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A STATISTICAL STUDY OF THE VARIATION OF WIND WITH HEIGHT

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A STATISTICAL STUDY OF THE VARIATION OF WIND WITH HEIGHT

By C. S. Durst, B.A.

Summary.—The variation of wind with height is examined by means of vector correlation coefficients in a similar manner to the variation of wind with distance and time published in *Geophysical Memoirs* No. 93.

The correlation coefficients are given for the British Isles up to 100,000 ft., for Habbaniya up to 40,000 ft. as indicating the conditions in middle latitudes, for Nairobi indicating conditions in the tropics and for Barrow, Alaska, indicating conditions in the far north.

In *Geophysical Memoirs* No. 93[1]* the discussion centres round the variation of wind with time and distance. The variation with height was originally included but, for various reasons, was excluded from that publication. Since then, Graystone[2] has given some correlation coefficients between winds at two heights, and others have been given by Ellison and Walshaw[3].

In dealing with winds it is possible to resolve the observed winds at any level into components $U + u$ and $V + v$ (where U and V are the mean of a large number of occasions), and then correlate the components at two heights thus forming two coefficients. Alternatively it is possible to use the vector correlation technique which gives a coefficient in some ways easier to use.

It is desired to find that wind at height b which is most likely to be associated with a given wind at height a. It is supposed that we know the mean vector winds at both heights. The desired wind at height b is $\overline{\mathbf{V}}_b + \mathbf{v}_b$ and the observed wind at height a is $\overline{\mathbf{V}}_a + \mathbf{v}_a$. It is supposed that $|\mathbf{v}_b|$ is equal to $R|\mathbf{v}_a|$ and that $\mathbf{v}_b$ is turned through an angle ϕ from $\mathbf{v}_a$. Then to find the most probable values of R and ϕ we have to minimize the sum

$$\Sigma\{|\mathbf{v}_b|^2 + R^2|\mathbf{v}_a|^2 - 2R|\mathbf{v}_a|\,|\mathbf{v}_b|\cos(\theta_{ab} - \phi)\}$$

taken over the available observations of $\mathbf{v}_a$ and $\mathbf{v}_b$. θ_{ab} is the angle between $\mathbf{v}_a$ and $\mathbf{v}_b$. The values of R and ϕ which make the sum a minimum are found in the usual way by equating to zero the partial differential coefficients of the sum with respect to R and ϕ. This gives at once

$$\tan\phi = \frac{\Sigma|\mathbf{v}_a|\,|\mathbf{v}_b|\,\sin\theta_{ab}}{\Sigma|\mathbf{v}_a|\,|\mathbf{v}_b|\,\cos\theta_{ab}},$$

$$R = \sqrt{\{(\Sigma|\mathbf{v}_a|\,|\mathbf{v}_b|\,\sin\theta_{ab})^2 + (\Sigma|\mathbf{v}_a|\,|\mathbf{v}_b|\,\cos\theta_{ab})^2\}}/\Sigma|\mathbf{v}_a|^2.$$

In the same way as in scalar correlation the total vector correlation coefficient r_{ab} is taken to be $R\sigma_a/\sigma_b$, where σ_a is written for $\sqrt{\{(\Sigma|\mathbf{v}_a|^2)/(n-1)\}}$ and σ_b for $\sqrt{\{(\Sigma|\mathbf{v}_b|^2)/(n-1)\}}$, and so

$$r_{ab} = \frac{\sqrt{\{(\Sigma|\mathbf{v}_a|\,|\mathbf{v}_b|\,\cos\theta_{ab})^2 + (\Sigma|\mathbf{v}_a|\,|\mathbf{v}_b|\,\sin\theta_{ab})^2\}}}{(n-1)\,\sigma_a\,\sigma_b}.$$

The associated quantities

$$r_{ab}' = \frac{\Sigma|\mathbf{v}_a|\,|\mathbf{v}_b|\,\cos\theta_{ab}}{(n-1)\sigma_a\,\sigma_b},$$

$$r_{ab}'' = \frac{\Sigma|\mathbf{v}_a|\,|\mathbf{v}_b|\,\sin\theta_{ab}}{(n-1)\sigma_a\,\sigma_b}$$

* The index numbers refer to the bibliography on p. 11.

