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SOME ASPECTS OF THE SYNOPTIC CLIMATOLOGY OF THE BRITISH ISLES AS MEASURED BY SIMPLE INDICES

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Introduction.—The Lamb catalogue of daily weather types over the British Isles covers the period from January 1873 to the present day. This catalogue is a slightly modified version of the original classification put forward by Lamb;[1] the classification consists of eight directional types each subdivided into three categories (e.g. westerly is subdivided into cyclonic westerly, westerly and anticyclonic westerly), and two non-directional types (cyclonic and anticyclonic). In addition there are some days on which the weather is unclassifiable under any of these types. Each type is designated by a letter as shown in Table I.

TABLE I—THE LAMB CATALOGUE OF DAILY WEATHER TYPES

	Anticyclonic	Unspecified	Cyclonic
Northerly	M	N	O
North-easterly	G	H	I
Easterly	D	E	F
South-easterly	J	K	L
Southerly	R	S	T
South-westerly	£	P	Q
Westerly	V	W	X
North-westerly	A	B	C
Non-directional	Y	U	Z

Each day since 1873 has been classified by one of the 27 letters given in Table I, following general rules laid down by Lamb.[1] The subjective element in the process of classifying inevitably leads to some differences of opinion on a small minority of occasions. Nevertheless the Lamb catalogue is a useful synoptic classification with practical applications. (It may be of interest to note that the percentage frequencies of occurrence of the three non-directional types Y, Z and U are 16 per cent, 14 per cent and 6 per cent respectively.)

For some purposes it is desirable to have a ready indication of the general character of a month (or other period). The full daily classification for a month contains a great deal of information about synoptic sequences and weather types, and it is often desirable to distil the synoptic essence, as it were, from such a detailed record ; the indices of progression, meridionality, and cyclonicity discussed in the following sections are intended to perform this function.

A computer programme enabled the indices to be calculated for the 92 years of the catalogue in half-monthly and monthly blocks.

Derivation of the indices.—

(*a*) *Index of progression* (*P*).—The progressive synoptic types which affect the British Isles are generally those classified as westerly ; blocked types are easterly or meridional. The non-directional cyclonic and anticyclonic classes may be associated with either progressive or blocked situations. As the Lamb catalogue consists of the synoptic classification of over 33,000 days, it would be a mammoth task to re-examine synoptic maps for all these days in order to reclassify them into progressive or blocked types. The following objective specifications for the daily value of *P* are considered to be synoptically meaningful even though arbitrary. For the purpose of obtaining an index of progression representative of a period of about 15 days or more, uncertainties in the significance of scores on one or two days are usually unimportant. Certainly practical experience with the use of the *P*-index over monthly periods lends strong support to the meaningfulness of the specifications.

TABLE II—DAILY SCORES ALLOCATED TO *P* ACCORDING TO THE SYNOPTIC TYPE

Types	Score
Westerly (ABC VWX £PQ)	2
Easterly (GHI DEF JKL)	−2
Meridional (MNO RST)	−1
Unclassifiable (U)	0
Non-directional cyclonic (Z)	depends on preceding types
Non-directional anticyclonic (Y)	depends on preceding types

Scores on days preceding Z or Y			Daily scores for sequences of *n* days of Z or Y			
			Z_1	Z_2	Z_3	. . . Z_n
2	2	2	2	2	−2	. . −2
−1/−2	2	2	2	0	−2	. . . −2
2	−1/−2	2	2	0	−2	. . . −2
−1/−2	−1/−2	2	2	−2	−2	. . . −2
		−1	−1	−1	−2	. . . −2
		−2	−2	−2	−2	. . . −2
			Y_1	Y_2	Y_3	. . . Y_n
2	2	2	2	0	−2	. . . −2
−1/−2	2	2	0	−2	−2	. . . −2
2	−1/−2	2	0	−2	−2	. . . −2
−1/−2	−1/−2	2	−2	−2	−2	. . . −2
		−1	−1	−2	−2	. . . −2
		−2	−2	−2	−2	. . . −2

Note : U days are ignored, and −1/−2 signifies any type with scores −1 or −2.

It will be noted in Table II that the scores allocated to sequences of Z and Y types depend on the synoptic types over the preceding three days (U days being ignored) when the immediately preceding day is westerly. Thus an isolated Y following at least three westerly days is regarded as progressive, and a spell of Y's is regarded as becoming blocked after the second day as often happens when a mobile baroclinic high cell develops and slows down. However, all Y's following an isolated westerly day are regarded as blocked. Moreover, it will be noted that the scores allocated to Z or Y days are always negative if the immediately preceding day is not westerly (ignoring U days). With a mixed sequence of Y and Z types (i.e. Y following Z or Z following Y) the convention is to treat the Y (or Z) according to whether the preceding Z (or Y) is scored as progressive (2), blocked (−2) or meridional (−1).

(*b*) *Meridional indices* (*S and M*).—Scores are allocated to each synoptic type as shown in Table III.

TABLE III—DAILY SCORES ALLOCATED ACCORDING TO MERIDIONAL FLOW

Types	Score
MNO (northerly)	−2
ABC GHI (north-west or north-east)	−1
YUZ VWX DEF	0
£PQ JKL (south-west or south-east)	1
RST (southerly)	2

The *S*-index for, say, a month is taken as the algebraic sum of the daily meridional scores. In other words the *S*-index gives the bias toward southerly (positive) or northerly (negative) types during the month.

The *M*-index is the sum of the daily scores irrespective of sign. *M* is a measure of the total meridionality during the month.

(*c*) *Index of cyclonicity* (*C*).—The scoring system is shown in Table IV.

TABLE IV—DAILY SCORES ALLOCATED TO *C* ACCORDING TO THE SYNOPTIC TYPE

Types	Score
Y (non-directional anticyclonic)	−2
MGD JR£ VA (directional anticyclonic)	−1
NHE KSP WBU	0
OIF LTQ XC (directional cyclonic)	1
Z (non-directional cyclonic)	2

Cyclonic types are given positive scores and anticyclonic types negative scores. The *C*-index for, say, a month is taken as the algebraic sum of the daily scores. The *C*-index is thus a measure of the net cyclonic or anticyclonic character of the month.

Calculation of the indices.—The indices were calculated by electronic computer for 12×92 months (1873–1964) of the Lamb catalogue. In fact the computer programme enabled a print-out to be made of the positive and negative scores achieved during the first 15 days and the second half of each month of the 92 years. These data readily gave the indices for half-monthly, monthly and mid-month to mid-month periods. The monthly and mid-month to mid-month scores for each year were also ranked and decile, quintile and tercile boundaries computed to facilitate the use of the indices in different applications.

A month is certainly a suitable unit of time over which the indices may be calculated. However, the indices may be profitably computed for various extended periods, such as a season or a year, although it is suggested that a lower limit for practical use is 10 days.

It is of interest that the four indices for a particular month can be worked out by hand in two or three minutes.

***P*-index—secular and seasonal variations.**—The secular trend and seasonal variations in progression and blocking in the neighbourhood of the British Isles may be seen from Table V.

TABLE V—MONTHLY AND YEARLY MEAN VALUES OF *P* FOR SPECIFIED PERIODS

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1873–79	13	−4	9	−1	−3	1	17	6	13	5	−1	5	60
1880–89	3	3	−5	−13	−13	−7	12	9	−1	−1	8	17	12
1890–99	5	5	13	−5	−15	−1	15	11	15	2	4	9	58
1900–09	27	12	11	6	−7	−8	17	25	1	15	9	19	127
1910–19	19	11	7	9	−9	12	9	13	9	3	16	29	128
1920–29	34	19	7	0	7	18	23	34	26	17	16	27	228
1930–39	25	6	5	−4	−12	9	30	15	4	17	14	16	125
1940–49	5	4	−8	12	−19	14	9	9	17	0	5	16	64
1950–59	5	−3	−18	−1	−17	2	8	4	16	9	5	16	26
1960–64	−5	−10	−16	−10	1	15	7	8	6	−5	0	0	−9
1873–1964	13	4	1	0	−9	7	16	14	10	5	8	15	84

Table V clearly demonstrates a secular trend in the yearly P-index from the very low value in decade 1880–89 to the notable maximum in decade 1920–29, followed by more or less steadily diminishing values. Evidently progressive synoptic types dominated the first 40 years of this century, and blocking was much more frequent before 1900 and after 1940. To a great extent the secular changes in the annual P-indices were closely reflected in the seasonal variations, particularly in winter and summer. Lamb[2] has demonstrated these trends from consideration of the frequency of his weather types.

The seasonal variation in blocking and progression may be seen from Figure 1, which shows the frequency of occurrence of $P \geqslant 0$ (i.e. overall progression) and $P < 0$ (i.e. overall blocking) for half-monthly periods (1873–1964). The predominance of progression in December and January weakens rapidly in February. On this half-monthly time scale, progression is marginally more frequent than blocking in March. Blocking becomes the more likely mode in April and increases in frequency to a notable maximum in late May, followed by a rapid fall-off in frequency in June. The important changes in frequency of the two basic types in June are undoubtedly part of a larger-scale circulation reorganization (see Brooks,[3] and Bryson and Lahey[4]). In summer the major type is obviously progression. However, a well-marked decrease in frequency of progression sets in during September in the 'normal' year and leads to a secondary maximum of blocking in late September. Thereafter a slow and somewhat irregular increase in progression takes place in the autumn, culminating in a sharper increase in progression and decrease in blocking in early December. The seasonal pattern of progression and blocking is also apparent in the long-period averages of the P-index for half-months throughout the year (not reproduced). These averages show a more pronounced increase in blocking from early to late April, a secondary maximum of blocking in early October rather than in late September and a more marked increase in progression from late November to early December than are indicated in Figure 1.

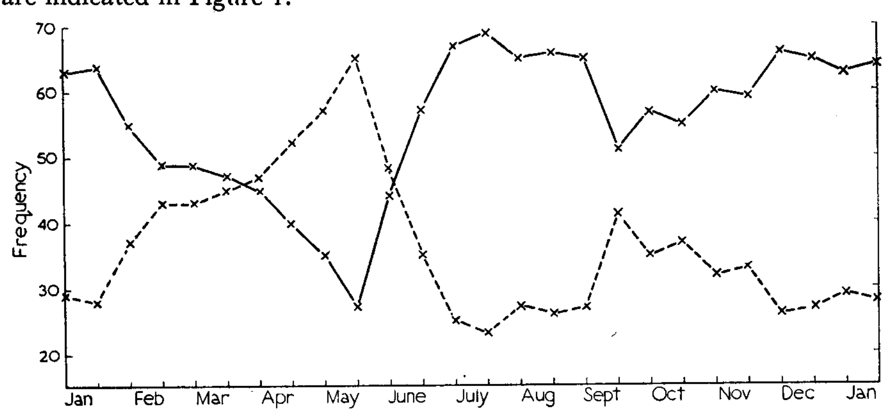

FIGURE 1—FREQUENCY OF OCCURRENCE OF HALF-MONTHLY INTERVALS (FIRST HALF AND SECOND HALF OF CALENDAR MONTHS) WITH $P \geqslant 0$ AND $P < 0$ DURING THE PERIOD 1873–1964

$P \geqslant 0$ x———x
$P < 0$ x- - - -x

Sumner[5] has presented monthly statistics for the period 1949–56 of the frequency of blocking anticyclones in various longitude bands ; in particular Table III of his paper gives figures for the longitude zone 0 to 19°W. It is of some interest to compare the indications of blocking throughout the year as suggested by our P values with Sumner's statistics. Both sets of figures agree that the two minima of blocking occur in July/August and in December/January, and that the main maximum is in spring with a secondary maximum in autumn. The main difference is that Sumner's data show March (59 occurrences) and May (57 occurrences) as equally blocked months whereas our Table II or Figure 1 indicates that May is the month of maximum blocking. However, mean monthly P values compiled for the same 8 years which Sumner investigated give $P = -18$ in March and $P = -16$ in May ; these P values are clearly consistent with Sumner's data on the frequency of occurrence of blocking anticyclones. The 8 years considered by Sumner, and indeed the 25 years from 1940 to 1964, were in fact characterized by much more blocking in March than the 50 years or so before 1940.

