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FURTHER ANALYSIS OF MONTHLY MEAN PRESSURE PATTERNS NEAR THE BRITISH ISLES (1874–1968)

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Summary. Monthly pressure patterns (1874–1968) in Hay's catalogue have been used to derive monthly and seasonal indices of flow, progression and meridionality (C_m, P_m and S_m indices) over the British Isles. A number of interesting relationships derived from these indices are found between pairs of monthly and seasonal pressure patterns over Britain at lags of up to 6 months and up to 8 seasons, and also between monthly and seasonal pressure patterns and simultaneous and subsequent monthly and seasonal temperature (central England) and rainfall (England and Wales) at lag intervals up to 6 months and up to 8 seasons. Results from the catalogue have also been used to show that significant differences exist between the synoptic patterns of summers in Britain in the odd and even years of the same period.

Introduction. A previous paper[1] analysed relationships between monthly and seasonal pressure patterns and simultaneous and following seasonal temperatures in central England (mainly for winter), using only part of the material included in Hay's catalogue of monthly pressure patterns. In this extension of the work use is made of all of the elements tabulated in the original catalogue to derive a homogeneous set of monthly and seasonal indices of flow (C_m), progression (P_m) and meridionality (S_m) over the British Isles covering the period 1874 to 1968, and corresponding to the C, P and S indices of Murray and Lewis.[2]

Indices of flow (C_m), progression (P_m) and meridionality (S_m). Full details of the information included in Hay's catalogue and of the procedures followed in deriving the indices are available for reference in the Meteorological Office, Bracknell. The following short description of the catalogue may also help in the interpretation of the results included in the remainder of this paper.

Derivation of flow indices (C_m). A flow index was devised which yielded a numerical measure of the cyclonicity or anticyclonicity of the mean pressure pattern near the British Isles for each month in the period. The index was made dependent upon flow curvature, flow pattern, pressure and pressure gradient; a method of scoring was devised which allowed for the effect of each of these elements and which gave consistent and satisfactory results in terms of synoptic patterns. The flow index was readily obtained from the sum of these scores, positive values being related to cyclonicity, negative values to anticyclonicity.

Derivation of indices of progression (P_m) and meridionality (S_m). Procedures broadly similar to those just described were followed to derive indices of progression and meridionality. Positive values of P_m indices were related to westerly flow; positive values of S_m indices were related to southerly flow.

Treatment of the data. The whole of the data (1874–1968) including the monthly and seasonal values of the C_m, P_m and S_m indices, together with ranked values and quintiles of the three indices for the same periods, were obtained by means of a computer programme and are available for reference in the Meteorological Office, Bracknell. For each index the minimum values are in quintile 1 and the maximum in quintile 5.

Monthly and seasonal pressure patterns derived from C_m, P_m and S_m indices. When C_m, P_m and S_m indices for months and seasons had been allocated to their appropriate quintiles, each flow pattern in the vicinity of the British Isles could be described by a group of three digits referring to the quintiles of C_m, P_m and S_m indices respectively. Thus a flow pattern for which the C_m, P_m and S_m quintiles were 5, 5, and 5 respectively, implied that the pressure pattern was strongly cyclonic, strongly westerly and strongly southerly.

This preliminary classification, according to the quintiles of the three indices, gives 125 patterns and these were divided into five sets or types of synoptic patterns as shown in Table I.

TABLE I—ALLOCATIONS OF 3-DIGIT* GROUPS AMONG FIVE TYPES OF SYNOPTIC PATTERN

Pattern type	3-digit groups included in pattern type	Number of 3-digit groups included in each pattern type
Blocked cyclonic (*bC*)	511 to 515, 521 to 525, 531, 535, 541, 545 411 to 415, 421, 422, 424, 425, 431, 435, 441, 445	27
Blocked anticyclonic (*bA*)	111 to 115, 121 to 125, 131, 135, 141, 145 211 to 215, 221, 222, 224, 225, 231, 235, 241, 245	27
Mixed	311 to 315, 321 to 325, 331 to 335, 341 to 345, 351 to 355	25
Progressive cyclonic (*pC*)	551 to 555, 542 to 544, 532 to 534, 451 to 455, 442 to 444, 432 to 434, 423	23
Progressive anticyclonic (*pA*)	251 to 255, 242 to 244, 232 to 234 223 151 to 155, 142 to 144, 132 to 134	23

* The digits represent quintiles of C_m, P_m and S_m indices.

This classification of monthly pressure patterns into five main types was used to derive contingency tables (i) relating monthly and seasonal pressure patterns over Britain with similar patterns at a lag of up to 6 months and up to 8 seasons and (ii) relating monthly and seasonal pressure patterns with simultaneous and subsequent monthly and seasonal temperatures (central England) and rainfall (England and Wales).

No attempt has been made to analyse all the results included in the individual rows (pressure pattern types) contained in the contingency tables, but all associations of possible value for forecasting or likely to be of synoptic interest are shown in Tables II, III and IV.

TABLE II—ASSOCIATIONS BETWEEN PRESSURE PATTERNS (C_m, P_m, S_m INDICES ASSOCIATED WITH C_m, P_m, S_m INDICES)

(a) Monthly relations

Lag *months/seasons*	Months/seasons associated	Chi-square	Initial pressure pattern	Pattern of following month/season *number of cases* bC	bA	Mixed	pC	pA	Totals
1	No cases								
2	February, April	28·8	*bC*	0	6	3	1	5	15
			bA	4	6	9	4	4	27
			Mixed	5	3	6	3	1	18
			pC	10	4	4	4	2	24
			pA	1	2	0	3	5	11
2*	October, December	26·9	*bA*	4	7	8	5	2	26
			pC	10	1	3	2	7	23
3	No cases								
4	May, September	30·2	*bC*	1	7	2	4	1	15
			bA	8	11	2	4	1	26
			pA	2	1	4	5	1	13
5	March, August	28·4	*bA*	3	9	7	1	3	23
			Mixed	6	2	4	5	1	18
6*	May, November	26·9	*bC*	2	1	8	3	1	15
			bA	7	3	3	8	5	26
			pC	2	9	3	6	4	24

(b) Seasonal relations

Lag	Months/seasons associated	Chi-square	Initial pressure pattern	bC	bA	Mixed	pC	pA	Totals
1, 2, 3 and 4	No cases								
5	Spring, summer (1 year later)	26·2	*bC*	5	0	6	4	1	16
			Mixed	5	5	0	2	4	16
			pC	4	6	5	1	8	24
5	Autumn, winter (1 year later)	27·3	*bC*	5	8	3	3	1	20
			pC	4	10	2	7	3	26
			pA	3	2	8	4	0	17
6, 7, 8	No cases								

* See also Table IV. Bold figures show a large departure from expected values.
In the 5×5 contingency tables from which these data are derived, chi-square values for the significance levels are :

Significance level *per cent*	Chi-square
90	23·5
95	26·3
98	29·6
99	32·0

Pressure patterns

bC blocked cyclonic
bA blocked anticyclonic
Mixed mixed patterns (broadly includes the middle quintiles of C_m, P_m and S_m indices)
pC progressive cyclonic
pA progressive anticyclonic

Lag associations between monthly mean pressure patterns. Associations between monthly mean pressure patterns near the British Isles were found to be significant at the 95 per cent level for each of the following pairs of months (see Table II) :

February and April* October and December May and September*
March and August* May and November

* See further discussion upon the validity of the results (page 195).

The May–September association is significant at the 98 per cent level.

Other cases of interest and deserving a mention are as follows :

February and June
June and September
October and March

These three associations are all significant at about the 90 per cent level.

Lag associations between seasonal mean pressure patterns. Relations between seasonal pressure patterns with lags of 1 to 8 seasons similarly yielded two associations reaching the 95 per cent significance level, namely spring with summer one year later and autumn with winter one year later.*

Pressure patterns and simultaneous temperatures. An association is found between monthly mean pressure patterns near the British Isles, defined in terms of quintiles of C_m, P_m and S_m indices, and simultaneous monthly mean temperatures over central England, which is statistically significant (at better than 95 per cent level) for each of the months September to March (inclusive). In September, October, January, February and March the relation is significant at better than 99 per cent level. The similar relation between simultaneous seasonal pressure patterns and temperatures is significant at the 95 per cent level in winter and spring and at better than 95 per cent level in summer, but not in autumn (significance below 90 per cent level). A scrutiny of the contingency tables (not included here) shows that the significance of these relations derives mainly from a tendency for progressive cyclonic patterns to be associated with mild months in autumn and early winter, and similarly for blocked patterns (both cyclonic and anticyclonic) to be associated with cold months during the winter half-year.

These results relating pressure patterns and simultaneous temperatures, and those in a later paragraph relating pressure patterns and simultaneous rainfall, broadly confirm the results already found by Murray and Lewis[2] on interrelations between their indices (*C*, *P* and *S* in their notation) and temperature and rainfall on a monthly time-scale.

Pressure patterns and subsequent temperatures. Tests for associations between pressure patterns and monthly temperatures (central England) made with lags from 1 to 6 months showed only one association which reached 95 per cent level of significance, namely that between October and November (1-month lag) (see Table III). Two other cases of possible interest are given in a footnote to Table III; these show the associations between pressure pattern in June and temperature in July, and between pressure pattern in June and temperature in August. In both cases results suggest that there is a tendency for cool summer months to follow progressive cyclonic Junes.

Another relationship between June pressure pattern and subsequent December temperature was significant at almost 95 per cent level, namely that blocked cyclonic and progressive anticyclonic Junes tend to precede very cold and cold Decembers respectively.

Similar tests in respect of seasons with lags between 1 and 8 seasons yielded one association which reached 95 per cent level, namely that between winter

* See further discussion upon the validity of the results (page 195).

TABLE III—ASSOCIATIONS BETWEEN PRESSURE PATTERNS (C_m, P_m, S_m INDICES) AND TEMPERATURES (CENTRAL ENGLAND)

(*a*) Monthly relations

Lag	Months/seasons associated	Chi-square	Initial pressure pattern	Temperature quintile 1	2	3	4	5	Totals
months				*number of cases*					
1	October, November	27·2	*bC*	1	1	4	5	1	12
			bA	**9**	2	2	4	**8**	25
			Mixed	1	5	4	3	4	17
			pC	5	4	7	4	2	22
			pA	1	**6**	3	2	1	13
2, 3, 4, 5 and 6	No cases								
(*b*) Seasonal relations									
seasons									
1 and 2	No cases								
3†	Winter, autumn	27·3	Mixed	**0**	1	4	5	**6**	16
			pC	**9**	3	4	2	1	19
4, 5, 6, 7 and 8	No cases								

† See also Table II. Bold figures show a large departure from expected values.