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are termed respectively the coefficients of simple stretch and simple turn. It will be noted that

$$r_{ab}{}^2 = (r_{ab}{}')^2 + (r_{ab}{}'')^2 \, .$$

The regression equation connecting $\mathbf{v}_b$ and $\mathbf{v}_a'$ can be written

$$\mathbf{v}_b = \frac{\sigma_b}{\sigma_a} r_{ab} \, \psi_\phi \, . \, \mathbf{v}_a \, ,$$

where ψ_ϕ is the linear vector operator, expressible in the matrix form

$$\begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix},$$

which denotes that the vector $\mathbf{v}_b$ is rotated positively through the angle ϕ from the vector $\mathbf{v}_a$. The graphical solution of this regression equation when $r_{ab}{}'' = 0$ is illustrated in Fig. 1 where OA represents the vector $\mathbf{V}_a$ on a particular occasion, OA′ represents the average $\overline{\mathbf{V}}_a$ and OB′ represents the average $\overline{\mathbf{V}}_b$.

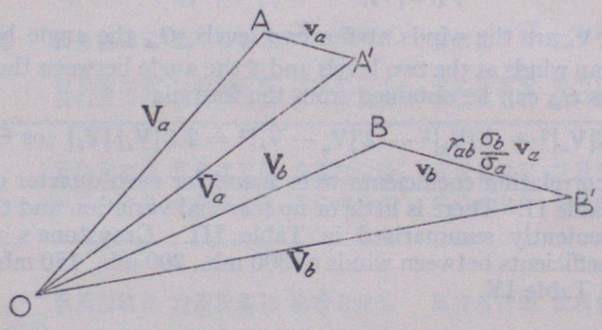


FIG. 1

To obtain $\mathbf{V}_b$ corresponding to this particular value of $\mathbf{V}_a$ join AA′, which gives $\mathbf{v}_a$ and draw from B′ a line BB′ ($\mathbf{v}_b$) parallel to AA′ and of length $r_{ab}{}'(\sigma_b/\sigma_a)$AA′. Then OB represents in direction and length the probable value of the wind at height b on this occasion.

If $r_{ab}{}''$ is not zero the length BB′ is $r_{ab}(\sigma_b/\sigma_a)$AA′ and the vector BB′ is rotated through an angle α_{ab} which is given by

$$\alpha_{ab} = \tan^{-1} \left\{ \frac{\Sigma|\mathbf{v}_a| \, |\mathbf{v}_b| \, \sin\theta_{ab}}{\Sigma|\mathbf{v}_a| \, |\mathbf{v}_b| \, \cos\theta_{ab}} \right\}.$$

The data used in the initial investigation were winds measured over Liverpool during the period June 1945 to May 1946, and correlation coefficients of simple stretch were calculated between winds at heights of 900, 700, 450, 300 ,200 and 100 mb., corresponding approximately to 3,000, 10,000, 20,000, 30,000, 40,000 and 53,000 ft. The calculations were lengthy and before they were undertaken a pilot examination was made to find out whether the correlation coefficient of simple turn was significant. The result is shown in Table I, where correlation coefficients of stretch and turn are shown between 900 mb. and all the other heights.

TABLE I—CORRELATION COEFFICIENTS OF SIMPLE STRETCH AND SIMPLE TURN AT LIVERPOOL, JUNE 1945–MAY 1946

Lower level	Upper level	Summer Stretch	Summer Turn	Summer Total	Winter Stretch	Winter Turn	Winter Total
mb.	mb.						
900	100	0·50	—0·05	0·50	..	..	..
900	200	0·54	—0·14	0·56	..	..	..
900	300	0·60	—0·25	0·64	0·61	0·03	0·61
900	450	0·62	—0·21	0·65	..	..	..
900	700	0·86	—0·15	0·87	0·87	0·14	0·88

The correlation coefficient of a simple turn is much less than that of simple stretch, and though it does exercise some influence in summer the error in neglecting it is not large.

