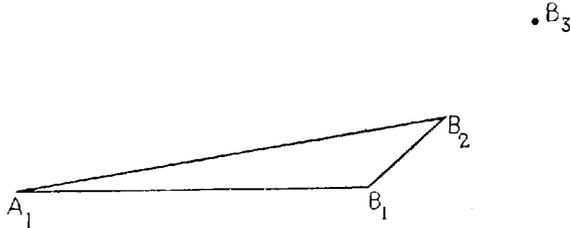


FIG. 2.

TABLE IV.—VECTOR CHANGES FROM STATIONS 1—2, 1—3, ETC., FOR GIVEN HEIGHTS.

| Height. | 1—2. | | 1—3. | | 1—4. | | 1—5. | | 1—6. | | 1—7. | |
|---------|----------|--------------------------|----------|--------------------------|----------|--------------------------|----------|--------------------------|----------|--------------------------|----------|--------------------------|
| | B_1B_2 | $\angle B_1\hat{A}_1B_2$ | B_1B_3 | $\angle B_1\hat{A}_1B_3$ | B_1B_4 | $\angle B_1\hat{A}_1B_4$ | B_1B_5 | $\angle B_1\hat{A}_1B_5$ | B_1B_6 | $\angle B_1\hat{A}_1B_6$ | B_1B_7 | $\angle B_1\hat{A}_1B_7$ |
| 2,000 | 3.3 | 8 | 3.9 | 10 | 4.8 | 12 | 5.0 | 12 | 5.2 | 13 | 5.5 | 14 |
| 4,000 | 3.8 | 9 | 4.1 | 10 | 5.1 | 13 | 5.3 | 13 | 5.7 | 14 | 6.4 | 15 |
| 6,000 | 3.1 | 8 | 4.0 | 10 | 4.6 | 12 | 5.7 | 15 | 6.0 | 15 | 7.5 | 20 |
| 10,000 | 3.1 | 10 | 3.4 | 10 | 4.7 | 15 | 4.2 | 14 | 4.8 | 16 | 5.3 | 18 |

The average values of B_1B_2 will be very nearly the same as the average values of the cross component of the wind's velocity, and they will increase slowly with distance after about 20 miles. The angles $B_1\hat{A}_1B_2, B_1\hat{A}_1B_3,$ etc., increase slowly after the same distance.

TABLE V.—VECTOR CHANGES WITH PLACE FOR DIFFERENT RANGES OF WIND VELOCITY.

| Height. | Velocity at Station 1. | B_1B_2 | $\hat{A}_{B_1B_2}$ | B_1B_3 | $\hat{A}_{B_1B_3}$ | B_1B_4 | $\hat{A}_{B_1B_4}$ | B_1B_5 | $\hat{A}_{B_1B_5}$ | B_1B_6 | $\hat{A}_{B_1B_6}$ | B_1B_7 | $\hat{A}_{B_1B_7}$ | No. of Cases. |
|---------|------------------------|----------|--------------------|----------|--------------------|----------|--------------------|----------|--------------------|----------|--------------------|----------|--------------------|---------------|
| | | | | | | | | | | | | | | |
| 2,000 | < 10 ft/s | 4·3 | 22 | 4·4 | 26 | 5·8 | 32 | 5·8 | 30 | 6·5 | 34 | 6·7 | 31 | 45 |
| | 11-20 " | 2·8 | 9 | 3·6 | 12 | 4·8 | 15 | 5·3 | 16 | 5·2 | 17 | 5·0 | 16 | 128 |
| | 21-40 " | 3·5 | 7 | 4·1 | 8 | 5·1 | 10 | 5·1 | 10 | 5·1 | 11 | 5·7 | 12 | 143 |
| | > 40 " | 4·0 | 5 | 4·6 | 5 | 5·5 | 6 | 7·1 | 6 | 5·6 | 6 | 7·5 | 8 | 34 |
| 4,000 | < 10 ft/s | 4·4 | 25 | 5·0 | 28 | 5·5 | 30 | 5·7 | 29 | 6·0 | 32 | 6·1 | 30 | 37 |
| | 11-20 " | 3·4 | 12 | 3·6 | 13 | 4·8 | 17 | 4·9 | 18 | 5·1 | 18 | 5·5 | 19 | 80 |
| | 21-40 " | 3·6 | 7 | 4·3 | 8 | 5·2 | 10 | 5·7 | 11 | 5·8 | 11 | 7·1 | 14 | 120 |
| | > 40 " | 6·0 | 6 | 5·1 | 6 | 6·8 | 8 | 6·8 | 6 | 7·8 | 9 | 8·0 | 9 | 17 |
| 6,000 | < 10 ft/s | 3·3 | 18 | 4·1 | 21 | 5·4 | 30 | 4·8 | 27 | 5·2 | 31 | 6·8 | 38 | 25 |
| | 11-20 " | 2·6 | 9 | 3·5 | 12 | 5·2 | 19 | 4·8 | 15 | 4·5 | 16 | 6·4 | 23 | 31 |
| | 21-40 " | 3·9 | 7 | 4·5 | 9 | 5·8 | 11 | 6·7 | 13 | 7·4 | 14 | 8·1 | 16 | 36 |
| | > 40 " | 7·2 | 4 | 7·3 | 7 | 9·2 | 9 | 13·3 | 12 | 10·7 | 11 | 16·5 | 17 | 13 |

TABLE VI.—AVERAGE DIFFERENCES EXPRESSED AS PERCENTAGES OF THE WIND VELOCITY AT STATION 1.

| Height. | Velocity at Station 1. | Maximum Difference in the following component (as percentage). | Cross components at various distances as percentages of the wind at Station 1. | | | | | |
|---------|------------------------|--|--|----|----|----|----|----|
| | | | Miles. | | | | | |
| | | | 13 | 19 | 35 | 41 | 51 | 57 |
| 2,000 | 11-20 ft/s | 12 | 18 | 22 | 29 | 32 | 33 | 31 |
| | 21-40 " | 5 | 13 | 14 | 18 | 18 | 18 | 20 |
| | > 40 " | 12 | 8 | 9 | 10 | 10 | 10 | 13 |
| 4,000 | 11-20 ft/s | 3 | 21 | 23 | 31 | 32 | 33 | 35 |
| | 21-40 " | 11 | 12 | 14 | 17 | 19 | 20 | 21 |
| | > 40 " | 9 | 11 | 10 | 13 | 10 | 16 | 15 |
| 6,000 | 11-20 ft/s | 11 | 17 | 22 | 33 | 30 | 30 | 40 |
| | 21-40 " | 13 | 13 | 15 | 18 | 21 | 23 | 24 |
| | > 40 " | 9 | 5 | 11 | 14 | 16 | 16 | 22 |

