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FOG AT LEEUWARDEN, THE NETHERLANDS

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Summary.—The diurnal variation of fog during a period of eight years at Leeuwarden is investigated. It is found that in general the diurnal and seasonal variation is similar to that found by N. E. Davis concerning London Airport. The connexion of fog with the surface wind direction is examined and it is shown that the probability of fog is relatively high in the case of winds from a southerly direction, partly due to the influence of the water areas south of the station.

Introduction.—As besides the work of C. Braak[1] little has been published on fog in the Netherlands it seemed worthwhile to make an analysis of fog at Leeuwarden, as sufficient observations of the meteorological station at Leeuwarden were available.

The geographical situation of Leeuwarden is shown in Figure 1. The meteorological station is about two kilometres north-west of the town. In the vicinity of Leeuwarden large water areas are present—the North Sea from west-south-west to north-east (250°–50°) and the Frisian lake district and the IJselmeer from south to south-west (180°–210°). Between 210° and 250° air masses originating from the North Sea first have to cross the peninsula of North Holland and a small part of the IJselmeer before reaching Leeuwarden.

The soil is clay and the country is flat and practically at sea level. As there are no industrial areas with a large amount of smoke pollution within a range of 100 kilometres, fogs are exclusively water fogs, which was proved by the observation that in almost all cases when fog occurred the relative humidity was more than 95 per cent.[2] The amount of domestic smoke in winter is probably so small that it can be neglected.

The eight-year period 1950–57 was investigated. Sufficient marks at various distances were available in that period to determine the visibility correctly.

Diurnal and annual variation of fog.—As the investigation of C. Braak[1] concerning the diurnal variation of fog for several stations in the Netherlands does not give much information, because only the 0800, 1400 and 1900 hour observations were used, we made an analysis similar to those published by N. E. Davis[3] in regard to London Airport and by W. E. Saunders and W. D. Summersby[4] in regard to Northolt Airport.

The number of hourly observations with a visibility less than one kilometre at a certain hour of the day was noted for periods of 15 days coinciding with the first or the second half of each month. The numbers for corresponding periods in eight successive years were added and the figures obtained in this way were grouped according to hours and months.

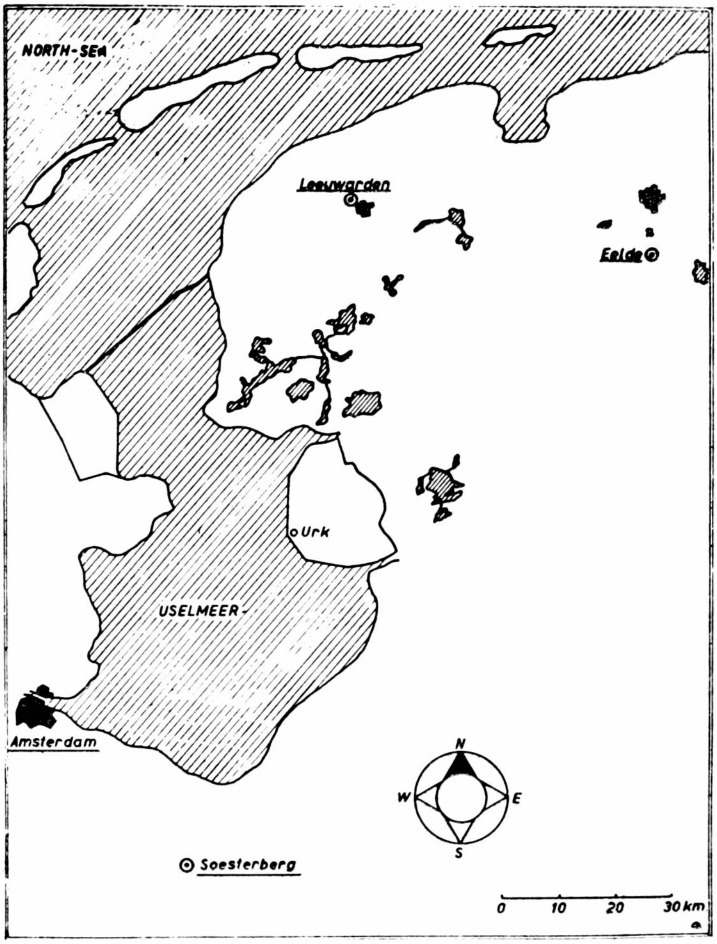

FIGURE 1—MAP SHOWING THE LOCATION OF LEEUWARDEN

These data include a relatively small number of occasions in which the poor visibility was due to heavy snowfall or showers in the winter months or to a very dense drizzle. The visibility was reduced to less than one kilometre by precipitation in 11 per cent of the observations, mainly in December, February and March. The result is shown by an isopleth map in Figure 2.

The most significant features appear to be as follows:

1. The low fog frequency in summer with a minimum in the second half of June and the gradually increasing frequency in August and September in the early morning near sunrise when fog clears between 0600–0800 G.M.T.
2. The rapid increase of fog frequency in October; the fog forms mainly between 1800–1900 G.M.T. and clears between 0800–1000 G.M.T. The first half of October shows a high maximum at sunrise.
3. The strongly increasing tendency for the fog to persist all day in November.

4. The further increase in December to a maximum frequency in the morning and the high percentage of fogs persisting all day.
5. The first half of January shows a relatively low fog frequency, but it increases again in the second half of that month.
6. February and March show a high maximum just before sunrise and from February to March there is an increasing tendency for fog to clear during the forenoon, but form again soon after sunset.
7. The rapid decrease in fog frequency in April both in the morning and the evening.
8. In May and the first half of June there is a low maximum at sunrise.

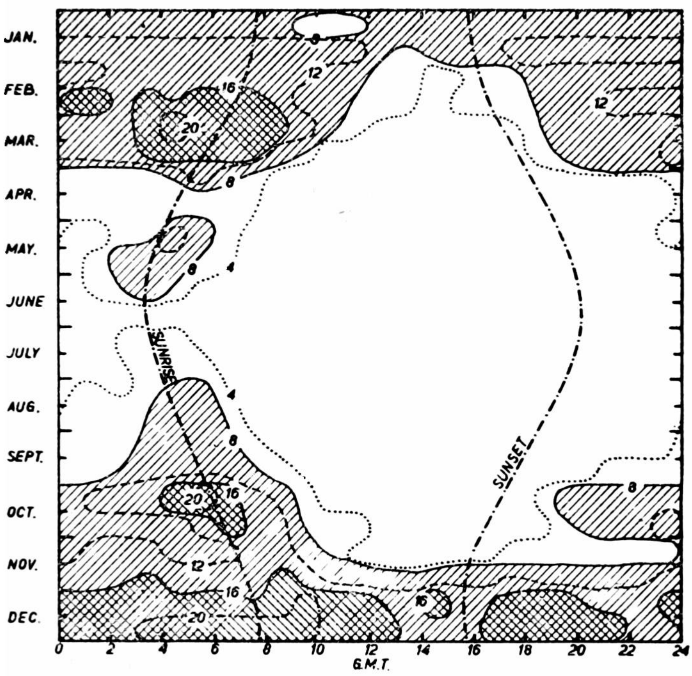

FIGURE 2—DIURNAL AND ANNUAL VARIATION OF FOG AT LEEUWARDEN

Comparison of the six months April–September and October–March, shows that only 16 per cent of the occasions were observed in the half-year April–September and these consisted almost exclusively of radiation fog in the early morning. The high frequency of fog in winter is due to the increasing length of night together with continued high humidity because of the predominance of moist maritime air masses in this season. From the second half of November to February the incoming solar radiation is often not sufficient to break down the strong night inversions and clear the fog.

In general Figure 2 shows the same frequency distribution as the corresponding diagram for the London area,[3, 4] but in detail a few differences can be seen. At Leeuwarden the morning maximum in the winter months is found at sunrise whereas in the London area the maximum is shifted to a couple of hours after sunrise, owing to the amount of smoke pollution from domestic fires, as was suggested by N. E. Davis.

