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AN ASSESSMENT SCHEME FOR AERODROME FORECASTS

By P. B. WRIGHT

Summary. A method is described which enables an assessment to be made, in a broad sense, of the usefulness of a set of terminal aerodrome forecasts. The test is confined to the elements of visibility, surface wind and low cloud, and the scoring system is such that an error in the neighbourhood of values critical for the landing and take-off of aircraft is marked more harshly than an error in another part of the range. The scheme also takes into account the use of PROB, TEMPO and INTER in a way which simulates the loss of value to the customer of a reduction in the preciseness of the forecast.

Introduction. This scheme is intended to assess the accuracy and usefulness of a terminal aerodrome forecast (TAF).* It has been devised in such a way that it is possible to :

(i) compare the accuracy of one set of TAFs with that of another, and
(ii) point out the occasions on which the TAFs are so badly in error that a study of the synoptic situation is called for.

Outline of the system. The assessment is confined to the elements of visibility, surface wind and low cloud. It has been assumed that conditions of visibility <4 km, wind speed $\geqslant 20$ kt,† or cloud 4–8 oktas below 1000 ft might lead to diversion of aircraft, and scales have been devised such that an error in the neighbourhood of the critical values is marked more harshly than one in another part of the range.

The scheme verifies the TAF at a particular time; it does not attempt to give an overall assessment. The method is thus akin to random sampling and tests the ability of a forecast, designed to apply to a continuous period, to predict the weather at a particular moment (or a finite number of moments) during that period. Thus, strictly, the accuracy of the forecast is not tested, but it is assessed in the way that it is often actually used by someone requiring a knowledge of the weather at specific times for planning purposes.

Briefly, the range of possible values of each element is divided into categories; a score of 10 points is awarded if the forecast weather is in the same category as the actual weather, with scores decreasing to zero as the difference between forecast and actual categories increases. The categories are chosen with relatively narrow ranges of values in the neighbourhood of the critical values quoted above. Probabilities are dealt with in such a way that a forecaster

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* See : London, Meteorological Office. Handbook of weather messages (Met. O. 510b), 6th Ed. 1971 (in press) or WMO No. 9 TP4 Volume B, 1971, for details.
† 1 kt $\approx$ 0·5 m/s.

cannot increase his average score by simply putting additional PROBs in every forecast, although he can reduce the number of occasions on which he gets a zero score. TEMPO and INTER are treated as if they were PROB 40.

The method.

Practical details. If it is desired to assess the TAF for midnight the first step is to extract from the TAF message the forecast information referring to midnight. The forecast may be for a specific value of each element and in this case the forecast is verified as follows :

(i) *Visibility.* Find the forecast category and the actual category from Table I. Calculate the error (E_v) as forecast category minus actual category, except that E_v is zero if

(*a*) actual visibility is less than 6 km and difference between forecast and actual is $\leqslant$ 200 m,

(*b*) actual visibility is from 6 to 10 km inclusive and the difference between forecast and actual is $\leqslant$ 2 km, or

(*c*) actual visibility is $>$ 10 km and difference between forecast and actual is $\leqslant$ 4 km.

(ii) *Wind.* First consider wind speed and find the forecast and actual categories according to Table II. Calculate the error E_s as forecast category minus actual category, except that E_s is zero if the difference between forecast and actual values is $\leqslant$ 4 kt. Find the wind direction error E_d from Table III; if the actual wind is calm $E_d = 0$. The wind error is then given by $|E_s| + E_d$.

(iii) *Cloud.* This element is rather more difficult to assess than the others because of the complex nature of the forecasts and the possible presence of two or more layers. If only one layer is involved, find the cloud error E_c from Table IV. If two or more layers are involved the following rules should be applied :

(*a*) Two layers of cloud are treated as identical if their amounts differ only within one of the ranges 1 to 3 oktas or 4 to 8 oktas and their heights differ only within one of the ranges 0 to 500 ft, 600 to 1000 ft, 1100 to 1500 ft or 1600 to 2000 ft.

(*b*) If one layer has to be compared with two layers, compare the one with each in turn and take E_c as the larger error.

(*c*) If 'sky obscured' is forecast, it may be taken as equivalent to '8 oktas at 100 ft' if this seems reasonable in the particular case. If 'sky obscured' occurs, it is taken as equivalent to '4–8 oktas at 0–500 ft' if the latter was forecast. In all other cases 'sky obscured' is indeterminate.

The score. For each element, the score $= 10-2|E|$, with a minimum possible value of zero. Negative score values are counted as zero.

Gradual changes. Suppose the forecast includes the expression 'GRADU from t_1 to t_2', denoting a gradual change in the value of an element or elements during the period t_1 to t_2. When verifying for midnight, if t_2 is midnight the gradual change is assumed to have been completed. If t_1 is midnight the change is assumed not to have started. If t_1 is before and t_2 after midnight the value of the element is interpolated between the extreme values forecast.

TABLE I—VISIBILITY CATEGORIES

Visibility	Category value
⩽100 m	1
200–300 m	2
400–600 m	3
700–900 m	4
1000–1300 m	5
1400–1700 m	6
1·8–2·2 km	7
2·3–2·7 km	8
2·8–3·3 km	9
3·4–3·9 km	10
4·0–4·6 km	11
4·7–5·9 km	12
6–8 km	13
⩾9 km	14

TABLE II—WIND SPEED CATEGORIES

Speed *kt*	Category value
0–6	1
7–12	2
13–16	3
17–19	4
20–25	5
26–35	6
⩾36	7

TABLE III—WIND DIRECTION CATEGORY ERRORS (E_d)

Error in direction	Actual speed *kt*			
	⩽6	7–12	13–19	⩾20
degrees	Category error E_d			
⩽20	0	0	0	0
30–40	0	0	1	2
50–60	0	1	2	4
70–90	0	2	3	5
100–120	1	2	4	5
130–180	1	3	5	5
F/c direction variable	0	1	3	5

TABLE IV—CLOUD CATEGORY ERRORS (E_c)

Actual cloud		Forecast cloud								
oktas	*hundreds of feet*	0	1–3* 16–20†	1–3 11–15	1–3 6–10	1–3 0–5	4–8 16–20	4–8 11–15	4–8 6–10	4–8 0–5
		Category error (E_c)								
0		0	½	1½	2½	3½	2	3	4	5
1–3	16–20	½	0	½	1½	2½	1	2	3½	5
1–3	11–15	1½	½	0	½	1½	1½	1	2½	4
1–3	6–10	2½	1½	½	0	1	2½	1½	1	2½
1–3	0–5	3½	2½	1½	1	0	3½	2½	2	1½
4–8	16–20	2	1	1½	2½	3½	0	1½	2½	3½
4–8	11–15	3	2	1	1½	2½	1½	0	1½	2½
4–8	6–10	4	3½	2½	1	2	2½	1½	0	1½
4–8	0–5	5	5	4	2½	1½	3½	2½	1½	0

* Top row : oktas † Bottom row : hundreds of feet.

Qualifying statements. The forecast for midnight may include a qualifying statement, for example, 'visibility 10 km with a 40 per cent probability of 2 km'. The first value (10 km) is called the PRIMARY, the other value the SECONDARY. The definition of the error *(E)* is now modified to be the category difference between the PRIMARY and ACTUAL, and the difference *(R)* is defined similarly except that the comparison is between PRIMARY and SECONDARY. TEMPO and INTER are assumed for this purpose to be equivalent to a 40 per cent probability. The procedure is now as follows :

First calculate *R* and *E*, then find the score from Table V, VI or VII whichever is appropriate :

Table V for PROB 40, TEMPO, INTER

Table VI for PROB 30, PROB 20
PROB 40 of TEMPO or INTER

Table VII for PROB 10
PROB 30 or 20 of TEMPO or INTER

The method of derivation of these tables is given in the Appendix.

TABLE V—SCORES FOR PROBABILITY 40 PER CENT

	Primary category error *(E)*												
*R**	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6
−4	3	4	6	7	6	5	6	4	3	3	2	0	0
−3	1	3	6	7	7	7	7	4	3	3	2	0	0
−2	0	1	5	7	7	8	9	5	3	3	2	0	0
−1	0	0	3	6	7	8	10	7	4	3	2	0	0
0	0	0	2	4	6	8	10	8	6	4	2	0	0
1	0	0	2	3	4	7	10	8	7	6	3	0	0
2	0	0	2	3	3	5	9	8	7	7	5	1	0
3	0	0	2	3	3	4	7	7	7	7	6	3	1
4	0	0	2	3	3	4	6	5	6	7	6	4	3
5	0	0	2	3	3	4	6	4	4	6	6	4	4
6	0	0	2	3	3	4	6	4	3	4	5	4	4
7	0	0	2	3	3	4	6	4	3	3	3	3	4
8	0	0	2	3	3	4	6	4	3	3	2	1	3

**R* = category difference between primary and secondary.

TABLE VI—SCORES FOR PROBABILITY 30 OR 20 PER CENT

	Primary category error *(E)*												
*R**	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6
−4	1	2	4	5	6	7	8	6	5	3	2	0	0
−3	1	1	4	5	7	7	9	6	5	3	2	0	0
−2	0	1	3	5	7	8	9	7	5	3	2	0	0
−1	0	0	3	4	7	8	10	7	6	3	2	0	0
0	0	0	2	4	6	8	10	8	6	4	2	0	0
1	0	0	2	3	6	7	10	8	7	4	3	0	0
2	0	0	2	3	5	7	9	8	7	5	3	1	0
3	0	0	2	3	5	6	9	7	7	5	4	1	1
4	0	0	2	3	5	6	8	7	6	5	4	2	1
5	0	0	2	3	5	6	8	6	6	4	4	2	2
6	0	0	2	3	5	6	8	6	5	4	3	2	2
7	0	0	2	3	5	6	8	6	5	3	3	1	2
8	0	0	2	3	5	6	8	6	5	3	2	1	1

* See footnote to Table V.

TABLE VII—SCORES FOR PROBABILITY 10 PER CENT

R*	Primary category error (E) -6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
-4	1	1	3	5	6	7	9	7	5	4	2	0	0
-3	0	1	3	5	6	8	9	7	5	4	2	0	0
-2	0	0	3	5	6	8	10	7	5	4	2	0	0
-1	0	0	2	5	6	8	10	8	5	4	2	0	0
0	0	0	2	4	6	8	10	8	6	4	2	0	0
1	0	0	2	4	5	8	10	8	6	5	2	0	0
2	0	0	2	4	5	7	10	8	6	5	3	0	0
3	0	0	2	4	5	7	9	8	6	5	3	1	0
4	0	0	2	4	5	7	9	7	6	5	3	1	1
5	0	0	2	4	5	7	9	7	5	5	3	1	1
6	0	0	2	4	5	7	9	7	5	4	3	1	1
7	0	0	2	4	5	7	9	7	5	4	2	1	1
8	0	0	2	4	5	7	9	7	5	4	2	0	1

* See footnote to Table V.

Further notes :

(i) If TEMPO, INTER or PROB are used, applying to a period beginning or ending at midnight, they are ignored.

(ii) If two or more qualifying statements (i.e. TEMPO, INTER or PROB) occur, they should be applied each in turn and the mean taken of the scores so calculated. However, if one of these is a PROB 10 or its equivalent, it is ignored.

(iii) For cloud it may be necessary to interpolate in Table V, VI or VII; if so, round off the score to the nearest integer above.