Two further cases of possible interest are shown below :

Lag	Months associated	Chi-square	Initial pressure pattern	Temperature quintile 1	2	3	4	5	Totals
month				*number of cases*					
1	June, July	24·4	*pC*	4	6	5	3	0	18
2	June, August	24·0	*pC*	6	4	3	4	1	18

pressure patterns and the temperature of the following autumn (3-season lag) (Table III). Also 25 progressive cyclonic autumns were followed by 5, 9, 6, 1 and 4 winters respectively in temperature quintiles 1, 2, 3, 4 and 5. This result suggests a tendency for a cold winter (T_2) to follow a progressive cyclonic autumn, in broad agreement with previous work by the author.[3] In this case, however, the significance level was just under 90 per cent.

Pressure patterns and simultaneous rainfall. A relation between pressure patterns and simultaneous monthly and seasonal rainfalls (England and Wales) is significant at better than 99 per cent level in all months and all seasons. In autumn and winter this result arises mainly because a strong association is apparent between progressive cyclonic patterns and wet months and between blocked anticyclonic patterns and dry months; while in spring and summer, blocked cyclonic patterns mostly occur with wet months and progressive anticyclonic patterns with dry months.

Pressure patterns and subsequent rainfall. Several lag associations (Table IV) were found between pressure patterns and monthly rainfall (England and Wales), significant at the 95 per cent level as follows :

1-month lag	No cases*
2-months lag	June with August
	September with November
	October with December
3-months lag	November with February
4-months lag	September with January

* See further discussion upon the validity of the results (page 195).

5-months lag	April with September
	May with October
	August with January
	October with March
6-months lag	May with November
	July with January

A significance level of 99 per cent attaches to the relation between October and March.

An additional case of interest is an association between February pressure pattern and April rainfall (significant at nearly 90 per cent level). For the 15 Februarys in which the pressure pattern was blocked cyclonic, the frequencies of April rainfall in terciles 1, 2 and 3 were 10, 3 and 2 respectively.

TABLE IV—ASSOCIATIONS BETWEEN PRESSURE PATTERNS (C_m, P_m, S_m INDICES) AND RAINFALL (ENGLAND AND WALES)

(a) Monthly relations

Lag	Months/seasons associated	Chi-square	Initial pressure pattern	Rainfall tercile 1	2	3	Totals
months				*number of cases*			
1	No cases						
2	June, August	17·2	*pC*	2	8	8	18
			pA	9	8	1	18
2	September, November	18·8	*bA*	4	8	13	25
			Mixed	10	7	0	17
			pA	1	3	6	10
2*	October, December	15·5	*bC*	7	0	5	12
			pC	3	13	6	22
3	November, February	16·7	*bA*	9	3	9	21
			pC	5	14	3	22
			pA	5	2	8	15
4	September, January	15·5	*bC*	7	4	2	13
			Mixed	9	6	2	17
			pC	2	11	11	24
5	April, September	16·4	*bC*	1	9	8	18
			pC	7	7	1	15
5	May, October	18·9	*bC*	3	1	10	14
			Mixed	5	10	1	16
5	August, January	15·6	Mixed	2	7	9	18
			pC	8	10	2	20
5*	October, March	23·2	*bA*	5	8	12	25
			Mixed	4	4	9	17
			pC	15	7	0	22
6*	May, November	18·8	*bA*	3	7	15	25
			pC	10	6	6	22
6	July, January	15·7	*bA*	13	4	10	27
			pC	3	12	6	21

(b) Seasonal relations

Lag	Months/seasons associated	Chi-square	Initial pressure pattern	Rainfall tercile 1	2	3	Totals
seasons							
1, 2, 3 and 4	No cases						
5	Spring, summer (1 year later)	16·9	*bC*	3	6	7	16
			Mixed	9	4	2	15
			pC	9	8	4	21
6	Autumn, spring (1 year later)	18·2	*pA*	7	7	3	17

* See also Table II. Bold figures show a large departure from expected values.

In the 5×3 contingency tables from which these data are derived, chi-square values for the significance levels are :

Significance level	Chi-square
per cent	
90	13·4
95	15·5
99	20·1

For seasonal rainfall two associations reached 95 per cent level, namely spring with summer one year later (i.e. 5-seasons lag), and autumn with spring one year later (i.e. 6-months lag). Additionally for the 19 autumns with blocked anticyclonic patterns, the frequencies of winters following with rainfall in terciles 1, 2 and 3 were 11, 4 and 4 respectively (significant at nearly 90 per cent level).

Validity of results. For the lag relations between monthly pressure patterns, 5 pairs of months out of a total of 72 pairs showed an association significant at 95 per cent level or better. Since 72 months were included in the tests, up to 4 months (more exactly 3·6 months) could reach 95 per cent level as a result of chance, and this suggests that some of the relations found are likely to be real.

For the association between pressure pattern and temperature there was one case (almost two cases, since the June–December relation also almost reached 95 per cent level) which was significant at 95 per cent level or better. Application of the argument above suggests that the one (almost two) case observed here could have occurred by chance.

For the relationships of pressure pattern and rainfall there were 11 pairs of months out of a total of 72 pairs for which an association at 95 per cent level, or better, was found. This suggests that some at least of the lag relations found for monthly rainfall here are real.

For seasonal relations the numbers of significant pairs of seasons associated at 95 per cent level were 1, 2 and 2 respectively for pressure pattern with temperature, pressure pattern with rainfall and pressure pattern with pressure pattern, with totals of 32 seasons involved in each case. Since up to two cases (more exactly 1·6 cases) of 95 per cent level of significance could arise by chance, the results for seasonal associations are of doubtful validity.

In the case of the associations between monthly pressure patterns with different lags, listed below, caution may be required in using the results, since for one or occasionally two cells in the contingency tables relating these pairs of months and pairs of seasons, the expected value, E, falls slightly below the figure of 2 quoted by Craddock and Flood[4] as a minimum value for safe application of the chi-square tests. Rather less reliance should be put upon the results for the cases shown below than for the remaining contingency tables where the expected value is above 2 in every one of the cells.

Monthly pressure patterns associated	Number of cells where the expected value $E \leqslant 2$
February and April	1
May and September	2
March and August	2
Autumn and winter (one year later)	1

A point of interest lies in the fact that in all three types of lag associations, the significance level for a lag of 1 month was found to be much lower than for lags of $\geqslant 2$ months. This result applies particularly in the case of the pressure pattern – rainfall relations, and evidently merits further study.

Synoptic patterns in the summers of odd and even years. The synoptic patterns derived from combinations of quintiles of C_m, P_m and S_m

indices have been used here to extend the conclusions of Sutton,[5] Davis,[6] Murray,[7] Poulter,[8] and others, regarding significant differences found by them between summers in Britain during odd years (mostly warmer and drier than average, i.e. good summers) and during even years (mostly cooler and wetter than average, i.e. bad summers). Table V shows how frequencies of synoptic patterns near the British Isles have been distributed between summers in odd and even years.

TABLE V—FREQUENCIES OF SYNOPTIC PATTERNS NEAR THE BRITISH ISLES IN SUMMER (1874–1963)

	SYNOPTIC TYPE					
	Blocked cyclonic	Blocked anticyclonic	Mixed	Progressive cyclonic	Progressive anticyclonic	Totals
Odd years	10	15	9	5	6	45
Even years	8	5	10	12	10	45
Totals	18	20	19	17	16	90

Chi-square = 9·16

A chi-square test applied to this table shows that such an uneven distribution between the frequencies in the different classes could only occur by chance on about one trial in 19 (significance level just below 95 per cent).

Using values of the Poulter index[5,8] for summers in London (Kew) for the period 1880–1965, Davis[6] found the scores for the odd-year summers averaged some 20 points higher than the scores for the even-year summers, and thence showed that this difference was significant at the 1 per cent level. Since the period considered by Davis has all but 8 years in common with the period considered in this paper (1874–1963), it seems reasonable to assume that the excess of good summers in odd years as compared with even years is associated with the excess of blocked anticyclonic types in odd years (as shown in Table V), and similarly that the excess of bad summers in even years occurred mainly in association with a higher frequency of progressive types (especially progressive cyclonic) in the even-year summers as compared with the summers in odd years (but see Table VI).

Support for these assumptions was readily obtained from Poulter's data for London. The 86 summers were divided into two classes which included 43 summers with Poulter indices above the median value and 43 summers with Poulter indices below the median value respectively. After subdividing both these classes into odd- and even-year summers, the incidence of summers in the four classes thus obtained was related to the five synoptic patterns as used in Table V. The resulting contingency table is shown at Table VI.

The value of chi-square = 29·4 in Table VI implies that the differences between frequencies of the odd- and even-year summers with Poulter indices respectively above and below the median value of the Poulter index are significant at the 99·5 per cent level. Large contributions to the high value of chi-square are made by the large differences, in rows 2 and 3 of Table VI, between actual and expected frequencies of blocked anticyclonic and of progressive cyclonic types. This table therefore gives support to the assumption that good summers in odd years are associated with blocked anticyclonic types and that bad summers in even years are associated with progressive cyclonic types.

TABLE VI—FREQUENCIES OF SUMMERS IN LONDON (KEW) RELATED TO THE POULTER INDEX, ODD AND EVEN YEARS AND SYNOPTIC PATTERNS NEAR THE BRITISH ISLES (1880–1965)

		SYNOPTIC TYPE					
Years	Poulter index values	Blocked cyclonic	Blocked anticyclonic	Mixed	Progressive cyclonic	Progressive anticyclonic	Totals
EVEN	>median value	**1** (3·5)*	4 (4·0)	3 (4·2)	4 (4·0)	**7** (3·3)	19
	<median value	7 (4·5)	**0** (5·0)	7 (5·3)	**8** (5·0)	**2** (4·2)	24
ODD	>median value	**1** (4·5)	**10** (5·0)	6 (5·3)	**3** (5·0)	4 (4·2)	24
	<median value	7 (3·5)	4 (4·0)	3 (4·2)	3 (4·0)	2 (3·3)	19
		16	18	19	18	15	86

* Expected values are shown in brackets. Values differing by 2 or more from expected are shown in bold. Chi-square = 29·4.

Synoptic patterns in the winters of odd and even years. The work described in respect of odd- and even-year summers was repeated for odd- and even-year winter synoptic patterns near Britain. The result is given in Table VII below. A chi-square test showed that the differences between the frequencies for odd and even years were not significant and could have arisen by chance.

TABLE VII—FREQUENCIES OF SYNOPTIC PATTERNS NEAR THE BRITISH ISLES IN WINTER (1874–1963)

	SYNOPTIC TYPE					
	Blocked cyclonic	Blocked anticyclonic	Mixed	Progressive cyclonic	Progressive anticyclonic	Totals
Odd years	8	11	9	13	4	45
Even years	9	14	7	6	9	45
Totals	17	25	16	19	13	90

Conclusions.