Secondly, the above authors find a minimum frequency in the early morning hours of December in the London area, which contrasts with the strong maximum at Leeuwarden for the corresponding time. However, from a second report on fog at London Airport by D. C. Evans[5] we may conclude that the reported minimum in December in the London area probably is not significant owing to the short period investigated.

As the London area and Leeuwarden broadly show the same features it may be assumed that in the greater part of the Netherlands the diurnal and annual variation of fog will be similar to that shown in Figure 2.

The connexion with the surface wind direction.—The relation between the fog frequency and the surface wind direction was investigated by choosing intervals of 30°* and counting the number of hourly observations of fog within each interval. We also noted the wind speed and the visibility in each case. The occasions in which the visibility was reduced by precipitation were omitted. The result of the eight-year period 1950–57 is shown in Table I and partly in Figure 3.

TABLE I—WEATHER CONDITIONS DURING FOG

Surface wind directions	Wind speed in knots 1–2	3–5	6–10	>10	Total number	Percentage	Visibility in metres <100	100–500	500–1000
degrees					*number of occasions*				
calm	723				723	22·3	208	336	179
010–030	18	18	27	9	72	2·2	6	43	23
040–060	39	36	37	2	114	3·4	21	54	39
070–090	55	60	58	25	198	6·1	22	105	71
100–120	41	61	97	27	226	7·0	37	95	94
130–150	44	59	33	12	147	4·5	23	75	49
160–180	62	110	153	31	356	11·0	70	173	113
190–210	133	192	302	136	763	23·6	142	381	240
220–240	67	67	124	46	304	9·4	51	157	96
250–270	45	35	43	19	142	4·3	24	69	49
280–300	18	16	31	12	77	2·4	12	35	30
310–330	12	24	15	4	55	1·8	12	23	20
340–360	9	26	22	6	63	2·0	13	34	16
Total number ...	1266	704	942	328	3240	100	641	1580	1019
Total number, calms excluded	543	704	942	328	2517		433	1244	840

Figure 3 shows a very steep maximum in the interval 190°–210°, that is, in the south to south-south-westerly direction, and a secondary maximum between 100°–120°. Wind speeds of 6–10 knots give the largest contribution to the total result.

Table 1 shows that in fog, visibilities of 100–500 metres are most frequent whereas dense fogs with a visibility of less than 100 metres only occur in 20 per cent of the total number of occasions. In the case of calms the percentage is somewhat higher.

In Table I is calculated the probability of a certain surface wind direction w during fog $p(f; w)$, however, the forecaster is more interested in the probability of fog in case of a given surface wind direction $p(w; f)$.

This can be calculated from:

$$p(w;f) = \frac{p(f;w)}{p(w)}\, p(f), \qquad \ldots\ldots(1)$$

$p(w)$ being the probability of the surface wind direction w and $p(f)$ the probability of fog without taking into account the wind direction.

* Use was made of the synoptic observation books, in which the surface wind direction is noted in tens of degrees. So an interval 010°–030° includes the noted wind directions 010°, 020° and 030° which corresponds with a real interval 005°–034°.

As the greater part of the observations of fog occur in the six months October–March, $p(w;f)$ was calculated for that period. The probabilities $p(f;w)$ for these months are slightly different from those in Table I, which were calculated for the period of twelve months.

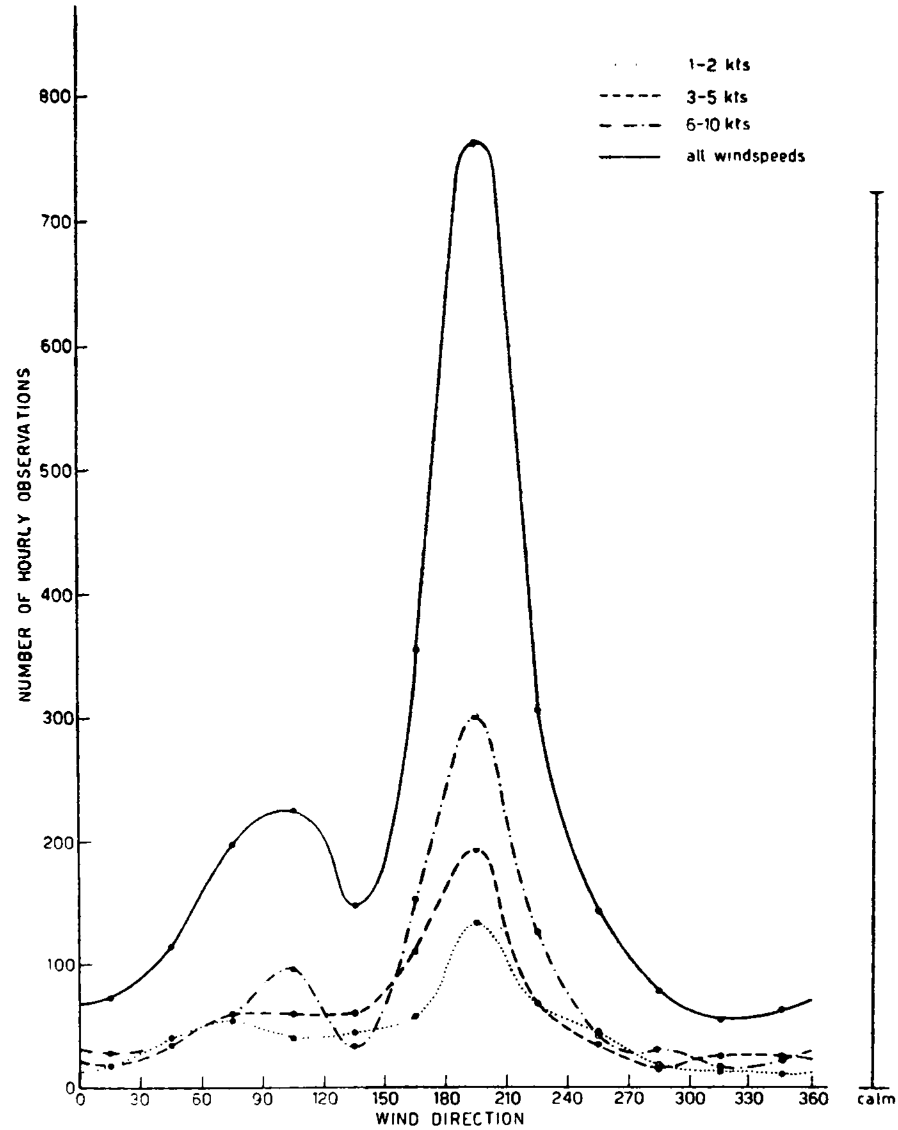

FIGURE 3—FREQUENCY DISTRIBUTION OF THE SURFACE WIND DIRECTION DURING FOG

Therefore $p(f;w)$, $p(w)$ and $p(f)$ were calculated from the hourly observations for the two three-month periods October–December and January–March, averaged over the eight years 1950–57. We calculated $p(f;w)$ and $p(w)$ without taking into account the wind speeds. For $p(f)$ we found 8·7 per cent in October–December and 6·7 per cent in January–March. The other probabilities are listed in Table II.

TABLE II

Surface wind directions	October–December			January–March		
	$p(f;w)$	$p(w)$	$p(w;f)$	$p(f;w)$	$p(w)$	$p(w;f)$
degrees			*percentages*			
calm	18·1	6·3	25·0	21·5	5·0	28·0
010–030	0·6	1·9	2·8	2·7	4·2	4·3
040–060	1·5	3·8	3·4	4·5	6·0	5·0
070–090	5·8	6·6	7·7	6·9	10·9	4·2
100–120	10·5	7·1	13·0	4·5	8·3	3·6
130–150	6·6	6·2	9·6	2·5	4·9	3·4
160–180	13·3	11·1	10·4	8·4	8·5	6·6
190–210	28·8	18·2	14·0	21·0	13·2	10·7
220–240	9·9	13·0	6·6	11·5	12·3	6·3
250–270	3·0	11·4	2·3	6·1	10·6	3·9
280–300	1·4	7·4	1·7	3·7	7·1	3·5
310–330	0·3	4·3	0·6	2·7	4·8	3·8
340–360	0·2	2·8	0·6	3·9	4·5	5·8

The most significant features are:

1. The close correlation between fog and calms in both periods.
2. The maximum of $p(w;f)$ connected with surface wind directions between 190° and 210° in both periods.
3. A maximum of $p(w;f)$ with east-south-easterly directions in October–December.
4. The low values of $p(w;f)$ with directions between west and north in October–December.