If, then, the correlation coefficient of a simple turn is neglected it is possible to obtain the coefficient of simple stretch quite easily from the formula

$$r_{ab}' = \frac{\Sigma|\mathbf{V}_a|\,|\mathbf{V}_b|\cos\Theta_{ab} - n|\overline{\mathbf{V}}_a|\,|\overline{\mathbf{V}}_b|\cos\beta}{\sqrt{\{(\Sigma|\mathbf{V}_a|^2 - n\overline{\mathbf{V}}_a^2)(\Sigma|\mathbf{V}_b|^2 - n\overline{\mathbf{V}}_b^2)\}}},$$

where $\mathbf{V}_a$ and $\mathbf{V}_b$ are the winds at the two levels, Θ_{ab} the angle between them, $\overline{\mathbf{V}}_a$, $\overline{\mathbf{V}}_b$ the mean winds at the two levels and β the angle between them. Moreover $\Sigma|\mathbf{V}_a|\,|\mathbf{V}_b|\cos\Theta_{ab}$ can be obtained from the formula

$$\Sigma|\mathbf{V}_a|^2 + \Sigma|\mathbf{V}_b|^2 - \Sigma|\mathbf{V}_a - \mathbf{V}_b|^2 = 2\Sigma|\mathbf{V}_a|\,|\mathbf{V}_b|\cos\Theta_{ab}\,. \qquad (1)$$

In this way correlation coefficients were found for each quarter of the year as is shown in Table II. There is little or no seasonal variation and the coefficients can be conveniently summarized in Table III. Graystone's values of the correlation coefficients between winds at 300 mb., 200 mb., 150 mb. and 100 mb. are set out in Table IV.

TABLE III—STRETCH VECTOR CORRELATION COEFFICIENTS BETWEEN WINDS AT VARIOUS HEIGHTS

mb.	ft.	900 mb. 3,000 ft.	700 mb. 10,000 ft.	450 mb. 20,000 ft.	300 mb. 30,000 ft.	200 mb. 40,000 ft.
100	53,000	0·41	0·54	0·59	0·60	0·73
200	40,000	0·54	0·73	0·83	0·89	
300	30,000	0·59	0·79	0·90		
450	20,000	0·65	0·85			
700	10,000	0·85				

By the use of big balloons Scrase[4] has obtained a number of ascents reaching to 80,000 or 100,000 ft. Correlation coefficients were calculated from these for combinations of the levels 50,000, 80,000 and 100,000 ft. as is shown in Table V and for practical purposes we may consider the pressure levels to be 130 mb., 20 mb. and 10 mb. These are based on a small sample of observations and the correlation coefficients in S.–N. and E.–W. components are clearly not representative ; however, the vector correlation coefficients appear reasonably consistent.

Further, a comparison was made between winds at various heights over Habbaniya and Barrow, Alaska, during 1949 and also over Nairobi. The correlation coefficients are given in Table VI.