(i) An association is found between monthly mean pressure patterns near the British Isles, defined in terms of quintiles of C_m, P_m and S_m indices, and simultaneous monthly mean temperatures over central England, which is statistically significant (at better than 95 per cent level) for each of the months September to March (inclusive). In five of these months the 99 per cent level is exceeded. The similar relation between simultaneous seasonal pressure patterns and temperatures is significant at the 95 per cent level in winter, spring and summer, but not in autumn.

(ii) A relation between pressure patterns and simultaneous monthly and seasonal rainfalls (England and Wales) is significant at better than 99 per cent level in all months and all seasons.

(iii) Associations were found between monthly mean pressure patterns near the British Isles for each of the following pairs of months : February and April, October and December, May and September, March and August, and May and November.

However, in view of the large number of associations tested (72), the significance of these apparent associations is doubtful.

(iv) Eleven lag associations were found between pressure patterns and monthly rainfall (England and Wales), significant at the 95 per cent level as follows :

1-month lag	No cases
2-months lag	June with August, September with November, October with December
3-months lag	November with February
4-months lag	September with January
5-months lag	April with September, May with October, August with January, October with March
6-months lag	May with November, July with January

By chance about 4 relationships would be expected to arise so that some at least of these apparent associations are likely to be real.

(v) In summer, blocked anticyclonic patterns near Britain have been found to occur in odd years more frequently than would be expected by chance, while progressive cyclonic patterns occurred in even years more frequently than would be expected by chance. This result agrees with work by Sutton, Davis, Murray, Poulter, and others, on significant differences between summers in odd and even years of the past 90 years.

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SAMPLING OF RAIN FROM A VARSITY AIRCRAFT

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Summary. Flights have been made in rain by the Varsity aircraft of the Meteorological Research Flight to determine the liquid water content field in the air above the top surface of the aircraft. The results have shown that the use of droplet sampling instruments is certainly unreliable within 120 cm of the surface because of splashing and concentration effects in the water-droplet field.

Introduction. The Meteorological Research Flight (MRF) has in the past sampled cloud and precipitation particles from the Varsity aircraft, and from the data obtained concentrations of water droplets, ice crystals and liquid water content were calculated (Singleton and Smith,[1] Cornford[2]). The instruments used to sample the drops and their efficiency in doing so have been discussed in detail elsewhere (Garrod[3]). However, no matter how efficient an instrument is in sampling droplets in flight, unless it is situated in a position where the droplets are representative of the free airstream, the results obtained will always be suspect.

Singleton and Smith[1] estimated the error in the droplet concentrations at the sampling position on the Varsity aircraft by applying the results of Dorsch and Brun's[4] mathematical investigation into the path of water droplets flowing around an ellipsoid of revolution. They concluded that there was a concentration effect for drops greater than 100-μm diameter, but stated that Dorsch and Brun's results were not entirely applicable because of the sharp discontinuity in the aircraft's profile.

This present note describes an instrument designed to measure water contents at positions spanning the original sampling position, in an attempt to estimate quantitatively the error in measuring the liquid water content of clouds from this position on the Varsity aircraft.

The water-droplet field near an aircraft. The air rises ahead of an aircraft (upwash) and sinks behind (downwash), and the streamlines are considerably distorted in the vicinity of the aircraft. The passage of air through propellers further complicates the flow. For turbulence investigations involving measurement of airflow angle, it is essential to have the instruments mounted as far forward as possible so that they are in a region where the flow distortion is small. When an aircraft enters a cloud, the local flow field deviates the individual drops or ice crystals by an amount dependent on their inertia. It has been found that near an aircraft's skin there can be regions where no droplets occur (shadow zones), while concentrations of droplets can occur at other locations (concentration zones). These effects have been noted in practice on struts of aircraft which have flown in supercooled cloud (Figure 1). Dorsch and Brun[4] have shown that concentration factors of 2 or 3 can occur, and that each droplet size has its own concentration factor at a given position.

Although Dorsch and Brun's work can be qualitatively applied to aircraft which approximate in shape to an ellipsoid of revolution, because of the huge computational effort necessary they could not take into account the effect of wings, bulges on the fuselage, engines, etc., all of which influence the airflow and hence the droplet field near an actual aircraft. In practice, the only way

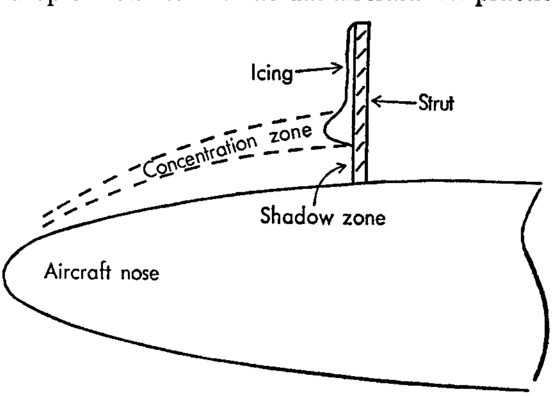


FIGURE 1—VARIATION IN LIQUID WATER CONTENT AROUND AIRCRAFT SHOWN BY THE THICKENING OF ICING ON STRUT

to find if there are concentration effects at a chosen sampling position is to measure the drop size distribution or liquid water content at various positions spanning the sampling position and determine whether gradients occur in these quantities at the sampling position. If they do occur, then the conclusion must be that the sampling position is not located in a region representative of the free stream conditions. An estimate must then be made of the magnitude of the error involved, and this usually necessitates the free stream values being measured simultaneously.

The sampling position. The location of the sampling position originally in use, and now under discussion, is 6 m from the nose of the aircraft and 45 cm above the top surface on the centre line (see Figure 2). Instruments, such as the aluminium-foil impactor, are held there by a long 38-mm diameter tube which is rigidly attached to a vertical structure inside the aircraft.

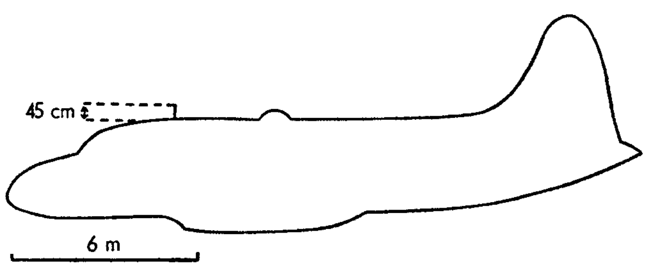


FIGURE 2—ORIGINAL SAMPLING POSITION ON AIRCRAFT

Indicated airspeed measurements have been made in this position out to 1·5 m from the skin. They are shown in Figure 3 for the pilot's indicated airspeed (IAS) of 110 kt (1 kt≈0·5 m/s). The air has accelerated over the top of the aircraft and its speed is still 10–15 kt higher than the pilot's IAS

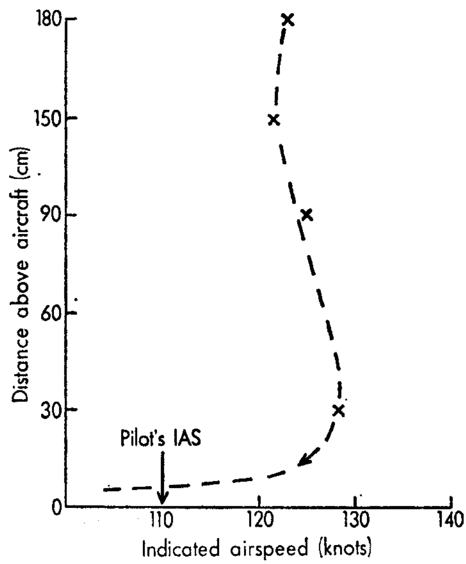
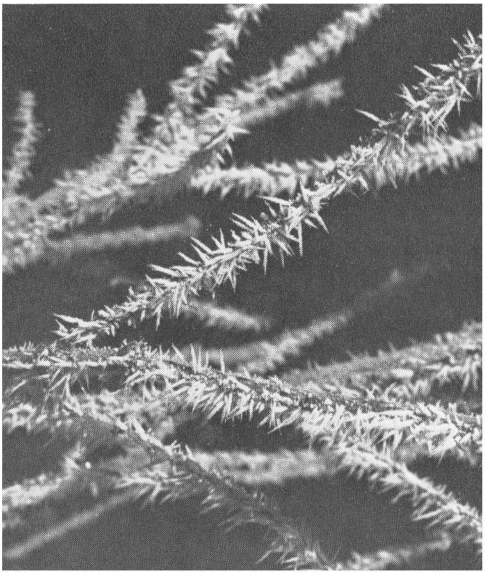
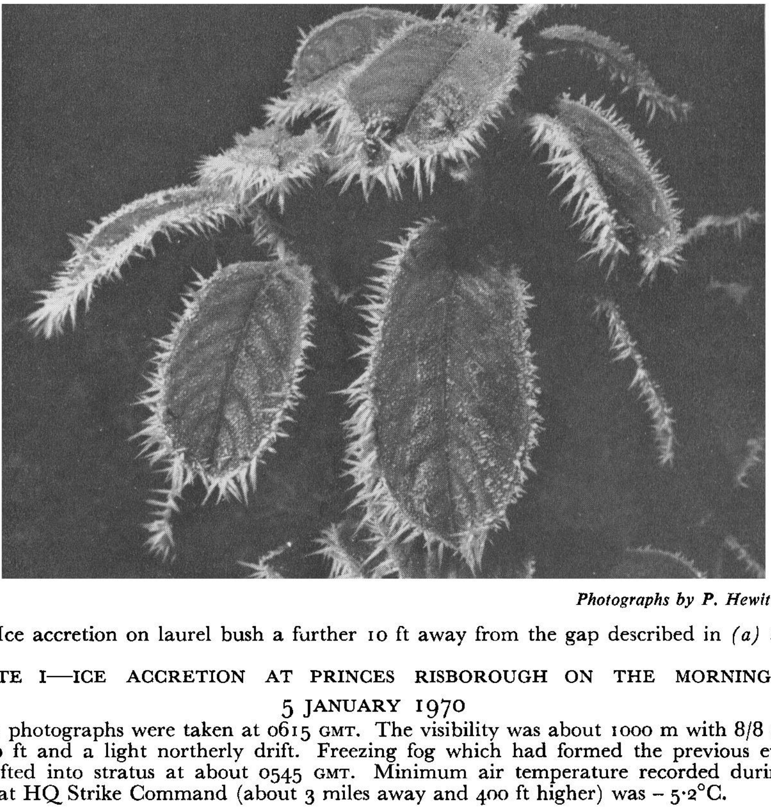


FIGURE 3—INDICATED AIRSPEED VARIATIONS ABOVE VARSITY AIRCRAFT



(a) Ice accretion on young lilac tree which was about 15 ft from an 8-ft gap between two houses, down which the wind had been funnelling all night. The longest needle was slightly less than 1 inch. There was no appreciable ice at 2100 GMT the previous evening so the total accretion had occurred in a maximum period of about 9 hours.