The maximum of $p(w;f)$ for the interval 190°–210° was investigated separately to find out if the fog probability is influenced by the water areas south of Leeuwarden. Therefore provisional investigations were carried out at Eelde and Soesterberg (Figure 1). At Eelde only the hourly observations of 1955, 1956 and 1957 were available, whereas we had the hourly observations at Soesterberg of 1954, 1955 and 1956 at our disposal. The probabilities $p(f)$ and $p(f;w)$ were calculated for the months October–March and summed over the three years in the same way as those of Leeuwarden.

For the corresponding periods $p(w)$ was calculated from wind frequency distributions for the two stations which were put at our disposal by the Director in Chief of the Koninklijk Nederlands Meteorologisch Instituut. From equation (1) $p(w;f)$ could be estimated and the result together with that for Leeuwarden for October-March is shown in Table III.

TABLE III

Surface wind directions	$p(w;f)$		
	Eelde	Leeuwarden	Soesterberg
degrees		*per cent*	
calm	27·9	26·5	20·5
010–030	4·4	3·7	5·9
040–060	1·9	4·5	3·2
070–090	6·8	6·1	1·7
100–120	8·5	7·9	3·3
130–150	6·9	6·7	2·2
160–180	7·5	9·1	3·7
190–210	7·4	12·4	8·3
220–240	5·2	7·0	4·2
250–270	3·2	3·1	1·2
280–300	3·4	2·6	1·3
310–330	3·6	2·2	2·3
340–360	2·2	3·7	1·2

Comparison of $p(w;\ f)$ for the three stations shows that at Leeuwarden $p(w;f)$ for surface wind directions between 190° and 210° is about 50 per cent higher than at Eelde and Soesterberg. In the intervals 160°–180° and 220°–240° $p(w;\ f)$ at Leeuwarden and Eelde is considerably higher than at Soesterberg, whereas at Soesterberg $p(w;\ f)$ in the interval 010°–030° is a little higher than at Eelde and Leeuwarden. Though the comparison is not quite correct, because the investigated periods are not the same for the three stations, it is clear that the fog probability $p(w;f)$ is considerably influenced by the IJselmeer and the lake district, resulting in relatively high fog frequencies at Leeuwarden in case of surface wind directions between 190° and 210°.

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REFERENCES

1. BRAAK, C.; The climate of the Netherlands. *Meded. ned. met. Inst., De Bilt*, No. 42, 1939.
2. BUMA, T. J.; A statistical study of the relationship between visibility and relative humidity. *Bull. Amer. met. Soc., Boston, Mass.*, **41,** 1960, (to be published).
3. DAVIS, N. E.; Fog at London Airport. *Met. Mag., London*, **80,** 1951, p. 9.
4. SAUNDERS, W. E. and SUMMERSBY, W. D.; Fog at Northolt Airport. *Met. Mag., London*, **80,** 1951, p. 255.
5. EVANS, D. C.; A second report on fog at London Airport. *Met. Mag., London*, **86,** 1957, p. 333.

ACCURACY OF RESULTANT WINDS AND STANDARD VECTOR DEVIATIONS OF WINDS COMPUTED FROM GROUPED FREQUENCIES OF SHORT-PERIOD DATA BY DIFFERENT METHODS

By D. DEWAR, B.Sc.

In their *Handbook of statistical methods in meteorology*[1] Brooks and Carruthers describe a procedure for computing the resultant winds and standard vector deviations from frequency summaries of grouped wind speeds. To compute resultant winds the data are grouped in 30-degree ranges of direction and 10-knot ranges of speed up to 39 knots after which 20-knot ranges are used up to 139 knots. For winds above 139 knots actual speeds are taken. Appropriate factors are used for each speed range so that when multiplied by the corresponding frequencies, approximations to the sums of the north–south and east–west components are obtained. Winds in the range 0–9 knots are regarded as calms and no account is taken of their speed. The standard vector deviation σ is obtained by subtracting the square of the speed of the vector mean wind ($V_R{}^2$) from the mean square of the individual wind speeds and taking the square root of this difference. The ranges of speed are the same as used for computing resultant winds. For each range an appropriate factor is used which, multiplied by the frequency for that range, is regarded as giving an approximation to the sum of the squares of wind speeds in the range. These multiplying factors are computed on the assumption that all speeds in a given speed range are equally likely though an allowance is made in the higher ranges for the fact that observed winds tend to be near the lower limits. Values of σ given in the summaries of upper air data published by the Meteorological Office[2] are computed using the method described by Brooks and Carruthers, but resultant winds are obtained by a modification of their method which should give greater accuracy as actual speeds in each direction range are used. It is implied in the *Handbook of statistical methods in meteorology*, though not expressly stated, that the method is intended for use with summaries of winds for a period of several years where the number of observations is 500 or more.

The question recently arose as to what errors are likely if the simple method of computing σ described in the Handbook is used for frequency distributions of less than 100 observations. The answer obviously depends on the extent to which the actual frequency distribution departs from the type of distribution on which the multiplying factors used in the Brooks and Carruthers method are based. A partial answer was provided by computing values of σ by the above method and two other methods of presumably greater accuracy for a station for which there were only three years of data giving less than 100 observations; the values obtained for three selected distributions by each method were then compared with accurate values of σ. Values of resultant winds were also computed by the method given in the Handbook and compared with accurate values and those obtained by the modification referred to above.

Considering first the computation of values of σ, the three methods used were:

(*a*) 10-knot speed ranges using the square of the mean speed of the actual winds in the range as the multiplying factor;

(*b*) speed ranges and factors as set out in the *Handbook of statistical methods in meteorology* (Table LXII, p. 189)[1];

(*c*) 10-knot speed ranges and factors based on the square of the speed at the mid-point of the range, except for the highest range each month where the actual speeds were used.

Table I gives the actual values obtained by method (*a*) and the departures from these values of σ computed by methods (*b*) and (*c*) which are regarded as being less accurate. Data are not given for the lower levels as there were relatively few winds of 40 knots or more.

If the values obtained by method (*a*) are accepted as a standard it is evident that there are appreciable errors (amounting to over 30 per cent in some cases) when method (*b*) is used; these probably arise from the use of 20-knot ranges of speed for grouping strong winds, the effect being, as would be expected, to make the values of σ too large. If the winds are grouped in 10-knot ranges (method (*c*)) and actual speeds used in the highest range each month, there are only a few significant departures though one of these (July 60 millibars) is a serious under-estimate. It is interesting to note that, at 200 and 150 millibars where winds are strong, the departures are mainly in the sense of too low a value of σ. A possible explanation is that in the lower speed ranges the mean speed of the actual winds is generally greater than the mean speed of the range and the use of actual speeds in the highest range removes the compensating effect of an over-estimate in this range.