TABLE II—STRETCH VECTOR CORRELATION COEFFICIENTS OF WINDS AT TWO HEIGHTS

Liverpool | Period : June 1945–May 1946

Lower level	Upper level	Mean wind Lower level		Mean wind Upper level		Standard vector deviation Lower level	Standard vector deviation Upper level	Standard vector difference	Stretch correlation coefficient	Mean wind Lower level		Mean wind Upper level		Standard vector deviation Lower level	Standard vector deviation Upper level	Standard vector difference	Stretch correlation coefficient
mb.	mb.	°	kt.	°	kt.	knots				°	kt.	°	kt.	knots			
		WINTER (December–February)								SUMMER (June–August)							
200	100	315	27	301	25	38	23	28	0·73	247	19	231	9	33	20	24	0·77
300	100	289	19	301	25	34	23	26	0·57	253	21	231	9	48	20	40	0·66
300	200	289	24	300	31	45	45	22	0·90	265	23	254	21	49	36	25	0·88
450	100	299	12	301	25	30	23	27	0·61	251	19	231	9	29	20	25	0·62
450	200	286	15	300	31	38	45	32	0·78	256	18	254	21	32	36	19	0·85
450	300	281	24	282	31	45	55	29	0·86	251	18	261	23	34	51	25	0·91
700	100	323	6½	301	25	24	23	28	0·59	239	8	231	9	22	20	17	0·66
700	200	314	16	300	31	24	45	38	0·64	252	10	254	21	23	36	26	0·77
700	300	279	17	282	31	29	55	39	0·82	253	10	261	23	24	51	37	0·82
700	450	279	17	281	24	29	45	27	0·87	253	10	251	18	24	34	21	0·85
900	100	238	3½	301	25	22	23	35	0·35	234	5½	231	9	17	20	19	0·50
900	200	252	7	300	31	22	45	48	0·46	250	7	254	21	18	36	34	0·54
900	300	259	12	282	31	25	55	48	0·61	253	8	261	23	17	51	45	0·60
900	450	259	12	281	24	25	45	36	0·67	253	8	251	18	17	34	29	0·62
900	700	259	12	279	17	25	29	16	0·87	253	8	253	10	17	24	12	0·86
		SPRING (March–May)								AUTUMN (September–November)							
200	100	232	3	339	2½	26	14	20	0·66	296	12	305	7	38	18	19	0·77
300	100	199	5	339	2½	33	14	31	0·43	291	10	305	7	39	18	19	0·74
300	200	209	8	259	5½	35	28	20	0·84	300	14	310	15	45	41	44	0·92
450	100	213	2	339	2½	24	14	23	0·41	286	5	305	7	31	18	22	0·73
450	200	220	5	259	5½	26	28	16	0·82	295	8½	310	15	34	41	20	0·89
450	300	231	7	226	11	32	40	17	0·91	279	11	298	18	35	46	20	0·94
700	100	88	2½	339	2½	19	14	20	0·30	215	5	305	7	22	18	20	0·62
700	200	148	2	259	5½	20	28	20	0·73	257	5½	310	15	23	41	30	0·78
700	300	204	2	226	11	23	40	31	0·67	252	8	298	18	24	46	32	0·84
700	450	204	2	231	7	23	32	20	0·81	252	8	279	11	24	35	20	0·86
900	100	98	5	339	2½	17	14	20	0·26	174	6	305	7	17	18	21	0·53
900	200	127	4½	259	5½	18	28	25	0·57	201	5	310	15	18	41	39	0·57
900	300	136	3	226	11	19	40	36	0·53	220	6	298	18	19	46	41	0·63
900	450	136	3	231	7	19	32	25	0·68	220	6	279	11	19	35	29	0·61
900	700	136	3	204	2	19	23	12	0·86	220	6	252	8	19	24	15	0·80

TABLE IV—STRETCH VECTOR CORRELATION OF WINDS AT TWO HEIGHTS

	Period	No. of obs.	Levels		Wind at upper level: Mean		Wind at upper level: S.V.D.*	Correlation coefficient
			km.	km.	°	kt.	kt.	
Tateno	Dec. 1950, 51, 52	86	6	9		109	42	0·68
Tateno	Dec.–Feb. 1950, 51, 52	242	6	9		110	47	0·66
			mb.	mb.				
Malta	July–Aug. 1950	112	300	200		36	24	0·70
Liverpool ..	Jan.–Feb. 1951	183	200	150	280	21	25	0·91
Langenhagen ..	July–Aug. 1951	116	200	150	252	22	24	0·88
Liverpool ..	Apr. 1951, 52	211	300	150	274	17	20	0·82
Habbaniya ..	Apr. 1951, 52	110	300	150	262	50	31	0·70
Downham Market and Hemsby	Apr. 1951, 52	223	300	150	269	17	19	0·72
Liverpool ..	Jan.–Feb. 1951	183	150	100	279	15	22	0·88
Downham Market and Hemsby	Apr. 1951, 52	223	150	100	270	11	15	0·90

* S.V.D. = Standard vector deviation.