(iv) For cloud, ignore PROB 10. If a cloud forecast is too complicated to assess consider only the lowest layer of 4–8 oktas.

(v) For wind, first find R_s and E_s for speed and the score for speed. For direction, it will be found that a qualifying statement is rarely used in practice; if it is, ignore it. E_d can be found as usual, and twice its value is then subtracted from the score already found, to obtain the total wind score.

Discussion and comparison with other methods. Two methods for testing the accuracy of TAFs have been published; von Bezold[1] described a very thorough method of verifying all details of a TAF for a continuous period rather than at isolated moments and the qualifying statements TEMPO and INTER are verified properly. PROB is treated as if it were TEMPO. Hoppestad[2] in a similar method verifies a TAF at hourly intervals through the period of validity, thus treating TEMPO and INTER in a nearly-proper manner. He deals with probability forecasts by considering the sets of all such forecasts over a period such as three months and this is the most proper way of verifying PROBS but it implies that scores cannot be attached to individual forecasts. Both of these methods deal only with visibility and cloud height. Also, both methods can be 'played'; that is, the forecaster may increase his average score by inserting additional TEMPOs or INTERs (or PROBs in von Bezold's method).

For the purpose of testing accuracy alone the present method is inferior to the above two methods. For example, the fact that verification is made only at one moment in the period of validity may result in a low score for a forecast which was correct for most of the time, or a high score for a generally poor forecast. The method of treating TEMPO and INTER does not give the highest scores to the most correct forecasts because a forecast of '*A* TEMPO *B*' which is completely correct cannot score more than 6 and may score only 4.

For these reasons, the present method may be regarded as assessing the usefulness of a TAF, the usefulness depending on both the accuracy and the preciseness of the forecast.* A precise (that is, unqualified) forecast has its maximum usefulness when it is correct (score = 10), and a minimum when it is so far wrong that any plans based upon it cannot be carried out (score=0). On the other hand, when a qualifying statement is introduced the forecast becomes less precise and its potential usefulness is therefore reduced (except when both the primary and the secondary forecast would lead to the same action by the user): however, there is a smaller chance that the forecast will be completely useless. This variation is reflected in the scoring system, in that the maximum possible score is lower than that for an unqualified forecast, but the chance of obtaining a very low score is reduced.

Over a period, the forecaster cannot 'play' the system to his advantage. Any attempt to do so, either by being over-cautious and introducing qualifying statements when none is needed, or by omitting them when they are called for, will result in a lower average score, although it may increase the score attained by an individual forecast.

Although an individual forecast which scores only 1 is not necessarily less useful than another which scores 6, the individual scores are of interest nevertheless if interpreted in the following way :

Score 0. Wrong forecast. To be avoided if at all possible (even at the risk of lowering the average score by putting in a PROB). Each such score deserves a study of the synoptic situation to see if such a score could be avoided in future.

Score 1–3. Misleading. It should be possible to improve forecasts on most of these occasions by a more thorough knowledge of the type of synoptic situation and the probabilities involved. Hence these forecasts should be classified according to synoptic situations and carefully studied. A small percentage of these scores cannot be avoided.

Score 4–6. Dubious. This range of scores must be expected to occur quite frequently, even with much better forecasting techniques, because of the tendency of certain elements (e.g. fog and rainfall) to be discontinuous in time and space and therefore difficult to forecast except with TEMPO, INTER, etc.

Score 7–9. Satisfactory. Such scores are an expression of the inherent variability of the weather and give no cause for concern.

Score 10. Correct.

Application of the method to a sample of TAFs. The method was applied to the forecasts issued by six master diversion airfields during March 1965. The forecasts used were those issued at 17 GMT, based upon the 12 or

* Strictly, the usefulness of a given forecast depends also upon the use to which it is put, and will vary from one customer to another, but this is a complex subject and is not considered here.

15 GMT chart, and were applicable to the period 18–09 GMT. The weather forecast for midnight was verified. The frequency distribution of scores for the elements of visibility, wind and cloud is shown in Table VIII. In this table the infrequency of odd-number scores for visibility and wind is caused by the use of whole numbers for the category values.

TABLE VIII—NUMBER OF OCCURRENCES OF EACH FORECAST SCORE FOR VISIBILITY, WIND AND CLOUD

	Forecast score												
	10	9	8	7	6	5	4	3	2	1	0	Indeterminate	Total
	Number of occurrences												
Visibility	34	5	28	11	23	6	24	11	10	1	24	9	186
Wind	59	0	49	1	27	0	24	2	11	0	6	7	186
Cloud	80	11	8	19	13	12	12	4	9	1	6	11	186

Out of the total number (177) of verifiable forecasts

(i) 5 (3 per cent) were correct for all three elements. (All scores = 10.)

(ii) 39 (22 per cent) were satisfactory for all three elements. (All scores 7–9.)

(iii) 106 (60 per cent) were not misleading for any of the three elements. (All scores 4–6.)

whereas

(iv) 71 (40 per cent) were misleading for at least one element. (At least one score < 4.)

(v) 34 (19 per cent) had at least one score of zero.

Conclusions. A method has been described which enables an assessment to be made, in a broad sense, of the usefulness of a set of terminal aerodrome forecasts. The method is reasonably easy to apply, and it is suggested that similar tests could usefully be carried out at stations which prepare TAFs. Such tests might enable the synoptic situations giving rise to bad forecasts to be pinpointed and, coupled with a study of the reasons for any poor forecasts, might help to improve the service. It should be borne in mind, however, that the tests described were carried out in 1965, and that any similar study carried out at present would need to be modified to take into account the lower limits of cloud height and visibility now considered critical for diversion of aircraft. Modification of some aspects of the tests might be worthwhile, for example, it might be better to verify a given forecast at more than one time during its period of validity. A valuable addition, if a long enough run of forecasts is available, would be the compilation of a table showing the distribution of scores for each category of each element at verification time.

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2. HOPPESTAD, S.; Verification of aerodrome forecasts for Oslo Airport. *Scient Rep, Norske Met Inst, Oslo,* No. 16, 1966.

APPENDIX

How Tables V–VII are produced. First suppose the forecast is for a unique value of an element. The scores obtained can be represented, for the various values of E, in a table :

TABLE IX—INITIAL SCORING ON ONE ELEMENT

	Value of E											Total
	−5	−4	−3	−2	−1	0	1	2	3	4	5	
Row A (score)	0	2	4	6	8	10	8	6	4	2	0	50

The array 2, 4, 6, 8, 10, 8, 6, 4, 2 is called 'Row A'; it is understood that all terms off the ends of the array are zeros.

Next, suppose the forecast is for 'P with a 40 per cent probability of S'. This is taken to mean that the probability of P is 60 per cent, and that of S is 40 per cent. Suppose for convenience that P and S are very widely separated, for example, P = 15 km visibility, S = 800 m. Suppose now that the actual visibility turns out to be 15 km, that is, P is correct. Instead of giving a score of 10, suppose we make the score dependent on the forecaster's confidence and award 6 points; similarly, if the actual visibility in this particular case were 800 m, the score would be 4 points. As in Table IX, we arrange an array of scores in decreasing order of magnitude on each side of both primary and secondary forecasts, such that the sum of the scores over all values of E is the same as it was before, namely 50.

To do this, and dropping now the supposition of wide separation, Row A is split into two arrays, Row B and Row C (see Table X), such that adding Row B and C term-by-term produces Row A; and such that the ratio of the highest terms of Rows B and C, and also that of the sums of the terms in Rows B and C, are both 6:4.

TABLE X—CONSTRUCTION OF SCORE FOR PRIMARY AND SECONDARY ELEMENTS

	Score											Totals
Row A	0	2	4	6	8	10	8	6	4	2	0	50
Row B	0	2	3	3	4	6	4	3	3	2	0	30
Row C	0	0	1	3	4	4	4	3	1	0	0	20

Row C is then moved horizontally relative to Row B, such that B is symmetrical about the category of P, and C is symmetrical about the category of S, where these statements are meaningful; or, in general, C is moved to the right by R steps. Rows B and C are then added together again to obtain Row D. For example, if $R = 3$, we get :

TABLE XI—ALLOCATION OF SCORE FOR PRIMARY AND SECONDARY ELEMENTS ($R = 3$)

	Score												
Row B	0	2	3	3	4	6	4	3	3	2	0		
Row C				0	0	1	3	4	4	4	3	1	0
Row D	0	2	3	3	4	7	7	7	7	6	3	1	0

Row D is then put in place of Row A in Table IX :

TABLE XII—COMBINED SCORE FOR PRIMARY AND SECONDARY ELEMENTS ($R=3$)

	Value of E											
	−5	−4	−3	−2	−1	0	1	2	3	4	5	6
Row D (score)	0	2	3	3	4	7	7	7	7	6	3	1

Table XII then indicates the score obtained, given $R = 3$, for any value of E.

This method ensures that a forecaster who 'plays safe' by forecasting two possibilities, is less likely to make a very low score, but also he is unable to score very highly.

Table V is calculated as the set of Rows D, as produced in Table XII, for different values of R.

If the probability was some value other than 40 per cent, the Rows B and C would be calculated accordingly. Table XIII shows the Rows B and C for different values of probability of the secondary element.

TABLE XIII—CONSTRUCTION OF SCORE FOR DIFFERENT PRIMARY ELEMENT SCORES AND VARIOUS PROBABILITIES OF THE SECONDARY ELEMENT

Value of probability *per cent*		Score								
50	Row A	2	4	6	8	10	8	6	4	2
	Row B	1	2	3	4	5	4	3	2	1
	Row C	1	2	3	4	5	4	3	2	1
40	Row B	2	3	3	4	6	4	3	3	2
	Row C	0	1	3	4	4	4	3	1	0
30	Row B	2	3	4	5	7	5	4	3	2
	Row C	0	1	2	3	3	3	2	1	0
20	Row B	2	3	5	6	8	6	5	3	2
	Row C	0	1	1	2	2	2	1	1	0
10	Row B	2	4	5	7	9	7	5	4	2
	Row C	0	0	1	1	1	1	1	0	0

Tables VI and VII correspond to Table V, but refer to probabilities 20 per cent and 10 per cent respectively. For probability 30 per cent, a table has not been produced; it is adequate to use Table VI.

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SURFACE WINDS AT MOMBASA, KENYA

By B. RAMSEY

Summary. An analysis of the mean hourly vector wind, scalar wind, and constancy (q), at Mombasa, averaged for each month of the year from April 1967 to March 1970, clearly shows the two well-marked periods of north-east and south monsoon, and the dominance of the latter. Constancy is high, especially in the mid-periods of these seasons, and there are some interesting features which show up in the land- and sea-breeze effects superimposed on the monsoons.

Data available. In mid-March 1967, a Dines pressure-tube anemometer was set up on the low cliff of Ras Serani, overlooking the entrance to the main harbour (Kilindini) at Mombasa (Figure 1). The site is well exposed to seaward, especially between east-north-east and south-south-west, and is about 60 feet above mean sea level. Daily anemograms have been analysed for mean hourly values of vector wind, scalar wind speed and, from these,

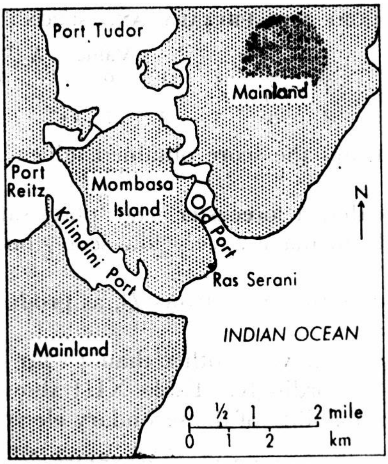

FIGURE 1—ANEMOMETER SITE, RAS SERANI, MOMBASA (04° 04′S 39° 42′E), AND ENVIRONS

constancy q^1. The instrument continues to give good service in spite of heavy exterior corrosion due to spray. The daily chart-changing has been left in the hands of the watchkeeping staff of the Signal Station, to whom thanks are due, through the Senior Harbourmaster, for providing this service.