For each computation of values of σ shown in Table I, the values used for $V_R{}^2$ were those obtained by a modification of the method described by Brooks

TABLE I—STANDARD VECTOR DEVIATION OF WIND AT KHARTOUM, 1953–55, COMPUTED BY DIFFERENT METHODS

	Height mb	Method (*a*) σ	Method (*b*)–(*a*) σ	Method (*c*)–(*a*) σ	Average speed kt	No. of observations
January	60	13	+1	+1	11	23
	100	23	0	0	22	40
	150	31	+4	0	35	42
	200	29	+2	0	39	42
	300	25	0	−1	32	44
	500	16	0	0	17	46
February	60	15	0	0	14	17
	100	21	+2	0	22	35
	150	27	+1	0	36	37
	200	30	+2	0	41	41
	300	25	0	0	34	42
	500	14	0	0	13	42
March	60	14	+2	+1	13	37
	100	20	+2	+1	22	59
	150	22	+2	−1	37	69
	200	22	0	−1	42	79
	300	21	+2	−1	36	82
	500	15	0	0	15	86
April	60	12	0	0	11	36
	100	19	+1	0	18	63
	150	21	+4	+1	32	70
	200	22	+3	0	35	72
	300	21	+2	0	29	74
	500	16	0	0	15	84
May	60	10	+1	+1	15	37
	100	16	+1	+1	15	70
	150	21	0	−1	23	79
	200	20	+2	−1	24	81
	300	20	0	−1	20	84
	500	11	0	0	10	85
June	60	10	−1	−2	29	40
	100	25	+2	0	39	80
	150	27	0	−1	39	84
	200	23	0	0	27	86
	300	15	0	0	16	87
	500	11	0	0	14	87
July	60	13	+1	−5	42	28
	100	23	+3	−1	63	69
	150	22	+2	−3	59	81
	200	14	+4	−2	41	82
	300	12	+1	+1	23	86
	500	12	+1	+1	19	91
August	60	13	+4	+1	36	30
	100	19	+3	−3	57	80
	150	18	+5	0	55	87
	200	15	+5	−1	39	88
	300	10	+1	+1	23	88
	500	11	0	0	18	88
September	60	13	+3	0	39	45
	100	18	+2	−2	36	70
	150	19	+1	−2	35	73
	200	16	0	−1	26	75
	300	12	+3	+1	16	76
	500	10	+2	+1	16	80

TABLE I—STANDARD VECTOR DEVIATION OF WIND AT KHARTOUM, 1953–55, COMPUTED BY DIFFERENT METHODS *cont.*

	Height *mb*	Method (*a*) σ	Method (*b*)–(*a*) σ	Method (*c*)–(*a*) σ	Average speed *kt*	No. of obser-vations
	60	12	+1	+1	17	50
	100	18	0	0	17	76
October	150	23	0	0	20	82
	200	22	0	0	20	83
	300	16	+1	+1	15	85
	500	10	0	0	10	88
	60	12	0	0	11	47
	100	19	+1	0	20	72
November	150	24	+1	−1	38	75
	200	24	+3	−1	41	78
	300	19	+2	−1	27	82
	500	12	0	0	12	83
	60	18	0	−1	15	40
	100	22	+2	+1	26	66
December	150	26	+4	0	48	73
	200	25	+3	0	52	75
	300	23	+3	0	41	76
	500	14	+1	0	18	78

and Carruthers; winds were grouped in 30-degree ranges of direction and resultant winds computed by using totals of wind speeds in each direction range and assuming the direction was at the mid-point of the range. Though this modification should give greater accuracy by using total speeds instead of frequencies multiplied by the speed of the mid-point of the range, it is still liable to error because of the assumption made regarding the direction and values of σ will be correspondingly affected. Accurate values of the resultant wind were therefore computed from components for each individual observation for the three selected distributions and the values of $V_R{}^2$ were used to compute an accurate σ from squares of individual speeds. These three comparisons—more would have been interesting but each computation involves much tedious arithmetic—have been supplemented by similar data for Aden, most of which had been worked up for another investigation. Resultant winds and standard vector deviations obtained by the different methods are given in Table II.

TABLE II—RESULTANT WINDS AND STANDARD VECTOR DEVIATIONS COMPUTED BY ACCURATE AND APPROXIMATE METHODS

	No. of obser-vations (1)	Accurate resultant wind (2)		Resultant wind by Brooks and Carruthers' method (3)		Resultant wind using 30-degree direction ranges and totals of wind speeds (4)		Accurate S.V.D. (5)	S.V.D. using values of $V_R{}^2$ computed as in column (4) and Method (*a*) (6)	Method (*b*) (7)	Method (*c*)* (8)
		deg	*kt*	*deg*	*kt*	*deg*	*kt*	*kt*	*kt*	*kt*	*kt*
Khartoum, 1953–55											
July, 100 mb	69	095	62	095	62	095	61	21	23 (21)	26	22
July, 60 mb	28	084	42	088	42	086	42	12	13 (12)	14	8
Aug., 100 mb	80	093	56	093	57	093	56	19	19 (19)	22	16
Aden											
1951, Jan., 200 mb	62	204	7	208	7	207	6	21	20 (20)	21	21
1952, Jan., 200 mb	62	290	33	289	33	288	32	29	30 (29)	32	30
1953, Jan., 200 mb	55	232	13	232	13	234	13	27	26 (26)	28	27
1954, Jan., 200 mb	62	221	5	228	6	224	6	22	22 (22)	23	22
1955, Jan., 200 mb	60	280	32	278	30	279	31	24	26 (24)	27	26

Figures in brackets in the column (6) are values of S.V.D. using the accurate values of $V_R{}^2$.
* For Khartoum, actual speeds were used in the highest range.

The values show some interesting features. They suggest that resultant winds can be computed with reasonable accuracy from limited data using 30-degree direction groups and either total speeds, as described above, or frequencies and factors as set out in the *Handbook of statistical methods in meteorology*. Values of standard vector deviation computed by using average speeds in each range agree best with the accurate values of σ but they may be in error by 10 per cent or more through the use of the approximate value of $V_R{}^2$ normally computed.

The results of this survey may be summed up by saying that, for wind distributions similar to those considered:

(*a*) grouping speeds in 20-knot ranges for higher speeds, though apparently satisfactory for computing resultant winds, will lead to appreciable errors in computing standard vector deviations;

(*b*) grouping speeds in 10-knot ranges to compute σ will give generally satisfactory results but some appreciable errors are likely; the apparent refinement of using actual speeds in the highest range may lead to a small systematic under-estimate;

(*c*) the computation of σ by using actual mean wind speeds of 10-knot ranges instead of factors appears to eliminate major errors but errors of 10 per cent or more can still arise from the use of an approximate value of $V_R{}^2$.

The conclusions, therefore, are that, when comparatively few data are available, the use of the method of computing σ set out in the *Handbook of statistical methods in meteorology* is likely to lead to appreciable inaccuracies and actual mean speeds of winds grouped in 10-knot ranges should be used; for computing resultant winds, however, the method given in the Handbook appears from the limited number of examples for which values have been computed to give a satisfactory value, but if total wind speeds of each direction range are available not much more arithmetic is required to use these values and so eliminate a possible source of error.

REFERENCES

1. BROOKS, C. E. P., and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953, pp. 187–190, 196–198.
2. London, Meteorological Office; Upper air data for stations maintained by the Meteorological Office. London.

NATURE OF DIURNAL VARIATION OF PRESSURE AT GIBRALTAR

By G. W. HURST, B.Sc.

Introduction.—A general note on surface pressure variation at Gibraltar was published[1] in which some mention of the diurnal change was made. At the suggestion of Professor S. Chapman, monthly values for the first four harmonics of the diurnal variation have been calculated and these are given below, with a discussion of the significance of the figures, both locally and in comparison with other stations.

Data.—The basic information consisted of hourly pressure values for the 10 years 1948–57 for North Front (36°09′N, 5°21′W, height 10 feet). These were tabulated monthly and annually, and analysed harmonically to four terms. The results are summarized in Table I.