TABLE V—CORRELATION COEFFICIENTS BETWEEN WINDS AT VERY HIGH LEVELS OVER SOUTHERN ENGLAND

(Observations obtained by big balloons)

Lower level	Upper level	Winter (Nov.–Apr.) (25 observations) S.–N. component	W.–E. component	Stretch Vector	Summer (May–Oct.) (26 observations) S.–N. component	W.–E. component	Stretch Vector	Year Stretch Vector
feet								
80,000	100,000	0·70	0·53	0·56	0·22	0·40	0·31	0·56
50,000	100,000	0·33	0·41	0·35	0·62	0·23	0·36	0·30
50,000	80,000	0·65†	0·09†	0·34†	0·23	0·55	0·42	0·31

No. of observations † 36.

TABLE VI—STRETCH VECTOR CORRELATION COEFFICIENTS BETWEEN WINDS AT DIFFERENT HEIGHTS

Period : 1949

Lower level	Upper level	Habbaniya Winter	Spring	Summer	Autumn	Nairobi Year	Barrow, Alaska Winter	Spring	Summer	Autumn
millibars										
300	200	0·92	0·85	0·92	0·82	0·43	0·62	0·77	0·75	0·60
500	200	0·62	0·67	0·43	0·57	0·09	0·34	0·71	0·60	0·51
500	300	0·77	0·79	0·62	0·70	0·22	0·51	0·79	0·74	0·83
700	200	0·47	0·49	0·30	0·40	..	0·21	0·52	0·51	0·38
700	300	0·64	0·69	0·21	0·43	0·04	0·45	0·53	0·58	0·49
700	500	0·77	0·63	0·53	0·63	0·22	0·60	0·69	0·76	0·71

Using the data given in these tables, diagrams can be constructed showing the variation in correlation coefficients between winds at various heights over the British Isles and over Habbaniya. This has been done, and is shown in Figs. 2 and 3. The lines form a reasonably consistent pattern and show that over the British Isles there is a high correlation between winds at 600 mb. and other levels even with those some distance above the tropopause, no doubt because