Photographs by P. Hewitt

(b) Ice accretion on laurel bush a further 10 ft away from the gap described in *(a)* above.

PLATE I—ICE ACCRETION AT PRINCES RISBOROUGH ON THE MORNING OF 5 JANUARY 1970

The photographs were taken at 0615 GMT. The visibility was about 1000 m with 8/8 stratus at 100 ft and a light northerly drift. Freezing fog which had formed the previous evening had lifted into stratus at about 0545 GMT. Minimum air temperature recorded during the night at HQ Strike Command (about 3 miles away and 400 ft higher) was – 5·2°C.

Photograph by courtesy of Royal Aircraft Establishment, Farnborough

PLATE II—VARSITY AIRCRAFT OF THE METEOROLOGICAL RESEARCH FLIGHT SHOWING THE WATER CATCHER MOUNTED IN THE INBOARD POSITION

See page 201.

even at 1·5 m from the skin. The differences between drop size distributions measured above the aircraft and the free stream distributions cannot be calculated from a knowledge of the airspeed profile alone; such differences can only be found by actual sampling.

The most complete way of sampling would have been to make simultaneous measurements of drop size distributions at several positions above the aircraft, but the complex instrument required for this would have involved a prohibitive time in design work and manufacture. It was therefore decided to measure the liquid water field above the aircraft, which instrumentally was far easier.

Design of water catcher. The final design of the water catcher was a compromise between what was meteorologically desirable and what was structurally possible. Ideally, simultaneous sampling every 15 cm out to some 3 m would have been desirable, but the final structure would have been aerodynamically unsafe, as the instrument was required to be mounted on the available structure inside the aircraft. Six sampling positions at 15-cm intervals were included in the final design, which meant that the outermost sampler was at 90 cm from the skin. However, the whole boom could be pushed out 30 extra centimetres, taking the outermost sampler to 120 cm from the skin, and the inner one to 45 cm (Figure 4*(b)*). The boom was made from a 63-mm diameter steel tube reducing to a 50-mm diameter tube inside the aircraft, where it was attached to the vertical structure.

The samplers, or water catchers, were 25-mm diameter recessed traps made of glass fibre and they extended forward about 50 mm from the boom (Figure 4*(a)*).

The samplers themselves affect the local airflow and hence the drop size distribution. If they are too large the distorted airflow patterns from each sampler will mutually interfere and reduce the samplers' collection efficiency; if the sampler is too small a very long exposure time is required. A 25-mm diameter sampler was considered small enough for the turbulence effects between samplers to be small, but large enough to ensure a short exposure time; it was also structurally safe. The samplers were in the shape of a recessed trap, which Golovin and Putman[5] have shown to be a most effective collector of airborne particles. Theoretically, such traps have a collection coefficient of about 80 per cent for 20-μm diameter droplets at an airspeed of 70 m/s. Wind-tunnel tests showed that the air inside the trap was relatively stagnant and that there was little tendency for air currents to force water back out of the traps. The collected water trickled down 6-mm diameter polythene pipes into collecting bottles in the aircraft. The bottles could be removed easily and the water emptied into a measuring cylinder. The bottles were not completely airtight, and the consequent small airflow down the pipes helped the downward flow of water but was not sufficient to cause appreciable evaporation in the bottles. The instrument mounted on the Varsity is shown in Plate II.

The collection efficiency of recessed traps is proportional to airspeed. However, no correction was made to the collected amounts of water for this effect as the airspeeds at the sampling positions were within 5 per cent of the mean. About 1–2 cm^3 of water remained in each tube in the form of small drops adhering to the walls. This gave an upper estimate of the error in measuring the amounts of water caught, although this would be mainly apparent in the first sample of each flight when the tubes were initially dry. On some samples, noted in Table I, too little water was collected to be of value and these samples were not analysed. The error in measuring the amount of water caught is estimated at between 5 and 10 per cent of the total, depending on the amount of water caught.

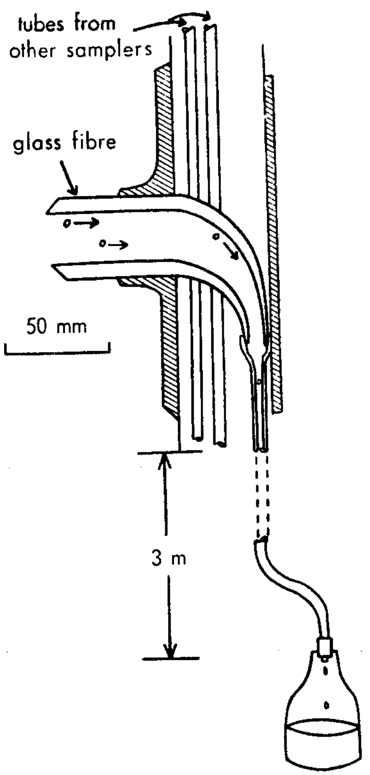


FIGURE 4(*a*)—INDIVIDUAL WATER CATCHER

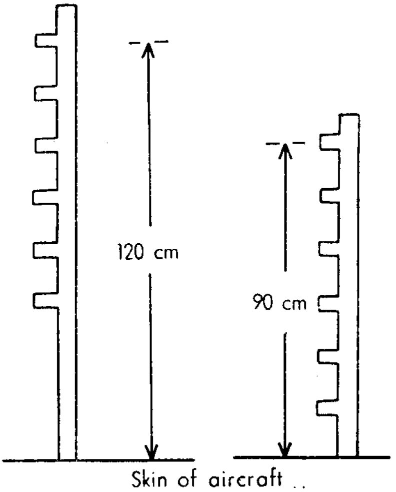


FIGURE 4(*b*)—OUTBOARD AND INBOARD SAMPLING POSITIONS OF WATER CATCHER

Flight technique. Flights were made over southern England on rainy days. During each sampling period the aircraft flew at a constant true air-speed in the range 120 to 180 kt. Sampling continued until about 30 cm^3 had been collected in each of the bottles, and the time to reach this figure was noted. The sampling time varied from 10 minutes to over an hour depending on the rainfall intensity. On each flight the object was to take as many samples as possible over the full speed-range, but on occasions few samples were obtained because the rain ceased, or the rain area drifted into controlled airspace.

Results. Table I presents the complete results of the eight flights made. For four of the flights the catcher was mounted in the 'inboard' position and there were 13 sampling periods; for the other four flights, the catcher was mounted 'outboard' and 18 sampling periods were obtained. The column *V* indicates the actual volume of water caught at each level, and under column *R* is recorded the ratio of the amount caught at that level to that caught at the 90-cm level. Ninety centimetres was chosen as a reference level because it was the farthest common sampling position from the skin for both the inboard and outboard positions. It was expected that there would be less variability in the amounts caught at 90 cm than at the inboard common sampling positions.

From Table I it can be seen that at any one level there is considerable variability in the relative amounts of water caught, the greatest variability being near the skin of the aircraft. The mean profile, Figure 5, does show that there is considerably more water near the skin and that the water content increases by 5 per cent between 90 and 120 cm. The high water content near the skin is probably due to splashing off the top of the aircraft. The increase above 90 cm can be attributed to either a concentration zone at or beyond 120 cm, or to a partial shadow zone at about 90 cm. It is not possible to say which is true, or if both are, as the free stream values are not known.

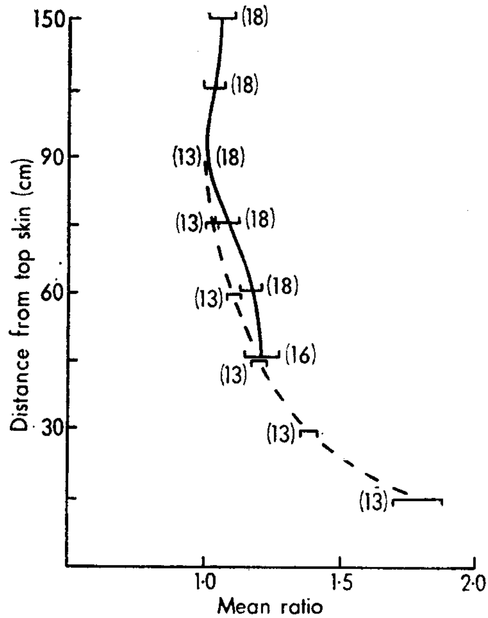


FIGURE 5—MEAN RATIO OF WATER CAUGHT AT GIVEN DISTANCE TO THAT CAUGHT AT THE 90-cm DISTANCE, WITH STANDARD DEVIATIONS

Number of samples is given in brackets.

Figure 6 shows the mean profiles for the inboard and outboard positions and they show the same general trend.

An analysis was made to see if there was a speed or 'rain intensity' effect. Rain intensity was defined as the amount of water caught at 90 cm divided by the sampling time. This was in no way an accurate determination of the

TABLE I—SUMMARY OF THE EIGHT WATER-CATCHING FLIGHTS

Distance above aircraft	16 June 1969		17 June 1969 Sample 1		Sample 2		Sample 3		Sample 4		23 June 1969 Sample 1		Sample 2	
cm	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*
90	15½	1	24	1	20½	1	19	1	35	1	17	1	10½	1
75	16½	1·06	25	1·04	20	0·97	19	1·00	38	1·08	19	1·12	10½	1·00
60	18	1·16	26½	1·10	20½	1·00	20½	1·08	34	0·97	18	1·06	10½	1·00
45	19½	1·26	30	1·25	25	1·22	22½	1·18	41½	1·18	22½	1·32	12½	1·18
30	23½	1·52	35	1·46	28½	1·39	28	1·47	45	1·29	25	1·47	14½	1·38
15	32	2·03	39	1·62	34	1·66	30	1·58	51	1·46	37	2·18	20½	1·95
True airspeed (kt)	140		120		120		140		180		140		120	
Sample period (min)	100		40		25		30		45		45		25	
Rain intensity (cm^3/min)	0·16		0·60		0·82		0·63		0·78		0·38		0·42	

Distance above aircraft	28 August 1969 Sample 1		Sample 1		Sample 3		10 September 1969 Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6	
cm	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*
120	16	1·06	13½	1·08	1·0		17½	1·25	16	1·14	13½	1·65	17½	1·25	13½	0·96	15½	1·15
105	15	1·04	13	1·04	1·0		18	1·28	16	1·14	11½	1·43	16	1·14	14	1·00	14½	1·07
90	16	1	12½	1	1·0		14	1	14	1	8	1	14	1	14	1	13½	1
75	17	1·04	13	1·06	1·0		18½	1·32	15	1·07	11½	1·43	14½	1·04	15	1·07	16	1·16
60	18	1·28	16	1·12	1·0		21	1·50	15½	1·10	6½	0·81	20½	1·46	16	1·14	18	1·33
45	Nil	(Leak)	Nil	(Leak)			19	1·35	18½	1·32	14½	1·81	19½	1·39	16	1·07	18	1·33
True airspeed (kt)	150		180		Not analysed		150		120		120		150		110		180	
Sample period (min)	45		65				60		30		30		20		35		30	
Rain intensity (cm^3/min)	0·36		0·19				0·23		0·46		0·27		0·70		0·40		0·45	

V = amount of water in cm^3. R = ratio of amount caught to amount caught at 90-cm level.