Results. From the analysis in Table I*(a)* it is obvious that the months December, January and February cover the north-east monsoon, March and November are transitional, while April to October inclusive are entirely south monsoon months. The separate months will be discussed briefly.

January. This month shows the full development of the north-east monsoon, with q (Table I*(b)*) averaging 93 for the 24-hour period and up to 98 in the hours ending at 14 and 22 local zone time (LZT = GMT + 3). All times in the text are LZT.

February. The north-east monsoon still dominates but there are signs of a breakdown beginning. Not only are winds lighter in the afternoon than at corresponding times in January but they are less constant. This decrease in q is due to occasional incursions northward over the area by the intertropical convergence zone (ITCZ), generally associated with a large pressure rise to the south following marked cyclone activity in the Madagascar/Mauritius area. This often brings welcome rain to the area in the middle of drought conditions which are commonly associated with the dry north-east monsoon. Most unusually, this breakdown occurred in January 1970 for a few days.

March. The ITCZ frequently affects the area, especially in the latter half of the month, and on the whole gradients are lighter and more variable than those in February. Constancy is at its lowest for the whole year as periods of full north-east monsoon alternate with some fairly fresh blows from the south. The lowest hourly figure of 47 between 03 and 04 LZT is the minimum hourly value for the year. Early morning winds are still in the north-westerly quadrant, but this direction has been reached through south rather than north as in the full north-east monsoon months. The normally lighter gradients allow the land- and sea-breeze effect to dominate and afternoon winds are

TABLE 1(a)—MONTHLY AND ANNUAL MEAN HOURLY VECTOR AND SCALAR SURFACE WINDS, MOMBASA HARBOUR ENTRANCE 1967–70

Time	Jan.		Feb.		Mar.		Apr.		May		June	
LZT	deg	kt	deg	kt	deg	kt	deg	kt	deg	kt	deg	kt
01	052	2·2 (2·5)	065	2·6 (3·4)	149	2·2 (3·8)	192	3·3 (4·7)	204	7·8 (8·7)	193	10·6 (11·1)
02	032	1·5 (1·8)	050	1·7 (2·5)	166	1·6 (3·1)	206	2·9 (4·1)	211	7·0 (7·8)	196	10·1 (10.7)
03	005	1·1 (1·3)	019	1·0 (1·7)	188	1·4 (2·8)	215	2·4 (3·6)	214	6·7 (7·5)	202	9·1 (9·7)
04	344	1·1 (1·2)	341	1·0 (1·2)	221	1·0 (2·2)	226	2·2 (3·6)	216	5·9 (6·7)	208	7·8 (8·5)
05	340	1·2 (1·3)	323	1·0 (1·2)	248	1·1 (2·0)	240	2·0 (2·8)	226	5·0 (5·6)	214	6·8 (7·7)
06	343	1·4 (1·5)	329	1·2 (1·4)	285	1·3 (2·0)	249	1·7 (2·8)	239	4·2 (4·6)	223	5·7 (6·6)
07	340	1·5 (1·6)	340	1·2 (1·5)	293	1·4 (2·0)	260	1·8 (2·7)	246	4·2 (4·5)	229	5·1 (5·9)
08	342	1·9 (2·0)	343	1·5 (1·7)	291	1·5 (2·1)	270	2·3 (2·8)	244	4·0 (4·4)	232	4·9 (5·6)
09	358	2·6 (2·8)	355	2·1 (2·7)	257	1·4 (2·2)	242	2·8 (3·4)	230	5·9 (6·2)	226	6·4 (6·8)
10	026	3·0 (3·3)	034	1·8 (3·2)	211	1·3 (2·5)	215	3·9 (4·7)	221	7·7 (8·0)	215	8·0 (8·3)
11	067	4·7 (5·3)	082	4·4 (5·7)	170	2·1 (3·6)	198	5·0 (5·7)	214	8·9 (9·4)	209	9·7 (10·0)
12	078	6·8 (7·4)	082	6·3 (7·7)	156	3·6 (5·4)	190	6·0 (6·7)	208	10·2 (10·6)	205	11·4 (11·6)
13	082	8·7 (9·1)	085	7·0 (8·6)	149	4·2 (6·6)	183	6·8 (7·7)	206	11·3 (11·6)	204	12·2 (12·4)
14	083	9·6 (9·8)	086	7·9 (9·4)	144	5·1 (7·1)	181	7·4 (8·3)	204	12·3 (12·5)	202	12·7 (12·8)
15	082	10·1 (10·5)	084	8·4 (9·7)	143	5·4 (7·6)	180	7·7 (8·7)	204	12·3 (12·5)	201	12·2 (12·5)
16	081	10·1 (10·5)	085	8·4 (9·6)	141	5·5 (7·9)	179	7·4 (8·7)	203	11·6 (11·9)	199	12·3 (12·7)
17	079	9·7 (10·0)	082	8·6 (9·6)	139	5·1 (7·8)	179	7·2 (8·3)	203	10·7 (11·0)	199	11·7 (12·0)
18	077	8·7 (9·2)	081	8·1 (9·1)	135	4·6 (6·8)	179	7·0 (8·1)	203	10·1 (10·4)	199	10·8 (11·4)
19	073	7·5 (7·8)	079	7·3 (8·1)	132	4·5 (6·3)	177	6·4 (7·6)	201	9·1 (9·6)	197	10·3 (10·7)
20	073	6·7 (6·9)	077	6·6 (7·3)	134	4·4 (6·2)	179	5·8 (7·0)	200	8·6 (9·2)	193	10·3 (10·7)
21	071	6·1 (6·4)	077	6·0 (6·9)	132	4·5 (6·2)	174	5·4 (6·5)	197	8·3 (9·1)	191	10·5 (11·0)
22	068	5·2 (5·5)	077	5·3 (6·2)	132	4·1 (5·9)	176	5·8 (6·3)	196	8·6 (9·4)	189	11·1 (11·6)
23	064	4·4 (4·6)	075	4·7 (5·6)	137	3·7 (5·6)	180	5·1 (6·2)	197	8·5 (9·2)	190	11·3 (11·8)
24	058	3·3 (3·4)	072	3·4 (4·4)	142	3·0 (4·7)	186	4·4 (5·3)	200	8·6 (9·4)	192	11·2 (11·7)

Time	July		Aug.		Sept.		Oct.		Nov.		Dec.	
LZT	deg	kt	deg	kt	deg	kt	deg	kt	deg	kt	deg	kt
01	192	11·2 (11·5)	185	9·1 (9·7)	183	8·6 (9·0)	171	6·8 (7·2)	180	1·8 (2·8)	043	1·9 (2·4)
02	196	10·2 (10·7)	189	8·3 (9·0)	187	7·7 (8·2)	175	6·1 (6·7)	207	1·3 (2·4)	022	1·3 (1·9)
03	199	9·6 (10·0)	194	7·5 (8·3)	192	6·7 (7·5)	180	4·9 (5·7)	215	1·2 (2·3)	348	0·9 (1·4)
04	202	8·5 (9·0)	194	7·3 (8·1)	198	5·8 (6·8)	186	3·8 (5·0)	248	1·1 (1·7)	338	1·1 (1·4)
05	206	7·7 (8·2)	194	6·7 (7·5)	214	4·6 (5·4)	195	2·6 (4·6)	258	0·9 (2·1)	334	1·2 (1·3)
06	208	6·1 (6·9)	198	5·7 (6·8)	219	4·2 (5·4)	210	2·6 (4·1)	264	1·0 (1·8)	330	1·4 (1·6)
07	214	5·4 (6·2)	200	5·5 (6·7)	226	3·7 (4·9)	221	2·3 (3·9)	294	1·2 (1·7)	332	1·4 (1·6)
08	227	4·9 (5·6)	205	5·1 (6·3)	224	4·0 (4·9)	217	2·5 (4·1)	280	1·2 (1·9)	337	1·8 (2·1)
09	221	6·1 (6·5)	202	7·0 (7·4)	205	7·0 (7·3)	204	4·0 (4·8)	225	1·4 (2·0)	003	2·2 (2·7)
10	212	8·3 (8·6)	198	8·6 (9·1)	198	8·3 (8·6)	195	5·1 (5·6)	204	1·9 (2·8)	032	2·2 (2·8)
11	207	9·8 (10·1)	194	9·6 (10·1)	191	9·1 (9·5)	188	5·9 (6·3)	184	2·6 (3·4)	067	3·6 (4·5)
12	204	10·8 (11·0)	194	10·3 (10·7)	190	9·2 (9·6)	183	6·5 (7·0)	168	3·6 (3·7)	082	5·8 (6·4)
13	203	11·9 (12·0)	192	10·6 (11·0)	189	9·5 (9·8)	179	6·9 (7·5)	165	4·5 (5·4)	084	7·1 (7·9)
14	201	11·9 (12·2)	193	11·1 (11·5)	187	9·5 (9·9)	177	7·3 (7·9)	161	4·5 (5·9)	083	7·5 (8·4)
15	200	12·0 (12·2)	192	11·5 (11·9)	186	9·6 (10·1)	176	7·8 (8·5)	164	4·9 (6·0)	083	7·9 (8·8)
16	198	11·5 (11·8)	189	11·6 (11·5)	184	9·7 (10·1)	173	8·0 (8·7)	165	5·1 (6·1)	080	7·8 (8·8)
17	198	11·3 (11·6)	188	10·2 (10·7)	184	9·6 (10·0)	173	8·0 (8·6)	166	4·9 (5·8)	076	7·7 (8·8)
18	198	11·0 (11·3)	187	9·6 (10·1)	181	9·6 (9·9)	172	7·9 (8·5)	165	4·6 (5·6)	074	6·8 (7·7)
19	194	10·2 (10·6)	182	9·2 (9·7)	177	9·6 (9·9)	169	7·8 (8·3)	166	4·5 (5·5)	069	5·9 (6·7)
20	190	10·2 (10·6)	178	9·3 (9·7)	175	9·9 (10·3)	164	7·9 (8·3)	165	4·5 (5·3)	067	5·4 (6·2)
21	190	10·9 (11·2)	178	9·7 (10·1)	175	10·1 (10·6)	163	8·3 (8·7)	163	4·4 (5·2)	064	5·0 (5·8)
22	188	11·2 (11·6)	179	10·2 (10·5)	175	10·2 (10·6)	162	7·8 (8·2)	161	3·4 (4·7)	060	4·5 (5·0)
23	190	11·4 (11·6)	181	10·2 (10·7)	178	9·9 (10·3)	164	7·4 (7·8)	166	2·8 (3·6)	058	4·0 (4·5)
24	191	11·2 (11·5)	182	9·6 (10·1)	181	9·3 (9·7)	168	6·9 (7·5)	170	2·2 (3·3)	052	2·9 (3·3)

Note : Values in brackets are scalar mean speeds.