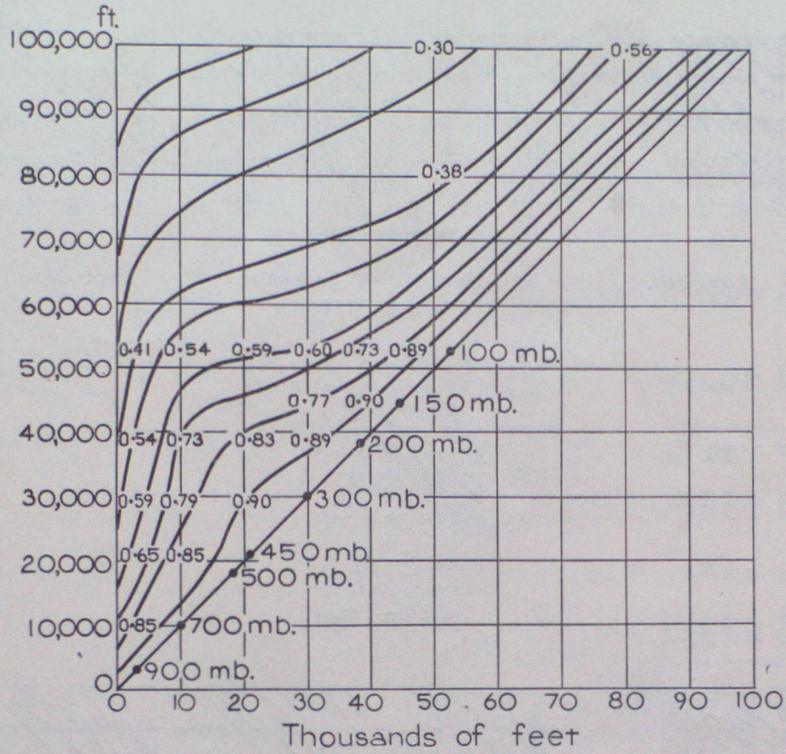


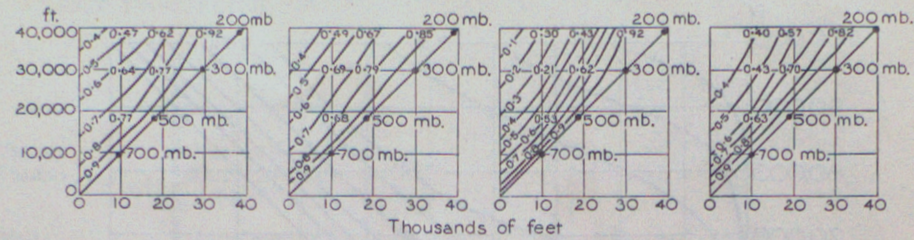
FIG. 2—STRETCH VECTOR CORRELATION COEFFICIENTS BETWEEN WINDS AT TWO HEIGHTS OVER SOUTHERN ENGLAND

the level of 600 mb. is about the centre of mass of the troposphere. It is at present not known how the lines should be drawn in the top left-hand corner of the diagrams, but even there they must follow somewhat on the pattern indicated.

It would seem that the correlation coefficients up to 200 mb. are lower over Habbaniya and very much lower over Nairobi than over the British Isles. This is not unexpected since the effects of geostrophic control are so much smaller towards the equator. One would expect the wind variations due to pressure gradients to affect a considerable depth of the atmosphere simultaneously, but the ageostrophic components of wind are likely to be propagated upwards or downwards by turbulence, a much slower process. In the tropics the ageostrophic components become increasingly predominant. The comparatively small correlation coefficients in the Arctic winter, as illustrated at Barrow, Alaska, are noteworthy.

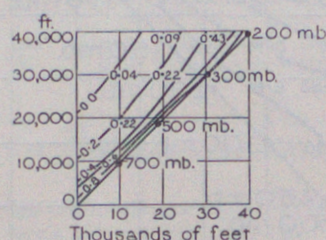
Provided that the average winds and standard vector deviations are known at different heights it is possible to construct the standard vector deviation of the mean winds up to any height, and this quantity is of interest in a number of problems.

Let $\mathbf{V}_z$ be the average wind at any height z and $\mathbf{V}_{nh}/n$ or $(1/n)\,\Sigma\mathbf{V}_z$ be the wind averaged from 0 to nh in steps of thickness h. Let $\mathbf{v}_z$ be the departure from the average wind at height z on a particular occasion, and further let it be assumed that this wind is averaged over a step h deep. Then the departure from the average of the mean wind over a layer from 0 to nh is given by $(1/n)\,\Sigma\mathbf{v}_z$ $(= \mathbf{v}_{nh}/n$, say) and the mean wind up to nh on this occasion is $(1/n)\,\Sigma(\mathbf{V}_z + \mathbf{v}_z)$.

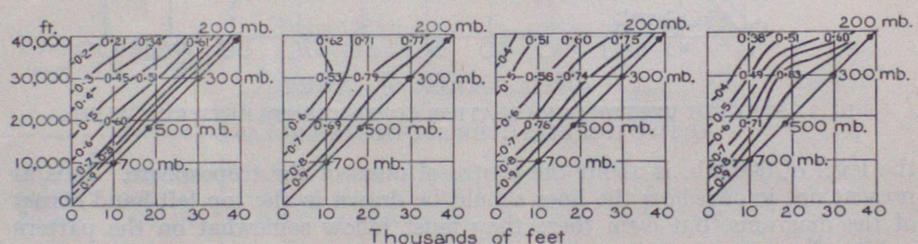


Dec.–Feb. Mar.–May June–Aug. Sept.–Nov.

Habbaniya, 1949



Nairobi—Year



Dec.–Feb. Mar.–May June–Aug. Sept.–Nov.