TABLE I—*continued*

Distance above aircraft	11 September 1969 (a.m.) Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		Sample 7		Sample 8	
cm	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*
120	8	1·00	6	0·75	12½	1·00	7½	1·07	10½	1·17	13	1·08	7½	1·07	1½	–
105	8½	1·06	7	0·88	12	0·96	7	1·00	8	0·94	11½	0·96	6	0·86	1	–
90	8	1	8	1	12½	1	7	1	9	1	12	1	7	1	1	–
75	9½	1·18	7½	0·94	13½	1·08	8	1·14	11½	1·28	10½	0·88	8	1·14	1½	–
60	10	1·25	8½	1·06	15	1·20	8	1·14	9½	1·05	14	1·17	6½	0·93	1½	–
45	10½	1·32	8½	1·06	16	1·28	8½	1·21	8	0·89	13	1·08	6	0·86	1½	–
30															Not analysed	
15																
True airspeed (kt)	150		180		120		120		150		180		180		150	
Sample period (min)	15		20		15		15		20		20		15		20	
Rain intensity (cm^3/min)	0·53		0·40		0·83		0·47		0·45		0·60		0·47		–	

Distance above aircraft	11 September 1969 (p.m.) Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		12 September 1969 Sample 1		Sample 2		Sample 3	
cm	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*	*V*	*R*
120													10½	0·64	16	0·91	16	1·00
105													12	0·73	17½	1·00	17½	1·09
90	14	1	6½	1	17	1	13	1	15½	1	8½	1	16½	1	17½	1	16	1
75	14	1·00	6	0·92	16	0·94	13½	1·04	17½	1·13	8	0·94	12½	0·76	17½	1·00	17	1·06
60	14	1·00	7	1·08	19	1·12	18	1·38	21½	1·38	9½	1·12	14	0·85	19½	1·11	18½	1·16
45	16½	1·18	8	1·24	19½	1·15	15½	1·19	20	1·29	9½	1·12	15	0·91	21½	1·23	20	1·25
30	20½	1·47	8	1·24	21½	1·26	18½	1·42	23	1·48	9½	1·12						
15	18½	1·32	7½	1·15	31	1·82	28	2·15	34	2·19	12	1·41						
True airspeed (kt)	150		110		120		175		170		140		150		120		180	
Sample period (min)	60		25		15		15		15		30		30		50		40	
Rain intensity (cm^3/min)	0·23		0·26		1·13		0·87		1·03		0·28		0·55		0·35		0·40	

V = amount of water in cm^3. *R* = ratio of amount caught to amount caught at 90-cm level.

true rainfall rates experienced, but it gave a means of comparing the average rates of rainfall between samples. These rates varied between 0·16 and 1·13 cm^3/min, and 0·50 cm^3/min was chosen as a mean rain intensity to divide

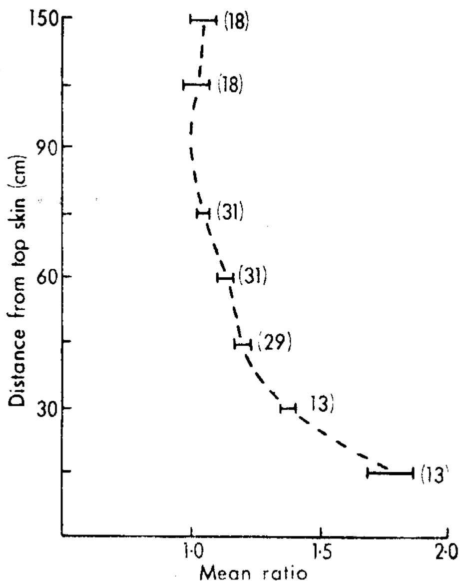


FIGURE 6—MEAN RATIO OF WATER CAUGHT AT GIVEN DISTANCE TO THAT CAUGHT AT THE 90-cm DISTANCE FOR INBOARD AND OUTBOARD POSITION, WITH STANDARD DEVIATIONS

Number of samples is given in brackets.

the samples. Figure 7 shows the four profiles obtained. All show basically the same shape but the profile for low speed/low rain has a greater value of water content at 120 cm.

Discussion. Ideally, to find the concentration factors for a given droplet size the aircraft would need to fly through a cloud of uniformly sized drops and to repeat for different sizes. This obviously is not possible and the actual amounts of water caught at each level has been the summation over all the drop sizes in the clouds through which the aircraft flew. The natural variability in drop size and water content in cloud and rain might be responsible for the differences in the profiles measured. For example, a portion of the sampling time might be in rain of a predominant drop size which had a large concentration factor at one level. The profile for that sample would show a peak at that level.

The previously used sampling position at 45 cm above the skin of the aircraft does appear to be unsuitable. Overall, that position caught 20 per cent more water than was caught at 90 cm. Splashing off the aircraft and local concentrations were no doubt responsible for this. Because of the increase in water caught above 90 cm, and because the sampling was restricted by instrument length to 120 cm, the free stream values of water content cannot be said to have been reached. A much longer instrument would be required to extend into the free stream region, but structurally this would be difficult.

Theoretical studies by the U.S. Naval Research Laboratory led to the design of a 14-ft (4·2 m) dorsal fin for their C-54 aircraft (slightly bigger than the Varsity) which was engaged on turbulence studies.[6] The fin was considered long enough to position the instrument in the undistorted airstream, but the author is unaware if confirmatory experiments were carried out. As the airflow is 10–15 kt higher than the true airspeed at a position 150 cm out from the Varsity, it is likely that a fin of similar size would be required to position instruments in the free airstream.

It is concluded that the measurements of drop size and liquid water contents in clouds from the present vertical sampling position in the MRF Varsity aircraft are certainly unreliable within 120 cm of the aircraft. The actual error in the measurement of liquid water content cannot be quantitatively given, as the free airstream values could not be measured.

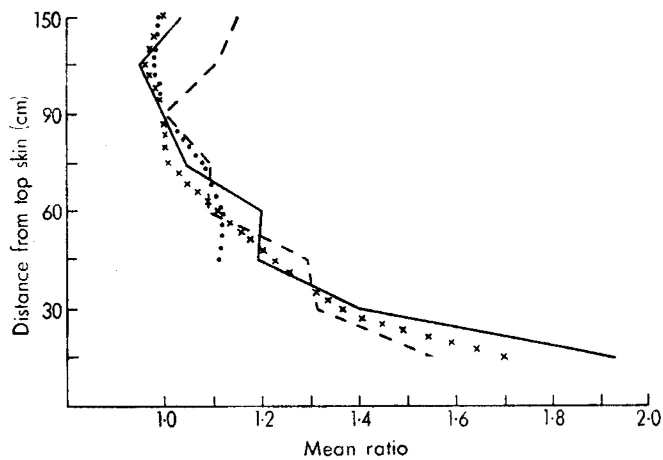


FIGURE 7—MEAN RATIO OF WATER CAUGHT AT GIVEN DISTANCE TO THAT CAUGHT AT THE 90-cm DISTANCE. RATIOS ARE MEANS FOR HIGH AND LOW TRUE AIR-SPEEDS AND HIGH AND LOW RAIN INTENSITIES

— — Low true airspeed and rain intensity
xxxxxx Low true airspeed and high rain intensity
. . . . High true airspeed and low rain intensity
——— High true airspeed and rain intensity

Distance above aircraft	LOW TRUE AIRSPEED				HIGH TRUE AIRSPEED			
	Low rain intensity		High rain intensity		Low rain intensity		High rain intensity	
	SD	Nos of samples	SD	Nos of samples	SD	Nos of samples	SD	Nos of samples
cm								
120	0·12	5	0	1	0·11	4	0·03	2
105	0·07	5	0	1	0·05	4	0	2
75	0·06	7	0·03	4	0·04	4	0·04	5
60	0·02	6	0·03	4	0·07	4	0·07	5
45	0·06	7	0·03	4	0·09	4	0·04	4
30	0·05	2	0·05	3			0·05	3
15	0·30	2	0·05	3			0·19	3

SD = standard deviation

Acknowledgements. The author would like to express his thanks to the MRF aircrew and observers for their fortitude in flying in such inclement weather, and to the Aerodynamics Department of the Royal Aircraft Establishment for the use of a wind-tunnel.

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AN OCCURRENCE OF HIGHLY LOCALIZED CLEAR-AIR TURBULENCE OVER THE SOUTHERN MEDITERRANEAN

By J. B. McGINNIGLE

At 1550 GMT on 28 November 1963, a report of highly localized clear-air turbulence was received from an aircraft *en route* from Tunis to Tripoli at flight level 19 500 ft (5·85 km). The track of this aircraft and the position where the turbulence was encountered are shown in Figure 1. A rapid temperature rise of 8 degC from − 28 to − 20°C was also reported to have occurred almost simultaneously.

On landing at Tripoli, the pilot described the turbulence as very severe, being in the form of only one 'bump' upwards, which dislodged many loose articles in the aircraft. Before and after the turbulence, the flight was completely smooth. At the time of the report, the aircraft was flying above a layer of altocumulus, whose top was estimated at 16 000 ft (4·8 km). Very shortly after the turbulence the edge of the cloud sheet was passed and thereafter generally clear skies were reported for the rest of the route.

Another aircraft *en route* from Rome to Tripoli flew over the turbulence position at 31 000 ft (9·3 km) within 25 minutes of the times of severe turbulence but reported only slight turbulence at debriefing.

Synoptic situation. Figure 1 shows the surface synoptic situation at 15 GMT on 28 November 1963. The cold front which extended south and south-west from the depression over southern Italy was moving south-east at 20 kt (1 kt ≈ 0·5 m/s) in the southern Mediterranean area. The front was very active in the north, near to the depression centre, but its passage along the north African coastline was marked only by a temporary increase in cloud and a slight veer of surface wind.

To face page 208

PLATE III—A 500-mb CONTOUR AND A 500–1000-mb THICKNESS CHART BEING PLOTTED BY THE 'ON-LINE' LINE DRAWER IN THE COMPUTER LABORATORY, BRACKNELL

The 500-mb contours are drawn first then the thickness (pecked) lines. The data are taken from a magnetic tape previously written during a numerical forecast run on the computer.