TABLE I(*b*)—MONTHLY AND ANNUAL MEAN HOURLY CONSTANCY *q* OF SURFACE WIND, MOMBASA HARBOUR ENTRANCE 1967–70

Time LZT	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
01	86	77	55	67	89	96	98	94	96	95	63	79	83
02	82	70	59	73	89	95	96	94	94	91	70	72	82
03	87	66	52	69	90	93	96	94	92	86	52	69	80
04	94	80	47	64	89	91	95	91	87	77	69	84	81
05	87	88	58	74	88	89	93	89	85	73	53	91	80
06	93	85	70	73	91	86	89	86	80	64	69	90	81
07	93	83	78	72	95	86	88	84	77	58	72	93	82
08	95	90	76	83	89	87	87	85	83	64	66	92	83
09	92	82	63	86	94	93	94	93	94	84	76	84	86
10	90	66	55	86	96	96	96	94	97	92	76	80	85
11	88	79	63	87	95	98	99	96	96	93	81	82	87
12	93	83	69	88	96	98	98	97	96	93	77	90	90
13	96	83	65	87	97	99	99	97	96	93	83	91	91
14	98	85	74	89	98	99	98	97	96	94	78	90	91
15	97	88	72	89	97	97	98	97	96	92	82	91	91
16	96	88	70	86	96	97	97	97	96	92	86	89	91
17	97	89	68	88	96	97	98	96	96	94	86	91	91
18	95	90	69	86	95	95	98	96	97	94	83	89	91
19	96	90	72	84	94	97	96	96	97	95	84	86	91
20	97	89	72	82	93	96	96	97	97	95	84	85	90
21	97	88	71	84	91	96	97	97	97	96	87	85	91
22	98	86	69	81	91	96	97	97	97	95	79	85	89
23	96	84	65	80	93	96	98	96	97	94	77	84	88
24	96	82	59	80	91	96	98	97	96	92	69	84	87
Mean	93	83	65	81	93	95	96	94	93	87	76	86	

almost normal to the mainland coast (Figure 2). A feature missing from the north-east monsoon but present in all the southerly months, shows up for the first time in March. This is an evening *increase* in wind speed, rather than a slow decrease, and it becomes more marked as the southerly monsoon develops (Figure 3). The cause is rather obscure, but it may be related to the ending of the land- and sea-breeze effect whereby the diurnal raising of the 850-mb level inland due to heating induces a circulation which involves slight subsidence a little way out to sea, after which the normal southerly wind of the monsoon resumes its uninterrupted flow.

April. Although not very strong on the average, the south monsoon is now well established and mean hourly speeds of 23 kt are reported by the month end. As in March, night-time winds retain a marked westerly component.

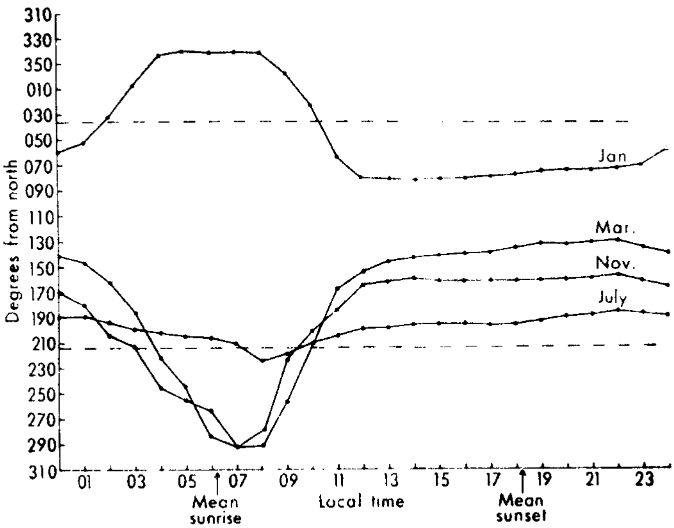

FIGURE 2—DIURNAL VARIATION OF WIND DIRECTION, MOMBASA

– – – Coastline 035–215°

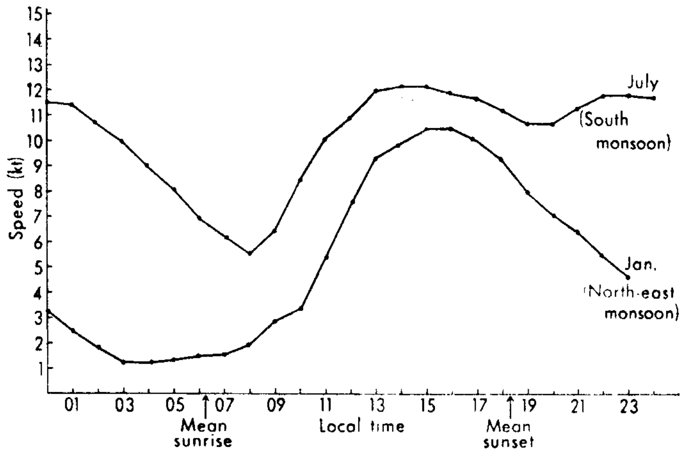

FIGURE 3—MEAN HOURLY SCALAR WIND SPEED, MOMBASA

Day-time winds are not backed so far to the south-east as in March because now the increased geostrophic wind builds up from the south. The evening increase remains slight and is an hour later. The period of maximum wind speed, 14 to 16 LZT, is about the same as in the previous three months but, as in March, and indeed in all the other southerly months, winds continue to back until the evening maximum has passed.

May. This is normally the wettest month of the year and the south monsoon is fully established. The flow is convergent on the whole as it passes northward tending to decelerate. The constancy q is much higher than in April, the monthly figure being 93 against 81, and the hourly figure reaching 98 at the time of maximum speed from 13 to 14 LZT. Early morning winds do not veer as far as they do in April and winds later in the day are further west of south than in any other month of this monsoon. This is probably due to the fact that at this time, the continental ridge is developing strongly from the south but is fairly closely adjacent to the equatorial trough which now extends from the Cape Guardafui area south-eastwards.

June. Early morning winds are nearer south than in May, and in fact, winds for the whole month are backed slightly. Highest speeds are in the hour 13 to 14 LZT, but there is a well-marked maximum from 22 to 23 LZT, two hours later than in March. Normally by the middle of the month the rains have ceased as the stream is no longer convergent but speed divergent following the release of the south-west monsoon across the Arabian Sea to India. June winds are the strongest of the year, reaching a scalar maximum of 12·8 kt from 13 to 14 LZT.

July. Winds this month are almost a copy of those for June, but still with a slight backing throughout the day and a slight decrease. Speed divergence has further increased as the Socotra area is now experiencing its strongest winds. Constancy, with a figure of 96 for the month is the highest of the year and reaches almost 100 between 10 and 11 LZT and 12 to 13 LZT. It does not fall below 87 (07 to 08 LZT) which is the highest minimum for the 24-hour period in any month.

August. This month shows a further slight backing and decrease in the strength of the south monsoon. Night winds veer least of any month and this results in the highest early morning minimum scalar speed of the year. The continued backing of the wind in the evening shows a mean component from east of south for the first time since April.

September. As the anticyclones of southern latitudes of the Indian Ocean increase their activity further to the east, and pressure begins to fall slightly over the southern parts of the interior of the continent, winds in September revert to the speeds of May but are backed by up to 20 degrees. In contrast to every month except its neighbour October, highest hourly wind speeds of the 24 hours are now at the evening maximum. Although q shows a steady fall from July, it is still remarkably high except between 04 and 08 LZT.

October. This is the last full month of south monsoon in normal years, and continues to show backing and weakening of the flow, especially by the end of the month. At this time the stream is becoming increasingly convergent as the ITCZ makes its southerly progress more apparent, and the 'short' rains may begin late in the month. As in the previous month, the strongest winds occur after dark (20 to 21 LZT) although scalar speeds at this time are the same as those in the period 15 to 16 LZT. Constancy is also highest at the evening maximum, reaching 96 in contrast to 58 from 06 to 07 LZT.

November. This may be called the other transitional month. However, there are rarely, if ever, years in which the north-east monsoon does not appear in March, whereas November may be an entirely southerly monsoon month. In 1968 the north-east monsoon did not start until 10 December. As in March, constancy drops in November to a monthly mean of 76, and the maximum speed of the day now reverts to the afternoon from 15 to 16 LZT. The early-morning breeze is once again in the north-west (normal to the coastline) as it overcomes the now weaker gradients. With the ITCZ making determined efforts to get south, this is often the second-wettest month of the year.

December. This month begins the short monsoon season of north-easterly winds, with average directions showing components from north throughout the 24 hours, and a higher constancy in the early land-breeze than in any other month. The fall in q after 08 LZT is, as in other north-easterly months, simply an indication of the varying times of onset of the sea-breeze. Afternoon mean wind directions are very like January and February but, as shows up in the south monsoon, there is a tendency for the wind to haul away from the coast as the season advances. Because December often has southerly winds at first, q is not as high as may have been expected, except as indicated above, in the period of the early land-breeze when it reaches 93 from 06 to 07 LZT.

Land- and sea-breeze effects. In this almost equatorial region, it may be expected that the land- and sea-breeze would be dominant the year round at Mombasa. Figure 2 indicates that this is true of the hotter north-east monsoon and the transition months, but much less so in the winter period of the southern monsoon.

Within a short time of the anemometer being erected, it became obvious that the land-breeze in the south monsoon was frequently not the result of a slow veer from the earlier wind of the afternoon and evening. In all months of the southerly season the wind from the sea remains more or less steady on about half the nights. On other nights, normally well after, but occasionally before, midnight, the land-breeze reaches the shore with an instantaneous change of speed and direction, almost as a front (Figure 4 is a schematic diagram of a typical trace on the anemogram). This occurs independently of the speed of the sea-wind before the change.