TABLE I—HARMONIC ANALYSIS OF PRESSURE VARIATION AT GIBRALTAR

Period	Mean pressure P_0	1st harmonic			2nd harmonic			3rd harmonic			4th harmonic		
		A_1	α_1	t_1	A_2	α_2	t_2	A_3	α_3	t_3	A_4	α_4	t_4
	mb	*mb*	°	*hr*	*mb*	°	*hr*	*mb*	°	*hr*	*mb*	°	*hr*
Jan.	1020·29	0·143	+2	0553	0·656	158	0945	0·251	−6	1008	0·109	−151	1003
Feb.	1019·58	0·142	−8	0633	0·692	151	0958	0·168	−10	1013	0·050	+173	1037
Mar.	1017·38	0·103	−6	0624	0·693	149	1003	0·058	−10	1013	0·007	−105	0915
Apr.	1015·74	0·084	−31	0804	0·657	144	1010	0·046	−166	1340	0·010	−80	0850
May	1016·08	0·138	−30	0800	0·599	141	1017	0·113	+164	1421	0·027	−166	1016
June	1016·97	0·256	−36	0825	0·575	138	1025	0·142	+165	1420	0·024	−171	1022
July	1016·19	0·381	−29	0757	0·591	137	1026	0·151	+172	1411	0·036	−149	0959
Aug.	1015·36	0·378	−24	0735	0·645	139	1022	0·104	+176	1405	0·036	−117	0929
Sept.	1016·89	0·241	−23	0732	0·697	143	1013	0·011	−67	1129	0·033	−118	0928
Oct.	1017·85	0·147	−20	0721	0·689	148	1003	0·110	−15	1020	0·047	−148	0957
Nov.	1018·57	0·127	−12	0648	0·643	150	1000	0·172	−17	1016	0·078	−171	1023
Dec.	1019·83	0·129	−13	0654	0·646	152	0956	0·233	−9	1013	0·114	−163	1013
Year	1017·45	0·187	−22°07′	0728	0·643	146°02′	1008	0·036	−8°23′	1011	0·044	−153°36′	1003

In this table the average pressure at any particular local time t hours is given by:

$$\text{pressure} = P_0 + \sum_{n=1-4} A_n \sin(15nt + \alpha_n),$$

where A_n = amplitude in mb of nth harmonic component

α_n = phase angle in degrees of nth harmonic component

t_n = local time (in hours and minutes) of maximum of nth harmonic component (nearest to midday)

P_0 = mean value of pressure in mb.

The usual assumption was made for the monthly data that the fourth harmonic was the highest needed; as a check, values for the fifth to ninth were extracted from yearly data: the amplitudes of these proved to be 0·028, 0·016, 0·005, 0·006 and 0·005 mb respectively. Clearly, little error is involved in the overall assessment of variation from the mean in neglecting the fifth and sixth harmonics, and almost none in neglecting higher ones.

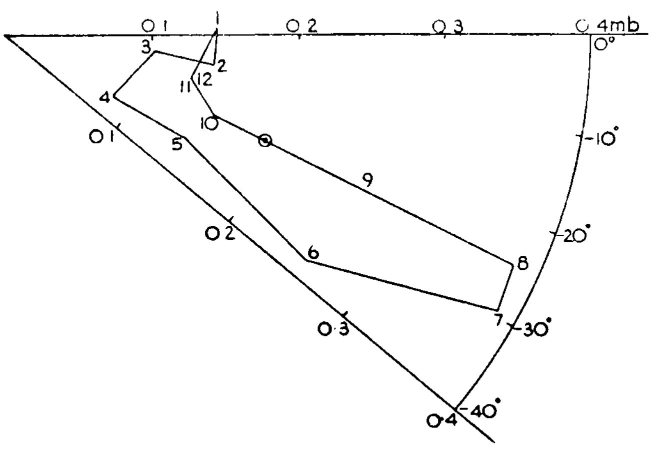

FIGURE 1—HARMONIC DIAL SHOWING AMPLITUDE AND PHASE ANGLE FOR 24-HOUR COMPONENTS

In this figure (and also Figures 2–5) 1, 2 . . . . . . represent January, February, etc.; the encircled value is the mean for the year.

Analysis of harmonics at Gibraltar

24-hour variation (component 1).—This is shown in Figure 1 in the harmonic dial form of phase angle and amplitude, and in Figure 6 in a different manner to bring out its contribution to the maximum of the actual diurnal change. It is seen that variation over the year as a whole follows a definite pattern. The time of maximum varies in a restricted range from about 0800 hours in summer to 0600–0700 hours in winter. Amplitude variation is considerable, however, and the relatively large summer values of the maxima tend to bring the lowest amplitude of the overall daily variation to late spring, and to accentuate considerably the evening minimum pressure in summer, as Figure 7 shows.

12-hour variation (component 2).—This is the main component at all times. It is of particular interest at Gibraltar, as Simpson[2] considered that the diurnal variation of pressure at any place could be broken down into equatorial and polar components defined by:

$$\text{equatorial component} = 1 \cdot 249 \cos^3\phi \sin(30t + 154^\circ) \text{ mb}$$

$$\text{and polar component} = 0 \cdot 183 (\sin^2\phi - \tfrac{1}{3}) \sin(30t + 105^\circ - 2\lambda) \text{ mb,}$$

where ϕ = latitude and λ = longitude, °E.

Effectively, the equatorial component is defined in terms of local time, and the polar component in G.M.T. The polar component reverses in sign at latitude 35°16′ and its value at Gibratlar (36°09′N) is therefore negligible at $0 \cdot 0027 \sin(30t + 116^\circ)$ mb. Simpson's equatorial amplitude of 0·658 mb at latitude 36°09′ is close to the 0·643 mb found in practice. The phase angle of 146° is also in quite close agreement; indeed, when one remembers that pressure

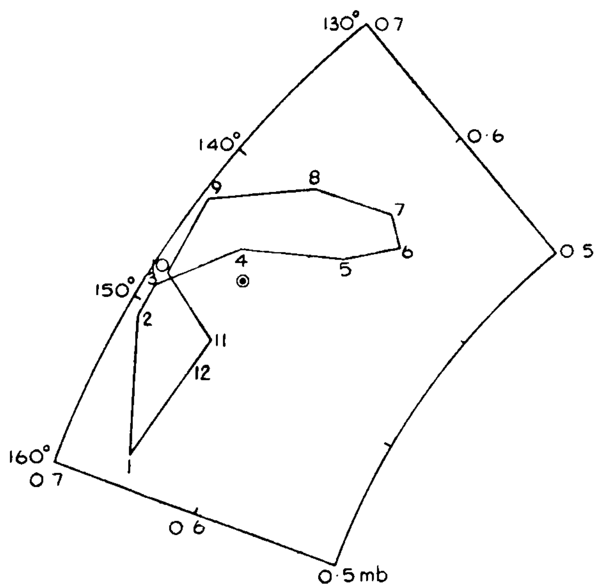

FIGURE 2—HARMONIC DIAL SHOWING AMPLITUDE AND PHASE ANGLE FOR 12-HOUR COMPONENTS

observations are conventionally read about 10 minutes before the nominal time of observation, the corrected phase angle of 151° is very near this theoretical figure. Figures 2 and 6 show that there is appreciable variation in the amplitude of component 2 during the year, with equal highest values in spring and autumn, and the lowest value in early summer. The time of maximum is distinctly later in summer than winter, though variations from the mean never exceed 23 minutes.

8-hour variation (component 3).—This variation, shown in Figures 3 and 6, is the most interesting of the harmonics, and constitutes the main reason for the much higher overall amplitude in winter than in summer. There is almost complete seasonal reversal, with a maximum in the winter months at about 1000 hours, and a minimum in summer at almost exactly the same time. At the equinoxes the term is almost negligible. The greatest amplitude occurs in winter, during which its effect is considerably more important than component 1.