Magnetic tapes, which form part of the magnetic-tape library (now containing 4000 tapes and still increasing), can be seen in racks behind the operator. The equipments in front of the racks are paper-tape punches.

PLATE IV—A 200-mb CONTOUR CHART BEING PLOTTED BY THE 'ON-LINE' DRAWER IN THE COMPUTER LABORATORY, BRACKNELL

Behind the line drawer is a line printer on-line to the KDF 9 computer. Although shown loaded with plain paper this equipment can be loaded with pre-printed stationery to produce charts of the 'zebra' type.

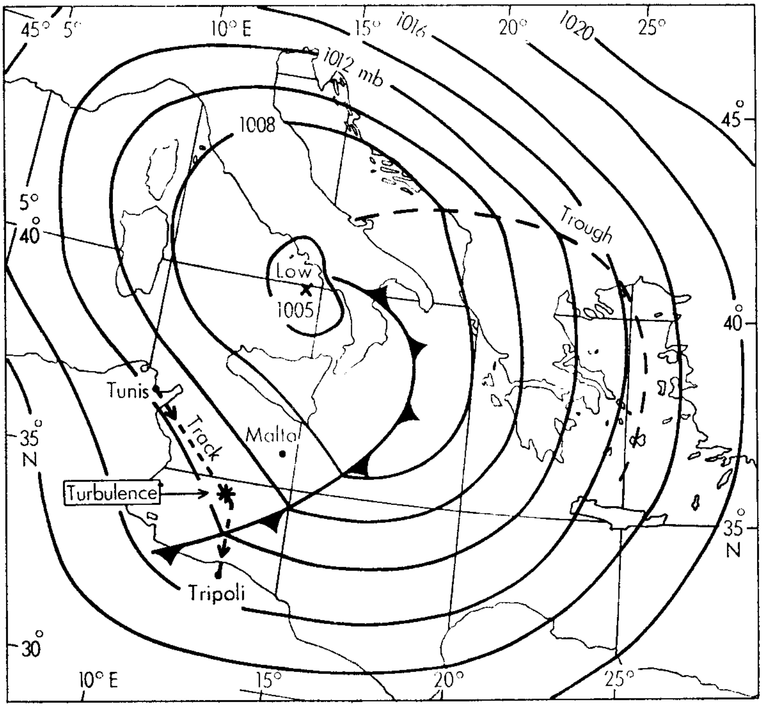

FIGURE 1—SURFACE ANALYSIS 15 GMT, 28 NOVEMBER 1963

The depression had been a feature over southern Italy for some days, and a cyclonic circulation was in evidence to above the 200-mb level. A belt of strong winds extended from southern France to Algeria and Tunisia and thence eastwards over Malta. A marked upper trough associated with the cold front existed at all levels up to 300 mb but was most sharp around the 500-mb level. A jet stream lay over Malta at 12 GMT on 28 November, when a maximum wind of 250° 110 kt was reported at 320 mb.

Discussion. The Malta radiosonde ascent for 12 GMT on 28 November was used for the analysis of the cold front. The tephigram is reproduced as Figure 2, and Figure 3 shows the hodograph which was constructed from the ascent winds. Inspection of these figures in combination with the surface analysis suggests that the upper frontal surface was at 520 mb, where a temperature inversion was reported.

The increases, with height, of the wind component normal to the front in the warm air shows that the front was a katafront, as can be seen from Figure 3, and this explains why there was a subsidence-type inversion at the frontal surface, completely masking the vertical increase of wet-bulb potential temperature which would be expected.

The position and time of the turbulence report indicate that the aircraft was in the frontal zone at the time and the very sudden temperature increase of 8 degC shows that this zone was very narrow.

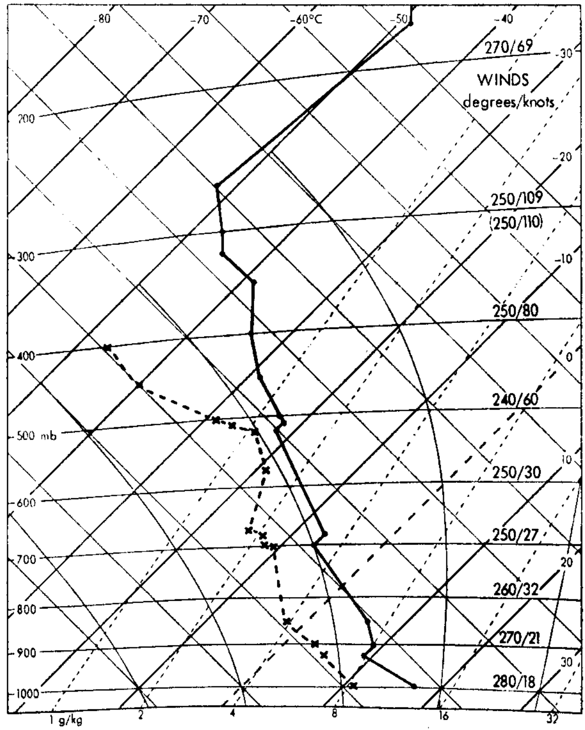

FIGURE 2—MALTA UPPER AIR ASCENT 12 GMT, 28 NOVEMBER 1963
——— Temperature - - - Dew-point

It is, however, surprising that there was no cloud in the frontal zone as the Malta ascent (Figure 2) shows that a lift of only 20 mb at 570–520 mb would produce condensation.

It therefore seems likely that the strong shear effect around 500 mb was inhibited by the downslope motion on the katafront, such that the effect was limited to less than 20 mb. Freeman* has shown that fronts have a dry zone within the frontal zone and the lack of cloud in the turbulence layer is most probably explained by this and the katafront effect. There is some indication of this dry zone between 700 and 600 mb on the Malta ascent although this ascent may have been too far into the cold air to indicate this feature properly.

The turbulence produced by the wind shear would be severely limited in vertical extent. The aircraft seems to have passed through the frontal zone within this dry and extremely turbulent layer, moving at sufficient speed (around 230 kt) to experience only one severe bump.

The other report of slight turbulence is assumed to be due to the normal shear effects adjacent to a jet-stream core.

* FREEMAN, M. H.; Fronts investigated by the Meteorological Research Flight. *Met. Mag., London,* **90,** 1961, pp. 189–203.

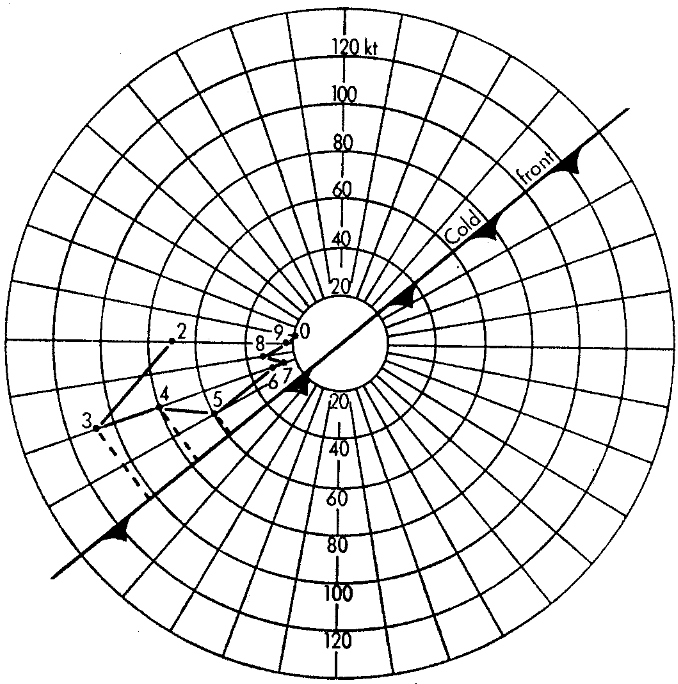

FIGURE 3—HODOGRAPH CONSTRUCTED FROM MALTA UPPER AIR ASCENT 12 GMT, 28 NOVEMBER 1963
0 = 1000 mb, 9 = 900 mb, 8 = 800 mb, etc.

REVIEWS

World survey of climatology Volume 8, Climates of northern and eastern Asia, edited by Hidetoshi Arakawa. 300 mm×215 mm, pp. 248, *illus.*, Elsevier Publishing Co. Ltd, 22 Rippleside Commercial Estate, Barking, Essex, 1969. Price: 225*s*.

With this volume Elseviers have now brought out three of the planned 15 volumes of the *World survey of climatology* under the direction of Professor Landsberg (formerly of the United States Weather Bureau), President of the World Meteorological Organization Commission for Climatology. No climatological reference work on this scale has appeared since Köppen and Geiger's famous *Handbuch der Klimatologie*, the first parts of which were published in 1930 and which stopped short of world coverage owing to the intervention of the Second World War before it was completed. This new work is therefore to be welcomed and this volume especially so, since it includes areas which never appeared in Köppen and Geiger.

The name of the volume here reviewed is misleading, because the Asiatic territories of the U.S.S.R. are to appear in Volume 7 *(Climates of the Soviet Union)*. The areas included in Volume 8 actually range from China (with some references to Mongolia), Korea and Japan in the north to Indonesia, straddling the equator, in the south. Volume 9 (called *Climates of southern and western Asia)* will deal with all the rest of Asia from Vietnam to the Near East. The editor of Volume 8 is the well-known meteorologist Hidetoshi Arakawa, now Professor of Physics at the Tokai University, Hiratsuka City, Japan, but from 1931 to 1968 a member of the staff of the Japanese weather service. The chapter on Japan is by Arakawa and S. Taga; that on China is by I. E. M. Watts, formerly Director of the Royal Observatory, Hong Kong.

More than one-third of the book is devoted to climatic tables in a standard format, giving for each month of the year average values of atmospheric pressure, surface air temperature and its diurnal range, sunshine, cloudiness, rainfall and evaporation, the observed extremes of some elements (including, where appropriate, deepest snow) and the frequencies of various kinds of weather such as precipitation days, thunderstorms, fog, gales and sandstorms. Completeness of these tables is, of course, subject to availability of data but a remarkable fullness has been achieved. Such tables are given for 40 places in China, 2 in Korea, 27 in Japan and 10 in the Philippines but none in Indonesia. Additionally, some items are given for a number of places in central Asia (e.g. Sinkiang) and Taiwan, for 44 places in the Philippine Islands and 10 places in Indonesia. The data for China are for somewhat varying periods, generally between about 1900 and 1950; those for Japan are all 1931–60. Many of the Philippine observational records were lost in the war, and the available data here given are for periods varying from about 7 to 59 years, mostly in the first half of this century. All the Indonesian information is recent, for periods ranging from 8 to 30 years between 1931 and 1960. This unfortunately includes nothing on thunderstorms, for which Java has long been renowned as having the highest frequency in the world. For the climatology of these islands reference will still have to be made to the prolific, high-quality data obtained and published during the Dutch colonial period: for some places more than 100 years of record exist.