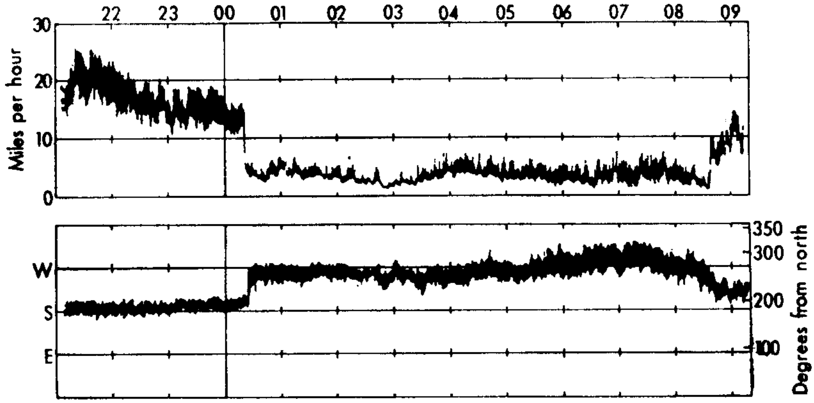

FIGURE 4—SCHEMATIC DIAGRAM OF A TYPICAL ANEMOGRAM SHOWING COMMENCEMENT OF LAND-BREEZE AT MOMBASA (SOUTH MONSOON)

An analysis was made (Table II) of the times of onset of sharp changes involved in land- and sea-breezes at the site. The table shows that in the north-east monsoon, while there is generally no land-breeze 'front', there is quite often a marked sea-breeze front. Figures 2 and 3 do not show these changes well as they are masked by averaging. The land-breeze front is thought to be due to the gradual build-up of a cold block of land-cooled air which spreads slowly towards the coast undercutting the sea-wind. Tops of palms at the time of change may still be moving under the influence of the sea-wind when the wind at the surface 70 to 100 feet below has ceased. Movement seaward is often restricted by warming over the lagoon, but on many occasions the seaward half of the lagoon is still well ruffled while the shoreward

TABLE II—AVERAGE TIMES OF SHARP LAND- OR SEA-BREEZE DISCONTINUITIES, MOMBASA HARBOUR ENTRANCE 1967–69

	Mean time (LZT) of onset of sea-breeze			Mean time (LZT) of onset of land-breeze		
	1967	1968	1969	1967	1968	1969
Jan.	No record	1039 (24)	1044 (13)	No record	0200 (4)	0049 (11)
Feb.	No record	0926 (14)	1059 (13)	No record	0110 (7)	0048 (12)
Mar.				0337 (8)	0226 (18)	0229 (19)
Apr.		No significant		0108 (20)	0050 (20)	0157 (24)
May				0136 (20)	0254 (17)	0415 (16)
June		discontinuities		0313 (22)	0323 (15)	0325 (18)
July				0446 (21)	0238 (20)	0420 (22)
Aug.		between		0220 (18)	0246 (16)	0308 (16)
Sept.				0138 (17)	0432 (24)	0306 (18)
Oct.		March and November		0249 (20)	0334 (18)	0345 (17)
Nov.				2312 (21)	0208 (12)	0108 (14)
Dec.	1035 (22)	1006 (13)	0956 (16)	No significant discontinuities		

Note : values in brackets are number of occasions.

half is smooth. The effective silence among the palms once the land-breeze has taken over is as good as an alarm clock. Why the process is not common in the early morning or night in the north-east monsoon is thought to be due to the fact that the geostrophic wind in that season is often offshore (340°) and the land-breeze forms more readily than the sea-breeze which has to 'break in' against this. The reverse holds for the south monsoon where the land-breeze is working against the geostrophic wind which is about 180° to 200°, or somewhat onshore.

Relationship with large-scale pressure changes. As noted above, there are only three months of the year when the average component for the month is from a northerly point. From Table III it may be seen that these are the only months in the year when the pressure at Lumbo, Mozambique (about 15°S 40°E) is lower than at Mombasa. That this pressure difference existed may have been assumed, but that it is so sensitive is remarkable and suggests an aid to forecasting winds in the Mombasa area. A survey of pressure changes at Tete, Mozambique, (about 16°S 33°E) confirms this and indicates that during the south monsoon a sharp rise of pressure there is very quickly followed by strong southerlies at Mombasa. The delay is about 12 hours and may be much less.

TABLE III—MONTHLY MEAN PRESSURE DIFFERENCES, MOMBASA MINUS LUMBO, MOZAMBIQUE (15°S 41°E)

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					millibars						
−1·1	−1·0	+0·2	+1·5	+1·6	+2·2	+2·2	+1·4	+0·7	+0·5	+0·2	−0·5

Comparison with Nairobi. In a previous survey[2] winds at Nairobi were summarized in rather the same way as has been done for Mombasa, except that 850- and 700-mb winds were included as well as the surface.

There are some points of interest and comparison. The north-easterly season is much longer at Nairobi than at the coast while only five months instead of nine have components from the south. The strongest winds are from north-east and not from south, and occur in February rather than June or July. Wind speeds at Nairobi in the south-easterly season are very low, but, as was indicated at the time, that station is very much on the western edge of the strong monsoon-flow of the Indian Ocean at that time of the year, and furthermore, it is almost at the 850-mb level. Constancy at Nairobi is very similar to that at Mombasa in the north-easterly season, but, because of the weakness of the flow in the winter, q-levels at that time are very much lower than at Mombasa.

Discussion. The investigation reveals a normal reversal of the monsoons with season and in a south latitude the southerly would naturally be dominant. However, the minor features superimposed on the monsoons are of interest, especially in connection with the large-scale pressure features of the region. The phenomenon of the land-breeze 'front' is perhaps unusual and it may be a useful exercise to install a recording rain-gauge at the anemometer site to investigate the shower-forming properties of this feature in the south monsoon. The north-east monsoon sea-breeze front, in common with the sea-breeze in many parts of the world, is often accompanied by a line of large cumulus which moves inland to the sea-breeze limit and there becomes stationary and often produces thunderstorms.

Acknowledgement. This article is published by permission of the Director-General of the East African Meteorological Department.

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2. RAMSEY, B.; Low-level wind flow at Nairobi. *Met Mag, London*, **95**, 1966, pp. 47–57.

551.524.33:519.2

AN ERRONEOUS USE OF THE CHI-SQUARE TEST

By P. B. WRIGHT

Summary. When the chi-square test of association is used to compare odd- and even-numbered years with respect to the sense of the change of temperature since the previous year (i.e. whether warmer or colder), the test must be modified because the sign of the change is partially dependent on the sign for the previous year. A Monte Carlo experiment has shown that the value of χ^2 obtained by the conventional method must be multiplied by a reduction factor of 0·6 before testing for significance.

In an investigation into the possible existence of a biennial oscillation in European summer temperatures, Davis* applied the chi-square test to compare odd and even years with respect to whether they were warmer or colder than the previous year. For ease of explanation, the problem may be rephrased as follows : Define the 'link' of the year M to have the value $+1$ if the summer of M was warmer than the summer of $M-1$, and the value -1 if colder, i.e. the link defines the sign or sense of the change of temperature since the previous year. The problem then is to assess the significance of the association between the link and whether the year is odd or even; that is, the question to be answered is whether there are significantly more (or less) odd positives and even negatives than would be expected in a series of random data. Davis assessed this by applying the chi-square test in the conventional way to contingency tables such as the example below :

	Link		
	+1	−1	Total
Odd	28	14	42
Even	14	28	42
Total	42	42	84

In this particular example, the value of chi-square was found to be 8·05, significant at better than one per cent.

Suppose a new contingency table were created by inserting every element in the above table twice. A table would be obtained with 168 items, the value of chi-square would be doubled and the significance level apparently improved. This procedure, of course, would not be used, because it is known that the additional 84 items would be completely dependent on the first 84 and so would add no further information.

* DAVIS, N. E.; The summers of north-west Europe. *Met Mag, London*, **96**, 1967, pp. 178–187.

However, the equivalent of this has already been done, albeit unwittingly, in obtaining the above contingency table in the first place. That is to say, the 84 elements in the table are not independent. This is because, in a *random* time series, the link of a given year is partially dependent on the previous link. Thus, suppose it is assumed that temperatures are randomly ordered, and suppose it is known that this year was warmer than last (although the actual values are not known), then it can be shown (see Appendix) that the probability is 0·67 that next year will be colder than this. In other words, if a given link of a random series is positive, the next link has a 0·67 probability of being negative.

It must be emphasized that the discussion here is *not* of meteorological dependence — the possible existence of persistence or cyclic behaviour. (That, after all, is what the test is trying to establish, and to do so the series is initially assumed to be random.) The dependence (or correlation) under discussion is *mathematical.*

Thus the number of independent items of data in the above contingency table is not 84, but somewhat less. This implies that the significance is less than was claimed, because the given degree of association (2 to 1) is more likely to be attained in a random sample of, say, 50 independent elements than in a sample of 84 independent elements. The problem of finding the correct value of the reduction factor by theoretical means is complex, and it is hoped to pursue this work further. An alternative approach is to perform a Monte Carlo experiment. This has been done by generating 10 000 random series each of 101 terms; the 100 links were designated 'odd' and 'even' alternately. Fuller details will be published later. The degree of association was found to exhibit a degree of scatter equivalent to that which would have been obtained using samples of 60 independent elements. Thus the correct value of the reduction factor is 0·6. (Strictly, the value given by the experiment was 0·592, with standard error of estimate 0·016.)

Hence the value of chi-square obtained by the conventional method must be multiplied by 0·6 before testing for significance. In the example on p.301, this yields the value 4·83, significant at about the three per cent level.

Appendix

To show that, in any randomly ordered series of real numbers, the probability that two adjacent links have opposite signs is 2/3.

(Let p(Z) mean : the probability that Z is true).

(i) Because the discussion is concerned only with links, it will suffice to consider the case of a random series from a population P with N values uniformly distributed in the range (0, 1). For, consider a random series from any population Q of N real numbers. Let the elements of Q be put into one-to-one correspondence with P by replacing them, in order of magnitude from the lowest, by the values

$$\frac{1}{N+1}, \frac{2}{N+1}, \ldots, \frac{N}{N+1}.$$

This transformation leaves unchanged the sign of the difference between any pair of elements. Hence the sequence of links formed from the transformed random series will be identical with the original sequence of links.

(ii) In the random series from P, let A, B, C be three successive points. Consider the links AB, BC. These links will have opposite signs if, and only if, either B is a maximum, or B is a minimum.

Let B have the value t. Then

$$\text{p }(B \text{ is a maximum}) = \text{p }(B > A \text{ and } B > C) = t^2.$$

Integrating over all values of t,

$$\text{p }(B \text{ is a maximum}) = \int_0^1 t^2 \, dt = 1/3.$$

By symmetry,

$$\text{p }(B \text{ is a minimum}) = 1/3.$$

Hence the probability that the links AB and BC have opposite signs is 2/3.

551.582(427):551.589.5

A NOTE ON WIND DIRECTIONS ASSOCIATED WITH LOW TEMPERATURES AND PRECIPITATION IN APRIL AT RIBBLEHEAD AND SQUIRES GATE

By B. INGHAM

Summary. In order to advise on the provision of shelter for ewes at lambing-time at a farm in Lancashire a study was made of observations in April from a coastal station and a hill station in north-west England. Tables and schematic diagrams are given showing the frequency of low temperatures and cold precipitation with various wind directions and speeds. At both stations there is a relatively high frequency of easterly winds and a relatively high frequency of precipitation with these winds. Nearly half of such precipitation occurs with temperatures 3°C or below and the highest frequency of temperatures 3°C or below occurs when the surface wind is easterly.

Early in January 1971, one of the District Agricultural Advisers, based at Preston, asked for assistance in the planning of artificial shelters for ewes at lambing-time at a farm approximately 800 ft* above MSL and just above Barnacre Reservoir on the west side of the Bowland Hills in Lancashire.

Apart from rainfall, there is little or no meteorological information for the area so there was no choice but to use observations from Blackpool Airport, Squires Gate, which lies some 17½ miles to the south-west of the farm close to the sea on the edge of a fairly broad flat plain — a markedly different site from that of the farm. Four observations, at 00, 06, 12 and 18 GMT, appear in the *Daily Weather Report*†, and these observations over the period 1961–70 were used to get some idea of the frequencies of wind directions associated with low temperature and cold precipitation, for it is cold and wet rather than cold alone which imposes the most stress on ewes and young lambs.

The analysis was done in the usual way for wind direction and speed with the added refinements of division of each speed range into a selection of temperature ranges and annotations of occurrences of precipitation. Occasions

* Distances and heights are given in traditional British units. Conversion factors to metric units are : 1 foot = 0·3048 m; 1 mile ≈ 1·6 km; 1 knot ≈ 0·5 m/s.
† London, Meteorological Office, *Daily Weather Report*.

of precipitation occurring at the time of observation only were counted; codings of 'weather in the past hour' were ignored. Quite a large complex table resulted from this analysis and to reduce its size the temperature classifications were reduced to two groupings, one including all temperature ranges, the other including only occasions of temperature 3°C and below. The simplified analysis is shown in Table I.