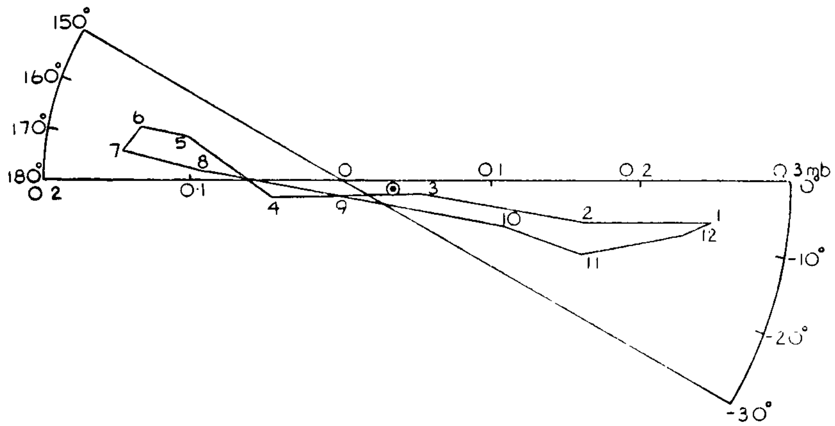

FIGURE 3—HARMONIC DIAL SHOWING AMPLITUDE AND PHASE ANGLE FOR 8-HOUR COMPONENTS

6-hour variation (component 4).—Never very important either because of its amplitude (exceeding 0·1 mb only briefly in winter) or phase angle, for the occurrence of the maximum is always within about an hour of 1000 hours; the appearance of Figures 4 and 6 associated with the low amplitude values does not suggest any particularly significant change through the year; for convenience, the maximum is shown at about 0400 hours instead of 1000 hours on Figure 6.

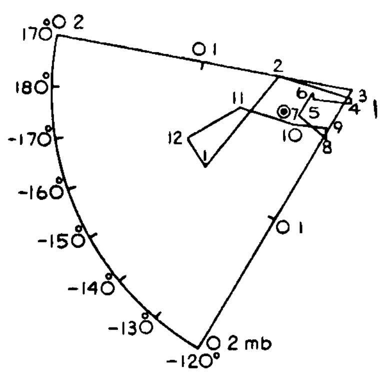

FIGURE 4—HARMONIC DIAL SHOWING AMPLITUDE AND PHASE ANGLE FOR 6-HOUR COMPONENTS

Components 1–4 *combined*.—Figures 5 and 6 show the result of combining the first four harmonics for the 1000 hours maximum, and agreement is very close between these values and those of the actual data. The time of the maximum varies between the close limits of 0952 hours (February) and 1008 hours (August); fluctuations appear random, and the mean time is almost exactly 1000 hours. The amplitude shows a very marked variation between 0·629 mb in May and 1·079 mb in January. The effect of the harmonic components, notably 2 and 3, upon these figures has been discussed above.

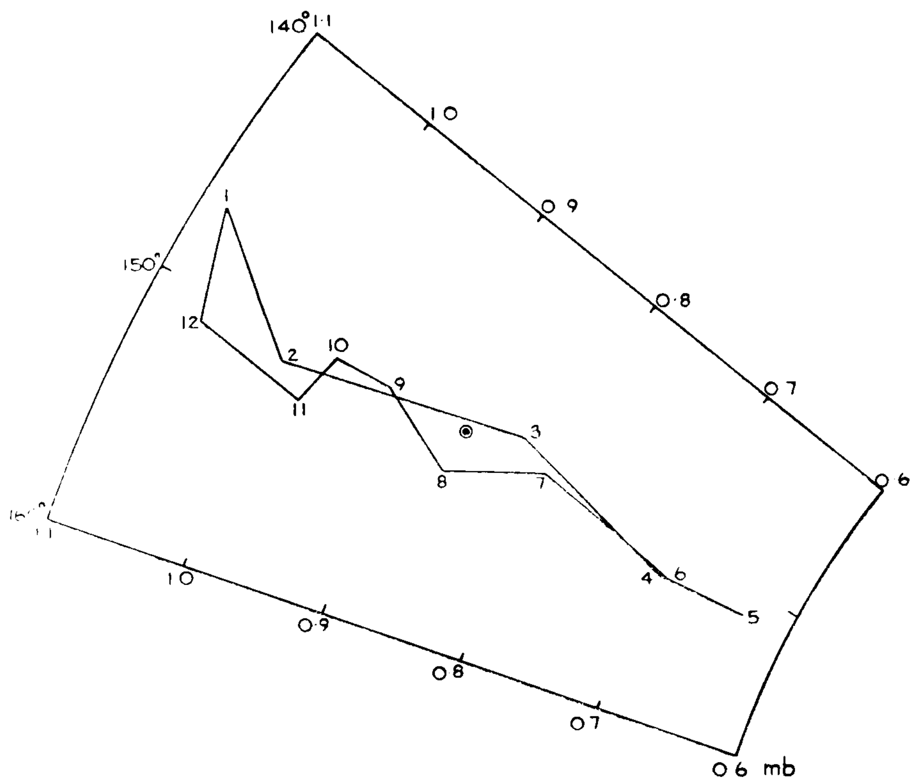

FIGURE 5—HARMONIC DIAL SHOWING AMPLITUDE AND PHASE ANGLE FOR COMPLETE COMPONENTS 1–4

The method of obtaining the sum effect of the n components was by taking an approximate time t_o of the extreme component, assuming that this was in error by a small amount x, and taking:

$$\text{pressure} = P = P_o + \Sigma A_n \sin \left\{ n\,(t_o + x) + \alpha_n \right\}.$$

For an extreme value $\dfrac{dP}{dx} = 0$,

$$\text{so } 0 = \frac{dP}{dx} = \frac{d}{dx} \Sigma A_n \sin\,(nt_o + \alpha_n) \cos nx + \frac{d}{dx} \Sigma A_n \cos\,(nt_o + \alpha_n) \sin nx$$

$$= \Sigma A_n \sin\,(nt_o + \alpha_n)\,(-\,n \sin nx) + \Sigma A_n \cos\,(nt + \alpha_n)\, n \cos nx.$$

As x is small, $\cos nx \simeq 1$, and $\sin nx \simeq nx$,

$$\text{so } x = \frac{\Sigma n\, A_n \cos\,(nt_o + \alpha_n)}{\Sigma n^2\, A_n \sin\,(nt_o + \alpha_n)}\,.$$