***S* and *M*-indices—secular and seasonal variations.**—Some light may be thrown on the nature of the blocking which occurred in the different decades by examining the mean values of the meridional indices, shown in Tables VI and VII.

TABLE VI—MONTHLY AND YEARLY MEAN VALUES OF S FOR SPECIFIED PERIODS (SOUTHERLY BIAS BEING POSITIVE)

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1873–79	11	3	−4	3	−4	6	0	3	1	10	−3	1	27
1880–89	15	10	3	0	4	−2	3	2	2	0	4	3	44
1890–99	4	9	−1	1	1	0	−5	1	3	0	10	10	33
1900–09	8	0	−2	2	1	2	−1	1	8	6	4	6	35
1910–19	3	6	1	−4	3	−5	−6	−2	1	2	−3	3	−1
1920–29	6	6	5	−3	−2	0	−3	0	−1	7	5	2	22
1930–39	1	1	4	−3	1	1	−3	2	1	−3	3	1	6
1940–49	4	−1	3	2	2	−2	−3	−3	2	9	2	5	20
1950–59	−2	−3	9	−7	−3	−5	−6	0	2	4	2	1	−8
1960–64	1	9	9	5	−5	−6	−10	−7	4	2	−1	−4	−3
1873–1964	6	4	3	−1	0	−2	−2	0	2	4	3	3	20

TABLE VII—MONTHLY AND YEARLY MEAN VALUES OF M (SUM OF MERIDIONAL TYPES) FOR SPECIFIED PERIODS

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1873–79	16	13	14	14	11	13	10	9	13	19	17	13	162
1880–89	20	17	15	13	14	14	14	16	15	13	11	16	178
1890–99	16	15	11	13	12	10	12	15	11	18	18	16	167
1900–09	14	12	8	13	15	12	9	7	14	16	12	12	144
1910–19	10	9	9	8	8	8	11	5	10	12	10	8	108
1920–29	11	14	12	12	11	10	6	6	7	11	14	15	129
1930–39	7	9	14	12	12	8	6	7	10	17	10	6	118
1940–49	15	13	10	11	13	11	11	10	9	16	18	14	151
1950–59	18	19	22	17	18	14	11	14	11	15	15	15	189
1960–64	11	19	21	18	15	10	14	14	14	16	9	18	179
1873–1964	14	14	14	13	13	12	10	10	11	15	13	13	152

It appears that the most meridional decade was 1950–59 and the runner-up was 1880–89 (1960–64 was also very meridional). There were some remarkable differences between the two decades as regards the direction of the meridional flow, as shown in Table VI ; a strong southerly bias was a feature of the 1880's, especially in winter ($S = 28$), whereas in the 1950's a northerly bias was marked in summer ($S = -11$) and winter ($S = -4$). In both decades the autumns showed a southerly bias. The least meridional decade was 1910–19, then came 1930–39, 1920–29 and 1900–09 in increasing order of meridionality. It is of interest that the least meridional decade showed a pronounced bias towards northerlies in the summer, as indeed did the most meridional decade, but the frequency of northerlies was of course less in the 1910's than in the 1950's.

The long-period average total meridionality (M) shows a minimum in the summer and a rather uniform higher value for the rest of the year with the maximum in October. The various decades generally had their lowest meridionality in the summer months as well, but the highest value was not always in October. There is a striking contrast between decade 1910–19 and decade 1950–59 ; on average, the month of least meridionality in the very meridional decade 1950–59 was almost as meridional as the month of greatest meridionality in decade 1910–19.

The main features of the long-period seasonal variation in S are the definite tendency to northerlies in the summer and southerlies from autumn to early spring. Even in decades when the winter southerly bias was weak or reversed (1950–59) or when the summer northerly bias was similarly abnormal (1880–89), there was a clear trend to a more northerly bias in summer relative to winter.

***C*-index—secular and seasonal variations.**—The variations in the *C*-index may be seen from Table VIII.

TABLE VIII—MONTHLY AND YEARLY MEAN VALUES OF C FOR SPECIFIED PERIODS (CYCLONIC BIAS BEING POSITIVE)

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1873–79	−6	−6	−5	−5	−11	−6	−5	4	−7	−4	−4	−7	−62
1880–89	−8	−4	−8	−6	−8	−13	2	−6	−5	−3	0	0	−59
1890–99	−7	−9	−5	−10	−10	−10	−5	−5	−8	−2	−4	−2	−77
1900–09	−2	−3	1	−3	−4	−6	−5	2	−8	4	−3	3	−24
1910–19	1	0	3	−8	−7	−1	−1	9	−9	1	5	6	−1
1920–29	4	2	−3	6	2	−3	3	7	−5	−2	−1	−1	9
1930–39	−2	−6	0	−5	−6	−7	7	−5	−6	0	−2	−3	−35
1940–49	0	−5	−12	−4	−6	−7	1	−3	−2	−7	−1	−8	−54
1950–59	−4	2	−5	−9	−4	1	1	8	−4	−6	1	3	−16
1960–64	−5	−6	−4	0	−7	−3	5	15	−3	−1	6	−5	−8
1873–1964	−3	−4	−4	−4	−6	−5	0	3	−6	−2	0	−1	−32

The most cyclonic decade was 1920–29 and the most anticyclonic was 1890–99, according to Table VIII.

The most cyclonic month in the 'normal' year is August, with July and November next ; the most anticyclonic months are May and September followed closely by June, but the whole period from late winter to early summer tends to have an anticyclonic bias. However, the seasonal variation suggested by the long-term averages was not always repeated in every decade. Particularly noteworthy were the unusually anticyclonic nature of the summer months of the decade 1890–99 and the cyclonic nature of April and May in the decade 1920–29. The main features of the most recent five-year period were the unusually cyclonic high summers and the anticyclonic winters.

Comparison of the monthly averages of C with the average England and Wales rainfall (R) for the period 1873–1964 is shown in Figure 2. A correlation between C and R is evident. The six wettest months were also the months with the six highest C values. It is noteworthy that Figure 2 suggests that the same numerical value of C is generally associated with relatively less

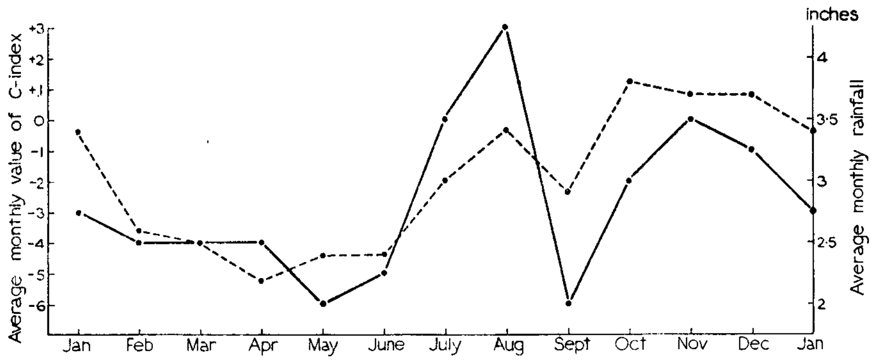

FIGURE 2—AVERAGE MONTHLY *C*-INDEX AND AVERAGE MONTHLY RAINFALL OVER ENGLAND AND WALES FOR THE PERIOD 1873–1964

C •———•

Rainfall •– – – –•

rain in high summer than in autumn and winter. This feature is probably related to the character and intensity of the cyclonic systems, which are in general more vigorous from early autumn to mid-winter when evaporation and heat transfer from the surrounding seas are greatest.

Quintiles and extremes.—The actual numerical value of any of the indices is, of course, of little significance by itself; there must be some standard for comparison. For this purpose it is useful to know whether a particular value of any index is high or low relative to the other members of the set. This can most easily be done by using deciles, quintiles or terciles. The 92 years of the catalogue months of the same name were ranked according to the values of each of the indices, and the approximate percentile boundaries were obtained. The quintile boundaries, which are generally the most useful in practice, are shown in Table IX.

TABLE IX—QUINTILE BOUNDARY VALUES OF *P*, *S*, *C* AND *M* FOR EACH MONTH

(*a*) *P* (progression)

Quintile	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5–4	35·5	24·5	24·5	16·5	9·5	23·5	32·5	32·5	31·5	26·5	25·5	35·5
4–3	20·5	11·5	7·5	2·5	−5·5	8·5	19·5	21·5	16·5	13·5	11·5	24·5
3–2	11·5	−4·5	−8·5	−8·5	−18·5	−2·5	11·5	8·5	4·5	−0·5	2·5	12·5
2–1	−4·5	−15·5	−23·5	−18·5	−27·5	−12·5	−3·5	−1·5	−7·5	−14·5	−8·5	−2·5

(*b*) *S* (southerly bias)

Quintile	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5–4	12·5	15·5	9·5	5·5	8·5	3·5	3·5	5·5	7·5	12·5	10·5	11·5
4–3	7·5	8·5	4·5	1·5	3·5	−0·5	−0·5	1·5	3·5	5·5	5·5	4·5
3–2	1·5	1·5	−0·5	−3·5	−2·5	−3·5	−4·5	−1·5	0·5	0·5	0·5	0·5
2–1	−2·5	−6·5	−6·5	−7·5	−7·5	−7·5	−8·5	−5·5	−3·5*	−2·5	−5·5	−4·5

(*c*) *C* (cyclonicity)

Quintile	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5–4	7·5	6·5	8·5	3·5	4·5	2·5	10·5	14·5	3·5	7·5	7·5	7·5
4–3	0·5	0·5	0·5	−0·5	−3·5	−1·5	5·5	5·5	−2·5	1·5	1·5	1·5
3–2	−5·5	−6·5	−7·5	−8·5	−10·5	−7·5	−2·5	−3·5	−8·5	−5·5	−3·5	−3·5
2–1	−12·5	−15·5	−15·5	−13·5	−16·5	−16·5	−11·5	−12·5	−15·5	−12·5	−8·5	−9·5

(*d*) *M* (meridionality)

Quintile	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5–4	20·5	19·5	19·5	18·5	18·5	15·5	14·5	14·5	17·5	21·5	19·5	17·5
4–3	15·5	15·5	14·5	13·5	14·5	11·5	10·5	10·5	12·5	15·5	14·5	13·5
3–2	11·5	10·5	11·5	10·5	10·5	8·5*	8·5	8·5	9·5	10·5	11·5	9·5
2–1	7·5	6·5	6·5	8·5	7·5	6·5	5·5	4·5	6·5	7·5	7·5	5·5*

Asterisks indicate the less-reliable figures.

From Table IX it is clear that, for example, the Januarys in which P was greater than 35·5 (in practice $P \geqslant 36$) consisted of the 20 per cent most progressive Januarys of the entire set of 92. As another example, January 1962 ($P = 31$) may be classified as in quintile 4, which puts this January in perspective as a month with predominantly progressive synoptic types, although not in the top category of progressiveness.

The extreme values of the indices and years of occurrence are summarized in Table X.