Tables of this type do not give the essentials at a glance and a series of diagrams was prepared showing the distribution of wind direction, precipitation and the occurrence of temperatures 3°C and below. Figures 1 and 2 are two examples. It should be noted that because of the discontinuous nature of the observations and the method of classification the drawing of envelopes enclosing the various values is not strictly correct but it serves very well the purpose of giving a substantially accurate picture which can be understood fairly quickly.

Figure 2, which has a zero line 0·2 cm from the centre in order to reduce crowding at the centre point, shows the distribution of wind direction, temperature and precipitation for wind speeds of 7 knots (Beaufort force 3) and above.

The relatively high frequency in April of winds with a component from the east is fairly well known but what may not be so well known is the (relatively) high frequency of precipitation with them. Inspection of Table I will show that at speeds up to 16 knots there is in fact a higher frequency of precipitation in the 080–100° grouping than for any other grouping. Moreover, nearly half of the precipitation with easterlies occurs with temperatures 3°C or below, and the highest frequency of temperatures 3°C or below also occurs when the surface wind is easterly. So it came as no surprise when during the first discussion at the farm about what should be done, and before any reference to these diagrams, the farmer said, 'It's protection against the south-east wind which blows round the shoulder of yon hill we need; we don't need to bother about the north wind — it may be cold but it's mostly dry'.

Although the occurrence of low temperatures at a station at sea level may give a good indication of the occurrence of snow on hills, it is reassuring to have independent confirmation of the correctness of such indications, especially as there were only 10 observations of snow or sleet* in the 1170 observations used in the analysis. Accordingly an analysis was made of the wind and weather at Ribblehead which stands at a height of 1023 feet above sea level and lies some 24 miles to the north-east of the farm. Apart from altitude, there is little similarity between the exposure of the farm and that of Ribblehead. The farm is virtually open to the west and south-west whereas Ribblehead lies in a pronounced col as may be seen from Figure 3.

The data analysed consisted of observations made hourly from 07 to 18 GMT for the Aprils of the six years 1961–63 and 1965–67. There were gaps on Sundays, Public Holidays and staff half-days, so that there is not a complete record of events, but it is the only available record. The wind analysis was made in the usual way with annotations for occasions of rain, snow and hail (drizzle being counted as rain, and sleet being included with snow). Coding of 'precipitation in the past hour' presented a problem — especially with regard to hail, for it seldom seems to fall at observation time — so to avoid duplication

* Sleet is here defined as snow and rain (or drizzle) together or snow melting as it falls.

TABLE I—PERCENTAGE FREQUENCIES* OF SPECIFIED WIND DIRECTIONS, SPEEDS, TEMPERATURES AND PRECIPITATION IN APRIL AT SQUIRES GATE

Speeds		350–010	020–040	050–070	080–100	110–130	140–160	170–190	200–220	230–250	260–280	290–310	320–340	Total
		Degrees from north												
		percentage frequencies												
Calm	*(a)*†	—	—	—	—	—	—	—	—	—	—	—	—	2·90
	(b)	—	—	—	—	—	—	—	—	—	—	—	—	0·09 (—)‡
	(c)	—	—	—	—	—	—	—	—	—	—	—	—	0·85
	(d)	—	—	—	—	—	—	—	—	—	—	—	—	— (—)
All speeds (except calm)	*(a)*	4·17	5·03	5·03	13·56	8·61	6·99	4·54	5·71	10·66	14·41	10·31	8·10	97·10
	(b)	0·68	0·77	0·93	3·24	1·71	1·45	1·79	1·45	2·97	2·47	1·28	0·77	19·53 (0·77)
	(c)	1·19	1·45	1·28	4·54	2·05	0·34	0·09	0·09	0·17	0·26	0·26	0·85	12·54
	(d)	0·17	0·09	0·09	1·19	0·09	—	—	—	—	0·09	—	0·17	1·85 (0·68)
4 knots or more	*(a)*	4·01	4·77	4·69	13·05	8·35	6·74	4·54	5·54	10·57	14·41	10·15	8·10	94·90
	(b)	0·68	0·77	0·85	3·07	1·71	1·45	1·79	1·45	2·97	2·47	1·28	0·77	19·27 (0·77)
	(c)	1·10	1·28	1·10	4·27	1·85	0·34	0·09	—	0·17	0·26	0·17	0·85	11·51
	(d)	0·17	0·09	0·09	1·19	0·09	—	—	—	—	0·09	—	0·17	1·85 (0·68)
7 knots or more	*(a)*	2·87	3·67	3·95	11·26	6·74	6·31	3·75	5·03	9·72	12·87	8·78	6·57	81·62
	(b)	0·68	0·68	0·77	2·90	1·62	1·45	1·45	1·36	2·64	1·96	1·11	0·77	17·39 (0·77)
	(c)	0·43	0·85	0·85	3·67	1·19	0·17	0·09	—	0·09	0·26	0·17	0·68	8·45
	(d)	0·17	0·09	0·09	1·19	0·09	—	—	—	—	0·09	—	0·17	1·85 (0·68)
11 knots or more	*(a)*	1·45	2·05	2·97	7·93	3·67	4·77	2·64	3·67	8·19	8·87	5·71	4·09	56·01
	(b)	0·17	0·51	0·51	2·39	0·93	1·28	1·02	1·28	2·30	1·37	0·93	0·43	13·22 (0·77)
	(c)	0·09	0·43	0·51	2·13	0·26	0·09	—	—	—	0·26	0·09	0·43	4·27
	(d)	0·09	0·09	0·09	1·11	0·09	—	—	—	—	0·09	—	0·17	1·71 (0·68)
17 knots or more	*(a)*	0·17	0·17	1·11	2·90	0·85	1·54	0·68	1·62	5·37	3·75	1·85	1·11	21·14
	(b)	—	0·09	0·09	0·77	0·26	0·68	0·34	0·68	1·71	0·93	0·43	0·17	6·14 (0·34)
	(c)	—	—	0·09	0·60	0·17	—	—	—	—	0·26	0·09	—	1·19
	(d)	—	—	—	0·34	0·09	—	—	—	—	0·09	—	—	0·51 (0·26)
22 knots or more	*(a)*	—	—	0·34	1·19	0·34	0·51	0·17	0·68	2·22	1·37	0·68	0·43	7·95
	(b)	—	—	—	0·34	—	0·26	—	0·34	0·85	0·34	0·26	—	2·39 (0·09)
	(c)	—	—	—	0·26	—	—	—	—	—	0·17	—	—	0·43
	(d)	—	—	—	0·17	—	—	—	—	—	0·09	—	—	0·26 (—)

* Percentages of 1170 observations in April 1961–70 for 00 (except 1967), 06, 12 and 18 GMT at Squires Gate (33 ft above MSL).
† *(a)* all occasions, *(b)* occasions with precipitation, *(c)* occasions with temperature ⩽3°C, *(d)* occasions with precipitation, and with temperature ⩽3°C.
‡ Values in brackets are percentage frequencies of snow.

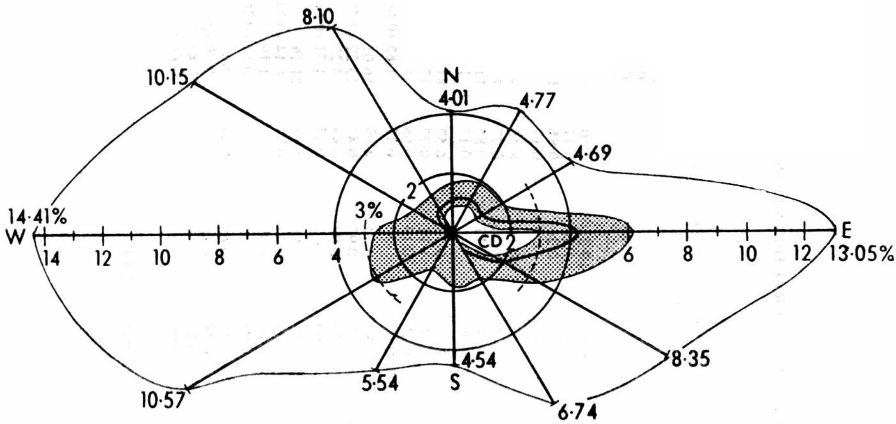

FIGURE 1—PERCENTAGE NUMBER OF OBSERVATIONS AT 00, 06, 12 AND 18 GMT, APRIL 1961–70 AT SQUIRES GATE OF WIND SPEED ⩾ 4 KNOTS, TEMPERATURE 3°C OR BELOW AND PRECIPITATION (STIPPLED AREA)

CD = Cold and dry.
Stippled area enclosed by thick line = temperature 3°C or below.

Total frequency of winds > 4 knots	94·90%	of 1170
Total frequency of winds with temperature 3°C or below	11·51%	
Total frequency of precipitation with winds > 4 knots	19·27%	
Total frequency of precipitation with temperature 3°C or below	1·85%	

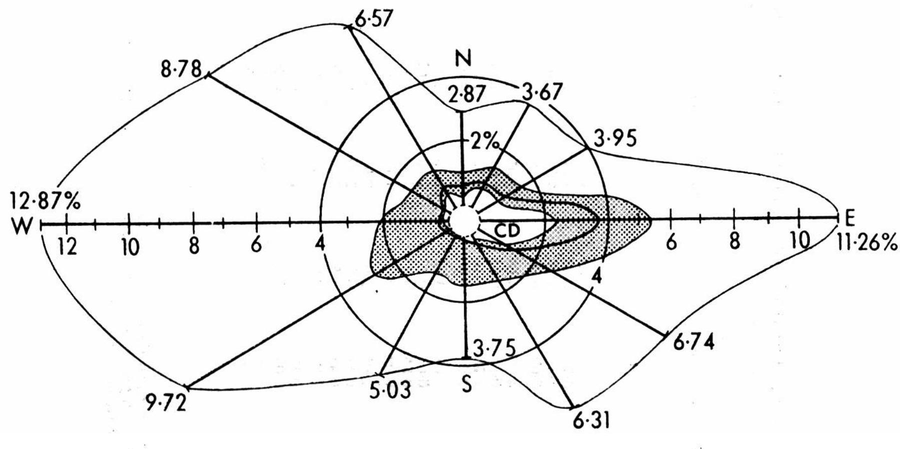

FIGURE 2—PERCENTAGE NUMBER OF OBSERVATIONS AT 00, 06, 12 AND 18 GMT, APRIL 1961–70 AT SQUIRES GATE OF WIND SPEED ⩾ 7 KNOTS, TEMPERATURE 3°C OR BELOW AND PRECIPITATION (STIPPLED AREA)

CD = Cold and dry.
Stippled area enclosed by thick line = temperature 3°C or below
Centre circle = zero line.