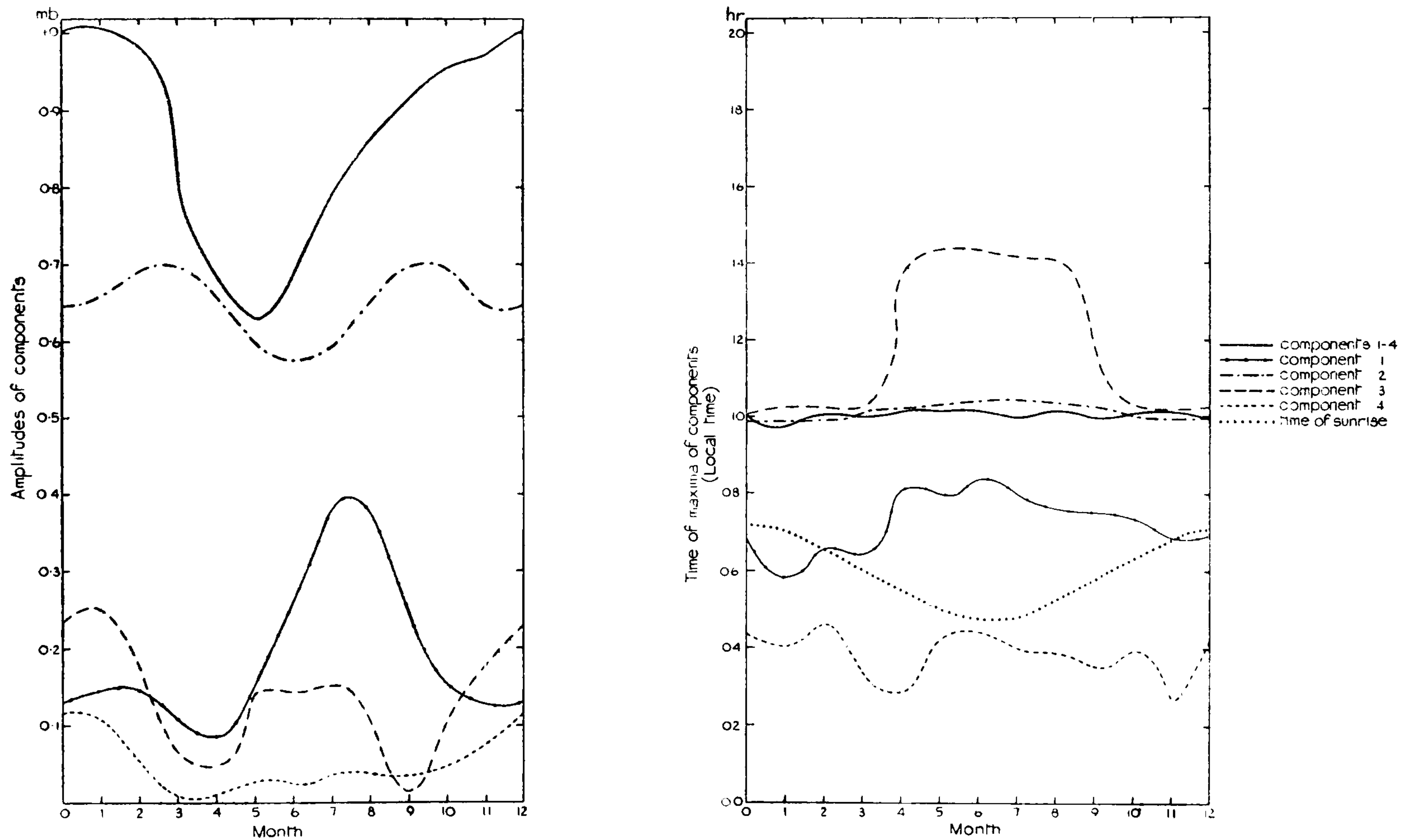

FIGURE 6—MONTHLY AMPLITUDE AND TIME OF MAXIMA OF COMPONENTS 1–4

Components 1–6 *combined.*—The fifth and sixth harmonics were calculated for the yearly mean, and times of maximum and minimum for this data were assessed using components 2 only, 1–3, 1–4 and 1–6. The results are summarized in Table II.

TABLE II—AMPLITUDE AND TIME OF EXTREME VALUES OF DIURNAL VARIATION

Extreme	Approximate local time	Estimations from graph		Harmonic terms used: Component 2		Components 1–3		Components 1–4		Components 1–6	
		A	*t*	*A*	*t*	*A*	*t*	*A*	*t*	*A*	*t*
	hr	*mb*	*hr*	*mb*	*hr*	*mb*	*hr*	*mb*	*hr*	*mb*	*hr*
Max.	1000	0·92	1014	0·64	1008	0·82	1001	0·86	1000	0·88	1014
Max.	2200	0·51	2208	0·64	2208	0·47	2220	0·51	2216	0·51	2211
Min.	0400	−0·54	0414	−0·64	0408	−0·48	0405	−0·48	0405	−0·51	0411
Min.	1600	−0·72	1620	−0·64	1608	−0·47	1610	−0·72	1613	−0·69	1631

Rather surprisingly, calculations based on component 2 alone give in most cases a more accurate time of extreme than the use of any number of harmonics up to four, but the addition of components 5 and 6 makes a big improvement. Amplitude, however, is almost always improved by the consideration of more harmonics.

Variation in times of minima.—Figure 7 shows the monthly pattern of the actual diurnal curve; times of sunrise and sunset at North Front are superimposed. The close relationship between the times of minima and the state of the sun is striking, with an average difference of 1 hour 50 minutes; there is rather more separation in winter than in summer in the mornings. Great precision is not possible with many of these times of minima, as the use of only four harmonics is insufficient to give a satisfactory correction x to an approximate time. The main term contributing to this oscillation in time of the minimum is the third, which occurs at about 0600 and 1400 hours in winter and 0200 and 1800 hours in summer.

The constancy of the times of maxima at 1000 and 2200 hours is also clearly brought out in the diagram, together with the markedly higher peak in the morning, as the maximum of component 1 would require.

General significance of first four harmonics.—Comparison was made of the first four harmonics with figures from other sources.[3–8]

As far as Gibraltar is concerned, the pattern of component 1 which emerged appeared quite definite, and one feels that a longer period would reproduce much the same pattern. The 24-hour variation does, however, vary widely between one area and another, and Jameson[3] found that values for A_1 and t_1 over the sea area adjacent to Crete were about 0·2 mb and 0400 hours; values for the sea area near Malta were 0·1 mb and 2300 hours; and north of Sicily there was variation between 0·17 mb at 2400 hours in summer and 0·3 mb at 1100 hours in winter. It is assumed that the greater summer amplitude at Gibraltar may well result from the increased heating to the north and to the south, and that the later time of summer minimum (2000 hours compared with 1800–1900 hours) is a consequence of longer solar heating.

Little need be said of component 2, for as already mentioned, its behaviour is normal for its latitude. The characteristics of component 3 were very similar to those of other stations in the latitude, as Table III shows.

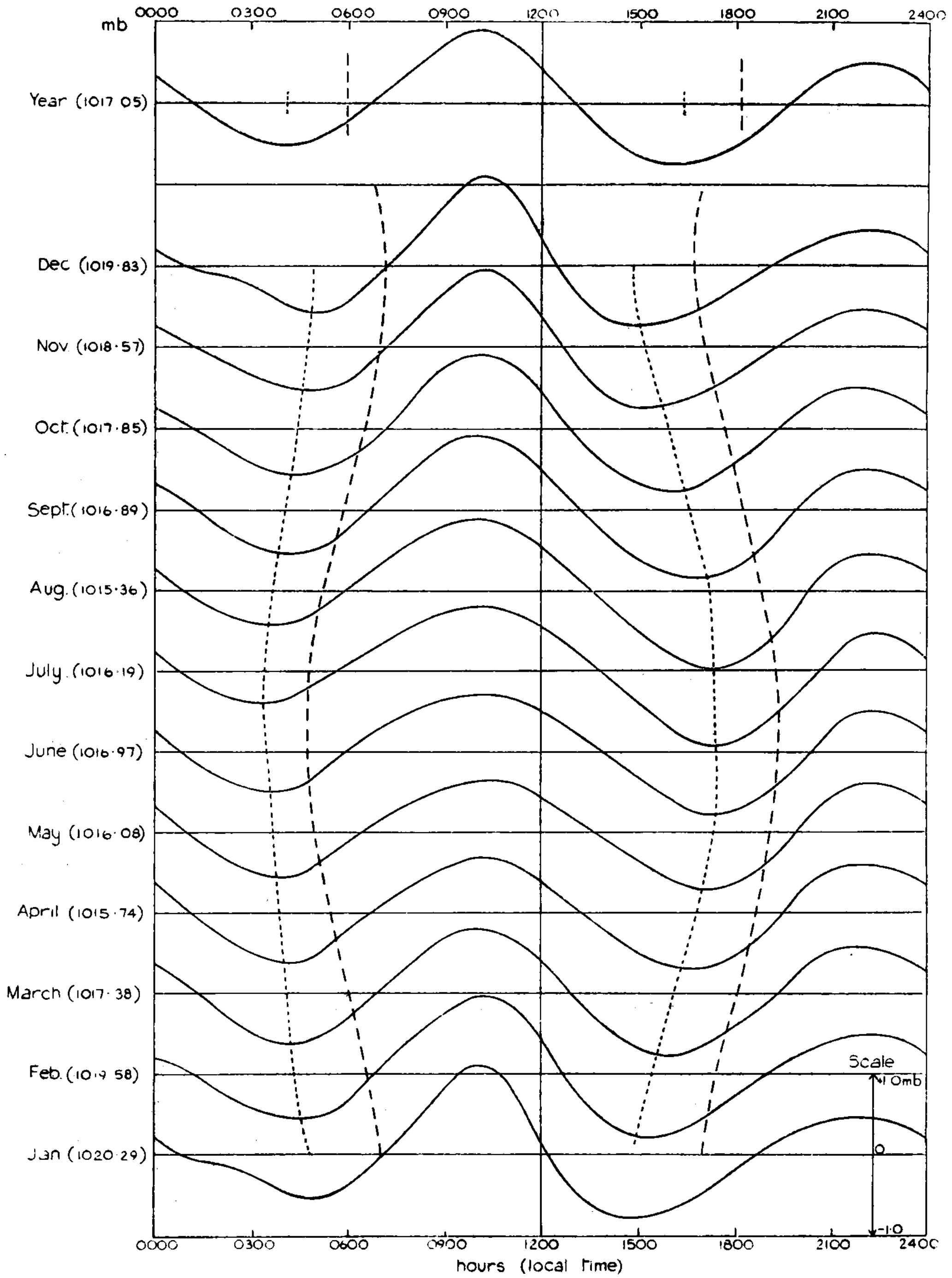

FIGURE 7—ACTUAL DIURNAL PRESSURE VARIATION AT GIBRALTAR

The pressures in brackets corresponding with the horizontal lines are mean values and the vertical separation between these lines represents one millibar.