TABLE X—EXTREME MONTHLY VALUES OF P, S, C AND M WITH DATES OF OCCURRENCE IN BRACKETS

	P	S	C	M
Jan.	62 (1921, 1923)	26 (1883, 1885)	21 (1948)	34 (1885)
	−54 (1963)	−21 (1945)	−28 (1964)	0 (1919, 1920, 1921, 1933)
Feb.	50 (1908, 1910, 1943)	28 (1899)	24 (1923)	31 (1902)
	−54 (1947)	−19 (1889)	−34 (1932)	0 (1935)
Mar.	56 (1921)	30 (1957)	37 (1909)	31 (1950)
	−41 (1909, 1964)	−19 (1878)	−46 (1953)	0 (1934)
Apr.	52 (1927)	17 (1894)	23 (1920)	33 (1950)
	−38 (1884)	−16 (1951)	−41 (1938)	0 (1914, 1948)
May	40 (1934)	15 (1878)	30 (1958)	38 (1954)
	−44 (1935)	−22 (1902)	−49 (1896)	1 (1925, 1934)
June	48 (1922, 1923)	22 (1879)	32 (1912)	26 (1879)
	−41 (1958)	−19 (1923)	−31 (1887)	1 (1934)
July	56 (1915)	20 (1904)	24 (1936)	28 (1883)
	−36 (1955)	−23 (1948)	−41 (1955)	0 (1925, 1934)
Aug.	54 (1922, 1929)	26 (1950)	38 (1963)	33 (1887)
	−36 (1947)	−21 (1960)	−30 (1880)	0 (1921, 1947)
Sept.	60 (1923)	20 (1901)	22 (1946)	30 (1903)
	−46 (1894)	−21 (1952)	−42 (1959)	0 (1917, 1924)
Oct.	59 (1923)	42 (1908)	33 (1907)	42 (1908)
	−48 (1960)	−23 (1887)	−28 (1879, 1962)	0 (1935, 1937)
Nov.	58 (1917, 1922)	28 (1881, 1902)	31 (1963)	32 (1921)
	−30 (1937)	−27 (1910)	−30 (1942)	2 (1887, 1919, 1928)
Dec.	57 (1929)	29 (1888)	29 (1959)	35 (1888)
	−46 (1927)	−16 (1950)	−26 (1879)	0 (1935)
Year	62 (Jan. 1921, 1923)	42 (Oct. 1908)	38 (Aug. 1963)	42 (Oct. 1908)
	−54 (Jan. 1963, Feb. 1947)	−27 (Nov. 1910)	−49 (May 1896)	0 (17 months)

It will be seen from Table X that the biggest range of variation of the P-index was observed in January (116 units, i.e. from −54 to 62) and the smallest in May (84) ; for the S-index the biggest range was in October (65) and the smallest in April (33) ; for C the biggest range was in March (83) and the smallest in January (49) ; and for M the biggest range was in October (42) and the smallest in June (25). The contrast between the extreme progressiveness of the mild Januarys of 1921 and 1923 and the extreme blocking of the exceptionally cold months of February 1947 and January 1963 is particularly worthy of note amongst the many interesting climatological facts contained in Table X.

Interrelations between the indices and rainfall on a monthly time-scale.—For each month of the year multiple contingency tables relating S, C and R (average rainfall over England and Wales) and C, P and R were prepared. For this purpose the P, S and C-indices were classified in terciles and R in two categories according to whether R was above or below the median value.

The contingency tables (not reproduced) show clearly that R (rainfall) is closely correlated with the C-index ; that the correlation between S and R is virtually zero ; and that there is some correlation between P and R which arises mainly from the moderate positive correlation between P and C. A month characterized by indices C and P in tercile 3 (i.e. progressive and cyclonic) has a high probability of having rainfall above normal over England and Wales ; similarly when the monthly C and P-indices are in tercile 1 the England and Wales rainfall is very likely to be below normal.

Contingency tables were also prepared to show the relationship between C in quintiles and R in terciles. A typical association is shown in Table XI.

TABLE XI—ASSOCIATION BETWEEN C (MONTHLY CYCLONICITY INDEX) IN QUINTILES AND R (AVERAGE MONTHLY ENGLAND AND WALES RAINFALL) IN TERCILES IN JANUARY (1873–1964)

		(anticyclonic)		C (quintiles)		(cyclonic)
		1	2	3	4	5
R (terciles)	1 (dry)	13	11	3	3	0
	2	4	7	12	7	2
	3 (wet)	1	1	4	9	15

Table XI and similar tables for other months indicate a highly significant statistical relationship between C and R in all months of the year. The most anomalous cases are undoubtedly those in which C_1 (quintile 1 of C) occurs with R_3 (tercile 3 of R) and C_5 with R_1. No anomalous case of these types was observed in February, September and November of the period 1873–1964 ; these three months exhibit a particularly high correlation between C and R. At the other extreme there were four anomalous cases in May (viz. C_1/R_3 in 1914 and 1943, C_5/R_1 in 1939 and 1940). Nevertheless the association between C and R in May is still highly significant (at 1 per cent level at least). It is of interest that there were six occasions when C_5 was associated with R_1 ; these all occurred from April to August when weak or small-scale depressions are much more likely than in autumn and winter.* On the other hand eight occasions of association between C_1 and R_3 were scattered throughout the year ; anomalous situations of this type may arise when a predominantly anticyclonic month has a few vigorous cyclonic systems which produce much rain from very moist and unstable air masses over England and Wales.

Interrelations between the indices and temperature on a monthly time-scale.—The association between the monthly P, S and C indices (in quintiles) and the mean monthly temperature anomaly (ΔT, in terciles) in central England was next examined. Tercile 1 for ΔT corresponded to the most negative (i.e. cold) anomaly.

There is a highly significant direct association between P and ΔT in the months December to March, which may be illustrated by the January relationship in Table XII ; it is clear that blocked types tend to be cold and

*In this connexion it needs to be noted that a day is classified as type Z (i.e. cyclonic) in the Lamb catalogue when a depression of any intensity is observed anywhere over the British Isles on at least one main synoptic chart ; thus a Z day with a weak or small-scale low over the periphery of the British Isles (e.g. over northern Scotland) might not be associated with much rainfall over England and Wales.

progressive types tend to be warm. April and November also show a significant though less close direct association between P and ΔT, but the relationship becomes of little or no practical use in the warmer part of the year from May to October.

TABLE XII—ASSOCIATION BETWEEN P (MONTHLY PROGRESSION INDEX) IN QUINTILES AND ΔT (MEAN MONTHLY CENTRAL ENGLAND TEMPERATURE ANOMALIES) IN TERCILES IN JANUARY (1873–1964)

		P (quintiles)				
		(blocked) 1	2	3	4	(progressive) 5
ΔT (terciles)	1 (cold)	15	5	8	2	0
	2	1	10	9	5	6
	3 (warm)	1	3	2	10	14

There is generally a significant direct association between S and ΔT in all months, although it is rather weak in the winter. The association is usefully close in all non-winter months ; it is particularly good in May, August and September, as exemplified by the May relationship shown in Table XIII.

TABLE XIII—ASSOCIATION BETWEEN S (MONTHLY SOUTHERLY BIAS INDEX) IN QUINTILES AND ΔT (MEAN MONTHLY CENTRAL ENGLAND TEMPERATURE ANOMALIES) IN TERCILES IN MAY (1873–1964)

		S (quintiles)				
		(northerly) 1	2	3	4	(southerly) 5
ΔT (terciles)	1 (cold)	11	9	7	1	1
	2	6	8	7	5	5
	3 (warm)	0	5	5	8	13

The relationship between C and ΔT is also of interest. It is not surprising that a highly significant inverse association exists between C and ΔT in the summer months (i.e. a cyclonic month tends to be cool), which may be illustrated by the July relationship shown in Table XIV.

TABLE XIV—ASSOCIATION BETWEEN C (MONTHLY CYCLONICITY INDEX) IN QUINTILES AND ΔT (MEAN MONTHLY CENTRAL ENGLAND TEMPERATURE ANOMALIES) IN TERCILES IN JULY (1873–1964)

		C (quintiles)				
		(anticyclonic) 1	2	3	4	(cyclonic) 5
ΔT (terciles)	1 (cold)	3	2	7	9	9
	2	2	8	6	6	9
	3 (warm)	15	6	4	4	1

The summer type of correlation between C and ΔT also applies in a weaker form in April, May and September. However, from November to February the association is direct (i.e. an anticyclonic month tends to be cold), but the relationship is not quite so close as the inverse association of high summer. In March and October there is little or no association between C and ΔT, and these months are evidently transitional.

Examination of all the contingency tables relating P, S or C with ΔT suggests that for practical purposes the best associations in particular months are as follows :

(a) between P and ΔT in December, January, February and March (positive correlation) ;

(*b*) between S and ΔT in April, May, September, October and November (positive correlation) ;

(*c*) either between S and ΔT (positive correlation) or between C and ΔT (negative correlation) in June, July and August (these two relationships are equally good).

The associations between the various indices and temperature over central England are broadly as would be expected from synoptic and climatological experience. Similarly, for other parts of the British Isles the nature of the relationships should be broadly inferable from the indices, particularly when the P, S and C indices are sufficiently different from 'normal' values to imply predominant synoptic types.

There is no *a priori* reason to expect any worthwhile association between M and ΔT. However, the variability of temperature should be related to the index of meridionality (M), but this aspect has not been systematically investigated.

Concluding remarks.—The indices conveniently categorize in a synoptically meaningful way the main features of the weather over the British Isles over extended periods of time. The indices are particularly helpful when comparisons have to be made between weather types of different months or mid-month to mid-month periods. Such comparisons inevitably arise in searching for analogous situations in the historical record. Analogues of the large-scale circulation may be selected because of similarity in the distribution over much of the northern hemisphere of monthly mean temperature or pressure or for other reasons, but it must always be necessary to be aware of the main synoptic character of the British Isles weather associated with such broad-scale analogues : the indices usefully add this essential, local information. Moreover the indices may equally well be used to summarize the main aspects of the weather in the month (or 30-day period) following the analogue.

A search for analogues of the synoptic situation near the British Isles may be made directly through the indices, but analogues selected in this way alone are unlikely in general to be satisfactory for long-range forecasting purposes unless supported by similarity in the large-scale circulation. However, some experiments incorporating the objective (computer) selection of analogues using the P, S, C and M-indices are planned.

Acknowledgement.—We are grateful for the assistance given by Mr J. D. Lankester in the preparation of the data.

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551.509.56

TESTS OF THUNDERSTORM FORECASTING TECHNIQUES

By W. E. SAUNDERS

Introduction.—A description is given of tests of various thunderstorm forecasting techniques carried out at certain forecasting offices under the author's control during the summer of 1965.

The methods tested.—The techniques used are listed below :

The Similä method.—Similä[1] provided an instability index Δ_T for the layer between 850 and 500 mb, assuming the former to be the condensation level. Δ_T is obtained from a diagram, as a function of the temperatures at these two levels. A humidity index Δ_U is obtained as a function of temperature and dew-point on another diagram. Values of Δ_T and Δ_U are drawn on a thunderstorm tendency chart. The thunderstorm tendency is assessed with the aid of numerical values of the indices and is large for large positive values of Δ_T and Δ_U.

The Showalter method.—This well-known index[2] is simply obtained by assuming ascent from 850 to 500 mb at the appropriate adiabatic lapse rates and then subtracting the resulting 500 mb temperature from the observed 500 mb temperature. Negative values indicate instability.

The Galway method.—Galway[3] introduced use of the forecast maximum surface temperature and the mean dew-point in the lowest 3000 feet. Using these, and assuming a dry adiabatic through the forecast surface maximum temperature, proceed to the corresponding condensation level, thence along the saturation adiabatic to 500 mb. Then proceed as with Showalter. This is known as the 'lifted index'.

The Rackliff method.—Rackliff's[4] index (Δ_T) is given by

$$\Delta_T = \theta_{w900} - T_{500}$$

where θ_{w900} = 900 mb wet-bulb potential temperature (°C)
T_{500} = 500 mb dry-bulb temperature (°C).

High values indicate instability. In non-frontal situations a value exceeding 30 is regarded as critical.