Barrow, Alaska, 1949

FIG. 3—SEASONAL VARIATION OF STRETCH VECTOR CORRELATION COEFFICIENTS BETWEEN DIFFERENT HEIGHTS

Moreover,

$$\left(\frac{1}{n}\mathbf{v}_{nh}\right)^2 = \frac{1}{n^2}\left(\sum_1^n \mathbf{v}_z\right)^2 = \frac{1}{n^2}\left(\mathbf{v}_a^{\,2} + \mathbf{v}_b^{\,2} + \mathbf{v}_c^{\,2} + \ldots + 2\mathbf{v}_a.\mathbf{v}_b + 2\mathbf{v}_a.\mathbf{v}_c + \ldots\right). \qquad (2)$$

If we denote the average of a large number of occasions by a vinculum then the variance of the mean wind up to height nh is given by

$$\Xi^2 = \overline{\left(\frac{1}{n}\mathbf{v}_{nh}\right)^2}$$

$$= \frac{1}{n^2}\left\{\overline{\mathbf{v}_a^2} + \overline{\mathbf{v}_b^2} + \overline{\mathbf{v}_c^2} + \ldots + 2\sqrt{(\overline{\mathbf{v}_a^2})}\sqrt{(\overline{\mathbf{v}_b^2})}\,r_{ab} + 2\sqrt{(\overline{\mathbf{v}_a^2})}\sqrt{(\overline{\mathbf{v}_c^2})}\,r_{ac} + \ldots\right\}$$

$$= \frac{1}{n^2}\sum_1^n\sum_1^n r_{pq}\sqrt{(\overline{\mathbf{v}_p^2}\,\overline{\mathbf{v}_q^2})}\;; \qquad \ldots\ldots (3)$$

or, proceeding to the limit,

$$\Xi^2 = \frac{2}{z^2}\int_0^z dy\int_0^y \sigma_x\sigma_y r_{xy}\,dx\,, \qquad \ldots\ldots (4)$$

where σ_x and σ_y are standard vector deviations of winds at heights x and y and r_{xy} is the stretch correlation coefficient between winds at those two heights, z being written for the height nh. It follows directly that

$$\frac{1}{z^2}\overline{\left\{\int_0^z (\mathbf{V}_z + \mathbf{v}_z)\,dz\right\}^2} = \frac{1}{z^2}\left\{\int_0^z \mathbf{V}_z\,dz\right\}^2 + \frac{2}{z^2}\int_0^z dy\int_0^y \sigma_x\sigma_y r_{xy}\,dz. \qquad \ldots\ldots (5)$$

The average winds and the standard vector deviation of winds are given month by month for Larkhill and Habbaniya in *Upper air data*[5,6]. Further, some estimates have been made of the mean wind components at 50,000, 80,000 and 100,000 ft. over southern England, and also at 60 mb. (63,000 ft.) over Habbaniya.

TABLE VII—VALUES OF WIND COMPONENTS AT VARIOUS HEIGHTS OVER SOUTHERN ENGLAND

		Dec.–Feb.		Mar.–May		June–Aug.		Sept.–Nov.		May–Oct.		Nov.–Apr.	
		S.-N.	W.-E.	S.-N.	W.-E.	S.-N.	W.-E.	S.-N.	W.-E.	S.-N.	W.-E.	S.-N.	W.-E.
ft.	mb.	*knots*											
100,000		—11	+70	—1	—6	—1	—23	—6	+19	—1	—15	—8	+45
80,000		—14	+23	—3	—6	—2	—13	—4	+9	—3	—8	—9	+15
53,000	100	—5	+20	—2	+10	+2	+10	—3	+18	+1	+11	—5	+17
50,000		—3	+23	—4	+11	—4	+12	—2	+18	—3	+13	—3	+19
45,000	150	—9	+23	—3	+13	+1	+21	—3	+28	+1	+21	—7	+22
39,000	200	—11	+28	—6	+17	0	+30	—5	+35	0	+29	—11	+27
30,000	300	—10	+32	—7	+21	+1	+32	—1	+35	+2	+30	—11	+30
18,000	500	—3	+24	—4	+15	+1	+22	+2	+24	+2	+20	—4	+23
10,000	700	—1	+18	—2	+10	+2	+14	+4	+17	+3	+13	—1	+16
5,000	850	+2	+14	—1	+6	+2	+10	+3	+13	+2	+9	+1	+12