– – – sunrise/sunset   - - - - diurnal curve minimum

TABLE III—VALUES OF COMPONENT 3 FOR VARIOUS STATIONS

Station	Position	Height	Winter			Summer			Annual		
			A	*α*	*t*	*A*	*α*	*t*	*A*	*α*	
		ft	*mb*	°	*hr*	*mb*	°	*hr*	*mb*	°	*hr*
Gibraltar	36N 5W	10	0·24	−8	1010	0·15	172	1410	0·04	−8	1010
Ksara	34N 36E	3012	0·24	20	0935	0·10	173	1405	0·09		
Bermuda	33N 65W	160	0·23	4	0955	0·11	169	1410	0·06	25	0935
Tenerife	28N 16W	7766	0·20	−10	1010	0·10	155	1435	0·05	15	0940
Santa Cruz	39N 31W	132	0·18	−14	1020	0·07	169	1410	0·05	−20	1025
Melbourne	38S 145E	93	0·18	3	0955	0·09	173	1405	0·05	13	0940

In this table *t* is given to the nearest five minutes.

There is a strong similarity in pattern for these stations, each with a high winter maximum at about 1000 hours, and a somewhat lower summer maximum (soon after 1400 hours), corresponding to the almost completely opposed phase. Annual mean figures are much lower in consequence of the opposed phase, but the times of maximum remain at 1000 hours or just before.

Component 4 does not call for much consideration in view of the smallness of amplitude. It is however worth noting that Gibraltar, Ksara and Bermuda all have amplitudes 0·08/0·11 mb in winter with a maximum 0905/1010 hours (corresponding to phase angle $-29°/-160°$) and that the summer amplitude is 0·02/0·04 mb, with no pattern in time or phase.

Acknowledgements.—It is wished to express real gratitude for the work of Mr. E. G. Ward, and the meteorological staff at Gibraltar for the extraction of hourly pressure information, and also to the staff at Uxbridge who assisted in many of the computations.

REFERENCES

1. HURST, G. W.; Variation in pressure at Gibraltar. *Met. Mag., London*, **87**, 1958, p. 294.
2. SIMPSON, SIR GEORGE; The twelve-hourly barometer oscillation. *Quart. J. R. met. Soc., London*, **44**, 1918, p. 1.
3. JAMESON, H.; Diurnal variation of pressure in the Mediterranean area. *Prof. Notes. met. Off., London*, **7**, No. 105, 1952.
4. CHAPMAN, S.; The lunar atmospheric tide in the Azores, 1894–1932. *Quart. J. R. met. Soc., London*, **62**, 1936, p. 41.
5. CHAPMAN, S., HARDMAN, M. and MILLER, J. C. P.; The lunar atmospheric tide at Melbourne 1869–1892, 1900–1914. *Quart. J. R. met. Soc., London*, **62**, 1936, p. 540.
6. BARTRUM, P. C.; The diurnal variation of atmospheric pressure at St. George's, Bermuda, during the years 1933 and 1934. *Quart. J. R. met. Soc., London*, **62**, 1936, p. 292.
7. TULLOT, I. F.; La variacion diurna de la presion atmosferica en el observatorio de Izaña (Tenerife). *Rev. Geofís., Madrid*, **6**, 1947, p. 450.
8. CHEVRIER, J.; Analyse harmonique de la variation diurne de la pression atmosphérique à l'Observatoire de Ksara. *C.R. Acad. Sci., Paris*, **229**, 1949, p. 946.

REVIEWS

The face of the sun, by H. W. Newton. 7 in. $\times 4\frac{1}{2}$ in., pp. 208, *illus.*, Penguin Books Ltd., Harmondsworth, Middx., 1958. Price: 3*s*. 6*d*.

The author of this book was for many years in charge of the solar department of the Royal Greenwich Observatory, and has used his expert knowledge to good effect in writing this account of what is known of the sun and its behaviour.

Although radiation from the sun is the ultimate source of energy for all atmospheric motions of meteorological importance, nevertheless the most obvious and interesting departures from uniformity observed on the sun—sunspots, flares, and prominences—appear to have no effect on weather or major atmospheric motions and influence only the fringe of the meteorologist's domain, the ionosphere, 70 kilometres and more above the surface of the earth. The Meteorological Office, however, has for many years taken a direct interest in these matters by virtue of the work carried on at the magnetic observatories at Lerwick and Eskdalemuir and in the Edinburgh office: meteorologists who are not quite clear what goes on there and why will find a sound and reasonably full account in this book of the connexion between solar activity, the earth's magnetism, ionospheric storms, and the aurora, as well as what is known of the basic facts of solar physics and of the sun's place in stellar evolution. There are 16 pages of photographs.

R. P. W. LEWIS

Notes on weather analysis in the Falkland Islands Dependencies, Antarctica. Scientific Reports No. 16. By A. W. Mansfield and S. D. Glassey. 12 in. $\times 9\frac{1}{2}$ in., pp. 27, *illus.*, H.M.S.O., London, 1957. Price: 12*s*.

This report on day-to-day synoptic analysis over the Falkland Islands Dependencies Survey sector of the southern oceans and coastal fringe of Antarctica will be useful to anyone engaged in meteorological analysis of any part of the zone 40°–70°S. The work was written in 1954 and so does not include International Geophysical Year results. Nevertheless a pretty sound general view of the large-scale features of the general circulation was already available, and the authors show themselves well aware of the literature.

Most attention is given to those situations which are of interest (and may be difficult to handle) just because they are departures from the norm—meridional flow, blocking, cumulus-type cloud and föhn winds giving high temperatures—but the text puts them in proper perspective. It would, however, have been useful in Table V if the frequencies of convective cloud types had been expressed as a percentage of *all* observations. Also the high temperature at King Edward Point, South Georgia should be compared with absolute maxima of 29°C in South Georgia itself and 30°–34°C in similar latitudes on the east coast of South America; the highest in the Falkland Islands is only 24°C.

There are interesting accounts of the behaviour of the Antarctic and polar fronts and of the preferred locations for frontogenesis, but the reviewer suspected a too rigid adherence to a two-front/three-air-mass model. Routine adoption of either two- or three-front models underrates the fluidity of the atmosphere. Granted that the sharp thermal boundaries in the ocean surface water, which more or less permanently ring the southern hemisphere are forever producing characteristic Antarctic, "polar" (cold-temperate) and subtropical air masses; nevertheless the flow of these air masses continually leads both to the occlusion process and to cold fronts and occlusions advancing into the lower latitudes. Hence the identity of the Antarctic and polar fronts is repeatedly changing, and frontogenesis is continually responsible for (i) creating the Antarctic front out of occlusions, and groups of occlusions in the sub-polar trough and (ii) transforming either the Antarctic front or old occlusions into the main polar front in deformation fields, such as that represented by the col over South America between the South Pacific and South Atlantic highs.

H. H. LAMB