The Jefferson method.—Jefferson[5] suggested a modification to Rackliff's index, such that it is independent of the general temperature of the air mass. He also introduced the 700 mb dew-point depression to allow for presence of dry air in middle levels. Jefferson's index (T_{mJ}) is given by

$$T_{mJ} = 1{\cdot}6\theta_{w900} - T_{500} - \tfrac{1}{2}T_{d700} - 8$$

where θ_{w900} = 900 mb wet-bulb potential temperature (°C)
T_{500} = 500 mb dry-bulb temperature (°C)
T_{d700} = 700 mb dew-point depression (°C).

A threshold value of 28 is suggested.

The Boyden method.—Boyden[6] drew attention to the necessity for allowing for advective changes in the upper air. He proposed an index (I) given by

$$I = Z - T - 200$$

where Z = 1000–700 mb thickness (decametres)
T = 700 mb dry-bulb temperature (°C).

This therefore strictly applies only to the layer up to 700 mb. The threshold value for thunderstorms is 94. Isopleths of the index are drawn on charts and assumed to move with the 700 mb wind.

The Miller and Starrett method.—This method[7] differs from those already listed. It consists of a graph of 850–500 mb temperature difference against 500 mb temperature, with a straight line separating thunderstorm occasions from others. The authors recommend using the diagram in conjunction with the current moisture pattern and possible trigger action.

The Hanssen method.—This is a purely objective method. Hanssen[8] related the incidence of thunderstorms in the Netherlands to four parameters : the barometric pressure, the extreme latitude of the 500 mb trough or ridge, the saturation deficits at 850 and 700 mb, and the 1000–700 mb thickness minus the 700–500 mb thickness. Diagrams are provided to obtain from the first two of these a parameter X, and from the last two a parameter Y. Values of X and Y are then used with a contingency table to produce a thunderstorm forecast.

Testing arrangements.—Methods were allocated to stations such that, where possible, a station which was already using a method should be responsible for testing it.

Tests were carried out on Mondays to Fridays in the period 1 April to 30 September 1965.

Forecasters were asked to use 0000 GMT upper air data with the chosen technique, allow for effects of advection and surface heating as seemed appropriate, and record a simple 'yes' or 'no' forecast for thunderstorms in the area covered by the Manby group of stations in the period 1200 – 2359 GMT. The area mentioned, and the locations of stations taking part in the tests, are shown in Figure 1.

The one exception to the procedure mentioned was that Hanssen's method is purely objective, so that no adjustments were made for advection or heating.

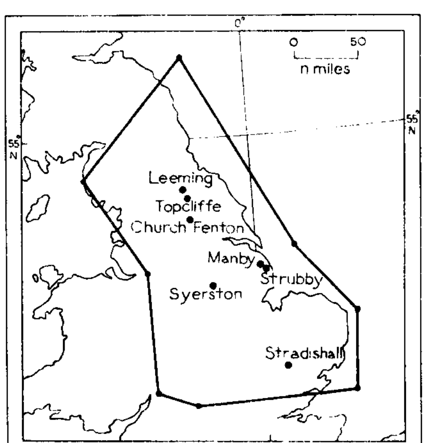

FIGURE 1—AREA COVERED BY TESTS, AND STATIONS TAKING PART

Also, at the time the tests were made, a diagram was not available for dealing with troughs or ridges lying to east of the area and on those occasions this technique was abandoned.

A record of whether thunderstorms actually occurred on each test day was kept in the main office at Manby, and subsequently used in marking results from the other stations. SFLOC reports were counted positive.

For purposes of comparison, it was considered worthwhile to include, with the results obtained for the various individual techniques, the results obtained by the Manby forecasters in the course of their ordinary forecasting practice. It was hoped that by this means, the results would show under what conditions general forecasting practice could be improved by use of the newer techniques, and which techniques are best suited for use in different circumstances. In the tables giving the results of tests, these Manby forecasts are included under the heading 'general practice'. The question whether or not thunderstorms were forecast was decided by ascertaining whether or not thunderstorms had been included in the routine forecasts or aviation warnings issued by Manby up to 1200 GMT. These forecasts and warnings relate to the same area as that covered by the tests, and the 'general practice' results are therefore fully comparable with those obtained by the other stations. Aids which were available in the forecast room at Manby included charts of the Boyden and Similä instability indices, and the objective diagrams of Hanssen. No allowance can be made for the extent to which any or all of these were used by forecasters. It may, however, be said that the separate techniques which were being tested at Manby were not dealt with by the forecasters responsible for the general forecasting, and every effort was made to test these techniques in an independent way.

Overall accuracy of thunderstorm forecasts.—Table I shows the overall correctness of forecasts that thunderstorms would or would not occur. This includes the results for all days of the tests.

TABLE I—OVERALL ACCURACY OF FORECASTS THAT THUNDERSTORMS WOULD OR WOULD NOT OCCUR

Method	Testing station	Number of forecasts	Number correct	Percentage correct
General practice	Manby	126	99	79
Rackliff	Syerston	119	91	76
Similä	Manby	125	90	72
Boyden	Topcliffe	123	87	71
Jefferson	Strubby	124	87	70
Miller/Starrett	Church Fenton	123	86	70
Hanssen	Manby	92*	64	70
Galway	Stradishall	124	81	65
Showalter	Leeming	124	80	65

*33 abandoned cases, on 8 of which thunderstorms occurred.

Overall accuracy of forecasts on frontal or trough days.—It is a matter of forecasting experience that thunderstorms are often more difficult to forecast on days when there is a front or isobaric trough over the area than on the straightforward convection days. The test results for these occasions were therefore analysed separately from the remainder.

Table II gives the overall accuracy of forecasts on days when there was a front or isobaric trough over the area.

TABLE II—OVERALL ACCURACY OF FORECASTS THAT THUNDERSTORMS WOULD OR WOULD NOT OCCUR ON FRONTAL OR TROUGH DAYS

Method	Number of forecasts	Number correct	Percentage correct
Boyden	42	35	83
Hanssen	35*	26	74
General practice	42	31	74
Jefferson	42	31	74
Similä	42	30	71
Rackliff	41	29	71
Galway	42	27	64
Miller/Starrett	41	25	61
Showalter	42	23	55

*Abandoned on 7 occasions, on 2 of which thunderstorms occurred.

Accuracy of forecasts that thunderstorms would occur on frontal and trough days.—Table III shows the accuracy of forecasts that thunderstorms would occur on these occasions.

TABLE III—ACCURACY OF FORECASTS THAT THUNDERSTORMS WOULD OCCUR ON FRONTAL AND TROUGH DAYS

Method	Number of forecasts	Number correct	Percentage correct
Boyden	16	13	81
Rackliff	10	7	70
Similä	13	9	69
General practice	16	11	69
Hanssen*	20	13	65
Jefferson	20	13	65
Galway	20	11	55
Miller/Starrett	13	7	54
Showalter	16	7	44

*See note under Table II.

Accuracy of forecasts that thunderstorms would not occur on frontal or trough days.—Table IV shows the accuracy of negative forecasts on these days.

TABLE IV—ACCURACY OF FORECASTS THAT THUNDERSTORMS WOULD NOT OCCUR ON FRONTAL OR TROUGH DAYS

Method	Number of forecasts	Number correct	Percentage correct
Hanssen*	15	13	87
Boyden	26	22	85
Jefferson	22	18	82
General practice	26	20	77
Galway	22	16	73
Similä	29	21	72
Rackliff	31	22	71
Miller/Starrett	28	18	64
Showalter	26	16	62

*See note under Table II.

The extent to which actual thunderstorms were forecast.—For some purposes, the extent to which actual thunderstorms are covered in forecasts may be more important than the accuracy of a forecast whether or not they will occur. Accordingly, the results were examined separately for days on which there were thunderstorms. These days were separated into those occasions of straightforward convection and those on which a front or trough was present.

Table V shows the extent to which actual thunderstorms were correctly included on the convection days, and Table VI the corresponding figures for the frontal or trough days.

TABLE V—INCLUSION IN FORECASTS OF THUNDERSTORMS WHICH ACTUALLY OCCURRED—CONVECTION DAYS

Method	Number of thunderstorms	Number forecast correctly	Percentage correct
General practice	29	22	76
Boyden	28	20	71
Hanssen*	23	16	70
Galway	28	19	68
Rackliff	27	17	63
Miller/Starrett	28	16	57
Jefferson	28	15	54
Showalter	28	15	54
Similä	29	15	52

*This method was abandoned on 6 days of this type.

TABLE VI—INCLUSION IN FORECASTS OF THUNDERSTORMS WHICH ACTUALLY OCCURRED—FRONTAL AND TROUGH DAYS

Method	Number of thunderstorms	Number forecast correctly	Percentage correct
Hanssen*	15	13	87
Boyden	17	13	76
Jefferson	17	13	76
Galway	17	11	65
General practice	17	11	65
Similä	17	9	53
Rackliff	16	7	44
Miller/Starrett	17	7	41
Showalter	17	7	41

*This method was abandoned on 2 days of this type.

Time occupied in applying the techniques.—The time taken in the daily routine application of a technique has a clear relation to its overall usefulness as a forecasting tool. Staff engaged on the tests were asked to give an estimate of the average time taken daily in each case. These estimates are given in Table VII.

TABLE VII—AVERAGE TIME TAKEN TO APPLY THE TECHNIQUE

Method	Average time daily to apply method *minutes*
Galway	5
Showalter	5
Miller/Starrett	5
Hanssen	5 – 10
Rackliff	10
Boyden	10 – 15
Jefferson	10 – 20
Similä	60

Discussion of results.—It has to be emphasized at the outset that the tests were carried out only over one summer, and that not all types of thunderstorm situation were well represented.

The results in Table I show that, taking all occasions together, the normal approach of the forecaster, which includes a subjective examination of tephigrams and other data, produces results which are better, though not very much better, than if he had concentrated on one of the techniques tested.

The results confirm that some more recently introduced instability-index techniques give more helpful results than earlier methods from which they were derived. The Similä method gives useful results, but takes appreciably longer to apply (see Table VII) than other methods of the same type.

Perhaps the most significant results are those in Tables II, III and IV, which show that on frontal or trough days forecasters who concentrated on

Photograph by courtesy of British Aircraft Corporation

PLATE I—PRESENTATION OF METEOROLOGICAL OFFICE AWARDS AT THE HEADQUARTERS OF THE GUILD OF AIR PILOTS AND AIR NAVIGATORS ON 5 MAY 1966

Mr. B. C. V. Oddie, C.B.E., Deputy Director (Outstation Services) presenting a briefcase to Captain D. B. Wilkie of BEA (see page 220).