The text of the present volume is liberally provided with maps, diagrams and subsidiary tables, and handsomely printed with lavish margins. Seventy-one pages are devoted to China and Korea, 12 to Japan, 45 to the Philippines and 15 to Indonesia. Systematic understanding is aimed at by considerable use of standard climatic classifications, particularly that of Köppen which is used in three of the four chapters. The chapter on Japan aims at being little more than a guide to the voluminous work and literature on the subject. The chapter on China is the most comprehensive and will be valued both by reason of the scarcity of informed texts in a western language on the climate of that country and for its attention to the meteorological and oceanographic influences at work. Nevertheless, rather more attention to the flow of the upper air and, particularly, the moisture transports involved in the rains of different seasons in China, would have been an advantage. This chapter has a specially good bibliography. The climate of the Philippines is also painstakingly described, with due attention to the atmosphere in depth and the main meteorological processes at work.

Among the special characteristics of the regions covered by this volume are the incidences of typhoons, exceptionally heavy rainfalls and disasters due to weather. Extreme rainfalls of around 1200 mm in 24 hours have been measured in the mountains both on Luzon (Philippines) and Taiwan, though outdone by one of 1870 mm on Réunion (21°S 55°E). Climatic history, and the two-thousand-year history of applied climatology in China, receive some notice in the book; but the range of behaviour of the present climate throughout the regions covered, as recorded, for instance, in the table (p. 19) on fatalities during typhoons at Hong Kong, in the frequent river floods and landslides in China and in the tabulation of weather disasters of various kinds in Japan since 1918, is more than sufficient to disrupt human planning regardless of any secular shifts of the average values and frequencies of various disturbances.

H. H. LAMB

World survey of climatology Volume 4, Climate of the free atmosphere, edited by D. F. Rex. 300 mm × 215 mm, pp. 450, *illus.*, Elsevier Publishing Co. Ltd, 22 Rippleside Commercial Estate, Barking, Essex, 1969. Price: 335*s.*

This volume is one of the 15 volumes planned under the direction of the recently elected President of the World Meteorological Organization Commission for Climatology, H. E. Landsberg, who is Editor in Chief of the series. The first 3 volumes discuss general climatology while the remaining 11 refer to the detailed climatology of different regions of the world. Only 3 volumes have so far been published (Volumes 2, 4 and 8) and it is likely to be several years before all volumes of this major work appear in print. D. F. Rex from the National Center for Atmospheric Research, Boulder, Colorado, has acted as editor for this volume and he has assembled an impressive list of authors for the eight chapters.

Chapter 1 is a brief but adequate introduction by the editor, the main part of the study being contained in the following seven chapters. Most readers will probably not quibble about the omission from the volume of any reference to the electrical properties of the atmosphere but some no doubt will be surprised not to find any reference to the climatology of the boundary layer which undoubtedly is important enough to merit a chapter on its own. Others will be equally surprised at the planned omission of any reference to chemical constituents of the natural atmosphere (except water vapour and ozone) or to the naturally occurring particulate matter suspended in the air. Although 'references' are given to reviews of pollution and atmospheric chemistry some discussion of these topics would have been desirable. The main part of the book starts with a rather lengthy dissertation on standard and supplementary atmospheres. This chapter is written very largely from the American point of view with most of the space being allocated to discussion and tables of the U.S. Standard Atmosphere, 1962 devised by the Committee on Extension to the Standard Atmosphere (COESA); COESA, representing a group of American organizations, has defined the atmosphere up to a height of 700 km and is attempting to get the International Civil Aviation Organization (ICAO) Standard Atmosphere extended upwards. To some extent it has a different approach from the Committee on Space Research (COSPAR) which likewise has produced a reference atmosphere (COSPAR International Reference Atmosphere, 1965) for the higher levels but which uses satellite data to define these and attempts to integrate downwards, while the COESA atmosphere is a logical extension of the ICAO atmosphere upwards.

This chapter also includes tables defining reference atmospheres for each 15° of latitude between 15° and 75°N up to 90 km. It is doubtful whether these data are very useful as they are ostensibly means round a latitude band.

In practice however, at the higher levels there are large departures from the proposed reference atmosphere in some longitudes and in general the variability of the lower stratosphere is much greater in some sectors than in others.

Chapter 3 on 'Temperature and humidity' in the troposphere contains some useful maps and diagrams but in some of them (notably Figure 5) the method of presentation is not ideal. In addition the readability of the text is occasionally spoiled by too frequent references with no clear connecting thread between the sentences.

To the reviewer the chapter by Reiter on 'Tropospheric circulation and jet streams' is easily the best in the book. It gives an excellent description of the dynamics of jet streams and their origin on a rotating globe. Of particular interest is the section showing the inadequacy of contour charts to describe even approximately the atmospheric motions in some synoptic situations, e.g. near converging jets and sharp upper troughs. In these cases the author clearly demonstrates that isentropic analysis sheds more light on what atmospheric motions are actually taking place. The chapter also contains more conventional but very readable descriptions on the origins of the subtropical jet, the tropical easterly jet, the polar-front jet and even the low-level jet. Some discussion is also included on the origin of tropical storms and on cyclones and anticyclones.

Chapters 5 and 6 on 'Major cloud systems' and 'Global distribution of cloudiness and radiation as measured from weather satellites' complement each other, both making extensive use of satellite data. These chapters tend to be out of date because of the rapid increase of knowledge attained from weather satellites over the last few years, practically all the examples inevitably being culled from data prior to 1965, but they do make very interesting reading and form one of the best accounts of the subjects yet seen in book form. No doubt some maps will need amendment in the light of later more accurate data but it is most interesting to see first attempts at maps of seasonal mean cloud cover over the globe and also similar maps showing the mean seasonal outgoing long-wave radiation and albedo over the globe. These maps are based on only one year of data; there is a liability to error in the albedo and radiation maps because of the fall-off with time in performance of the radiation instruments, and in the maps of mean cloudiness because of the technique of preparing the maps by allocating arbitrarily a brightness to each grid point and then averaging the brightness to produce a mean cloudiness. As the authors say, this technique leads to difficulty especially in distinguishing between snow or ice and cloud. Nevertheless these two chapters fulfil a useful function in presenting much comparatively new data and clearly indicate the great promise for the future which satellites present.

The chapter on the stratosphere is slanted towards the upper stratosphere and in particular on observations obtained from the Meteorological Rocket Network (MRN). This inevitably refers mostly to American data as the MRN began there in 1959 but it is a little surprising to find no reference at all to rocket observations from Europe and, in fact, the British Isles do not even appear on the map showing the location of rocket observations stations! This chapter in general gives the impression of being written some time ago, especially as no mention is made of rocket observations later than 1963; however, it does include summaries of upper stratospheric wind data for the four years 1960–63.

The last chapter, on ozone is one of the best and covers most aspects — photo-chemical theory, methods of observation, mean vertical distributions at different latitudes, seasonal variations in the distribution of ozone, transport by the general circulation, the importance of ozone in stratospheric dynamics, etc. Altogether the chapter contains about the most comprehensive account of the role of ozone in atmospheric studies that has appeared in a general volume.

The book as a whole is well produced, with good print and few mistakes. Diagrams are mostly clear, although there are a few exceptions to this, the reproductions of some of the satellite photographs in particular being fuzzy. Figure 7 on page 222 has an erroneous caption and there are other small errors, but overall these are very few.

Altogether this is a very useful volume although, in common with most books written by several authors, the standard is rather variable. The price will not commend the book to many private meteorologists but it is hoped that the series will be given a place in all worthwhile meteorological libraries.

R. A. S. RATCLIFFE

World survey of climatology Volume 2, General climatology, 2, edited by H. Flohn. 300 mm×215 mm, pp. xii+266, *illus.*, Elsevier Publishing Co. Ltd, 22 Rippleside Commercial Estate, Barking, Essex, 1970. Price: 225*s*.

This is Volume 2 of a series of 15 planned to cover the whole field of climatology. The first 4 volumes deal with general aspects and include one on the climatology of the free atmosphere. Five general topics are covered in the five chapters of the present volume. They and their authors are: General circulation, H. Riehl; Physical processes near the earth's surface, E. L. Deacon; Topoclimates, R. Geiger; Local wind systems, H. Flohn; Climatic fluctuations, H. H. Lamb. The treatment is descriptive, supported by typical observations and the outlines of theory. Broad results of the more important researches are presented, supplemented in all sections by comprehensive reference lists. The text throughout is illustrated with clear and informative diagrams.

In Chapter 1 the as yet incompletely solved problem of the general circulation is discussed having regard to the fundamental requirements of the global budgets of heat and momentum and, to a less extent, of water vapour. It is shown that the simple heat engine type of circulation, e.g. the Hadley cell, by itself is not reconcilable with the requirements of momentum balance. Hence follows the necessary part played in the transport of heat and momentum by the long waves of the upper troposphere and the surface anticyclones and depressions — circulations simulated in rotating dishpan experiments. The relevance of these experiments to the problem is discussed.

Chapter 2, on physical processes near the earth's surface, discusses the radiation balance, heat conduction into the ground, evaporation, transpiration and turbulent transfer, from the point of view of the basic physics, with illustrative observational data. The significance of these processes in relation to fog, atmospheric pollution and the diurnal variation of meteorological elements is considered.

The next two chapters are concerned mainly with mesoscale features of climate. That on 'Topoclimates' deals with the relations between land forms and local climates, including such topics as valley and mountain climates, radiation on slopes and the climate in caves. The chapter on 'Local wind systems' includes the thermally driven land- and sea-breezes, mountain and valley winds and the dynamically driven mountain waves. Where appropriate the descriptions are backed by theoretical considerations. The final chapter is a summary of the author's work, extending over at least 15 years, on climatic variation, especially during historical times. Mr Lamb is expert at the marshalling and sifting of evidence, often scanty, and his contribution to this volume surveys, in enjoyable readable form, his many contributions to the subject. In conclusion the possible causes of climatic variation are briefly assessed, for example, astronomical factors, volcanic activity and the extent of the polar ice.

This is a handsomely produced volume containing clearly written and well-illustrated surveys of researches to be otherwise found in numerous and widely dispersed papers. It is a book to be enjoyed by the general meteorological reader who might not have the time or the stamina to digest all the original literature.

A. G. FORSDYKE

Invention of the meteorological instruments, by W. E. Knowles Middleton. 260×155 mm, pp. xiv+362, *illus.*, Johns Hopkins Press, Baltimore, Maryland 21218, 1969. Price: £5 14*s*.