TABLE VIII—QUARTERLY VALUES OF WIND COMPONENTS AT VARIOUS HEIGHTS OVER HABBANIYA

		Dec.–Feb.		Mar.–May		June–Aug.		Sept.–Nov.	
		S.–N.	W.–E.	S.–N.	W.–E.	S.–N.	W.–E.	S.–N.	W.–E.
ft.	mb.	*knots*							
63,000	60	+3	+33	+2	+13	+4	—15	—2	+19
53,000	100	0	+43	+6	+35	+10	+9	+6	+31
45,000	150	—2	+63	+5	+49	+11	+23	+11	+48
39,000	200	—2	+73	+12	+64	+10	+28	+11	+52
30,000	300	0	+63	+12	+53	+7	+26	+9	+49
18,000	500	+2	+33	+7	+29	+3	+13	+4	+21
10,000	700	+2	+15	+3	+16	—2	+10	+1	+14
5,000	850	0	+6	0	+5	—9	+10	—2	+5

Tables VII–IX together with the values shown in Figs. 2 and 3 give the data necessary to evaluate equation (4). Table X gives the mean wind to various heights

$$\left(\frac{1}{z}\int_0^z \mathbf{V}\,dz\right)$$

and the standard vector deviation (Ξ) for southern England and Habbaniya in summer and winter, from which expression (4) can at once be derived.

Thus even though the winter winds are on average stronger in the higher levels over Habbaniya than over England the deviations in the mean winds are smaller. Moreover at Nairobi, in the tropics, the correlation coefficients between winds at different levels is much lower than over the British Isles and also the normal winds at levels to at least 40,000 ft. are quite light, from which it may be judged that the standard vector deviation of the mean winds up to different heights is much smaller in the tropics than over the British Isles.

TABLE IX—STANDARD VECTOR DEVIATIONS OF WIND OVER SOUTHERN ENGLAND AND HABBANIYA

		Southern England		Habbaniya			
		Winter (Nov.– Apr.)	Summer (May– Oct.)	Dec.– Feb.	Mar.– May	June– Aug.	Sept.– Nov.
ft.	mb.			*knots*			
100,000	..	39	9	..	..	..	..
80,000	..	21	8	..	..	..	..
50,000	100	23	16	23	23	19	22
45,000	150	29	27	32	33	26	28
39,000	200	41	39	41	38	29	32
30,000	300	53	45	45	38	27	30
18,000	500	39	31	30	23	17	19
10,000	700	29	21	19	18	15	15
5,000	850	26	19	16	16	12	13

TABLE X—VECTOR MEAN WINDS AND STANDARD VECTOR DEVIATION OF WINDS AVERAGED OVER THE LAYER FROM THE SURFACE TO VARIOUS HEIGHTS OVER SOUTHERN ENGLAND AND HABBANIYA

	Southern England						Habbaniya					
	Winter (Nov.–Apr.)			Summer (May–Oct.)			Winter (Dec.–Feb.)			Summer (June–Aug.)		
	Mean wind		S.V.D.*	Mean wind		S.V.D.	Mean wind		S.V.D.	Mean wind		S.V.D.
ft.	°	kt.	kt.	°	kt.	kt.	°	kt.	kt.	°	kt.	kt.
100,000	287	22	22	276	7	15	..		..	..		..
80,000	287	19	24	271	11	18	..		..	..		..
60,000	285	19	28	268	16	22	270	44	..	254	17	..
50,000	284	21	31	268	17	25	270	45	..	259	19	..
40,000	284	23	34	265	19	27	269	41	27	264	18	16
30,000	281	21	34	262	17	26	268	31	24	272	14	14
20,000	275	16	29	258	13	21	266	19	19	288	12	12
10,000	265	12	25	255	9	18	266	7	15	310	13	11
5,000	260	10	24	255	7	18	270	4	15	320	16	11

* S.V.D. = Standard vector deviation.

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Erratum

Page 2, line 36 ; *for* " $\sqrt{\{(\Sigma|\mathbf{v}_b|^2)\ (n-1)\}}$ " *read* " $\sqrt{\{(\Sigma|\mathbf{v}_b|^2)/(n-1)\}}$ "

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