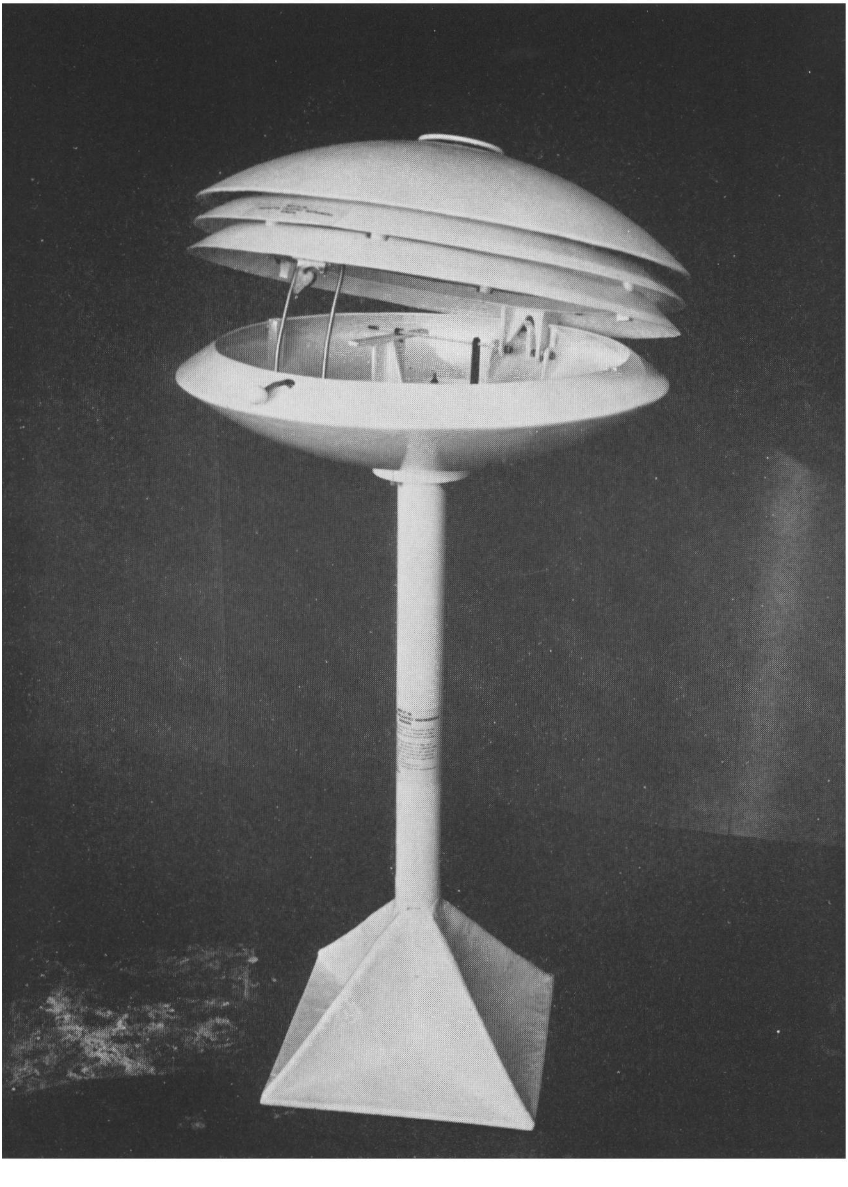

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PLATE II—EXPERIMENTAL INSTRUMENT SCREEN MADE OF FIBREGLASS

This screen is undergoing trials to determine its suitability as a replacement for the more familiar Stevenson screen. Although the screen is initially slightly more expensive, the virtual elimination of maintenance costs, the ease of repair and the complete immunity to fungoid and insect attack offer considerable advantages.

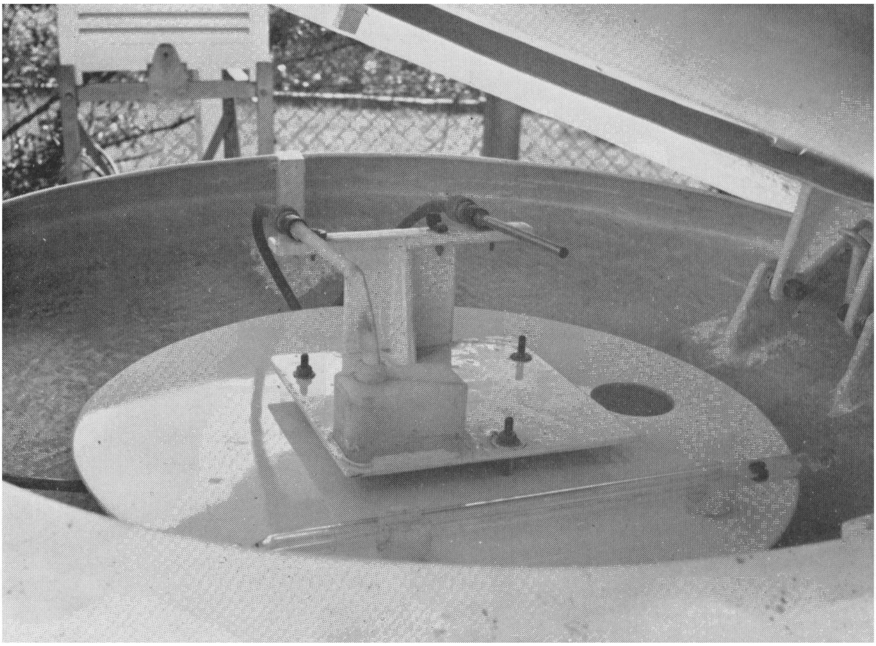

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PLATE III—INSIDE VIEW OF EXPERIMENTAL SCREEN

The screen which is constructed by the Instrument Development Branch is circular and has a single large louver and hinged lid. The photograph shows wet and dry resistance thermometers, and a standard glass thermometer used during comparisons with the standard wooden thermometer screen.

To face page 209

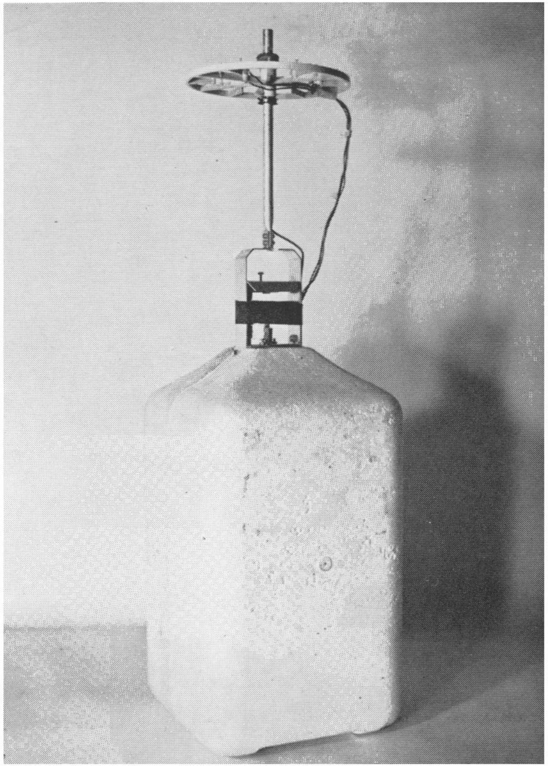

PLATE IV—GENERAL VIEW OF THE NEW RADIOSONDE MARK 3 AS PRODUCED BY AN INITIAL MANUFACTURING CONTRACT

The thermometer element and humidity sensor are shown.

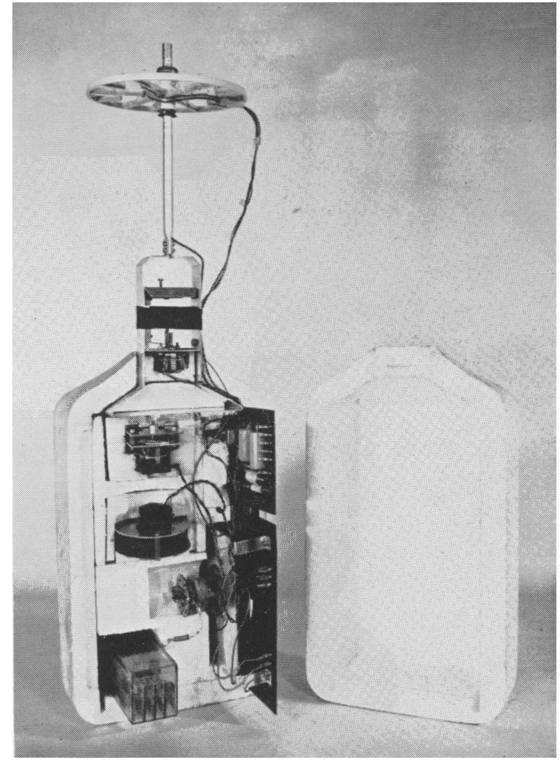

PLATE V—RADIOSONDE MARK 3 WITH EXPANDED POLYSTYRENE COVER REMOVED

The pressure sensor, reference inductance, batteries and telemetry are shown.

a particular technique produced better results than forecasters using 'general practice'. The Boyden technique, which was designed to include use in the mobile type of situation, provided the most useful overall results on days of this type. The testing station (Topcliffe), where this technique had been in use since it was published in 1963, commented on its special usefulness in frontal or trough situations and also mentioned that this method often allows quite small areas of thunderstorm activity to be defined and forecast.

A further Topcliffe comment was that in straightforward convection situations the Boyden method tends to overestimate the thunderstorm probability, and on these occasions some other index is useful. Tables I and II confirm this impression and suggest that the Rackliff method is perhaps the most useful aid on these occasions. Table V, however, shows that the Boyden method is still the most useful aid on convection days if the object is to include in forecasts as many as possible of the thunderstorms which actually occur. This point is a significant one, since some users of forecasts may prefer to receive a number of wrong forecasts in order not to miss warning of storms that do occur.

Table VI is simply a rearrangement of some of the material already included in Table III, and these two tables should be regarded together. Thus, if the object is to include as many as possible actual thunderstorms, Table VI shows that on frontal or trough days the Hanssen method gives the best results when it can be used, and Table III shows the extent to which 'yes' forecasts were wrong. Table VI also shows that the Boyden and Jefferson methods were equally useful in ensuring mention of storms when they occurred, on frontal or trough days, while Table III shows that the Boyden method contributed a higher proportion of successful 'yes' forecasts.

As regards thunderstorm forecasting, the tests seem to lead to the following conclusions :

(i) On straightforward convection days, one of the recently introduced instability index methods gives useful assistance to the forecaster. There is an indication that the Rackliff method is the most helpful.

(ii) On days when fronts or troughs are expected in the area, more weight should be given to the instability index, and on these occasions the Boyden index seems definitely the most helpful.

(iii) The Hanssen objective method already shows usefulness on frontal or trough days. This should be well worth further development, using British Isles data, and providing for use on all occasions.

Acknowledgement.—Some forty forecasters shared in the task of collecting data, and keeping the check sheets on which the tests were marked. Some were in the position of testing the technique which they already regarded as the most helpful, but many were well aware that the method they were testing would not necessarily be the most effective of its kind. All have contributed to the results, and it is desired to express appreciation of the efforts of all concerned.

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A REMARK ON SYNOPTIC CHARTING OF MOISTURE

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In his paper Kirk[1] showed that the synoptic aspects of humidity distribution have not yet been satisfactorily used in practice. He discussed also a method for charting moisture characteristics in a situation with moist air advection to western Europe.

In the present author's previous paper[2] another method of computing humidity characteristics for use on synoptic charts has been shown. The principle

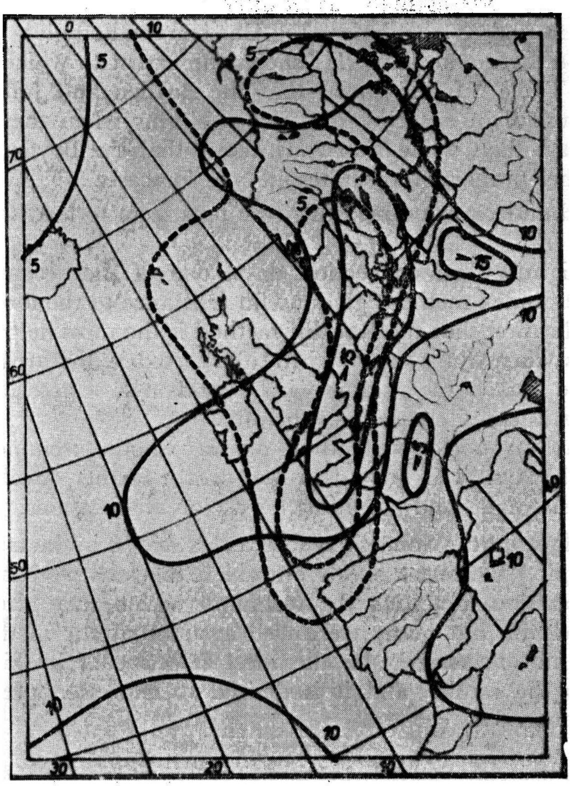

FIGURE 1—PRECIPITABLE WATER IN THE LAYER 1000–700 MILLIBARS AT 1200 GMT, 9 DECEMBER 1964

——— Precipitable water in grammes
– – – – Isohyets in millimetres

of it is well known as 'precipitable water'. It can be derived from the equation

$$M_v = \frac{\bar{q}(p_1 - p_2)}{g} \quad \ldots (1)$$

where M_v is the integral mass of water vapour in the layer between pressure surfaces p_1 and p_2, $\bar{q}$ is the mean specific humidity (computed as an arithmetic mean of values of specific humidity at the surfaces p_1 and p_2) and $g = 9{\cdot}80665$ metres/second^2. We assume that the maximum possible value of precipitable water can be computed from the mean temperature of the corresponding layer in all cases.