Total frequency of winds > 7 knots	81·62%	of 1170
Total frequency of winds with temperature 3°C or below	8·45%	
Total frequency of precipitation with winds > 7 knots	17·39%	
Total frequency of precipitation with temperature 3°C or below	1·85%	

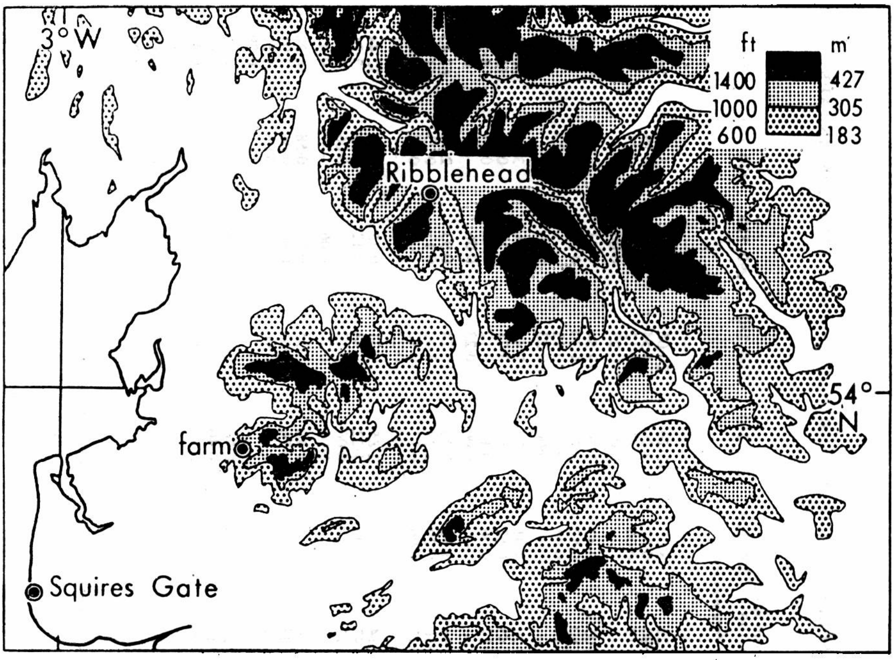

FIGURE 3—LOCATION OF THE FARM, SQUIRES GATE AND RIBBLEHEAD

in the counting of some occurrences or missing some altogether, 'past hour' codings were counted only when there was no precipitation reported at the previous hour. The complete analysis is shown in Table II. From this table diagrams such as Figure 4 may be constructed, showing frequencies of wind direction and associated forms of precipitation. Figure 4 refers to winds of 11 knots (Beaufort force 4) or more which without too much error can be considered an approximate equivalent of the 7 knots or more at Squires Gate used in Figure 2. Whereas there is a fair degree of symmetry about the east–west axis in Figure 2, there is distortion in Figure 4 which may fairly be attributed to restrictions on airflow by local topography. Comparison of the two figures suggests that when circumstances are such that the surface wind at Squires Gate might be easterly then it would probably be east-north-east at Ribblehead. It can be seen from Figure 4 that the sector 050–070° provides the greatest individual frequency of occurrence of precipitation and once again nearly half of it occurs as snow or sleet. When winds are from a westerly point, hail makes a larger contribution to the frequency of 'cold' precipitation than does snow, as can be seen from Table II; this is not unexpected.

Surface wind directions in hilly areas are subject to various constraints and in the absence of observations it is seldom possible to identify the precise direction of flow in a given set of circumstances. But if the commonest wind direction in the easterly sector can be identified then there is probably little doubt that that direction will also be the one with the greatest frequency of 'cold' precipitation and is therefore the direction against which there is greatest need for shelter.

Some surprise was expressed that the frequency of precipitation with easterly winds was as high as with westerly winds, for there is a strongly held

TABLE II—PERCENTAGE FREQUENCIES* OF SPECIFIED WIND DIRECTIONS, SPEEDS, TEMPERATURES AND PRECIPITATION IN APRIL AT RIBBLEHEAD

Speeds		Degrees from north 350–010	020–040	050–070	080–100	110–130	140–160	170–190	200–220	230–250	260–280	290–310	320–340	Total
		percentage frequencies												
Calm	*(a)*†	—	—	—	—	—	—	—	—	—	—	—	—	5·70
	(b)	—	—	—	—	—	—	—	—	—	—	—	—	0·29
All speeds (except calm)	*(a)*	7·33	6·34	16·05	8·37	4·54	3·55	6·22	3·60	13·20	20·05	1·63	3·43	94·30
	(b)	1·16	0·47	2·21	0·87	0·64	1·45	1·80	0·52	3·20	4·54	0·23	0·29	17·38
	(c)	0·17	0·06	1·98	1·28	0·06	0·29	0·17	0·06	0·17	0·12	—	0·23	4·59
	(d)	0·12	—	—	—	—	—	—	—	0·06	0·23	0·06	—	0·47
4 knots or more	*(a)*	6·97	6·16	15·76	8·08	4·42	3·49	6·05	3·43	12·50	19·54	1·63	3·37	91·40
	(b)	1·16	0·35	2·09	0·81	0·64	1·45	1·80	0·52	3·20	4·30	0·23	0·29	16·84
	(c)	0·17	0·06	1·98	1·28	0·06	0·29	0·17	0·06	0·17	0·12	—	0·23	4·59
	(d)	0·12	—	—	—	—	—	—	—	0·06	0·23	0·06	—	0·47
7 knots or more	*(a)*	6·34	5·24	14·31	7·15	3·60	3·02	5·29	2·91	10·29	17·45	1·16	3·20	80·00
	(b)	0·99	0·29	2·09	0·81	0·47	1·28	1·45	0·52	2·91	3·78	0·17	0·23	15·00
	(c)	0·17	0·06	1·98	1·28	0·06	0·29	0·17	0·06	0·17	0·12	—	0·23	4·59
	(d)	0·12	—	—	—	—	—	—	—	0·06	0·23	0·06	—	0·47
11 knots or more	*(a)*	4·65	4·18	12·62	5·82	2·50	1·86	3·96	1·80	7·73	15·24	0·93	2·15	63·43
	(b)	0·81	0·06	1·69	0·76	0·41	0·81	1·16	0·29	2·39	3·02	0·17	0·23	11·80
	(c)	0·17	0·06	1·98	1·16	0·06	0·29	0·17	0·06	0·17	0·12	—	0·17	4·42
	(d)	0·06	—	—	—	—	—	—	—	0·06	0·23	0·06	—	0·41
17 knots or more	*(a)*	2·85	2·21	7·85	2·85	0·58	0·64	1·34	0·35	2·85	9·31	0·35	1·28	32·44
	(b)	0·47	—	1·10	0·52	0·29	0·29	0·47	0·06	1·22	2·44	0·12	0·23	7·21
	(c)	0·17	—	1·51	1·05	—	0·17	0·17	—	0·06	0·12	—	0·06	3·31
	(d)	0·06	—	—	—	—	—	—	—	0·06	0·23	0·06	—	0·41
22 knots or more	*(a)*	0·87	1·45	4·13	1·45	0·23	0·12	0·64	—	1·40	5·35	0·12	0·58	16·34
	(b)	0·12	—	0·58	0·12	0·23	0·12	0·23	—	0·76	1·63	0·06	0·06	3·91
	(c)	—	—	0·52	0·81	—	—	0·12	—	—	0·06	—	0·06	1·57
	(d)	0·06	—	—	—	—	—	—	—	—	0·23	—	—	0·29
28 knots or more	*(a)*	0·12	0·52	1·45	0·12	0·17	—	0·23	—	0·76	2·31	0·06	0·35	6·07
	(b)	—	—	0·23	—	0·17	—	0·12	—	0·40	0·98	—	—	1·91
	(c)	—	—	0·23	0·06	—	—	0·06	—	—	0·06	—	—	0·40
	(d)	—	—	—	—	—	—	—	—	—	0·23	—	—	0·23
34 knots or more	*(a)*	—	0·06	0·52	—	—	—	0·06	—	0·23	0·58	—	0·17	1·62
	(b)	—	—	0·06	—	—	—	—	—	—	0·35	—	—	0·41
	(c)	—	—	—	—	—	—	—	—	—	—	—	—	—
	(d)	—	—	—	—	—	—	—	—	—	—	—	—	—

* Percentages of 1720 observations in April 1961–63 and 1965–67 for 07–18 GMT at Ribblehead (1023 ft above MSL) with some gaps, e.g. at weekends.
† *(a)* all occasions, *(b)* occasions with rain, *(c)* occasions with snow, *(d)* occasions with hail.

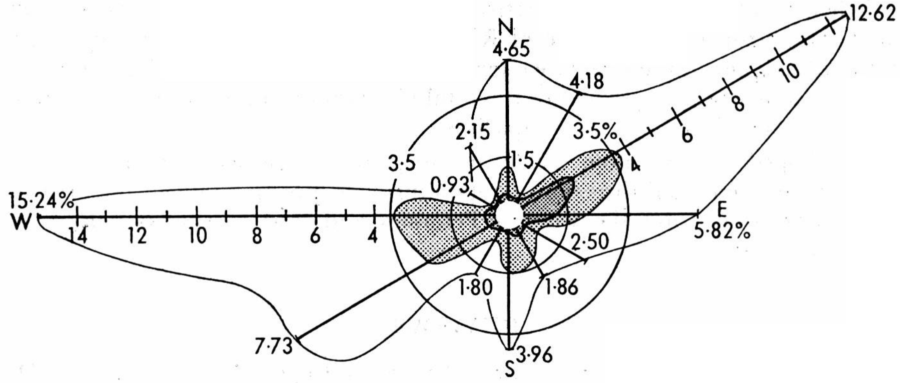

FIGURE 4—PERCENTAGE NUMBER OF OBSERVATIONS AT 07–18 GMT, APRIL 1961–63, 1965–67* AT RIBBLEHEAD OF WIND SPEED ⩾ 11 KNOTS AND ALL PRECIPITATION (STIPPLED AREA) INCLUDING SNOW AND HAIL

* Some missing — see text.
Stippled area enclosed by thick line = snow and hail.
Centre circle = zero line.

Total frequency of winds > 11 knots	63·43%	of 1720
Total frequency of all precipitation	16·63%	of 1720
Total frequency of snow and hail	4·83%	of 1720

belief that a mountain barrier affords protection from the weather to places on the lee side. In this connection, some distinction should be drawn between phenomena occurring with surface winds associated with a fairly deep established current which is changing only slowly — an example in this case is the breaking of North Sea stratus — and phenomena occurring with surface winds which form part of the circulation of a moving system. Figures from the originals of Tables I and II confirm the impression given by Figures 1 and 2 about the relative frequency of precipitation with easterly and westerly winds. If winds of 4 knots and stronger are considered, there was precipitation on a slightly higher proportion of occasions when the wind was easterly than when it was westerly (see Table III).

TABLE III—FREQUENCY* OF PRECIPITATION WITH EASTERLY AND WESTERLY WINDS IN APRIL AT SQUIRES GATE AND RIBBLEHEAD

	SQUIRES GATE Wind	SQUIRES GATE Precipitation	RIBBLEHEAD Wind	RIBBLEHEAD Precipitation
	number of occasions		*number of occasions*	
Easterly (050–130°)	305	65	410	106
	(1 occasion in 4·7)			
Westerly (230–310°)	412	79	551	139
	(1 occasion in 5·2)		(about 1 occasion in 4 in both cases)	

* See footnote to Tables I and II for details of observations.

When winds of 17 knots and stronger in the case of Squires Gate and 22 knots and stronger in the case of Ribblehead are considered the proportion is slightly higher in the case of westerlies but the number of actual occurrences forms such a small proportion of the total observations that too much reliance should not be placed on this comparison.

It is hoped that this note will draw attention to the features of the associations between wind direction, temperature and precipitation in the area of north Lancashire and the western Pennines and lead to similar studies in other hill areas.