In '*Invention of the meteorological instruments*' Dr Middleton deals with the inventions and improvements which have led, step by step, to the equipment currently employed in meteorology. Perhaps of even greater interest, he considers in detail the early deliberations which eventually resulted in a clear understanding of the physical quantities involved. In no case are the difficulties of this latter stage illustrated more clearly than in regard to pressure, the existence of which is undetectable by human sensation. Short-term variations in the pressure of the atmosphere caused some confusion in interpreting the results of the early experiments designed to demonstrate the nature of pressure within the free air, although eventually it was the equipment used for these demonstrations which provided the Torricellian tube, the basis of the present mercurial barometer.

As Dr Middleton states in his preface, it would require many volumes to cover completely all the variations of design of each of the many meteorological instruments. The general meteorologist, concerned primarily with the derived observation, is taken as concisely as possible through the initial philosophical considerations and the subsequent physical design of measuring equipment applicable for each of the main meteorological observations made at ground level — atmospheric pressure, temperature, humdity, rainfall and evaporation, wind direction and force and the duration of sunshine. Further chapters deal with multiple recording instruments, such as the meteorographs, and with devices for measuring phenomena above ground level. In meteorographs and balloon-borne sonde equipment, whether transmitting by radio or otherwise, no meteorological conceptions are involved, original invention being limited to the mechanics of recording or transmitting the response of sensors already in use at ground level. Although specialized sensors, such as those for measuring ozone in the upper air, have in fact been invented, it has been the author's deliberate intention to exclude reference to devices developed for specific research applications and not as yet accepted for routine meteorological observation. Similarly no descriptions are given of the many older devices which, having played no useful part in the general evolution of meteorology, have now been abandoned.

The term 'invention' is a difficult one to define accurately, and in no field is this more true than when applied to meteorological equipment. It would seem most appropriate in instances relating to a single original conception — an entirely new instrument or method hitherto unknown. Strictly, however, it is equally applicable to many of the smaller steps in a prolonged sequence of improvements, and examples of both cases are illustrated within this volume. The term, although still used in the popular press, has somewhat dropped from favour since Victorian days, when any change of design, however small, tended to be considered as an invention. No doubt Dr Middleton himself had this somewhat outmoded application in mind, when including it in the title of his book, the style of which is intended to conjure up a suggestion of medieval learning.

It is perhaps unfortunate that so many inventors evolved so many variations of design in basically similar instrument, backing each with his own choice of units for the resultant measurement. The results of each school of thought clinging firmly to its own practices are still felt in modern meteorology, to a degree which is not always appreciated, despite international guidance and control.

The great antiquity of some of the observations and of their corresponding instrumentation, albeit by simple methods, will surprise many of Dr Middleton's readers. The earliest known rain-gauge, used in India, is ascribed to the fourth century BC, while as the Grecian 'Tower of the winds' was used to aid the determination of wind direction in 100 BC it is difficult to believe that earlier simple aids to this end were not in fact available. The requirement — a directional reference point and some easily blown material — would leave no permanent trace and no written reference is known. The very active development of refined equipment for observing, recording and, to a limited extent, transmitting observations by mechanical methods was so exhaustive during the eighteenth and nineteenth centuries that little further is possible by such means. Only limited improvements related to cost or convenience can be achieved, using materials or production methods not then available. It is to electronics that further development must now turn, a field already in wide use for the transmission of observations, but one which may eventually suggest entirely new observational techniques and provide measurements not merely at a single point in space, but representative of a prescribed volume or layer of the atmosphere.

The general style used for the presentation of '*Invention of the meteorological instruments*' follows that of the author's earlier works on the barometer and the thermometer, to which it forms a fitting companion volume. Numerous references to the details of the earlier writings on each of the instruments described will satisfy the instrumental specialist, and many of the reproduced letters and diagrams date back to Renaissance times. Dr Middleton has obviously delved deeply into his subject and demonstrates great skill in the work of editing, retaining only those items essential to the development of his theme. The result has been the production of a book which, while most useful for reference, remains easily readable by the student or general meteorologist. Perhaps, above all, the work gives a clear conception of the age and width of scientific thought, and of the associated technical ingenuity displayed throughout the centuries.

A. L. MAIDENS

NOTES AND NEWS

Conference plans detailed atmospheric studies

Approximately 100 scientists from 25 countries meeting in Brussels completed a 5-day conference on 20 March 1970 with a unanimous agreement on plans for two major international projects within the so-called Global Atmospheric Research Programme (GARP). The broad objective of GARP is to increase our understanding of the large-scale behaviour of the atmosphere with a view to determining for what period of time ahead it is physically possible to forecast the weather. This increased understanding of these processes would also help us to know more about the factors which determine climate and hence perhaps to assess the possibilities of artificial climate modification.

Weather forecasts at present are fairly accurate for one day ahead but the accuracy decreases rapidly as the period of the forecast increases. The useful limit of forecasts is at present of the order of 5 days. Recent theoretical studies have however indicated that useful forecasts may be possible for up to 2 or 3 weeks ahead. GARP is aimed at testing and improving these theories. For this purpose we need observational data in more detail than is available for daily use by the World's Meteorological Services. The two projects discussed at the Brussels conference are designed to obtain these additional observations.

The first project, known as the GARP Tropical Experiment, will include a 3-month period of intensive observations in the Atlantic between 10°S and 20°N. It will be held in 1973 or 1974, the exact date depending on the availability of a geostationary meteorological satellite over the area. In addition to the observations from this and other orbiting satellites it is expected that there will be a fleet of 20 or more research ships from about 8 countries making special observations over the area of the experiment. Some research aircraft are also to be used and commercial ships and aircraft in the area at the time of the experiment will be invited to participate. The resulting observations will be used by research groups in many countries to find out more about the energy-exchange processes in the tropical atmosphere.

The second project will cover the whole world and includes an observing experiment lasting a whole year, beginning some time in 1975 or 1976. The proposed observing system includes four geostationary satellites, at least two polar orbiting satellites and two balloon sub-systems. The first of these will consist of some 300 balloons drifting with the winds at a height of about 12 km. The balloons will measure temperature and pressure and the observations will be collected by an orbiting satellite which will also determine the position of the balloons from which it will be possible to deduce the wind. The second balloon sub-system consists of large carrier balloons at a much greater height from which radiosondes can be dropped by parachute when required. As it falls, the radiosonde will be located by a navigational aid system and the observations will again be collected by satellite.

The proposals made by the conference will be considered by the two sponsoring bodies, namely the World Meteorological Organization and the International Council of Scientific Unions. It is expected that the countries willing to participate in the GARP Tropical Experiment will meet in London in the summer of 1970 to discuss the plans in more detail.

The conference was held at the Headquarters of the Royal Meteorological Institute of Belgium at Uccle, and was presided over by the Director of the Institute, Professor J. Van Mieghem.

WMO PRESS RELEASE

Further information on GARP may be obtained in the *GARP Publications Series* issued by WMO and ICSU and distributed by the WMO Secretariat, Geneva.

No. 1 An introduction to GARP. (1969)
No. 2 Systems possibilities for an early GARP experiment. (1969)
No. 3 Planning of the First GARP Global Experiment. (1969)

LETTERS TO THE EDITOR

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Winter precipitation over East Anglia

In his paper on the forecasting of winter precipitation over East Anglia, Mr M. F. Smith[1] compares the results he obtained with results from applying relationships which I[2] established. These comparisions are not valid because he uses the relationships in a way that was never intended.

In comparing the accuracy of various methods I made it clear that I was relating each index to the form of the precipitation falling at the time the corresponding temperatures were measured. The usefulness of each method depends on this accuracy and on how successfully the index can be forecast.

On the other hand, Mr Smith relates his predictors to the form of precipitation in the 12 hours following the upper air observation. Moreover, he classes this precipitation as snow if snow falls at any time in the 12-hour period. It is clear that any figures I found to correspond to a 50 per cent probability of snow at the time the upper air observation was made will greatly underestimate the probability of snow falling at any time in the subsequent 12 hours. In general, if an index is devised which relates to a simultaneous weather event in a small area, then if either the area or the period is extended the index is bound to 'under-forecast' the occurrence of the event.

11 St Omer Road
Guildford, Surrey C. J. BOYDEN

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1. SMITH, M. F.; Winter precipitation over East Anglia. *Met. Mag., London,* 99, 1970, pp. 20–27.
2. BOYDEN, C. J.; A comparison of snow predictors. *Met. Mag., London,* 93, 1964, pp. 353–365.

In a most interesting and useful article,[1] Smith refers to a short paper[2] which I wrote nearly 20 years ago. The purpose of my early note was to present some statistics on the association between the form of precipitation over the British Isles and four meteorological variables, namely surface temperature, height of freezing level, 1000–700-mb thickness and 1000–500-mb thickness. Information on the association of precipitation with the last two synoptic variables was very desirable since the 'thickness' technique in upper air analysis and forecasting had then become well established in British practice. These simple synoptic climatological statistics, which were quite novel at the time, were intended in particular to give some help in interpreting prognostic maps in terms of the form of precipitation. Some years later another short paper[3] was written in which graphs showed the likelihood of rain or snow in relation to *(a)* surface temperature and height of freezing level (0°C isotherm) and *(b)* surface temperature and 1000–500-mb thickness, but I stated that such diagrams could only be useful as a general guide over longer periods and not in short-period prediction when, to quote my words, 'the forecaster must clearly depend on his scientific diagnosis of the meteorological situation'.

I think it is relevant to say that the data for my papers were collected over three cold seasons from November 1948 to March 1951 from seven radiosonde stations, all but one of which are situated in the north and west of Britain. At these stations and during that particular period there was much showery-type precipitation and this dominated the overall statistics. The mean 'critical' figure for 1000–500 mb thickness was in fact lower than it would have been if most of the data had been collected from stations nearer the continent and during a period in which most of the precipitation had been associated with warm-type fronts approaching from the south-west or south of Britain or with continental airstreams. Both of these synoptic types generally have higher values of 1000–500 mb thickness than have unstable weather types with the same level of surface temperature. Subsequently Boyden[4] found a somewhat higher mean 'critical' 1000–500 mb thickness, but his data were selected from four unusually snowy winters, 1955–56, 1957–58, 1961–62 and 1962–63 which were, on average, synoptically more 'blocked' than my three winters which were characterized by progressive synoptic types.

In view of the practical importance of accurate forecasts of heavy snowfall to road, rail and air traffic I am sure that there is a need for much more work to be done on developing practical forecasting techniques. For very short-period, local forecasts practical techniques need not be linked specifically to numerical forecast procedures. On the other hand, for useful predictions of snow over longer periods, such as a day or so, it would seem most desirable to develop techniques, based on the synoptic and physical factors of relevance to the formation or melting of snow. The techniques should make use of meteorological variables which can be included directly into numerical forecasting procedures or which can be derived from whatever thermal or circulation maps or data are (or will be) produced by computer methods.

Meteorological Office, Bracknell

R. MURRAY

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NOTICES

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