Considering this fact we can write the equation for the relative value of precipitable water as follows :

$$M_v^R = \frac{M_v}{(M_v)_{\max}} \times 100$$

where M_v^R is the relative precipitable water, and $(M_v)_{\max}$ can be derived from equation (1) by replacing $\bar{q}$ with $\bar{q}_{\max}$ (i.e. specific humidity in saturated air.)

The values computed for individual aerological stations are plotted on the synoptic chart. Figures 1 and 2 show the results for M_v and M_v^R for one of the

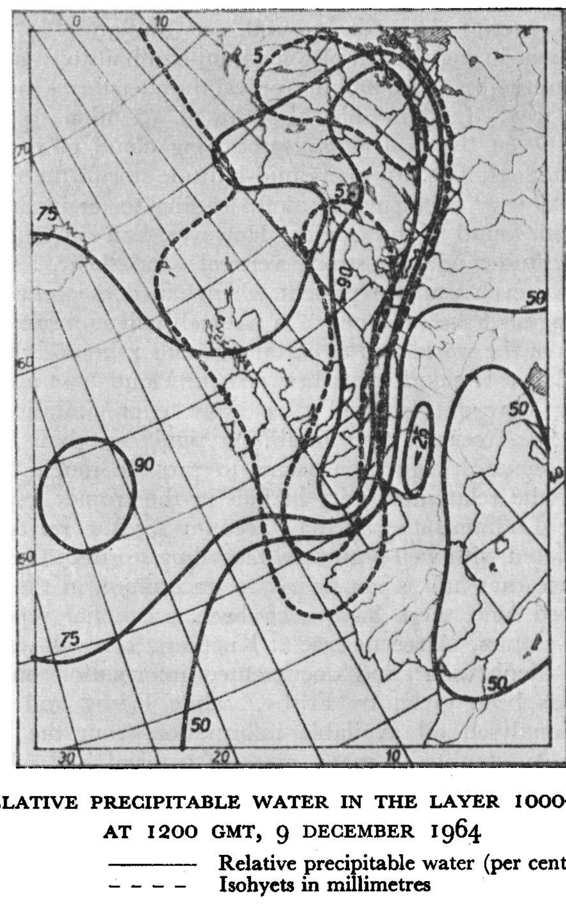

FIGURE 2—RELATIVE PRECIPITABLE WATER IN THE LAYER 1000–700 MILLIBARS AT 1200 GMT, 9 DECEMBER 1964

———— Relative precipitable water (per cent of $(M_v)_{\max}$)
– – – – Isohyets in millimetres

cases computed by Kirk.[1] The pecked lines are isohyets for 0 and 5 millimetres of precipitation (for the time interval of the chart $\pm$ 6 hours).

From the pattern of relative precipitable water it follows that this method of showing humidity distribution on the synoptic charts seems to be of some use to meteorologists in the weather service.

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THE OCCURRENCE AND DISTRIBUTION OF HAIL IN AFRICA

By H. W. SANSOM

Introduction.—The incidence of thunderstorms over parts of Africa is as high as or higher than anywhere else in the world,[1] but reports of hail are relatively rare, except in certain areas. Fawbush and Miller[2] have stated that hail seldom occurs at the ground when the wet-bulb freezing-level is more than 3650 metres above the ground, but Ludlam[3] has shown that the amount of melting during the fall of a medium-size hailstone is not very great, and so the apparent absence of hail in tropical thunderstorms must be explained in some other way. Ludlam[4] has also drawn attention to the differences in structure between the typical hail-producing cloud of mid-latitudes and the tropical cumulonimbus. In many mid-latitude storms there is considerable wind shear, with very strong winds aloft, leading to an inclined updraught, but this is seldom found in the tropics. However, hail can undoubtedly form in temperate latitudes without strong vertical wind shear, and strong shear is not always (or even usually) present when hail does occur in the tropics. Appleman[5] suggested the existence of a natural 'hail suppression mechanism' in certain areas of the world and at certain seasons ; he postulated that when a thick, dense layer of cloud exists between the cloud base and the freezing-level, the rising large droplets will often grow to precipitation size and fall out as rain before freezing, thus inhibiting significant hail formation. On the whole, Appleman's suggestion seems to provide much the most likely explanation for the relative scarcity of hail in the tropics, especially at low altitudes, while Ludlam's theory may account for the rarity of the really large hail associated with well-organized travelling storms. There is, however, growing evidence that hail is not nearly so uncommon in the tropics as was formerly believed, and there have even been occasional reports of hail at sea level in the tropics. A recent case at Kuching, Sarawak was described by Stemmler and Stephenson[6] and documented information on a number of known cases has been given by Frisby,[7] while Frisby and Sansom[8] have surveyed and analysed all available information from the entire tropical belt. There are undoubtedly many cases of tropical hail which are never reported.

Areas of hail occurrence in Africa.—Hail is virtually unknown over Africa between 20°N and 30°N, on the Atlantic coast north of 25°S, and on the Indian Ocean coast north of 15°S ; hail has, however, been reported at Mauritius (20°S), where there is a reliable report of a hailstorm occurring over the sea, and at the Grande Comore Island (12°S) in the Mozambique Channel. There have been occasional reports of hailstorms in West Africa even at fairly low elevations, but on the east coast, where thunderstorms are much less common (see Figure 1), hail is extremely rare north of Mozambique. There have been, however, reports of occasional hail in one locality not far inland from Mombasa, Kenya. Figure 2 indicates, in very general terms, the point frequency of hailstorms over Africa ; it is based on information obtained from many sources, and covering varying periods. Figure 3 shows

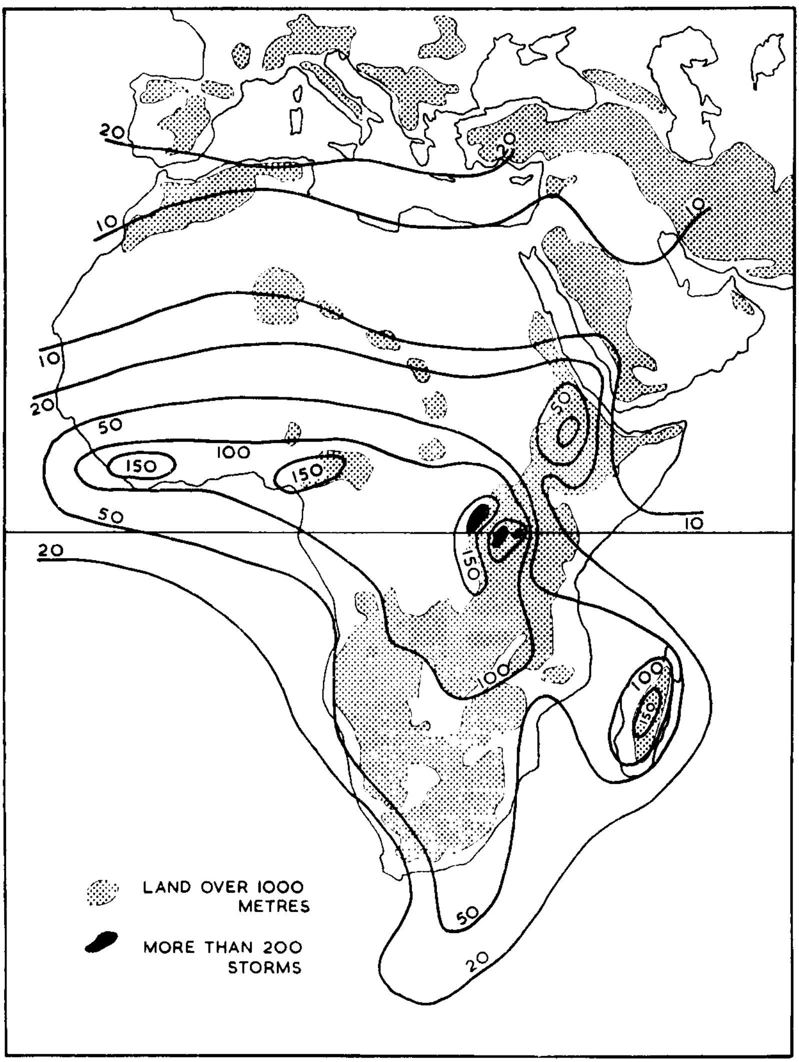

FIGURE 1—MEAN ANNUAL FREQUENCY OF THUNDERSTORM DAYS OVER AFRICA

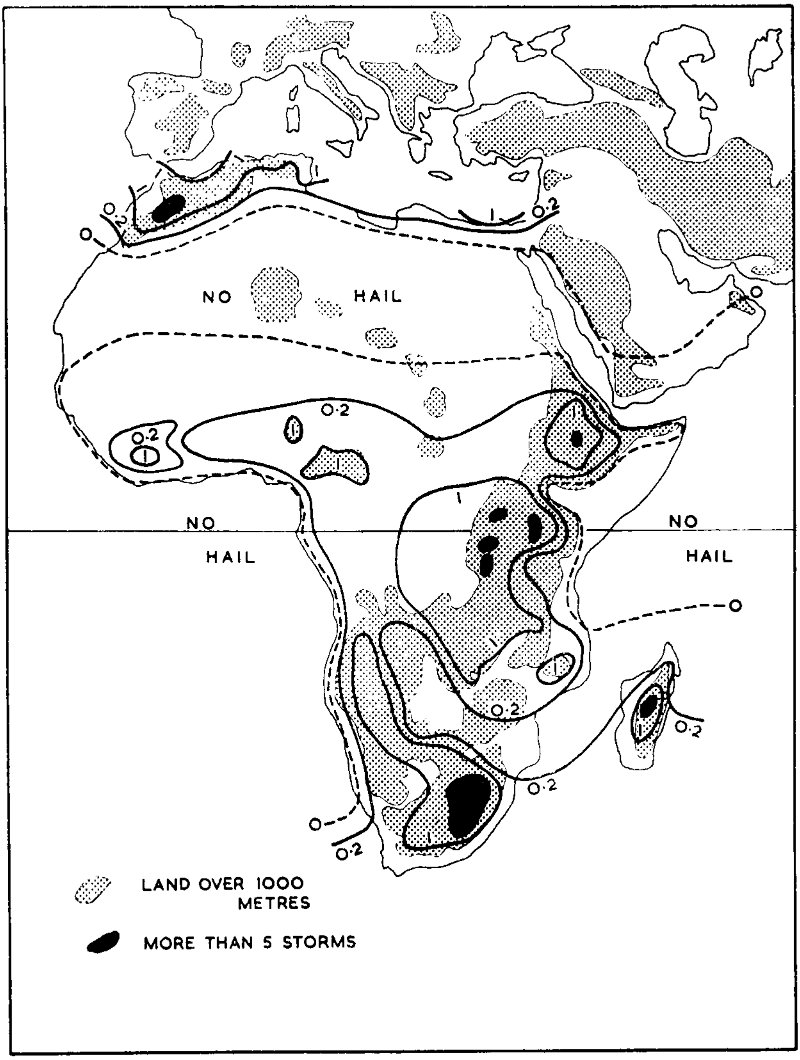

FIGURE 2—MEAN ANNUAL FREQUENCY OF HAIL AT A POINT

the main hail months in each area, but hail does, of course, often occur outside these months.