REVIEWS

Forecasters' guide to tropical meteorology, Technical Report No. 240, by G. D. Atkinson. 265 mm × 200 mm, pp. xviii + 381, *illus.*, Air Weather Service (MAC) USAF, Scott Air Force Base, Illinois 62225, 1971. Price: $6. (Available to the public from National Technical Information Service, Springfield, Va 22151.)

This report, described as a *Forecaster's guide to tropical meteorology,* is not only up to date, but is just about as comprehensive a survey as could be found of the present state of the practical side of tropical meteorology. It is dated 1 April 1971, and the enormous bibliography containing 357 references dated up to and including 1970, indicates the amount of research that has gone into the preparation of the book.

The book is, on the whole, very clearly presented. Typographical errors are minimal, a rare example being the reference on page 6–25 paragraph 4 to figure 6–17 instead of 6–18. Also, typically transatlantic, much of the measurement of temperature and precipitation is in Fahrenheit and inches. The format is loose-leaf, allowing as it must for further addition resulting from the almost explosive increase in tropical work going on currently. Diagrams and tables, of which there are vast numbers, are generally clear and straightforward apart from a few minor exceptions such as some rather overcrowded charts of streamlines, isotachs and nephanalyses, but these were no doubt reduced for publication. Practically all areas of the world are dealt with, although, perhaps naturally, there is much reference to south-east Asia and the Pacific. The author is very much aware of shortcomings in tropical forecasting, especially any type of medium or long range, except in those areas which may be more easily linked with more well-documented middle-latitude areas. Data lack is still the greatest drawback, but, as he states at the end, much of the GARP effort will be directed at the tropics and he concludes 'during the next several decades tropical meteorology should be one of the most exciting and challenging areas of the atmospheric sciences'.

Very little in the report is concerned with forecasting conditions at sea, and considering the amount of the earth's surface which is water between the Tropics, this is perhaps rather an omission. The author does, however, emphasize the tremendous importance of up-to-date satellite information, and judging from some of the recent coverage of the Indian Ocean seen by the reviewer, it is obvious that APT readout should become universal at all stations of any size having responsibility for sea areas.

Oddly lacking in such a practical manual is any reference to the work of Johnson and Mörth in 1958–59 on pressure contour analysis in Africa, in spite of this having been published as long ago as 1962. Nor was there apparently any reference to Findlater's work on the cross-equatorial low-level jet. Apart from the areas near the Indian peninsula, much of the enormous area of the Indian Ocean is rather neglected. It is presumably left to readers to add their own notes in these spheres. Otherwise, the report is a must for all who are, or will be, working in, or in contact with, the Tropics.

B. RAMSEY

The physics of clouds, (second edition), by B. J. Mason. 242 mm × 165 mm, pp. xvi + 671, *illus.*, Oxford University Press, Ely House, 37 Dover Street, London W1, 1971. Price: £12.

Everybody working in the field of cloud physics is familiar with the first edition of this book, which for over a decade has been recognized as the most comprehensive and authoritative text on all microphysical aspects of the subject. A great amount of experimental research has been undertaken in this period, and the need for a revision has become clear, although the new work has in few respects demanded any drastic change of concept. The new edition extends the survey of the research literature from 1956 to about the beginning of 1970. In spite of extensive rewriting the book has increased in size by nearly 50 per cent (and in price by over 300 per cent).

The claim that it gives a detailed account of experimental and theoretical advances in the study of the microphysical processes is well justified, and in this respect the book has no rival and is an indispensable guide. It has retained exactly the same form and scope (9 chapters with the same headings) as its predecessor, and has been produced with the same care and rather old-fashioned elegance. Only in some minor respects can criticisms be raised.

The first is one not yet open to remedy, and indeed which the author straightway himself makes in his preface: it is the unfortunate absence of a secure dynamics of cloudy atmospheric motions, long sorely needed to provide a context for the microphysics and to allow its confident application to atmospheric events. This deficiency does not diminish the value of the book.

In the chapter on the artificial modification of clouds and precipitation more discussion might have been given to procedures for assessing the magnitude of the effect of seeding operations than can be compressed into two pages, for this is a problem of fundamental importance (with more general implications), not readily overcome by some programme of 'randomized' operations. Its difficulty is illustrated by the description of some particular seeding projects, but it is strange that these do not include the (weekly) periodic silver iodide emissions directed by Langmuir between December 1949 and March 1950. The possible results of this experiment, more dramatic than any so far made, provoked passionate controversy at the time, and provide an unrivalled example of the difficulty of using statistical methods to test the validity of operations for which there is no physical theory.

The chapter on radar techniques and observations has been brought up to date by the discussion of Doppler techniques and of the more recent ways in which radar echo intensity and configuration have been used to infer the form of airflow in precipitation. Most of the examples of radar displays are those used in the first edition, and do shameful injustice to those who have devised the modern data presentations, which are far more accurate and comprehensive, and even strikingly impressive as a kind of abstract art.

The chapter on the electrification of clouds, a subject to which the author himself has made many important contributions, is a particularly interesting one in view of the cursory treatment to be found in most texts and the way in which the important references are scattered about in the research literature. If the phenomena have little bearing on the motion of the atmosphere, which has come to be the predominant concern of meteorologists, they are nevertheless amongst the most spectacular of meteors and the most provocative to atmospheric physicists; apparently the number of alternative theories has increased, but still no one is much more convincing than the others.

It must be emphasized, however, that the main value of the book rests on the chapters other than the three specifically mentioned, that is, on those which concern the nucleation and growth of water drops and ice crystals in air. The extensive studies which have been made should be of great interest to physicists outside the field of meteorology, while cloud physicists will appreciate the unswerving thoroughness with which they are passed under review and conveniently referenced.

Finally, a personal reaction can be addressed to the publishers: the book would be easier to handle and to read if it had a larger page size.

F. H. LUDLAM

Global effects of environmental pollution, edited by S. F. Singer. 240 mm × 160 mm, pp. 218, *illus.*, D. Reidel Publishing Company, P.O. Box 17, Dordrecht – Holland, 1970. Price: Dfl. 40.

The concluding discussion in this volume describes the symposium which gave rise to it as a 'curtain raiser for world-wide efforts to set up a global monitoring system of crucial pollution parameters as well as for the forthcoming United Nations Conference of 1972 dealing with the problems of the human environment'. It is undoubtedly true that since then (December 1968) the scene has been rapidly filled with a mounting interest and clamour for activity in this field.

The volume collects, under the editorship of S. F. Singer, 18 papers by a group of well-known authors brought together to this symposium by the American Association for the Advancement of Science. There is a grouping of the papers into four main sections dealing with the chemical balance of gases in the atmosphere, the nitrogen cycle, effects on climate and the role of the oceans in the pollution problem. There is of course a good deal of overlapping of interest in these sections.

Meteorologists will not be surprised to find contributions here from S. Manabe — though rather surprisingly the one dealing briefly with the effects of carbon dioxide on the radiative convective equilibrium of the atmosphere appears in the group on chemical balance rather than in that on effects on climate.

In general the papers provide a rather balanced and unsensational questioning of the present inadequate state of knowledge and understanding over the whole field. It is undoubtedly possible to find issues which perhaps were not questioned sufficiently. One example which immediately occurred to the writer, in the paper on inadvertent modification of weather, is the virtual acceptance of the original claim that increased rainfall in La Porte, Indiana, was a direct result of pollution, whereas there has since been a challenging of the whole validity of the rainfall record concerned. Another, in the paper on interaction between the oceans and the land, is the contention that the main reason for recently increased acidity in the rains over Sweden is 'of course, increased industrial air pollution by SO_2'. But in a field in which many may regard printed paper as a by no means neglible source of pollution this slim rather well-produced volume will be relatively welcome, at a price (£4) which is at least consistent with the current trend.

F. PASQUILL

NOTES AND NEWS

Global Atmospheric Research Programme

Atlantic Tropical Experiment. The Global Atmospheric Research Programme (GARP) Atlantic Tropical Experiment developed jointly by the World Meteorological Organization and the International Council of Scientific Unions is an effort designed by some 25 nations to provide a basis for estimating the effects of the smaller tropical weather systems on the larger-scale atmospheric circulations and to provide comprehensive data against which the validity of numerical predictions can be tested in the tropics.

As now planned the central location of the experiment will be an area 1000 by 1000 km at a distance of about 1000 km from the west coast of Africa between latitude 5 degrees and 15 degrees north. During the months of June, July and August 1974, a fleet of some 20 ships will be equipped with modern instruments for probing the atmosphere, for making temperature and wind soundings and for flying tethered balloons each with a chain of instruments extending from the surface of the sea to 1000 m or more if possible. A geostationary satellite over South America will constantly survey the area recording both visible light and invisible infra-red rays revealing temperatures and humidities, while aircraft will be directed to these areas for more detailed studies of individual disturbances. The intention is that weather disturbances forming over the African mainland south of the Sahara Desert will be carefully mapped as they pass this network of stations over the Atlantic Ocean.

Global experiment. The Atlantic Tropical Experiment is the forerunner of an experiment to be conducted on a global scale two years later. A number of questions raised by the global experiment will by necessity have to be answered by the tropical experiment for the former to be successful in trying to understand how the atmosphere circulates and how variations of this circulation generate weather.

In 1976 an intensive observation of the atmosphere will be carried out by a series of at least six satellites, two in polar orbit and four in geostationary position, each of the latter surveying about one-quarter of the tropical and subtropical latitudes. To supplement the satellite coverage, and because in the tropics winds need to be measured directly, a series of carrier balloons with special dropsondes may be used to measure winds in tropical latitudes. Balloons will also be used in the southern hemisphere to provide critical reference observations that will permit more reliable use of satellite observations. Since vast ocean areas in the southern hemisphere are frequently covered with clouds, thereby making low-level atmospheric readings from satellite elevation less reliable, a system of buoys is also being developed to make complementary surface observations.

WMO PRESS RELEASE

Special merit promotion of Dr R. J. Murgatroyd, O.B.E.

It is a pleasure to record that Dr R. J. Murgatroyd has been granted promotion to Deputy Chief Scientific Officer under the scheme which permits the promotion of scientists of exceptional ability in research without any consequential change in their administrative responsibilities. Promoted to Senior Principal Scientific Officer in 1957, Dr Murgatroyd was freed of administrative responsibilities in 1963 in order to enable him to pursue his important studies of the circulation of the stratosphere and mesosphere, on which subjects he is one of the world's leading experts.

Dr Murgatroyd's studies have examined the radiative heat sources and sinks in the stratosphere and above, and he has evaluated the consequent meridional circulations which, although too slow to be observed directly, are of vital importance in determining the structure of the higher atmosphere. Dr Murgatroyd has extended his studies to consideration of the mixing processes involved and has made fundamental contributions to the nature of large-scale mixing in a stratified medium such as the stratosphere.

Recognizing that a comprehensive explanation of stratospheric motion must start from the fundamental dynamical equations, Dr Murgatroyd has initiated the computer programming of the numerical simulation of the stratospheric circulation by direct numerical integration of the dynamical and thermodynamical equations. Such methods have been shown to give valid explanations of important features of the lower atmosphere. The Meteorological Office is fortunate to have a scientist of Dr Murgatroyd's wide interests and experience to exploit the potential of this approach to the understanding of the stratosphere and mesosphere.

J. S. SAWYER

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