The main hail areas are :

1. Morocco (especially Atlas Mountains)
2. Rwanda, Burundi, and parts of the Congo (Democratic Republic)
3. Western Kenya
4. Western Uganda
5. Ethiopia
6. Transvaal and Orange Free State, in the Republic of South Africa ; Basutoland and Swaziland
7. The high plateau of Madagascar.

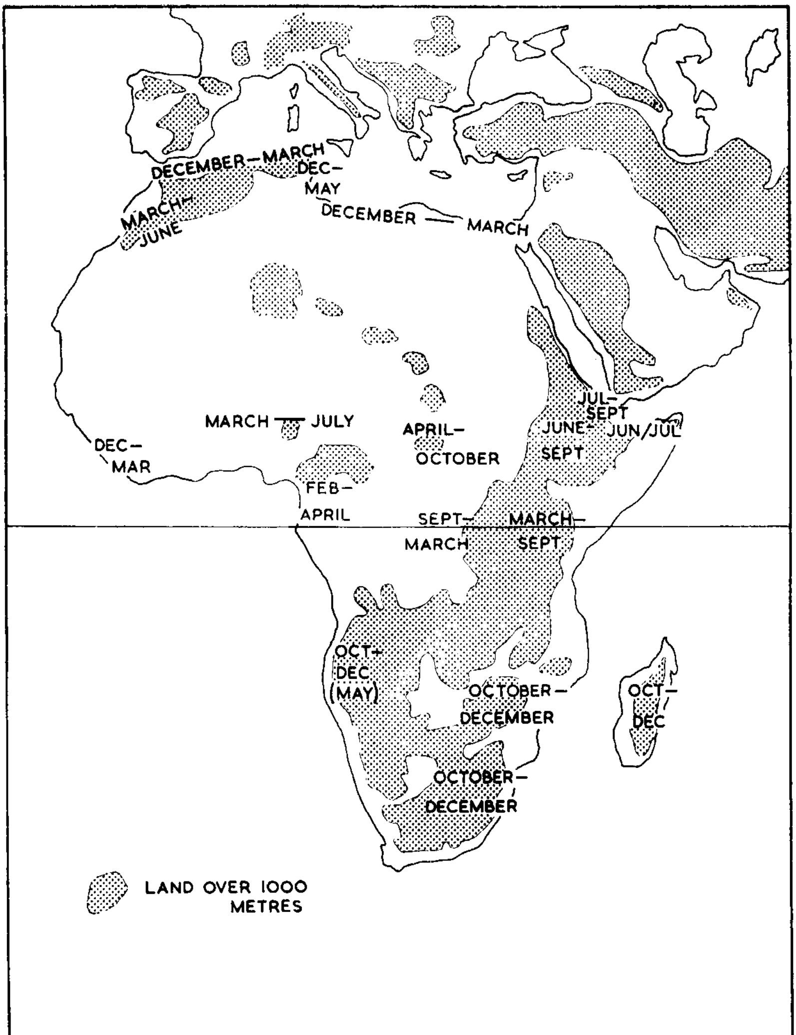

FIGURE 3—MAIN HAIL SEASONS THROUGHOUT AFRICA

These will be considered separately, and brief notes given on each area.

1. *Morocco.*—

(*a*) Coastal plains : occasional storms mainly December to March.

(*b*) Atlas Mountains : up to 5 storms per year, with peak frequency during months March to June.

2. *Rwanda and Burundi, and Congo.*—

(*a*) Hail frequencies in excess of 5 storms per annum near the western border of Rwanda and Burundi (east of Lakes Kivu and Tanganyika), particularly during the months of September to March (peak frequency in February).

(b) In Kivu Province of the Congo Republic, to the west and north of Lake Kivu, hail frequencies in excess of 5 storms per annum are reported (up to 9 storms per annum north of the Lake). The highest monthly frequencies occur in the months September to March with a peak in February.

(c) Up to 2 storms per annum are reported from south-west parts of Katanga Province during the months September to March, with the highest monthly frequency in October.

Further details of the frequency of hail in this area are contained in a paper by Bultot.[9]

3. *Western Kenya.* — Sansom[10] has discussed the occurrence of hail in East Africa but a recent hail reporting survey has shown that in western Kenya hail is even more frequent than was originally suspected. The hail area extends from Mount Elgon in the north, through the Nandi Hills to the Kericho area. The hail frequency at a point exceeds 5 storms per annum over much of the area, and reaches 10 in parts of the Kericho district. No month is free from hail.

The number of days per annum on which hail is reported somewhere in the western Kenya hail area (1°N to 1°S, 34°E to 36°E) is well over 100, with over 50 days per annum in the Kericho area alone (i.e. on the 25,000 acres of tea estates, nearly all of which are within 10 miles of Kericho township at 0°22'S, 35°17'E).

TABLE I—THE MONTHLY AND MEAN ANNUAL OCCURRENCE OF HAIL IN WESTERN KENYA (1960–64)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Days of thunder	10	11	16	21	23	18	15	18	20	18	17	13	200
Days of hail (W. Kenya)	5	6	13	9	9	13	10	15	15	10	5	4	114
Days of hail (Kericho area)	2	3	6	3	4	6	6	5	7	7	2	3	54

A more detailed temporary hail-reporting scheme introduced during August and September 1965 indicated that hail was reported on 51 out of 61 days during these two months. It therefore seems clear that a high proportion of thunderstorms in this area contain some hail.

Although the sizes of hailstones normally reported are quite small (generally below 1 cm in diameter) hailstones of diameter greater than 2·5 cm are not uncommon, and golf-ball size stones are occasionally reported.

4. *Western Uganda.*—Hail is occasionally reported in thunderstorms around the north-western shores of Lake Victoria, and no part of Uganda is entirely free from hail, but the highest frequency occurs in Toro, near the Ruwenzori Mountains, where the point frequency is between 5 and 10 per annum, occurring mainly during the months September/October and January to March.

5. *Ethiopia.*—Over the Ethiopian plateau around Addis Ababa, thunderstorms are very frequent from March to October, and hail is quite often reported between June and September, but severe hailstorms also occasionally occur during April. The average frequency is 6 storms per annum.

6. *Transvaal, Orange Free State, Basutoland and Swaziland.*—Point frequencies in excess of 5 per annum occur over quite a wide area, and the high ratio of hail days to thunderstorm days indicates that the great majority of thunderstorms in this area contain hail. The peak hail months are October to March, with a very marked maximum in November (when most of the large hail occurs) and a secondary maximum in March. A few winter hailstorms also occur in May, June and July. Quite large hailstones (over 4 cm in diameter) are sometimes reported. Further information on hail in the area around Pretoria has been given by Carte.[11]

7. *Madagascar.*—Over the high ground of Madagascar, around Tananarive, hail frequencies up to 6 per annum occur, and the peak months are October to December. Hail has occasionally been reported on the coast, mainly in the Mozambique Channel, but also at Grande Comore (Comore Islands, 12°S).

8. *Hailstorms in other parts of Africa.*—Although hail is far from common in the southern Sudan and Chad, where the frequency of occurrence is about once in 5 years (during April to October), quite large hailstones are reported to have fallen in both countries. At Fort Archambault in Chad, in October 1958, a man was killed by a hailstone weighing over 50 grammes (diameter perhaps 6 cm), and in a storm at Daga Post (9°N, 34°E) in the southern Sudan in April 1954, hailstones 'the size of a man's fist' were reported, with an alleged weight of over 2 kg. Such a vast weight would require a diameter of about of about 16 cm, and some exaggeration in the weight must be suspected, although the report was emphatically confirmed by the local District Commissioner after specific enquiries had been made by the Government Meteorologist.

A considerable amount of information on hail in West Africa (the former French territories) is contained in a paper by Bougnol[12] who mentions a hailstorm at St Louis on the coast of Senegal. All available information from this and many other areas has been reviewed and analysed by Frisby and Sansom,[8] who quote monthly hail frequencies wherever possible for individual stations.

Conclusion.—It should be noted that in most areas the peak hail frequency does not necessarily occur in the wettest month, but more often towards the beginning and end of rainy seasons, or at the end of a dry spell in the rainy season. Sansom[10] showed that hail is unlikely when there is widespread low-level convergence ; tropical hailstorms are usually associated with diurnal instability thunderstorms when intense local convection gives rise to the very strong upcurrents required for hail formation. Geographical and topographical features undoubtedly lead to the existence of certain favourable hail 'breeding-areas'.

No attempt has yet been made to relate the incidence of hail over Africa to particular synoptic situations, but it is now evident that many tropical thunderstorms contain hail, and that the frequency of hail in some parts of Africa is surprisingly high.

The problem of forecasting hail in tropical Africa is not likely to have a simple solution, but it seems probable that the best results will be obtained by using some form of stability index.

Acknowledgements.—This paper, which was originally prepared for a Seminar on Tropical Meteorology held in Nairobi in November 1965, is

published with permission of the Director, East African Meteorological Department. The assistance of the Directors of other meteorological services throughout Africa in supplying detailed information is most gratefully acknowledged. Miss J. E. Tomsett assisted in the preparation of the final copies of the diagrams.

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BIOMETEOROLOGICAL CONFERENCE IN LEBANON, 1–6 APRIL 1966

This, the first Biometeorological Conference of the Middle and Far East, was organized by Dr S. W. Tromp, Head of the Biometeorological Research Centre, Leiden, Holland. No formal papers were presented ; instead a team of invited consultant specialists in human, animal and plant biometeorology was assembled to discuss problems of health and economic development with their opposite numbers in the Middle East. The cost was in great part borne by the Lebanese Government and various organizations in the Lebanon, such as the Development Bank. The conference was held in the 5000-foot winter resort of Laklouk.

Among the invited consultants were about ten scientists from the United Kingdom including R. W. Gloyne and G. W. Hurst of the Meteorological Office ; in the fields of entomological, pathological and veterinary studies British scientists were also well represented. Six working groups were formed to conduct discussions in between the opening and closing plenary sessions. Two were closely related to meteorological problems : one on agricultural biometeorology, chaired by Dr Gloyne, and another on crop protection, chaired by Dr J. M. Hirst, Rothamsted Experimental Station, Harpenden.

The original intention had been to discuss Middle and Far East problems generally, but representation from outside the Lebanon was very low, because of financial and other difficulties, and in fact deliberations were mostly confined to the Lebanon. Below are indicated briefly subjects discussed of direct meteorological interest.

Agricultural biometeorology.—The real need was for co-ordination of meteorological services to meet agricultural requirements. At least three different authorities were interested in climatology in the Lebanon, and perhaps to some extent they went their separate ways ; the network of 40 climatological and 80 rainfall stations did not therefore represent quite as satisfactory an organization as might be expected. Instruments required improvement and standardization—many differently designed rain-gauges were in use, for example. Improvement was needed in measurement of solar radiation, the recording of temperatures below the ground, and also in assessment of the deposition of dew. Deliberations were greatly helped by the presence of Dr G. A. de Veille, the World Meteorological Organization agricultural meteorology specialist temporarily in the Lebanon, and Dr L. A. R. Ramdas (a retired Indian meteorologist) with a wide background of semi-arid climates. Valuable contributions were also made by other consultants in the group, including Professor H. Gaussen and Dr P. Legris, French ecological climatologists, and Mr A. J. W. Borghorst, a Dutch instrument specialist. Visits were paid by the author to the Beirut civil airport meteorological office which controlled the synoptic network and a few of the climatological stations, to the observatory at Ksara and to Abde, a Ministry of Agriculture research station near Tripoli. The office at Beirut was the only forecast office in the Lebanon, and obviously provided the high standard of professionalism expected from an international civil airport. Ksara was an observatory of long standing where seismological observations were also maintained. Some of the equipment in use was old, and some very up-to-date ; strange to British eyes were the 22-cm diameter pluviometers equipped with taps and standing $1\frac{1}{2}$ metres high, and a screen 2 metres high large enough to house half a dozen normal Stevenson screens. At Abde, instruments included thermometers at several depths, and also lysimeters.

Aside from questions of administration and networks, problems were somewhat different from expected. Irrigation was, of course, of major importance, but water itself was fairly readily available from wells and springs, and rainfall was adequate for about half the year in many areas ; melting snow was also a water source. Shelter too was a real problem, and much in the way of somewhat *ad hoc* shelter belts already existed, especially near the coast, where salt problems also occurred.

Crop protection.—The author divided his time between the agricultural biometeorology and the crop protection working groups ; the latter embraced both entomological and pathological questions.

In entomology, as in meteorology, there were some highly qualified Lebanese specialists and much was known about some of the most modern ideas of pest population control, etc. The main difficulty appeared to be communication between the scientists and the farmers—many of whom were very small land owners or users who farmed as a part-time job. It was fascinating to see oxen and a hand plough still in use in some mountain areas ; this was much more surprising here than it would have been elsewhere in the Middle East as Lebanon is a wealthy country with a degree of development in many ways comparable with western standards. Much of the more steeply sloping land was terraced and tilled in very small units, of which the more remote were being given up (with some consequent erosion problems) because of emigration from the countryside. A morning was spent discussing insect migration and its possible relevance to Lebanese problems. Some mention was also made of relating meteorology to insect populations. An indication was given of the role of meteorology in the British Ministry of Agriculture extension services. Dr T. Lewis of the Experimental Station, Rothamsted, Harpenden (Chairman of the sub-section on entomology) gave an account to members of the agricultural group of his work on relationships between insect distributions and shelter belts.

A little time was also spent by the pathology sub-group in discussing meteorological matters, mainly on spore movements and disposal, and the relationships between current weather and diseases such as potato blight. There seemed a more serious shortage of specialist pathologists than of most other scientists, and in some particular fields (for example, nematodology) no specialist existed in the country.

The meeting finished on the evening of 6 April with the presentation by the respective Chairmen of recommendations of the six working groups.

G. W. HURST

NOTES AND NEWS

Meteorological Office awards to captains and navigators of civil aircraft

A pleasant ceremony was arranged on Thursday, 5 May 1966, by the Guild of Air Pilots and Air Navigators at their headquarters in South Street, Mayfair, with the Master of the Guild, Marshal of the Royal Air Force, Sir Dermot Boyle, G.C.B., K.C.V.O., K.B.E., A.F.C., presiding.

The annual Meteorological Office awards for long and meritorious service in the provision of weather reports from aircraft were made for 1965 to Captain D. B. Wilkie of British European Airways and Captain P. Siegel of British United Airways. They received presentation briefcases from Mr B. C. V. Oddie, C.B.E., Deputy Director (Outstation Services), Meteorological Office (Plate I).

Presenting the briefcases on behalf of the Director-General of the Meteorological Office, Mr Oddie stressed the importance of reports of the weather conditions existing over the air lanes, and expressed gratitude to the airlines and aircrew for their voluntary service in furthering the development of accurate weather forecasting. The reports were a very valuable contribution towards the safe and economic operation of the airlines.

Fifteen awards of books, suitably inscribed, are also being given by the Meteorological Office to the following captains and navigators who have provided the best series of reports (in-flight, post-flight or on debriefing) during the 12 months ended 31 December 1965 : Captains J. D. Barnes, G. R. Buxton, W. M. Reid, E. E. Langmead, S. M. Gooch, and G. Hall of BOAC; Captains J. Welford, B. J. Thwaites, A. L French, E. Caesar-Gordon, D. H. Turnbull and K. R. Blevins of BEA ; and Messrs J. F. Archer, R. R. Webb, and G. W. Simpson, navigating officers of BUA.

REVIEWS

The biological significance of climatic changes in Britain, edited by C. G. Johnson and L. P. Smith. $9\frac{1}{4}$ in × 6 in, pp. x + 222, *illus.*, Academic Press Inc., (London) Ltd., Berkeley Square House, Berkeley Square, London, SW1, 1965. Price: 42*s*.

During the summer half-year agricultural meteorologists are kept fully occupied with seasonal tactics. During the winter, however, they have more time to worry over questions of longer-term strategy. One such problem which has recently been coming increasingly to the forefront is that of the biological implications of climatic fluctuations. Current farming practice and agricultural policy are largely geared to weather conditions as experienced by the present generation ; what repercussions, particularly on food production, might be expected to flow from the degree of climatic change for which past records suggest that we ought, in prudence, to plan ?

In 1964, Iowa State University organized a symposium on 'Weather and our food supply' which was mainly concerned with grain production as affected by climatic change. The present publication, which consists of the proceedings of a symposium held in London in October 1964 under the auspices of the Institute of Biology, covers a far wider biological field. It opens with a masterly summary by Mr H. H. Lamb of what is known of the dimensions of past climatic change in Britain, and a consideration by Mr James A. Taylor of the biological consequences in marginal upland and peat areas, where the effects can be most clearly seen. It closes with a synopsis by Mr L. P. Smith of the agricultural significance of possible future seasonal trends, and an analysis by Professor A. N. Duckham of the broad repercussions of short-term climatic change on different types of farming operations. In between, the consequences of meteorological fluctuations are related not only to vegetable crops and farm livestock, but also to grasses, wild plants, fish and other marine organisms.

No one with the slightest knowledge of the complex biometeorological problems involved will expect to find a neat series of answers at the end of this book. What it does supply is an authoritative survey of the present position in this fascinating and important field, a pinpointing of the aspects of the problem which require further research, and (by no means least valuable) a bibliographic guide to the maze of interdisciplinary literature in which details of the most recent work is hidden.

For agricultural meteorologists—and for many others concerned with the interaction of climate and living things—this book is a must ! It would also, I suggest, be an excellent investment for ambitious young scientists in search of an uncrowded research niche with a promising future.

P. M. AUSTIN BOURKE

Atmosphärische Elektrizität, Teil II, by H. Israël. $6\frac{1}{2}$ in × $9\frac{1}{4}$ in, pp. x + 503 + 5 folded maps, *illus.*, Akademische Verlagsgesellschaft, Geest and Portig K.-G., Leipzig C1, Sternwartenstrasse 8, East Germany, 1961. Price : DM 66.

This second volume completes Professor Israël's large 'Handbuch' on atmospheric electricity. The first volume (reviewed in *Met. Mag*, **88,** 1959, p. 119) consisted mainly of a survey of basic facts and relevant basic physics, followed by a long and detailed technical discussion of atmospheric ionization.

The present volume is divided into three main heads : electric fields, electric charges and electric currents ; an appendix includes a detailed account of methods of measurements.

It is a somewhat depressing commentary on the state of the literature that the author in his introductory chapter, after discussing the confusion over sign conventions, recommends that we cease to speak of positive and negative fields and currents, and refer rather to the fine-weather direction and its reverse ; he further decides to write out every equation twice, firstly in c.g.s. units, secondly in 'rationalized' units.

The work is encyclopaedic in its scope ; the bibliographies in the two volumes list, in all, nearly 2000 papers. An attempt at completeness on this scale has its disadvantages ; the reader who desires to get an up-to-date picture may waste time in tracking down references which are unimportant or outmoded.

Again, the arrangement of the book leads to difficulties. If a reader is seeking information, for example, about phenomena of disturbed weather, he will find certain aspects in all three main sections and there is inevitably some repetition and need for referring back or forward from section to section and even from volume to volume.

One suspects that Professor Israël's real interest lies in the electrical phenomena of fair weather. Here the discussion is detailed, comprehensive and stimulating. By comparison, the treatment of field-charges due to lightning and of atmospherics — both of these are considered under electric fields — is brief and superficial. Rather surprisingly the full derivation, from Maxwell's equations, of the field due to a radiating elementary dipole is given in an appendix.

This is of course a book which any serious worker in the field must have accessible. Professor Israël is to be congratulated on its completion.

T. W. WORMELL

Auroral phenomena (experiments and theory), edited by Martin Walt. $9\frac{1}{4}$ in $\times$ $6\frac{1}{2}$ in, pp. vi +170, *illus.*, Oxford University Press, Amen House, Warwick Square, London, EC4, 1965. Price : 40*s*.

This book contains nine chapters based on papers read at a symposium on aurora organized by, and held at, the Lockheed Missiles and Space Company in January 1964. The purpose of the symposium was to provide not only a forum for the discussion of recent research, but also an opportunity for specialists, using widely different techniques for investigating one and the same phenomenon, to meet and discuss their problems and results.

The first two chapters on morphology and spectroscopy review the results of surface observations, and the third, on the interaction of energetic particles with the atmosphere, is concerned with the interpretation of auroral luminosity in terms of excitation mechanisms. On the basis of the appearance of auroral forms, their height and their spectral characteristics, auroral displays may be classified into five apparently distinct groups, namely, the polar glow appearing sometimes over the polar cap ; the polar cap aurora consisting of weak discrete forms inversely correlated with sunspot number and magnetic activity ; high red arcs in the F-region ; medium grey arcs at heights around 200 km ; and the familiar 'polar aurora' of arcs, bands and rays. In the last chapter, summarizing the symposium, Omholt however classifies the aurora according to excitation mechanisms into four groups. These are the polar glow aurora associated with polar cap absorption events caused by protons in the MeV range ; the high red arc which may result from local electric discharge mechanisms but whose origin is not yet clear ; the electron-excited aurorae consisting of the well-known forms which are caused by electrons accelerated in the vicinity of the earth through the interaction of the solar wind with the outer magnetosphere ; and the proton-excited aurora consisting of a weak glow, with relatively strong hydrogen lines, in the form of a broad band elongated geomagnetically east–west which before midnight lies south of, and in the early morning hours north of, the bright electron aurora.

There are chapters on balloon measurements of X-rays in the auroral zone ; on satellite studies of the precipitation of energetic particles into the atmosphere ; on electromagnetic measurements of aurorae, i.e. on radio noise associated with aurora, on scintillations and on radar auroral reflection ; and on co-ordinated measurements by satellite of the distribution of particle fluxes, optical luminosities and ionospheric electron densities. Finally, preceding Omholt's summary, there is a critical appraisal of recent work on the theory of auroral particles and bombardment.

The book provides a valuable account of the present state of investigations of aurora by the various physical techniques.

J. PATON

The story of gliding, by Ann and Lorne Welch. $5\frac{1}{2}$ in × $8\frac{3}{4}$ in, pp. xv+211, *illus.*, John Murray, 50 Albemarle St, London, W1, 1965. Price : 28*s*.

Meteorologists who become involved in gliding usually learn from the sport, not so much by acquiring factual data as by the accumulation of impressions gleaned from experience in the air and from talking and reading about the subject.

The latest book by Ann and Lorne Welch is another of the type that conveys to the reader realistic impressions of the art and science of soaring flight.

After describing the almost legendary earliest attempts at gliding, the authors give an account of the daring experiments of the 18th and 19th centuries, then they trace the 20th century progress that stemmed from the application of scientific method to the principles and practice of flight.

The book provides light entertaining reading, and for the meteorologist can stimulate speculation on what concepts of airflow and convection the pioneers had in mind as they planned and eventually carried out this particular conquest of the air.

C. E. WALLINGTON

CORRIGENDA

Meteorological Magazine, March 1966, page 78, Table II : in heading for 'Figure 5' read 'Figure 6' ; under 20.11.3., against $T_{700} - T_{300}$, for '45' read '44'.

Meteorological Magazine, May 1966, page 135, equation (19) ; for '100^2' read '1000^2'.

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